Hydro Québec

Summary of Knowledge Acquired in Northern Environments from 1970 to 2000

Summary
of Knowledge Acquired
in Northern Environments
from 1970 to 2000

Hydro-Québec

September 2001

Author and title (for citation purposes):

HAYEUR, Gaëtan. 2001. *Summary of Knowledge Acquired in Northern Environments from 1970 to 2000*. Montréal: Hydro-Québec.

Foreword

Hydro-Québec first established an environment function 30 years ago, when the Québec government decided to build the La Grande complex. Since then, the company has produced a great many studies and reports. A review of the knowledge acquired seems especially timely now, as Hydro-Québec is regularly asked what it has learned from these environmental assessments and studies.

To date, summary reports have been written on particular subjects such as mercury, fish and the archaeological heritage, but no concise overview has been published covering the knowledge acquired of both the biophysical and the social environment. The goal of the following report is consequently to summarize the knowledge arising from studies carried out for the company's hydroelectric projects in northern Québec, and specifically north of the 48th parallel.

The report is completed by two bibliographies. The first contains the works cited in the body of the text, in alphabetical order. The second lists, by field, over 150 scientific publications and papers presented at international events. Readers who would like further information on specific topics are invited to consult these bibliographies.

For our English readers, we have included a list of French organization names and acronyms with unofficial English translations, on the front inside cover.

Our thanks go to all those who contributed to preparing this summary report.

Gaëtan Hayeur
Writing and research

Claude Demers
Coordination

Table of Contents

Tables

Figures

Figure 1
Main hydroelectric generating stations in Québec

Introduction

Through its electricity generation, transmission and distribution activities, Hydro-Québec plays an important role throughout Québec, both in its regular operations (see Figure 1) and in project design and planning. It must therefore employ considerable resources in the environment. Since the early 1970s, Hydro-Québec has maintained permanent teams of specialists directly involved in environmental protection and enhancement on a daily basis.

In a company such as Hydro-Québec, environmental studies must lead to an assessment of the impacts arising from its projects and operations as well as to the formulation of mitigation, management and enhancement measures. Environmental specialists at Hydro-Québec have consequently developed new methods that are better adapted to the particular requirements of the company's activities, which demand concrete, functional results.

In addition, there is now a broader range of concerns, going beyond simple environmental protection to include environmental monitoring and follow-up, the development and implementation of measures aimed at integrating facilities and operations into the environment as well as possible, and the notion of optimum enhancement.

In presenting this review of its principal environmental activities over the past 30 years, Hydro-Québec wishes to increase awareness of its achievements to date and, above all, of the rationale behind the selection, acceptance, construction and operation of its facilities.

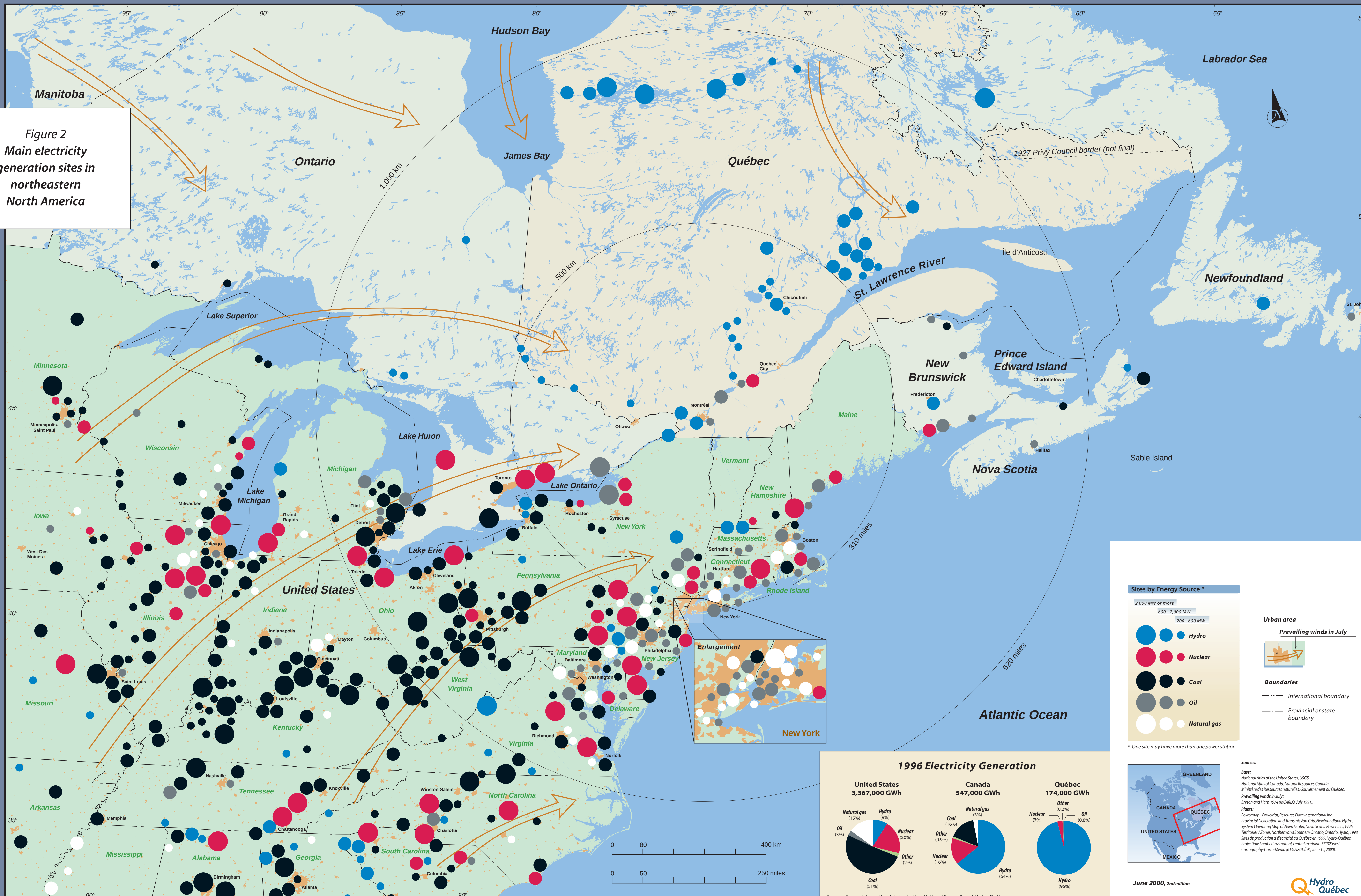
The report is divided into three chapters. The first traces the development of Hydro-Québec's approach to integrating environmental concerns. It briefly describes the environmental studies conducted for northern projects, whether these projects were carried out or not. It also presents an overview of the human and financial resources committed to environmental activities. The second chapter discusses the knowledge acquired through the development of the La Grande hydroelectric complex. This project gave rise to the James Bay and Northern Québec Agreement (JBNQA), the Northeastern Québec Agreement (NQA), and the implementation of a unique, wide-ranging environmental monitoring and follow-up program mainly for the biophysical environment. At the end of the chapter, readers will find a summary of mitigation and compensation measures implemented by Hydro-Québec in order to make its projects and operations environmentally acceptable. The last chapter presents the conclusions, lessons learned and recommendations that have emerged from Hydro-Québec's environmental studies and experiments as a whole, and those of its partners.

Finally, a bibliography lists the reference works on which our review is based, in alphabetical order.

1

Hydro-Québec and the Environment

Figure 2
Main electricity generation sites in northeastern North America



1 Hydro-Québec and the Environment

This first chapter illustrates the important and often innovative role Hydro-Québec has played in the environmental field. It is worth noting certain facts about the company that are often overlooked. Hydro-Québec is one of the 10 largest electric companies in the world in terms of installed capacity and generating output, and ranks first worldwide for hydropower generation. This fact is largely explained by the natural characteristics of Québec's territory, which contains immense river systems but lacks any fossil fuels. It was logical to develop this considerable hydroelectric potential, a source of renewable, non-polluting energy, to meet Québec's energy needs. This situation has also allowed Québec to avoid the emission of greenhouse gases and other pollutants created by thermal power production (see Figure 2).

Unlike European countries and the United States, which developed almost all of their hydroelectric potential in the first half of the 20th century, Hydro-Québec began tapping its potential on a large scale only in the second half of the century, a period that coincided, as we know, with increased awareness of environmental matters. It was therefore only natural for Hydro-Québec to emphasize environmental protection and enhancement in the construction and operation of its hydroelectric facilities. This context should be kept in mind during the reading of this first chapter.

Hydro-Québec's interest in the environment dates back to the early 1970s, about the time it started building its megaprojects in the James Bay region. Since then, to ensure that its hydroelectric facilities are designed, built and operated with the greatest possible respect for the environment, Hydro-Québec has continuously increased its environmental knowledge of both the biophysical and the social environment. In 2000, the company had an installed generating capacity of 31,512 MW (93% hydroelectric) and 153 environmental specialists posted throughout the various units to support the managers responsible for environmental impacts (see Table 1). This large, multidisciplinary team of environmental specialists maintained by a single company is unique in North America (Hydro-Québec, 1999).

Vegetation grows back quickly after a forest fire.

*Table 1 – **Hydro-Québec: Key figures, 2000***

Total installed generating capacity (MW)[1]	**31,512**
Hydroelectric	29,246
Nuclear	675
Conventional thermal	1,591
Total sales (TWh)	**190**
Exports	37
Transmission system (km)	**32,283**
Distribution system (km)	**106,448**
Number of customer accounts	**3,528,825**
Number of employees	**19,416**
Revenue ($ millions)	**11,429**

1. Hydro-Québec also has access to most of the output from Churchill Falls generating station, with a rated capacity of 5,428 MW.

Environmental studies conducted for northern hydroelectric projects played a decisive role in the establishment of the environment unit in 1972 and in its rapid growth. In addition, while its activities concentrated mainly on impact assessment, Hydro-Québec also developed an environmental awareness that extended to all of its operations.

The company introduced an environment code governing construction and operating activities in 1981 and an environment policy in 1984. Sustainable development was added as an objective in the 1989 development plan.

In its initial environment policy, Hydro-Québec affirmed that it was responsible for the protection and enhancement of the natural resources it uses and supplied guidelines for the managers assuming this responsibility. On the strength of this policy, Hydro-Québec was deemed a trailblazer by Environment Canada (Environment Canada, 1991). In 1998, the company adopted a new environment policy to comply with ISO 14001. This policy advocates the judicious use of resources from a perspective of sustainable development and specifies orientations for public health and safety as well as the research required for the application of the policy.

A specialized environmental documentation centre was set up as early as 1973. By 1999, it housed nearly 19,000 scientific articles, reports and other publications. Close to half these documents were written by or for Hydro-Québec and concern environmental research and studies for the company's generation and transmission projects and facilities. The documents are all listed in an easy-to-use on-line catalog.

In 1985, the Advisory Committee on the Environment, made up of members from outside the company, was formed. The committee's original mandate was to advise Hydro-Québec on strategic orientations and make recommendations on environment-related matters. Its role has recently been expanded to include community relations.

It was also in 1985 that Hydro-Québec launched the environmental enhancement program, which basically granted funding for enhancement initiatives in regions affected by construction projects. In 1993, it became an integrated policy providing assistance not only for environmental enhancement but also for regional and Aboriginal community development. These activities are complementary to the mitigation measures and spinoff optimization programs applied during project implementation. From 1985 to 1998, Hydro-Québec allocated some $63 million to 745 initiatives of all kinds, ranging from wildlife habitat improvements to the creation of green spaces, treatment of wastewater and restoration of heritage sites.

The company instituted a program of environmental audits in 1994, aimed primarily at verifying compliance with legal provisions and Hydro-Québec's own regulations, as well as identifying risk situations and determining remedial measures.

In 1996, corporate directives on environmental follow-up of projects were adopted. These directives are in keeping with Hydro-Québec's environment policy, and complement the guidelines for environmental impact assessments. One of the main goals is to make each unit involved in a project, from planning to operation, responsible for implementing its own part of the environmental follow-up program.

Hydro-Québec joined the Environmental Commitment and Responsibility Program (ECR) of the Canadian Electricity Association (CEA) in 1997. Under this program, the company produces an annual report on its results. Measures to establish an ISO 14001–compliant environmental management system by 2002 were launched the same year.

In the *Strategic Plan 2000–2004* published in 1999, Hydro-Québec reaffirmed the three conditions to be met by its development projects:

- They must be profitable under current market conditions.
- They must be environmentally acceptable, in accordance with the principles of sustainable development.
- They must be well received by local communities.

In 2000, the company adopted a directive on the environmental acceptability and favorable reception of new developments, rehabilitation projects, and operation and maintenance activities.

For a number of years, Hydro-Québec has played an active part in various international committees and organizations dedicated to environmental protection and the promotion of hydroelectricity and other forms of renewable energy in a context of sustainable development. They include the International Energy Agency, the World Commission on Dams and the International Association for Impact Assessment. As a result of the knowledge acquired by Hydro-Québec in the past 30 years, the company's competence is recognized by all these organizations.

Figure 3
Northern Québec

1.1

Hydro-Québec and environmental studies in the North

In 1971, the Québec government made the decision to develop the hydroelectric potential of the James Bay drainage basin (*James Bay Region Development Act,* National Assembly of Québec, July 1971). While the large hydroelectric developments of the 1950s and 1960s, such as those on the Bersimis River, on the Manicouagan and Aux Outardes rivers, and at Churchill Falls, were built before the concept of environmental protection had been developed, the same approach could not be used in the early 1970s. In fact, the environment would become one of the most important aspects of all the James Bay hydro projects, as it would be, moreover, for all other projects subsequently undertaken by Hydro-Québec (see Figure 3).

1.1.1 Projects involving the James Bay and Hudson Bay drainage basins

Environmental studies for the La Grande complex cannot be discussed without mention of the James Bay and Northern Québec Agreement (JBNQA), signed in 1975 by the governments of Canada and Québec, Hydro-Québec, the Société d'énergie de la Baie James (SEBJ – James Bay Energy Corporation), the Société de développement de la Baie James (SDBJ – James Bay Development Corporation), the Crees of Québec as represented by the Grand Council of the Crees of Québec, and the Inuit of Québec as represented by the Northern Quebec Inuit Association.

Chapter 8 of the Agreement clearly defines the La Grande complex (1975), then under construction, along with the measures intended to mitigate its environmental and social impacts. It presents the rationale behind certain remedial measures in the reservoirs or diversion zones, such as land clearing and flow regulation.

The signatories of the JBNQA allowed for the possibility of future hydroelectric developments within the boundaries of the territory concerned, in particular Grande-Baleine (Great Whale) and Nottaway–Broadback–Rupert (NBR), which would also come under the environmental protection regimes established in chapters 22 and 23 of the Agreement.

Section 2.11 ("Social environment") contains more details on the JBNQA and subsequent agreements. Interested readers may want to consult the article "The Unknown James Bay and Northern Québec Agreement" by Georges Beauchemin of the Québec government's Aboriginal affairs office, published in Issue 97 of the magazine *Forces* (1992).

SEBJ, established in December 1971 and later to become a Hydro-Québec subsidiary, was given the mandate of developing the hydroelectric potential of the rivers on the Québec side of James Bay. Three projects were studied: La Grande, Grande-Baleine, and NBR.

La Grande complex

In July 1971, a federal-provincial task force was formed to evaluate the possible environmental impacts of developing the hydroelectric potential of the James Bay region. Practically nothing was known of the region from an ecological standpoint. All the scientists who had studied the James Bay region or the northern environment took part in the task force. During the 1970s, the James Bay region of Québec became the main site for ecological research in Canada.

In 1973, federal and provincial agencies, along with SDBJ, signed the Biophysical Agreement establishing the division of responsibilities and costs related to the various studies.

SEBJ, for its part, concentrated its efforts on an overall ecological study of the bodies of water in the territory covered by the project. After the Agreement expired in 1979, SEBJ carried on its follow-up studies and inventories, in particular through the environmental monitoring network (EMN) set up in 1977. A description of this follow-up, which continues today, will be found in section 2.4.

On the subject of the La Grande complex (1975), the JBNQA calls for the establishment of two bodies to oversee environmental protection (biophysical and social environments), made up of representatives appointed by SEBJ and the Aboriginal nations:

- The La Grande Complex Remedial Works Corporation (also known by its French acronym SOTRAC), in charge of studying, planning and implementing remedial measures and programs to mitigate negative impacts on the Crees' activities, particularly hunting, fishing and trapping
- The Groupe d'étude conjoint Caniapiscau-Koksoak (GECCK – Caniapiscau-Koksoak Joint Study Group), in charge of studying impacts on the Caniapiscau–Koksoak region and proposing mitigation measures; the GECCK studies mainly concerned the effects of the Caniapiscau diversion on the Koksoak salmon—an important resource for the Inuit of Kuujjuaq (formerly Fort Chimo)

Finally, the Agreement reinforced the role of SEBJ's Environmental Experts Committee and provided for the appointment of one Cree and one Inuit representative. This advisory body was asked to formulate environmental protection recommendations for SEBJ management.

The Agreement allowed the La Grande complex to be built and defined specific obligations in terms of acceptability, mitigation measures and remedial works designed to better integrate the complex into the environment. It thus contributed significantly to increased environmental awareness in Québec and the rest of Canada. In addition, it provided a specific legal framework for the project developer's obligation to carry out impact assessment studies that are evaluated and examined openly and publicly by committees which include representatives of the Aboriginal peoples and of the governments of Québec and Canada. The Agreement thus paved the way for the amendments to Québec's *Environment Quality Act* pertaining to impact assessment studies.

Because the La Grande complex is so large and is the only one of the three projects described in the JBNQA to have been built, the environmental studies conducted for the other two projects are sometimes forgotten. Concurrently with the environmental studies program implemented for the La Grande complex, described in Chapter 2, Hydro-Québec launched two other large-scale environmental study programs. These concerned the drainage basins of the Grande rivière de la Baleine and the Petite rivière de la Baleine, located further north (the Grande-Baleine project, often known as Great Whale), and the basins of the Nottaway, Broadback and Rupert rivers, located further south (the NBR project).

Grande-Baleine project

In environmental terms, after the studies for the La Grande complex, the most comprehensive studies were those carried out for the Grande-Baleine project over a period of nearly 20 years, namely from 1971 to 1982 and then from 1988 to 1993. They covered the biophysical environment in all its aspects and, to a lesser extent, the social environment in the vast territory located north of the La Grande complex, and gave rise to more than 1,000 scientific reports and articles between 1971 and 1992. A summary of these studies was included in a draft design submitted in August 1993 to the Québec and Canadian governments in order to secure authorization to proceed with the project, which was ultimately set aside in 1994.

Of the studies carried out in connection with the Grande-Baleine project, three major programs are notable for advancing the body of knowledge, namely those concerning caribou, land use and economic development in remote regions.

The caribou studies, conducted in cooperation with the Québec government department responsible for wildlife management, added to our understanding of the relationship between this ungulate and its environment, its migrations, its calving grounds and the different ways it occupies its far-flung territory from season to season. The studies revealed, for example, that caribou use the region's large, frozen natural bodies of water as a shortcut to reach adjacent spruce-lichen stands. Hydro-Québec's specialists were consequently able to predict that the La Grande reservoirs would be used in the same way.

The Grande-Baleine social environment studies, begun in the early 1970s, were ahead of their time. Environmental impact assessments were then relatively unconcerned with the socioeconomic reality of human populations, being confined almost exclusively to physical and biological phenomena. In the case of the La Grande complex, efforts were concentrated mainly on mitigation and compensation measures related to hunting, fishing and trapping. To better evaluate the impacts of the Grande-Baleine project, it was essential to clearly identify which changes in Aboriginal land use resulted from the project itself and which from the application of the JBNQA. Considerable effort was devoted to this question by a multidisciplinary team of specialists from Hydro-Québec as well as from its partners, consulting firms and universities.

Despite an agreement in principle signed in 1993 by the Inuit of the region, the Grande-Baleine social environment studies did not result in final agreements with the communities concerned. They nonetheless paved the way for an approach based on dialogue. It is only through this type of approach that a project can improve the socioeconomic situation of the populations affected.

NBR project (Nottaway–Broadback–Rupert)

The NBR project, too, gave rise to major environmental studies. Begun in 1966, the study of the three river basins continued almost uninterrupted until 1994. As with the studies for the Grande-Baleine project, these studies covered all aspects of the biophysical and social environment and generated over 1,000 reports.

1.1.2 Ungava Bay projects

From 1975 to 1982, Hydro-Québec carried out numerous environmental studies in the Ungava region to learn about the principal components of the ecological zones and socioeconomic environment of this vast northern territory. The studies were also designed to bring out the main environmental issues raised by the development of the hydroelectric potential of the Arnaud, Aux Feuilles, Koksoak–Caniapiscau–Aux Mélèzes (KCM), À la Baleine and George rivers, all of which empty into Ungava Bay. The basin of the Caniapiscau River, the upper course of which was diverted into the Grande Rivière basin in 1984, has been the focus of intensive environmental studies since 1973 in connection with the construction of the La Grande complex.

1.1.3 North Shore projects

From 1975 to 1982, the year the last turbines in the Manicouagan and Rivière aux Outardes projects went into operation, Hydro-Québec studied the hydroelectric potential of several drainage basins along the North Shore (the region of Québec located along the North Shore of the St. Lawrence River, between the mouth of the Saguenay River and the Labrador border). Along with the technical studies, environmental studies were conducted in the basins with the greatest potential. In the early 1980s, with the oil crisis and the expected slowdown in electricity demand growth, Hydro-Québec temporarily abandoned these studies. Some of them had resumed by the end of the decade.

Since the projects concerned a number of Atlantic salmon rivers, Hydro-Québec instituted a wide-ranging program of studies to evaluate the salmon-producing potential of the North Shore rivers. This program, carried out in cooperation with Québec's Ministère du Loisir, de la Chasse et de la Pêche (Department of Recreation, Fish and Game), was designed to provide a comprehensive, detailed understanding of the sites frequented or likely to be frequented by salmon. Once this potential was known, it could be compared with the hydroelectric potential. A better understanding of the economic and social value of both these important resources allows an enlightened choice to be made regarding basins that could be developed with a minimum of constraints for the salmon, and would also provide data that could be used to improve the river basins' potential.

After seven years of studies (1983–1989), an atlas of Atlantic salmon habitats on the North Shore and in part of the Saguenay basin was published. Through photo-interpretation and field surveys, some 50 rivers were fully or partially characterized in terms of their quality and productivity as salmon habitats. This atlas, which also contains data on salmon harvesting, is a very useful tool for managers of the salmon resource, specialists concerned with projects of all kinds, and the people who actually harvest the resource. The research formed the basis of the impact assessment on the effect of flow reduction on the Moisie River salmon population as part of the Sainte-Marguerite-3 project.

Manic-Outardes complex

By 1975, the North Shore hydroelectric projects on the Manicouagan and Aux Outardes rivers, begun in 1959, were nearing completion. Only Manic 3 and Outardes 2 reservoirs had not yet been impounded. While these projects were not subject to any environmental protection obligation, Hydro-Québec took the initiative of evaluating the reservoirs' possible impacts on the aquatic wildlife. Lake trout spawning grounds were consequently built in both reservoirs before filling began. In addition, Hydro-Québec stocked Outardes 2 reservoir with rainbow smelt and landlocked salmon, and built a fish ladder in one of the tributaries to allow landlocked salmon to reach new spawning grounds. Nesting sites for waterfowl were also set up in Outardes 2 reservoir. This reservoir became a kind of pilot project for studies on changes in fish populations and riparian plant communities.

Romaine project

From 1975 to 1980, Hydro-Québec carried on environmental studies in the basin of the Romaine, a river that empties into the Gulf of St. Lawrence. Over the six years, Hydro-Québec and its partners drew up nearly 200 reports on the main environmental elements in the region.

Sainte-Marguerite-3 project

Since 1985, Hydro-Québec has conducted major studies on the biophysical and social environment in the basins of the Sainte-Marguerite and Moisie rivers on the North Shore of the St. Lawrence. One particular aspect of these studies should be noted here. Since the project originally called for the diversion of two tributaries of the Moisie, one of the main salmon rivers in Québec, Hydro-Québec instituted an innovative, extensive program of studies on the biology and behavior of the salmon, in order to assess the consequences of a reduction in flow on the Moisie salmon population. The program, overseen by an independent scientific committee of salmon specialists, led to the creation of a hydrodynamic and biological model of the salmon habitat in the Moisie, among other results. This model, the value of which has been recognized by the scientific community and by a federal-provincial committee of specialists, represents a major contribution to the understanding of salmon behavior and of ecological factors linked to its river habitat, as well as to the evaluation of the effect of a reduction in flow on this habitat.

In February 1994, after public hearings and a review of the project by the federal and provincial governments, Hydro-Québec obtained authorization to build an 882-megawatt generating station on the Sainte-Marguerite, but without diverting any tributaries of the Moisie. The planned diversion was to be studied by a federal-provincial committee formed to examine the impacts on the salmon and on fishing. In December 1996, this committee submitted its report to the two governments; an excerpt follows.

> The Committee is of the opinion that in the short and even the medium term it will be difficult to improve on the knowledge of the biology of Moisie River salmon accumulated over the last ten years—the last two in particular. There is so much variability in natural elements and in predicted modifications in flow conditions that any changes stemming from the diversion will probably not be great enough to be distinguished from those that are completely natural. The Committee therefore believes that continuing its work at this stage would yield very little new information that might influence an environmental decision about diverting the Carheil and Pékans rivers.
>
> However, should the provincial and federal governments decide to authorize the diversion, the Committee believes the environmental monitoring recommendations in Section 3.5 of this report should be considered. (Federal/Provincial Committee on the Biology of Moisie River Salmon, 1996)

Following this positive report, Hydro-Québec presented a new application to the Québec government for authorization to carry out the diversion. No decision has been made to date. Sainte-Marguerite-3 generating station itself is scheduled for commissioning in 2001.

Other innovative steps taken as part of the Sainte-Marguerite project include

- The establishment of a joint scientific committee with representatives from Hydro-Québec and the Conseil Attikamek-Montagnais

- The 1994 signing of the Uashat mak Mani-Utenam Agreement between Hydro-Québec and the Uashat-Maliotenam Innu band

- The creation of SOTRAC (Sainte-Marguerite) remedial works corporation

Lac-Robertson development

In 1991, the Québec government authorized Hydro-Québec to build Lac-Robertson hydroelectric generating station, on the Lower North Shore, and shut down the diesel-fired thermal power plants that had supplied the region's isolated villages—a much more polluting form of generation than hydropower.

Using knowledge acquired over 20 years in northern environments, Hydro-Québec was able to complete the 21-MW generating station in 1995 in accordance with the principle of sustainable development. Hydro-Québec's main concerns were to minimize the negative impacts of the project and maximize the economic spinoffs in this remote region. One of the ways it did this was by signing an agreement with the local communities on environmental follow-up.

1.1.4 Ashuapmushuan project

In the early 1970s, Hydro-Québec conducted its first environmental studies in the drainage basin of the Ashuapmushuan, one of the main tributaries of Lac Saint-Jean. These studies, set aside after a few years and then resumed in 1988, covered the principal aspects of the biophysical and social environment and contributed, above all, to a better understanding of the landlocked salmon population in Lac Saint-Jean and its largest tributaries, local land use by the Aboriginal people, and regional economic development. The project was shelved in 1993.

1.1.5 Power transmission system

To carry electricity from generating stations in the north to urban centres in the south, Hydro-Québec built more than 30,000 km of high-voltage lines (over 120 kV), largely in uninhabited areas. Route selection, line construction and maintenance in accordance with the environment policy and regulatory provisions required numerous environmental studies. Hydro-Québec devised a routing method that has gained widespread acceptance. This method incorporates environmental concerns into every stage of a project's study (Hydro-Québec and Dessau, 1996).

Hydro-Québec also conducted major research on the protection and enhancement of deer and moose habitat and farmland, on integrated vegetation control and on the identification and assessment of impacts on the landscape. The company introduced an international action plan in 1987 to study the environmental and health effects of the electrical and magnetic fields of power lines in agricultural and urban surroundings.

1.2 Agreements with Aboriginals

Over the last quarter-century, Hydro-Québec has signed numerous agreements with Aboriginal nations. In fact, it was the first North American electric utility to sign such agreements.

Negotiating these agreements afforded an opportunity to reconcile the company's objectives with the interests of local communities. Despite occasional divergences of opinion, the talks took place in a climate of understanding and mutual respect.

In working with Native communities, Hydro-Québec had two main challenges to meet: first, it had to seek to reduce the impact of its projects and operations on the traditional way of life, and it could not do this without conducting a series of consultations prior to any development project.

The Aboriginal way of life and traditional values throughout northern Québec have changed rapidly over the past 40 years. Previously nomads gaining their sustenance from hunting and fishing, Native people have now settled in communities and become part of the cash economy.

Since the signing of the JBNQA, Hydro-Québec has been aware that its projects have a major impact on the Aboriginal way of life and on the social and economic structures of their communities. Even in the earliest agreements, it acknowledged this fact and sought appropriate ways to offset it, or at least to limit the extent of the impacts.

The best tool for this was the SOTRAC, a non-profit, jointly owned company with a mandate to carry out remedial works. Each SOTRAC is, first and foremost, an organization created to serve the interests of communities directly affected by a hydropower project. Its job is to reduce the negative impacts of the project, promote the continued use of the lands directly affected, and encourage the pursuit of traditional activities.

In addition to overseeing the implementation of remedial measures, the SOTRAC is a forum where contentious issues arising from the project can be discussed and debated. It also ensures ongoing dialogue towards achievement of the goals and objectives stated in the JBNQA.

The second major challenge was to ensure that the design and execution of its projects and activities would help Aboriginal nations participate in the Québec economy. To this end, all the agreements provide for ways and means of stimulating regional economic development; for example, priority goes to Native-owned businesses in the awarding of contracts for construction, maintenance, repair and various services. In fact, the contract award process is designed to ensure that at least some of the work is done by Aboriginal suppliers.

Hydro-Québec has conducted information campaigns in Aboriginal communities to ensure that Native-owned businesses were well informed about the company's business practices and administrative procedures. It has also promoted joint ventures so that Aboriginal businesses could acquire expertise in new fields.

In some cases, negative impacts have persisted even after a project has been completed. For this reason, the more recent agreements provide for joint committees to ensure effective implementation of the agreement, to review its implementation and to serve as a permanent forum for the settlement of any conflicts or disputes.

1.3

Human resources

Hydro-Québec's environment function quickly took on an important role, in terms of both human and financial resources.

From 1982 to 1990, Environment personnel averaged more than 200 employees. If external human resources are included, the annual work force totaled nearly 300 person-years. The Environment staff has always been made up primarily of specialists in the various fields of study. In 2000, following a reduction in the number of new projects, the workforce totaled 150 (Hydro-Québec, 1990 and 1994).

In conducting environmental studies, Hydro-Québec also calls upon specialized firms with which it has often developed highly advanced skills in particular fields such as habitat modeling, satellite-image mapping and archaeology in northern environments.

Hydro-Québec supports three university research chairs in the environmental field:

- The Hydro-Québec–NSERC–UQAM Environmental Research Chair (research into mercury and greenhouse gases)
- The NSERC–École polytechnique de Montréal Industrial Chair in Site Bioremediation
- The Université de Montréal Environmental Design Chair

Hydro-Québec also participates in a number of programs and studies together with partners from the public and private sectors:

- Various Québec and Canadian government departments, including the provincial departments of environment and natural resources, Environment Canada, Fisheries and Oceans Canada, and National Defence
- Environmental protection organizations such as the Fédération québécoise de la faune (Québec Wildlife Federation), Fédération québécoise pour le saumon atlantique (Québec Atlantic Salmon Federation) and Ducks Unlimited Canada
- Universities, including McGill and the universities of Québec, Sherbrooke, Montréal and British Columbia
- Research centres such as the northern studies centre, the Québec interuniversity group for oceanographic research, and the Inuit and circumpolar study group—all at Université Laval
- Corporations such as Bell Canada, Ontario Hydro, Électricité de France, Électrabel (Belgium) and Vattenfall (Sweden)
- International organizations including the International Union of Producers and Distributors of Electrical Energy (UNIPEDE), the International Hydropower Association (IHA) and the International Commission on Large Dams (ICOLD)
- Organizations such as the Cree Regional Authority, the Chisasibi, Eastmain, Whapmagoostui, Wemindji and Mistissini band councils, the James Bay Eeyou Corporation, the SOTRACs of Sainte-Marguerite and Opimiscow, and the Bersimis salmon committee

1.4

Scientific publications

Studies carried out by Hydro-Québec and its partners have generated some 8,000 reports and hundreds of scientific articles in all environmental fields (biophysical and social environment), and numerous databases on such subjects as reservoirs, fish, mercury, archaeological sites and remote communities. Because of its scope and diversity as well as the quality of the information, this contribution to the environmental sciences and to an understanding of northern environments is likely unique in North America, if not the world. Nearly all of the scientific reports and a number of the scientific articles produced by Hydro-Québec have been published in French only, however, and are not very widely distributed in the English-speaking scientific community. In recent years, the active participation of the company's environmental specialists and managers in international committees for environmental protection has helped increase awareness of the value and importance of the past 30 years of studies conducted by Hydro-Québec and its partners.

1.5

Financial resources

Since the environment unit was first established in 1972, Hydro-Québec has spent over a billion dollars on the environment. The following list includes some of the environmental protection, enhancement and research activities conducted over this period, and specifies the amounts committed (see Table 2).

If we add up all the amounts Hydro-Québec has allocated to the various categories of environmental spending defined by Statistics Canada, the annual total ranges between $61.4 million and $127 million from 1990 to 1994, for an annual average of $96 million (Statistics Canada, 1995; Hydro-Québec, 1996).

