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Risk-based Design Method for Aids to Navigation in the St. Lawrence River

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Since the accepted measures in the marine industry are metric and imperial, both measures are used in this report where appropriate.

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- Lower St Lawrence Pilots Corporation
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Abstract

This project builds on expertise developed in the Arctic Tanker Risk Analysis and Canso research projects. Before the completion of this project, no analytical tool was capable of measuring the relative safety benefits of a particular configuration of aids to navigation in a complex waterway, such as a river with a dredged main channel.

The aim of this project was to enhance the Canso 99.9% preprocessor so that it was capable of measuring differences in navigational safety in the St. Lawrence River in a precise, track by track, method. The result was the minimum safe design (MSD) Excel program. The MSD program was developed with significant input from pilots, masters and Canadian Coast Guard captains. A preliminary risk analysis of traffic and accident frequency in the Laurentian Region was completed to compare the results of the MSD program to the historical record. A detailed risk assessment with a consequence analysis for the waterway between Lac St. Pierre and Trois Rivières was completed to illustrate the extent of potential human and environmental impact of an oil spill and a gasoline release event.

Key words

Risk analysis, St. Lawrence River, aids to navigation, shiphandling, pilotage

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Executive Summary

Background

The Short-Range Aids to Navigation Modernization Plan was introduced in the autumn of 1996 following intense budgetary reduction pressures within the Canadian Coast Guard (CCG). Among the various cost-cutting measures investigated was the level of service (LOS) for conventional aids to navigation. The short-range aids availability for the worst month of the year was reduced from 85 percent to 75 percent.

In 1994 and 1995 the maritime community stakeholders, shipowners and pilots met with the CCG to announce the results of their independent analyses regarding aids to navigation that could be removed or modified in the Laurentian Region. The second stage entailed a preliminary LOS analysis to evaluate the pertinence of each stakeholder's position regarding changes to the configuration of aids to navigation. Given the context of financial pressures and partial cost recovery from users, a major divergence of opinion emerged. The Canadian Shipowners Association and the St. Lawrence Shipowners Association agreed to the removal of 44 percent of commercial lighted buoys while the Central and Lower St. Lawrence Pilotage Corporations proposed a reduction of only 12.5 percent.

Within this discussion framework, negotiations could not proceed. It was felt that the divergent opinions of waterway users would only be further accentuated if the LOS adopted could not be justified based on mariner's best practice (MBP). We have adopted a structured approach in analysing the differences between identified needs and the theoretical LOS. This approach will enable the CCG to justify a short-range aids system that ensures navigation safety without increasing navigation complexity on the St. Lawrence River, while facilitating seaborne trade.

The approach employed in this study consists of a navigation risk analysis, following on from the Canso Strait study where navigation risk was quantitatively assessed based on the availability of short-range aids to navigation. The method allows risk estimates to be established based on historical casualty rates as a function of the short-range aids configuration and the potential accident consequences (losses). However, the Canso model was not directly applicable to the St. Lawrence given the major differences in navigation conditions in these two waterways. This tool was developed into the minimum safe design (MSD) pre-processor. The calculated safety zone around the ship now includes numerous improvements to measure navigational differences in a waterway. With the MSD tool, a short-range aids configuration can be designed to meet the LOS calculated for each route segment along the river.

To ensure that the results from this project were acceptable to all St. Lawrence River mariners and stakeholders, stakeholders participated throughout the project to assist in calibrating the model. They provided the needed feedback to help incorporate their best navigation practices and knowledge of the particular conditions into the risk-based model.

Methodology

In applying MSD techniques to the decision-making process for aids to navigation LOS, we sought to strike a balance between waterway safety and efficiency. To ensure this balance, an exhaustive description of the vessel characteristics, the waterway, climatic conditions and mariner experience/human factors was required.

The relationships between channel width (CW), shiphandling and navigation are based on documents such as “Approach Channels – A Guide for Design”, International Association of Ports and Harbours; “Manoeuvring Guidelines for Navigable Waterways”, CCG; and “Procedures Manual for Design and Review of Marine Short-Range Aids to Navigation Systems”, CCG. The design approach builds on the Canso Strait study, which considered the CW provided relative to the MSD for the plausible worst case situation that the mariner may face defined as a probability of about 1 in 1000 transits of the channel. The risk is estimated by the relationship between the ratio CW/MSD and observed accident frequencies.

The study team, with input of local knowledge from pilots and masters, developed a conceptual design. Configuring and testing of the MSD structure by CCG officers and subject matter experts considered the complexities of navigation in the St. Lawrence River. This led to the development of a working prototype.

To summarize, significant input from professional mariners has guided the MSD development and its configuration for the St. Lawrence River. However, fine-tuning will be required to enable the MSD tool to respond to situations and gaps in functionality. The experience and expertise of the river pilots, CCG navigators and merchant vessel captains were captured to the fullest possible extent in the development of MSD.

Design requirements

The MSD model for the St. Lawrence, compared to the Canso MSD method, must reflect the complexity of the St. Lawrence, but at the same time be easier to understand, both for the designers and for the stakeholders. This was achieved through:

- A more detailed representation of MBP for shiphandling and positioning in a channel,

- A more detailed representation of the sections of the channel (e.g. specific turns, traverses, shoreline characteristics),

- A focus on the basic assumptions of the MSD model and a reduction of the display of arithmetic calculations,

- A hierarchical structure to the model use that considers the model components in bite-sized pieces that correspond to actual situations and locations on the river, and

- A data input requirement that is no more demanding than the current CCG LOS design process.

MSD development approach – assisted by expert users

The MSD method, illustrated in Figure 1, estimates the MSD for the CW, for specific time periods and river sections. The safe design is conditional on factors such as the design vessel, the aids to navigation configuration and the skill and knowledge of pilots and captains.

The MSD is width of the channel required for safe navigation by a design vessel for the given conditions in the river section and time period. The MSD CW is composed of three basic widths that are independent of each other and added together. The three distance elements are:

- A physical width to allow for the vessel's beam and drift due to winds and currents,

- A width to allow for shiphandling about a desired course, manoeuvrability due to squat, the resistance of brash ice, passing distance and bank clearance, and

- A width to allow for positioning confidence. This distance considers the aids to navigation available in the time period, bridge performance, etc.

The safety level of each river section is examined given a suitable range of worst plausible navigation situations.

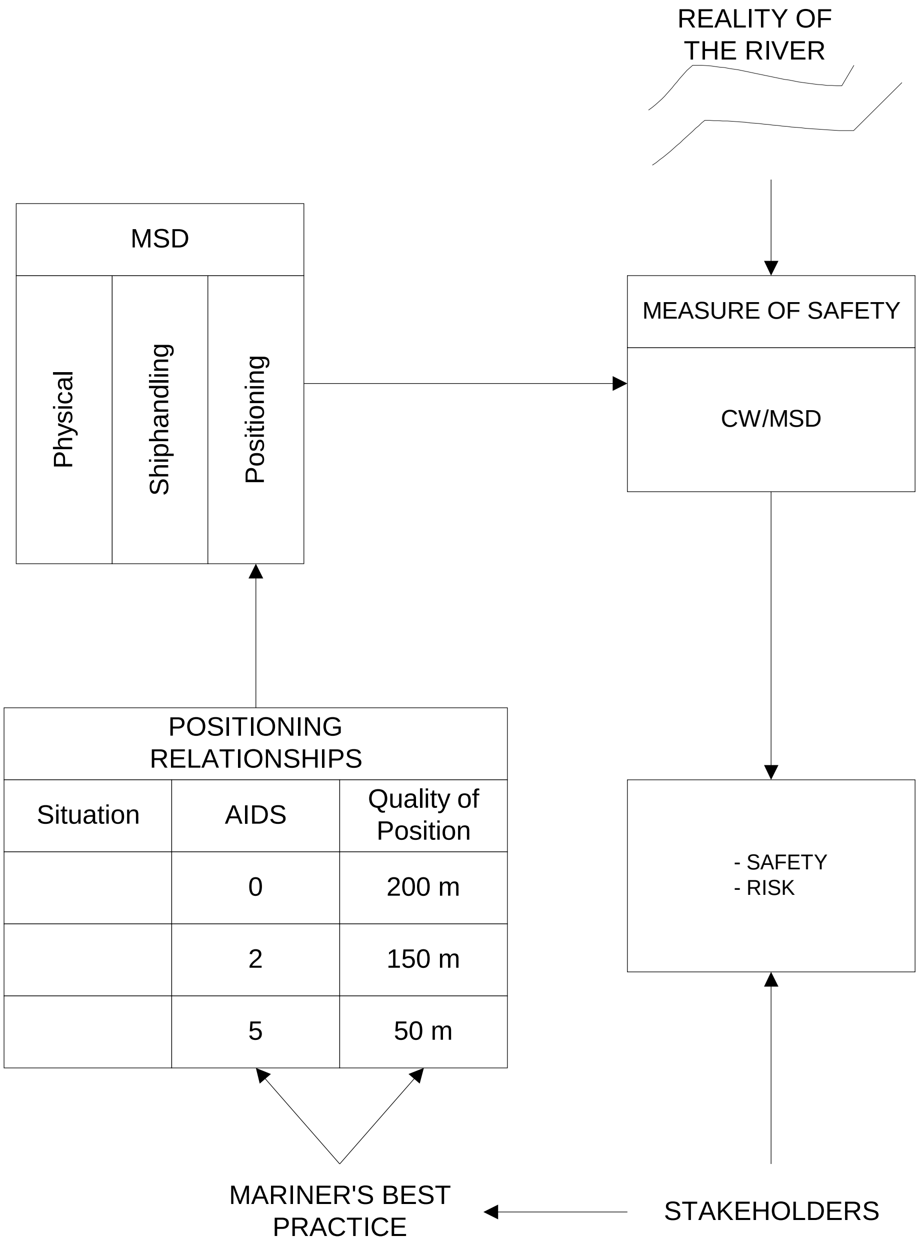

Figure 1. Link between aids to navigation and risk in the MSD pre–processor

MSD Results

Goal

The ultimate goal of the MSD approach is to examine the impact of changes in aids to navigation on waterway safety in keeping with the primary objective of balancing safety with marine transportation efficiency, while ensuring environmental protection.

Validation of MSD method

Comparisons of the MSD and CW data to accident data indicate the expected relationship between CW/MSD and accident rates for the areas studied (see Figure 2).

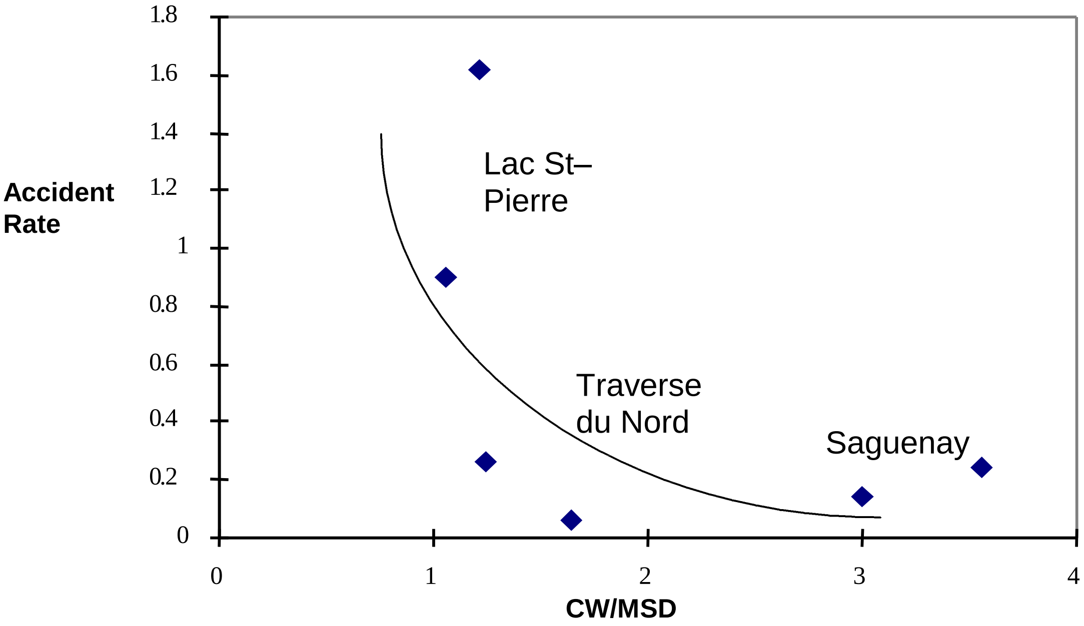

Figure 2. CIP Accident Rate versus CIP median CW/MSD ratio

Validation of the MSD method using accident data was limited by the available data. This is good for marine safety. It is unlikely that sufficient accident data will ever be available and it will be necessary to continue to incorporate expert opinion into the MSD method.

The MSD method results are correlated to existing practice and this, along with the positive reception from stakeholders, suggests that the MSD method provides a systematic and logical method for assessing safety requirements and the level of risk on the river.

Application of the MSD tool to the St. Lawrence River

The number of river sections for which MSD values have been estimated is limited. Eventually, as the MSD method is used, estimates for most parts of the river should be made for most conditions. One direct comparison of the impact of the configuration of aids to navigation is provided in Table 1. This shows an increased risk in the Course Pointe du Lac with the removal of aids in an Association des armateurs du St-Laurent (AASL) scenario.

Table 1. Comparison of the Bi–directional CW/MSD Ratios for Two Aids Configurations in Courbe Pointe du Lac

		Channel width / MSD ratio		
Section number	Section name	AASL Aids	Existing Aids	Change
1	R/M – C–63	1.40	1.40	
2	Pont Laviolette	**0.77**	**0.77**	
3	Pointe–des–Ormes – St. François	1.20	1.60	
4	Courbe Nicolet	1.28	1.28	
5	Courbe Pointe du Lac	1.06	1.06	
6	Course Pointe du Lac	**0.89**	1.23	**–28%**
7	Course Pointe du Lac	**0.94**	1.07	**–12%**
8	R/M S–54	**0.95**	**0.95**	

Conditions: summer, one nmi visibility, two container vessels

Accident rates

A detailed analysis of marine casualty rates in the St. Lawrence River was conducted (see Table 2). Some observations of the accident analysis include:

- Of the sample of 137 accidents analysed in the Laurentian Region, 30 percent were collisions and 60 percent were groundings,
- Most of the accidents involved bulk carriers and cargo vessels, followed by oil and petroleum product tankers,
- The highest accident rates occur in Grondines and Pointe-des-Ormes, where one could expect an accident (probably a grounding by a bulk carrier or cargo vessel) with a “high damage degree” about once every five years, and
- Summer accident rates are significantly lower than winter rates.

Table 2. Annual Accident Rates by CIP Area and Damage Degree

CIP Area					Total		Breakdown by Damage Degree ***					
#	Name	Annual Traffic Count (95/96)**	Length (nmi, rounded)	Traffic nmi (Count x nmi actual)	Accident (Count per 22.5 years)	Annual Accident RATE*	High		Medium		Low	
							Count per 22.5 years	Annual RATE*	Count per 22.5 years	Annual RATE*	Count per 22.5 years	Annual RATE*
5	ESCOUMINS	4 857	17	81 112	3	0.16	0	0.00	0	0.00	3	0.16
6	HAUT–FOND PRINCE	4 928	13	65 542	2	0.14	2	0.14	0	0.00	0	0.00
7	ILE BLANCHE	4 871	11	55 042	3	0.24	0	0.00	2	0.16	1	0.08
0	CAP AU SAUMON	4 849	19	90 676	1	0.05	1	0.05	0	0.00	0	0.00
8	CAP–AUX–OIES	4 876	21	102 396	1	0.04	0	0.00	0	0.00	1	0.04
9	GRAND–POINT	4 866	16	77 856	0	0.00	0	0.00	0	0.00	0	0.00
10	CAP BRULE	4 869	14	69 627	4	0.26	2	0.13	0	0.00	2	0.13
11	ST. LAURENT	4 923	16	78 768	1	0.06	0	0.00	0	0.00	1	0.06
13	QUEBEC	4 488	10	44 431	23	**2.30**	1	0.10	7	**0.70**	10	**1.00**
14	ST. AUGUSTIN	4 535	12	53 967	8	0.66	4	**0.33**	3	0.25	1	0.08
15	DONNACONA	4 535	14	62 130	6	0.43	0	0.00	2	0.14	3	0.21
16	GRONDINES	4 538	14	61 263	17	**1.23**	5	**0.36**	3	0.22	8	**0.58**
17	BATISCAN	4 557	16	72 912	13	0.79	2	0.12	1	0.06	10	**0.61**
19	POINTE–DES–ORMES	4 321	15	63 087	23	**1.62**	5	**0.35**	7	**0.49**	9	**0.63**
20	YAMACHICHE	4 354	10	44 411	9	0.90	2	0.20	4	**0.40**	3	0.30
21	ILE DES BARQUES	4 357	14	62 305	11	0.78	0	0.00	2	0.14	7	0.50
22	TRACY	4 080	12	50 592	4	0.35	0	0.00	0	0.00	4	0.35
24	CAP ST. MICHEL	4 179	11	45 969	0	0.00	0	0.00	0	0.00	0	0.00
25	MONTREAL EST	4 424	9	38 046	8	0.93	2	0.23	0	0.00	5	**0.58**
	Grand Total			1 220 132	137	0.50	26		31		68	
CASUALTY TYPE												
Collisions					41		4		18		12	
Groundings					80		21		6		49	
Strikings					16		1		7		7	
Mean						0.58		0.11		0.14		0.28
Standard Deviation						0.62		0.13		0.20		0.29
Mean + 1 SD						1.20		0.24		0.34		0.57

*e.g., for ESCOUMINS: 4857 x 16.7 =81 112 vessel miles per year. 3/22.5 = .13 accidents per year or per 81 112 nmi, or .16 accidents per 100 000 nmi traveled. Accident data from 1/20/75 to 7/7/97.

** Includes all merchant vessels except for ferries for one year (95–96).

*** For 9% of the set of 137 records, damage degree is "unknown". These records are included in the grand total only.

The CIP areas with rates more than 1 SD above the mean are shown in bold typeface.

