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

Prepared by

B. Judson
GeoInfo Solutions Ltd.

J. Shortreed
Institute for Risk Research, University of Waterloo

J.D. Reid
Transportation Development Centre, Transport Canada

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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.

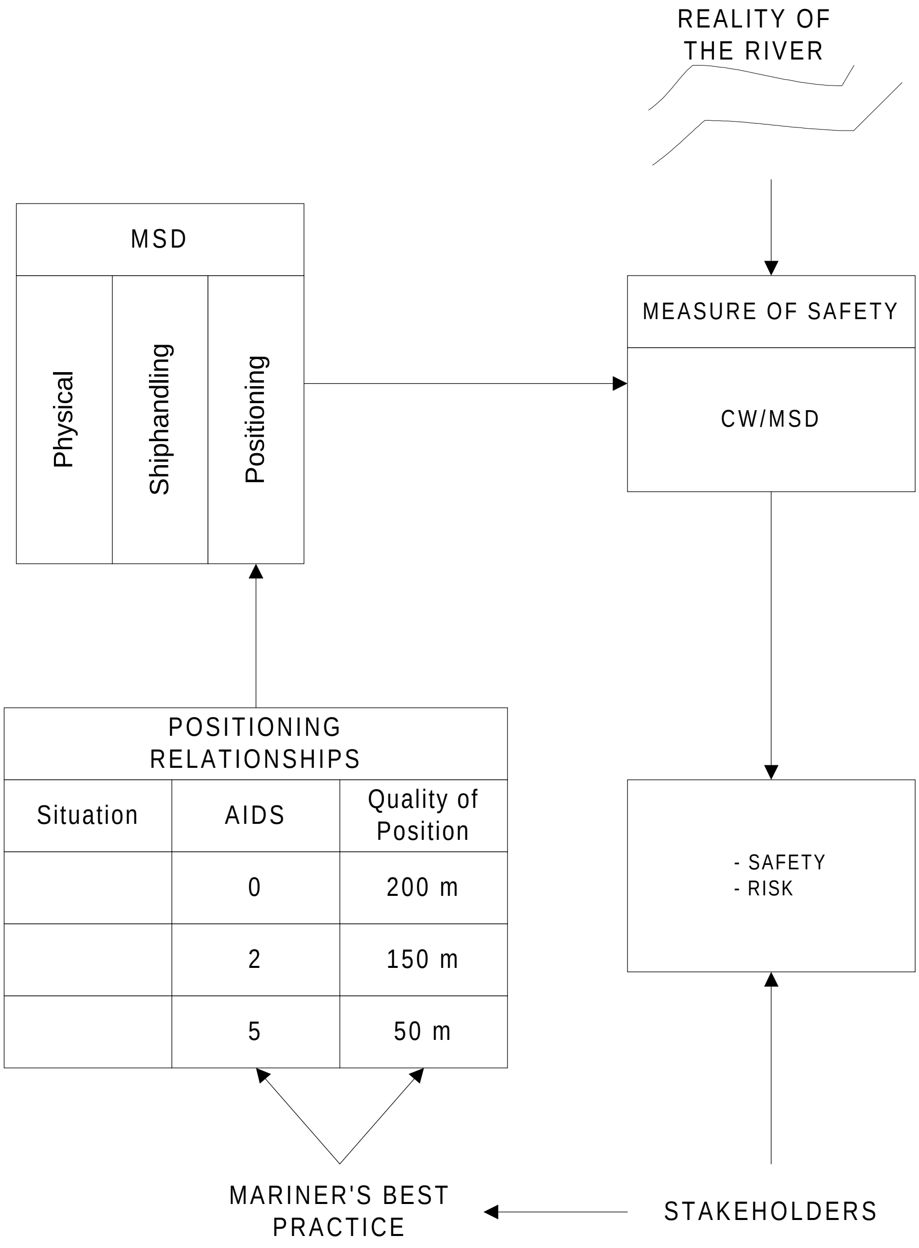
The MSD is width of the channel required for safe navigation by a design vessel for the given conditions in the river section and time period. The MSD CW is composed of three basic widths that are independent of each other and added together. The three distance elements are:

- 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.



POSITIONING RELATIONSHIPS

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

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).