Table 2
Environmental protection and enhancement activities: Overview, 1972 to 1999

Activity	**Cost** ($ millions)
Environmental impact studies and assessments (not including mitigation and compensation measures) *(1974–1995)*	297
Action plan on electric and magnetic fields *(1986–1995)*	20
La Grande environmental monitoring network *(ongoing since 1977)*	23
Research and knowledge development *(1974–1996)*	130
Action plan on mercury and greenhouse gases *(1988–1999)*	20
Environmental Enhancement Program *(1985–1999)*	66
Environmental studies and measures at the La Grande complex (not including compensation to Aboriginals) *(1972–1999)*	250
Action plan on PCBs *(1985–1995)*	130
PCB disposal program *(1995–1998)*	24

2

Lessons from 30 Years of Environmental Studies in the North

2 Lessons from 30 Years of Environmental Studies in the North

The following chapter is based on all the environmental studies carried out by Hydro-Québec, its subsidiary SEBJ and its partners and, in particular, on the data collected from environmental monitoring and follow-up at the La Grande complex.

The chapter begins with some brief background information on the James Bay region and the La Grande complex, along with the main environmental protection measures implemented during the construction of this complex. Next, an outline of the environmental follow-up program summarizes the physical changes produced in aquatic environments, the remedial measures applied during construction to prevent or reduce changes in these environments, and the chemical and biological effects of the changes. The terrestrial and social environments are discussed separately at the end.

2.1

James Bay region

The James Bay region of Québec extends roughly from 49 to 55 degrees north latitude and covers more than 400,000 km^2—equivalent to the area of Germany or two-thirds of France.

Part of the Canadian Shield, the region forms a vast platform characterized by complex geological formations that date back to the Precambrian era, some 2.5 billion years ago.

During the Quaternary period, the repeated advances of the glaciers eroded the bedrock. The last ice age, which lasted approximately 85,000 years, ended about 5,000 years ago. Its traces are still apparent in outcrops in the uplands and till deposits (rock debris left behind by the glaciers) in depressions and on hillsides.

Taiga.

Taiga after an extensive fire.

From west to east, the topography features a coastal plain 150 km wide, with scattered peat bogs and clay deposits; a hilly central plateau with numerous lakes; and an area of rougher terrain. Nearly 8,000 years ago, the Tyrrell Sea covered the coastal plain up to today's elevation of 290 m, forming a sedimentation basin in which major deposits of silty clay and fine sand accumulated.

Climate

In addition to the vast and barren landscape, there is the further hardship of a cold continental climate.

Winter sets in by late October and stays until early May, with a mean minimum temperature of about -23°C in January. The mercury can dip as low as -50°C in the dead of winter, and the cold is made even more bitter by strong winds. Snow is less of a problem, as the region receives less precipitation than Montréal: 765 mm of rain or snow on average every year, compared with 1,050 mm in Montréal. Summers are fairly warm: in July, the mean temperature is around 14°C, with occasional highs of up to 34°C. In these northern latitudes, summer evenings are long, warm and bright.

Hydrography

The hydrographic system on the Québec side of James Bay consists of several major rivers having few tributaries and fed almost directly by the lakes of the intermediate plateau.

The rivers are fed by rain and snowfall. They experience heavy spring floods from snowmelt, followed by a summer low-water season that varies in severity from year to year. The fall flood, resulting from rainfall, appears as a rise in the waters that begins to subside in November.

Fish

The region is home to 27 species of fish, which decrease in number from south to north and from west to east. There is no Atlantic salmon in the rivers that empty into James Bay. The most abundant species found in the region are longnose sucker, white sucker, lake whitefish, cisco, northern pike, lake trout, walleye, brook trout and ouananiche (landlocked salmon). The latter was formerly found only in the Caniapiscau River basin. Since the diversion of the upper course of this river into the Grande Rivière, however, this species has been caught downstream from some of the La Grande generating stations.

On the whole, the fish here grow more slowly than in the southern regions of Québec, but their greater longevity allows them to reach a comparable size. They show generally low fertility, late maturity and widely spaced breeding cycles.

Vegetation

The region lies in the middle of the taiga, a sparse forest dotted with numerous peat bogs in the coastal plain. The forest consists mainly of black spruce, jack pine, larch and aspen. Because the trees reach only 10 to 15 cm in diameter, they are unsuitable for commercial harvesting in the northern half of the region. Here and there, burns may be seen—vestiges of fires started by lightning in the long summer dry spells and fed by cladonia (reindeer moss). A small number of deciduous trees grow in the few places both protected from the wind and exposed to the sun.

Mammals

Although the density of animal populations is generally lower than in southern Québec, owing to the harshness of the climate, there is a great diversity of species. Thirty-nine species of mammals, including moose, caribou, beaver, muskrat, lynx, otter, red fox, black bear, mink, snowshoe hare, red squirrel and marten, have been spotted in the region. The first three species have been the most thoroughly inventoried, due to their economic or recreational value.

Birds

The coasts of James Bay offer a wide range of habitats suitable for migratory birds (islands, sandbars, coastal swamps, peat bogs). Inland, however, habitats with waterfowl potential are not so numerous. Among the species found along the coast are geese (Canada goose, snow goose), dabbling ducks (mallard, black duck), diving ducks (scaup, goldeneye, merganser), sea ducks (common eider, scoter) and small wading birds (sandpiper, plover, etc.).

Human populations

Despite the harsh climate, there has long been a human presence in the James Bay region, which includes all or part of the drainage basins of six major rivers. According to archaeological excavations carried out in areas affected by the La Grande complex, human presence dates back about 4,000 years. Over 12,000 Crees live in eight villages scattered over the region as well as the village of Whapmagoostui, located just outside the northern boundary. A number of Inuit also live at the northern edge of the region, although most Inuit are north of the 55th parallel.

The non-Native population totals more than 10,000, concentrated mainly in the mining towns in the south of the region. In the northern part, the only permanent non-Native village is Radisson. Since the opening of the Matagami–Radisson highway, the region has also been visited by tourists and non-Native hunters and anglers (see Figure 4).

2.2

La Grande complex

The area that supplies the La Grande hydroelectric complex with water encompasses the drainage basin of the Grande Rivière as well as the upper drainage basin of the Caniapiscau River to the east (Laforge diversion) and the Eastmain and Opinaca rivers to the south (EOL diversion, now called Boyd-Sakami), representing a total area of nearly 177,000 km^2. Developing the complex involved the construction of eight generating stations and eight reservoirs in two phases (SEBJ, 1996).

Phase I of the work, which began in 1973 and ended in 1985, gave rise to the construction of La Grande-2 (Robert-Bourassa),* La Grande-3 and La Grande-4 generating stations. Each of these generating stations has its own reservoir, as do the diverted rivers, namely the Caniapiscau, Eastmain and Opinaca. Opinaca reservoir, created by the EOL diversion, provides Robert-Bourassa generating station with an additional mean annual flow of 835 m^3/s. Caniapiscau reservoir, the head reservoir in the La Grande complex, acts as an interannual flow regulator with its input of a mean annual flow of approximately 795 m^3/s. The installed capacity of the three generating stations is 10,282 MW, their annual output totals 64.6 TWh, and their load factors range from 57% to 63%. The reservoirs created in Phase I have a total area of 11,335 km^2, with an interannual drawdown of 4 m to 13 m.

The EOL and Laforge diversions doubled the energy potential of the Grande Rivière. The EOL diversion resulted in a 90% reduction in the flow of the Eastmain at its mouth, while the Laforge diversion reduced the flow of the Caniapiscau at its mouth by 48%. The mighty Koksoak River, fed in part by the Caniapiscau, experienced a 35% reduction in flow at its mouth in Ungava Bay. As a result of these substantial inflows, the mean annual flow of the Grande Rivière at its mouth doubled from 1,700 m^3/s to 3,400 m^3/s, and the mean winter flow increased more than tenfold, from 500 m^3/s to over 5,000 m^3/s.

Phase II, which got under way in 1987, did not engender nearly as many physical changes as Phase I. Along the route of flow already defined by the Phase I structures, five generating stations were added: La Grande-1, La Grande-2-A, Laforge-1, Laforge-2 and Brisay. These generating stations increased the installed capacity of the complex by 4,954 MW and its annual output by 18.3 TWh, with a load factor of about 60%.

Three new reservoirs were also built: La Grande 1 (70 km^2), Laforge 1 (1,288 km^2) and Laforge 2 (260 km^2). With a total area of 1,618 km^2, these reservoirs have a drawdown ranging from 1.5 m to 8 m (SEBJ, 1996).

In 1999, the La Grande complex had an installed capacity of 15,244 MW and annual output of 80.7 TWh. The drainage basin of the Grande Rivière, as developed, covers 176,800 km^2. Reservoir area totals 12,953 km^2. If all the bodies of water existing prior to development are factored in, the area flooded is equivalent to about 6% of the Grande Rivière watershed (see Table 3).

* La Grande-2 generating station, dam and reservoir were renamed Robert-Bourassa generating station, dam and reservoir in 1996.

Table 3 – ***La Grande complex, 2000***

	Reservoir level, max. (m)	Reservoir level, min. (m)	Area at max. level (km^2)	Active storage (hm^3)	Type of generating station	Number of generating units	Type of turbine	Installed capacity (MW)	Annual output (TWh)	Max. usable flow (m^3/s)	Rated net head (m)	Load factor (%)	Year of commissioning
PHASE I													
Robert-Bourassa (La Grande-2)	175.3	167.6	2,835	19,365	U	16	F	5,328	35.2	4,300	137.2	57	1979–1981
La Grande-3	256.0	243.8	2,428	25,200	S	12	F	2,304	12.3	3,260	79.2	62	1982–1984
La Grande-4	377.0	366.0	765	7,160	S	9	F	2,650	14.6	2,520	116.7	61	1984–1986
EOL (Opinaca)	215.8	211.8	1,040	3,395									1980
Caniapiscau	535.5	522.6	4,275	39,070									1984
Subtotal			**11,343**	**94,190**		**37**		**10,282**	**62.1**				
PHASE II													
La Grande-1	32.0	30.5	70	98	S	12	P	1,368	7.5	5,950	27.5	57	1994–1995
La Grande-2-A	*	*	*	*	U	6	F	1,998	2.2	1,620	138.5	57	1991–1992
Laforge-1	439.0	431.0	1,288	6,857	S	6	F	840	4.5	1,610	57.3	60	1993–1994
Laforge-2	481.1	479.6	260	390	S	2	K	310	1.8	1,200	27.4	69	1996
Brisay	**	**	**	**	S	2	K	446	2.3	130	37.5	70	1993
Subtotal			**1,618**	**7,345**		**28**		**4,962**	**18.3**				
TOTAL			**12,961**	**101,535**		**65**		**15,244**	**80.4**				

Notes: * Robert-Bourassa reservoir (formerly La Grande 2) was built during Phase I.

** Caniapiscau reservoir was built during Phase I.

Type of generating station
U Underground
S Surface

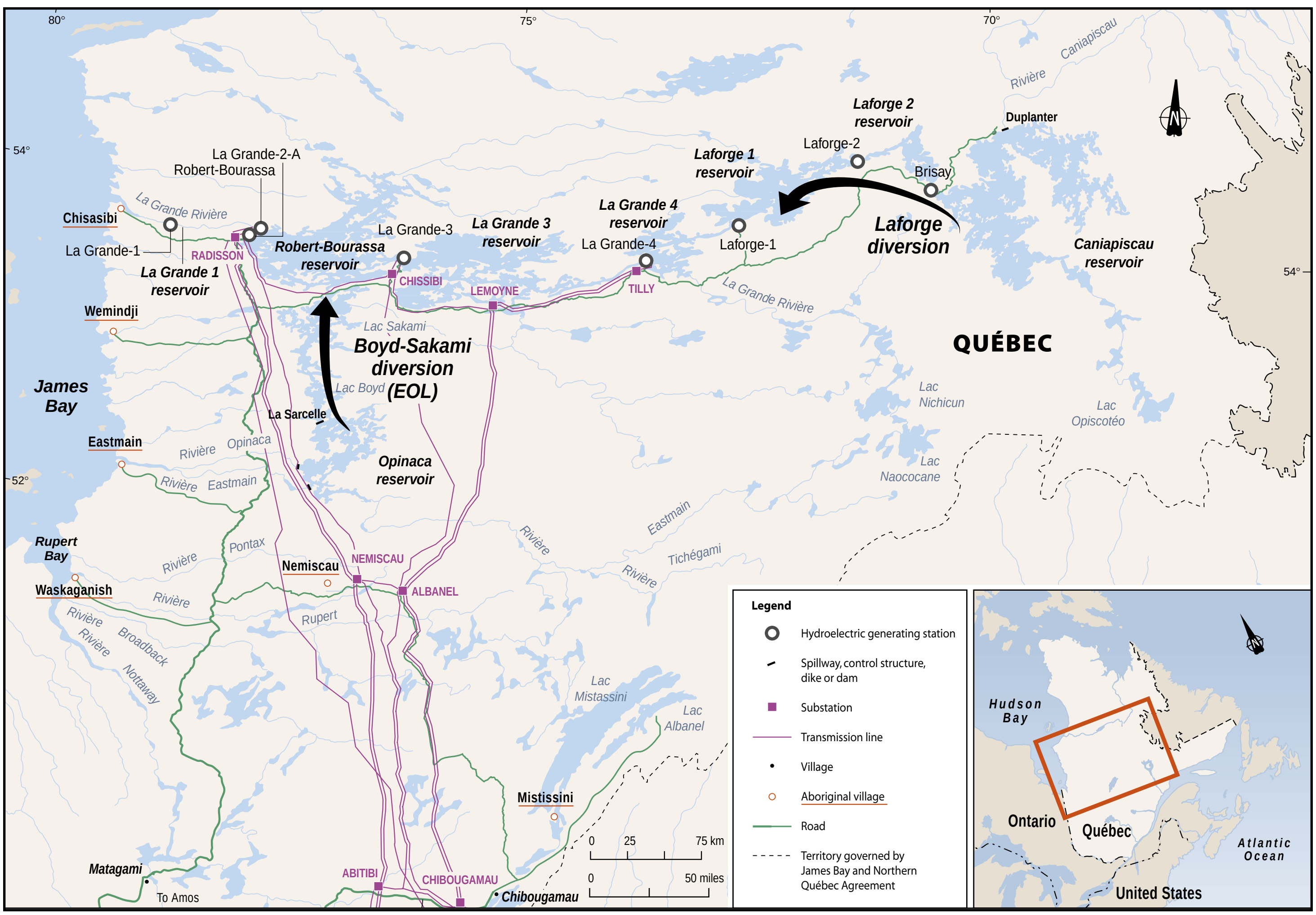
Type of turbine
F Francis
P Propeller
K Kaplan

To carry the electricity to the major load centres in southern Québec, seven transmission lines were built: six 735-kV lines and one 450-kV direct-current line. Running a total length of 10,000 km, these lines mainly serve the people of Québec, but also allow exports of surplus electricity to the United States.

Developing the La Grande complex also called for the construction of seven airports and 1,300 km of road, half of it paved (see Figure 4).

*Two 735-kV lines spanning a stream.
Note how the banks are protected by vegetation.*

Figure 4 – ***La Grande complex***



2.3

Environmental protection during construction

A project the size of the La Grande complex—an endeavor that took over 20 years—cannot be built without changing the biophysical and social environments concerned. It was essential to define, from the outset, the main environmental protection principles to be applied during the design, construction and use of the roads and building sites. Seven activities were targeted: selection and use of sources of natural materials (quarries and sandpits), design and construction of roads, construction of camps and villages, treatment and disposal of wastewater, drinking water supply and purification, disposal of solid and liquid waste, and construction of fuel depots (SEBJ, 1987).

The guidelines developed for these seven activities were intended, first of all, to specify the objectives, principles and means favored by SEBJ, in order to guide the designers and builders with respect to environmental protection. The guidelines were incorporated into the tender documents, so that any company taking part in the work was contractually responsible for applying them and, consequently, for protecting the environment.

To provide effective site supervision from an environmental standpoint, an environmental protection supervisor was included in the management team for each work site. This supervisor formed a direct liaison with environment personnel at head office. During Phase II of the work, the environmental protection supervisors were also responsible for compliance with government environment policies and laws as well as Hydro-Québec's environment code.

After project completion, Hydro-Québec and the Cree Regional Authority undertook a cleanup of all the areas used: leveling the ground, consolidating steep slopes and loosening the soil to facilitate regrowth of the ground cover. These activities are now nearing completion. Grasses and leguminous plants were seeded by air, and 11 million trees and shrubs were planted.

2.4

Environmental follow-up studies

The La Grande complex is the subject of the most extensive follow-up program ever implemented by Hydro-Québec. Much of this program concerns the aquatic environment of reservoirs and diversion zones. To learn what changes had occurred in the new aquatic systems, an environmental monitoring network (EMN) was established in 1977. This network, which is unprecedented in its scope, was designed by some 15 internationally respected scientists from around the world.

The objectives were defined as follows:

- Study the physical, chemical and biological changes in the reservoirs and aquatic environments affected, using a scientific approach of recognized value
- Use the information collected to rationalize remedial measures and reservoir management
- Take advantage of this experience to improve impact forecasting methods

It was decided to begin the monitoring two years before the scheduled date of formation or transformation of major water systems. To ensure that the desired information was obtained, the observation points, parameters measured and sampling frequency had to be chosen judiciously. Three criteria guided the selection of the sites used: representativeness of the environment, uniqueness of the environment and ability to encompass all the changes.

Altogether, 27 permanent sampling stations measuring 20 or so parameters were installed, some of them at control sites not affected by the work. The principal parameters studied concerned water quality, phytoplankton, zooplankton, the benthos, fish and fish mercury concentrations. To illustrate the extent of this monitoring network, let us quote one of the scientists who took part in its design, Norman G. Benson, of the United States Fish and Wildlife Service: "I had never seen an environmental assessment scheme as thorough as the one the SEBJ was preparing to undertake. And yet I had made a detailed study of the Missouri River reservoirs in the United States and I was also well aware of the studies on the Tennessee Valley Authority reservoirs." (Carpentier, 1992)

In addition to the EMN, which essentially targeted reservoirs and diversion zones, the program involved observing changes in James Bay, its estuaries and the coastal environment, as well as the effects of the construction on riparian habitats and populations of ptarmigan, waterfowl, caribou, beaver, moose and hare. Monitoring of the social environment covered land use for wildlife harvesting, economic spinoffs, and mitigation measures implemented in the area of the La Grande complex.

In 1985, Hydro-Québec modified the program to take the newly acquired knowledge into account. After recognized mathematical tests had confirmed that the modifications did not diminish the value of the interpretations, certain parameters concerning water quality, plankton and the benthos were abandoned. Others, such as fishing yields, mercury levels and the economic situation of remote communities, were retained and made more precise, for a better understanding of long-term changes.

For Phase II of the La Grande complex, which began in 1987, Hydro-Québec devised a specific environmental follow-up program to fulfill the obligations set out in the certificates authorizing the construction of the six new generating stations and three new reservoirs. This Phase II follow-up program was harmonized to avoid duplication of studies and optimize the knowledge acquired.

Since 1993, a committee made up of specialists from Hydro-Québec, SEBJ and the Québec government has been in charge of harmonizing environmental follow-up programs for aquatic and riparian environments in the La Grande complex.

The environmental follow-up program at the La Grande complex is still in operation today (see Table 4). Consequently, the area of the complex remains a gigantic natural laboratory that allows us to observe changes in the environment. The data and lessons drawn from this program will enable us, in the following sections of this report, to define the transformation of the sites observed and the effects of this transformation on the biological environment.

Table 4 – ***Environmental follow-up: La Grande complex (phases I and II)***

Natural Environment		Human Environment	
Land wildlife and habitats	**Environmental Monitoring Network (EMN)**	**Way of life and regional economy**	**Land use**
• Remedial measures • Waterfowl • Beaver • Caribou	• Water quality and biological productivity • Fish populations • Fishing yields • Mercury level • Fish parasites • Estuaries and coastal habitats	• Statistical data bank • Assessment of human impacts • Impacts: - social - cultural - economic • Economic spinoffs • Study of similar situations	• Changes in traplines • Wildlife harvesting by workers and visitors to the region • Access to territory via new roads

2.5

Physical, chemical and biological changes in the reservoirs

Reservoir creation transforms rivers and streams, lakes, peat bogs and terrestrial environments into one vast expanse of water whose level, from then on, varies according to energy needs. However, the changes affecting reservoir tributaries do not extend beyond the physical boundaries of the tributaries.

The reservoirs created by Hydro-Québec are of two general types: reservoirs like Robert-Bourassa (La Grande 2) and Manic 3, in which a valley is flooded, and reservoirs like Caniapiscau and Manicouagan, which extend existing large lakes and regulate water availability to hydroelectric complexes from year to year. The reservoirs thus formed differ from natural lakes in that they store water from spring and fall floods in order to release it later, mainly in winter. A natural lake eliminates flood inflows more gradually, and its level drops much less during the winter.

The scope of the physical changes following impoundment depends on the geomorphology of the area. Zones of clay, silty sand, and sand and gravel are susceptible to erosion, which may be set in motion by the rising of the waters. This phenomenon, associated with the submersion of the terrestrial environment, contributes to an increase in turbidity. The length of the filling period (with or without ice cover) and the water residence time may also affect the extent of the process. Subsequently, during operation, steep banks made up of the materials mentioned above may be eroded by the effects of drawdown and waves. Leaching of the submerged soils also leads to chemical action with a direct effect on water quality. Generally speaking, as will be seen in greater detail later on, these phenomena taper off within a few years.

Most of the remedial work carried out prior to impoundment—excluding the construction of dikes built as reservoir retaining structures—is basically intended to improve the biological quality of the new ecosystem (deforestation and clearing of tributary mouths, reconstitution of riparian habitats, etc.) or to facilitate local access and conditions of use (boat ramps, net-fishing sites, navigation corridors, disposal of wood debris, etc.). In addition, around the 70-km^2 La Grande 1 reservoir, all the forested area was cleared between the natural level of the Grande Rivière and the 33.0-m level, i.e., 1 m above the maximum reservoir level. In accordance with the Chisasibi Agreement, the clearing, which took five years (from 1989 to 1993), was carried out by the Cree Construction and Development Company.

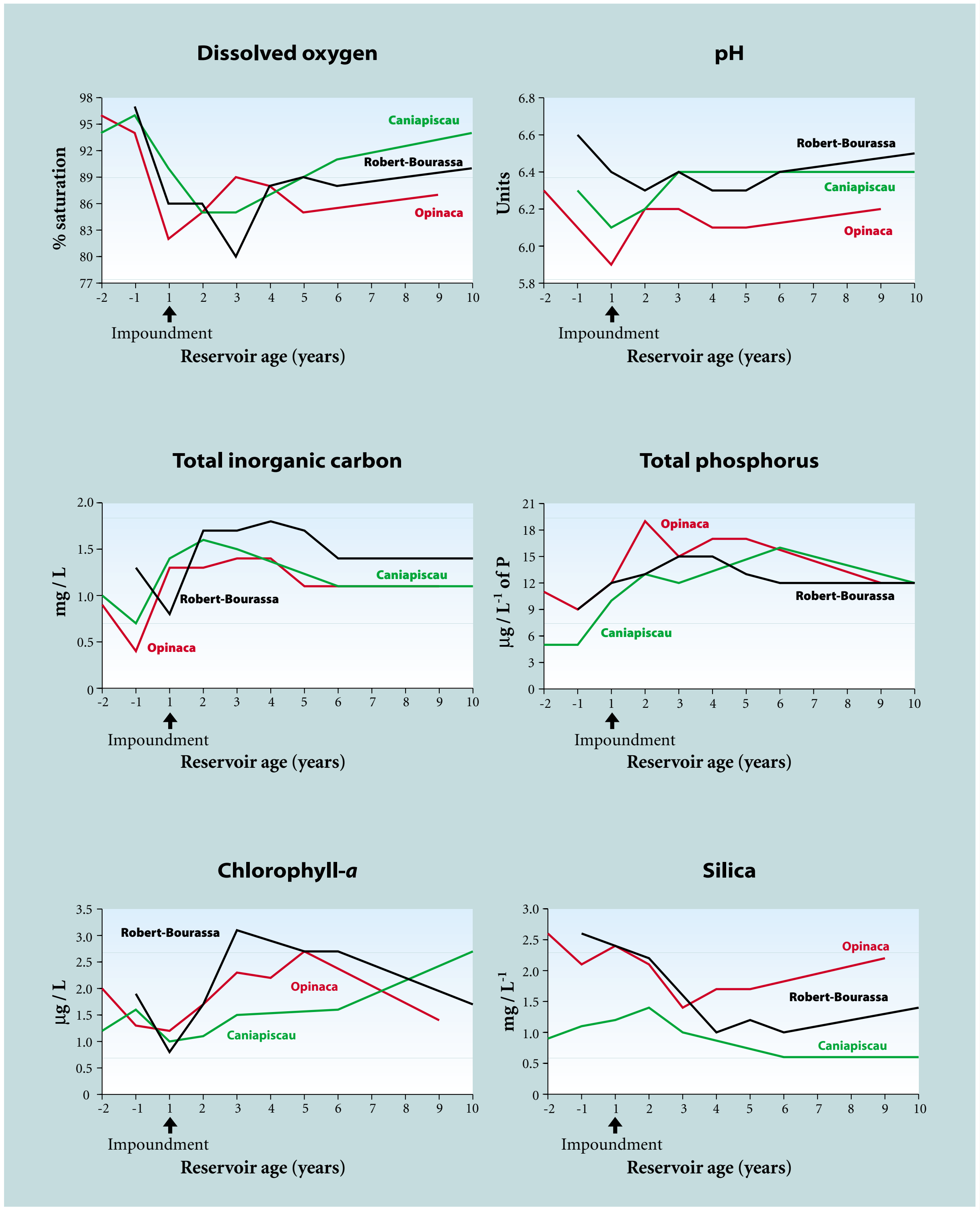
As the objective was to obtain information on changes in the new aquatic environment, the follow-up first examined the quality of the water as a support environment, and fish as the principal resource. It also covered phytoplankton, zooplankton and benthic organisms, since Hydro-Québec wished to determine whether fish would suffer from any shortages down the food chain.

2.5.1
Water quality

The follow-up measured 26 physical and chemical parameters related to water quality. Only those parameters most representative of changes in the environment are examined here, namely oxygen saturation percentage, pH, total inorganic carbon, total phosphorus, chlorophyll-*a* and silica. These parameters are easy to measure and they constitute good indicators of biological productivity.

Figure 5 illustrates changes in values in the photic zone of Robert-Bourassa, Opinaca and Caniapiscau reservoirs during the ice-free season. The photic zone is the portion of water with the greatest maximum biological production; it generally corresponds to a depth of 10 m in the reservoirs studied. What stands out first is the fact that the changes observed in this zone were generally limited and always remained well within the range of values favorable to strong biological productivity. The slight variations observed from one reservoir to the next may be explained by the specific characteristics of each one: area of land flooded, density and type of vegetation flooded, length of filling period, configuration, average depth and water residence time.

Figure 5 – ***Changes in main parameters linked with the decomposition of submerged organic matter in the photic zone (ice-free period): La Grande complex reservoirs***



The changes in water quality are explained mainly by the following three phenomena:

- Submersion of vegetation and forest soils, which causes mineral salts and soil nutrients to dissolve in the water—a process that is accelerated by wave action on forest soils. This phenomenon, which occurs at the start of impoundment, partly explains the rapid increase in total phosphorus concentration and the decrease in pH.
- Mixing of waters of various qualities from rivers and lakes in the flooded zone.
- Decomposition of vegetation and humus in flooded soils by a series of micro-organisms, such as bacteria. In decomposing this organic matter, the micro-organisms consume dissolved oxygen and release CO_2, resulting in a decrease in pH. This phenomenon is accompanied by a release of minerals and nutrients such as phosphorus.

The greatest changes in the physical and chemical parameters were recorded in late winter in deep-water zones. Throughout the period of ice cover (generally from December to June), dissolved-oxygen levels in deep zones gradually decrease through the action of decomposition organisms, since the ice impedes any oxygen input from the atmosphere. However, this short-term phenomenon is very limited in relation to reservoir volume and is quickly offset by the spring-time mixing of waters. The small areas of low oxygen level have very little impact on overall reservoir water quality.

In Opinaca and Robert-Bourassa reservoirs, the changes in the physical and chemical characteristics of water reached a peak fairly quickly, two to three years after filling began. After nine or ten years, the principal parameters had returned to pre-construction values. In Caniapiscau reservoir, the maximum values of total phosphorus and silica were reached between year 6 and year 10. The return to values representative of natural conditions was nearly complete after 14 years, in this case.

It seems that the much more gradual impoundment of this reservoir—which took place over three years, compared with six months to a year for the other reservoirs—played a part in extending the time needed for a return to initial conditions.

The short duration of the changes is largely due to the fact that, contrary to what was originally believed, only a small portion of the flooded organic matter (forest soils and vegetation) is readily and rapidly decomposable in the cold water of the reservoirs. Tree branches, trunks and roots, as well as the underlying soil humus, have been found intact in 60-year-old reservoirs (Van Coillie et al., 1983).

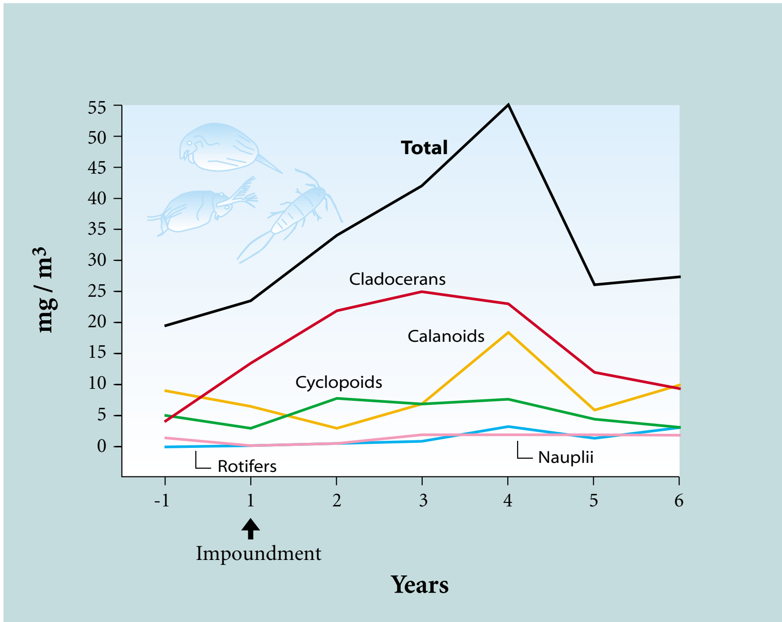
The monitoring of reservoirs in the La Grande complex clearly indicates that it only takes 10 to 15 years for the water to regain physical and chemical characteristics similar to those found in natural lakes (Schetagne, 1994).

2.5.2 Phytoplankton

Changes in phytoplankton populations were monitored through measurement of chlorophyll-*a*, the pigment responsible for photosynthesis in plants suspended in the water. The level of chlorophyll-*a* is a good indicator of the biomass of these organisms.

The increase in nutrient levels, particularly phosphorus, observed in all the reservoirs was reflected in a threefold increase in chlorophyll-*a* levels. The chlorophyll-*a* levels followed the same pattern of change as the water quality parameters. They rose rapidly from the time of impoundment, then declined and stabilized at levels comparable to natural values after about 10 years in the case of Opinaca and Robert-Bourassa reservoirs, and after about 15 years for Caniapiscau.

Figure 6 – ***Changes in zooplanktonic biomass: Robert-Bourassa reservoir***



2.5.3 Zooplankton

The abundance and biomass of zooplanktonic organisms grew markedly in all reservoirs in the La Grande complex as a result of the enrichment of the water and the availability of organic matter produced by the decomposition of submerged plant matter. Zooplanktonic biomass showed the same pattern of change as phytoplanktonic biomass, with a lag of about a year. Rotifers were chiefly responsible for the increase in density, while cladocera, which are much larger organisms, were responsible for the increase in biomass (see Figure 6).

Water residence time is the factor that most affected the abundance of zooplanktonic organisms. In rivers, the residence time is too short to allow these organisms to complete their entire life cycle. When they are found in a river, they have almost always come from a lake that is part of the river system. This may also be one of the reasons why zooplanktonic biomass reached its maximum twice as quickly in Caniapiscau reservoir (formed by enlarging lakes) as in Robert-Bourassa reservoir (created by damming a river).

2.5.4 Benthos

Benthic organisms had to adapt to the major physical transformations related to reservoir creation. After a slight decline in the diversity of these organisms due to the increased scarcity of less mobile species and of species better adapted to fast-running water, the new aquatic environments were rapidly occupied by lake-dwelling species. The presence of the extensive substrates supplied by submerged plants considerably increased the surfaces available for species in search of food.

In addition, examinations of fish stomach contents and monitoring of fish populations revealed that the diversity and quantity of benthic organisms were sufficient to bring about substantial increases in growth rates and condition factors (plumpness index) of fish species that feed on the benthos, such as lake whitefish, and their predators, such as pike.

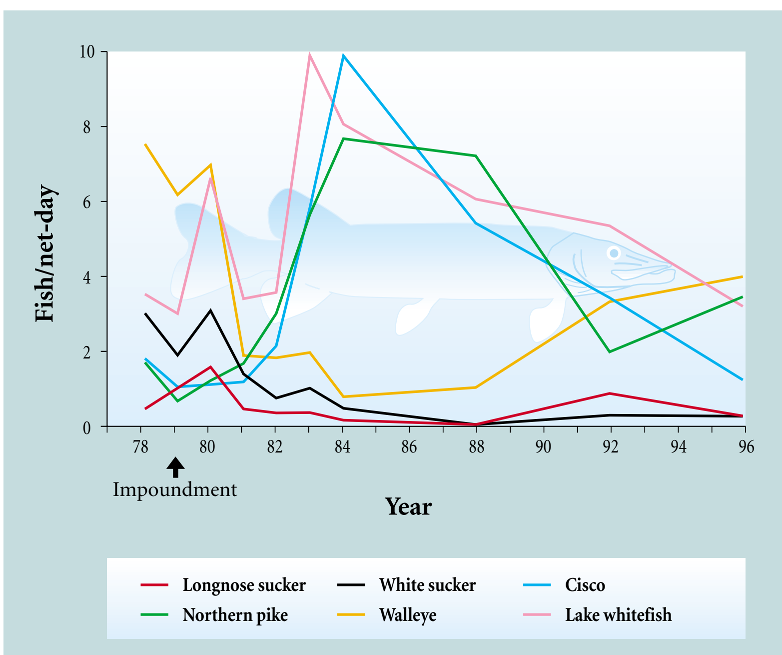
2.5.5 Fish

Fish communities have been monitored almost continuously since 1977, by means of 27 permanent experimental fishing stations spread throughout the complex, including 5 control sites in unmodified environments. The fish were caught with multifilament gill nets 47.5 m long by 2.4 m high. The nets were put out for approximately 48 hours from 1977 to 1982 and for 24 hours from 1983 to 1994; this was done once a month, from June to October in the western section of the complex and from June to September in the eastern section (Caniapiscau reservoir and Caniapiscau River). Since 1995, 48-hour fishing sessions have been conducted in July and August. From 1977 to 1999, more than 90,000 fish were caught and analyzed in order to monitor changes in fish communities in environments modified by the La Grande complex.

