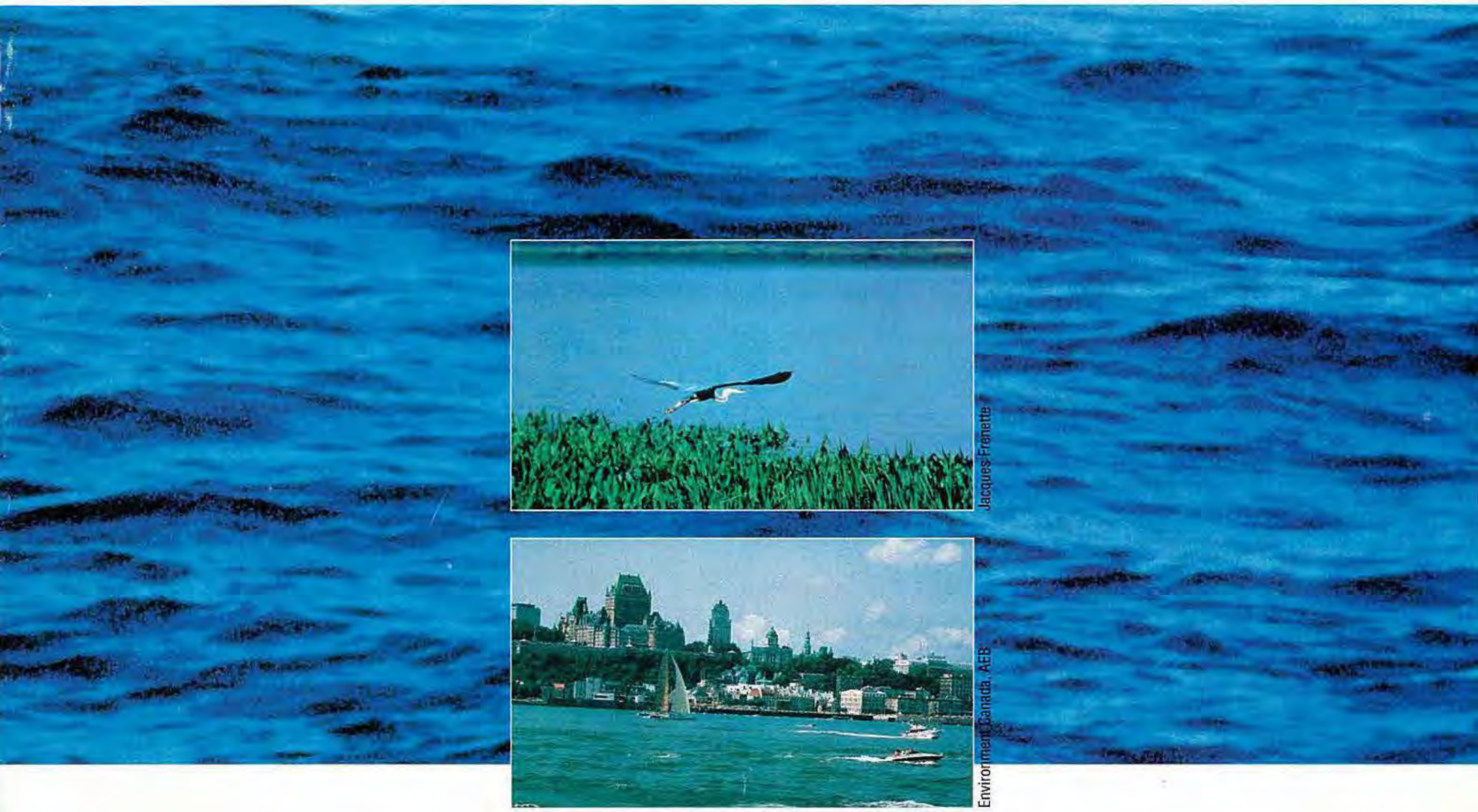
The St. Lawrence:
The Ever-Changing River



Jacques Frenette

Environment Canada, AEB

A River worth knowing

Do you know the St. Lawrence? Of course you do, since you are probably among the 80% of Quebecers who live in the St. Lawrence Plain. We are all familiar with the St. Lawrence; our poets have celebrated its majestic beauty, and marvelled at the force and destructive power of its rage. If you live along the Fluvial Section or in the Lower Estuary, you certainly know if the water that flows past your house is salty, or whether it ebbs and flows with the tide.

The St. Lawrence is, in fact, a unique and highly complex ecosystem, since it changes constantly throughout the length of its course.

Over the past few years, a number of researchers have enthusiastically studied this clay-footed colossus. Environmental concerns have also intensified interest and stimulated research, with the result that the St. Lawrence is giving up more and more of its secrets. We now have a better idea of the importance of hydrodynamic circulation, and its influence on the animal and plant life as well as the lives of shoreline residents. But in many ways, we are still just getting to know our mighty river.

Marcel Houle

Masses of water!

