



Environmental Monitoring at the La Grande Complex – Evolution of Mercury Levels in Fish - Summary Report 1978 - 2012

Executive Summary – October 2013





1. Background and Objectives

The development of the La Grande hydroelectric complex required the impoundment of large reservoirs, the diversion of several rivers and flow reductions in sections of rivers. It brought about major physical and hydrological modifications. A large-scale environmental monitoring network (EMN), was established to evaluate the physical, chemical and biological changes caused by these modifications, to rationalize remedial measures and management of the developed waterbodies, and to improve impact prediction methods for future projects.

When the La Grande complex was built, the temporary increase in fish mercury levels in reservoirs was a virtually unknown phenomenon, apart from the relatively high mercury levels that had been observed in some reservoirs in Canada and the United States. Monitoring of fish mercury levels began before the La Grande complex reservoirs were impounded, as an EMN complementary study, and became a regular component of the EMN program as soon as the increase in fish mercury levels was observed. The specific objectives of the mercury monitoring were to evaluate the temporal evolution of the phenomenon in the different types of modified environments, to inform fish consumers and to improve impact prediction methods for future projects.

This monitoring, initiated as a commitment of the Société d'énergie de la Baie-James (SEBJ), meets several Hydro-Québec obligations related to the Mercury Agreements of 1986 and 2001, as well as several conditions of the certificates of authorization for the construction of the La Grande Complex's Phase II (La Grande-1, La Grande-2A, Laforge-1 and Laforge-2 generating stations) and Phase III (Eastmain-1, Eastmain-1A, Sarcelle powerhouses and Rupert diversion). Map 1 shows the layout of the La Grande Complex.

2. Methods

From 1978 to 2012, namely before and after the development, fish were caught at 97 sampling stations distributed throughout natural lakes and modified environments in the La Grande complex region. Fish were also caught along the east coast of James Bay.

At each sampling station, and for each sampling campaign, the goal was to catch 30 fish, with all lengths evenly represented, from each of the following target species: lake whitefish, longnose sucker, northern pike, walleye and lake trout. Less abundant species, such as burbot, speckled trout, cisco, round whitefish and lake sturgeon, were also occasionally sampled. At most stations, sampling was usually carried out every 2 years from 1978 to 2000, then every 4 years. Over 45,000 fish flesh samples were analyzed for total mercury using the standard Cold Vapour Atomic Absorption Spectrophotometry method. The following measurements were also taken for each fish analyzed for mercury: total length, weight, sex, sexual maturity and age. The stomach contents were also examined for piscivorous species.

The statistical approach was based on the calculation of mean fish mercury levels for standardized lengths using the *Polynomial regression analysis with indicator variables*. The standardized lengths, which usually correspond to the average length caught by the multiple-mesh-size gill nets used, are the following: 400 mm (16 in) for lake whitefish, longnose sucker and walleye; 600 mm (24 in) for lake trout and 700 mm (28 in) for northern pike.

