In 2004, the Navigation Consensus Building Committee tabled a Sustainable Navigation Strategy for the St. Lawrence River. The aim of the strategy is to reduce the environmental impact of navigation, while ensuring that this mode of transportation can continue to develop on the river. In its strategy, the Committee set out eight priorities and a related five-year action plan (2004-2009). One of the priorities was the assessment of the adaptation options available to commercial navigation to respond to water level fluctuations caused by climate change.

This study is the first step towards implementing that priority. Climate change is a highly complex field and the study of the adaptation measures that could be used to mitigate the potential declines in water levels in the St. Lawrence is a highly sensitive issue that generates lively discussion. This study is therefore intended to examine what could be done to protect against the adverse effects of climate change on navigation, without recommending any particular adaptation measure.

We are pleased to present this exploratory study on climate change and marine transportation on the St. Lawrence River. In the light of the discussions of the Navigation Consensus Building Committee, we are well aware that the scope of this issue goes well beyond the framework of navigation activities. As a result, we hope that this study will prompt additional studies and ideas in this area and that the discussion will be expanded to include a broader range of stakeholders.

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SUMMARY

This document is the result of a preliminary assessment of possible technical and logistical adaptation measures for addressing climate change impacts on commercial navigation. This initiative flows from one of the priorities identified by the Navigation Consensus Building Committee in its Sustainable Navigation Strategy for the St. Lawrence River. It is assumed that before attempting to address lasting low water levels on the river portion of the St. Lawrence River through adaptation measures targeting directly and exclusively the St. Lawrence itself and affecting its resources and those of its physical and human environment, we would examine possibilities offered by the management of the entire Great Lakes–St. Lawrence watershed, particularly the control afforded by the Moses-Saunders dam. However, the identification and analysis of such possibilities were beyond the scope and resources of this study and were therefore not included in it. As a result, the amount of information provided on a particular option, or lack thereof, should not be interpreted as a position in favour of or against that option.

A number of climate change scenarios predict a decline in inflows to the Great Lakes–St. Lawrence system. Such a decline could have a significant impact on various activities, including commercial navigation on the St. Lawrence River. For that reason, the Navigation Consensus Building Committee felt it advisable, in the context of sustainable navigation, to

study adaptation options that would make it possible to maintain existing levels of marine and port activities. This exploratory study is the first step in addressing climate change adaptation for commercial navigation on the St. Lawrence. Additional studies will have to be conducted to provide further details on the various scenarios analyzed.

The study is divided into two parts. The first part examines the magnitude and spatial distribution of the anticipated decline in water levels in the river section of the St. Lawrence (Montreal–Quebec City section). It uses a digital hydraulic model that incorporates the results of the most recent climate scenarios for the Great Lakes and Ottawa River watersheds as well as scenarios predicting a rise in sea levels. Simulations were carried out using the water levels of a normal water year and low water year as references, from which the values derived from climate projections were subtracted. Where the water year type in about 2050 corresponds to a normal water year, the declines observed on the St. Lawrence would not adversely affect commercial navigation activities. Under the four climate change scenarios considered, the water depth at Montreal would be above chart datum for all months. More serious impacts are anticipated, however, when the simulations use a low water year as a reference. According to the most pessimistic climate change scenario, WD (warm and dry), water level declines of up to 1 metre below chart datum could occur at Montreal, and of approximately 30 centimetres below chart datum at Trois-Rivières. This situation would continue for several consecutive months, hence the concerns regarding impacts. According to the simulations, the effect of water level declines would stop around Bécancour. It should be noted that these simulations did not consider the specific operating regime of the Moses-Saunders dam, which regulates inflows from Lake Ontario to the St. Lawrence River. The adjustment of this regime will likely be the first adaptation measure implemented, because commercial navigation is one of the priority uses designated in the Canada–U.S. Boundary Waters Treaty. If a scenario such as WD comes to pass, it will certainly put this measure to the test in terms of its ability to provide inflows. Under the new regulation plan that will soon be adopted by the International Joint Commission, efforts will be made to share the impacts between the upstream (Great Lakes) and downstream (St. Lawrence River) sections of the system when required. This openness to sharing suggests that the management of the dam cannot solve everything and that adaptation measures will have to be taken both upstream and downstream if the critical climate change scenarios become a reality.

It is very difficult to predict the recurrence of a hydrological event of this magnitude, since the probability of future climate conditions reproducing past conditions is low. However, it is clear that a succession of years in which water levels are below chart datum would have a greater impact than if there were alternating low water years, i.e., normal water cycle fluctuations. Given the uncertainty associated with climate forecasts, specifically the magnitude and direction of future events, caution is advised in interpreting the projections. The role played by many factors has yet to be determined. Therefore, the hydrologic simulations performed and their effect on water levels must be viewed from the perspective that the anticipated weather events would occur as we are currently able to forecast, which, of course, remains to be determined. These projections were used to explore various adaptation strategies that would mitigate the impacts of the anticipated water level declines.

