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Transport Canada

Guidance Document

AREA RISK ASSESSMENT METHODOLOGY DEVELOPMENT FOR SHIP-SOURCE OIL SPILLS IN CANADIAN WATERS

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Enhancing Society Together

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Acronyms, Abbreviations, Definitions

AIS	Automatic Identification System
API	American Petroleum Institute
ARA	Area Risk Assessment
CCG	Canadian Coast Guard
COE	Consequence of Exposure
FOE	Frequency of Exposure
FOS	Frequency of Spill
OHFs	Oil Handling Facilities
PAIH	Protected Areas and Important Habitats
POE	Probability of Exposure
$Risk_S$	Risk Score
SBM	Single Buoy Mooring
SAR	Species at Risk
TSS	Traffic Separation Scheme
TSB	Transportation Safety Board
TSEP	Tanker Safety Expert Panel
ULCC	Ultra large crude carrier
VLCC	Very large crude carrier

Accident[1] – An accident resulting directly from the operation of a ship other than a pleasure craft, where the ship sinks, founders or capsizes, is involved in a collision [includes strikings and contacts], sustains a fire or an explosion, goes aground, sustains damage that affects its seaworthiness or renders it unfit for its purpose, or is missing or abandoned.

Incident[1] – 1) The ship makes unforeseen contact with the bottom without going aground; fouls a utility cable or pipe, or an underwater pipeline; is involved in a risk of a collision; sustains a total failure of a) the navigation equipment if the failure poses a threat to the safety of any person, property or the environment, b) the main or auxiliary machinery, or c) the propulsion, steering, or deck machinery if the failure poses a threat to the safety of any person, property or the environment; 2) All or part of the ship's cargo shifts or falls overboard; 3) The ship is anchored, grounded or beached to avoid an

[1] Reference: http://www.tsb.gc.ca/eng/stats/marine/2015/ssem-ssmo-2015.asp#3.0

occurrence; or 4) There is an accidental release on board or from the ship consisting of a quantity of dangerous goods or an emission of radiation that is greater than the quantity or emission levels specified in Part 8 of the Transportation of Dangerous Goods Regulations.

Marine Occurrence[1] – a) any accident or incident associated with the operation of a ship and b) any situation or condition that the TSB has reasonable grounds to believe could, if left unattended, induce an accident or incident described above.

1.0 Introduction

1.1 Purpose of ARA Methodology

The Area Risk Assessment (ARA) Methodology was developed to fulfill the recommendation from the Tanker Safety Expert Panel (TSEP) November 2013 report (Government of Canada, 2013), that a consistent methodology be used to assess the risks posed by ship-source oil spills in Canadian Waters. The ARA Methodology will:

1) Provide Government and other stakeholders with a framework to assess/evaluate existing spill prevention, preparedness and response activities to reduce the risk from ship-source oil spills; and
2) Determine the most vulnerable areas within Canadian Waters to a ship-source oil spill, taking into consideration:
    a) Existing spill preparedness and response activities;
    b) Local geography;
    c) Environmental sensitivities; and
    d) Ship traffic volumes.

This Guidance Document outlines the step by step process for the User to follow in order to apply the ARA Methodology. **Section 2** provides an overview of the ARA Methodology, including the principles of risk management and the general approach. The ARA Methodology consists of four phases which are summarized in **Sections 3 through 6**.

Additional technical details are provided in various appendices to the Guidance Document that the User can reference as needed when utilizing the ARA Methodology[2].

1.2 Limitations of the ARA Methodology

The Guidance Document summarizes the use of Version 5.0 of the ARA Methodology, which has various limitations that are highlighted below:

1.2.1 Source and Type of Oil Spills

The ARA Methodology is limited to evaluating the risks posed by oil spills – 1) vessels equipped with Automatic Identification System (AIS)[3] and 2) releases from oil handling facilities (OHFs) during oil transferring operations when a vessel is present.

[2] In the final version of this ARA Methodology Guidance Document we will provide a concordance table that outlines the purpose of this document as well as the Appendices. This will point the User in the right direction if they want more information on specific topics.

Land-based oil spills are not included in the ARA Methodology except for spills from equipment that are designed to transfer oil between a vessel and an OHF. This includes loading arms/hoses and single-point mooring buoys but excludes land-based oil infrastructure such as storage tanks and pipelines.

The oil types include crude oil and refined petroleum products shipped as cargo or used as bunker oil in vessels. Oils are grouped into five categories based on their behaviour in water, which is a function of their unique density and hydrocarbon composition. A summary of the five categories is presented in **Section 2.2.1**.

Other hazardous and noxious substances are excluded.

1.2.2 Locations and Root Causes of Oil Spills

The ARA Methodology is applicable to Canadian Waters south of the 60th parallel. Ship-source oil spills that originate outside of Canadian Waters are included in the ARA if the oil spills originate within 12 nm of the Canadian coastline (e.g. from the Strait of Juan de Fuca)[4]. The location limitations of the ARA Methodology are presented in **Table 1-1**.

Table 1-1: Limitations on the Application of the ARA Methodology

Item Description	Limitation
1. Arctic Waters (above 60th parallel)	Currently, the ARA Methodology was developed to be applied to all Canadian Waters south of the 60th parallel only.
2. Fresh Waters (e.g. Great Lakes)	The ARA Methodology has only been validated in four areas and only one freshwater environment (St. Lawrence River). Some changes may be required to apply the ARA Methodology to a larger freshwater environment, such as the Great Lakes.
3. Spills Outside Canadian Waters	Spills that originate outside of Canadian Waters are excluded with the exception of those originating within 12 nm of the Canadian coastline.

Oil spills from intentional acts (e.g. acts of terrorism or illegal dumping) and legal discharges are excluded. However, oil spills from machinery failure or hull failure are included.

1.2.3 Consequences of Oil Spills

The ARA Methodology takes into account the biological sensitivities (e.g. Marine Protected Areas), the physical environment (e.g. Shoreline Classification) and socio-economic factors (e.g. impacts to commercial fisheries) when determining the consequences of ship-source oil spills.

[3] AIS carriage requirements are stated in Subsection 65(3) of the Navigation Safety Regulations (Transport Canada, 2005) and states "Every ship, other than a fishing vessel, of 500 tons or more that is not engaged on an international voyage shall be fitted with an AIS, but if it was constructed before July 1, 2002 it need not be so fitted until July 1, 2008."

[4] The 12 nm from Canadian coastline is based on the United Nations Convention of the Law of the Sea (UN, 1994) and serves as a surrogate for spills originating in US waters that can enter Canadian waters.

As stated in **Section 1.2.2**, the consequences of oil spills will only be assessed within Canadian Waters south of the 60th parallel, even if the spill originates from US waters. For spills that originate from outside Canadian Waters, the consequences will be evaluated only in Canadian territorial waters as defined in the United Nations Convention of the Law of the Sea (UN, 1994).

The consequences of ship-source oil spills are evaluated until the end of the spill scenario (30 days) and therefore do not take into account post-spill rehabilitation and restoration of the biological, physical and socio-economic conditions.

2.0 Overview of ARA Methodology

2.1 Principles of Risk Management

Organizations of all types face internal and external factors that make it uncertain how they will achieve their objectives. Managing uncertainty in decision-making relies upon identifying, quantifying and analyzing those factors. More specifically, the ARA Methodology seeks to identify and evaluate the risks (uncertainties) posed by ship-source oil spills to allow the uncertainties to be characterized and integrated into spill prevention, planning and management. In this context, "risk" as is defined for the ARA Methodology translates to:

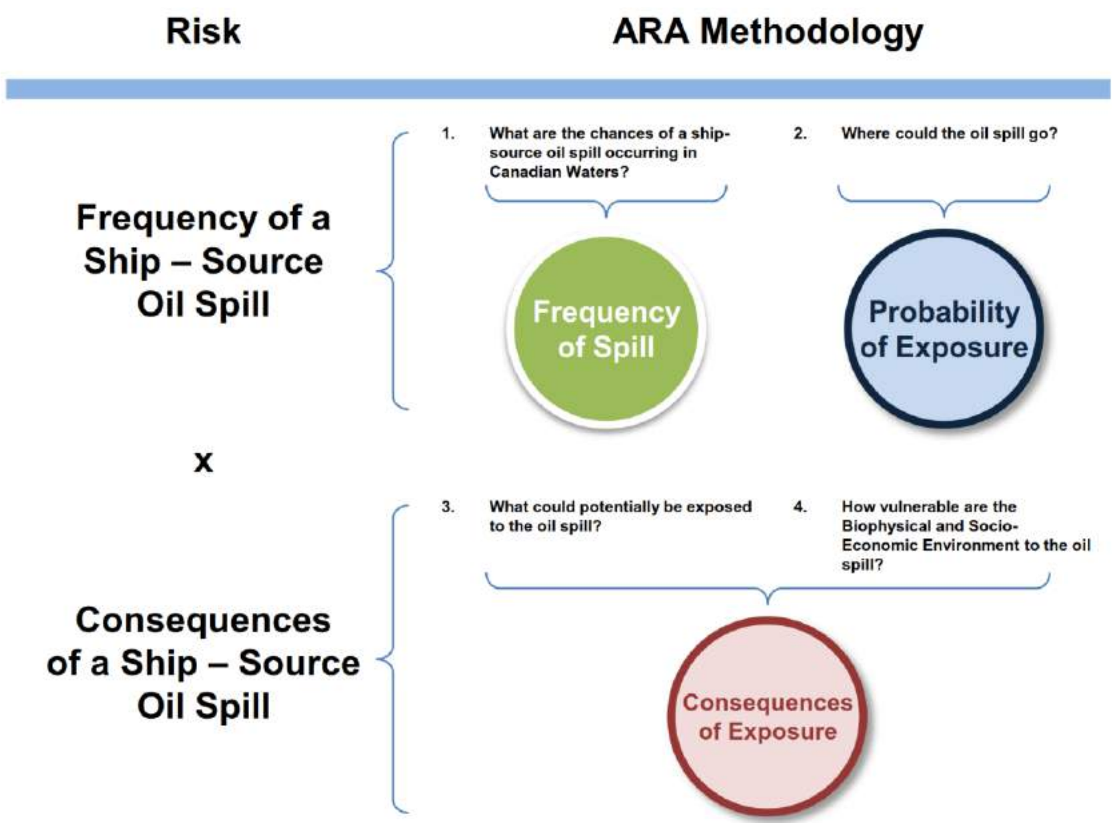


Figure 2-1: How the ARA Methodology Defines Risk

There are many different principles that can be applied to managing risk, and the ARA Methodology is built upon the approach within CAN/CSA-ISO 31000-10 Risk Management – Principles and Guidelines (see **Figure 2-2**).

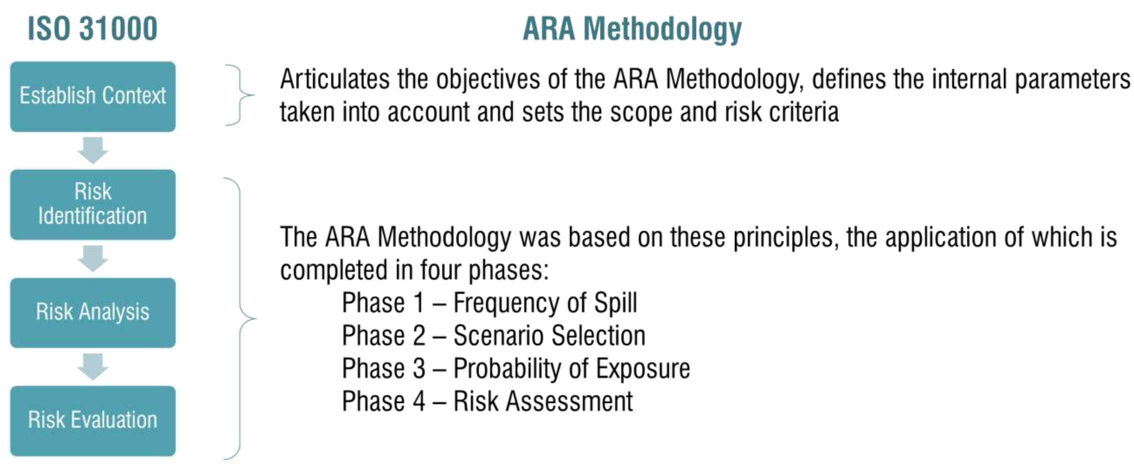


Figure 2-2: ARA Methodology – Principles Based on CAN/CSA-ISO 31000-10

2.2 Establishing Context

Establishing the context of the ARA Methodology involves describing the Government of Canada's objectives for the risk assessment (as stated in **Section 1.1**), defining the factors taken into account when assessing the risk of a ship-source oil spill and establishing the scope for the assessment.

The ARA BowTie Diagram is a graphical tool used to communicate the scope of the ARA Methodology and illustrates the linkages between potential causes, preventative and mitigative controls and consequences of a ship-source oil spill, which are all key factors within the ARA Methodology. The simplified ARA BowTie is illustrated in **Figure 2-3** with a general overview provided in this section. Additional details on the ARA BowTie are provided in **Appendix B**.

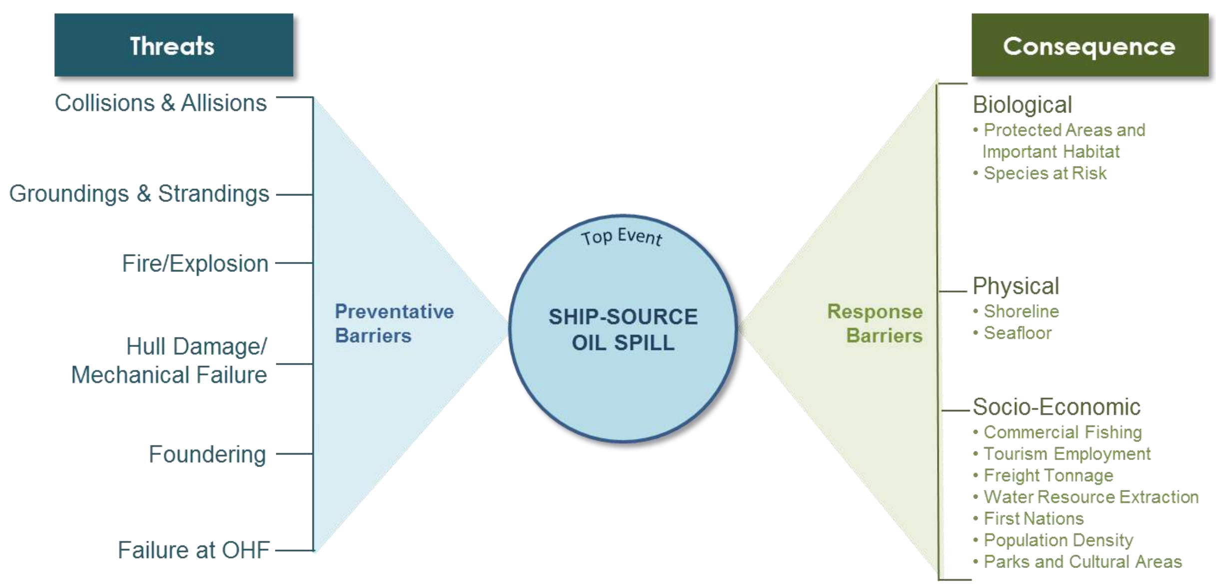


Figure 2-3: Simplified ARA BowTie Diagram

The ARA BowTie is comprised of three fundamental parts:

1. **Hazard and Top Event** – The center of the BowTie identifies the focus of the ARA Methodology. The "Hazard" is the activity – which is the movement of ships within Canadian Waters and includes those that carry crude oil as cargo. The "Top Event" is a ship–source oil spill in Canadian Waters.
2. **Threats** – The left side of the BowTie identifies the potential causes of a ship-source oil spill in Canadian Waters that are considered within the ARA Methodology. In order for risk to manifest itself, it begins with the *Threats*. The *Threats* are triggering events that have the potential to cause a ship-source oil spill. *Preventative Barriers* focus on reducing or eliminating the likelihood that the *Threats*, if they were to occur, could cause a ship-source oil spill. An example of a *Preventative Barrier* is "Pilotage".
3. **Consequences** – The right side identifies the consequences of a ship-source oil spill in Canadian Waters. Within the ARA Methodology, the consequences of a ship-source oil spill will be quantified from a biological (e.g. impacts to marine mammals), physical (e.g. impacts to shoreline, protected habitat), and socio-economic (e.g. disruption to commercial fishery) perspective, which are called *Risk Receptors*. There are *Response Barriers* that focus on reducing or eliminating the consequences of a ship-source oil spill. An example of a *Response Barrier* is "Deployment of Spill Booms".