Consequence analysis

The consequence analysis component of the project addressed the worst plausible outcomes from a marine shipping scenario on the St. Lawrence River. The 1996 Data Archive and Distribution System (DADS) database was reviewed to determine the commodities shipped and the frequency of shipment. An initial examination of the data revealed that the list of hazardous products carried included many different petrochemical products out of the 71 category groupings. Bunker C heavy fuel oil was number 11 on the list (ordered by trip frequency) with 92 trips, and gasoline was number 12 with 87 trips. These two commodities were retained for study under an oil spill scenario and a fire/explosion scenario, both within the Lac St. Pierre segment of the river.

Oil spill scenario

A product tanker carrying bunker C heavy fuel oil collides with another vessel in the Pointe-du-Lac turn of Lac St. Pierre. This causes a 1 350 m^3 oil spill which affects numerous shoreline resources (see Figure 3).

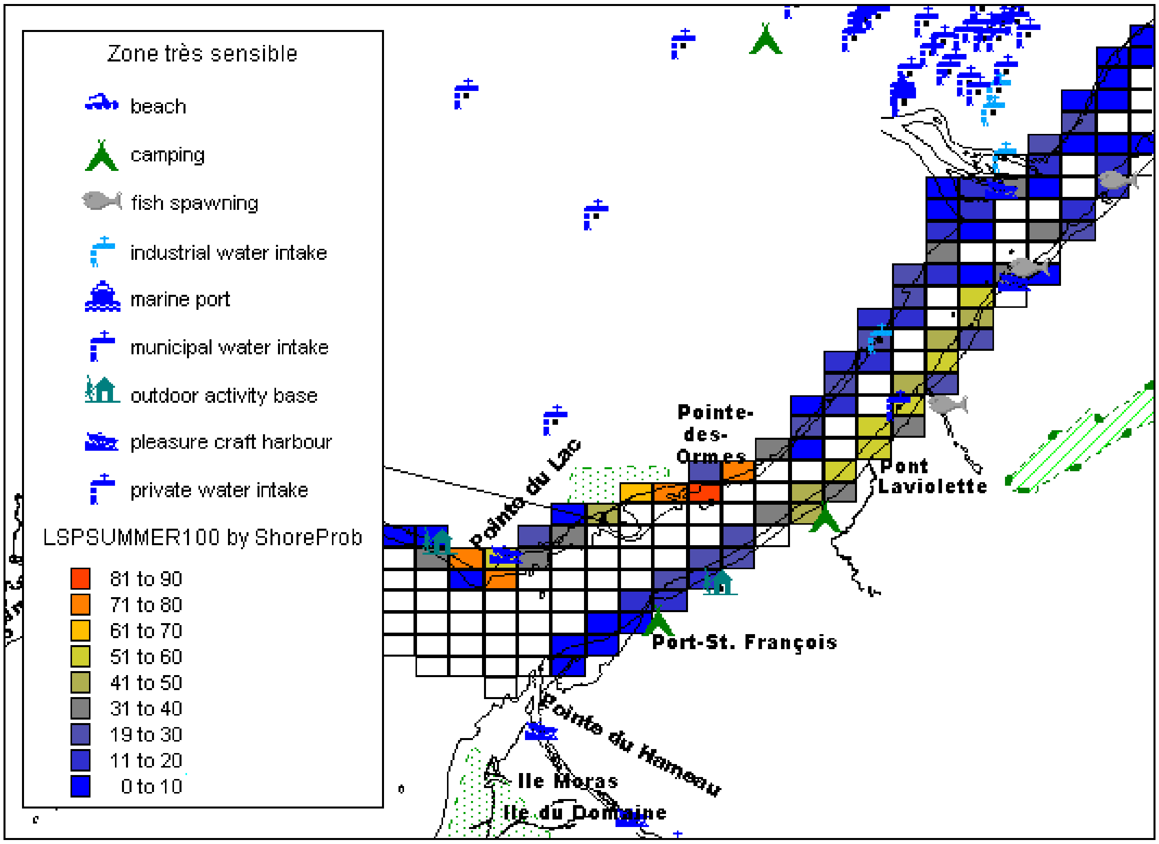

Figure 3. Shoreline Impacts – September Winds

The consequence magnitude for the oil spill scenario in Lac St. Pierre was measured as a probability of a spill of 1 350 m^3 given a collision. This probability is 0.013. Therefore, the annual probability of a spill was measured as the annual probability of a collision involving a tanker (.054) times the conditional probability of the spill (0.013). Given these estimates, one would expect a medium-sized oil spill once every 1 428 years or 0.0007 per year. (Note: this estimate is just for the Pointe-des-Ormes area.)

Infrastructure clean-up and other civil damages are likely to reach the level predicted in the *Arctic Tanker Risk Analysis* spill cost model – the highest category of civil damages cost of $1 700 000. Clean-up of the river and the shoreline environment would exceed $13.9 million; fines for environmental damage could reach the maximum $1 million; vessel damage, cargo and business loss could exceed $5 million. This brings the cost of a single 1 350 m^3 oil spill to $22.2 million. The annual oil spill cost in Pointe-des-Ormes is $15 580; however, vessel damages alone due to collisions would be incurred once every three years and the cost could be as high as $5.6 million per incident, or $2 million per year.

Gas fire/explosion scenario

A product tanker carrying gasoline collides with another vessel near the port of Trois Rivières while on Course Pointe-des-Ormes, causing a 1 350 m^3 gasoline release event.

The oil spill modelling tool “Oilmap” was used to estimate impacts of the gasoline spill. Initially, the discharging of liquid cargo and results are computed and displayed for the possible outcomes for the mixture under study. For gasoline, three main outcomes are possible: a pool fire, a flash fire or an explosion. Each scenario produced an impact zone that would include industrial facilities and port infrastructure within the port of Trois Rivières. Of the various figures produced, a chart of the flash fire flame envelope was selected to show the extent of potential impact of the worst plausible case (see Figure 4). Flash fires are lethal to all inside the flame envelope.

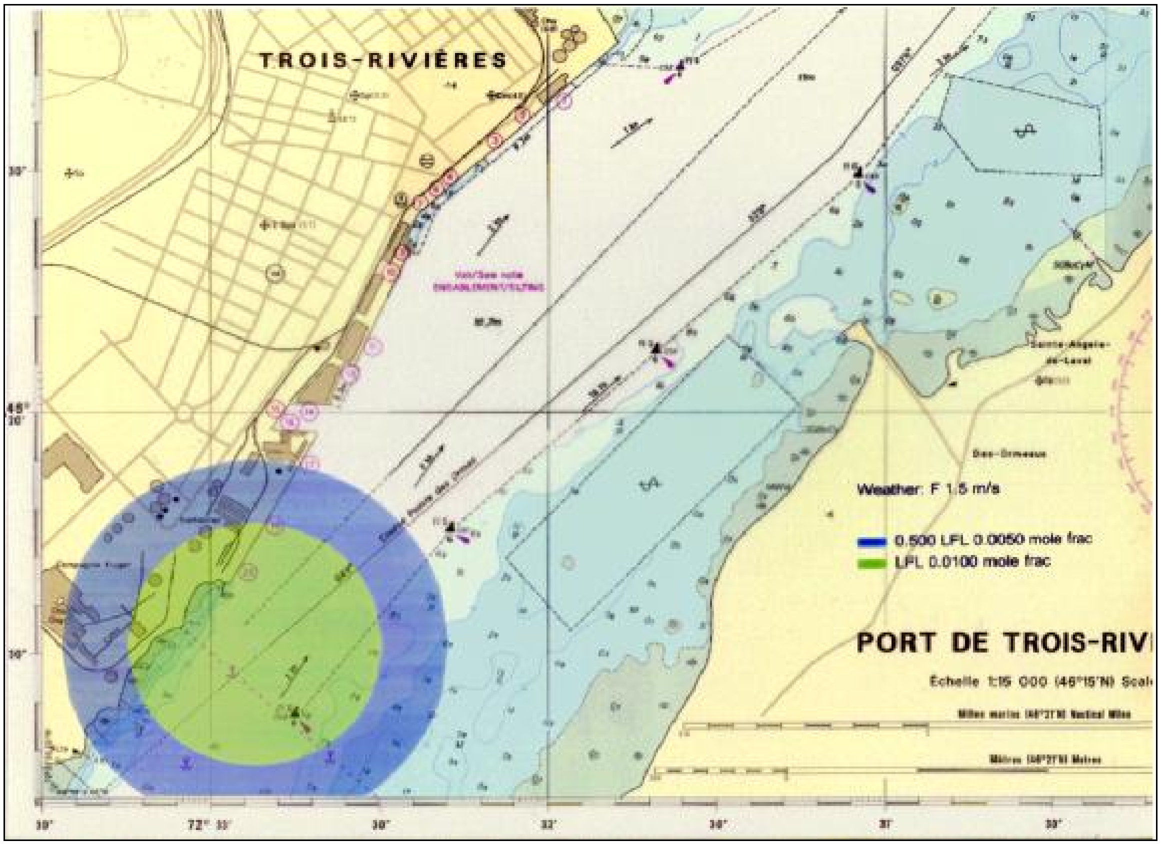

Figure 4. Flash Fire Flame Envelope

Conclusions

- The MSD method and results reflect existing practice. This, along with the positive reception from stakeholders (including government and industry), suggests that the MSD method provides a systematic and logical way of assessing safety requirements and the level of risk on the river.

- Future inclusion of other accident causes in the MSD tool is possible if supported by evidence. As well, the design enables consideration of other navigation safety measures such as differential global positioning system (DGPS), electronic chart display and information system (ECDIS) and Marine Communications and Traffic Services (MCTS).

- The frequency of collisions involving through traffic in the Pointe-des-Ormes area was estimated as 8 in 22.5 years or 0.36 per year. There is a 15 percent chance that the vessel is an oil or oil product tanker (40/259).

- A valuation of the tanker collision risk was provided to indicate the costs of one of many possible risk scenarios. If the oil spill cost is $22.2 million, the annual cost in Pointe-des-Ormes is $15 580; however, vessel damages due to collisions would be incurred once every three years and the cost could be as high as $5.6 million per incident or $2 million per year.

- The MSD tool was used to make numerous comparisons between the effect of vessel type, navigation conditions and aids to navigation configurations on safety in the St. Lawrence River in the Laurentian Region. A change in the LOS of aids to navigation proposed by AASL will affect safety on the river and potential consequence costs. For example, a summer, low visibility scenario involving two container vessels in Course Pointe-du-Lac showed an increased risk of 28 percent.

Recommendations

- The MSD tool will be released to workshop members for further review. A log should be kept of any changes so that the positioning relationships can be modified to reflect expert opinion.

- In light of the MSD analysis results for the three study areas, which showed a change in risk depending on the LOS of aids to navigation, any changes to current provision of aids to navigation or pilotage services should consider an MSD analysis for the waterway in question.

- The development team should work with CCG to investigate the effect of electronic aids to navigation, such as DGPS with ECDIS, on the positioning quality component in the MSD tool.

- The MSD tool and the Marine Navigation Safety System (MNSS) should be used to estimate potential consequence costs for a section of river and these estimates should be compared to various LOS provision costs.

- CCG should continue to develop and incorporate additional expert judgment into the model by applying the MSD method to additional segments of the river. Validation of the MSD method using accident data was limited by the available data. It is unlikely that sufficient accident data will ever be available and it will be necessary to continue to incorporate expert opinion into the MSD method to refine the precision of MSD estimates and broaden its applicability to different waterways.

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Glossary

A/C or R/M	Alteration of course or route modifiée
CIP	Calling-in-point
DADS	Data Archive and Distribution System
LOS	CCG Level of Service
MBP	Mariner’s best practice, i.e., what MSD mariners agree is acceptable
MCTS	Marine Communications and Traffic Services
MSD	Minimum safe design for a particular time period for a particular “worst plausible case” situation
Section	A single track (turn or straight)
Time period	One of six time periods for analysis: • winter good visibility* day • winter good visibility night • winter poor visibility • summer good visibility day • summer good visibility night • summer poor visibility
Traverse	A set of track segments or sections to analyse
Worst plausible case	For pilotage, e.g., winter, ice, wind from southeast

*Note: Poor or good visibility is as defined in the CCG Preliminary Threat Rating Guide depending upon vessel type and location.

1 Introduction

1.1 Context

The Short-Range Aids to Navigation Modernization Plan was introduced in the autumn of 1996 following intense budgetary reduction pressures that were experienced within the Canadian Coast Guard (CCG). Among the various cost cutting measures investigated was the level of service (LOS) for conventional aids to navigation. The short-range aids availability for the worst month of the year was reduced from 85 percent to 75 percent.

In 1994 and 1995 the maritime community stakeholders, shipowners and pilots met with the CCG in order to announce the results of their independent analyses regarding aids to navigation that could be removed or modified in the Laurentian Region. The second stage entailed a preliminary level of service analysis to evaluate the pertinence of each stakeholders position regarding changes to the configuration of aids to navigation. Given the context of financial pressures and partial cost recovery from users, a major divergence of opinion emerged. The Canadian Shipowners Association and the St. Lawrence Shipowners Association agreed to the removal of 44 percent of commercial lighted buoys while the Central and Lower St. Lawrence Pilotage Corporations proposed a reduction of only 12.5 percent.

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The approach employed in this study consists of a navigation risk analysis, following on from the Canso Strait study where navigation risk was quantitatively assessed based on the availability of short-range aids to navigation. The method allows risk estimates to be established based on historical casualty rates as a function of the short-range aids configuration and the potential accident consequences (losses). However, the Canso model was not directly applicable to the St. Lawrence given the major differences in navigation conditions in these two waterways. This tool was developed into the minimum safe design (MSD) pre-processor. The calculated safety zone around the ship now includes numerous improvements to measure navigational differences in a waterway. With the MSD tool, a short-range aids configuration can be designed to meet the LOS calculated for each route segment along the river.

To ensure that the results from this project were acceptable to all St. Lawrence River mariners and stakeholders, they participated throughout the project to assist in calibrating the model. They provided feedback to help incorporate their best navigation practices and knowledge of the particular conditions into the risk-based model.

1.2 Background

The relationships between channel width (CW), shiphandling and navigation are based on documents such as “Approach Channels – A Guide for Design”, International Association of Ports and Harbours; “Manoeuvring Guidelines for Navigable Waterways”, CCG; and “Procedures Manual for Design and Review of Marine Short-Range Aids to Navigation Systems”, CCG. The design approach builds on the Canso Strait study, which considered the CW provided relative to the minimum safe design (MSD) for the plausible worst case situation that the mariner may face defined as a probability of about 1 in 1 000 transits of the channel. The risk is estimated by the relationship between the ratio CW/MSD and observed accident frequencies.

The St. Lawrence River is among the most difficult navigable waterways in the world, with a length of over 400 nmi between Les Escoumins and Kingston, many course changes, severe ice in winter, heavy traffic, channel widths near the minimum and restricted channel depth.

The scope of this study focused on the examination of the risk in three study areas: Lac St. Pierre, Traverse du Nord and the approaches to the Saguenay River. These areas pose unique challenges to navigation in winter and summer, and provide an excellent test bed for the MSD pre-processor development. Examples include: the “s” turn of Courbe Pointe du Lac and Courbe Nicolet, as well as the narrows of Pont Laviolette in the Lac St. Pierre study area; the moving ice and crosscurrent in proximity to buoy K108 in Traverse Nord and the strong crosscurrents and traffic interaction north of Ile Rouge in the Saguenay approaches.

The study team, with input of local knowledge from pilots and masters, developed a conceptual design. Configuring and testing of the MSD structure by Coast Guard officers and subject matter experts considered the complexities of the three study areas. This led to the development of a working prototype, as well as the identification of several relationships where further examination and input of expertise were required:

- Manoeuvring and vessel performance in ice,
- Manoeuvring and vessel type, and
- Positioning techniques.

To summarize, significant input from professional mariners has guided the MSD development and its configuration for the St. Lawrence River. However, fine-tuning will be required to enable the MSD tool to respond to situations and gaps in functionality. The experience and expertise of the river pilots, CCG navigators and merchant vessel captains were captured to the fullest possible extent in the development of MSD.

1.3 Objective

The objective of the risk-based design method was to develop the MSD tool with the assistance of expert users (pilots, captains). In applying MSD techniques to the decision-making process for aids to navigation LOS, we sought to strike a balance between waterway safety and efficiency. To ensure this balance, an exhaustive description of the vessel characteristics, the waterway, climatic conditions, mariner experience/human factors, historical accident record and risk receptors was required.

The purpose of the MSD development was to assess the 99.9% pre-processor application to the St. Lawrence River and investigate the changes required to properly adapt the model to the St. Lawrence River scenarios and include the following characteristics:

- Ship manoeuvrability as a function of: ship type, speed, displacement, draft, freeboard, windage, under keel clearance including the effects of tides, water level and currents,

- Navigable channel sizes, type of channel bottom, squat, turns and anchorages,

- Environmental elements including currents (head, cross and following), winds, visibility, ice, day/night and winter/summer navigation,

- Human factors – best navigation practices (years of experience, pilotage and Marine Communications and Traffic Services (MCTS),

- Uni- and bi-directional traffic,

- Influence of specific short range aids to navigation and the total configuration within the route segment under study, and

- Type of cargo carried (i.e., loaded, ballast, container).

4

2 Requirements

2.1 Design Requirements

The MSD model for the St. Lawrence, compared to the Canso 99.9% method, must reflect the complexity of the St. Lawrence, but at the same time be easier to understand, both for the designers and for the stakeholders. This was achieved through:

- A more detailed representation of MBP for shiphandling and positioning in a channel,

- A more detailed representation of the sections of the channel (e.g. specific turns, traverses, shoreline characteristics),

- A focus on the basic assumptions of the MSD model and a reduction of the display of arithmetic calculations,

- A hierarchical structure to the model use that considers the model components in bite-sized pieces that correspond to actual situations and locations on the river, and

- A data input requirement that is no more tasking than the current CCG LOS design process.

