SCIENTIFIC AND TECHNICAL REPORT

THE ENVIRONMENTAL RISKS AND IMPACTS OF NAVIGATION ON THE ST. LAWRENCE RIVER

Report ST-188E

The Environmental Risks and Impacts of Navigation on the St. Lawrence River

Serge Villeneuve and Louise Quilliam
State of the St. Lawrence Environment

St. Lawrence Centre
Environmental Conservation
Environment Canada – Quebec Region

August 2000

NOTICE TO READERS

Please direct any comments you have on the contents of this report to the St. Lawrence Centre, Environmental Conservation, Environment Canada – Quebec Region, 105 McGill Street, 7th Floor, Montreal, Quebec, H2Y 2E7.

Correct citation for this publication:
Villeneuve, S., and L. Quilliam. 2000. *The Environmental Risks and Impacts of Navigation on the St. Lawrence River*. Scientific and Technical Report ST-188E. Environment Canada – Quebec Region, Environmental Conservation, St. Lawrence Centre. 153 pages.

Catalogue No. En153-109/1999E
ISBN 0-662-28969-2

Management Perspective

The St. Lawrence Vision 2000 Action Plan carries on the work begun in 1988 by the governments of Canada and Quebec to conserve and protect the St. Lawrence River, with the ultimate goal of reclaiming its use for the population. One of the objectives of the "Decision Support" area of action is to enhance the current knowledge base on the St. Lawrence River and to share this information with decision makers and the general public.

Accordingly, the main objective of this report is to describe and analyse an environmental issue relating to the St. Lawrence River, from a decision-support standpoint and for an informed readership.

The results presented here stem from an analysis based on a "Pressure-State-Response" framework. This approach has been applied in an effort to identify causal links among the pressures exerted on the St. Lawrence by natural disasters and human activities, the state of the river environment and its resources, and existing response mechanisms — that is, the decisions made and measures taken to remedy the problems.

The report covers the Quebec portion of the St. Lawrence River from Cornwall, Ontario to Blanc-Sablon, Quebec, on the north shore and the Gaspé on the south shore, as well as the Magdalen Islands.

Perspective de gestion

Le plan d'action Saint-Laurent Vision 2000 poursuit les efforts amorcés en 1988 par les gouvernements fédéral et provincial pour conserver et protéger le Saint-Laurent afin d'en redonner l'usage à la population. L'un des objectifs du domaine d'intervention « Aide à la prise de décision » consiste à enrichir les connaissances sur le Saint-Laurent et à transmettre cette information aux décideurs et au grand public.

C'est dans ce contexte que s'inscrit ce rapport dont le principal objectif consiste à décrire et analyser un enjeu environnemental lié au Saint-Laurent dans une perspective d'aide à la prise de décision et qui s'adresse à une clientèle avertie.

Le rapport présente les résultats de leur analyse en fonction d'une approche Pression-État-Réponse qui vise à établir des liens de causalité entre les pressions exercées par les catastrophes naturelles et les activités humaines sur le Saint-Laurent, l'état des milieux et des ressources et les réponses existantes, c'est-à-dire les décisions et les mesures adoptées pour y remédier.

Le présent rapport couvre la portion québécoise du Saint-Laurent comprise entre Cornwall et Blanc-Sablon sur la rive nord, Gaspé sur la rive sud et les îles de la Madeleine.

Production Team

Research and Writing	Serge Villeneuve and Louise Quilliam Environment Canada
Editing	Patricia Potvin Environment Canada
Translation	Public Works and Government Services Canada
Map Production	François Boudreault Environment Canada

Contributors

Department of Fisheries and Oceans Canada

Maurice Lamontagne Institute	Michel Gilbert
Canadian Coast Guard	Laurence Mazaudier, Gervais Bouchard, Pierre Cloutier, Francine Richard, Pierre Rouleau, D'Arcy McKenny
St. Lawrence Centre	Brigitte Cusson Jean-François Bibeault

Table of Contents

List of Figures

List of Tables

1 Introduction

With the publication of the United Nations (UN) report on sustainable development (better known as *Our Common Future* or The Bruntland Report) and follow-up at the international summits of Rio de Janeiro (1992) and Kyoto (1997), the significant environmental impacts of the transportation industry worldwide became recognized. Transportation is responsible for a major share of energy consumption, greenhouse gas emissions (carbon monoxide, carbon dioxide and methane) and other polluting emissions, particularly nitrogen oxides, polycyclic aromatic hydrocarbons (PAHs) and sulphur dioxide (TRB 1997). The environmental performance of highway, rail, air and waterborne transportation differs substantially in certain respects. This study will not focus on the environmental benefits of one mode of transportation over another, but rather on the key environmental impacts associated with commercial shipping and pleasure boating.

The St. Lawrence River has been a central element in the social and economic development of Quebec and northeastern North America, and continues to play a major role today, providing passage for more than 100 million tonnes of waterborne cargo every year (CCG 1997). Pleasure boating activities are also important because they offer the opportunity for more immediate contact with the river and its resources.

Despite the existence of protective measures, navigation continues to be a source of pressure on the St. Lawrence River ecosystem, and the resulting impacts may have significant social costs. It is therefore critical that ways be found to alleviate the pressures considered of greatest concern by implementing pertinent (societal response) measures to protect the environment and prevent pollution.

Navigation, one of the formative elements in the river's development, exerts many pressures on the St. Lawrence River ecosystem. Construction of the St. Lawrence Seaway significantly changed the river's hydrodynamics and destroyed or altered benthic and riparian habitats. (The effects of channel building in the river between Montreal and Quebec City on the river's hydrodynamics have not been studied). The development of port infrastructure has contributed to the creation of artificial (i.e. built-up) shorelines. In addition, ship channel and port facility maintenance requires the annual dredging of several hundred thousand cubic metres of sediment. These activities may have an impact on the dredging sites themselves as well as on the disposal sites. Through the flushing of ballast water, non-native species have been introduced into the Great Lakes–St. Lawrence watershed. Some of these species, such as the Zebra Mussel, have had significant effects on the ecology of river and lake habitats, making it very expensive to maintain municipal and industrial water intakes (Gauthier and Steel, 1996). The high volume of ship traffic and the transport of dangerous goods, including several million tonnes of hydrocarbons, are also a potential source of environmental degradation in both port areas and throughout the St. Lawrence. Vessel movements (commercial ships and pleasure craft) can contribute to shoreline erosion and hence to the loss of productive habitats, as well as disturbing certain animal species. Biocides such as the tributyltins contained in the antifouling paints used on boat hulls present a risk of contamination for some organisms.

The issue of navigation-generated waste and its management has scarcely been studied, although the waste may be an insidious source of contamination and disturbance for aquatic and marine organisms. In light of the diversity and magnitude of the environmental disturbances generated by all these pressure sources and the often irreversible character of environmental change, there is a clear need to study the impact of navigation-related environmental impacts. A better understanding of the nature and extent of the pressures exerted by past and present activities, their effects on the ecosystem and the societal responses that have been implemented will help improve decision making related to managing the vital natural heritage of the St. Lawrence River.

As its overall objective, this report will look at the pressure, state and response factors associated with navigation on the St. Lawrence River and the relationships between them. This overall objective may be broken down into several specific objectives, as follows:

- Determine the nature and scope of the main pressures exerted by navigational activities on the St. Lawrence River.
- Assess the effects of navigation on natural habitats, resources and uses of the river.
- Identify and assess, from an environmental perspective, the regulatory and voluntary measures implemented to eliminate or minimize the effects of the different pressures.
- Assess the value of knowledge and information on the above aspects.

- Identify possible actions to minimize effects on the environment and reduce navigation-related risks along the St. Lawrence River, in keeping with the principle of sustainable development.

Chapter 2 provides basic information on navigation on the St. Lawrence River and the "Pressure-State-Response" framework used to analyse the information.

Specific problems related to the issue of navigation are dealt with in Chapter 3, and Chapter 4 sets out conclusions and possible avenues for improving decision making. The problem of the uncertainty surrounding the various issues and the remaining knowledge gaps is also covered in this final chapter.

2 General Information

2.1 COMMERCIAL NAVIGATION

2.1.1 Development of the ship channel[1]

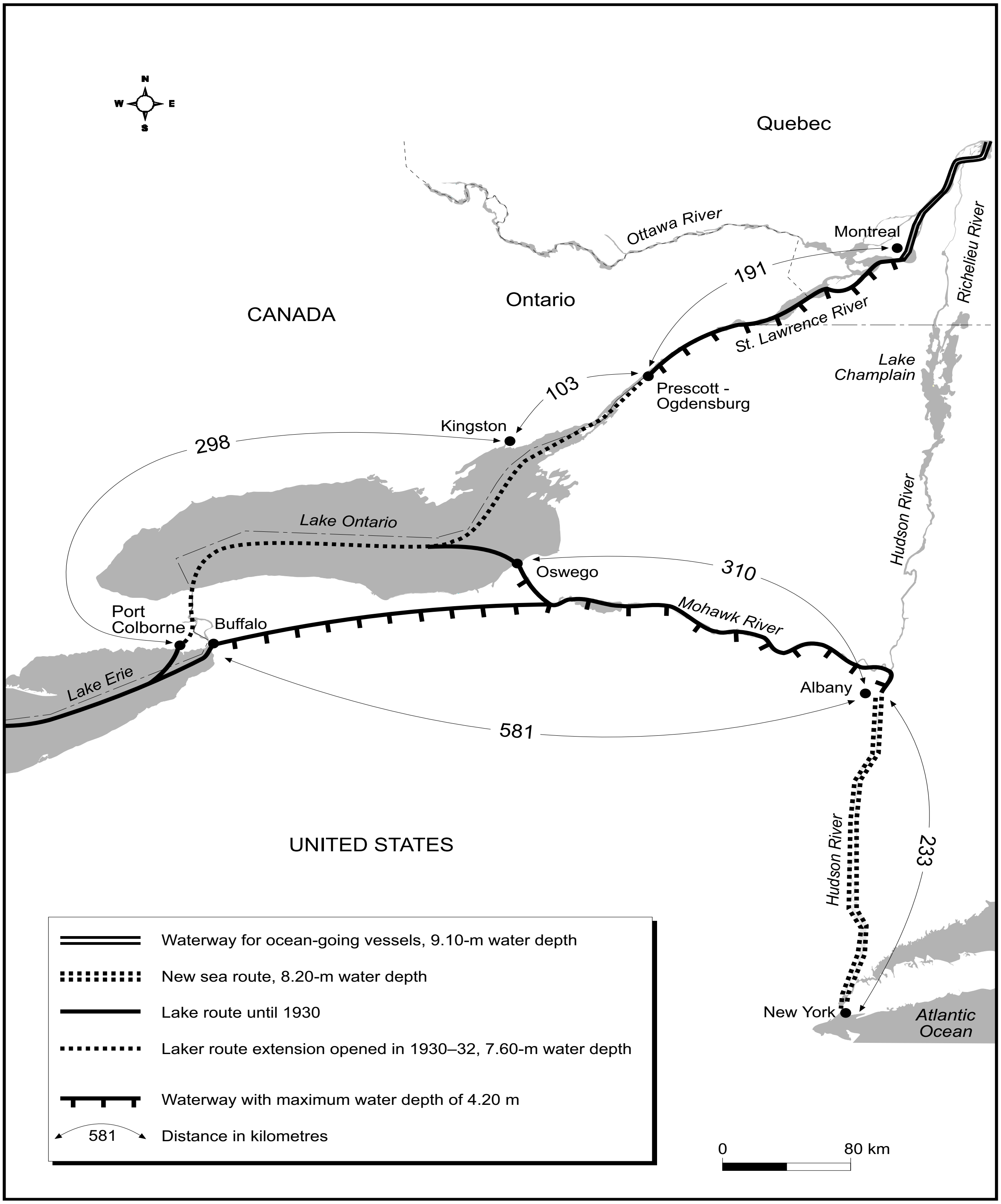
The relatively late development of a seaway system under American and Canadian jurisdiction between the Great Lakes and the St. Lawrence River clearly reflects the divergent political and economic interests of the two partners and the different perspectives on development of the provinces of Upper Canada and Lower Canada (Sussman 1978, Lasserre 1980). In addition, an extensive industrial infrastructure and shipping fleet developed in the Great Lakes region despite the non-existence of a shipping channel in the Upper St. Lawrence. Before the St. Lawrence River was even promoted as an access route to the sea from the Great Lakes, the Erie Canal (linking Lake Erie to the Hudson River) had been built in the United States and the Rideau Canada (linking Lake Ontario to the Ottawa River) had been built in Canada (Lasserre 1980).

In early colonial days, ocean-going vessels sailed up the St. Lawrence River as far as Quebec City. A river fleet (wooden canoes, sailboats, longboats and barges) took over from there and provided transportation as far as Montreal. From Montreal, only birch bark canoes were used for travel upstream to the Great Lakes (Lasserre 1980). The very first project to improve transportation on the St. Lawrence River was started in 1700 by the Father Superior of the Sulpician Order. The project, consisting of a channel 1.6 km long, 3.6 m wide and 0.45 m deep for circumventing the Lachine Rapids, was never completed (Sussman 1978). In 1783, the British Army built four small bypass canals (510 m) with locks between lakes Saint-François and Saint-Louis (Lasserre 1980). The Lachine Canal, completed in 1825, was 13.6 km long and 1.5 m deep. Its six locks, measuring 30 m long and 6 m wide, raised or lowered the water level by 13.5 m (Lasserre 1980). Until the completion of a deep-water channel between Lake Ontario and Montreal in 1959, many projects were undertaken upstream and downstream from this section of the river to permit the passage of increasingly larger vessels.

[1] The term *ship channel* refers to the waterway below Montreal; the term *seaway* applies to the waterway above Montreal.

For a long time, the section between Prescott–Ogdensburg, Ontario (upstream limit of the International Rapids) and Montreal was a bottleneck in the waterway between the Great Lakes and the St. Lawrence Estuary (Figure 1). The 65-m drop in elevation represented both a serious obstacle to navigation and a vast potential source of hydro-electric power, located close to a heavily industrialized region. There were rapids in three places along this section of the river. At the upstream end, there was the International Rapids section (with rapids at Galop Island, at the site of the former Rapide Plat Canal and at Farran Point and Long Sault), which extended over 60 km with a drop in elevation of 25 m. Further downstream, there was the Soulanges Rapids section (Coteau Rapids, Cedar Rapids, Split Rock Rapids and Cascades Rapids) between lakes Saint-François and Saint-Louis, which extended over 29 km with a drop in elevation of 25 m. Finally, near Montreal, there was the Lachine Rapids section with a drop in elevation of 12 m. The remaining three-metre drop in level occurs in St. Mary's Current at the outlet of the La Prairie Basin (Lasserre 1980, Morin et al. 1994). From Montreal, the St. Lawrence River flows seaward over a declining slope to the Portneuf Rapids, which mark the lowest point in the river's downstream elevation (Couillard 1987). In 1848, bypass canals (Lachine, Beauharnois and Cornwall) equipped with locks ensured a minimum water depth of 2.7 m for shipping; this depth was increased to 4.2 m in 1904 when the Soulanges Canal was built on the north bank of the St. Lawrence River. At the time, vessels had 24 or 25 locks to pass through (depending on whether they were moving upstream or downstream) in this section of the St. Lawrence Seaway. Although the laker route was extended in 1932 to the Thousand Islands section — that is, from Kingston to Prescott–Ogdensburg (with a water depth of 7.6 m) — it was not until major construction was undertaken between 1954 and 1959 that Lake Ontario and Montreal were finally linked by a channel with a minimum water depth of 8.2 m.

Construction of these navigation facilities began at the same time as the building of major hydro-electric infrastructure (see Section 2.1.2). Damming of the waters has turned this portion of the 294-km-long St. Lawrence Seaway into a waterway with only seven locks (two in the Lesser La Prairie Basin, two in Beauharnois, two at Barnhart Island, and one at Iroquois) and 50 km of canals (Lasserre 1980).



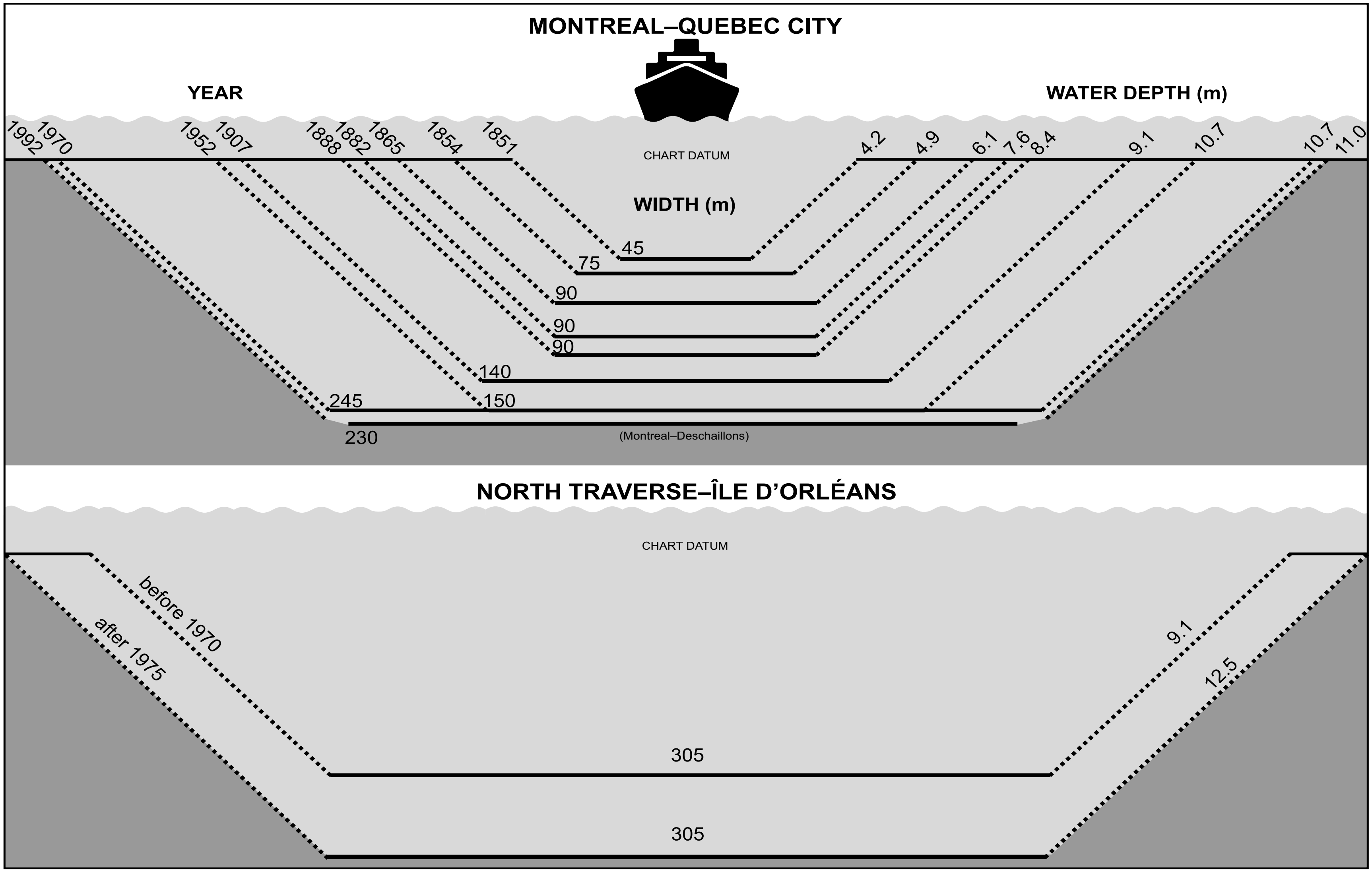
Source: Based on data from Lasserre 1980.

Figure 1 Facilities built to overcome navigational bottlenecks between the Great Lakes and marine ports, 1930–32

Figure 2 profiles ship-channel development between the Cap Tourmente area and Montreal between 1851 and 1992. Prior to 1912, the South Channel was used to reach Île d'Orléans. However, in 1912, the North Traverse channel, with a depth of 9.1 m and width of 183 m was opened. In the following decades, the channel was widened to 305 m. From 1971 to 1974, large-scale dredging operations were undertaken to provide a depth of 12.5 m over 32 km. As a result of this dredging work and other dredging off Saint-Pétronille, the Port of Quebec can now accommodate 15-m-draft vessels by taking advantage of favourable tides (Procéan et al. 1996).

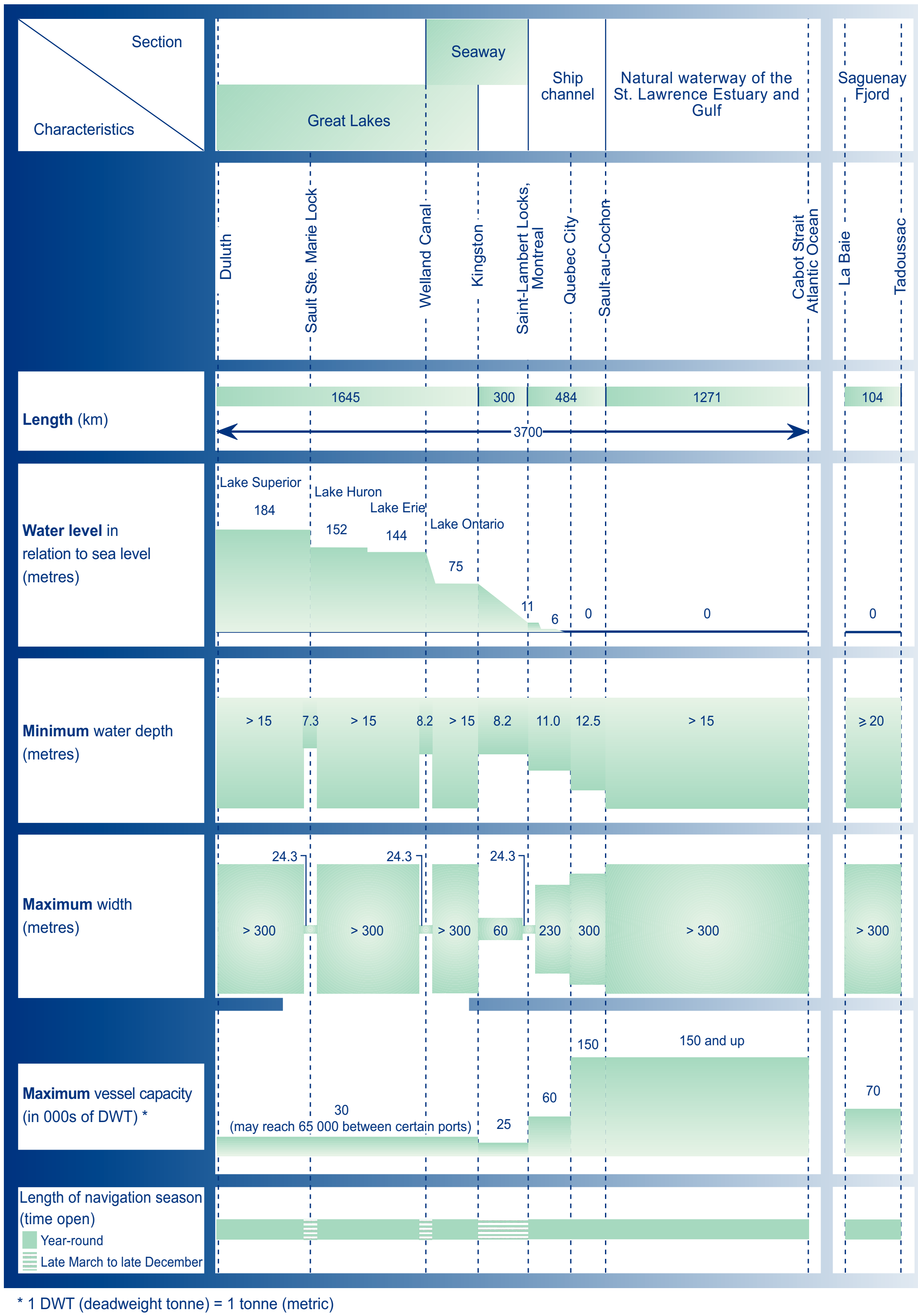
The first dredging work between Montreal and Quebec City (1844–1851) deepened the channel in Lake Saint-Pierre from 3 m to 4.2 m over an area 45 m wide to provide a uniform navigational draft as far as Montreal (Lasserre 1980). In subsequent dredging projects (1854, 1865, 1882 and 1888), the ship channel was further deepened to 8.4 m and widened to 90 m (Figure 2). Almost 60 years after the first dredging operations were carried out, ocean-going vessels could travel as far upstream as Montreal in a channel 9.1 m deep and 140 m wide. After 1907, the increasingly deeper draft requirements of ocean-going vessels made additional dredging work necessary; in 1970 the channel was 10.7 m deep and 245 m wide in the straight sections and 457 m wide in the curved sections. By 1992, the channel had been deepened to 11 m and widened to 230 m in the area upstream from the tide water section, i.e. between Deschaillons and Montreal. Despite a water depth of 10.7 m below chart datum in the section downstream from Deschaillons, ships can navigate in water 11.3 m deep by taking advantage of favourable water levels generated by the tides (SLC 1996a). In fall 1998, the Port of Montreal Corporation (PMC) began a project to dredge 48 shoals between Montreal and Cap à la Roche to provide a minimum water depth of 11.3 m along the entire length of the ship channel.

Figure 3 shows the principal characteristics of the waterway between the Great Lakes and the Gulf of St. Lawrence.



Source: Based on data from CCG 1994, Lasserre 1980.

Figure 2 Changes in St. Lawrence River ship channel clearances between Montreal and Sault-au-Cochon from 1851 to 1992



Source: Adapted from SLC and Laval University 1991.

Figure 3 Characteristics of the St. Lawrence River–Great Lakes Waterway

2.1.1.1 *Ship channel route*

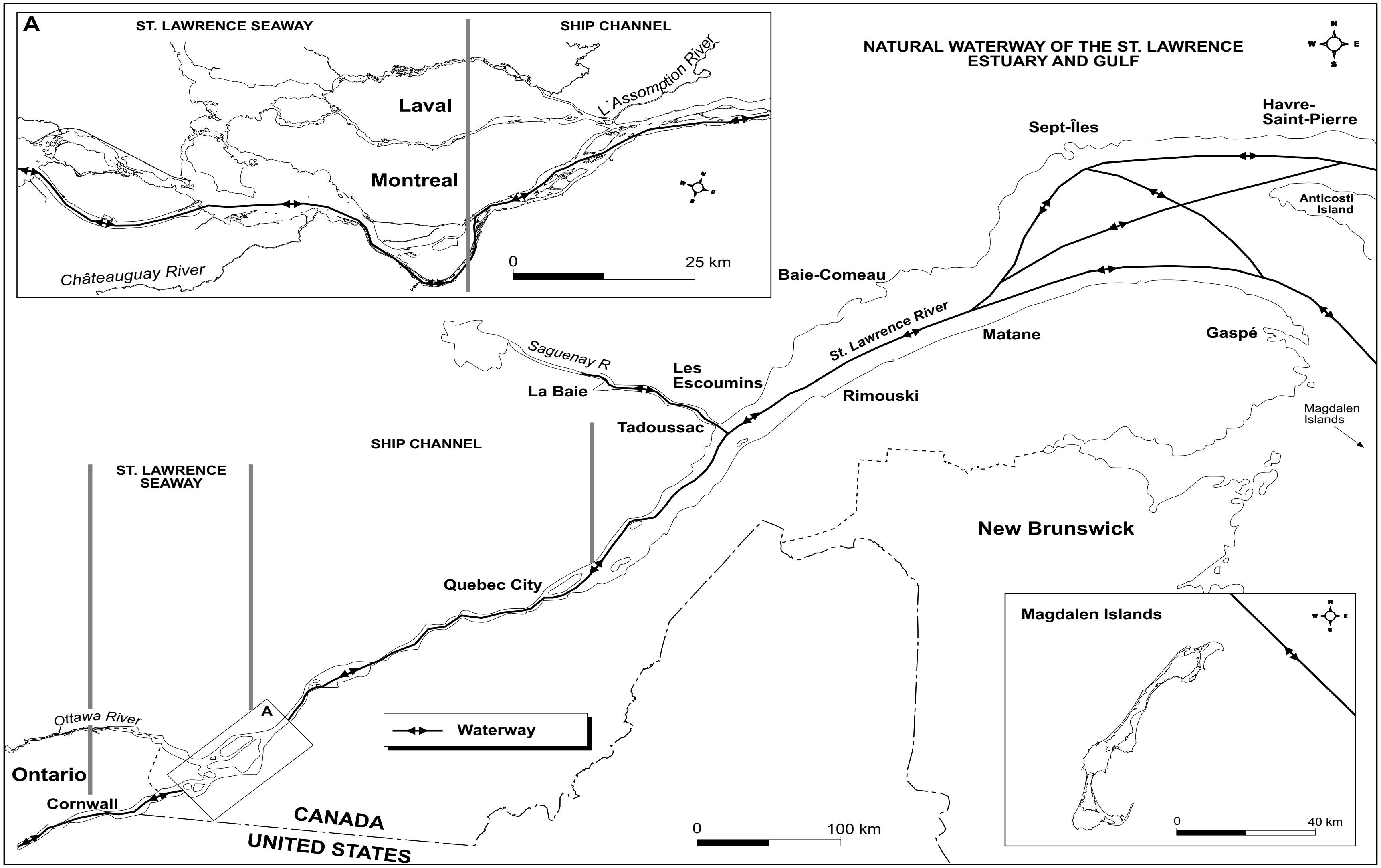
The Quebec portion of the St. Lawrence ship channel is divided into four sections (Figure 4):

- A deep natural seaway between the Gulf of St. Lawrence and Pointe d'Alliance (near Cap Tourmente).
- A ship channel from Pointe d'Alliance to Montreal consisting of dug channels linking natural basins.
- The St. Lawrence Seaway from Saint-Lambert to Cornwall (and beyond) consisting of canals, dredged channels and seven locks.
- The Saguenay Fjord, whose channel consists of a natural channel from the river mouth to La Baie and a dug channel along its upper reaches as far as Chicoutimi.

2.1.2 Concurrent harnessing of Upper St. Lawrence River hydro-electric power potential

As electricity became a vital new energy source in the late 19th century, the hydro-electric power potential of the St. Lawrence River quickly caught the attention of powerful financial interests. In 1920, it was estimated that about $1.5 billion was required to develop the river's hydro-electric potential between the International Rapids and Montreal, and a group of private-sector entrepreneurs was already prepared to invest 90% of this sum (Lasserre 1980).

Lasserre, the author of an in-depth study of waterborne transportation on the St. Lawrence River (1980), explains the series of protracted, intermittent negotiations between the United States and Canada that led to the development of a Great Lakes link to the sea via the St. Lawrence River. He clearly demonstrates that the construction of a deep-water channel between Lake Ontario and Montreal would not have come about if the vast hydro-electric power potential of the International Rapids had not been developed at the same time (Lasserre 1980). Both the energy industry and the marine transportation industry have therefore contributed to the extensive changes to the river ecosystem in this section of the St. Lawrence.



Source: Based on data from SLC and Laval University 1991.

Figure 4 St. Lawrence waterway between Cornwall and the Gulf of St. Lawrence

The first canal infrastructure built between Salaberry Island and the south shore of the St. Lawrence in 1854 soon had to be replaced, starting in 1895, with more efficient facilities, which still only partially harnessed the waterway. Three types of hydro-electric power plants were built: canal power plants (Soulanges and Cornwall), river bypass power plants (Beauharnois), and power plants partially harnessing the rapids (Lachine and Les Cèdres) (Lasserre 1980).

When the Beauharnois power plant was built between 1932 and 1961 to take advantage of the drop in elevation between lakes Saint-François and Saint-Louis, it was by far the most large-scale project undertaken during that period on the St. Lawrence River. The plant's headrace, measuring 21 km long, 1 km wide and 9 m deep, received almost all of the river's discharge, except for about 1300 m^3/s of flow channeled over the river's residual bed. In addition to dams, many dikes were built to maintain water levels or channel water flow, such as the structures between Coteau-du-Lac and Salaberry Island. Power generated at the Beauharnois power plant increased during this period from 400 000 to 2 161 000 horsepower (Lasserre 1980).

Mammoth changes also took place in the International Rapids section (Iroquois to Cornwall). By the time the work ended in 1959, 259 km^2 of rapids had been submerged. On the Canadian side, seven villages were wiped off the map and 6500 residents had to be relocated (Lasserre 1980). The Iroquois Dam (one lock) now controlled the water level of Lake Ontario and the newly-created Lake St. Lawrence extended to the two locks at the Moses Saunders Dam (Cornwall). The Coteau works and the Beauharnois Dam (two locks), initially built to raise the water level of Lake Saint-François, controlled the level of this lake, and the South Shore Canal (26 km, two locks) emptied into the ship channel near the Port of Montreal.

These vast work sites employed 22 000 workers at the peak of construction in 1957, with 10 000 working on the St. Lawrence Seaway and 12 000 on various hydro-electric power facilities. These numbers do not include workers involved in the third phase of construction of the Beauharnois power plant project (1956–61). The cost of the projects exceeded $1 billion, with $431 million going solely towards construction of the St. Lawrence Seaway. Canal building in this section of the Seaway proper required the dry excavation or dredging of 86 589 000 m^3 of material. Another 75 448 000 m^3 of material had to be excavated to permit the harnessing of hydro-electric power in the International Rapids section, and 191 000 000 m^3 to build the

Beauharnois headrace. To illustrate the scale of these projects, the amount of material excavated exceeded by 15% the amount excavated during construction of the Panama Canal (Lasserre 1980).

2.1.3 The St. Lawrence waterway in the North American trade context

Most of the following information is taken from Lasserre's study (1997) of issues facing the Great Lakes–St. Lawrence Waterway. This system, one of the main gateways to the North American continent since the early days of European colonization, has a deep-draft channel extending 3700 km, with only 15 locks to negotiate for vessels heading to Chicago and 16 locks for those heading to Thunder Bay at the northern tip of Lake Superior. It gives access to one of the largest industrial regions in North America. Three-quarters of Canada's industrial plants and close to half of the United States' plants (46%) are located in the Great Lakes Basin (Great Lakes Foundation 1992). Lasserre says in his study (1997) that he believes that the term "seaway" hides an important dimension of the St. Lawrence waterway, which accommodates three types of vessels: ocean-going vessels, river- and ocean-going vessels, and inland waterway vessels. River- and ocean-going vessels are specially designed to travel on this waterway and have drafts of 27 000 deadweight tonnes (DWT), whereas lakers travelling upstream from the Welland Canal may have drafts of up to 65 000 DWT. Ocean-going vessels making trips to Quebec City and Montreal may have drafts varying between 60 000 DWT and 150 000 DWT. Vessels used for transshipping cargo in Middle North Shore ports (Baie-Comeau, Port-Cartier and Sept-Îles) have capacities of several hundred thousand deadweight tonnes.

In his study (1997), Lasserre considers that the St. Lawrence River ports — at least the Upper St. Lawrence ports (Montreal, Contrecœur, Sorel, Trois-Rivières and Quebec City) — comply in every respect with the transportation hub or "gateway" concept. They constitute a port system that provides tri-modal (even quadri-modal) access to the interior, a good balance between bulk, container and general cargo traffic, and a high-quality tertiary sector in a major city that handles all of the port-activity-related banking and management functions.

Marine transportation is still Canada's foremost mode of cargo transportation, ahead of rail, highway and air systems. The marine transportation industry is characterized by its huge load capacities, specializations and a marked acceleration in cargo handling. Waterborne inland cargo traffic in Canada increased from 42.1 million tonnes (Mt) to 100.6 Mt between 1961 and 1995, while international cargo traffic increased from 84.2 Mt to 259.8 Mt during the same period.

Quantities of bulk and general cargo handled in St. Lawrence ports (Montreal–North Shore) have remained unchanged at about 90 Mt since the early 1980s. The corresponding quantities transshipped in the Montreal–Lake Erie section have stayed in the 50-million-tonne range since reaching peaks of more than 70 Mt between 1977 and 1979. The Port of Montreal has always been Canada's principal port for containerized freight. In 1995, the port handled 7.2 Mt, compared with total tonnages of 4.5 Mt in Vancouver and 3.7 Mt in Halifax. Cargo traffic on the Mississippi River, by far the busiest waterway system in North America, increased from 400 Mt to 630 Mt between 1975 and 1994. Between 1970 and 1995, the quantity of cargo handled in Canada's Atlantic-coast ports increased from 15 Mt to 30 Mt and in Canada's Pacific-coast ports from 30 Mt to 90 Mt.

The St. Lawrence waterway is now facing strong competition from intramodal and intermodal handlers. The Port of New York and the Gulf of Mexico ports are serious competitors for containerized freight, as is the Port of Halifax, which handles a share of this cargo traffic and sends it westward by train. In addition, the St. Lawrence waterway has lost a portion of the petroleum products market in the Quebec City–Montreal corridor to Ultratrain, owned by Canadian National. A substantial tonnage of feed grain from the Canadian Prairies is also shipped to Quebec City by train and then transshipped onto ocean-going vessels. Sometimes these trains go all the way to the Port of Halifax.

2.1.4 Energy efficiency of waterborne transportation compared with other modes of transportation

The transportation industry (passengers and commodities) is known for its very high energy consumption. According to estimates, this sector accounts for 28% of total energy expenditures in Canada and 27% in the United States (Thorp 1993). A study of fuel consumption by different modes of transportation in Canada revealed that highway transportation, accounting for 74.5% of energy requirements in 1988, was well ahead of other modes of transportation and that personal automobile travel consumed much more fuel than trucks transporting goods (Thorp 1993). Other modes of transportation consumed less fuel. They are, in descending order, air transport (8.4%), pipeline transport (7.1%), waterborne transport (5.4%) and rail transport (4.6%). It should be noted that waterborne transportation is still the primary mode of cargo transport in Canada (Lasserre 1997). Although some people contend that waterborne transportation is clearly the least expensive and least polluting mode of transportation, there is very little data to support this notion (Lasserre 1997, 1989).

To assess the environmental impacts of a modal shift from waterborne commodity movements to rail or highway system commodity movements, the Great Lakes Foundation conducted a study in which 11 modal shift scenarios in the Great Lakes–St. Lawrence River system were analysed. In four of these scenarios, the shifts took place in the Fluvial Section: e.g. movement of petroleum products from Sarnia to Montreal and movement of iron ore from Sept-Îles to Hamilton, including a vessel-to-rail alternative from Quebec City (Thorp 1993). The study initially established that fuel consumption was between 45 and 86 tonnes/km/litre for trucks, between 180 and 338 t/km/L for rail and between 200 and 550 t/km/L for waterborne transport. For all of the scenarios taken together, it was found that rail transport consumed 44% more fuel than waterborne transport, although it used 100% more in some scenarios. Commercial-shipping-related fuel savings were accompanied by proportional reductions in polluting emissions, such as polycyclic aromatic hydrocarbons (PAHs), carbon monoxide, nitrogen oxides and volatile organic compounds (VOCs). The same study pointed out that ships generate the least noise pollution because most ship channels are far from shore and residential areas. It was also found that waterborne transportation had a significantly lower risk of accidents than rail or truck transportation (Thorp 1993).

2.1.5 Navigation infrastructure

This section describes the main infrastructure built along the shores of the St. Lawrence River for commercial shipping activities, including commercial ports, shipyards, canals and locks making up the St. Lawrence Seaway and aids to navigation. Vessels are also discussed in this section of the report although they are considered navigation equipment rather than navigation infrastructure.