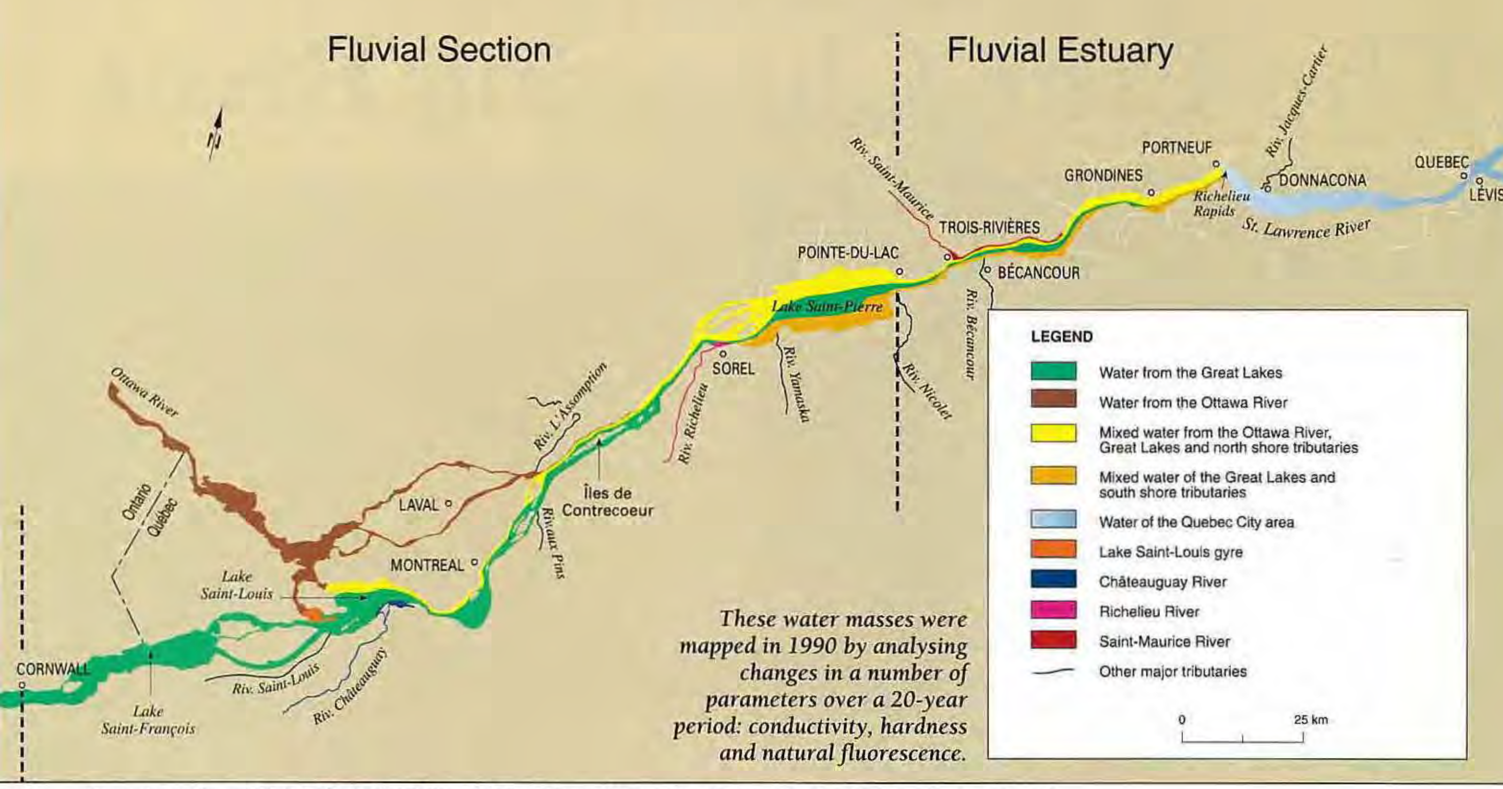
Any discussion of the water of the river involves specifying the particular water mass in question, since the composition of this water is not uniform. The river is made up of different water masses: adjoining fresh water segments upstream of Donnacona, followed by a mixing zone between Donnacona and Île d'Orléans. In the Upper Estuary, a mixing zone lies between the fresh and salt waters, followed by stratified water masses in the Lower Estuary and Gulf.

From Cornwall to Donnacona: Different water masses that remain distinct

From Cornwall to Donnacona, the waters of the St. Lawrence are fresh and always flowing towards the Gulf, or downstream. This stretch is characterized by alternating narrow stretches of rapids and wider, more shallow stretches known as riverine lakes: Lake Saint-François, Lake Saint-Louis and Lake Saint-Pierre. At the inlets to these lakes, current

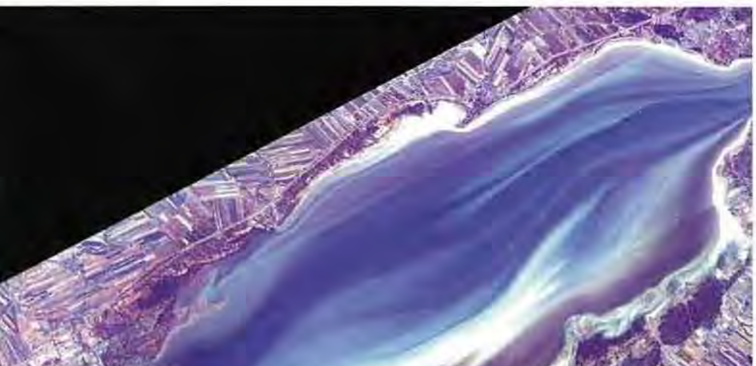
Environment Canada
Environnement Canada
Saint-Laurent Vision 2000
Québec Science

St. Lawrence water masses between Cornwall and Donnacona



These water masses were mapped in 1990 by analysing changes in a number of parameters over a 20-year period: conductivity, hardness and natural fluorescence.

Source: Lamarche, modified. 1992. *Quality of Water for Direct Human Consumption.* Environment Canada, Quebec Region, Montreal.



Remote sensing image showing the turbidity of water masses in Lake Saint-Pierre on October 20, 1990. The very turbid water (high suspended solids content) coming from some tributaries shows up white. The main water mass of the Great Lakes appears as dark blue, and the purple along the north shore is the Ottawa River water mass.

Source: Environment Canada, St. Lawrence Centre. 1990.

speed drops, except in the ship channel, favouring the deposition of suspended solids in certain parts of these lakes.

The tributary waters emptying into the river flow along the banks over sometimes long distances before mixing with the waters of the river. Upstream of Donnacona, located 40 km from Quebec City, the St. Lawrence contains four main water masses (see map above) and nine lesser water masses coming from its main tributaries. Among the main water masses are those of the Great Lakes (green waters) and the Ottawa River (brown waters).

The colours of the two main water masses are not indicative of pollution, but result instead from the natural characteristics of these waters. Brown waters simply have more suspended solids and dissolved organic carbon, which makes them cloudier and imparts a brownish hue.