3 Understanding the MSD Method

The MSD method is closely related to the international approach of the Permanent International Association of Navigation Congresses (PIANC) (1), the International Association of Lighthouse Authorities (IALA) (2) and CCG (3), as well as the method used by the United States Coast Guard (USCG) (4). This allows the basic relationships in the method to be validated against other recognized authorities and existing practices.

To understand the MSD method, three contexts are considered:

- The design and policy environment for decisions on the channel and its level of service,
- The structure of the MSD method and its acceptance by stakeholders as being a valid representation of requirements for channel design, and
- Detailed relationships and parameter values for squat, vessel turning characteristics, effects of tides and currents, and other maritime fundamentals that govern the movement and safety of vessels.

These contexts are discussed in sections 3.1, 3.2 and 3.3.

3.1 The Design and Policy Environment

The following statements and assumptions were identified at the MSD design stage to characterize the design and policy environment for MSD:

- The St. Lawrence River Channel should be designed for the “ultimate” design vessels that are possible given the natural limitations of the river, especially the depth of the river,
- The risk implications of very detailed changes in aids to navigation, or CW are of interest so that the change in risk can be weighed against the costs of the changes by the decision-makers and the stakeholders, e.g., implementation costs and consequence costs avoided such as oil spill clean-up. It is recognized that these estimates of the changes in risk will depend as much on expert opinion as on scientific analysis,
- The MSD method must be validated through consultation and dialogue with stakeholders. The dialogue must be based on “real” situations of specific design vessels in specific sections of the river, for specific times of the year and for typical “bridge” activities. The MSD method must be capable of effective and efficient risk communications,

- The MSD channel design is the minimum channel width acceptable to the stakeholders, for the specified conditions and operating rules. This acceptability is based on the “plausible worst case” situation that generally will be observed once on an annual basis. It does not consider the worst case imaginable or possible, but rather the probable worst case. Acceptability of stakeholders would be based on MBP,

- It is expected that there will be operating rules that will declare the channel “unavailable” or “available with restrictions” for two-way or even one-way traffic for specific conditions and situations (e.g. ice, wind, visibility, draught),

- The MSD method should be logical, have a rational framework, be easy to understand, be expandable to incorporate new and emerging technologies. Its development approach should use scientific methods. It should not be necessary to change the basic approach of the MSD method when faced with new policy issues,

- The variation in MSD CWs with different locations in the river should correspond, generally, to variations in the historical accident frequency observed for those locations. This should also be true for different seasons of the year, and time of the day, or night, when visibility is good or limited. This will provide some confidence in the method,

- The major decisions (involving best practice and operating conditions) by mariners, CCG (Marine Navigation Services, Marine Communications and Traffic Services) for the St. Lawrence, are limited to decisions about: the speed of the vessels, one-way versus two-way traffic, “no go” conditions, dredging of the channel, allowable vessels, number of pilots required, required navigational aids and provision of aids to navigation,

- It is assumed that expert mariners will be required to provide input to MSD given the inherent complexity of the river, the required speed of decisions that must be made for a safe passage, and the consequences of an accident, and

- These statements and assumptions should be amended or added to from background documents and the experience of subject matter experts.

3.2 The MSD Approach, Structure and Acceptance by Stakeholders

The approach to the MSD method application is outlined in Figure 1. The policy environment – involving major policy questions such as dredged CW, aids to navigation, requirements for navigational aids and operational rules – is the main driving force for the method. The method is intended to provide information to assist decision-makers.

The "reality of the river" is a key element of the approach in Figure 1. The sections of the channel, the time periods (e.g. winter/summer, good visibility/poor visibility and day/night), the selection of the design vessel(s), characteristics of the river and the historical accident frequency combine to give a detailed realistic description of the river channel. This is necessary, since the risks and the provision of mitigation measures depend to a great extent on local knowledge and experience of the mariners. Without a detailed and realistic description of the channel, it is not possible to obtain input from the stakeholders and to evaluate alternative policies.

The stakeholders (CCG, pilots, ship owners, marine authorities, etc.) are essential to the success of applying the MSD method, since there is limited data for scientific analysis, and expert opinion must be used extensively. Stakeholder input is required for the completeness of the characterization of the channel, the logical validity of the MSD method, the relationships in the MSD method, the reasonableness of the estimated MSD, and verification of the relative risk estimates for the different sections and time periods.

As indicated in Figure 1, the MSD method estimates the minimum safe design for the channel width, for specific time periods and sections. The safe design is conditional on the design vessel, the aids to navigation provided, the skill and knowledge of the pilots, and so forth. The ratio of (CW/MSD) is compared to the observed accident frequency for each time period and section; if possible, however, it is likely that aggregation over sections and perhaps time periods will be required to make a statistically valid comparison and development of confirming relationships between (CW/MSD) and risk.

Once the MSD method is considered satisfactory by the stakeholders, it can be used to estimate the changes in risk levels under different policies. It should be noted that the comparison of MSD and CW can result in three outcomes for the specified design vessel:

- The section and time period is acceptable for two way traffic,
- The section and time period is acceptable for only one way traffic, and
- The section and time period is unavailable for use.

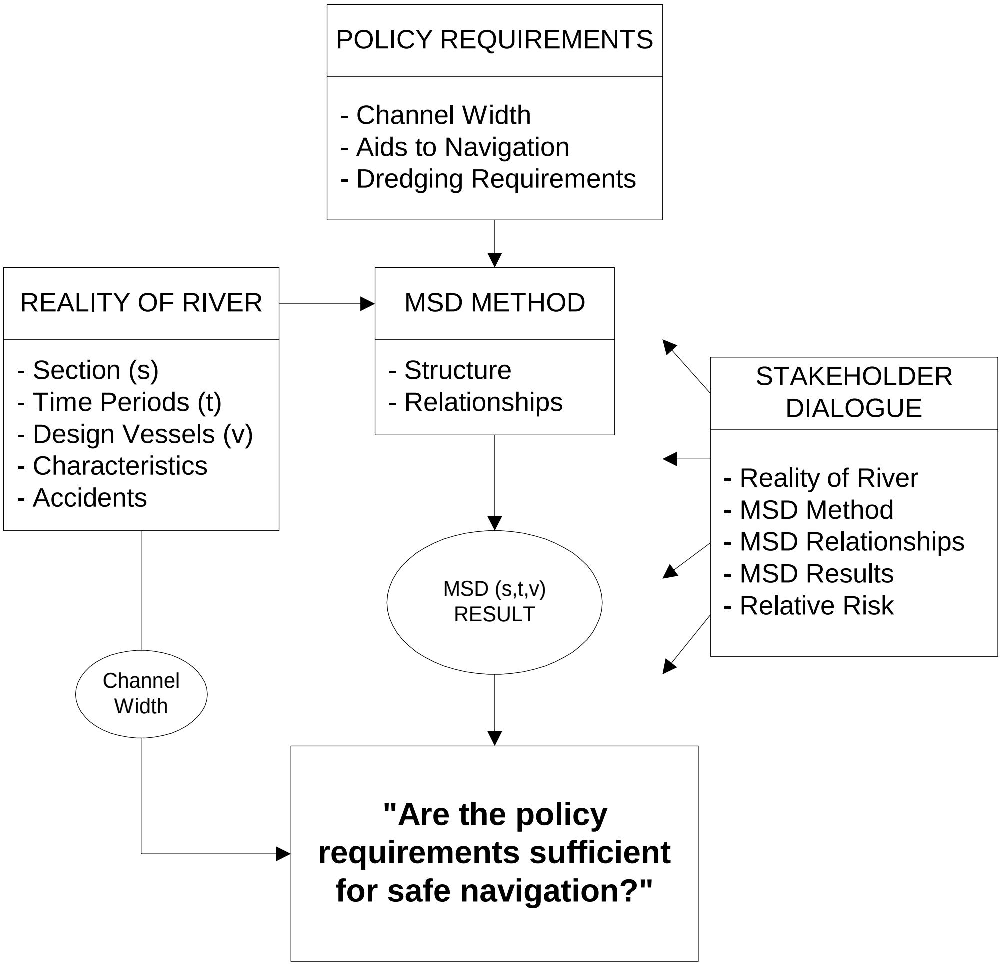


Figure 1. MSD Approach

Figure 1 indicates that the MSD method has two major components: the structure of the method, and the relationships within the method (also see Section 3.3).

Figure 2 illustrates the structure of the MSD method with the major output being the MSD for prevention of groundings. This is given as a distance of the width of the channel for the given conditions for the section and time period. The MSD CW is composed of three basic widths that are independent of each other and are added together. The three distance elements are:

- a physical width to allow for the vessel's beam and drift due to winds and currents,
- a width to allow for shiphandling about a desired course, manoeuvrability due to squat, the resistance of brash ice, passing distance and bank clearance, and
- a width to allow for positioning confidence. This distance considers the aids to navigation available in the time period, bridge performance, etc.

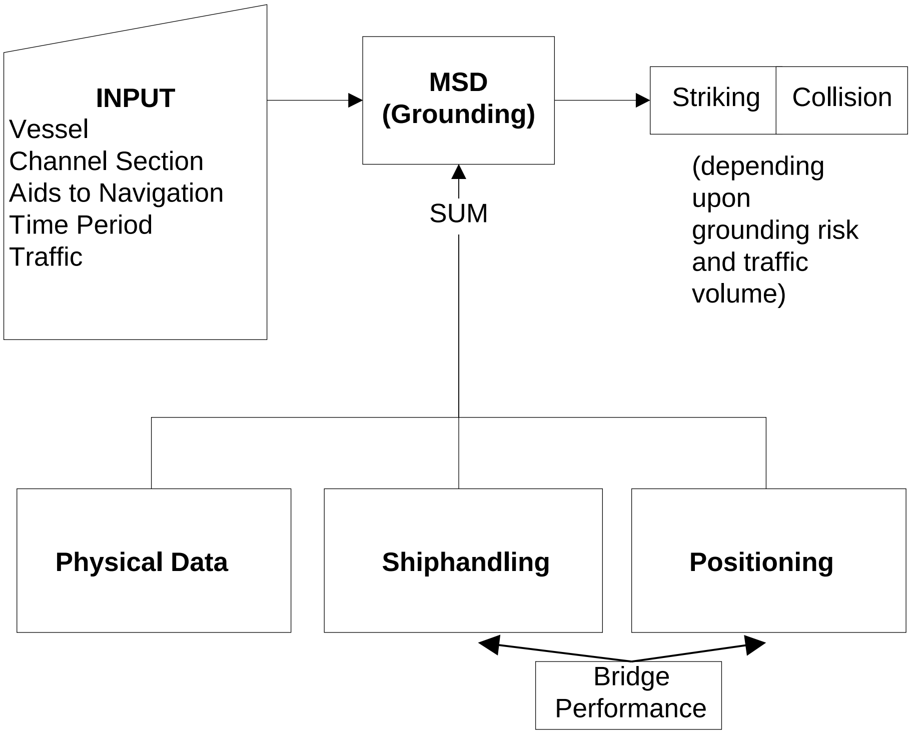


Figure 2. Basic Structure of MSD Analysis

The safety level of each river section is examined given a suitable range of worst plausible navigation situations.

The ultimate goal of the MSD approach is to examine the impact of changes in aids to navigation on waterway safety in keeping with the primary objective of balancing safety with marine transportation efficiency, while ensuring environmental protection.

3.3 MSD Relationships

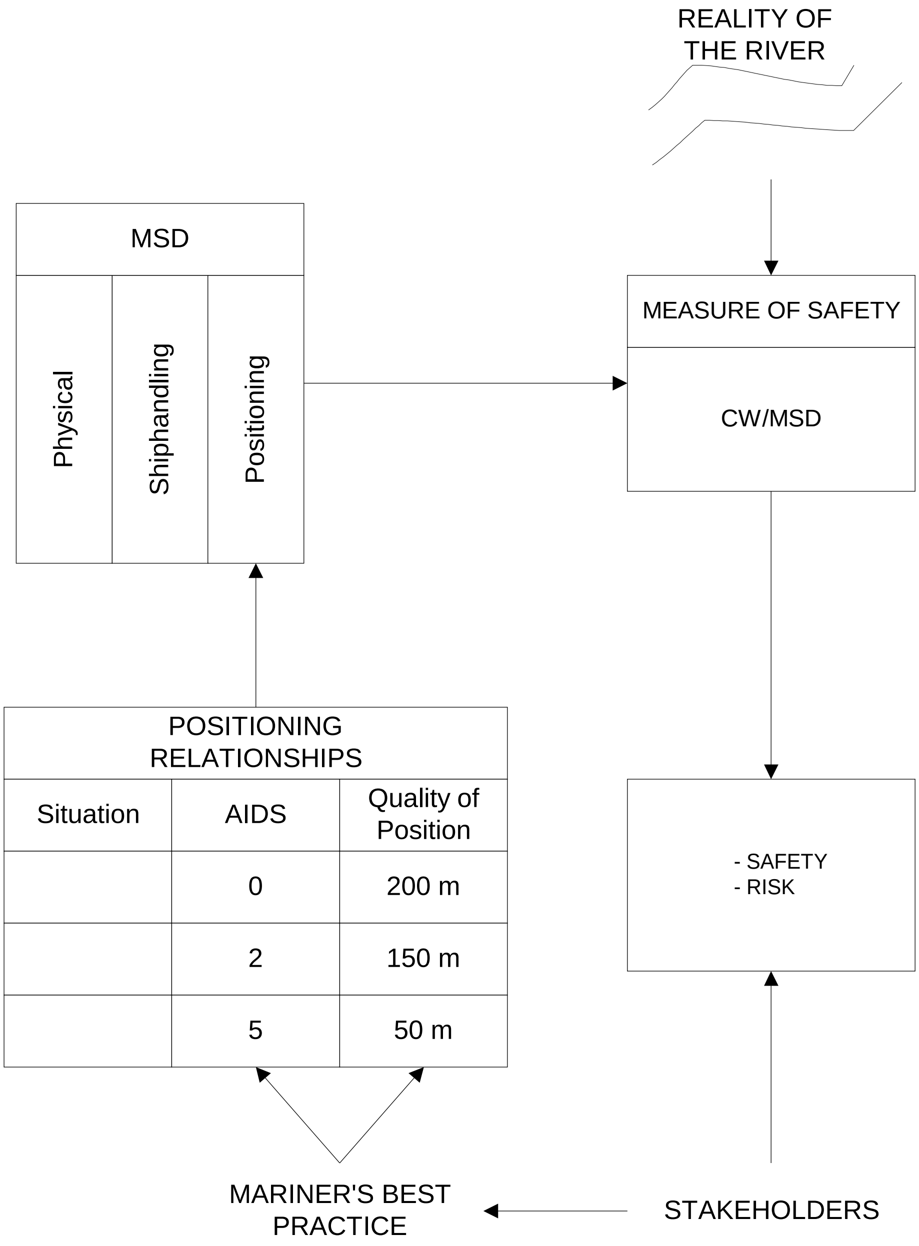
The standard relationships referred to in Figures 1, 3 and 4 were developed based on traditional maritime knowledge (e.g., rules of the road and methods used for positioning), on experience with the channel, measured performance of vessels, accident data and descriptions, etc. In each case the relationships were examined, validated or modified and then validated by the expert stakeholders.

Table 1 provides a checklist to show where each factor listed in the design objectives is addressed in specific sub-components in the MSD preprocessor.
Note that:

- The MSD process requires the examination of these variables for each section, time periods (winter, summer, day, night, visibility) and design vessel(s), and
- Special consideration of the defined CW is required to correctly analyse separate one-way traffic routes in open water (e.g., the approaches to the Saguenay River).