2.1.5.1 *Commercial ports*

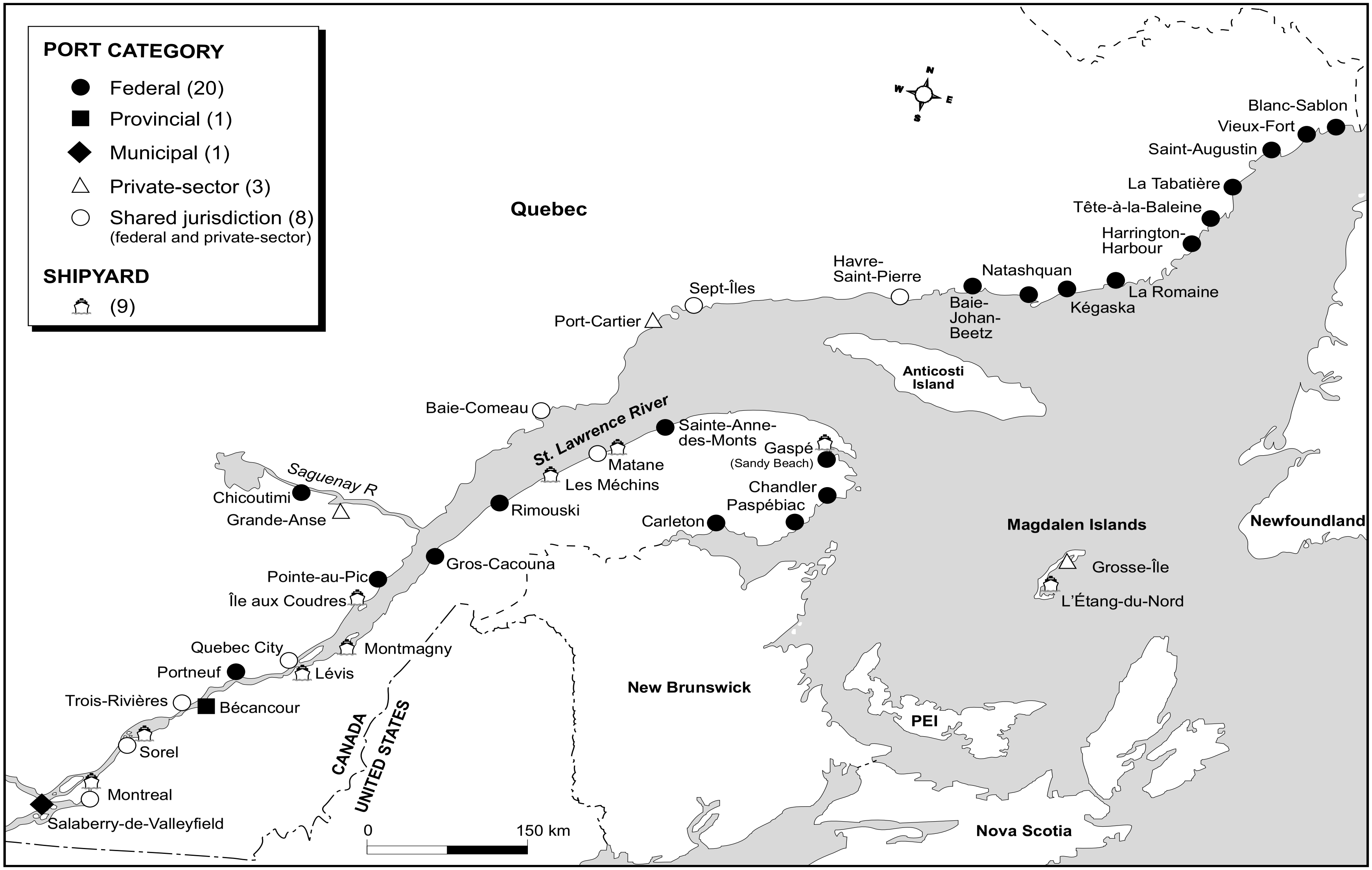
The ports in question in this report are used for marine transportation purposes, particularly the handling (loading and unloading) of trade commodities. We have excluded ports used for the landing of fishery products. The information used herein is drawn from unpublished 1995 data on annual cargo traffic in the ports of Fisheries and Oceans Canada's Laurentian Region (CCG 1995b).

In 1995, Quebec's port network consisted of 32 commercial ports able to accommodate vessels of various types and sizes, ranging from barges to 300 000-tonne lakers that dock in some of the North Shore ports (Figure 5). In 1995, over 110 million tonnes (Mt) of commodities were handled by these commercial ports (CCG 1995b, Quilliam and Millet 1998). This represented about 30% of Canada's total cargo traffic, thus making Quebec the leading province for marine transportation based on tonnage handled and the value of commodities moving through its ports. Bulk commodities accounted for most of the cargo traffic that moved through St. Lawrence River ports in 1995, with dry bulk goods representing the largest tonnages. Also in 1995, the Lower Estuary and Gulf section ranked highest in terms of quantities of commodities handled, averaging more than 50% of the total handled in St. Lawrence River commercial ports.

CHARACTERISTICS OF THE MAIN PORTS

Ten of the main St. Lawrence River commercial ports posted annual cargo traffic of more than 1 Mt in 1995. The total tonnage handled by these ports amounted to 107.8 Mt (CCG 1995b). Table 1 lists the tonnage figures for each of these ports.

The Port-Cartier facilities handled 24.4 Mt in 1995, the largest tonnage handled by a St. Lawrence River port and the second largest handled by ports across Canada (CCG 1995b). Port-Cartier's activities mainly involve the handling of iron ore extracted from North Shore mines (over 16 Mt) and grain (over 6 Mt). International cargo trade accounts for more than 80% of this port's activities (Statistics Canada 1996).



Source: Based on data from CCG 1995b.

Figure 5 St. Lawrence commercial ports and shipyards in 1995

Table 1
Total tonnage handled in the main St. Lawrence River commercial ports in 1995

Port	Total tonnage (Mt)
Port-Cartier	24.4
Sept-Îles	23.2
Montreal	19.2
Quebec City	17.7
Baie-Comeau	7.5
Sorel	5.1
Grande-Anse (formerly Port-Alfred)	3.6
Havre-Saint-Pierre	2.9
Trois-Rivières	2.6
Bécancour	1.4
Total	**107.8**

Source: Based on data from CCG 1995b.

Note: These commercial ports are considered major ports because they handled more than 1 Mt in 1995.

The Port of Sept-Îles' activities centre on the shipping of iron ore, which accounted for 20 Mt of the 23.2 Mt of cargo handled in 1995 (CCG 1995b). The port also handled 600 000 t of bituminous coal, 550 000 t of green coke and bituminous coal, and 375 000 t of gasoline and fuel oil. At this port, international cargo trade made up 80% of total cargo traffic (Statistics Canada 1996).

The ports of Port-Cartier and Sept-Îles (exclusively dry bulk cargo ports) have traditionally dealt with the Great Lakes, shipping North Shore ore to the steel mills of Hamilton, Ontario and Pittsburgh and Chicago in the United States. They also unload grain brought in from the Canadian Prairies by lakers, store it in their silos, and then load it onto ocean-going vessels bound for overseas destinations (Commonwealth of Independent States [former Union of Soviet Socialist Republics], South America, Africa and the Middle East). However, this market has shifted in the past few years as the ports serve an increasingly international clientele at the expense of trade with the Great Lakes. Because of new cargo handling techniques (self-unloaders) developed by the St. Lawrence River shipping companies, most lakers are now equipped with self-unloading equipment to unload or transship bulk cargo from ocean-going vessels, whether or not they are docked at wharf side, thus increasing the efficiency of cargo forwarding.

Although it handles dry bulk and liquid cargo, the Port of Montreal is one of the main ports for containerized cargo in North America. In 1995, containerized goods accounted for over 7 Mt of the 19.2 Mt handled in the port (CCG 1995b). In addition, containerized goods handled in the Port of Montreal make up 44% of the international containerized freight handled in Canada. The port handles a huge variety of goods, including 3.6 Mt of petroleum products (gasoline and fuel oil). International cargo trade represents about 70% of total tonnage (Statistics Canada 1996).

The Greater Montreal area is Canada's transportation hub and the centre of Quebec's marine transportation industry. It is primarily in Montreal that ship owners, marine transportation industry players and international shipping lines have their offices and do business. The total amount of commodities handled in the Port of Montreal is expected to reach 22.6 Mt in 2002 (Port of Montreal 1998).

The Port of Quebec is both a dry and liquid bulk cargo port. Most of the cargo traffic is petroleum products (gasoline, fuel oil and crude oil), grain and iron ore. Of 17.7 Mt handled in 1995, petroleum products (gasoline and fuel oil) accounted for 3.7 Mt and crude oil transshipped at the Ultramar refinery wharves in Saint-Romuald accounted for 6.6 Mt (CCG 1995b). The port also handled 3.5 Mt of grain and 1.8 Mt of iron ore. International cargo trade accounts for slightly more than 75% of the Port of Quebec's activities (Statistics Canada 1996).

Large ocean-going vessels with a maximum capacity of 150 000 t cannot travel on the St. Lawrence River upstream from the Port of Quebec, which is 1300 km from the Atlantic Ocean. Owing to the water depth advantage along with modern port facilities and full intermodal connections, the Port of Quebec is able to maintain its position as one of Canada's major ports in terms of tonnage and to handle not only bulk cargo but also general cargo, such as newsprint and rail cars for the Chunnel linking England and France.

Most of the other major St. Lawrence River commercial ports, such as Baie-Comeau, Sorel, Grande-Anse (formerly Port-Alfred), Havre-Saint-Pierre, Trois-Rivières and Bécancour specialize in dry bulk cargo handling.

The Port of Baie-Comeau facilities are used to transship grain and petroleum products, export aluminum and newsprint and unload salt. International cargo trade makes up close to 70% of the port's activities (Statistics Canada 1996). The total tonnage handled in 1995 was 7.5 Mt (CCG 1995b).

The main commodities handled in the Port of Sorel are steel, grain, wood and a wide variety of general cargo. International marine transportation activities account for slightly under 50% of this port's activities (Statistics Canada 1996). The total tonnage handled in 1995 was 5.1 Mt (CCG 1995b).

The Alcan port facilities in Baie-des-Ha!-Ha! handle mainly ore and aluminum products, which made up 2.6 Mt of the 3.6 Mt handled in 1995 (CCG 1995b). Stone-Consolidated products are also handled in this terminal. Since the early 1990s, land-based transportation has been used in this region to move hydrocarbons. International cargo traffic accounts for more than 90% of the port's activities (Statistics Canada 1996).

Most of the activity in the North Shore Port of Havre-Saint-Pierre involves the shipment of titanium ore to the Port of Sorel (2.3 Mt). Compared with the average in other ports, there is relatively little international cargo traffic in the Port of Havre-Saint-Pierre, i.e. 13% of total cargo traffic (Statistics Canada 1996). In 1995, 2.9 Mt was handled (CCG 1995b).

The main categories of cargo handled in the Port of Trois-Rivières are grain (1.1 Mt) and iron ore (583 000 t). The port also handles 83 000 t of petroleum products (gasoline and fuel oil). Foreign cargo trade accounts for 80% of the port's activities (Port of Trois-Rivières, 1996). A total of 2.6 Mt was handled in 1995 (CCG 1995b).

The main commodities handled in the Port of Bécancour are alumina (800 000 t) and magnesite (200 000 t) (Société du Parc Industriel et Portuaire de Bécancour 1996). International cargo traffic is a major component of the port's activities at close to 90% (Statistics Canada 1996). The total tonnage handled in 1995 was 1.4 Mt (CCG 1995b). It should be mentioned that volumes handled and port ranking can change from year to year.

COMMERCIAL PORT ADMINISTRATION

The administration of the 33 St. Lawrence River commercial ports (see Section 2.1.5.1) is relatively complex: 20 ports are under federal jurisdiction; one is under provincial jurisdiction;

one is under municipal jurisdiction; three are owned by the private sector; and eight report to both federal authorities and the private sector (Figure 5).

The ports under federal jurisdiction are governed by two separate Acts administered by Transport Canada. The *Canada Ports Corporation Act* provides a framework for local port corporations (i.e. Montreal and Quebec City), and divisional ports (i.e. Trois-Rivières, Chicoutimi and Sept-Îles). The *Public Harbours and Port Facilities Act* governs the activities of the 15 other federal ports. It should be noted, however, that Transport Canada is undergoing major restructuring under the new *National Marine Policy* (Transport Canada 1995a). Consequently,

- The ports of Montreal and Quebec City will become Canada Port Authorities (CPAs), which are non-profit corporations under federal supervision. The CPAs will be fully responsible for all port matters and must be self-financing, with most of the administrators appointed after consultations are held with port users. The CPAs will be independent management corporations with mandates requiring them to follow strict business discipline in their operations and full financial accountability principles. However, the government will continue to be the owner of the federal lands involved.
- Nine ports will remain under federal jurisdiction as designated remote ports (Baie-Johan-Beetz, Blanc-Sablon, Harrington Harbour, Kegaska, La Tabatière, Natashquan, La Romaine, Saint-Augustin and Tête-à-la-Baleine).
- The nine other ports will be deemed regional ports and will be transferred over the next six years, with assistance from the $125-million Port Divestiture Fund (Transport Canada 1995a), to the provincial government, municipal governments, community organizations or private-sector interests. Some of these ports may apply for Canada Port Authority status if they are deemed financially independent.

2.1.5.2 *Shipyards*

About 30 Quebec companies specialize in shipbuilding and repairs. Of these companies, nine have built ships of more than 100 t and four account for 80% of Quebec's shipbuilding activity and rank among Canada's largest shipyards. They are Marine Industries in Sorel, Versatile Vickers in Montreal, MIL-Davie in Lévis, and Groupe Maritime Verreault in Les Méchins (SLC and Laval University 1991). These four shipyards provide maintenance for most of the ships plying the St. Lawrence River and the Great Lakes, many of which were built by the three companies with building yards (Figure 5). Of lesser importance are the shipyards in

Montmagny, Île aux Coudres, Matane, Gaspé and Étang-du-Nord in the Magdalen Islands (SLC and Laval University 1991).

2.1.5.3 *Canals and locks*

The St. Lawrence Seaway system, extending close to 300 km between Montreal and Lake Ontario, is linked by four short canals with a total length of less than 110 km (Figures 6). These canals include seven gravity-operated locks, which raise or lower ships by up to 75 m (SLSA 1998).

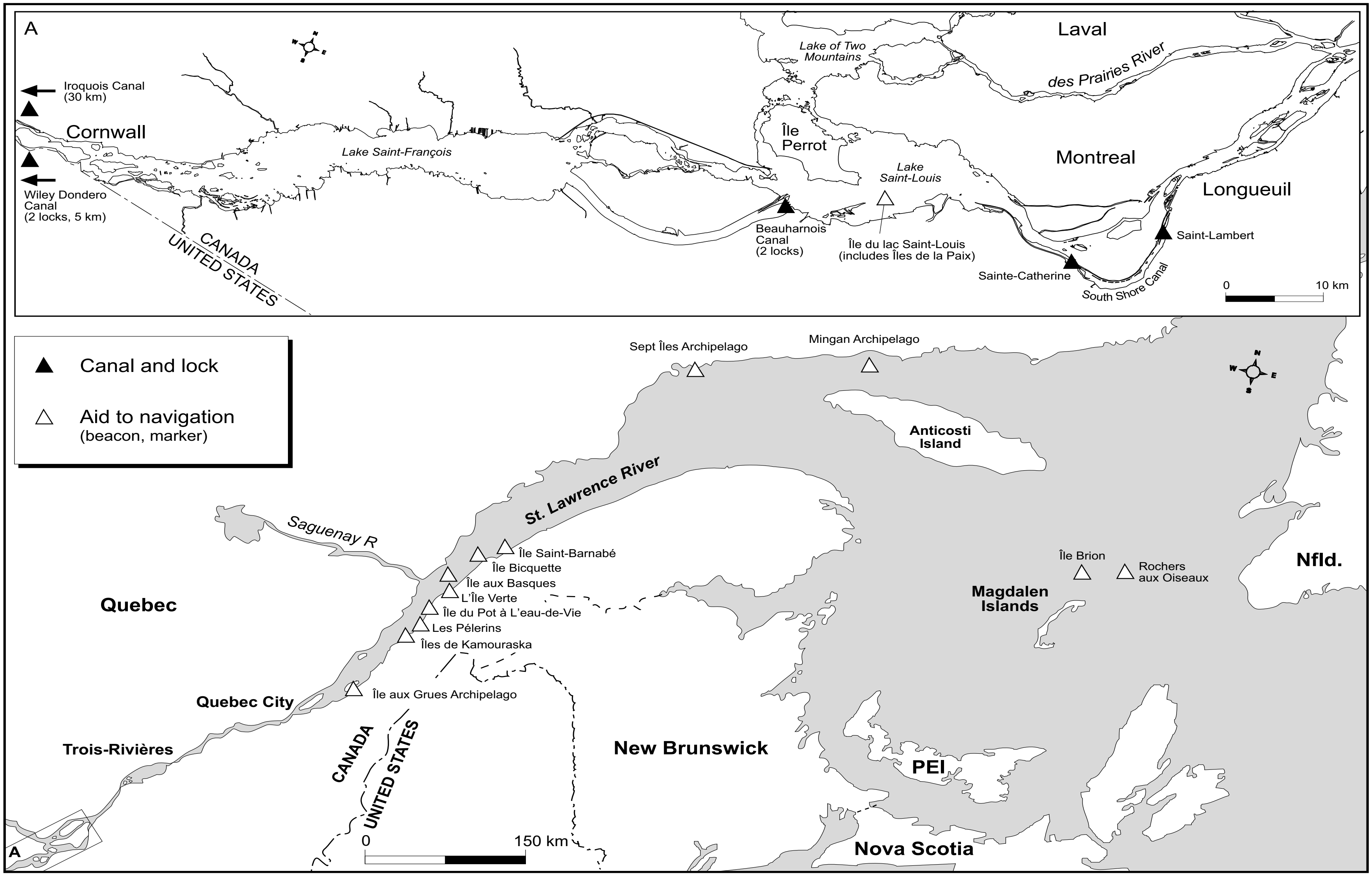
- *South Shore Canal*: two locks; extends 26 km between the Port of Montreal and Lake Saint-Louis (across from Saint-Lambert and Sainte-Catherine).
- *Beauharnois Canal*: two locks; extends 21 km between Lake Saint-Louis and Lake Saint-François.
- *Wiley Dondero Canal*: two locks on the American side; extends 15 km; provides access to Lake St. Lawrence and bypasses the International Rapids section of the river (Iroquois Canal at Cornwall).
- *Iroquois Canal*: one lock and one water-level control facility; extends 0.6 km.

Each lock is 233.5 m long, 24.4 m wide and 9.1 m deep. A lock fills with 90 000 m^3 of water in just over seven minutes and passage through a lock takes about 45 minutes. The locks have built-in safety mechanisms to prevent accidents and signalling systems to eliminate unnecessary delays.

The locks have a lift system for ships up to 222.5 m long and 23 m wide and routinely lift them nearly 184 m (level of Lake Superior) above sea level. The locks are also used by pleasure craft that meet certain draft requirements.

The St. Lawrence Seaway lock and canal system above Montreal shuts down for a few months each winter.

The St. Lawrence Seaway Authority also operates and maintains the Welland Canal and its eight locks linking Lake Ontario to Lake Erie, as well as St. Marys Falls, whose four locks connect Lake Huron with Lake Superior.



Source: Based on data from Gingras et al. 1997, SLC and Laval University 1991.

Figure 6 Canals, locks and aids to navigation on the St. Lawrence River islands

2.1.5.4 *Vessels*

Cargo is transported on the St. Lawrence River on several types of vessels, ranging from barges to giant 300 000-tonne bulk cargo carriers, depending on the physical constraints imposed by the available water depth. Cargo from overseas is carried on ocean-going bulk cargo carriers or container ships to one of the St. Lawrence River commercial ports (the Port of Montreal can accommodate ocean-going vessels of all types, including container ships able to carry up to 2800 20-foot containers or the equivalent) (Port of Montreal 1998). From there, cargo bound for the inland areas of the continent, particularly the industrialized areas of the Great Lakes, is carried on lakers.

Although tonnage itself is not a limiting factor for St. Lawrence River shipping, vessels with drafts greater than 150 000 deadweight tonnes (a ship's total allowable weight, including passengers, crew, cargo and fuel) do not continue upriver beyond Quebec City. However, some large vessels with drafts exceeding the minimum water depth (calculated on the basis of available water depth minus the underkeel clearance factor, i.e. margin expressed in centimetres of water depth required for safe vessel manoeuvrability) have taken advantage of water-level variations and tidal action to make trips upstream from Quebec City. This is especially true in the North Traverse downstream of Île d'Orléans (Figure 6). In 1991, 87% of ships navigating the St. Lawrence River had deadweight tonnages of less than 50 000 t and 94% could navigate upstream as far as the Saint-Lambert Lock because their drafts were less than 11 m (CCG 1993b).

2.1.5.5 *Aids to navigation*

The aids to navigation marking the St. Lawrence River waterway constitute an infrastructure of marine signalling devices installed along the shoreline, on islands and in the water. The devices, used as visual aids for mariners, have been installed in very specific places to ensure navigation safety in the St. Lawrence ship channel and the Saguenay Fjord. The St. Lawrence River has close to 588 fixed aids to navigation, including beacons and land-based range markers, and 677 floating aids to navigation (buoys), most of which are located between Cornwall and Grondines (SLC 1996a). These visual aids making up the Canadian aids to navigation system overseen by the Canadian Coast Guard component of Fisheries and Oceans Canada help to guide commercial vessels, pleasure craft and fishing boats alike. Figure 6 shows the location of aids to navigation (beacons and markers) installed on the St. Lawrence River islands.

2.2 PLEASURE CRAFT

Recreational and tourist activities, including St. Lawrence River-related activities, have grown significantly in recent years. A study entitled *Enquête Santé sur les Usages et les Perceptions du Saint-Laurent,* conducted by the Quebec Public Health Centre (CSPQ), as part of the SLV 2000 action plan, provides an estimate of the popularity of pleasure boating on the St. Lawrence River. The study was conducted in 1995 in the form of a telephone survey of a random sample of 14 819 respondents living in riverside municipalities. The CSPQ gathered and processed the data to draw comparisons between each of the ten health and social services regions bordering the St. Lawrence. The study's pleasure-craft corpus includes data on sport fishers who use boats to practise their sport but excludes ferries.

In 1995, more than 700 000 residents of St. Lawrence River shoreline communities as a whole (17% of the shoreline population) were involved in pleasure-craft activities. Higher numbers of residents took part in pleasure-craft activities in the marine portion of the St. Lawrence (25.8% in Gaspé–Magdalen Islands and 28.1% in North Shore–Anticosti Island) and in large bodies of water popular with sport fishers (23.8% in Mauricie–Bois-Francs, 27.1% in Lanaudière and 22.3% in Montérégie) (Table 2) (Bouchard et al. 1999). One out of every two Canadians participates in pleasure-craft activities at least once a year, helping to generate economic activity of between $3–4 billion (CCG 1995a).

2.2.1 Navigation infrastructure

The infrastructure discussed in this report includes boat launching ramps, marinas and pleasure craft harbours and wharves required for recreational boating activities. For information on aids to navigation used by pleasure craft operators, see Section 2.1.5.5 above, which also describes these navigational facilities from the standpoint of commercial shipping.

Table 2
Participation rates of riverside populations in pleasure boating on the St. Lawrence River, by health and social services region, in 1995

Health and social services region	Proportion of residents participating in pleasure-craft activities (%)
Gaspé–Magdalen Islands	25.8
North Shore–Anticosti Island	28.1
Lower St. Lawrence	12.3
Quebec City	18.6
Chaudière–Appalachians	18.8
Mauricie–Bois-Francs	23.8
Lanaudière	27.1
Montérégie	22.3
Montreal	13.3
Laval	12.5

Source: Bouchard et al. 1999, Quilliam and Millet 1998.

Our information comes from an inventory of principal shoreline infrastructure providing access to the St. Lawrence in environmental emergencies, which was compiled by Environment Canada's Environmental Protection Branch (EPB). This inventory does not always specify whether the infrastructure is used for pleasure-craft activities or commercial shipping (hence the number of wharves and launch ramps may be overestimated), except in the case of marinas, which are obviously for pleasure craft. It should be noted that many commercial ports also have marinas and tourist cruise facilities (Transport Canada 1995c) and that pleasure boating takes place alongside other activities in commercial ports and fishing harbours (Transport Canada 1995a).

Many of the pleasure boating facilities provide access to the St. Lawrence and its shoreline, including 92 launch ramps, 100 marinas and 105 wharves (EPB 1996, Quilliam and Millet 1998). The EPB inventory indicates that there are two growth areas at either end of the St. Lawrence River. In 1996, the Fluvial Section of the St. Lawrence River had the highest percentage of launch ramps, i.e. 52% (48/92), and marinas, i.e. 54% (54/100) (Table 3). The

Lower Estuary and Gulf section had the most wharves, i.e. 52% (55/105) (EPB 1996, Quilliam and Millet 1998).

Table 3
Pleasure boating infrastructure in 1996

Type of infrastructure	Fluvial Section	Fluvial Estuary	Upper Estuary and Saguenay	Lower Estuary and Gulf	Total
Launch ramps	48	3	11	30	92
Marina	54	15	17	14	100
Wharf	16	14	20	55	105
Total	**118**	**32**	**48**	**99**	**297**

Source: Based on data from EPB 1996, Quilliam and Millet 1998.

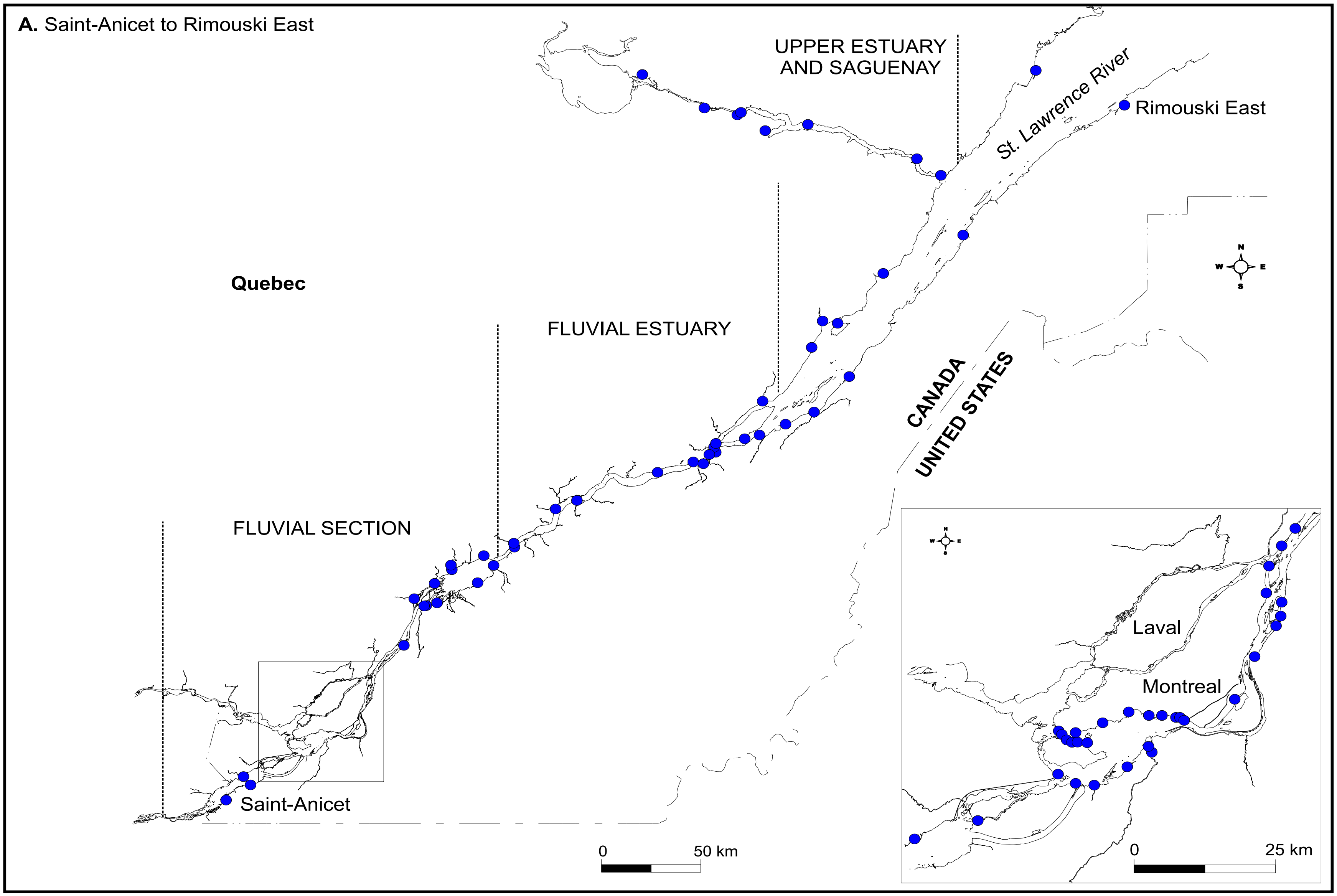
Note: Marinas include pleasure craft harbours.

Figures 7 to 9 give a breakdown of the infrastructure used for pleasure craft activities along the St. Lawrence River.

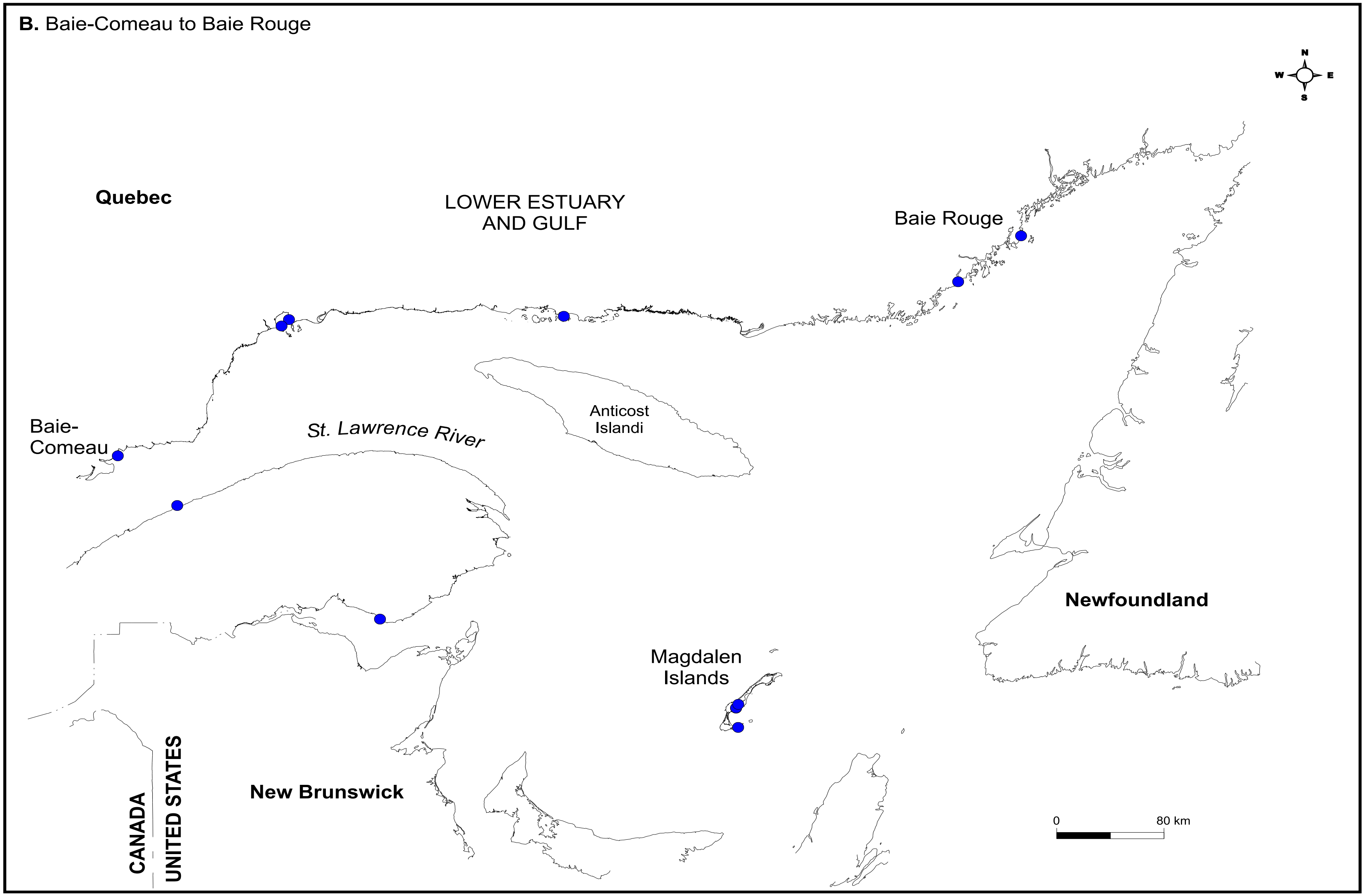
Pleasure boating includes activities associated with the tourism industry, such as international cruises, excursion cruises and ferry boat trips. These aspects are discussed in Section 2.2.2.

ADMINISTRATIVE AUTHORITIES RESPONSIBLE FOR PLEASURE BOATING INFRASTRUCTURE

Environment Canada’s inventory of principal shoreline infrastructure does not always specify the administrative authority responsible for launch ramps, marinas and wharves. However, the inventory indicates that many wharves (37/105) and launch ramps (26/92) are administered by federal and municipal authorities, respectively. The Canadian Coast Guard manages and maintains a network of access points along the St. Lawrence. It is gradually divesting them in co-operation with port authorities (CCG 1998).

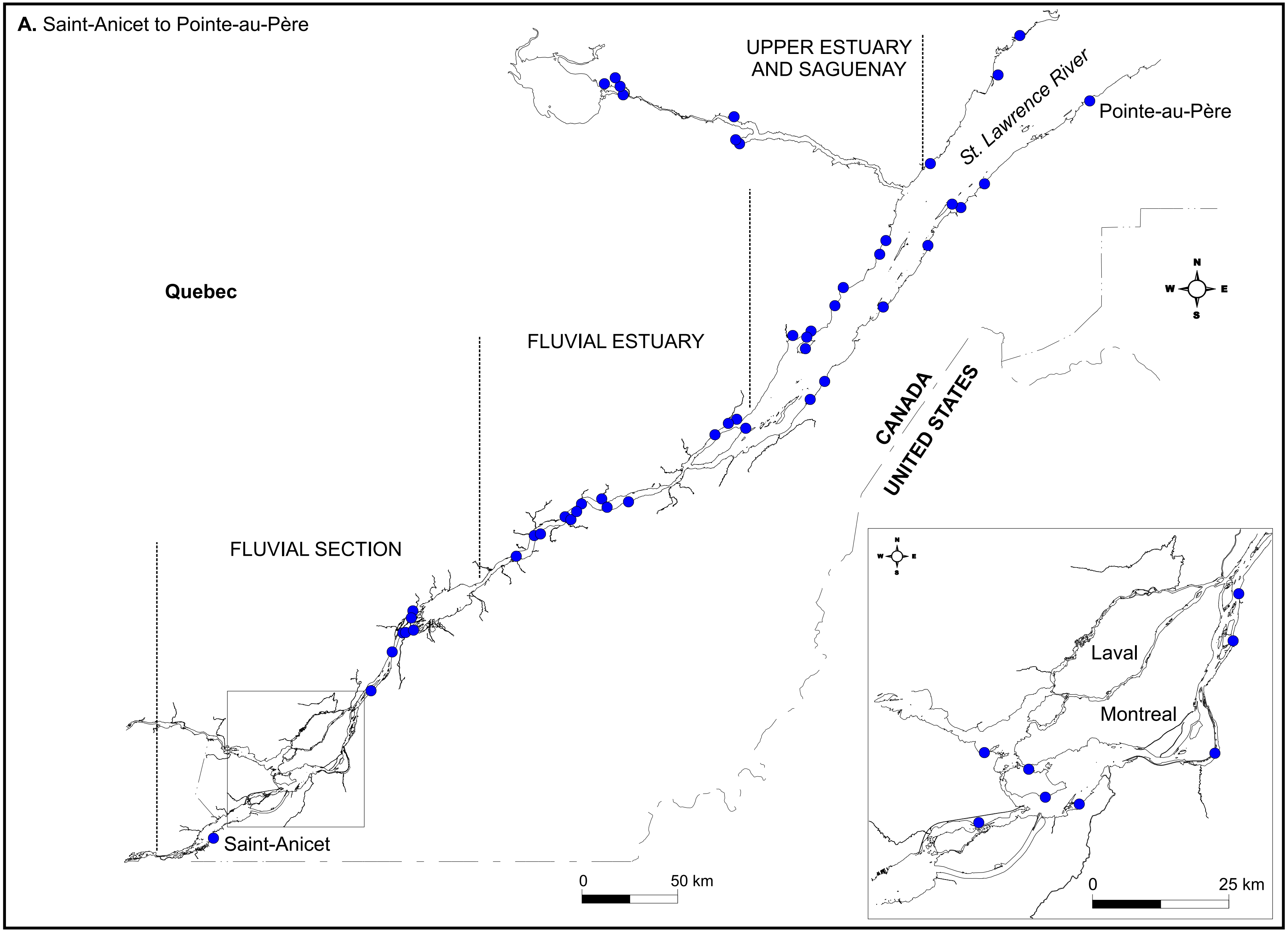


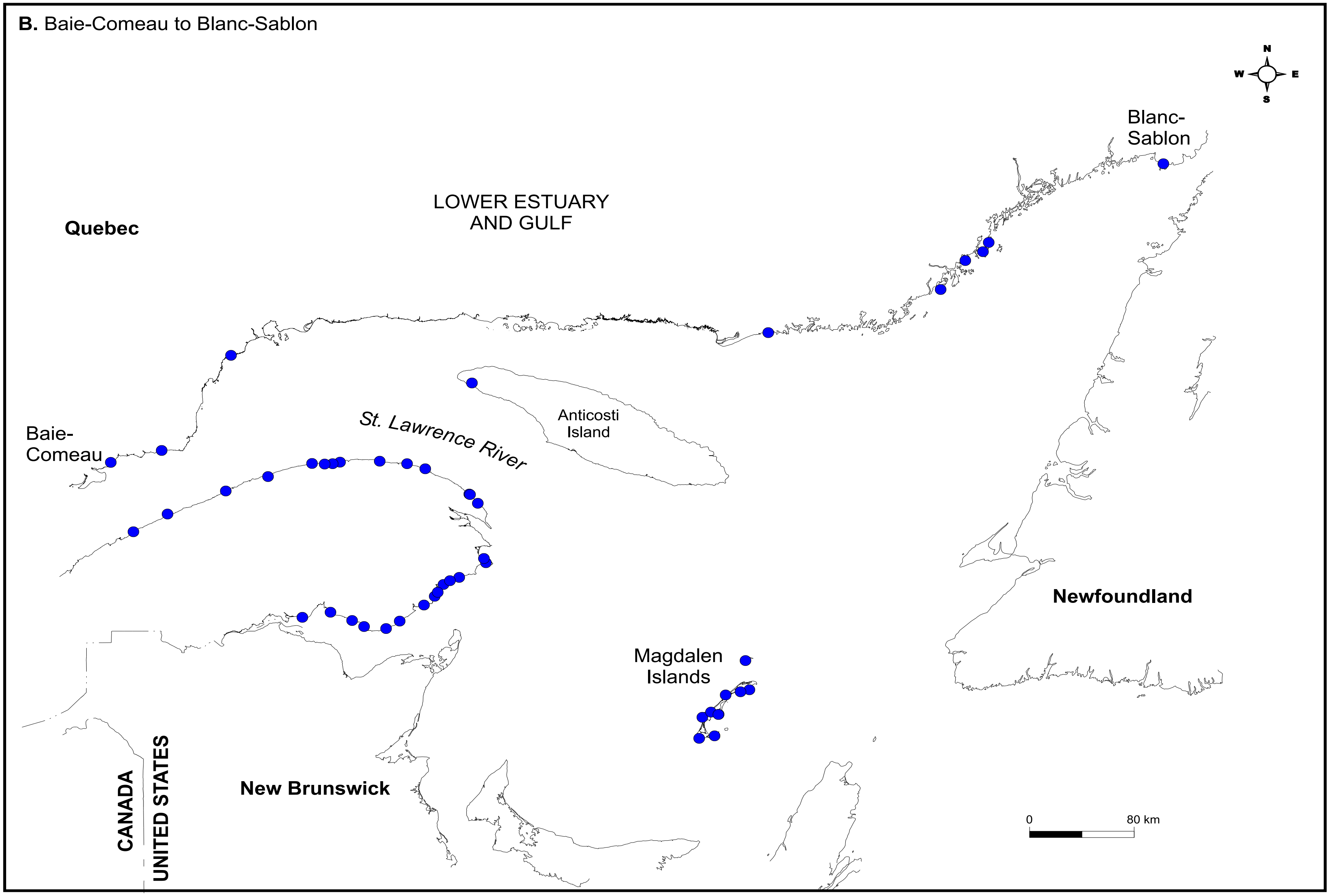
A. Saint-Anicet to Rimouski East
UPPER ESTUARY
AND SAGUENAY
St. Lawrence River
Rimouski East
Quebec
FLUVIAL ESTUARY
CANADA
UNITED STATES
FLUVIAL SECTION
Saint-Anicet
0
50 km
Laval
Montreal
0
25 km



Source: Based on data from EPB 1996.