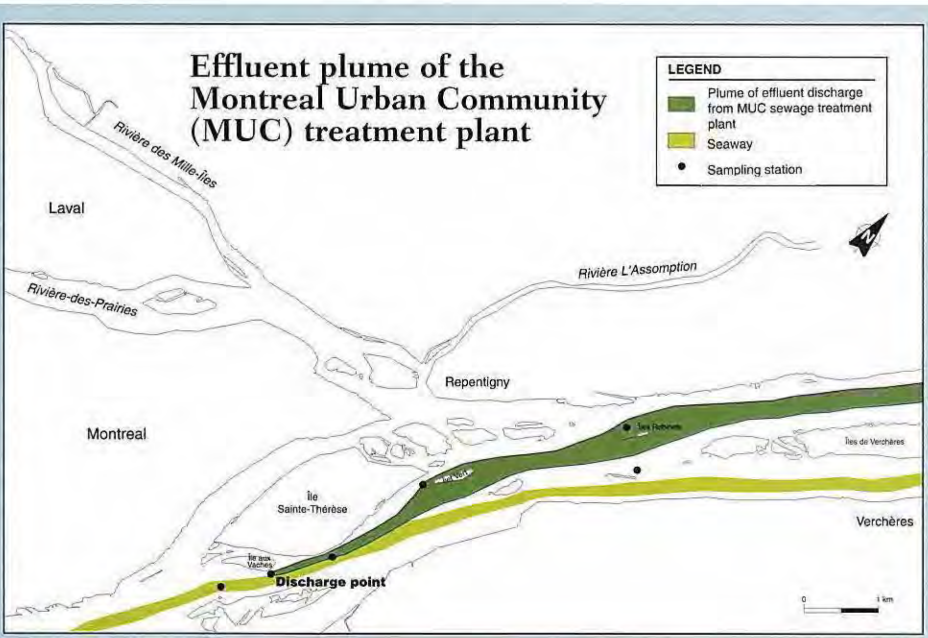
In certain parts, such as Lake Saint-Pierre, the river is very wide for its shallow depth. This physical particularity, and seasonal flow changes, allow the water mass of each river that feeds into it to remain distinctive. The impact of the flow of tributaries to the river is very small compared to the force of inertia and the river's great velocity, keeping the water from the tributaries flowing downstream along the banks. We can then see two different water masses flowing side by side over long distances before mixing completely with the water of the river. The location of water masses varies with the seasons, and their flow regime is subject to changes in discharge or level. In the spring, melting snow causes the water level in the river and its tributaries to rise, causing a sideways movement of water masses.

Certain human activities, such as the construction of a dam to supply water to the Beauharnois power station and construction of the St. Lawrence Seaway, have brought changes in the flow pattern of the St. Lawrence. Dredging of the Seaway, built between 1954 and 1959, contributed to an increase in the water volume in the ship channel and a reduction along the banks. At Montreal, nearly 90% of the river flows through this channel, and current speed is normally 2 to 3 m/s, whereas it

Tracking Pollution

Understanding the dispersal of pollutants in the river first requires an understanding of how water masses behave. The case of the effluent plume from the Montreal Urban Community (MUC) sewage treatment plant is a good example of this. For many years, the MUC has been studying the quality of the water surrounding Montreal Island, as well as analysing certain metals in the sewage plume from the treatment plant. The MUC and Environment Canada's St. Lawrence Centre have undertaken a joint project to determine the concentration and dilution of PCBs and PAHs along the effluent plume of the sewage treatment plant.

Following a physico-chemical treatment at the plant located in Rivière-des-Prairies, the treated water is piped to Île aux Vaches, where it is discharged into the river at a depth of 7 m. This plume mixes so gradually with the river water that it remains distinctive as far as 11 km downstream from its discharge point.

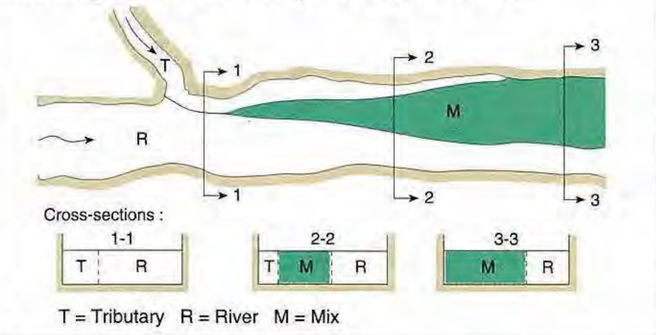


Source: Montreal Urban Community. 1994. 1994 sampling program. Ecology monitoring network. Service de l'Environnement, Direction de l'Assainissement de l'Air et de l'Eau.

"Based on weather conditions and the respective flows of the river and the effluent, the concentrated part of the plume might be found at varying depths, move towards the riverbanks and dilute more or less rapidly," explains Thao Pham, a biologist with Environment Canada. This is why physico-chemical measurements and measurements of contaminants at various depths are taken early in the season, inside and outside the plume, at increasing distances from the effluent. The vertical and horizontal distribution of the plume is checked by measuring the pH, conductivity, dissolved oxygen and turbidity using a multi-probe apparatus giving instantaneous readings. "With this instrument, we can find out right away if we are in the effluent plume," Ms Pham adds.

Despite its distinctive physico-chemical characteristics, the effluent can be seen with the naked eye for only 5 km downstream of the discharge point. Conductivity has proved to be a very efficient instantaneous tracer. Some substances contained in the wastewater, such as iron, increase its conductivity. The results of these measurements enable us to check for the presence of substances that are not completely removed by sewage treatment, as these substances might have a negative impact on the river environment for up to several kilometres downstream of the discharge point. The research project will end in 1996.

Mixing of a Tributary and the River



Source: From Frenette and Verrette, modified. 1976.

is only 0.05 to 0.2 m/s near the banks. Thus, a drop of water flowing through the channel takes about eight hours to cross Lake Saint-Pierre. Outside of this channel, it takes three days longer to cover the same distance. As a result, pollutants discharged near the river's edge tend to flow alongside the banks longer than those discharged into the central water mass.

A living river, a river that can overflow

Seasonal variations in the flow of the St. Lawrence are controlled in part by the International St. Lawrence River Board of Control, which regulates the inflow from the Great Lakes. The water level of Lake Ontario and the

Water Masses

A water mass is a volume of water that is distinguished by certain physico-chemical characteristics (salinity, conductivity, pH, hardness, colour, temperature, turbidity, suspended solids content). The physico-chemical signature of the water is determined by such things as the geology of the watershed in which the water mass originates. For example, the "green waters" from the Great Lakes are generally hard. They are thus very good conductors; that is, they are effective in transmitting electric current. They are also low in turbidity and nutrients. The "brown waters" from the rivers running over the rocks of the Canadian Shield tend to be relatively soft and highly turbid, and their conductivity is thus low. The identity of each water mass is also influenced by effluent from the various human activities in each watershed.

