FINAL STUDY REPORT
PREPARED FOR
TRANSPORT CANADA

Risk Assessment for Marine Spills in Canadian Waters

Phase 1: Oil Spills South of 60th Parallel

CLIENT: RFP N#T8080-120080
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January 2014

WSP
SL ROSS

Risk Assessment for Marine Spills in Canadian Waters
Phase 1, Oil Spills South of the 60th Parallel

Final Version

Presented to

Transport Canada

from

WSP Canada Inc.

Approved by : ________________________________

Jérôme Marty, Ph.D.

JANUARY 2014

131-17593-00

As part of its global expansion,
GENIVAR Inc. intends to change its name to WSP Canada Inc.
on January 1, 2014.
This change has no impact on the content of this report.

EXECUTIVE SUMMARY

This study estimates the risk of pollution from marine oil spills in Canadian waters south of the 60^{th} parallel. The need to conduct this risk assessment was identified by Transport Canada, following the 2010 recommendations of the Commissioner of the Environment and Sustainable Development (CESD). The Minister of Transport, in naming the Tanker Safety Expert Panel, also requested that the risk assessment be used to inform its review of Canada's preparedness and response arrangements for ship-source spills. The objective of this pan-Canadian study is to provide an overall risk estimate, using a formal process that could be applied and further refined in future assessments.

The approach developed in the study involved the following key elements:

- The Canadian coast was divided into four sectors (Pacific, Atlantic, Estuary/Gulf of St. Lawrence, and the Great Lakes/St. Lawrence Seaway System). Each sector was further divided into sub-sectors that were further divided into three zones representative of nearshore, intermediate and deep-sea environments. A total of 77 zones were allocated a frequency of spill and an environmental sensitivity, which were then applied to generate a risk estimate.
- Mean annual Canadian traffic data from vessels larger than 150 t was estimated using Lloyd's worldwide 2011 to 2012 traffic data.
- Mean annual Canadian oil volumes were estimated using Lloyd's APEX data (2002 to 2012) as well as Transport Canada's commodity movement data, considering two classifications of oil: crude oil and refined products.
- Oil spill frequencies were described for crude, refined cargo, and fuel according to four spill volume categories ranging from 10 m^3 to ≥ 10,000 m^3. Spill frequencies were calculated using Lloyd's worldwide casualty data (2003 to 2012) for large size spills and from actual oil spills in Canadian waters using the Canadian Coast Guard (CCG) incident database (MPIRS). The incident records were validated with data from the International Tanker Owners Pollution Federation (ITOPF) and other sources.
- The probability of an oil spill at sea impacting the shoreline were estimated by transport models that include variables of oil type, spill size and weather conditions.
- The Environmental Sensitivity Index (ESI) was based on environmental geographic layers describing the physical, biological and human environments in each of the 77 zones. Metrics entered in ESI calculations were derived from Geographic Information System (GIS) procedures.

- Shoreline types, wetlands and ice data were used to calculate the Physical Sensitivity Indicator (PSI). Several datasets (coastal zone delineation, ecologically and biologically significant areas (EBSAs); bird distribution) were combined to produce the Biological Resource Indicator (BRI). Similarly, social and economical data (commercial fisheries, tourism employment, freight tonnage and intensity of freshwater use) were compiled to calculate the Human-Use Resource Index (HRI). All data collected to produce the Environmental Risk Index (ERI) were retrieved from various federal departments of the Government of Canada.
- The spill frequencies, the ESI and the risk estimates were determined using spreadsheet calculations and displayed in a GIS layout.

The chosen methodology is appropriate for a large scale risk assessment and provides a Canadian-wide estimate of risk. This method limits the level of details for which oil spill risks can be described.

This report presents current oil spill risk results based on the most recent 10 years of vessel traffic and oil volumes combined with current environmental information. Appendix 4 describes the potential effects of future projects in terms of traffic, oil volumes and associated risks.

This report describes the data that have been collected and explains the methodology that has been applied to calculate risk estimates. This report also identifies the data limitations and the assumptions made in the calculations. These elements are incorporated into recommendations on how to use the risk results to develop oil spill response and on how to improve the method and refine risk estimates in the future.

The following key findings summarize the results of this analysis:

- The probability of spills varies greatly across the country. The largest marine traffic volumes are observed in the Pacific sector where the probability of small size fuel spills is the highest. The zones with the highest probability of a large spill occurring were the waters around the southern tip of Vancouver Island, the Cabot Strait including southern Newfoundland, the eastern coast of Cape Breton Island and the Gulf of St. Lawrence and the St. Lawrence River.
- These spills have the potential to cause significant damage should they occur in a sensitive area. Environmental Sensitivity Index (ESI) results indicate that the zones of highest potential impact were located in the Estuary and the Gulf of St. Lawrence as well as in the southern coast of British Columbia, including Vancouver Island. Overall, a higher ESI score was observed in nearshore zones compared with intermediate and deep-sea zones.

- The combination of the probability and environmental sensitivity calculations produced the Environmental Risk Index (ERI). Risk values vary greatly across the country. Overall the highest values were observed for small spills, due to their relatively higher frequency of occurrence. The risk of large spills is generally low in Canada. The risk generally increases in nearshore zones compared with deep-sea zones with the exception of the Pacific sector where US traffic may increase deep-sea probabilities. This increase in risk in nearshore zones is related to an increase in environmental sensitivity.
- The results indicated that the Estuary and Gulf of St. Lawrence, the St. Lawrence River, the southern coast of British Columbia as well as sub-sectors 4, 5 and 6 in the Atlantic sector are the areas at the greatest risk from large oil spills (Maps 1 to 3). For the rest of the country, the risk posed by spills over 10,000 m^3 was much lower. The study also identified that there is a higher risk of small and medium spills in every sector of the country, especially those in the 100 to 999 m^3 range. These smaller spills can also cause significant damage and are likely to happen much more frequently than the larger spills.

These results demonstrate the need for Canada to tailor its preparedness efforts for each sector of the country, as the risks across the country are demonstrably different.


Risk Assessment for Marine Spills in Canadian Waters
Phase 1: Oil Spills South of 60th Parallel
Overall ERI for Crude Oil Spills South of the 60th Parallel
0 150 300 600 km
January 2014
File: 131_17593_c1_Canadian_Cargo_Crude_10_99_131223.mxd
WSP
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Map 1
Kalaallit Nunaat (Greenland)
USA (Alaska)
Beaufort Sea
Baffin Bay
Iqaluit
Whitehorse
Yellowknife
Pacific Ocean
Labrador Sea
Hudson Bay
St. John's
Edmonton
Vancouver
Victoria
Regina
Winnipeg
Quebec
Fredericton
Halifax
Ottawa
Toronto
USA
Atlantic Ocean
ERI Relative Scale
Very Low
Low
Medium
High
Very High
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM


Risk Assessment for Marine Spills in Canadian Waters
Phase 1: Oil Spills South of 60th Parallel
ERI for Refined Products Spills (100 to 999.9 m³ spill volume) South of the 60th Parallel
0 150 300 600 km
January 2014
File: 131_17593_c2_Canadian_Refined_Oil_100_999_131223.mxd
WSP
SL ROSS
Map 2
USA (Alaska)
Kalaallit Nunaat (Greenland)
Beaufort Sea
Baffin Bay
Iqaluit
Whitehorse
Yellowknife
Pacific Ocean
Labrador Sea
Hudson Bay
St. John's
Edmonton
Vancouver
Victoria
Regina
Winnipeg
Quebec
Fredericton
Halifax
Ottawa
Toronto
USA
Atlantic Ocean
ERI Relative Scale
Very Low
Low
Medium
High
Very High
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM


Risk Assessment for Marine Spills in Canadian Waters
Phase 1: Oil Spills South of 60th Parallel
Overall ERI for Fuel Oil Spills South of the 60th Parallel
0 150 300 600 km
January 2014
File: 131_17593_c3_Canadian_Fuel_Oil_10_99_131223.mxd
WSP
SL ROSS
Map 3
Kalaallit Nunaat (Greenland)
Beaufort Sea
Baffin Bay
USA (Alaska)
Iqaluit
Whitehorse
Yellowknife
Pacific Ocean
Labrador Sea
Hudson Bay
St. John's
Edmonton
Vancouver
Victoria
Regina
Winnipeg
Quebec
Fredericton
Halifax
Ottawa
Toronto
USA
Atlantic Ocean
ERI Relative Scale
Very Low
Low
Medium
High
Very High
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM

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WSP Canada Inc.

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Reference to be cited:

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LIST OF APPENDICES

LIST OF ABBREVIATIONS

AANDC	Aboriginal Affairs and Northern Development Canada
AOC	Area of Concern
BRI	Biological Resource Indicator
CCG	Canadian Coast Guard
CESD	Commissioner of the Environment and Sustainable Development
CFI	Commercial Fishing Intensity
cP	Centipoise
CWF	Canadian Wildlife Service
DFO	Fisheries and Oceans Canada
EBSA	Ecologically and Biologically Significant Area
EC	Environment Canada
EEZ	Exclusive Economic Zone
EGSL	Estuary and Gulf of St. Lawrence
ERI	Environmental Risk Index
ESI	Environmental Sensitivity Index
FTI	Freight Tonnage Index
GIS	Geographic Information System
GT	Gross Ton
HNS	Hazardous and Noxious Substance
HRI	Human-Use Resource Index
IBA	Important Bird Area
IJC	International Joint Commission

LIST OF ABBREVIATIONS (cont.)

IMO	International Maritime Organization
IOPCF	International Oil Pollution Compensation Fund
ITOPF	International Tanker Owners Pollution Federation
MARPOL	Marine Pollution (International Convention 1973/1978)
MEPC	Marine Environment Protection Committee
MPIRS	Marine Pollution Incident Reporting System
NAO	North Atlantic Oscillation
NHS	National Household Survey
NLS	Newfoundland and Labrador Shelf
nm	Nautical Miles
NRCan	Natural Resources Canada
PC	Parks Canada
PSF	Potential Spill Frequency
PSI	Physical Sensitivity Indicator
SA	Surface Area
SEA	Strategic Environmental Assessment
SLROSM	SL Ross Oil Spill Model
TC	Transport Canada
TEI	Tourism Employment Intensity
WUI	Freshwater Use Intensity

1. INTRODUCTION

1.1 Context

In the fall of 2009, the Commissioner of the Environment and Sustainable Development (CESD) conducted an audit titled *Oil Spills from Ships* (Office of the Auditor General of Canada, 2010). The objective of the audit was to determine whether the Canadian Coast Guard (CCG), Transport Canada (TC) and Environment Canada (EC) were prepared to respond adequately to oil spills from ships. The audit, tabled in Parliament in December 2010, constituted Chapter One of the 2010 Fall Report of the CESD (Office of the Auditor General of Canada, 2010).

The CESD's report found that while TC and the CCG have carried out risk assessments related to oil spills from ships, a consistent or systematic approach had not been used in the past, nor had there been any formal processes ensuring that risks were reassessed on an ongoing basis.

As a consequence, the CESD recommended that: "Building on the risk assessment conducted to date, Transport Canada and the Canadian Coast Guard should conduct a risk assessment related to ship-source oil spills covering Canada's three coasts. The risk assessment should be conducted in consultation with Environment Canada and the shipping industry. Transport Canada and the Canadian Coast Guard should put in place processes so that risks are reviewed on an ongoing basis and the risk assessment is updated as required. The Canadian Coast Guard should ensure that the risk assessment considers the three roles that it plays (federal monitoring officer, on-scene commander, and resource agency)."

While the three concerned departments have agreed to implement this recommendation, TC's own research and analysis indicated that future planning for environmental response would benefit from broadening the scope of the CESD-recommended risk assessment to consider:

- The Great Lakes/St. Lawrence Seaway region (i.e., extend study beyond Atlantic, Pacific and Arctic waters);
- Potential ship-source spills of hazardous and noxious substance (HNS) (i.e., extend the study beyond oil spills to include other substances).

1.2 Objectives

The objective of this study is to complete a risk assessment in two phases: Phase 1 for ship-source oil spills south of the 60th parallel, and Phase 2 for ship-source oil spills north of the 60th parallel (Arctic) and for HNS in Canadian waters. This pan-Canadian risk assessment will provide the Government of Canada with information upon which appropriate prevention, preparedness, response, mitigation and recovery measures can be planned.

1.3 Study Area (for Phases 1 and 2 Combined)

The study area includes Canadian waters, as defined by *Canada's Oceans Act*:

- Territorial seas (0 to 12 nm);
- Contiguous zone (12 to 24 nm);
- Exclusive Economic Zone (EEZ; 0 to 200 nm);
- Internal waters: Great Lakes, St. Lawrence and Arctic waters (north of 60th parallel).

1.4 Limitations (for Phase 1 specifically)

To facilitate the reader's understanding, it is important to present the limitations of the study. This will be further discussed in the interpretation and associated recommendations. The following are the limits for the Phase 1 study:

- The study area is narrowed to Canadian waters, as defined by Canada's Oceans Act (excluding Arctic waters), and does not include rivers (other than the St. Lawrence River), tributaries and non-Canadian waters.
- Pollution sources are limited to ships (barges carrying oil as cargo, vessels above 400 GT and oil tankers above 150 GT) and major oil handling facilities. Consequently, offshore and onshore oil and gas development (offshore installations, exploration rigs and pipelines) are outside of the scope of the study.
- Oil will be categorised as crude oil, refined oil and fuel (such as diesel).
- This study is based on data obtained from various federal departments and agencies. In addition, traffic data, casualty data and oil movement data were acquired via Lloyd's and the International Tanker Owners Pollution Federation (ITOPF). Data from provincial, territorial and municipal sources are not considered with the exception of provincial parks and protected areas.

- Weather data (temperature, precipitation, wind, glaze, storms, and surge), iceberg presence and commercial hunting activities (birds and marine mammals) are outside of the scope of the study.
- Provincial laws and regulations on risk management are not considered.
- No responses (either mechanical recovery of oil or alternative response techniques such as dispersants) to spills are considered in this risk assessment. The results from the study assume the absence of a response and will provide a "worst case" scenario for each zone.
- No marine oil spill prevention measures are considered in this report. Appendix 1 included maps depicting the sectors where prevention measures are in place, including regulatory oversight, pilotage, port policies, as well as industry's voluntary practices and procedures.

2. METHODOLOGY

2.1 Scope

The methodology herein is for Phase 1 of the risk assessment: ship-source oil spills south of the 60th parallel.

2.2 General Approach

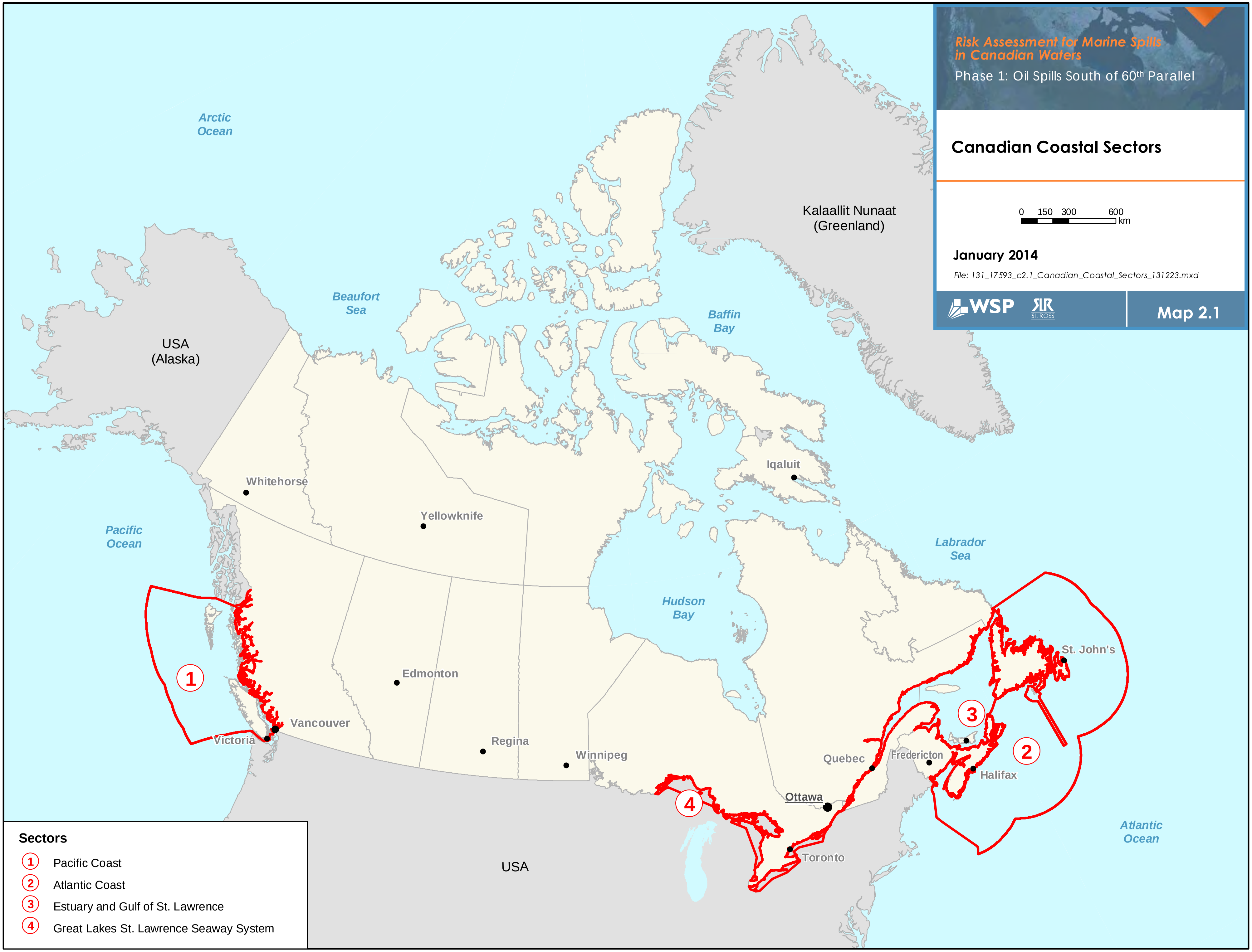
The general approach of the present study involves the following key elements:

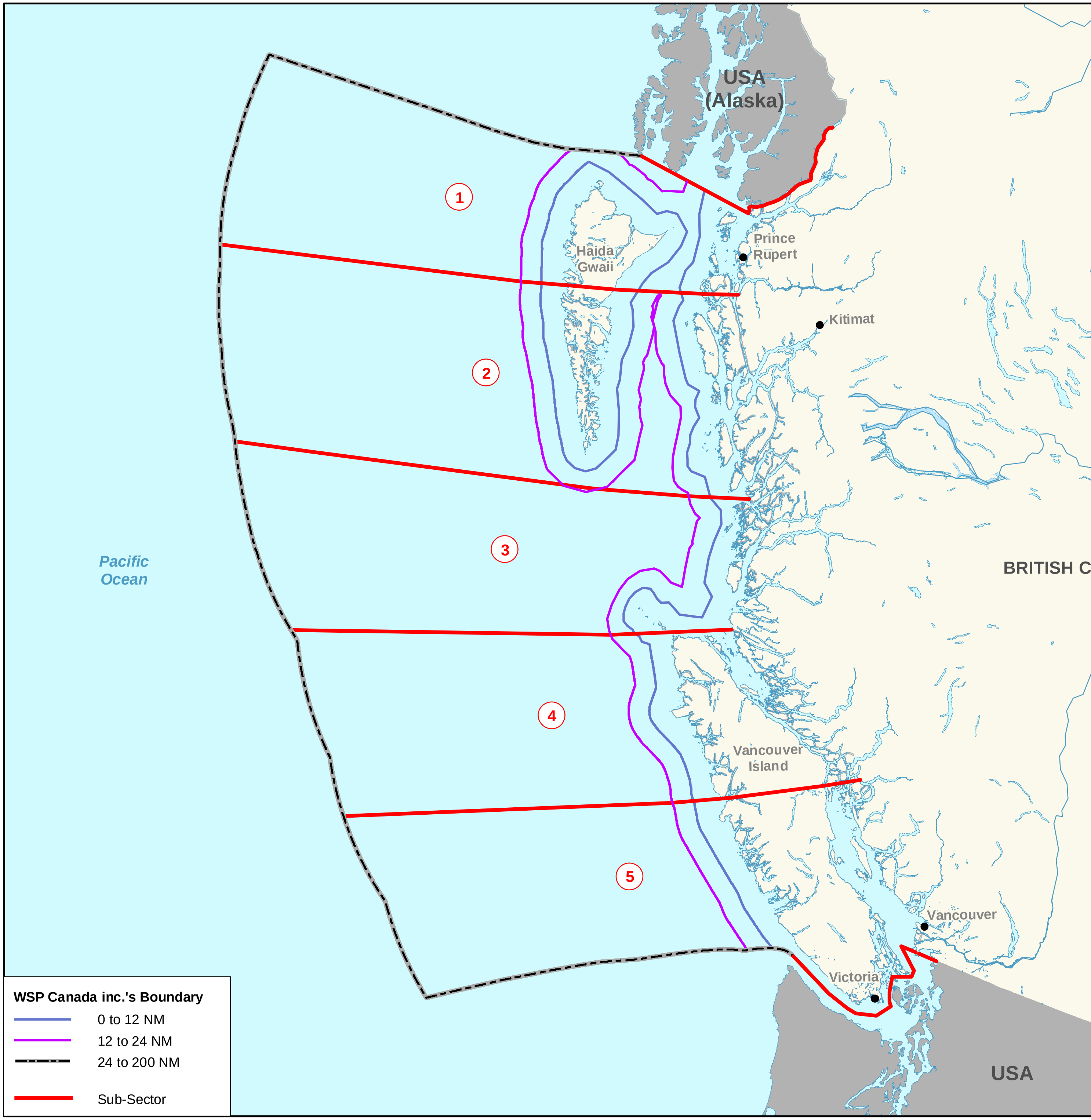
- The Canadian coastal waters are divided into 4 main sectors, which are in turn divided into smaller sub-sectors, for a maximum number of 77 zones;
- Shipping densities as well as vessel types and size distribution in each zone are estimated from international and federal data.
- Oil spill frequencies for ships are obtained from the most recent 10 years of world-wide accident data.
- The behavior of oil spills (surface area over time) is estimated from simple transport and fate models, which depend on the oil type, the spill size and location characteristics.
- The environmental sensitivity index (ESI) is calculated based on physical, biological and human metrics that are further mapped to illustrate their spatial distribution in each zone.
- The overall environmental risk index (ERI) is determined using a spreadsheet calculation, and is mapped to present its spatial distribution, using Geographic Information System (GIS) tools.

2.3 Definition of Canadian Coastal Sectors and Sub-Sectors

Given the large area of Canadian waters south of the 60th parallel, they are divided into four main Canadian coastal sectors (Map 2.1), namely:

- Pacific coast (Sector 1; Map 2.2);
- Atlantic coast (Sector 2; Map 2.3);
- Estuary and Gulf of St. Lawrence (Sector 3; Map 2.4);
- Great Lakes/St. Lawrence Seaway System (Sector 4; Map 2.5).


Risk Assessment for Marine Spills in Canadian Waters
Phase 1: Oil Spills South of 60th Parallel
Canadian Coastal Sectors
0 150 300 600 km
January 2014
File: 131_17593_c2.1_Canadian_Coastal_Sectors_131223.mxd
WSP
SL ROSS
Map 2.1
Arctic Ocean
Beaufort Sea
Baffin Bay
Kalaallit Nunaat (Greenland)
USA (Alaska)
Pacific Ocean
Labrador Sea
Hudson Bay
Atlantic Ocean
USA
Whitehorse
Yellowknife
Iqaluit
Edmonton
Regina
Winnipeg
Vancouver
Victoria
Quebec
Fredericton
Halifax
St. John's
Ottawa
Toronto
1
2
3
4
Sectors
1 Pacific Coast
2 Atlantic Coast
3 Estuary and Gulf of St. Lawrence
4 Great Lakes St. Lawrence Seaway System



Risk Assessment for Marine Spills in Canadian Waters

Phase 1: Oil Spills South of 60th Parallel

Pacific Coast - Sector 1

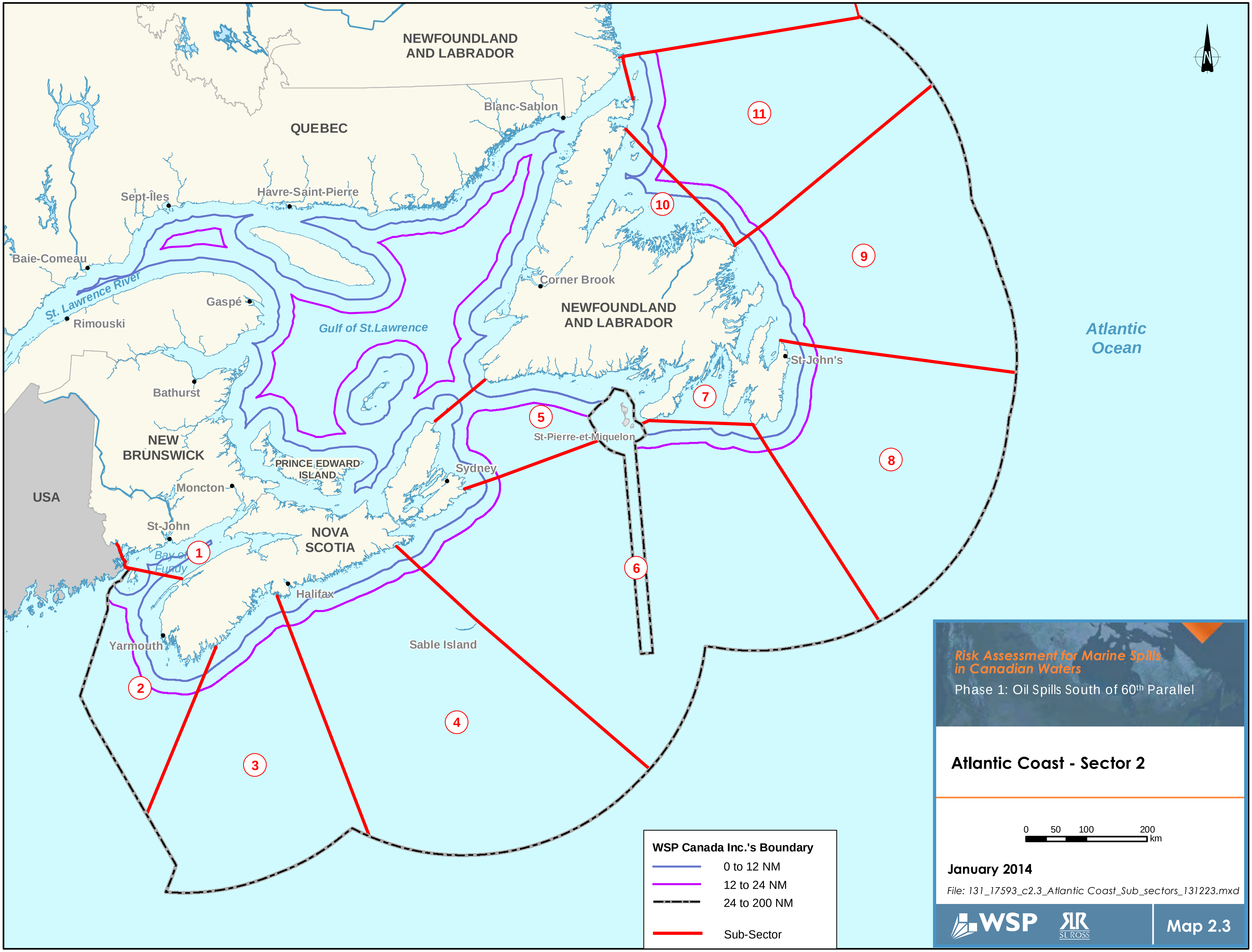
0 30 60 120 km

January 2014

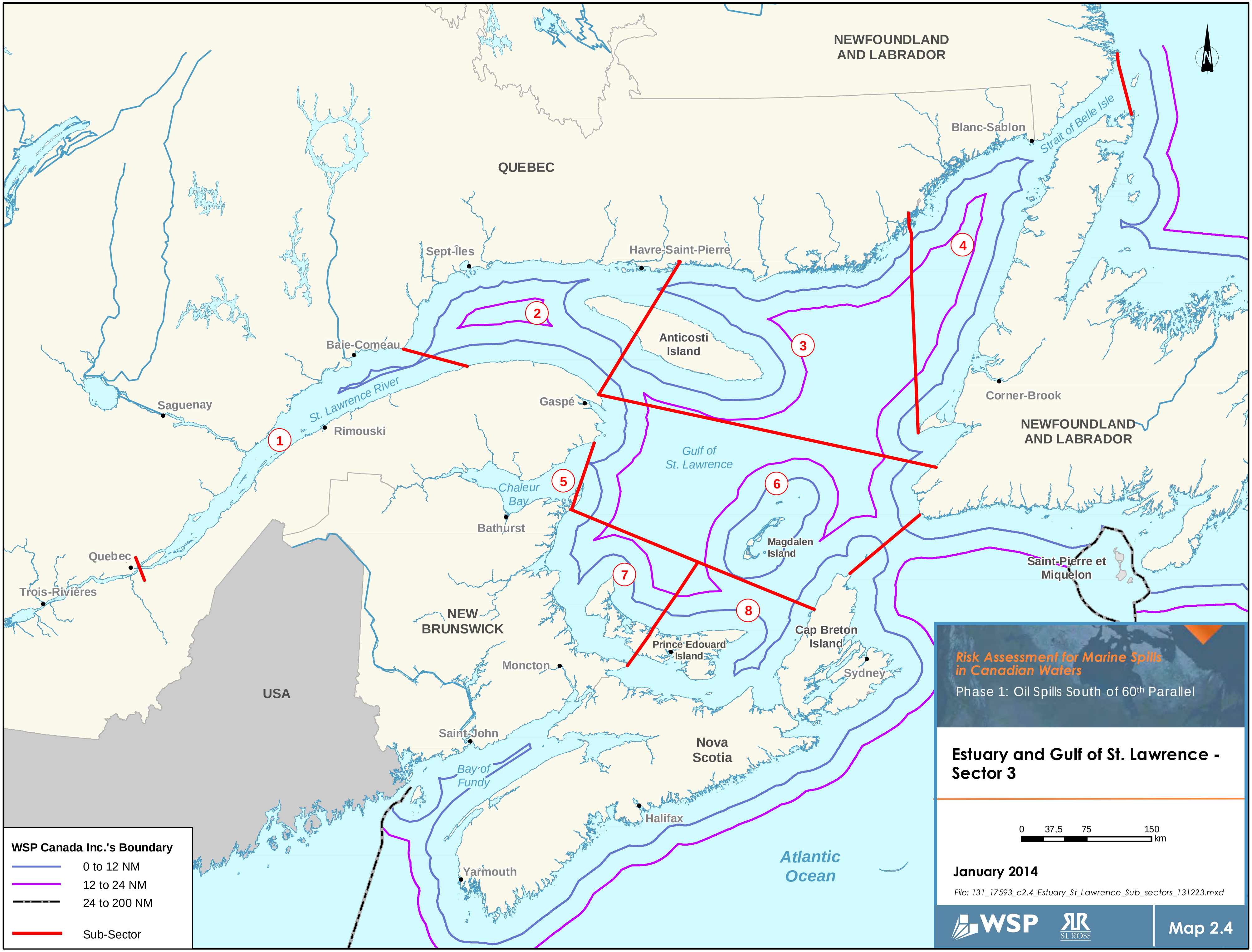
File: 131_17593_c2.2_Pacific Coast_Sub_sectors_131223.mxd