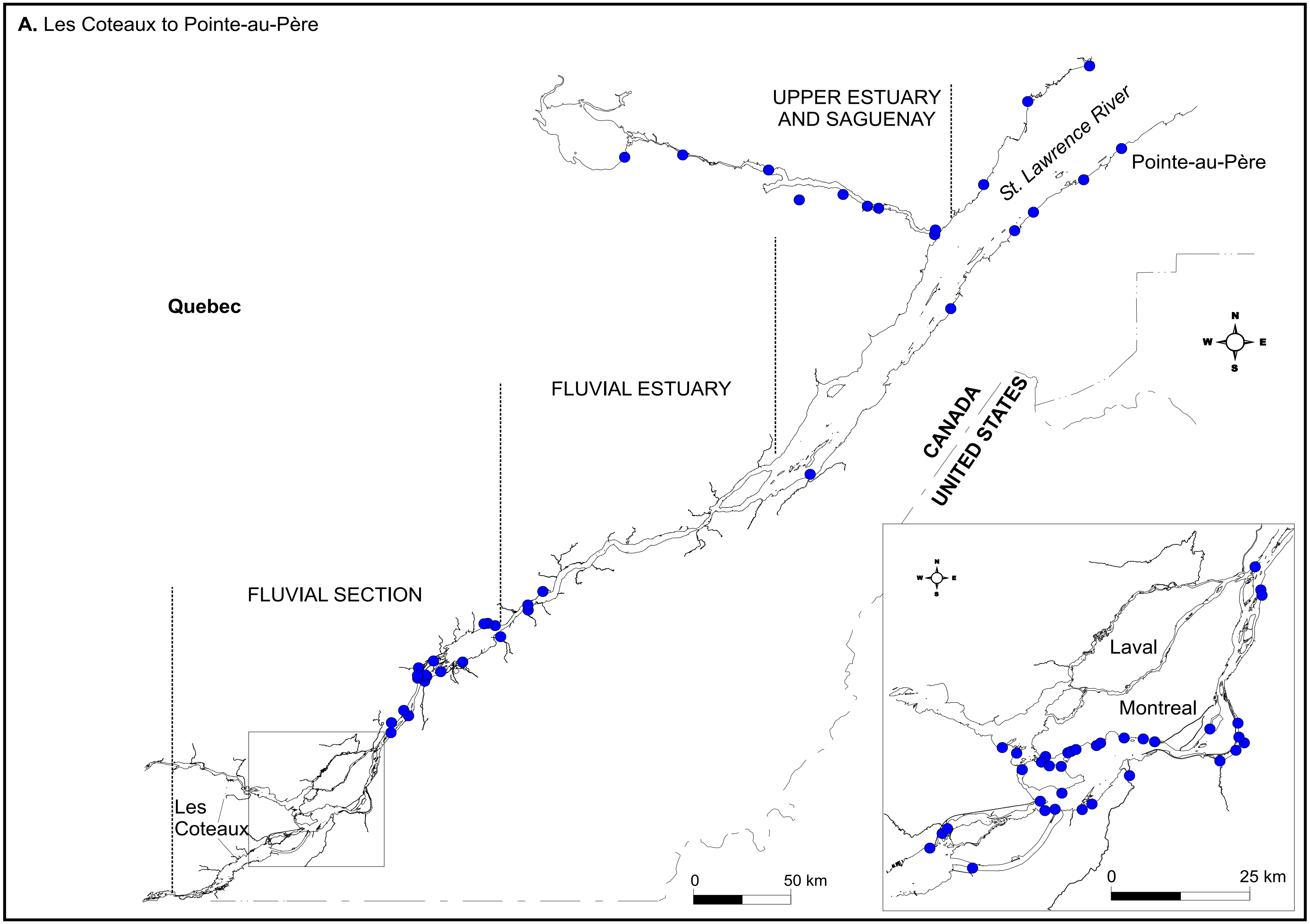
Figure 7 Distribution of marinas along the St. Lawrence River

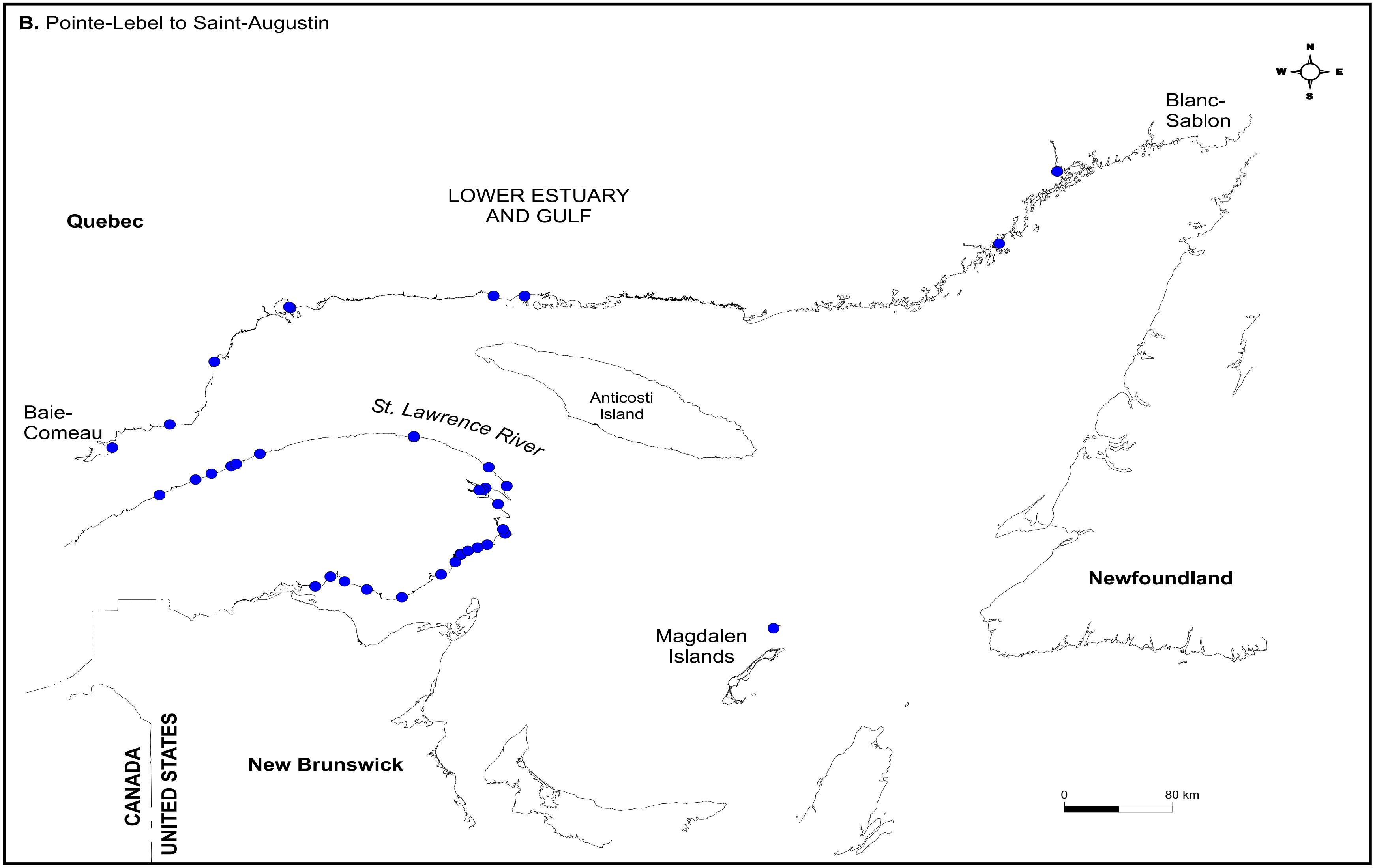

A. Saint-Anicet to Pointe-au-Père
UPPER ESTUARY AND SAGUENAY
St. Lawrence River
Pointe-au-Père
Quebec
FLUVIAL ESTUARY
CANADA
UNITED STATES
FLUVIAL SECTION
Saint-Anicet
0
50 km
N
W
E
S
Laval
Montreal
0
25 km



Source: Based on data from EPB 1996.

Figure 8 Distribution of wharves along the St. Lawrence River


A. Les Coteaux to Pointe-au-Père
UPPER ESTUARY
AND SAGUENAY
St. Lawrence River
Pointe-au-Père
Quebec
FLUVIAL ESTUARY
CANADA
UNITED STATES
FLUVIAL SECTION
Les
Coteaux
0
50 km
Laval
Montreal
0
25 km
N
W
E
S



Source: Based on data from EPB 1996.

Figure 9 Distribution of boat-launching ramps along the St. Lawrence River

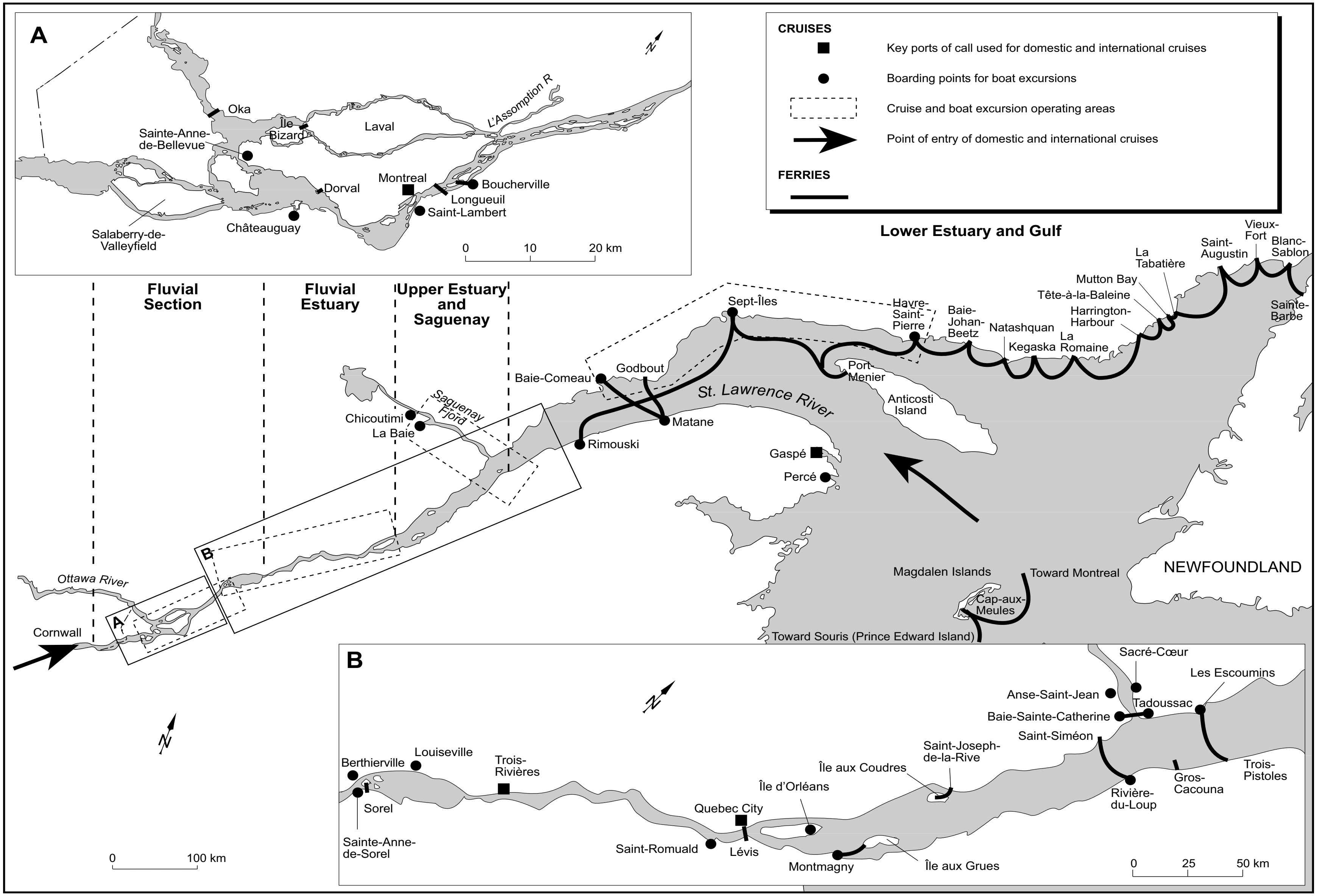
2.2.2 Cruise ships and ferry boats

International cruises have soared in popularity in North America. The St. Lawrence River has much to offer as a cruise destination: proximity to several major ports of embarkation on the eastern U.S. seaboard; panoramic scenery; special events, such as festivals at boarding points and ports of call; the quality of port facilities and air links; and safety of the route and itinerary, and the presence of urban tourism centres. The cruise industry can help to revitalize historical districts along the river because the presence of cruise ships is an added tourist attraction. The Gulf of St. Lawrence is the entry point for international cruises bound for key ports of call upriver at Gaspé, Quebec City, Trois-Rivières and Montreal (Figure 10). The annual economic spinoffs from international cruises amount to more than $20 million (SMVSL 1998).

From a traffic standpoint, extended cruises account for a small percentage of port operations and profits. For example, they generate 5% of the sales and 10% of the profits of the Port of Quebec (Ségal 1997). However, this market has posted some growth since the 1980s and attracts a clientele that is financially well-off, sensitive to the integrity of coastal scenery, and interested in observing wildlife like birds and marine mammals (Economic Planning Group of Canada and Daniel Arbour and Associates 1991).

To promote St. Lawrence River cruise itineraries rather than specific ports, the ports of Quebec City and Montreal set up the St. Lawrence International Cruise Committee in 1994. The Committee brings together representatives from the Montreal and Quebec City tourism offices, Aéroports de Montréal, Tourism Canada and the Quebec Tourism Ministry (MTQ). Although it was hoped that the number of ports of call for international cruises could be increased to 18 along the St. Lawrence (SMVSL 1998), cruise ships only stop at the ports of Quebec City and Montreal for the time being.

Table 4 contains extended cruise traffic data for the ports of Montreal and Quebec City for the period from 1989 to 1997. On average, there were 83 cruise ship stopovers per year in the Port of Quebec, including 50 stopovers by ocean-going vessels and 33 by river cruise ships.



Source: Based on data from The Economic Planning Group of Canada and Daniel Arbour and Associates 1991, SLC 1996a, SLC and Laval University 1991.

Figure 10 St. Lawrence River cruise and ferry routes

These ships carried an average of 35 000 or more passengers (Riel 1997). During the same period, the Port of Montreal was visited each year by between 5 and 15 passenger liners (an average of 11 per year) and welcomed between 19 078 and 47 047 passengers on average during 34 recorded stopovers (Table 4) (Martini 1998). The overall trend in cruise traffic in the ports of Quebec City and Montreal matches that of the cruise industry as a whole, with bigger ships carrying greater numbers of passengers.

Table 4
Extended cruise traffic in the ports of Quebec City and Montreal from 1989 to 1997

	Port of Quebec			Port of Montreal	
Year	No. of stopovers		No. of passengers	No. of stopovers	No. of passengers
1989	55	(28/27)	22 163	17	21 606
1990	79	(42/37)	34 783	24	30 869
1991	126	(82/44)	51 363	41	47 047
1992	121	(67/54)	41 141	54	34 872
1993	88	(59/29)	38 642	41	30 626
1994	80	(51/29)	36 401	40	33 920
1995	82	(55/27)	38 991	38	27 384
1996	55	(32/23)	21 334	26	19 078
1997	61	(34/27)	35 475	25	29 324
Average	**83**	**(50/33)**	**35 588**	**34**	**30 525**

Source: Based on data from Riel 1997, Martini 1998.

Note: Figures in parentheses indicate the ratio of ocean-going vessels to river cruise ships.

Excursion cruises are also an important activity on the St. Lawrence River in summer. Excursion cruise ships stop at ports of call, sail around the river’s islands and archipelagos, and conduct marine-mammal-watching tours along with specialty/activity cruises. Most of the traffic generated by this tourism activity is concentrated in four main areas along the St. Lawrence River: Montreal to the inlet to Lake Saint-Pierre; Trois-Rivières to the eastern tip of Île d’Orléans; Baie-Comeau to Havre-Saint-Pierre; and the Saguenay Fjord (Figure 10). Excursion cruises are also offered on many Quebec lakes. It is estimated that close to 100 companies are active in the excursion cruise industry on the St. Lawrence River and Quebec's lakes and carry more than 900 000 passengers. According to recent statistics, the direct and indirect economic spinoffs from this activity in Quebec amount to almost $100 million (Tittley 1997).

The popularity of excursion cruises on the St. Lawrence River is a very recent phenomenon, not seen since the days of the popular cruises that sailed from Montreal and Quebec City to the major vacation hotels in Pointe-au-Pic and Tadoussac at the end of the last century (Economic Planning Group of Canada and Daniel Arbour and Associates 1991, Tittley 1992). In 1989, Quebec's excursion cruise industry carried 613 168 passengers, or barely 45% of the number carried in the Niagara–Thousand Islands region alone. The Montreal, Quebec City and Saguenay Fjord regions each accounted for one-quarter of the Quebec market (Tittley 1992). According to an analysis of the Quebec market in 1996 (Tittley 1997), the number of customers stood at over 900 000 in 1996, down 10% from the number for 1995, owing to bad weather. Of the 93 boat operators surveyed, 60 were operating on the St. Lawrence River and its major tributaries, double the number recorded in 1989. The fleet consisted of 169 boats, of which only one-quarter could carry more than 150 passengers. The 130 boats operating on the St. Lawrence River accounted for 79% of the seasonal passenger capacity, or more than 3.2 million. The survey noted an increase in the number of companies operating at the mouth of the Saguenay River and in the Mingan area, and recorded 111 service points, including 76 on the St. Lawrence. The main attractions at 46 of these service points were nature observation and interpretation (marine mammals, birds and geomorphology), not to mention the beautiful coastal scenery.

Ferries play a fundamental role in regions with large bodies of water. They serve as extensions for highways in places where bridges cannot be built and link areas separated by water channels. Some ferries carry more than 100 vehicles and hundreds of passengers and make crossings of many tens of kilometres. This is especially true in eastern Quebec between the north (Baie-Comeau) and south (Matane) shores of the Lower Estuary of the St. Lawrence River (Figure 10). Ferries provide services to isolated communities 1acking highway or rail connections; for example, on the Lower North Shore between Havre-Saint-Pierre and Blanc-Sablon. In addition to passengers, ferries also carry essential goods to these remote communities.

Ferry services in Quebec are operated by either the Société des Traversiers du Québec (STQ) or private-sector companies (Tittley 1997).

2.3 CONCEPTUAL MODEL

The “Pressure-State-Response” (PSR) model in Figure 11 outlines each of the pressure components and various phenomena associated with St. Lawrence River navigation that theoretically must be addressed in any discussion about the issues related to environmental impacts. This model provides an essential focus for our analysis and illustrates the web of relationships between the various pressure sources, the state of the environment and responses or initiatives implemented to remedy the situation. More detailed information on the PSR framework is provided in the Appendix.

2.4 ADDRESSING THE ISSUE OF ENVIRONMENTAL IMPACTS

Many factors must be examined in order to address the issue of environmental impacts associated with navigational activities on the St. Lawrence. Two types of activity must be taken into account above all: commercial navigation associated with cargo transportation, and pleasure boating associated with recreation and tourism (including, although they are commercial in nature, boat excursion and cruise activities). Despite some overlap between these two types of navigation from the standpoint of pressure sources and response measures, they differ from each other in terms of objectives, stakeholders and methods used. It was therefore deemed better to examine the two types of activity separately to ensure greater coherence and to more effectively meet the various management requirements of commercial navigation and pleasure craft decision makers and clienteles.

The issue related to the environmental effects of navigation is also characterized by the wide diversity of pressure sources that can affect, to varying degrees, every component of the St. Lawrence River ecosystem. These effects may be temporary or permanent and may be physical, chemical or biological in nature. In some cases, the impacts are real; in others, potential risks are involved. And depending on the type of pressure, the effects may be sporadic, diffuse or cumulative (Figure 11). This diversity makes it difficult to deal with all of the pressure sources uniformly. The PSR model adopted for the purposes of this report offers a partial solution for these environmental impact issues because it isolates each pressure component and analyses it from the standpoint of its effects on the environment and related societal responses. The model clearly delineates every aspect of the environmental impact issue.

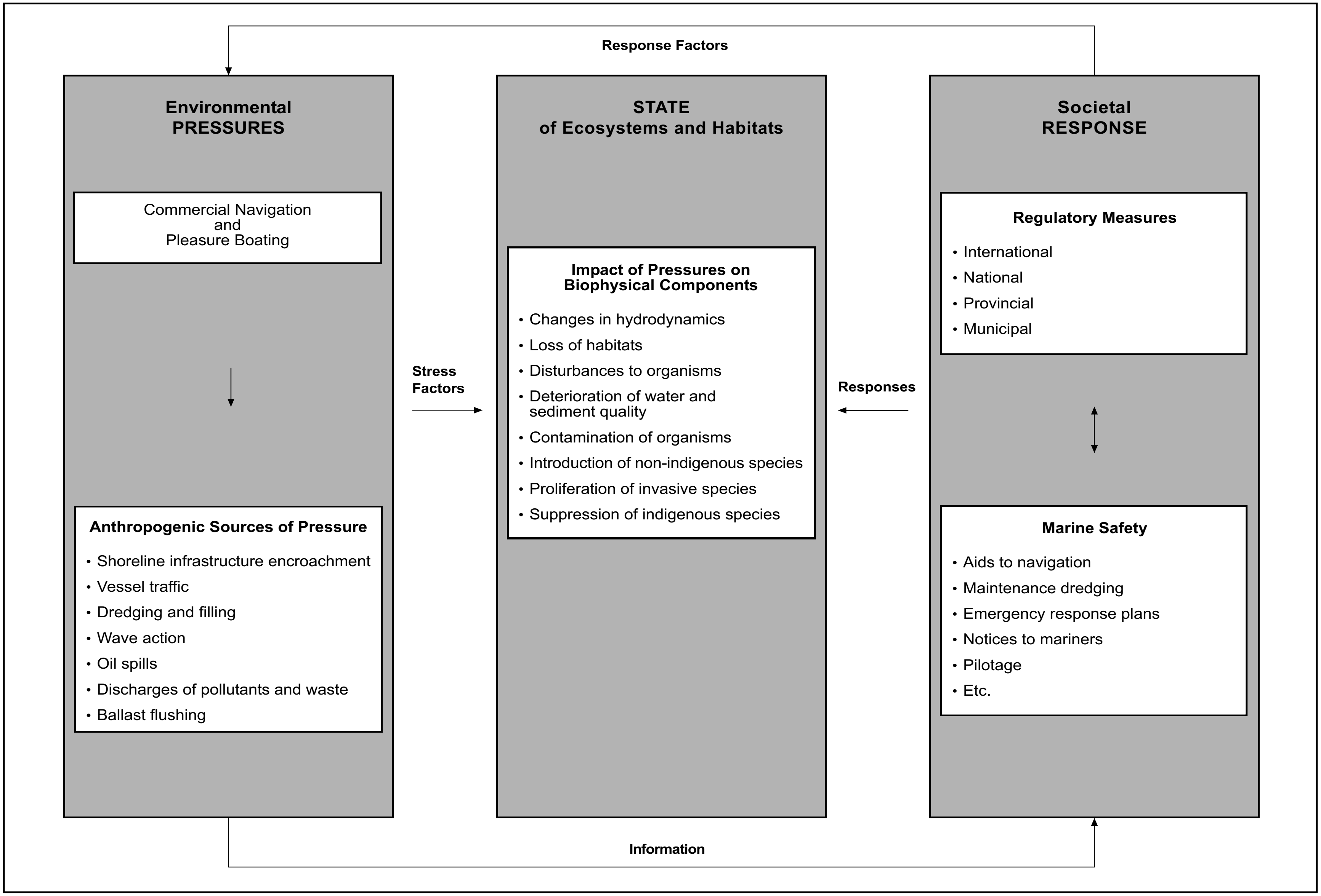


Figure 11 "Pressure-State-Response" model applied to the issue of the environmental impacts of navigation on the St. Lawrence River

The eight variables selected are discussed in Chapter 3. Commercial navigation data are presented first, followed by pleasure craft data, where available.

The order in which these environmental pressures are dealt with is based on the nature of the activities from which they arise. First there are pressures generated by activities to permit or promote commercial navigation: infrastructure, traffic and dredging.

Then there are pressures directly related to commercial navigation. The first one is spills, which represent a potential risk rather than a permanent source of pressure. There are also recurrent pressures: ship-generated wake waves, ballast flushing, contamination from organotin compounds, and poor waste management.

Note, however, that these pressures are not presented in any particular order of importance because certain major characteristics have not been taken into consideration here, such as the reversible or irreversible nature of the environmental impacts and the social cost. Chapter 4 deals more specifically with the relative importance of the pressure sources in a context of sustainable development.

Note also that this report examines current pressure sources, which nonetheless requires that we look at earlier activities which still have an impact on the various components of the St. Lawrence ecosystem. The construction of the St. Lawrence Seaway is a good example of earlier activities that continue to have an environmental impact. Finally, it should be pointed out that this study deals exclusively with commercial and pleasure craft navigation. It does not take the commercial fishing fleet, Navy vessels or Canadian Coast Guard ships into account.

3 Problems Surrounding the Issue

This chapter examines the different pressure sources associated with commercial shipping and pleasure boating that variously affect the St. Lawrence ecosystem and to which society has responded in a number of ways. Eight pressure sources have been identified: shipping infrastructure, activity intensity, dredging, spills, wave action, the introduction of non-native species through ballast flushing, organotin contamination, and the management of waste from ships.

3.1 SHIPPING INFRASTRUCTURE

The development of marine transportation on the St. Lawrence has required the creation of infrastructures to facilitate the transshipping of cargo. The issues here are the pressures arising from the area taken up by the main commercial ports on the shores of the St. Lawrence, and, at the same time, the effects of port development on river uses and the environment, including the loss of natural habitats, biodiversity and access to the riverbanks.

3.1.1 Commercial shipping

3.1.1.1 *Pressure components*

The development of the St. Lawrence system's commercial ports can be considered a permanent source of physical pressure on the environment. Their construction, especially that of wharves for transshipment operations, has resulted in encroachment on riparian habitats. It should be noted that, in some North Shore ports, transshipping is done directly from ship to ship and no land-based facilities are required (SLC and Laval University 1991).

The total surface area of all the ports along the St. Lawrence (commercial ports situated in Fisheries and Oceans Canada's Laurentian Region) is over 1400 hectares (ha). The main ports are Sept-Îles (432 ha), Port-Saguenay (320 ha), Montreal (250 ha), Quebec City (200 ha), Matane (95 ha), Chandler (52 ha), Trois-Rivières (30 ha) and Baie-Comeau (29 ha). The remaining St. Lawrence facilities cover less than 20 ha. There are more than 200 berths, which together measure more than 46 000 metres (Table 5; Transport Canada 1995b).

Table 5
Main facilities and berths in the main commercial ports on the St. Lawrence River

Port	Area of port facilities (ha)	Length of berths (m)	Number of berths
Sept-Îles	432	1 785	7
Port-Saguenay*	320	947**	4***
Montreal	250	25 000	100
Quebec City	200	9 500	51
Matane	95	-	-
Chandler	52	-	-
Trois-Rivières	30	2 666	16
Baie-Comeau	29	1 920	11
Sorel	< 20	1 640	10
Port-Cartier	< 20	1 217	5
Bécancour	< 20	1 123	5
Havre-Saint-Pierre	< 20	353	3
Total	> 1 408	**> 46 151**	**> 212**

Source: Transport Canada 1995b, Port of Montreal 1998, SLC and Laval University 1991, SLC 1996a.

* Ports of Chicoutimi and Grande-Anse (formerly Port-Alfred) combined.
** Port of Grande-Anse only.
*** Port of Grande-Anse only.

The Port of Montreal, a 250-ha terminal, has around 100 berths occupying some 25 km of waterfront (Table 5). It is the largest container port in Canada and has four modern container terminals occupying 70 ha. The containers are transshipped at 18 berths with a total length of over 3000 metres. For non-containerized cargo (iron, steel, alloys, forest products, foodstuffs, machinery, etc.) the Port of Montreal has more than 30 berths, 20 transit sheds, including a temperature-controlled warehouse, and open spaces. Raw materials and bulk liquid products (gasoline, fuel oil, naphtha, etc.) are handled at specially designed berths. The Port of Montreal can accommodate up to 14 tankers at once. There are also three terminals for handling dry bulk (iron ore, salt, gypsum, fertilizers, etc.). The Montreal Port Corporation operates its own grain terminal, which has an elevator with a storage capacity of 260 000 tonnes.

The Port of Quebec extends along the south shore, from the mouth of the Chaudière River to Saint-Michel-de-Bellechasse. On the north shore, the port stretches from Cap-Rouge to

Beauport. The site developed by the Port of Quebec Corporation measures 200 ha (Table 5). The Corporation owns 3500 ha of riverbed (Port of Quebec 1998) and has 51 wharves with a total berthing space of 9500 m (Transport Canada 1995b, SLC and Laval University 1991).

The remaining ports have between three and sixteen berths and berthing spaces of between 300 m and 3000 m (Transport Canada 1995b, SLC and Laval University 1991).

3.1.1.2 *Effects on the environment* (STATE COMPONENTS)

LOSS OF NATURAL HABITATS

The development of port facilities, especially wharf construction, can contribute to the loss of natural habitats and biodiversity. However, it is difficult to assess adequately the environmental impact of these developments in terms of how many hectares and plant and animal species are lost, there being little historical data to shed light on what the environment was like prior to development, which, in most cases, predated the introduction of environmental assessment legislation. One wonders, therefore, what proportion of the more than 1400 ha (see Section 2.1.1) representing the total area covered by port facilities can be considered a lost natural environment.

LOSS OF SHORE ACCESS

Construction of port facilities can result in a loss of shore access and may, therefore, interfere with current or planned riverbank uses: recreation and tourism, residential or industrial development, etc. Here again it is difficult to assess the losses adequately because of the lack of historical data.

3.1.1.3 *Action* (RESPONSE COMPONENTS)

As regards the loss of natural habitats and biodiversity, Fisheries and Oceans Canada's Policy for the Management of Fish Habitat supports the principle of "no net loss of habitat." It would therefore be reasonable to expect equivalent compensation for any inevitable habitat losses. There are various federal and provincial laws and regulations, such as the *Canadian Environmental Assessment Act* and Quebec's *Environment Quality Act,* which provide frameworks for environmental assessments, whose aims include preventing, eliminating or reducing the potential impacts of future port developments on wetlands and biodiversity.

To our knowledge, there are no measures intended to prevent, eliminate or reduce the loss of shore access associated with the development of commercial ports. It should be noted that there is a trend toward enhancing and reclaiming recreational areas previously allocated to commercial shipping interests. New port infrastructure projects are assessed by Quebec's public environmental consultation body, the *Bureau d'Audiences Publiques sur l'Environnement* (hereinafter referred to as BAPE).

3.1.2 Pleasure boating

The growth of boating activities on the St. Lawrence has required the creation of infrastructure to meet the needs of boaters. This section, therefore, deals with marinas, including pleasure craft harbours, wharves and boat launching ramps, all of which can alter shores to various extents.

3.1.2.1 *Pressure components*

The development of a pleasure boating infrastructure along the St. Lawrence River can be seen as a source of permanent physical pressure on the environment, since such infrastructure has encroached on riparian habitats. However, it is impossible to quantify the extent to which the 105 wharves, 92 launch ramps and 100 marinas (see Section 2.2.1) have encroached upon these habitats without any information on the size of the area developed.

3.1.2.2 *Effects on the environment* (STATE COMPONENTS)

LOSS OF NATURAL HABITATS AND BIODIVERSITY

The construction of marinas, wharves and boat launching ramps on the St. Lawrence is a factor in the loss of natural habitats and biodiversity. Wharves, launch ramps and marinas will all have different environmental impacts, with marinas normally having the most significant effects. Mauvais's 1991 study attributes three types of impact to marina construction: those arising from the construction of the site, those associated with the effects of the structure, and those resulting from the use of the marina.

Building (or expanding) a new marina often requires sediment dredging. Although the problem of contaminated sediment seems less serious in the case of marinas as compared to commercial ports, the impact of dredging activities should not be dismissed. These activities destroy riparian sites, which are often rich in riparian vegetation and important habitats and spawning grounds for certain species of fish. Dredging may also result in sediments being swept downstream and settling in nearby habitats.

The hydrodynamics of a site may also be affected by the physical presence of a marina — to various degrees and depending upon how substantial (surface area, mass, etc.) the structures (e.g. protective walls) are. These structures can also create new sediment deposition areas, which can modify existing habitats.

Use of the marina can also disturb wildlife species, if there are intensive boating activities in a limited area (Drolet 1998). In addition, concentrations of large numbers of boats and recreational services (food services, maintenance, etc.) can generate solid and liquid pollutants that can affect water quality and sediments near or inside port areas, inasmuch as septic tanks are not emptied as per regulations.

3.1.2.3 *Action* (RESPONSE COMPONENTS)

Generally speaking, pleasure boating infrastructure construction or maintenance work is subject to Quebec's *Environment Quality Act*. Under section 31 of the Act, all work (dredging, digging, filling, straightening, disposal, etc.) extending over a distance of 300 m or more, or covering an area of at least 5000 m^2, undertaken in waters outside federal property requires an environmental impact study and must be authorized by a government decree as part of the environmental impact assessment process (SLC 1993b). Moreover, under section 22 of the Act, an application for an authorization certificate must be made in respect of all dredging or filling projects, irrespective of volumes or areas involved (SLC 1993b).

The purpose of an environmental impact assessment is to identify the effects of a given project and to propose mitigation measures to minimize them. The environmental impact assessment process could give rise to a public hearing on the effects of a given project. The hearing is held by a committee that reports to BAPE. Consultations were held on a number of projects, including the project to expand the marina at the Salaberry-de-Valleyfield boating centre and the one to build a marina at La Baie (BAPE 1988, 1990).

The *St. Lawrence Beluga Recovery Plan*, drafted jointly by Fisheries and Oceans Canada and the World Wildlife Fund (WWF), recommends assessing the short- and long-term effects of any project to construct wharves or marinas in areas inhabited by Beluga Whales (Drolet 1998). Non-governmental organizations have on a number of occasions proposed a moratorium on the construction of new marinas, notably during the international forum on the future of the Beluga, held in Tadoussac in 1988, and during a workshop on Beluga disturbance, held at the behest of DFO in 1989 (Drolet 1998).

3.1.3 Synopsis

Table 6
Commercial shipping and pleasure boating infrastructure on the St. Lawrence River: Summary of the issues

Pressure components	State components	Response components
Commercial shipping		
Past projects were more numerous and more extensive than contemporary developments. Encroachment on shoreline, and dredging. Major commercial ports take up 1400 ha and cover 46 km of shoreline.	Loss or degradation of riparian habitats and biodiversity. Altered hydrodynamics. Activities that could pollute the environment (organic and inorganic contaminants). Loss of uses.	New developments are subject to federal and provincial environmental assessment processes.
Pleasure boating		
Encroachment on shoreline, and dredging. There are 100 marinas, 105 wharves and 92 boat launching ramps.	Loss or degradation of riparian habitats and biodiversity. Altered hydrodynamics.	New developments are subject to federal and provincial environmental assessment processes. Proposed moratorium on developing new marinas in areas where Belugas are found.

3.2 INTENSITY OF ACTIVITIES

Commercial ships of various sizes and types, from barges to giant bulk cargo carriers, use the St. Lawrence waterway. This section will look at ship movements in the St. Lawrence as a source of pressure and the effect of disturbances to wildlife on the river's biological communities.

3.2.1 Commercial shipping

3.2.1.1 *Pressure components*

Canadian Coast Guard records for 1995 show 6825 commercial ships visiting the St. Lawrence's main ports (CCG 1995b); these figures do not include the many ships that sailed to the Great Lakes without calling at any of the St. Lawrence ports (Table 7). In 1995, 3907 commercial ships travelled the busiest stretch of the river, between Baie-Comeau and Havre-Saint-Pierre, while only 141 ships visited the Saguenay, the quietest part of the system. In the Montreal–Quebec City section, 2777 ship movements were recorded in 1995. A total of 798 ships sailed between foreign ports and the Great Lakes region in 1995 (SLSA 1995). As a number of these ships made more than one trip along the St. Lawrence, the total number of transits was higher. In 1991, for example, Canadian Coast Guard estimates put the total number of commercial ship movements in the St. Lawrence at 10 000 (SLC 1996a).

Table 7
Number of ships in the St. Lawrence's main commercial ports in 1995

Port	Section*	Number of ships
Montreal	FS	1446
Quebec City	FE	793
Baie-Comeau	LEG	781
Sept-Îles	LEG	752
Port-Cartier	LEG	589
Sorel	FS	268
Trois-Rivières	FE	195
Havre-Saint-Pierre	LEG	162
Port-Saguenay	UE	141
Bécancour	FE	75
Total		**6825**

Source: Based on data from CCG 1995b.

* FS: Fluvial Section. FE: Fluvial Estuary. UE: Upper Estuary. LEG: Lower Estuary and Gulf.

3.2.1.2 *Effects on the environment* (STATE COMPONENTS)

Commercial ship movements in the navigation channel can disturb some fish and bird populations, while in the estuary there is a risk of collisions with marine mammals in summer (Drolet 1998).

The many commercial ships that ply the St. Lawrence could disturb wildlife, especially in the Fluvial Section, where the ship channel is close to shore. Sectors that are highly frequented by fish and bird populations, such as the fluvial lakes, are particularly sensitive to commercial shipping (Drolet 1998).

Studies by Holland (1986) and Killgore et al. (1987) on the Mississippi River in the United States show that marine traffic can influence the distribution and survival of fish eggs and larvae near navigation channels; no similar study exists for the St. Lawrence (Drolet 1998).

The extent of such impacts greatly depends not only on the physical characteristics of the hydrological system and the species involved, but also on the type of ship, movement frequency, time of year and behaviour of the mariner.

3.2.1.3 *Action* (RESPONSE COMPONENTS)

The Canadian Coast Guard's *Sailing Directions* recommend that crews be particularly vigilant in certain sectors of the St. Lawrence in order to avoid colliding with whales (DFO 1992, Drolet 1998).

The Canadian Coast Guard (CCG) also issues *Notices to Shipping* to encourage mariners to slow down in certain river corridor sections during the spring freshet so as to reduce shore erosion from wave action (see Section 3.5.4). Although not the main objective, introducing speed limits of this nature could help minimize wildlife disturbances in these sectors. However, these are voluntary measures suggested by the CGG, which has no legal authority to verify compliance or to impose sanctions on those failing to comply (Cloutier 1997, Drolet 1998). *Notice to Mariners No. 12*, which sets out the general framework for these speed limits, states that regulations of this type "might impose unrealistic speed restrictions on some vessels, thereby making navigation unsafe by reducing their ability to maintain steerageway, or cause undue economic and recreational restraints" (DFO 1996, Drolet 1998). Meanwhile, there have been efforts to raise awareness about navigational speed limits among members of the St. Lawrence

River Pilots Association. The aim of a study by the St. Lawrence Centre, as part of its Program on the impacts of water-level variations, is to better assess the impact of wake waves and the intensity of shore erosion attributed to them.