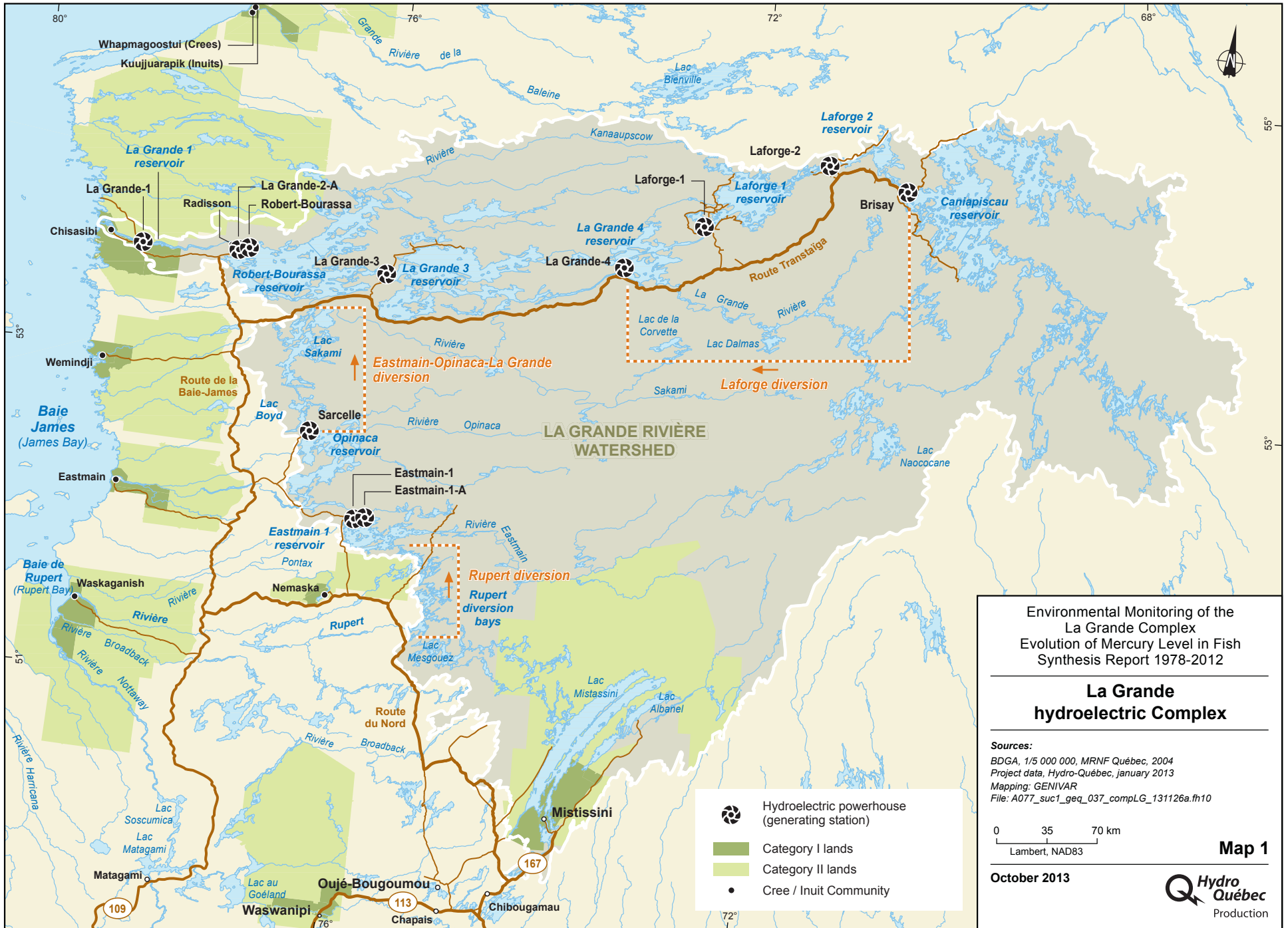
3. Main Lessons Learned

The extent and duration of the temporary increases in fish mercury levels were clearly defined. The main lessons learned are as follows.

3.1 Natural Lakes

The main lessons derived from the regular monitoring of fish mercury levels in natural lakes are:

- Mercury levels in individual fish vary greatly. They may vary by a factor of 4 for a given species, of a given length, within a given lake. They however gradually increase as a function of fish length or age;
- Mean mercury levels in fish of standardized lengths for a given species may also vary considerably (by as much as fourfold) from one lake to the next, without any particular geographic trend, but rather as a function of water quality. The highest levels are generally found in lakes with coloured water, rich in dissolved and particulate organic matter;



Environmental Monitoring of the
La Grande Complex
Evolution of Mercury Level in Fish
Synthesis Report 1978-2012

**La Grande
hydroelectric Complex**

Sources:
BDGA, 1/5 000 000, MRNF Québec, 2004
Project data, Hydro-Québec, January 2013
Mapping: GENIVAR
File: A077_suc1_geq_037_compLG_131126a.fr10

0 35 70 km
Lambert, NAD83

Map 1

October 2013

Hydro Québec
Production



- Mean mercury levels in non-piscivorous species, ranging from 0.05 to 0.30 mg/kg, are always considerably lower than the Canadian marketing standard for fishery products (0.5 mg/kg of total mercury), whereas piscivorous species often slightly exceed the standard, with values ranging from 0.30 to 1.11 mg/kg;
- Regular monitoring of fish mercury concentrations in a number of natural lakes does not show any trend, either upward or downward, over periods of 22 to 28 years.