WSP SL ROSS

Map 2.2



NEWFOUNDLAND AND LABRADOR
QUEBEC
Blanc-Sablon
Sept-Îles
Havre-Saint-Pierre
Baie-Comeau
St. Lawrence River
Rimouski
Gaspé
Gulf of St.Lawrence
Corner Brook
NEWFOUNDLAND AND LABRADOR
St-John's
Atlantic Ocean
Bathurst
NEW BRUNSWICK
PRINCE EDWARD ISLAND
USA
Moncton
St-John
Bay of Fundy
NOVA SCOTIA
Sydney
St-Pierre-et-Miquelon
Halifax
Yarmouth
Sable Island
1
2
3
4
5
6
7
8
9
10
11
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM
Sub-Sector
Risk Assessment for Marine Spills in Canadian Waters
Phase 1: Oil Spills South of 60th Parallel
Atlantic Coast - Sector 2
0 50 100 200 km
January 2014
File: 131_17593_c2.3_Atlantic Coast_Sub_sectors_131223.mxd
WSP
SL ROSS
Map 2.3


NEWFOUNDLAND AND LABRADOR
QUEBEC
Blanc-Sablon
Strait of Belle Isle
Sept-Îles
Havre-Saint-Pierre
Anticosti Island
Baie-Comeau
Saguenay
St. Lawrence River
Rimouski
Gaspé
Corner-Brook
NEWFOUNDLAND AND LABRADOR
Gulf of St. Lawrence
Chaleur Bay
Bathurst
Magdalen Island
Saint-Pierre et Miquelon
Quebec
Trois-Rivières
NEW BRUNSWICK
Prince Edouard Island
Cap Breton Island
Moncton
Sydney
USA
Saint-John
Nova Scotia
Bay of Fundy
Halifax
Atlantic Ocean
Yarmouth
1
2
3
4
5
6
7
8
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM
Sub-Sector
Risk Assessment for Marine Spills in Canadian Waters
Phase 1: Oil Spills South of 60th Parallel
Estuary and Gulf of St. Lawrence - Sector 3
0 37,5 75 150 km
January 2014
File: 131_17593_c2.4_Estuary_St_Lawrence_Sub_sectors_131223.mxd
WSP
SL ROSS
Map 2.4


Risk Assessment for Marine Spills in Canadian Waters
Phase 1: Oil Spills South of 60th Parallel
Great Lakes and St. Lawrence Seaway System - Sector 4
0 50 100 200 km
January 2014
File: 131_17593_c2.5_Great Lakes St Lawrence_Sub_sectors_131223.mxd
WSP
SL ROSS
Map 2.5
WSP Canada Inc.'s Boundary
0 to 12 nm
12 to 24 nm
Sub Sector
Thunder Bay
Lake Superior
Sault Ste. Marie
ONTARIO
QUEBEC
Saguenay
Ottawa River
Lake Michigan
Lake Huron
Quebec
Trois-Rivières
Montreal
Ottawa
St. Lawrence River
Toronto
Hamilton
Sarnia
Windsor
Lake Ontario
Lake Erie
USA
1
2
3
4
5

Each Canadian coastal sector is divided into smaller sub-sectors. The lateral boundaries of the sub-sectors have been chosen to divide each main sector into segments with a length of approximately 500 km. Each sub-sector is also divided into three zones, where applicable, with regard to distance from the shoreline:

- Nearshore zone (0 to 12 nm from shore);
- Intermediate zone (12 to 24 nm from shore); and
- Deep-sea zone (24 to 200 nm from shore).

In total, the oil spill risks are presented as an average value (ERI – Environmental Risk Index) for:

- 15 zones in sector 1;
- 30 zones in sector 2;
- 21 zones in sector 3;
- 11 zones in sector 4.

2.4 Data Collection

Different datasets are required to calculate the probability and the potential impact of hypothetical oil spills. Specific details on the data assembled for this study are provided in the following sections. An evaluation of data quality and the limitations of these datasets are provided in sub-section 2.5. This analysis will provide insight on potential over/under estimations and will help identify data gaps where more detailed datasets would be beneficial to refine the overall study.

2.4.1 Vessel Traffic Data

In order to generate an estimate of the probability of oil spills in Canadian waters, Canadian traffic data are retrieved from federal and international sources. Due to the low incidence of events in Canadian waters, worldwide casualty data are used to estimate the probability of medium and large-scale spills. In order to produce an estimate of casualty frequency, casualties are divided by worldwide traffic data. Thus, frequencies are calculated as global estimates (based on Canadian data where available, and worldwide data for larger spill sizes) and also refined for a set of selected countries characterized by similar regulations to Canada. These frequencies are multiplied by specific traffic data for each geographic sector identified above.

Cargo volume and shipping traffic data from Canadian and worldwide sources is used to generate an estimate of the probability of oil spills in Canadian waters. Due to the low incidence of casualties in Canadian waters, worldwide data is used to estimate the probability of medium and large-scale spills. The worldwide casualty rates are scaled down to produce an estimate for Canada based on the relative shipping volumes and traffic. These frequencies are then apportioned to the various sectors and sub-sectors based on analysis of Canada-only cargo volume and traffic data.

2.4.2 Environmental Data

The spill probability data is further applied to identify the impacts to a series of environmental components (see list below). The data assembled has mostly been provided by federal authorities and used to qualify environmental sensitivity. To integrate this sensitivity into the risk assessment, the following components of the physical, biological and human environments were considered:

- Physical environment: bathymetry, tide, littoral geomorphology, physical oceanography and ice conditions;
- Biological environment: meroplankton, invertebrates, fishes, birds, marine mammals, reptiles, coastal zone, and protected area;
- Human environment: commercial fishing, aquaculture, port activity, tourism employment intensity and coastal population density in freshwater environments.

These components are based exclusively on international and federal data provided by federal ministries (DFO, EC and TC). With the exception of information on protected areas, data from provincial, territorial and municipal governments have not been included in this study.

The produced metrics are mapped to present their spatial distribution and facilitate the interpretation.

A specific indicator outlining the presence or absence of an Aboriginal group or an Aboriginal treaty right was not included in the study. A series of maps are also included in Appendix 3 that illustrate the location of Aboriginal communities and population densities, treaty boundaries and Statement of Interest boundaries that could be impacted by oil spills.

Data on Aboriginal communities was retrieved to cover several characteristics such as tourism employment intensity, commercial fisheries and freshwater use. These characteristics were integrated in the HRI indicator. As the HRI intends to be an economic indicator, it would have been inappropriate to give more weight for Aboriginal commercial fisheries than non-Aboriginal commercial fisheries. The same logic applies to the tourism and freshwater use indicator.

2.5 Uncertainties

There are many sources of uncertainty in the risk methodology. The main ones are considered to be:

- Spill frequency was estimated in this study based on the historical occurrence of incidents over the most recent ten years. There will always be uncertainty in predicting events in the future based on the past, and particularly based on events that seldom occur.
- The use of worldwide incident data to estimate spill frequencies may overstate the likelihood of spills in Canadian waters given the robust marine governance regime and as evidenced by the actual spill record in recent decades. The difference should not be overwhelming, as indicated by a comparison of incident data in other countries with similar regimes.
- The estimated frequency of spills of refined product may be over-stated in the 1,000 to 9,999 m^3 size category due to the under-reporting of refined product carriage on a worldwide basis, used to estimate the spill frequency. This does not apply to the smaller size ranges, which were based on actual Canadian spill statistics.
- The estimated frequency of spills in all three zones of Pacific sub-sector 5 and the deep-sea zones on sub-sectors 1 and 4, are heavily influenced by the inclusion of crude oil cargo en route to refineries in northern Washington State. Although the additional likelihood of spills in sub-sector 5 is clear, this may overstate the likelihood of spills in the deep-sea zones on sub-sectors 1 to 4.
- The ESI is a very simplified measure of environmental sensitivity. The method used has led to ESIs that are relatively high for the nearshore zone and much lower for most intermediate and deep-sea zones.
- For the PSI calculations:
    - Shoreline types were ranked according to the Environment Canada classification. However, some shoreline segments were not characterized and the information was not available for these areas. In that case, shoreline type was indicated as “not classified”. Thus, in order to obtain a representative PSI for these coastline segments, they were redistributed equally amongst other shoreline types.

- The "median of ice concentration when ice is present" variable was used to describe and map the PSI by shoreline category. These data considers the total concentration of ice throughout the course of a year. The charts produced using this classification, represent the statistical normal ice concentration when ice is present with a high level of confidence. PSI mapping for this shoreline category was achieved using ice concentrations greater than 1/10 (i.e. traces); the latter is rather used to describe open water.

- For the BRI calculations:
  - Data used was provided by federal ministries (DFO, EC and TC) as well as international organisations. With the exception of information on protected areas, data from provincial, territorial and municipal governments have not been included because of the limited timeframe of this study.
  - Except for the Great Lakes and St. Lawrence Seaway System sector, the EBSA data (determined by DFO) were used to identify the main productive area of each marine Canadian sector. As indicated by DFO, the EBSA delimitation should not be interpreted as strict and definitive. Although the criteria are similar for the determination of regional EBSA (uniqueness, concentration, function), the methodology used by each DFO regional department is different.
  - Bird data are different in each sector. For sectors 2 (Atlantic Coast) and 3 (Estuary and Gulf of St. Lawrence (EGSL)), data have been provided by Canadian Wildlife Service (CWS), which were used to determine concentration areas and colonies. The difficulties of obtaining similar datasets for the two other sectors has allowed for regional disparities. For sector 1 (Pacific Coast), the EBSA and IBA data were used, while the protected area data, including IBA, were used for sector 4 (Great Lakes and St. Lawrence Seaway System).

- For the HRI calculations:
  - The nearshore tonnage data collected is the relative raw annual tonnage (international and interior) of each port located in a sub-sector. It does not take into account the merchandise type. Therefore, a high value merchandise (e.g. refined fuels) with medium freight tonnage could end up scoring less on the index than a low value merchandise with a slightly higher tonnage (e.g. raw iron ore).

- The relative tourism intensity data used is provided by the 2011 National Household Survey (NHS, 2011). Since the census divisions are not in line with the sub-sector divisions, an expert judgment was made to include in each sub-sector a whole census division when this division had more than a fifth of its area in the designated sub-sector. Moreover, since some divisions have a significant inland area in addition to their coastal shoreline, the tourism data includes, in some case, tourism employment data not related to the shoreline/marine tourism industry.
- The fishing index was calculated using fishing value by port. These data provide a solid idea of the relative importance of the fisheries in each sub-sector; however they do not take into account the activity by fishing location. Hence if a fisherman operates in a different sub-sector than the port where he arrives with the fish, his activities will be accounted in a different sub-sector.
- The aquaculture data was not available by aquaculture site. An average value was given using the total aquaculture sites for finfish and shellfish in each province. Then, the value for each sub-sector was calculated by multiplying the average value by the total number of sites in the sub-sector. Therefore, it could induce a bias towards a sub-sector with numerous small scale aquaculture sites versus a sub-sector with few larger scale and more productive sites.
- As in the tourism index, total population for each nearshore zone was assessed using the data from the NHS (2011). Therefore, the same limitation regarding the inland area and the border persists. However, since this indicator only applies only to the St. Lawrence Seaway, and as it is the home of a larger population basin, the census divisions tend to be much smaller than in the relatively scarcely populated areas of the Atlantic coast.

Great uncertainties exist in the risk calculation for the Great Lakes/St. Lawrence Seaway System sector. The reasons of such uncertainties are described below. Based on these elements, a separate risk analysis would be beneficial for the Great Lakes/St. Lawrence River to better capture the specificity of the freshwater environment.

- The study was based on environmental metrics using comparable descriptors to allow for a pan-Canadian comparison of environmental sensitivity and risk. The data available for all sectors of the Great Lakes/St. Lawrence Seaway System differed greatly from other the other marine sectors.

- Spill frequency was estimated in this study based on the historical occurrence of incidents over the most recent ten years. There will always be uncertainty in predicting events in the future based on the past, and particularly based on events that seldom occur.
- The use of worldwide incident data to estimate spill frequencies may overstate the likelihood of spills in Canadian waters given the robust marine governance regime and as evidenced by the actual spill record in recent decades. The difference should not be overwhelming, as indicated by a comparison of incident data in other countries with similar regimes.
- The estimated frequency of spills of refined product may be over-stated in the 1000 to 9999 m^3 size category due to the under-reporting of refined product carriage on a worldwide basis, used to estimate the spill frequency. This does not apply to the smaller size ranges, which were based on actual Canadian spill statistics.
- With regards to transport data, the current calculations are based on mean yearly traffic data. However, the seaway is only open during the ice free period, which implies that traffic estimates per year under estimate the spill probability. If we consider that the seaway is closed 30% of the year, then the probability of spill should be increased by the same value.
- The current study considered only Canadian traffic (i.e. transits involving at least a Canadian location for departure or destination). It is likely that most of the vessels in the Great Lakes region is involving Canadian destinations, however, including the US vessel movements would have increased the risk probability.
- The ESI is a very simplified measure of environmental sensitivity. The method using has led to ESIs that are relatively high for the nearshore zone and much lower for most intermediate and deep-sea sub-sectors.

3. TECHNICAL APPROACH

3.1 Spill Frequency Methodology and Results

3.1.1 Overview

The likelihood of a spill occurring was estimated by historical spill rates using Canadian and worldwide spill statistics. In general, this involved a correlation of the number of accidents or spills against an exposure variable. Accident rates were determined separately for crude oil and refined products carried as cargo and oil carried as fuel, described in turn below. In each case, spill statistics were analysed for the most recent 10-year period, 2003 to 2012.

The overall risk assessment consisted of two primary elements: an estimation of the potential frequency of spills and an estimation of the potential consequences should a spill occur. The following describes the methodology in determining the potential spill frequency. The approach borrows heavily from the methodologies used in two previously completed risk studies:

- *Environmental Oil Spill Risk for the South Coast of Newfoundland* (RMRI for Transport Canada, 2009);
- *Assessment of the Risk of Pollution from Marine Oil Spills in Australian Ports and Waters* (DNV for Australian Maritime Safety Authority, 2011).

3.1.2 Oil Spill Accident Data

Accident data was acquired from three main sources: the CCG *Marine Pollution Incident Reporting System* (MPIRS); the Lloyd's casualty database; and spill incident records maintained by the International Tanker Owners Pollution Federation (ITOPF).

MPIRS lists all marine pollution incidents occurring in Canadian waters (CCG, 2013), with information on the region within Canada in which the incident occurred, type of material spilled, accident cause, and estimated pollution volume with multiple entries for a given incident showing updates of incident status and pollution amounts if applicable. The primary use of MPIRS in this study was for spill incidents in the smaller size categories (described below) for which worldwide data was suspected to be unreliable due to under-reporting. MPIRS appeared to be a comprehensive listing of incidents that occurred in Canadian waters, and a summary of polluting incidents drawn from it appears later in the report. One limitation of the MPIRS data was that it did not classify spills as to whether they were from “cargo” as opposed to “fuel”, which would have been helpful in this study as these spill types were analyzed separately. As a result, for spills of refined products, which could have hypothetically been either cargo or fuel, assumptions were made based on the type of vessel involved, the type and severity of the incident, and other notes within MPIRS.

A database was acquired from Lloyds that detailed all marine casualties over the past ten years regardless of whether the incident involved pollution (Lloyds, 2013a). This database was used to provide a breakdown of incidents by cause, and as an initial listing of those incidents that did result in pollution. The Lloyds data was of mixed quality when it came to the reporting of polluting incidents, with numerous records only partially filled out, ambiguities in the reporting of spill volume, and inconsistencies in the classification of the spilled material. A significant effort was made to provide consistency and accuracy in the information, including cross-referencing with other data sources.

ITOPF regularly publishes statistics on pollution incidents involving tank vessels, and were available to provide summary information on spill incidents over the most recent 10 years involving pollution of 7 t and greater (ITOPF, 2013). Although lacking in details on accident causes and specific locations, the ITOPF database was of particular value as a cross-reference for spill types and volumes.

3.1.3 Accident Exposure Data

As noted, oil spill accidents were compiled on a worldwide basis. In order to estimate the frequency for Canada, an exposure variable was required.

A series of studies by the U.S. Minerals Management Service (MMS, now known as the Bureau of Ocean Energy Management, Regulation and Enforcement) investigated the occurrence rates of tanker accidents against various spill exposure variables and found that the simplest and most reliable indicator was volume of oil transported. Simply put, it was determined that spill rates could be expressed, for a range of spill size categories, as an average number of spills per billion barrels transported. The MMS studies were updated periodically until the 1990s but have not been revisited since, but they did show a steady decrease in the likelihood of casualties and resulting spill volumes, due to a number of factors including tanker design, increasing governance and overall scrutiny of the marine transportation industry. The phased-in implementation of double-hull tankers may have also had a beneficial effect on spill rates in more recent years, particularly in the category of very large or catastrophic events. The trend has continued to present times as evidenced by regular reports from the ITOPF. In any case, it is important in interpreting accident data to reflect current trends and implemented mitigation measures. The focus was on cargo volumes and accident rates over the past decade.

In the case of crude oil and refined products carried as cargo, the exposure variable was simply the volume of each respective category carried on an annual basis for the period of interest. Information from the Lloyds APEX database (Lloyds, 2013b) was used for this purpose; it reports volumes of crude and refined products shipped worldwide, with a breakdown by year, country of origin, and country of destination. Compared with similar data from Canadian sources, the APEX data appeared to significantly under-report the carriage of refined products. As a result, the accident rates estimated and used in this study are likely somewhat conservative, that is, they overstate the likely frequency of refined products carried as cargo. For all calculations involving the potential spillage of refined products as cargo in Canadian waters, and for the apportioning of spill frequency among the various sectors and sub-sectors of Canada, Transport Canada commodity traffic data was used (Transport Canada, 2013).

In the case of oil carried as fuel, the variable was number of vessel movements, for all vessels greater than 150 t. Information was acquired from the Lloyds Fairplay database to provide an overall count for the period 2002 to 2011 of commodity vessel movements internationally, and an overall count of all vessel movements, commodity and otherwise in Canadian waters (Lloyds, 2013c). The international movement data was used to provide the proportion of risk exposure that would pertain to Canada, and the detailed Canadian movement data was used to proportion the risk exposure amongst sectors and sub-sectors within Canada. In analysing the Canadian movement data supplied by Lloyds, a major shortcoming was found in the data in that movements recorded prior to 2010 did not include broad classes of vessels such as ferries, passenger vessels, and pilot boats. Given that these vessels comprise a significant proportion of traffic movement in many sectors, only data covering the final two years of the record, 2010 and 2011, were used in the analysis.

To evaluate the number of transits per sub-sectors, Canadian ports were first located from reliable port directories, and classified according to their respective location. International ports were also located from reliable port directories, and were assigned an international region (Northern Europe, Mediterranean Europe, Africa, North America, South America, Asia, and Australia) to allow future computation of potential sea routes.

For each of the single combination of origin and destination ports' location, the most efficient sea route was identified using the Dijkstra's algorithm, a graph search algorithm that solves the single-source shortest path problem for a graph with non-negative edge path costs, producing a shortest path tree. In our case, the shortest paths are sequences of adjacent Canadian sub-sectors linking origin and destination regions. Given that no real distances were computed, the shortest path was evaluated on the basis of the number of sub-sectors crossed during transit.

For some combinations of origin and destination ports, two paths crossing the same number of sub-sectors sometimes occurred (mostly for transits across the EGSL sub-sectors). In these cases, the sea route between Newfoundland and Cape Breton Island was used.

Figures 3.1 and 3.2 provide an overview of the transit calculations per sector as well as per sub-sectors within each sector.

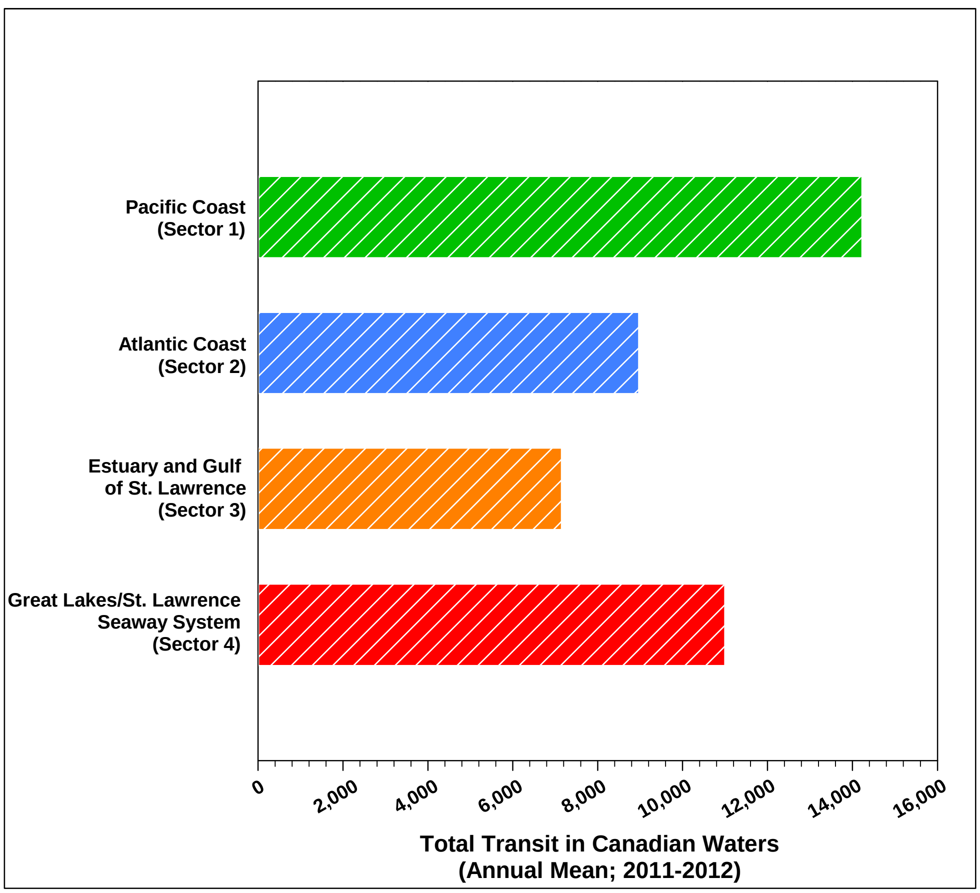


Figure 3.1 Mean Annual Number of Transit (2011-2012) per Sector.

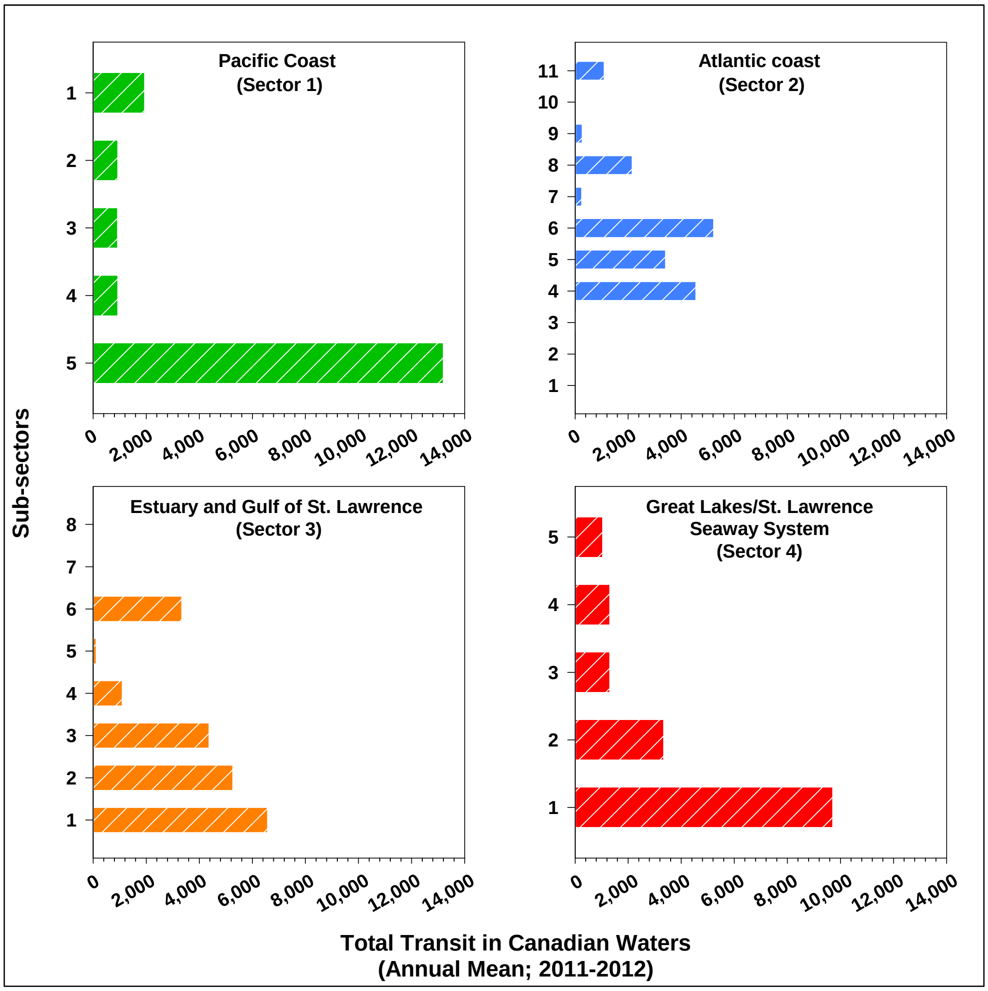


Figure 3.2 Mean Annual Number of Transit (2011-2012) for Each Sub-Sector per Sector.

The same computations were performed to produce an estimate a total volume of oil as cargo for each studied area (see hereafter).

3.1.4 Spill Size Categories

The likelihood of a spill occurring has an inverse correlation to spill size, with smaller events occurring more frequently and catastrophic events occurring only rarely. For this reason a set of spill size categories is established and the historical frequency estimated for each one separately. As an example, in the 2009 Transport Canada study for the South Coast of Newfoundland (RMRI, 2009) the following categories were used:

- 1 to 49 barrels; (0.16 to 8 m^3);
- 50 to 999 barrels (8 to 160 m^3);
- 1,000 to 9,999 barrels (160 to 1,600 m^3);
- 10,000 to 99,999 barrels (1,600 to 16,000 m^3);
- 100,000 to 199,999 barrels (16,000 to 32,000 m^3); and
- > 200,000 barrels (>$32,000^3$).

One problem with adopting the categories from this study is the anomalous result comparing the top two tiers, where a greater frequency was indicated for the highest category than for the second highest. This is likely due to the fact that the second highest tier represented a relatively narrow size range, compared with the other tiers which reflect order of magnitude bands. For the current study, the following size ranges were used: 10, 100, 1,000, and 10,000 m^3. The latter three categories roughly correspond to the tiers specified in the *Canada Shipping Act, 2001*; one additional category is added at the low end to encompass smaller spills.

3.1.5 Accident Statistics

It would have been preferable to focus only on spills in Canadian waters to reflect risk factors specific to the Canadian environment. This was not possible, however because there have been very few large ship-source spills in Canada in recent years, and none at all in the two highest spill size categories. Therefore, international data was also used. For the smallest size categories, there have been spills in Canada in the last decade: the data is recorded in the MPIRS maintained by the CCG. Within the cargo data, a distinction was made between crude oil and refined products, and separate accident rates calculated for each one.

The worldwide record for ship-related incidents over the most recent ten years of record is summarized in Table 3.1.

Table 3.1 Worldwide Spill Incidents, 2003 to 2012.

Volume (m^3)	10 to 100	100 to 1,000	1,000 to 10,000	10,000 and greater
Crude	10	7	9	2
Refined Cargo	22	21	11	0
Fuel	34	23	3	0
Other/Unknown	3	0	1	0
Total	**69**	**51**	**24**	**2**

Sources: Lloyds, 2013a; ITOPF, 2013, and others.