Stéphane Lorrain, SLC

Lake Saint-Louis. The lower right-hand corner shows Montreal Island.

Shoreline erosion

Phytoplankton: Another signature of water masses

The aquatic environment is home to phytoplankton – from the Greek, *phuton* (plant) and *plagktos* (drifting) – a basic link in the food chain. This group is made up of many hundreds of species of single-celled algae drifting with the current. The small size of these algae, their rapid reproduction rate (only a few days), and their phenomenal diversity make them ideal indicators for measuring the biological impact of pollutants discharged into the water.

Phytoplankton vary with natural factors such as water clarity, hardness and temperature. This explains why phytoplankton communities are different from one water mass to another. It is thus essential to distinguish variations induced by various pollutants from other factors of variation. The short-term impact of a pollutant on phytoplankton might result in a variation in overall abundance or in its ability to conduct photosynthesis, for example.

Environment Canada's St. Lawrence Centre has been conducting research in this area since the spring of 1994. The "field" of study was made up of ten stations located between Varennes and Repentigny. Water is sampled weekly for quality and to check for certain contaminants and phytoplankton.

The position of each station is fixed and generally corresponds to a zone of influence located upstream that can be identified by its chemical and biological signature: the Varennes Industrial Park, the Port of Montreal (industrial wastewater), the discharge from the MUC sewage treatment plant, Rivière-des-Prairies (farm runoff). Monitoring these stations in the coming years should allow us to measure the effects on phytoplankton of installing wastewater interceptors or changing farming practices.

quantity of water flowing towards Montreal are thus determined by criteria aimed, for example, at ensuring a minimum water level in the Port of Montreal, safe navigation and the elimination of extreme levels in Lake Ontario and in the St. Lawrence.

The mean annual flow of the river gradually increases from 7800 m^3/s at Cornwall to 11 500 m^3/s at Trois-Rivières. Around Montreal, the Great Lakes and the Ottawa River respectively contribute an average of 80% and 16% of the total flow of the St. Lawrence. During spring floods, however, the inflow from partially or unregulated tributaries may double the river's flow.

Variations in water levels also affect shoreline land use. While we may dream of a home near the St. Lawrence or on some other river, we must consider the protection of shoreline natural habitats and also the floods caused by high waters. To prevent damage due to flooding and stave off urban development in flood plains, the federal and provincial governments have jointly mapped and designated flood-prone areas. In these designated flood zones, no structure may be built without special permission.

Much depends on water levels

Water levels are important for many fish species, which find appropriate spawning areas in the lowlands on either side of the St. Lawrence and at the mouths of rivers flooded in the spring. Use of these locations as spawning grounds depends on a favourable combination of many physical factors including topography, vegetation, water temperature and the abundance of food. The size of these spawning grounds varies with the water level.

Maintenance of high water levels in the spring helps fish swim upstream to their spawning grounds and may even have positive effects on the annual production of certain species. This according to a study of Northern pike, which spawn in the Rivière aux Pins, whose mouth is located near Boucherville. This river is considered one of the best fish spawning grounds of the Montreal Archipelago: at least 16 of 44 fish species recently inventoried in the river spawn here.