3.2 Reservoirs

The main lessons derived from the monitoring of mercury levels in standardized-length fish from reservoirs are the following:

- Reservoir impoundment leads to a significant increase of mercury levels in all fish species, by factors ranging from 2 to 8 times the levels recorded in natural environments;
- Maximum levels in non-piscivorous species (from 0.33 to 0.72 mg/kg), are generally reached 4 to 11 years after impoundment, while those in piscivorous species (1.65 to 4.66 mg/kg) are observed after 7 to 14 years;
- In non-piscivorous species, mean maximum levels often remain below the Canadian marketing standard for fishery products but sometimes slightly exceed it, whereas in piscivorous species, peak levels may be 3 to 9 times higher than the standard;
- The increases are temporary, however, and the return to levels representative of natural lakes is generally completed 10 to 20 years after impoundment for non-piscivorous species, and generally after 20 to 30 years in piscivorous species when no further flooding occurs (Figure 1);
- All the reservoirs exhibit the same general pattern of change in fish mercury levels, and the slight variations observed may be explained by physical and hydraulic characteristics particular to the reservoirs. Flooded terrestrial area, annual water volume, filling time, and extent of drawdown are believed to be important factors, as well as water temperature, quality and density of flooded decomposable materials and fish diet;
- For a given reservoir, fish mercury levels may vary significantly from one sampling station to another, but no systematic pattern is observed, except for stations exhibiting particular characteristics.

3.3 Immediately Downstream from Reservoirs

The main lessons derived from the monitoring of mercury levels in standardized-length fish caught immediately downstream from the La Grande complex reservoirs are the following:

- Mercury levels in lake whitefish caught immediately downstream from generating stations, or flow control structures, are often significantly higher than those recorded in the upstream reservoir (Figure 2). This phenomenon is also occasionally observed in longnose sucker. These usually non-piscivorous species become piscivorous here due to the abundance of small fish made more vulnerable to predation by their passage through turbines or control structures;
- In lake whitefish, this change in diet is mainly seen in large specimens (> 400 mm in length);
- The difference in mean levels observed upstream and downstream would be a function of the characteristic of the structures, such as the water head and the presence or absence of turbines, rendering the small fish more or less vulnerable to predation;
- The maximum mercury levels reached downstream, as well the difference between upstream and downstream levels, decrease over time. Mean mercury levels recorded in the last few sampling campaigns for standardized-length lake whitefish allow unrestricted consumption (< 0.29 mg/kg);
- In piscivorous species like northern pike, the differences between areas above and below reservoirs are smaller and often not significant, as these species always have a piscivorous diet.