With the exception of Caniapiscau reservoir, the changes in fish populations were much the same in all reservoirs in the La Grande complex. By way of example, Figure 7 illustrates the changes in mean numerical fishing yields for the principal species caught at the stations on Opinaca reservoir. The first year saw a decrease in yields due to the dispersal of populations in a larger volume of water. This decline was quickly followed, in subsequent years, by an increase in yields resulting from the overall enrichment of the water. After 15 years or so, yields returned to levels comparable to those observed in undisturbed natural environments.

In Opinaca and Robert-Bourassa reservoirs, northern pike and lake whitefish contributed most to the increase in fishing yields after impoundment. For several years, these two species, along with walleye, dominated reservoir fish species. Longnose sucker and white sucker, which had been among the most abundant species along with walleye and lake whitefish, became scarce; catches were 2 to 15 times less

Figure 7 – ***Changes in fishing yields, by species: Opinaca reservoir***



numerous than prior to impoundment. Lake sturgeon, lake trout, round whitefish and brook trout, which were already marginal species, became rare, and have often been absent from catches for several years.

An examination of the age structures of the populations of lake whitefish, cisco and northern pike in Opinaca and Robert-Bourassa reservoirs reveals strong recruitment in the last few years for each of these species, as well as a good life span: in fact, the fish have a longevity comparable to that of their congeners in neighboring natural lakes. In the case of walleye, the initially low recruitment, particularly in Robert-Bourassa reservoir, improved starting in the eighth year. After about 10 years, the catches revealed strong recruitment in all the reservoirs where walleye had been present under natural conditions.

In Caniapiscau reservoir, there was no marked decrease in the total volume of catches in the first year, nor any rapid increase in population densities after several years. Rather, a gradual increase in catches was observed, as was the case with nutrients. This phenomenon, which was specific to Caniapiscau reservoir, is explained by the longer filling period and the colder water temperature.

In 1991, in Caniapiscau reservoir, the overall fishing yield was 24 fish/net-day, compared to 19.5 fish/net-day before impoundment and 14.8 fish/net-day in natural lakes. Since 1995, overall fishing yields have returned to approximately the same levels as before impoundment. The changes in overall yields are largely due to the most abundant species, lake whitefish. Northern pike, which is absent from a number of natural lakes in the region, does not seem to be making as much progress in Caniapiscau reservoir as in the other reservoirs.

In all the reservoirs, lake trout is having difficulty adapting to the new conditions. Its growth is rapid, as is that of the other species, but the scarcity of young specimens seems to indicate a recruitment problem. As this fish spawns in fairly shallow water in fall, and its eggs are incubated in winter (a season that corresponds to an increase in electricity demand), the seasonal drop in reservoir water level may explain this phenomenon.

All reservoir fish species achieved a growth rate and condition factor higher than those observed at the control sites. Thirteen years after impoundment, the species' overall average condition factor was greater than or equal to the level observed prior to impoundment.

2.6

Physical, chemical and biological changes in modified-flow environments

To generate the greatest amount of energy at the lowest possible cost, river flow is increased by the addition of water diverted from neighboring drainage basins. A diversion creates two new environments that are radically different from each other. In the river downstream from the damming point, flow is reduced to whatever is brought in by tributaries, while along the diversion channels the flow increases substantially. As for the area downstream from the generating station, the flow is regulated according to plant operations.

2.6.1
Reduced-flow rivers

Reduced-flow sections of partially diverted rivers display a drop in water level, exposure of banks, a reduction in the area and volume of water, a decrease in the range of annual fluctuations in water level, and an increase in flow-through time. In general, these changes increase the stability of the environment. On the other hand, hydrological modifications often lead to phenomena such as erosion, sedimentation and turbidity, particularly at confluences, where the tributaries must adapt to the new level in the river. The extent and duration of these phenomena vary according to the geomorphology of the river's bed and banks.

The reduced-flow sections of the Eastmain, Opinaca, Caniapiscau and Koksoak rivers differ in terms of geomorphological and hydrological characteristics, and this has affected their evolution following the reduction in flow.

Eastmain and Opinaca

The flows of the Eastmain and Opinaca, at their mouths, fell by 90% and 87%, respectively. The water level dropped by 1 m to 4 m over the 160 km of the Eastmain and the 110 km of the Opinaca. Since these rivers have a gentle slope, the decline in water level resulted in a total surface exposure of 36 km^2. In addition, because the exposed beds mainly comprised fine materials such as clay and silty sand, erosion through surface runoff and gullying soon occurred, leading to a rapid increase in turbidity.

To lessen these impacts, the reduced-flow sections of the Eastmain and Opinaca were the object of five remedial measures: two weirs on the Eastmain and two weirs and a spur dike on the Opinaca. In addition to curbing erosion phenomena, these structures helped reestablish natural water levels over a distance of 90 km, or about a third of the exposed portion of the two rivers. One of the weirs also restored the natural level in a 15-km section of the Petite rivière Opinaca, a tributary of the Opinaca.

Since the diversions, water quality in the reduced-flow sections has been determined mainly by that of the small tributaries. These tributaries flow over marine deposits, which are less resistant to the water's action and are partly covered with peat bogs. Consequently, the tributaries bring in water with neutral pH and containing more minerals, organic matter and nutrients than water upstream from the diversion points, which flows over glacial deposits.

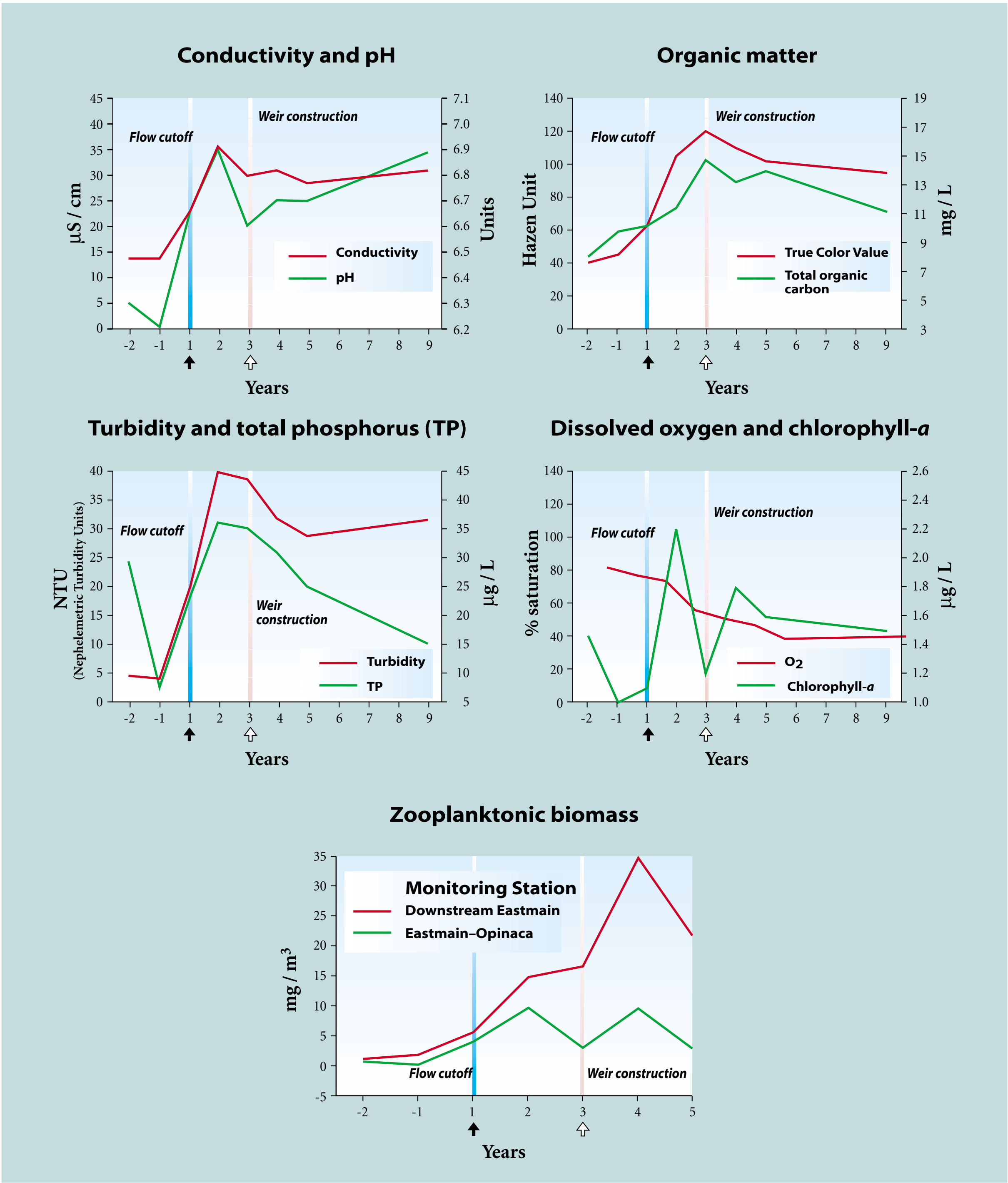
Erosion of the exposed banks also increased the concentration of organic matter and hence the mineral content of the water. The residence time, much greater following the drop in flow and the construction of dikes and weirs designed to raise water levels, also helped dissolve minerals and nutrients.

The enrichment of the water in turn promoted biological production, despite the increase in turbidity. In fact, in the new environment—which is more like that of a series of long, narrow, calm lakes interspersed with brief rapids—phytoplanktonic, zooplanktonic and benthic biomasses grew considerably (see Figure 8).

Weir no. 8 on the Opinaca River. Note planting on the right, and traces of a recent fire on the left.

Figure 8

Changes in main water quality parameters at Eastmain–Opinaca station: Reduced-flow segment of Eastmain River



In the Eastmain, fishing yields rose quickly as a result of greater population density due to decreased water volume. Yields subsequently fell somewhat and varied from station to station, but remained higher than baseline values, that is, those prior to the reduction in flow. After 12 years, the principal species, including lake sturgeon, walleye and northern pike, continued to show these yields, although the lake whitefish yield declined.

After 16 years, the relative abundance and number of catches in slow-moving, or lentic, zones were several times higher than under natural conditions for cisco and walleye. Conversely, lake sturgeon decreased slightly in abundance, although its average size continued to rise, perhaps pointing to low recruitment. The shrinking of spawning habitat and the Aboriginal fishery may explain this decline. Populations of lake whitefish, white sucker and longnose sucker show stable fishing yields, comparable to those observed under natural conditions. In swift-water, or lotic, zones, the abundance and fishing yields of the principal species changed very little, remaining comparable to pre-development levels (Doyon and Belzile, 1998).

Caniapiscau
The 457 km of the Caniapiscau and the 136 km of the Koksoak downstream from the closing dikes lost 40% and 30%, respectively, of the inflows from their watersheds, resulting in a 48% reduction in flow for the Caniapiscau at its confluence with the Koksoak and 35% where the Koksoak empties into Ungava Bay. These rivers flow through deep, narrow valleys with generally rocky banks that are not highly susceptible to erosion. Their sedimentary regime consequently remained virtually unchanged. Moreover, for about two-thirds of the Caniapiscau, natural sills control the water level in slow-flowing sections very effectively and thus reduce the extent of drops in level, which range from 0.5 m to 2 m depending on the location.

This major river section, which is still impressive despite the decrease in its flow, has remained practically unchanged in chemical and biological terms. There has been a decrease in phytoplanktonic biomass, which had stemmed essentially from inflows from large lakes in the upper course of the river before its diversion to the Grande Rivière. Zooplanktonic and benthic densities and biomasses are the same as before the diversion.

In the Caniapiscau, the fish population differs somewhat from that of the Grande Rivière basin. Ten species are present; in order of importance, the top six are longnose sucker, lake whitefish, lake trout, white sucker, brook trout and landlocked salmon. There are few northern pike, and no lake sturgeon or walleye. In 1987, six years after the diversion, catches of all species combined had more than doubled compared with natural conditions. Since then, they have gradually declined, and are now similar to baseline levels.

2.6.2 Diversion zones

The rivers and lakes fed by diverted waters experienced an increase in flow and level. As in the case of reservoirs and reduced-flow rivers, the extent of the resulting physical changes varies according to flow and geomorphology.

Eastmain–Opinaca–La Grande (EOL) diversion
In the La Grande complex, the water diverted from the upper basins of the Eastmain and Opinaca flows from Opinaca reservoir to Boyd and Sakami lakes before entering Robert-Bourassa reservoir some 150 km below the diversion points. Levels in Boyd and Sakami lakes rose by about 2 m prior to the commissioning of Robert-Bourassa generating station. Since then, they have fluctuated according to natural inflows and the operation of the control structures. The outlet of Boyd Lake became a major river, with a flow of up to 2,000 m^3/s in June. To better control these two areas, prevent erosion and avoid or reduce submersion of the most productive zones, Hydro-Québec carried out various remedial measures.

The route of the diverted flows was marked by a number of phenomena with adverse effects on water quality: inflows from Opinaca reservoir, oxygenation of water in rapids and erosion of the clayey banks of lakes and narrow sections of the Boyd River. The combined effects of these phenomena meant that the water's physical and chemical characteristics remained relatively stable, except for those related to erosion and nutrients. Turbidity increased slightly for four years, while phosphorus levels doubled temporarily, then returned to initial values after ten years or so.

The increase in nutrient levels also resulted in greater phytoplanktonic biomass over the route followed by the diverted flows. From the third to the fifth year after diversion, chlorophyll-*a* levels were twice as high as in Sakami Lake prior to diversion and slightly higher than in Opinaca reservoir.

Zooplanktonic biomass fell somewhat due to the shorter water residence time. Today, planktonic biomass is comparable to that of a natural lake.

In the increased-flow section of the EOL diversion, fish populations were dominated by walleye (26%), lake whitefish (25%), and longnose and white suckers (12% and 14%) under natural conditions. Twelve years after diversion, lake whitefish and white sucker represented only 6% and 2%, respectively, of total catches. They have given way to walleye, which accounts for 45% of catches, longnose sucker (26%) and northern pike (16%) (Deslandes et al., 1994). In 1996, walleye was by far the most abundant species, with 58% of catches (Doyon and Belzile, 1998). An analysis of age structures shows strong recruitment for the principal species.

Laforge diversion

On the other diversion route, which runs 250 km from Caniapiscau reservoir to La Grande 4 reservoir, passing through Laforge 2 and Laforge 1 reservoirs along the way, the risks of erosion were very low. In this case, the goal of the remedial measures was to prevent or limit submersion of the most productive areas. Numerous dikes were therefore built in the lower portion of this route, reducing the total area flooded by 290 km^2. In view of the stability of this environment, the zone has been monitored only since the impoundment of Laforge 1 reservoir in 1993. In comparison with the phenomena that occurred on the route of the EOL diversion, which is much more susceptible to erosion, the aquatic environment of the Laforge diversion zone and the wildlife using it have remained essentially the same.

Grande Rivière (increased and regulated flow)

Downstream from a generating station, the river's flow is described as regulated; it varies according to how the generating station is being operated. In winter, when energy demand peaks, mean flows are higher than under natural conditions. In spring and summer, a time of reduced electricity consumption in Québec, mean monthly flows are generally lower and more constant than under natural conditions.

Rapid changes in water level, too, are more frequent than under natural conditions, as turbine throughputs may vary hourly, daily or weekly to meet energy demand. Water that has passed through the turbines is colder in summer and warmer in winter. The water has the same quality as in the upstream reservoir, except for parameters affected by turbulence in rapids. The turbulence causes oxygenation in the water, a discharge of CO_2 and a restoration of pH. Bank erosion may increase turbidity. The higher flow and temperature than under natural conditions have the effect of reducing the extent, thickness and persistence of ice, and often create ice-free zones. The ice breakup can pull up and crush riparian vegetation, depending on the slope of the bank. In summer, exposed areas are subject to erosion. These phenomena are more pronounced in places where fine materials are dominant. Balanced conditions are restored as the banks stabilize.

In the La Grande complex, after the run-of-river La Grande-1 generating station was commissioned in 1995, the section of the Grande Rivière between kilometre 37 and kilometre 112 became La Grande 1 reservoir. The mean annual flow in the 37-km section downstream from the generating station, which had already been doubled by the inflow from the two diversions, varies with the generating station's mode of operation. Although the banks in this section were generally more stable than those in the section submerged by La Grande 1 reservoir, a number of remedial measures were applied here to prevent or reduce the effects of flow regulation. These include stabilization work on the south and north banks below the generating station and on the south bank between kilometre 12 and kilometre 15 (at the Cree village of Chisasibi).

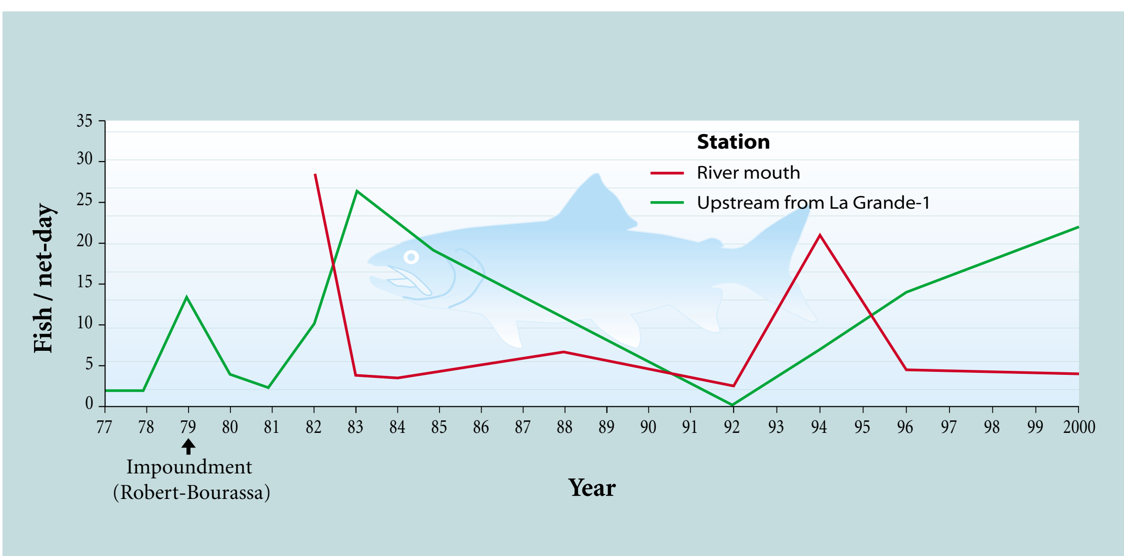
The overall fishing yield in the increased- and regulated-flow section downstream from Robert-Bourassa generating station has fluctuated considerably. During the impoundment of Robert-Bourassa reservoir, the reduction in flow and, consequently, in the volume of downstream water resulted in a denser fish population, which led to a spectacular increase in fishing yields.

Figure 9 shows that the number of catches subsequently fell, before abruptly climbing again in 1983. Since then, the number of catches has declined continuously, eventually returning, in 1992, to its level prior to the impoundment of Robert-Bourassa reservoir. Longnose sucker has remained the dominant species, accounting for over 50% of total catches.

After La Grande-1 generating station was commissioned in 1995, fishing both upstream and downstream from this generating station revealed changes in fish populations. The fishing yield in the forebay of La Grande-1 rose considerably, as a result of a marked increase in catches of longnose sucker and somewhat smaller increases in catches of lake whitefish and northern pike. Lake whitefish and northern pike were represented by a large number of two-year-old specimens, indicating improved reproductive success in the summer after impoundment. In the Grande Rivière below La Grande-1 generating station, longnose sucker, round whitefish and brook trout are now the principal species caught in July and August (Doyon and Belzile, 1998).

In 1990, a study on fish entrainment was conducted at Robert-Bourassa generating station. It showed that the fish entering the water intake are ciscos—cisco being a pelagic, or deepwater, species—especially yearlings (90 to 130 mm long) and the current year's young (20 to 50 mm long). A similar study was conducted at Brisay in 1997. Contrary to Robert-Bourassa reservoir, the area around Brisay generating station contains no lake cisco; however, it does contain a population of dwarf whitefish, whose pelagic behavior is similar to that of the cisco. The study concluded that the fish entering the water intake are mainly the current year's young whitefish and that they start migrating downstream in early August.

Figure 9 – ***Change in fishing yield, all species: Grande Rivière***



2.7

Physical, chemical and biological changes in estuary zones and along the northeast coast of James Bay

In the following text, an *estuary* is defined as the lower portion of a river, located between its outlet into the sea and the first obstacle beyond which the tides cannot pass, regardless of the salinity observed. The coastal zone comprises the waters that flow along seashores and littoral areas subject to tides. An estuary is a place where marine and fluvial forces meet; the freshwater flow is therefore a major factor influencing physical conditions, including water circulation and salinity. If the freshwater flow is much weaker than the tidal flow, the mixing of fresh and salt water will take place within the estuary. If, on the other hand, the freshwater flow is much greater than the tidal flow, the two masses of water will mix outside the estuary. Because they are less dense, fresh water and brackish water spread out on top of salt water; this spread is called a *plume*. For the same flow, a plume extends over a greater surface under ice than in open-water conditions.

Among the estuaries influenced by the La Grande complex, those of the Eastmain and Koksoak rivers experienced reductions in their natural flows of 90% and 35%, respectively. The mean annual flow in the Grande Rivière estuary doubled from 1,700 m^3/s to 3,400 m^3/s; although the winter flow multiplied tenfold, the flow in the estuary is now regulated by power station operations.

2.7.1 Eastmain estuary

Since the reduction in the river's flow, the Eastmain estuary has been governed more by marine forces. This entire 27-km section is subject to tidal action. The current reverses with each tidal cycle, and the salt water penetrates 10 to 12 km inland in summer and 13 to 15 km under ice, with decreasing salinity. The net downstream current is no longer able to expel the fine sediments suspended in the water into James Bay, and the estuary has become a sedimentary deposit zone, whereas it was eroding under natural conditions.

Because of the increased water residence time, enrichment in nutrients and drop in flow velocities, planktonic productivity has risen, while the new sedimentary conditions and the saltwater intrusion have favored the development of more abundant and diversified benthic communities (Messier, Ingram and Roy, 1986).

Now more productive, the estuary offers favorable conditions for the growth of all fish. The saltwater intrusion affects only the downstream half of the estuary, and spawning and wintering grounds still exist for the fish, including lake cisco and lake whitefish. The main effect of the reduction in river flow has been an upstream shift of fish populations due to the saltwater intrusion over the first 10 to 12 km from the mouth. Marine species (especially fourhorn sculpin) have penetrated further into the river, and freshwater species too (longnose sucker and walleye in particular) have been pushed upstream.

Eastmain estuary and James Bay. In the foreground: Rivière à la Pêche, a tributary of the Eastmain.

The mouth of the Grande Rivière. Small delta islands in James Bay can be seen in the foreground.

2.7.2 Koksoak estuary

Given the extent of the tides here, which are among the largest in the world, the reduction in freshwater flow had very little impact on the physical, chemical and biological characteristics of the Koksoak estuary. Considering the spaces and volumes involved, the slight increase in saltwater intrusion had no observable effect on the fish populations. The Groupe d'étude conjoint Caniapiscau-Koksoak (GECCK), which conducted follow-up studies for more than ten years, including five years before the diversion, "was unable to identify any measurable impacts on the fish as a result of the Caniapiscau River diversion." (GECCK, 1985)

2.7.3 Grande Rivière estuary and northeast coast of James Bay

The Grande Rivière estuary now handles river flows that average twice as much as under natural conditions. For flows from 1,700 to 1,800 m^3/s, salt water does not penetrate the estuary, and the current does not reverse. These conditions have always prevailed in winter, as well as generally in summer, since 1985. The erosion rate on the sensitive estuary banks, i.e., from the mouth to La Grande-1 at kilometre 37, has varied considerably over the years. Under natural conditions, before Robert-Bourassa reservoir was created in 1978, the erosion rate was 57,000 m^3 a year. From 1978 to 1991, it rose 49%, with a brief return to natural conditions from 1991 to 1993 just before La Grande-1 came on line. From 1997 to 1999 the rate was 38,100 m^3 a year. Given the sensitivity of the banks, erosion activity may increase again, depending on how the generating stations are operated.

The increase in river current has meant renewed erosion of banks and sandy bottoms in the inner delta (the first 10 km from the mouth) of the estuary and an acceleration of the extension of the outer delta (5 km off the mouth) toward the west.

Development of the Grande Rivière did not change the summer temperature or salinity of the coastal waters, considering the spatio-temporal and even interannual variations in these parameters due to the tides and meteorological phenomena.

The physical changes are much more pronounced in winter than during the rest of the year. The winter flow can exceed 5,000 m^3/s, or more than 10 times baseline, with the result that in February the estuary is covered with a fragile ice sheet from the mouth to kilometre 20. However, although the thickness of landfast ice along the east coast of James Bay has varied over time and space, it has been affected very little by the substantial increase in winter flow from the Grande Rivière.

Two types of ice may be found in James Bay: landfast ice, which occupies a width of 15 to 25 km along the northeast coast, and offshore floes, made up of ice sheets floating in stretches of open water. As was previously mentioned, the plume always occupies a larger area under ice cover than in open-water conditions. Under natural conditions, the winter plume was entirely confined beneath the landfast ice. At a turbine flow of 4,000 m^3/s or more, the winter plume now occupies three times the baseline area if large expanses of open water are present in James Bay (Messier and Anctil, 1996), or four to five times the baseline area if expanses of open water are scarce.

Any increase in plume area means a drop in the salinity of coastal waters in the top six metres of the water column north and south of the Grande Rivière. Prior to development, coastal salinity was low during the spring flood. The flood generally peaked in the third or fourth week of May, reaching 4,000 to 6,000 m^3/s, at a time when landfast ice was still present. The increase in winter river flows has not created new low-salinity conditions in the coastal waters, but since the projects were built, these conditions now last much longer.

The fish community in the Grande Rivière estuary consists of annual migrators (lake whitefish, cisco and sea trout) and resident specimens (longnose sucker, round whitefish and some individuals belonging to migratory species). The estuary accommodates the same populations and offers favorable spawning and wintering conditions for all species present, despite the major alterations brought about in the hydrological regimen of the Grande Rivière. For the past 15 years, migratory fish have stayed in James Bay, just as they did under natural conditions, and returned to the river at the same dates. Studies on movements of migratory species in James Bay confirm that these fish do not go beyond the limits of the river's summer plume. It is possible, although this has not been specifically observed, that the wintering and spawning grounds have shifted downstream as a result of the increased winter flow. Salmonids that winter in the Grande Rivière or at its mouth do not encounter more difficult conditions than those that find shelter in the other tributaries along the northeast coast of James Bay, as evidenced by growth, condition and recruitment data. To better evaluate the effects of the changes in salinity on the coastal ecosystem influenced by the plume, the submerged eelgrass communities offered a very good indicator, and have been the subject of intensive monitoring since 1980.

These communities, which grow in the many shallow bays located along the coast, provide substrates for a variety of organisms living on the leaves, in the sediments and on sediment surfaces. In particular, they offer shelter to young fourhorn sculpin, the dominant species in the coastal fish community (Dignard et al., 1991; Lalumière et al., 1994).

Eelgrass growth is influenced by a combination of local physical factors, such as slope, water transparency and exposure to the erosive action of waves and ice, or climatic factors such as sunshine. Interannual variations (either upward or downward) in density and biomass are therefore common and normal. Such variations may also be attributable to ongoing postglacial continental uplift, which averages 1 to 1.5 cm a year at James Bay.

Up to now, there has been nothing to indicate that the coastal salinity existing since the La Grande complex began operation has affected the distribution, density or biomass of eelgrass communities. Summer salinity conditions have not changed relative to natural conditions. In winter, the plant can survive at salinities of less than 1‰, as is shown by monitoring results gathered at a station near the mouth of the Grande Rivière (Julien et al., 1996).

2.8

Mercury

The health effects caused by severe mercury poisoning have long been known. These effects have been described in studies of events such as the Minamata Bay epidemic in Japan, caused by industrial discharges of methylmercury that contaminated the fish and shellfish, and in Iraq, following the consumption of grain treated with a methylmercury-based fungicide (Nishimura and Kumagai, 1983; Marsh et al., 1987). However, the effects of prolonged mercury exposure arising from consumption of fish with high mercury levels remained unknown until recently.

When construction of the La Grande complex started, the phenomenon of the temporary increase in fish mercury levels in reservoirs was also unknown. In the late 1970s, studies conducted in the United States and Manitoba indicated high mercury concentrations in fish in recently formed reservoirs. For the development of the La Grande complex, Hydro-Québec therefore undertook studies to determine the factors related to this complex phenomenon.

It took more than 20 years of environmental follow-up by Hydro-Québec, including the analysis of tens of thousands of fish, and over 10 years of studies—by various university research teams, the Canadian Wildlife Service (Environment Canada), the Freshwater Institute (Fisheries and Oceans Canada) and Hydro-Québec—to reach a better understanding of the mercury issue (Lucotte et al., 1999).

The study of health risks for consumers of fish, in this case the Crees, was carried out under the terms of the Mercury Agreement, signed in 1986 by the Québec government, the Crees of Québec, the Société d'énergie de la Baie James and Hydro-Québec. The health component was the responsibility of the Cree Board of Health and Social Services of James Bay (Dumont et al., 1998).

The following section summarizes the knowledge acquired from these years of intensive research.

2.8.1 Mercury in the natural environment

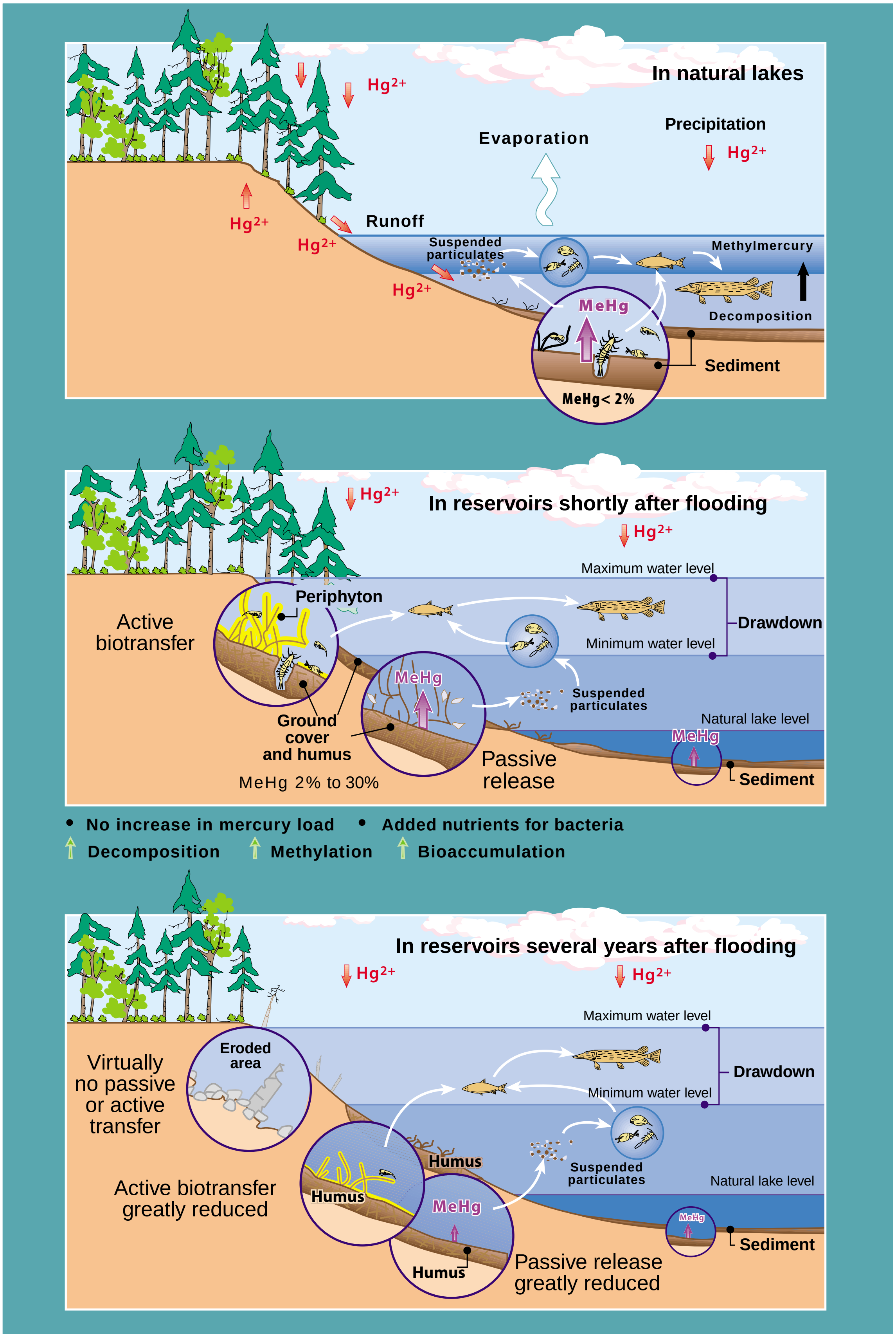
Mercury is a heavy metal found throughout the environment, both in remote northern regions and in urban or industrial areas. The principal natural sources of mercury are rocks and the earth's crust, volcanoes, forest fires and oceanic evaporation. Mercury also comes from anthropogenic sources, mainly emissions from the combustion of coal and petroleum products, waste incineration, metal refining, specific industrial processes (e.g., chloralkali plants) or mining activities. Inorganic mercury dissipates readily and enters the atmosphere, where it can travel thousands of kilometres before it is oxidized and falls back to the ground or into the water with precipitation. Worldwide, it is generally recognized that mercury emissions of natural origin and those of human origin are roughly equivalent, at approximately 4,000 tonnes per year (Nriagu, 1989).