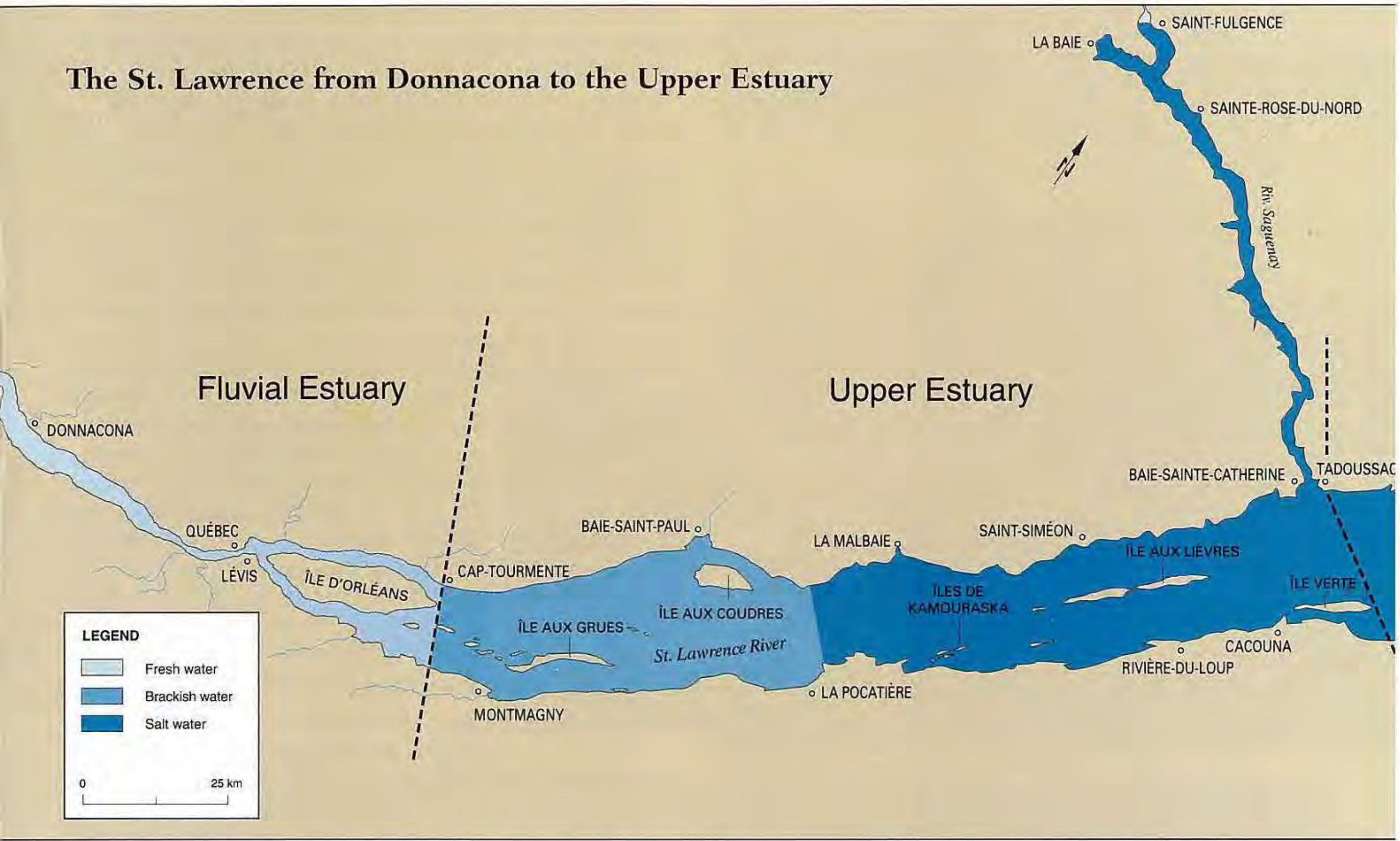
Powerful currents; habitats to protect

Moving water has tremendous power and its erosion-causing potential is great. The natural phenomenon of erosion depends on the hydrodynamic conditions of the waterway in question, shore topography (degree of slope, for example), the nature of the bottom and the vegetation covering it.

Over the past 30 years, bank erosion has become a problem on some islands due to a number of factors, including deforestation, and changes in wave and current patterns caused by rising water levels and a deepening of the ship channel. Between Montreal and Lake Saint-Pierre, nearly 50% of the 224 islands are affected to varying degrees by erosion, mainly due to the wave action generated by the passage of ships.

The effects of erosion can be attenuated by stabilizing banks. A project of this type was initiated in 1991 in the Contrecoeur Islands archipelago. This formation is made up of two chains of islands lying parallel to the shore (barrier islands and low-lying islands), between which vast aquatic plant communities and marshes have developed. The presence of barrier islands, located closer to the ship channel, protects the natural lower-lying islands closer to the south shore of the river from erosion. Erosion threatens to destroy these barrier islands, thus causing regression of the aquatic plant communities and marshes that are of recognized ecological importance.

Chipeau Island is one of these barrier islands. This artificial island was built up with dredged sediment from construction of the St. Lawrence



Seaway. A bank stabilization technique combining the use of wood caissons and transplanted vegetation produced mixed results. The following year, an improved version of the same technique was used at Île aux Corbeaux in the Berthier-Sorel archipelago with better results. The caisson structure and the network of plant roots are stabilizing the bank and cutting wave action.

From Donnacona to the Upper Estuary: Mixing the river

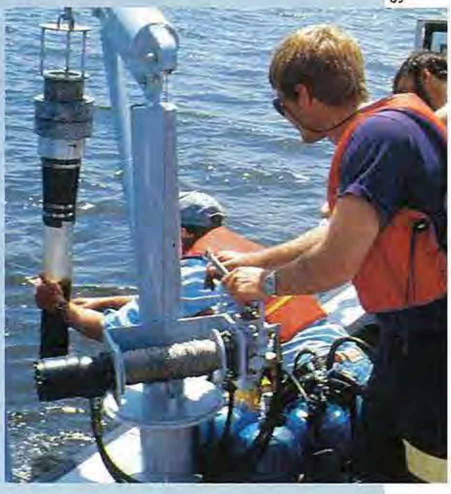
The river is transformed as it moves from Donnacona to the mouth of the Saguenay, widening rapidly downstream of Quebec City. From a width of 1 km at the Quebec Bridge, the river broadens to 15 km at the eastern tip of Île d'Orléans, and then to 20 km-wide upstream of Île aux Coudres. The bathymetry also changes quickly; many islands and shallows can be seen along the south shore downstream from Quebec City, while the river is deeper along the north shore. The mean annual flow at Quebec City is over 12 000 m³/s. The water is fresh up to the eastern tip of Île d'Orléans. The mixing zone between fresh and salt water, or brackish water zone, stretches from Île d'Orléans to the vicinity of La Pocatière (see map above). In this zone, the salinity of the surface water rises sharply from 0‰ to 20‰.

The tidal influence really begins at the outlet of Lake Saint-Pierre and increases in the Upper Estuary. Downstream of Portneuf, the movement is strong enough to change the direction of the current as the tide rises. Between Portneuf and Quebec City, the waters of the river's tributaries, previously distinctive, now begin to mix. A number of factors are responsible for this mixing: the high velocity of the river water, turbulence caused by passage of the Richelieu Rapids, and the effect of the tide and the current reversal on the depth of the entire river. The Great Lakes water

Understanding to act effectively

Understanding the behaviour of water masses and hydrodynamics in general is essential to the management of a number of activities. For example, a thorough understanding of hydrodynamics can:

- Help locate the zone of influence of a tributary and the wastewater it contains in the fluvial environment;
- Facilitate interpretation of water quality measurements taken in the field, although the analytic results of a water sample taken in an area strongly influenced by the passage of industrial wastewater should not be extended to the entire water mass;
- Guide a municipality in choosing a drinking water intake site;
- Permit intervention to protect wildlife where changes in the hydrodynamics of the river bring about changes to habitats;
- Help in the fight against pollution by supporting work to decrease pollution sources and mitigate negative effects on the environment. In the final analysis, this works to protect human health.



Stéphane Lorrain, SLC

Danielle Gingras

mass and that of the north shore tributaries-Ottawa River mix lose their specific identities just above the Jacques-Cartier River. From that point to Île d'Orléans, we find an almost homogeneous fresh water mass.

Downstream of Île d'Orléans, the mixing process begins anew. The complex process of water circulation in the Upper Estuary is linked to area bathymetry and to dynamic factors such as current type (surface, tidal, residual), swell, waves and drift ice. But tide is really the dominant force in this mixing process. The area of great turbidity between Île d'Orléans and Île aux Coudres is the result of these new hydrodynamic conditions which contribute to trapping suspended matter. Saline stratification begins to appear at different tidal phases: the fresh water spreads over the salt water, although not uniformly.