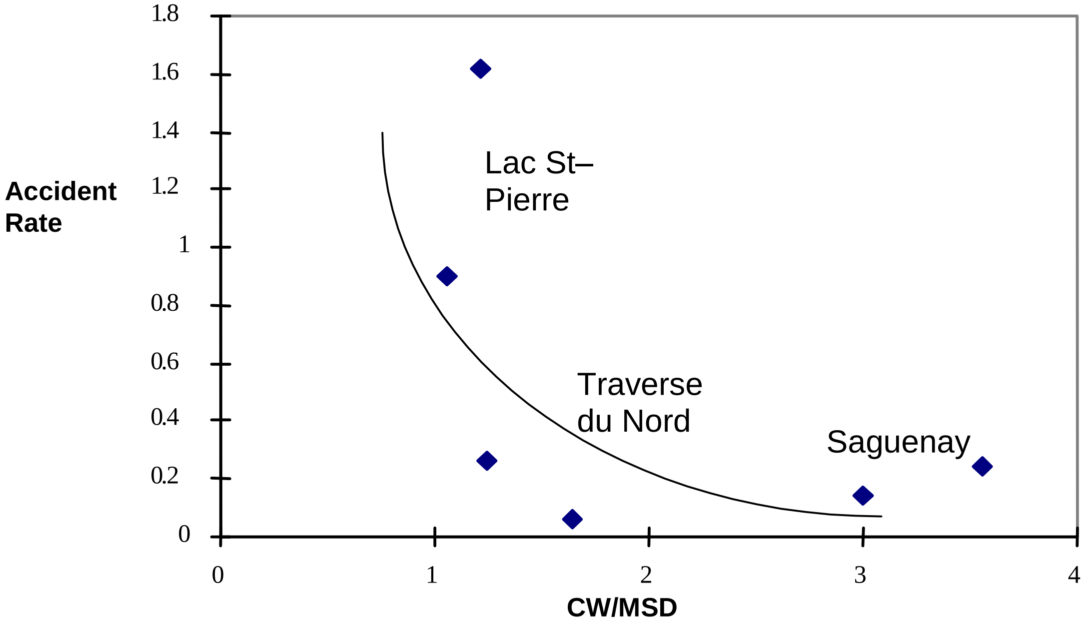


Figure 2. CIP Accident Rate versus CIP median CW/MSD ratio

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 rat es.

Table 2. 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.

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).