Under Fisheries and Oceans Canada's new *Oceans Act*, marine protected areas will be created; these could help protect marine mammals and monitor commercial shipping more effectively (Drolet 1998).

3.2.2 Pleasure boating

The pleasure craft covered under this section are sailboats and motorboats. Sailboards, dinghies, sea kayaks, canoes and rowboats are not considered in this document.

3.2.2.1 *Pressure components*

NUMBER OF PLEASURE CRAFT

The popularity of recreational boating sometimes results in large concentrations of vessels, especially in the fluvial lakes of the St. Lawrence, the Montreal–Sorel stretch and coastal areas near marinas in the Estuary and Gulf. Generally speaking, the recreational boating season runs from the beginning of May until the end of October, although the peak period of activity is between mid-June and early September. In 1994 in the Quebec City area, 30% of ship movements were recorded in July and 28% in August; the respective figures for May, June, September and October were 4%, 14%, 15% and 9% (CCG 1995a).

Boating activities can disturb and harass wildlife to a variable extent depending on their intensity. The concept of intensity is difficult to quantify, however, due to the lack of adequate units of measurement. While the number of boats may be a determining variable, the physical characteristics of the boat, the areas visited, the time of year, the susceptibility of the various species and even the behaviour of the mariner are other potentially significant variables.

In the absence of more accurate indicators, we will describe this pressure source using data that are somewhat general: the number of craft and their spatial and temporal distribution.

There are an estimated two million pleasure craft in all of Canada and over 350 000 in Quebec (CCG 1995a). According to Zins Beauchesne and Associates (1997), the number of boats, excluding personal watercraft, owned by Quebec households reached 670 000 in 1995.

Under the *Canada Shipping Act*, the Canadian Coast Guard must provide a boater identification service. However, the present system is paper-based and does not have a master file. Moreover, it only covers craft of over 10 HP. According to the Standing Committee on Transport, the system "is essentially useless and a shambles... (and) (w)hat is required is a new computerized system for licensing recreational boats." (Standing Committee on Transport 1995). This lack of easily compiled, accurate data limits our ability to describe the intensity of this activity.

The data in Table 8 show the preponderance of craft in the Montreal and Sorel sections (76.8% of all pleasure craft navigating the St. Lawrence in 1998) and the marked rise in the number of motorboats in the Montreal sector between 1983 and 1988 (Drolet 1998). However, data from Bouchard et al. (1999) indicate that close to 92 000 people used a motorboat and 23 000 sailed in the region of Montreal in 1996.

It is estimated that around 60 000 pleasure craft (sailboats and especially motorboats) now use the St. Lawrence and water bodies in and around Montreal each summer (DFO 1998a). It is difficult to evaluate the number of smaller boats (those less than 5 m long) with any precision. Ten years earlier, there were 40 754 registered pleasure craft (sailboats and motorboats) on the St. Lawrence, an increase of 20.6% in five years (CCG 1997).

Table 8
Number of pleasure craft in each section of the St. Lawrence between 1983 and 1998

	1983		1988	
Section	Sailboats	Motorboats	Sailboats	Motorboats
Gaspé	193	1 410	323	1 780
Rimouski	127	850	201	618
Baie-Comeau	168	2 852	312	2 920
Quebec City	1 210	1 438	1 262	1 903
Trois-Rivières	604	4 802	647	3 168
Sorel	844	8 198	1 532	8 275
Montreal	3 410	7 687	4 090	13 723
Total	**6 556**	**27 237**	**8 367**	**32 387**

Source: Based on data from CCG 1997; Drolet 1998.

NUMBER OF WHALE-WATCHING TOUR VESSELS

In recent years, the whale-watching industry has expanded rapidly. In 1996, there were an estimated 48 vessels offering whale-watching tours between Baie-Sainte-Catherine and Les Escoumins, twice as many as in 1991 (Table 9).

The fleet consists of large vessels that can accommodate dozens of passengers and small craft that take twelve passengers or less.

Table 9
Estimated number of whale-watching vessels in the St. Lawrence Estuary from 1990 to 1996

Year	Number of vessels
1990	22
1991	24
1992	28
1993	34
1994	39
1995	45
1996	48

Source: Based on data from Michaud and Gilbert 1993, Canadian Heritage 1997.

MOVEMENTS OF TOUR VESSELS

A better way to describe the intensity of pleasure-boating activities is to look not only at the number of vessels, but also at the number of movements they made.

Between 1993 and 1995, there was a steady increase in tour-vessel movements in the Montreal (> 59%) and Les Escoumins (> 17%) areas (Table 10). There are a considerable number of whale-watching excursions in the Les Escoumins area, details of which appear later in this section.

Table 10
Movements of tour vessels in the three MCTS* zones between 1993 and 1995

Year	Les Escoumins	Quebec City	Montreal	**Total**
1993	12 547	4 729	8 767	**26 043**
1994	14 540	7 755	12 755	**34 699**
1995	14 652	5 142	13 912	**33 706**

Source: Based on data from CCG 1997.

* MCTS refers to the Marine Communications and Traffic Services of the Canadian Coast Guard.

These activities are largely concentrated in the summer months. For example, in the Quebec City region in 1994, 30% of these movements were recorded in July and 28% in August; May, June, September and October accounted respectively for 4%, 14%, 15% and 9% of annual movements (CCG 1995a).

As for whale-watching tours in the estuary at the mouth of the Saguenay Fjord, their number has increased at least tenfold since the birth of the industry in the early 1980s, to today's level of over 7500 tours per year (Table 11). Boat operators now work at full capacity to meet the demand, especially in mid-season when observation vessels criss-cross this sector from dawn until dusk. However, marinas in the region have almost reached full capacity, which could limit the industry's expansion.

3.2.2.2 *Effects on the environment* (STATE COMPONENTS)

Pleasure boating (including observation activities) has given rise to large groups of small vessels coming together in certain sectors and disturbing species that frequent coastal and riparian habitats. Pleasure craft are very prone to causing disturbance, because their manoeuvrability allows them to travel in shallow shoreline areas where there are concentrations of many bird and fish species. This creates certain risks for wildlife, including the dispersal of families of ducks, which can increase duckling predation. Pleasure craft can also get close to marine mammals in the St. Lawrence Estuary and disturb their normal behaviour (Drolet 1998).

Table 11
Estimated number of whale-watching vessel movements in the St. Lawrence Estuary between 1980 and 1996

Year	Vessel movements
1980	424
1981	1063
1982	1433
1983	913
1984	1295
1985	1365
1986	1463
1987	2052
1988	2168
1989	ND
1990	2339
1991	3222
1992	4349
1993	4961
1994	ND
1995	ND
1996	> 7500

Source: Based on data from Michaud and Gilbert 1993, Lynas 1990, Trépanier et al. 1989, Payer and Breton 1984, Canadian Heritage 1997.

ND: Not determined.

According to Drolet (1998), the effects of pleasure craft on wildlife can be summarized as follows:

- There is very little scientific documentation of the impact on fish of vessel movements and noise. However, it is known that pleasure craft can alter habitats (increased turbidity, destruction of aquatic plant communities, turbulence, wake waves [Section 3.2.3], etc.) in ways that are harmful to fish during their various life stages.
- The main effects observed among marine mammals include avoidance or escape behaviour (moving to other sites, increased dive times and frequencies), altered vocal behaviour and collisions with vessels. No one knows the long-term effects of these behaviours on populations in the St. Lawrence.

- Several studies show that birds can be disturbed by pleasure craft activities. The most frequently reported effects are increased preying upon the young and decreased breeding success.

3.2.2.3 *Action* (Response components)

RECREATIONAL BOATERS

The increased number of recreational boaters observed over the past 15 or so years has raised concern among the public, non-governmental organizations and departments in charge of managing and conserving the St. Lawrence River, its habitats and resources. Indeed, Drolet's study (1998) mentions the difficulty of regulating pleasure boating effectively and the local nature of the various response measures. Fisheries and Oceans Canada's (DFO) *Marine Mammal Regulations* prohibits the disturbance of marine mammals. However, it is difficult to apply these regulations, because there is no definition of "disturb." In 1983, moreover, a *Code of Ethics* for boaters was published indicating how best to approach marine mammals and how close to get to them during observation. However, these are merely guidelines and are not legally binding.

Under DFO's new *Oceans Act*, marine protected areas will be created; these could help protect marine mammals and monitor pleasure craft more effectively.

The Saguenay–St. Lawrence Marine Park (SSLMP) has also recently begun a wide-reaching awareness program by installing signs on wharves and in marinas to encourage park visitors to engage in non-intrusive marine-mammal watching. A pamphlet entitled *Attention Kayakers and Boaters,* which provides information about marine mammal disturbance (with a special focus on the Beluga Whale and Harbour Seal) and how to behave around marine mammals, is also distributed to those visiting the SSLMP.

The St. Lawrence Beluga Recovery Plan, drafted jointly by DFO and the World Wildlife Fund (WWF), recommends carrying out research on the short-term impacts of pleasure craft.

MARINE MAMMAL WATCHING EXCURSIONS

The rapid and constant growth of observation activities has raised concerns among all stakeholders. In 1983, DFO developed a *Code of Ethics* for excursion vessel captains indicating how best to approach marine mammals and how close to get to them during observation.

However, these are merely guidelines and are not legally binding; it is up to the captains to decide whether they will comply.

Under DFO's new *Oceans Act* marine protected areas will be created; these could help protect marine mammals and monitor whale-watching excursions more effectively.

Under section 7 of the *Marine Mammal Regulations* it is forbidden to disturb marine mammals. DFO officers and SSLMP wardens carry out sea surveillance with assistance from the riverside population.

The SSLMP has also recently begun a vast awareness program by installing signs on wharves and in marinas to encourage non-intrusive whale watching and the protection of Beluga Whales. Attempts are also under way to bring together all the stakeholders and introduce an integrated strategy to sustain long-term marine-mammal-watching activities in the SSLMP's sector.

Many recommendations have been made by the Beluga Recovery Team, some of which target the whale-watching industry. These recommendations include revamping current harassment regulations, introducing speed limits for vessels in certain sectors, making the current *Code of Ethics* legally binding, and increasing the number of fishery officers in the Beluga's summer habitat.

3.2.3 Synopsis

Table 12
Intensity of navigation activities on the St. Lawrence River:
Summary of the issues

Pressure components	State components	Response components
COMMERCIAL SHIPPING		
Records for 1995 show 6825 ships registered at ports in the St. Lawrence, with another 798 ships travelling between the Great Lakes and the Atlantic.	Potential disturbance of fish (little data) and birds, especially in the fluvial lakes, and also of marine mammals in the Upper and Lower estuaries. Resuspension of sediments in shallow areas, which could lead to the recirculation of contaminants.	DFO issues *Sailing Directions* warning mariners of the risk of collisions with whales in the Upper and Lower estuaries. *Notices to Shipping* encourage mariners to slow down in certain sectors of the Fluvial Section in order to reduce wave action, which erodes the banks. Under the *Oceans Act*, marine protected areas (MPAs) will be set up, which will help control and reduce certain pressures on resources and habitats in areas deemed to be sensitive.
PLEASURE BOATING and MARINE-MAMMAL WATCHING		
Nearly 41 000 pleasure craft on the St. Lawrence in 1988, up 20% since 1983. The busiest sectors are the fluvial lakes (Saint-François, Deux-Montagnes, Saint-Louis and Saint-Pierre), the Montreal–Sorel stretch and areas close to some marinas in the Upper Estuary. Since activities began 15 years ago, the number of excursions has increased substantially. The number of excursion vessels doubled from 24 to 48 between 1991 and 1996.	Little data available on the acknowledged effects of disturbance of fish and birds (Lachine Rapids). Effects observed among marine mammals are avoidance or escape behaviour (moving to other sites, increased dive times and frequencies), altered vocal behaviour and more collisions. Suspension of sediments in shallow areas, which could lead to the recirculation of contaminants.	DFO's small craft guide recommends several measures to minimize the disturbance of marine mammals. The new *Oceans Act* will result in more effective monitoring of pleasure craft. Disturbing or interfering with marine mammals is prohibited under the *Marine Mammal Regulations.* DFO conducts surveillance, but it is difficult to apply the regulations because the word "disturb" has not been defined. The Lachine Rapids Co-ordination Committee has proposed a series of regulatory measures to reduce pressures due to pleasure craft and a program to raise public awareness of these pressures.

3.3 DREDGING ACTIVITIES

There are two types of dredging: capital and maintenance dredging. Capital dredging takes place when new harbours are developed, waterways are widened or deepened and, less frequently, when contaminated sites are restored. Maintenance dredging is a recurrent activity designed to maintain the dimensions of a site after capital dredging. In dredging activities, both the excavation and disposal of dredged materials have environmental impacts. These are dependent on the quantity, nature and quality of the dredged materials, the duration of the work, time of year it is carried out, and the nature of the habitats at the dredging and disposal sites. The environmental problems of a waterway project and a port project are very different and will greatly depend on which of the two above-mentioned categories the project falls under.

3.3.1 Pressure components

Work began on the development of the St. Lawrence ship channel in the middle of the 19th century. Since then, millions of cubic metres of sediments have been dredged. It was more the need to widen the channel than to make it deeper which necessitated removing such large quantities of material. As a result of some seven capital dredging projects (Figure 2), the channel's depth and width between Montreal and Deschaillons grew from 4.9 m and 75 m, respectively, in 1840, to 10.7 m and 245 m (with a maximum bend width of 457 m), respectively, in 1971 (Procéan et al. 1996). The estimated cost of the work carried out between 1840 and 1971 was $300 million in 1971 dollars. Given that sources (Procéan et al. 1996, Lasserre 1980) put the cost of dredging 32 million cubic metres of sediments to widen the channel between 1952 and 1971 at between $46 million and $60 million, based on the costs incurred, the seven capital dredging projects carried out between 1840 and 1971 must have involved the removal of between 190 000 000 m^3 and 240 000 000 m^3 of materials. This estimate does not take into account the millions of cubic metres of sandy sediments removed by dredging in 1912 to create the 9.1-m-deep and 305-m-wide North Traverse, nor the additional 10 700 000 m^3 removed between 1971 and 1975 to increase its depth to 12.5 m (Lasserre 1980), nor the work carried out in 1992 to increase the depth of the 230-m-wide channel between Montreal and Deschaillons from 10.7 m to 11 m.

The latest capital dredging project on the St. Lawrence was the one begun by the Montreal Port Corporation in September 1998; it was due to end in 1999. Selective dredging of an estimated 222 000 m^3 of shoals between Montreal and Cap à la Roche will increase the minimum depth of the navigable channel from 11.0 m to 11.3 m (Procéan et al. 1996).

Capital dredging projects in the main St. Lawrence ports, including Montreal, Trois-Rivières and Quebec City, have required multiple operations. No comprehensive studies have been done, except in the case of the Port of Quebec, where about 30 capital dredging operations are recorded between 1913 and 1975. These involved moving nearly 13 000 000 m^3 of sediments in the river or along its banks and the on-shore disposal of around 5 000 000 m^3 excavated during some 20 maintenance dredging operations between 1942 and 1984 (Procéan 1991).

Given that the sediment discharge from the St. Lawrence is rather low compared to that of other large rivers, it is not surprising that annual quantities of dredged materials are, likewise, quite small. Between 1983 and 1996 maintenance dredging (ship channel, ports and marinas) resulted in the removal of 7 269 504 m^3 of sediment, an annual average of 519 250 m^3 (Table 13). Quantities varied from 1 383 109 m^3 in 1983 to 190 759 m^3 in 1994 (EPB 1997).

Roughly half of all dredged sediments come from harbours in the Lower Estuary and the Gulf, where five maintenance dredging operations were conducted at 32 sites during the reference period (SLC 1993a). Most of the approximately 2 214 298 m^3 (30% of the total) of material dredged in the Fluvial Estuary comes from a succession of dredging operations in the Batiscan and Portneuf anchorage areas, the bend at Bécancour, the Cap-Santé Traverse and the North Traverse (SLC 1993a). In the Fluvial Section — that is, the sector between Cornwall and the Lake Saint-Pierre outlet — dredging activities are limited, with most material being removed from bends in the waterway in Lake Saint-Pierre (SLC 1993a).

There is a great variation in maintenance dredging activities in the main ports, with the Port of Montreal clearly leading. Although there is no accurate assessment of the volumes dredged, the average dredging expenses incurred over a ten-year period are \$2,350,000 for the Port of Montreal, \$130,000 for Rimouski, \$84,000 for the Port of Trois-Rivières, \$71,000 for Portneuf, and less than \$40,000 for the ports of Quebec City, Baie-Comeau, Sorel, Matane, Gros-Cacouna, Chandler and Carleton (Transport Canada 1995b).

Table 13
Volume of sediment dredged from the St. Lawrence between 1983 and 1996

	Volume of dredged sediment (m^3)				
Year	Fluvial Section	Fluvial Estuary	Upper Estuary–Saguenay	Lower Estuary–Gulf	Total
1983	9 000	335 023	268 621	770 465	1 383 109
1984	1 860	159 570	101 515	408 601	671 546
1985	0	141 971	79 572	276 249	497 792
1986	19 600	199 546	40 545	206 095	465 786
1987	25 333	194 029	75 855	124 408	419 625
1988	112 683	374 825	116 524	289 717	893 749
1989	14 834	187 747	70 918	136 186	409 685
1990	82 577	102 935	58 100	165 026	408 638
1991	32 694	215 928	82 233	72 416	403 271
1992	58 158	72 126	67 730	694 220	892 234
1993	45 407	126 027	59 170	97 581	328 185
1994	37 194	34 755	61 575	57 235	190 759
1995	33 463	42 433	77 500	59 272	212 668
1996	5 400	27 383	59 674	ND	92 457
Total	**478 203**	**2 214 298**	**1 219 532**	**3 357 471**	**7 269 504**
Average	**34 157**	**158 164**	**87 109**	**258 267**	**519 250**
%	**7**	**30**	**17**	**46**	**100**

Source: EPB 1997, SLC 1993a.

ND: Not determined.

To help compare maintenance dredging efforts in the St. Lawrence with those in other waterways or ports, Table 14 shows the annual volume of materials dredged from European ports in 1985 and from North American waterways and ports in 1998. The volumes of sediment excavated each year in other bodies of water are more than an order of magnitude larger than those dredged from the St. Lawrence River as a whole.

Table 14
Approximate volume of sediment dredged each year from North American (1998) and European (1985) waterways and ports

Port or waterway	Country	Quantity (m^3/year)
Mississippi (ports and waterways, downstream stretch)	United States	86 000 000
Rouen (port)	France	5 600 000
Fraser (downstream stretch, 1990)	Canada	5 500 000
Rotterdam (port)	Netherlands	4 000 000
Dunkirk (port)	France	3 000 000
Baltimore (port)	United States	2 100 000
Hamburg (port)	Germany	2 000 000
Delaware (downstream stretch)	United States	1 900 000
Columbia (downstream stretch)	United States	1 600 000
Bordeaux (port)	France	1 600 000
Buffalo (port)	United States	1 200 000
St. Lawrence (ports and ship channel, Cornwall–Gulf)	Canada	500 000

Source: World Dredging Mining and Construction 1998 (United States), Donze 1990 (Europe), Environment Canada and British Columbia Ministry of Environment, Lands and Parks 1992 (Fraser).

Dredged material disposal sites, which are carefully monitored, are scattered along the fluvial corridor on either side of the ship channel. These sites vary widely in area and storage capacity. Some are no longer used, either because they are full or too far from dredging sites. In a given project, attempts will generally be made to use a minimum of disposal sites so as to limit the associated environmental impacts (Procéan et al. 1996).

Almost all dredged sediments are disposed of in open water, generally close to the dredging site. During construction of the waterway, substantial volumes were also deposited along the shores and on islands. In some cases, around Boucherville, Varennes and Contrecœur, for example, the dredged material was used to create islands; there are no comprehensive studies on the number or scale of these deposits (Richard 1998), except for the Île aux Sternes, near the north shore, just downstream from the outlet of Lake Saint-Pierre. This island was created in 1965 and is a recognized ecological reserve. Instances of dredged materials having to be contained because of their contamination levels are somewhat rare; however, this was the case for materials dredged from the Port of Cap-aux-Meules (Lavergne 1998).

3.3.2 Effects on the environment (STATE COMPONENTS)

Dredging activities have a great variety of potential environmental impacts on both dredging sites and disposal sites (Environment Canada 1994a). Each dredging project has its own characteristics. The most obvious impacts of a capital dredging project are hydrodynamic alteration and the loss of aquatic plant and animal habitats. The main potential effects on water quality include temporary increases in turbidity and suspended solids, recirculation of pollutants, and changes to the sediment particle size at dump sites (Environment Canada 1994a). Altering the bottom topography could affect plant and animal life by degrading or modifying the feeding and spawning areas of fish and by disturbing the structure of benthic communities. The intensity of the impact depends on the nature, quantity and quality of sediments found at the dredging and dump sites. Obviously, maintenance dredging and dumping of uncontaminated or only slightly contaminated coarse sediments in sites far from inhabited areas and located in extremely large bodies of water (the North Traverse) will have lesser impacts and attract less attention than will dredging of fine, contaminated sediments in harbours located in smaller bodies of water, where disposal sites are in great demand (Lake Saint-Pierre).

The most significant dredging operations in the St. Lawrence predate the introduction of environmental protection legislation; moreover, there is hardly any habitat inventory information from that time. Consequently, we are unable to describe and quantify the alterations and habitat losses caused by these developments. In Quebec, the environmental effects of the monumental work that went into creating the St. Lawrence Seaway and the hydro-electric facilities between Kingston and the La Prairie Basin were without precedent: retaining structures transformed long stretches of rapids into lakes; along a stretch of about 20 km, between lakes Saint-François and Saint-Louis, the river flow was reduced by 16% after the river was diverted into the Beauharnois Canal (Armellin and Mousseau 1998); the La Prairie Basin was made into a canal; a channel 230-m wide and 11.3-m deep links the natural river basins between Montreal and Cap à la Roche. However, with the powerful analysis tools made available by the recent development of mathematical models and the incredible advances in informatics, it may be possible to describe and quantify the changes in the river's hydrodynamics resulting from the dredging and disposal operations involved in creating the ship channel (Cantin 1998). Recently, Morin et al. (1994) used a mathematical model of hydrodynamic conditions in Lake Saint-François, before and after the development of the St. Lawrence Seaway, to explain the distribution of different types of sediments and aquatic plant communities.

It is estimated that, in the entire St. Lawrence system between 1945 and 1988, dredging operations altered habitats covering an area of 12 588 ha (Robitaille et al. 1988; Table 15); 48% (5983 ha) in the Fluvial Section and 40% (4982 ha) in the Fluvial Estuary. Losses of biomass and plant and animal species have never been assessed.

Table 15
Area of fish habitats altered by dredging between 1945 and 1988

	Area (ha)				
	Fluvial Section	Fluvial Estuary	Upper Estuary	Lower Estuary and Gulf	Total
Dredging*	4 749	4 204	576	410	9 939
Disposal**	1 234	778	477	160	2 649
Total	**5 983**	**4 982**	**1 053**	**570**	**12 588**

Source: Based on data from Bouchard and Millet 1993, and modified by Gilles Shooner and Associates Inc. 1991, 1988.

* Dredging to construct and maintain the St. Lawrence Seaway (Cornwall–La Prairie), port facilities, marinas and shipyard slipways.

** Dumping of dredged materials in open waters or in contained sites (Magdalen Islands).

Although there is no study that can be used to quantify the nature and extent of contaminant resuspension during dredging operations in the St. Lawrence, the quantities would appear to be limited when compared with the mass of sediment resuspended during wind and rain storms. It was suspected, for example, that vessels engaged in dockside manoeuvres at low tide near solid bulk cargo transshipping wharves in the Port of Quebec could resuspend sediments contaminated by heavy metals (zinc and cadmium). A study showed that the turbidity plume created by propeller movements was limited and that contamination was strictly confined to the harbour (Procéan 1993).

Successive dredging operations at the mouth of the Saint-Charles River have caused very extensive encroachment. The land occupied by the Daishowa paper mill, the entire sector behind the solid bulk cargo transshipping wharves (wharves 50 to 53, the beach, etc.), and the Dufferin–Montmorency Highway right-of-way in the city limits of Beauport were constructed using dredged materials.

3.3.3 Action (Response components)

Today, all types and phases of dredging projects are governed by some 20 federal and provincial regulatory provisions (SLC 1993b). Dredging activities are subject to, or must comply with, provisions of the *Canadian Environmental Protection Act* (CEPA), the *Canadian Environmental Assessment Act* (CEAA), the *Fisheries Act*, the *International River Improvements Act*, the *Migratory Birds Convention Act* (MBCA), the *Navigable Waters Protection Act* (NWPA) and all pursuant regulations. As for provincial jurisdiction, a whole series of regulations and directives stem from Quebec's *Environment Quality Act* (EQA), the most important being the *Regulation respecting the Environmental Impact Assessment and Review* (Q-2, r.9) and the *Regulation respecting the Administration of the Environment Quality Act* (Q-2, r.1; SLC 1993b), pursuant, respectively, to sections 31 and 22 of the EQA. Both levels of government have adopted provisional criteria respecting the quality of sediments in the St. Lawrence (SLC and MENVIQ 1992).

In spite of the environmental protection afforded by this legislation, many people are apprehensive about the environmental impact of dredging operations, particularly in the freshwater section. The fact that the most substantial dredging operations conducted in the St. Lawrence did not have to take into account environmental aspects or the resource destruction that is correctly or incorrectly attributed to them continues to stoke these fears.

In the case of capital dredging operations in the ship channel upstream from Quebec City, the public wants to know about the authorities' plans regarding the channel's final dimensions or when river dredging will cease; the ship channel is seen as a ditch that swallows up the river current, an impassable gulf for organisms that inhabit the riparian areas on either side of the channel. The public is also concerned about management of dredged material, especially sediment from often-contaminated harbours.

Under current provincial and federal environmental assessment processes, the environmental screening of a dredging project will first try to minimize the negative environmental effects by identifying the most environmentally and economically appropriate execution time frame, type of dredging equipment and dredged-material management method. It so happens, however, that clamshell-bucket dredging is the most common form of dredging in the St. Lawrence and that the most frequent, and least expensive, management method is open-water disposal (SLC 1992). When a disposal site is used repeatedly and when it is located in a limited body of water in a section with several types of users, the public's fears only increase. This is evident from maintenance dredging projects at the Port of Sorel's wharf 2 (Transport Canada 1997) and wharves 14 and 15 (BAPE 1998). In both cases, the environmental assessments conducted on behalf of the project promoters recommended disposing of dredged materials in open water, in Lake Saint-Pierre opposite Yamachiche. The review by Quebec's public consultation body, BAPE (wharves 14 and 15; BAPE 1998), and public consultations held in Yamachiche (wharf 2; PWGSC 1997) highlighted public fears about the management of dredged materials and bemoaned the lack of a clear policy backed by a long-term vision on this issue.

However, a task force was set up by the Interdepartmental Multidisciplinary Committee (Fisheries and Oceans Canada, Public Works and Government Services Canada and Environment Canada), under the project to carry out selective dredging of shoals in the waterway between Montreal and Cap à la Roche The task force was charged with looking into ways of putting dredged materials to good use by creating wildlife habitats or consolidating and protecting the shores against erosion, all within a regional development context; that is, setting up a broad-based project that would include various dredging operations and the needs of many user groups (GTCIM 1996). These objectives are perfectly in keeping with a coherent dredged-material management policy. To round out its mandate and support the execution of approved projects, the task force recommended that a body be created to ensure the "sustainable" management of dredged materials.

The task force decided on a development project at Trois-Rivières, similar to the successful 1965 Île aux Sternes project (SLC 1996a). It consisted of a shoal (submergent marsh), an emergent marsh and a small island that could even accommodate ponds. This 10-ha development was scheduled for the S-10 dredged material disposal site in Lake Saint-Pierre south of the waterway, just downstream from the Sorel Islands. The project required approximately 410 000 m^3 of materials. The required dredging operations had to be carried out within a very tight time frame. Contaminated materials from the Port of Sorel had to be covered quickly with uncontaminated materials from the waterway; the surface area had to be large enough and the materials piled high enough to resist the effects of ice. Had sediment from the Port of Sorel (70 000 m^3), from the ship channel in Lake Saint-Pierre (90 000 m^3), and from annual maintenance dredging operations (12 500 m^3) been used, it would have taken approximately 20 years to complete the project. Consequently, the project had to be scaled down and a decision was made to develop a single shoal requiring 225 000 m^3 of materials that could be completed in the space of a few years (GTCIM 1996).

This exercise showed that the numerous constraints, including dredging small volumes distributed over too large an area, the limited possibilities of using the materials because of their particle size, ice, substantial hydrodynamic forces, the involvement of many different promoters, shared jurisdiction and legal liability for new developments (GTCIM 1996) are great impediments to the execution of such projects. All of these variables should be taken into consideration, alongside economic constraints, when a coherent dredged-material management policy is eventually drawn up. The other projects reviewed by the task force would be worth examining as part of any long-term look at the issues. There should be public representation on any body created to manage dredging operations and the use of dredged materials.

3.3.4 Synopsis

Table 16
Dredging activities in the St. Lawrence River:
Summary of the issues

Pressure components	State components	Response components
HISTORICAL Major waterway projects between 1850 and 1970 (7 dredging projects: 190 to 240 million m^3 between Montreal and Quebec City) carried out before implementation of environmental protection measures. No precise details of the millions of m^3 dredged from ports. Historically, dredged materials dumped on shore (or on islands) and in open water. CURRENT Environmental pressures relate to both excavation activities and dumping of dredged materials. Last capital dredging project (220 000 m^3) completed in 1999. Annual maintenance dredging in the St. Lawrence as a whole yields low volume: 500 000 m^3. Greater public concern about projects carried out in limited, potentially contaminated bodies of water near urban areas, with various potential uses, than worry about projects in large bodies of water farther from urban areas. Today, disposal takes place in open water in specially designated and clearly defined areas. On-shore containment is rare (Cap aux Meules). Anticipated decrease in water levels could result in greater demands for dredging.	Alterations of hydrodynamic conditions. Habitat loss due to filling at excavation and disposal sites. Increases in turbidity and suspended solids. Recirculation of contaminants. Enormous habitat alteration due to the Seaway: Beauharnois and La Prairie Basin. Altered habitats after dredging activities in the Port of Quebec, which changed the profile of the north shore. Between 1945 and 1988, 12 600 ha of habitat altered, mostly in the Fluvial Section (48%) and the Fluvial Estuary (40%). No information on losses of biomass or plant and animal species.	Some 20 federal and provincial regulatory instruments apply to one or more phases of a dredging project. Current provisional criteria respecting sediment quality need to be re-assessed. A clear and coherent dredged-material management policy should be defined. Projects to make use of dredged materials must be reviewed within a long-term management framework. No data on the cumulative environmental impacts (hydrodynamics and habitats) of dredging the ship channel.

3.4 SPILLS

Because of the heavy vessel traffic in the St. Lawrence, the harsh climatic conditions and the nature of the freight being transported, spills constitute a major problem for shipping. We need to know the frequency, nature and effects of past spills and to assess the hypothetical risks of a major spill, which is a real, although remote, possibility.

3.4.1 Pressure components

VOLUME AND NATURE OF GOODS HANDLED

One of the main variables to consider when describing the pressures associated with shipping is the volume and nature of the commodities involved. Table 17 shows that the tonnage handled in Quebec's commercial ports has been increasing since 1993 and reached over 110 million tonnes (Mt) in 1995. This 20% increase in the tonnage handled has been accompanied by a 14% rise in the number of vessels using the commercial ports on the St. Lawrence.

Table 17
Annual growth of marine traffic in commercial ports on the St. Lawrence River between 1993 and 1995

	1993	1994	1995
Total tonnage (Mt)	91.6	101.9	110.4
Dangerous goods (Mt)	55.4	63.1	64.6
Number of vessels	5979	6565	6825

Source: CCG 1997.

During this three-year period, around 60% of all cargoes fell into the "dangerous goods" category (60.5%, 61.9% and 58.5% of the total tonnage in 1993, 1994 and 1995, respectively). It should be mentioned, however, that this category is taken from the United Nations classification system adopted by CANUTEC (1996), and includes products, which, when compared with one another, have very different risk levels (e.g. hydrocarbons and iron ore).

This data is limited to cargoes handled in the commercial ports of the St. Lawrence, and it does not include all goods transported along the river. Comprehensive data would have to include vessels travelling between a Great Lakes port and a foreign country or the Maritimes without calling at a port on the St. Lawrence.

In 1995, as many as 11 Mt of goods were transported on 798 vessels travelling between foreign countries (excluding the U.S.) and the Great Lakes region (SLSA 1995). The main categories of cargoes handled were agricultural products (2.3 Mt) and iron and steel products (2.2 Mt). This cargo traffic also included some 300 000 t of miscellaneous chemical products and over 225 000 t of gasoline, fuel oil and other petroleum products.

SPATIAL CONCENTRATION OF ACTIVITIES

In Chapter 2 we mentioned that commercial shipping activities are concentrated in a few ports. Over 95% of all goods are handled in the ten main ports, with Port-Cartier, Sept-Îles, Montreal and Quebec City accounting for three-quarters of all the freight tonnage involved (CCG 1997), including dangerous goods (Table 18).

This spatial concentration is an important aspect when you consider that around 95% of oil spills occur in ports or at oil-handling facilities, not in the ship channel (Savard 1997). Awareness of this situation helps target high-risk zones. We should point out, however, that, though accidents are more frequent during loading and unloading, the quantities spilled are also lower. Although post-collision spills are less frequent, much larger volumes are involved (Environment Canada 1987).

The nature of the risks will, therefore, vary enormously from one port to another, depending on the type and volume of the dangerous goods they handle.

Table 18
Volume, nature of materials and number of vessels in the ten main St. Lawrence ports in 1995

Port	Tonnes handled	% of total tonnage	Dangerous goods	% of total tonnage of dangerous goods	Number of vessels	% of all vessels
Port-Cartier	24 483 893	22.2	8 645 067	13.4	589	8.7
Sept-Îles	23 262 122	21.1	22 494 610	34.8	752	11.0
Montreal	19 224 447	17.4	8 095 157	12.5	1 446	21.2
Quebec City	17 721 448	16.1	13 345 814	20.6	793	11.6
Baie Comeau	7 522 488	6.8	573 395	0.9	781	11.4
Sorel	5 163 411	4.7	3 748 218	5.8	268	3.9
Grande-Anse	3 552 449	3.2	2 974 866*	4.6	141	2.1
Havre-Saint-Pierre	2 864 587	2.6	2 883 140	4.5	162	2.4
Trois-Rivières	2 570 660	2.3	470 576	0.7	195	2.9
Bécancour	1 406 022	1.3	452 820	0.7	75	1.1
Subtotal	107 771 527	97.6	63 683 663	98.5	5 202	76.2
*Other ports***	2 630 339	2.4	963 442	1.5	1 623	23.8
Total	**110 401 866**	**100**	**64 647 105**	**100**	**6 825**	**100**

Source: CCG 1997.

* Including tonnage from the Port of Chicoutimi.
** Commercial ports handling less than one million tonnes in 1995, excluding Valleyfield (209 000 t in 1995), Cap-aux-Meules (76 000 t in 1993; Transport Canada 1995b), and Havre-Aubert (16 000 t in 1993; Transport Canada 1995b).

Over 99% of the dangerous goods handled at the Port of Quebec, for example, is flammable liquids (Table 19); more specifically, crude oil (6.7 Mt), gasoline and fuel oil (3.3 Mt) (Statistics Canada 1996). The wharves belonging to Ultramar, which house the largest quantities of hydrocarbons in Quebec, are therefore of vital importance. Vessels capable of carrying up to 160 000 t of petroleum products visit these wharves. There are more movements involving vessels[2] carrying petroleum products in the Port of Quebec than in any other port on the St. Lawrence (Guerrier and Paul 1996).

[2] Vessels sailing past the port and those that call at the port.

Table 19
Volumes of each class of dangerous goods* handled in the ports of Quebec City and Montreal in 1994

	Volumes of each class of dangerous goods (thousands of tonnes)									
	Explosives	Gases	Flammable liquids	Flammable solids	Oxidizing agents	Toxic materials	Radioactive materials	Corrosive materials	Misc. products	Total
Quebec	0	0	10 623	0	0	4	0	25	2	10 654
Montreal	3	13	6 084	50	36	52	14	93	113	6 457

Source: Environment Canada 1996a.

*According to the United Nations classification system.

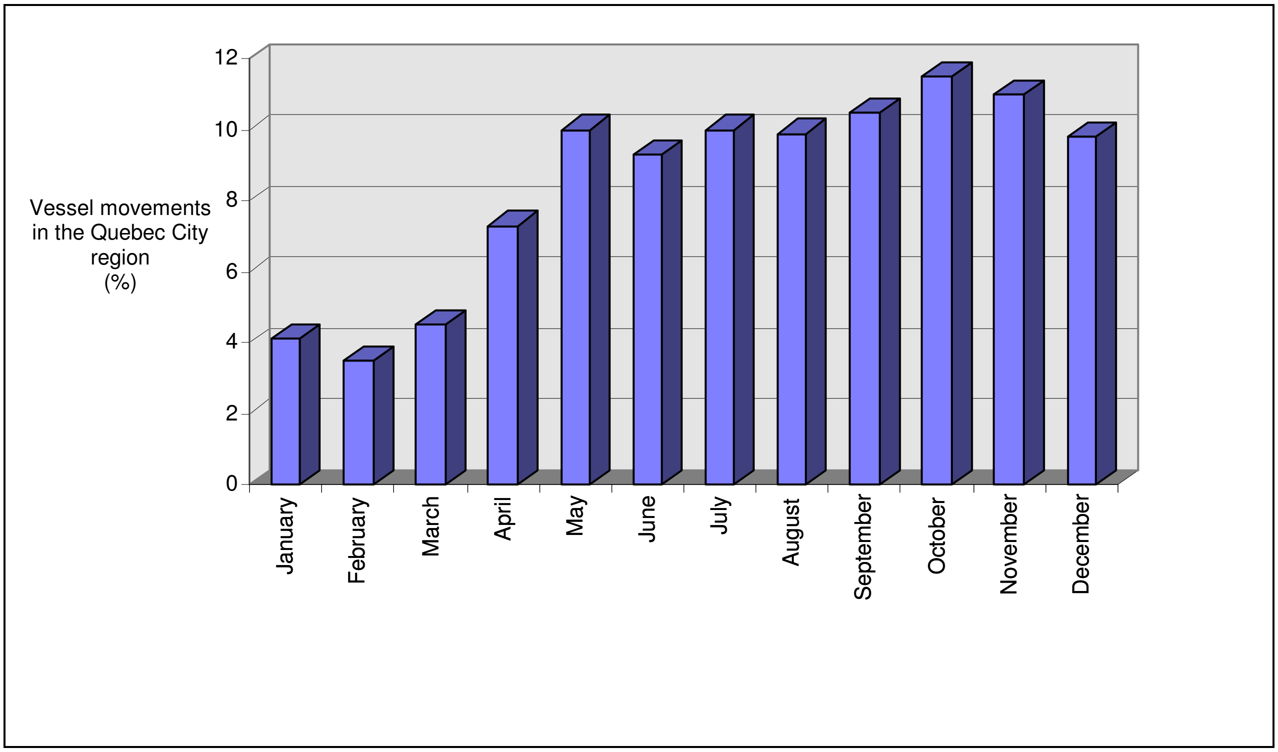
Flammable liquids (essentially, gasoline and fuel oil) are also the main class of dangerous goods handled at the Port of Montreal. Although the total tonnage of dangerous goods is lower than in Quebec City, the products are more diverse, with 1400 different types of dangerous goods moving through the port each year. As Table 19 shows, there is product-handling in each of the nine classes of dangerous goods (Environment Canada 1996a).

TEMPORAL DISTRIBUTION OF SHIPPING ACTIVITIES

Although the St. Lawrence ship channel is open and boats can sail as far as the Port of Montreal year-round, shipping activities are nevertheless greatly reduced in winter. The number of commercial ship movements in the Quebec City region drops by half in January, February and March, and accounted for only 12% of all recorded movements in 1994 (Figure 12).