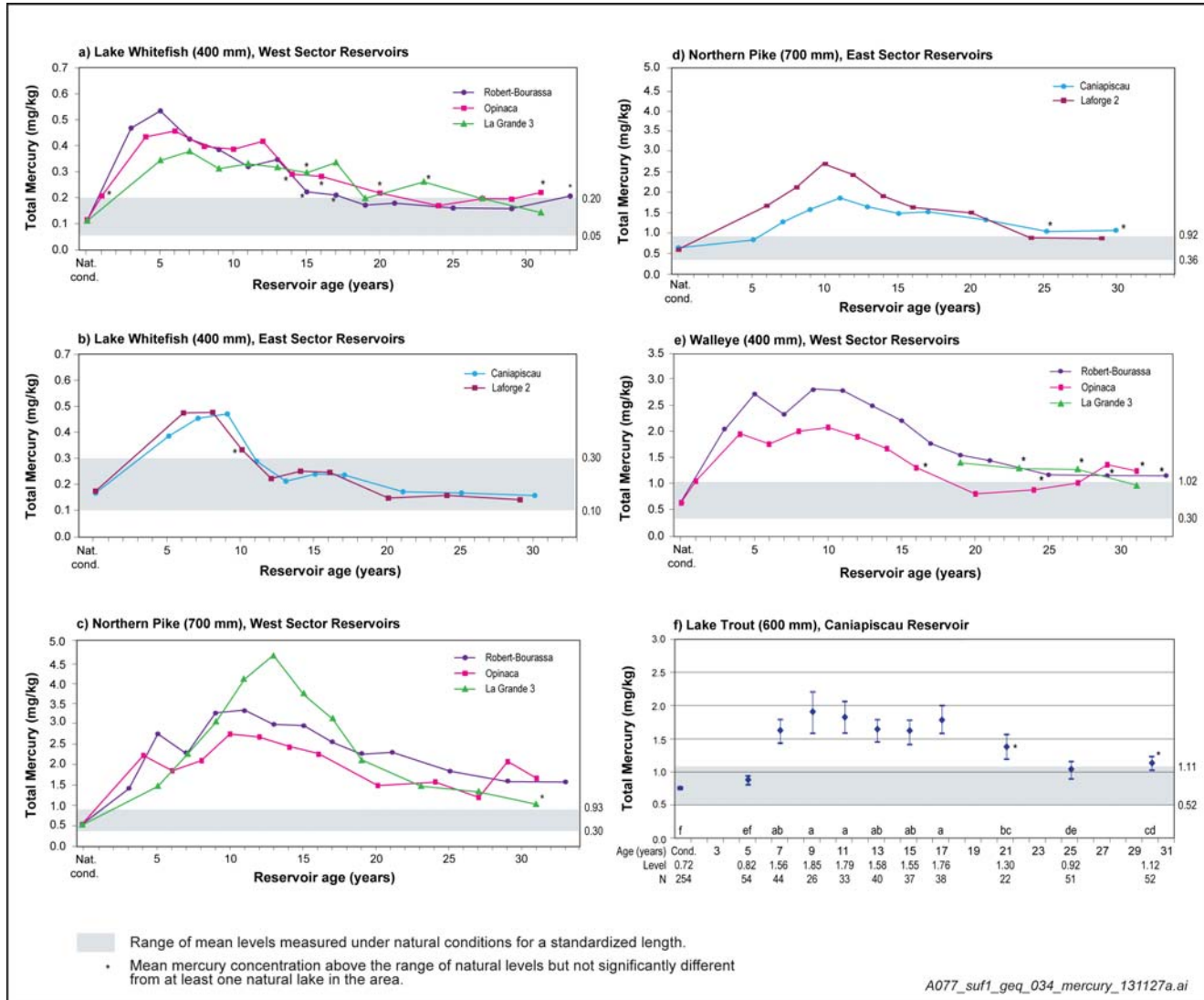


Figure 1: Temporal Evolution of Mean Mercury Levels in Standardized-Length fish in Main La Grande Complex Reservoirs

3.4 Diversion Routes

The main lessons derived from the monitoring of mercury levels in standardized-length fish caught along the Laforge and Eastmain-Opinaca-La Grande diversion routes are the following:

- The evolution of fish mercury levels recorded along diversion routes confirms that mercury is exported from reservoirs and transferred to fish living downstream;

- In some waterbodies along these flow routes, mercury levels may be higher than those in the reservoir providing the inter-basin transfer, because of the combined effect of mercury export downstream from the reservoir and additional mercury production from the local flooding of terrestrial environments;