That is the focus of the second part of the study, which explores a number of adaptation options for commercial navigation in relation to the potential water level increases they would yield.

The options can be divided into two categories: one excludes all physical changes to the river, whereas the other includes physical changes. They are examined from the viewpoint of sustainable development requirements, i.e., taking into account a number of their economic, environmental and social impacts. Three classes of water level fluctuations were identified and a set of options was associated with each class:

1- Small fluctuations (0–15 cm): evaluation of potential water level increases obtained by improving the accuracy of *technical and technological* tools.
2- Moderate fluctuations (15–50 cm): evaluation of potential increases obtained as a result of *physical changes to the river* (dredging and hydraulic structures).
3- Large fluctuations (50 cm and over): evaluation of potential increases obtained through *structural adaptations* (ship configuration tailored to the conditions of the St. Lawrence) and *organizational adaptations* (restructuring of port activities).

The analysis of the potential rise in water levels that would result from technological (COWLIS network) and technical (squat equation) options reveals that the results would be limited. With respect to the COWLIS network, it does not predict the river water levels with a sufficient degree of accuracy. The current discrepancy between predicted values and observed values exceeds, after only four days, the safety margin that carriers use for overseas shipments. Reducing this safety margin would result in a gain of water column use of between 20 and 30 centimetres. Significant advancements in meteorological forecasting are therefore critical if this option is to be included as an adaptation strategy. With respect to the squat equation, studies are being carried out on the St. Lawrence to verify whether the equation currently used is optimal for all types of ships. Experiments conducted on other navigable waterways indicate that, in some cases, several additional centimetres can be gained by using an alternative equation. However, these new equations occasionally yield values that are lower than the observed values, and that are sometimes even below the underkeel clearance specifications. We will therefore have to wait for the results of the study conducted on the St. Lawrence to know whether gains are possible.

The analysis of the river development option suggests that water level declines could be offset by physical changes to the river. In the case of dredging, a preliminary calculation of the sediment volumes to be removed was conducted on the basis of the declines forecast by the most pessimistic scenario (WD) and the intermediate scenario (NWD - not as warm and dry). The volume of sediment was estimated at 1.6 million m^3 and 930,000 m^3, respectively. Costs of approximately of $70 million (WD) and $42 million (NWD) were estimated, not counting the costs of environmental impact studies, environmental compensation measures and residual effects. A very brief overview of certain environmental impacts is presented; if this option is selected, the assessment should be completed and the impacts quantified. Although the costs of the dredging option are relatively low, its effectiveness is also relative, since the deepening of the channel does not make it possible to retain water.

A number of numerical simulations were performed on various types of hydraulic structures, dikes and dam between Montreal and Trois-Rivières. They were conducted using a reference scenario under which the flow rate of the St. Lawrence was reduced to 5,000 m^3/s at Sorel. This flow rate causes a decline in water levels of just over 1 m at Montreal, which corresponds to the results of the WD climate scenario. The results obtained with cross dikes show a potential water-level rise of 90 cm at Montreal when the simulations are performed on a series of three cross dikes located several kilometres apart. However, these dikes were located relatively close to Montreal, between Lanoraie and Verchères. Even if the rise is significant, it is still about 20 cm below chart datum. Moreover, one problem observed with this type of structure is that a downward water movement is created at the outlet of the dikes, which would result in a water-level decline of about 20 cm over several dozen kilometres. The design of the structures could correct this effect. Simulations were performed on the same type of dikes, this time located upstream of Trois-Rivières. The observed water-level rise was 35 cm at Montreal and could be considered significant given that Montreal is 120 km apart from the structures. Other simulations were also conducted with 7-km long longitudinal dikes, connected to cross dikes located in the Verchères sector. The observed increase in the water level at Montreal would be 1.6 m and the levels would be close to 50 cm above chart datum. The outlet of the structure, in the form of a diffuser, would appear to resolve the problem of downward water movement. A final simulation was performed with a dam and locks located upstream of Trois-Rivières. This structure increases the water level at Montreal by close to 2 m (1 m above chart datum). This strong increase indicates that the free-flow stage of the dam should be adjusted downward to limit the negative effects. Although interesting from a hydraulic perspective, since it would make it possible to recover the entire area of the water body lost due to climate change, this option would have several environmental disadvantages, such as obstructing species migration and altering sediment transport. If significant interest is shown in this option, studies on the design of these structures should be conducted to take into account the impacts on the environment and to mitigate their negative effects. A general overview of the environmental impacts relating to the erection of hydraulic structures is presented in section 2.3.6. The approximate cost of these structures ranges from \$50 million to just over \$500 million, and does not include the costs of environmental compensation measures or operating and maintenance costs.