FREQUENCY OF SPILLS

The steady growth in total tonnage and number of vessels between 1993 and 1996 was not matched by a similar upward trend in the number of spills (Table 20). Moreover, when we look at the total number of spills from vessels and terrestrial or unknown sources, we can see a drop in the number of spills between 1993 and 1996, in spite of the increased total tonnage and number of ships. A more detailed analysis should be conducted before concluding that this drop is the result of improved preventive measures.



Source: CCG 1995b.

Figure 12 Monthly distribution of vessel movements in the Quebec City region in 1994

More spills occur in summer than in any other season, although monthly data vary from year to year. It is also interesting to note the relatively high number of spills in January, February and March, in spite of the reduced vessel traffic (Figure 12). It may be that there is an increased risk of spills because of the harsh climatic conditions at that time of year.

Table 20
Frequency of spills between 1993 and 1996

Spills	1993	1994	1995	1996
From vessels	47	58	51	56
From a land-based or unknown source	149	128	124	105
Total number of cases	196	186	175	161

Source: CCG 1997.

NATURE AND MAGNITUDE OF SPILLS

Based on the information available on the number of spills in the river, it is impossible to describe the pressure shipping brings to bear on the St. Lawrence ecosystem. Such an understanding would also require knowledge of the nature and the magnitude of these spills and an ability to situate them in relation to the main ecological zones. Although data on the nature and the magnitude of spills appear in the various incident reports, we are unable to synthesize the information for the period under consideration because the Environment Canada and Canadian Coast Guard databanks are not kept up to date.

An Environment Canada study (1996a) provides a synthesis of the type and the magnitude of spills between 1975 and 1994 in five harbours (Montreal, Chicoutimi, Quebec City, Sept-Îles and Trois-Rivières). In these five ports, 968 accidents were recorded, 87.6% involving ships, 10.3% involving land-based facilities, and 2.1% involving rail or road carriers. In 95% of these incidents, the products spilled were hydrocarbons and derivatives; slightly more than 4% of the accidents involved miscellaneous chemical products. In more than 80% of accidents, a volume of less than one tonne was spilled, although between 100 and 1000 tonnes was spilled in six cases. We should point out that these data refer solely to accidents in the various harbours and that 12% are not related to shipping[3] (Environment Canada 1996a).

3.4.2 Effects on the environment (STATE COMPONENTS)

The extent of the ecological impacts of an oil spill is dependent on a great number of factors. According to Mielke (1990, in Guerrier and Paul 1996), there are 12 factors, as follows:

- the size of the spill and the length of exposure
- the type of product spilled
- the form of the product spilled: altered, emulsified or intact
- the environment (critical habitat: calving, spawning or nesting ground, etc.) where the spill occurs

---

3 It is interesting to note that, while the Canadian Coast Guard conducts exhaustive surveys of spills caused by shipping, no similar studies are carried out for accidents attributable to other sources. The lack of substantial data on land, rail and road accidents in the ports of Montreal, Quebec City and Trois-Rivières leads one to believe that the number of accidents in these harbours is probably underestimated. (Environment Canada 1996a).

- environmental stresses and meteorological parameters
- the time of year
- development stages of the organisms affected: juveniles, adults, etc.
- if the oil is in solution, suspension or adsorbed onto particles
- distribution in the water column
- the effect of oil on biotope competition
- previous spills
- clean-up techniques.

Assessing the ecological effects of these spills therefore requires a detailed analysis of the various accidents. However, the information needed to assess or estimate these effects is not available. The information gathered for this report does not allow us to describe the extent of the areas affected by spills, the resultant wildlife losses or any residual effects of the spills.

Interestingly, while we may have the impression that there are generally few residual impacts, because the whole response effort following a spill is aimed at containing, recovering and cleaning up the spilled oil, we cannot conclude that the various recovery measures can fully restore aquatic ecosystems and disturbed coastal areas. The extent of the disparity between the post-recovery situation and the one that would have prevailed had the spill not taken place depends on the resilience of the particular ecosystem. It should be said that Environment Canada's Environmental Emergency Response Team is conducting research on the issues related to impact assessments and ecosystem recovery following spills (Jarry 1997).

3.4.3 Action (Response components)

PREVENTIVE MEASURES

Several measures have been implemented to reduce the risk of shipping accidents: these include aids to navigation, keeping records of water levels, maintenance dredging, communication services, ice-breaking operations and the pilotage system, all of which are the responsibility of the Canadian Coast Guard (CCG 1995a).

The system of aids to navigation helps mariners determine their position. There are conventional (654 floating aids, 254 winter spar buoys and 501 fixed aids), electronic (a ship calibrating radiobeacon, 28 radar beacons and three differential global positioning system (DGPS) stations and audible aids (eight fog signals). Under the new marine policy, however, conventional aids were to be progressively replaced by electronic systems between 1997 and 2000. Thus, beginning in April 1997, 25% of buoys in the ship channel were taken out of service along with 12 major shore lights; at the same time there was a 33% reduction in the number of shore lights on wharves (CCG 1997).

The CCG's Waterways Development Service monitors channel water levels and oversees maintenance dredging operations, so that commercial shipping can continue uninterrupted.

The Marine Communications and Traffic Services issues meteorological information and a variety of notices to shipping. It also oversees marine traffic and ensures that vessels entering Canadian waters comply with standards.

The Canadian Coast Guard also conducts ice-breaking operations in the ship channel and port facilities.

As with all major waterways throughout the world, pilotage services are available in the St. Lawrence River. The current pilotage system was set up in 1972 under the *Pilotage Act* to allow mainly foreign vessels to sail swiftly and safely through Canadian waters. The new *Canada Shipping Act* retains the regional Pilotage Authority structure, including the Laurentian Pilotage Authority. The Act also provides for a review of the designated compulsory pilotage areas and a reduction of operating costs (Minister of Transport's Office 1996). At present, when a ship bound for the Great Lakes enters the river, a licensed pilot steers it from Les Escoumins to Quebec City; there, a second pilot takes over until the vessel reaches Trois-Rivières, where a third pilot steers it to the Saint-Lambert Lock. In winter, vessels must have two licensed pilots on board.

RESPONSE MEASURES

A series of measures has also been introduced so that public and private marine stakeholders can respond adequately should a spill occur.

The regulatory framework for river transportation is largely defined in Chapter 36 of the *Canada Shipping Act*, adopted in 1993 further to the Brander-Smith Commission's report

(PRPTSMSRC 1990). The Act deals with tankers of more than 150 tonnes, other vessels of more than 400 tonnes, and handling facilities. Vessels are required to:

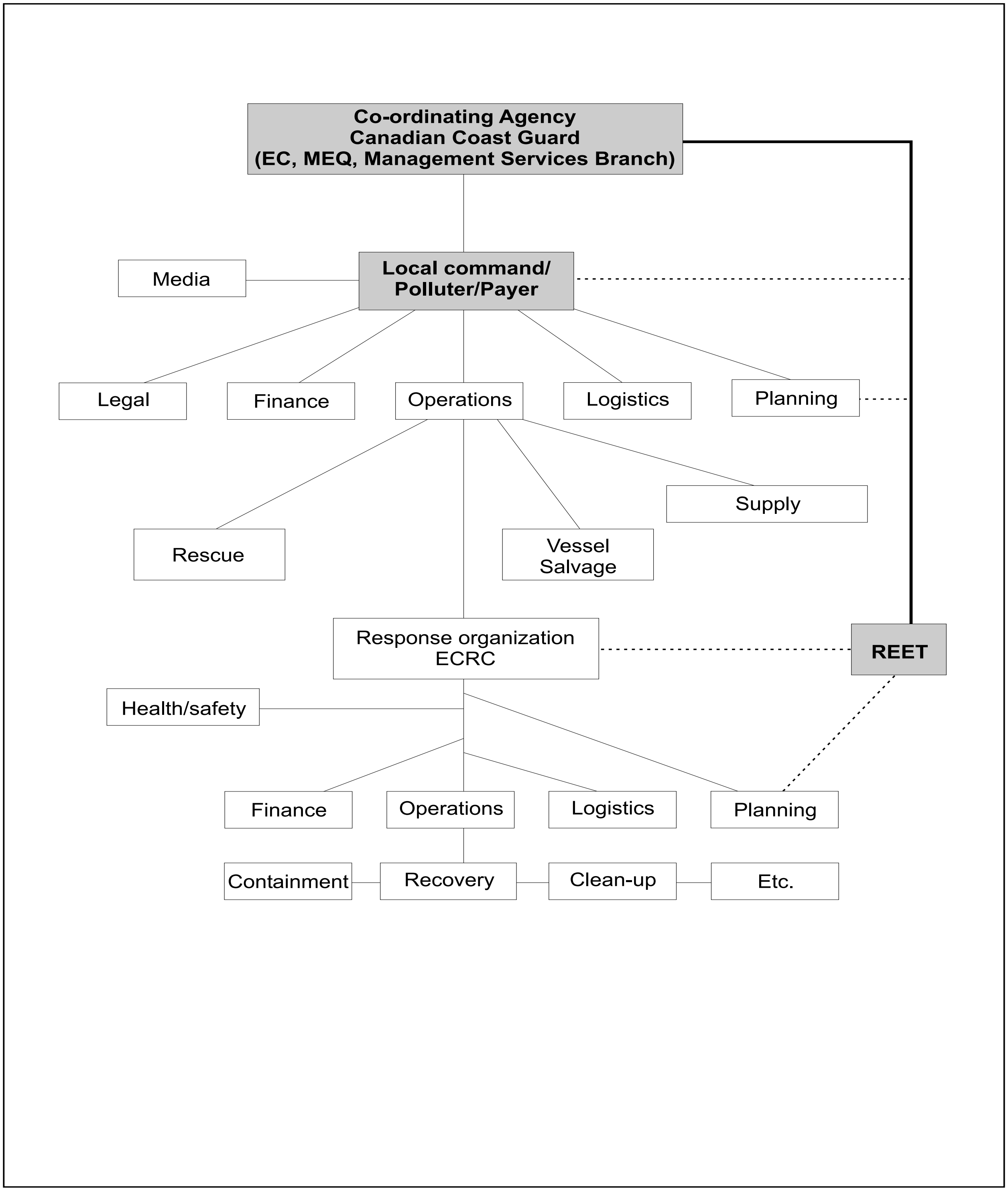
- have a shipboard emergency response plan for oil pollution
- have an arrangement with a response organization to which a certificate of designation has been issued
- have on board a declaration of compliance.

Oil-handling facilities must:

- comply with regulations respecting the response procedures, equipment and resources that an oil-handling facility must have on site for dealing with an oil pollution incident
- have an arrangement with a response organization to which a certificate of designation has been issued
- hold a declaration of compliance.

The only certified response organization operating in the St. Lawrence River is the Eastern Canada Response Corporation (ECRC). ECRC supplies the equipment and staff for containment, recovery and clean-up operations following an oil spill in the river. It has three main warehouses (Verchères, Lévis and Sept-Îles) with equipment capable of handling an oil spill of up to 10 000 tonnes. This organization is funded by vessels and oil-handling facilities: the company receives an annual fee of $450 from each of the 2500 vessels transporting hydrocarbons along the St. Lawrence and royalties of 39.1¢ for each tonne of oil, or 19.6 ¢ for each tonne of asphalt that is transshipped (Martin 1998).

Figure 13 is a diagram of the response protocol in the event of a spill and shows the place of each public and private stakeholder within the Unified Command Structure. For spills in the St. Lawrence, response co-ordination is generally the responsibility of the CCG. The polluter (local command) takes responsibility for all operations and costs. The ECRC, the corporation called upon to respond, conducts containment, recovery and clean-up operations.



Source: Jarry 1997

Figure 13 Industry response structure: Unified command

Alongside this organizational structure, the Regional Environmental Emergency Team (REET) or *Panel of Experts* can assemble, at the site of an emergency, stakeholders who have the various skills needed to protect the environment. A REET could therefore consist of staff from Environment Canada, Fisheries and Oceans Canada, Canadian Heritage, Quebec's ministries of Environment (MEQ) and Agriculture, Fisheries and Food (MAPAQ), along with the Public Health Directorate, and private-sector stakeholders, NGOs, municipalities, and universities.

The task of REET members is to "pool their knowledge, identify the environmental concerns associated with the accident, share the scientific and technical advice provided by their respective organizations, and establish a consensus regarding the ecosystems to be protected and the actions to be given priority" (Environment Canada 1994b). The REET co-ordinator can then provide the local command with a joint response concerning the operation implementation strategy. In accordance with the Act, the three priority response sectors, Quebec City, Montreal and Sept-Îles, now have an emergency response plan (Martin 1998).

Biotreatment, burning, spill-treating agents and mechanical clean-up are a few of the many theoretically appropriate spill clean-up techniques that exist. The first three are hardly ever used in Quebec: biotreatment is increasingly losing favour with the scientific community, and burning is not used because of the sensibilities of riverside residents and the lack of technical means for this type of response. The use of spill-treating agents, which are not readily available in Quebec, is still controversial (Jarry 1995, in Guerrier and Paul 1996).

We should also mention that all costs associated with an environmental mishap are chargeable to the polluter under the "polluter pays" principle defined in the *Canada Shipping Act*. No financial assessments have been made of the total costs incurred in connection with spills that have taken place. The Canadian Coast Guard's expenses for its emergency-response role as co-ordinator or federal monitoring agency was $57,000 in 1994, $193,000 in 1995, and $284,000 in 1996 (Savard 1997).

3.4.4 Synopsis

Table 21
Oil spills in the St. Lawrence River:
Summary of the issues

Pressure components	State components	Response components
Dangerous goods made up around 60% of the 110 Mt of goods handled by ports on the St. Lawrence in 1995. The Port of Quebec handles the largest quantities (10 Mt) of dangerous goods, 99% of which are petroleum products. Frequency of spills (1993–96): 50 to 55 per year. Between 1975 and 1994, there were 968 spills in five ports (48 per year); 87% caused by shipping; less than 1 t in 80% of cases; in six cases, the volume was between 100 t and 1000 t. Around 95% of spills occur in ports (small volumes). Spills due to collisions are somewhat rare, but involve larger volumes.	Environmental impacts vary according to the nature of the product, the size of the spill, the time of year, the location and the spill frequency, etc. There is little data available to assess the scope and the extent of the effects of spills on organisms.	PREVENTIVE MEASURES Numerous government services help improve marine safety and reduce the risks of environmental catastrophes: pilotage, aids to navigation, communication and traffic systems, close monitoring of water levels, waterway maintenance, ice breaking, etc. Several regulatory measures have been implemented nationally and internationally to protect the environment. Ports and vessels transporting dangerous goods must have an emergency response plan. PROTECTIVE MEASURES Certified response agency: ECRC (containment, recovery and cleaning), in Montreal, Lévis and Sept-Îles.

3.5 WAVE ACTION

Wave action refers to a disturbance created by waves from motorized vessels that can cause shore erosion. A vessel in motion causes divergent and cross-sectional wake waves that, respectively, touch the shore at an angle and perpendicularly (Panasuk 1987). The vessel's thrust causes a slight increase in the water level (bow wave), followed by a trough, a drawdown of the water level created by the propeller drawing in water and hull suction; this is followed by a counterwave, a sudden surge in the water level (Panasuk 1987).

Although shoreline erosion can be aggravated by anthropogenic factors, it is primarily a natural process involving, successively or simultaneously, and with differing strengths, wind, ice, water levels, currents and runoff. The degree of erosion will also depend on shore characteristics such as the slope, sediment texture, orientation vis-à-vis the erosive forces and the type and extent of plant cover (Ouellet and Baird 1978).

3.5.1 Pressure components

The variables that determine the force of the waves generated by a motorized vessel are its speed, tonnage, hull shape, the distance between the vessel and the shore and the wave frequency (period). The only available data are for commercial shipping, as no overall information has been compiled on the magnitude and the extent of the impact of wake waves from pleasure craft in the area under consideration.

Panasuk (1987) collated studies on shoreline erosion in the St. Lawrence, starting with the first research projects carried out in the 1960s, for the specific purpose of assessing the effects of wave action. Distance criteria set at that time (Table 22) are still used to assess the extent to which wave action contributes to shore erosion (see Brebner 1967 and Public Works Canada 1968, in D'Agnolo 1978). Thus, it is held that if the distance (d) between the shore and the centre of the ship channel is less than 305 m (1000 feet), erosion is mainly (90%) due to shipping. Between 305 m and 610 m, there is a linear relationship whereby, between 305 m and 457 m (1500 feet), shipping plays a greater role than the wind, while between 457 m and 610 m (2000 feet), the opposite is true. Lastly, beyond 610 m, erosion is essentially (90%) attributable to wind action (Table 22). According to the studies, the equivalence point for the two variables would be between 396 m (1300 feet) and 457 m (D'Agnolo 1978). It should be remembered that these data refer to snapshot measurements of waves and do not represent the relative importance of each of the two variables for a given period.

Table 22
Distance criteria used to assess the relative contributions of wind and shipping to shore erosion

Distance	Relevant variables
d < 305 m	Erosion due to shipping (90%)
305 m < d < 457 m	Shipping > wind
457 m < d < 610 m	Wind > shipping
d > 610 m	Erosion due to wind (90%)

Source: D'Agnolo 1978.

Note: d = distance between the shore and the centre of the ship channel

This is precisely what Ouellet (1992a, 1992b) wanted to assess in the fall of 1991 at two sites (Sainte-Marthe-du-Cap-de-la-Madeleine and Champlain) where the shores are, respectively, 1650 m and 275 m from the centre of the ship channel. A comparison of the energy of wind-generated waves with that of ship-generated waves shows that the latter are responsible for 10% (8–11%) of the erosion at the first site and 30% (26–35%) at the second site. According to a study conducted at these two sites in 1985, wave action from ships was responsible for 24% (23–25%) of the erosion at Sainte-Marthe-du-Cap-de-la-Madeleine and 45% (31–56%) at Champlain (Ouellet 1987, 1985). The author considers that these differences are mainly due to the reduction of vessel traffic in recent years, but the distance between the channel and the shore, the time of year, the winds used to re-create the waves and the fact that no erosion threshold has been set also play a role.

There are various ways of calculating wave energy; in some cases, assessing the relevant parameters can be critical. Thus, it is essential to know the wave period to determine the boundary conditions beyond which erosion takes place; using too large a wave period will exaggerate the effect of ship-generated waves compared to wind-generated waves (Ouellet 1992b). Panasuk (1987) considers that most wave action studies have focused on surge periods —

as in Ouellet's studies (1992a, 1992b, 1987, 1985) — and overlooked drawdown periods, even though the latter may be responsible for a substantial proportion of shore erosion, an opinion shared by Ouellet (1992a, 1992b). Panasuk (1987) reports maximum water-level variations of 1.14 m, or 44 cm above and 70 cm below the initial level — the entire force of the return flow. This variation, which takes a minute to complete, equals more than 70% of the annual variation between the highest and the lowest water levels. However, Panasuk (1987) does not state how these variations compare with those from wind-generated waves.

There is fairly accurate information about the extent and severity of shore erosion in the freshwater section, i.e. the stretch between Cornwall and the eastern tip of Île d'Orléans (Argus 1996a, 1991). However, it is not possible to distinguish natural from anthropogenic erosion, because of the number of factors involved and their relative importance at different times of year. A study of shore erosion and sediment transport in the Varennes–Contrecœur stretch of the river, conducted by the St. Lawrence Centre, is intended to better distinguish between these factors. Nevertheless, there is substantial shoreline erosion in some areas, specifically between Montreal and Sorel, where the shores of islands in the Contrecœur and Berthier–Sorel archipelagos are particularly affected (Argus 1996a, 1991). According to these latest studies, the highest return flow rates are found on shores located less than 600 m from the centre of the ship channel, the resulting erosion being largely due to ship-generated waves.

3.5.2 Effects on the environment (STATE COMPONENTS)

In 1994, a detailed inventory was used to assess the state of the shores between Cornwall and Île d'Orléans and to group them by problem type (Argus 1996a). These data are featured in Figure 14 and in Table 23. Of the 1532 km of shoreline in the Fluvial Section, 55% (848 km) is in its natural state: 169 km on the north shore, 220 km on the south shore and 459 km on islands. Upstream from Repentigny, only 20% (95 km) of the shores are in their natural state compared with 80% (458 km) in the downstream portion of the Fluvial Section and 61% (296 km) in the Fluvial Estuary.

In the Fluvial Section as a whole, erosion affects nearly 400 km of shoreline, three-quarters of which (301 km) are on islands. The most affected sector is between Repentigny and

Pointe-du-Lac, where 268 km (67%) of the shores are eroded, including 232 km of island shoreline (Table 23).

Table 23
Breakdown of natural shores subject to erosion between Cornwall and Cap-Tourmente

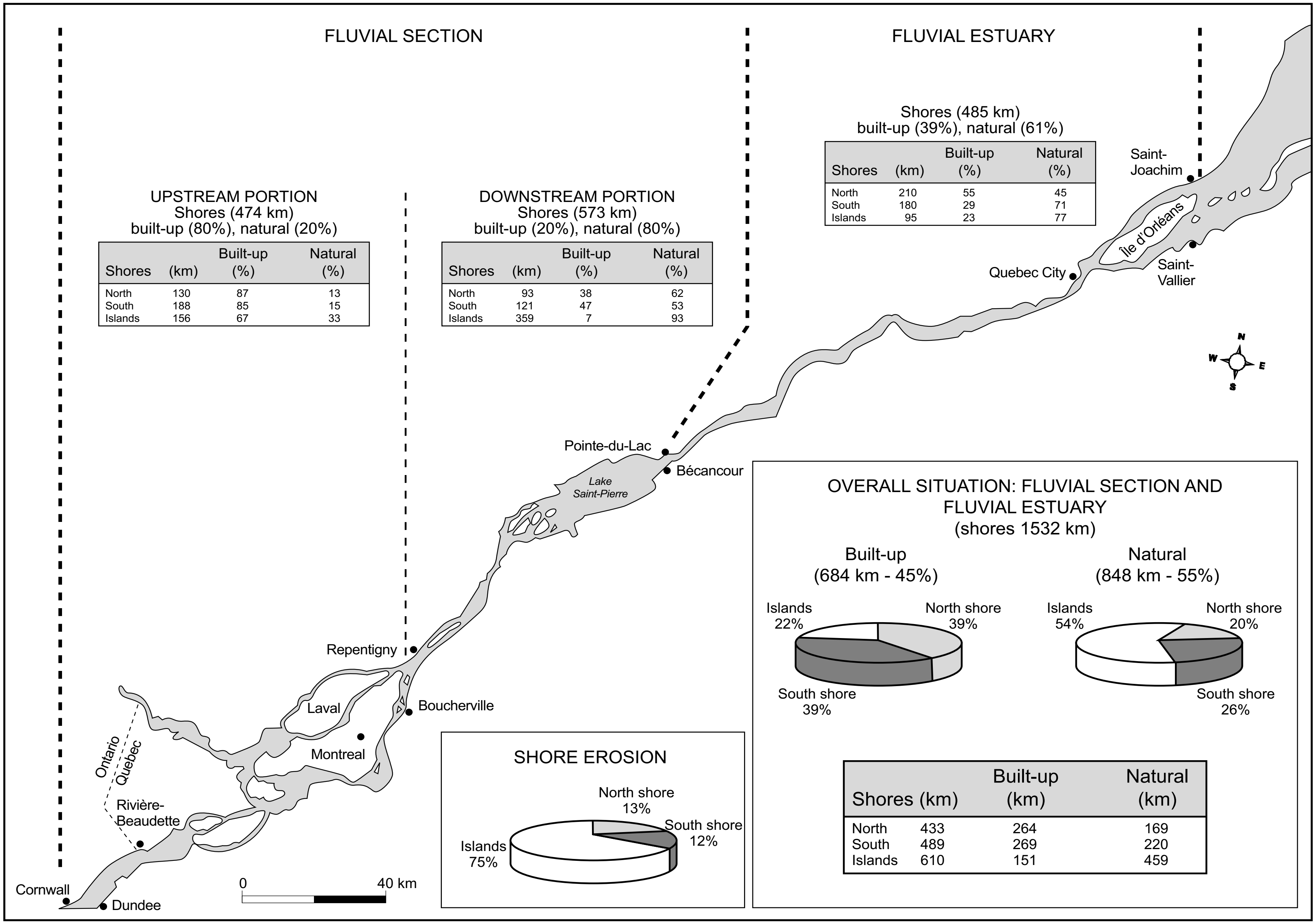
	North shore	South shore	Islands	Total
Section	Length of eroded shoreline (km)			
Cornwall–Repentigny	5.8	4.2	28.6	38.6
Repentigny–Pointe-du-Lac	15.7	20.3	231.8	267.8
Pointe-du-Lac–Cap-Tourmente	30.1	21.5	40.8	92.4
Total	**51.6**	**46.0**	**301.2**	**398.8**

Source: Argus 1996a.

Erosion affects 47 km of the 83 km of shoreline on the 50 islands under federal jurisdiction between Montreal and Sorel, with over two-thirds occurring in the archipelagos between Contrecœur and Berthier–Sorel (Table 24; Lehoux et al. 1997). Half of the approximately 20 km of eroded shores located less than 610 m from the centre of the ship channel are, in fact, less than 305 m therefrom (Table 25); 19 of the 50 islands are affected. In the various archipelagos, the shores affected are as follows: Varennes (3.25 km), Sainte-Thérèse (1.25 km), Verchères (3.7 km), Contrecœur (6.8 km) and Berthier–Sorel (4.7 km). The majority of eroded areas either affect or are adjacent to waterfowl habitats.

3.5.3 Action (Response components)

Two types of measures can be used to counter shore erosion caused by wave action: preventive measures intended to reduce impacts at source and protective measures aimed at protecting the affected environments.



Source: Based on data from Gingras et al. 1997, Argus 1996a, Bernier et al. 1998.

Figure 14 State of St. Lawrence shores between Cornwall and Île d'Orléans in 1994

Table 24
Breakdown of erosion on the 50 islands under federal jurisdiction between Montreal and Sorel

Archipelago	Number of islands	Perimeter (km)	Eroded shores (km)	Eroded shores (%)
Boucherville	5	13.6	4.45	33
Sainte-Thérèse	1	1.8	1.8	100
Varennes	4	7.25	4.25	59
Verchères	4	4.1	3.7	90
Contrecœur	27	22.35	13.85	60
Berthier–Sorel	9	33.55	18.95	56
Total	**50**	**82.65**	**47.0**	**57**

Source: Lehoux et al. 1997.

Table 25
Breakdown of eroded shores less than 610 m from the centre of the ship channel on islands under federal jurisdiction between Montreal and Sorel

	Length of eroded shoreline (km)		
Archipelago	< 305 m*	305–610 m**	Total
Varennes	2.0	1.25	3.25
Sainte-Thérèse	0.9	0.35	1.25
Verchères	2.8	0.9	3.7
Contrecœur	0.7	6.1	6.8
Berthier–Sorel	3.55	1.15	4.7
Total	**9.95**	**9.75**	**19.7**

Source: Lehoux et al. 1997.

* Located less than 305 m from the centre of the ship channel.
** Located between 305 m and 610 m from the centre of the ship channel.

VESSEL SPEED LIMITS

Our knowledge of the relative importance of the different factors involved in shore erosion is quite limited. There is, however, a consensus regarding the impacts of vessel speeds and water levels: wave height and force are proportional to vessel speed and, during the spring freshet, high water levels carry off large areas of sloping shores. Some scenarios have been suggested regarding the order of events and critical periods. In some instances, the base of the sloping shore carried off by the freshet may have been destabilized during the previous year by ship-generated waves and wind action when water levels were low (D'Agnolo 1978); in other cases, the slope, no longer protected by the lower part of the bank, may have been subjected to the full force of the high water levels (Rouleau 1997).

Relevant information about speed limits to be observed in a given body of water or section is contained in the Canadian Coast Guard's *Notices to Mariners* and *Notices to Shipping* (DFO 1998b). For instance, *Notice to Mariners No. 12* warns mariners about the dangers of excessive speeds to people and habitats and encourages caution. This notice states that these voluntary measures are more flexible than strict regulations, which "might impose unrealistic speed restrictions on some vessels, thereby making navigation unsafe by reducing their ability to maintain steerageway, or cause undue economic and recreational restraints" (DFO 1998b). It is useful to remember that these are voluntary measures and that the ultimate responsibility to comply with these notices lies with the person in charge of the vessel. An awareness program aimed at the St. Lawrence River Pilots Association was also introduced.

In the sector most affected by wave action from commercial shipping, the Contrecœur and Berthier–Sorel archipelagos, there are no such strict measures for any period of the year. Greater knowledge of the critical periods and conditions, as well as of factors conducive to shore erosion, would make it possible to give users better information; this, in turn, would encourage more ready acceptance of regulatory measures.

SHORE PROTECTION

The Canadian Coast Guard took over management of the shore protection program from Public Works Canada. The program was intended to monitor erosion caused by commercial shipping or aid to navigation facilities (CCG 1993a). It funded the construction of protective structures on private properties worth more than double the project cost. When these properties were less than 610 m (2000 ft) from the ship channel, the CCG paid the entire cost of the work; the contribution dropped to 50% for shores that are between 610 m and 915 m (3000 ft) away. It was felt that erosion on shores more than 915 m from the centre of the ship channel was not due to commercial shipping (CCG 1993a).

In the 1980s, the CCG spent around $1,500,000 on this program, with grants going to municipalities such as Varennes, Verchères, Contrecœur, Champlain, Sorel and Deschaillons. In recent years, funding under the program decreased dramatically. The program was abolished in 1997 by Fisheries and Oceans Canada, although a contribution was made to complete work on Saint-Quentin Island, opposite Trois-Rivières (Rouleau 1997). The commercial fleet does not help finance measures to protect and restore shores eroded by wave action; this is not the case with spills, where whoever is responsible for the impact contributes to the response measures.

Besides rip-rap, there are several methods for stabilizing banks on land and in water (Argus 1996a, Massicote et al. 1996). Pilot projects have been conducted in the Îles de la Paix, Varennes, Contrecœur (Argus 1996b) and Berthier–Sorel archipelagos. Because of the prohibitive cost of materials and labour for stabilization projects, larger-scale projects are not carried out. Studies are under way at the Canadian Wildlife Service to determine action priorities for the islands under federal jurisdiction; these priorities are based on potential losses of productive habitats and threatened or vulnerable species (Lehoux 1998).

3.5.4 Synopsis

Table 26
Effects of ship-generated wave action on the shoreline of the St. Lawrence River: Summary of the issues

Pressure components	State components	Response components
Erosion is a natural phenomenon aggravated by anthropogenic factors. It involves several variables: wind, ice, current, runoff and bank characteristics (slope, orientation relative to erosive forces, sediment texture and the type and extent of plant cover). Wave action depends on vessel speed, tonnage and hull shape, the distance from the shore and the frequency with which the waves are produced. Studies only focus on the effects of waves with short wave periods and not on those with long wave periods. A snapshot measurement reveals that if the distance (between the shore and the centre of the channel) < 305 m → erosion is due to ships (90%); if the distance > 610 m → erosion is due to the wind (90%). In the fall of 1991 wake waves were responsible for 30% (Champlain) and 10% (Cap-de-la-Madeleine) of erosion. Quite a bit is known about the extent and the scale of erosion in the freshwater sector, but nothing about the proportions respectively due to natural and anthropogenic variables. Little is known about critical periods for erosion and event scenarios.	Fifty-five percent of the 1532 km of shoreline in the Fluvial Section is in its natural state, by far the largest part of it being downstream from Repentigny. About 400 km of shoreline is eroded, 300 km of which is on the islands. The Contrecoeur and Sorel archipelagos are the most affected. 20 km of the eroded shores are less than 610 m from the centre of the ship channel, including 10 km that are less than 305 m away. Shores may retreat up to 3 m/year. There are substantial losses of waterfowl habitat.	PREVENTIVE MEASURES *Notice to Mariners No. 12* contains information about the dangers of excessive speeds to people and habitats (voluntary measure). An awareness program for pilots has been introduced. There are no strict preventive measures for the most affected sectors (Sorel and Contrecoeur archipelagos). PROTECTIVE MEASURES The federal shore protection program was abolished in 1997 (funding for protective works for shores less than 915 m from the centre of the ship channel). The commercial fleet does not contribute to restoration programs. There are several shore protection methods and pilot projects have been conducted upstream from Sorel.

3.6 BALLAST FLUSHING AND INTRODUCTION OF NON-NATIVE SPECIES

Since the introduction of steel hulls in the middle of the 19th century, water has regularly been used as ballast in the ballast tanks of ships. Discharging ballast water is the most effective way to disperse non-native species and has no parallel on land (Carlton and Geller 1993). The process is as follows: when a vessel leaves a river or sea port it takes on a quantity of water proportional to the cargo it is carrying (the less cargo there is, the more water is introduced into the ballast tanks); this water is then completely or partly discharged near the river or sea port where the cargo is unloaded or loaded. Depending on where it was taken on, the water (and sediments, if it was drawn from a shallow area) may contain a potentially rich assemblage of species that have a planktonic stage, including a mass of micro-organisms, invertebrates, algae and fish. In spite of the difficult conditions, a fraction of the organisms trapped in the ballast tanks will survive the voyage and may be introduced into new ecosystems (Carlton 1996a, Locke et al. 1993).

Increased vessel size, the dramatic growth of marine traffic during recent decades — in terms of cargo size, the number of trips and cargo ports — and greater navigation speeds mean that there is an ever-increasing risk of proliferation of non-native species. It is estimated, for example, that the world's commercial fleet transports around 3000 species every day (Carlton and Geller 1993) and discharges several hundred million tonnes of ballast water each year (Locke et al. 1993).

An estimated 10–15% of introduced species become invasive and have serious impacts on the environment (ANSTF 1998, Williamson and Fitter 1996). However, when all the cryptogenic species are included — those species that cannot be definitively categorized as being native or exotic — this percentage may increase (Carlton 1996b). The speed at which a species spreads will depend on its own characteristics (its propagation method) and those of the receiving environment (hydrodynamics, physical and chemical conditions). An invasive species normally has some of the following attributes: abundant and widely distributed in its original range, highly environment-tolerant, high genetic variability, short generation time and early sexual maturity, rapid growth, high reproductive capacity, broad diet (opportunistic feeding), gregariousness, possessing natural dispersal methods and may benefit from human activity (Ricciardi and Rasmussen 1998).

The introduction of exotic species has an impact on the environment, the economy and public health (Table 27). Unlike chemical contamination, biological infestation can spread and is permanent; while it is possible to check the propagation of an introduced species, it is impossible to eradicate it completely. The pressing need to limit the introduction of new species into aquatic ecosystems is thus readily understandable.

Table 27
Type of impacts that may follow the introduction of non-native species

Environmental effects	Economic impacts	Public health considerations
Predation	Industrial water intakes	Risk of cholera (bacteria)
Parasitism	Municipal water intakes	Risk of diarrhea (dinoflagellates)*
Competition	Nuclear power plant water intakes	
Introduction of new pathogens	Commercial fishing	
Gene pool	Sport fishing	
Habitat alteration	Water sports	

Source: ANSTF 1998.

*Bourgeois et al. 1999

3.6.1 Pressure components

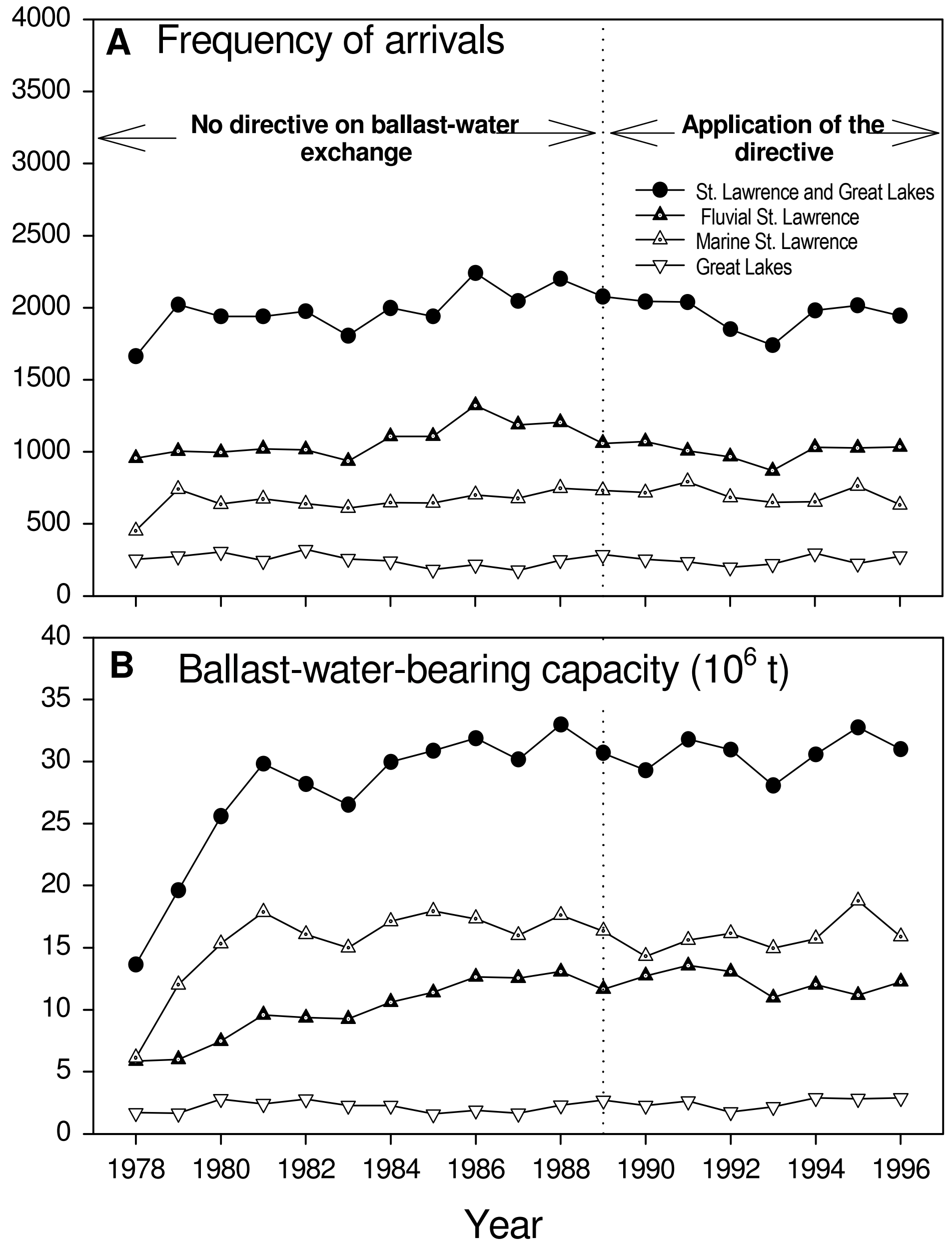
According to a recent study carried out under St. Lawrence Vision 2000 (Bourgeois et al. 1999), there was very little change in the volume of foreign vessel traffic on the St. Lawrence River between 1978 and 1996, the average being 1972 vessels per year (Figure 15, Table 28).

Approximately 250 (13%) of these sail as far as the Great Lakes, while the remainder dock at a port in the marine section (674 vessels, 34%) or in the freshwater section (1048 vessels, 53%). The distribution of the estimated total volume of ballast these vessels can carry (approximately 29 Mt per year) is as follows: 8% for the Great Lakes, 38% for the freshwater section and 54% for the marine section (Figure 15, Table 28).