2.2.1 Definition of Oil Categories

Given that the focus of the ARA Methodology is ship-source oil spills in Canadian Waters, an understanding of the types of oil transported in Canadian Waters and their respective behavior in sea water is required. In general, the behavior of oil in water is based upon its mobility which is a function of its density and hydrocarbon composition. Within the ARA Methodology, oils are categorized into one of five (5) Oil Categories as presented in **Table 2-1** and displayed in **Figure 2-4** as an input to the ARA Methodology.

Table 2-1: ARA Methodology Oil Categories

Oil Category	Description
Light Evaporator	Less dense than sea water; highly volatile – prone to evaporation Examples – jet fuel, gasoline
Medium Evaporator	Less dense than sea water; volatile – prone to evaporation Examples – light grade crude ,fresh diluted bitumen (with 30% condensate)
Medium Floater	Less dense than sea water; marginal volatility Examples – diesel fuel, fuel oils, medium grade crude
Heavy Floater	Marginally less dense than sea water; limited volatility Examples – heavy grade crude, heavy refined oils
Heavy Sinker	At or more dense than sea water, especially in high sediment environment Examples – very heavy grade crude

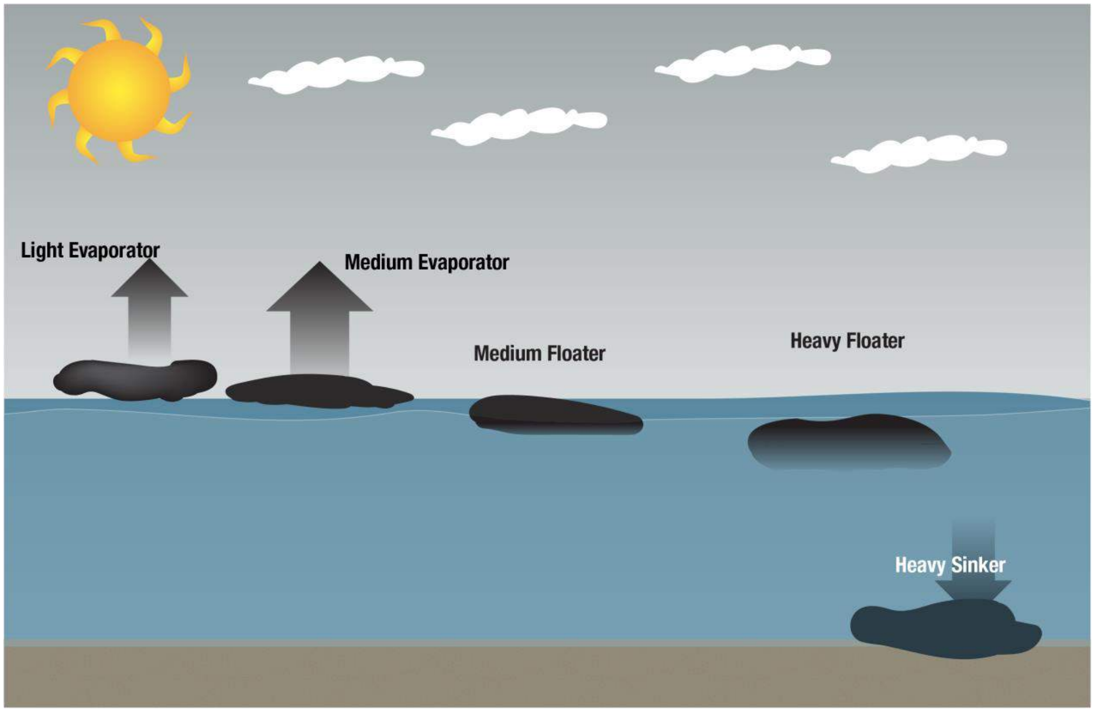


Figure 2-4: Oil Categories Included in ARA Methodology

Refer to **Appendix C** for a summary of the process for selecting the Oil Category for input to the ARA Methodology.

2.2.2 Definition of ARA Methodology Study Area

As stated in **Section 1.2.2**, the ARA Methodology can be applied to Canadian Waters located south of the 60th parallel, with the following limitations listed in **Table 2-2**.

Table 2-2: ARA Methodology Study Area Limitations

Item Description	Limitation
1. Arctic Waters (above 60th parallel)	Currently, the ARA Methodology was developed to be applied to all Canadian Waters south of 60th parallel only.
2. Fresh Waters (i.e. Great Lakes)	The ARA Methodology has only been validated in four areas and only one freshwater environment (St. Lawrence River). Some changes may be required to apply the ARA Methodology to a larger freshwater environment, such as the Great Lakes.
3. Locations of ship-source oil spills	Spills that originate outside of Canadian Waters are excluded with the exception of those discussed in **Section 1.2.2**.

In order to adequately examine the risks of ship-source oil spills spatially in each Study Area, the area is divided into a grid. The ARA Methodology will assess the risks of ship-source oil spills in both a horizontal (grid cell) and vertical (grid layer) perspective as illustrated in **Figure 2-5**. The horizontal grid cells are selected to provide adequate spatial resolution for assessing the risk of oil spills and vertically there will be the following four grid layers where oil can manifest itself:

- Shoreline;
- Water Surface;
- Water Column; and
- Seafloor.

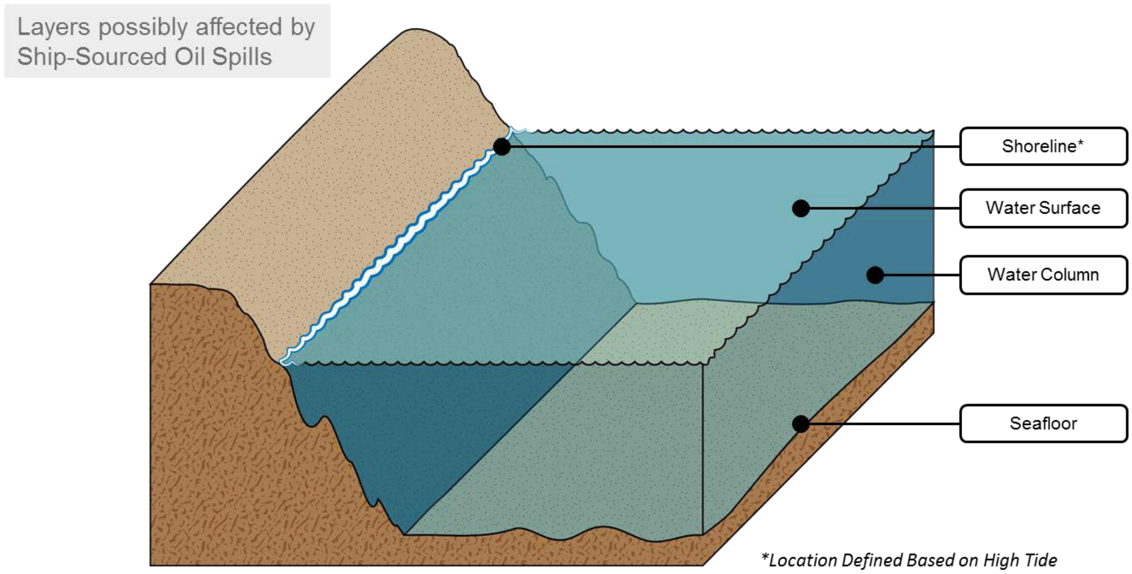


Figure 2-5: Grid Layers That Compose a Grid Cell

Figure 2-6 illustrates the sub-division of the Bay of Fundy Study Area into grid cells as an example. There will be situations where a grid cell will cover both water and shoreline, in which case the edge of the grid cell will be aligned to the shoreline using ArcGIS. The size of the grid cells can be adjusted by the User as required in order to provide adequate resolution for assessing the risk of ship-source oil spills. The grid presented in **Figure 2-6** is the methodology's standard size of 2 nm by 2 nm.