Around Quebec City, tidal action creates an alternate flow for the waters of the St. Lawrence. As the tide goes out, the flow is directed downstream, while it turns upstream as the tide rises. This movement governs the dispersal of pollutants discharged into the river at this point, and municipal or industrial sewage may thus flow past Quebec City two or three times before it all flows downstream.

Léo-Guy De Repentigny, CWS

Tidal support for Scirpus marshes

Water level variations caused by tides do influence the biological environment. As a result of the strong tides, large intertidal zones or flats (submergent at high tide and emergent at low tide) have developed in the Upper Estuary. These areas, normally called wetlands, are characterized by the degree of salinity of the water, variations in water level and the nature of the soil and vegetation. Scirpus marshes, for example, are found in fresh or brackish water areas subjected to the action of tides.

These rushes are the favoured food of the Greater snow goose. The Scirpus marsh is mainly concentrated at Cap Tourmente, a staging area for Greater snow geese in the Île d'Orléans channel, in the L'Île-aux-Grues archipelago and on the Montmagny flats. The Scirpus marsh vegetation stabilizes sediments during the summer and favours their deposition, thus forming a vast reservoir of nutrients for the benefit of both plants and geese.

The productivity of Scirpus marshes is closely linked to sediment transport. Tides, waves and ice, along with the cycle of the seasons, promote major sediment exchanges between the intertidal zones of the Upper Estuary and the main channel. The fine sediments accumulated off the northern channel at the end of winter are pushed by the tide toward the flats, particularly those of Cap Tourmente. These sediments are then trapped during the growing season. In the fall, when migrating Greater snow geese invade the Cap Tourmente flats to feed, they strip the marsh, causing the massive erosion of sediments accumulated during the summer. These sediments are then transported upstream with the rising tide and partially deposited in the north channel and north of Île d'Orléans, only to be brought back down to Cap Tourmente during the spring flood.

From the Lower Estuary to the Gulf: Worlds superimposed

From the Saguenay to Pointe-des-Monts, the waters of the St. Lawrence form the Lower Estuary. After Pointe-des-Monts is the Gulf, where the river becomes so wide you can no longer see across to the other side. In the Lower Estuary and Gulf, water circulation is distinguished by eddies, currents and upwellings of cold water. The stratification of the water is also evident.

Hydrodynamic modelling: Going with the flow

The currents of the Estuary and Gulf are very complex, as those who sail these waters well know. It is important to be able to predict the movement of surface waters so as, for example, to come to the assistance of a vessel adrift, protect sensitive areas from the effect of toxic products in the event of a spill or limit the areas to be searched for persons lost at sea.

This complex movement of waters constitutes a huge challenge to scientists developing hydrodynamic forecasting models. This is the case for researchers working on the physics of the marine environment at the Maurice Lamontagne Institute (MLI) of Fisheries and Oceans, who are developing a model for the St. Lawrence Estuary from Trois-Rivières to Anticosti Island.

Numerical modelling is a tool that enables us to summarize all the information needed to estimate how waters will move. This computer simulation draws upon a considerable amount of information such as bathymetry, the geographic boundaries of the study area, winds, precipitation, ice formation, air temperature, currents and salinity. The computer can simulate complex natural systems such as the ocean or the air and predict probable trends in these systems. We can thus predict the effect of tidal currents on the dispersal of oil spills in the St. Lawrence. Modelling, however, does not replace direct measurement. This information is thus augmented by observations made in the field which serve to verify the solutions developed by modelling.

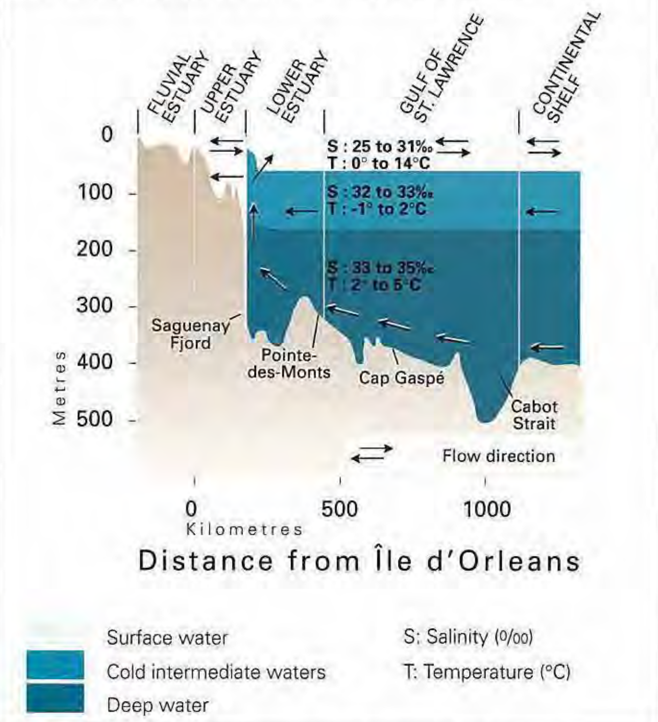
For example, when the Rio Orinoco went aground off Anticosti Island in October 1990, the MLI forecasting team went into action. The results of forecast calculations showed when leaking fuel from the tanker would reach Port-Menier Bay. In general, forecasting movements of oil from the Rio Orinoco was very successful; the contaminated beaches were all within the sectors identified by the forecasts.

In the Lower Estuary and Gulf, three water masses are superimposed due to their temperature and salinity. During the summer, we can distinguish relatively warm surface waters (0 to 14°C), cold intermediate waters (-1 to 2°C) and slightly warmer deep waters (2 to 5°C) fed by water from the Cabot Strait. From the surface layer to the deepest layer, the degree of salinity also increases. In the winter, the surface and intermediate layers become one as the surface layer is cooled by the cold winds. This new cold layer, which is about 60 to 200 m deep, covers an immense, relatively warm water mass 200- to 400 m-deep in the Gulf.