The original intention was to determine an “incidents per tonne” rate based on worldwide commodity data. However, it became apparent that the APEX commodity data understated the total cargo volumes, to some extent for crude oils but to a significant extent for refined products. Instead, the aforementioned worldwide spill rates were scaled down to the Canadian context using the fraction of crude oil and refined commodities shipped to and from Canada versus that of the world, using the APEX data. As well, Lloyd’s transit data was used to calculate a similar fraction of total commodity movements versus that of the world. The two were averaged to provide the required scaling factor. Nonetheless, Transport Canada-supplied commodity data for crude and refined products were used for the most important aspect of this risk study, the correct apportioning of volume-related spill frequency among the sub-sectors of Canada. Similarly, detailed transit information on all vessel traffic, commodity-related and otherwise, was used to apportion transit-related spill frequency (i.e., fuel spills) among the sub-sectors.

Table 3.2 Canadian versus Worldwide Commodity and Transit Data

Cargo Volume Factor	2.54%
Traffic Factor	1.57%
Average	2.06%

Simply applying these factors, and dividing 10-year frequencies by 10 for an annual spill rate results in the following worldwide spill rates for the specified spill size categories. Spills listed as “Other/Unknown” product type have been brought into the other product types according to their ratios of the original total (e.g., 10/69 or 15% of the other spills were placed into the crude category.

Table 3.3 Estimated Annual Spill Rates for Canada Based on Worldwide Casualty Data

Volume (m^3)	10 to 100	100 to 1,000	1,000 to 10,000	> 10,000
Crude	0.022	0.014	0.019	0.004
Refined Cargo	0.047	0.043	0.024	0.000
Fuel	0.073	0.047	0.006	0.000
Total	**0.142**	**0.104**	**0.049**	**0.004**

The comparative statistics for spills in Canadian waters for the same period are summarized in Table 3.4.

The four underlined data points in Table 3.4 exceed the worldwide estimated spill rates, perhaps due to mis- or under-reporting of spills in other parts of the world. As such, the Canadian rates were used in subsequent estimations of predicted spill frequencies.

Table 3.4 Actual Annual Canadian Spill Frequency, 2003 to 2012.

Volume (m^3)	10 to 100	100 to 1,000	1,000 to 10,000	> 10,000
Crude	0	0	0	0
Refined Cargo	0.6	0.1	0	0
Fuel	1.9	0.6	0	0
Total	**2.5**	**0.7**	**0**	**0**

Source: CCG, 2013.

As well, since there were no spills in any of the other spill type or size range categories, the worldwide statistics were used, as summarized in Tables 3.5 and 3.6. Table 3.6 lists the spill rate as a "return period", the inverse of the frequency, or the average number of years between spills for ease of comparison.

Table 3.5 Overall Canadian Spill Frequency Estimates: Annual Estimate.

Volume (m^3)	10 to 100	100 to 1,000	1,000 to 10,000	> 10,000
Crude	0.022	0.014	0.019	0.004
Refined Cargo	0.600*	0.100*	0.024	0.000
Fuel	1.900*	0.600*	0.006	0.000
Total	**2.522**	**0.714**	**0.049**	**0.004**

* Rates based on Canadian data; all other rates based on worldwide data.

Table 3.6 Overall Canadian Spill Frequency Estimates: Return Period, years.

Volume (m^3)	10 to 100	100 to 1,000	1,000 to 10,000	> 10,000
Crude	46.4	69.2	51.6	242.3
Refined Cargo	1.7	10.0	42.2	-
Fuel	0.5	1.7	154.8	-
Total	**0.4**	**1.4**	**20.2**	**242.3**

3.1.6 Breakdown of Spill Frequencies by Nearshore/Intermediate/Deep-sea Zones

A final breakdown of spill frequencies for all three spill types (crude oil cargo, refined oil cargo, and fuel) is needed to classify the spill locations within each sub-sector according to nearshore, intermediate and deep-sea zones as defined earlier. This was done for each of the incidents listed in the casualty database, although it is acknowledged that information was often incomplete and assumptions were made based on the type of incident, noted effects of the incident, and other information within the Lloyds, MPIRS, and ITOPF databases. Based on this analysis, the breakdown of spill location (Table 3.7) was determined, and used to apportion spill frequencies accordingly.

Table 3.7 Summary of Generalized Spill Location from Casualty Incident Data.

Nearshore Zone	45%
Intermediate Zone	35%
Deep-sea Zone	20%

3.1.7 Additional Risk in Pacific Sector Related to Washington State Traffic

The Strait of Juan de Fuca and environs experience additional risk associated with tanker traffic supplying crude oil to refineries in northern Washington State. While other parts of Canada may also experience additional risk associated with passing tankers, the situation in the Pacific sector is unique given the significant volumes of crude oil, and to a lesser extent refined product, that are being shipped in nearshore waters that would have a direct and substantial effect on the Canadian environment and related resources.

The potential spill frequency associated with this traffic was estimated using annual shipping volumes to these Washington State refineries, and applying the annual volume to the volume indices for the appropriate sub-sectors in the Pacific sector.

An estimate of the annual volume of crude oil cargo passing through the Strait of Juan de Fuca is contained in Nuka (2013), with an average for the years 2011 and 2012 listed below passing Neah Bay (the northwest extremity of the State of Washington) and Point Roberts, close to Richmond (British Columbia).

Table 3.8 Persistent Oil as Cargo, Annual Average 2011 and 2012

Neah Bay	35,304,199 m^3
Point Roberts	2,749,189 m^3
Difference	32,555,011 m^3
Difference, converted to tonnes	27,671,759 t

The estimated volume passing Point Roberts approximately corresponds to the crude oil volumes noted elsewhere in this study as that transiting from Vancouver harbour, so the difference between the Neah Bay and Point Roberts locations can be inferred as the volume transiting to Washington refinery locations. This volume of 27 Mt/year is in the range of the cumulative nominal capacity of the refineries in northern Washington. (It is known that these refineries derive some of their crude input from pipeline, but a breakdown was not available.)

The additional potential spill frequency is significant in that it is based on the volume of oil transported, and the volume in question is approximately 10 times that of the volume originating from Vancouver harbour. As such it must be added to the estimated "made-in-Canada" spill frequencies.

As noted previously, potential spill frequency is estimated per sub-sector according to the relative volumes transported across each sub-sector, on a national basis, with a further breakdown in each zone as per nearshore, intermediate, and deep-sea designations. The Washington State risk would clearly affect the intermediate and deep-sea zones in Pacific sub-sector 5. In a strict sense, it may not affect the nearshore zone; however, given that the nearshore zone includes the approaches to port including waters up to 12 nm from shore, it is quite likely that a spill originating from Washington State traffic could affect Canadian waters, and is therefore included in the spill rate estimates although it would not necessarily occur in the nearshore zone of Pacific sub-sector 5.

Finally, depending on the origin of the tanker traffic visiting Washington it could also affect the deep-sea zones of Pacific sub-sectors 1 through 4. Based on analysis of tanker calls at the three main refineries in northern Washington, an estimated 66% of all tanker calls, on a DWT-basis, originate in Valdez, Alaska, the terminal serving the Trans-Alaska Pipeline. Based on this, 66% of the implied risk of Washington State traffic as estimated above was also applied to the deep-sea zones of Pacific sub-sectors 1 through 4.

Similarly, for refined products carried as cargo, Table 3.9 provides the estimated volumes for 2011 and 2012:

Table 3.9 Non-Persistent Oil as Cargo, Annual Average 2011 and 2012

Neah Bay	17,692,359 m^3
Point Roberts	6,383,420 m^3
Difference	11,308,939 m^3
Difference, converted to tonnes	9,612,598 t

Source : Nuka, 2013.

Similar to the above discussion, the difference between the Neah Bay and Point Roberts locations can be inferred as the volume transiting to and from Washington locations. In the case of refined products, the additional potential spill frequency is significant but not as dramatic as in the case of crude oil cargo with the Washington volume approximately one-and-a-half times the British Columbia volume, and will impose a corresponding increase in potential spill frequencies.

In contrast with the potentially affected areas for spills of crude oil, it is assumed here that all traffic of refined products to and from Washington State involves trade with the continental States and points south. As such, the only affected zones in Canada are the nearshore, intermediate and deep-sea zones of Pacific sub-sector 5.

Figure 3.3 provides an overview of oil as cargo volume per sector, with the additional impact of U.S. cargo on the Pacific sector total volume.

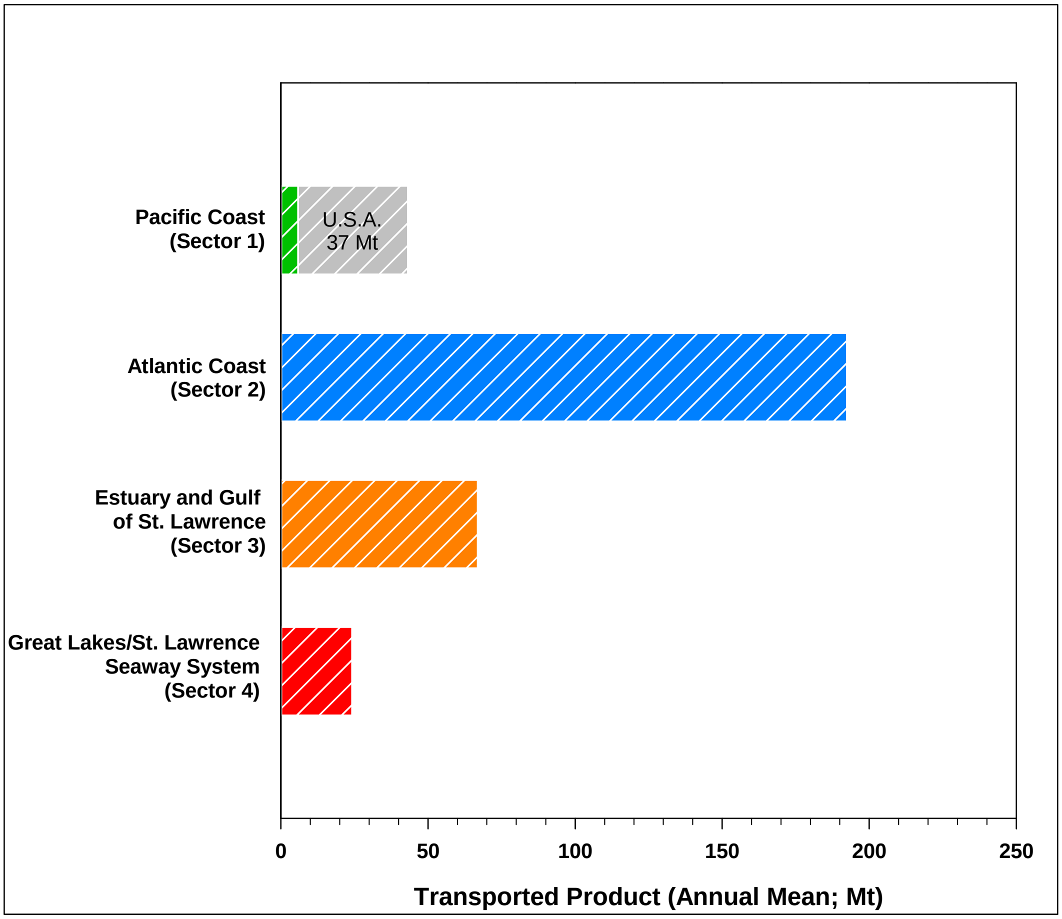


Figure 3.3 Mean Annual Volume of Oil Carried as Cargo per Sector (Mt)

Figure 3.4 provides the detailed breakdown per sub-sectors for the Pacific sector of oil as cargo volume per sub-sector, with the additional impact of U.S. cargo on the Pacific sector total volume.

3.1.8 Breakdown of Spill Frequencies by Casualty Type

Casualties are identified in the overall database as to primary cause or event leading to the pollution incident, and this may be of interest in the consideration of prevention measures. The incident causes are summarized in Table 3.10.

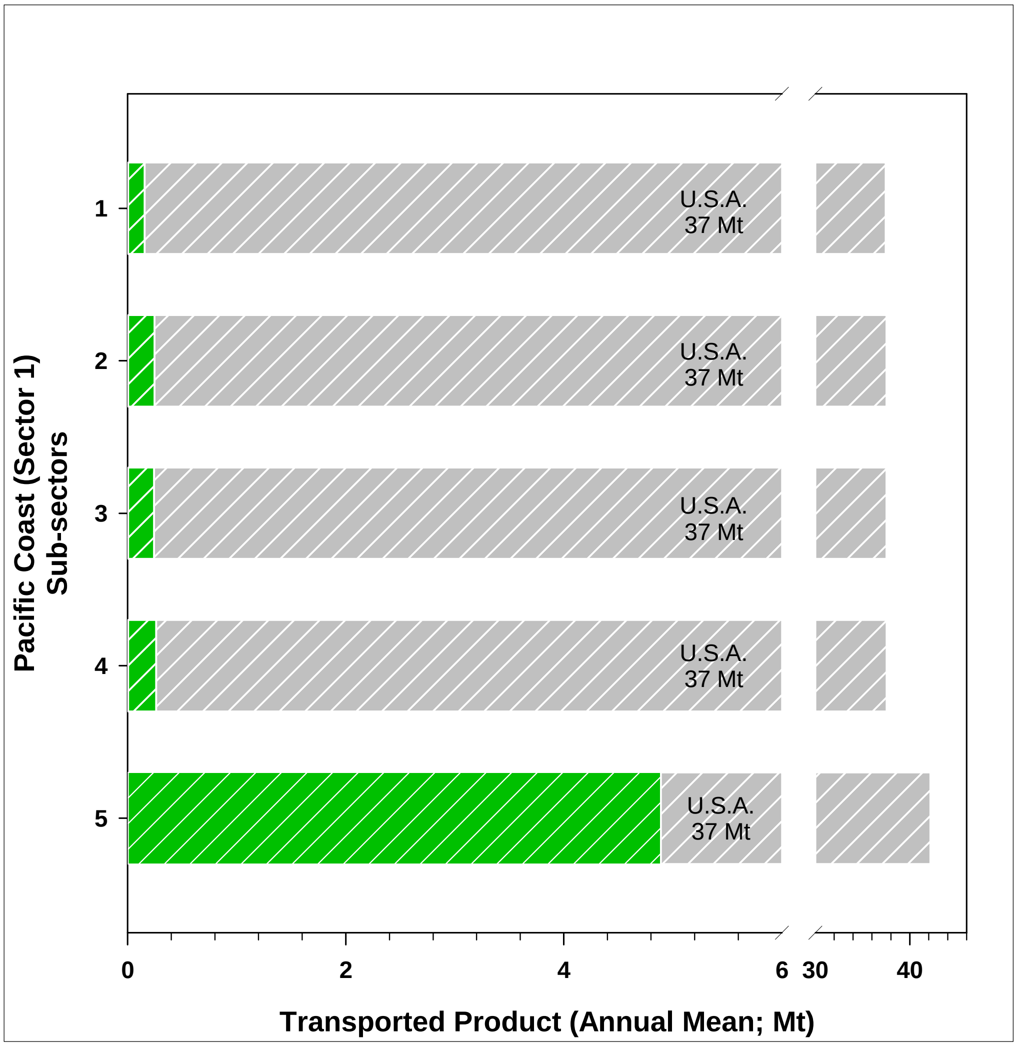


Figure 3.4 Mean Annual Volume of Oil Carried as Cargo per Sub-sector for the Pacific Sector (Mt)

Table 3.10 Spill Frequencies by Casualty Type.

Volume (m^3)	10 to 100	100 to 1,000	1,000 to 10,000	> 10,000	**Total**
Collision	26	19	7	1	**53**
Loading/Unloading	12	9	5	0	**26**
Grounding	10	9	1	1	**21**
Contact	4	5	5	0	**14**
Foundered	8	3	1	0	**12**
Hull Damage	6	3	2	0	**11**
Machinery Damage	3	1	2	0	**6**
Fire/Explosion	0	2	1	0	**3**

Collisions are the dominant spill cause, and this is reflected in each of the spill size categories. Loadings and unloadings are the second leading cause, and perhaps surprisingly, include a number of spills in the second highest spill category. Groundings are the third leading cause but are mainly seen in the two smallest size categories.

3.1.9 Comparison of Spill Accident Statistics: Canada versus Rest-of-World

One of the obvious concerns over using international casualty data is that it may overstate the likely spill frequency in Canada, which has had few large spills, attributable in part to a robust marine governance structure, relatively low traffic density, and a variety of risk reduction measures. Based on this, the spill rates in Canada and other similar countries with good marine governance were compared with other countries. For the purposes of this brief analysis, the following countries were considered to be “Canada-like”:

- Australia;
- Canada;
- Germany;
- Denmark;
- Spain;
- Finland;
- France;
- Republic of Ireland;
- Iceland;
- Japan;
- Netherlands;
- Norway;
- Sweden;
- United Kingdom;
- United States of America.

Spills of 100 m^3 and greater are listed in Table 3.11, grouped according to those thought to have “Canada-like” regulatory standards and those that do not.

Table 3.11 Grouping of Spills by Regulatory Standard.

Spill Location	Spill size range (m^3)		
	100.0 to 999.9	1,000 to 9,999	10,000 and greater
South Atlantic and East Coast South America	2	0	0
Arabian Gulf and approaches	4	2	1
Australasia	*0*	*0*	*0*
Baltic	*1*	*0*	*0*
Bay of Bengal	0	1	0
Canadian Arctic and Alaska	*0*	*1*	*0*
East African Coast	1	0	0
East Mediterranean & Black Sea	2	3	0
Great Lakes	*0*	*0*	*0*
Gulf of Mexico	*3*	*3*	*0*
Indian Ocean	1	0	0
Japan, Korea and North China	7	1	1
North Atlantic	1	0	0
North American west coast	*2*	*0*	*0*
North Pacific	0	0	0
Red Sea	1	0	0
South American west Coast	0	0	0
South China, Indo China, Indonesia and Philippines	10	6	0
Suez Canal	0	2	0
British Isles, North Sea, English Channel, Bay of Biscay	*7*	*3*	*0*
United States eastern seaboard	*2*	*2*	*0*
Russian Arctic and Bering Sea	1	0	0
West African coast	1	0	0
West Indies	2	0	0
West Mediterranean	*3*	*0*	*0*
Total	51	24	2
Incidents in "Canada-like" countries	18 (35%)	9 (38%)	0 (0%)

As indicated in Table 3.11, the difference is tangible but not overwhelming: 35% of the spills occurred in countries with “Canada-like” regulatory standards compared with the exposure metric of 43% of oil trade as measured by unloadings. What may be significant is that there were no spills of greater than 10,000 m^3 in “Canada-like” countries, while there were two such spills in other countries.

This indicates that there is not a wide variability in spill rates among different governance structures around the world, except perhaps at the highest end of the spill size ranges, and gives credibility to the use of worldwide statistics for the estimated used in this report for Canada.

3.2 Environmental Sensitivity Index (ESI)

This section outlines the index developed to assess the environmental sensitivity to oil spills in the different environments. Its purpose is to quantify the relative risk associated with oil spills in different geographical regions, to convert the estimates of oil spill frequencies into indicators of environmental risk.

The following sub-sections describe the approach used and detail each of the indicators that compose the Environmental Sensitivity Index (ESI).

3.2.1 General Approach

Based on existing literature (Office of Response and Restoration, 2013; DNV, 2011; Cohen, 2010; NOAA, 2002), a relative index, called the Environmental Sensitivity Index (ESI), was selected to evaluate the sensitivity of each zone. The ESI incorporates three indicators:

- The Physical Sensitivity Indicator (PSI), that is the degree of difficulty involved in the coastal clean-up operations.
- The Biological Resource Indicator (BRI), the sensitivity level of natural resources that are affected by an oil spill.
- The Human-Use Resource Index (HRI), the direct commercial losses caused by a spill, in addition to an evaluation of the damage caused to social resources.

The relative weight of each indicator is based on a review of costs breakdown of worldwide oil tanker spills from 1992 to 1997 (DNV, 2001). This breakdown is consistent with the weights used by Cohen (2010).

$$ESI = 0.3(PSI) + 0.5(BRI) + 0.2(HRI)$$

Although this method allows for a relatively good quantification of environmental sensitivity, it has some limits:

- The indicators (PSI, BRI and HRI) are each expressed as average values representing an entire zone. They characterise the general sensitivity for each of the zones. Because of the length of each sub-sector, the overall index will not represent the vulnerability of specific locations but an average for the whole zone. These indicators are considered as global (large scale) indicators.

- The ESI values will be relatively high for nearshore zones, and much lower for most intermediate and deep-sea zones. Although this does not always reflect the real sensitivity of the environment, no other more accurate method has been developed. The use of the ESI is justified, especially in the current study over large areas.
- The use of averaged numbers of ESI inevitably results in a loss of detail within each zone. The high-sensitivity areas within a zone might be concealed if they are surrounded by relatively low-sensitivity areas, especially since the sub-sectors are so large.

3.2.2 Physical Sensitivity Indicator (PSI)

Shoreline classification allows for the attribution of a rank according to a scale related to sensitivity, natural oil persistence and ease of clean-up. Since most coastal regions include diverse shoreline types, the physical sensitivity indicator (PSI) in a given area will be calculated as a function of the ranks for each shoreline type as follows:

$$PSI_{type} = Rank / 6$$

The ranks for each shoreline are based on a ranking of 1 to 12 (Table 3.12). This in effect defines Rank 6 (gravel beaches and rocks breakwaters) as the average.

It should be noted that the sensitivity ranking is controlled by the following factors (NOAA, 2002):

- Relative exposure to wave and tidal energy;
- Shoreline slope;
- Substrate type; and
- Biological productivity and sensitivity.

The rank for each shoreline type is determined according to factors listed in Table 3.12 (NOAA, 2002). The average ranking is 6 (gravel beaches and rock breakwaters), with a PSI of 1.

The average PSI value for a zone is calculated from the length (L) of each type of shoreline divided by the total length of shoreline, as well as from the surface area (SA) of each zone type divided by the total surface area of the zone:

$$PSI_{zone} = \sum_{types} \frac{L_{component}}{L_{total}} PSI_{type} + \sum_{types} \frac{SA_{component}}{SA_{total}} PSI_{type}$$

$L_{component}$ = length of the considered component
L_{total} = total length of the nearshore zone
$SA_{component}$ = surface area of the considered component
SA_{total} = total surface area of the zone
PSI_{type} = physical sensitivity indicator (PSI) in a given zone

In the case of open seas (> 12 nm from shore), a 0.36PSI will be used. This value is based on the average cost of clean-up per tonne in offshore environments when compared to nearshore environments (Etkin, 2000).

Table 3.12 Shoreline Type and Rank

Description	Rank	Examples
Exposed vertical impermeable substrate	1	Exposed rocky shores, cliffs, exposed solid structures
Exposed non-vertical impermeable substrate	2	Rocky wave-cut platforms
Semi-permeable substrate; low potential for oil penetration and burial; infauna present but not abundant	3	Fine-grained sand beaches
Medium permeability; medium potential for oil penetration and burial; infauna present but not abundant	4	Coarse grains sand beaches
Medium to high permeability; high potential for oil penetration and burial; infauna present but not abundant	5	Mixed sand and gravel beaches[a]
High permeability; high potential for oil penetration and burial	6	Gravel beaches and rocks breakwaters (riprap)
Exposed, flat, permeable substrate; infauna usually abundant.	7	Exposed tidal flats[b]
Sheltered, impermeable substrate, hard; epibiota usually abundant	8	Sheltered rocky shores and sheltered artificial structures
Sheltered permeable substrate; infauna usually abundant	9	Semi-exposed tidal flats
Sheltered, flat, semi-permeable substrate, soft; infauna usually abundant	10	Sheltered tidal flats
Vegetated emergent wetlands	11	Marches, swamps, wetlands, eelgrass
Glaciated coasts	12	Ice infested waters, ice floes, frazil ice

a Potential habitat for spawning nursery such as capelin.
b Potential habitat for benthic organisms such as clams and mussels.

3.2.3 Biological Resource Indicator (BRI)

Distribution of biological resources in Canadian waters is highly variable. To account for this variability, a similar method to that developed by DNV (2011) was used to create a Biological Resource Indicator (BRI).

For the purpose of this study, the BRI is calculated as follows:

$$BRI_{zone} = \sum \frac{L_{component}}{L_{total}} W_{component} + \sum \frac{SA_{component}}{SA_{total}} W_{component}$$

$L_{component}$ = length of the considered component
L_{total} = length of the nearshore zone
$SA_{component}$ = surface area of the considered component
SA_{total} = surface area of the zone
$W_{component}$ = component sensitivity weighting.

For intermediate and deep-sea zones that do not include any of the identified components, the BRI is assumed to be related to that of the nearest nearshore zone with the following weight (adapted from DNV, 2011):

- 0.4x the BRI for the adjacent nearshore zone (intermediate zones)
- 0.1x the BRI for the adjacent nearshore zone (deep-sea zones).

The biological components considered for the BRI are: protected areas, species at risk, coastal zone, birds, mammals, reptiles, fish, meroplankton and invertebrates. To each of these groups, a weight has been attributed that reflects their estimated overall ecological sensitivity to oil spills (Table 3.13). This weighting scheme is primarily based on the DNV study (2011) that uses a scale from 1 to 25. The specific weight attributed to each component is based on the Strategic Environmental Assessment (SEA) for the Gulf of St. Lawrence study (GENIVAR, 2013) and from other marine environmental studies (dredging, harbour, etc.).

3.2.4 Human-Use Resource Index (HRI)

Assessing human activity related to each sub-sector is extremely complex and no simple indicator monitoring the vulnerability of human activity to oil spills exists. Therefore, the proposed methodology will use a combination of 4 indicators:

- Commercial fishing intensity (CFI);
- Tourism employment intensity (TEI);

Table 3.13 Sensitivity Weighting and Justification for Selected Biological Components

Component	Description	Weight (W)	Justification
Protected Area	• UNESCO sites • Ramsar sites • Important Bird Area (IBA) • Federal and provincial protected areas	25	A high sensitivity weighting is given to this component because these sites represent, as defined by IUCN (2008), a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values.
Species at risk	• Species' critical habitats identified in a recovery strategy or in an action plan	25	A high sensitivity weighting is given to this component because these critical habitats are necessary for the survival or recovery of a red-listed wildlife species.
Coastal Zone	• Coastal zone (0-50 m depth) in marine environment • Coastal zone (0-25 m depth) in freshwater environment	20	A high sensitivity weighting is given to this component because it is in this zone that the shoreline habitats of specific interest are concentrated. These habitats (e.g. wetlands, laminaria beds, coral or sponge reef) are necessary for several biological functions (spawning, nesting, wintering and alimentation) of many species.
Bird	• Legal bird colony • Concentration area	15	A medium-high sensitivity weighting is given to this component because birds affected by an oil spill have less chance of survival because of the irreversible consequences to their plumage as well as their physiological response.
Mammals	• Ecologically and biologically significant area (EBSA) for marine mammal (cetaceans and pinnipeds)	10	A medium sensitivity weighting is given to this component since most of the marine and aquatic mammals using Canadian waters are identified as special-status species, but they still have a high capacity of avoidance.
Reptile	• Concentration area	10	A medium sensitivity weighting is given to this component because most of the marine and aquatic reptiles using Canadian waters are identified as special-status species, but still have a high capacity of avoidance.
Fish	• EBSA for demersal and pelagic fishes	8	A medium-low sensitivity weighting is given to this component as fishes are relatively abundant and because their avoidance capacity is high (physiological systems of detection of contaminants: gills, lateral lines, osmosis, etc.).
Meroplankton	• EBSA	6	A low sensitivity weighting is given to this component because, although meroplankton would be responsible for the recruitment (eggs and larvae), its large geographical distribution makes it relatively resilient to an oil spill.
Invertebrate	• EBSA	4	A low sensitivity weighting is given to this component because, although invertebrates are important in the food chain, its large geographical distribution makes it relatively resilient to an oil spill.

- Freshwater use intensity (WUI);
- Freight tonnage index (FTI).

Adapted from DNV (2011), the Human-Use Resource Index (HRI) formula is:

$$HRI = 0.55CFI + 0.20TEI + 0.15WUI + 0.10FTI$$

Details on the chosen indicators are presented below.

The HRI in the Australian risk assessment study (DNV, 2011) is based on three indicators: fishing intensity, passenger vessel intensity and the presence of national parks. Based on their judgement, the DNV proposed a weight of 0.8 for the fishing industry and 0.2 for the tourism industry (0.1 for the passenger vessels and 0.1 for the presence of national parks[1]).

The present study needs to include additional components to reflect the particularity of the Canadian economy. Since an important part of the study area is composed of freshwater and because numerous Canadians use this water for sanitary (including drinking water) and industrial uses, it was necessary to include a water consumption component in the HRI. The importance of marine transportation to the Canadian economy also justified a port component. Moreover, data available for Canadian waters differs from data available in Australia. Because of unavailable vessel data, the tourism industry has been represented by a single indicator of activity generated from passenger vessels and coastal landmarks.

Similar to the methodology used by DNV (2011), this formula results in a relatively high importance granted to the fisheries sector, as this sector becomes the most vulnerable in an oil spill (despite a slight decrease of its relative weight to include new indicators). Finally, the methodology used the same relative weights as the DNV formula for the tourism industry.

From this analysis the attributed weights are:

- 0.55 for fishing industry;
- 0.20 for tourism industry;
- 0.15 for water usage;
- 0.10 for port industry.

[1] In this study, the BRI indicator is used to assess the presence of national parks. In the HRI, the tourism employment intensity takes into account the effect of the presence of a national park on regional tourism employment.

3.2.4.1 Commercial Fishing Intensity (CFI)

To assess fishing intensity in each of the zones, the port value of commercial fishing and the value of the fish, shellfish and aquaculture in each zone is determined and compared to a national average. The data is provided by Department of Fisheries and Oceans (DFO) as well as the provinces for Great Lakes and St. Lawrence Seaway System sector.