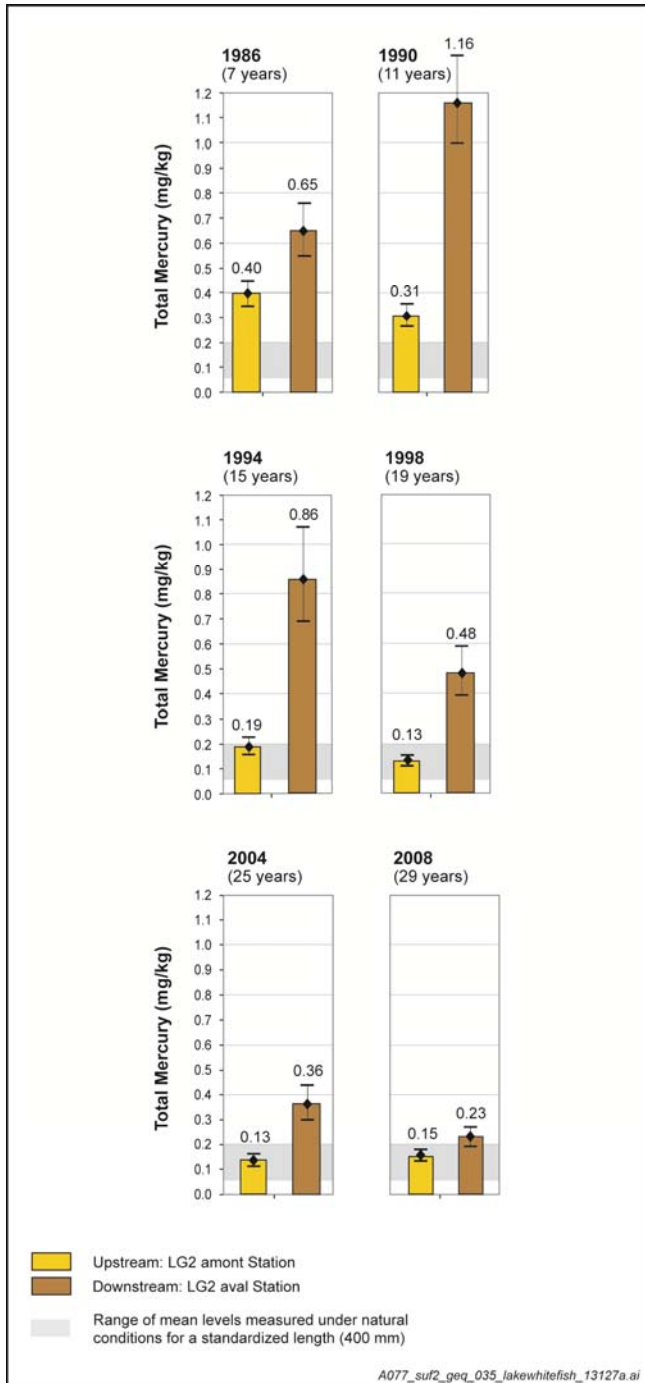


Figure 2: Comparison of Mean Mercury Levels in Lake Whitefish of Standardized Length Upstream and Immediately Downstream from the Robert-Bourassa Generating Station

- The presence of a large waterbody along a diversion route would greatly reduce the transfer of mercury to downstream fish, as it allows for the sedimentation of the mercury adsorbed onto suspended particulate matter and provides still-water conditions that greatly reduce zooplankton entrainment;
- There is no cumulative increase in fish mercury levels when a series of reservoirs is built along the same flow route (Figure 3), as the influence of a given reservoir is significant only in the reservoir located immediately downstream.

3.5 Reduced-Flow Rivers

The main lessons derived from the regular monitoring of mercury levels in standardized-length fish caught in reduced-flow rivers are the following:

- In reduced-flow rivers, where the closures were total and permanent, fish mercury levels generally remained within the range of mean levels observed under natural conditions;
- When large volumes of reservoir water are spilled into these rivers, even if only for a few months, the result is a significant increase in mercury levels in both piscivorous and non-piscivorous fish. The increase may be as great as that observed in the reservoirs, though shorter in duration. This shows that mercury is exported downstream from reservoirs and quickly transferred to downstream fish, most likely by reservoir-produced zooplankton;
- During these spillages, the extent of the mercury export, the downstream distance over which it could be felt and the duration of the increase in fish levels beyond those measured in natural environments appear to depend on the dilution of all the components in the water column by the tributaries of the residual drainage basin, as well as on the presence or absence of a large waterbody allowing sedimentation of suspended particulate matter and predation of entrained zooplankton by aquatic organisms in that waterbody.