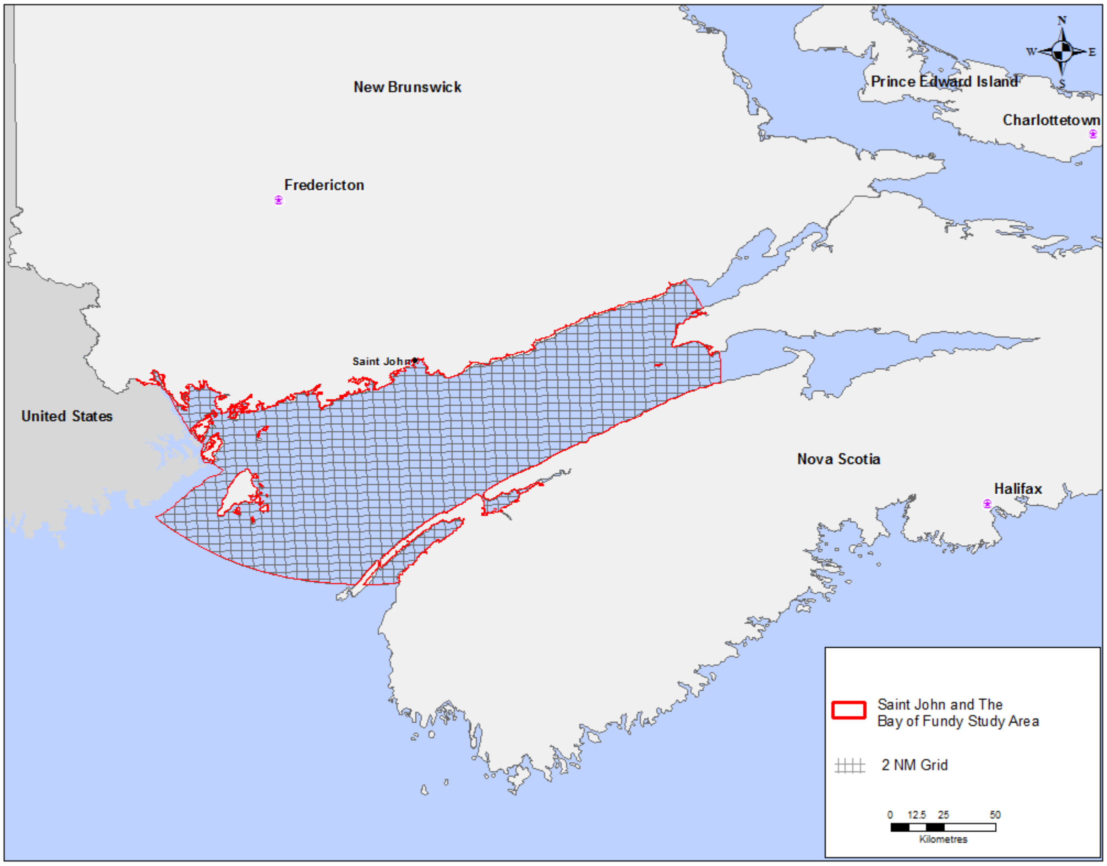


Figure 2-6: Bay of Fundy Grid Cell Map

2.2.3 Definition of Spill Volumes

The frequency of an oil spill is based on an analysis of the traffic density, oil volumes and ship movements in the Study Area using the SAMSON Model. The Model calculates the frequency, volume, location and oil type of a potential ship-source oil spill within each grid cell. Additional details on the SAMSON Model are presented in **Appendix D**.

The ARA Methodology then uses this data to evaluate statistically-defined oil spill volumes from both ship and OHF sources based on the Annual frequency of occurrence (general expressed as 1/years) or the Return Period (the inverse of the Annual Frequency of Occurrence).

The Return Period is commonly used to present the frequency of an event such as a flood, wind storm or earthquakes. For example, if the Return Period for a flood is 100 years, the Annual Frequency is 1.0×10^{-2} (or 1% chance each year of a 1:100 year flood event). This does not mean that if a 1:100 year flood occurred today that the next flood will occur in about 100 years. Instead, it means that in any given year, there is a 1% chance that it will happen, regardless of when the last event occurred. Within the ARA Framework, the "event" is a ship-source oil spill, as illustrated in the ARA BowTie in **Figure 2-3**.

The following oil spill volume types, based on a defined Total Return Period within an individual grid cell are presented in **Table 2-3** as a way for the User to communicate the type of oil spill. As shown in **Table 2-3**, the User has the ability to define other Oil Spill Volume Types as deemed appropriate for the Study Area (i.e. Level 3 = 1:10,000 years or 1.0 x 10^{-4} Total Frequency).

Table 2-3: Oil Spill Volume Types in ARA Methodology

Oil Spill Volume Types	Total Return Period (per Grid Cell)	Total Frequency (F) per year (per Grid Cell)
Level 1	1:1,000 years	1.0 x 10^{-3}
Level 2	1:5,000 years	2.0 x 10^{-3}
Level [##]	1:[User to insert value] years	[1/Total Return Period]

For the ARA Methodology, oil spill volumes were grouped into eight (8) classes (called "Spill Volume Class") for ease of determining the Risk Score, as well as to align the spill size ranges within the varying types of vessels that can be present within a Study Area, as presented in **Table 2-4**. By doing this, the User will have the ability to calculate the statistically-defined volumes of oil spills for:

- All ship types within a Study Area per grid cell; or
- A specific ship type (e.g. an AFRAMAX tanker) per grid cell within a Study Area.

Table 2-4: Spill Volume Classes in ARA Methodology

Spill Volume Class	Outflow – Spill Volume		Vessel Type	Typical Spill Volume from Bunker or Cargo tank (m^3)
	From (m^3)	To (m^3)		
1	0.01	30	Fishing, Recreation	Bunkertank <30
2	30	150	Small Commercial	Bunkertank <150
3	150	1,000	Medium Commercial	Bunkertank <1K
4	1,000	5,000	General Purpose Med. Range Tanker	Bunkertank <5K 1x Cargo Side 5k
5	5,000	15,000	Long Range 1 Tanker Panamax	1x Cargo Side 12k
6	15,000	30,000	Aframax	1x Cargo Side 10k + 1x Cargo Centre 17k
7	30,000	100,000	New Panamax Suezmax VLCC ULCC	1x Cargo Side 17k + 1x Cargo Centre 40k
8	>100,000			N/A (Spill exceeds volume of 2 largest tanks)

2.3 Risk Assessment Approach

The ARA Methodology, as illustrated in **Figure 2-2**, is completed in four phases. The first step is to determine the frequency of a ship-sourced oil spill (Phase 1) within the prescribed Study Area, thereby focusing efforts to identify the oil spill volume and type at specific locations (Phase 2) to be selected as scenarios for modeling. Before the final phase, the Probability of Exposure is determined (Phase 3). These phases enable the risk assessment (Phase 4) to be completed to better understand and evaluate the risks for the selected oil spill volume types at specific locations within the Study Area. A graphical illustration of the ARA Methodology Application is presented in **Figure 2-7**. Further details on each phase are provided in the following sections.