This indicator will also include data from the Aboriginal commercial fishing industry, which is captured within the DFO data, ensuring that the Aboriginal fishing industry sensitivity to oil spills is taken into account.

It is important to highlight that this indicator does not consider recreational or traditional fishing. The importance of this industry is notable and an oil spill could damage the recreational fishing stock as well. However, the absence of comparable data and the fact that this study is restricted to federal and international data, and some provincial data from Quebec and Ontario for commercial fisheries, limits the ability to include recreational fishing into the CFI. Nevertheless, as an absolute index, it will provide an overall vulnerability in the event of an oil spill.

As in the methodology used by DNV (2011), the fishing intensity for different offshore distances will be as follow:

- Nearshore zone = CFI;
- Intermediate zone = 0.5 CFI;
- Deep-sea zone = 0.1 CFI.

3.2.4.2 Tourism Employment Intensity (TEI)

In the DNV study (2011), two indicators were used to assess the importance of the tourism activity in zones: the relative frequency of passenger cargo and the presence of natural landmarks. In Canada, data for passenger vessels were unavailable. Consequently, the relative importance of tourism in each zone has been modified and will use the ratio of the tourism industry's employment versus total employment. The data will be extracted from the 2011 National Household Survey at the census division level and the accommodation and food services data will be used. The census divisions in coastal regions will be selected for each of the sub-sectors. This method will express the economic vulnerability of each sub-sector to a potential collapse in tourism following a spill. It is important to emphasize that the HRI in this study does not specifically take into account national parks and other landmarks, since their influence on tourism is indirectly included in the tourism employment intensity index. Moreover, since there is no data related to the specific marine tourism available, a broader indicator has been used. Statistical data as well as precise spatial data are available from the 2011 National Household Survey results.

Since the majority of tourism attractions are located in the nearshore zone, the different coefficients for offshore distances are as follow:

- Nearshore zone = TEI;
- Intermediate zone = 0.2 TEI;
- Deep-sea zone = 0.05 TEI.

3.2.4.3 Freight Tonnage Index (FTI)

Cargo transportation is a significant economic activity and the closure of a seaway due to a potential oil spill could trigger important costs. To assess the importance of cargo activity, annual national and international total tonnage in each port will be extracted from TC's shipping data (available for each Canadian port). This information will be used to calculate the total cargo activity of each zone. The data will be compared to the national average in order to determine the relative importance of the cargo activity in each of the sub-sectors.

A port closure may be triggered by a spill only if it occurs in a nearshore zone. Moreover, since ports are usually protected from the open sea, it is unlikely that an offshore spill would impact them. In the Massachusetts Department of Environmental Protection study (2009), only the coastal spills were taken into account when evaluating spill risks for ports. However, there is still a potential for port closures risk for oils spills that occur farther from the coast. To reflect this reality, the different distance components are set as follow:

- Nearshore zone = FTI;
- Intermediate zone = 0.1 FTI;
- Deep-sea zone = 0.01 FTI.

3.2.4.4 Freshwater Use Intensity (WUI)

Socio-sanitary conditions as well as numerous industrial activities use freshwater as an intake in the Great Lakes. Since this study focuses on the coastal parts of Canada as well as the Great Lakes and the St. Lawrence Seaway System, it is important to take the freshwater usage into account. However, data on individual water intakes (water volumes, population relying on water intake, etc.), was not available. In order to remedy to this, coastal population is used as a proxy. The hypothesis is that the greater the population base, the more freshwater will be used from the Great Lakes or in the St. Lawrence Seaway sector.

Accordingly, the coastal population for each of the sub-sectors along the freshwater seaway was compared to the average of all sub-sectors. This index was used to define the freshwater consumption intensity.

As there are no deep-sea zones in the freshwater seaway, this zone is not considered in the present index. However, for the nearshore zone, fresh water intakes could still prove vulnerable in the event of an oil spill in the intermediate zone. Consequently, distance components have to be established:

- Nearshore zone = WUI;
- Intermediate zone = 0.6 WUI.

Table 3.14 Component Description and Justification

Component	Description	Weight	Justification
Commercial Fishing Intensity (CFI)	Value of commercial fishing at each port, value of fish, shellfish and seaweed farming in the area	0.55	Measure the relative importance of fishing and aquaculture in each sub-sector.
Tourism Employment Intensity (TEI)	Intensity of the tourism employment	0.20	Identify coastal regions where employment in the tourism industry is high and thus vulnerable to an oil spill.
Freshwater Use Intensity (WUI)	Coastal population (freshwater only)	0.15	Identify freshwater sub-sectors that are vulnerable to oil spills.
Freight Tonnage Index (FTI)	Tonnage of national and international cargo at each Canadian port.	0.10	Give a relative index of port activity across Canada and identify high intensity ports

3.3 Environmental Risk Index (ERI)

3.3.1 Selection of Risk Metrics

As in the methodology used by DNV (2011), the Environmental Risk Index (ERI) has been chosen to estimate the relative risk sensitivity of each zone to oil spills. This index allows the integration of environmental considerations into the risk analysis. The ERI is defined as:

$$ERI = \sum FC[Q^{0.72}ESI + P_s Q_s^{0.72} ESI_s]$$

where F represent the frequency of spills, Q the quantity of oil, Q_s the quantity of oil reaching the shore and ESI_s, the environmental sensitivity index at the shoreline.

The 0.72 value (equation above) and the unit cost (C_U) = $42,906 (equation below) are rounded values from the Marine Environment Protection Committee study (MEPC, 2011) and converted into CAD$. The next section details how the C_U and the Q exponent are derived.

In practice, to make the spill rate explicit and in order to take into account the oil type, the ERI is calculated as:

$$ERI = F_{spill}(C_u C_t Q^{0.72} \times ESI \ + C_s P_s Q_s^{0.72} \times ESI_s)$$

In this equation, C_t represents the relative cost for the specific type of oil in the spill. Details of the relative oil spill costs are found in Table 3.16. The relative cost for the spill quantity (C_Q) is calculated by dividing the cost of a 1 tonne spill by the average cost of a 1 tonne spill (see values in Table 3.15) as follow:

$$C_Q = \frac{\sum FQ^{0.72}}{\sum FQ}$$

$$C_Q = \frac{\sum P_s {Q_s}^{0.72}}{\sum P_s Q_s}$$

Oil Weathering Influence

To properly assess the behaviour of an oil spill, environmental conditions such as average winds, temperature and wave activity must be considered. The model SLROM spill (see description in chapter 4 of this report) was applied for each zone. The end result of the model is the fraction of oil F_m (50%) remaining after T_m (hours). When F_m (50%) could not be reached, F_m was calculated using the longest time available (720 hours). This model run allowed for the calculation of the degradation rate of different fuel types as defined below:

$$H = \frac{-0.3T_m}{\log(F_m)}$$

Oil Drifting Influence on Cost Estimates

The next step was to calculate the time (T_{shore}) it would take to the spill to reach the shore for the average distance (D_{zone}) of each sub-sectors. In this study, D_{zone} was defined as:

- D_{zone} = 6 nm for the nearshore zone;
- D_{zone} = 18 nm for the intermediate zone;
- D_{zone} = 88 nm for the deep-sea zone.

The speed of drifting was estimated using a drifting factor of 3% (RV_{drift}) of the average wind speed for each zone (V_{wind}). Therefore, T_{shore} was calculated as:

$$T_{shore} = \frac{D_{zone}}{V_{wind}RV_{drift}}$$

Therefore the oil quantity reaching the shore (Q_s) as a factor of the total oil spill (Q) was estimated using the following equation:

$$Q_s = Q \times 2^{\frac{-T_{shore}}{H}}$$

In order to include the probability that the wind blows toward the coast, an estimation of the proportion of the time that the wind blows in a perpendicular direction to the coast was calculated for each sub-sector, using buoys data. Therefore, the probability of a spill reaching the shore (P_s) equals the general probability of a spill (P) multiplied by the probability of the wind reaching the shore (P_{wind}).

$$P_s = P_{wind} \times V_{wind}$$

Shore Length Affected

The average shore length affected by the spill adds significant costs to the cleanup costs of a volume of oil spilled in the ocean but cleaned before reaching the shore. The shore length (D_s) affected by the spill is estimated using the following equation:

$$D_s = \sqrt{\frac{4Q_s}{\pi \times t \times SG}}$$

Where:

- Q_s is the quantity of oil reaching the shore
- t is the plume thickness in meter (0.1 mm)
- SG is the specific gravity of the type of the oil spilled

Costs Effect of Oil Reaching the Shore

In the baseline scenario, where no oil reaches the shore, the overall cleaning cost of an oil spill (C_b) is calculated using:

$$C_b = C_u \times Q^{0.72}$$

Where:

- C_u is the cleaning cost of average crude oil
- Q is the total quantity spilled

The costs of spills affecting the shore length (D_s) relative to the costs where virtually no shore is affected is estimated in Etkin (2000) and DNV (2011):

$$C_s = C_b + 8 \times \frac{D_s}{1000}$$

3.3.2 Cost Component of the ERI (C_U and Exponent) and Justifications

The cost component of the overall ERI formula is extracted from the MEPC database, which is managed by the International Maritime Organisation (IMO). MEPC has constructed a spill database of costs related to marine oil spills using data from the United States government, the Norwegian government and the International Oil Pollution Compensation Fund (IOPCF).

This metric captures the total clean-up costs of an oil spill. Moreover, it includes some of the commercial losses and environmental damages. However, environmental damages are not comprehensively captured, which limits the use of the metric. Neither does it capture ship repair costs, loss or revenue of shipowners, fines and loss of oil. In this report, this metric is hence used to demonstrate the relative cost of an oil spill rather than an absolute cost. The use of this metric as a relative indicator instead of an absolute indicator limits the need to proceed with further adjustments.

As shown in Figure 3.5, there is a negative relation between oil spill size and oil spill costs as the result of the economy of scale obtained from larger spills. The resulting regression formula for spills larger than 0.1 t is derived as (Table 3.15):

$$C = 42{,}301Q^{-0.7233}$$

for C in USD$ and Q in tonnes

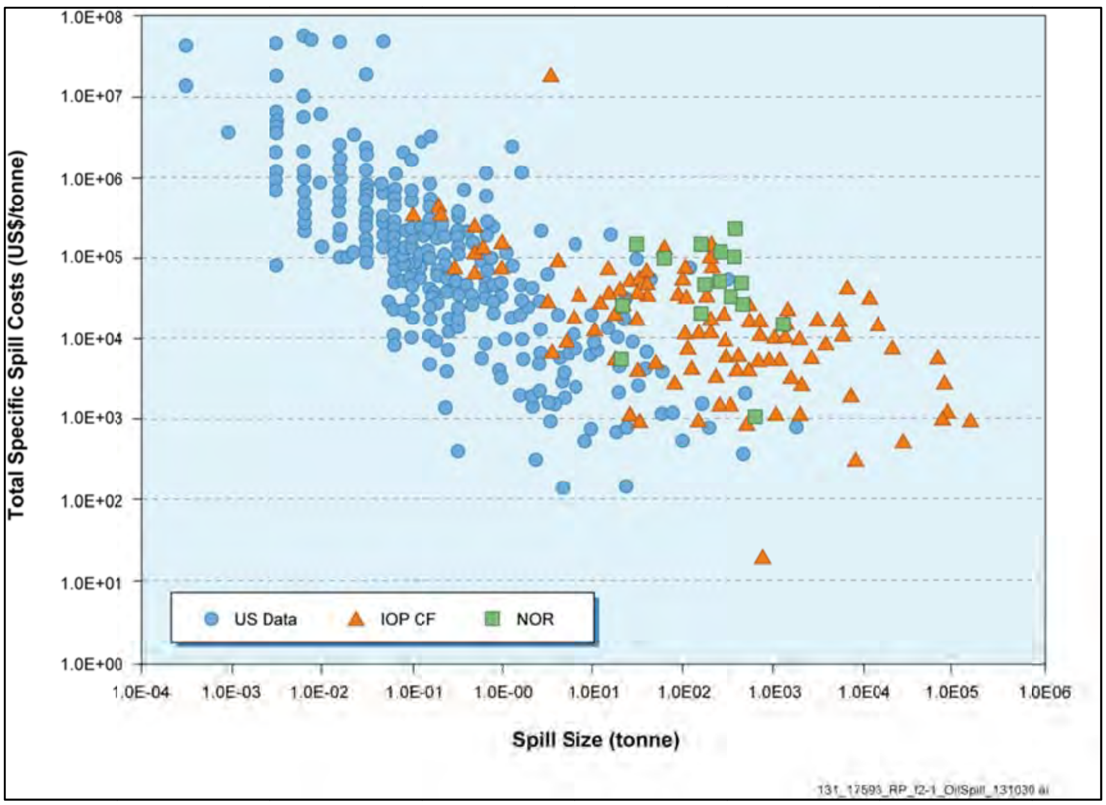


Figure 3.5 Specific Oil Spill Cost Data in 2009 USD (spill cost per tonne) (MEPC, 2011)

Table 3.15 Regressions Derived from the Consolidated Database and Converted in CAD$

Dataset	f(V) = Total Spill Cost, $CAD (TSC) (2009 USD)	Reference
All Spills	68,237 $V^{0.5893}$	MEPC 62/INF.24
V > 0.1 t	42,906 V^{07233}	MEPC 62/186

Sources: MEPC, 2011; DNV, 2011

Plotted in a graph, the all spills regression formula clearly demonstrates the decreasing per unit costs of clean-up as the volume of the spill increases caused by the economy of scale (Figure 3.6).

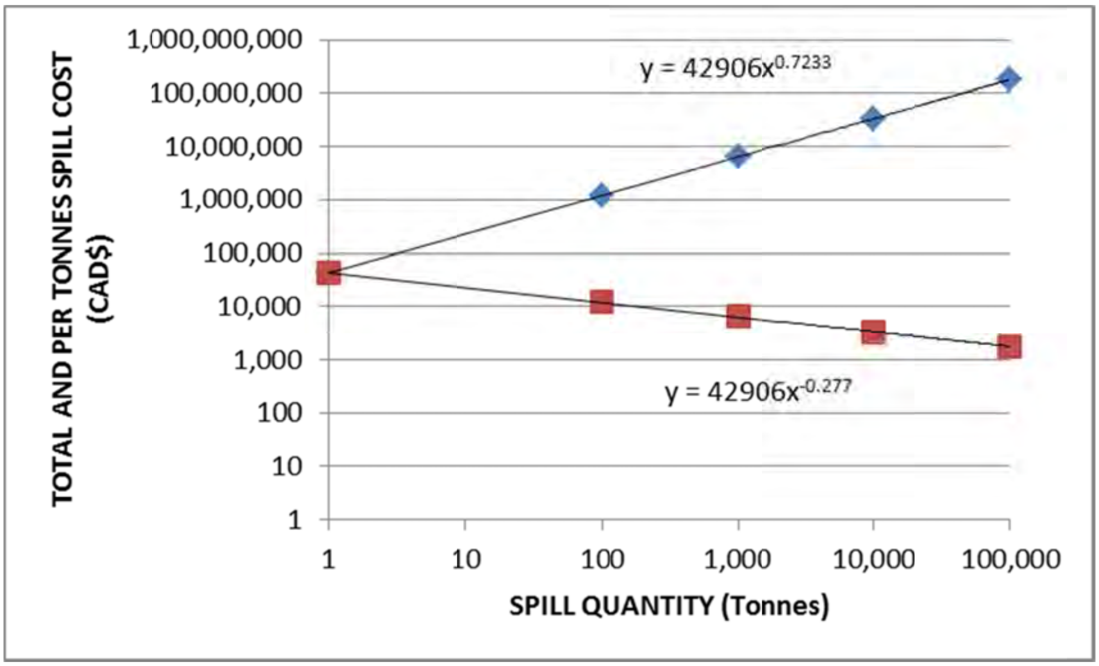


Figure 3.6 Total and Per Tonnes Spill Costs (CAD$) (GENIVAR, 2013, MEPC, 62/WP13)

3.3.3 Relative Oil Spill Factors (C_T)

The clean-up costs are significantly influenced by the type of oil. The following table presents an average of the clean-up costs per fuel type (Etkin, 2000). The baseline scenario is represented by the average crude oil (Table 3.16).

Table 3.16 Relative Oil Spill Clean-Up Costs per Tonne

Oil Type	Clean-Up Cost ($/t)	Relative Cost
Heavy Crude	$8,663	1.18
Average Crude	$7,354	1.00
Light Crude	$4,327	0.59
Diesel	$2,341	0.32
Heavy Fuel Oil	$17,194	2.34

Sources: Etkin, 2000; DNV, 2011

Lighter oils will tend to dissipate faster than heavier oils, thus reducing the labor and capital costs required for clean-up.

Clean-up costs are also very sensitive to the oil spill response from the authorities: a rapid intervention with the appropriate tools will significantly diminish the impacts of an incident. However, this study focuses on identifying relative spill risks without taking into account the response strategy.

4. CHARACTERISTICS OF OIL SPILLS CAUSED BY VESSEL TRAFFIC AND MAIN IMPACTS

4.1 Introduction

For the purposes of the estimation of the consequence portion of the risk assessment, a characterization of the potential spill effects is required. Knowledge of spill behavior is important to all aspects of spill response, and is particularly important in estimating spill effects. Crude and refined oil products vary widely in their properties and in their persistence in the marine environment. The proportions of various hydrocarbon compounds give a particular product its properties. Crude oils contain a wide range of compounds, from very light compounds such as dissolved gases (e.g., methane, propane) and light hydrocarbons (e.g. pentane, benzene) to heavy compounds such as waxes and asphaltenes. Crudes vary greatly in the relative proportion of these compounds, and because of this, their spill properties and behavior vary greatly. When spilled at sea, crude oils weather, generally selectively losing their lighter compounds, causing the oil's properties to change. Refined products include gasoline (from the lighter ends of the crude oil), diesel (a slightly heavier cut from the crude, also known as No.2 fuel oil) and residual fuel oils (also known as bunker fuels, No.6 fuel oil, IFO 380). This section describes the basic aspects of oil spill behaviour in terms of its likely fate in the marine environment.

As discussed in the spill frequency analysis, potential spill causes could include collisions, groundings, fire, explosion, strikings, structural failure, and loading/offloading operations. While these are considered separately in the frequency analysis, for the purposes of damage estimation, they will be considered collectively as a single entity (i.e. as a spill of oil released over a relatively short period of time).

Spill scenarios representing the selected spill size categories and oil types will be modeled using the proprietary SL Ross Oil Spill Model (SLROSM) to estimate the spill properties of interest over a period of up to 10 days. For modeling purposes, the spill size categories, selected based on considerations of the spill frequency analysis, are: 10; 100; 1,000; and 10,000 m^3. The oil types that will be considered in the scenario descriptions are:

- Oil carried as fuel, specifically marine diesel;
- Crude oil carried as cargo; and
- Refined product carried as cargo.

Modified bitumen products represent the majority of the "crude carried as cargo" in Pacific sub-sector 5. They are not modeled as a separate category in this spill behaviour analysis but are represented as “persistent crude”.

Changes in spill behaviour depend to some extent on the environmental conditions at the time of the spill, as described in greater detail below. However, over the range of wind and sea conditions typically experienced in the Canadian marine environment, changes in oil properties are not overly sensitive to variations in climatic values, so a single set of wind and sea conditions will be used in the analysis.

4.2 General Aspects of Spill Fate and Behavior

The fate and behavior of oil spilled at sea will be largely dependent on oil properties. These properties may in return be affected by different weathering processes. They are detailed hereafter.

4.2.1 Physical Properties of Oil

There are four key properties of interest:

- Density is a measure of the oil's weight per unit volume (commonly expressed in grams per millilitre (g/ml). Density is important as it determines whether the oil will sink or float when spilled on water. If the oil density is less than water – 1.0 g/ml for freshwater and about 1.03 g/ml for salt water – it floats, otherwise it sinks.
- Viscosity is a measure of a fluid's resistance to flow, (expressed in centipoise (cP)). Oil viscosity is critical in dispersant work because thin, non-viscous oils (<2,000 cP) are readily dispersible, but heavy, highly-viscous oils (>10,000 cP) oils are not. Viscosity is also important when recovering oil with skimmers and transferring it with pumps. For a given oil type, viscosity will be greater in cold waters.
- Surface Tension is an indicator of an oil's tendency to spread and disperse, and is measured in milliNewtons per metre (mN/m).
- Pour Point is a measure of the temperature below which oil will not flow. It represents the point at which the oil starts to solidify or gel as it cools and is measured in temperature units as either degrees Fahrenheit or Celsius.

4.2.2 Oil Weathering Processes

When oil is spilled at sea, it is subject to several weathering processes as illustrated in Figure 4.1. The main processes that will influence the persistence and environmental effects are drifting (advection), spreading, evaporation, oxidation, natural dispersion-dissolution of oil in water, water-in-oil emulsification and sedimentation).

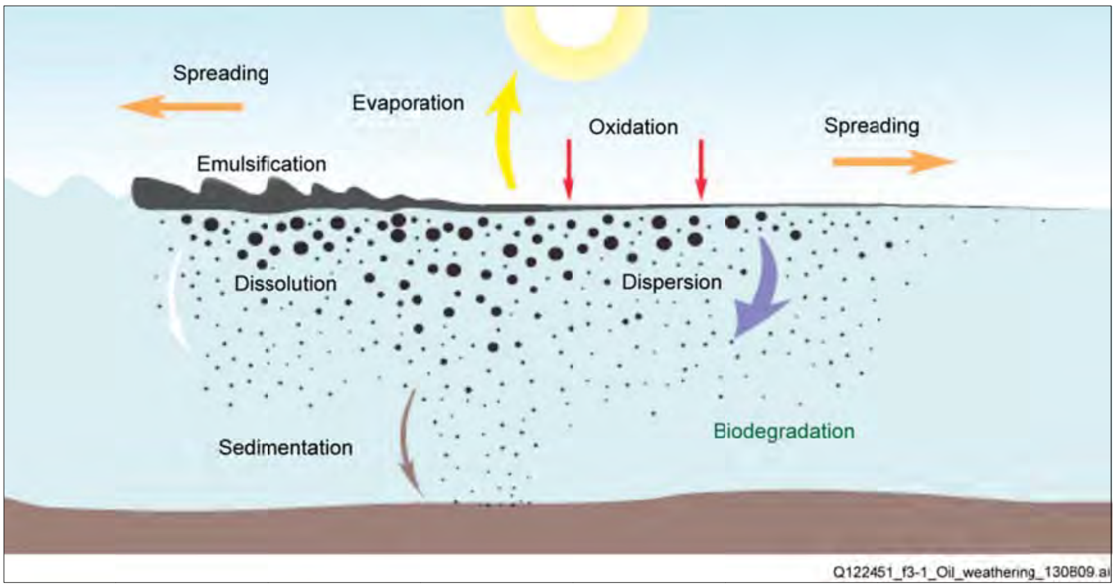


Figure 4.1 Oil Weathering Processes

4.2.2.1 Spreading

When oil is spilled on water, it spreads and thins, forming a thin slick. Spreading is important because it:

- Leads to large increases in the area of the spill; and
- Leads to decreases in the thickness of the spill.

Spreading curves can be used to provide a rough approximation of the spill area over time for a given spill volume. For a more accurate answer one must use computer-based models that may take into account additional variables such as changes in oil properties and wind and current effects. Whether spreading curves or computer modeling are used, they provide idealized or theoretical description of spreading, and are based on a continuous slick of uniform thickness. The most important difference in real life is that after the first few hours in the environment, an oil slick is seldom continuous and of uniform thickness.

The relatively fast rate of oil spreading is demonstrated in Figure 4.2. This model, which originated from a methodology first developed in the late 1970s, is still used extensively today.

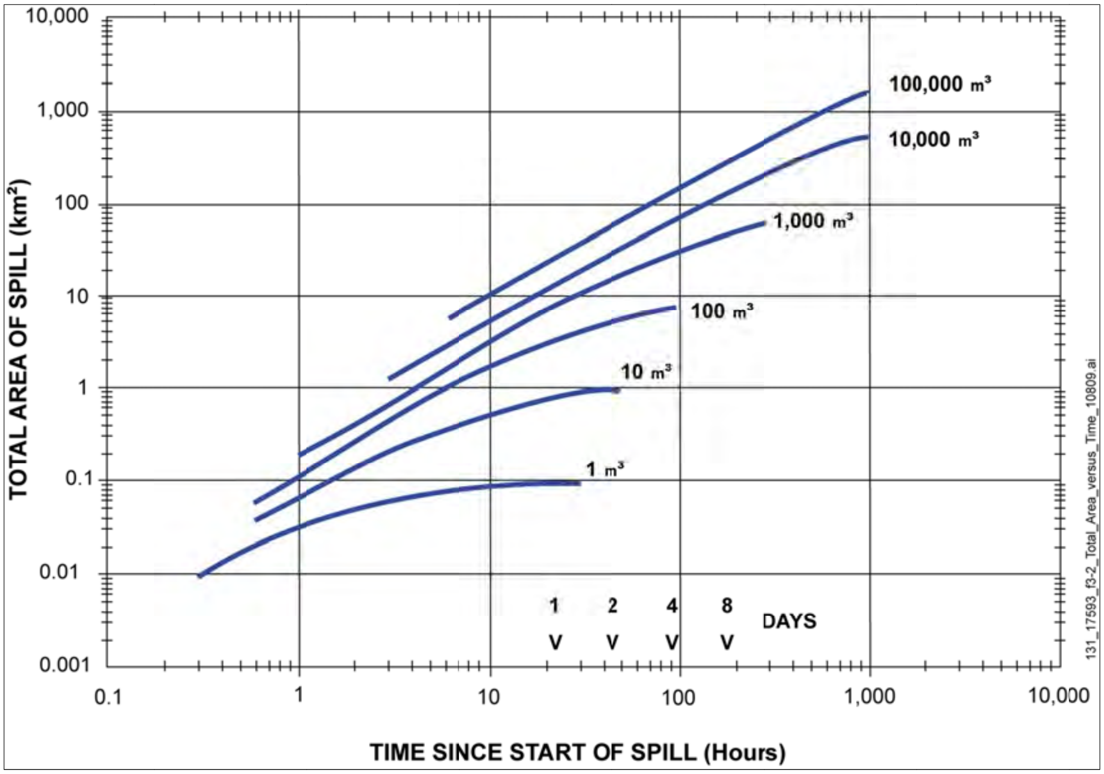


Figure 4.2 Total Area of Slick (thick + thin) versus Time

This figure shows that for a spill of 1,000 m^3 (6,300 barrels), the total slick area reaches about 10 km^2 in one or two days.

4.2.2.2 Spill Movement

As soon as oil is spilled, it starts to spread out over the sea surface. An oil slick is carried by the surface layer (the upper few centimetres) of water: the driving forces for this surface layer include wind, the local components of large-scale circulation patterns, tidal influences, and freshwater inflows.

An approximation of slick movement can be made using some very simple methods: a basic rule-of-thumb is that the slick will move at about 3% of the wind speed at 10 to 15 degrees to the right of the wind direction due to the Coriolis effect, with the speed and direction modified by the addition of other water currents. Other currents (tidal, freshwater influences) are added to the wind effects using vector addition.

Computer-based models can be used to estimate the movement of a spill, and they typically use a basic calculation procedure similar to this vector technique. The advantage of computer models is the ability to store and use large quantities of historical current and weather information that may vary for a specific location and the time of year. Note that the main problem in estimating slick movements during a spill is generally the unavailability or poor quality of local water current data, rather than a poor understanding of how a slick moves due to wind and current forces.

4.2.2.3 Evaporation

As soon as oil is spilled, the lighter, more volatile hydrocarbons begin to evaporate. This is important for two reasons. First, for crude oils and light refined oils, evaporation leads to a significant reduction in the total spill volume. Second, evaporation leads to changes in the properties of the oil, which in turn may affect other weathering processes such as dispersion and emulsification. The volatile light ends come out of solution when the oil is exposed to the atmosphere. It is the proportion of these light ends that will determine the evaporative potential of a given oil. Most crude oils and all light refined products, such as gasoline, have a high proportion of light ends that will tend to evaporate from a slick on open waters. On the other hand, heavier oils such as Bunker C have few light ends and will lose little to evaporation. Oil evaporation is controlled by several factors such as:

- Slick thickness – the thinner the slick, the greater the proportion of the slick is exposed to the atmosphere, and hence available for evaporation; therefore, the evaporation rate increases and the slick thickness declines;
- Temperature – oil will evaporate faster with higher temperatures, just as water evaporates faster on a hot day. Note that although evaporation rates will be decreased in cold temperatures, gasoline and most crude oils will still evaporate at freezing temperatures; and
- Wind speed – the greater the wind speed, the greater the potential evaporation rate.

These three factors can be modeled and used to make predictions based on the slick thickness, temperature, and wind speed for a given spill.

An example of evaporative loss for light refined products and crude oils is presented hereafter: for a slick of 1 mm or less, wind speeds of 20 km/h, and water temperatures of 5° C, the volume loss would be in the range of 25 to 30% within 12 hours, and up to 50% within one day.

Empirical evaporation curves can be useful to make rough estimations of evaporative loss; a more accurate calculation would require computer modeling that would take into account the change in slick thickness over time.

4.2.2.4 Oxidation

Oils react chemically with oxygen either breaking down into soluble products or forming persistent compounds called tars. This process is promoted by sunlight and the extent to which it occurs depends on the type of oil and the form in which it is exposed to sunlight. However, this process is very slow and even in strong sunlight, thin films of oil break down at no more than 0.1% per day. The formation of tars is caused by the oxidation of thick layers of high viscosity oils or emulsions. This process forms an outer protective coating of heavy compounds that result in the increased persistence of the oil as a whole.