Mercury exists in the environment in metallic form (Hg^0), inorganic form (Hg^{2+}), and organic forms including methylmercury (CH_3Hg^+). It is released into the environment mainly in metallic or inorganic form. The inorganic forms of mercury, largely of human origin, are also the source of the methylmercury present in the terrestrial and aquatic ecosystems of northern Québec. Indeed, concentrations of total mercury in the surface sediments of natural lakes have risen gradually since the 1940s and today average 2.3 times pre-industrial levels (Lucotte et al., 1995). Methylation takes place through the action of microorganisms, mainly in aquatic environments, where it is closely associated with the natural processes of organic decomposition. However, methylmercury is not stable in the aquatic environment, and is sometimes converted to inorganic mercury. As well, a certain amount is dissipated into the atmosphere (see Figure 10).

Mercury concentrations in the surface sediments of natural lakes not affected by mercury from local sources generally range from 0.005 to 0.5 mg/kg (Johansson et al., 1995; Verta et al., 1990; Lucotte et al., 1995). Methylmercury generally accounts for less than 2% of total mercury concentration in the sediments, rarely exceeding 0.008 mg/kg. This is much lower than the levels found in the surface sediments of the St. Lawrence River (an industrialized environment), which are as high as 4.8 mg/kg (Jarry et al., 1985).

Methylmercury is hydrophobic and binds readily with mineral and organic particles suspended in the water, and with plankton, periphyton and insects living at the water-sediment interface. Through biological magnification, mercury concentrations increase with each trophic level of the food chain. Piscivorous fish thus accumulate more methylmercury than fish that feed on insects or plankton. Concentrations vary with fish size, age and growth rate. In the flesh of freshwater fish, it is generally estimated that mercury is present mainly in the form of methylmercury, the proportion of which rises with trophic level, increasing from around 80%–90% in non-piscivorous fish to about 90%–99% in piscivorous species (Laarman et al., 1976; Lasorsa and Allen-Gil, 1995).

Figure 10 – ***Natural mercury cycle***



In Canada, the marketing standard for fishery products is set at 0.5 mg/kg by the federal authorities (Health and Welfare Canada, 1985). Since the early 1970s, a great many commercial fisheries have been shut down in northwestern Québec, as well as in the St. Lawrence valley and Great Lakes region, because of excessive mercury levels in piscivorous species such as walleye and northern pike. In the United States and several European countries, the standard is less restrictive, and fish may be marketed with a concentration of up to 1 mg/kg in the flesh.

2.8.2 Mercury in the La Grande complex

Reservoir impoundment raises the water level and floods a large quantity of terrestrial organic matter (vegetation and surface organic horizons of the soil). In the first few years of reservoir existence, this organic matter undergoes accelerated bacterial decomposition, which promotes mercury methylation. The production of methylmercury is largely determined by the quantity and nature of the organic matter flooded as well as biotic and abiotic factors such as bacterial activity and the physical and chemical characteristics of the water (pH, dissolved oxygen, oxidation-reduction potential, etc.) (Lucotte et al., 1999; Johnston et al., 1991; Schetagne and Verdon, 1999b; Gilmour and Henry, 1991).

Research on fish.

The bioavailability of mercury for aquatic wildlife in reservoirs increases in a proportion that depends on many factors: the land area flooded, duration of impoundment, water residence time in the reservoir, volume of water, proportion of soil flooded in shallow water (where biotransfer is at its maximum), water quality, food web in the flooded environment, fish population dynamics, etc. (Brouard et al., 1990; Jones et al., 1986; Doyon et al., 1996).

At the La Grande complex, monitoring conducted since 1978 indicates that maximum mercury levels in reservoir fish are three to six times higher than those of fish living in natural environments. Maximum concentrations are reached after 5 to 10 years in species feeding on plankton and insects, and after 10 to 15 years in piscivorous species (Verdon et al., 1991; Chartrand et al., 1994).

Thereafter, levels gradually return to values similar to those measured in fish in natural lakes in the region (see figures 11 and 12); this occurs after 10 to 20 years in non-piscivorous species and after 20 to 30 years in piscivorous species (Schetagne and Verdon, 1999a).

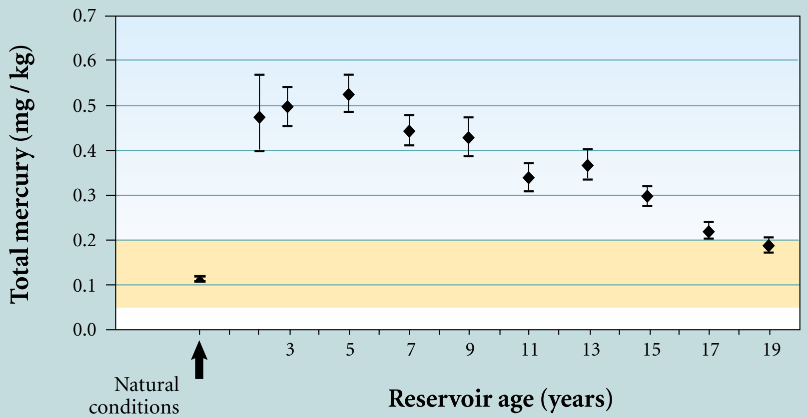
Observations in other reservoirs in the Canadian Shield and Finland also point to a return to mercury levels comparable to those of fish in surrounding natural lakes about 20 to 30 years after impoundment (Verdon et al., 1991; Verta et al., 1986).

Monitoring of fish mercury levels at the La Grande complex also reveals that mercury is carried downstream from reservoirs, especially by suspended particulates in the water such as organic debris, and by plankton, aquatic insects and small fish (Messier and Roy, 1987; Brouard et al., 1994; Montgomery et al., 1996).

*Figure 11 – **Changes in mercury levels in lake whitefish: La Grande complex reservoirs***

LAKE WHITEFISH (400 mm)

A – Confidence interval for mean mercury concentration, 95% probability: Robert-Bourassa reservoir



Comparison of mean mercury concentrations in standard-length specimen (0.05 significance level)

Reservoir age (years)	Natural lakes h	2 (1981) ab	3 (1982) ab	5 (1984) a	7 (1986) b	9 (1988) bc	11 (1990) de	13 (1992) cd	15 (1994) e	17 (1996) f	19 (1998) g
Mean level	0.11	0.47	0.49	0.52	0.44	0.43	0.33	0.36	0,29	0.22	0.19
Lower limit	0.106	0.396	0.451	0.483	0.405	0.387	0.305	0.333	0.270	0.201	0.172
Upper limit	0.116	0.566	0.540	0.565	0.471	0.470	0.366	0.399	0.314	0.234	0.201
N	503	28	150	134	148	140	101	102	164	156	154

Note: If the letter differs from one column to the next, it indicates a significant difference from one sampling year to the next, since the 95% confidence intervals do not overlap.

Bars indicate 95% confidence intervals

Range of mean concentrations in natural lakes

B – All La Grande complex reservoirs

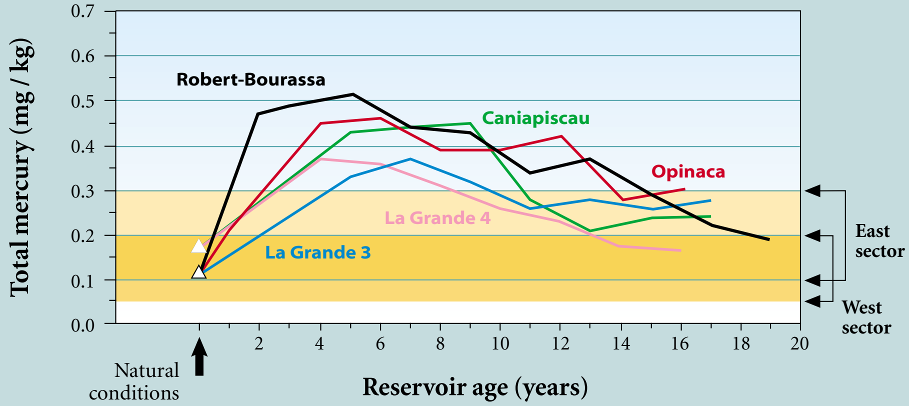
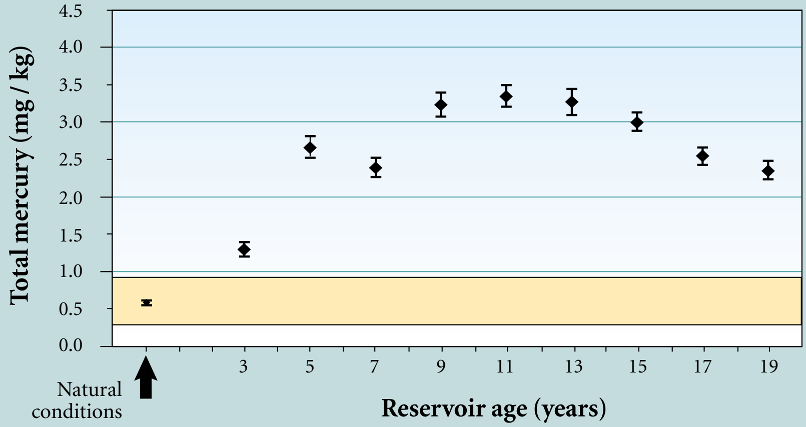


Figure 12 – ***Changes in mercury levels in northern pike: La Grande complex reservoirs***

NORTHERN PIKE (700 mm)

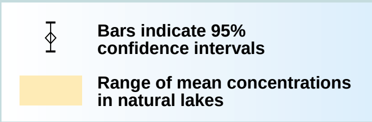
A – Confidence interval for mean mercury concentration, 95% probability: Robert-Bourassa reservoir



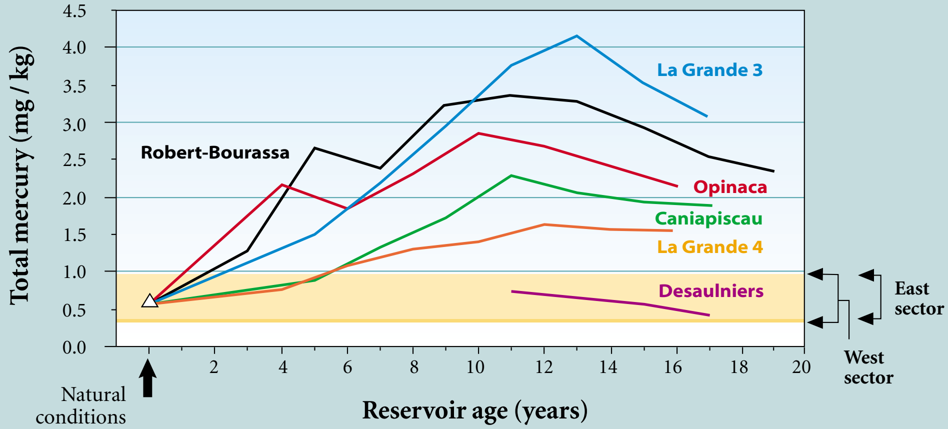
Comparison of mean mercury concentrations in standard-length specimen (0.05 significance level)

Reservoir age (years)	Natural lakes f	3 (1982) e	5 (1984) c	7 (1986) cd	9 (1988) ab	11 (1990) a	13 (1992) ab	15 (1994) b	17 (1996) cd	19 (1998) d
Mean level	0.60	1.28	2.63	2.39	3.21	3.33	3.26	2.99	2.53	2.34
Lower limit	0.568	1.179	2.492	2.264	3.049	3.183	3.088	2.867	2.407	2.213
Upper limit	0.634	1.376	2.769	2.517	3.381	3.479	3.429	3.116	2.647	2.464
N	373	147	148	150	139	114	85	167	146	155

Note: If the letter differs from one column to the next, it indicates a significant difference from one sampling year to the next, since the 95% confidence intervals do not overlap.



B – All La Grande complex reservoirs



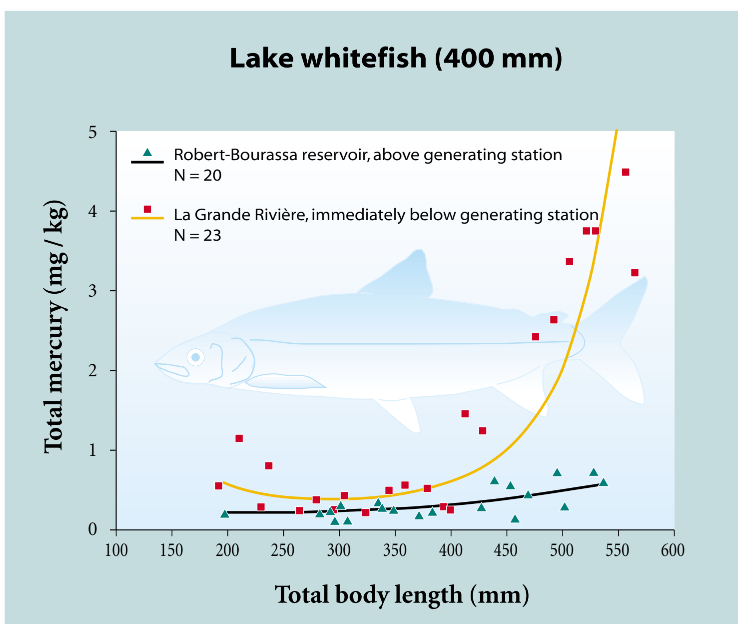
Mercury levels in generally non-piscivorous fish may sometimes be higher immediately downstream from a generating station than they are upstream. This phenomenon has been observed in lake whitefish caught below Robert-Bourassa generating station, which have mercury levels 2.5 times higher than specimens caught in the reservoir (see Figure 13). In this case, the large individuals caught downstream fed mainly on small fish arriving from the reservoir after swimming through the turbines.

The creation of reservoirs in the Grande Rivière drainage basin had little effect on mercury levels in fish along the east coast of James Bay. An increase in these levels was observed only in the zone of freshwater influence from the Grande Rivière, namely over a distance of 10 to 15 km on either side of the mouth (Schetagne and Verdon, 1999b).

2.8.3 Mercury and health

The presence of mercury in the environment is cause for concern due to its potential toxicity for humans. Except for cases of industrial exposure, the main source of human exposure to mercury is the consumption of fish. Humans are exposed most to methylmercury, the principal organic form of mercury. Because of their way of life, which centres largely on hunting and fishing activities, the James Bay Crees are generally more exposed to methylmercury than the Québec population as a whole.

Figure 13
Relation between mercury and length of lake whitefish caught upstream and downstream from Robert-Bourassa generating station (1992)



With this in mind, the Grand Council of the Crees of Québec, Hydro-Québec, the Québec government, SEBJ and the Cree Regional Authority signed the Mercury Agreement (1986), which aimed to

- Determine the nature and scope of the problem caused by mercury in the environment, with particular attention to the waters in the La Grande complex (1975)

- Take steps to minimize health risks due to mercury in the environment

- Mitigate the existing and possible negative impacts on the Crees, their way of life and their hunting, fishing and trapping activities, and establish mitigation measures

Methylmercury in the organism

In humans, the methylmercury present in ingested foods is absorbed almost entirely by the digestive tract; from there, it is distributed unevenly through the various tissues in the body. It reaches its highest levels in the brain and hair. Once absorbed, methylmercury is gradually converted to inorganic mercury, through an enterohepatic cycle. When the methylmercury present in the blood passes into the liver, it is returned to the intestine through the bile ducts. Each time it passes through, the liver transforms part of it into inorganic mercury. Very little of this inorganic mercury is absorbed by the intestine, and it therefore passes into the feces. Microbial intestinal activity may accelerate the elimination process by also transforming the methylmercury into inorganic mercury. As a result, more than 90% of the dose ingested will eventually be eliminated in the feces.

The half-life for eliminating the body burden was measured in a number of volunteers, and found to be approximately 70 days. The half-life of methylmercury in the blood, however, is around 40 to 50 days (Smith and Farris, 1996).

Methylmercury concentrations in hair are proportional to the blood concentration at the time each hair is formed, and remain unchanged at that specific point throughout the life of the hair. Since hair grows around 1 cm a month, the mercury concentration measured over a centimetre of hair reflects the mean concentration for the corresponding month. This is the technique used to measure mercury concentrations in humans.

Toxicity of methylmercury in adults and fetuses

It is mainly through studies conducted on populations exposed to acute poisoning in Minamata Bay, Japan (industrial pollution), and Iraq (contaminated grain) that the neurotoxicity of methylmercury in humans has been quantified and characterized.

A few months after initial exposure, the earliest symptom is the appearance of numbness in the extremities and sometimes around the mouth. These symptoms seem to occur at methylmercury concentrations between 250 and 500 mg/kg (ppm). At progressively higher doses, a number of neurological disorders appear, including a lack of coordination, constriction of the visual field and inability to speak.

Studies conducted in Iraq revealed that children were more affected than their mothers. At concentrations between 160 and 320 mg/kg in the mother's hair, children suffered from a syndrome similar to cerebral palsy. At more than 400 mg/kg, there were a number of deaths among the children. In 33 mother-child pairs studied where the maximum concentration in the mother's hair was less than 10 mg/kg, no abnormality was observed. A recent analysis of data from the poisoning in Iraq places the toxic threshold at 114 mg/kg in the mother's hair (Crump et al., 1995).

These cases of acute poisoning are in no way comparable to the exposure levels of populations consuming substantial quantities of fish, as is the case of the James Bay Crees.

Intervention threshold

The daily exposure threshold is currently the subject of debate in the scientific community. Two epidemiological studies conducted recently in the Seychelles and in the Faroe Islands yielded contradictory results as to the exposure threshold at which the human fetus was at risk.

The Seychelles study arrived at a NOAEL ("no observable adverse effect level") of about 25 mg/kg of mercury in the mother's hair (Crump et al., 2000). This would translate into an allowable daily dose of about 2.5 µg per kilogram of body weight. The Faroe Islands study, on the other hand, arrived at a NOAEL of about 1 mg/kg in the mother's hair (Grandjean, 2000), which would translate into an allowable daily dose of about 0.1 µg per kilogram of body weight. As for the small doses resulting from fish eating, it is difficult to assess the risk to the fetus since the exposure threshold at which the fetus is at risk is currently the subject of scientific debate.

In the case of the Faroe Islands study, it should be mentioned that the mercury exposure was mainly from the consumption of whale meat, which is also contaminated by other neurotoxic compounds. Consequently, the conclusions of this study cannot be directly applied to populations exposed to mercury from fish consumption.

The Cree Board of Health and Social Services of James Bay, an organization controlled and managed by the Crees, has set the intervention threshold for hair mercury concentrations at 30 mg/kg for adults in general and 15 mg/kg for women of child-bearing age (15 to 39 years old). These thresholds take into account the importance of fish in the Crees' diet.

Since there is no treatment for the effects of mercury poisoning once they have appeared, the only possible intervention consists of stopping the exposure by replacing the contaminated food with another food containing less or no contamination. The natural mercury elimination process allows the body burden to return to a safe level.

2.8.4 Level of exposure among the James Bay Crees

Fish is an important food source for the James Bay Crees. A study in the mid-1970s showed that fish accounted for 15% to 20% of the game eaten by the Crees. Around the same time, before the reservoir impounding, high mercury levels due to industrial pollution were discovered in the fish in lakes and rivers south of the James Bay region. This discovery led the Crees to change their fishing habits and their diet. When a large increase in fish mercury levels in the La Grande reservoirs was noted in the early 1980s, the Crees' apprehension grew.

Given the importance of fish in the Cree diet and the high mercury concentrations found in certain species, both in natural lakes and in reservoirs, the mercury problem affects all nine communities of the James Bay Crees. The families that regularly engage in traditional activities (some 30% of the population) run the greatest risk of exposure to high levels of methylmercury, especially those who eat piscivorous fish from lakes or reservoirs.

Under the Mercury Agreement (1986), the Cree Board of Health and Social Services of James Bay was responsible for monitoring the Crees' level of exposure to mercury (Dumont et al., 1998).

According to the most recent results, measured in 1993 and 1994 in 3,599 individuals from the nine Cree communities, only five adults (all of them aged 50 or over) displayed concentrations greater than 30 mg/kg in their hair, and no woman of child-bearing age had a concentration above the intervention threshold of 15 mg/kg (Dumont, 1995). The results show that mercury exposure among the Crees has gradually declined since 1984. In 1993–1994, the mean level was 3.8 mg/kg in the population as a whole, and over 90% of the people had concentrations of 7.1 mg/kg or less. Concentrations have also decreased considerably in mothers and newborns (Girard and Dumont, 1995; Dumont et al., 1998).

Now that information campaigns have raised Cree awareness about mercury in reservoir fish, any risk of exposure stems largely from the consumption of fish caught in lakes and rivers untouched by the La Grande complex. In fact, Crees in the village of Whapmagoostui, who do not have road access to the reservoirs in the La Grande complex, showed the highest hair mercury concentrations of the nine James Bay Cree communities.

In 1995, the Cree Board of Health and Social Services of James Bay recommended to the Crees that they eat fish at least twice a week, especially non-piscivorous species such as cisco, lake whitefish, brook trout, lake sturgeon and longnose sucker (James Bay Mercury Committee, 1995). This recommendation was based on the observations that mercury exposure among the Crees was under control, that fish is a high-quality food obtained relatively cheaply and that fishing plays an important role for the Crees, socially, culturally and economically. Today, specimens of suitable size for consumption from all these non-piscivorous species—even specimens from modified environments that are part of the La Grande complex—may be consumed without restriction by all. However, women of child-bearing age are advised to limit their consumption of certain types of fish caught in specific environments immediately below generating stations. Consumption of piscivorous fish caught in modified environments is still not recommended for such women, but is permitted, in moderation, for all other consumers. These recommendations should become even less restrictive in future, given the progressive diminution of mercury content in fish from reservoirs and other altered environments (James Bay Mercury Committee, 1998).

Under the terms of the Mercury Agreement (1986), numerous community fishery projects started up in the Cree villages between 1986 and 1996. To make these fisheries safer, accurate maps indicating recommended fishing sites, sizes and species were supplied to users (Tremblay and Langlois, 1996).

2.9

Greenhouse gases

Reservoir creation causes the flooding of an extensive land surface. Some of the submerged plant biomass decomposes at a rate that varies according to the nature and physical conditions of the surrounding environment. This decomposition favors the production of greenhouse gases (GHGs) such as methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) (Duchemin et al., 1995).

The greenhouse gases emitted by a reservoir are also created by the decomposition of biomass from three other sources: the reservoir's net primary production, dissolved organic matter or particulates brought into the reservoir by surface water and runoff from the various drainage basins feeding it, and atmospheric CO_2 falling back into the surface water. To determine the greenhouse gas contribution resulting from the creation of a reservoir, it is first necessary to determine the volume of greenhouse gas emissions from the reservoir's drainage basin before and after flooding of the vegetation.

Even with the intensive research and studies carried out since 1993 by Hydro-Québec in close cooperation with university research centres, it is still not possible to determine the output of the different sources of GHGs in a drainage basin or to establish the temporal changes in global GHG emissions.

An analysis of experimental results obtained at the La Grande complex reveals that the rate of GHG emission at the water-air interface of Laforge 1 reservoir in the first five years (1993–1997), and of Robert-Bourassa reservoir in years 15, 16 and 19 (1993, 1994 and 1997) after impoundment, varies considerably over both space and time, with an overall average of 1,900 mg CO_2 /m^2-day. The variations from year to year are substantial (from 1,280 to 3,060 mg CO_2 /m^2-day), as are variations between sampling sites (from ±430 to 1,400 mg CO_2 /m^2-day), depending on the year.

Since only a small portion of the flooded plant matter decomposes over a 10- to 15-year period in a northern reservoir (see section 2.5.1 on water quality), it might be expected that GHG emissions would fall off considerably after several years. In fact, much older reservoirs, such as Manicouagan (28 years) and Gouin (80 years), still emit 1,175 to 1,275 mg CO_2 /m^2-day, implying that submerged organic matter represents a much smaller proportion of a reservoir's total GHG output than might initially have been believed. This hypothesis is reinforced by the fact that GHG emissions from the reference lakes chosen for Manicouagan and Gouin reservoirs are comparable to or greater than those from the reservoirs themselves (Duchemin et al., 1999; HydroQuébec–NSERC–UQAM Environmental Research Chair, 1999).

Studies under way on the reference lakes will help determine hydroelectric reservoirs' contribution to GHG emissions. According to current data, which may be considered conservative, thermal power plants fired by natural gas and coal emit 14 times and 28 times more greenhouse gas, respectively, per GWh than the La Grande hydroelectric generating stations. Every GWh of hydraulic origin produced and sold in Québec prevents the atmospheric discharge of 500 to 700 tonnes of CO_2 (research in progress, Hydro-Québec–NSERC–UQAM Environmental Research Chair).

2.10

Terrestrial environment

At their maximum levels, the reservoirs in the La Grande complex cover nearly 13,000 km^2. Not including preexisting bodies of water, the land flooded represents close to 11,000 km^2. A little more than 6% of the land surface of the developed Grande Rivière drainage basin was flooded. The submerged environments did not all have the same value for wildlife. The spruce-lichen forest is important for caribou in winter, the shrubs and riparian vegetation are sought after by moose and small game, such as ptarmigan, and the wetlands are used by waterfowl. A small portion of these environments, which are widespread throughout the area of the La Grande complex, was flooded. On a physical level, a sizable transformation took place; on a biological level, it is not so simple to calculate the losses.

The aquatic environment has the advantage of being much more stable than the terrestrial environment, a fact that partly explains the absence of major fluctuations in fish populations. The terrestrial environment, which is subject to random weather events and forest fires, cannot guarantee much stability for the wildlife it supports. Consequently, the energy transfer efficiency per kilogram of biomass produced is much greater in cold-blooded animals, like whitefish and pike, than it can be in warm-blooded animals like caribou and geese.

According to the studies, biomass in the drainage basins of the Grande Rivière and the Grande Rivière de la Baleine is three to four times greater in lakes than in rivers, reaching approximately 20 kg/ha in lakes. In the La Grande complex reservoirs, biomass amounts to 25 kg/ha in the first few years. In the case of terrestrial wildlife, the total available biomass of the principal species of interest is about 1 kg/ha. Around 60% of this biomass comes from migratory herbivores such as caribou, waterfowl and ptarmigan, which previously derived only a small portion of their energy from the flooded terrestrial environments. The other 40% (produced locally) stems mainly from herbivores such as hare, beaver, muskrat, porcupine and grouse. Carnivores, at the top of the food chain, represent only a very small part of the terrestrial biomass.

In terms of biomass production, the loss of terrestrial environments is offset substantially by the extension of the aquatic environment. It is nonetheless an ecological loss that has a particular effect on the habitat of nonmigratory species. Since terrestrial wildlife is not as captive to its habitats as aquatic species, it is much harder to determine the losses caused by the La Grande complex. However, monitoring and follow-up carried out before, during and after construction of the complex yielded considerable new knowledge about changes in vegetation on the new banks and the behavior of terrestrial wildlife in such cases.

2.10.1 Changes in riparian vegetation

Riparian vegetation, that is, vegetation growing next to bodies of water, undergoes alternating submersion and exposure. Although the growth and zonation of riparian vegetation are based on several factors, the difference in water level between the spring flood season and the summer low water is what mainly determines the width of this strip of vegetation. That is why vegetation is usually narrower and less diversified along lakeshores than along rivers and streams (Foramec, 1992).

Area around the Boyd-Sakami reservoirs and lakes (EOL diversion)

Follow-up at the La Grande complex revealed that the growth, distribution and zonation of plants around reservoirs were governed by the duration of flooding, extent of fluctuations in water level, slope, type of substrate and importance of erosive agents (ice, wind, current, waves, etc.) (SEBJ, Groupe Dryade and Foramec, 1985).

Following the diversion of the Eastmain River, riparian vegetation is colonizing the exposed banks.

Five years after the impoundment of the reservoirs in the La Grande complex, banks exposed to erosive agents were treeless, and no species had begun colonizing the eroded surfaces. On more sheltered banks, trees were still standing, but it was only near the maximum reservoir level that any of them showed any vitality. A few tall shrubby forest species (willow and alder) were also to be found there. The plant communities on very sheltered peaty banks were stable over a width of several metres at the maximum reservoir level, as a result of either the lifting of the peat or the greater tolerance of these species to occasional submersion. Certain herbaceous species with a wide ecological range took advantage of the erosion of the layer of organic matter and the variability in water level to grow near the high-water mark (SEBJ, Groupe Dryade and Foramec, 1985).

Ten years after the La Grande reservoirs were impounded, natural agents were slowly stripping the exposed banks, willows persisted in the tree stands, and sedges and grasses had colonized the areas near the maximum reservoir level (Hydro-Québec, 1989). The herbaceous plants had taken advantage of the exposed nature of the environment and the drop in water level caused by the lower runoff in recent years, and had spread.

Today, nearly 20 years after impoundment, annual species can be seen on the frequently flooded portion of the banks, instead of herbaceous plants, which cannot survive the frost when they are exposed for more than one winter. At the high-water mark, a young scrubland is growing in the most favorable areas. However, a large part of the current riparian vegetation represents a temporary situation: it may disappear if the reservoir level returns to its maximum. Altogether, the natural reconstitution of the reservoirs' riparian vegetation remains limited, and varies according to runoff, type of substrate, and the generating stations' mode of operation.

In the Boyd-Sakami diversion, the behavior of the riparian vegetation over the first five years was similar to that observed in the reservoirs, since the water level in that period varied in the same way in both environments. Subsequently, better flow regulation at the

Opinaca reservoir control structure allowed certain herbaceous and shrubby species to colonize the cleared banks, close to the maximum water level (Hydro-Québec, 1989). Today, after 20 years, this trend still holds, and the vegetation is seen to be more developed along the rivers than on the reservoir banks.

Banks of reduced-flow rivers

On the reduced-flow rivers of the La Grande complex (Eastmain, Opinaca and Caniapiscau), the process of plant recolonization of gently sloping exposed surfaces was relatively rapid in the case of flats consisting of fine materials: right from the first year, floristic diversity had increased by 23% on the Opinaca and Eastmain. Exposed aquatic plants quickly regressed, while species in the upper riparian zone proliferated. After eight years, shrubby species in the upper riparian zone had expanded considerably over the whole bank, at the expense of pioneer wetland species. Flats consisting of fast-draining coarse materials underwent similar changes, but at a much slower rate.

Banks consisting of sand or clay had to be stabilized by the seeding of herbaceous species and the planting of shrubs. In all, 145 ha of exposed banks along the Opinaca and Eastmain were seeded and fertilized. After two to three years, the seeded areas were 100% covered, compared to 70% for unseeded areas. In taking up all the available space, the vegetation counteracted the phenomena of river and wind erosion. The planting of shrubs and herbaceous seedlings was much less successful. A substantial percentage of the 318,500 seedlings planted on the banks of the Opinaca and Eastmain died within two years. After seven years, the banks where willow and alder had been planted did not show greater coverage than banks that had not been planted.

Today, nearly all the exposed banks of the Opinaca and Eastmain are fully covered with vegetation. A herbaceous stratum occupies the lower zone, while the upper zone is entirely occupied by shrubs.

The rockier banks of the Caniapiscau River were colonized much more slowly than those of the Opinaca and Eastmain, especially since controlled spillages carried out in the first and second years after reservoir impoundment (1984–1985) delayed natural colonization. Three years after the spillages, upstream from Cambrien Lake (a widening in the Caniapiscau River), banks consisting of clay-silt displayed a broader riparian willow forest and incipient herbaceous colonization of the lower zone. Eight years later, in September 1996, this trend continued, with more diversified plant composition seen even on substrates of coarse materials. A tree stratum occupied the upper zone.

The exposed banks of Cambrien Lake, like those of the river further downstream, were not as extensive as the banks further upstream; they had vegetation coverage over at least 50% of their surface 15 years after the reduction in flow. In addition, at Cambrien Lake, a pronounced widening of the riparian ecotone was observed on the upper zone of the old banks, along with a thin, relatively sterile strip made up of the old sand beach lower down, followed by varied vegetation that already had the appearance of an ecotone in the new lower zone (Denis and Hayeur, 1998).

In general, the exposed banks of reduced-flow rivers in the La Grande complex have become covered with vegetation, leading to an extension of the former riparian ecotones. This expansion partially offsets the loss of riparian ecotones due to reservoir creation.

Recolonization of the dried-up bed of the Caniapiscau. In the background: Caniapiscau reservoir.

2.10.2 Behavior of terrestrial wildlife in modified environments

The monitoring of modified environments increased our understanding of the impact of the La Grande complex developments on the principal terrestrial species, particularly the nonmigratory species that used these environments before, during and after construction of the complex.

Reservoir impoundment and presence

The creation of a reservoir causes the displacement of essentially land-based, nonmigratory species that had previously used the flooded areas. Snowshoe hare, for example, which is distributed quite evenly over the area of the La Grande complex, had to move and occupy a much smaller territory in which intra-specific competition and predation have established a new balance. The signs of this mammal's presence reveal a population density ranging between 0.6 and 2.1 ind./km, depending on the phase in the abundance cycle (Perreault and Nault, 1984; Groupe Roche Boréal, 1991), so that it is very difficult to establish the actual loss which the hare population of the La Grande complex may have undergone. Some observations tend to show that the loss is less than had initially been anticipated, on the basis of land surfaces lost. At the start of impoundment of Robert-Bourassa reservoir, in November 1978, and during the following winter, a large number of hares traveled about on the reservoir ice. Several islands in the reservoirs were consequently colonized by this mammal. Recent observations reveal that these islands are still extensively used by snowshoe hare during winter.