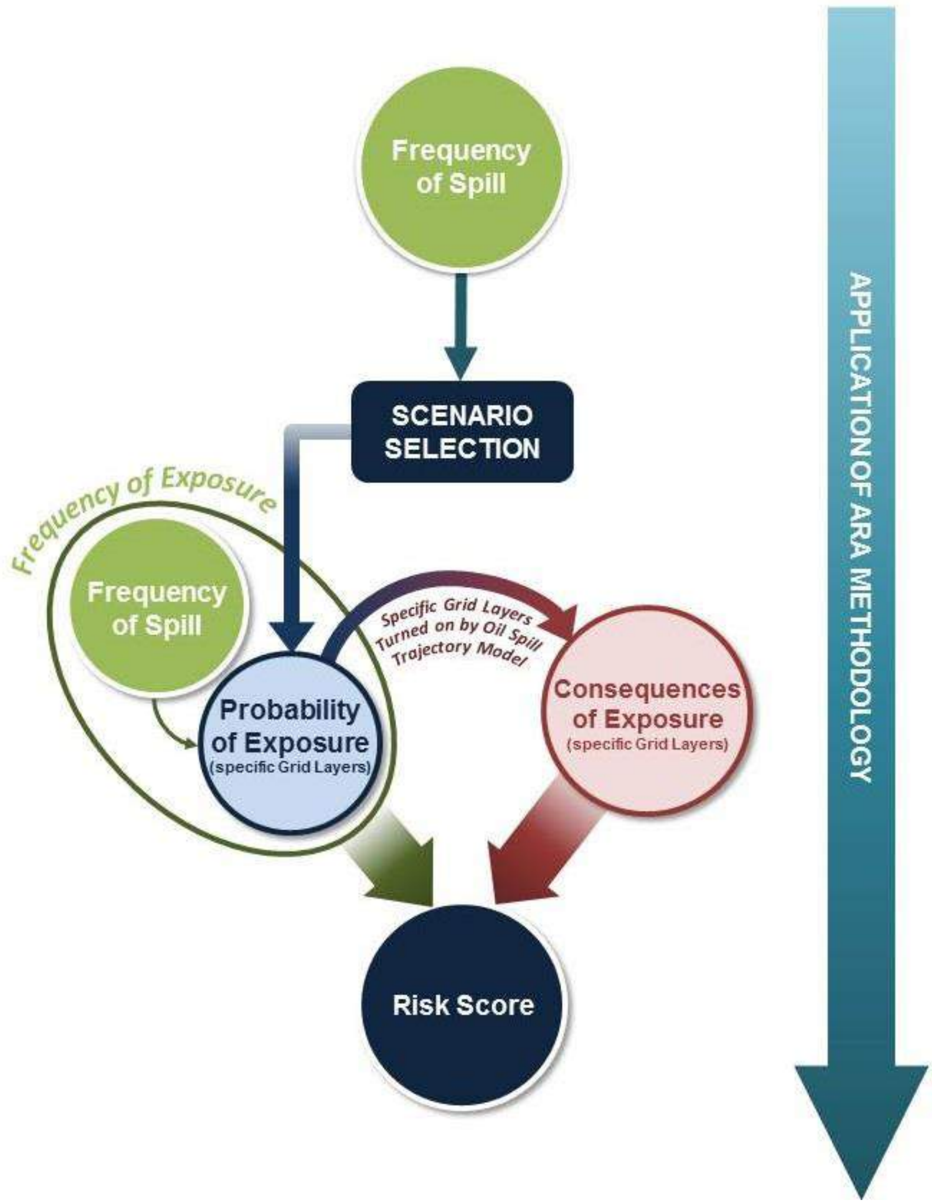


Figure 2-7: ARA Methodology Decision Flow Chart

2.3.1 Phase 1 – Frequency of Spill

The frequency of ship-source oil spills (FOS) from tankers that carry oil as cargo and from other vessels that use oil as propulsion fuel is calculated using the SAMSON Model. The primary inputs to the SAMSON Model are summarized in **Table 2-5**. Additional details on the SAMSON Model and the calculation of the FOS from OHFs are provided in **Appendix D**.

Table 2-5: Primary Inputs to Determine Frequency of Spill

Primary Inputs to SAMSON Model	Description	Source(s)
AIS Data	Includes the number and type of ships that are present and operate within the Study Area.	Canadian Coast Guard (CCG)
Ship-Based Failure Rates	Number of incidents and accidents that can occur per ship type.	Statistical Analysis[5]
Failure Rates of OHF Loading Equipment	Number of incidents and accidents that can occur per OHF.	International Statistics

Individual risk maps are generated for each of the eight (8) Spill Volume Classes (see **Table 2-4**) in each Study Area as outputs from Phase 1. Additional details on Phase 1 are provided in **Section 3.0** of this report. The risk maps will aid the User to determine the scenarios, as described in Phase 2.

2.3.2 Phase 2 – Scenario Selection

Scenario selection is the process, completed by the User, of taking the outputs of Phase 1 – Frequency of Spill, and utilizing the data to select the grid cells which are at highest risk. Additional details on Scenario Selection are presented in **Section 4.0** of this Guidance Document. The scenario selection phase generates locations, volumes and oil categories on which to perform oil spill fate and trajectory modeling in Phase 3 – Probability of Exposure.

2.3.3 Phase 3 – Probability of Exposure

Stochastic oil spill fate and trajectory modeling is completed for each spill scenario selected in Phase 2 to calculate the probability of exposure (POE). It consists of generating multiple oil trajectory simulations at the same source location that have varying spill start times (i.e. during different seasons) selected at random from a multi-year period. The output of the stochastic analysis is the probability of oil being present above a measurable threshold (usually defined as a thickness and/or concentration which would harm a *Risk Receptor* **IF** contact was made) in the four vertical grid layers (see **Section 2.2.2**).

[5] Canadian data pertaining to accidents and reportable incidents from the Transportation Safety Board's (TSB's) Marine Safety Information System (MARSIS) were analyzed and compared to International statistics. International statistics were used as there is not enough incident and accident statistical data in Canada to allow for a meaningful statistical comparison.

2.3.4 Phase 4 – Risk Assessment

The final phase in the Risk Assessment involves calculating the Risk Score ($Risk_S$) associated with a specific oil spill scenario. The POE values for each grid layer within each grid cell (from Phase 3) is combined with the FOS value associated with the ship-source oil spill accident (from Phase 2) to derive annual frequencies that any of the three Risk Receptors could be exposed to oil **IF** they were present. This is called the Frequency of Exposure (FOE).

Various datasets are utilized to determine the presence/type of the Risk Receptors – called Consequence of Exposure (COE), within each grid layer of each grid cell. The COE values are combined with the corresponding FOE values to calculate the $Risk_S$. Detailed information on Phase 4 is presented in **Section 6.0**.

3.0 Phase 1 – Frequency of Spill

The Frequency of Spill (FOS) is the first phase of the ARA Methodology and intended to identify locations within each Study Area that are more likely to experience oil spills. The FOS determines the following within each grid cell in the Study Area:

1. Frequency and location of a ship-source accident;
2. Type of ship(s) involved in the accident;
3. Frequency of an oil spill for various oil spill volume classes; and
4. Type of oil that is spilled.

Determining the FOS involves calculating the frequency of marine accidents from vessels using the Safety Assessment Model for Shipping and Offshore (SAMSON Model), which provides spill frequency, size, location, oil type and vessel type in a two-step process presented in **Figure 3-1**. The first step involves determining the frequency and location of various accidents occurring. The second step determines the frequency and volume of oil outflowing from the accident in the first step. Technical details on the SAMSON Model are provided in **Appendix D.**

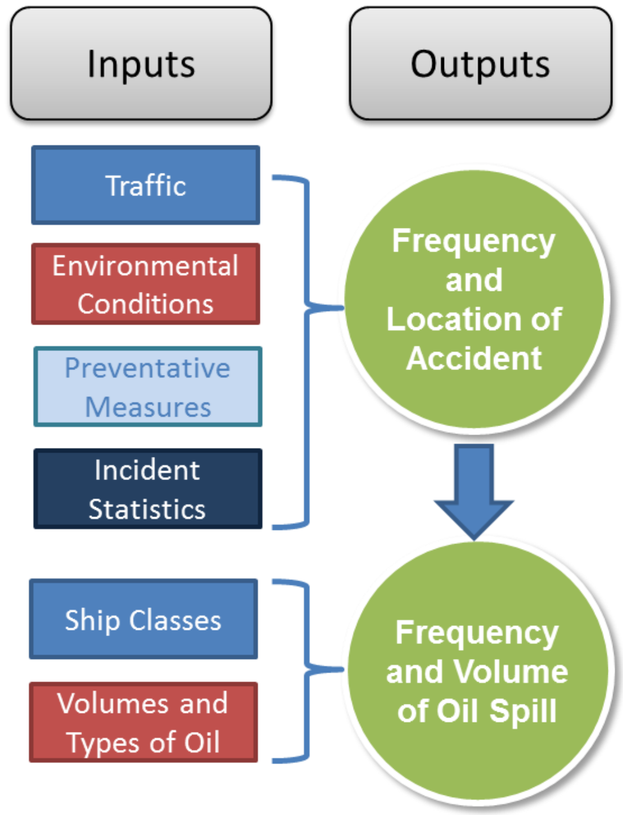


Figure 3-1: SAMSON Model Inputs and outputs

3.1 Frequency and Location of Accident

The inputs into the SAMSON Model are as follows:

- Automatic Identification System (AIS) traffic data;
- Environmental data (bathymetry, local conditions, wind and current data);
- Preventative measures(traffic separation schemes, use of pilotage); and
- Volumes and oil types being transported by particular ship classes.

Any baseline year of AIS data can be used to conduct the analysis.