The structural adaptation option relates to ship configuration. The objective of this option would be to adapt the structure of ships to the hydraulic conditions of the St. Lawrence by reducing their draft. The latest generation of ships built for the St. Lawrence was designed with a smaller draft (10.78 m) by lengthening the hull to 294 m while maintaining a width of 32.2 m. This configuration appears to have a number of limitations in terms of the pressure exerted on the hull and the maneuverability of the ships in the bends of the river. The possibility of widening the ships while still reducing their draft should therefore be examined. This would involve several constraints, including the review of the shipping channel design standards – based on a typical ship with a width of 32.2 m – and the cost of the construction of a container ship, which is currently US\$60 million. At first glance, this option would require that a fleet of ships be reserved especially for the St. Lawrence or for rivers that do not have structures that would restrict the passage of the ships due to their width. In a context of growing economic trade in which the marine sector would be increasingly used for the overseas transportation of goods, the flexibility of a fleet—i.e., its ability to navigate several waterways without limitations—would likely be a determining criterion for shipowners.

The option of reorganizing port activities was analyzed, taking into account the direct costs of a partial transfer of activities from the Port of Montreal to another port along the St. Lawrence that would be less affected by water level declines. The objective of the exercise carried out in section 2.5 was to obtain an overall picture of the direct costs and impacts of this option.

The scenarios analyzed include a partial transfer of shipments, i.e., certain bulk and container shipments, to Quebec City, Trois-Rivières, Bécancour or a combination of these ports. An overview of the economic role of the port of Montreal is presented in order to provide a clear understanding of the issues involved. Each port is then described, and the direct costs are estimated for a scenario of 400,000 containers. The estimated costs range from $230 to $260 million and include only such factors as wharf construction, the purchase of land and warehouses, etc. The addition of indirect costs, such as the construction of railroads, roads and highways to ensure effective intermodal transport, would quickly increase the estimated costs. The cost of constructing a railroad is on the order of $492,000/km, whereas the cost of constructing a road and highway is $1.5 million/km and $7 million/km, respectively. These estimates do not include the costs of environmental studies. If these indirect factors are included and if all activities are transferred (approximately 1.2 million containers), the cost of a harbour restructuring would easily reach $1 billion. The environmental and social impacts of such an operation would also be significant. If we keep the same ratio that currently exists in Montreal for the movement of goods to markets, namely 60% by rail and 40% by truck, it would mean that there would be an additional 450 trucks daily on the roads of the receiving port under the partial transfer scenario. Significant pressure would be placed on the local and regional road networks, and there would be inconveniences to residents (congestion, noise, pollution, deterioration of roads, etc.). An increase in greenhouse gas emissions would also have to be expected due to the fact that marine transportation is more energy-efficient than other modes of transportation and produces fewer greenhouse gas emissions per tonne-kilometre of cargo carried. A final point to be raised with respect to the restructuring of port activities deals with the interest of carriers in transferring their activities from one location to another. Over time, the port of Montreal has developed multimodal links that make it a hub for eastern North America. The port's main competitors are located not on the St. Lawrence River but along the U.S. East Coast. One of the challenges of this option would very likely be to find sufficient economic incentives to encourage carriers to opt for another port on the St. Lawrence rather than to transfer their activities to a port on the U.S. East Coast.

In the port restructuring option, cabotage could be an alternative solution that would maintain marine transportation. The possibility of using shallower draft ships to transport goods from a deep-water port to either Montreal, or to a city in the Great Lakes region, would have to be examined in greater detail. This option would be more environmentally and socially advantageous than using trucks and trains. It would also be necessary to consider a port restructuring for container storage and purchasing handling equipment. To make this option more attractive, these costs, as well as the costs associated with operations (increased number of transshipments, acquisition of specialized ships and infrastructure for handling containers, increased risk of spills, etc.), should be equitably amortized. The main advantage of cabotage is that it could be part of the long-term plan of government and port authorities designed to reduce the economic impacts on the most affected harbour authorities and port cities. Lastly, it should be pointed out that cabotage, although it would appear to be potentially favourable to commercial navigation, would not resolve the problem of the decline in water levels for other uses of the St. Lawrence.

This report presents an exploratory study of a number of adaptation options and, to the extent possible, their economic, environmental and social impacts, with the objective of initiating a discussion on climate change adaptation measures. It identifies some of the strengths and weaknesses of each option and illustrates the complexity of analyzing the various options on the basis of sustainable development criteria. Additional studies would be required to clearly determine options that are consistent with this sustainable development and to identify further options. A number of initiatives have emerged both in Canada and abroad such that climate change adaptation measures are now being taken into consideration. The impacts of climate change go beyond navigation activities alone and the Navigation Consensus Building Committee is of the view that a discussion of the future role of the St. Lawrence with regard to sustainable development and more integrated management should be initiated in the coming years.