Table 1. Coverage of Design Factors by MSD Sub–component

Variable	Course length, width, depth, etc.	Wind & current drift, vessel speed & beam	Squat, security margin & underkeel clearance	Passing distance, coursekeeping	Manoeuvring in ice	Squat effects and bank clearance	Positioning by radar & aids to navigation	Positioning by visual methods & aids to navigation
Vessel								
course	X	X						
speed		X	X		X			
displacement		X						
beam		X	X	X		X		
draught		X	X					
length		X						
windage or freeboard		X						
horsepower					X			
cargo			X					
navigation aids							X	X
squat & clearance			X			X		
Channel Section								
visibility				X			X	X
natural targets							X	X
depth & tide	X		X			X		
navigable width	X		X			X		
bottom/bank profile and type						X		
turn/straight/anchorage	X			X			X	X
ice concentration					X		X	X
relative wind speed and direction		X			X			
relative current speed and direction		X			X			
Aids to Navigation								
buoys							X	X
ranges							X	X
fixed targets							X	X
Bridge Performance								
workload, fatigue, ergonomics, resources				X			X	X



Situation	AIDS	Quality of Position
	0	200 m
	2	150 m
	5	50 m

Figure 3. Link Between Aids to Navigation and Risk in the MSD Pre–processor

4 The MSD Channel Design or Analysis Process

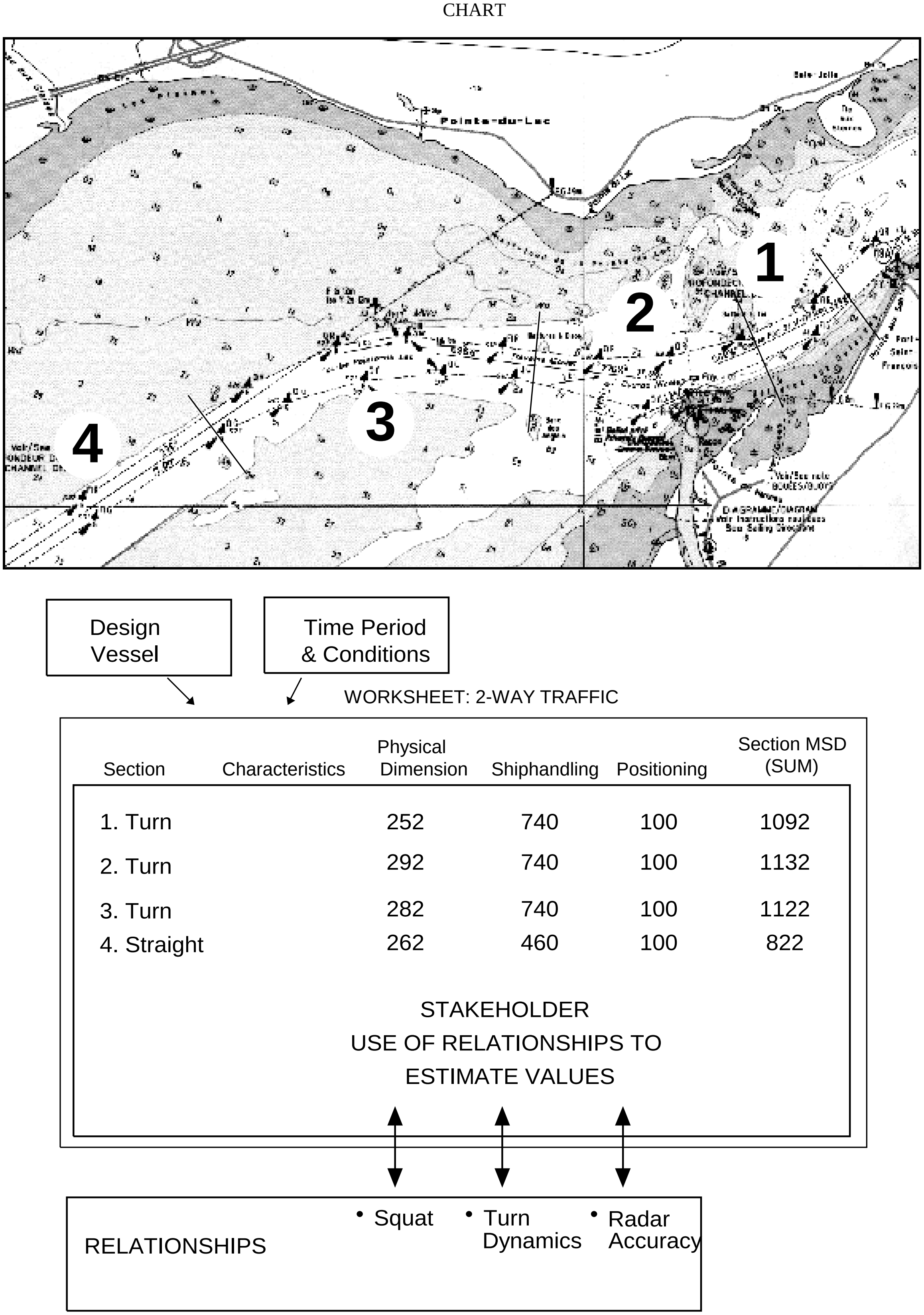
The MSD method first estimates the required CW for one-way operation. This requires the input of data into the Excel MSD tool to estimate three components:

- physical dimensions,
- shiphandling, and
- positioning.

Next, the MSD is estimated for two-way operation based on the selection of a “plausible worst case” situation for the design vessel to be passed. The MSD method is used for the design vessel to be passed to estimate the one-way requirements and then both one-way requirements are combined and the redundant components, such as bank clearance removed and the passing separation added.

Upbound and downbound use of the channel are evaluated separately and the maximum MSD is used. Since most of the estimation procedure is identical for upbound and downbound traffic (with some differences, for example, the design vessel load status may change), the procedure is very efficient once one direction has been completed. In this and other mechanics of the MSD procedure the sequence of time periods, sections and design vessels are selected to maximize the ease of use and the capture of expert opinion.

Figure 4 illustrates the worksheet and procedure for applying the MSD method. The first step is to section the traverse being analysed using the available charts. Then the analyst records all the characteristics of the channel that affect the design vessel. This is done section by section in the direction of the transit. Then the stakeholders are consulted on the MSD and the three CW elements: physical dimension, shiphandling and positioning.



Section	Characteristics	Physical Dimension	Shiphandling	Positioning	Section MSD (SUM)
1. Turn		252	740	100	1092
2. Turn		292	740	100	1132
3. Turn		282	740	100	1122
4. Straight		262	460	100	822

Figure 4. Procedure for MSD Method

5 The Positioning Functional Relationship

Two processes are described in this section. They are defined as:

- *MSD channel design or analysis positioning accuracy estimation process*: "The process of selecting an appropriate aids to navigation configuration as part of an MSD design or MSD analysis", and

- *The process of developing positioning quality and navigation aids relationships*: "The process of developing a decision tree that describes the relationship between aids and positioning quality using expert navigation input".

5.1 Analysis of Positioning Accuracy and Aids Configurations

Figure 5 shows how the positioning relationship would be used for design or analysis. The river situation for each section would be available from Figure 4 and this would include the identification of "good visual targets", such as church steeples, well-defined rock cliffs and hydro towers.

The "basic" aids to navigation for the given conditions are determined first by considering:

- Basic aids determined from previously considered time periods and visibility conditions,

- Additional targets (including Racons) required for:
  - Confirming position,
  - Locating turns and/or wheel over positions,

- Additional buoys required, and

- Ranges required.

Note that this is an iterative process since the ranges for one section will provide a range for the next section for vessels going in the opposite direction. Ranges that require a structure in the river will create a target. Buoys for other time periods and visibility conditions will already be a "basic" aid. Limited experience suggests that by considering section by section and then revisiting sections it is possible to reach an equilibrium set of basic aids in a reasonable time..

Once the basic aids for a section are defined, the positioning algorithm in the MSD tool automatically determines the positioning distances. Since positioning distance completes the estimation of the MSD CW, it is possible to compare it to the actual CW through the ratio (CW/MSD). The (CW/MSD) ratio is automatically calculated for one- and two-way traffic.

If the (CW/MSD) ratio is not acceptable, the aids are enhanced and the positioning relationships are used to find the change in the positioning distance and the revised (CW/MSD) ratio is checked for acceptability. This process continues for either the one-way or two-way traffic until:

- (CW/MSD) is acceptable, or
- It is not practical to improve MSD any more and the availability of the channel is set to:
    - Available for two way (less than desired LOS),
    - Available for one way for time period, or
    - Unavailable for the time period.

When the two loops, A and B, are completed, loop C is used to consider another time period. The suggested order for considering time periods is:

- Winter, good visibility, day,
- Winter, good visibility, night,
- Winter, poor visibility,
- Summer, good visibility, day,
- Summer, good visibility, night, and
- Summer, poor visibility.

However, this order should be examined after more experience with the method.

Consistent with good optimization principles, enhanced aids to navigation should be considered along with changes in availability, widening of the channel by dredging, provision of enhanced pilotage, improvements in navigational aids (e.g. portable ECDIS for pilots), additional anchorages and other ways of improving safety.

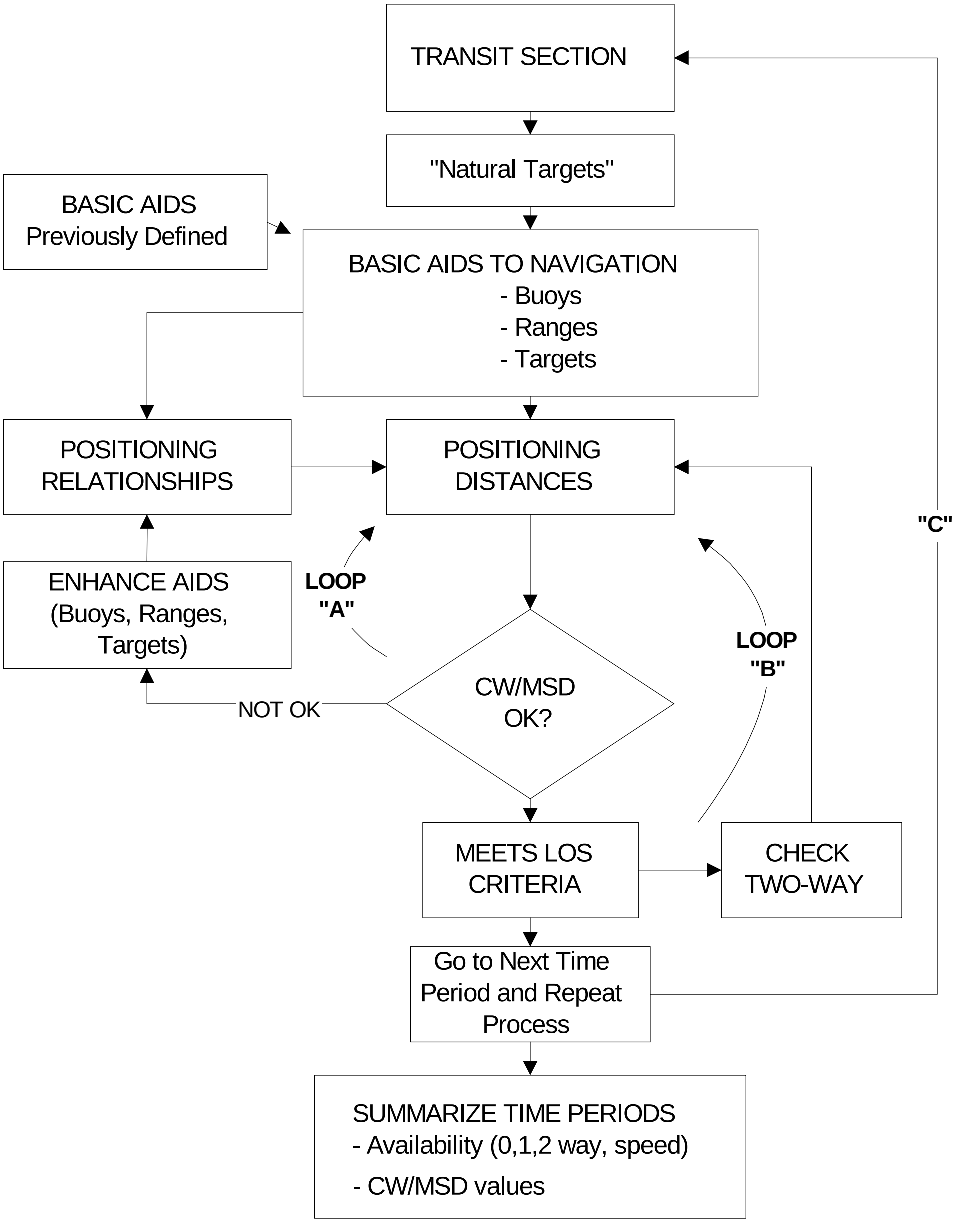


Figure 5. Analysis of Positioning Quality

5.2 Positioning Relationship and Accuracy Table Development Process

5.2.1 Background

The development of relationships between aids to navigation and positioning quality was a critical step in the development of the MSD method. The PIANC document indicates that aids to navigation are "of crucial importance" to "define the width and alignment of the channel" but the PIANC design process suggests otherwise. Specifically, the range from moderate to excellent aid provision is from 0.5 beams to 0.0 beams (i.e., only a 50' range from moderate to excellent aids). However, this is not supported by MBP, or IALA. IALA correctly indicates that a 95% accuracy in a gyro bearing is equivalent to 1°, which, at one mile distance represents 100' in uncertainty in lateral position.

Experts with local navigation knowledge were able to examine the design of the MSD tool at several stages in workshops. While the final positioning quality decision tree was only reviewed once by pilots, masters and marine organizations, more review is planned as the MSD tool is released to workshop members for further review. A log should be kept of these changes so that the positioning relationships can be modified to reflect expert opinion.

The development process is described below. The method used to establish positioning accuracy relationships is illustrated in Figure 6.

5.2.2 The process

In order to develop a "scale" of positioning quality for the river that is consistent in its interpretation (basic, 1st enhancement, 2nd enhancement), but is also related to the situations and conditions in the river, a passage is planned, tracks are plotted on a chart and the waterway is subdivided into unique turn and straight sections. Some differences requiring a unique section include: a different method of navigation, a different depth, a different channel width and different currents. Refer to Appendix C for further indications of section subdivisions.

Ideally, each time period, as described in section 5.1, is examined and the aids to navigation are assessed for their positioning quality, beginning at a "basic" configuration and advancing, up to three enhancement levels. Figure 6 illustrates this process and indicates the method of checking for consistency of positioning quality estimation. At completion, the resulting "positioning relationship" table is created, a sample of which is shown in Table 2.

Basic aids to navigation are the minimal set of aids needed to comfortably transit a traverse of the river, under the given conditions for the time period. The aids are dependent on the characteristics of the river, such as length of straight, degree of turn and cross currents, but are independent of the CW. The aids are grouped into seven categories.

Enhanced aids are not continuous (i.e., 1, 2, 3 or more aids), but are logical groupings of additional aids:

- That are considered in terms of incremental improvement in positioning from the basic set of aids,
- That are logical in terms of MBP; for example, if a basic turn marking consisted of two gated buoys at the turn and one buoy at each end marking the start of turn, then the first enhancement might be two additional buoys to create gated buoys at each end. Also, this increase from four to six buoys per turn would be repeated at all turns in the traverse. So, if there were, for example, four turns, the enhanced arrangements of buoys would be an increase of eight buoys,
- That have a noticeable difference in positioning (e.g. 20-30 m), so that an incremental enhancement is a noticeable step up in positioning accuracy (this sets a limit in the number of enhancements considered,
- That are selected from either: buoys, ranges or fixed targets (including Racons), and
- Where, if possible, the levels of enhancement are limited to two or three additional levels of aids to navigation.

Not enough time was available to examine all aids to navigation levels for each time period, vessel type and conditions. During this study, four types of configurations were examined under numerous conditions. These included: aids to navigation configurations for winter, summer, the present configuration and the configuration proposed for analysis by Association des armateurs du St-Laurent (AASL). There was sufficient time over the course of the project for five ship captains to examine over 100 unique sections or time periods and estimate positioning accuracies.

The characteristics for each section and its positioning quality were tabulated and sorted by the position quality in descending order. Then the sections were grouped into logical aids to navigation configurations where a common rule described the aids, visibility and method of navigation. At this point, there were discrepancies; these were examined and resolved, usually with the addition of another rule describing a unique situation.

Once the discrepancies were corrected, a functional relationship was developed from a decision tree with positioning quality estimates for each time period (*good visibility*: winter, summer, day, night; *poor visibility*: winter, summer). The positioning function then responds to the aids to navigation configuration presented in the MSD tool and outputs a positioning quality value.

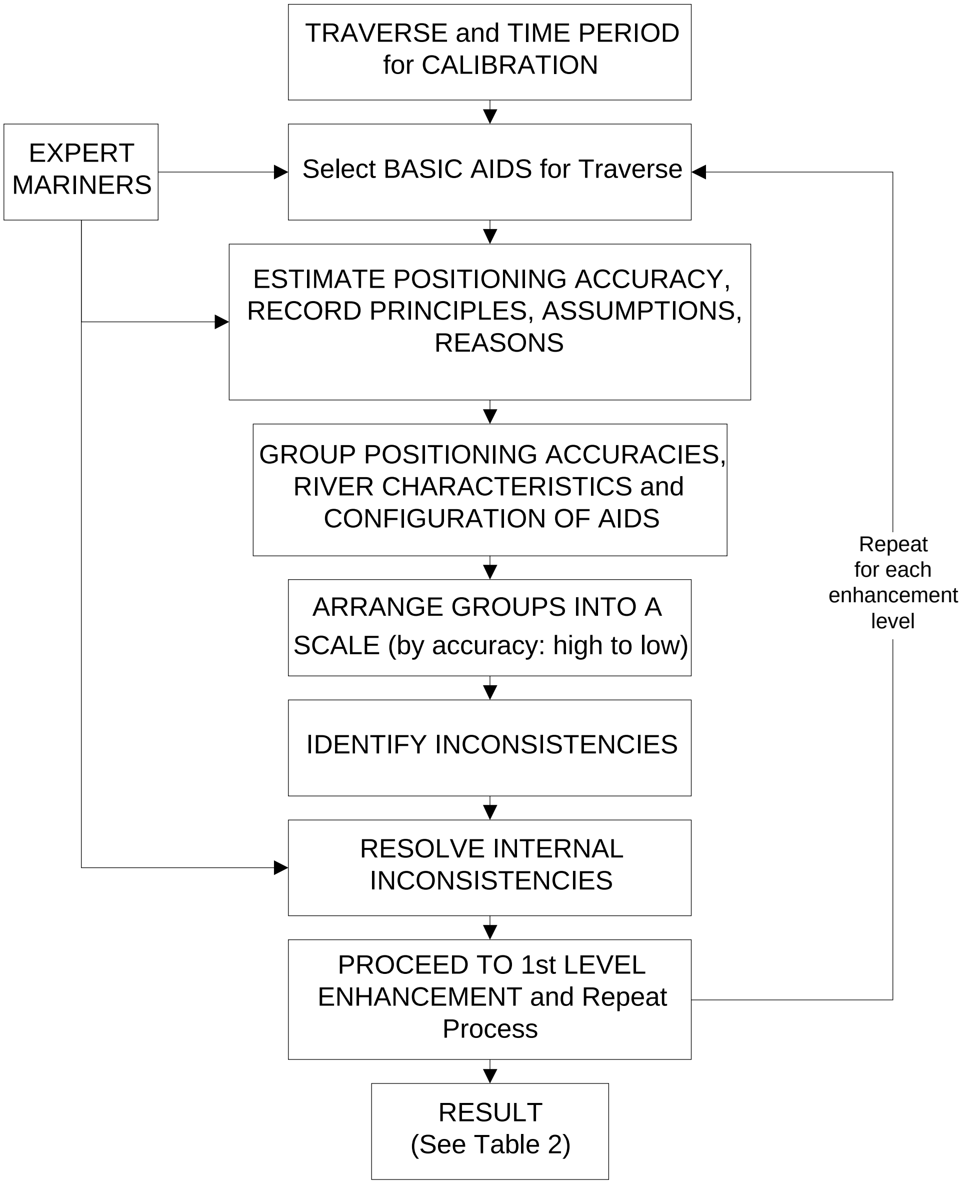


Figure 6. Development Process for Positioning Tables

Table 2. Example of Positioning Relationships

Radar range scale (nm)	Radar precision (m)	Good radar targets	Racons	Fixed aids	Good visual lead marks	Good visual turning marks	Ranges	Buoys	Primary navigation method	Confirmation navigation method	CW – positioning quality (m)
1.5	71	4	2	0	yes	yes	yes	4	R	R	15
1.5	71	4	2	0	yes	yes	no	3	V	R	23
1.5	71	3	0	0	yes	yes	no	5	V	R	23
1.5	71	1	1	2	yes	yes	yes	9	V	R	15
3	83	2	1	1	yes	yes	yes	9	V	R	15
3	83	3	0	0	yes	yes	yes	4	V	R	15
3	83	3	1	2	yes	yes	yes	4	V	R	15
1.5	71	3	1	2	yes	yes	yes	5	V	R	15

Notes:

1. Several situations will have the same aids configurations and the same positioning accuracy.

2. Several situations will have different aids configurations but the same positioning accuracy because of different time periods, or because different combinations produce similar positioning quality.