The SAMSON Model estimates the frequencies of ship accidents (including collisions and allisions, groundings and strandings, hull damage/mechanical failure, and foundering) for different ship types.

Data is sourced from world-wide shipping accident data obtained from the IHS Fairplay Database for the period of 1995 to 2012.

The conditions that cause the various accidents reflect local conditions in each Study Area, including traffic density, tidal currents, wind speed and direction and preventative measures. The SAMSON Model combines various accident scenarios, as described in **Table 3-1**, with AIS traffic data from Canada, to calculate the frequency of an accident.

Table 3-1: SAMSON Model Accident Types

SAMSON Model Accident Type	Description
Collisions	The frequency of collision when ships enter a defined domain between each other. The frequency of collision is based on ship type, speed and international collision statistics.
Allisions	The frequency of allision is calculated when a ships enters a defined domain of another ship at anchor. The frequency of allision is based on ship types, speed of the vessel, location of the anchored vessel and international allision statistics.
Groundings (includes Strandings)	The frequency of grounding or stranding is calculated using the frequency of a ship having a technical failure or navigational error based on international statistics and the proximity of the ship to a fixed object to strike (stranding) or to run aground.
Hull Damage/ Mechanical Failure	The frequency of hull/machinery failure is determined from the nautical miles the ship has sailed within the Study Area.
Foundering	The frequency of foundering is determined from the nautical miles the ship has sailed within the Study Area.

3.2 Frequency and Volume of Oil Spill

The frequency and volume of oil spills from ships involved in an accident in the SAMSON Model is established based on the ship classes provided in worldwide oil spill data. More specifically, the SAMSON Model takes the following factors into account:

- Type of ship – design, construction (e.g. layout of tanks and double hull construction) and functionality (SAMSON Model has a database of 42 different ship classes);
- Which part of the ship was impacted by the accident;
- The calculated force of the accident; and
- The probability that a tank is loaded with oil.

For additional details on the 42 different ship classes and how oil spill outflow is calculated in the SAMSON Model, refer to **Appendix D**.

As stated in **Section 2.2.1**, the ARA Methodology uses five oil categories to define the range of oils that each of the 42 different ship classes can carry, as an input to the FOS analysis. Refer to **Appendix C** for a summary of the process for selecting the Oil Category for input to the ARA Methodology. The SAMSON outputs include the volume and the type of oil spilled as well as the Spill Volume Class it belongs to as defined in **Section 2.2.3**.

The primary output of the SAMSON Model is a compiled geo-referenced database that contains:

- Type of accident, location, vessel type(s) and vessel(s) size; and
- Individual frequency, volume and oil category for each accident.

The Total Frequency (F), which is the summation of the individual frequency of all accidents that exceed the minimum Outflow Volume for each Spill Volume Class, is then calculated by SAMSON for each grid cell in the Study Area – for a total of eight Total Frequency (F) values. Each Total Frequency (F) value is then classified and colour-coded based on the FOS Categories defined in **Table 3-2**. A visual representation of the FOS Scores is also generated by SAMSON for each of the Spill Volume Classes.

Table 3-2: Frequency of Spill (FOS) Categories, Scoring, Description, Definitions and Colour Code

FOS Category	FOS Score (Annual Total Frequency)	Description	Definition[6] (Total Return Period)	Colour Code
FOS-10	3.16×10^{-1}	Very High	<1:10 years	
FOS-9	3.16×10^{-2}	High	1:10 - 1:99 years	
FOS-8	3.16×10^{-3}	Medium	1:100 - 1:999 years	
FOS-7	3.16×10^{-4}	Low	1:1,000 - 1:9,999 years	
FOS-6	3.16×10^{-5}	Very Low	1:10,000 - 1:99,999 years	
FOS-5	3.16×10^{-6}	Extremely Low	1:100,000 - 1:999,999 years	
FOS-4	3.16×10^{-7}		1:1,000,000 - 1:9,999,999 years	
FOS-3	3.16×10^{-8}		1:10,000,000 - 1:99,999,999 years	
FOS-2	3.16×10^{-9}		1:100,000,000 - 1:999,999,999 years	
FOS-1	3.16×10^{-10}		1:1,000,000,000 - 1:9,999,999,999 years	

The FOS Categories defined in **Table 3-2** are based on a Total Return Period – the inverse of the frequency. For example, FOS-3 category has a FOS Score of 3.16×10^{-3} occurrences per year, the inverse of which is one occurrence every 316 years. As a result, Total Return Period and Frequency can be used interchangeably. Two example outputs from Phase 1 (FOS maps for the Southern Portion of BC Pilot Area) are provided in **Figure 3-2** and **Figure 3-3** for two Spill Volume Classes >0.01 m^3 and >30,000 m^3. Further details on how the User can utilize the FOS maps for Scenario Selection are provided in **Section 4.0**.

[6] The Total Return Periods defined in **Table 3-2** cannot be used to represent the frequency of individual ship-source oil spill accidents.

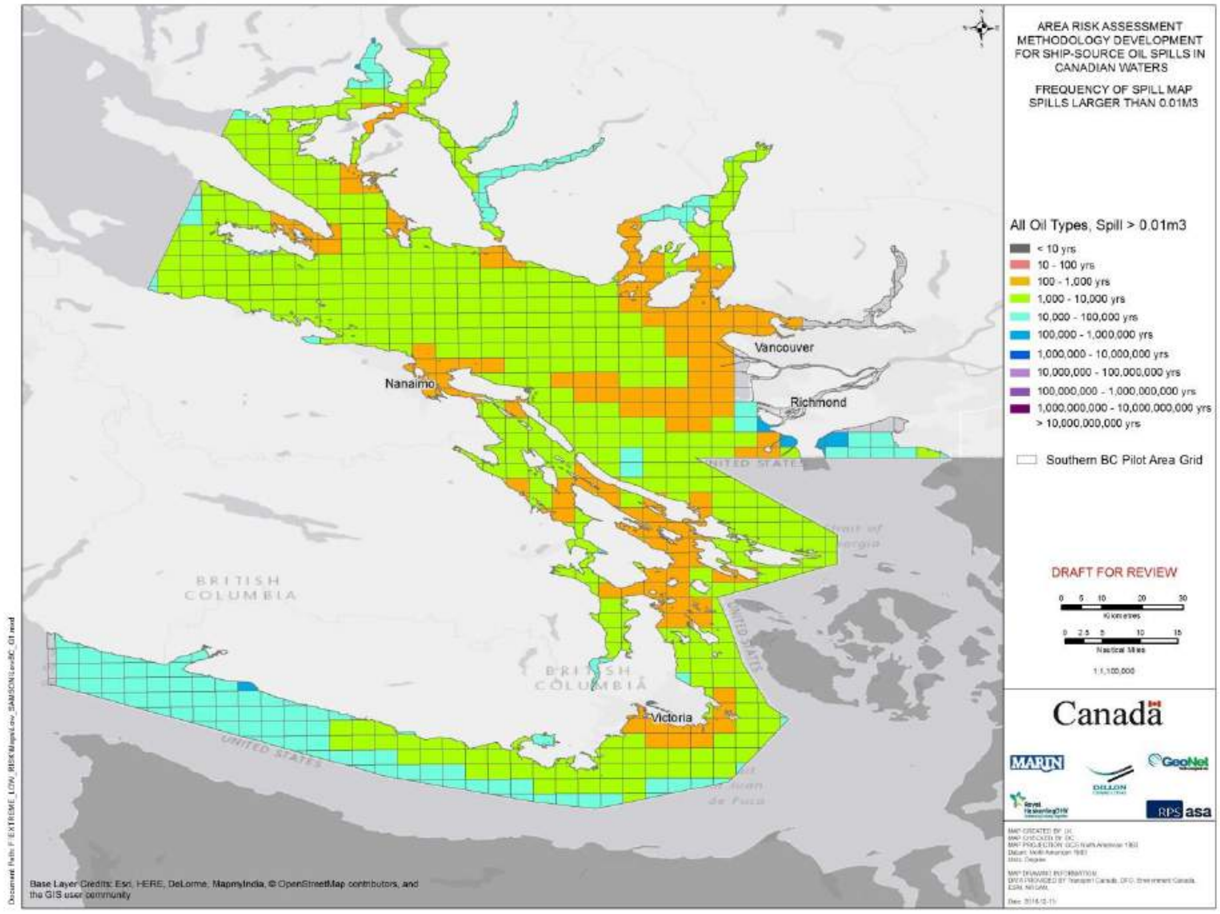


Figure 3-2: Example FOS Map for Spills >0.01 m³ – Southern Portion of BC Pilot Area