4.2.2.5 Dispersion

Natural dispersion, as opposed to dispersion following the addition of chemical dispersing agents, can be an important process for oil removal from the water surface. Dispersion is a natural mixing process in which small droplets will tend to be permanently suspended in the water column, their natural buoyancy unable to overcome the forces of large scale mixing currents through the water body (Figure 4.3). Agitated sea conditions will enhance oil dispersion – which will help oil degradation by microorganisms. Oil dispersion can also be enhanced using natural or chemical dispersants.

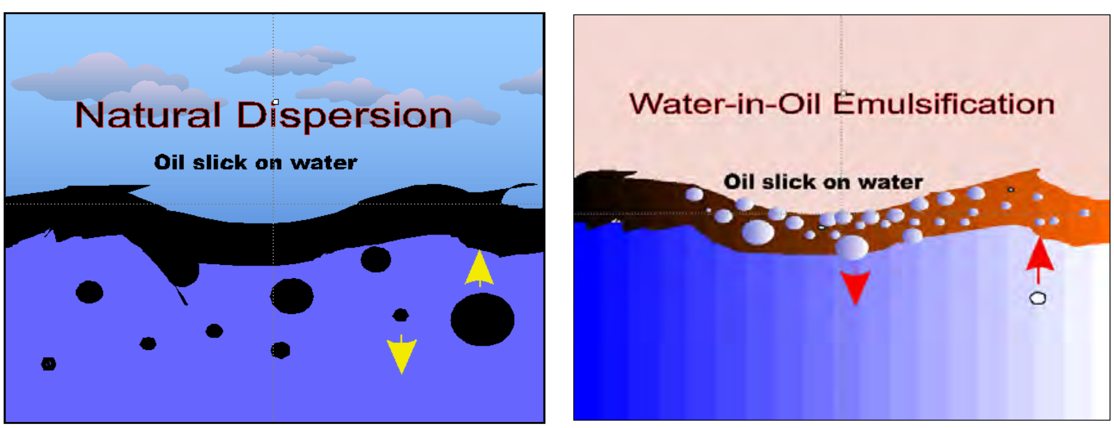


Figure 4.3 Natural Dispersion and Formation of Water-In-Oil Emulsion

4.2.2.6 Emulsification

Emulsification is important because:

- It is a process in which water droplets are incorporated into the slick, leading to increases in the total volume of spilled product between three and four times; and
- It leads to tremendous increases in the viscosity of the slick, which makes it resistant to natural and chemical dispersion and makes it more difficult to recover with skimmers and transfer with pumps.

Emulsification tends to compete with the dispersion process in that dispersion will essentially cease once oil emulsifies. Water droplets become entrained into oil slicks when resurfacing water droplets rise under and re-coalesce into a slick or when water is mixed directly into the slick by waves. In some oils, the emulsions formed are unstable and the water droplets themselves coalesce and settle out of the oil. However, in other oils, the emulsions are stabilized by asphaltenes and resins that accumulate on the surfaces of the water droplets, preventing them from coalescing.

Oils with an asphaltene content greater than 0.5% tend to form stable emulsions which may persist for many months after the initial spill has occurred. Those oils containing a lower percentage of asphaltenes are less likely to form emulsions and are more likely to disperse.

4.2.2.7 Sedimentation

Some heavy refined products have densities greater than one and so will sink in fresh or brackish water. Sinking mostly occurs due to the adhesion of particles of sediment or organic matter to the oil. Shallow waters are often laden with suspended solids providing favourable conditions for sedimentation. It has to be noted that when small oil droplets are coated with very fine minerals, they form oil-mineral-aggregates of neutral buoyancy which are easily degraded and dispersed in the marine environment.

4.2.2.8 Biodegradation

Micro-organisms or microbes in seawaters can partially or completely degrade oil to water soluble compounds and eventually to carbon dioxide and water. However, some compounds in oil may still not degrade. The main factors affecting the efficiency of biodegradation are the levels of nutrients (nitrogen and phosphorus) in the water, the water temperature and the ambient level of oxygen. The biodegradation process is thus more efficient at the oil-water interface due to the availability of oxygen. Oil droplets formation (either by natural or chemical dispersion), will enhance the surface area of the oil and increases biodegradation.

4.2.3 Summary

The above weathering processes and their effects on oil properties, fate and behavior are incorporated in the SLROSM. The model was be used for each of the identified scenarios to estimate the likely fate and behaviour of the spill.

From the perspective of potential environmental effects, the key parameters to be identified for each scenario are:

- Likely persistence of the spill: small spills of refined products may dissipate prior to oiling shorelines and affecting coastal resources;
- Extent of the spill over time: overall spill dimensions will determine the areal extent of coastal and shoreline effects;
- Potential movement of the spill given typical weather conditions for a given region in the study area.

4.3 Main Environmental, Economic and Social Impacts Associated with Marine Oil Spills

Ship-source oil spills can disturb the environment significantly and cause economic losses, upsetting the quality of life in coastal and inland water environments. Primarily due to the reinforcement of international laws and conventions, the total number and volume of tanker spills have considerably decreased since the 1970s despite an increase in hydrocarbon shipping (Boile *et al.,* 2005; Burgherr, 2007). According to Burgherr (2007), the total volume of oil from tanker spills was reduced by 56% from the 1970s to the 1980s and by 9% from the 1980s to the 1990s. Nevertheless, many spills are still occurring in ecologically and socio-economically sensitive areas as a consequence of trajectories of major transport routes.

An extensive review of potential environmental effects related to an accidental oil spill was carried out for the Government of Quebec, in the context of the *Strategic Environmental Assessment of Hydrocarbons Exploration and Development in the Anticosti, Madeleine and Baie des Chaleurs Basins* (SEA2) (GENIVAR, 2013). Even though this report's aim was to examine effects of hydrocarbons exploitation in Quebec's part of the Gulf of St. Lawrence and the Baie des Chaleurs, the review in its general form is highly pertinent for oil spills in all of the Canadian waters. For an in-depth discussion of environmental and socio-economic effects of potential oil spills, the reader is therefore referred to this report.

This chapter briefly assesses the potential environmental, economic and social effects of ship-related oil spills. In the following sub-sections, a brief overview of effects (magnitude, degree, etc.) is presented as well as the short-term and long-term effects of a potential oil spill.

4.3.1 Generalities

Before identifying the specific effects of an accidental oil spill, it is important to understand the particular conditions which may influence the magnitude, the degree, the nature and the duration of these effects.

The magnitude of effects caused by a spill is closely related to the characteristics of the receiving environment:

- Site-specific physical characteristics (e.g., shoreline habitat, sediment type, topography, currents, hydrology);
- Coastal resources in the area of influence of the spill;
- Physiological and behavioural characteristics of coastal resources (e.g., avoidance behaviour);
- Type and intensity of human activities.

The degree of effects is also related to the type and the volume of the spill and various exposure features:

- Chemical characteristics of oil types (e.g., toxicity, absorption rates of living organisms, etc.);
- Volume of the oil spilt and exposure concentrations in various media (e.g. air, water, sediments, soil and food);
- Exposure media category, such as a direct exposure (water, sediments and air) or an indirect exposure (food);
- Exposure duration (acute, chronic);
- Period of year when a spill occurs (related to the lifecycle of marine resources, the weathering of oil, etc.).

Additionally, the type and the effectiveness of the clean-up response will be decisive factors both in the nature of the environmental and socio-economic damages and on the intensity of these damages. Clean-up attempts (including both chemical and physical methods) can occasionally be more damaging to the natural environment than the oil itself, with indirect effects (especially due to trophic web interactions and biogenic habitat loss) that expand beyond the initial direct losses and delay the recovery process (Peterson *et al*., 2003; Vandermeulen and Ross, 1995; Zhu *et al*., 2004).

Large-scale spill events can result in effects that are both direct (e.g. acute-phase mortality of aquatic life, contamination of fishing gear, etc.) and indirect (e.g. chronic mortality due to ingestion of polluted food, bioaccumulation through the food web, contamination of drinking water intake sites, etc.). Indirect and chronic exposure effects on the natural environmental have been shown to sometimes persist for decades (Culbertsen *et al*., 2008a; 2008b; Peterson *et al*., 2003; Matkin *et al*., 2008), which can also be the case for socio-economic effects. In general terms, the magnitude of socio-economic effects is highly dependent on the intensity of the human activity in the surrounding environment of the oil spill, with more important effects found close to the urban areas, the productive fishery grounds as well as the recreational and touristic areas.

Additonalyy, effects on the natural habitats from oil spills occurring in freshwater will resemble those of marine spills (Steen *et al.,* 1999). However, spills in freshwater have a much higher potential of contaminating water supplies (surface as well as groundwater), affecting areas of concentrated populations, manmade structures and other human activities (NOAA, 1994).

4.3.2 Effects

The main potential environmental effects associated with oil spills are the contamination of the natural environment, as well as littoral and coastal infrastructures. Contamination could also alter the quality of fishery and aquaculture products and prompt significant negative socio-economic effects, especially for the commercial fishery and tourism industries that represent the main economic drivers in many Canadian coastal communities.

A list of potential effects associated with ship-related oil spills is provided in Table 4.1. Effects have been categorized as either short-term or long-term effects. The *Exxon Valdez* oil spill triggered an increase in available scientific literature on the subject. Many of the long-term effects listed are derived from research carried out after this event.

4.3.2.1 Short-Term Effects

During the acute exposure phase, floating oils, and to a lesser extent beached oils, are the primary stressors for aquatic resources that are in direct contact with oil, such as birds, marine and freshwater mammals as well as intertidal flora and fauna (Hartung, 1995). Oiling of fur or feathers causes loss of insulating capacity and can lead to death and mass mortality from hypothermia, drowning and ingestion of hydrocarbons (Peterson *et al*., 2003). Recent studies show that even small quantities of oil in the environment can induce mortality in aquatic birds (GENIVAR, 2013).

Effects related to oil spills are often difficult to evaluate: one to two years after the *Deepwater Horizon* spill in the USA, there was still no clear depiction of the short-term (and long-term) effects on habitats, marine organisms and fisheries (Sumaila *et al*., 2012; McCrea-Strub *et al*., 2011). Other specific uncertainty factors add to this difficulty, e.g. Williams *et al.* (2011) report an important underestimation of cetacean mortality related to oil pollution, as on average only 2% of carcasses are recovered. With regards to humans, effects measured in terms of economic losses vary greatly depending on how far reaching the assessment is carried out. As such, research on the economic losses related to the *Deepwater Horizon* incident indicated effects on fishery, tourism, and restaurant sectors as well as other service-based sectors (GENIVAR, 2013).

As stated previously, environmental effects are not only dependent on the volume of oil in the habitat, but also on the timing and the location of a spill in relation to lifecycles and habitat requirements of potentially affected species. Sensitivity of aquatic biota to hydrocarbon pollution is highly species-specific and relies on the physiological and behavioural characteristics, but also on the type of oil contaminating the environment. Due to the chemical composition of light crude oil, comprising of easily soluble toxic compounds, it is generally considered more toxic than heavy crude oil, but the latter can induce greater physical damages due to its high viscosity (Semelin, 2004). Also, species-specific variations to different types of oil can be important (Zhu *et al*., 2004). Generally, avoidance behaviour, observed for many marine birds, seals and cetaceans, can significantly reduce direct effects (Hartung, 1995). Sessile benthic species are relatively more sensitive, but the absence of avoidance behaviour has also been documented for some species of cetaceans (Matkin *et al*., 2008) and sea turtles (NOAA, 2010).

Other particular species-specific behaviours will also place certain aquatic fauna at a particular risk to petroleum pollution, as is the case for sea turtles with their indiscriminating feeding and inhalation of large volumes of air before dives (NOAA, 2010).

4.3.2.2 Long-Term Effects

Long-term effects are related to the persistence of oil in the environment (Section 4.2.2). The ingestion of contaminated food (such as oiled mussels), may represent the most important exposure pathway for aquatic fauna during a chronic phase. Chronic exposure to contaminated sediments is also important for fauna or vegetation.

The long-term effects of an oil spill also include the spinoffs on associated market sectors. Moreover, large-scale oil spills might have considerable long-term consequences on social structure and public health, interfering with traditions and causing cultural disruptions (GENIVAR, 2013; Ngaio and Sumaila, 2012).

The duration of effects depends on both ecological and market recovery times. Ecological recovery is measured by how quickly individuals and populations of species return to pre-spill conditions. It is determined by factors such as oil type, exposure duration, water temperature, degree of weathering, spill response and the individual and species-specific life history traits. In most environmental habitats, recovery is completed within 2-10 years after a spill event, but in some exceptional cases, such as in salt marshes, effects may be measurable for decades after the event (Kingston, 2002). In the case of the *Exxon Valdez* oil spill in Prince William Sound (Alaska, USA) in 1989, the persistence of sub-surface oil in sediments and its chronic exposure continues to affect some of the wildlife through delayed population reductions, indirect effects and trophic interactions 20 years beyond the acute phase of the spill (EVOSTC, 2010). Four decades after the oil spill In Wild Harbour (USA), *Spartina alterniflora* beds had a reduced stem density and biomass (Culbertsen *et al*., 2008a) and mussels in oiled locations showed decreased growth and filtration rates (Culbertsen *et al*., 2008b).

Long-term effects on the population in the aquatic environment (especially on mobile fauna) are especially difficult to confirm. Benthic invertebrates may be more at risk than fish species due to the fact that more or less sessile organisms are likely to suffer higher initial rates of mortality and exhibit long recovery times as a result of exposure to oil-saturated habitats (McCrea-Strub *et al*., 2011). Nearshore demersal fish can also suffer from long-term chronic exposure, as indicated in masked greenlings and crescent gunnels by biomarkers on hydrocarbons 10 years after the *Exxon Valdez* spill (Jewett *et al*., 2002). Mortality in sea ducks and sea turtles due to chronic exposure was also reported many years after the spill (Peterson *et al*., 2003; Jewett *et al*., 2002) and other results indicate that effects on cetacean populations can last beyond 20 years after the acute exposure phase (Matkin *et al*., 2008; EVOSTC, 2010).

Market recovery estimations are based on the time required for effected industries to be fully restored to pre-spill conditions (Sumaila *et al*., 2010). The length of time required is influenced by the duration of the aquatic area closures (e.g. commercial fisheries, recreational fisheries), the public perceptions on seafood safety and the perceived effects of the aesthetic quality of the environment. Even after the full ecological recovery of the aquatic resources, fisheries can be far from re-established, as is still the case for herring fisheries in the *Exxon Valdez* spill area (Sumaila *et al*., 2012; EVOSTC, 2010). As reviewed by GENIVAR (2013), negative perceptions associated with the quality of fishery products, even for fisheries that have not been contaminated and also for regions not directly affected by the spill, can be far more important than the direct economic losses. This also holds true for the tourism sector and all other related spinoff sectors.

Table 4.1 Potential Environmental and Socio-Economic Effects due to Oil Spills in Canadian Waters.

Component	Potential Effect	
	Short-Term	Long-Term
Environmental		
Sediment Quality	• Contamination of coastal sediments by hydrocarbons.	• Sediments may act as long-term reservoirs for biologically available hydrocarbons, implying the chronic exposure of toxic compounds to aquatic life (Peterson *et al*., 2003).
Water Quality	• Deterioration of water quality.	• Deterioration of water quality.
Riparian and Aquatic Vegetation	• Die-off caused by contact with oil spill or chemical products used to mitigate the oil spill (Zhu *et al*., 2004; Hatcher and Larkum, 1982). • Reproduction in population or growth-rate or abnormal growth after initial impact (Zhu *et al*., 2004). • Damage to the riparian habitats due to clean-up activities (Vandermeulen and Ross, 1995).	• Loss of habitat or flora species conducive to the presence of several wildlife species for feeding, shelter and spawning. • Chronic contamination of eelgrass beds growing in sheltered bays (Zhu *et al*., 2004; Culbertsen *et al.,* 2008a). • Modification of algal composition favoring opportunistic plants (EVOSTC, 1994).
Plankton	• Acute mortality of specimens in contact with oil spill (Almeda *et al*., 2013; GENIVAR, 2013). • Decrease of planktonic abundance and diversity (Almeda *et al*., 2013).	• Subletal effects on zooplankton including alterations in feeding, development and reproduction (Almeda *et al.,* 2013). • Bioaccumulation of oils in zooplankton leading to negative trophic interactions (Peterson *et al*., 2003; Almeda *et al.,* 2013).
Invertebrates	• High acute mortality of specimens in contact with oil spill (bilvalves, crabs, shrimps) (Sumaila *et al.,* 2010). • Mortality of eggs and larvae leading to the decrease in recruitment. • Decreased growth rate of invertebrate larvae (GENIVAR, 2013). • Alteration of composition and abundance of benthic fauna. • Mortality of intertidal or nearshore communities due to clean-up activities such as hot water and high pressure (EVOSTC, 1994).	• Chronic mortality of shellfish species that burrow in contaminated sediments. • Decrease of invertebrate abundance and diversity, food intake and growth rate (Culbertson *et al*., 2008a; 2008b). • Absorption, ingestion and bioaccumulation of hydrocarbons in organs and tissues making them unsuitable for consumption. • Contamination of invertebrates leading to negative trophic interactions (transfer of toxic compound to higher trophic levels). • Alteration of structural composition of invertebrate communities (privileging or more tolerant species). Note: Suspension-feeding clams and mussels concentrate and slowly metabolize hydrocarbons, which leads to chronically elevated tissue contamination (Peterson *et al*., 2003).

Table 4.1 (cont.) Potential Environmental and Socio-Economic Effects due to Oil Spills in Canadian Waters.

Component	Potential Effect	
	Short-Term	Long-Term
Environmental (cont.)		
Fishes	• Acute mortality of specimens in contact with oil spill, especially for nearshore fish (direct physical effects such as coating of gills and suffocation). • Diminution of abundance in heavily contaminated areas (avoidance behavior). • Reduction in food availability because of possible contamination of invertebrates, fish and plankton. • Mortality of eggs and larvae. • Altered natural behaviors related to predator avoidance or feeding.	• Chronic mortality of resident species (abnormal functioning of gills, increased hepatic enzymes, decreased growth, organ damage) (GENIVAR, 2013). • Ingestion and absorption of hydrocarbons in organs and tissues, which can make it unsuitable for consumption (GENIVAR, 2013). • Decrease in recruitment, food intake and growth rate. • Deterioration of the quality of spawning areas, feeding areas and shelters due to contaminated riparian habitats. • Reduced and altered embryo development (Peterson *et al.*, 2003, Murakamia *et al.*, 2008). • Long-term exposure of fish embryos to weathered oil (3- to 5-ringed PAHs) has population consequences through indirect effects on growth, deformities, and behavior with long-term consequences on mortality and reproduction (Peterson *et al.*, 2003). • Modified migratory pathways (IPIECA, 2007).
Mammals	• Acute mortality of specimens in contact with oil spill (especially young individuals and mammals with fur, such as sea-otters, seals or polar bears) (Williams *et al.*, 2011). • Reduction in food availability because of possible contamination of invertebrates, fish and plankton. • Diminution of abundance in heavily contaminated areas (avoidance behavior). • Relocation of population due to increased acoustic noise from clean-up vessels, decreased food availability, etc. (Ackleh and Loup, 2012). • Irritation of eyes and respiratory membranes (Hartung, 1995). • Reduction in filtration capacity (baleen whales). Note: Oil coats the furs of marine mammals with furs. This leads to a decrease in the fur's natural ability to insulate the animal's body, which may lead to hypothermia and possibly death in exposed animals.	• Increased mortality rates due to chronic exposures of resident species (Peterson *et al*., 2003). • Reduction in the size of mammal populations (Matkin *et al*., 2008). • Absorption of hydrocarbons in certain tissues and organs leading to sublethal effects. • Substantial effects over the long term through interactions between natural environmental stressors and compromised health of exposed animals, through chronic toxic exposure from ingesting contaminated prey or during foragin around persistent sedimentary pools of oil, and through disruption of vital social functions (Peterson *et al*., 2003).

Table 4.1 (cont.) Potential Environmental and Socio-Economic Effects due to Oil Spills in Canadian Waters.

Component	Potential Effect	
	Short-Term	Long-Term
Environmental (cont.)		
Reptiles	• Acute mortality of hatchlings, juveniles and adults in contact with oil spill (Howard, 2012; NOAA, 2003). • Reduction in food availability because of possible contamination or reduced abundance of invertebrates, fish and algae. • Reduced lung diffusion capacity. • Damaged eyelid and nasal tissue. • Damage to the skin, blood, digestive and immune systems, and salt glands. • Ingestion of tarballs causing starvation from gut blockage, decreased absorption efficiency, absorption of toxins, effects of general intestinal blockage (such as local necrosis or ulceration), interference with fat metabolism, and buoyancy problems caused by the build-up of fermentation gases (NOAA, 2003). Note: Lack of avoidance capacity (Lutcavage *et al.,* 1995) indiscriminate feeding in convergence zones and large predive inhalations increase sensitivity of sea-turtles to oil spills (NOAA, 2003).	• Absorption, ingestion and bioaccumulation of hydrocarbons in organs and tissues. • Reduced reproductive success: increased egg mortality and deformities (Howard, 2012). Note: Ingestion of tarballs by sea-turtles is well known. However, the consequences of chronic exposure to oil in the form of ingested tarballs is not well documented (NOAA, 2003).
Birds	• Acute mortality of specimens in contact with oil spill (especially diving birds and shorebirds) due to alteration of buoyancy (leading to drowning) or reduced thermal insulation causing hypothermia (Hartung, 1995). • Mortality due to excessive preening leading to ingestion of oil. • Starvation due to increase in energy demands (Hartung, 1995). • Mortality of chicks due to parenting failure (mortality of adults).	• Increased mortality rates due to chronic exposures (Peterson *et al.*, 2003). • Ingestion of food leading to absorption of hydrocarbons in certain tissues and organs (Hartung, 1995). • Ingested oil can cause lethal and sublethal effects including damage to the liver, pneumonia and brain damage (Hartung, 1995). • Reduction of nesting and feeding areas due to contaminated riparian and pelagic habitats.

Table 4.1 (cont.) Potential Environmental and Socio-Economic Effects due to Oil Spills in Canadian Waters.

Component	Potential Effect	
	Short-Term	Long-Term
Environmental (cont.)		
Birds (cont.)		• Reduced reproductive success (reduction of fertility, egg laying and hatching, abandon of nests, and alteration of parental behavior). • Contamination of eggs in nests which leads to mortality of chicks or abnormalities. • Reduced chick growth. • Reduction in mean eggshell thickness and strength (Stubblefield *et al.*, 1995). • Substantial impacts over the long term through interactions between natural environmental stressors and compromised health of exposed animals, through chronic toxic exposure from ingesting contaminated prey or during foraging around persistent sedimentary pools of oil, and through disruption of vital social functions in socially organized species (Peterson *et al.*, 2003).
Economic		
Commercial Fisheries, Aquaculture Sealing and Related Spinoff Sectors	• Reduced fish catches (value or quantity). • Alteration of the quality of crustaceans, molluscs, fish and farmed stocks that make them unsuitable for consumption (IPIECA, 2007). • Soiling and contamination of fishing gear, vessels and aquaculture facilities (until complete disappearance of oil from the region) resulting in an increase in operation costs (additional cleaning and maintenance costs; GENIVAR, 2013). • Reduced income due to the suspension of fishing and hunting (polluted zones and presence of clean-up activities; GENIVAR, 2013). • Decreased income from seal hunting due to loss of value of stained seal furs, if it is still always possible to go hunting. • Reduced or suspended activity for seafood and fish transformation plants requiring pumped (non-contaminated) water for operations.	• Tainting and associated economic effects: negative perception associated with the quality of fishery products, even for regional fisheries that have not been contaminated (GENIVAR, 2013). • Decrease of the current year's spat collection and loss of production in the medium term (aquaculture). • Decrease in economic spinoffs for certain sectors (seafood processing, marketing, transportation, wholesale, retail and services, etc.). • Increased vessel costs for fishermen due to increased distances to resources (relocation of resources and fishing) (IPIECA, 2007).

Table 4.1 (cont.) Potential Environmental and Socio-Economic Effects due to Oil Spills in Canadian Waters.

Component	Potential Effect	
	Short-Term	Long-Term
Economic (cont.)		
Shipping	• Significant increase in regional maritime and inland waterway traffic caused by the activities of containment, clean-up and recovery made by boat. • Disruption or delays of port activities due to contaminated waters or infrastructures. • Interruption or delays of shipping due to contaminated waters in seaways. • Interruption of shipping in case of contaminated ship hulls (Stratfor, 2010).	n/a
Employment and Investment	• Significant loss of income and employment for communities whose economy is mainly based on fishing and tourism. • Increased costs associated with the practice of certain activities, such as fishing. • Decreased revenue to ferry service providers (reduced tourism) or increased revenue due to ferry traffic from spill clean-up crews.	• Significant loss of income and employment for communities whose economy is mainly based on fishing and tourism. • Significant loss of income for all spin-off sectors related to fisheries and tourism (GENIVAR, 2013).
Tourism and Recreation	• Interference with touristic and recreational activities (whale watching excursion, scuba diving, sailing, sea kayak, etc.). • Decline in recreational fishing (closures, fear of contamination, unavailability of boats and congestion at sites outside the affected area) (EVOSTC, 1994). • Decreased revenue to ferry service providers.	• Decrease of the economic spinoffs of the sector. • Displacement of touristic and recreational activities to neighbouring (non-contaminated) coastal or inland water communities or possible decrease of tourism also in these regions due to regional tainting (GENIVAR, 2013). • Decreased in cruise-related tourism. • Decline in recreational fishing: closures, fear of contamination, unavailability of boats and congestion at sites outside the affected area (EVOSTC, 1994; Butler and Sayre, 2010).
Social		
Aboriginal’s Use	• Interference with Aboriginal marine use activities.	• Decrease of the economic spinoffs associated with commercial fisheries. • Decrease of traditional fishing holding spiritual and cultural significance (affecting the social, cultural, educational and other benefits from activity) (Ngaio and Sumaila, 2012). • Cultural dislocation, psychological stress and disruption of social infrastructure (Ngail and Sumaila, 2012). • Health of population directly affected.

Table 4.1 (cont.) Potential Environmental and Socio-Economic Effects due to Oil Spills in Canadian Waters.

Component	Potential Effect	
	Short-Term	Long-Term
Social (cont.)		
Landscape	• Spoiling of aesthetic quality and disruptive activities of clean-up crews. • Alteration of the landscape quality.	• Alteration of the integrity of coastal and sub-marine archaeological resources and heritage sites (listed or not) (GENIVAR, 2013). • Persistent sub-surface reservoirs of petroleum drifting on beaches (GENIVAR, 2013).
Health and Quality of Life	• Increased psychological stress (due to oil spill) resulting in direct health effects such as stomach aches, headaches, and insomnia (GENIVAR, 2013).	• Cultural dislocation, psychological stress and disruption of social infrastructure (Ngaio and Sumaila, 2012). • Health of population directly affected (anxiety, post-traumatic stress disorder, depression, etc.) (GENIVAR, 2013; Ngaio and Sumaila, 2012).

5. PACIFIC COAST

5.1 Sector Description

5.1.1 Physical Features

Pacific Canadian waters lie in a transition zone between coastal upwelling (California Current) and downwelling (Alaskan Coastal Current) regions, and experience strong seasonality and considerable freshwater influence. Variability is closely coupled with events and conditions throughout the tropical and North Pacific Ocean, experiencing frequent El Niño and La Niña events particularly over the past decade (DFO, 2012). However, there exist some particular characteristics associated with certain areas of the Pacific Coast, such as in the North coast and in Hecate Strait, in the western coast of Vancouver Island as well as in the Georgia Strait.

The North Coast and Hecate Strait are coastal areas located along the eastern boundary of the sub-polar northeast Pacific Ocean (Map 5.1). This part of sector 1 (Pacific coast) is adjacent to the large-scale cyclonic circulation of the sub-polar gyre, in particular the sluggish Alaska Current which flows northward towards the head of the Gulf of Alaska. Within this area, the circulation of the waters of the Hecate Strait and the broad shelf of Queen Charlotte Sound is dominated by seasonally-reversing, wind-driven flows, as well as buoyancy-driven currents due to the coastal freshwater discharge. At the shelf break, downwelling winds dominate throughout much of the year, disrupted by a short period of upwelling during summer months. Mesoscale eddies form over the shelf and propagate westward to the deep ocean which leads to a significant exchange of fluid with the deep ocean, transporting nutrients from the shelf into the sub-polar gyre (DFO, 2010; Cummins and Haigh, 2010).

The area of the western Coast of Vancouver Island generally includes the transition zone between two eastern boundary current systems (i.e. the California Current and the Alaska Current), on the west coast of North America (Map 5.1). Over the mid and outer shelves, surface water flow is southward in the summer and northward in the winter in response to the large scale pressure systems and their associated winds. Over the inner shelf there is a northward flowing buoyancy current that is present throughout the year (i.e. the Vancouver Island Coastal Current) that brings nutrient-rich waters into this part of sector 1 from the Juan de Fuca Strait. Wind patterns cause upwelling during the summer and downwelling in the winter. This physical circulation drives both the chemical and biological systems of the area (DFO, 2010).

The Strait of Georgia is a semi-enclosed sea located between Vancouver Island and mainland British Columbia (Map 5.1). Water circulation in the Strait is dominated by estuarine exchange (out at the surface, in at depth) and by tidal and wind mixing.

The Strait is highly productive, supporting commercial, Aboriginal and recreational fisheries. It is also surrounded by a growing urban population, which is putting pressure on the ecosystem of the Strait. Global climate change acts locally through changes in seawater and river temperatures, in the oxygen concentration and pH of inflowing deep water and in the timing of river discharges. Other changes have resulted from local human activities, such as shipping, fishing, discharge of contaminants and habitat destruction, including the construction of hard edges, which will interact with sea level rise (Johannessen and McCarter, 2010; DFO, 2010).