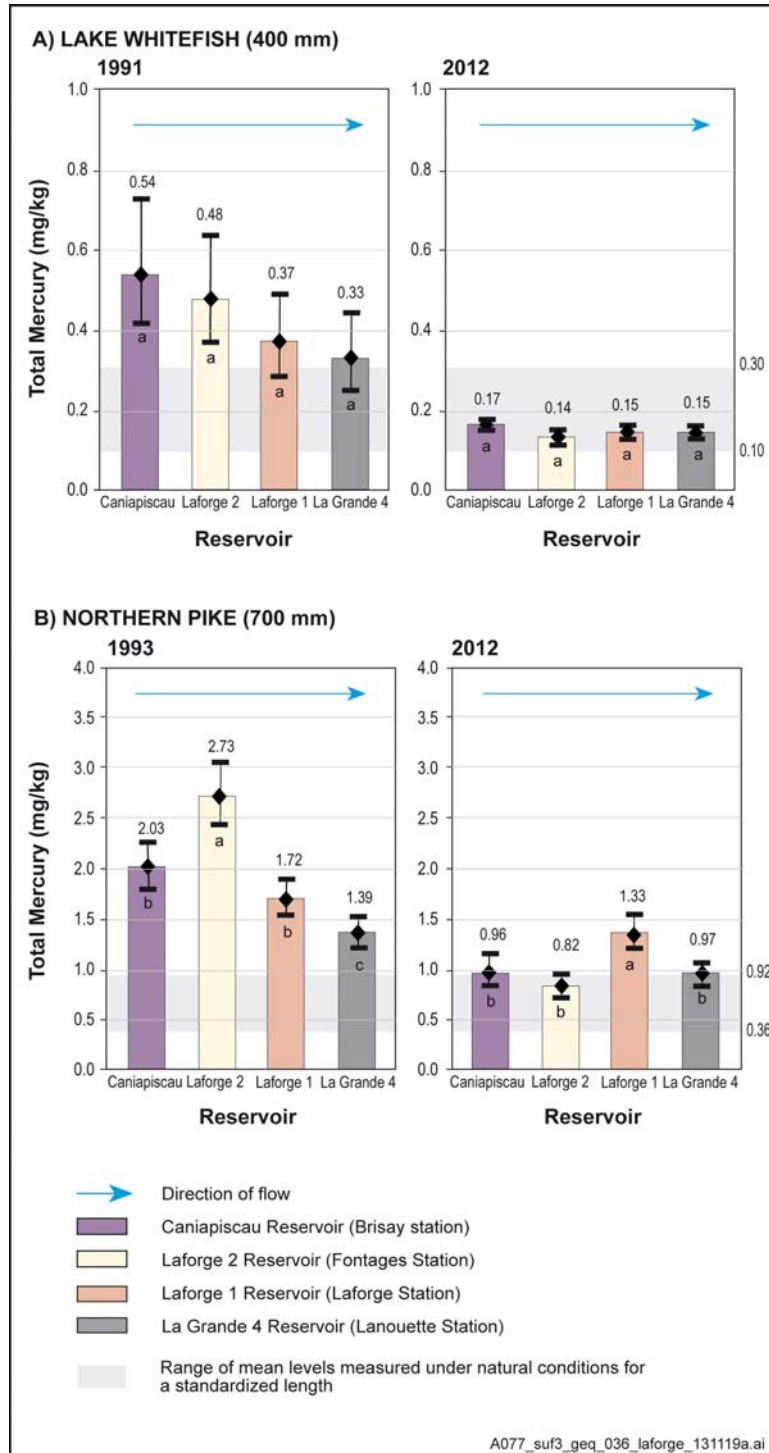


Figure 3: Spatial Comparison of Mercury Levels in Lake Whitefish and Northern Pike of Standardized Length along the Laforge Diversion



3.6 Effect on Fish Consumption

The main effects of the temporary increase in mercury levels on fish consumption (Table 1) are the following:

Natural Lakes

- As a result of the great variability in mercury levels in consumption-size fish in the area's natural lakes, the consumption recommendations vary from no restriction to a maximum of 8 meals per month for non-piscivorous species, and from 2 to 8 meals per month in piscivorous species, depending on the species and the considered natural lake.

Modified Waterbodies

Lake Whitefish

- During peak mercury levels in 500-mm lake whitefish, the consumption recommendations were reduced to 2 to 8 meals per month according to the modified waterbody, compared to no restriction on consumption applying to the majority of natural lakes. Exceptionally, a maximum of one meal per month was applicable for lake whitefish caught immediately below the Robert-Bourassa generating station;
- Depending on the modified waterbody, the additional restrictions on consumption of lake whitefish lasted from 0 to 26 years, compared to the recommendations applied to natural lakes in the area, which vary from no restriction to a maximum of 8 meals per month;
- The mean mercury levels recorded for lake whitefish during the last readings, in all modified waterbodies, allow a maximum of 8 meals per month, which corresponds to the recommendation for natural lakes in the area.

Piscivorous Species

- During peak mercury levels, consumption recommendations applicable to 800-mm northern pike, 500-mm walleye and 600-mm lake trout were reduced to a maximum of 2, 1, or less than 1 meal per month depending on the species and the modified waterbody, compared to the maximum of 4 meals per month recommended for most natural lakes.