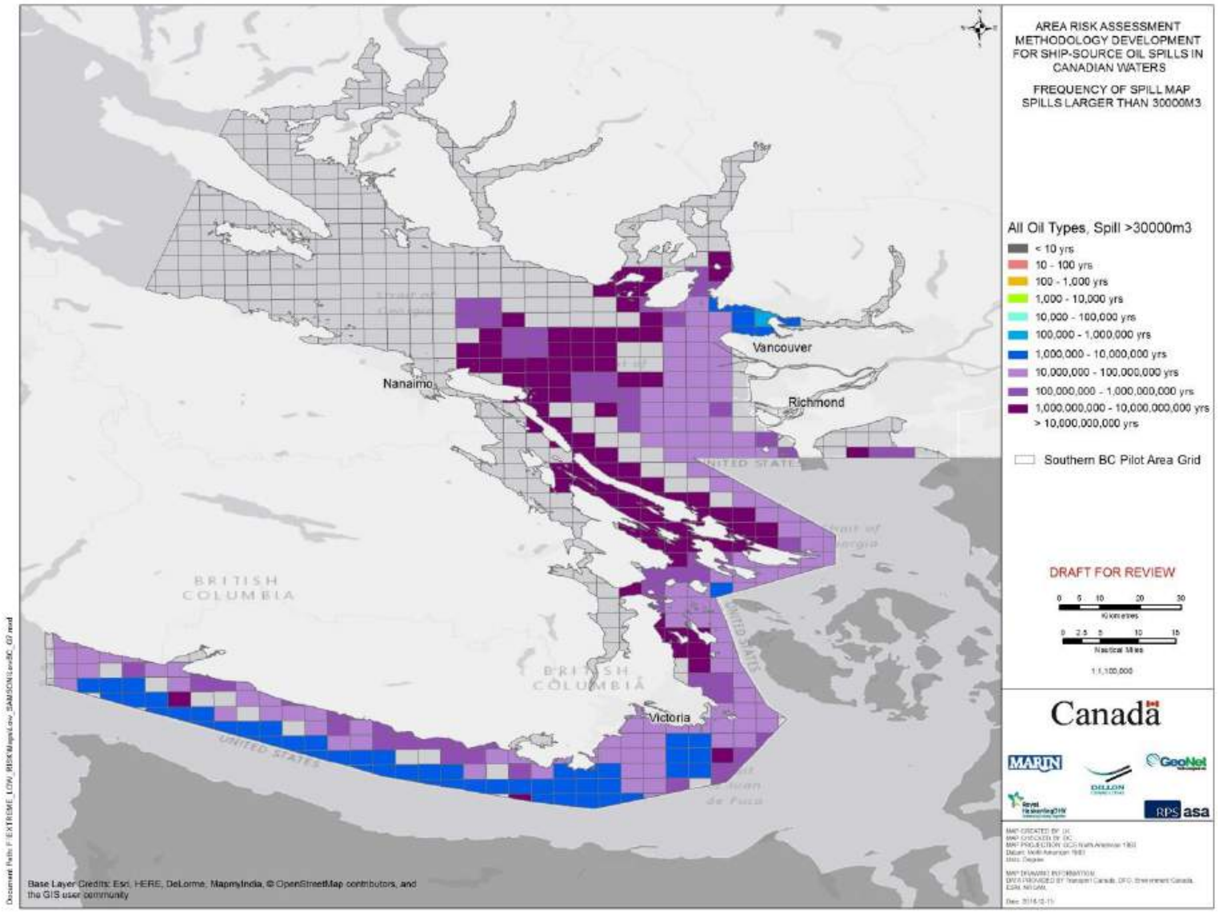


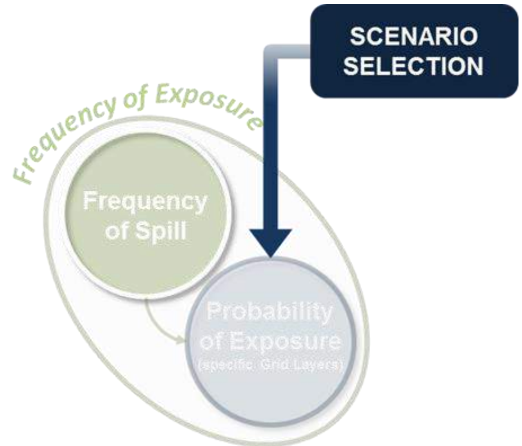
Figure 3-3: Example FOS Map for Spills >30,000 m^3 – Southern Portion of BC Pilot Area

3.3 Oil Spill Frequencies at OHFs

Oil spill frequencies and volumes from OHFs are estimated from international statistics on oil spills from OHFs from select countries with similar regimes to Canada, as outlined in **Appendix D**. Oil spill statistics from Canadian OHFs alone cannot be solely relied upon given the varied causes and volumes of oil spills being reported. The frequency and volume of oil spills from OHFs are calculated based on the transfer mechanism used at the OHF (loading arm or hose), transfer rate, volume of oil transferred in the baseline year, and the presence of shutdown valves. For each OHF the probability of an oil spill will be calculated for two spills sizes that are based on the transfer mechanism used at the OHF.

4.0 Phase 2 – Scenario Selection

There are two methods that the User can choose from to select the scenarios to bring forward for analysis in Phases 3 and 4 of the ARA Methodology.



Method 1 – identify and prioritize the highest Total Frequency (F) locations within the Study Area for ship-source oil spills.

Method 2 – identify the largest oil spill volume scenarios.

Further details on each of the three methods are provided in the subsequent sections.

4.1 Method 1 – Highest Priority Scenarios based on Total Frequency

The objectives of Method 1 are to a) identify and prioritize the highest Total Frequency (F) locations within the Study Area for ship-source oil spills and b) select specific (i.e. individual) ship-source oil spill scenarios from the highest Total Frequency (F) locations for further analysis within the ARA Methodology.

A three-step process is employed to achieve these two objectives, the details of which are provided below.

Step 1 – Determine the ARA Total Return Period Threshold
The ARA Total Return Period Threshold is based on the inverse of the Total Frequency (F), and will therefore be compared to the Total Frequency (F) that is calculated for each of the eight Spill Volume Classes.

Two ARA Total Return Period Thresholds are currently defined within the ARA Methodology as shown in **Table 2-3**. However, the User has the ability to use other ARA Total Return Period Thresholds (i.e. 1 in 10,000 years).

Step 2 – Identification of ARA Total Return Period Threshold Locations
A comparison is done of FOS Maps for two different Spill Volume Classes to identify specific grid cells where the FOS Category, corresponding to the ARA Total Return Period Threshold, changes. To illustrate this, two FOS Maps (see **Figure 4-1**) for the Southern Portion of British Columbia Pilot Area were compared to identify Level 1 ARA Total Return Period Threshold locations – one for Spill Volume Class 1 (>0.01m^3) and one for Spill Volume Class 2 (>30 m^3).

Within the 4 highlighted grid cells, the FOS Score drops from FOS-8 to FOS-7 as the Spill Volume Class increases from >0.01m^3 to >30 m^3. This indicates that within the highlighted area, the cumulative frequency (F) equates to a corresponding Total Return Period of 1,000 years for Spill Volume Class 1 - between 0.01 and 30 m^3. The data outputs from the SAMSON Model for one of the four highlighted grid cells is then further analyzed in Step 3.

Step 3 – Analysis of Individual Ship-Source Scenarios within a Specific Spill Volume Class
To illustrate how Step 3 is completed, a SAMSOM sample output from one of the four highlighted grid cells in **Figure 4-1,** is presented in **Table 4-1**. The outputs illustrate that for Spill Volume Class 1, the corresponding Total Return Period = 226 years (corresponds to FOS-3), whereas Spill Volume Class 2 has a Total Return Period = 2,871 years (corresponds to FOS-2).