6 Completion of the MSD Process: Overall LOS

At this point, for one traverse there may be up to ten sections, each with six time periods, and for each a value of (CW/MSD). It is necessary for some purposes to find a common measure of the LOS for the traverse. The following suggestions are presented.

6.1 Level of Service

For CCG LOS or "design availability", a method of combining (CW/MSD) ratios and availability is proposed here that accounts for the frequency of occurrence of the time periods (winter, summer, good/poor visibility, etc.) and traffic volumes encountered.

At present, commercial LOS is met if aids to navigation are visible to establish position 75 percent of the time. To use the MSD tool to meet this LOS definition, simply determine whether CW/MSD ratios provide sufficient safety after entering into the MSD tool the minimum visibility threshold that occurs 75 percent of the time. Examples of conventional CCG LOS applied to commercial vessels in the study area can be found in Appendix D.

6.2 Risk

The risk associated with each time period and section (i.e., a function of (CW/MSD)) is weighted by the relative number of vessels in each time period and the relative length of each section.

Risk along the waterway can then be determined by considering the magnitude of potential consequences. Risk receptors can be analysed by examining the maps provided in the Marine Navigation Safety System (MNSS), where Geographic Information System (GIS) and accident database functionality are available. The consequence analysis undertaken in this study is presented in Section 8.

The risk of alternative aids to navigation designs can be compared by examining the difference in the CW/MSD risk ratios. Any difference will result in a multiplier that can be applied as an adjustment to the accident rates calculated in MNSS. The accident analysis undertaken in this study is summarized in Section 7 and detailed in Appendix A.

Design availability might be more accurately determined by weighting the CW/MSD ratio for each time period (day, night, winter, summer, low visibility, good visibility) by the percentage occurrence of each time period, or, additionally, by the relative number of vessels in each time period. Thus, the "design availability" would be a function of an overall weighted CW/MSD.

If, for example, the chosen aids to navigation design was:

- “Unavailable” for one-way traffic, i.e., did not support, winter poor visibility navigation (annual occurrence 2 percent),
- “Available” for one-way traffic for 10 percent of the time, and
- “Available” for two-way traffic all other time periods,

then the annual LOS would be 88 percent.

7 Accident Analysis

7.1 Summary

7.1.1 Scope

To conduct a risk assessment of selected marine accident scenarios in the St. Lawrence River and to validate results of the MSD tool, an accident analysis was required. This involved the computation of annual, summer and winter collision, grounding and striking frequencies for commercial vessels.

Depicted in Figure 7 are three study areas: the Saguenay approaches, the Traverse du Nord and Lac St. Pierre. Also indicated are MCTS calling-in-points (CIPs) within the study areas. The Maritime Safety Information System (MARSIS) database was used for accident analysis and the MCTS Data Archive and Distribution System (DADS) database was used for traffic analysis. Waterway areas defined in this study as "CIP areas" were used as the common geographical units for calculating accident rates.

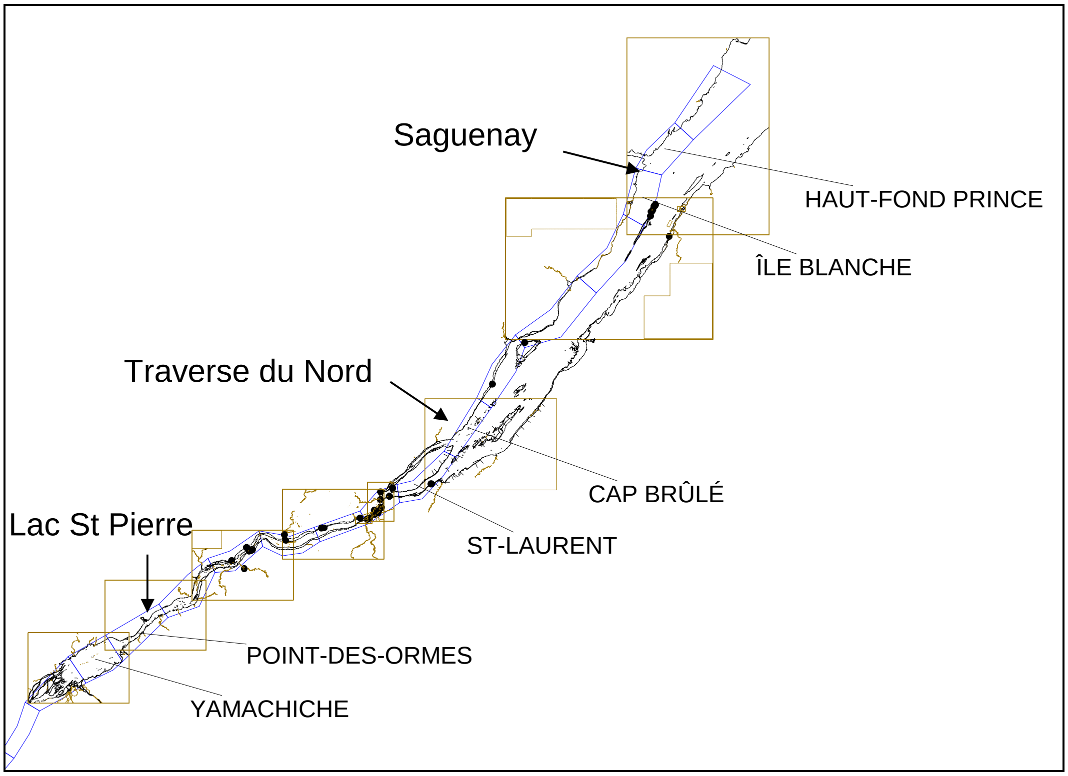


Figure 7. Saguenay, Traverse du Nord and Lac St. Pierre Study Areas

7.1.2 Accident rates

- Of the sample of 137 accidents analysed in the Laurentian Region, 30 percent were collisions and 60 percent were groundings (See Table 5),
- Most of the accidents involved bulk carriers and cargo vessels, followed by oil and petroleum product tankers (See Table 4),
- The highest accident rates occur in Grondines and Pointe-des-Ormes where one could expect an accident (probably a grounding by a bulk carrier or cargo vessel) with a “high damage degree” about once every five years (See Table 5), and
- Summer accident rates are significantly less than winter accident rates (See Table 6).

7.1.3 Validation of MSD method

- Comparisons of the MSD and CW data to accident data indicate the expected relationship between CW/MSD and accident rates for the areas studied (See Figure 9),
- Validation of the MSD method using accident data was limited by the available data. This is good for marine safety. It is unlikely that sufficient accident data will ever be available and it will be necessary to continue to incorporate expert opinion into the MSD method, and
- The MSD method results are correlated to existing practice and this, along with the positive reception from stakeholders, suggests that the MSD method provides a systematic and logical method for assessing safety requirements and the level of risk on the river.

7.2 Objective

The objective of the accident analysis was to validate and confirm the approach used in MSD method for channel design. While there is over 20 years of data, the validation of the MSD method requires much more data to examine the details of the model, so the validation must be at some intermediate level that considers aggregated sections of the river and aggregated time periods. As indicated by the results, the accident analysis is sufficient to broadly confirm the method but the validity of the model details still depends on the careful elicitation of expert opinion. In addition, it will be seen that the data limitations preclude more extensive analysis of existing data.

To meet this objective the following tasks were required:

- develop the risk profile of the river, especially with respect to groundings, collisions, and strikings involving tankers, merchant and passenger vessels,

- obtain accident rates for specific sections of the river for comparison to the MSD results and validation of the MSD methodology, and

- focus on accidents related specifically to shiphandling and positioning in the river, related to the provision of aids to navigation.

7.3 Methodology

7.3.1 Overview of approach

The purpose of comparing the CW/MSD values to accident rates was to validate the method with historical accident occurrences. A lower value of CW/MSD was expected to be associated with higher accident rates because it represents a waterway section with higher navigation risk. However, this examination was limited by the data sets; these included:

- only 137 accidents (non-mechanical failure, by through traffic only) occurred in the waterway between Escoumins and Montreal areas in 22½ years, and

- just over 100 CW/MSD estimates.

With a subset of only 137 accidents related to the value of aids to navigation and navigational aids, there was limited data to validate the MSD method which has dozens of parameters and is applied to hundreds of sections in the St. Lawrence River (see Figure 8). Even at the level of CIP areas, there are two CIP areas with no accidents and three with only one accident. Thus, the accuracy of the accident data is limited even before consideration of summer/winter and other factors.

The number of river sections for which MSD values have been estimated is limited and many of the estimates are still preliminary. They have been made in order to estimate parameters in the MSD method and to use expert opinion to formulate the model structure, especially for the “positioning” component of the MSD tool. Not all the aids configurations examined with the MSD tool were directly comparable. One direct comparison is provided in Table 3 where CW/MSD ratios less than one are indicated in bold type.

Table 3. Comparison of the Bi–directional CW/MSD Ratios for Two Aids Configurations in Courbe Pointe du Lac

		Channel width / MSD ratio		
Section number	Section name	AASL Aids	Existing Aids	Change
1	A/C– C–63	1.40	1.40	
2	Pont Laviolette	**0.77**	**0.77**	
3	Pointe–des–Ormes – St. François	1.20	1.60	
4	Courbe Nicolet	1.28	1.28	
5	Courbe Pointe du Lac	1.06	1.06	
6	Course Pointe du Lac	**0.89**	1.23	**–28%**
7	Course Pointe du Lac	**0.94**	1.07	**–12%**
8	A/C S–54	**0.95**	**0.95**	

Conditions: summer, one nmi visibility, two container vessels

The limited accident data will not change, but it is expected that as the MSD method is used, there will eventually be estimates for most parts of the river for most conditions. All MSD worksheets prepared for the study areas are included in Appendix B.

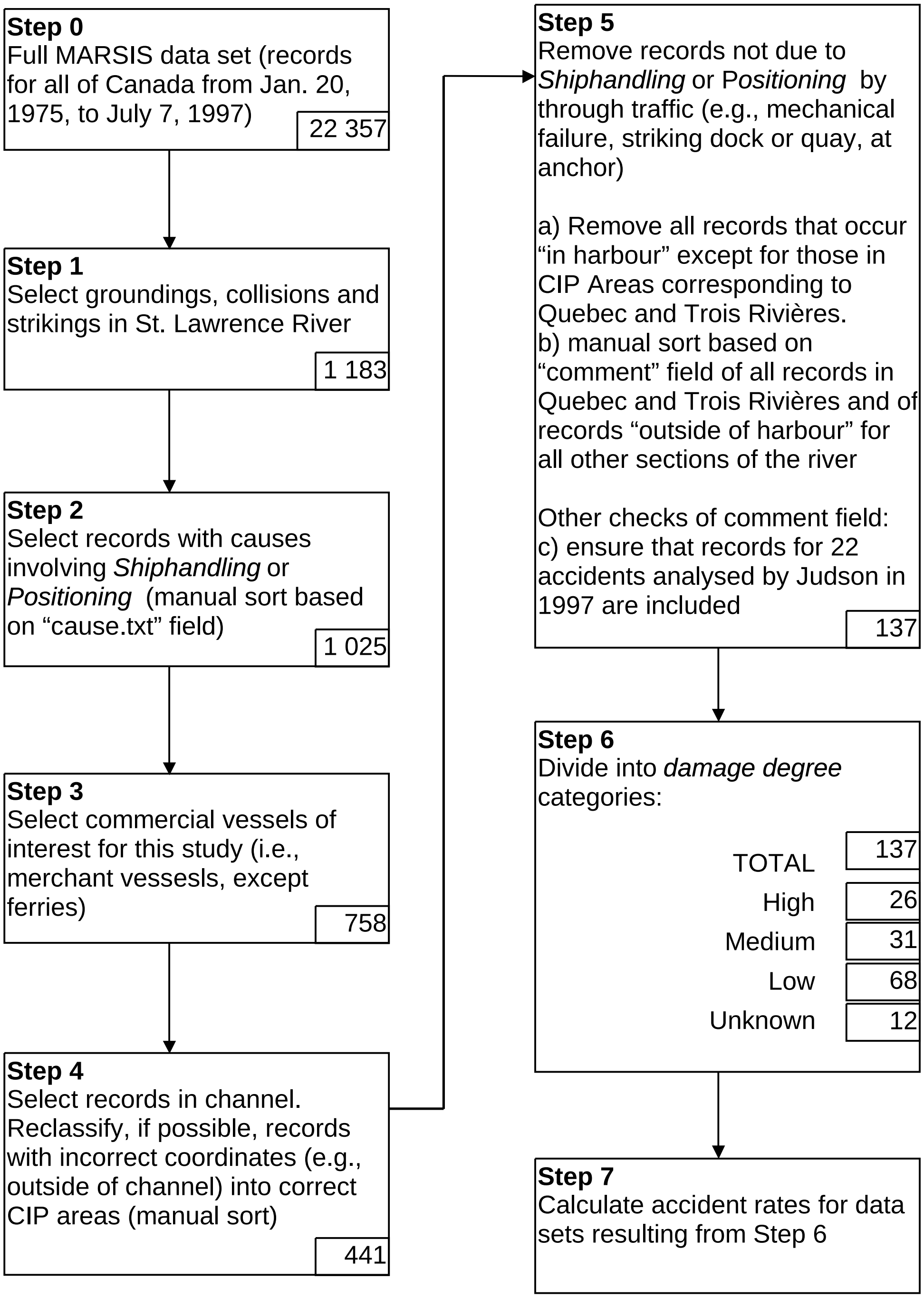


Figure 8. Overview of Data Selection Steps (revised October 22, 1998)

Note: The number of accident records resulting from each step is shown in the box in bottom right corner.

7.4 Results

Table 4 shows the total number of commercial vessel accidents in the Laurentian Region (using exiting MARSIS and MCTS boundaries) that involved shiphandling or positioning difficulties, between 1975 and 1997. Records from this intermediary table meeting further criteria were ultimately grouped as a set of collisions, groundings and strikings:

- Of commercial traffic (in bold type), except ferries,
- In a navigation channel and not involved in an arrival or departure to a dock or anchorage, and
- Where the accident was probably due to an error in shiphandling or positioning.

Most of the accidents involved bulk carriers and cargo vessels followed by oil and petroleum product tankers.

Table 4. Selected Commercial Vessels of Interest by Accident Type

Vessel Type	Selected	Collision	Grounding	Striking	Grand Total
Bulk	**X**	**128**	**110**	**136**	**374**
Cargo	**X**	**63**	**43**	**79**	**185**
Chemical_tanker	**X**	**6**	**5**	**7**	**18**
Container	**X**	**7**	**6**	**11**	**24**
Ferry		13	6	11	30
Fishing	**X**	**3**	**3**	**1**	**7**
Government		23	18	26	67
LPG_LNG_carrier	**X**	**0**	**1**	**0**	**1**
Other_over_20m		9	12	7	28
Other_under_20m		24	2	7	33
Passenger	**X**	**12**	**11**	**21**	**44**
Tanker_over_50000 DWT	**X**	**0**	**0**	**2**	**2**
Tanker_under_50000 DWT	**X**	**40**	**28**	**35**	**103**
Tug		46	32	27	105
Tug with oil barge		2	2	0	4
Grand total		376	279	370	1025
Total		**259**	**207**	**292**	**758**

Table 5 provides estimates of accident rates for the St. Lawrence River. After further refining of the data set using the process outlined in Figure 8, accident rates were calculated for 19 areas along the river centred on the position of a MCTS CIP. This type of reference position was chosen because it is a consistent point of vessel traffic data capture for DADS. An explanation of the process used to calculate these accident rates is provided at the bottom of Table 5. Other details and definitions are provided in Appendix A.

Table 5 indicates that 30 percent of accidents are collisions and 60 percent are groundings. The highest accident rates occur in Grondines and Pointe-des-Ormes, where one could expect an accident (probably a grounding) with a “high damage degree” about once every five years. For Grondines, this translates to 0.35 accidents every 100 000 nmi travelled in this section of the river.