- Compared to the consumption recommendations applied to piscivorous fish in natural lakes in the area, which vary from 2 to 8 meals per month, the additional restrictions on consumption lasted from 0 to 8 years for lake trout, from 16 to 21 years for walleye, and from 0 to 30 years for northern pike, depending on the modified waterbody;
- The mean mercury levels recorded during the latest sampling campaign allow for a maximum of 2 to 4 meals per month of consumption-size piscivorous fish depending on the species and the modified waterbody, which corresponds to the recommendation applied to many lakes in the area, most of the few exceptions allowing for a maximum of 1.8 meals per month. The only true exception is northern pike caught in Lake Sakami, for which a maximum of 1 meal per month is still recommended.

4. Objectives and Obligations Met

Phase I of La Grande Complex

The synthesis report on the evolution of mercury levels in fish at the La Grande Complex – 1978 to 2000 shows that the objectives and commitments concerning mercury related to Phase I of the La Grande Complex were fully met:

- By the extensive monitoring carried out, the extent and duration of the post-impoundment increase in fish mercury levels was clearly established and the main processes involved were identified, as well as the underlying physical and biological factors;
- The concerned local populations were continuously informed of the evolution of fish mercury levels by a number of methods:
 - The Cree, via the James Bay Mercury Agreements (1986 and 2001);
 - The sport fishers, via the "Guide de consommation du poisson de la pêche sportive en eau douce du Québec", which was regularly revised with the James Bay monitoring data;



Table 1 Consumption Recommendations for Main Fish Species in the Modified Waterbodies of the La Grande Complex

Waterbody	Lake Whitefish (500 mm)				Northern Pike (800 mm)				Walleye (500 mm)				Lake Trout (600 mm)			
	Natural Levels	Maximum	Last Survey	Return	Natural Levels	Maximum	Last Survey	Return	Natural Levels	Maximum	Last Survey	Return	Natural Levels	Maximum	Last Survey	Return
Reservoirs																
Robert-Bourassa	0.08 - 0.34	0.69	0.26	Yes	0.37 - 1.22	4.19	2.02	No	0.55 - 1.47	3.61	1.65	Yes				
Opinaca	0.08 - 0.34	0.60	0.31 ²	Yes	0.37 - 1.22	3.50	2.04 ²	No	0.55 - 1.47	2.93	1.75 ²	Yes				
La Grande 3	0.08 - 0.34	0.60	0.37	Yes	0.37 - 1.22	5.47	1.59	Yes	0.55 - 1.47	2.55 ⁶	1.54	Yes				
La Grande 4	0.15 - 0.41	0.32	0.22	Yes	0.59 - 1.28	1.97	1.44	Yes					0.52 - 1.11	n/a	0.97 ⁷	Yes
Caniapiscou	0.15 - 0.41	0.39	0.25	Yes	0.59 - 1.28	2.17	1.43	Yes					0.52 - 1.11	1.85	1.12	Yes
La Grande 1	0.08 - 0.34	1.92	0.28	Yes	0.37 - 1.22	6.25	1.03	Yes	0.55 - 1.47	5.87	1.61	Yes				
Laforge 1	0.15 - 0.41	0.44	0.22	Yes	0.59 - 1.28	2.06	2.06	No								
Laforge 2	0.15 - 0.41	0.40	0.27	Yes	0.59 - 1.28	2.73	1.18	Yes								
Immediately downstream from reservoirs																
Robert-Bourassa downstream	0.08 - 0.34	2.14	0.50	No	0.37 - 1.22	5.92	1.60 ⁵	Yes	0.55 - 1.47	2.43 ⁶	1.61	Yes				
Opinaca downstream	0.08 - 0.34	1.13	0.43 ²	Yes	0.37 - 1.22	3.15	2.09 ²	No	0.55 - 1.47	3.14	1.86 ²	Yes				
Caniapiscou downstream	0.15 - 0.41	0.52	0.27	Yes	0.59 - 1.28	2.74	1.08	Yes					0.52 - 1.11	2.81	0.98	Yes
Laforge 1 downstream	0.15 - 0.41	0.46	0.33	Yes	0.59 - 1.28	2.14	1.54	Yes					0.52 - 1.11			
Diversion Routes																
EOL	0.08 - 0.34	0.80	0.26 ³	Yes	0.37 - 1.22	4.62	3.23	No	0.55 - 1.47	3.17	2.11	No				
Reduced Flow Rivers																
Caniapiscou ¹	0.15 - 0.41	0.58	0.05 - 0.17 ⁴	Yes									0.52 - 1.11	1.54	0.46 - 0.72 ⁴	Yes