For semiaquatic species like beaver and muskrat, the situation seems to have been less unfavorable. Monitoring of the beaver, whose presence is easier to observe in aerial inventories, supplied considerable data on the behavior of this rodent during and after impoundment.

In the spring following the start of impoundment at La Grande 3 reservoir, some beavers had gradually moved along the edge of stands of flooded deciduous trees. They had survived the winter in their lodges with their stores of food. Others had traveled up to 3.5 km to colonize a new territory (SEBJ and SOTRAC, 1983). One pair of adults tagged with a radio transmitter in the spring of 1981 was observed with a kit the following October (SEBJ and SOTRAC, 1983). The young are therefore able to survive impoundment.

The monitoring of nine beavers tagged with radio transmitters when La Grande 4 reservoir was impounded yielded much the same observations (SEBJ and SOTRAC, 1984). Adult beaver moved with the rising waters and built several lodges, even adding more stories. The beaver did not all leave the reservoir; some migrated to new banks. Birch and aspen stands made available by the impoundment created environments very favorable to beaver in some parts of the reservoir.

A study of Robert-Bourassa and Opinaca reservoirs was begun in the fall of 1982—four years and two years, respectively, after impoundment. Five beavers in Robert-Bourassa reservoir and seven in Opinaca reservoir were tagged with radio transmitters. The beavers' behavior was observed to change with the seasons. In fall, beaver were found around the edge of the reservoirs, in deciduous stands. Certain signs revealed that these places had been used for several years. A rapid rise in water level could lead to a migration to other sites, either along the edge of the reservoir or beyond. The winter drop in water level prompted the beaver to move to the drawdown zone, where they made use of the empty spaces formed under the ice. It was even observed that a lodge was extended by a tunnel several metres long which enabled the beavers to reach the surface of the water in complete safety. In spring, as soon as the ice melted, the beaver left the reservoir and settled in neighboring aquatic environments. This migration generally took place over short distances and before the littering period. The beaver stayed in these areas for the first months of summer. These numerous displacements likely mean a higher mortality rate due to predation.

While they do not establish a survival rate, the studies show that a certain number of beaver survive reservoir impoundment and some of them even manage to use the drawdown zone.

Reservoir drawdown zone

This zone (including the banks of new islands) was long considered a sterile environment for wildlife in general. In the impact assessments conducted in the early 1980s, these new surfaces, stripped bare and often strewn with wood debris, were thought of as waste spaces of no value to wildlife. Since the early 1990s, a number of observations made during aerial and land-based inventories have tempered this negative assessment. Tracks observed in the drawdown zone indicate that various animal species, ranging from insects and other invertebrates to black bear and caribou, use the area; thus, what might be called a *drawdown ecology* exists (Doucet and Giguère, 1991).

A comparative study of the biological diversity of the islands in La Grande 3 reservoir, 11 years after its creation, and the islands in neighboring large, natural lakes showed that there is no appreciable difference between the two groups of islands (Crête et al., 1997). The species diversity, richness and composition were similar. Furthermore, a comparison of the species abundance and populations of small mammals and birds revealed that isolation had not reduced the islands' biological diversity, which was slightly greater than on the mainland (Crête et al., 1995).

For several years, numerous shorebirds and ducks have been observed at the high-water level, which is teeming with aquatic insects. A recent study conducted in Laforge 1 (La Grande complex) and Robertson (North Shore) reservoirs, designed to evaluate the areas' use by waterfowl in comparison with reference zones located outside the reservoirs, produced very interesting results. This study reveals that waterfowl use the shallow or partly submerged areas of reservoirs, especially when these areas are occupied by a tangle of dead shrubs and wood debris. Waterfowl richness totaled 13 species in the 25-km^2 sample section of Laforge 1 reservoir and 8 species in the sample sections of Robertson reservoir. Several broods were noted in the two reservoirs. The study also yielded the observation that population density, of both individuals and broods, was higher at Laforge 1 reservoir than in the corresponding reference zone, and similar to that of the reference zone for Robertson reservoir (Morneau, 1998).

To enhance the ecological value of a section of Laforge 1 reservoir, the Société Opimiscow-SOTRAC carried out measures to improve the area for waterfowl in 1977. A 1999 survey conducted by Hydro-Québec revealed an increase in the birds' use of the area (Morneau, 1999). It is too early, however, to be certain of the value of this enhancement measure.

The studies show that reservoir drawdown zones can no longer be considered a sterile environment, abandoned by wildlife. Even though this zone can vary from one year to the next and does not always have the same value for the species using it, it clearly constitutes a habitat and must be considered as such.

Banks of reduced-flow rivers

The monitoring of beavers' use of the Opinaca and Eastmain rivers revealed a regular increase in signs of presence after the reduction in flow. The number of occupied lodges rose from 9 to 32, over seven years, in the river sections monitored. These observations show that the beaver took advantage of the reduction in flow and the presence of shrubby vegetation on the exposed flats.

Reconnaissance conducted in September 1996 on the new flats of the Caniapiscau revealed that the area was used by a variety of wildlife. Droppings and a variety of tracks (geese, gulls, rodents, hares and fox) were observed, crisscrossing caribou trails. The new banks of Cambrien Lake were also extensively used by wildlife. During the same reconnaissance mission, thousands of American black duck and geese were observed browsing in the new ecotone, all along the lakeshore. A more thorough examination of the banks revealed gull, hare, fox, wolf and caribou tracks (Denis and Hayeur, 1998).

Taken as a whole, the observations made along the banks of the reduced-flow rivers show that these environments have lost none of their ecological value; on the contrary, they have been enriched.

2.10.3 Impact of hydroelectric developments on migratory wildlife

For migratory species, the new environmental conditions were less unfavorable than they may have been for nonmigratory species. The migratory species that used the flooded land areas did so only at a specific time of year and to meet only a part of their energy needs. Furthermore, as migratory animals, they had access to all the modified environments. To evaluate the impacts of northern hydroelectric developments on the habitat and changes in the populations of migratory species most sought after by Aboriginal people, Hydro-Québec carried out several major studies in cooperation with the public authorities concerned. The following pages present the results for waterfowl and caribou.

Waterfowl

Waterfowl, which includes geese and ducks, is a wildlife resource of international interest by virtue of its migratory nature. It has been the subject of numerous studies and inventories in northern Québec. This research has been done since 1949 to support waterfowl management by the Canadian and American public authorities, and over the past 20-plus years to evaluate the impact of the hydroelectric developments in this region. The studies carried out by the Canadian Wildlife Service and by Hydro-Québec quite likely represent the largest and richest body of information on the distribution of nesting waterfowl species in eastern North America.

Some 90% of the area of Québec is part of the Canadian Shield, a platform of Precambrian origin whose biological productivity is known to be fairly low. Nevertheless, because of its immensity, this territory is important for the waterfowl populations that migrate via southern Québec to the United States. Québec hosts a little over a million breeding pairs throughout its territory (1,600,000 km^2), comprising some 30 species. These species prefer wetlands, where they find food and shelter, although they generally build their nests on dry land.

Reservoirs used for electricity generation occupy approximately 1.5% of Québec's total land mass. The La Grande complex affected about 0.8% of the surface area of places used by waterfowl during the summer breeding period inland. Using a simple mathematical calculation, it was estimated that 7,000 to 9,000 breeding pairs were displaced by this development, assuming that the reservoir banks had no reproductive value for waterfowl. However, as recent studies have revealed, when reservoir banks are gently sloping and hold a tangle of shrubs and wood debris, or when they are half-submerged, thus creating small ponds and wetlands, they constitute a favorable nesting environment for waterfowl. No precise calculation has yet been done to determine the extent of this type of environment as a percentage of the reservoirs as a whole. However, it is apparent that the latest data call into question the calculation of habitat losses, which considered the areas modified by the hydroelectric developments to hold no value for waterfowl.

By way of example, the borrow pits located alongside highways and access roads were judged by ecologists to be biologically sterile places after they had been used. In fact, the pools that form at the bottom of the excavations contain the first water released from the ice cover in spring, making them preferred stopover areas for waterfowl migrating north.

In view of the fact that the riparian environment of reduced-flow rivers has become more favorable for waterfowl wherever the ecotone has expanded, the extent of habitat losses and the number of displaced nesting pairs must again be reduced from initial estimates.

Recent studies illustrate the ability of wildlife to adapt to changes (of natural or human origin) in its habitat. This ability is much greater than might have been believed.

It is clear that the number of birds affected by habitat losses is small in comparison with the total waterfowl population, although it is practically impossible to give a precise figure. Hunting yields in southern Québec do not reveal any notable difference between the periods preceding (1976–1978) and following (1985–1987) Phase I of the construction of the La Grande complex, as regards waterfowl hunting success for all species combined.

For more than 20 years, Hydro-Québec has constantly sought to improve waterfowl habitat. Since 1990, the company has taken part in joint waterfowl habitat enhancement endeavors with the Fondation de la faune du Québec (Québec Wildlife Foundation). And as was already mentioned, Hydro-Québec has carried out extensive improvements for waterfowl along the Vincelotte River, Opinaca and Laforge 1 reservoirs, and James Bay, among other places. Many of these projects were joint efforts between Hydro-Québec and Cree trappers, as part of the activities of the remedial-measures corporations (SOTRACs).

Caribou

The caribou (or reindeer) is a circumboreal cervid species numbering several million in Lapland (2.5 million of them domesticated) and nearly 2 million in the Northwest Territories and Alaska. In northern Québec and Labrador, the population is around 1 million, up from several thousand individuals in the early 1950s (Audet, 1979; Hayeur and Doucet, 1992).

The caribou of northern Québec and Labrador travel over a territory of more than 1,000,000 km^2 which runs from the Labrador Sea to James Bay and Hudson Bay, and from the 49th to the 60th parallel. These lengthy migrations meet two requirements: the constant search for enough food to feed the whole herd, which is sometimes very large; and the return every spring, at least for the great majority, to the usual calving grounds.

In summer, caribou feed mainly on lichen, shrubs and herbaceous plants. In winter, their main food source is lichen, which they sometimes gather off the trees but mainly browse on the ground by digging through the snow. In northern Québec and Labrador, three types of environment provide the caribou with most of their food: spruce-lichen forest, shrubby heath and lichen heath. Spruce-lichen forest occupies the centre of the region, between the 50th and 56th parallels. In this type of spruce forest, the trees cover 25% to 40% of the ground. The remaining surface is often covered by a thick layer of lichen, when it has not been trampled or over-browsed by the caribou. At higher latitudes and altitudes, shrubby heath and lichen heath increase in importance, replacing the spruce forest.

Experience seems to have taught the caribou that in winter the lichens associated with plant communities along the edges of frozen rivers and bodies of water always represent reliable food sources. These stretches offer an easy access route and are often used by the caribou. The presence of a complex network of frozen rivers and lakes in a vast area covered by lichen-containing plant communities enables the caribou to reach these feeding grounds with a minimum expenditure of energy.

Tracks left by caribou using a snow-covered road.

There are two distinct types of calving grounds: the peaty zones in the south and, further north, the high tundra plateaus. These open areas allow the caribou to see a long way off, providing them with better protection against predators.

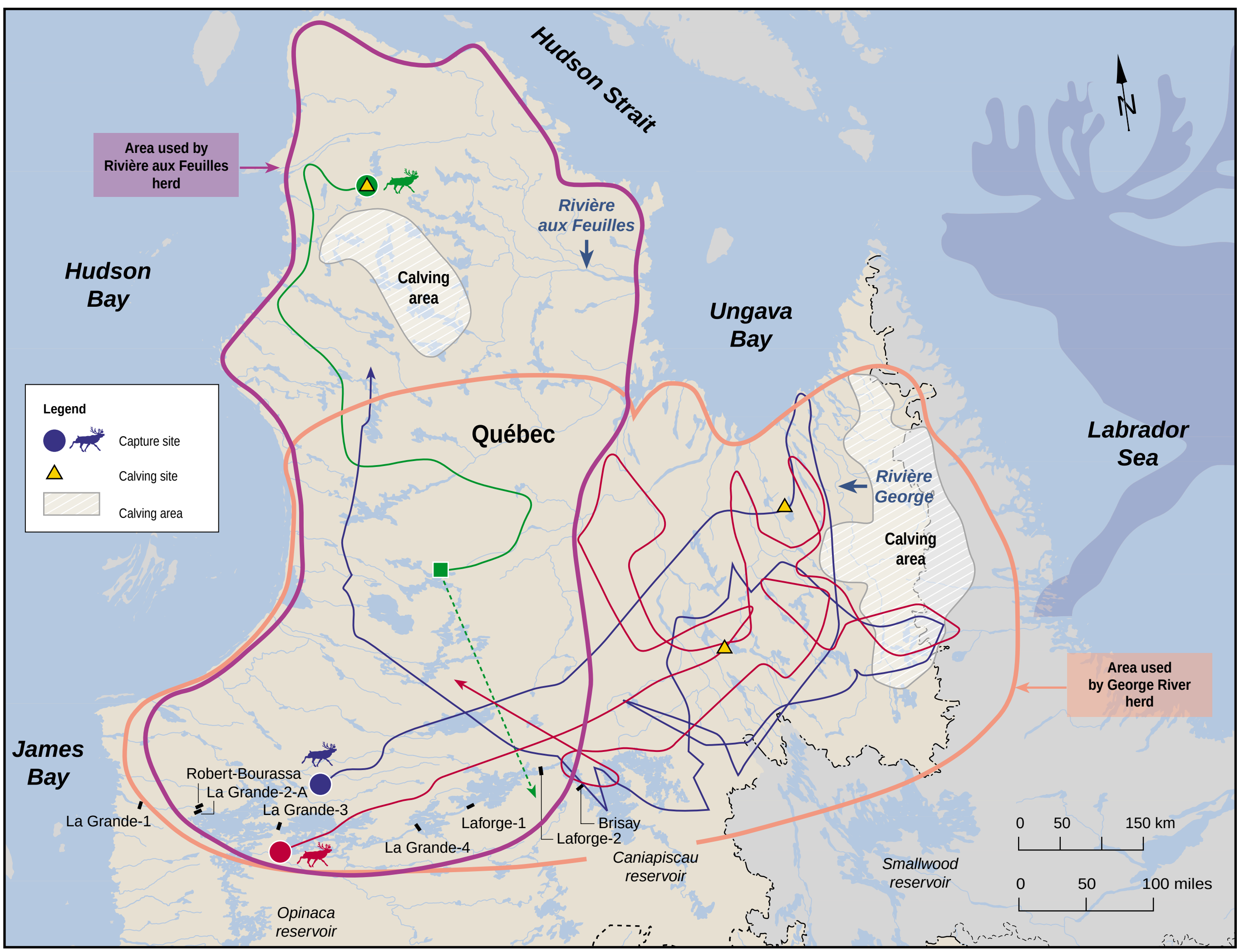
The flooding of surfaces totaling 13,000 km^2 for the requirements of the La Grande complex led to a net loss of a little over 1% of the 1,000,000-km^2 caribou range of northern Québec and Labrador. Considering the use made by the caribou of this immense territory (see Figure 14), it is difficult, if not impossible, to translate the loss of area into loss of habitat and to assess the impact on the caribou population, especially since the region's caribou population grew spectacularly between 1970 and 1990, increasing from a hundred thousand or so to about a million. Since then, the population has seemed to hold steady, although recent observations show a decline.

Monitoring of a small caribou herd in the Caniapiscau reservoir area before, during and after construction of the La Grande complex provided answers to questions about the caribou's movements in winter and their use of the calving grounds south of Caniapiscau Lake (used by several hundred individuals), as well as about the impacts caused by the impoundment, the ice breakup during drawdown, the presence of roads, and hunting.

The many overflights carried out during reservoir impoundment never revealed the presence of any large mammals in distress because of the impoundment, with or without ice cover.

In winter, the water level in Caniapiscau reservoir may vary by several metres. The drop in water level causes the ice to break up around the edge. On the whole, however, this breakup is minimal for the reservoirs in the La Grande complex, where the banks are generally not very steep. It was observed that the caribou have no trouble reaching nearly all the reservoir banks (Doucet et al., 1992).

*Figure 14 – **Movements of three caribou monitored by telemetry from March 1991 to February 1992***



In 1981 and 1982, 42 females were fitted with tracking radio-collars. Of these 42 females, 19 had calved in the area around Caniapiscau Lake prior to impoundment. Sixteen of these 19 females returned to the same area, that is, within 20 km of the site where they had calved the year before. The other three shifted their calving sites by a distance of about 100 km (Paré and Huot, 1986). It might be tempting to conclude that the impoundment caused the displacement of around 15% of the females. However, if we compare these data with those obtained on the Bienville Lake calving grounds between 1976 and 1979, we observe that, in this untouched region, females might calve in places more than 100 km apart from one year to the next. The impoundment therefore cannot be the only cause of the change in calving sites by the three females in the Caniapiscau herd mentioned above (Hayeur and Doucet, 1992).

The studies conducted on caribou populations that used the region of Caniapiscau Lake and Bienville Lake before the impoundment of the La Grande reservoirs revealed that the animals used these large frozen surfaces to reach the adjacent spruce stands and heaths in search of lichen. It could be assumed that future reservoirs would also play a role as travel routes. Since the winters of 1981 and 1982, tens of thousands of caribou have used the La Grande reservoirs. These reservoirs have become not just access roads, but also new winter feeding grounds for the caribou, as their banks and islands are partly occupied by spruce-lichen stands. Before the reservoirs were created, these spruce stands were too far from the frozen water routes to be used by caribou. Near the banks, there are also peat bogs, shrubby heaths and lichen heaths that may serve as calving and feeding grounds.

A major study by ecologist A. T. Bergerud et al. (1984) concerning the impact of development on the caribou showed beyond all doubt that highways, just like other kinds of infrastructure, are not an obstacle to caribou movements. A great many observations made during the construction and operation of the La Grande complex bear out the conclusions of Bergerud's study.

Bergerud mentions that the accessibility afforded by a new highway can considerably increase sport and subsistence hunting and jeopardize the survival of a small herd if there are no controls. In Québec, since hunting by non-Natives is strictly regulated and the herd size remained at around a million animals throughout the 1990s, the opposite problem arises. For about 10 years, the government department in charge of hunt management has tried to increase the annual harvest and reduce the size of the caribou population, which, according to specialists, is too high for the habitat's capacity. The number of permits per hunter has consequently risen from one to two, and a winter hunt has been introduced.

It appears difficult to evaluate the impact of the La Grande complex on the caribou population, but the follow-up has not revealed any unfavorable effects. Hydro-Québec is continuing the research program launched in 1985 on the ecology of the caribou, in cooperation with the department in charge of wildlife management in Québec. With the help of satellite images, Hydro-Québec has produced digital maps of the main plant communities that cover nearly all of the caribou's distribution area. Since 1991, Hydro-Québec and the Québec department of environment and wildlife have implemented a major program for monitoring caribou movements by satellite using the Argos data collection system. A number of animals fitted with radio-collars and belonging to different herds are thus being monitored on an ongoing basis. The program provides a better understanding of migration patterns based on the habitats used, and is of great value in managing this important resource.

2.11

Social environment

Social impacts became a primary concern as soon as work began on the La Grande complex. Impact assessment studies were ordered both by Cree organizations and by Hydro-Québec. These studies no doubt constitute the first attempts to forecast the impacts of hydropower developments on northern communities (Salisbury et al., 1972; Stewart, 1974; Feit and Penn, 1974; Langlois, 1974). After the JBNQA was signed in 1975, its provisions, along with relations between Hydro-Québec and Native organizations, became the determining factors in the nature and the very existence of social impact assessment in the La Grande complex zone.

It was anticipated that evaluating the social impacts of a project would be quite difficult. Instead of depending on impact assessment studies, therefore, the JBNQA set up an ongoing exchange mechanism—the La Grande Complex Remedial Works Corporation (SOTRAC), jointly run by the Crees and SEBJ—to evaluate the repercussions on the Cree way of life and to oversee the mitigation measures. Consequently, it was no longer up to SEBJ or Hydro-Québec to study the impacts of the La Grande complex on the Aboriginal way of life. Nevertheless, provincial legislation on cultural property demanded that the historic and prehistoric heritage be protected. For many years, therefore, social impact assessment consisted mainly of archaeological research in areas liable to be altered by reservoirs, transmission lines or other infrastructure.

To evaluate the impacts of the Grande-Baleine project (which was subject to the new government regulation on environmental impact assessments, effective 1979), it became necessary to understand and differentiate between the impacts of the La Grande complex and those of the JBNQA on the Aboriginal people of northern Québec.

Starting in 1985, the La Grande environmental follow-up program, which had previously focused on the biophysical environment, was modified to include studies on the economy and social impacts. However, such studies require the participation of the people affected, and few of them were actually carried out for lack of an agreement with the Cree communities. The studies ordered by Hydro-Québec were therefore based on available literature and on surveys of non-Cree residents and users of the James Bay region.

But in 2000, for the first time, a major follow-up study was initiated in cooperation with the Crees who use the area east of La Grande-4 generating station. Its aim is to determine the social and economic impacts and the impacts on land use, with the direct participation of the Crees.

This section outlines what is known about the archaeological heritage and the status of Aboriginal communities before the construction of the La Grande complex. After briefly presenting the JBNQA and subsequent agreements, it goes on to review the consequences of the project. The latter analysis focuses more on land use by the Crees, who were affected the most by the physical and biological changes related to construction of the complex. The section concludes with a discussion of game hunting and fishing in the lands made accessible by the La Grande roads.

With respect to archaeology, the review is based on research conducted between 1972 and 1979 under the James Bay Biophysical Agreement, which brought together the federal-provincial task force responsible for the preliminary assessment of environmental impacts, Environment Canada and the Société de développement de la Baie James (SDBJ). The cost of this research was shared by Québec's Ministère des Affaires culturelles (Department of Cultural Affairs) and SDBJ. Since 1979, the cost of archaeological research has been covered by Hydro-Québec.

As far as the other aspects of the social environment are concerned, our discussion is based primarily on four reviews. One of these, the only one published, is by Richard Salisbury (1986) of McGill University and deals with Cree regional development; the others were ordered by Hydro-Québec. They take stock of the economic repercussions of the La Grande complex between 1975 and 1992 (Thibodeau and Rioux, 1995), present statistics on social change in Cree and Inuit communities between 1970 and 1990 (Simard and GÉTIC, 1996), and sum up the knowledge about the social impacts of the complex and the agreements on

Cree and Inuit communities between 1970 and 1985 (Centre de recherche et d'analyse en science humaine, 1996). Although hundreds of documents were inventoried and used in these reviews, very few of them provide information about the impacts of hydropower developments as perceived by the Crees. Of those few studies, most were conducted by Cree organizations or by joint organizations such as SOTRAC. And finally, our discussion is based on studies conducted by Hydro-Québec on the use of the James Bay region by non-Native hunters and anglers (Nobert et al., 1992).

It should be noted that no other northern hydroelectric development has, to our knowledge, been the subject of as many follow-up studies of the impacts on the social environment.

2.11.1 Archaeological heritage

In 1972, the Québec government passed the *Cultural Property Act*, demonstrating for the first time a concern for archaeological heritage. This concern was again reflected in the Biophysical Agreement signed in 1973 by the federal and provincial governments and SDBJ, as archaeology was the only aspect of the social environment covered by this agreement.

Archaeological research was conducted from 1972 on, throughout the years of construction of the La Grande complex. Aboriginals always participated in the field surveys. The goal was to locate and protect the region's archaeological resources and gather as much information as possible on the prehistoric and historic sequences of land occupation and use by Aboriginal peoples.

The work was conducted in several stages. Systematic reconnaissance and inventories were first carried out in all areas likely to be affected by the construction of the La Grande complex. This work uncovered more than 2,000 archaeological sites containing more than 350,000 artifacts, thousands of animal bones and traces of habitation. Concrete remedial measures were then applied. For example, archaeological excavations were conducted on a number of representative sites. The artifacts collected in these excavations underwent analysis in order to reconstruct the Aboriginal peoples' past way of life.

Over the years, Hydro-Québec developed a method for working in stages: evaluation of archaeological potential, validation, inventory, excavation and analysis. This method is still used with success in all northern development projects, and always with the participation of Aboriginal people, especially those living in communities near the development site.

Archaeological dig.

2.11.2 Aboriginal way of life before the project development

The analysis of the data collected establishes that conditions suitable for human presence were achieved 6,500 to 5,500 years before the present day, and that human settlement dates back 3,500 years. Until A.D. 450, only the upper basins of the Grande Rivière and the Caniapiscau were used regularly, by nomadic hunters from the Great Lakes region. During the following period, up to 1650, occupation was extended to the lower basins, first of the Grande Rivière and then of the Caniapiscau, pointing to a possible new wave of immigration combined with population growth among the existing inhabitants. Then the sites show continuity of lifestyle until the arrival of the Europeans. This continuity suggests that the inhabitants were the ancestors of today's Indian peoples of Québec and Labrador (Cree, Naskapi and Innu), who all belong to the same ethnolinguistic family (Cree Regional Authority, 1985; Cerane, 1993). The Inuit territory, further north, has been occupied for about 3,500 years by immigrants from the Dorset and Thule cultures, who arrived from the northwest via southern Baffin Island. Since very early in their history, the Crees and Inuit have made use of different resources: mostly inland for the former, and marine for the latter.

The excavations revealed that all these groups traded goods with each other and with Aboriginal inhabitants further south. The fur trade, and to a lesser extent the whale oil industry which got under way here in the late 18th century with the establishment of Hudson's Bay Company trading posts, was a turning point for the region's Aboriginal populations. The harvesting of resources, which until then had been centred on subsistence, began to adjust to a market economy, although barter continued to be the basis of trade for a long time. The trapping of fur-bearing animals, in particular, allowed one of the few marketable resources in the region to be exploited, while also helping to maintain a way of life to which the Aboriginal people are deeply attached.

The whole territory now known as James Bay and Nunavik (part of what was then called Rupert's Land) was ceded to Québec in two stages: the first in 1898 and the second in 1912. This is the territory now governed by the JBNQA, and it is made up of the watersheds of James Bay, Hudson Bay and Ungava Bay. In actual fact, however, the Hudson's Bay Company—the main enterprise involved in the fur trade—and Canada's Department of Indian Affairs remained the key players in the region. During the 1930s, an initial intervention by the Québec government resulted in a major development in the way wildlife resources were harvested. Overharvesting of beaver, which had led to a famine in the James Bay region, prompted the Québec government to subdivide the entire region into beaver reserves and then into traplines. A "tallyman" was placed in charge of each line (an area that could sometimes cover hundreds of square kilometres), and quotas were established to ensure continuity of the resource. The demarcation of traplines took into account family ties and the areas traditionally trapped by each family (Cree Regional Authority, 1985).

Cree winter camp, consisting of a modern building and a conical tent covered with snow.

The 1950s marked another turning point. The introduction of large-scale programs in the fields of health, education and social services meant that a growing proportion of the population became more sedentary, or permanently settled, and led to the start of the villages. Once this process of settlement took hold, it affected the traditional mode of subsistence, centred on hunting, fishing and trapping. In the 1960s, fewer and fewer Cree families left the village to go hunting or trapping in the fall. Getting outfitted and chartering air-taxis to travel to the hunting grounds grew increasingly expensive, and credit to finance these activities became harder to obtain. While the cost of hunting rose considerably, the price of furs was stagnant or on the decline. The main solution was to find summer work in the village or in the bush to be able to buy the goods essential for winter trapping.

There was little job security for the Crees, particularly in the inland villages; the few jobs offered were for unskilled labor and were poorly paid. Those who did not manage to land a summer job sometimes had to give up their hunting season on distant traplines and be content to hunt and trap closer to the village. The traplines farthest from the villages and the most expensive to reach began to be abandoned. Hunters who did exploit remote, hard-to-reach traplines then found themselves isolated from the Chisasibi hospital and from the dispensaries that had just been built in the villages. This situation led to overworking of traplines (or community spaces) located close to villages. At the same time, the gradual introduction of a money-based economy in the villages increased families' dependence on cash, making it more and more necessary to resort to the labor market. Finally, the settlement process exposed people to outside cultural influences in a number of forms: non-Native minorities (often made up of government employees) that held skilled jobs in the villages, public programs (and the dissemination of the values associated with them), mandatory schooling, attendance at educational institutions in the south, greater availability of consumer goods, telephone, television (after 1976), etc.

In 1971, just before the La Grande project was announced, more than a third of the then-current population of 5,000 Crees lived year-round in the villages. Five of the seven Cree villages were located on the east coast of James Bay. Fort George—the largest of them, with 1,500 inhabitants in 1971—occupied an island opposite the mouth of the Grande Rivière (SEBJ, 1987).

A similar process occurred with the Inuit. The harvesting of marine resources, which does not require stays of several months at great distances from the village, was more conducive to the settlement process. Starting in the 1940s and 1950s, moreover, some of the Inuit began to derive substantial income (wages and indirect spinoffs) from the military bases set up on two sites that would become villages (Kuujjuaq and Kuujjuarapik, then called Fort Chimo and Great Whale). The facility and housing construction programs and the jobs offered in the public service sector also generated considerable income. From the mid-1960s on, as well, a network of cooperatives grew up in the areas of handicrafts, consumer goods, restaurants and recreational activities, providing many Inuit with an introduction to managing companies and their own affairs. As with the Crees, however, the traditional activities changed radically: although modern means of transportation increased productivity, they also made it costlier to practise traditional activities. Income derived from the carving market came to exceed that from hunting and fishing.

Between 1900 and 1972, the Inuit population grew from 2,000 to 3,700, living in 14 villages along Hudson Bay, Hudson Strait and Ungava Bay. The most populous village, Kuujjuaq, near the mouth of the Koksoak (see Figure 3), had a population of nearly 600 in 1972 (SEBJ, 1987).

The path followed by the Naskapis is harder to reconstruct. After first staying near Kuujjuaq, and then Fort Mackenzie (a depot), where the Department of Indian Affairs hoped they would be able to provide for their needs by hunting, the Naskapis settled in 1956 in Schefferville, where they shared a village with an Innu community. It seems that, after they left Kuujjuaq (where a number of them had held jobs at the military base during the Second World War), the Naskapis experienced a precarious existence, as reflected by their many moves. They enjoyed only very limited access to the labor market, although some of them found work at Iron Ore Company after the band settled in Schefferville. The Naskapi population totaled 325 in 1970 (Sénécal and Égré, 1997).

2.11.3 The agreements and Aboriginal peoples

The JBNQA is a key factor underlying the social and economic changes that affected the Crees and Inuit who signed the agreement in 1975. The Naskapis later signed a similar accord, the Northeastern Québec Agreement (NQA). Together, the JBNQA and the NQA directly affect three First Nations (23,686 people in 2001) living in 25 villages (9 Cree, 15 Inuit and 1 Naskapi) in the James Bay and Northern Québec Territory (see Table 5). The JBNQA was briefly described in the first chapter. This section adds further details on the main provisions of this agreement.

In the JBNQA, the Crees and Inuit of Québec gave up their land claims in return for the rights and privileges granted or acknowledged by the federal and provincial governments. They gained financial compensation, land, and specifically defined rights in a number of areas such as local and regional self-government, harvesting of wildlife resources and pursuit of traditional activities, economic development, administration of justice, health, social services, education and environmental protection. The Naskapis of Québec obtained similar rights under the NQA. It is worth pointing out that only one of the 30 chapters of the JBNQA, Section 8 (Technical Aspects), deals with the planned hydropower facilities and related infrastructure.

Cree house in the village of Chisasibi.

Table 5
Aboriginal populations of northern Québec, 2001

Nation	Communities	Residents	Non-residents	Total
INUIT	Akulivik	462	10	472
	Aupaluk	150	4	154
	Chisasibi	96	14	110
	Inukjuak	1,130	84	1,214
	Ivujivik	254	10	264
	Kangiqsualujjuaq	639	66	705
	Kangiqsujuaq	510	35	545
	Kangirsuk	415	52	467
	Kuujjuaq	1, 436	121	1,557
	Kuujjuarapik	468	109	577
	Puvirnituq	1,231	111	1,342
	Quaqtaq	294	26	320
	Salluit	959	109	1,068
	Tasiujaq	214	9	223
	Umiujaq	327	43	370
TOTAL **Inuit population**		**8,585**	**803**	**9,388**
NASKAPI	Kawawachikamach	**734**	**53**	**787**
CREE	Chisasibi	3,109	131	3,240
	Eastmain	544	26	570
	Mistissini	2,621	280	2,901
	Nemiscau	522	70	592
	Oujé-Bougoumou	511	106	617
	Waskaganish	1,640	481	2,121
	Waswanipi	1,138	426	1,564
	Wemindji	1,057	116	1,173
	Whapmagoostui	709	23	732
TOTAL **Cree population**		**11,851**	**1,659**	**13,510**
GRAND TOTAL		**21,170**	**2,515**	**23,685**

Source: Ministère de la Santé et des Services sociaux, registre des autochtones, 2001.

A central element of these two agreements is the land regime (see Figure 15). The JBNQA and NQA lands (1,066,000 km^2, or two-thirds of the entire territory of Québec) are divided into three categories. Category I lands (14,022 km^2) are reserved for the exclusive use of the Crees, Inuit and Naskapis; this is where their villages are built. Category II lands (155,735 km^2) are contiguous to Category I lands. These are public lands on which the Aboriginal signatories have exclusive hunting and fishing rights and have a say in the land management. Category III lands (896,242 km^2) are the remaining public lands, where Aboriginal people are entitled to pursue their harvesting activities under the hunting, fishing and trapping regime set forth in the JBNQA. The beneficiaries enjoy exclusive harvesting rights for certain wildlife species over almost all of these lands, as well as exclusive trapping rights.

To encourage the pursuit of traditional activities, the JBNQA also introduced an income security program for the Crees, which provides financial assistance for families or individuals who hunt or trap. A different program was set up, again under the JBNQA, to assist Inuit hunters and fishers.

In addition to providing an exact, detailed description of the hydroelectric facilities planned and authorized, the JBNQA set up an environmental protection regime that would determine the nature of the environmental studies to be conducted.