Table 5. Annual Accident Rates by CIP Area and Damage Degree

CIP Area					Total		Breakdown by Damage Degree ***					
							High		Medium		Low	
#	Name	Annual Traffic Count (95/96)**	Length (nmi, rounded)	Traffic nmi (Count x nmi actual)	Accident (Count per 22.5 years)	Annual Accident RATE*	Count per 22.5 years	Annual RATE*	Count per 22.5 years	Annual RATE*	Count per 22.5 years	Annual RATE*
5	ESCOUMINS	4 857	17	81 112	3	0.16	0	0.00	0	0.00	3	0.16
6	HAUT–FOND PRINCE	4 928	13	65 542	2	0.14	2	0.14	0	0.00	0	0.00
7	ILE BLANCHE	4 871	11	55 042	3	0.24	0	0.00	2	0.16	1	0.08
0	CAP AU SAUMON	4 849	19	90 676	1	0.05	1	0.05	0	0.00	0	0.00
8	CAP–AUX–OIES	4 876	21	102 396	1	0.04	0	0.00	0	0.00	1	0.04
9	GRAND–POINT	4 866	16	77 856	0	0.00	0	0.00	0	0.00	0	0.00
10	CAP BRULE	4 869	14	69 627	4	0.26	2	0.13	0	0.00	2	0.13
11	ST. LAURENT	4 923	16	78 768	1	0.06	0	0.00	0	0.00	1	0.06
13	QUEBEC	4 488	10	44 431	23	**2.30**	1	0.10	7	**0.70**	10	**1.00**
14	ST. AUGUSTIN	4 535	12	53 967	8	0.66	4	**0.33**	3	0.25	1	0.08
15	DONNACONA	4 535	14	62 130	6	0.43	0	0.00	2	0.14	3	0.21
16	GRONDINES	4 538	14	61 263	17	**1.23**	5	**0.36**	3	0.22	8	**0.58**
17	BATISCAN	4 557	16	72 912	13	0.79	2	0.12	1	0.06	10	**0.61**
19	POINTE–DES–ORMES	4 321	15	63 087	23	**1.62**	5	**0.35**	7	**0.49**	9	**0.63**
20	YAMACHICHE	4 354	10	44 411	9	0.90	2	0.20	4	**0.40**	3	0.30
21	ILE DES BARQUES	4 357	14	62 305	11	0.78	0	0.00	2	0.14	7	0.50
22	TRACY	4 080	12	50 592	4	0.35	0	0.00	0	0.00	4	0.35
24	CAP ST. MICHEL	4 179	11	45 969	0	0.00	0	0.00	0	0.00	0	0.00
25	MONTREAL EST	4 424	9	38 046	8	0.93	2	0.23	0	0.00	5	**0.58**
	Grand Total			1 220 132	137	0.50	26		31		68	
CASUALTY TYPE												
Collisions					41		4		18		12	
Groundings					80		21		6		49	
Strikings					16		1		7		7	
Mean						0.58		0.11		0.14		0.28
Standard Deviation						0.62		0.13		0.20		0.29
Mean + 1 SD						1.20		0.24		0.34		0.57

*e.g., for ESCOUMINS: 4857 x 16.7 =81 112 vessel miles per year. 3/22.5 = .13 accidents per year or per 81 112 nmi, or .16 accidents per 100 000 nmi traveled. Accident data from 1/20/75 to 7/7/97.

** Includes all merchant vessels except for ferries for one year (95–96).

*** For 9% of the set of 137 records, damage degree is "unknown". These records are included in the grand total only.

The CIP areas with rates more than 1 SD above the mean are shown in bold typeface.

Table 6 and Figure 9 show that even with a small number of sample points, it is possible to see that higher accident rates equate to lower values of CW/MSD.

Table 6. Comparison of CW/MSD Values and CIP Accident Rates (Bi–directional*)

CIP Area	CIP Number	CIP Median CW/MSD	CIP Accident Rate (Annual)	CIP Accident Rate (Summer)
Haut–fond Prince	6	3.0	0.14	0.07
île Blanche	7	3.55	0.24	0
Cap Brûlé	10	1.24	0.26	0
St. Laurent	11	1.64	0.06	0
Pointe–des–Ormes	19	1.21	1.62	0.56
Yamachiche	20	1.06	0.90	.30

* For CIPs 6 and 7 the bi-directional CW/MSD was estimated from the unidirectional values by a factor of .54 (average for sections 10-11) to make results comparable.

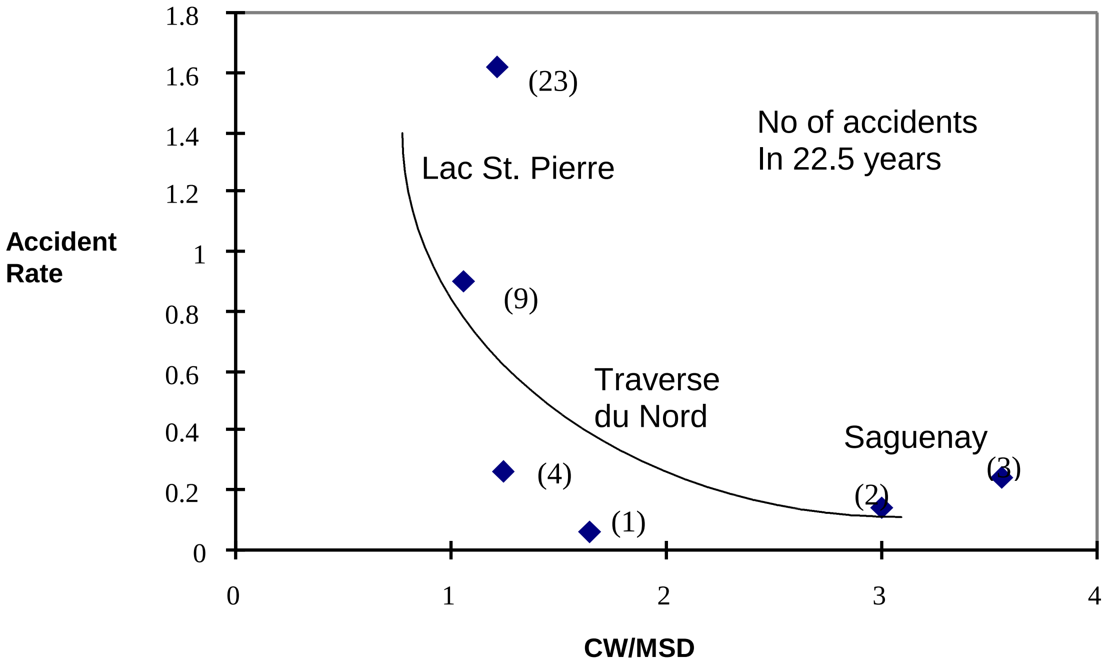


Figure 9. CIP Accident Rate versus CIP Median CW/MSD Ratio

However, comparing the CW/MSD ratio to historical accident locations is more difficult. Figure 10 shows grounding locations and CW/MSD values for a summer scenario in Lac St. Pierre (CW/MSD values are indicated as “DMS”).

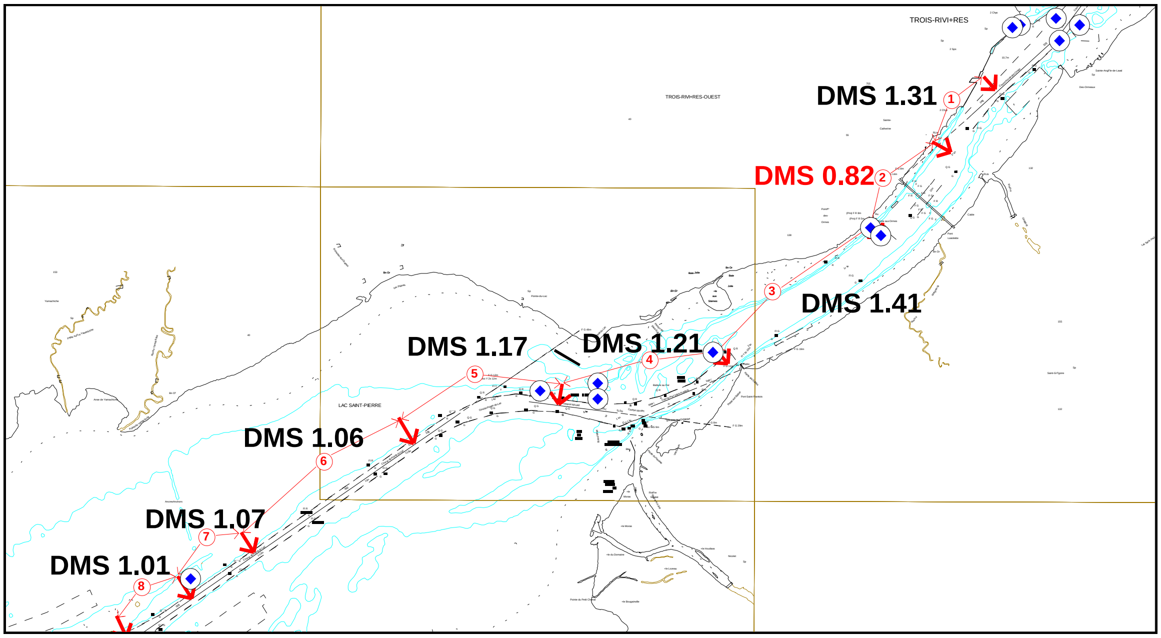


Figure 10. Grounding Positions and CW/MSD

While there is a general relationship between CW/MSD and observed accident rates, there may not be a one-to-one correspondence between historical accident location and grounding risk for several reasons:

- The MSD tool is evolving to better reflect MBP, which keeps 99.9% of vessels safe; but, some accidents have a random component that no regulation or aids to navigation infrastructure can change,
- The measurement of channel width is less exact in turns and open water, and
- MSD includes many primary factors for safe navigation – but there are additional secondary causes of accidents.

Some of these accident causes considered but not automated in MSD include:

- Additional impacts of turns: heel squat is part of “safety margin” which is applied to turns and straight sections,
- The effects of ports and port traffic on workload,
- Accidents due to changes in pilots, both prior to and after the changeover point,
- Additional impacts of bridges,

- Accidents that are initiated at mile (m) resulting in a grounding at (m)+(x) nmi so there is a distance lag between the source of the accident and the location of the accident. For example, some pilots indicated that they took extra care in the difficult sections of the river and might sometimes “let down their guard” after the difficult section. This is a type of reverse feedback effect, and

- Location of higher incidence of fatigue.

The data limitations preclude the identification of these causes from accident data. However, it may be possible to obtain evidence to support the future inclusion of some of these and other secondary factors in addition to the primary causes already incorporated in the MSD method. Some sources of evidence might be from the observation of “close calls” or the systematic collection of reliable expert opinion with test of internal consistency.

8 Consequence Analysis

The consequence analysis component of the project addressed the worst plausible outcomes from a marine shipping scenario on the St. Lawrence River. The 1996 DADS database was reviewed to determine the commodities shipped and the frequency of shipment. An initial examination of the data revealed that the list of hazardous products carried included many different petrochemical products out of the 71 different category groupings. Bunker C heavy fuel oil was number 11 on the list (ordered by trip frequency) with 92 trips and gasoline was number 12 with 87 trips. These two commodities were retained for study under an oil spill scenario and a fire/explosion scenario, both within the Lac St. Pierre segment of the river.

8.1 Oilspill Modelling

This scenario assumes a product tanker, carrying bunker C heavy fuel oil, collides with another vessel in the Pointe-du-Lac turn of Lac St. Pierre where historically, a significant number of marine incidents have occurred. One hold in the 3x6 configuration is ruptured at the waterline, setting up a 24-hour spill event. The 5 000 m^3 tank is initially 90 percent full and 30 percent of the contents or 1 350 m^3 is spilled into the river (see MIL Systems report # 1736-0011-01 for detail (5)).

To facilitate the consequence analysis, the oil spill model “Oilmap” was deployed to investigate the probability of shoreline oiling and to examine the fates and amount of oil contacting risk receptors in the study area. Hydrodynamic modelling of the St. Lawrence River included:

- Mean river flow by season, and
- Actual currents in the river influenced by tidal effects, seasonal observations, tributaries and bathymetry.

Significant sources of data included the Canadian Hydrographic Services current atlas for the river and electronic chart vector data supplied by Nautical Data International.

Wind records were also assembled from Environment Canada’s Nicolet station for a five-year period. Hourly records for the period 1993-98 were properly formatted in terms of wind speed and direction in preparation for use by the consequence model.

The consequence analysis was based on a series of three stochastic studies for the months of February, May and September to investigate seasonal effects. In this mode of operation, 100 trials per month were simulated where spill start times were randomly selected, constrained by the month studied and 48 hours of wind data was ingested for each trial. Hence, a spill trajectory for each trial was computed and the spillets contacting the shore are recorded. The ensemble of the 100 trajectories was then analysed to produce the probability of shoreline oiling. Overall river flow rates were selected by season prior to each stochastic study. The oiling probability results were found to be relatively insensitive to the seasonal flow rate changes.

The scenario results produced shoreline impact probability maps by grid cells of 0.84 km length in ranges of 10 percent impact probability. A map for each of the months studied can be found in figures 11–13.