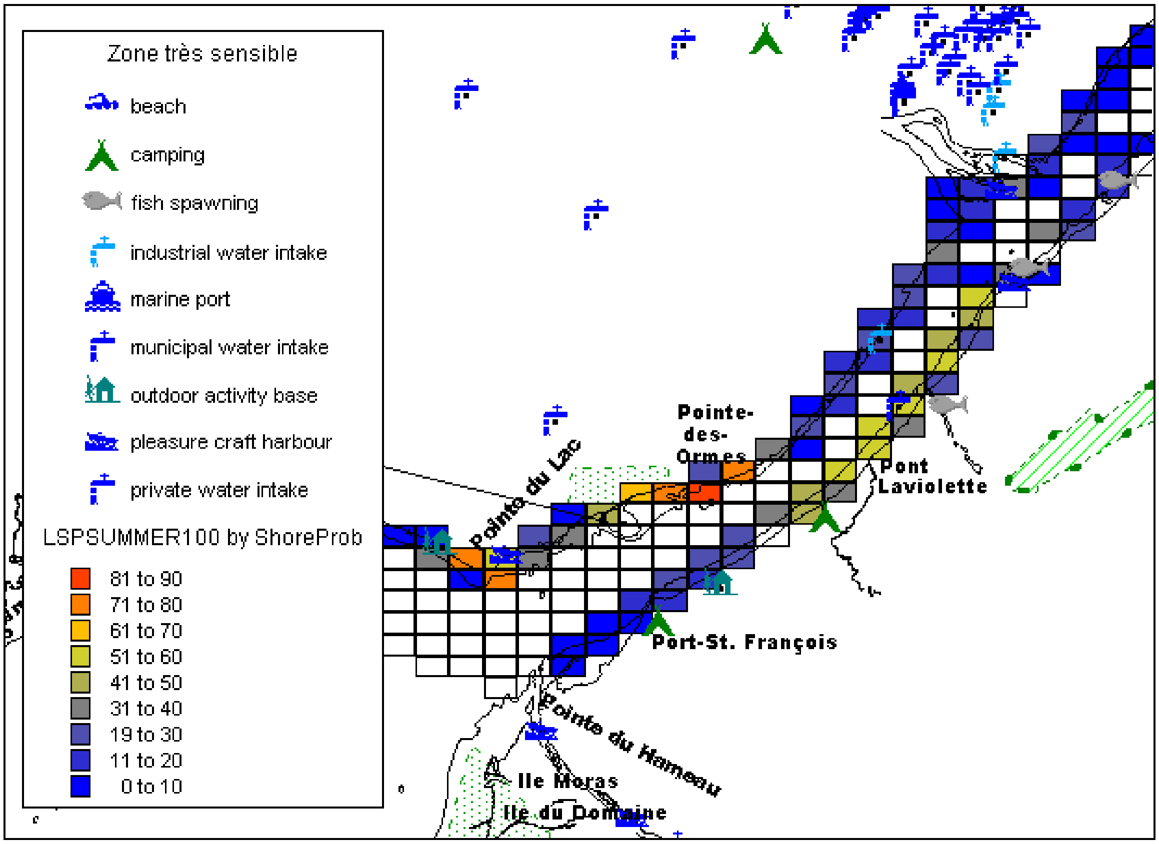


Figure 3. Shoreline Impacts – September Winds

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 PHAST consequence modelling application 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.

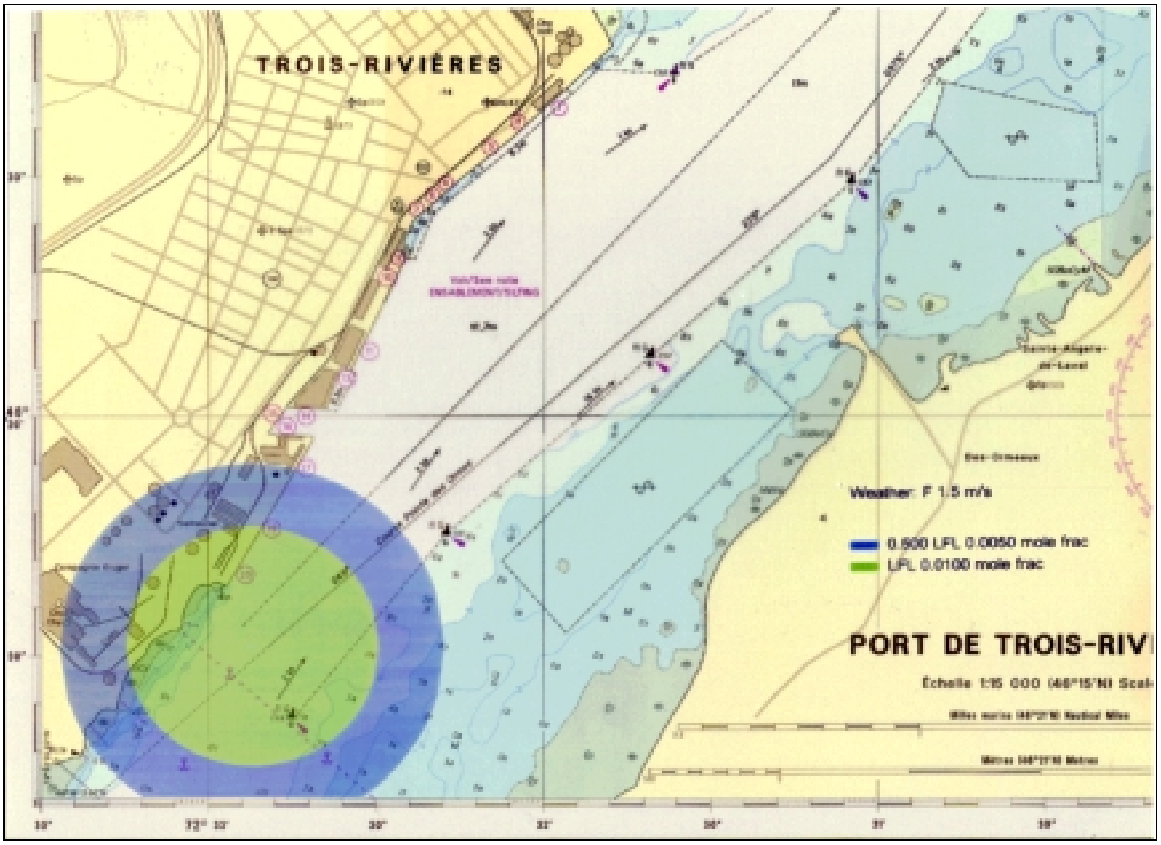


Figure 4. Flash Fire Flame Envelope

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.