Under the JBNQA, the La Grande complex (1975) could be built as described without undergoing an environmental impact assessment. However, the NBR and Grande-Baleine complexes, as well as any substantial modification to the La Grande complex (1975), would be subject to the environmental protection regime set out in the JBNQA. Hydro-Québec had to implement certain mitigation measures to attenuate the negative effects on Cree hunting, fishing and trapping activities, and it could decide whether or not to proceed with a social impact assessment. Crees and Inuit were to be represented on the committee or commission in charge of environmental impact assessment. For projects south of the 55th parallel, the governments of Canada and Québec and the Cree Regional Authority had equal representation on the assessment committee. The JBNQA also specified what information was to be contained in an environmental or social impact assessment report.

In the years following the signing of the JBNQA, other agreements were ratified (see tables 6 and 7) as Hydro-Québec, the Crees and the Inuit agreed on modifications to the La Grande complex (1975) or amendments to the JBNQA.

- The Chisasibi Agreement, which provided for resettlement of the Crees of Fort George Island, at their own request, in the new village of Chisasibi on the banks of the Grande Rivière. The terms and conditions were laid out in the Agreement, and the Government of Canada and SEBJ defrayed $50 million of the expense in lieu of commitments and obligations initially agreed to for the village of Fort George. The Chisasibi Agreement also made it possible to build La Grande-1 further downstream than first stated in the JBNQA.
- The Sakami Lake Agreement (1979), which set forth compensation, remedial measures and other benefits for the Cree community of Wemindji following the rise in water level in Sakami Lake to a level higher than that provided for in the JBNQA. The remedial work was to be done by Sakami-Eeyou Corporation.
- The La Grande (1986) Agreement, which provided for compensation, remedial measures and mitigation measures covering some of the developments in Phase II of the La Grande complex (La Grande-1, La Grande-2-A and Brisay generating stations, and the Radisson–Nicolet–Des Cantons transmission line), community benefits (connection of five villages to the power grid), economic measures (training and hiring of Crees for generating station operation) and other measures of benefit to the James Bay Crees. The Agreement also called for the establishment of the James Bay Eeyou Corporation to replace SOTRAC, in order to ensure a more efficient structure governing relations between Hydro-Québec and the James Bay Crees and to administer the funds needed to finance the remedial and mitigation measures. Under the Agreement, Hydro-Québec further undertook to carry out a series of measures, such as building a road to the north bank of the Grande Rivière, providing Chisasibi with a reliable water intake, and facilitating the use of Hydro-Québec infrastructures by the Crees.

Figure 15
Hydropower facilities and Aboriginal communities in northern Québec

- The 1986 Mercury Agreement, which instituted a mercury program designed to reduce health risks and develop remedial measures intended to allow the Crees to carry on their harvesting activities and preserve their way of life. This program was implemented by the James Bay Mercury Committee, made up of seven members representing the various parties concerned.

- The Kuujjuaq (1988) Agreement, which specifies compensation and remedial measures to fulfill the obligations set forth by the JBNQA regarding the Caniapiscau diversion. In return, the Inuit waived recourse against Hydro-Québec for any adverse consequences of the Caniapiscau diversion, except for the possible effects of methylmercury production north of the 55th parallel due to the La Grande complex (1975) or any other hydroelectric development. The agreement also provided for the creation of Kuujjuamiut Inc., an organization whose mission includes identifying and carrying out mitigation measures.

- The La Grande (1992)–Opimiscow Agreement, which provides for compensation, environmental enhancement measures and additional remedial measures related to certain developments in Phase II of the La Grande complex (Laforge-1 and Laforge-2 generating stations, the Lemoyne–Tilly and La Grande-2-A–Radisson transmission lines, the 12th 735-kV line, series compensators). The agreement provides for the establishment of the Société Opimiscow-SOTRAC, made up of an equal number of Cree and Hydro-Québec representatives. This corporation manages the remedial measures fund and oversees implementation of the measures.

Table 6
Agreements between Hydro-Québec and First Nations (Cree, Inuit, Naskapi)

Agreement	Year	Project	Nations
James Bay and Northern Québec Agreement	1975	La Grande complex	Cree and Inuit
Northeastern Québec Agreement	1978	La Grande complex	Naskapi
Chisasibi Agreement	1978	La Grande complex	Cree
Sakami Lake Agreement	1979	La Grande complex	Cree
La Grande (1986) Agreement	1986	La Grande complex	Cree
Mercury Agreement (1986) C.Q.–H.Q.	1986	La Grande complex	Cree
Kuujjuaq (1988) Agreement	1988	La Grande complex	Inuit
La Grande (1992)–Opimiscow Agreement	1993	La Grande complex	Cree

The Crees and Inuit of Québec, the Québec government, other Québec representatives and the Canadian government began negotiating in early 1974. In November of that year, the parties reached an agreement in principle that would lead to the signing of a historic pact, the James Bay and Northern Québec Agreement.

Table 7
Compensation and cost of mitigation measures provided for by agreements between Hydro-Québec, the governments of Canada and Québec, and First Nations of Québec (Cree, Naskapi, Inuit)

James Bay and Northern Québec Agreement ($ millions)							
	Indemnities			**Remedial measures**			**Total**
	Canada	**Québec**	**Hydro-Québec**	**Canada**	**Québec**	**Hydro-Québec**	
Inuit of Québec	13.8	48.8	30.4	–	–	–	93.0
Crees of Québec	20.7	72.7	45.4	–	–	30.0	168.8
Northeastern Québec Agreement ($ millions)							
	Indemnities			**Remedial measures**			**Total**
	Canada	**Québec**	**Hydro-Québec**	**Canada**	**Québec**	**Hydro-Québec**	
Naskapis	1.585	5.065	3.0	–	–	–	9.650
Crees	0.0375	0.1135	–	–	–	–	0.151
Inuit	0.0375	0.1135	–	–	–	–	0.151
Subsequent agreements ($ millions)							
Agreement	**Indemnities**			**Remedial measures** (projects, studies, infrastructure)			**Total**
	Canada	**Québec**	**Hydro-Québec**	**Canada**	**Québec**	**Hydro-Québec**	
Crees							
Chisasibi (1978)	–	–	–	10.0	–	40.0	50.0
Sakami Lake	–	–	8.0	–	–	17.5	25.5
La Grande (1986)	–	–	97.0	–	–	15.0	112.0
Mercury (1986)	–	–	–	–	4.4	12.4	16.8
Opimiscow (1992)	–	–	50.9*	–	–	25.0	75.9
Inuit							
Kuujjuaq (1988)	–	–	34.5	–	–	14.0	48.5
GRAND TOTAL	**36.160**	**126.792**	**269.2**	**10.0**	**4.4**	**153.9**	**600.452**

* $50 million (in 1992 dollars) over a 50-year period and $900,000 for the cost of the negotiations and the formation of the remedial works corporation Opimiscow-SOTRAC.

2.11.4 Impact of the La Grande complex on the harvesting of wildlife resources

Almost all of the La Grande complex is located on Cree traplines. The construction and operation of the complex—reservoir impounding, alteration of river flows, building of roads and power lines—therefore have a definite impact on the Crees' wildlife harvesting activities. The information available can be used to determine the geographical extent of the alterations, assess the impacts on Cree users, and observe the mitigation measures implemented.

Traplines

Since the 1930s, the entire territory used by the Crees has been divided into traplines. Each line is the responsibility of a tallyman who is in charge of managing the beaver trapping. According to the latest estimates (1989 boundaries), there are 286 traplines belonging to nine Cree communities, and together they cover 368,823 km^2 (see Table 8).

Table 8
Cree traplines affected by the La Grande complex*

Community	Trapline						Reduced-flow river** (km)
	Total area (km^2)	Flooded area (km^2)	% of area affected	No. of traplines	No. affected	% of traplines affected	
Chisasibi	82,082	8,179	9.9	40	26	65.0	199
Eastmain	15,668	916	5.8	15	4	26.7	274
Mistissini	121,372	2,262	1.9	75	1	1.3	0
Nemiscau	15,502	0	0	15	0	0	0
Oujé-Bougoumou	10,714	0	0	14	0	0	0
Waskaganish	29,203	0	0	34	0	0	0
Waswanipi	32,250	0	0	52	0	0	0
Wemindji	28,373	1,877	6.6	20	10	50.0	38
Whapmagoostui	33,659	0	0	21	0	0	0
Total	**368,823**	**13,234**	**3.6**	**286**	**41**	**14.3**	**511**

* Areas are accurate to within ± 15 km^2 and lengths are accurate to within ± 125 m, according to source maps scaled 1: 250,000. Values include overlapping of traplines belonging to two different communities. Data undergoing validation at Hydro-Québec (April 2001).

** Length of reduced-flow river crossing traplines.

Calculating the surface area affected by various parts of the La Grande complex can give a quantitative indication of the extent of the change brought about. It does not, however, give any indication of the quality of the wildlife habitat before or after development, or of its importance to the Crees. A reservoir floods both rivers and riparian ecotones, which are of value to hunters, fishers and trappers; but it also floods bare hilltops which are of little interest to anyone. Similarly, the surface area now taken up by roads can be considered lost habitat, but at the same time the roads provide fast and affordable access to wildlife resources.

The La Grande reservoirs flooded 13,234 km^2 or 3.6% of the total Cree trapping area. However, it is important to realize that not all communities were affected to the same extent.

Chisasibi suffered the greatest impact, with 26 of its 40 traplines (over 8,000 km^2) flooded. And within the community, the effect on some families and individuals was much greater than on others; in fact, five traplines were 80% flooded by reservoir impounding.

Wemindji, Eastmain and Mistissini were not affected as drastically by reservoir flooding, while the five other Cree communities were not affected at all. Eastmain was, however, affected by the diversion of the Eastmain and Opinaca rivers.

Of course, the biological richness and cultural importance of the land flooded cannot be expressed in square kilometres.

Resource harvesting method

Apart from the mercury issue discussed earlier, the construction and operation of the La Grande complex considerably disrupted the resource harvesting methods used by the Cree people. However, the road network, remedial measures and the many mitigation and enhancement measures carried out lessened the project's impact on resources harvested and facilitated access to those resources significantly. The changes to resource harvesting methods particularly affected the following communities, in order of severity: Chisasibi, Eastmain, Wemindji and Mistissini.

The people of Fort George gained access to the road network when they were relocated to Chisasibi. Talks between the Crees and the Canadian and provincial governments led to the construction of roads to Wemindji, Eastmain and Waskaganish. These roads, along with the generating facility access roads, provide easier access to traplines located far from the villages.

The new road network has had a major effect on resource harvesting methods. Trucks, all-terrain vehicles and snowmobiles are more practical and economical than planes for traveling inland. Winter roads, logging roads and reservoirs have become the preferred routes for reaching fishing, hunting and trapping grounds. Whereas the most favorable sites for resource harvesting used to determine where camps were located, it is now proximity to roads and reservoirs that serves as the main criterion. The improvement in means of transport has improved the geographical distribution of activities.

The remedial work and mitigation measures were designed to make wildlife resources more available (improvement of habitats in affected and unaffected areas) and to improve access and harvesting conditions for the Crees. Various measures such as the establishment of navigation maps, selective clearing and the building of boat landings and snowmobile trails have also facilitated both summer and winter use of the reservoirs (in particular, Robert-Bourassa reservoir) as routes to adjoining or nearby traplines.

The La Grande reservoirs provided the Crees with new transportation routes and new hunting, fishing and trapping areas. The only data available are for Robert-Bourassa and Caniapiscau reservoirs in the first years of existence. Impounding began in 1979 for Robert-Bourassa reservoir and in 1984 for Caniapiscau. The Chisasibi Crees seem to have familiarized themselves very quickly with Robert-Bourassa, because it was accessible by road and because remedial facilities such as boat ramps and docks had already been installed there. At the request of Cree users, other such facilities were installed and navigation corridors cleared (SEBJ, 1987). It appears that the Chisasibi Crees fished extensively in the reservoir until the mid-1980s, then all but stopped when the risk of mercury exposure became known (Weinstein and Penn, 1987). No studies are available for La Grande-3 and La Grande-4 reservoirs; however, we know that few remedial measures were carried out there.

As for Caniapiscau reservoir, the road through this area facilitated use of the reservoir by the Chisasibi Crees. Caribou hunting expanded considerably in this area after the early 1980s as the caribou population grew. The same is true of geese, which became more numerous in the interior. The difficulties experienced by Cree users in this area had to do with the use of reservoirs for transportation (Berkes and Cuciurean, 1987). These difficulties were no doubt offset by the year-round availability of the road east of La Grande-4 reservoir and certain remedial measures implemented during construction of Laforge-1 and Laforge-2. The road network seems to have enabled a greater number of Crees from various communities, including Chisasibi and Mistissini, to hunt in the back country far away from the villages.

Flow modification in the rivers affected by the La Grande complex made it more difficult to get around and to practise traditional activities, especially fishing (SEBJ, 1987; SEBJ, 1996). Because of the new hydrological conditions in the Grande Rivière below La Grande-1 (mean flow doubled, winter flow increased tenfold, and little or no ice cover), fishing was much more difficult in the estuary, and coastal wildlife was no longer accessible by snowmobile from the river mouth. However, the roads built during construction of the complex and a bridge at La Grande-1 powerhouse facilitate resource harvesting on either bank of the estuary and along the coast north and south of the river. The reduction in mean flow—90% at the mouth of the Eastmain and 87% in its tributary, the Opinaca, below Opinaca reservoir—greatly altered the activities of the Eastmain Crees and, to a lesser extent, the Wemindji Crees around these rivers. Remedial work was carried out on the Eastmain and Opinaca (weirs, plantations, etc.), in areas where erosion and the drop in water level were more severe. These measures enabled populations of aquatic and riparian wildlife to remain stable and even, in the case of some fish species, to increase.

In the east part of the complex, the flow at the mouth of the Vincelotte was reduced by 67% in Phase I and was completely cut off in Phase II. Major remedial work was done on this river by Société Opimiscow-SOTRAC to improve the productivity of wildlife habitats and resource harvesting conditions for the Crees (roads, weirs, portages, waterfowl habitats, plantations, etc.) (Chee-Bee Cree Construction, 1998; SEBJ, 1996).

There are no data on the use of these rivers by the communities concerned after the implementation of remedial measures.

The Inuit of Kuujjuaq were affected by the reduction in flow on the Caniapiscau and Koksoak rivers. The approximately 30-cm drop in water level at Kuujjuaq increased navigation difficulties at low tide upstream from this village, and appears to have created problems for hunters and fishers using the river to travel or to harvest its resources. The monies paid under the Kuujjuaq Agreement ($48.5 million) were mainly intended to compensate the Inuit for these negative consequences and to mitigate the impacts. Kuujjuamiut Inc. was charged with administering the funds and overseeing the remedial work.

For the Naskapis, the harvesting of wildlife resources—mainly caribou hunting—does not seem to have been affected. The caribou population has grown significantly in the past 20 years and occupies an increasingly extensive area, unrelated to the presence of the hydroelectric developments.

Sport fishing and hunting

Recreational fishing and hunting have been practised since the road was opened up to non-Native populations in 1986—mainly in the southern part of the James Bay region and, increasingly, east of the Robert-Bourassa facilities.

Since the number of non-Native hunters and anglers has grown rapidly, Hydro-Québec, together with Québec's Ministère de l'Environnement et de la Faune (Department of Environment and Wildlife), has set up a monitoring program to assess the impact of sport fishing and hunting on animal populations.

Under this program, nearly 11,000 vehicles, and close to 27,000 visitors, were recorded in 1991 at the entrance to the James Bay highway (Nobert et al., 1992).

The several hundred operating personnel working for Hydro-Québec (or its subcontractors), who live in the region more or less permanently, also take part in fishing (in 44% of cases) and hunting (in 10% of cases), but only on Category III lands.

Sport fishing and hunting practised by non-Natives may constitute a source of conflict with the Crees over this vast territory, which is difficult to monitor. However, these activities represent an important source of economic development. A number of fishing and hunting outfitting operations have already been established.

Despite a lack of data on certain species, the Ministère de l'Environnement et de la Faune concluded in 1991 that the state of fishing resources in the James Bay region as a whole did not pose any particular problem.

In the early 1990s, the recreational harvesting of wildlife seemed to comply overall with the JBNQA fishing and hunting regime as regards the exclusive rights held by the Crees over certain parts of the territory or certain species. The few difficulties observed (estimated to represent 0.08% of catches) are largely attributable to sport fishermen from outside the region and seem to stem mainly from a lack of information. Recreational hunters and anglers also report few conflicts with the Crees in their chance encounters; 90% of them describe these encounters as pleasant (Nobert et al., 1992).

The roads built for the complex do not go to Inuit or Naskapi villages or the lands they use. The presence of sport hunters and fishers in these areas is therefore unrelated to the La Grande complex.

2.11.5 Economic and social development of Aboriginal peoples

The impacts of the La Grande complex on subsistence activities have affected mainly certain Cree communities (both positively and negatively). However, many of the social and economic consequences in the villages since the 1970s arise mainly from the implementation of the JBNQA and NQA rather than from the presence of the complex itself. As is the case for impacts on hunting, fishing and trapping, the data available allow us to identify certain aspects of social and economic change in the communities, but do not offer an explanation.

De-isolation of Cree communities

After 1970, four previously isolated Cree villages were linked to the road network built for the La Grande complex. Fort George ended its isolation in the early 1970s when a road was built from the James Bay coast to the La Grande-2 work site. This road was then connected to the Radisson-Matagami highway.

For the other three villages (Eastmain, Wemindji and Waskaganish), the end of isolation was the result of talks with the federal and provincial governments provided for in the JBNQA. The roads to Eastmain and Wemindji were completed in 1995, while the Waskaganish road is scheduled for completion in 2001. The opening of the permanent road to Wemindji was the subject of a follow-up on economic and social spinoffs conducted by the Cree Nation of Wemindji and Hydro-Québec (Roche, 1997). On the whole, the end of isolation has been beneficial. It has had positive sociocultural and economic impacts, promoting exchanges with urban centres and other Cree communities in addition to bringing down the cost of some consumer goods. However, it has also had some negative effects due to the aggravation of certain social problems, especially among young people.

The JBNQA also provided for the establishment of Waswanipi and Nemiscau in their present locations. More recently, the village of Oujé-Bougoumou was built near Chibougamau.

The Crees and economic changes

For the Crees, economic changes came from many different sources and varied in their magnitude. Those brought about by the JBNQA were no doubt the most significant, due to the salaries paid by the many Cree organizations it created, along with the Income Security Program (ISP) for Cree trappers and hunters. Workers' salaries and contracts awarded to Cree businesses constituted another source of economic change.

The consequences for subsistence activities in the bush must be placed in the context of the ISP created under the JBNQA (1975). The ISP—a Québec government program—is designed to preserve the traditional way of life by providing assistance, mainly financial, to families or individuals who hunt or trap on a more or less regular basis (at least 120 days a year). The Office de sécurité du revenu was set up in 1979 and administers the program. The number of program beneficiary units (families or individuals) held steady at around 1,200 during the 1980s and 1990s; this corresponds to over one-third of the Cree population at the time (see Table 9). Income from the ISP and the availability of a road network led to greater use of motorized transport by the Crees.

One fact seems definite: traditional activities are no longer as important as they were, in terms of income. Even though hunters' income more than tripled from 1971 to 1981, according to Salisbury (1986), the share of income from traditional activities fell from 61% to 43%, while the share represented by wages rose from 23% to 52%. This gap has widened even more in the past 15 years. In 1996, Simard estimated the 1990 average annual income of a family of five involved primarily in subsistence activities at $28,000, while that of an equivalent family living mainly on wages amounted to $47,800.

Table 9
Income Security Program for Cree hunters and trappers: Increase in benefits, 1976 to 1998

Year	Number of beneficiaries	Number of units	Average payment per unit ($)	Total ($)
1976–1977	4,046	979	4,719	4,619,901
1980–1981	3,043	874	6,880	6,013,120
1984–1985	3,710	1,205	9,491	11,436,655
1988–1989	3,372	1,217	9,979	12,144,443
1992–1993	2,994	1,225	12,146	14,878,850
1996–1997	2,595	1,190	11,749	13,981,310
1997–1998	2,696	1,264	11,889	15,027,696

Source: Cree Hunters and Trappers Income Security Board

This sizable increase in total wages, a sign of growth in employment, is no doubt one of the most important spinoffs of the JBNQA and, to a lesser extent, the construction of the complex. Previously, jobs were seasonal and provided little security. A considerable proportion of jobs are now permanent and much better paid. Offered most often by one of the many organizations established in the wake of the Agreement (or by band councils), jobs are concentrated mainly in the public service sector, which has developed at the local and regional levels as a result of decentralization (Simard and GÉTIC, 1996).

The extremely rapid growth in the population, which more than doubled between 1971 and 1998 as a result of a significant increase in life expectancy and a sharp decline in infant mortality, accentuated the need for housing and community facilities. The expansion in public services and construction in the villages has, in turn, led to the development of business activities. This factor, combined with the economic spinoffs of the contracts awarded by SEBJ and Hydro-Québec, fostered the development of Cree enterprises. Phase II of the La Grande complex (1987–1992) represented wage spinoffs (construction jobs) for the Cree villages, mainly Chisasibi, totaling $27 million in current dollars from 147,120 person-days of employment, or more than 670 jobs.

The formation and development of Cree businesses between phases I and II of the La Grande complex played a major role in increasing the value of contracts awarded by Hydro-Québec and its subsidiaries to Cree companies for Phase II ($480 million between 1989 and 1998) compared with Phase I ($3.8 million). And while the contracts awarded in Phase I mainly covered clearing operations, Phase II contracts were much more diversified, and included construction, maintenance or repair of roads, dams, dikes and buildings, provision of services, etc. The remedial work carried out by partly Aboriginal-run companies (SOTRAC, Eeyou and Opimiscow) also represented a substantial source of spinoffs in the Cree villages (Thibodeau and Rioux, 1995) (see Table 10).

Table 10

Contract awards by Hydro-Québec and its subsidiaries to Crees, Inuit and Naskapis: Economic spinoffs, 1989 to 1998

Year	Crees ($)	Inuit ($)	Naskapis ($)	Total ($)
1989	39,949,130	1,407,826	–	41,356,956
1990	43,358,890	1,684,266	–	45,043,156
1991	46,428,971	13,728,934	1,791,549	61,949,454
1992	45,464,884	18,833,595	3,699,421	67,997,900
1993	36,802,640	15,985,614	2,714,226	55,502,480
1994	53,155,664	13,855,775	2,381,972	69,393,411
1995	36,191,558	17,726,168	2,381,972	56,299,698
1996	9,077,533	10,214,101	347,100	19,638,734
1997	22,425,675	9,605,405	2,274,821	34,305,901
1998	16,803,503	18,332,652	1,454,114	36,590,269
TOTAL	**349,658,448**	**121,374,336**	**17,045,175**	**488,077,959**

Finally, the construction of the La Grande complex also led to the founding of a new village in the heart of Cree territory—the village of Radisson—now inhabited mainly by workers in charge of operations at the complex.

Inuit

As of 2001, the Inuit population totals 9,389, living essentially in 15 villages spread out along the coast of Hudson Bay, Hudson Strait and Ungava Bay. A few dozen Inuit live in Chisasibi.

In many respects, the JBNQA has had similar economic, social and cultural consequences in Inuit villages as were observed in Cree villages. The complex itself, being very far away from the Inuit, did not have much of a direct impact, but the villages did benefit from urban reconstruction or refurbishing programs. Part of the amount ($34.5 million) paid to the town of Kuujjuaq as compensation for the flow reduction in the Koksoak was used to build community facilities. A number of Inuit businesses were consequently formed and secured many contracts from Hydro-Québec and its subsidiaries. Economic spinoffs totaled more than $120 million from 1989 to 1998 (see Table 10).

Naskapis

The Northeastern Québec Agreement, and more specifically the Income Security Program which it instituted, enabled the Naskapis, who numbered 787 in 2001, to pursue their traditional activities (caribou hunting, crafts, etc.).

The 1983 creation of Kawawachikamach, 15 km northeast of Schefferville, fulfilled a long-held aspiration of the Naskapis to have their own village. For the Naskapis, the economic spinoffs from contracts awarded by Hydro-Québec and its subsidiaries amounted to some $17 million between 1991 and 1998 (see Table 10).

2.11.6 Cree perception of the impact of the developments and agreements

While only a small fraction of the hunting territories were affected by reservoir flooding, greater ease of access to these territories allowed a larger number of hunters to use them and observe the physical changes. Many Aboriginal people, particularly the older ones, have a negative perception of the consequences of the complex and the JBNQA. This perception persists despite the fact that the extent of the physical changes is not necessarily reflected in the impact on animal populations, that the studies often reveal that the effects on wildlife and resource harvesting are not always as great as anticipated, and that conditions in some cases have actually improved.

Certain provisions of the agreements, especially the creation of new villages (Chisasibi and Nemiscau), the ensuing displacement of populations, and dependence on government programs, have no doubt contributed to this perception. A comparable situation can be seen in the families who were relocated to make way for the construction of Mirabel airport. For many people, it will always be hard to distinguish between the impacts caused directly by the construction of the complex, those caused by the JBNQA, and the ones that are simply a result of modernization (such as television).

2.11.7 Economic spinoffs for Québec

For over 50 years, the growth of the hydroelectric industry in Québec has been a development factor that has generated considerable economic spinoffs in the regions in which projects have been built. The construction of the La Grande complex led to substantial economic spinoffs in the Abitibi–Témiscamingue and Saguenay–Lac-Saint-Jean regions, totaling some $700 million in wages and nearly $300 million in purchases of goods and services (see Table 11).

*Table 11 – **La Grande complex: Economic spinoffs, 1975 to 1992***

Abitibi-Témiscamingue region

	Phase I 1975 to 1981	**Phase II** 1987 to 1992
Construction wages	($ millions, 1981)	($ millions, current)
Total wage spinoffs	320	40
Average annual wages	46	8
Goods and services	($ millions, 1978)	($ millions, current)
Total goods and services	135	30
Average annual wages	9.5	2.5 to 3
Other annual remuneration	9.5	2.5 to 3

Saguenay–Lac-Saint-Jean region

	Phase I 1975 to 1981	**Phase II** 1987 to 1992
Construction wages	($ millions, 1981)	($ millions, current)
Total wage spinoffs	278	38
Average annual wages	40	7.6
Goods and services	($ millions, 1978)	($ millions, current)
Total goods and services	N/A	100
Average annual wages	N/A	7.5 to 10
Other annual remuneration	N/A	7.5 to 10

Sources: Phase I: James Bay Employers Association
Phase II: Special data compilations by SEBJ

Economic spinoffs from hydroelectric projects are not restricted to the host regions. Nearly everything involved in the construction of hydroelectric facilities is made in Québec, particularly in the central and urban regions. This is a highly advantageous situation for Québec compared with nuclear or thermal power generation, for which most of the economic spinoffs would leave the province (Groupe SECOR, 1992).

In addition, hydroelectricity costs in Québec are among the lowest in the world, a fact that, as well as benefiting all Quebecers, encourages the presence of energy-intensive industries such as aluminum and paper mills. Finally, since hydroelectric facilities can easily last more than 50 years and their construction cost is fully paid off during that period, future generations can enjoy very low-cost power production. This is another major advantage that must be factored into any comparison of different sources of electricity.

2.12

Mitigation, compensation and enhancement measures

Since the construction of the La Grande complex, Hydro-Québec has worked to develop a considerable number of measures designed to remedy, mitigate or compensate for impacts caused by the construction and operation of its hydroelectric facilities. These measures cover both the biophysical and the social environment.

Hydro-Québec distinguishes between three types of measures, which we will describe briefly here.

Mitigation measures are intended to eliminate the negative effects of a project or reduce them to an environmentally acceptable level. These measures are applied essentially in the zone directly affected by a facility and concern the physical changes as well as the consequences of those changes on the biophysical and social environment (for example, presence of a reservoir, modification of flow, loss of wildlife habitat or traplines, or access to territory). The measures most often involve the construction of weirs, introduction of controlled flows, seeding, building of roads and trails, etc.

Compensation measures are meant to compensate for the negative effects of a project's construction that cannot be eliminated by mitigation measures at the work site; to be effective, they must be applied after the results of the mitigation measures have been observed.

Enhancement measures are designed to improve the condition of a biophysical environment or social situation not directly affected by the construction of a project; they may cover a situation existing outside a project's study zone.

Each project entails its own set of measures. Compensation or enhancement measures for one project may become mitigation measures for another. Given the large number of measures implemented by Hydro-Québec in the past 30 years, the following list does not take these considerations into account but simply offers examples of the types of measures applied most often. These examples are drawn from the following reports: SEBJ, 1985; SEBJ, 1994; Sbeghen, 1994; Lessard, 1995; Chee-Bee Cree Construction, 1998; Verdon, 1999; IEA and SWG, 1999.

aquatic environment
terrestrial environment
land use and wildlife harvesting
landscape
community health and well-being

Measures related to the aquatic environment

- Structures (weirs, bottom outlets) and generating station operating methods designed to maintain a residual flow
- Management of fish populations to reduce the abundance of certain species in favor of others (intensive and selective fishing, management of water levels)
- Capture and relocation of fish
- Construction of spawning grounds
- Creation of fish shelters
- Fish stocking
- Incubation (fish eggs)
- Fish counting systems
- Fishways allowing migration
- Fish-repellent devices (acoustic, electric and stroboscopic repellents) upstream and downstream from generating stations
- Construction of weirs designed to maintain a certain water level
- Construction of baffles designed to improve fish habitat
- Blocking off of bays to protect certain zones in a reservoir from drawdown effects
- Intensive trapping of beaver before impoundment
- Relocation of beaver before impoundment
- Creation of ponds for waterfowl

Measures related to the terrestrial environment

- Erosion control by means of rockfill, gabions, seeding with herbaceous plants and planting of shrubs
- Improvement of wildlife habitat by various means:
  - vegetation control
  - seeding with herbaceous plants and planting of shrubs
  - selective clearing
  - creation of small islands
  - installation of nesting platforms for osprey

Regeneration cutting (selective clearing) across from the village of Chisasibi. James Bay can be seen in the background.

Measures related to land use and wildlife harvesting

- Recovery of resources before impoundment (beaver, wood)
- Recovery and disposal of floating wood debris
- Construction of boat ramps for easier water access
- Construction of docks for seaplanes and canoes
- Development of net-fishing areas (selective clearing before impoundment)
- Clearing of navigation channels
- Preparation of navigation charts
- Construction of portage trails and towing gear for small craft
- Construction of permanent and winter roads
- Construction of camps and storage facilities for wildlife harvesters
- Installation of signage and information boards
- Clearing of snowmobile trails
- Monitoring of wildlife harvesting
- Stabilization of banks (rockfill, gabions)

Boat ramp near Chisasibi.

Mitigation measure at Laforge-1, making canoe portaging easier.

Measures related to landscape

- Selective clearing
- Restoration of areas disturbed by construction activities (planting and seeding)
- Landscaping
- Construction of lookouts and nature-interpretation points

Measures related to community health and well-being

- Archaeological excavations and inventories
- Commemorative sites for burial grounds
- Dissemination of information about mercury
- Means for providing easier access to lakes with low fish mercury levels
- Installation of radiocommunication systems
- Adoption of a contract award policy giving preference to Aboriginal businesses
- Job training programs

Village of Chisasibi in the mid-1980s.

3

Impacts of Hydroelectric Development:

Thoughts, Conclusions and Lessons Learned

3 Impacts of Hydroelectric Development: Thoughts, Conclusions and Lessons Learned

Chapter 2 looked at the knowledge acquired in the past 30 years on the impacts of hydroelectric development on the biophysical and social environment. Although that chapter mainly considered the results of the environmental monitoring and follow-up carried out at the La Grande complex, many other studies conducted by Hydro-Québec and its partners have contributed to expanding the knowledge discussed. Much of the data obtained by these studies, whether for the Grande-Baleine, Manic-Outardes, Robertson or Sainte-Marguerite-3 projects, corroborated the information gathered at the La Grande complex. Changes in water quality and fish methylmercury levels, for example, are the same in all the reservoirs studied. The method of harvesting natural resources by Aboriginal people has generally developed along the same lines.

La Grande-1 hydroelectric development, viewed from downstream.

Hydro-Québec has learned a great deal in the past 30 years about how to carry out projects with the greatest possible respect for the environment, and about remedial, mitigation and compensation measures, maximizing economic spinoffs, etc.

It is now possible to draw conclusions and lessons based on facts which, in view of their scientific value, can guide future hydroelectric development projects in comparable environments. This chapter presents the principal conclusions emerging from the research and follow-up studies on the biophysical and social environments, and then points out lessons and formulates recommendations for carrying out environmental studies in connection with hydroelectric projects.

3.1

Principal conclusions: Biophysical environment

Aquatic environment

In northern Québec, a hydroelectric generating station reservoir, whatever its size, constitutes an ecosystem whose biological productivity compares favorably with that of a natural lake or terrestrial ecosystem of the same area. For the first five years of its existence, a reservoir shows a water quality slightly below that of a natural lake, but nonetheless favorable to the biological environment; moreover, biological productivity increases during these years. After 10 years, reservoir water quality is comparable to that of neighboring natural lakes. The composition of fish communities evolves in favor of lake-dwelling species, and fishing yields are generally a little higher than in neighboring natural lakes. These results have also been observed in other reservoirs in Canada, Finland and Sweden.

In rivers where the flow is reduced or increased, water quality changes very little and remains favorable to primary production and to wildlife in general.

Water quality and biological productivity in environments comparable to those studied should no longer be considered subjects of major concern requiring intensive research. In some cases, where well-founded doubts exist, baseline monitoring and follow-up studies should be conducted, but only on the parameters considered most relevant for water quality and biological productivity.

The phenomena of erosion and sedimentation must be evaluated with the greatest possible accuracy, as must any necessary remedial measures.

Changes in flow, temperature and salinity in the estuaries of James Bay and the coastal environment affected by the freshwater plume have had no observable impact on the aquatic wildlife that uses these areas on a regular basis, as this wildlife adapts well to changes.