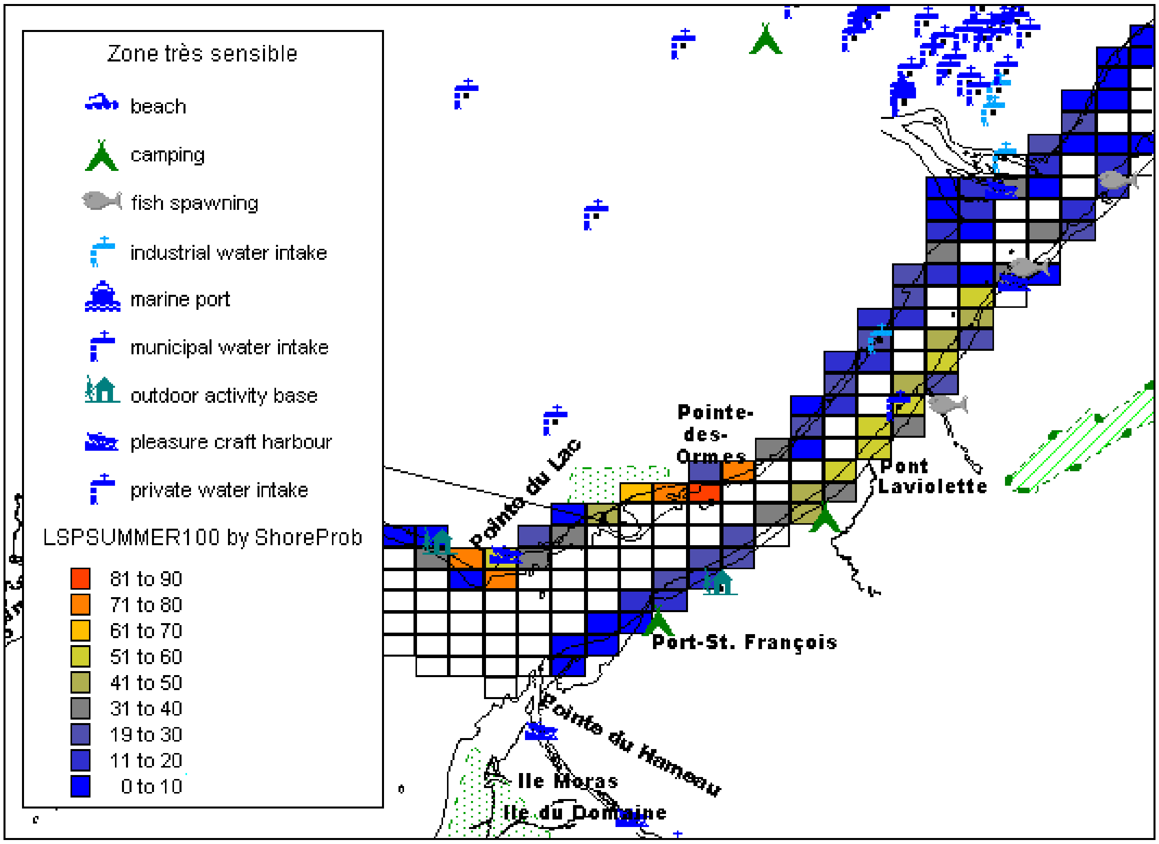


Figure 11. Shoreline Impacts – September Winds

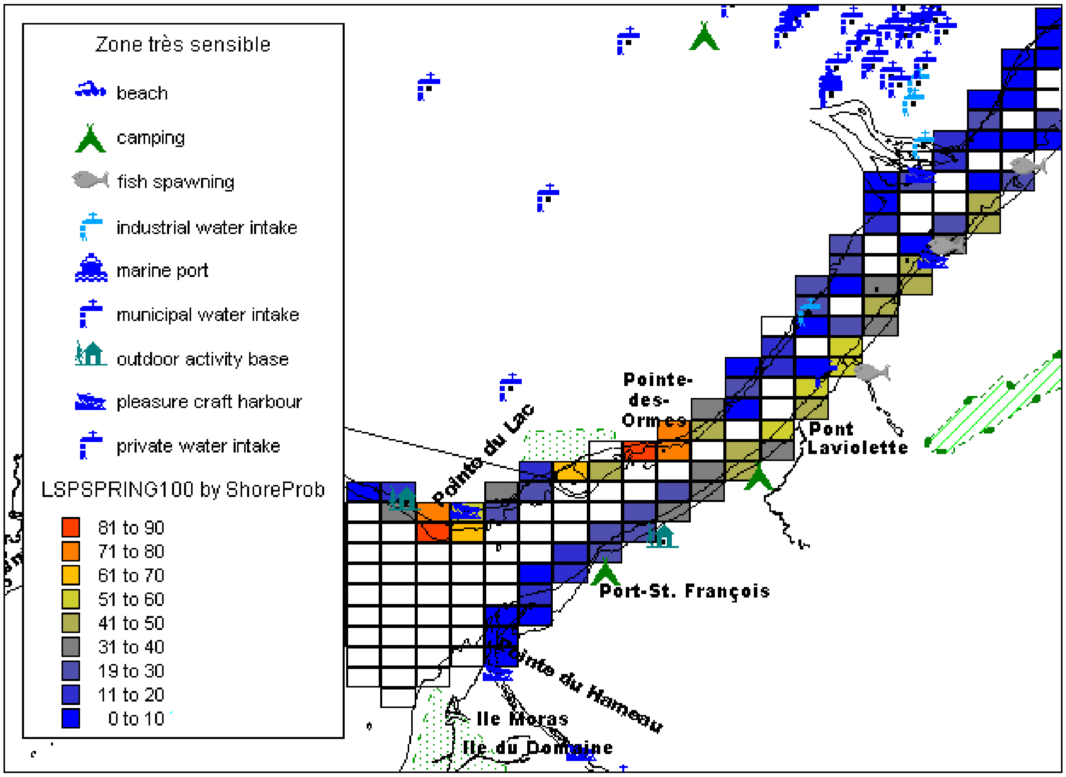


Figure 12. Shoreline Impacts – February Winds

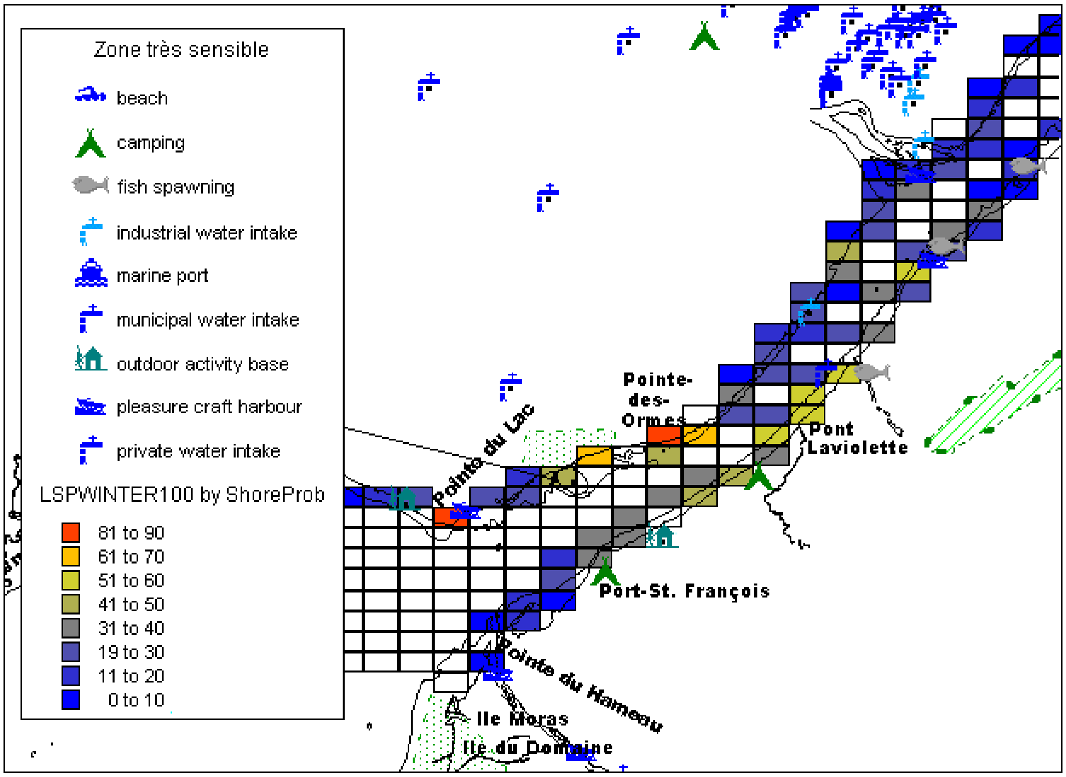


Figure 13. Shoreline Impacts – May Winds

8.1.1 Oil spill results

For each of the three months where stochastic trials were run, a specific oiling trend was noted. The higher probability zone extends from the Pointe-du-Lac turn to Trois Rivières/Cap-de-la-Madeleine, where the oiling probability exceeds 20 percent in all cases. The total shoreline distance is approximately 16 km on either side of the river. Other trends common to the three stochastic are listed in Table 7.

Table 7. Probability of Shoreline Oiling by Shoreline Resource Receptor

Shoreline Resource	Percentage Probability Hit
Pointe–du–Lac village (outdoor activity base, marina)	80%
Ile–aux–Sternes ecological reserve	60–70%
Pointe–des–Ormes	85%
Industrial water intake (Kruger Pulp & Paper)	15–25%
Port infrastructure – Trois Rivières	40%
Marina – Trois Rivières	30%
Camp site – Port St. François	25%
Outdoor activity base – Port St. François	40%
Campsite – Becancour	40%
Municipal water intake – Becancour	50%
Fish spawning – Rivière Godefroy	50%
Marina – Becancour	55%
Fish spawning – St. Angèle de Laval	55%
Fish spawning – Trois Rivières	25%

Financial costs of oil spill events depend on the amount and type of product spilled, the location and timing of the spill event, the sensitive areas affected, the weather during clean-up and the techniques deployed. Ninety percent and above of the total cost of a spill can be attributed to the shoreline clean-up procedures. The *Oil Spill Intelligence Report* (6) suggests an upper boundary for on-shore clean-up at $150-$300 K per tonne recovered. Others have suggested US$19 000 (7) and CDN$22 000 (8) are more typical figures.

Proximity of the spill to populated areas where beaches, marinas and cultural land use are prevalent will drive the cost to the high end of the upper boundary. The same is true for viscous crudes and heavy fuel oils, where persistence of these hydrocarbons is higher than for lighter products. The largest expense in shoreline clean-up is for disposal of oily debris.

Following the impact of the 1967 Torrey Canyon spill, the International Maritime Organization (IMO) sponsored a international legal conference on maritime pollution damage to establish the Civil Liability Convention (CLC) where the polluter pays principle applies. The signing parties to the CLC agreed that the ship owner (at the time of a pollution incident) is liable for damages caused unless the incident is caused by:

- An act of war,
- An exceptional natural phenomenon,
- The malicious act of a third party, or
- The negligence of a government authority in maintaining navigational aids.

Note that even so-called minor spills could require a complex response operation, triggering an incident command system. The various coordinators, managers and trained personnel wearing protective gear (in need of decontamination prior to every meal), damage assessment teams and lawyers contribute to the costs, which escalate according to their respective per diem charge-out rates.

The Courbe Pointe-du-Lac spill costs must take into account the following categories:

- Tanker costs: value of lost oil, tanker repair costs and lost business opportunity or chartering costs,
- Incident report filing costs: provincial, national, insurer, fund,
- Initial clean-up costs: on-scene coordinator fees, response organization fees, command centre fees,
- Mechanical containment and recovery costs: booms, equipment, clothing, logistics, disposal, permits,
- Manual shoreline clean-up costs: equipment, clothing, logistics, disposal, permits,
- Additional costs: worker compensation claims, damage costs due to clean-up work, media relations,
- Restoration costs: replanting wetland plant species, restocking fish, expert evaluation of spill damage,
- Settlement costs: legal fees, civil damages,

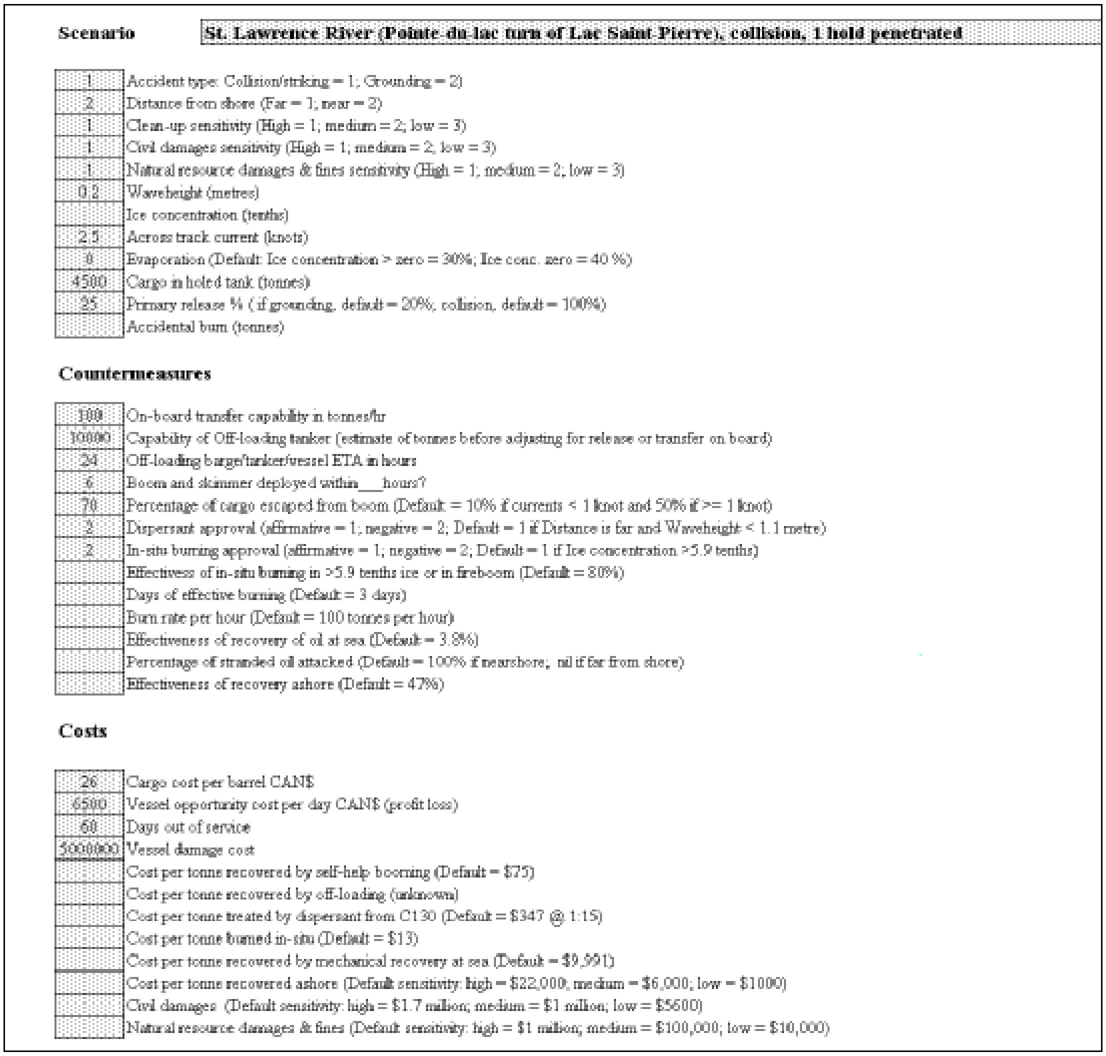
- Industrial and municipal water intake damages, and

- Business losses: outdoor activity bases, marinas, campsites, etc.

8.1.2 Actual cost estimates

The St. Lawrence River spill cost model developed in the Arctic Tanker Risk Analysis program was adapted for this project.

Considering the cost categories listed above, the total cost of a 1 350 m^3 spill would exceed $22.2 million (see Figure 14). Figure 14 provides details of the range of costs expected to result from an oil spill. Details of the source for these estimates are in the report TP12325E (8), pp. 47-68; however, some specific cost estimates for the Courbe Pointe-du-Lac are provided in Figures 14–15.



Scenario **St. Lawrence River (Pointe-du-lac turn of Lac Saint-Pierre), collision, 1 hold penetrated**

1	Accident type: Collision/striking = 1; Grounding = 2)
2	Distance from shore (Far = 1; near = 2)
1	Clean-up sensitivity (High = 1; medium = 2; low = 3)
1	Civil damages sensitivity (High = 1; medium = 2; low = 3)
1	Natural resource damages & fines sensitivity (High = 1; medium = 2; low = 3)
0.2	Waveheight (metres)
	Ice concentration (tenths)
2.5	Across track current (knots)
0	Evaporation (Default: Ice concentration > zero = 30%; Ice conc. zero = 40 %)
4500	Cargo in holed tank (tonnes)
25	Primary release % (if grounding, default = 20%, collision, default = 100%)
	Accidental burn (tonnes)

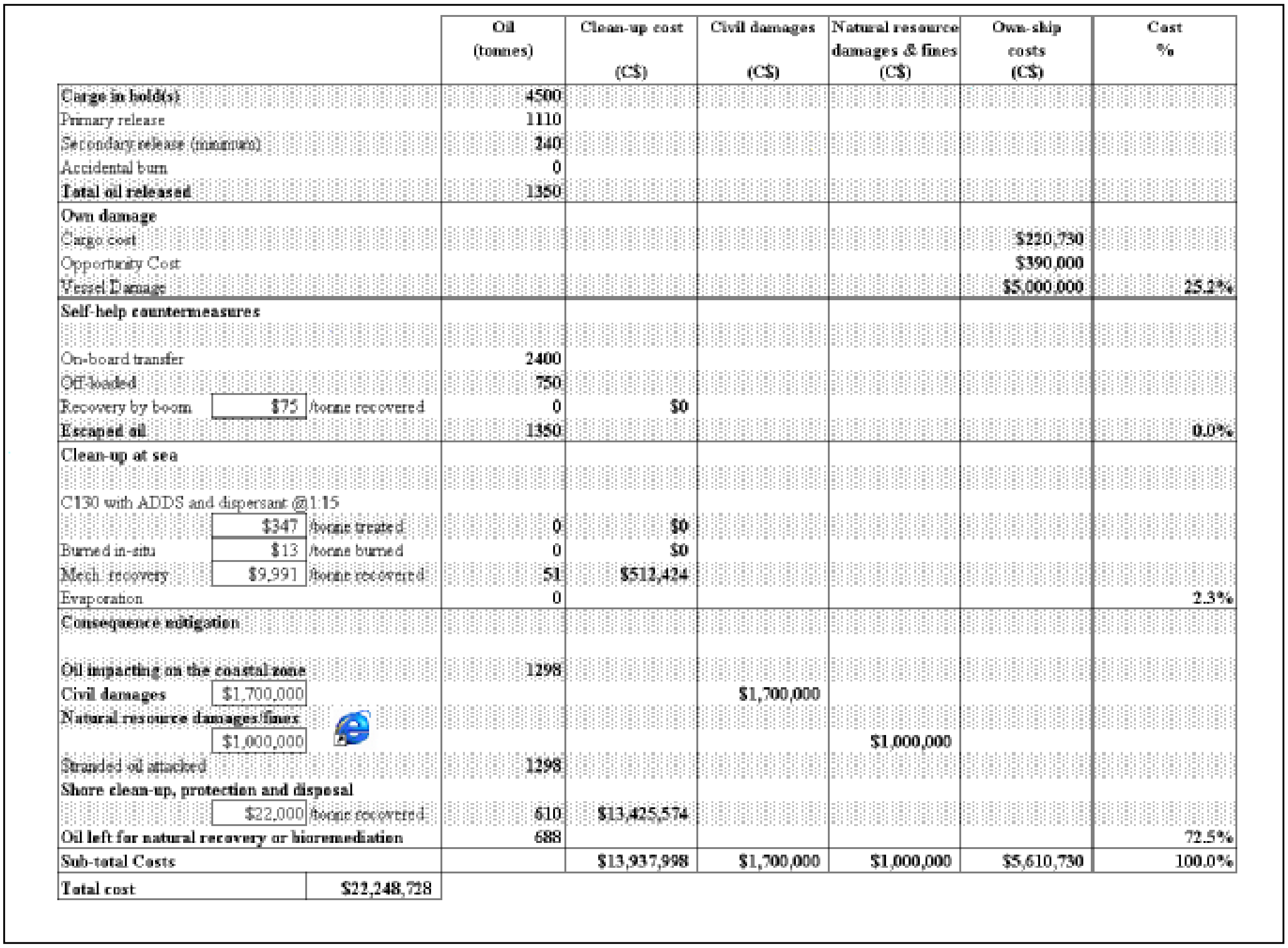
Countermeasures

100	On-board transfer capability in tonnes/hr
10000	Capability of Off-loading tanker (estimate of tonnes before adjusting for release or transfer on board)
24	Off-loading barge/tanker/vessel ETA in hours
6	Boom and skimmer deployed within___hours?
70	Percentage of cargo escaped from boom (Default = 10% if currents < 1 knot and 50% if >= 1 knot)
2	Dispersant approval (affirmative = 1; negative = 2; Default = 1 if Distance is far and Waveheight < 1.1 metre)
2	In-situ burning approval (affirmative = 1; negative = 2; Default = 1 if Ice concentration >5.9 tenths)
	Effectivess of in-situ burning in >5.9 tenths ice or in fireboom (Default = 80%)
	Days of effective burning (Default = 3 days)
	Burn rate per hour (Default = 100 tonnes per hour)
	Effectiveness of recovery of oil at sea (Default = 3.8%)
	Percentage of stranded oil attacked (Default = 100% if nearshore; nil if far from shore)
	Effectiveness of recovery ashore (Default = 47%)

Costs

26	Cargo cost per barrel CAN$
6500	Vessel opportunity cost per day CAN$ (profit loss)
60	Days out of service
5000000	Vessel damage cost
	Cost per tonne recovered by self-help booming (Default = $75)
	Cost per tonne recovered by off-loading (unknown)
	Cost per tonne treated by dispersant from C130 (Default = $347 @ 1:15)
	Cost per tonne burned in-situ (Default = $13)
	Cost per tonne recovered by mechanical recovery at sea (Default = $9,991)
	Cost per tonne recovered ashore (Default sensitivity: high = $22,000; medium = $6,000; low = $1000)
	Civil damages (Default sensitivity: high = $1.7 million; medium = $1 million; low = $5600)
	Natural resource damages & fines (Default sensitivity: high = $1 million; medium = $100,000; low = $10,000)

Figure 14. Spill Cost Model Parameters



			Oil (tonnes)	Clean-up cost (C$)	Civil damages (C$)	Natural resource damages & fines (C$)	Own-ship costs (C$)	Cost %
Cargo in hold(s)			4500					
Primary release			1110					
Secondary release (minimum)			240					
Accidental burn			0					
Total oil released			1350					
Own damage								
Cargo cost							$220,730	
Opportunity Cost							$390,000	
Vessel Damage							$5,000,000	25.2%
Self-help countermeasures								
On-board transfer			2400					
Off-loaded			750					
Recovery by boom	$75	/tonne recovered	0	$0				
Escaped oil			1350					0.0%
Clean-up at sea								
C130 with ADDS and dispersant @1:15								
	$347	/tonne treated	0	$0				
Burned in-situ	$13	/tonne burned	0	$0				
Mech. recovery	$9,991	/tonne recovered	51	$512,424				
Evaporation			0					2.3%
Consequence mitigation								
Oil impacting on the coastal zone			1298					
Civil damages	$1,700,000				$1,700,000			
Natural resource damages/fines								
	$1,000,000					$1,000,000		
Stranded oil attached			1298					
Shore clean-up, protection and disposal								
	$22,000	/tonne recovered	610	$13,425,574				
Oil left for natural recovery or bioremediation			688					72.5%
Sub-total Costs				$13,937,998	$1,700,000	$1,000,000	$5,610,730	100.0%
Total cost	$22,248,728							

Figure 15. Spill Cost Model Output

Municipal and industrial water intake clean–up costs

Municipal water intake clean-up costs were estimated at $50 000 per system. Industrial water intake clean-up costs were given a much less certain estimate of five times the municipal costs, or $250 000. The Municipality of Becancour was consulted to provide the following assumptions and breakdown of costs to clean up an oil-fouled municipal water intake:

Assumptions:

- Insufficient advance warning to shut down system prior to bunker C trajectory arrival,
- On-site staff (24 hr) gets a visual on oiling of the internal basin, proceeds with shut down, and
- Quick response requirement: outside contractors at x2 cost factor.