Finally, more than 50% of the entire sector’s shoreline corresponds to rock cliffs (30.5%) and rock with gravel or sand beach (21.9%). The others shoreline types which are significantly abundant in this sector are rock, sand and gravel beaches (13.2%) as well as sand and gravel beaches or flats (10.8%) (Map 5.1). Based on the 1981-2010 February ice-covered data, the entire sector has no ice-cover throughout the year.

5.1.2 Biological Features

Pacific Canadian waters support important resident and migratory populations of invertebrates, demersal and pelagic fishes, marine mammals and seabirds.

Phytoplankton is found at the base of all aquatic food weds. The carrying capacity of marine ecosystems (e.g. diversity, abundance and recruitment) is highly dependent on variations in the abundance, timing and composition of plankton. Phytoplankton also plays a crucial role in climate change through the export of fixed carbon dioxide during photosynthesis towards the deep oceans.

There are 33 Ecologically and Biologically Significant Areas (EBSAs) identified by DFO in the Pacific Coast sector (Map 5.1). They are respectively located in the Northern shelf ecoregion (18 EBSAs) and in the southern shelf ecoregion (15 EBSAs). Essentially, these EBSAs are used as feeding, reproductive and wintering area as well as migratory corridors by meroplankton, invertebrates, fishes and marine mammals, including special-status species. Among these EBSAs, the entire Strait of Georgia is important for several species of fish, notably anadromous salmonids which rear in the Strait and undertake migrations to and from other coastal and oceanic regions in the Pacific Ocean through Johnstone Strait and Juan de Fuca Strait. Also, the nearshore areas along the west coast of Vancouver Island are important for local species and for feeding by migrating grey whales (DFO, 2013).

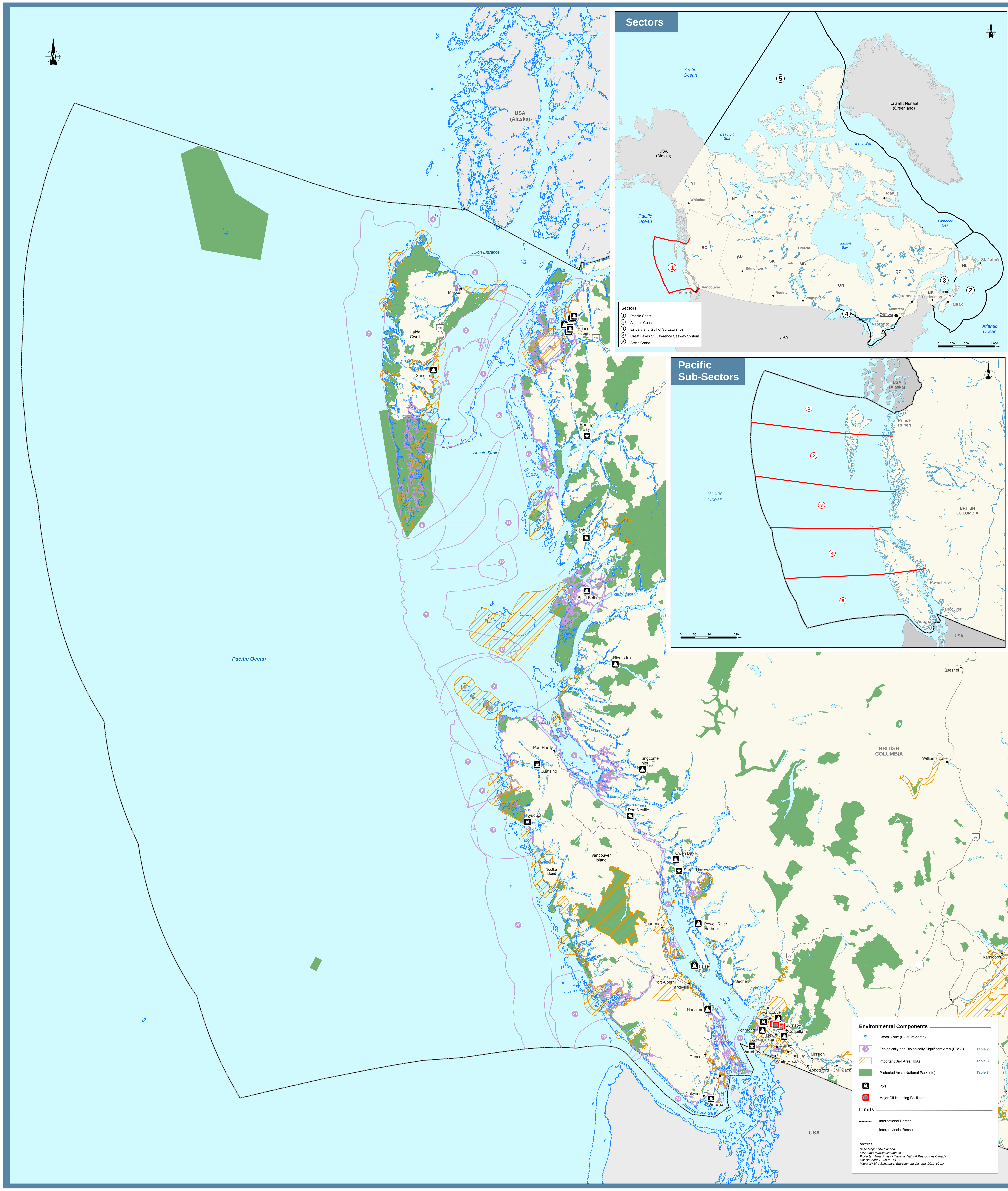


Table 1 Shoreline Types and Distribution

Shoreline Type	Length (km)	Proportion (%)
Channel	59.3	0.1
Estuary, Marsh and Lagoon	2,269.1	6.0
Gravel Beach or Flat	1,571.6	4.2
Man-made Structure	445.8	1.2
Mud Flat	179.5	0.5
Not Classified	1,381.5	3.7
Rock Cliff	11,474.7	30.5
Rock Platform	747.5	2.0
Rock, Sand and Gravel Beach	4,985.3	13.2
Rock with Gravel or Sand Beach	8,228.6	21.9
Sand Beach or Flat	2,228.8	5.9
Sand and Gravel Beach or Flat	4,052.8	10.8
Total Shoreline in the Pacific Sector	**37,614.5**	**100.0**

Source: Environment Canada, 2013

Table 2 Characteristics of Ecologically and Biologically Significant Areas (EBSA).

EBSA	Particular Characteristics
NORTHERN SHELF ECOREGION	
1. Hecate Strait Front	• Aggregation of zooplankton.
2. McIntyre Bay	• Aggregation of zooplankton, marine birds, eulachon, razor clams, Dungeness crabs and Weathervane scallops. • Rearing area for halibut. • Presence of northern killer whales during the summer. • Feeding area for humpback whale.
3. Dogfish Bank	• Aggregation of marine birds and Dungeness crabs. • Larval rearing area for many invertebrate species. • Rearing area for Pacific cod and flatfish.
4. Learmonth Bank	• Aggregation of phytoplankton. • Foraging area for marine birds. • Large aggregations of corals and fin whales.
5. Brooks Peninsula	• Aggregation of sea otters, green sturgeon and Olympia oysters. • Breeding and rearing area for marine birds. • Spawning and rearing area for lingcod.
6. Cape St. James	• Aggregation of halibut, corals, rockfish, blue whale, sei whale and fin whale. • Pupping and foraging area for Steller sea lion. • Feeding area for marine birds.
7. Shelf Break	• Aggregation of Pacific hake (in warmer years), corals, sponges and tanner crab (high bycatch). • Marine bird colonies and foraging area. • Feeding area and migratory route for sperm whale, fin whale, blue whale and sei whale. • Foraging area for humpback whale, fur seal and eulachon. • Spawning area for sablefish, Dover sole and rockfish (Pacific ocean perch, yellowtail and yellowmouth).
8. Scott Islands	• Aggregation of sea otters. • Key breeding area for marine birds. • Foraging and migration route for gray whale. • Feeding area for humpback whale. • Breeding area for Steller sea lion. • Spawning and rearing area for Pacific cod, lingcod and sablefish. • Foraging area for Pacific hake (warm years) and herring (summer).
9. North Island Straits	• Foraging area for resident killer whale (summer to fall) and gray whale. • Aggregation of humpback whale, shrimp, green sea urchins and sea otters. • Migratory route for salmon and herring. • Breeding area for marine birds.
10 to 13. Sponge Reefs	• Presence of reef-building hexactinelid sponges (globally unique).
14. Chatham Sound	• Staging area for black and white winged scoters during migrations. • Aggregation of green sea urchins (Prince Rupert area), Dungeness crab and shrimps. • Spawning area for herring. • Feeding area for resident killer whale (summer) and humpback whale (summer to fall).
15. Haida Gwaii Nearshore	• Aggregation of fin whale, humpback whale, red urchins and sea cucumber. • Spawning area for herring. • Foraging area for Pacific cod. • Important area for Steller sea lion pupping and northern abalone aggregations.
16. Central Mainland	• Aggregation of sea otters. • Steller sea lion rookery. • Moulting and sheltering areas for marine birds (sooty shearwaters). • Feeding area for northern killer whale, fin whale and humpback whale. • Important area for gray whale migrations.
17. Bella Bella Nearshore	• Aggregation of sea otters, geoducks, red urchins, sea cucumbers, manila clams, shrimps and northern killer whale. • Spawning and rearing area for herring.
18. River Mouths and Estuaries	• Aggregation of salmon and eulachon.
SOUTHERN SHELF ECOREGION	
19. Brooks Peninsula	• Aggregation of marine birds, sea otters, corals, sponges, tanner crab and smooth pink shrimp. • Migratory routes for blue whale, sperm whale, sei whale, fin whale, humpback whale, gray whale, green sturgeon and Pacific hake. • Foraging and migration route for sardine and juvenile salmon. • Foraging and haulout sites for Steller sea lion. • Spawning and rearing area for herring. • Petrale sole winter spawning and summer distribution.
20. Shelf Break	• Presence of Pacific sleeper sharks and basking shark. • Aggregation of big skate, longnose skate, sandpaper skate, English sole, corals, sponges and smooth pink shrimp. • Migration and foraging area for sardine and juvenile salmon. • Migration area for Pacific hake. • Foraging area for marine birds, blue whale, sei whale, sperm whale, fin whale, fur seal and Steller sea lion. • Important feeding area for humpback whale, herring and eulachon. • Spawning area for Dover sole and petrale sole.
21. Continental Shelf off of Barkley Sound	• Aggregation of green sturgeon, Dungeness crab and shrimp (five species). • Migration route and feeding area for gray whale (summer) and eulachon (offshore). • Foraging area for pelagic marine birds, humpback whale, southern resident killer whale, harbour porpoise (summer), northern fur seal and Pacific hake. • Foraging and haulout area for Steller sea lion. • Spawning, rearing and foraging area for herring, sand lance, sardine and Pacific cod.
22. Juan de Fuca Eddy	• Aggregation of harbour porpoise, gray whale, northern fur seal, green sturgeon, basking shark, Dover sole, petrale sole and shrimps. • Foraging area for marine birds, southern resident killer whale, humpback whale, eulachon, sardine, Pacific hake and herring. • Foraging and haulout for Steller sea lion. • Migration route and foraging for juvenile salmon. • Spawning area for sand lance.
23. Barkley Sound and Alberni Inlet	• Presence of Pacific hake (resident) inshore stocks. • Aggregation of Pacific loons and ducks (winter), pelagic seabirds (pigeon guillemots, marbled murrelets), basking shark, Olympia oyster, Pacific oyster and shrimp. • Migration route for green sturgeon and adult and juvenile salmon. • Wintering and foraging area for surf scoters. • Nesting area for gull and pelagic cormorants. • Foraging area for resident gray whale, humpback whale, harbour seal, Steller sea lion, sardine and adult and juvenile salmon. • Spawning and foraging area for herring.
24. Juan de Fuca Strait	• Presence of southern resident killer whale critical habitat. • Aggregation of harbour porpoise, Dover sole (summer), Pacific hake, green sea urchins and Dungeness crabs. • Migration route for eulachon, juvenile and adult Pacific salmon. • Foraging area for resident gray whale, juvenile and adult Pacific salmon. • Spawning and migration route for herring.
25. River Mouths and Estuaries	• Presence of salmon and marine birds.
STRAIT OF GEORGIA ECOREGION	
26. Strait of Georgia	• Rearing for juvenile salmon.
27. Discovery Passage	• High densities of green urchin, spiny and pink scallops. • Foraging and haulout area for harbour seals. • Rearing and spawning area for herring. • Migration route for salmon.
28. Desolation Sound and Pendrell Sound	• Aggregation of purple-hinged rock scallop. • Wintering habitat for surf scoters. • Breeding area for marbled murrelets. • Migration routes for juvenile and adult salmon. • Rearing and spawning area for herring. • Foraging area for hake. • Pacific oyster recruitment.
29. Baynes Sound	• High density of butter clam. • Staging area for marine birds (e.g. brant, harlequin ducks). • Foraging and haulout area for Steller sea lion. • Spawning and rearing area for herring.
30. Southern Gulf Islands	• Presence of seven glass sponge reef complexes. • High densities of harbour porpoise (summer), green sea urchin, pink and spiny scallops, Tanner crab and Dungeness crabs. • Critical habitat for southern resident killer whales. • Foraging and haulout area for harbour seals. • Rearing areas for juvenile salmon, herrings and possibly eulachon. • Spawning area for herring.
31. Fraser River Estuary and Boundary Bay	• Presence of glass sponge reef. • High abundance of harbour porpoise, Dungeness crab, shrimp and anadromous species. • Critical habitat for southern resident killer whales. • Foraging and haulout area for harbour seals. • Rearing area for juvenile salmon, eulachon and herring. • Spawning area for herring and walleye Pollock.
32. Sponge Reefs	• Presence of 16 glass sponge reef complexes in the Strait of Georgia.
33. All River Mouths and Estuaries	• Aggregations of anadromous species. • Staging and migration route for anadromous species (salmon and eulachon). • Foraging area for marine birds and mammals.

Source: DFO, 2013.

Table 3 Type of Marine and Coastal Protected Area

Protected Area Type	Number	Surface Area (km^2)
International Designation		
Important Bird Area (IBA)	66	14,627.6
Federal Designation		
Migratory Bird Sanctuary	7	25.0
National Marine Conservation Area	1	3,386.2
National Park of Canada	3	354.2
National Wildlife Area	3	4.3
Marine Protected Area	1	5,921.8
British Columbia Designation		
Conservancy	93	11,274.0
Ecological Reserve	41	638.4
Protected Area	5	40.9
Provincial Park (Class A)	168	5,550.1
Wildlife Management Area	11	228.9
Total	**399**	**42,051.4**

Table 4 Demographic and Economic Overview

Total Coastal Population (2011)	3,167,545 inhabitants
British Columbia	
Population	3,167,545 inhabitants
Urban Centers	Vancouver, Prince George and Victoria
Key Economic Sectors	Tourism, commercial fisheries and forestry.

Source: Statistics Canada, 2013; Canadian Encyclopedia, 2013

Risk Assessment for Marine Spills in Canadian Waters

Phase 1: Oil Spills Risk Assessment

Pacific – Sector 1

1 : 1 500 000

0 15 30 60 90 km

January 2014

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Map 5.1

Most of the sea birds use the Pacific Coast for feeding, resting and breeding. Their distribution is a function of the presence of fishes (e.g. eulakane) on which they feed. In this sector, the more abundant colonial birds are the Cassin's Auklet and the Ancient Murrelet (NABCI-Canada, 2013).

The coastal zone (0-50 m depth) includes a number of ecosystems of small extent that have particularly high biodiversity as well as high primary and secondary production, and therefore are important for wildlife and humans using these resources, including wetlands and eelgrass beds. It is also a reproductive, feeding and wintering area for some marine species, such as fish and marine mammals.

5.1.3 Human Features

The coastal zone ecosystem is exposed to a wide variety of human pressures and uses (e.g. aquaculture, habitat destruction, addition of nutrients and contaminants, maritime shipping and commercial fishing) that pose a significant threat to its ecological integrity and sustainability.

Essentially, the coastal zone of the Pacific coast counts some localities, with urban centres, such as Vancouver, Prince George and Victoria (British Columbia). The coastal population was approximately 3,167,500 inhabitants in 2011 (Map 5.1).

The Pacific Coast's key economic sectors are tourism, commercial fisheries and forestry. This sector includes the most important number of finfish and shellfish aquaculture sites in Canada. This industry had a 2011-production of $465 million for British-Columbia with over 95% of the production aimed at finfish farming. For the entire province, the commercial landing value of fishing in 2011 topped $273 millions. Important all over coastal British-Columbia, the tourism industry represents a large part of the province economy. The major port locations are found in the Vancouver and Prince Rupert areas.

Due to high habitat and wildlife diversity in the coastal zone, many areas have been protected by international, federal or provincial regulations. A total of 399 protected areas are present in the Pacific coast, which occupy 42,051 km^2. They include important bird areas (IBAs), migratory bird sanctuaries, national marine conservation areas, national parks of Canada, national wildlife areas, marine protected areas, conservancies, ecological reserves, protected areas, provincial parks and wildlife management areas (Map 5.1).

5.2 Vessel Traffic Description

The following description and tables summarize the estimated spill frequency for the Pacific Coast sector and its sub-sectors. Tables 5.1 to 5.3 are presented indicating the potential spill frequency for each of the three oil type (crude oil cargo, refined oil cargo, and oil carried as fuel), for each of the four spill size ranges, with a breakdown per sub-sector and zone (nearshore, intermediate and deep-sea). Summary maps indicate the combined frequency for all spill sizes and zone per oil type (Map 5.2).

For ease of comparison, the summary tables are presented with frequency as “return periods”, or average number of years between events.

For the nearshore and intermediate zones, only sub-sector 5 has a significant potential spill frequency (PSF) for crude oil cargo, reflecting the inexistence of transportation in the other four regions. The deep-sea zones in all five sub-sectors do have a significant PSF given that a substantial number of tankers transit from Alaska to Washington State. The nearshore and intermediate zones of sub-sector 5 also reflect this added PSF from U.S. traffic, making sub-sector 5 comparable to some of the heavily-trafficked sub-sectors in Eastern Canada.

For refined product cargo and fuel spills, sub-sector 5 dwarfs the other Pacific sub-sectors, reflecting the substantial traffic of refined products throughout sub-sector 5 as well as the overall level of marine traffic in the case of fuel spills. Indeed, the PSF for fuel spills in sub-sector 5 is the highest in the country (i.e., shortest return period).

5.3 Overall Risk Results

The Environmental Risk Index (ERI) has been calculated for each oil type (crude oil, refined products and fuel), along a gradient of spill volumes (4 classes from 10 to 10,000 m^3). The following maps illustrate ERI values according to five categories or risk (from very low to very high). The definition of the categories involves a natural break calculation using ArcGIS (Table 5.4). Based on this method, class breaks are chosen in function of the best grouping of similar values and in order to maximize the difference between classes. A detailed map was produced for each zone and the following sub-sections provide an overview of the ERI results for each map.

Table 5.1 Cargo Crude Return Periods

Sub-sector	Cargo Crude Return Periods (years)											
	Nearshore Zone (0-12 nm)				Intermediate Zone (12-24 nm)				Deep-sea Zone (24-200 nm)			
	S	M	L	XL	S	M	L	XL	S	M	L	XL
1	16,728,924	24,984,757	18,622,898	87,446,650	21,508,617	32,123,259	23,943,726	112,431,407	2,653	3,962	2,953	13,868
2	1,693,435	2,529,156	1,885,158	8,852,047	2,177,274	3,251,772	2,423,775	11,381,203	2,652	3,961	2,952	13,863
3	1,693,435	2,529,156	1,885,158	8,852,047	2,177,274	3,251,772	2,423,775	11,381,203	2,652	3,961	2,952	13,863
4	1,693,435	2,529,156	1,885,158	8,852,047	2,177,274	3,251,772	2,423,775	11,381,203	2,652	3,961	2,952	13,863
5	719	1,074	800	3,758	924	1,380	1,029	4,831	1,617	2,416	1,801	8,455

Table 5.2 Cargo Refined Return Periods

Sub-sector	Cargo Refined Return Periods (years)											
	Nearshore Zone (0-12 nm)				Intermediate Zone (12-24 nm)				Deep-sea Zone (24-200 nm)			
	S	M	L	XL	S	M	L	XL	S	M	L	XL
1	2,662	15,974	67,450	-	3,423	20,538	86,721	-	5,990	35,942	151,762	-
2	1,735	10,410	43,956	-	2,231	13,385	56,515	-	3,904	23,423	98,902	-
3	1,769	10,613	44,813	-	2,274	13,646	57,617	-	3,980	23,880	100,830	-
4	1,632	9,792	41,344	-	2,098	12,589	53,157	-	3,672	22,031	93,025	-
5	135	811	3,423	-	45	272	1,148	-	79	476	2,010	-

Table 5.3 Fuel Return Periods

Sub-sector	Fuel Return Periods (years)											
	Nearshore Zone (0-12 nm)				Intermediate Zone (12-24 nm)				Deep-sea Zone (24-200 nm)			
	S	M	L	XL	S	M	L	XL	S	M	L	XL
1	53	167	15,494	-	68	214	19,920	-	119	375	34,861	-
2	123	390	36,242	-	158	502	46,597	-	277	878	81,545	-
3	124	391	36,364	-	159	503	46,753	-	278	881	81,818	-
4	123	388	36,077	-	158	499	46,384	-	276	874	81,172	-
5	7	23	2,143	-	9	30	2,755	-	16	52	4,821	-

Table 5.4 Class Breakdown to Determine Environmental Risk Index (ERI) Classes.

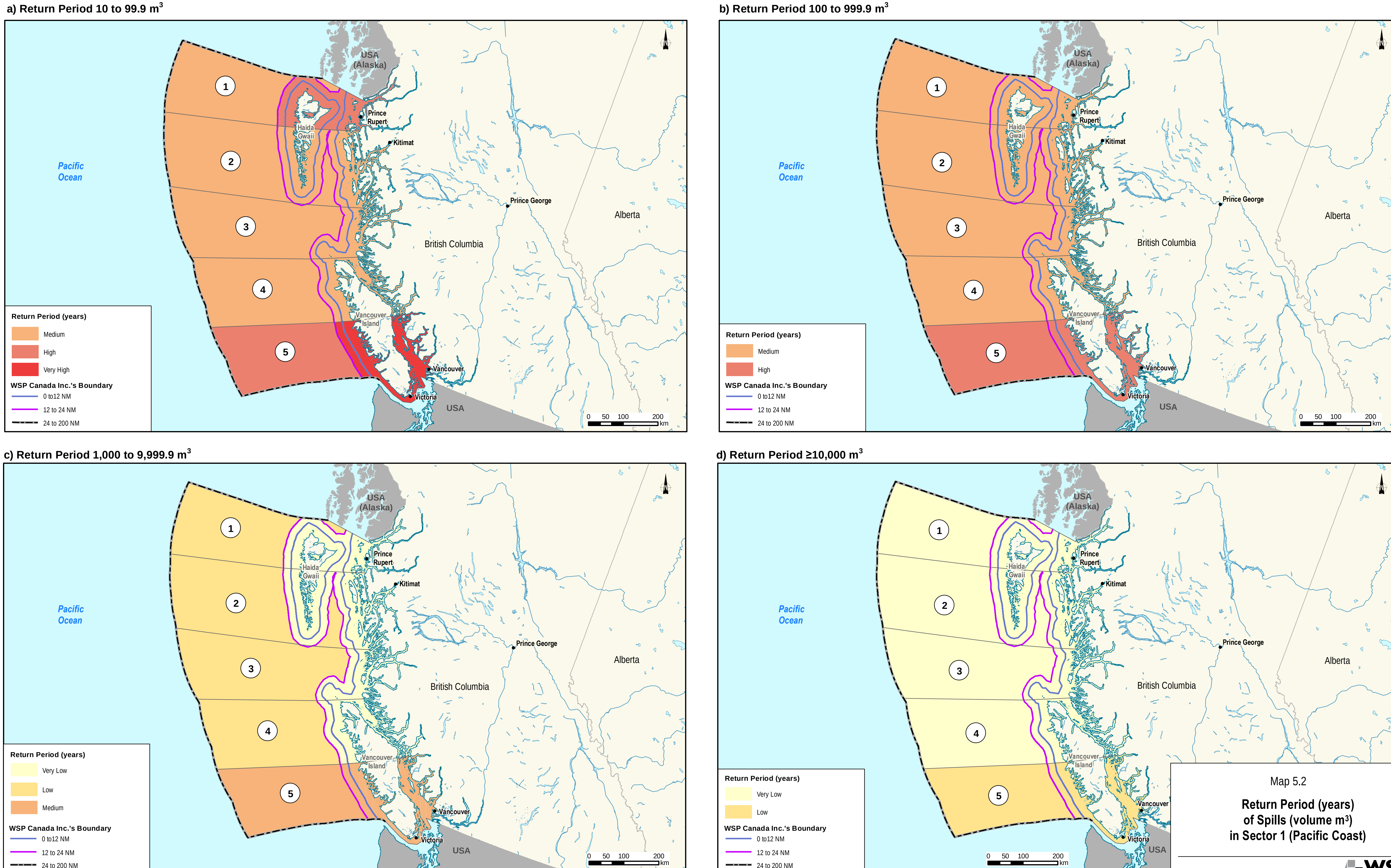
ERI Class	Natural Breakdown			
	10-99.9 m^3	100-999.9 m^3	1,000-9,999 m^3	≥ 10,000 m^3
Crude Oil				
Very High	134.8 to 347.6	628.3 to 1,221.6	8,601.2 to 37,798.7	3,727.1 to 9,613.1
High	62.1 to 134.8	366.5 to 628.3	3,482.9 to 8,601.2	1,718.4 to 3,727.1
Medium	28.3 to 62.1	169.7 to 366.5	1,537.5 to 3,482.9	783.0 to 1,718.4
Low	10.1 to 28.3	49.3 to 169.7	449.6 to 1,537.5	278.1 to 783.0
Very Low	0.0 to 10.1	0.0 to 49.3	0.0 to 449.6	0.0 to 278.1
Refined Oil				
Very High	4,608.7 to 58,806.7	735.0 to 2,346.9	932.1 to 1,535.2	7,895,456.7 to 23,298,700.7
High	794.3 to 4,608.7	267.2 to 735.0	336.4 to 932.1	3,004,643.6 to 7,895,456.7
Medium	305.5 to 794.3	130.0 to 267.0	132.2 to 336.4	1,238,071.0 to 3,004,643.6
Low	105.4 to 305.5	49.8 to 130.0	33.3 to 132.2	0.0 to 1,238,071.0
Very Low	0.0 to 105.4	0.0 to 49.8	0.0 to 33.3	0.0 to 0.0
Fuel Oil				
Very High	4,201.6 to 12,771.6	15,242.0 to 25,008.8	939.8 to 1,583.4	0.0 to 0.0
High	1,208.2 to 4,201.6	4,839.3 to 15,242.0	398.8 to 939.8	0.0 to 0.0
Medium	468.1 to 1,208.2	2,002.4 to 4,839.3	122.0 to 398.8	0.0 to 0.0
Low	155.3 to 468.1	685.5 to 2,002.4	41.4 to 122.0	0.0 to 0.0
Very Low	0.0 to 155.3	0,0 to 685.5	0,0 to 41.4	0.0 to 0.0

5.3.1 Crude Oil Environmental Risk Index

5.3.1.1 10 to 99.9 m^3 Oil Spill Size

Map 5.3a presents the ERI values for the Pacific sector and its analysis allows for the following observations:

- Zones with very high ERI values are present along the west and south coast of Vancouver Island as well as in the Strait of Georgia (sub-sector 5 – nearshore and intermediate zones). These zones encompass the Victoria and Vancouver areas. The very high risk values are due to high spill frequency in these zones, as well as medium ESI scores as a result of higher PSI of certain shorelines (ranks of 8 and greater) and high fisheries landings in this area.
- The deep-sea zones of the southern and northern sub-sectors (1 and 5) have medium ERIs. These areas are located to the west of the Graham and Vancouver islands. Despite a low ESI, the medium risk is a result of elevated spill frequencies in those zones.
- ERI ranges from low to very low in all other zones within the sector.



Map 5.2

Return Period (years) of Spills (volume m³) in Sector 1 (Pacific Coast)

January 2014

WSP

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5.3.1.2 100 to 999.9 m^3 Oil Spill Size

Results for 100 m^3 spills (Map 5.3b) show that:

- Zones with very high ERI values are the same as for spills of 10 m^3, with the exception of the intermediate zone west of Vancouver Island (sub-sector 5) where the ERI is high, rather than very high. The lesser environmental risk level in this zone is associated with a smaller ship frequency in this category of spill.
- In the other zones, the ERI varies from low to very low.

5.3.1.3 1,000 to 9,999.9 m^3 Oil Spill Size

ERI in this category of spill are shown on Map 5.3c and illustrate that:

- The nearshore and intermediate zones of sub-sector 5 (southern part of Vancouver Island and the Georgia Strait) have very high ERI values. These zones generate the highest spill frequency in the Pacific sector for 1,000 m^3 spills. In addition, the ESI is qualified as medium for these zones.
- The two deep-sea zones of sub-sectors 1 and 5 have high ERI values. These zones are located at the south and north ends of the sector (west of Vancouver and Graham islands). The risk rating is greater than for lesser spills due to higher spill frequencies in this category.
- The remaining zones have either medium or very low ERI ratings.

5.3.1.4 ≥ 10,000 m^3 Oil Spill Size

As shown on Map 5.3d:

- Very high ERI are attributed to the nearshore and intermediate zones of sub-sector 5. The main factor which influences the ERI values is the high spill frequencies.
- Low ERI values are attributed to spills of this magnitude.
- In the remaining zones, ERI values are medium, low or very low.