Mercury

Mercury exists under natural conditions, but approximately 50% of the mercury emissions observed today are human in origin: they stem mainly from the combustion of fossil fuels like coal, industrial and mining activities, and waste incineration. Québec produces relatively little in the way of emissions, but it receives mercury produced beyond its borders and carried by the wind. Reservoir impoundment and the ensuing organic decomposition promote the methylation of mercury and its bioaccumulation in the food chain. The extent of the phenomenon depends on the amount of organic decomposition. Maximum mercury levels in reservoir fish are three to six times higher than levels in fish in natural lakes, and are reached after a period of 5 to 10 years, depending on whether the species feed on other fish or not. Levels return to their initial values after a period of 20 to 30 years. The same pattern has been observed in other reservoirs in Canada, the United States and Finland. There is no evidence that piscivorous animal or fish species are affected by these levels.

Mercury and health

Exposure to mercury is not necessarily linked to the flooding of reservoirs. There is some health risk for major consumers of fish, regardless of the place of origin of the fish. However, this risk can be controlled when it is properly understood by the authorities and consumers. The Cree Board of Health and Social Services of James Bay set up an information program under the terms of the Mercury Agreement. This program has shown that it is possible to considerably reduce mercury exposure before it reaches the intervention threshold, and to do so without overly reducing the consumption of fish, an essential dietary component, simply by avoiding certain species and fishing spots. The scientific and social value of this lesson is significant; it alone is enough to justify the human and financial effort expended by all the players involved in the past 20 years.

Terrestrial environment

The transformation of a terrestrial environment into an aquatic environment constitutes a major change. The loss of a terrestrial environment leads to the displacement or death of the nonmigratory animals that inhabited it. However, the riparian environments lost through flooding are partially replaced by the riparian environments that form on the exposed banks of reduced-flow rivers. The biological diversity of reservoir islands is comparable to that of islands in natural lakes; even the reservoir drawdown zone is used by a variety of wildlife. The development projects studied did not harm the migratory species of interest; the populations of these species (caribou, for example) even increased to the point where the hunt had to be expanded. The new body of water forms a much more stable, productive environment than the land space lost. On the basis of biomass production, the loss of terrestrial environment is largely offset by the gain in terms of aquatic environment.

3.2

Principal conclusions: Social environment

In the early 1950s, well before the launch of the La Grande project, the advent of paid labor and government programs in the fields of health, education and social services, combined with the high cost of transportation in the region, gave rise to a more sedentary lifestyle among Aboriginal peoples. This trend affected the traditional way of life, centred around hunting, fishing and trapping: fewer and fewer families spent the winter in the bush, and animal populations living near the villages were overharvested.

Starting in 1972, for a period of about 20 years, the construction of the La Grande complex and, to a greater extent, the provisions of the various agreements (especially agreements with the Crees) accelerated the settlement process already under way. The combination of a large number of factors related to the complex (impoundment of a portion of the trapping territory, building of roads, establishment of Aboriginal businesses, paid labor, etc.) and the agreements (self-government, land use regime, assistance programs for hunters, compensation, creation and modernization of villages, etc.) played a part in accelerating the evolution of Aboriginal societies (especially the Crees) to the point where they increasingly resemble the industrialized society of the South. According to a number of experts, this evolution—in many ways similar to that observed after other hydroelectric and road-building projects in northern Canada and Scandinavia—was of overall benefit to the Crees and other Aboriginal peoples on several levels.

The rapid modernization of Aboriginal societies is not without its problems, of course. In addition, unemployment has grown considerably since the 1990s as growth in the service sector and construction activities arising from the implementation of the JBNQA have slowed down, and this has worsened the social problems. Considering the remote location, the population growth and the relative lack of resource diversity, few economic sectors can support sustainable development. For this reason, the future of the territory will largely depend on the desire for cooperation among the various players.

These comments apply mainly to the northern part of the territory. It should also be mentioned that considerable efforts have been made to promote employment and other regional economic spinoffs in the Abitibi–Témiscamingue, Saguenay–Lac-Saint-Jean and North Shore regions.

3.3

Lessons and recommendations drawn from the environmental studies

The need for targets

The environmental monitoring and follow-up show that impact assessment in the initial project phase is nearly always exaggerated. However, this observation relates more to the biophysical environment than the social environment, which does not always receive adequate attention in impact assessments.

In addition, environmental studies look at too many elements whose importance is not adequately defined and recognized by all of the parties concerned. Such studies are required by law; however, it is not always clear how these requirements should be interpreted or applied. The same holds true for measures intended to mitigate the negative effects or increase the positive effects of a project.

We believe that the selection and relevance of elements to be considered in environmental studies must be based at the outset on the broadest experience possible. The analysis must take into account all the results of previous follow-up studies in order to allow a judicious selection of elements to be used and eliminate needless ones. The negative effects that are clearly known may be assumed without the need for repeated observation through long and costly studies. It is important, instead, to emphasize mitigation and compensation measures.

Measures designed to make a project more acceptable and more profitable must be understood in their broadest sense, and must play a part in every stage of a project. Some mitigation measures must be defined at the time of project planning and design, in order to eliminate the negative effects anticipated or reduce them as much as possible. Subsequently, compensation and enhancement measures serve to offset any residual negative effects and improve the state of the biophysical and social environments. In many cases, it is preferable to wait for the results of the environmental follow-up before implementing the measure.

All these stages must be carried out in partnership with the community.

The need to learn from the past

For northern environments comparable to those studied in Québec, the data from the environmental follow-up and the resulting mathematical models are now reliable enough that changes in water quality and fish communities can be predicted, as can the release and bioaccumulation of methylmercury following the creation of reservoirs and changes in the hydrological regimen. For these elements, it is no longer necessary to take hundreds of samples over long periods of time. A few checks before and after facility construction are sufficient to verify the accuracy of the predictions.

The studies must focus on the habitats of species to which particular value is attached. Inventories must be kept to the essential and used only to determine the scope of these habitats. Natural resources valued by the users must be the priority for study. The Aboriginal people's know-how and their traditional knowledge of their environment must be put to maximum use. The studies must serve to develop mitigation or compensation measures, rather than simply determining impacts that are not easily quantifiable, that will rarely be agreed upon by the parties concerned, and that might involve lengthy, costly and inconclusive studies.

In terms of monitoring physical and biological changes in a modified environment, anything that cannot be either verified or measured according to recognized scientific methods should be rejected. The same principle should apply to selecting and implementing mitigation and compensation measures.

Collaborative efforts

The scope of environmental studies sometimes goes beyond the direct needs of the project at hand. Although this can be useful and contribute to the advancement of knowledge, it also makes the project considerably more expensive to build and the lead time quite a bit longer.

Research of this nature must be recognized for what it is by all players, and its costs shared equitably among the public authorities concerned. Care must also be taken to ensure that this research helps to improve the project evaluation process.

Perceptions of issues

Environmental elements that are highly complex and difficult to study because they react to a large number of factors often become controversial issues in environmental studies. This type of issue is usually the subject of heated debate in the scientific community and should come more under the heading of long-term research than impact assessment. Often, the project developer has no choice but to conduct lengthy and costly studies, without any assurance that the results will be deemed satisfactory. These studies deplete considerable funds, which would be much better used for mitigation and compensation measures designed to improve the well-being of the communities concerned.

All parties must recognize from the outset that an environmental impact assessment must lead to a decision that meets time, space and cost requirements. The whole process must not start anew each time. In addition, the efforts devoted to environmental studies must be equivalent for all types of projects that have impacts on natural resources.

Hydro-Québec has faced a number of issues during environmental studies to obtain authorization for projects. These issues often included perceptions, unverified hypotheses and facts all mixed together, so that it became difficult to determine the real importance of the issue. Some examples are climate, biodiversity, mercury and health, greenhouse gases, cumulative effects and most of the issues affecting local communities. The possible effects related to these issues were not all of the same importance, but they all sparked more or less the same reactions, described below.

- **Climate**
  At the time the La Grande project was launched, a number of authors had predicted that the climate of the northern hemisphere would be altered by the creation of the reservoirs. It took many years of studies to demonstrate that reservoirs, just like large natural lakes, affect only the climate of the area immediately surrounding them, i.e., a zone that rarely exceeds 20 kilometres or so for a lake the size of Lac Saint-Jean, which measures approximately 1,000 km^2 in area (Météoglobe Canada, 1991).

  In 1990, some scientists were predicting that freshwater flow regulation related to the hydroelectric developments would have notable impacts on the North Atlantic climate (Misak, 1993). Fortunately, this alarmist prediction proved wrong. Other scientists concluded that, even if this freshwater regulation extended to all the rivers and streams in the watersheds of Hudson Bay and James Bay, there would be no reason to connect this phenomenon to changes in the North Atlantic climate and that, if there were such an impact, it would be impossible to detect (Leblond et al., 1996).

  Today, the scientific data on reservoirs' effect on climate are sufficiently accurate and reliable for this phenomenon to no longer be considered an issue in northern Québec and comparable environments.

- **Biodiversity**
  The impact of hydroelectric developments on biodiversity is another controversial topic, though not in the case of the La Grande complex. It is easy for some authors to present biological diversity as a stable condition which no development ought to modify, without even offering any practical proposals for measuring the changes or maintaining the diversity. Presented this way as a serious concept, biodiversity becomes a powerful weapon in the hands of anyone who opposes a project.

  Hydro-Québec approaches biodiversity by instead evaluating the effects of its developments on the habitats of vulnerable species and species of economic value so as to determine whether these effects could have notable consequences on biological diversity in a given region. The studies reveal that no species has been threatened by the developments that have been built and that the new environments compare very favorably with neighboring environments that were not affected by the developments (see the section on terrestrial environment).

  A concerted approach must be targeted at the very beginning of the environmental studies. The species to be considered and the scope and limits of the studies required of the developer must be clearly stated at the outset.

- **Mercury and health**
  It has taken more than 20 years of studies to better understand the problem of mercury and show that this problem also exists in natural lakes, and that it is even preferable, in terms of health, to eat moderate amounts of fish with low levels of mercury than not eat any at all.

The studies must continue to consider everything that may constitute a health hazard. In addition, the studies and any ensuing measures and activities must be the responsibility of all parties concerned and not only the developer. In this respect, the example of the Mercury Agreement should be followed.

- **Greenhouse gases**

  The studies show that many natural ecosystems, for example the ecosystems of lakes and swamps, are at the root of substantial greenhouse gas emissions. Reservoir emissions are exaggerated when no allowance is made for the emissions that would occur naturally in any case.

  To be able to determine the net volume of a reservoir's greenhouse gas emissions, the volumes of emissions from the drainage basin before and after reservoir creation must be known. Reservoir emissions reach their maximum two years after flooding, then decrease for about ten years and finally stabilize at a level comparable to that of a natural lake.

  At the La Grande complex, we estimate the gross volume of greenhouse gas emissions at 33 tonnes of CO_2 equivalent per terawatthour (on the basis of data collected at the end of 1999). Emissions from the complex are thus 14 times lower than those of gas-fired power plants, and 28 times lower than those of coal-fired power plants with a comparable energy output.

  To allow an accurate quantification of the net volume of greenhouse gas emissions given off by reservoirs over a long period, Hydro-Québec has embarked upon an additional, five-year research program (2000–2004) covering the whole drainage basin of the La Grande complex. The different means of electrical generation are to be compared using an analysis based on life cycle, that is, an analysis that takes into account emissions due to facility construction and operation, in particular reservoir emissions, as well as the extraction and transportation of fuels. This method highlights the advantage offered by hydroelectricity, as emissions from the extraction and processing of fossil fuels are much greater, per unit of energy generated, than reservoir emissions.

3.4

Conclusion

We have tried to outline the scope and diversity of Hydro-Québec's activities in the complex environmental domain. The studies conducted and the knowledge acquired represent a major scientific contribution to the understanding of the biophysical and social environment in northern regions. Indeed, what would we know about northern Québec today, were it not for a decision made in 1971 to develop its hydroelectric potential?

Hydro-Québec is proud to have played a part in developing the analytic methods and environmental protection and enhancement measures on which current practices are based. The company believes it is able to forecast, with a very acceptable degree of accuracy, the impact of its northern projects and above all, whenever applicable, to carry out its projects with a minimum of harmful effects and a maximum of favorable environmental impacts.

In the past 30 years, Hydro-Québec has gained considerable environmental know-how. This know-how, acquired through the competence of its personnel and partners and through enormous investments, is intended to be of use to all those who must decide on future hydroelectric development projects. In this regard, particular efforts should be made to disseminate this know-how in English.

We hope the lessons and recommendations presented here will be found worthy of consideration and give rise to much-needed reflection.

Air Creebec, a Cree enterprise based at the La Grande airport.

4

Bibliography

- Works Cited
- Other References by Field

Works Cited

AUDET, R. 1979. Histoire du caribou du Québec–Labrador et évolution des populations. *Recherche amérindienne au Québec* 9: 17–27.

BEAUCHEMIN, G. 1992. The unknown James Bay and Northern Québec Agreement. *Forces* 97 (spring 1992): 14–28.

BERGERUD, A.T., R.D. JAKIMCHUK and D.R. CARRUTHERS. 1984. The buffalo of the North: Caribou *(Rangifer tarandus)* and human developments. *Arctic* 37: 7–22.

BERKES, F., AND R. CUCIUREAN. 1987. *Chisasibi Community Land Use in the Lower La Grande Sector and the Laforge-Caniapiscau Sector and the Definition of Remedial Measures.* Report for the Chisasibi Band Council.

BROUARD, D., D. DEMERS, R. LALUMIÈRE, R. SCHETAGNE and R. VERDON. 1990. *Summary Report: Evolution of Mercury Levels in Fish of the La Grande Hydroelectric Complex, Québec (1978–1989).* Report by Groupe Environnement Shooner Inc. for Vice-présidence Environnement, Hydro-Québec.

BROUARD, D., J.-F. DOYON and R. SCHETAGNE. 1994. Amplification of mercury concentration in lake whitefish *(Coregonus clupeaformis)* downstream from the La Grande 2 reservoir. James Bay, Québec. In *Mercury Pollution: Integration and Synthesis,* International Conference on Mercury as a Global Pollutant (1992), Monterey, CA, eds. C.J. Watras and J.W. Huckabee. Boca Raton, FL: Lewis Publishers. 369–380.

CARPENTIER, JEAN-MARC. 1992. James Bay: An unprecedented environmental assessment program – An interview with Norman G. Benson, American biologist. *Forces* 97 (Spring): 80–84.

CENTRE DE RECHERCHE ET D'ANALYSE EN SCIENCE HUMAINE (ssDcc inc.). 1992–1996. *Bilan des connaissances sur les impacts humains du Complexe hydroélectrique La Grande et des conventions du Québec nordique.* Report for Vice-présidence Environnement, Hydro-Québec, 4 vols.

CERANE. 1993. *Projet Laforge-2. Interventions archéologiques 1982–1992.* Société d'énergie de la Baie James.

CHAMBERLAND, A., C. BÉLANGER and L. GAGNON. 1996. L'hydroélectricité face aux autres options – Émissions atmosphériques. *Ecodecision* 19: 56–60.

CHARTRAND, N., R. SCHETAGNE and R. VERDON. 1994. *Enseignements tirés du suivi environnemental au complexe La Grande.* Proceedings of 18th Congress of the International Commission on Large Dams. Paris: ICLD. 165–190.

CHEE-BEE CREE CONSTRUCTION. 1998. *Overview Report Remedial Measures 1993–1997*. Société Opimiscow-SOTRAC.

CREE HUNTERS AND TRAPPERS INCOME SECURITY BOARD. 1999. *Annual Report 1997–1998.* Text published in French, English and Cree.

CREE REGIONAL AUTHORITY. 1985. *La synthèse archéologique et ethnohistorique du complexe La Grande.* Report for the Société d'énergie de la Baie James.

CRÊTE, M., B. DROLET, J. HUOT, M.-J. FORTIN and G.J. DOUCET. 1995. Chronoséquence après feu de la diversité de mammifères et d'oiseaux au nord de la forêt boréale québécoise. *Canadian Journal of Forest Research* 25: 1509–1518.

CRÊTE, M., J. HUOT, M.-J. FORTIN and J. DOUCET. 1997. Comparison of plant and animal diversity on new reservoir islands and established lake islands in northern boreal forest of Québec. *The Canadian Field Naturalist* 111: 407–416.

CRUMP, K., J. VIREN, A. SILVERS, H. CLEWELL III, J. DEARHEART and A. SHIPP. 1995. Reanalysis of dose-response data from the Iraqi methylmercury poisoning episode. *Risk Analysis* 15: 523–532.

CRUMP, K.S., C. VAN LANDINGHAM, C. SHAMLAYE, C. COX, P.W. DAVIDSON, G.J. MYERS and T.W. CLARKSON. 2000. Benchmark concentrations for methylmercury obtained from the Seychelles child development study. *Environmental Health Perspectives* 108 (3): 257-263.

DENIS, R., and G. HAYEUR, 1998. *Bilan du suivi environnemental de la portion de la rivière Caniapiscau et Koksoak située à l'aval des ouvrages de dérivation.* Hydro-Québec document.

DESLANDES, J.-C., S. GUÉNETTE and R. FORTIN, 1994. *Evolution of Fish Communities in Environments Affected by the Development of the La Grande Complex, Phase I (1977–1992).* Report by Université du Québec à Montréal (UQAM) for Hydro-Québec.

DIGNARD, N., R. LALUMIÈRE, A. REED and M. JULIEN. 1991. *Habitats of the Northeast Coast of James Bay.* Occasional publication No. 70, Canadian Wildlife Service, Environment Canada.

DOUCET, G.J., D. MESSIER, M. JULIEN and G. HAYEUR. 1988. Compatibility between reservoir downstream flow regime and caribou ecology in northern Québec. In *Proceedings of the Third North American Caribou Workshop,* Wildlife Technical Bulletin No. 8, Alaska Department of Fish and Game. 173–184.

DOUCET, J., and M. GIGUÈRE. 1991. *Étude de la biodiversité faunique dans les zones riveraines des réservoirs du complexe La Grande. Rapport de terrain : septembre 1991.* Hydro-Québec document.

DOUCET, J., F. NOISEUX and S. COUTURIER. 1992. *Caribou and wolf activity as determined by satellite telemetry on the La Grande hydroelectric complex reservoirs.* Poster session presented at the 48th Northeast Wildlife Conference, Norfolk, Vermont.

DOYON, J.-F., and L. BELZILE. 1998. *Réseau de suivi environnemental du complexe La Grande (1977–1996). Suivi des communautés de poissons et étude spéciale sur le doré (secteur ouest du territoire).* Report by Groupe-conseil Genivar inc. for Direction Expertise et Support technique de production, Hydro-Québec.

DOYON, J.-F., A. TREMBLAY and M. PROULX. 1996. *Régime alimentaire des poissons du complexe La Grande et teneurs en mercure dans leurs proies (1993–1994).* Hydro-Québec document.

DUCHEMIN, E., R. CANUEL, M. LUCOTTE and P. FERLAND. 1999. *Étude sur la production et l'émission de gaz à effet de serre par les réservoirs hydroélectriques d'Hydro-Québec et des lacs naturels – Volume 2, Rapport scientifique.* UQAM and Hydro-Québec–NSERC–UQAM Environmental Research Chair.

DUCHEMIN, E., M. LUCOTTE, R. CANUEL and A. CHAMBERLAND. 1995. Production of the greenhouse gases CH_4 and CO_2 by hydroelectric reservoirs of the boreal region. *Global Biogeochemical Cycles* 9: 529–540.

DUMONT, C. 1995. *Exposition au mercure méthylique ; activités du programme en 1993 et 1994.* Report for the Cree Board of Health and Social Services of James Bay.

DUMONT, C., M. GIRARD, F. BELLAVANCE and F. NOËL. 1998. Mercury levels in the Cree population of James Bay, Quebec, from 1988 to 1993/94. *Canadian Medical Association Journal* 158: 1439–1445.

ENVIRONMENT CANADA. 1991. *Aperçu des politiques environnementales adoptées par l'industrie canadienne.*Ottawa: Environnement Canada.

FEDERAL/PROVINCIAL COMMITTEE ON THE BIOLOGY OF MOISIE RIVER SALMON. 1996. *Projet d'aménagement hydroélectrique du Complexe Sainte-Marguerite-3, Rivière Sainte-Marguerite, Québec. Deuxième rapport annuel aux gouvernements.* Montréal: Hydro-Québec.

FEIT, H., and A.F. PENN. 1974. *The Northward Diversion of the Eastmain and Opinaca Rivers as Proposed: An Assessment of Impacts on the Native Community at Eastmain Village.* Montréal: Grand Council of the Crees (of Quebec).

FORAMEC inc. 1992. *Complexe Grande-Baleine. Avant-projet Phase II. Étude de la végétation riveraine et aquatique.* Report for Vice-présidence Environnement, Hydro-Québec.

GILMOUR, C.C., and E.A. HENRY. 1991. Mercury methylation in aquatic systems affected by acid deposition. *Environmental Pollution* 71: 131–169.

GIRARD, M., and C. DUMONT, 1995. Exposure of James Bay Cree to methylmercury during pregnancy for the years 1983–1991. *Water, Air and Soil Pollution* 80: 13–19.

GRANDJEAN, P., P. WEIHE and R.F. WHITE. 2000. Delayed neurotoxicity due to developmental exposure to methylmercury. Presented at the 25th International Conference on Heavy Metals in the Environment, 6–10 August 2000. University of Michigan, Ann Arbor, Michigan. Available at http://www.sph.umich.edu/eih/heavymetals/TechnicalProgram.html (contribution no. 1162).

GROUPE D'ÉTUDE CONJOINT CANIAPISCAU-KOKSOAK (GECCK). 1985. *Recommandations concernant le détournement de la rivière Caniapiscau.* Report for Direction Environnement, Société d'énergie de la Baie James.

GROUPE ROCHE BORÉAL. 1991. *Aménagement hydroélectrique d'Eastmain 1. Étude d'impact sur l'environnement. Avant-projet. Rapport sectoriel no 17 : petite faune et grande faune.* Report for Vice-présidence Environnement, Hydro-Québec.

GROUPE SECOR. 1992. *Le potentiel de développement économique régional des filières électriques.* Report for Vice-présidence Environnement, Hydro-Québec.

HAYEUR, G., and J. DOUCET. 1992. Le caribou et le complexe La Grande. In *Les enseignements de la phase I du complexe La Grande,* eds N. Chartrand and N. Thérien. 59th Congress of the Association canadienne-française pour l'avancement des sciences (ACFAS), 22–23 May 1991. 137–148.

HEALTH AND WELFARE CANADA. 1985. *Guidelines on the Chemical Contaminants of Fish and Fish Products in Canada.* Ottawa: Health and Welfare Canada.

HYDRO-QUÉBEC, 1989. *Suivi des travaux d'atténuation sur les milieux riverains, Complexe La Grande : rapport 1989.* Montréal: Hydro-Québec.

HYDRO-QUÉBEC. 1990. Hydro-Québec and the Environment. In *Hydro-Québec Development Plan 1990–1992, Horizon 1999.* Montréal: Hydro-Québec.

HYDRO-QUÉBEC. 1994. *Plan d'affaires 1995 de la vice-présidence Environnement.* Montréal: Hydro-Québec.

HYDRO-QUÉBEC. 1996. *Environmental Performance Report 1995.* Report by Vice-présidence Communication for Vice-présidence Environnement et Collectivités, Hydro-Québec.

HYDRO-QUÉBEC. 1999. *Environmental Performance Report 1998.* Montréal: Hydro-Québec.

HYDRO-QUÉBEC, and DESSAU. 1996. *Méthode d'évaluation environnementale Lignes et Postes.* Montréal: Hydro-Québec.

HYDRO-QUÉBEC and LAVALIN ENVIRONNEMENT inc. 1989. *Études des effets environnementaux cumulatifs du programme d'équipement. Phase 2 : Analyse de douze enjeux environnementaux : rapport synthèse de la première étape : Préliminaire.* Montréal: Lavalin Environnement.

HYDRO-QUÉBEC–NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL OF CANADA (NSERC)–UNIVERSITÉ DU QUÉBEC À MONTRÉAL (UQAM) ENVIRONMENTAL RESEARCH CHAIR. 1999. *Production de gaz à effet de serre par les réservoirs hydroélectriques. Analyse et synthèse des données pour les années 1993 à 1999.* Montréal: Hydro-Québec–NSERC–UQAM Research Chair.

INTERNATIONAL ENERGY AGENCY (IEA) AND SUBTASK III/6 WORKING GROUP. 1999. *Hydropower and the Environment: Efficiency of mitigating measures.* Hydropower Technology and Programs.

JAMES BAY MERCURY COMMITTEE. 1995. *Mercury: Questions and Answers.* Montréal: James Bay Mercury Committee.

JAMES BAY MERCURY COMMITTEE. 1998. *Summary Report: Evolution of Fish Mercury Levels at the La Grande Complex. Volume 2: Regional Characterization of Fish Mercury Levels for Cree Consumers in the James Bay Region.* Montréal: James Bay Mercury Committee.

JARRY, V., P. ROSS, L. CHAMPOUX, H. SLOTERDIJK, A. MURDOCH, Y. COUILLARD and F. LAVOIE. 1985. Répartition spatiale des contaminants dans les sédiments du lac Saint-Louis (fleuve Saint-Laurent). *Water Pollution Research Journal of Canada* 20: 75–99.

JOHANSSON, K., A. ANDERSON and T. ANDERSSON. 1995. Regional accumulation pattern of heavy metals in lake sediments and forest soils in Sweden. *The Science of the Total Environment* 160/161: 373–380.

JOHNSTON, T.A., R.A. BODALY and J.A. MATHIAS. 1991. Predicting fish mercury levels from physical characteristics of boreal reservoirs. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 1468–1475.

JONES, M.L., G.L. CUNNINGHAM, D.R. MARMOREK, C. WREN and D. DEGRAAF. 1986. *Mercury Release in Hydroelectric Reservoirs.* Montréal: Canadian Electrical Association.

JULIEN, M., J.J. FOURNIER, R. LALUMIÈRE and C. LEMIEUX, 1996. The La Grande hydroelectric project and eelgrass monitoring in coastal James Bay. In *Ecohydraulics 2000: Proceedings of the Second International Symposium on Habitat Hydraulics, Québec City, June 1996,* International Association for Hydraulic Research, eds. M. Leclerc, H. Capra and S. Valentin. Québec City: INRS-Eau. A99–A110.

LAARMAN, P., W.A. WILLFORD and J.R. OLSON, 1976. Retention of mercury in the muscle of yellow perch *(Perca flavescens)* and rockbass *(Ambloplites repestris). Transactions of the American Fisheries Society* 2: 296–300.

LALUMIÈRE, R., D. MESSIER, J.J. FOURNIER and C.P. McROY, 1994. Eelgrass meadows in a low Arctic environment, the northeast coast of James Bay, Québec. *Aquatic Botany* 47: 303–315.

LANGLOIS, A.P. 1974. Implications sociales et écologiques des aménagements hydroélectriques futurs/Social and ecological implications of future hydroelectric projects. In *World Energy Conference* IX, 1–21.

LASORSA, B. and S. ALLEN-GIL. 1995. The methylmercury to total mercury ratio in selected marine, freshwater and terrestrial organisms. *Water, Air and Soil Pollution* 80: 905–913.

LEBLOND, P.H., J.R. LAZIER and A.J. WEAVER. 1996. Can regulation of freshwater runoff in Hudson Bay affect the climate of the North Atlantic? *Arctic (*September 1996): 348–355.

LESSARD, M. 1995. *Réservoir Outardes-2 : bilan des aménagements écologiques.* Report for Vice-présidence Environnement, Hydro-Québec.

LUCOTTE, M., A. MUCCI, C. HILLAIRE-MARCEL, P. PICHET and A. GRONDIN, 1995. Anthropogenic mercury enrichment in remote lakes of northern Québec (Canada). *Water, Air and Soil Pollution* 80: 467–476.

LUCOTTE, M., R. SCHETAGNE, N. THÉRIEN, C. LANGLOIS, A. TREMBLAY and HYDRO-QUÉBEC (Hydraulique et environnement). 1999. *Mercury in the Biogeochemical Cycle: Natural Environments and Hydroelectric Reservoirs of Northern Québec (Canada).* Environmental Science Series. Berlin: Springer-Verlag.

MARSH, D.O., T.W. CLARKSON, C. COX, G.J. MYERS, L. AMIN-ZAKI and S. AL-TIKRITI, 1987. Fetal methylmercury poisoning relationship between concentration in single strands of maternal hair and child effects. *Archives of Neurology* 44: 1017–1022.

MESSIER, D., and F. ANCTIL, 1996. On under-ice river plumes in James and Hudson Bays. In *Ecohydraulics 2000: Proceedings of the Second International Symposium on Habitat Hydraulics, Québec City, June 1996*, eds. M. Leclerc, H. Capra and S. Valentin. Québec City: INRS-Eau. A447–A458.

MESSIER, D., R.G. INGRAM and D. ROY. 1986. Physical and biological modifications in response to La Grande hydroelectric complex. In *Canadian Inland Seas,* Elsevier Oceanography Series 44, ed. I.P. Martini. New York: Elsevier Science Pub. Co. 278–284.

MESSIER, D., and D. ROY. 1987. Concentration en mercure chez les poissons au complex hydroélectrique de La Grande Rivière (Québec). *Le Naturaliste canadien* 114: 357–368.

MÉTÉOGLOBE CANADA INC. 1991. *Complexe Grande-Baleine. Avant-projet Phase II. Impact sur le climat.* Report for Vice-présidence Environnement, Hydro-Québec.

MISAK, L. A. 1993. *Climate variability and change with respect to hydroelectric development in northern Québec. Great Whale Environmental Assessment. Paper 1.* Montréal: Great Whale Review Support Office.

MONTGOMERY, S., M. LUCOTTE and J. RHEAULT, 1996. *Total mercury and methylmercury accumulation in suspended particulate matter and plankton of a flooded system of northern Québec.* Poster presented at the 4th International Conference on Mercury as a Global Pollutant, August 1996, Hamburg, Germany.

MORNEAU, F. 1998. *Utilisation des réservoirs par la sauvagine pour la reproduction (Laforge-1 et Robertson)*. Report for Hydraulique et Environnement, Groupe Production, Hydro-Québec.

MORNEAU, F. 1999. *Programme de suivi environnemental du Complexe La Grande. Utilisation des aménagements correcteurs par la sauvagine sur la rivière Vincelotte et dans le secteur W-1 du réservoir Laforge 1 en 1999.* Report for Hydraulique et Environnement, Hydro-Québec.

NISHIMURA, H., and M. KUMAGAI, 1983. Mercury pollution of fishes in Minimata Bay and surrounding water: Analysis of pathway of mercury. *Water, Air and Soil Pollution* 20: 401–411.

NOBERT, M., S. BEAUDET, D. VANDAL and L. ROY. 1992. Use of roads in the James Bay region for sport fishing and hunting. In *Les enseignements de la phase 1 du complexe La Grande, eds. N. Chartrand and N. Thérien.* 59th Congress of the Association canadienne-française pour l'avancement des sciences (ACFAS), 22–23 May 1991. 190–210.

NRIAGU, J.O. 1989. A global assessment of natural sources of atmospheric trace metal. *Nature* 338: 47–49.

PARÉ, M., and J. HUOT, 1986. *Surveillance écologique du Complexe La Grande : synthèse des études sur le caribou de la région de Caniapiscau.* Report by Université Laval for the Société de la Baie James (SEBJ).

PERREAULT, R., and R. NAULT. 1984. *Complexe hydroélectrique de La Grande Rivière. Écologie du lièvre d'Amérique (Lepus americanus). Vol. 1. Synthèse bibliographique.* Report by Société multidisciplinaire d'études et de recherche de Montréal (SOMER) for Hydro-Québec and Société d'énergie de la Baie-James (SEBJ).

ROCHE ASSOCIÉS LTÉE. 1997. *Follow-Up Study on the Socio-Economic Impacts of the Permanent Road to Wemindji.* Final report for Hydro-Québec and the Cree Nation of Wemindji.

SALISBURY, R.F. 1986. *A Homeland for the Cree – Regional Development in James Bay 1971–1981.* Montréal: McGill–Queen's University Press.

SALISBURY, R.F., F.G. FILION, F. RAWJI, D. STEWART, SDBJ and HYDRO-QUÉBEC, 1972. *Development and James Bay: Social Implications of the Proposals for the Hydroelectric Scheme.* Report for the Société de développement de la Baie James.

SBEGHEN, J. 1994. *Revue synthèse sur les mesures d'atténuation et de compensation.* Report for the James Bay Mercury Committee.

SCHETAGNE, R. 1994. Water quality modification after impoundment of some large northern reservoirs. *Archiv für Hydrobiologie,* Special Issues 40: 223–229.

SCHETAGNE, R., and R. VERDON. 1999a. Post-impoundment evolution of fish mercury levels at the La Grande complex. Québec, Canada (from 1978 to 1996). In *Mercury in the Biogeochemical Cycle: Natural Environments and Hydroelectric Reservoirs of Northern Québec (Canada),* eds. M. Lucotte. R Schetagne, N. Thérien, C. Langlois, A. Tremblay and Hydro-Québec (Hydraulique et Environnement). Environmental Science Series. Berlin: Springer-Verlag. 235–238.

——— 1999b. Mercury in fish of natural lakes of northern Québec. In *Mercury in the Biogeochemical Cycle: Natural Environments and Hydroelectric Reservoirs of Northern Québec (Canada),* eds. M. Lucotte, R. Schetagne, N. Thérien, C. Langlois, A. Tremblay and Hydro-Québec (Hydraulique et Environnement). Environmental Science Series. Berlin: Springer-Verlag. 115–130.

SÉNÉCAL, P.P., and D. ÉGRÉ. 1997. *Les impacts humains du complexe hydroélectrique La Grande et des conventions nordiques sur les communautés autochtones.* Montréal: Hydro-Québec.