The Saguenay Fjord

Where the waters of the Saguenay Fjord meet those of the St. Lawrence, particular oceanographic phenomena occur. During the summer, the fresh, warm waters of the Saguenay (17°C in July) form a surface layer 20-m thick which floats over the deep, very cold (0 to 1.5°C) and very salty water of the fjord. At the mouth of the Saguenay, the presence of a shallow sill causes upwellings of deep water at each tidal cycle. The deep waters of the fjord are thus mixed and renewed by the cold, dense waters that flow into the fjord from the estuary. This deep, highly oxygenated layer is very rich in nutrients, thus encouraging the proliferation of a wide variety of organisms. Marine mammals frequent this area, since it abounds with the food they need. Zooplankton, the preferred food of Blue whales, is abundant, as are small fish such as Herring and Capelin, on which Beluga whales feed.

Stratification of St. Lawrence waters



Source: Adapted from Brunel. 1970. Les grandes divisions du Saint-Laurent: 3e commentaire. *Revue de Géographie de Montréal* 24(3): 291-294.

Water circulation: Many elements are involved

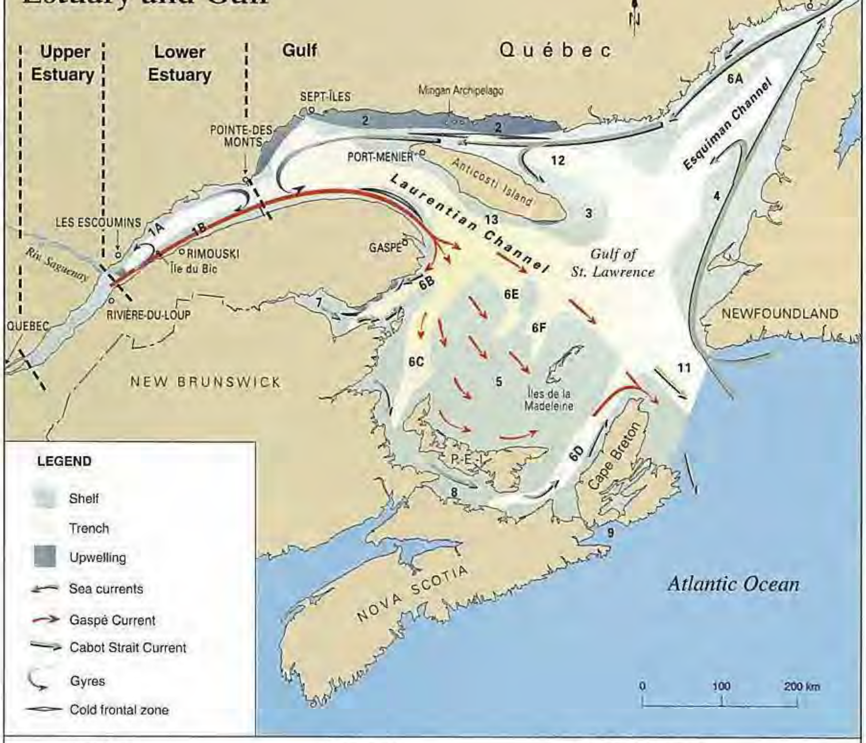
Many elements influence water circulation in the Lower Estuary and Gulf, including winds, atmospheric variations, tidal cycles, inflows of fresh water, mixing of waters, cold water upwellings, the effect of the earth's rotation, bottom topography and coastal relief.

In the Lower Estuary and Gulf, great transient eddies known as gyres are seen regularly between Pointe-des-Monts and the western tip of Anticosti Island, between Rimouski and Pointe-des-Monts, and between Les Escoumins and Rimouski. These gyres occasionally cause cross-currents heading northward in the area of Île du Bic and southward around Pointe-des-Monts.

The surface waters of the Gulf generally circulate in a counter-clockwise direction (see figure opposite). The Gaspé Current is a nutrient-rich surface current, about 40 to 50 m-deep. It follows the Gaspé peninsula and disperses eastward to form the Cabot Strait Current. This current, which heads towards the outside of the Gulf, occupies the entire southern section of the Cabot Strait to a depth of 250 m.

Less is known about circulation at greater depths; however, we do know that the prevailing westerly winds cause deep, cold water upwellings off Tadoussac, on the north shore of Chaleur Bay, south of Anticosti Island and around the Mingan Islands. These upwellings have major repercussions on surface water circulation. As well, the meeting of tidal currents and the topographical slope of the sea bottom in the Jacques-Cartier Strait off the Mingan Islands also bring cold water to the surface. These inflows of cold water result in the constant enrichment of surface waters in the nutrients necessary to the growth of certain marine organisms such as phytoplankton. ■

Currents and underwater relief of the Lower Estuary and Gulf



SHELVES		TRENCHES		BAYS AND STRAITS	
1A	Les Escoumins	6A	Mécatina	7	Chaleur Bay
1B	Gaspé	6B	Chaleur Bay	8	Northumberland Strait
2	Côte-Nord	6C	Shediac	9	Canso Strait
3	Anticosti	6D	Cape Breton	10	Strait of Belle Isle
4	Newfoundland	6E	Bradelle west	11	Cabot Strait
5	Îles de la Madeleine	6F	Bradelle east	12	Jacques-Cartier Strait
				13	Honguedo Strait

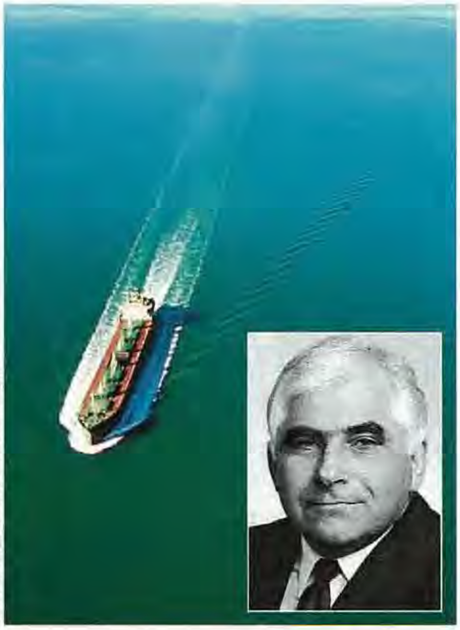
Source: St. Lawrence Centre and Laval University, modified. 1991. Environmental Atlas of the St. Lawrence - *A River, Estuaries and a Gulf: Broad Hydrographic Divisions of the St. Lawrence.* Environment Canada, Quebec Region, Montreal.