Table 28
Statistics on the number of stopovers, vessel types, ballast-bearing capacity and origin of foreign marine traffic using the St. Lawrence navigable channel between 1978 and 1996

	Annual average (± standard deviation)	Percentage (%)
Arrivals		
Great Lakes	249 ± 39	13
Fluvial St. Lawrence	1 048 ± 104	53
Marine St. Lawrence	674 ± 75	34
Total	1 972 ± 140	
Type of vessel		
General cargo	738 ± 75	38
Tanker	209 ± 44	11
Bulk cargo carrier	1 020 ± 141	52
Average tonnage (t)		
Ballast-bearing capacity (Mt)	28.7 ± 4.7	
Great Lakes	2.3 ± 0.5	8
Fluvial St. Lawrence	10.8 ± 2.3	38
Marine St. Lawrence	15.6 ± 2.8	54
Total	20 743 ± 2 762	
Season		
Winter	265 ± 50	13
Spring	580 ± 56	28
Summer	582 ± 46	28
Fall	618 ± 52	30
Region of origin - UN FAO classification		
Northwest Atlantic	213 ± 38	11
Northeast Atlantic	1 002 ± 91	52
Mediterranean Sea	220 ± 39	11
West central Atlantic	347 ± 56	18
Other FAO region	130 ± 27	7

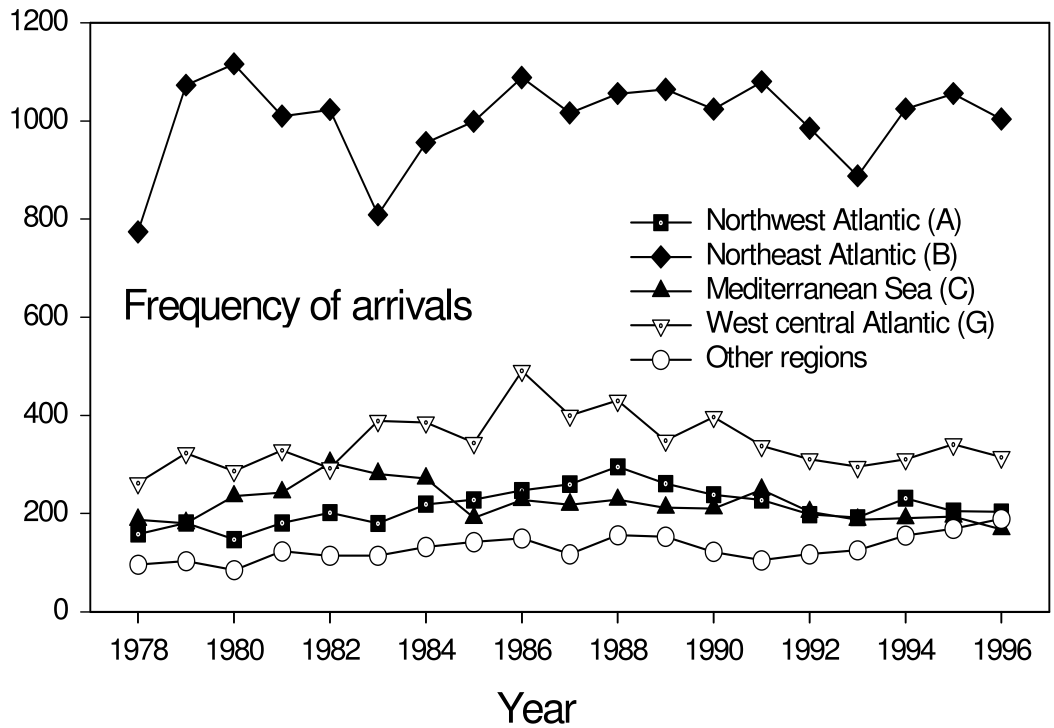
Source: Bourgeois et al. 1999.



Source: Bourgeois et al., 1999.

Figure 15 Trends in foreign vessel traffic and ballast-water-bearing capacity in the St. Lawrence waterway from 1978 to 1996

The substantial increase in the ballast-bearing capacity between 1978 and 1981 can be attributed to the increased size of vessels bound for marine ports (Bourgeois et al. 1999). Over 50% of the vessels come from northeastern Europe (according to the classification system of the Food and Agriculture Organization of the United Nations, FAO), followed, in descending order, by vessels from the west central Atlantic (20%), the northwest Atlantic (10%) and the Mediterranean–Black Sea area (10%) (Figure 16).



Source: Bourgeois et al., 1999.

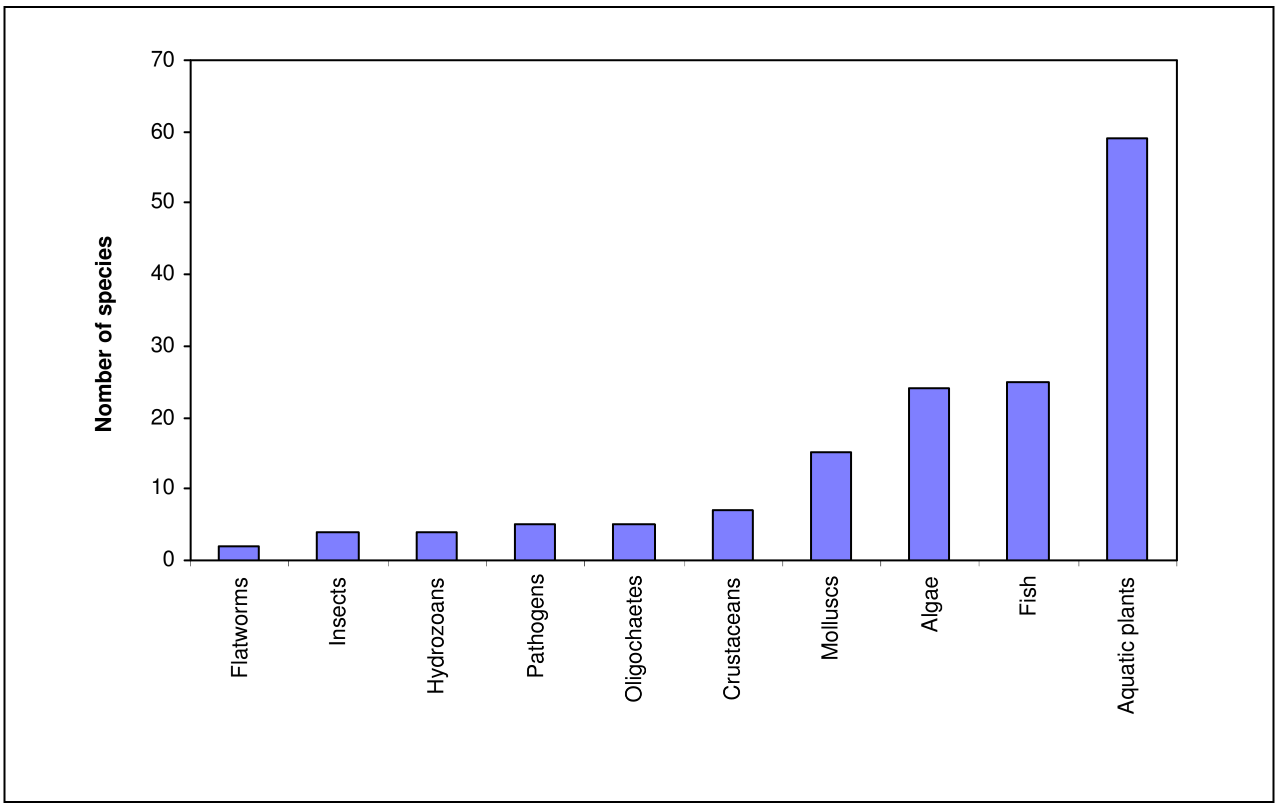
Figure 16 Trends in vessel traffic using the St. Lawrence waterway from 1978 to 1996, by region of origin (FAO classification system)

The volumes of discharged ballast water depend not only on the size of the vessels but also on the commercial characteristics of each port. Thus, in 1996, 87% of vessels bound for the marine section reported they were carrying ballast, while figures for the freshwater section and the Great Lakes were 20% and 4%, respectively (Bourgeois et al. 1999). The data for 1994 to 1996 show that the annual amounts of ballast water discharged in these three sections were 10.3 Mt, 2.7 Mt and 0.25 Mt, respectively. In the freshwater section, activities are concentrated in the Port of Montreal (70% of stopovers and 60% of the ballast-bearing capacity) and, to a lesser degree, in the Port of Quebec (19% of stopovers and 27% of the ballast-bearing capacity); on the North Shore, the ports of Port-Cartier, Sept-Îles and Baie-Comeau are the busiest in the marine section, with 60% of stopovers and 90% of the ballast-bearing capacity (Bourgeois et al. 1999).

The data examined by Bourgeois et al. (1999) cannot provide accurate information about the handling of ballast water — that is, where and at what depth, ballast water was exchanged as recommended in a preventive measure adopted in 1989 (*Voluntary Guidelines for the Control of Ballast Water Discharges from Ships Proceeding to the St. Lawrence River and Great Lakes* or VGCBWD; see Section 3.6.3). Moreover, according to the authors, there has been hardly any follow-up to this control measure. In fact, even vessels scrupulously following the VGCBWD could still transport freshwater-tolerant species (Locke et al. 1993). Data on the number and density of species present in the ballast tanks of ships visiting ports in the area under consideration are very sketchy (see Gauthier and Steel 1996, and Section 3.6.2) and cannot provide a detailed portrait of the degree and the extent of the pressures on the St. Lawrence ecosystem. It appears, therefore, that ballast water is still bringing pressure to bear on the integrity of the St. Lawrence, although the risks have been reduced as a result of the measures introduced in May 1989.

3.6.2 Effects on the environment (STATE COMPONENTS)

The first appearances of exotic species in the Great Lakes–St. Lawrence Basin date back to 1810 (Mills et al. 1993). This group of authors have listed 139 non-native species belonging to several taxonomic groups; 40% of them appeared after 1950. Although the sources from which the Great Lakes–St. Lawrence Basin came to be infested by these organisms have never been identified, ballast water is suspected of being the main vector. Mills et al. (1993) claim that between 1960 and 1991, or immediately following the construction of the St. Lawrence Seaway (1954–59), which gave ocean-going vessels access to the Great Lakes (Figure 17), ships were responsible for introducing 29 species out of a total of 45. This estimate is based on a series of assumptions, as it could not be established beyond doubt in any of these cases that ballast water was the sole source of infestation (Gauthier and Steel 1996).



Source: Based on data from Mills et al. 1993.

Figure 17 Number of species introduced into the Great Lakes–St. Lawrence, by taxonomic group

Several of these species have not yet been detected downstream of the Great Lakes. Between 10 and 15 of the 139 introduced species have had noticeable ecological and economic effects. Five species, however, have had particularly significant effects on the Great Lakes (IJC and GLFC 1990). Only one of them, the Zebra Mussel, is found throughout the freshwater section

(SLC 1996a). The distribution of the Quagga Mussel (*Dreissena bugensis*) is similar to that of the Zebra Mussel, although it has a much lower density (SLC 1996a).

The **Sea Lamprey** (*Petromyzon marinus*) is native to coastal regions on both sides of the Atlantic. This organism, which is a parasite living on other species of fish, seems to have entered the Great Lakes from the Welland Canal in 1921. The lamprey quickly devastated commercial fish populations, including Lake Trout. It is estimated that the five Great Lakes are home to an adult population of 575 000 lampreys, in spite of the $168 million spent to control them (Gauthier and Steel 1996).

The **Sand Flea** (*Bytotrephes cederstroemi*), a carnivorous cladoceran around 1 cm long, appeared in the 1980s. This species feeds on other cladocerans, especially *Daphnia* which are also eaten by several planktivorous fish. Its distinguishing feature is a long spine that partly protects it from predation by small fish. The appearance of *Bytotrephes* in Lake Michigan coincided with a dramatic reduction of the *Daphnia* population (Lehman and Cáceres 1993); fish populations may also be affected by the competition. It is difficult to predict the long-term impacts of this organism. However, the ability (or inability) of some fish to consume this organism seems to be a determining factor in the evolution of the food chain in some parts of the Great Lakes (Lehman and Lehman 1996).

The **Pope** or **Ruffe** (*Gymnocephalus cernuus*) has been observed in Lake Superior since 1986. This small (10–15 cm long) member of the perch family seems to have been introduced at the Port of Duluth. In the St. Louis River, near Duluth, Yellow Perch populations and those of other small fish eaten by piscivorous fish dropped dramatically as Ruffe populations increased. The Ruffe's characteristics could allow it to spread quickly in favourable environments; its chances of reaching the fluvial sector in the near future are limited, however (de Lafontaine 1997).

The **Round Goby** (*Neogobius melanostomus*) was observed in the early 1990s in the St. Clair River downstream from Lake Huron. This fish likes to live on rocky bottoms and can grow to a length of 25 cm. It is now found at several sites in the Great Lakes. When a few individuals reach a favourable site, the populations can grow very quickly. As many as 20 individuals per square metre have been counted (Marsden and Jude 1995).

The **Zebra Mussel** (*Dreissena polymorpha*), a bivalve mollusc native to the Caspian Sea, a landlocked sea in western Asia, was seen for the first time in Lake St. Clair between lakes Huron and Erie in 1988. Since then it has propagated at an astonishing rate throughout the Great Lakes Basin and in the navigation channels linking the lakes to one another or to the Hudson and Mississippi rivers, in certain stretches of these rivers and their tributaries, and in Lake Champlain and its outlet, the Richelieu River (ANSTF 1998). It has also been observed right along the freshwater section of the St. Lawrence as far as Île d'Orléans (SLC 1996a). Further downstream the salinity of the water would prevent it from propagating. Its distribution in North America and Europe is closely linked to waterways (Johnson and Carlton 1996). The availability of solid substrates could also be a factor limiting its distribution and dispersal in the St. Lawrence (Mellina and Rasmussen 1994).

The Zebra Mussel is a sedentary organism that filter-feeds on particles in the water column. It is very prolific: a female can lay up to 40 000 eggs. Gametes are fertilized in the water column. The veligerous larvae remain in the water mass (planktonic) for three to four weeks before attaching themselves to solid substrates such as rocks, wood, metal, cement, certain water plants and even other hard-shelled organisms such as unionid mussels and crayfish (Kilgour and Mackie 1993). Zebra Mussels can reach densities of around 200 000 individuals/m^2 (Mackie 1991). At such densities, they can have serious impacts on the economy — fouling municipal or industrial water intakes — and on the environment — reducing primary production (Holland 1993, Leach 1993), and causing a shift in the food chain from the pelagic to the benthic zone (Lowe and Pillsbury 1995, Skubinna et al. 1995). The environmental impacts of this species in the fluvial sector of the St. Lawrence are less well documented, however.

The expansion of the Zebra Mussel's range in the St. Lawrence has been monitored since 1990 (Lapierre et al. 1994, SLC 1996a). Navigation buoys marking the ship channel are used to estimate annual recruitment. The results obtained using this approach indicate that there was high recruitment at most of these sites in 1990, rising still further in 1991 before dropping off dramatically by 1996, the last year for which data are available (Table 29).

Table 29
Mean densities of Zebra Mussels on navigation buoys between Lake Saint-François and Cap-aux-Oies, from 1990 to 1996

	Number of individuals per square metre						
Area	1990	1991	1992	1993	1994	1995	1996
Fluvial Section							
Lake Saint-François	20.53	3.08	3.63	1.64	2.22	0.16	0.44
Beauharnois Canal	2.50	0.48	0.90	0	0.52	0	0.08
Lake Saint-Louis	0.14	0.34	0.01	3.31	0.17	0.27	0.40
Port of Montreal	0.24	2.71	0.04	0.42	0	0.33	0.01
Longue-Pointe–Lake Saint-Pierre	0.01	0.14	0.04	0.01	0	0.06	0
Fluvial Estuary							
Lake Saint-Pierre	0	0.22	0.03	0.02	0	0.45	0
Lake Saint-Pierre–Donnacona	0.05	0.64	0.01	0.12	0.06	0.29	0.01
Donnacona–Quebec City	0.04	3.48	0.05	1.80	0.30	1.12	0
Quebec City–Sault-au-Cochon	0.06	23.76	0.20	2.34	0.20	1.18	0
Sault-au-Cochon–Cap-aux-Oies	0	-	0	0	0	0	0

Source: Quilliam and Millet 1998 based on data from SLC 1996a.

This trend does not indicate that the Zebra Mussel is in decline. Proliferation of the mussels seems linked to flow conditions at the time the veligerous larvae attach themselves to solid substrates. Thus, in years when the flow is strong, the mussels are less abundant and there is greater spatial heterogeneity than in years when the flow is weak (Cusson 1997). Other factors may influence annual recruitment; however, the Zebra Mussel has not been present in the St. Lawrence long enough for its population dynamics to be well understood. The number of Zebra Mussels at 13 sites between Cornwall and Île d'Orléans (Table 30) increased greatly between 1991 and 1996, but not at the Louise Basin in the Port of Quebec (Lapierre et al. 1994, SLC 1996a). The largest densities recorded at these sites are clearly lower than in the Great Lakes and other bodies of water in North America (ANSTF 1998, Mackie 1991).

Table 30
Mean densities of Zebra Mussels at various sites in the St. Lawrence River between 1990 and 1996

	Number of individuals/m^2		
Stations	1991	1992	1996
Cornwall (W)	0	--	841.3
South Lancaster	--	40.5	109.8
Beauharnois	9.0	22.1	1 131.3
Pointe Péladeau	0	--	805.4
Boucherville	1.4	--	21.4
Tracy (W)	5.9	--	172.9
Île Lapierre	0.5	--	4.3
Île aux Sternes	0	--	3.1
Port of Bécancour (W)	18.2	1 631.1	10 035.0
Portneuf (W)	0	--	14.2
Louise Basin (W)	--	20 620.0	2 485.8
Lévis Wharf (W)	6.0	--	223.6
Île d’Orléans	--	287.3	454.1

Source: Lapierre et al. 1994, SLC 1996a.

(W): wharves

The distribution of non-native species in the marine section is not well documented. Due to the lack of baseline data, it is not possible to determine whether some species of toxic dinoflagellates, which are responsible for paralytic shellfish poisoning, are indigenous or not (Bourgeois et al. 1999).

Gosselin et al. (1995, in Gauthier and Steel 1996) report that, in the summer of 1992, 62% of the 60 ballast water samples taken from vessels in the Magdalen Islands contained low concentrations of dinoflagellates (single-celled algae) considered toxic. In another study (Roy 1994, in Gauthier and Steel 1996), dinoflagellate cysts were found in three vessels. In 1990 and 1991, 99 species of phytoplankton, 69 diatoms and 30 dinoflagellates were counted in 86 vessels bound for the Great Lakes and the upper reaches of the St. Lawrence (Subba Rao et al. 1994, in Gauthier and Steel 1996).

Pleasure craft can play a substantial role in the spread of non-native species from one infested drainage basin to another, or to areas further upstream in the same watercourse. Johnson et al. (1999), looking at boats leaving Lake St. Clair, discovered veligerous larvae in all the compartments — in descending order, fish tanks, bait buckets, bilge water and engine cooling water — they sampled. They also found adults and juveniles. Contrary to what might have been expected, the latter were not found on the hull but were attached to weeds pulled up by, and wrapped around, the boat's towrope or, less frequently, on the anchor. This shows the importance of truly knowing what the dispersal vectors are to promoting the most effective control methods (Johnson 1999, Johnson et al. 1999).

Not counting the St. Lawrence and the Richelieu River, the extent of Zebra Mussel dispersal in bodies of water in Quebec is not known, nor is the infestation potential of pleasure craft. The fact that the presence of this species has not yet been reported in lakes has more to do with the limited detection efforts than with its low dispersal. Bergeron (1995) assessed the Zebra Mussel's potential for survival in 2934 lakes and 144 rivers in Quebec based on its tolerance of certain physico-chemical variables in the water (pH and calcium level). Environmental characterization data are sketchy, thereby limiting the scope of the diagnosis. Nevertheless, it was shown that the conditions in 97% of the lakes are not favourable to the growth of Zebra Mussels — i.e. 55% of the 152 lakes south of the St. Lawrence and 97% of the 2782 lakes north of the St. Lawrence. The alkaline conditions ($pH \geq 7.4$) and the extensive mineralization ($Ca^{++} \geq 20$ mg/L) upon which this pest species thrives were mostly found in some lakes in the Lower St. Lawrence, in the Gaspé Peninsula and, to a lesser degree, in the Ottawa Valley and Abitibi regions. The alkalinity and mineralization conditions in the 58 rivers south of, and 86 rivers north of, the St. Lawrence were, respectively, 80% (of 112 stations) and 13% (of 135 stations) favourable. Most of the south shore rivers are located between the basins of the Nicolet and Châteauguay rivers. As for north shore rivers, suitable conditions are restricted to their lower reaches in the St. Lawrence Lowlands. These results could be validated by systematic sampling of the environments best suited to the propagation of Zebra Mussels.

3.6.3 Action (Response components)

With a view to preventing the introduction of non-native species, Fisheries and Oceans Canada and Environment Canada, working together with the U.S. Coast Guard, the Great Lakes Fishery Commission and representatives of the commercial fleet, developed the *Voluntary Guidelines for the Control of Ballast Water Discharges from Ships Proceeding to the St. Lawrence River and Great Lakes* (VGCBWD), which have been in effect since May 1, 1989 (CCG 1993a). As the name indicates, these guidelines are voluntary and compliance with them remains subject to the commercial fleet's willingness to co-operate. At the same time, other countries, including Australia and the United States, as well as the International Maritime Organization (IMO) adopted similar measures.

The VGCBWD document states that all ships using the St. Lawrence waterway west of 63° west longitude should exchange their ballast at sea, as far from land as practicable in a water depth of not less than 2000 m. For those ships that have not left the North American continental shelf or, when the safety of the ship requires it, the exchange may be made within the Laurentian Channel in water depths exceeding 300 m, east of 63° west longitude. The voluntary guidelines are based on the hypothesis that ballast water from the open sea contains fewer organisms than water taken in near the coast or ports, and that organisms adapted to salt water have fewer chances of surviving in fresh water, thus reducing the likelihood that non-native species will be introduced.

Bourgeois et al. (1999) pointed out that foreign ships calling at Gulf ports south of the Gaspé Peninsula and west of 63° west longitude are not subject to the VGCBWD. Although there is not much traffic there, there is still a possibility of infestation, and control measures could be applied there too. As mentioned in the previous section, because of the lack of baseline data, it is not possible to determine whether some toxic dinoflagellate species found in the Lower Estuary and Gulf of St. Lawrence are indigenous or not. Given the risks to human health and the aquaculture industry, the existing control measures could be extended to the entire St. Lawrence drainage basin.

Locke et al. (1993) tried to assess the effectiveness of the VGCBWD by monitoring transshipment operations and the type of ballast water carried by 546 foreign ships entering the Great Lakes–St. Lawrence Basin upstream from Quebec City between May 1990 and May 1991.

According to their findings, 88% of the ships complied with the VGCBWD. Some of the violators were guilty of incomplete deballasting, and therefore represented a smaller risk. The authors estimated that 26 ships may have discharged fresh water from foreign countries. Based on the type of zooplankton found in the ballast water of ships exchanging in the open sea, the authors estimated that these operations were between 67% and 86% effective. Some of the species they came across were already present in the Great Lakes. However, four new species from New Orleans and Belgium had never previously been encountered in the Great Lakes–St. Lawrence Basin and are considered potential invaders. It appears that the position of the pump intake may limit the effectiveness of the exchange by allowing some water to remain in the ballast tanks. Even if the quantities are small compared with ballast tank capacity, they can, nevertheless, contain a large number of organisms (Locke et al. 1993). Therefore, instead of being considered an impenetrable barrier for organisms, the exchange of ballast water in the open sea should be considered a form of filtering (Locke et al. 1993). In spite of the limited effectiveness of the VGCBWD, it is thought that these measures have considerably reduced the risk of species introduction and that they may even have prevented the introduction and spread of the Zebra Mussel and other species into the Great Lakes–St. Lawrence Basin (Locke et al. 1993).

Under the guidelines adopted by the IMO in 1991, as with those introduced by Australia the previous year, ships should avoid taking on ballast water in shallow areas, in sectors where dredging operations are conducted, where toxic algae blooms are observed, and where it is suspected that the water contains infectious disease agents (cholera). Such provisions could also be implemented in Canada.

Gauthier and Steel (1996) reviewed the various treatment and treatment-free management methods recommended for rendering ballast water harmless. Various methods, both physical (screening and filtering, ultraviolet rays, electric current, heating, etc.) and chemical (chlorine, copper and silver salts, ozone, hydrogen peroxide, anoxia, biocides, etc.) are used on board ship or in ports. Their performances vary and some are clearly too expensive. The solution could be integrated ballast management as suggested by Carlton et al. (1995, in Gauthier and Steel 1996). Such a strategy would include measures applicable during the crossing or when the ship calls at port, while other measures would involve changing some aspects of ship structure, new designs for ships or standards that were acceptable to the marine industry. At the international level, a task force set up by the IMO has been given a mandate to develop suitable methods for preventing infestation from ballast water (IMO 1998).

Astonishing amounts of money are spent on controlling non-native species. The millions of dollars spent every year to control the Zebra Mussel would be enough to cover the cost of preventive measures for countering upcoming invasions (Johnson and Carlton 1996). However, it is difficult to predict how successful colonization by exotic species will be. Indeed, with a long-standing transportation corridor, it is worth considering the factors that result in a species invading a particular environment in a particular year rather than 10 or 20 years previously; the facts suggest that more than one condition must be met for colonization to be a success (Carlton 1996a).

The tools available to us for predicting or monitoring invasions by non-native species are quite limited. Existing prediction and dispersal models make valid hypotheses but offer few concrete responses. Many deplore the lack of experimental data and affirm that the most reliable way to find out about an exotic species' ability to displace a native species is by closed-circuit experimentation (Carlton 1996a, Kareiva 1996). Recently, Ricciardi and Rasmussen (1998) proposed an empirical prediction method based on three criteria: *a*) identifying the potential places of origin of the invasive species and discovering their dispersal methods; *b*) selecting potential invaders using a generic biological profile common to these species (see the introduction to Section 3.6); and *c*) using historical data on invasions by these species elsewhere. Using this method, Ricciardi and Rasmussen (1998) targeted 17 invertebrate species from the Ponto Caspian basin (Black and Caspian seas and the Sea of Azov) with the potential to invade the Great Lakes–St. Lawrence Basin. This is the region from which pests such as the Zebra and Quagga mussels, the Ruffe and the Round Goby are thought to have come. The problem with such an approach is that all areas where there is intensive marine transportation are now likely to be seen as being very susceptible to infestation. Indeed, given that the Great Lakes and the Chesapeake and San Francisco bays are now home to many pests, they can be seen to be on a par with the Ponto Caspian basin.

As far as the St. Lawrence is concerned, we have very little knowledge of the magnitude and the extent of the role pleasure craft play in the propagation of exotic species. Moreover, there is no monitoring of the presence of these species in the basins of the tributaries of the St. Lawrence, with the exception of the Zebra Mussel, which will soon be the subject of a monitoring program set up by Quebec's Environment Ministry (MEQ). The program will look at some lakes and rivers and will have a public participation component. (Lapierre 1998).

While it is impossible to eradicate an introduced species, the rate of infestation and the invasion of other rivers can be reduced. Designing effective monitoring and awareness programs requires thorough knowledge of the invader's biology and ecology (its dispersal methods) and the uses to which the bodies of water in question are put. The study conducted by Johnson et al. (1999) bears witness to this. Initially, attempts will be made to control the factors favourable to the spread of these pests. For example, because of the small volumes of water involved, Zebra Mussel veligers are a less likely source of propagation than adults or juveniles (Johnson 1999). Moreover, the conditions needed for successful colonization by the Zebra Mussel (high numbers concentrated in a single area) support the claim that simple protective measures and minimal public education would be enough to prevent secondary drainage basins from being infested (Johnson 1999).

Our knowledge of how non-native species spread is very limited and research in this area is still in its infancy (Kareiva 1996).

3.6.4 Synopsis

Table 31
Ballast flushing in the St. Lawrence River:
Summary of the issues

Pressure components	State components	Response components
Ballast flushing is the most effective way to disperse non-native species (hundreds of millions of tonnes of water each year; worldwide, shipping transports 3000 species every day). Biological infestation is permanent and can increase. Increased risks of proliferation due to larger ships, growth of traffic (cargo and passenger) and navigation speeds. 10–15% of introduced species become invasive. Introduced species cause environmental, economic and public health problems. Of the 2000 foreign ships that sail the St. Lawrence, 34% travel the marine section, 50% the freshwater section and 13% go to the Great Lakes. The ballast-bearing capacity is 29 Mt per year. Volume of ballast discharged each year (1994 to 1996): marine section 10.3 Mt, freshwater section 2.7 Mt, and the Great Lakes 0.3 Mt. Ports involved: Montreal, Quebec City, Port-Cartier, Sept-Îles and Baie-Comeau. Ponto Caspian basin ports are thought to be the major source of invasive species. Little data on the number and the diversity of species present in ballast water. 99 phytoplankton species found in 86 ships bound for the upper reaches of the St. Lawrence in 1990. Reportedly-toxic dinoflagellates found in 37 of 60 ballast water samples taken in the Magdalen Islands in 1992.	The first species were introduced into the Great Lakes–St. Lawrence Basin as early as 1810. To date, at least 138 species have been introduced. Since construction of the St. Lawrence Seaway, ships are thought to have introduced 29 of the 45 species found. Five invasive species: Sea Lamprey, Sand Flea, Ruffe, Round Goby, and Zebra Mussel. Only the Zebra Mussel has spread to the freshwater section (and to the Richelieu and Ottawa rivers). Estimated densities in the St. Lawrence are much lower than those measured in the Great Lakes or in other navigable waterways. Because of the lack of historical data, it is impossible to determine whether some species of dinoflagellates are native or not.	*Voluntary Guidelines for the Control of Ballast Water Discharges from Ships Proceeding to the St. Lawrence River and Great Lakes* (VGCBWD) have been in effect since 1989: all ships sailing west of 63^{o} west longitude should exchange their ballast as far from land as practicable in a water depth of not less than 2000 m or in water depths exceeding 300 m east of 63^{o} west longitude. The VGCBWD do not apply to ships calling at ports south of the Gulf, west of 63^{o} west longitude. Apart from the study dating from 1990–91, there is practically no follow-up of protective measures. In view of the environmental risks, control measures in force could be extended to the entire St. Lawrence drainage basin. Predictive models to prevent invasion are very limited. Integrated management (various methods) seems the most effective approach. Little clear information about the handling of ballast water: exchange location and water depth.

3.7 ORGANOTIN (TRIBUTYLTIN) CONTAMINATION

Not counting oil contamination from the transshipment of petroleum products or shipwrecks, the primary source of chemical pollution from shipping is the release of organotins and, in particular, triorganotins used as biocides in antifouling paint. The following information is largely taken from the work of Moore et al. (1992), the purpose of which was to develop recommendations for these compounds with respect to water quality in Canada.

Since the 1960s, organotins have been mainly used by industry and agriculture as heat stabilizers for polyvinyl chlorides (PVC), catalysts and biocides in antifouling paints or wood preservatives. These compounds exist in several forms. Depending on the number of organic substituents, they are referred to as mono-, di-, tri- or tetra-organotins. The organic groups in alkyltins (methyl, ethyl, propyl, butyl, etc.) and aryltins (phenyl and vinyl) are bound to an atom of tin (Sn) that is also linked to an anionic group (chloride, fluoride, oxide, etc.). The toxicity of organotins increases with the number of organic groups that are attached to the tin atom and their composition. The toxicity of alkyltins increases as the length of the side-chain (butyl > propyl > ethyl > methyl) rises. The biocidal properties of triorganotins, especially tributyltins (TBTs), have been known for a long time; the latter are some of the most powerful contaminants known to humankind and are primarily used as biocides in antifouling paint for boat hulls (Chau et al. 1997). Phenyltins are the only aryltins for which any toxicity data are available and are as toxic as butyltins.

Organotins have a great affinity to adsorb to particles, so much so that dissolved-phase concentrations are very small compared with the levels found in sediments or in solids suspended in water; this proclivity increases as salinity rises. Bioaccumulation potential increases with the number and size of organic-fragment groups linked to the tin atom; however, some aquatic and marine organisms can metabolize and/or eliminate these compounds. Their degradation in water is primarily due to bacteria, the effects of chemical and photolytic mechanisms being negligible. Their persistence is thought to be low to moderate in water and moderate in sediments. Depending on the mechanisms involved, their half-life can exceed 12 months.

Given how toxic some of these organic compounds can be, they are on the Priority Substances List drawn up in accordance with the 1988 *Canadian Environmental Protection Act* (CEPA).

3.7.1 Pressure components

As historical and current data on environmental releases of organotins are very sketchy, it is impossible to get an accurate picture of the extent and scale of their distribution in water (Chau et al. 1997, Moore et al. 1992). Although organotins (dibutyltins and dioctyltins) are primarily used in Canada as heat stabilizers in products containing PVCs, the use of TBTs as biocides in antifouling paint, especially in the form of bis(tributyltin) oxide, is the primary cause of their presence in the aquatic environment and the main potential source of contamination (Moore et al. 1992).

Before the introduction of protective measures in 1989 (see Section 3.7.3), the widespread use of TBTs on the hulls of vessels of all sizes, fishing nets and lobster traps was largely responsible for contamination in coastal areas and inland rivers. At that time, cheap antifouling paints used on pleasure craft released TBTs faster than any other source, at a rate reaching 5 $\mu g/cm^2/d$ (Moore et al. 1992).

The only data on the use of organotins in Canadian waters is contained in a study conducted in the Maritime provinces in 1986–87 — before the protective measures came into effect. According to this study, 3.44 t of tributyltins were used that year, 53% as biocides in antifouling paint and 24% as a preservative for lobster traps (Kieley 1989, in Moore et al. 1992). With accurate data on the use of these compounds on commercial ships and pleasure craft that navigate the St. Lawrence watershed, it would be possible to gauge the risks to aquatic organisms.

3.7.2 Effects on the environment (State components)

The toxicity of organotins is thought to be linked to an excessive accumulation in cell membranes, resulting in their destabilization and rupture. Their toxicity seems to increase with rising salinity. These compounds are also held to be powerful adenosinetriphosphatase (ATP) enzyme inhibitors. Butyltins are blamed for the prevalence of imposex — the growth of male genitalia on females — which caused the decline of gastropod populations on the Atlantic Coast (see Moore et al. 1992). According to these authors, marine bivalves form the group of organisms most vulnerable to organotin toxicity, although this vulnerability can vary by more than one order of magnitude within a given group or type. The lethal and sublethal effects of acute or chronic exposure can be observed with Sn concentrations of around 10^{-8} g/L (Moore et al. 1992).

Our knowledge of the level of tributyltin contamination in the St. Lawrence system is essentially based on a few studies with only a limited number of samples. In the Gaspé Peninsula, Blue Mussels and starfish were analysed for their tissue concentrations of TBT and its degradation products, dibutyltin (DBT) and monobutyltin (MBT) (Normandeau 1997, Pelletier and Normandeau 1997). Sediment samples were also measured, as were Blue Mussels at four ports and one reference site in the Lower Estuary (Saint-Louis et al. 1997). Chau et al. (1997) measured the levels of several organotins, including those mentioned above, in water and sediment from the harbours of Montreal and Quebec City, and in sewage from the Montreal Urban Community's treatment plant. The results are summarized in tables 32 through 35.

Table 32
Comparison of minimal and maximal butyltin concentrations in water and sediments at five stations between Cornwall and Quebec City in 1994

		TBT		DBT		MBT		Total	
Sites	*N*	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Water (Sn, ng/L)									
St. Lawrence at Cornwall	2							0	
St. Lawrence at Quebec City*	1							0	
Richelieu at Sorel	2							0	
Montreal harbour	6		5.3		3.9		14.9	0	22.9
Quebec City harbour	3		8.5		D			0	8.5
Sediments (Sn, ng/g, dry weight)									
St. Lawrence at Cornwall	2		19.2		9.4		6.8	0	35.4
St. Lawrence at Quebec City*	1	179.0		102.4		80.9		362.3	
Richelieu at Sorel	2		4.6		4.0		D	0	8.6
Montreal harbour	5	21.7	198.2	25.9	79.0	15.0	60.4	62.6	332.4
Quebec City harbour	25	55.4	126.0	37.1	14.4	D	8.7	92.5	149.1

Source: Chau et al. 1997.
*1993.
Note: D = detected, but levels too low to quantify (Sn, 0.5–2.5 ng/g dry weight).

The TBT level, measured in Sn units, in water from the harbours of Montreal and Quebec City is 5.3 ng/L and 8.5 ng/L, respectively (Table 32). No butyltin was detected in water from the mouth of the Richelieu River or in the St. Lawrence itself near Cornwall and Quebec City. Canada’s interim criterion for the protection of aquatic life (chronic exposure) is 8 ng/L of TBT (Moore et al. 1992), a level met only in the Quebec City harbour (Chau et al. 1997).

In the area under consideration, there are no data for assessing the quality of sea water with respect to TBT (interim criterion of 1 ng/L). The highest TBT concentrations in Canadian waters (Chau et al. 1997) were recorded in the harbours of Vancouver (21.2 ng/L Sn) and Halifax (27.2 ng/L Sn). In the United States, levels of 800 ng/L and 270 ng/L were found in Chesapeake Bay and the Port of Honolulu, respectively (Moore et al. 1992). Dividing the latter values (nanograms per litre) by two makes it easier to compare them with the previous values (nanograms of Sn per litre).

The TBT levels in sediments from the five previously mentioned sites vary from a dry weight of 4.6 ng/g to one of 98.2 ng/g (Table 32). Sediments from harbours in the marine section of the St. Lawrence show a similar level of contamination (as the latter values are expressed in nanograms of Sn per gram and not in nanograms per gram, like the former values, they have to be multiplied by two for a true comparison), apart from Rimouski East, where the Sn concentration is 410 ng/g (Table 33).

Table 33
Minimal and maximal butyltin concentrations in sediments from four harbours and one park along the St. Lawrence Lower Estuary

		Butyltin concentrations (Sn, ng/g, dry weight)							
		TBT		DBT		MBT		TBT/DBT	
Site	*N*	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Les Méchins	8	4.7	58.3	< 0.2	14.7	< 0.5	< 0.5	0.9	8.0
Baie-Comeau	8	< 0.2	< 0.2	< 0.2	27.7	< 0.5	< 0.5	-	-
Rimouski East	8	< 0.2	410.0	4.8	19.2	< 0.5	13.7	0.2	75.8
Gros-Cacouna	8	< 0.2	21.7	< 0.2	61.1	< 0.5	30.5	0.4	1.1

		Butyltin concentrations (Sn, ng/g, dry weight)							
		TBT		DBT		MBT		TBT/DBT	
Site	*N*	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Parc du Bic	8	< 0.2	0.7	< 0.2	4.2	< 0.5	< 0.5	-	0.2

Source: Saint-Louis et al. 1997.

A 75.8 TBT/DBT ratio at the Rimouski East harbour seems, moreover, to point to recent contamination (Table 33). There is no interim TBT criterion for sediment quality. For example, Chau et al. (1997) report much higher levels in sediments from the harbours of Saint John, N.B. (3212 ng/g), Vancouver (2525 ng/g) and Halifax (1347 ng/g). Saint-Louis et al. (1997) correctly point out that low TBT concentrations do not necessarily mean small discharges. Thus, the lower concentrations found in the Port of Baie-Comeau are more likely due to the powerful hydrodynamics; in other words, the TBT does not reach the sediments and is removed from the port by currents and tides.

TBT levels (reported in Sn units) detected in mussels and starfish in the Lower Estuary and Gulf of St. Lawrence range from 10 ng/g to 152 ng/g and from 13 ng/g to 31 ng/g, respectively (tables 34 and 35). The highest butyltin concentrations were recorded near the ports of Les Méchins (Saint-Louis et al. 1997) and Gaspé (Pelletier and Normandeau 1997). Excluding the much higher concentrations found in mussels in the port of Les Méchins, the low TBT levels these organisms exhibit in the Lower Estuary and Gulf of St. Lawrence as a whole, combined with the high levels of DBT and MBT, are indicative of widespread low-intensity contamination (Pelletier and Normandeau 1997).

Table 34
Minimal and maximal butyltin concentrations in mussels harvested from four harbours and one park along the St. Lawrence Lower Estuary

		Butyltin concentrations (Sn, ng/g, dry weight)							
		TBT		DBT		MBT		Total	
Sites	*N*	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.

Les Méchins	16	21.9	151.9	18.3	321.8	< 1.0	128.2	50.1	828.3
Baie-Comeau	14	< 0.4	86.3	< 0.4	55.1	< 1.0	8.9	-	141.4
Rimouski Est	16	4.8	72.0	< 0.4	77.5	< 1.0	31.2	-	136.5
Gros-Cacouna	16	< 0.4	40.3	< 0.4	65.3	< 1.0	10.0	-	91.9
Parc du Bic	16	< 0.4	28.0	< 0.4	31.0	< 1.0	29.2	-	66.6

Source: Saint-Louis et al. 1997.