SIMARD, J.-J. and GROUPE D'ÉTUDES INUIT ET CIRCUMPOLAIRES (GÉTIC). 1996. *Tendances nordiques. Les changements sociaux 1970–1990 chez les Cris et les Inuits du Québec. Une enquête statistique exploratoire.* Québec City: Groupe d'études inuit et circumpolaires, Université Laval, 2 vols.

SMITH, J.C., and F. FARRIS, 1996. Methylmercury pharmacokinetics in man: A reevaluation. *Toxicology and Applied Pharmacology* 137: 245–252.

SOCIÉTÉ D'ÉNERGIE DE LA BAIE-JAMES (SEBJ). 1985. *Manuel d'exploitation – Complexe La Grande – Phase I : Consignes relatives à la protection de l'environnement.* Montréal: SEBJ.

SOCIÉTÉ D'ÉNERGIE DE LA BAIE-JAMES (SEBJ). 1987. *The La Grande Rivière Hydroelectric Complex – The Environmental Challenge.* Montréal: SEBJ.

SOCIÉTÉ D'ÉNERGIE DE LA BAIE-JAMES (SEBJ). 1994. *Complexe La Grande Phase II : Enjeux environnementaux et aménagements correcteurs. Faits saillants.* Montréal: SEBJ.

SOCIÉTÉ D'ÉNERGIE DE LA BAIE-JAMES (SEBJ). 1996. *Le complexe hydroélectrique de La Grande Rivière. Réalisation de la deuxième Phase.* Montréal: SEBJ.

SOCIÉTÉ D'ÉNERGIE DE LA BAIE-JAMES (SEBJ), GROUPE DRYADE, and FORAMEC. 1985. *Surveillance écologique du complexe La Grande. Synthèse des études sur les zones riveraines.* Montréal: SEBJ.

SOCIÉTÉ D'ÉNERGIE DE LA BAIE-JAMES (SEBJ) and SOCIÉTÉ DES TRAVAUX DE CORRECTION DU COMPLEXE LA GRANDE (SOTRAC). 1983. *Complexe hydroélectrique de La Grande rivière. Le castor dans la région de La Grande 3 et son comportement durant la mise en eau du réservoir.* Montréal: SEBJ.

SOCIÉTÉ D'ÉNERGIE DE LA BAIE JAMES (SEBJ) and SOCIÉTÉ DES TRAVAUX DE CORRECTION DU COMPLEXE LA GRANDE (SOTRAC). 1984. *Complexe hydroélectrique de La Grande Rivière. Comportement du castor durant la mise en eau du réservoir La Grande 4.* Montréal: SEBJ.

STATISTICS CANADA. 1995. *Enquiry into Environmental Protection Expenses,* No. 4-2200-6. Ottawa: Statistics Canada.

STEWART, DONALD. 1974. *Urbanization in the James Bay Region: The Impact of Establishing Construction Camps and the Permanent Town of Radisson on Fort George and its Cree and Inuit Population.* Montréal: McGill University, Program in the Anthropology of Development.

THIBODEAU, J.C., and P. RIOUX. 1995. *Retombées économiques de La Grande,* Montréal: INRS-Urbanisation.

TREMBLAY, A., and C. LANGLOIS. 1997. *Mitigative Measures Implemented from 1989 to 1995 Under the Mercury Program in Conjunction with the James Bay Crees.* Report for the James Bay Mercury Committee.

VAN COILLIE, R., S.A. VISSE, P.G.C. CAMPBELL and H.G. JONES. 1983. Évolution de la dégradation de bois de conifères immergés durant plus d'un demi siècle dans un réservoir. *Annales de limnologie* 19: 129–134.

VERDON, R. 1999. *Bilan des aménagements réalisés par Hydro-Québec pour l'ichtyofaune.* Report for Groupe Production, Hydro-Québec.

VERDON, R., D. BROUARD, C. DEMERS, R. LALUMIÈRE, M. LAPERLE and R. SCHETAGNE. 1991. Mercury evolution (1978–1988) in fishes of La Grande hydroelectric complex, Québec, Canada. *Water, Air and Soil Pollution* 56: 405–417.

VERTA, M., J. MANNIO, P. LIVONEN, J.P. HIRVI, O. JÄRVINEN and S. PIEPONEN. 1990. Trace metals in Finnish headwater lakes; effects of acidification and airborne load. In *Acidification in Finland,* eds. P. Kaupp, K. Kenthamies and P. Anttila. Heidelberg, Germany: Springer-Verlag. 883–908.

VERTA, M., S. REKOLAINEN and K. KINNUNEN. 1986. Causes of increased fish mercury levels in Finnish reservoirs. *Publications of the Water Research Institute of Finland* 65: 44–71.

WEINSTEIN, M. and A. PENN. 1987. Mercury and the Chisasibi fishery. Report prepared for the Cree Regional Authority.

Other References by Field

1

Estuarine and coastal

BENOÎT, R., A. REED, M. JULIEN and R. LALUMIÈRE. 1996. Habitat mapping and wildfowl (*Anatidae*) surveys on the northeast coast of James Bay, Québec. *Game and Wildlife/Gibier et Faune Sauvage* 13: 177–189.

CARON, O., and D. ROY. 1980. Coupure de La Grande Rivière ; période critique pour la faune aquatique en aval du barrage de LG 2. *Eau du Québec* 13: 23–28.

D'ANGLEJAN, B. 1982. Patterns of recent sedimentation in the Eastmain estuary, prior to river cut-off. *Le Naturaliste canadien* 109: 362–374.

D'ANGLEJAN, B., and J. BASMADJIAN. 1987. Change in sedimentation following river diversion in the Eastmain estuary (James Bay), Canada. *Journal of Coastal Research* 3: 347–468.

DIGNARD, N., R. LALUMIÈRE and M. JULIEN. 1995. *Gentiana nivalis L. (Gentianaceae)* new to Québec. *Rhodora* 97: 375–379.

DIGNARD, N., R. LALUMIÈRE, A. REED and M. JULIEN. 1991. *Habitats of the Northeast Coast of James Bay.* Occasional paper No. 70. Canadian Wildlife Service, Environment Canada.

DODSON, J.J., Y. LAMBERT and L. BERNATCHEZ. 1985. Comparative migratory and reproductive strategies of the sympatric anadromous coregonine species of James Bay. In *Migration: Mechanisms and Adaptive Significance,* ed. M.A. Rankin. Contribution to Marine Science, Supplement 27. 296–315.

FREEMAN, N.G., J.C. ROFF and R.J. PETT. 1982. Physical, chemical and biological features of river plume under an ice cover in James and Hudson Bays. *Le Naturaliste canadien* 109: 745–764.

GRENON, J.-F. 1982. The macrobenthic fauna of the Eastmain River estuary (James Bay, Québec), before diversion. *Le Naturaliste canadien* 109: 793–802.

INGRAM, R.G. 1982. Mean and tidal circulation of the Eastmain River (James Bay). *Le Naturaliste canadien* 109: 733–743.

INGRAM, R.G., B.F. D'ANGLEJAN, S. LEPAGE and D. MESSIER. 1986. Changes in current regime and turbidity in response to a freshwater pulse in the Eastmain Estuary. *Estuaries* 9: 320–325.

INGRAM, R.G., L. LEGENDRE, Y. SIMARD and S. LEPAGE. 1985. Phytoplankton response to freshwater runoff: The diversion of the Eastmain River, James Bay. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1216–1221.

JULIEN, M., J.-J. FOURNIER, R. LALUMIÈRE and C. LEMIEUX. 1996. The La Grande hydroelectric project and eelgrass monitoring in coastal James Bay. In *Ecohydraulics 2000: Proceedings of the Second International Symposium on Habitat Hydraulics, Québec City, June 1996,* eds. M. Leclerc, H. Capra and S. Valentin. Québec City: INRS-Eau, A99–A110.

LALUMIÈRE, R., D. MESSIER, J.-J. FOURNIER and C.P. McROY. 1994. Eelgrass meadows in a low Arctic environment, the north-east coast of James Bay, Québec. *Aquatic Botany* 47: 303–315.

LAMBERT, Y., and J.J. DODSON. 1982. Structure et rôle des facteurs physiques dans le maintien des communautés estuariennes de poissons de la baie James. *Le Naturaliste canadien* 109: 815–823.

———. 1990. Influence of freshwater migration on the reproductive patterns of anadromous populations of cisco *(Coregonus artedii)* and lake whitefish *(C. clupeaformis)*. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 335–345.

LEPAGE, S. and R.G. INGRAM. 1986. Salinity intrusion in the Eastmain River estuary following a major reduction of freshwater input. *Journal of Geophysical Research* 91: 909–915.

———. 1988. Estuarine response to a freshwater pulse. *Estuarine, Coastal and Shelf Science* 26: 657–667.

MESSIER, D. 1985. Modifications physiques dans l'estuaire de la rivière Koksoak à la suite de la coupure de la rivière Caniapiscau. In *Proceedings of the Kativik Environment Conference,* eds. P. Jacobs and H. Chatagnier. Kativik Regional Authority. 261–280.

MESSIER, D., and F. ANCTIL. 1996. On under-ice river plumes in James and Hudson Bays. In *Ecohydraulics 2000: Proceedings of the Second International Symposium on Habitat Hydraulics, Québec City, June 1996,* eds. M. Leclerc, H. Capra and S. Valentin. Québec City: INRS-Eau. A447–A458.

MESSIER, D., R.G. INGRAM and D. ROY. 1986. Physical and biological modifications in response to La Grande hydroelectric Complex. In *Canadian Inland Seas,* ed. I.P. Martini. Elsevier Oceanography Series 44. New York: Elsevier Science Pub. Co. 403–424.

MESSIER, D., S. LEPAGE and S. DE MARGERIE. 1989. Influence du couvert de glace sur l'étendue du panache de La Grande Rivière (baie James). *Arctic* 42: 278–284.

MORIN, R., and J.J. DODSON. 1986. The ecology of fishes in James Bay, Hudson Bay and Hudson Strait. In *Canadian Inland Seas,* ed. I.P. Martini. Elsevier Oceanography Series 44. New York: Elsevier Science Pub. Co. 295–325.

MORIN, R., J.J.DODSON and G. POWER. 1980. Estuarine fish communities of the eastern James-Hudson Bay coast. *Environmental Biology of Fishes* 5: 135–141.

———. 1981. The migrations of anadromous cisco *(Coregonus artedii)* and lake whitefish *(C. clupeaformis)* in estuaries of eastern James Bay. *Canadian Journal of Zoology* 59: 1600–1607.

———. 1982. Life history variations of anadromous cisco *(Coregonus artedii),* lake whitefish *(C. clupeaformis),* and round whitefish *(Prosopium cylindraceum)* populations of eastern James–Hudson Bay. *Canadian Journal of Fisheries and Aquatic Sciences* 39: 958–967.

OCHMAN, S., and J.J. DODSON. 1982. Composition and structure of the larval and juvenile fish community of the Eastmain river and estuary, James Bay. *Le Naturaliste canadien* 109: 803–813.

OUELLET, Y., and P. DUPUIS. 1986. Effets de la coupure de la rivière Eastmain (Baie James) sur son régime hydrodynamique estuarien. *Le Naturaliste canadien* 113: 369–381.

OUELLET, Y., and Y. ROPARS. 1980. Modèle mathématique de la rivière Koksoak. *Canadian Journal of Civil Engineering* 7: 477–491.

REED, A., R. BENOÎT, R. LALUMIÈRE and M. JULIEN. 1996a. *Duck Use of the Coastal Habitats of Northeastern James Bay.* Occasional paper No. 90. Canadian Wildlife Service, Environment Canada.

———. 1996b. *Goose Use of the Coastal Habitats of Northeastern James Bay.* Occasional paper No. 92. Canadian Wildlife Service, Environment Canada.

ROY, D. 1982. Répercussions de la coupure de la Grande Rivière à l'aval de LG 2. *Le Naturaliste canadien* 109: 883–891.

2

Reservoirs and rivers

DENIS, R., and G. LÉVESQUE. 1988. Suivi de l'évolution géomorphologique des berges et du lit de la rivière Eastmain, à l'aval des ouvrages de dérivation (1980–1984*). Proceedings of the 16th International Congress on Large Dams, San Francisco.* Paris: ICOLD. 611–631.

DESLANDES, J.-C., S. GUÉNETTE, Y. PRAIRIE, D. ROY,. R. VERDON and R. FORTIN. 1995. Changes in fish population affected by the construction of the La Grande complex (Phase 1), James Bay region, Québec. *Canadian Journal of Zoology* 73: 1860–1877.

DESLANDES, J.-C., R. VERDON, D. ROY and R. FORTIN. 1995. Changes in lake whitefish *(Coregonus clupeaformis)* populations affected by the construction of the La Grande hydroelectric complex (Phase 1), James Bay, Québec. *Archiv für Hydrobiologie, Special Issues, Advances in Limnology* 46: 473–482.

DOYON, J.-F., L. BERNATCHEZ, M. GENDRON, R. VERDON and R. FORTIN. 1998. Comparison of normal and dwarf populations of lake whitefish *(Coregonus clupeaformis)* with reference to hydroelectric reservoirs in northern Quebec. *Archiv für Hydrobiologie, Special Issues, Advances in Limnology* 50: 97–108.

DUCHEMIN, E., M. LUCOTTE, R. CANUEL and A. CHAMBERLAND. 1995. Production of the greenhouse gases CH_4 and CO_2 by hydroelectric reservoirs of the boreal region. *Global Biogeochemical Cycles* 9: 529–540.

DUMONT. P., and R. FORTIN. 1978. Quelques aspects de la biologie du grand corégone *Coregonus clupeaformis* des lacs Hélène et Nathalie, territoire de la Baie-James. *Canadian Journal of Zoology* 56: 1402–1411.

MAGNIN, E. 1977. *Écologie des eaux douces du territoire de la Baie-James.* Montréal: Société d'énergie de la Baie-James.

MESSIER, D., and D. ROY. 1987. Effets de la coupure des rivières Eastmain-Opinaca et Caniapiscau en aval des ouvrages de dérivation. In *Proceedings of the Symposium on Interbasin Transfer of Water: Impacts and Research Needs for Canada – Saskatoon, Saskatchewan,* eds. W. Nicholaichuk and F. Quinn. Ottawa: National Hydrology Research Centre. 367–384.

MÉTHOT, G., and B. PINEL-ALLOUL. 1987. Fluctuations du zooplancton dans le réservoir LG-2 (Baie James, Québec) : relation avec la qualité physico-chimique et trophique des eaux. *Le Naturaliste canadien* 114: 369–379.

MORRISON, K.A., and N. THÉRIEN. 1987. Importance de la considération des effets convectifs par les modèles prévisionnels de la dynamique du plancton. *Le Naturaliste canadien,* 114: 381–388.

———. 1996. Release of organic carbon, Kjeldahl nitrogen and total phosphorus from flooded vegetation. *Water Quality Research Journal of Canada* 31: 305–318.

MORRISON, K.A., N. THÉRIEN and B. MARCOS. 1987. A comparison of six models for nutrient limitations on phytoplankton growth. *Canadian Journal of Fisheries and Aquatic Sciences* 44: 1278–1288.

PINEL-ALLOUL, B. 1991. Annual variations of the phytoplankton community during impoundment of Canadian subarctic reservoirs. *Verhandlungen Internationale Vereinigung für Limnologie* 24, Theoretische und angewandte Limnologie: 1282–1287.

PINEL-ALLOUL, B., and G. MÉTHOT. 1984. Étude préliminaire des effets de la mise en eau du réservoir LG-2 (territoire de la Baie James, Québec) sur le seston grossier et le zooplancton des rivières et des lacs inondés. *Internationale Revue der gesamten Hydrobiologie* 69: 57–78.

ROY, D. 1989. Physical and biological factors affecting the distribution and abundance of fishes in rivers flowing into James Bay and Hudson Bay. In *Proceedings of the International Large River Symposium,* Canadian Special Publication of Fisheries and Aquatic Sciences No. 106, ed. D.P. Dodge. Ottawa: Dept. of Fisheries and Oceans. 159–171.

ROY, D. and D. MESSIER. 1987. Répercussions du transfert des eaux des rivières Eastmain-Opinaca et Caniapiscau dans La Grande Rivière (Québec). In *Proceedings of the Symposium on Interbasin Transfer of Water: Impacts and Research Needs for Canada – Saskatoon, Saskatchewan,* eds. W. Nicholaichuk and F. Quinn. Ottawa: National Hydrology Research Centre. 169–183.

———. 1989. A review of the effects of water transfers in the La Grande hydroelectric complex (Québec, Canada). *Regulated Rivers* 4: 299–316.

THÉRIEN, N., and K.A. MORRISON. 1984. The evolution of water quality in large hydro-electric reservoirs: A model of active and stagnant zones. In *The biosphere, Problems and Solutions: Proceedings of the Miami International Symposium on the Biosphere, 23–24 April 1984, Miami Beach, Florida,* ed. T.N. Veziroglu. Studies in Environmental Science 25. Amsterdam, NY: Elsevier Scientific Pub. Co. 25: 287–296.

———. 1985. Modèle prévisionnel de la qualité des eaux du réservoir hydro-électrique LG-2 : considération des zones hydrauliques actives et stagnantes. *Revue Internationale des Sciences de l'Eau* 1: 11–20.

THÉRIEN, N., K. MORRISON, M. DE BROISSIA and B. MARCOS. 1982. A simulation model of plankton dynamics in reservoirs of the La Grande River complex. *Le Naturaliste canadien* 109: 869–881.

3

Mercury

BROUARD, D., J.-F. DOYON and R. SCHETAGNE. 1994. Amplification of mercury concentration in lake whitefish *(Coregonus clupeaformis)* downstream from the La Grande 2 reservoir, James Bay, Québec. In *Mercury Pollution: Integration and Synthesis,* CA, eds. C.J. Watras and J.W. Huckabee. Boca Raton, FL: Lewis Publishers. 369-380.

CABANA, G., A. TREMBLAY, J. KALFF and J.B. RASMUSSEN. 1994. Pelagic food chain structure in Ontario Lakes: A determinant of mercury levels in lake trout *(Salvelinus namaycush)*. *Canadian Journal of Fisheries and Aquatic Sciences* 51: 381–389.

CHEVALIER, G., C. DUMONT, C. LANGLOIS and A. PENN, 1997. Mercury in northern Québec: Role of the mercury agreement and status of research and monitoring. *Water, Air and Soil Pollution* 97: 53–61.

CLARKSON, T. 1998. Methylmercury and fish consumption: Weighing the risks. *Canadian Medical Association Journal* 158: 1465–1466.

DESGRANGES, J.L., J. RODRIGUE, B. TARDIF and M. LAPERLE. 1998. Mercury accumulation and biomagnification in Ospreys *(Pandion haliaetus)* in James Bay and Hudson Bay Regions of Québec. *Archives of Environmental Contamination and Toxicology* 35: 330–341.

DMYTRIW, R., A. MUCCI, M. LUCOTTE and P. PICHET. 1995. The partitioning of mercury in the solid components of dry and flooded forest soils and sediments from a hydroelectric reservoir, Québec (Canada). *Water, Air and Soil Pollution* 80: 1099–1103.

DOYON, J.-F., R. SCHETAGNE and R. VERDON. 1998. Different mercury bioaccumulation rates between sympatric populations of dwarf and normal lake whitefish (*Coregonus clupeaformis*) in the La Grande complex watershed, James Bay, Québec. *Biogeochemistry* 40: 203–216.

GRONDIN, A., M. LUCOTTE, A. MUCCI and B. FORTIN. 1995. Mercury and lead profiles and burdens in soils of Quebec (Canada) before and after flooding. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 2493–2506.

KIDD, K.A., R.H. HESSLEIN, R.J.P. FUDGE and K.A. HALLARD. 1995. The influence of trophic level as measured by $\delta^{15}N$ on mercury concentrations in freshwater organisms. *Water, Air and Soil Pollution* 80: 1011–1015.

KIM, J. P. 1995. Methylmercury in rainbow trout *(Oncorhyncus mykiss)* from lakes Okareka, Okaro, Rotomahana, Rotorua and Tarawera, North Island, New Zealand. *The Science of the Total Environment* 164: 1011–1015.

LANGLOIS, C. and R. LANGIS. 1995. Presence of airborne contaminants in the wildlife of Northern Québec. *The Science of the Total Environment* 160/161: 391–402.

LANGLOIS, C., R. LANGIS and M. PÉRUSSE. 1995. Mercury contamination in northwest Québec environment and wildlife. *Water, Air and Soil Pollution* 80: 1021-1024.

LOUCHOUARN, P., M. LUCOTTE, A. MUCCI and P. PICHET. 1993. Geochemistry of mercury in two hydroelectric reservoirs in Québec, Canada. *Canadian Journal of Fisheries and Aquatic Sciences* 50: 269–281.

LUCOTTE, M., A. MUCCI,. C. HILLAIRE-MARCEL, P. PICHET and A. GRONDIN. 1995. Anthropogenic mercury enrichment in remote lakes of northern Québec (Canada), *Water, Air and Soil Pollution* 80: 467–476.

LUCOTTE, M., R. SCHETAGNE, N. THÉRIEN, C. LANGLOIS, A. TREMBLAY and HYDRO-QUÉBEC. 1999. *Mercury in the Biogeochemical Cycle: Natural Environments and Hydroelectric Reservoirs of Northern Québec (Canada).* Environmental Science Series. Berlin: Springer-Verlag.

MESSIER, D., and D. ROY. 1987. Concentrations en mercure chez les poissons au complexe hydroélectrique de La Grande Rivière. *Le Naturaliste canadien* 114: 357–368.

MONTGOMERY, S., A. MUCCI and M. LUCOTTE. 1996. The application of in situ dialysis samplers for close interval investigations of total dissolved mercury in interstitial waters. *Water, Air and Soil Pollution* 87: 219–229.

MONTGOMERY, S. A. MUCCI, M. LUCOTTE and P. PICHET. 1995. Total dissolved mercury in the water column of several natural and artificial aquatic systems of northern Quebec (Canada). *Canadian Journal of Fisheries and Aquatic Sciences* 52: 2483–2492.

MORRISON, K.A., and N. THÉRIEN. 1991. Experimental evaluation of mercury release from flooded vegetation and soils. *Water, Air and Soil Pollution* 56: 607–619.

———. 1994. Mercury release and transformation from flooded vegetation and soils: Experimental evaluation and simulation modelling. In *Mercury Pollution: Integration and Synthesis,* eds. C.J. Watras and J.W. Huckabee, Boca Raton, FL.: Lewis Publishers. 355–365.

———. 1995a. Changes in mercury levels in lake whitefish (*Coregonus clupeaformis*) and northern pike (*Esox lucius*) in the LG-2 reservoir since flooding. *Water, Air and Soil Pollution* 80: 819–828.

———. 1995b. Fluxes of mercury through biota in the LG-2 reservoir after flooding. *Water, Air and Soil Pollution* 80: 573–576.

MUCCI, A., M. LUCOTTE, S. MONTGOMERY, Y. PLOURDE, P. PICHET and H. VAN TRA. 1995. Mercury remobilization from flooded soils in a hydroelectric reservoir of northern Québec, Robert-Bourassa: Results of a soil resuspension experiment. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 2507–2517.

PLOURDE, Y., M. LUCOTTE and P. PICHET 1997. Contribution of suspended particulate matter and zooplankton to MeHg contamination of the food chain in mid-northern Québec (Canada) reservoirs. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 821–831.

TREMBLAY, A., L. CLOUTIER and M. LUCOTTE. 1998. Total mercury and methylmercury fluxes via emerging insects in recently flooded hydroelectric reservoirs and a natural lake. *The Science of the Total Environment* 219: 209–221.

TREMBLAY, A., and M. LUCOTTE. 1997. Accumulation of total mercury and methylmercury in insect larvae of hydroelectric reservoirs. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 832–841.

TREMBLAY, A., M. LUCOTTE , M. MEILI, L. CLOUTIER and P. PICHET. 1996. Total mercury and methylmercury contents of insects from boreal lakes: Ecological, spatial and temporal patterns. *Water Quality Research Journal of Canada* 31: 851–873.

TREMBLAY, A., M. LUCOTTE and I. RHEAULT. 1996. Methylmercury in a benthic food web of two hydroelectric reservoirs and a natural lake. *Water, Air and Soil Pollution* 91: 255–269.

TREMBLAY, A., M. LUCOTTE and D. ROWAN. 1995. Different factors related to mercury concentration in sediments and zooplankton of 73 Canadian lakes. *Water, Air and Soil Pollution* 80: 961–970.

TREMBLAY, A., M. LUCOTTE and R. SCHETAGNE. 1998. Total mercury and methylmercury accumulation in zooplankton of hydroelectric reservoirs in northern Québec (Canada). *The Science of the Total Environment,* 213: 307–315.

TREMBLAY, G., P. LEGENDRE, J.-F. DOYON, R. VERDON and R. SCHETAGNE. 1998. The use of polynomial regression analysis with indicator variables for interpretation of mercury in fish data. *Biogeochemistry* 40: 189–201.

VERDON, R., D. BROUARD, C. DEMERS, R. LALUMIÈRE, M. LAPERLE and R. SCHETAGNE. 1991. Mercury evolution (1978–1988) in fishes of the La Grande hydroelectric complex, Québec, Canada. *Water, Air and Soil Pollution* 56: 405–417.

WORLD HEALTH ORGANIZATION (WHO). 1990. *Environmental Health Criteria 101: Methylmercury.* Geneva, Switzerland: WHO.

4

Terrestrial

BIDER, J.R. 1976. The distribution and abundance of terrestrial vertebrates of the James and Hudson Bay regions of Quebec. *Cahiers de Géographie de Québec* 20: 393–408.

BRODEUR, S., F. MORNEAU, R. DÉCARIE, J.J. NEGRO and D.M. BIRD, 1994. Breeding density and brood size of rough-legged hawks in northwestern Québec. *Journal of Raptor Research* 28: 259–262.

BRODEUR, S., F. MORNEAU, J.J. NEGRO, R. DÉCARIE and J.-L. DESGRANGES. 1995. Southern extension to the breeding range of the gyrfalcon, *Falco rusticolus,* in eastern North America. *Arctic* 48: 94–95.

COUTURIER, S., J. BRUNELLE, D. VANDAL and G. ST-MARTIN. 1988. Changes in the population dynamics of the George River caribou herd, 1967–87. *Arctic* 43: 9–20.

CRÊTE, M., and G.J. DOUCET 1998. Persistent suppression in dwarf birch after release from heavy summer browsing by caribou. *Arctic and Alpine Research* 30: 126–132.

CRÊTE, M., B. DROLET, J. HUOT, M.-J. FORTIN and G.J. DOUCET. 1995. Chronoséquence après feu de la diversité de mammifères et d'oiseaux au nord de la forêt boréale québécoise. *Canadian Journal of Forest Research* 25: 1509–1518.

CRÊTE, M., J. HUOT, M.-J. FORTIN and G.J. DOUCET. 1997. Comparison of plant and animal diversity on new reservoir islands and established lake islands in the northern boreal forest of Québec. *The Canadian Field Naturalist* 111: 407–416.

CRÊTE, M., and M. MANSEAU. 1996. Natural regulation of cervidae along a 1000 km latitudinal gradient: Change in trophic dominance. *Evolutionary Ecology* 10: 51–62.

DÉCARIE, R., F. MORNEAU, D. LAMBERT, S. CARRIÈRE and J.-P. SAVARD. 1995. Habitat use by brood-rearing waterfowl in subarctic Québec. *Arctic* 48: 383–390.

DOUCET, G.J., and J.R. BIDER. 1979. Hydroelectric developments in northern Québec. In *Northern Resource Developments: Fish and Wildlife Implications. Transactions of the 44th North American Wildlife and Natural Resources Conference: March 24–28, 1979,* Harbour Castle Hilton Hotel, Toronto, Ontario, eds. T.R. Berger and N.M. Simmons. Washington, DC: Wildlife Management Institute. 225–234.

DUCRUC, J.-P., R. ZARNOVICAN, V. GERARDIN and M. JURDANT. 1976. Les régions écologiques du territoire de la Baie James : caractéristiques dominantes de leur couvert végétal. *Cahiers de Géographie de Québec* 20: 365–392.

GOUVERNEMENT DU QUÉBEC and MINISTÈRE DU LOISIR, DE LA CHASSE ET DE LA PÊCHE (MLCP). 1988. *Validation des sites potentiellement dangereux pour le caribou sur le territoire du Nouveau-Québec.* Report by René Nault and Didier Le Hénaff.

GUERTIN, G., G.J. DOUCET and G.C. WEARY. 1984. Moose distribution and winter habitat on the Lower North Shore of the St. Lawrence River – Québec. *Alces* 20: 27–45.

MANSEAU, M., J. HUOT and M. CRÊTE. 1996. Effects of summer grazing by caribou on composition and productivity of vegetation: Community and landscape level. *Journal of Ecology* 84: 503–513.

MESSIER, F., H. HUOT, D. LE HÉNAFF and S. LUTTICH. 1988. Demography of the George River caribou herd: Evidence of population regulation by forage exploitation and range expansion. *Arctic* 41: 279–287.

MORNEAU, F., S. BRODEUR, R. DÉCARIE, S. CARRIÈRE and D.M. BIRD. 1994. Abundance and distribution of nesting Golden Eagles in Hudson Bay, Québec. *Journal of Raptor Research* 28: 220–225.

5

Social

BERKES, F. 1979. An investigation of Cree Indian domestic fishery in northern Québec. *Arctic* 32: 46–70.

———. 1982. Preliminary impacts of the James Bay hydroelectric project, Québec, on estuarine fish and fisheries. *Arctic* 35: 524–530.

BERKES, F., and C.S. FARKAS. 1978. Eastern James Bay Cree Indians: Changing patterns of wild food use and nutrition. *Ecology of Food and Nutrition* 7: 155–172.

GOUVERNEMENT DU QUÉBEC. 1997. *The Amerindians and the Inuit of Québec: Eleven Contemporary Nations.* Québec City: Secrétariat aux affaires autochtones.

CANADIAN RESEARCH COUNCIL ON ENVIRONMENTAL ASSESSMENT. 1985. *Évaluation des incidences environnementales : exposé sur la recherche – Social Impact Assessment: A Research Prospectus.* CRCEA Publication 1-85.

NIEZEN, R. 1993. Power and dignity: The social consequences of hydro-electric development for the James Bay Cree. *Canadian Review of Sociology and Anthropology* 30: 510–529.

SÉNÉCAL, P., and D. ÉGRÉ. 1998. Les impacts du complexe hydroélectrique La Grande sur les communautés autochtones. *Recherches amérindiennes au Québec* 28 (1): 89–103.

VINCENT, S., and G. BOWERS (under the direction of). 1985. *James Bay and Northern Quebec: Ten Years After.* Proceedings of the Forum on the James Bay and Northern Québec Agreement, Ten Years After. Organized by the Société de recherches amérindiennes au Québec. Montréal.

6

Miscellaneous

CHARTRAND, N., and C. DEMERS. 1992. Repercussions of hydroelectric developments in northern Québec, Canada: The case of the La Grande complex in James Bay. In *Hydropower '92: Proceedings of the 2nd International Conference on Hydropower, Lillehammer, Norway, June 16–18, 1992,* eds. E. Broch and D.K. Lysne. Rotterdam: A.A. Balkema. 253–259.

CHARTRAND, N., J. DOUCET, D. ÉGRÉ, G. HAYEUR, R. SCHETAGNE and R. VERDON. 1992. Lessons from environmental monitoring of the La Grande complex – phase 1. *Energy Exploration and Exploitation* 10: 183–198.

CHARTRAND, N., R. SCHETAGNE and R. VERDON. 1994. *Enseignements tirés du suivi environnemental au complexe La Grande.* Proceedings of the 18th International Congress on Large Dams. Paris: ICOLD. 165–190.

CHARTRAND, N., and N. THÉRIEN, eds. 1992. *Les enseignements de la phase 1 du complexe La Grande.* 59th Congress of the Association canadienne-française pour l'avancement des sciences (ACFAS), Sherbrooke, 22–23 May 1991. Montréal: Hydro-Québec.

DEMERS, C., and N. CHARTRAND. 1992. Lessons from 17 years of environmental monitoring at the La Grande Project, Québec, Canada. In *Hydropower '92: Proceedings of the 2nd International Conference on Hydropower, Lillehammer, Norway, June 16–18, 1992,* eds. E. Broch and D.K. Lysne. Rotterdam: A.A. Balkema. 273–280.

DENIS, R. 1995. Le réseau de suivi environnemental d'Hydro-Québec au complexe La Grande. *Proceedings of the Atelier d'orientation sur l'écozone du Bouclier boréal région du Québec,* Réseau d'évaluation et de surveillance écologiques. Canadian Wildlife Service (CWS), Environment Canada. 34–46.

———. 1996. Environmental follow-up, monitoring and surveillance: an overview of two corporate guidelines at Hydro-Québec. *Proceedings of the 16th Annual Meeting of the International Association for Impact Assessment (IAIA), Estoril, Portugal*. 337–341.

DENIS, R., M. GIGUÈRE and J.-M. CARPENTIER. 1995. Grands enseignements du suivi environnemental de la ligne à courant continu à 450kV Radisson-Nicolet-Des Cantons. In *Fifth International Symposium on Environmental Concerns in Rights-of-Way Management,* eds. G.J. Doucet, C. Séguin and M. Giguère. Montréal: Hydro-Québec. 499–508.

DUBEAU, D. 1992. Studying the cumulative environmental effects of Hydro-Québec's installation plan. *Energy Exploration & Exploitation* 10: 175–182.

GUERTIN, G., C. DEMERS and M. PÉRUSSE. 1993. La Grande Rivière: In accord with its environment, a case study. *Water Resources Development* 9: 387–409.

PETERSON, E.B. 1987. *Cumulative Effects Assessment in Canada: An Agenda for Action and Research.* Hull: Canadian Research Council on Environmental Assessment.

www.hydroquebec.com/environment

Legal deposit — 3rd quarter 2001
National Library of Canada
Bibliothèque nationale du Québec
ISBN 2-550-36964-5

For a copy of this document,
please call **1 800 363-7443**.

Electronic version available at
www.hydroquebec.com/environment

2001G291A

Ce document est également publié en français.

Hydro Québec