5.3.2 <u>Refined Crude Environmental Risk Index</u>

5.3.2.1 10 to 99.9 m^3 Oil Spill Size

Map 5.4a allows for the following observations:

- The nearshore zone, located along the southern part of Vancouver Island (including the Georgia Strait) in sub-sector 5 has a high ERI value. These results are due, in large parts, to the very high spill frequencies calculated in this zone. Moreover, the ESI is qualified as medium, due to the shoreline's sensitivity (rank 8 or higher – having a strong influence to the final PPSI score) and high fisheries landings in this zone (influencing the HRI).
- High ERI values are attributed to the intermediate and deep-sea zones of sub-sector 5. The high risk results are based on the higher spill frequencies.

The other Pacific Coast sub-sectors, including nearshore, intermediate and deep-sea zones, show ERI values which vary from low to very low. These results confirm that these zones are less in use to transport refined crude oil than others Canadian zones.

5.3.2.2 100 to 999.9 m^3 Oil Spill Size

Based on Map 5.4b results, the following observations can be made:

- Except for the nearshore and intermediate zones of sub-sector 5, the ERI values vary from low to very low in the Pacific coastal waters.
- High ERI values are attributed to the nearshore and intermediate zones of sub-sector 5. The high spill frequencies can explain this result and, in a lesser extent, the medium ESI values observed.

5.3.2.3 1,000 to 9,999.9 m^3 Oil Spill Size

The Map 5.4c allows for the following observations:

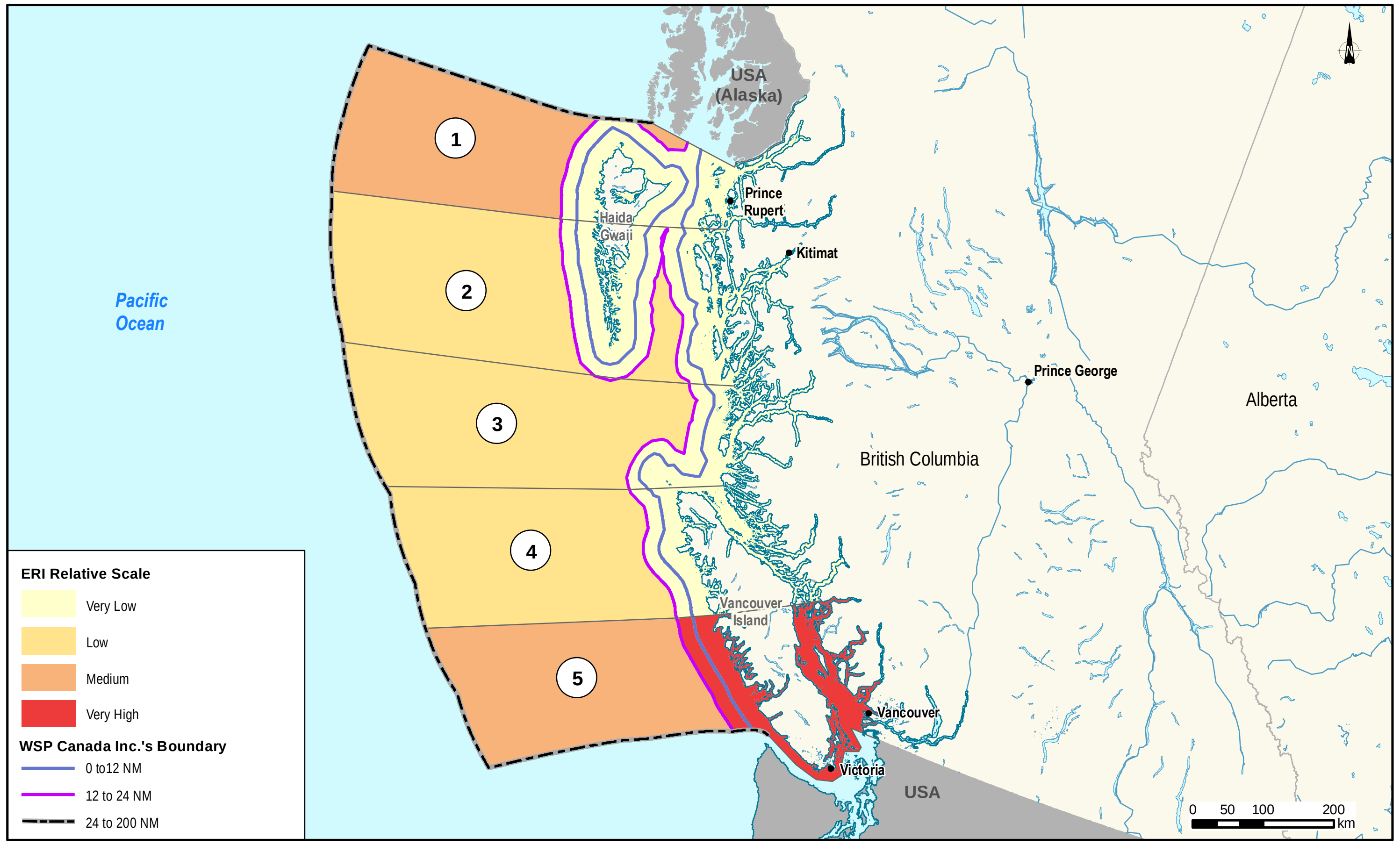
- All the Pacific Coast zones show very low ERI values. Despite a high or medium ESI in most of the nearshore and intermediate zones, the refined oil volume transported is very low.

5.3.2.4 ≥ 10,000 m^3 Oil Spill Size

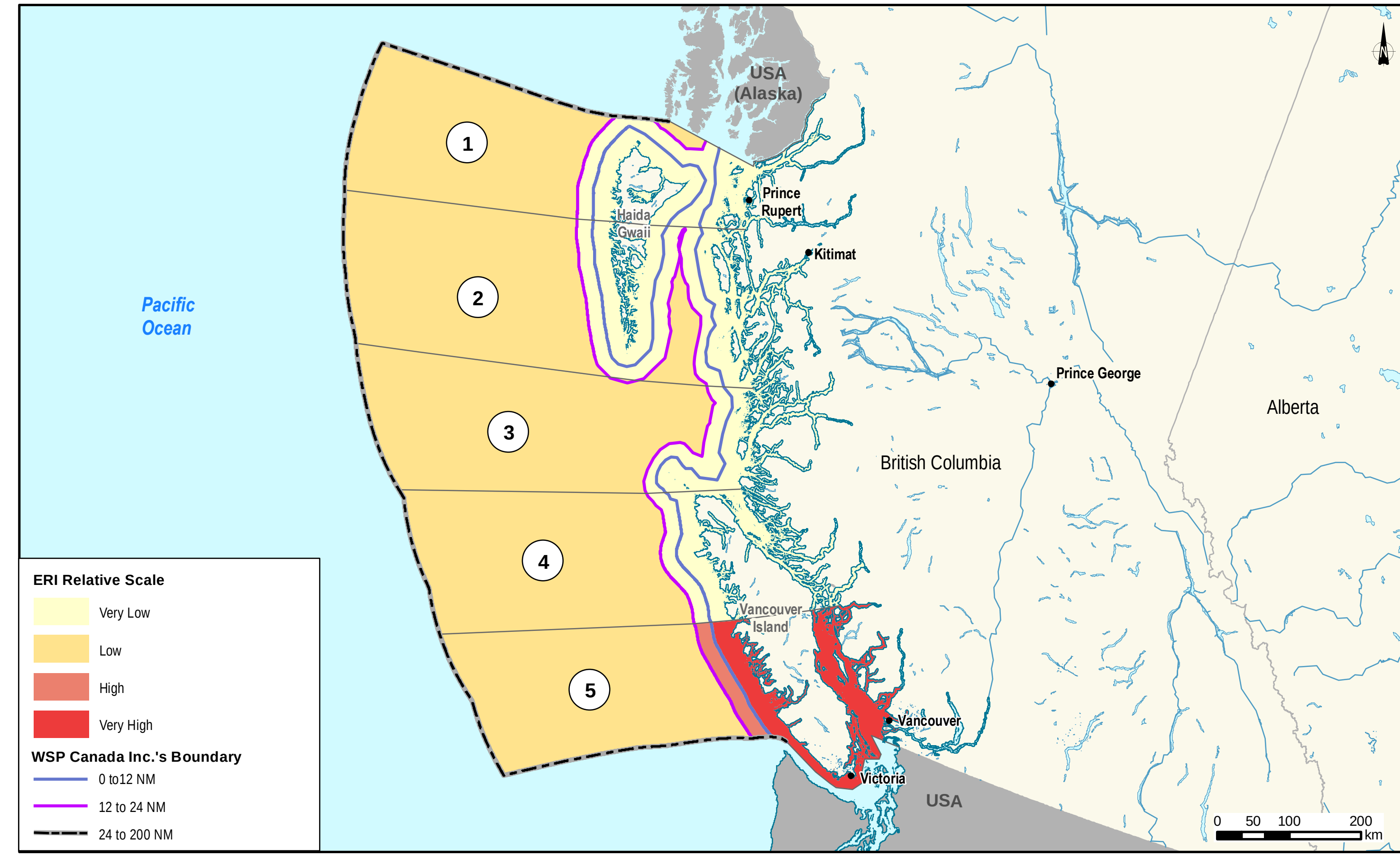
Results for 10,000 m^3 spills (Map 5.4d) show that:

- All the Pacific coast zones have very low ERI values. Despite a high or medium ESI in most of the nearshore and intermediate zones, the spill frequencies calculated are almost null. As a safety precaution (principle of sustainable development), a very low ERI has been given to this scenario.

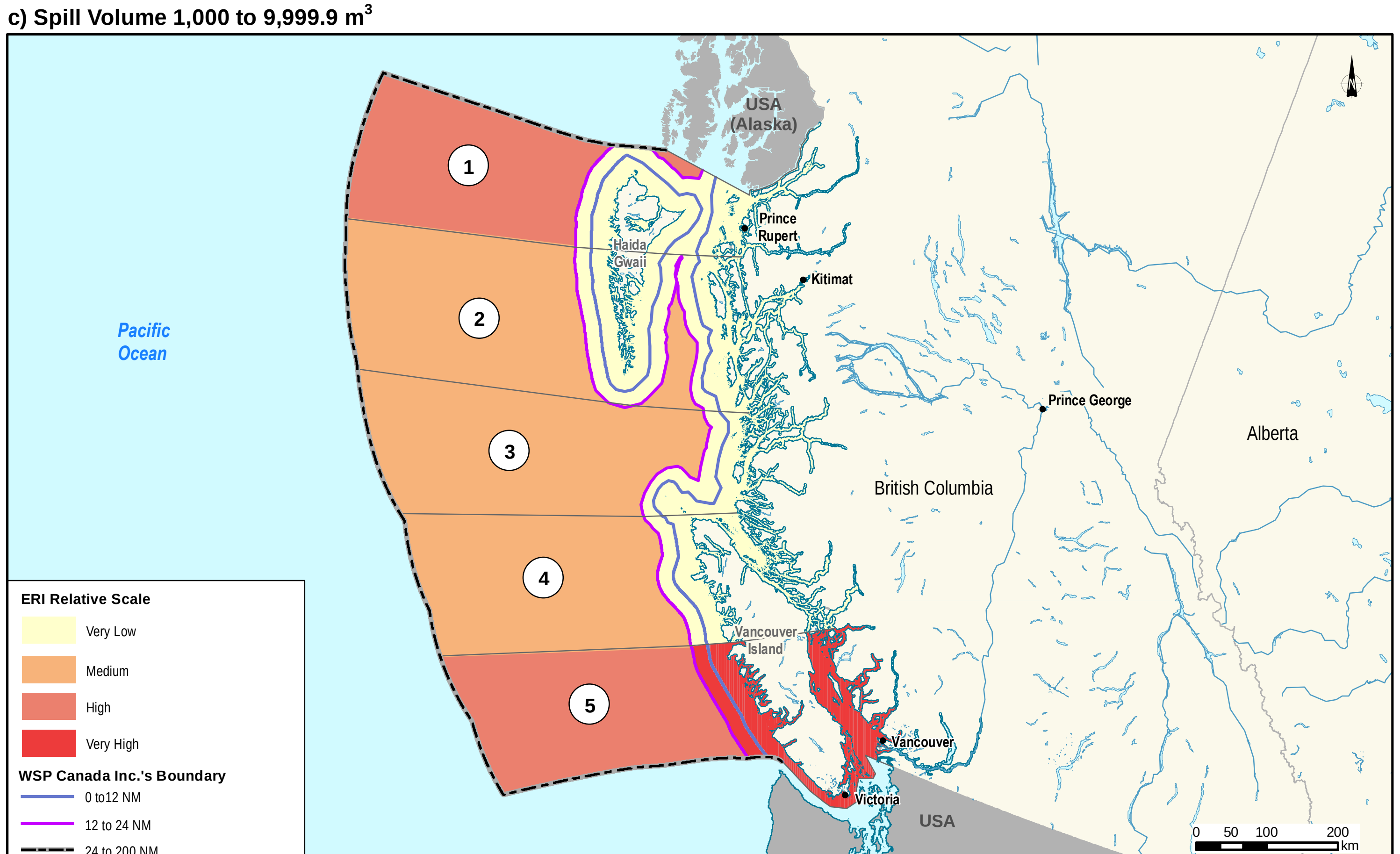
a) Spill Volume 10 to 99.9 m^3



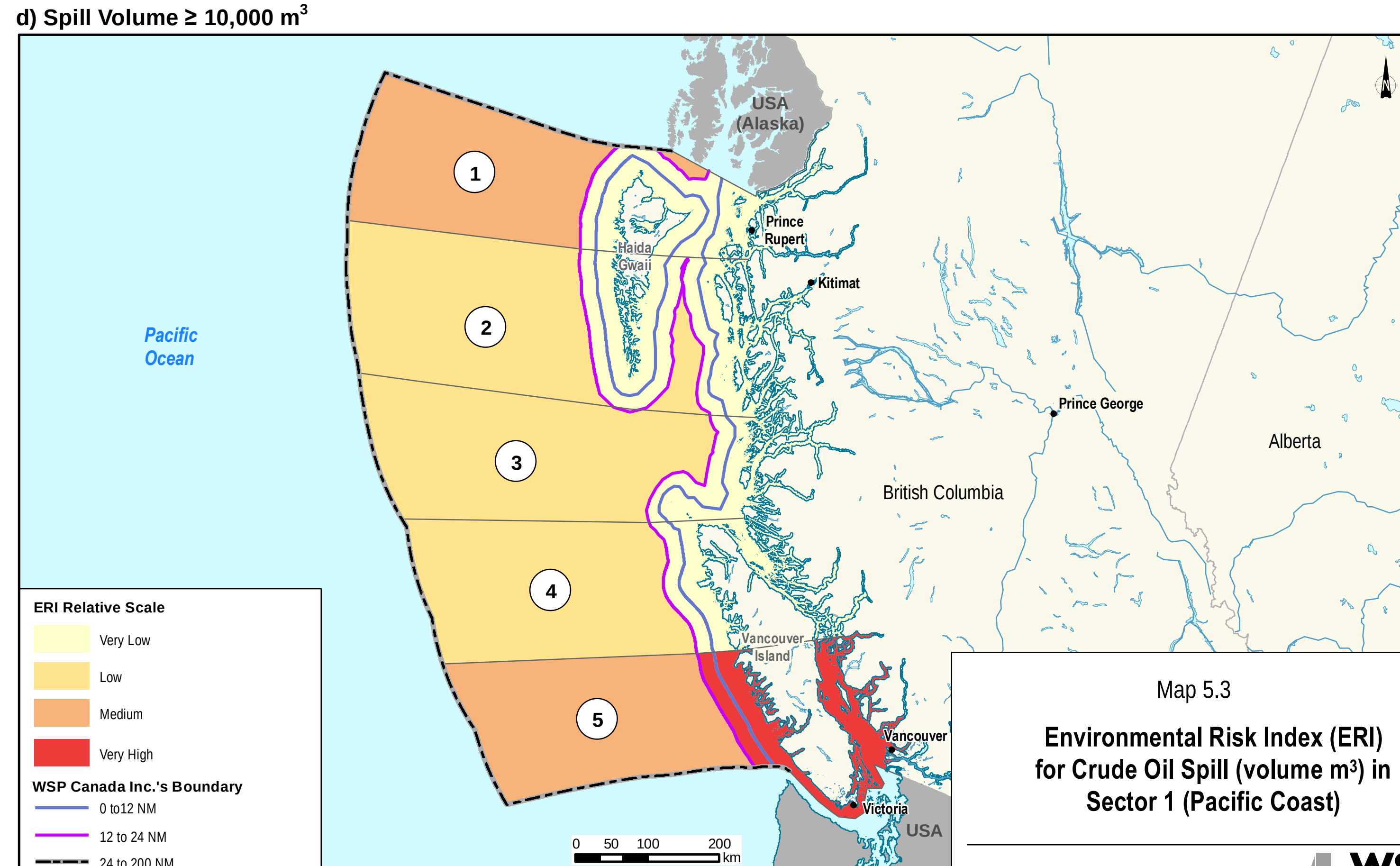
b) Spill Volume 100 to 999.9 m^3



c) Spill Volume 1,000 to 9,999.9 m^3



d) Spill Volume ≥ 10,000 m^3



Map 5.3

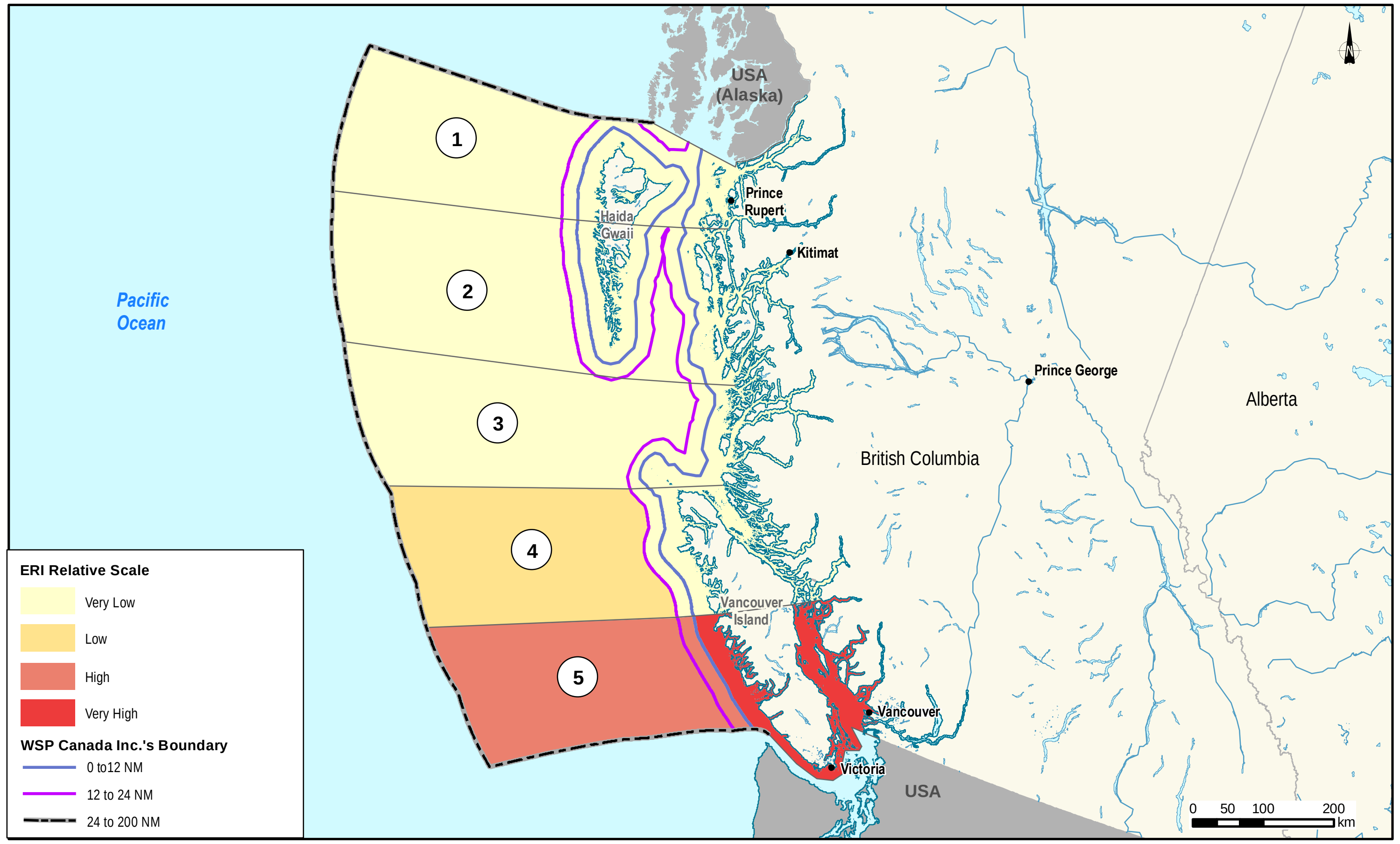
Environmental Risk Index (ERI) for Crude Oil Spill (volume m^3) in Sector 1 (Pacific Coast)

January 2014

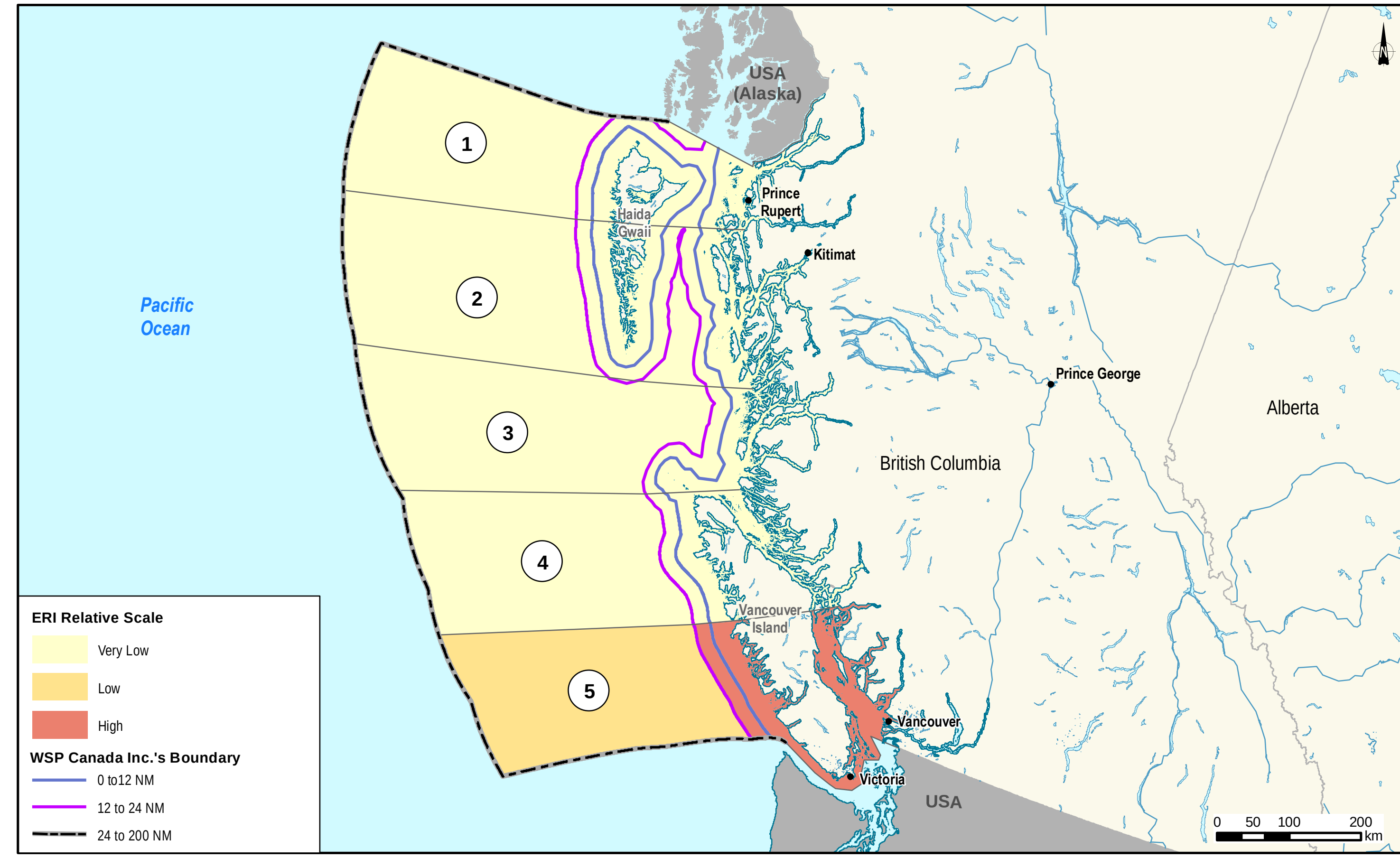
WSP

File: 131_17593_c5.3_Cargo_Crude_Pacific_131223.mxd

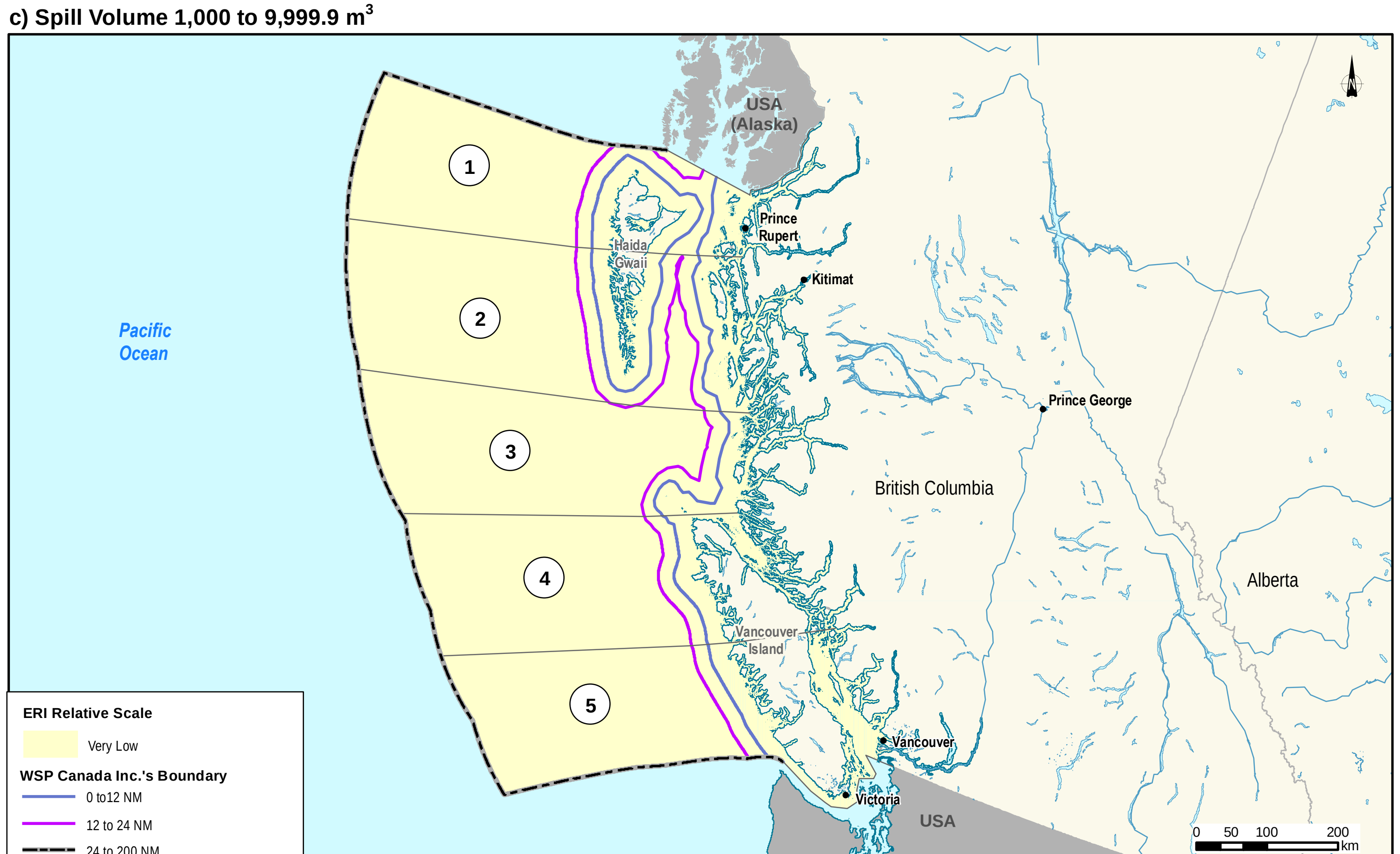
a) Spill Volume 10 to 99.9 m^3



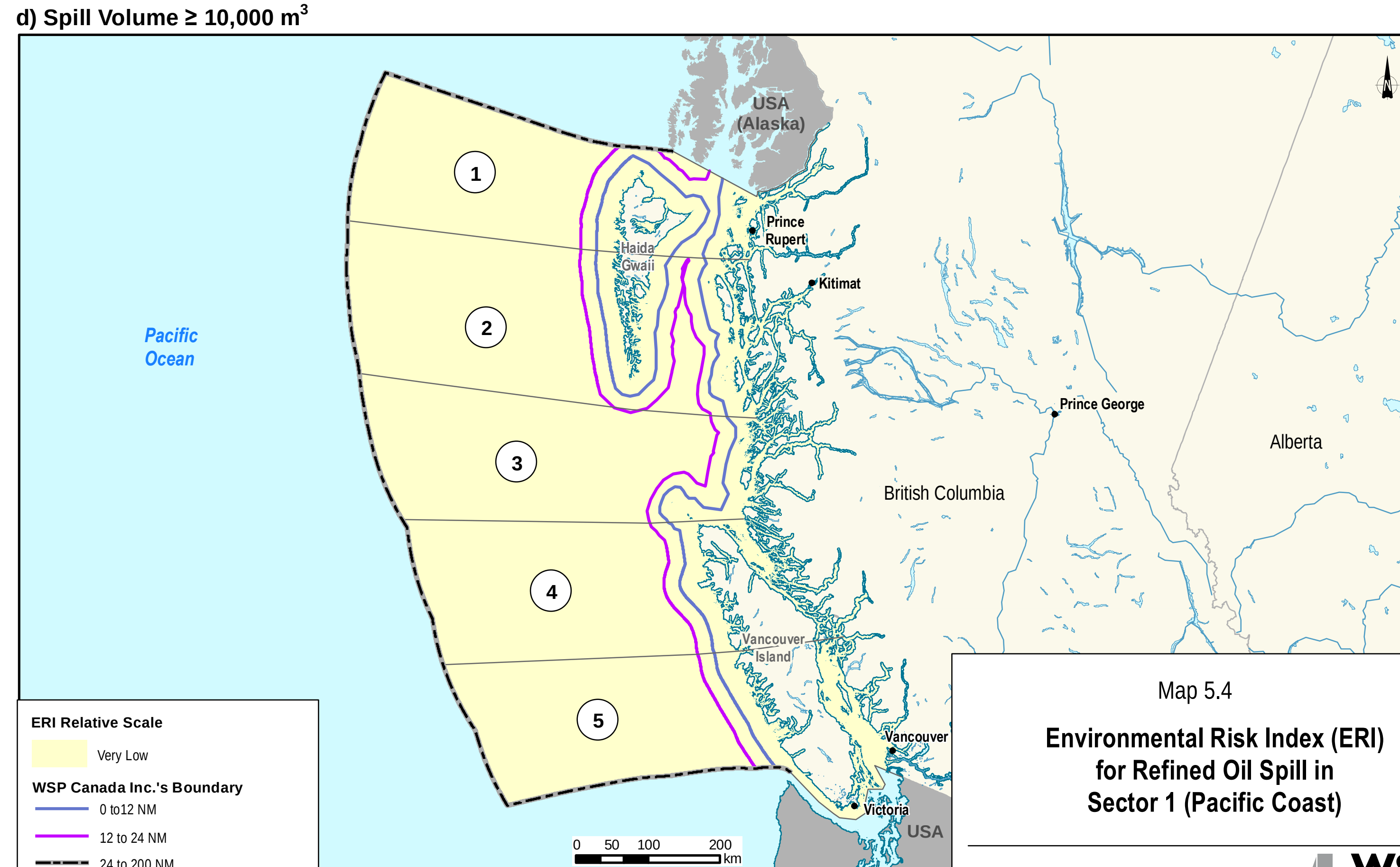
b) Spill Volume 100 to 999.9 m^3



c) Spill Volume 1,000 to 9,999.9 m^3



d) Spill Volume ≥ 10,000 m^3



Map 5.4

Environmental Risk Index (ERI) for Refined Oil Spill in Sector 1 (Pacific Coast)

January 2014

WSP

File: 131_17593_c5.4_Cargo_Refined_Pacific_131223.mxd

5.3.3 Fuel Environmental Risk Index

5.3.3.1 10 to 99.9 m^3 Oil Spill Size

Based on Map 5.5a, the following observations can be made:

- The highest ERI values were observed in the nearshore zone located along the southern part of Vancouver Island (including Georgia Strait) (sub-sector 5 – very high) and its intermediate zone (high). These results are in large part caused by the elevated spill frequencies in this zone. Moreover, the ESI is medium, due to the shoreline's sensitivity (ranked 8 or higher – influencing the PSI) and high fisheries landings (influencing the HRI).
- The nearshore zone of sub-sector 1 (Prince Rupert coast and along Graham Island) as well as the deep-sea zone of sub-sector 5 have medium ERI values. The spill frequencies determine in large parts the results obtained.
- The other Pacific coast zones show ERI values which vary from low to very low.