Note: Colors indicate consumption recommendations in number of meal per month and associated mercury concentrations:

	No restriction (12 or more)	≤ 0,29 mg/kg	1:	Data from 3 stations sampled at 100, 275 and 355 km from Caniapiscou reservoir.
	8	0,30 à 0,49 mg/kg	2:	Sampling in 2011.
	4	0,50 à 0,99 mg/kg	3:	Sampling in 2008.
	2	1,00 à 1,99 mg/kg	4:	Sampling in 1995. Range of values obtained at the 3 stations sampled.
	1	2,00 à 3,75 mg/kg	5:	Probable values as per the level obtained for 700-mm northern pike.
	<1	> 3,75 mg/kg	6:	Absence of data the peak year according to the results at a length of 400 mm.
			7:	Level obtained for 700-mm lake trout.
			n/a:	Not available, too much missing data in the time series.

- Map-type fish consumption guides were produced for the waterbodies of the La Grande Complex and of the Grande rivière de la Baleine, the Petite rivière de la Baleine and the Nottaway, Broadback and Rupert rivers regions, as well as a booklet-type guide : "The northern fish nutrition guide – La Grande complex";
- The development of two models to predict fish mercury levels in reservoirs enabled the improvement of impact prediction methods for future projects.

Phase II of La Grande Complex

The conditions related to mercury specified in the certificates of authorization for the construction of Phase II were also fully met by the monitoring and studies carried out by Hydro-Québec and its subsidiary SEBJ. These were:

- To monitor, from 1991 to 2000, mercury levels in fish in the La Grande Rivière, from the Robert-Bourassa reservoir to the shores of James Bay, for the La Grande-2A and La Grande-1 projects;



- To monitor, from 1993 to 1999, fish mercury levels along the Laforge diversion, to pursue the development of mercury modeling and to study the extent of mercury transfer downstream from the reservoirs, for the Laforge-1, Laforge-2 and Brisay projects.

Although its commitments with respect to mercury were fully met, Hydro-Québec recommended in 2002 that additional measurements be taken of mercury levels in piscivorous fish at the La Grande complex until their return to levels representative of natural lakes in the area. This activity was conducted mainly with a view to managing the potential health risk for fish consumers.

The additional monitoring campaigns carried out from 2003 to 2012 in all waterbodies modified by the development of the La Grande complex Phase I and II, as well as the production and distribution in 2013 of "The Northern Fish Nutrition Guide – James Bay Region", show that the objective of managing potential health risks for fish consumers was well met.

5. Recommendations

Considering the following reasons, it is not recommended to continue the monitoring of mercury levels in fish in the waterbodies modified by the La Grande complex Phase I and II:

- The conditions related to mercury specified in the construction certificates of authorization have been fully met;
- The objective of the additional monitoring campaigns carried out from 2003 to 2012, which was the management of the potential health risks for fish consumers, was achieved;
- The mean mercury levels obtained in lake whitefish, during the latest sampling campaigns, allow the same consumption recommendations as for natural lakes in the area;
- The mean mercury levels recorded during the latest sampling campaign in consumption-size northern pike caught in most reservoirs, immediately

downstream of most generating stations and in reduced flow rivers, allow as a whole a maximum of 2 to 4 meals per month, which corresponds to the recommendation applied to natural lakes in the area;

- The mean mercury levels measured during the latest sampling campaigns in consumption-size walleye and lake trout from most modified waterbodies, allow for a consumption of 2 to 4 meals per month, which correspond to that recommended for those caught in natural lakes in the area;
- The consumption recommendations applied are very safe, considering the built-in safety factor to make sure everybody is well protected. For example, the consumption recommendation for predatory fish from the Robert-Bourassa reservoir is 2 meals per month, but in fact, to reach the mercury level at which health symptoms may appear, most people would have to eat at least one meal per day, for a whole year.

It is also recommended that the monitoring of mercury levels in Lake Sakami fish be continued in conjunction with that of the waterbodies modified by the development of Phase III of the La Grande complex. In accordance with the certificates of authorization, this monitoring is scheduled to continue until mean mercury levels allow the same consumption rates as for those of natural lakes in the area, which means until their levels fall back below 0.5 mg/kg in non-piscivorous fish, and below 1.99 mg/kg in piscivorous fish.