The St. Lawrence: A navigational obstacle course

A sound understanding of the hydrodynamic behaviour of the river is essential to navigation. Use of a river pilot is mandatory from Les Escoumins onward. Today, 190 pilots ply their trade on the river. Michel Pouliot, President of the Corporation of the Lower St. Lawrence Pilots, is one of them. A native of Île d'Orléans, Michel Pouliot has been a pilot for almost 30 years. On the eve of his retirement, his passion for the river remains intact.

Québec Science: What are the first things you do when you board a ship?

Michel Pouliot: We first have to check the condition of the ship, the quality of the equipment and crew, because these are both crucial to a successful trip. We also have to study weather conditions to be able to anticipate problems that might occur several hours in advance. With large tankers, we have to study the weather forecast even more closely.



Canadian Coast Guard, Laurentian Region

Q.S.: What are the main navigational problems encountered in the stretch between Les Escoumins and Île d'Orléans?

M.P.: There are strong currents and high tides. There are narrow stretches with many dangerous currents. In the summer, there is mist, while in winter there is snow and ice. Certain situations can surprise us, for example a gust of wind, fog, or an unexpected snowfall in difficult areas. All this makes the river harder to navigate. But we sailors learn to accept the fact that things happen when we least expect them. We're prepared for that.

Q.S.: Where do these problems occur?

M.P.: It starts at the entrance of the Saguenay. The current is very strong at that point, and it changes very quickly. It can vary from hour to hour because of the tides and the influence of the river water flowing into the St. Lawrence. This is also an area where there are long flats and reefs. In the summer, there is a lot of fog, and in the winter we get vapour caused by cold and snow. The ship channel also narrows because of the islands of the St. Lawrence, which are right in the middle of this section.

In the Île aux Coudres area, the currents are extremely strong. The ship channel is very narrow, and we have to pay close attention because of the abrupt changes in current. Then, after La Malbaie, the passage is very narrow and shallow. It had to be dredged to allow ships to pass at all times, but we still have to wait for high tide to go through with large oil tankers with their deep draft. At low tide, they wouldn't make it. We then have to get around the southern part of Île d'Orléans, which is also quite narrow.

Q.S.: You never take the south side of the river?

M.P.: We use it only when ships have to take on cargo at Cacouna. On the north shore, there is more water and more room.

Q.S.: What was your worst piloting experience on the river?

M.P.: It was about twenty years ago. Right after I boarded a ship at Les Escoumins, an engine broke down and the ship drifted for 12 hours in a violent northwesterly gale. There was no help anywhere nearby. The tide carried us to an area where we could clearly see the reefs. The vessel stopped just a few hundred feet from the reefs, near Tadoussac. It was a miracle we didn't hit them.

Q.S.: What is your happiest memory?

M.P.: Oh, I have lots of them, I really have been lucky. Piloting the Queen Elizabeth II the first time she called at Quebec City in 1981 is one of my fondest memories. I had read all the history of the different captains of the Queen Elizabeth and the Queen Mary, and so I was very moved to be standing on the bridge of the Queen Elizabeth as she left Quebec. ■

St. Lawrence UPDATE

This fact sheet was prepared as part of the environmental reporting activities on the state of the St. Lawrence River, and was produced by the St. Lawrence Centre of Environment Canada in cooperation with *Québec Science*.

Concept and Research
Danielle Gingras, St. Lawrence Centre

Graphic Design
Normand Bastien

Writing
Hélène Perrault and Danielle Gingras

Production
Québec Science – St. Lawrence Centre

The first edition of this report appeared as a supplement to *Québec Science* magazine, Volume 33, No. 6, March 1995.

For more information, please contact the St. Lawrence Centre, Conservation Branch, Environment Canada, 105 McGill Street, 4th Floor, Montreal, Quebec H2Y 2E7.
Tel: (514) 283-7000.

Printed on recycled paper with non-toxic inks.
Published by Authority of the Minister of the Environment

Cat. No.: En40-213/8-1995E
ISSN 1180-1204
ISBN 0-662-23019-1
Aussi disponible en français sous le titre :
Le Saint-Laurent : Un fleuve en mouveme

References

Argus Groupe Conseil Inc. 1991. *L'érosion des îles du Saint-Laurent - tronçon Montréal -lac Saint-Pierre.* Prepared for the Canadian Wildlife Service, the Canadian Coast Guard and the St. Lawrence Centre.

D'Anglejan, B.F. 1990. *Recent sediments and sediment transport processes in the St. Lawrence Estuary.* Oceanography of a Large-Scale Estuarine System. The St. Lawrence Coastal and Estuarine Studies. Springer-Verlag, Berlin, 39:109-129.

El-Sabh, M.I., E. Bourget, J.M. Bewers and J.-C. Dionne. 1979. *L'Océanographie de l'estuaire du Saint-Laurent.* Collected papers. *Naturaliste canadien* 106 (1).

Frenette, M., and J.-L. Verrette. 1976. Environnement physique et dynamique du fleuve Saint-Laurent. *L'Ingénieur*, March-April:13-24.

Lefaivre, D. 1992. *Post-mortem de l'incident du Rio-Orinoco.* Canadian Coast Guard, Emergency at sea, internal report. pp. 73-75.

Massé, G., R. Fortin, P. Dumont, and J. Ferraris. 1988. *Étude et aménagement de la frayère multispécifique de la rivière aux Pins et dynamique de la population de Grand Brochet, Esox lucius L., du fleuve Saint-Laurent, Boucherville, Québec.* Ministère du Loisir, de la Chasse et de la Pêche, Service de l'aménagement et de l'exploitation de la faune, Montreal. Tech. Rep. 06-40.

Saucier, F. 1994. L'océanographie physique du Saint-Laurent et de la baie d'Hudson simulée par ordinateur. *L'Euskarien* 16(1):37-41.

Savard, M. 1989. *Pour que demain soit - L'état de l'environnement au Saguenay–Lac-Saint-Jean, pour un développement durable.* Editions JCL Inc.

Verrette, J.-L. 1990. *Délimitation des principales masses d'eau du Saint-Laurent (Beauharnois à Québec).* Les Consultants Hydriques for Environment Canada, Conservation and Protection, Quebec Region, St. Lawrence Centre, Montreal.