Table 35
Mean butyltin concentrations in mussels and starfish from eight sites between Île du Bic and Gaspé

	Average butyltin concentrations (Sn, ng/g, dry weight)							
	TBT		DBT		MBT		Total	
Organism	Ave.	Min./max.	Ave.	Min./max.	Ave.	Min./max.	Ave.	Min./max.
Whole mussels	16	10/41	32	23/49	30	17/49	78	57/124
Starfish (gonads)	21	13/31	78	40/134	18	17/21	117	47/183
Starfish (caecum)	19	14/30	62	44/99	20	17/24	101	75/137

Source: Pelletier and Normandeau 1997.

There is no data bank on butyltin contamination of freshwater biota in the area under study. The limited data available can only provide a snapshot of butyltin contamination; it is impossible to give an authoritative opinion about the loads present in the various bodies of water and the relative contributions of commercial ships and pleasure craft.

3.7.3 Action (Response components)

Previous widespread use of biocides containing TBT in fresh water and salt water caused some contamination of the coastal environment and inland waters before the enactment of the *Pest Control Products Act* (*Consolidated Statutes of Canada*, Chapter P-9) and its regulations in 1989. With the advent of these regulatory measures, all products containing organotins had to be registered and the use of antifouling paints containing TBT was limited to ships more than 25-m long, with the exception of aluminum hulls. Moreover, the rate at which TBT is released from these paints must not exceed 4 $\mu g/cm^2/d$.

Like several countries that have adopted similar protective measures, Canada carried out a study to verify the effectiveness of these measures five years after their introduction (Chau et al. 1997). This study concluded that, in Canada as a whole, butyltin concentrations had decreased in fresh water but not in salt water; the reductions observed in freshwater and saltwater sediments are very small, partly on account of the persistence of these compounds. Because of the dearth of data from the area under consideration, it is impossible to confirm whether the butyltin levels follow the trends observed in Canada as a whole.

More in-depth studies on the toxicity of butyltins will be required before appropriate recommendations on water and sediment quality can be issued with the aim of protecting resources and practices (Moore et al. 1992).

Given that TBTs are highly toxic, in April 1998, the IMO's Marine Environment Protection Committee agreed to charge a task force with designing draft regulations to have organotins gradually withdrawn from antifouling paint and to suggest a time frame for their elimination (IMO 1998). Alternatives are currently under study, including copper- or silicone-based paints and mechanical or physical methods (ultrasound, electrolysis) of cleaning ship hulls without putting them in dry dock (IMO 1998). As a signatory to the IMO conventions, Canada could support these regulatory measures.

3.7.4 Synopsis

Table 36
Organotin (tributyltin) contamination in the St. Lawrence River: Summary of the issues

Pressure components	State components	Response components
TBTs used as biocides in ship hull antifouling paints are the major source of organotins in the aquatic environment. TBTs are powerful contaminants with Sn concentrations in the nanogram-per-litre range. Widespread use before 1989: ship hulls, fishing nets and lobster traps. No data on quantities used in the aquatic environment of the study area.	Very sketchy data about concentration in water and sediments in the freshwater section. Levels detected in water and sediments in the St. Lawrence are low compared with those found in major Canadian harbours; however, little data is available. TBT concentrations in water from the Quebec City harbour meet the interim criterion for the protection of aquatic organisms in fresh water. There is no criterion for the quality of sediments. The toxicity of organotins increases with salinity. Molluscs (gastropods and bivalves) are most vulnerable to TBT toxicity. Low butyltin concentrations found in Blue Mussels and some starfish in the Estuary and Gulf point to widespread low-intensity contamination.	In 1989, regulations required that all products containing organotins be registered and limited the use of antifouling paints containing TBT to ships more than 25-m long, with the exception of aluminum hulls. The rate at which these paints release TBT must not exceed 4 $\mu g/cm^2/d$. Since 1989, the Canada-wide trend has been towards lower concentrations in fresh water, but not in salt water. In Canada, reductions of TBTs in fresh- and saltwater sediments are very small. It is impossible to confirm these trends because of the lack of data for the St. Lawrence. Other studies are needed to be able to decide on appropriate quality criteria for the protection of organisms and uses. IMO is currently designing draft regulations for the gradual withdrawal of organotins in antifouling paints and will suggest other economically viable ways of cleaning hulls.

3.8 WASTE MANAGEMENT

Commercial ships and pleasure craft generate significant quantities of organic and inorganic liquid and solid waste (plastics, glass, metal, paper, cardboard, organic matter, dangerous goods, etc.) that vary according to the type of activities and number of people involved. In this section, the concept of waste does not include the discharge of oil or dangerous goods following accidental spills or shipwrecks (see Section 3.4), but is limited to domestic, operational and maintenance wastes resulting from the day-to-day use of a vessel or ship and includes sewage, solid waste of all sorts, waste oil and other chemical substances. The management problems associated with handling shipping waste are the concern of ship operators and port and marina administrators alike. Although it is not the pressure source with the greatest effect on the quality of the St. Lawrence, the inefficient management of this waste can have a substantial impact on the aquatic environment

3.8.1 Pressure components

Microbial pollution (pathogens) from the discharge of wastewater is a public health issue. Inputs of phosphorus and nitrogen cause eutrophication and environmental degradation. Releases of chemical contaminants increase the load of organic and inorganic pollutants that may affect humans and aquatic organisms. Some animals die as a result of ingesting or being trapped by some forms of solid waste. Waste can also be a nuisance to ships: fishing lines can get tangled in their propellers and debris can clog pumps.

We know how much commercial traffic there is on the St. Lawrence and, although we are unable to estimate pleasure craft traffic with as much accuracy, we can nevertheless give a rough estimate. However, we have no data on the quantities of solid and liquid waste coming from commercial shipping and pleasure craft, nor on how much of this waste is disposed of in port facilities designed for this purpose and how much is discharged directly into the aquatic environment.

It is acknowledged that, in previous decades, raising awareness of the environmental impacts of waste and debris among mariners and recreational boaters helped reduce the quantities discharged. However, as far as dumping of waste in the marine environment is concerned, recreational boaters are less guilty than commercial fishers (Ellis and Podlich 1997). Economic imperatives or the certain knowledge that what is about to be dumped overboard has no negative impact on the environment are often used to justify actions that are otherwise reprehensible.

The three main obstacles to sound waste management on ships are the lack of crew training in the use of waste management equipment, the lack of space and facilities for storing waste, and the sanitation problems (odours, vermin) caused by its storage (Ninaber 1997). In addition, there are the problems linked to the availability of waste disposal facilities in ports and the requirements of regulatory provisions, which can vary from one country or province to another (Ninaber 1997).

Given the lack of data on discharges of wastewater in the area under consideration, we will refer, for information purposes, to a study conducted in Sweden (SEPA 1994), which shows that such discharges can be quite substantial. This study estimated that, in the summer season (two months), the amount of untreated sewage generated by a fleet of 195 000 pleasure craft was equivalent to the amount discharged each year by a community with a population of 32 500.

As far as solid waste is concerned, an inventory compiled in 1992 between the Île d'Orléans and Les Escoumins (Roche Ltée 1993) showed that plastic was the most prevalent form of waste (more so than glass, metal, paper, cardboard, etc.) in terms of weight (61%), volume (85%) and number (85%). Plastic debris density varied from 1 kg to 44 kg per km of shoreline. In the absence of any discernible upstream-downstream gradient, the largest quantities found on the south shore can be attributed to local hydrodynamic conditions. This debris came from a variety of sources. Thus, domestic and recreational activities were respectively responsible for 47% and 13% of the weight and 41% and 31% of the number. Jerrycans used by haulers and shipping accounted for 14% of the weight and 2% of the total number of waste objects. It is very obvious that shipping may also be responsible for some of the waste in the domestic and recreational activity category. For example, the abundance of coffee-cup lids (over 1000) found at the Saint-Joseph-de-la-Rive station was thought to come from the Île aux Coudres ferry (Roche Ltée 1993).

The large majority of recreational activities are concentrated in the freshwater section, an area for which there is no data on waste management or the effects of waste on aquatic organisms.

3.8.2 Effects on the environment (STATE COMPONENTS)

As far as we know, no exhaustive study has been carried out on the effects of solid waste from shipping on the health and survival of species in the St. Lawrence. However, it is reasonable to assume that cases in which aquatic organisms are strangled or become entangled are rather rare in the study area, because even a relatively normal rate of injuries or deaths from waste would soon have attracted the attention of aquatic and marine wildlife specialists. We should also acknowledge, at the same time, that a land-based report or even an inventory of a large area of water would only show a fraction of the accidents. In this respect, Laist (1997) offers a good description of the factors likely to skew the results of an inventory (sampling and detection frequency, analyses, extrapolations, etc.) on marine organisms becoming entangled in waste and ingesting plastics. Laist’s study gives a detailed list of 267 marine species (mammals, reptiles, fish, birds and crustaceans) for which there are data on entanglement (136 species) and ingestion (177 species).

A report Canada recently presented to the IMO’s Marine Environment Protection Committee stated that between 20 000 and 100 000 oiled seabirds die each year off the coast of Newfoundland, even when no major spill has been reported (IMO 1998). Analyses of birds and water samples showed that the oils in question were heavy oils containing lubricating and hydraulic oil residues. These results suggest that most of the oil discharged in this area is illegally dumped waste oil and does not come from tanker spills (IMO 1998).

3.8.3 Action (RESPONSE COMPONENTS)

Ports, ships and regulations are factors to be considered in the management of commercial shipping and pleasure craft waste (Ninaber 1997). Mariners must, of course, behave responsibly; however, there must be adequate port and marine facilities, and national and international regulatory measures must be coherent and promote co-operation among all users (Wallace 1997).

Three sets of regulations enacted under the *Canada Shipping Act* (*Consolidated Statutes of Canada*, Chapter S-9) apply to the disposal of sewage by commercial shipping and pleasure craft in the study area. The *Great Lakes Sewage Pollution Prevention Regulations* state that no ship shall discharge sewage into the Great Lakes and the St. Lawrence River as far east as the

Saint-Lambert Locks. The sector downstream from Montreal is governed by the *Non-Pleasure Craft Sewage Pollution Prevention Regulations* and the *Pleasure Craft Sewage Pollution Prevention Regulations*. However, as these bodies of water are not designated in regulations issued by riverside municipalities, the two regulations cannot be applied. In other words, there are no regulatory restrictions covering the discharge of untreated sewage in the aquatic environment downstream of Montreal.

There are, however, a series of voluntary measures that encourage recreational boaters to manage their sewage (and their solid waste) soundly. *Protecting the Aquatic Environment: A Boater's Guide* (DFO 1998c) encourages users to *a)* use land-based sanitary facilities whenever possible to avoid having to use pump-out facilities to remove sewage waste, *b*) use non-toxic products to clean and disinfect boats, *c*) reduce the volume of waste that will have to be managed during a cruise (use re-usable products), and *d*) recycle residual materials. There are no data we can use to measure compliance with these measures. A study of marinas would thus be useful.

Ellis and Podlich (1997) consider that the importance of giving boaters adequate environmental protection information should never be underestimated. These authors maintain that any program intended to reduce the quantity of waste recreational boaters produce must try to reach a target group and not boaters as a whole. Entering a partnership with the target group increases the project's chances of success and provides greater knowledge of the benefits reaped by the boaters themselves. For example, besides describing the risks that fishing line represents to aquatic wildlife, a fishing-line recycling program should emphasize the damage and the expense that a line wrapped around a propeller can cause (Ellis and Podlich 1997).

Notice to Mariners No. 32, *Pollution: Compliance with Canadian Regulations* (DFO 1998b) reminds shipmasters of their duties as regards compliance with *Canada Shipping Act* regulations. Besides the two regulations mentioned above, reference is made to the *Oil Pollution Prevention Regulations*, the *Garbage Pollution Prevention Regulations*, the *Pollutant Substances Regulations*, the *Dangerous Chemicals and Noxious Liquid Substances Regulations,* and the *Air Pollution Regulations*. The *International Convention for the Prevention of Pollution from Ships*, known as *MARPOL 73/78* (IMO 1998) contains several regulatory provisions respecting pollution by all forms of waste: noxious liquid substances (Annex II), harmful substances carried in packaged form (Annex III), sewage (Annex IV) and garbage (Annex V). Since July 1, 1998, Annex V has required all ships weighing 400 deadweight tonnes (DWT) and over to have a waste management plan detailing storage, processing (incineration) and disposal procedures. It also mentions a formal ban on ocean disposal of plastics (IMO 1998) and stipulates that ports in countries that have signed the Convention must be equipped with waste disposal facilities or services.

The various types of solid and liquid waste recovery facilities available in the main ports on the St. Lawrence are shown in Table 37. The ports of Montreal and Quebec City offer their clients fixed and mobile facilities. The remaining ports have no facilities and entrust all recovery services (mobile facilities) to certified firms. Ships' agents bear the costs and make arrangements with recovery firms contracted to transport waste of every type to the appropriate disposal sites in accordance with applicable regulations.

Table 37
Solid and liquid waste recovery facilities in the main St. Lawrence ports

Port	Waste		Wastewater	Petroleum waste products	Chemicals
	Domestic	International			
Montreal	F	F	M	F, M	M
Sorel	M	M	M	M	M
Trois-Rivières	M	M	M	M	M
Bécancour	M	M	M	M	M
Quebec	F	F	M	F, M	F, M
Port Saguenay (Grande-Anse)	M	M	M	M	M
La Baie (Alcan)	M	M	M	M	M
Baie-Comeau	M	M	M	M	M
Port-Cartier	M	M	M	M	M
Sept-Îles	M	M	M	M	M
Havre-Saint-Pierre (QIT- Fer et Titane Inc.)	M	M	M	M	M

Source: Acres International Limited 1990, Collard 1998, Page 1998, Couture 1998, Bourgeois 1998, Richard 1998.

Note: F (fixed facility), M (mobile installation).

The *Health of Animals Regulations* adopted further to the *Health of Animals Act*, (*Consolidated Statutes of Canada*, 1990, Chapter 21) prohibit the importing of ship's refuse that may contain an animal product or by-product, unless it is transported in a leak-proof container to an incinerator or an approved sanitary landfill site and buried in accordance with the applicable provisions. This explains why small ports and those far from large communities with municipal incinerators must charge high fees for managing foreign waste and, consequently, why ships very rarely use their services. These conditions only foster reprehensible behaviour (Ninaber 1997). This may explain complaints about waste from foreign ships being found on the northern coast of the Gulf (Morisset 1999).

It goes without saying that the 3R strategy (reduce, reuse and recycle) applies to the management of all types of waste, even commercial-shipping and pleasure-craft waste. Here, too, the main benefits will come from waste reduction. Packaging, which constitutes a tremendous amount of waste, should be rethought to take into account the limitations inherent to shipping. Similarly, a standard, international policy (*MARPOL 73/78*) on the shipboard sorting of waste and on ways of recovering recyclable materials in ports would help alleviate the problem by reducing the volume of waste (Ninaber 1997). This same author makes some proposals in support of an international integrated waste-management plan under *MARPOL*:

- Introducing so-called green measures for the onboard packaging and storing of products to promote the 3Rs.
- Setting minimum standards respecting the space to be allocated to, and facilities for, waste management.
- Drawing up regulations for onboard waste management and disposal plans.
- Developing pollution-prevention training programs for crews.
- Promoting technological exchanges and co-operation with developing countries for the introduction of land-based waste management infrastructure.

Over the last decade, many industrial sectors have instituted pollution-prevention policies. In this respect, the shipping industry appears to be lagging far behind, with shipowners content to do no more than comply with regulatory requirements.

3.8.4 Synopsis

Table 38
Management of shipping waste in the St. Lawrence River:
Summary of the issues

Pressure components	State components	Response components
There are no comprehensive data on the management of liquid and solid waste from commercial shipping and pleasure craft. The discharge of wastewater is a public health issue and one related to eutrophication and environmental contamination in the busiest areas.	There is no comprehensive study of these issues for the area under consideration. A study of the area off the coast of Newfoundland reports that between 20 000 and 100 000 seabirds die each year as the result of ships illegally dumping waste oil. Aquatic organisms can be strangled or get entangled in plastic debris.	Although it is possibly not the major pressure source as far as the quality of the St. Lawrence is concerned, efforts must be made to minimize the effects of ship waste. Existing regulations for the area west of the Saint-Lambert Lock are being enforced. East of Montreal, regulations governing commercial shipping and pleasure craft cannot be enforced, because the bodies of water have not been designated by all riverside municipalities. *Notice to Mariners No. 32* is a voluntary measure. The *MARPOL 73/78* convention contains several regulations respecting pollution from all sorts of waste: e.g. noxious liquid substances (Annex II), sewage (Annex IV) and garbage (Annex V). Since July 1, 1998, under *MARPOL 73/78*, ships weighing 400 DWT and more must have a waste management plan (storage, processing and disposal). All ports provide fixed or mobile waste recovery facilities or the services of specialized firms. These services are seldom used, because of the high costs, and waste is dumped into the environment.

3.9 GENERAL ANALYSIS

In the past, shipping has not been immune to prevailing attitudes in other sectors of the economy: the last priority in the planning process was the anticipated environmental consequences of the sector's growth. The near-infinite carrying capacity attributed to the oceans was likewise ascribed to the large inland bodies of water. At the heart of this credo lay the idea that pollutants would be diluted by the huge water masses and waste would disappear once immersed in water.

In the past thirty years, environmental concerns have gained ground in industrialized countries to the point that there is now a commitment to take these concerns into consideration during the decision-making process. Given that shipping is an international activity and given the marked differences among the regulations in force in various countries, efforts were made to adopt internationally applicable measures to protect the environment and prevent pollution by shipping. In this respect, the 1948 establishment of the International Maritime Organization (IMO), a UN agency specializing in international maritime law, which entered into force in 1958, was a turning point. In 1998, the 155 member states and two associate members of the IMO were responsible for 95% of the world's shipping capacity (IMO 1998). The adoption of the *International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78),* and its subsequent amendments, is a good illustration of the growing attention being paid to protecting the aquatic and marine environments; the 102 countries that signed this convention are responsible for 93% of the world's shipping capacity (IMO 1998). This convention and its annexes are concerned with several types of pollution (oil, noxious liquid substances, harmful substances in packaged form, sewage, garbage and, in the near future, air pollution). These regulatory measures must, of course, be implemented in each member country and monitored to ensure they produce the desired environmental benefits. Among IMO member countries, Canada seems to be at the forefront concerning the adoption and enforcement of regulatory measures to protect the environment and prevent pollution resulting from activities associated with sea and river navigation. The numerous laws and associated regulations provide a framework for these activities.

Commercial shipping and pleasure boating still affect the aquatic and marine environments, and our knowledge of the magnitude and extent of some of the pressures, and their effects on the health of the ecosystem, remains quite limited. Tables 39 and 40 summarize the conclusions drawn from an analysis of the eight variables used in this study.

Because of the lack of data describing habitats and resources prior to the development of on-shore infrastructure and substantial capital dredging projects, accurate conclusions cannot be drawn about losses and gains of habitat and resources resulting from hydrodynamic changes, encroachment and filling. The absence of a comprehensive map showing the topography of the natural river channel and the series of sections affected by successive dredging operations in the ship channel, between the North Traverse and Montreal, helps fuel the most alarmist hypotheses about the effects of these operations on the freshwater section.

Defining an integrated dredged-material management policy and beneficial uses for these materials will lead to a greater appreciation of dredging projects. Both of these goals, moreover, could help solve the problem of shoreline erosion due to wave action. Needless to say, efforts will first of all be made to reduce the causes of erosion at the source.

The constant growth of the St. Lawrence’s navigational safety system continues to provide evidence that transporting cargo, especially dangerous goods, by ship is still a safe, economical and environmentally-sound solution. Although the number of accidental spills and the quantities involved are limited, efforts will be made to keep this form of pollution to a minimum.

There is limited tributyltin (TBT) contamination on the shores of the marine section; the lack of data on contamination in the freshwater section makes it impossible to draw any conclusions. No information is available on the quantities of organotins used by shipping in the St. Lawrence as a whole.

Table 39
Overview of the environmental issues associated with commercial shipping on the St. Lawrence River

Variable	Affected section*	Pressures	State	Responses
INFRASTRUCTURE	SL	• Previous large-scale developments (local impact). • Hydrodynamic alterations. • Habitat loss from dredging and filling.	• Alteration of habitats encompassing an area of 12 600 ha between 1945 and 1988. • No details of biodiversity and biomass losses.	• New projects are subject to the existing environmental assessment processes.
TRAFFIC INTENSITY	UE/S, LE/G	• Potential resuspension of contaminants from sediments in shallow areas. • Potential disturbance of whales.	• Limited data (Port of Quebec) indicate that contaminants stay where they are. • Effects of disturbance on whales not shown.	• Regulatory measures require minimum underkeel clearance. • Voluntary measures encourage mariners to slow down in areas frequented by whales.
DREDGING	SL	• Previous large-scale dredging operations. • Low annual volume of maintenance dredging. • Hydrodynamic modifications and loss of habitat. • Anticipated climate changes could increase dredging requirements.	• Between 1945 and 1988 habitat alteration affected an area encompassing 12 600 ha. • No details of biodiversity and biomass losses. • No assessment of the cumulative impact of successive dredging operations on the waterway.	• Highly developed regulatory system. • New projects are subject to the existing environmental assessment processes. • Dredged-material management policy has yet to be defined. • Reclaiming dredged material remains an option.
SPILLS	SL	• Small number of spills each year. • Great majority of spills are small.	• Major accidents very unlikely. • Potentially substantial impacts, because of the limited effects of any responses in the freshwater section.	• Highly developed and proven navigational safety system. • Largest ports have emergency response plans. • Response team on continuous duty.

Variable	Affected section*	Pressures	State	Responses
WAVE ACTION	FS	• Detailed knowledge of areas affected. • The relative contributions of natural and anthropogenic forces still have to be established. • Little is known about critical periods for erosion and event scenarios.	• Loss of waterfowl habitat mostly affects islands in the freshwater section. • Loss of fish habitat still has to be established.	There are voluntary measures in place (*Notices to Mariners*, etc.). • There are no regulatory measures for the most affected sections. • Shore-protection pilot projects were carried out on islands upstream of Sorel. • A financial contribution from shipowners could be considered.
BALLAST FLUSHING	SL	• Details of volumes discharged in the various sections. • There is not much data on the diversity and abundance of species present in ballast water. • Ponto Caspian basin ports are thought to be the main sources of invasive species.	• At least 139 non-native species have been introduced into the St. Lawrence, 10–15% of which are thought to be invasive. • Of the five invasive species in the Great Lakes, only the Zebra Mussel has reached the freshwater section. • Because of the lack of historical data, it is impossible to say whether or not some species are native (algae, dinoflagellates).	• Protective measures (VGCBWD) do not cover the entire St. Lawrence. • There is very little follow-up of the VGCBWD. • Integrated management (several methods) seems the best approach. • Solving the problem requires international co-operation.
ORGANOTINS	SL	• The contaminant load is unknown.	• Diffuse low-intensity contamination in the marine section. • There is little data on contamination in the Fluvial Section.	• The use of antifouling paint is forbidden on vessels less than 25-m long, but is allowed on aluminum hulls.
WASTE	SL	• The contaminant load is unknown.	• No data.**	• There are regulatory and voluntary measures in place.

* SL: St. Lawrence as a whole; FS: Fluvial Section; FE: Fluvial Estuary; UE/S: Upper Estuary + Saguenay; LE/G: Lower Estuary + Gulf.

** By "no data" we mean that, to our knowledge, no comprehensive report exists on this issue, although relevant isolated data may exist.

Table 40
Overview of the environmental issues associated with pleasure boating on the St. Lawrence River

Variable	Affected section*	Pressures	State	Responses
INFRASTRUCTURE	SL	Construction of 100 marinas, 105 wharves and 92 boat launching ramps. Modification of hydrodynamics. Loss of habitat from dredging and filling.	No data.**	New projects are subject to the existing environmental assessment processes.
TRAFFIC INTENSITY	FS, UE/S, LE/G	Potential disturbance of birds (Lachine Rapids) and whales.	No data.	Environmental protection plan being drawn up for the Lachine Rapids. Awareness program for boaters.
DREDGING	SL	Maintenance dredging in existing marinas. Modification of hydrodynamics. Habitat loss.	No data.	New projects are subject to the existing environmental assessment processes.
SPILLS	SL	Low-volume spills while tanks are being filled.	No data.	Awareness program for boaters.
WAVE ACTION	FS, FE	Secondary-channel shore erosion (Sorel delta), but no quantitative data.	No data.	Awareness program for boaters.
BALLAST FLUSHING	FS, FE	Potential spread of non-native species to other drainage basins.	The Zebra Mussel is present in the Richelieu River basin and at the confluence of the Ottawa River and the Rideau Canal.	Awareness program for boaters.
ORGANOTINS	SL	Contaminant load not known.	Insufficient data for the freshwater section (FS, FE). Diffuse low-intensity contamination detected in the marine section, probably due to commercial shipping.	The use of antifouling paint is forbidden on vessels less than 25-m long, but is allowed on aluminum hulls.
WASTE	SL	Contaminant load not known.	No data.	Awareness program for boaters.

* SL: St. Lawrence as a whole; FS: Fluvial Section; FE: Fluvial Estuary; UE/S: Upper Estuary + Saguenay; LE/G: Lower Estuary + Gulf.

** By "no data" we mean that, to our knowledge, no comprehensive report exists on this issue, although relevant, isolated data may exist.

The major ecological, economic and public health consequences associated with the introduction of non-native species are such that no effort should be spared to prevent any new species from entering the St. Lawrence basin. The fact that non-native invaders in the Great Lakes have had little success to date in the fluvial environment, with the exception of the Zebra Mussel, is no guarantee of safety. Our limited knowledge in this area prevents us from extrapolating as to the environmental impact of the introduction of any species, whether plant or animal, microscopic or macroscopic. The problem of species being transported in ballast would appear to require an integrated management approach, one that includes the implementation of measures on ships and in ports and has the support, in the form of international co-operation, of all stakeholders.

Lastly, it has been shown that the intentional dumping of solid and liquid waste can spell disaster for aquatic and marine organisms. The lack of data on the nature and the magnitude of discharges in the area under consideration makes it impossible to draw any conclusions. Similarly, there are no comprehensive data that would allow us to assess the effectiveness of current control measures. A study of the management of waste produced by boaters showed that some of the environmental impacts from pleasure craft could in fact be mitigated through awareness programs aimed at specific groups of boaters or users in a particular area.

4 Conclusions and Priorities

The transportation industry is responsible for 21% of the human-source greenhouse gas (GHG) emissions generated worldwide. In Canada, the corresponding figure is 30% (CST 1998). Because fossil fuels provide for over 99% of our energy needs (55 billion litres in 1996), with 70% going to passenger transportation and 30% to cargo transportation, the resulting polluting emissions include both organic and inorganic substances. Although energy consumption has remained constant (i.e. increasing in proportion to the rate of population growth), the energy requirements for cargo transportation have nearly doubled since 1979 (CST 1998). The projected increase in energy demand for cargo transportation over the next few decades will have to be offset by an environmentally friendly transportation system if we are to comply with the *Kyoto Protocol* adopted in 1997. These energy considerations and others, such as the environmental impact of the highway infrastructure alone, should be dealt with in a comprehensive environmental assessment of navigation activities on the St. Lawrence, and so should the parameters covered in this study that clearly have more direct impacts on the river.

The following sections identify knowledge gaps and other uncertainties related to the available data. The section on management concerns sets out environmental objectives and possible courses of action for reducing the environmental pressures associated with navigation, improving the measures adopted to deal with these pressures, and gaining a better understanding of navigation-related environmental problems.

4.1 KNOWLEDGE GAPS RELATED TO NAVIGATION ISSUES

Knowledge gaps and uncertainties related to the available data were discussed in the previous chapter, particularly with regard to the effects of dredging and infrastructure on river hydrodynamics and habitats, disturbance of species and habitats caused by vessel traffic, the risks to flora and fauna from spills, ship-induced shoreline erosion, the introduction of non-indigenous species through ballast discharges, and poor waste management. In Section 4.2, possible courses of action are suggested to address these issues. Here, we will limit the discussion to problems that have not been looked at in this study, but which nonetheless have a substantial environmental impact.

4.1.1 Contribution of substandard ships to river pollution

The condition of a ship, its crew and the crew's qualifications are very indicative of the importance accorded to environmental protection by shipowners and charterers. According to a fact-finding mission conducted in France (Le Grand 1994), close to 40% of the world's fleet did not meet standards in the early 1990s. A substandard ship poses a risk to marine transportation safety because of its aging structure and equipment, poorly trained crew and non-compliance with safety regulations. It was reported that 82% of the insurance claims registered in 1992 involved ships more than 15 years old, although ships of this age accounted for only 41% of the fleet.

Canada applies the regulatory provisions defined in the International Maritime Organization (IMO) Port State Control Program, which empowers governments to inspect foreign vessels to check whether they comply with IMO standards. Various units in federal government departments (Transport Canada, Fisheries and Oceans Canada, and Environment Canada) are required to check vessel compliance with safety and environmental standards. Despite these officially-sanctioned efforts, some of these old hulks could still break up at sea, leading to the all-too-familiar environmental disaster, such as that caused by the bulk cargo carrier *Flare,* which broke up off the coast of Newfoundland in 1997 on its way to the St. Lawrence. Only strict international regulations can prevent this type of catastrophe. It would also be interesting to study the trends related to the number of substandard ships over the past three decades. Research could also be conducted on the changes in environmental standards over the same time period with respect to allowable releases to aquatic environments and to the atmosphere.

4.1.2 Environmental management at port facilities

Port facilities, like ships, sometimes have impacts on the environment. Day-to-day environmental management of commercial ports is complex and may be viewed in various ways. To enhance environmental compliance, port activities and facilities must meet the requirements of the existing regulatory provisions. In addition to applying these measures, a port authority may promote the use of best environmental practices exceeding regulatory requirements, so as to better position itself in relation to its competitors, from an environmental protection standpoint. To date, no study has been carried out that would be helpful for assessing and comparing the environmental performance of the main commercial ports on the St. Lawrence based on a particular practice or the principal activities carried out in a given port; nor do we have any data to illustrate the changes in environmental practices over the past three decades.

4.1.3 Environmental benefits of waterborne transportation versus other modes of transportation

Although commercial navigation has direct environmental impacts, an environmental assessment of this transportation sector would not be complete without a comparison of the environmental effects of other modes of transportation. Given that cargo transportation is a necessity in today's society, it is appropriate to choose the mode of transportation causing the fewest environmental disruptions. Quantities of energy consumed, polluting emissions, waste produced (e.g. tires) and noise are clearly the first variables to consider. The impact of the different modes of transportation on surrounding areas must also be taken into consideration (area covered by transportation networks, habitat fragmentation, dredging, etc.) as should the risk of accidents. An objective comparison of the modes of transportation requires that the actual costs of network maintenance plus fuel and waste management costs be taken into account.

4.2 MANAGEMENT CONCERNS

4.2.1 Environmental objectives

From a sustainable development standpoint, it may be desirable to set environmental objectives[4] for commercial navigation and pleasure boating on the St. Lawrence River in order to safeguard and maintain or reclaim uses associated with these activities. The proposed environmental objectives are not intended to be comprehensive; instead they are limited to the

---

[4] An environmental objective is a guideline, threshold or target to be met that is linked to either a human activity, a pressure exerted by a human activity or an ecosystem component affected by environmental pressures. These objectives are intended to: keep human activities at levels that will not have serious or irreversible effects on ecosystems; reduce or restrict pressures to levels acceptable for ecosystems and associated uses; and protect, rehabilitate or restore ecosystems.

variables selected in the previous chapter. Environmental objectives could also be established for air and water quality, use of shoreline sites and perhaps environmental training for ship crews.

4.2.1.1 *Dredging and sediment quality*

Recent technological advances in real-time data acquisition and modeling have made it possible to use available water depths more effectively, thereby precluding the need for some dredging work. It would be useful to devise tools to show the benefits derived from safe and optimum management of the ship channel.

In cases where dredging is required, it should be carried out under an integrated dredging-management policy, which has yet to be established. Solutions for making use of dredged material must therefore be found. The feasibility of projects for using dredged material cannot be assessed until definitive sediment quality assessment criteria have been established.

4.2.1.2 *Shoreline erosion*

It has been demonstrated that ship-generated wake waves are partly responsible for shore erosion, particularly on the islands between Montreal and Sorel. Additional data is required to distinguish between losses attributable to wave action and losses caused by natural phenomena (water levels, wind, ice, etc.). A more in-depth study would help to reveal the modes of action of the phenomena concerned and their relative importance. In turn, this information would help to establish a better framework for preventive and protective measures and determine the scale of the anticipated effects.

4.2.1.3 *Introduction and control of non-native species*

It is imperative that the spread of invasive non-indigenous species be monitored; however, protective measures to combat their dispersal are limited in number and effectiveness. One key characteristic of invasive non-native species is that they become permanently established. Control measures are often limited to cleaning water intakes (Zebra Mussels) or large-scale harvesting of the invading species (lampreys), and are known to have little effect.

It is becoming clear that priority must be given to preventive measures. These exotic pests can be effectively managed by applying preventive measures on board ships and in ports and by incorporating appropriate changes into the design of new ships. If we want to accurately assess the impact of existing measures, the number and diversity of species present in ballast water must be continuously monitored. Similarly, an effort should be made to accurately determine the status of specific organisms in the St. Lawrence River ecosystem, i.e. whether they are indigenous or exotic, using routine gene marking techniques.

4.2.1.4 *Waste management*

In light of the wide-ranging impacts that deliberate discharges of waste oil off the coast of Newfoundland have had on birds, it is likely that these discharges have had an effect on the St. Lawrence River, at least in the marine section. The available data are very fragmentary and cannot be used to assess the situation, not even in a cursory fashion.

Data must be gathered on the quantities and types of waste generated, the quantities processed (incinerated) on board ships and disposed of in port facilities, the quantities of material recycled and source reductions in order to evaluate changes in existing response measures and changes in user habits.

4.2.1.5 *Precautionary principle*

It is sometimes difficult to identify the causal relationships between shipping and pleasure craft activities and the state of an ecosystem. There are many grey areas in the way observations are interpreted. However, this does not justify not having pertinent environmental objectives or not taking concrete action.

The precautionary principle calls for a prudent approach to environmental issues: where an activity poses a threat to the environment or human health, precautionary measures should be taken even if the scientific evidence is incomplete. This basic principle underlying the sustainable development concept is gaining increasing international currency (VanderZwagg 1994). The 1990 *Bergen Declaration* states that in order to achieve sustainable development, policies must be based on the precautionary principle and that where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

Canada has upheld the precautionary principle in international courts and the principle is mentioned in many programs and pieces of legislation (*Green Plan, Comprehensive Air Quality Management Framework Agreement, Fisheries Act*, *Canadian Environmental Assessment Act*, *Canadian Environmental Protection Act*, etc.) (VanderZwagg 1994). The *Oceans Act*, passed in 1997, also endorses this principle.

4.2.2 Possible actions

From the analyses conducted for this study, certain conclusions can be drawn with respect to the pressures of commercial and recreational navigation which affect the state of the river environment and the measures implemented to overcome those pressures. These conclusions are outlined in Table 41, with possible actions grouped under four headings: *a*) Intervention Strategies, *b*) Regulatory Measures *c*) Education and Awareness and *d*) Knowledge Acquisition. Some of the suggestions centre on the environmental effects of navigation while others focus on the environmental benefits of waterborne transportation as compared to highway or rail transportation.

Table 41
Specific conclusions and possible actions relative to the main navigation-related environmental pressures

Intervention Strategies

- Ensure that boating activities are developed in harmony with habitat and wildlife protection. (Consult the technical report and fact sheet on disturbance of wildlife species of the St. Lawrence River).
- Further to enactment of the *Oceans Act*, promote the establishment of marine protected areas to safeguard populations at risk and ensure that multiple uses are maintained.
- The establishment of an integrated management policy for dredging projects would make it possible to draw up a master plan for making good use of dredged material and restoring eroded shorelines; an organization made up of the principal stakeholders could handle long-term planning.
- Monitoring of freshwater and saltwater habitats sensitive to oil spills will help determine the most effective intervention techniques.
- Continue monitoring the spread of non-native species and their effects on the dynamics of riparian and aquatic communities (flora and fauna).
- In co-operation with the IMO, promote integrated management of ballast water discharges by implementing management methods on board ships and at port facilities.
- Encourage the adoption of a pollution prevention policy by ship and port authorities; the adoption of an environmental management policy promotes the adoption of an environmental culture within organizations rather than a culture of hostility towards environmental concerns.
- Draw up a profile of the trends of the past 20 years in the number of substandard ships identified by the various federal government agencies responsible for inspecting ships.
- Adjust marine traffic databanks so that vessels making more than one stopover in St. Lawrence ports are recorded as entering the ship channel only once.

Regulatory Measures

- Recent environmental assessments of dredging projects have uncovered deficiencies and inaccuracies in the interim sediment quality assessment criteria for the St. Lawrence; these criteria should be reviewed.
- In certain sensitive areas, reduced navigation speed during critical periods (high water levels) would help to minimize shoreline erosion resulting from ship-generated wake waves.
- The financial participation of shipping companies in efforts to restore eroded shorelines would help protect productive waterfowl habitats.
- Following the IMO example, promote a total ban on the use of antifouling paints containing tributyltins.
- Establish sediment quality criteria for butyltins to protect organisms and uses.
- Adopt regulatory measures, such as those proposed by the IMO in its Waste Management Plan.

Knowledge Acquisition

- Use existing data to produce maps showing the natural channel of the St. Lawrence River along its longitudinal axis and the changes in the ship channel following successive capital dredging operations.
- The transportation industry is responsible for a large share of energy consumption and, consequently, for an equally large share of the planet's greenhouse gas emissions; it is therefore appropriate to assess the environmental effects of the various modes of transportation and the impact that would result from a shift from waterborne to rail or highway transportation.
- Navigation-related environmental effects can only be fully assessed through analysis of a sustainable transportation strategy; such a study would promote recognition of navigation as a sustainable mode of transportation.

Education and Awareness	Knowledge Acquisition (cont'd.)
• The way in which environmental information is disseminated to groups concerned should ensure a climate of trust among stakeholders so that setbacks are avoided, such as those encountered in public consultations on the selective dredging of Fluvial Section shoals. • Set up awareness programs for pleasure craft operators showing the advantages of ecological waste management for them and for habitat protection purposes. • Promote reductions in the volume of wasted generated by ships. • Promote waste sorting and recycling of residual materials generated on board vessels.	• Using digital modeling to compare past and current hydrodynamic conditions would help to assess the extent to which ship channel construction has altered the river's hydrodynamics and to identify areas that have undergone the greatest changes and the extent of the human-induced alterations to the St. Lawrence River. • Determine the extent to which wave action from ships has eroded shorelines on the most heavily affected islands between Montreal and Sorel. • Determine the density and diversity of organisms present in ballast water in order to assess the effectiveness of the current regulatory measures designed to prevent the spread of invasive species. • Develop predictive methods for evaluating the risk of invasion by species from high-potential regions such as the Black Sea, the Caspian Sea and the Sea of Azov.

References

Acres International Limited. 1990. *Directory of Reception Facilities for Marine Wastes in Canada*. Canadian Coast Guard and Transport Canada.

Adriaanse, A. 1993. *Environmental Policy Performance Indicators: A Study on the Development of Indicators for Environmental Policy in the Netherlands*. The Netherlands: Ministry of Housing, Physical Planning, and Environment.

ANSTF – Aquatic Nuisance Species Task Force. 1998. (Web site: http://www.anstaskforce.gov).

Argus (Les Consultants en Environnement Inc.). 1996a. *Projet pilote d'ouvrage de protection contre l'érosion et de restauration des dépôts de matériaux dragués dans le secteur des îles de Contrecœur (rapport synthèse).* For Environment Canada, Canadian Wildlife Service, and Canadian Coast Guard. 66 pages + appendixes.