Municipal clean-up cost:

- Water intake $2 000,
- Basin $5 000,
- Conduits $2 000,
- Pumps x4 $20 000,
- Decanters, flash mix, etc. $20 000, and
- Total cost is $50 000.

Industrial clean-up cost:

- Industrial water intake clean-up should be about five times the municipal clean-up costing given that the volume of water handled is 12 times that of the municipal facility – this also takes into account the lower complexity of the water treatment system for industrial use.

The study zone did not extend downstream to include the Becancour industrial intake, but it did include the Kruger industrial intake. Therefore, a $250 000 cost was applied to clean up the water intakes for this facility.

Small marina business loss and vessel clean–up costs

A small marina with bar/restaurant would probably suffer a $20 000 loss per week. The vessel owners would also incur clean-up costs for their yachts this – could reach $14 000 assuming a small marina has an average of 20 yachts in the water. A boat hauling company (9) was consulted who provided cost information. Yacht clean-up costs were estimated at $700 per vessel using an average boat length of 9.5 m. This includes: boat lifting, round trip hauling of 300 km, clean-up and disposal of oily wastes.

In summary, infrastructure clean-up and civil damage costs would be at least $342 000. This includes: three marinas, a municipal water intake and an industrial water intake. Business loss for the three marinas would total about $60 000 for one week. Other losses such as tourism revenue and recreation impacts have not been valuated and would likely increase the $342 000 to the highest category of civil damages cost of $1 700 000 estimated for an area of high sensitivity in the spill cost model. Clean-up of the river and the shoreline environment would exceed $8 million; fines for environmental damage could reach the maximum $1 million; vessel damage, cargo and business loss could exceed $5 million. This brings the cost of a single 1 350 m^3 oil spill to $22.2 million.

8.2 Gasoline Fire/Explosion Modelling

This scenario assumes a product tanker carrying gasoline collides with another vessel near the port of Trois Rivières while on course Pointe-des-Ormes. This sets up a 1 350 m^3 release event which was modelled using the PHAST consequence modelling package.

When considering the potential hazard for fire or explosion in tankers, the initiation mechanism is important. When petroleum is ignited, the gas emanating from the liquid burns as a visible flame. A specific proportion of air mixing must take place for burning to occur. The limiting proportions, expressed as a percentage by volume of petroleum gas in air are known as the *upper and lower flammability limits* (UFL, LFL). The gas mixtures encountered in normal tanker practice can range from 1 percent gas by volume in air (LFL) to 10 percent gas by volume in air (UFL). To control the risk of fire/explosion on a tanker, ignition sources and flammable atmospheres must not be present at the same place and time.

Gasoline is transported as a liquid in product tankers and is classified as a flammable liquid with an LFL of 1.4 percent and a UFL of 7.6 percent at 20ºC. It is moderately toxic by inhalation, ingestion and contact.

8.2.1 Scenario modelling

Three wind speeds were selected from Environment Canada records for the analysis. These included: wind speeds of 1.5 m/s with Pasquill atmospheric stability *F*, 5.6 m/s with stability *A* and 7.2m/s also with stability *A*. Stability *A* is very unstable while *F* is a very stable atmosphere.

Given the nature of the assumed collision, a catastrophic rupture would lead to an instantaneous release as the worst plausible event. A release on fresh water would result. The chemical properties of the gasoline product were specified in the mixture database including temperatures and pressures of interest.

The model initially computes discharging of the liquid cargo and the results are displayed for the possible outcomes for the mixture under study. For gasoline, three main outcomes are possible: a pool fire, a flash fire and an explosion. Each scenario produced an impact zone that would include industrial facilities and port infrastructure within the port of Trois Rivières.

8.2.2 Fire/explosion results

Flash Fire Flame Envelope

The worst plausible case arises from the *F* stability, 1.5 m/s case. Flash fires are lethal to all inside the flame envelope. At the LFL specified for gasoline, the radius of the envelope is approximately 500 m and at 0.5 LFL it extends beyond 600 m, as depicted in Figure 16. The impact zone would include industrial facilities and port infrastructure within the port of Trois Rivières.

Radiation Radii for Pool Fire

Three heat radiation levels are specified:

- 4 kW/sq m: 20 seconds of exposure will reach the pain threshold and second degree burns (skin blistering) are likely,
- 12.5 kW/sq m: 4 seconds to pain threshold, and
- 37.5 kW/sq m: causing equipment damage and is lethal.

The results are not particularly sensitive to weather conditions as wind only affects tilt angle of the radiation zone above the pool fire.

Figure 17 shows the 37.5 kW zone extending to approximately 200 m and the 4 kW zone to 350 m. The 200 m zone would barely extend to the shoreline in this case. The impact zone would also include industrial facilities and port infrastructure within the port of Trois Rivières.

Late Ignition Explosion Overpressure

The 1.5 m/s F stability case is again the worst plausible situation of the three weather cases. Figure 18 depicts locations for the most severe late ignition explosion overpressures (shock waves). At .21 bars, steel frame buildings can be distorted and severed from their foundations. An ignition source must be present for the vapour cloud explosion to occur. The impact zone would include industrial facilities as well as port infrastructure.

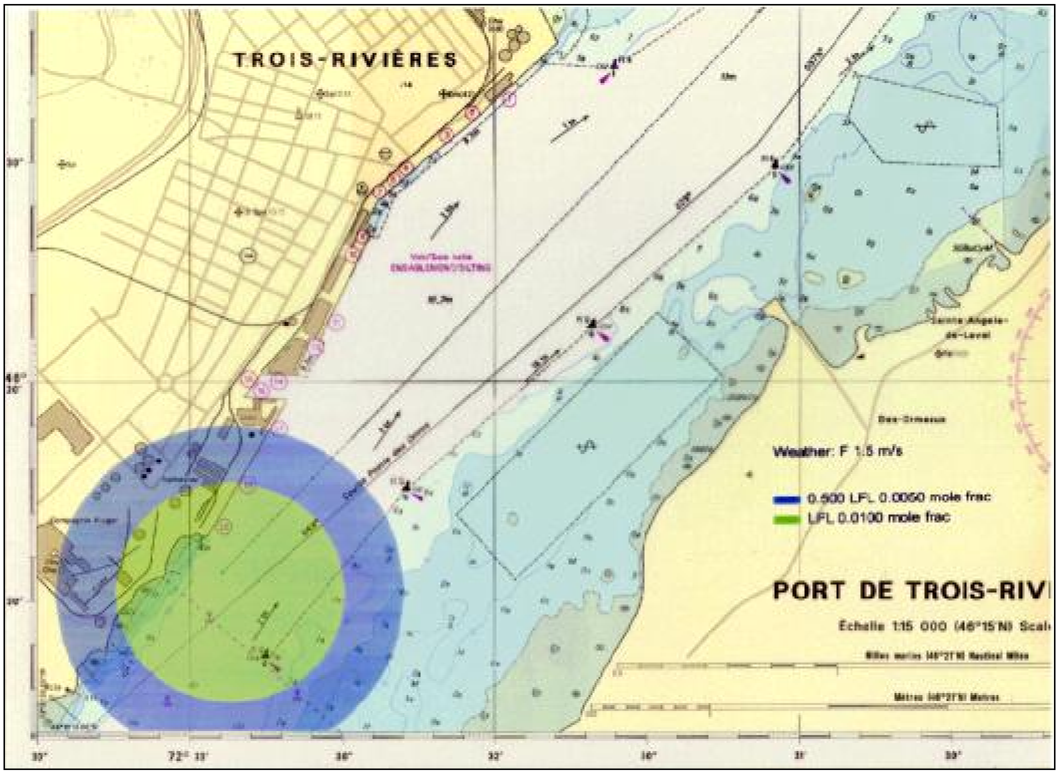


Figure 16. Flash Fire Flame Envelope

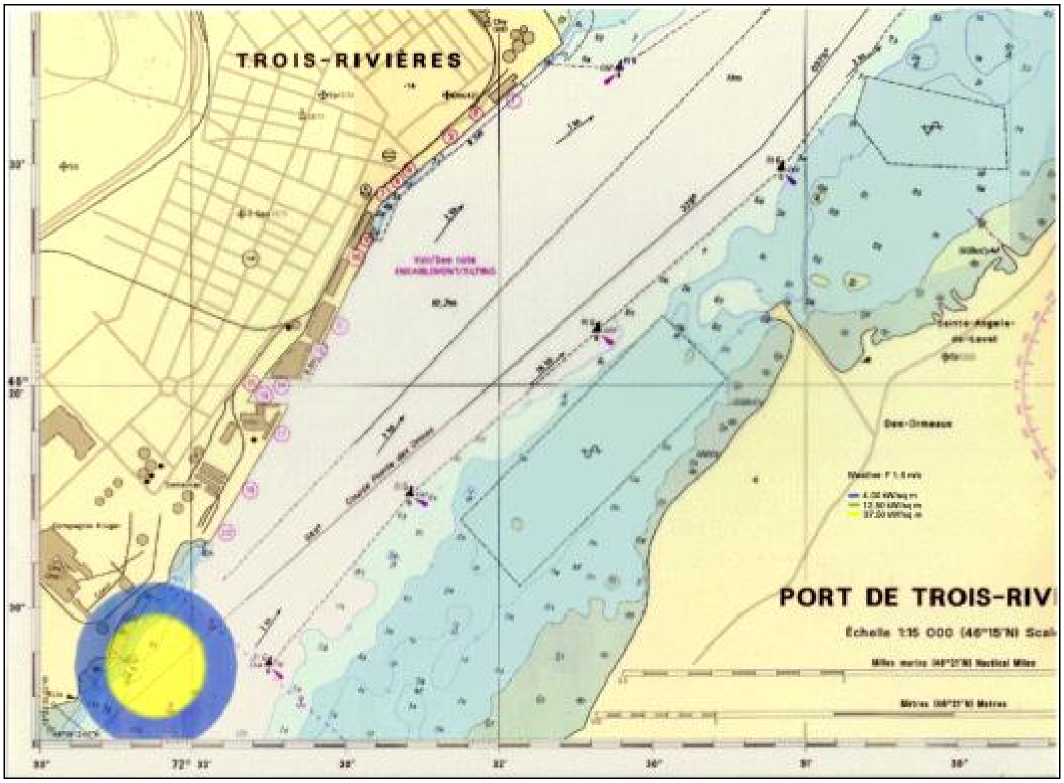


Figure 17. Radiation Radii for Pool Fire

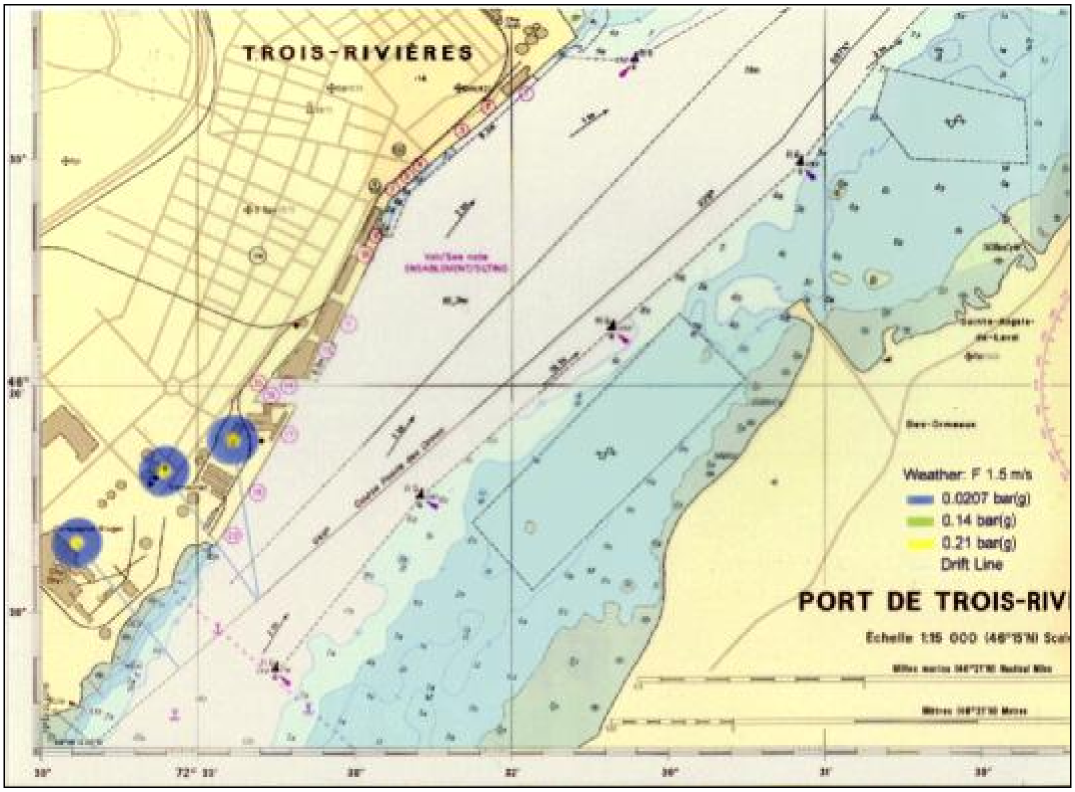


Figure 18. Late Ignition Explosion Overpressure

9 Conclusions and Recommendations

9.1 MSD Tool

Comparisons of the MSD and CW data to accident data indicated the expected relationship between CW/MSD and accident rates for the areas studied. Validation of the MSD method using accident data was limited by the available data. As it is unlikely that sufficient accident data will ever be available, it will be necessary to continue to incorporate expert opinion into the MSD method. Improvements are possible through the use of MSD and assessment of results.

The MSD method and results reflect existing practice. This, along with the positive reception from stakeholders (including government and industry), suggests that the MSD method provides a systematic and logical method for assessing safety requirements and the level of risk on the river.

Future inclusion of other accident causes in the MSD tool is possible if supported by evidence. As well, the design enables consideration of other navigation safety measures such as differential global positioning system (DGPS), electronic chart display and information system (ECDIS) and MCTS.

9.2 Risk Analysis

The risk analysis draws together the accident, traffic and consequence analysis work of sections 7 and 8. The accident analysis covered a wide area of the St. Lawrence River and provided a broader range of vessel and accident details than originally anticipated in the scope. The consequence analysis focused on two collision scenarios in the Trois Rivières area: one involving a gasoline tanker and the other a fuel oil tanker.

The frequency of a collision involving through traffic in the Pointe-des-Ormes area was indicated to be 8 in 22.5 years or 0.36 per year (see Appendix A, Table 10). There is a 15 percent chance that the vessel is an oil or oil product tanker (40/259, see Table 4).

The consequence magnitude for the oil spill scenario in Lac St. Pierre was measured as a probability of a spill of 1 350 m^3 given a collision. This probability is 0.013 (see Table 8). Therefore, the annual probability of a spill was measured as the annual probability of a collision involving a tanker (.054) times the conditional probability of the spill (0.013). Given these estimates, one would expect a medium-sized oil spill once every 1 428 years or 0.0007 per year (note: this estimate is just for the area of Pointe-des-Ormes).

Table 8. Oil Spill Probability

Consequence Magnitude	Grounding	Collision	Striking
p(spill > 10 K t given a casualty)	0.0006	0.0003	0.0001
Average spill size	10000	10000	10000
p(spill > 136 & <10K t given a casualty)	0.029	0.013	0.007
Average spill size	900	900	900
p(spill < 136 t given a casualty)	0.065	0.019	0.040
Average spill size	15	15	15

Source: Marine Navigation Safety System (10)

There are many ways of bringing the spill costs into perspective. A cost-benefit analysis was not required, but a valuation of the tanker collision risk was provided to indicate the costs of one of many possible risk scenarios. If the oil spill cost is $22.2 million, the annual cost in Pointe-des-Ormes is $15 580, however, vessel damages due to a collisions would be incurred once every three years and these could reach as high as $5.6 million per incident or $2 million per year.

The MSD tool was used to make numerous comparisons between the affect of vessel type, navigation conditions and aids to navigation configurations on safety in the St. Lawrence River in the Laurentian Region. A change in the level of service of aids to navigation proposed by AASL will have an effect on the safety in the river and the potential consequence costs. These changes in safety are documented in Appendix B. For example, a summer, low visibility scenario involving two container vessels in Course Pointe du Lac showed an increased risk of 28 percent. In this section, the channel width required for safe navigation (MSD) was less than the actual channel width (see Table 3).

9.3 Recommendations

- The MSD tool will be released to workshop members for further review. A log should be kept of any changes so that the positioning relationships can be modified to reflect expert opinion.

- In light of the MSD analysis results for the three study areas, which showed a change in risk depending on the LOS of aids to navigation, any changes to current provision of aids to navigation or pilotage services should consider an MSD analysis for the waterway in question.

- The development team should work with CCG to investigate the effect of electronic aids to navigation, such as DGPS with ECDIS, on the positioning quality component in the MSD tool.

- The MSD tool and MNSS should be used to estimate potential consequence costs for a section of river and these estimates should be compared to various level of service provision costs.

- CCG should continue to develop and incorporate additional expert judgment into the model by applying the MSD method to additional segments of the river. Validation of the MSD method using accident data was limited by the available data. It is unlikely that sufficient accident data will ever be available and it will be necessary to continue to incorporate expert opinion into the MSD method to refine the precision of MSD estimates and broaden its applicability to different waterways.

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