5.3.3.2 100 to 999.9 m^3 Oil Spill Size

Based on the Map 5.5b, the following observations can be made:

- Except for the nearshore and intermediate zones of sub-sector 5, the ERI values vary from low to very low in the Pacific Coast waters.
- High ERI values are attributed to nearshore and intermediate zones of sub-sector 5. The high spill frequencies are the most influential in determining these results and, in a lesser part, the medium ESI values obtained.

5.3.3.3 1,000 to 9,999.9 m^3 Oil Spill Size

As shown on Map 5.5c:

- High ERI scores are attributed to the nearshore zone of sub-sector 5. The main factor which influences the ERI value is the high spill frequencies of the area.
- Low ERI values are encountered for spills of this magnitude.
- In the remaining zones, ERI values are medium, low or very low.

5.3.3.4 ≥ 10,000 m^3 Oil Spill Size

Results for 10,000 m^3 spills (Map 5.5d) show that:

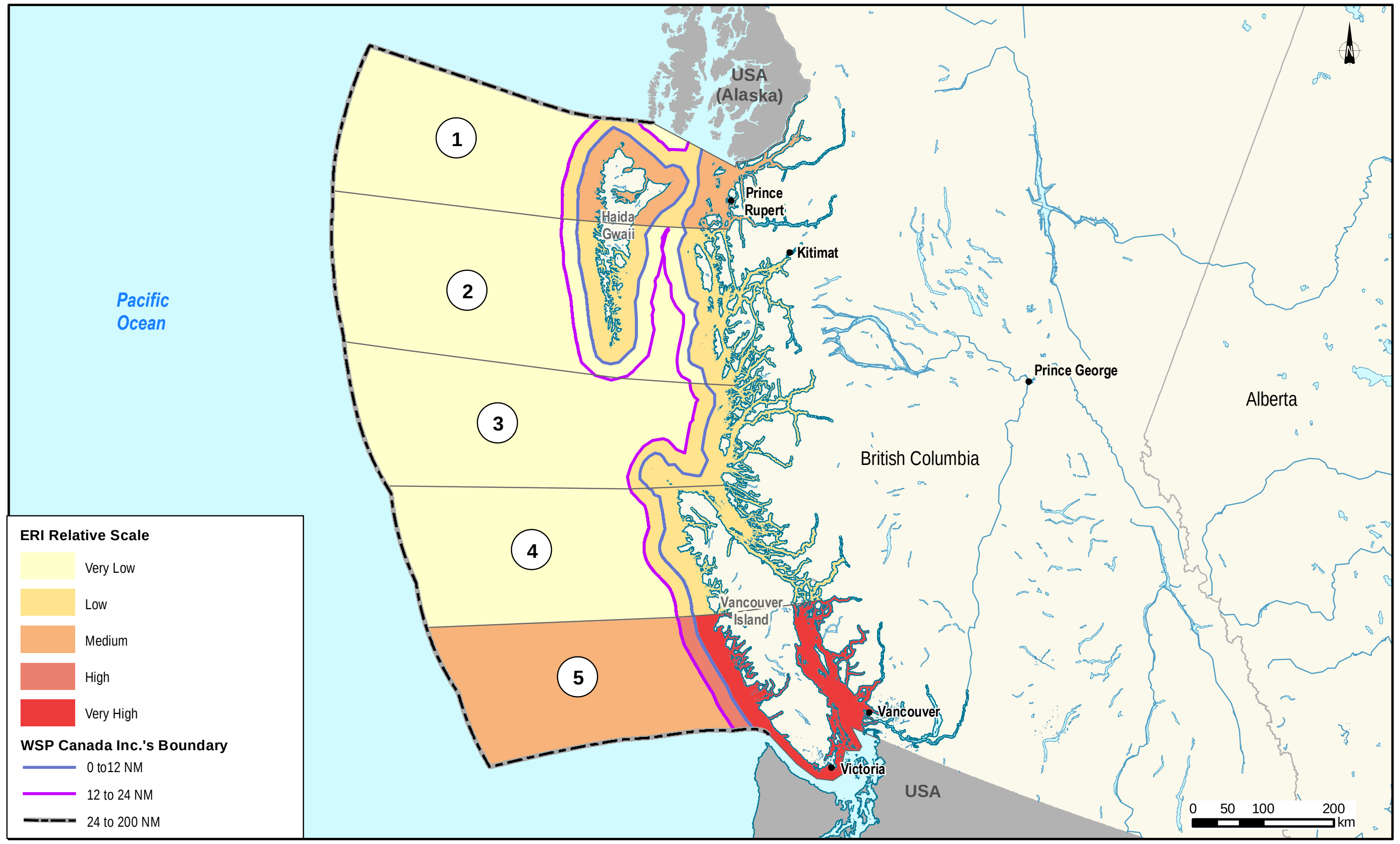
- The entire Pacific coast has very low ERI values. Despite a high or medium ESI in most of the nearshore and intermediate zones, the spill frequencies calculated area almost null. As a safety precaution (principle of sustainable development), a very low ERI score has been given for this scenario.

5.3.4 Environmental Sensitivity Index (ESI)

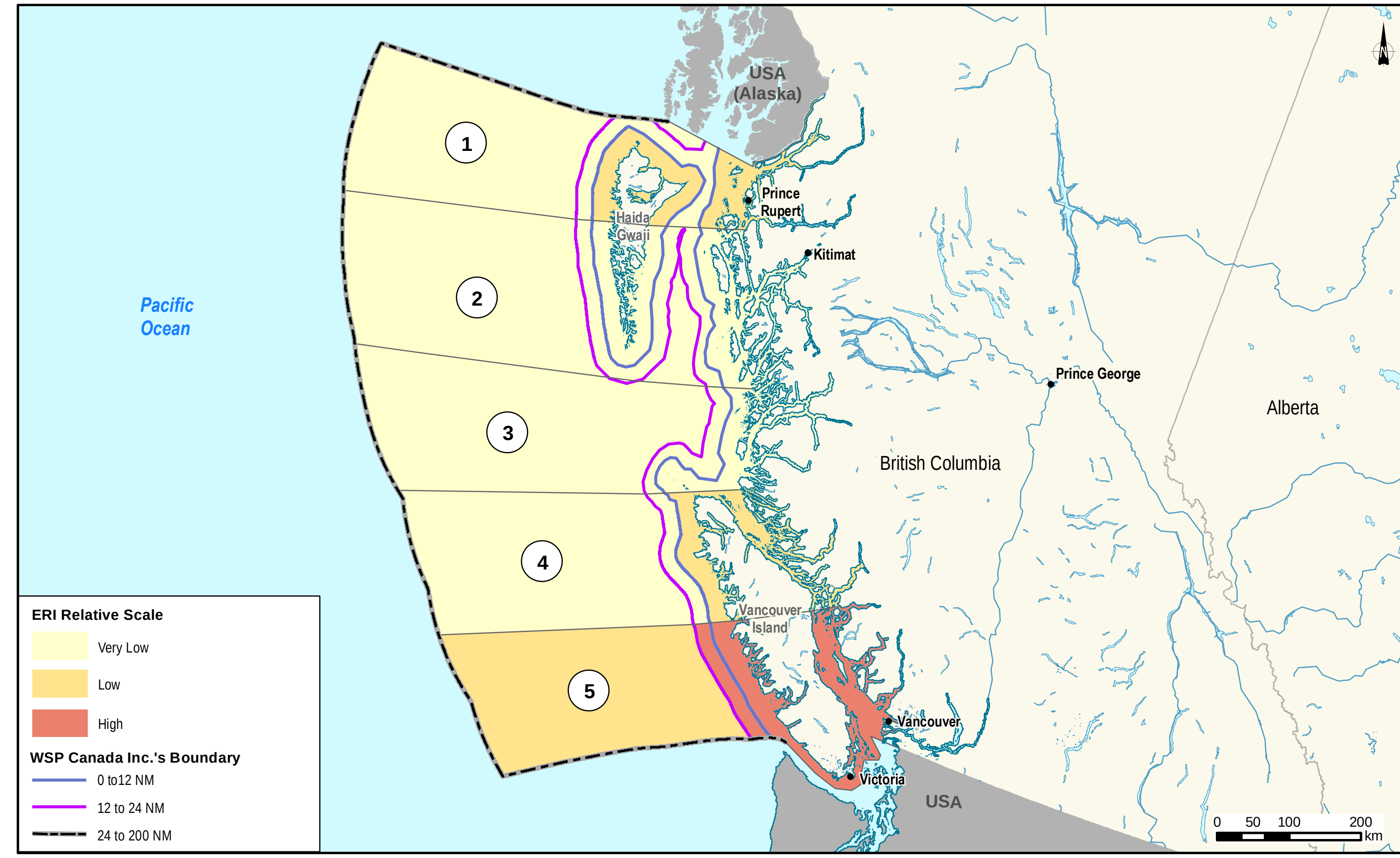
In addition to the very high and high ERI zones, there are others sensitive zones in the Pacific Coast sector which may be affected by future increases in volumes (Map 5.6; Appendix 2 – Map A).

The nearshore zone of the entire Pacific coast sector has a medium ESI, except in sub-sector 4 (northern part of Vancouver Island) where the ESI score is high. The Pacific coastline is extremely rugged and offers particular physical and biological conditions which increase the biological productivity of the area. The importance of the coastal zone for many biological functions (reproduction, feeding and wintering), the presence of many EBSAs as well as high commercial fisheries landings are also determining features of this sector.

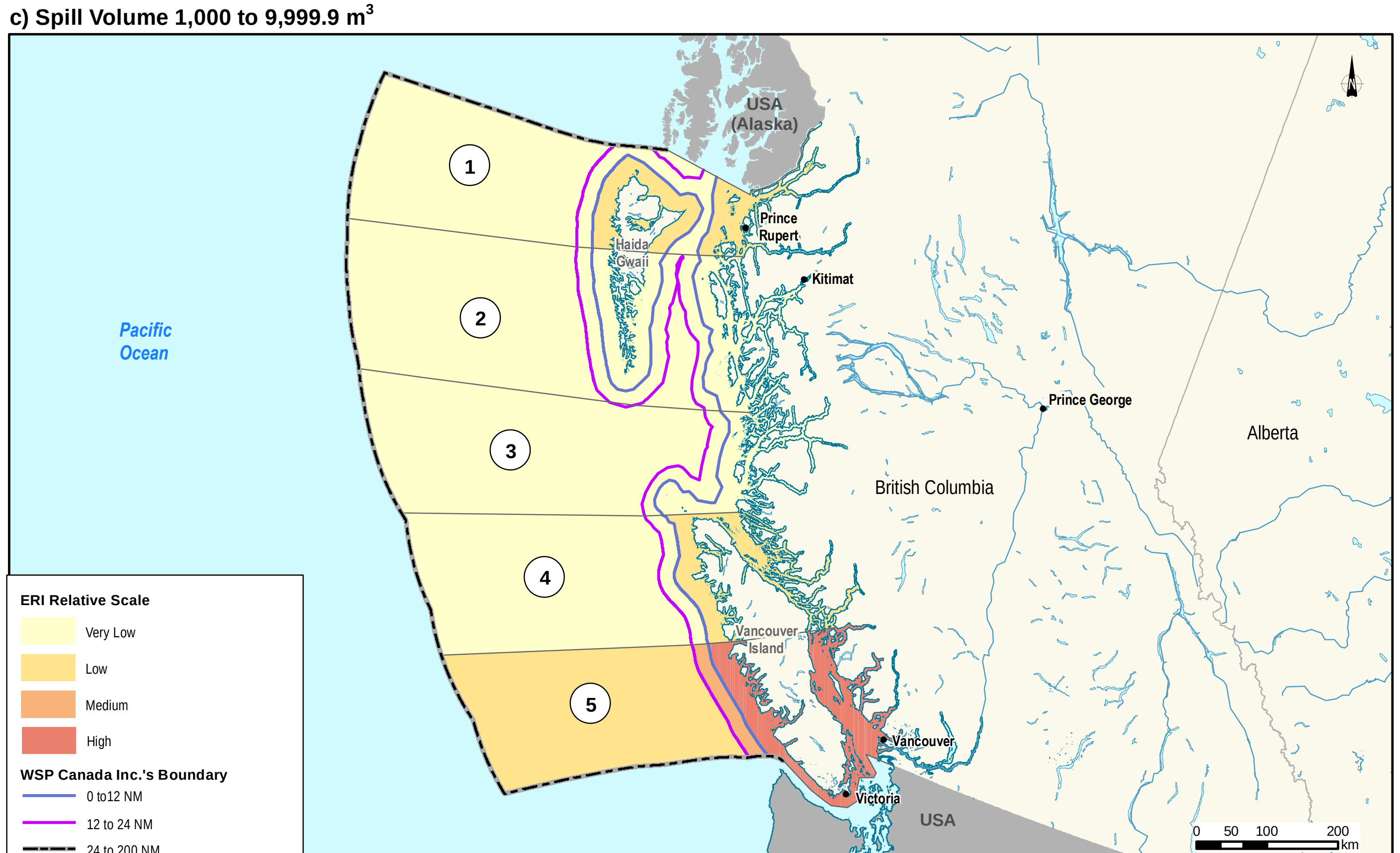
a) Spill Volume 10 to 99.9 m^3



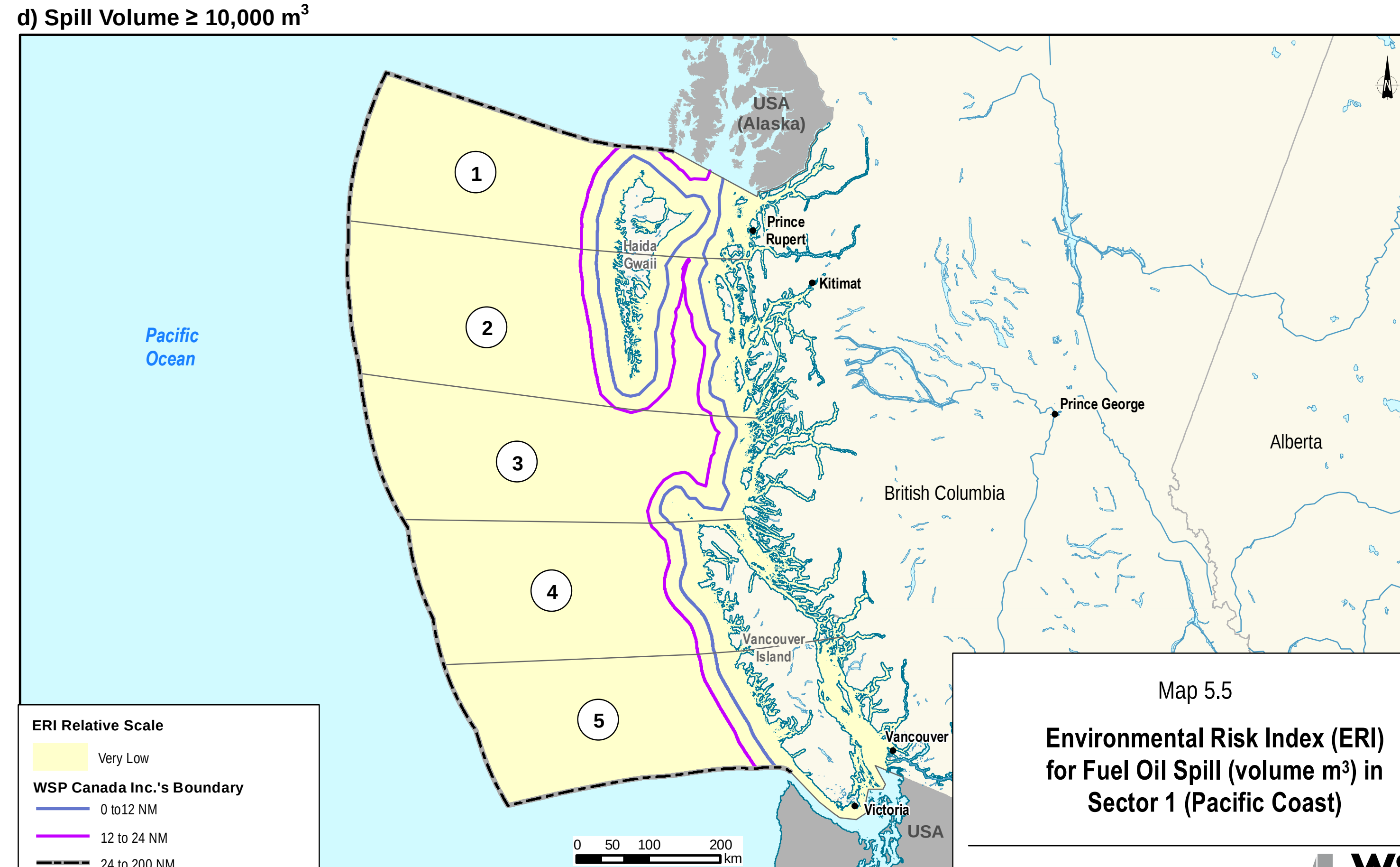
b) Spill Volume 100 to 999.9 m^3



c) Spill Volume 1,000 to 9,999.9 m^3



d) Spill Volume ≥ 10,000 m^3



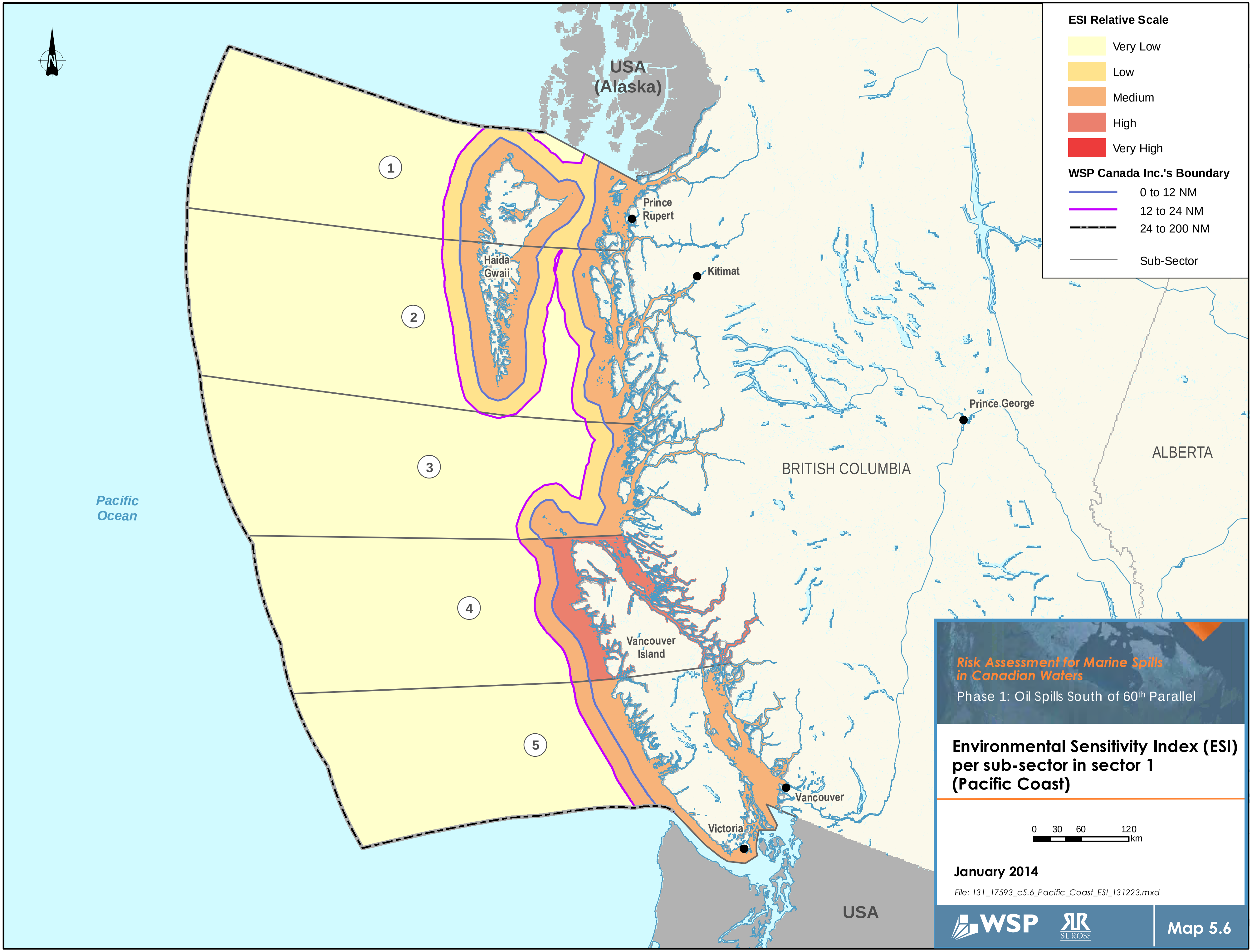
Map 5.5

Environmental Risk Index (ERI) for Fuel Oil Spill (volume m³) in Sector 1 (Pacific Coast)

January 2014

WSP

File: 131_17593_c5.5_Cargo_Fuel_Pacific_131223.mxd


ESI Relative Scale
Very Low
Low
Medium
High
Very High
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM
Sub-Sector
USA (Alaska)
Prince Rupert
Kitimat
Prince George
ALBERTA
BRITISH COLUMBIA
Haida Gwaii
Vancouver Island
Vancouver
Victoria
USA
Pacific Ocean
1
2
3
4
5
Risk Assessment for Marine Spills in Canadian Waters
Phase 1: Oil Spills South of 60th Parallel
Environmental Sensitivity Index (ESI) per sub-sector in sector 1 (Pacific Coast)
0 30 60 120 km
January 2014
File: 131_17593_c5.6_Pacific_Coast_ESI_131223.mxd
WSP
SL ROSS
Map 5.6

6. ATLANTIC COAST

6.1 Sector Description

6.1.1 Physical Features

With the exception of the Grand Banks and the Scotian Shelf, the Atlantic Canadian waters are mostly deep water. Characteristics can be associated with these two particular sectors of the Atlantic Coast. A brief summary is given for each of them in the following paragraphs.

The Gulf of Maine and Scotian Shelf area is bounded by the Hague Line to the southwest (defining the international border with the United States) and by the southern edge of the Laurentian Channel to the northeast. It includes coastal portions of Nova Scotia and New Brunswick. The North Atlantic Oscillation (NAO) is the dominant atmospheric pattern in the North Atlantic Ocean and a significant large-scale abiotic driver of this area. The circulation patterns on the Scotian Shelf are governed by its complex topography and by the influence of three major currents: 1) the warm, salty Gulf Stream over the continental slope to the south, 2) the downstream influence of the cold Labrador Current from the north, and 3) the cool, fresh Scotian Shelf Current derived from the outflow of the Gulf of St. Lawrence (DFO, 2010).

The Newfoundland and Labrador Shelf (NLS) area extends off the eastern coast of Canada, and encompasses one of the largest continental shelves in the world. Ranging from the northern tip of Labrador south, the NLS is greater than 2.5 million km^2 and exhibits significant variations in seabed structures and habitats that is shown by its extensive coastal forms, offshore banks, slopes and canyons. The NAO has been a dominant factor in recurrent atmospheric oscillations in the North Atlantic and the NLS exhibits considerable variability. Variations in the NAO are related to many climatic, oceanographic and ecological features in the marine ecosystems of Newfoundland and Labrador, including iceberg flows, ocean temperatures, the strength of the Labrador Current, and the distribution and biology of many species (DFO, 2010).

About 50% of the entire sector’s shoreline is of bedrock. The other shoreline types which are significantly abundant in this sector are pebble and cobble beaches (19.5%), mixed-sediment beaches (10.8%) and boulder beaches (10.7%) (Map 6.1). Based on the 1981-2010 February ice-cover data, the majority of the sector is covered by ice during this period.

6.1.2 Biological Features

Atlantic Canadian waters support important resident and migratory populations of invertebrates, demersal and pelagic fishes, marine mammals and seabirds. In combination with influences from the southerly-flowing Labrador Current, but in unison with other drivers, the waters off Newfoundland and off the Labrador Shelf are some of the most productive in the world. Given its temperate nature the NLS supports an impressive diversity of marine life, including various species of coldwater corals, plankton, fish, mammals, reptiles and seabirds (DFO, 2010).

Phytoplankton is found at the base of all aquatic food webs. The carrying capacity of marine ecosystems (e.g. diversity, abundance and recruitment) is highly dependent on variations in the abundance, timing and composition of plankton. Phytoplankton also plays a crucial role in climate change through the export of fixed carbon dioxide during photosynthesis into the deep oceans.

There are 92 Ecologically and Biologically Significant Areas (EBSAs) identified by DFO in the Atlantic Coast sector (Map 6.1). They are respectively located in the Bay of Fundy (Nova Scotia; 16 EBSAs), the Atlantic Coast of Nova Scotia (20 EBSAs), the offshore of Nova Scotia (31 EBSAs) and the Newfoundland and Labrador territory (25 EBSAs). Essentially, these EBSA are used as feeding, reproductive and wintering area, as well as migratory corridor by meroplankton, invertebrates, fishes and marine mammals, including special-status species.

Most of the sea birds use the Atlantic Coast for feeding, resting and breeding. Their distribution is a function of the presence of fishes (e.g. capelin, cod) on which they feed. In this sector, the highest density of colonial bird is the Leach's Storm Petrel (9,361,986 couples), while the Common Eider and the Semiplamated Plover are respectively the more abundant waterfowl specie (326,081 individuals) and shorebirds specie (1,166,909 individuals) (Map 6.1). The entire Atlantic coastline is used by colonial birds, while the most important marine bird concentrations are found on the NLS.

The coastal zone (0-50 m depth) includes a number of ecosystems of small extent that have particularly high biodiversity as well as high primary and secondary production, and that are therefore important for wildlife and humans using these resources. It is also a reproductive, feeding and wintering area for some marine species, such as fish and marine mammals.