Argus (Les Consultants en Environnement Inc.). 1996b. *Restauration naturelle des rives du Saint-Laurent entre Cornwall et l'île d'Orléans. Volume 1: Guide d'interventions;.Volume 2: Tronçon 1 de Dundee à Boucherville (rive sud), de Rivière-Beaudette à Repentigny (rive nord); Volume 3: Tronçon 2 de Boucherville à Nicolet (rive sud), de Repentigny à Pointe-du-Lac (rive nord); Volume 4: Tronçon 3 de Nicolet à Saint-Antoine-de-Tilly (rive sud), de Pointe-du-Lac à Neuville (rive nord); Volume 5: Tronçon 4 de Saint-Antoine-de-Tilly (rive sud) à Saint-Vallier (rive sud), de Neuville à Saint-Joachim (cap Tourmente) (rive nord).* For Environment Canada, Canadian Wildlife Service, Ministère des Transports du Québec, James Bay Energy Corporation, and Ducks Unlimited Canada.

Argus (Groupe-Conseil Inc.). 1991. *L'érosion des îles du Saint-Laurent – Tronçon Montréal–lac Saint-Pierre*. For Environment Canada, Canadian Wildlife Service, and Canadian Coast Guard.

Armellin, A., and P. Mousseau. 1998. *Synthèse des connaissances sur les communautés biologiques du secteur d'étude Vallayfield-Beauharnois. Zones d'intervention prioritaire 3 et 4.* Technical Report. Environment Canada – Quebec Region, Environmental Conservation, St. Lawrence Centre.

Arsenault, G. 1995. *Prise en compte de la ressource faunique lors de la régularisation de l'eau du fleuve Saint-Laurent*. Mémoire du ministère de l'Environnement et de la Faune du Québec déposé auprès du Conseil international de contrôle du fleuve Saint-Laurent, Montréal, 7 novembre 1995.

BAPE – Bureau d'Audiences Publiques sur l'Environnement. 1998. *Programme décennal de dragage d'entretien aux quais 14 et 15 à Sorel par James Richardson International (Québec) limitée.* Rapport d'enquête et d'audience publique.

BAPE. 1991. *Projet Soligaz: Approvisionnement et entreposage souterrain de liquides de gaz naturel à Varennes*. Rapport d'Enquête No. 41.

BAPE. 1990. *Rapport d'enquête et d'audience publique. Agrandissement de la marina du centre nautique de Salaberry-de-Valleyfield.*

BAPE. 1988. *Rapport d'enquête et d'audience publique. Projet de marina à La Baie.*

Bergeron, L. 1995. *Les niveaux extrêmes d'eau dans le Saint-Laurent: Ses conséquences économiques et l'influence des facteurs climatiques*. For Environment Canada, Atmospheric Environment Branch.

Bergeron, P. 1995. *Exigences écologiques de* Dreissena polymorpha *et* Dreissena bugensis *et prévisions relatives à leur occurrence dans les lacs et les rivières du Québec*. Biorex Inc. for the Ministère de l'Environnement et de la Faune du Québec.

Bernier, L., P. Lachance, L. Quillaim, and D. Gingras. 1998. *Rapport sur l'état du Saint-Laurent: La contribution des activités urbaines à la détérioration du Saint-Laurent*. Technical Report. Federal-provincial SOE team, composed of representatives of Environment Canada, Fisheries and Oceans Canada, and the Ministère de l'Environnement et de la Faune du Québec. Sainte-Foy, Quebec.

Bouchard, H., and P. Millet. 1993. *The St. Lawrence River: Diversified Environments*. Thematic Report. "St. Lawrence UPDATE" series. Environment Canada, Conservation and Protection – Quebec Region, St. Lawrence Centre. Montreal.

Bouchard, L. M., J. Grondin, and P. Maurice. 1999. "Navigation de plaisance," in *Enquête santé sur les usages et les perceptions du Saint-Laurent,* under the supervision of E. Dewailly, J. Grondin, and S. Gingras. Final Report submitted to the Health Component of St. Lawrence Vision 2000.

Bourgeois, M., M. Gilbert, and B. Cusson. 1999. *Évolution du trafic maritime en provenance de l'étranger dans le Saint-Laurent de 1978 à 1996 et implications pour les risques d'introduction d'espèces non indigènes*. Canadian Technical Report of Fisheries and Aquatic Sciences (in press).

Bourgeois, V. 1998. Personal communication. Port Master, Port of Sept-Îles.

BST – Bureau de la Sécurité des Transports. 1996. *Réflexion sur la Sécurité Maritime* No. 11.

Canada Ports Corporation. 1991. *Impacts économiques du réseau*. Ports Canada.

Canadian Heritage. 1997. Unpublished data. Parks Canada, Saguenay–St. Lawrence Marine Park, Tadoussac.

Cantin, J. F. 1998. Personal communication. Environment Canada – Quebec Region, Atmospheric Environment Branch.

CANUTEC – Canadian Transport Emergency Centre. 1996. *Dangerous Goods: Initial Emergency Response Guide, 1996.* Transport Canada.

Carlton, J. T. 1996a. Pattern, process, and prediction in marine invasion ecology. *Biological Conservation* 78: 97–106.

Carlton, J. T. 1996b. Biological invasions and cryptogenic species. *Ecology* 77: 1653–1655.

Carlton, J. T., and J. B. Geller. 1993. Ecological roulette: The global transport of nonindigenous marine organisms. *Science* 261: 78–82.

CCG – Canadian Coast Guard. 1998. (Web site: http://www.qc.dfo-mpo.gc.ca/en/navig/ garde-c.html).

CCG. 1997. Unpublished data on annual vessel traffic. Fisheries and Oceans Canada.

CCG. 1995a. *Service Profile*. Fisheries and Oceans Canada.

CCG. 1995b. Unpublished data on vessel movements. Fisheries and Oceans Canada.

CCG. 1994. St. Lawrence ship channel map VN-200.

CCG. 1993a. Voluntary guidelines for the control of ballast water discharges from ships proceeding via the St. Lawrence Seaway.

CCG. 1993b. *Directive administrative sur le développement des voies navigables: Protection des rives*. Fisheries and Oceans Canada.

CCME – Canadian Council of Ministers of the Environment. 1996. *State of the Environment Reporting Guidelines for CCME Member Jurisdictions*. Dovetail Consulting and Salasan Associates Inc., for the CCME State of the Environment Working Task Group.

Chau, Y. K., R. J. Maguire, M. Brown, and S. P. Batchelor. 1997. Occurrence of organotin compounds in the Canadian aquatic environment five years after the regulation of antifouling uses of tributyltin. *Water Quality Research Journal of Canada* 32: 453–521.

Cloutier, P. 1997. Personal communication. Canadian Coast Guard, Laurentian Region, Marine Program Branch, Maritime Communications and Traffic Services, Quebec.

Collard, G. 1998. Personal communication. Director General, Port Saguenay.

Couillard, D. 1987. Quality of suspended and bottom sediment of the St. Lawrence system (Canada). *Hydrological Sciences Journal* 32: 445–467.

Couture, G. 1998. Personal communication. Director, Environment and Quality, Québec-Cartier Mining Co.

CST – Centre for Sustainable Transportation. 1998. *Sustainable Transportation Monitor*. March 1998. Toronto.

Cusson, B. 1997. Personal communication. Environment Canada, St. Lawrence Centre, Montreal.

D'Agnolo, F. 1978. *Étude d'érosion: Partie du fleuve Saint-Laurent entre Montréal et Sorel, 1974-1976*. Transport Canada and Canadian Coast Guard, Laurentian Region.

De Lafontaine, Y. 1997. Personal communication. Environment Canada, St. Lawrence Centre, Montreal.

DFO – Department of Fisheries and Oceans Canada. 1998a. (Web site: http://www.qc.dfo.ca/en/navig/incd-mar/part_1.htm#activ).

DFO. 1998b. *Notice to Mariners, Annual Edition 1998* (Notices 1 to 46).

DFO. 1998c. *La protection du milieu aquatique. Guide à l'usage du plaisancier*. Canadian Coast Guard. 26 pages.

DFO. 1996. *Notice to Mariners, Annual Edition 1996* (Notices 1 to 46).

DFO. 1992. *Sailing Directions: St. Lawrence River: Ile Verte to Quebec.*

Donze, M. (ed.). 1990. *Shaping the Environment: Aquatic Pollution and Dredging in the European Community*. Published on the occasion of the eleventh lustrum of the Association of Dutch Dredging Contractors. Delwel, The Hague.

Drolet, R. 1998. *Rapport sur l'état du Saint-Laurent: Le dérangement des espèces fauniques du Saint-Laurent.* Technical Report. Federal-provincial SOE Team, comprised of representatives of Environment Canada, Fisheries and Oceans Canada, and the Ministère de l'Environnement et de la Faune du Québec. Sainte-Foy, Quebec.

Economic Planning Group of Canada and Daniel Arbour and Associates. 1991. *Situational Analysis of the Overnight and Excursion Cruise Industry on the Great Lakes–St. Lawrence River and Interconnecting Waterways. Volume 1: Overnight Cruise Ships.*

Ellis, J. E., and M. Podlich. 1997. "Recreational Waters and Marine Debris: How Can We Effectively Reduce Littering? *In* J. M. Coe, and D. B. Rogers, eds., *Marine Debris: Sources, Impacts and Solutions,* pp. 271–276. Springer Series on Environmental Management. New York: Springer-Verlag.

Environment Agency of England and Wales. 1996. *The Environment of England and Wales*. Environment Agency, England and Wales, Bristol.

Environment Canada. 1996a. *Évaluation des risques aux ports de Montréal, Chicoutimi, Québec, Sept-Îles et Trois-Rivières*. Environmental Protection Branch, Environmental Emergencies Division, Montreal.

Environment Canada. 1996b. *Dragage sélectif des hauts-fonds; voie navigable du Saint-Laurent*. Direction des évaluations environnementales, Analyse environnementale.

Environment Canada. 1994a. *Répercussions environnementales du dragage et de la mise en dépôt des sédiments*. Les Consultants Jacques Bérubé Inc., for the Technology Development Section, Environmental Protection Branch, Quebec and Ontario regions.

Environment Canada. 1994b. *Éco Urgences.* Fact sheet. Environmental Protection Branch, Environment Canada, Quebec Region.

Environment Canada. 1987. *Summary of Spill Events in Canada 1974-1983*. Report EPS 5/SP/1.

Environment Canada, and British Columbia Ministry of Environment, Lands and Parks. 1992. *State of the Environment for the Lower Fraser River Basin.* SOE Report No. 92-1. State of the Environment Reporting.

EPB – Environmental Protection Branch. 1997. Data base on dredging and sediments in the St. Lawrence (DRAGSED). Environment Canada – Quebec Region, Montreal.

EPB. 1996. Data base on recreational/tourist infrastructures of the St. Lawrence River (socio-ecological directory). Environment Canada – Quebec Region, Montreal.

Freedman, B., C. Staicer, and N. Shackell. 1993. *Recommendations for a National Ecological Monitoring Program.* Dalhousie University, Department of Biology and School for Resource and Environmental Studies, Halifax, Nova Scotia.

Gauthier, D., and D. A. Steel. 1996. *A Synopsis of the Situation regarding the Introduction of Nonindigenous Species by Ship-transported Ballast Water in Canada and Selected Countries*. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2380.

Gingras, D., A. Armellin, M. J. Auclair, G. Fortin, M. Fournier, A. Jourdain, C. Loiselle, P. Millet, L. Quilliam, and Y. St-Jacques. 1997. *The River at a Glance.* Environment Canada – Quebec Region, Environmental Conservation, St. Lawrence Centre.

Government of Australia. 1994. *State of the Environment Reporting: Framework for Australia*. Department of the Environment, Sport and Territories, Australia.

Great Lakes Foundation. 1992. *Une région en transition: Comment assurer un avantage écologique durable pour la région des Grands Lacs et du Saint-Laurent*. Ottawa.

GRID-Arendal. 1997. *State of the Environment Norway 1997*. Global Resource Information Database (GRID), Arendal, Norway. (Web site: http://www.grida.no/prog/norway/ index.html).

GTCIM – Groupe de Travail du Comité Interministériel Multidisciplinaire. 1996. *Évaluation des possibilités d'utilisation des matériaux de dragage à des fins bénéfiques dans le cadre du projet de dragage sélectif des hauts-fonds dans la voie navigable entre Montréal et le Cap à la Roche*. Mandated by Fisheries and Oceans Canada for the Multidisciplinary Interdepartmental Committee.

Guerrier P., and M. Paul. 1996. *Le projet SHORES santé humaine: Organisation de la réponse d'urgence dans l'estuaire du Saint-Laurent*. Final Report. Comité de santé environnementale du Québec. 103 pages.

Hodge, T., S. Holtz, C. Smith, and K. H. Baxter. 1995. *Pathways to Sustainability: Assessing our Progress.* National Round Table on the Environment and the Economy. Ottawa.

Holland, L. E. 1986. Effects of barge traffic on distribution and survival of ichthyoplankton and small fishes in the upper Mississippi River. *Transactions of the American Fisheries Society* 115(1): 162–165.

Holland, R. E. 1993. Changes in planktonic diatoms and water transparency in Hatchery Bay, Bass Island area, Western Lake Erie since the establishment of the zebra mussel. *Journal of Great Lakes Research* 19: 617–624.

Hudon, C. 1995. *Considérations sur l'inclusion du critère de "préservation des ecosystèmes naturels" dans la régularisation du niveau dans le bassin Saint-Laurent–Grands Lacs.* Environment Canada – Quebec Region, Environmental Conservation, St. Lawrence Centre. Montreal.

IJC and GLFC – International Joint Commission and the Great Lakes Fishery Commission. 1990. *Exotic Species and the Shipping Industry: The Great Lakes–St. Lawrence Ecosystem at Risk*. A Special Report to the Governments of the United States and Canada.

IMO – International Maritime Organization. 1998. (Web site: http://www.imo.org/imo/news/298/birds.html).

Indicators for Evaluation Task Force. 1996. *Indicators to Evaluate Progress under the Great Lakes Water Quality Agreement*. International Joint Commission. (Web site: http://www.great-lakes.net:2200/partners/IJC/).

Jarry, V. 1997. Personal communication. Environment Canada, Environmental Protection Branch, Montreal.

Johnson, L. E. 1999. Post-establishment spread of the zebra mussel (*Dreissena polymorpha*): Potential mechanisms for the further spread in Ireland. In preparation.

Johnson, L. E., and J. T. Carlton. 1996. Post-establishment spread in large-scale invasions: Dispersal mechanisms of the zebra mussel *Dreissena polymorpha. Ecology* 77: 1686–1690.

Johnson, L. E., A. Ricciardi, and J. T. Carlton. 1999. Overland dispersal of the zebra mussel (*Dreissena polymorpha*): A risk assessment of mechanisms associated with transient recreational boating. In preparation.

Jourdain, A., and J. F. Bibeault. 1995. *Synthèse et analyse des connaissances sur les aspects socio-économiques du secteur Québec-Lévis. Zone d'intervention prioritaire 18.* Technical Report. Environment Canada – Quebec Region, Environmental Conservation, St. Lawrence Centre. Montreal.

Jourdain, A., J. F. Bibeault, and N. Gratton. 1995. *Synthèse des connaissances sur les aspects socio-économiques du Saguenay. Zones d'intervention prioritaire 22 et 23.* Technical Report. Environment Canada – Quebec Region, Environmental Conservation, St. Lawrence Centre. Montreal.

Kareiva, P. 1996. Developing a predictive ecology for non-indigenous species and ecological invasions. *Ecology* 77: 1651–1652.

Kilgour, B. W., and G. L. Mackie. 1993. "Colonization of different construction materials by zebra mussel (*Dreissena polymorpha).*" *In* T. F. Malepa and D. W. Schloesser (eds.), *Zebra Mussels: Biology, Impacts and Control*, pp. 167–174. Boca Raton, Florida: Lewis Publisher/CRC Press.

Killgore, K. J., A. C. Miller, and K. C. Conley. 1987. Effects of turbulence on yolk-sac larvae of paddlefish. *Transactions of the American Fisheries Society* 116 (4): 670–673.

Laist, D. W. 1997. "Impacts of Marine Debris: Entanglement of Marine Life in Marine Debris Including a Comprehensive List of Species with Entanglement and Ingestion Records." *In* J. M. Coe and D. B. Rogers (eds.), *Marine Debris: Sources, Impacts and Solutions*, pp. 99–139. Springer Series on Environmental Management, New York: Springer-Verlag.

Lapierre, L. 1998. Personal communication. Ministère de l'Environnement du Québec, Direction des écosystèmes aquatiques, Québec.

Lapierre, L., J. Fontaine, B. Cusson, and C. Ménard. 1994. *Distribution spatiale des larves et stades fixés de moule zébrée dans le Saint-Laurent au cours de 1991*. Environment Canada – Quebec Region, Environmental Conservation, St. Lawrence Centre, Montreal.

Lasserre, J. C. 1997. *Le présent et l'avenir du système navigable Saint-Laurent–Grands Lacs: Quels enjeux?* Transport Canada, Transportation Development Centre.

Lasserre, J. C. 1989. *Le Québec et le Saint-Laurent: pour une analyse des problèmes de compétitivité de la voie d'eau*. For the Secrétariat à la Mise en Valeur du Saint-Laurent.

Lasserre, J. C. 1980. *Le Saint-Laurent, grande porte de l'Amérique.* "Les Cahiers du Québec" series. Ed. Hurtubise HMH Ltée, Ville LaSalle.

Lavergne, Y. 1998. Personal communication. Public Works and Government Services Canada, Quebec Region.

Leach, J. H. 1993. "Impacts of the Zebra Mussel (*Dreissena polymorpha*) on Water Quality and Fish Spawning Reefs in Western Lake Erie." *In* T. F. Malepa and D. W. Schloesser (eds.), *Zebra Mussels: Biology, Impacts and Control,* pp. 381–397. Boca Raton, Florida: Lewis Publisher/CRC Press.

Le Grand, J. F. 1994. *Transport maritime: Plus de Sécurité pour une mer et un littoral plus propres*. Mission d'information sur la sécurité du transport maritime et la pollution du litoral. Collection "Les Rapports du Sénat" No. 500. Paris.

Lehman, J. T., and C. E. Cáceres. 1993. Food-web responses to species invasion by a predatory invertebrate: *Bythotrephes* in Lake Michigan. *Limnological Oceanography* 38: 879–891.

Lehman, J. T., and D. A. Lehman. 1996. Status of the nonindigenous invertebrate predator *Bythotrephes cederstroemi* (Crustacea: Cladocera) in lakes Erie, Huron and Michigan. Proc. Symp. on Nonindigenous Species in Western Aquatic Ecosystems. Portland State University Lakes and Reservoirs Program Publ. No. 96-8: 7–14.

Lehoux, D. 1998. Personal communication. Environment Canada – Quebec Region, Canadian Wildlife Service.

Lehoux, D., D. Dauphin, C. Grenier, M. Melançon, and L. Lapointe. 1997. *Plan directeur pour la stabilisation des îles fédérales en erosion dans le tronçon Montréal-Sorel*. Canadian Wildlife Service for Fisheries and Oceans Canada, and Canadian Coast Guard. 54 pages + 7 cartographic plates.

Locke, A., D. M. Reid, H. C. Van Leeuwen, W. G. Sprules, and J. T. Carlton. 1993. Ballast water exchange as a means of controlling dispersal of freshwater organisms by ships. *Canadian Journal of Fisheries and Aquatic Sciences* 50: 2086–2093.

Lowe, R. L., and R. W. Pillsbury. 1995. Shift in benthic algal community structure and function following the appearance of zebra mussels (*Dreissena polymorpha*) in Saginaw Bay, Lake Huron. *Journal of Great Lakes Research* 21: 558–566.

Lynas, E. M. 1990. "St. Lawrence Whale Research and Regional Economic Development." In *Compte-rendu du Forum International pour l'Avenir du Béluga*, pp. 147–160. Tadoussac 1988. Presses de l'Université du Québec.

Mackie, G. L. 1991. Biology of the exotic zebra mussel (*Dreissena polymorpha*) in relation to native bivalves and its potential impact in Lake St. Clair. *Hydrobiologia* 219: 251–268.

MacLaren, V. 1996. *Developing Indicators of Urban Sustainability: A Focus on the Canadian Experience.* Canada Mortgage and Housing Corporation, Intergovernmental Committee on Urban and Regional Research. Toronto: ICURR Press.

Marsden, J. E., and D. J. Jude. 1995. *Round Gobies Invade North America*. Ohio Sea Grant Communication.

Martin, V. 1998. Personal communication. Eastern Canada Response Corporation Ltd. (ECRC).

Martini, F. 1998. Personal communication. Montreal Port Corporation, International Affairs Services.

Massicote, B., L. Côté, S. Bélanger, and B. P. Harvey. 1996. *Guide d'évaluation environnementale des techniques de stabilisation des berges*. Les Consultants en Environnement Argus Inc., for Fisheries and Oceans Canada, Fish Habitat Management Division.

Mauvais, J. L. 1991. *Les ports de plaisance: Impacts sur le littoral*. Institut Français de Recherche pour l'Exploitation de la Mer, Service de la documentation et des publications.

Mellina, E., and J. B. Rasmussen. 1994. Patterns in the distribution and abundance of zebra mussel (*Dreissena polymorpha*) in rivers and lakes in relation to substrate and other physicochemical factors. *Canadian Journal of Fisheries and Aquatic Sciences* 49*:* 1501–1506.

Michaud, R., and M. Gilbert. 1993. *Les activités d'observation en mer des baleines dans l'estuaire du Saint-Laurent: Situation actuelle et problématique*. For Parks Canada, Quebec Region.

Mills, E. L., J. H. Leach., J. T. Carlton, and C. L. Secor. 1993. Exotic species in the Great Lakes: A history of biotic crises and anthropogenic introductions. *Journal of Great Lakes Research* 19: 1–54.

Minister of Transport's Office. 1996. Press release, June 10, 1996.

Moore, D. R. J., D. G. Noble, S. L. Walker, D. M. Trotter, M. P. Wong, and R. C. Pierce. 1992. *Canadian Water Quality Guidelines for Organotins.* Scientific Series No. 191. Environment Canada, Ecosystem Sciences and Evaluation Directorate. 45 pages + appendices.

Morin, J., P. Boudreau, and M. Leclerc. 1994. *Réhabilitation de l'écosystème du Saint-Laurent. Lac Saint-François: Les bases de la modélisation hydrodynamique*. Rapport de recherche No. R-412. Institut National de la Recherche Scientifique, INRS-Eau.

Morisset, J. 1999. Personal communication. Fisheries and Oceans Canada, Laurentian Region. Sept-Îles.

MUC – Montreal Urban Community.1997. *Rapport du comité technique sur les rapides de Lachine*. Commission de l'aménagement.

Ninaber, E. 1997. "MARPOL Annex V, Commercial Ships and Port Reception Facilities: Making it Work.." *In* J. M. Coe and D. B. Rogers (eds.), *Marine Debris: Sources, Impacts and Solutions*, pp. 239–243. Springer Series on Environmental Management. New York: Springer-Verlag.

Normandeau, C. 1997. "Étude de la contamination des étoiles de mer de l'estuaire du Saint-Laurent par les composés butylétains." Master's thesis, Université du Québec à Rimouski. 150 pages.

OECD – Organization for Economic Co-operation and Development. 1995. *Environmental Performance Reviews: Canada*. Paris.

OECD. 1994. *Environmental Performance Reviews: Japan*. Paris.

OECD. 1993a. *Environmental Indicators: Common Framework and Terminology.* Environment Directorate, Group on Environmental Performance. Paris.

OECD. 1993b. *OECD Core Set of Indicators for Environmental Performance Reviews*. OECD/GD(93)179. Paris.

Ouellet, Y. 1992a. *Sainte-Marthe-du-Cap-de-la-Madeleine: Étude comparative des vagues générées par les navires et par le vent*. Civil Engineering Department, Laval University, for Transport Canada.

Ouellet, Y. 1992b. *Champlain: Etude comparative des vagues générées par les navires et par le vent*. Report GCT-92-04. Civil Engineering Department, Laval University, for Transport Canada.

Ouellet, Y. 1987. *Champlain: Étude sur les phénomènes d'érosion littorale*. Department of Public Works Canada.

Ouellet, Y. 1985. *Sainte-Marthe-du-Cap-de-la-Madeleine: Étude sur les phénomènes d'érosion littorale*. Department of Public Works Canada.

Ouellet, Y., and W. Baird. 1978. Érosion des rives dans le Saint-Laurent. *Canadian Journal of Civil Engineering* 5: 311–323.

Page, C. 1998. Personal communication. Manager, Maritime Agency, Alcan Port Facilities, La Baie.

Panasuk, S. 1987. *L'érosion actuelle et récente des îles de Varennes dans la région de Montréal*. Research Report. Université du Québec à Montréal.

Payer, C., and M. Breton. 1984. *Étude socio-économique de l'industrie d'observation des baleines au Québec.* Fisheries and Oceans, Quebec Regional Directorate, Fish Management. Quebec.

Pelletier, É., and C. Normandeau. 1997. Distribution of butyltin residues in mussels and sea stars of the St. Lawrence Estuary. *Environmental Technology* 18: 1203–1208.

Port of Montreal. 1996. *Dragage sélectif des hauts-fonds pour optimiser le chargement des navires à fort tirant d'eau circulant dans le chenal maritime entre Montréal et Cap à la Roche*. Synthesis of environmental study.

Port of Montreal. 1994. *Tour d'Horizon*.

Port of Montreal. 1998. (Web site: http://www.port-montreal.com/english/index.htm).

Port of Quebec. 1998. (Web site: http://www.portquebec.ca).

Port of Trois-Rivières. 1996. Unpublished data on marine transport.

Procéan. 1993. *Évaluation des imports-exports de contaminants dans les secteurs central et aval de l'estuaire de la Rivière Saint-Charles (Port de Québec): Synthèse.* Environment Canada, Conservation and Protection – Quebec Region, Environmental Protection Branch.

Procéan. 1991. *Plan d'intervention des secteurs aquatiques contaminés: Port de Québec, secteur P1Q1, phase I, estuaire de la Rivière Saint-Charles*. Environment Canada, Conservation and Protection – Quebec Region, Environmental Protection Branch.

Procéan, Les Consultants Jacques Bérubé, and GDG Environnement. 1996. *Étude en vue d'une dragage sélectif des hauts-fonds dans la voie navigable entre Montréal et le cap à la*

Roche. Report presented to the Canadian Coast Guard. 395 pages, 86 tables, 88 figures, 4 maps, 11 appendices.

PRPTSMSRC – Public Review Panel on Tanker Safety and Marine Spills Response Capability. 1990. *ProtectingOur Waters.* Final Report.

PWGSC – Public Works and Government Services Canada. 1997. Unpublished proceedings of the information session on the environmental study of dredging in the port of Sorel. Municipality of Yamachiche, October 16, 1997.

Quilliam, L., and P. Millet. 1998. *Rapport sur l'état du Saint-Laurent: Mise à jour des indicateurs environnementaux du Rapport-synthèse sur l'état du Saint-Laurent. Supplément au Volume 2: L'état du Saint-Laurent.* Technical Report. Federal-provincial SOE Team, comprised of representatives of Environment Canada, Fisheries and Oceans Canada, and the Ministère de l'Environnement et de la Faune du Québec. Montreal.

Republic of Tunisia. 1996. *The State of the Environment National Report*. Ministry for the Environment and Land Use Planning.

Ricciardi, A., and J. B. Rasmussen. 1998. Predicting the identity and impact of future biological invaders: A priority for aquatic resource management. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 1759–1765.

Richard, L. 1998. Personal communication. Superintendent, Rail Maintenance and Repairs, QIT - Fer et Titane, Havre-Saint-Pierre.

Riel, L. 1997. *Rapport annuel de l'activité des navires de croisière au Port de Québec pour l'année 1997.* Société du port de Québec, Service de l'exploitation/capitainerie. 36 pages.

Robichaud, A., and R. Drolet. 1998. *Rapport sur l'état du Saint-Laurent – Les fluctuations des niveaux d'eau du Saint-Laurent.* Technical Report. Federal-provincial SOE Team, comprised of representatives of Environment Canada, Fisheries and Oceans Canada, and the Ministère de l'Environnement et de la Faune du Québec. Sainte-Foy.

Robitaille, J. A., Y. Vigneault, G. Shooner, C. Pomerleau, and Y. Mailhot. 1988. *Physical changes to fish habitat in the St. Lawrence River from 1945 to 1984 and effects on commercial fisheries.* Canadian Technical Report of Fisheries and Aquatic Sciences No. 1608.

Roche Ltée. 1993. *Caractérisation des débris de plastique de l'estuaire du Saint-Laurent*. For Fisheries and Oceans Canada.

Rouleau, P. 1997. Personal communication. Fisheries and Oceans Canada, Canadian Coast Guard.

Saint-Louis, R., E. Pelletier, and C. Gobeil. 1997. "Contamination récente par le tri-*n*-butylétain de l'estuaire maritime du Saint-Laurent, Canada. ZONE CÔTIÈRE CANADA 96." Conférence internationale Les zones côtières : gestion intégrée et développement durable.

Savard, R. 1997. Personal communication. Fisheries and Oceans Canada, Canadian Coast Guard.

SCOPE – Scientific Committee on Problems of the Environment. 1994. *Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development*. Preliminary Report. Project on Indicators of Sustainable Development, for the United Nations Commission on Sustainable Development and World Bank.

Segal, A. 1997. Marketing to cruise lines: Selling cities or routes? Presentation during the special session on marine transportation of the Northeast Association of State Transportation Officials (NASTO), organized by the Secrétariat à la Mise en Valeur du Saint-Laurent, June 11 in Quebec City.

SEPA – Swedish Environmental Protection Agency. 1994. *Environmental Impact of Pleasure Craft, Fishing Vessels and Working Vessels*. 24 pages.

Skubinna, J. P., T. G. Coon, and T. R. Batterson. 1995. Increased abundance of submersed macrophytes in response to decreased turbidity in Saginaw Bay, Lake Huron. *Journal of Great Lakes Research* 21: 476–488.

SLC – St. Lawrence Centre. 1996a. *State of the Environment Report on the St. Lawrence River. Volume 1: The St. Lawrence Ecosystem.* "St. Lawrence UPDATE" series. Environment Canada – Quebec Region, Environmental Conservation, and Editions MultiMondes. Montreal.

SLC. 1996b. *State of the Environment Report on the St. Lawrence River. Volume 2: The State of the St. Lawrence.* "St. Lawrence UPDATE" series. Environment Canada – Quebec Region, Environmental Conservation, and Editions MultiMondes. Montreal.

SLC. 1996c. Unpublished data from the zebra mussel and quagga mussel buoy colonization monitoring program in the St. Lawrence River. Environment Canada – Quebec Region, Environmental Conservation. Montreal.

SLC. 1993a. *Qualité des sédiments et bilan des dragages sur le Saint-Laurent*. Lucie Olivier and Jacques Bérubé, for Environment Canada, Technology Development Branch.

SLC. 1993b. *Cadre législatif de gestion des sédiments au Québec.* Les Consultants Jacques Bérubé Inc. for Environment Canada, Technology Development Branch.

SLC. 1992. *Guide to Selecting and Operating Dredging Equipment and Related Practices*. Les Consultants Jacques Bérubé Inc., with the collaboration of Public Works and Government Services Canada, and the Ministère de l'Environnement du Québec.

SLC and Laval University – St. Lawrence Centre and Université Laval. 1991. *Environmental Atlas of the St. Lawrence – International Navigation Route: Commercial Shipping on the St. Lawrence.* St. Lawrence "UPDATE" series. Environment Canada, Conservation and Protection, Quebec Region, Montreal.

SLC and MENVIQ – St. Lawrence Centre and Ministère de l'Environnement du Québec. 1992. *Interim Criteria for Quality Assessment of St. Lawrence Sediment.* Environment Canada, Conservation and Protection, Quebec Region. Montreal.

SLSA –St. Lawrence Seaway Authority: 1995. *The St. Lawrence Seaway Authority: Traffic Report - Navigation Season 1995.* St. Lawrence Seaway Authority and St. Lawrence Seaway Development Corporation. Ottawa.

SLSA – St. Lawrence Seaway Authority (now called the St. Lawrence Seaway Management Corporation). 1998. (Internet site: http://www.seaway.ca).

SMVSL – Secrétariat à la Mise en Valeur du Saint-Laurent. 1998. *Guide des croisières internationales sur le Saint-Laurent.* 36 pages.

Société du Parc Industriel et Portuaire de Bécancour. 1996. Unpublished data on marine transport.

Standing Committee on Transport. 1995. *A National Marine Strategy: Report of the Standing Committee on Transport*.

Statistics Canada. 1996. *Shipping in Canada*. Catalogue No. 54-205.

Sussman, G. 1978. *The St. Lawrence Seaway: History and Analysis of a Joint Water Highway.* Canada-U.S. Prospects Series. C.D. Howe Research Institute and National Planning Association, Montreal. 84 pages.

Thorp, S. 1993. *Great Lakes and St. Lawrence River Commerce: Safety, Energy and Environmental Implications of Modal Shifts*. Great Lakes Commission: Ann Arbor, Michigan. 55 pages + appendices.

Tittley, L. 1997. *Profil de l'industrie des croisières-excursions au Québec en 1996*. Association des croisières-excursions du Québec. 41 pages + appendices.

Tittley, L. 1992. Les croisières de longue durée et les excursions nautiques sur le Saint-Laurent: Tendances et perspectives. *Téoros* 11(3): 31–34.

Transport Canada. 1997. *Évaluation environnementale préalable du projet de dragage au quai n^o 2 à Sorel*. SAG-Environnement, Public Works and Government Services Canada and Les Consultants Jacques Bérubé Inc. 110 pages + 6 appendices.

Transport Canada. 1996. *Batiscan*. Prospectus.

Transport Canada. 1995a. *National Marine Policy*.

Transport Canada. 1995b. *National Marine Policy*. Harbour and Ports, Quebec.

Transport Canada. 1995c. *Vers un réseau de communautés portuaires; profil des ports publics*.

TRB – Transportation Research Board. 1997. *Toward a Sustainable Future: Addressing the Long-term Effects of Motor Vehicle Transportation on Climate and Ecology*. Special Report 251. National Research Council, Committee for a Study on Transportation and a Sustainable Environment. National Academy Press: Washington.

Trépanier, S., G. Shooner, J. Therrien, and M. Breton. 1989. *Étude socio-économique sur l'industrie d'observation des baleines au Québec.* Department of Fisheries and Oceans, Quebec Regional Directorate, Fish Management.

U.S. EPA – United States Environmental Protection Agency. 1995. *Conceptual Framework to Support Development and Use of Environmental Information in Decision Making*. Document No. 239-R-95-012. Washington, D.C. (Web site: http://www.epa.gov/indicator/frame/).

VanderZwagg, D. 1994. *La LCPE et le principe ou l'approache de précaution. Examen de la LCPE: Document d'élaboration des enjeux.* Environment Canada, Environmental Protection, Office of the Canadian Environmental Protection Act. Hull, Quebec.

Wallace, B. 1997. "A Strategy to Reduce, Control and Minimize Vessel-Source Marine Debris." *In* J. M. Coe and D. B. Rogers (eds.), *Marine Debris: Sources, Impacts and Solutions,* pp. 277–286. Springer Series on Environmental Management. New York: Springer-Verlag.

Williamson, M., and A. Fitter. 1996. The varying success of invaders. *Ecology* 77: 1661–1666.

World Dredging, Mining and Construction. 1998. *Special Focus: Dredging Programs 1998.* pp. 8, 10, 14, 18–19.

Zins Beauchesne and Associates, and Groupe SECOR. 1997. *Étude sur le nautisme : Portrait du nautisme au Québec et potentiel de développement dans le grand Montréal. Rapport final sur l'industrie et le marché du nautisme*. Association Québécoise de l'Industrie

Nautique, Federal Office of Regional Development - Quebec, Ministère de la Métropole, Tourisme Québec, and the Montreal Urban Community.

Appendix

PRESSURE-STATE-RESPONSE FRAMEWORK

The report, *The Environmental Risks and Impacts of Navigation on the St. Lawrence River* has been prepared by using the "Pressure-State-Response" (PSR) framework to organize and analyse the information on this environmental issue relating to the St. Lawrence. This conceptual framework is currently a standard model applied in drafting state-of-the-environment reports and in establishing environmental indicators. It was developed by the Organization for Economic Co-operation and Development (OECD) for use in designing environmental indicators (OECD 1993a, 1993b) and assessing the environmental performance of OECD member countries (OECD, 1994; 1995). Many countries and organizations have used the OECD framework in the analysis of environmental information (e.g. Adriaanse 1993, CCME 1996, Environment Agency of England and Wales 1996, Government of Australia 1994, GRID-Arendal 1997, Republic of Tunisia 1996, SCOPE 1994). Although the terminology employed in the documentation may vary, the general principles proposed in the PSR framework still have wide currency today.

The PSR framework proposed by the OECD is a general outline of the causal links between **pressures** exerted on the environment by human activities, changes in the **state** of the environment caused by these pressures and societal **responses —** that is, the measures adopted to address the pressures or the state of the environment. Although it has various limitations, the model applies to all levels of activity and all types of problems. In addition, despite its relatively simple appearance, it takes into account the variability and dynamics of ecosystems and the complex interactions between natural components and human activities.

The context in which this general framework is used largely determines how it applies to actual cases. Some organizations have sought to improve or clarify the OECD model, either because of experience gained from using the PSR framework or out of a desire to include other dimensions, particularly the ecosystem vision of interactions between human beings and their environment (e.g. CCME 1996, Government of Australia 1994, Indicators for Evaluation Task Force 1996, U. S. EPA 1995). In addition, some writers, such as Freedman et al. (1993), Hodge et al. (1995) and MacLaren (1996), have expanded on these concepts and their application to knowledge of the state of the environment and environmental problems. They do not directly refer to the PSR model but nonetheless draw on the same principles of cause and effect between the sources of environmental disturbance, their effects on the state of ecosystems and the response measures adopted.

When the present report was prepared, some adjustments and clarifications were necessary to apply the OECD framework. The figure on the following page shows the modified model, which has the following characteristics:

- **Pressures** on the environment are broken down into four levels, three of which are human-induced. The first level identifies structural factors that have a decisive influence on human activities (e.g. population growth and international trade agreements). The second level identifies human activities deemed to exert pressure on the environment (e.g. agricultural activities, industrial plants and urban activities). The third level includes direct pressures generated by these activities, i.e. waste discharges, wildlife harvesting or biophysical changes. The fourth consists of natural disaster pressures, i.e. natural phenomena on a scale exceeding the limits usually observed in ecosystems (e.g. floods and earthquakes) and producing direct pressures similar to those generated by human activities.
- **State** refers to the condition and quality of and changes observed in biophysical components and ecological processes and the presence of stress factors in the environment. It refers to ecosystems, habitats or specific natural resources. From an ecosystem perspective involving human beings and their activities, the concept of state also refers to uses, human-source benefits and human health issues associated with the environment.
- **Response** refers to measures implemented and decisions made by various societal agents (e.g. governments, private-sector companies, non-governmental organizations, citizens and international organizations) to deal with pressures and the state of the environment. The responses, which may vary greatly (e.g. legal, administrative, voluntary actions, funding and tax measures, education and joint action), are intended to prevent, eliminate or reduce the pressures or remedy their impacts. Responses must be adapted to suit the changes that have occurred in the state of the environment.
- The human dimension of the model cuts across the pressure, state and response components. When uses, human-source benefits and human health issues are incorporated into the state of the environment components, the model expresses the ecosystem vision wherein human beings are an important element of the system and emphasizes the need to analyse cause-and-effect relationships between the pressure, state and response components from a management and decision-making perspective.

- The arrows indicate a cause-and-effect relationship or an interaction between pressure, state and response components, except for the arrows pointing toward the responses; they show the flow of information to be used in developing and assessing responses.

The knowledge targeted in applying the PSR framework relates to the condition and quality of components, changes that have been observed, as well as interactions between components and effects generated by them. To gain a better understanding of the environmental issues related to the St. Lawrence River, it was necessary to first look at the context and problems since these determined how the information should be processed and incorporated into the analysis and synthesis.