For Spill Volume Class 1, SAMSON generated 2,683 individual ship-source oil spill scenarios that have corresponding Individual Frequencies (f) between 1.79 x 10^{-16} (or 1 in 5 quadrillion years) and 9.88 x 10^{-4} (or 1 in 1,012 years). The scenarios are sorted with the highest Individual Frequency (f) selected as the scenario to bring forward for analysis in Phase 3. In this specific example, the following scenario was identified:

Level 1 Oil Spill Scenario
Incident Type: Foundering of recreation vessel
Oil Category: Marine Diesel (MF)
Volume: 3 m^3
Individual Frequency (f) = 9.88 x 10^{-4} or 1 in 1,012 years

The key consideration when completing Phase 2 is to select a Total Return Period Threshold, which then defines which FOS Maps (from Phase 1) to examine. Once the specific grid cells are identified (as shown in **Figure 4-1**), the SAMSON Model outputs will determine the size of the oil spill and the oil category to bring forward to Phase 3 – Probability of Exposure.

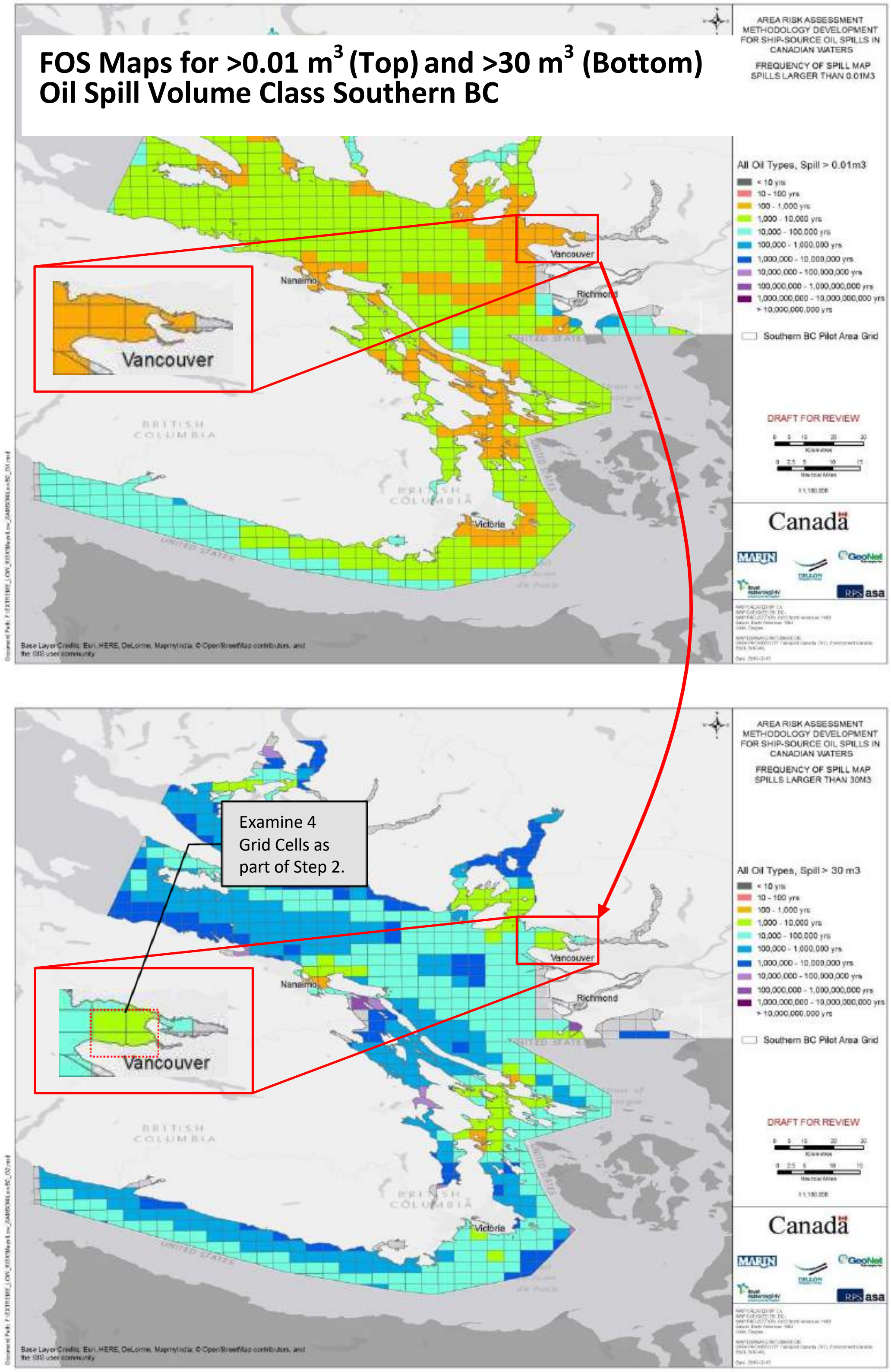


Figure 4-1: Step 2 of Scenario Selection - Comparison of FOS Maps

Table 4-1: Analysis of Sample SAMSON Outputs for Grid Cell in Vancouver Harbour (Refer to Figure 4-1)

Spill Volume Class	Outflow - Spill Class (m^3)		Vessel Type	Number of Scenarios Generated by SAMSON	Individual Frequency (f) of a Scenario per Year		Total Frequency (F) of Spill Volume Class (equals Summation of all Individual Frequencies)	Total Frequency (F) of Spill Volume Class + all Larger Spill Volume Classes	Total Return Period Per Spill Class in Years[7] (1/Total Frequency)
	From	To			Minimum	Maximum			
1	**0**	**30**	**Recreation**	**2,683**	**1.79×10^{-16}**	**9.88×10^{-4}**	**4.08×10^{-3}**	**4.42×10^{-3} or**	**226**
2	30	150	Small commercial	3,960	6.59×10^{-17}	3.63×10^{-6}	2.39×10^{-5}	3.48×10^{-4} or	2,871
3	150	1,000	Medium commercial	4,450	2.97×10^{-17}	5.28×10^{-6}	1.45×10^{-4}	3.24×10^{-4} or	3,082
4	1,000	5,000	General purpose Med. Range Tanker	2,842	1.32×10^{-16}	3.75×10^{-6}	1.63×10^{-4}	1.80×10^{-4} or	5,557
5	5,000	15,000	Long range 1 tanker Panamax	1,00	1.13×10^{-15}	5.05×10^{-7}	1.06×10^{-5}	1.67×10^{-5} or	59,711
6	15,000	30,000	Aframax	716	5.61×10^{-20}	5.17×10^{-7}	5.08×10^{-6}	6.15×10^{-6} or	162,663
7	30,000	100,000	New Panamax Suezmax VLCC ULCC	716	2.48×10^{-28}	1.43×10^{-7}	1.01×10^{-6}	1.07×10^{-6} or	993,755
8	>100,000			528	4.18×10^{-16}	3.21×10^{-8}	5.99×10^{-8}	5.99×10^{-8} or	16,700,093

[7] Colour coding based on FOS Definitions – see **Table 3-2: Frequency of Spill (FOS) Categories, Scoring, Description, Definitions and Colour Code**

4.2 Method 2 – Highest Priority Scenarios based on Oil Spill Volume

The objectives of Method 2 are to a) identify and prioritize the largest oil spill volume locations within the Study Area for ship-source oil spills and b) select specific (i.e. individual) ship-source oil spill scenarios from specific Spill Volume Classes for further analysis within the ARA Methodology.

A three-step process is employed, the details of which are provided below.

Step 1 – Select Spill Volume Class FOS Map

Depending on the specific requirements for the ARA, the User will select the FOS map for a specific Spill Volume Class. For example, if the intent of the ARA is to analyze the largest possible spill within the Study Area, the User will select the largest Spill Volume Class FOS Map, which for the Southern Portion of British Columbia is Spill Volume Class 8 (>100,000 m3) – see **Figure 4-2**.

The largest Spill Volume Class FOS map is examined by the User to identify specific grid cell(s) that correspond to the highest FOS Score, the idea being that those specific grid cells will have the largest oil spill volumes with the largest Total Frequency.

Step 2 – Identification of the Highest ARA Total Return Period Threshold Locations

The one grid cell highlighted in **Figure 4-2** has the highest FOS Score – with an ARA Total Return Period Threshold between 100,000 and 1,000,000 years.

Step 3 – Analysis of Individual Ship-Source Scenarios within a Specific Spill Volume Class

The SAMSON output of the highlighted grid cell from the Southern Portion of British Columbia Pilot Area in **Figure 4-2,** is examined for Spill Volume Class 8.

A total of 399 of individual ship-source oil spill scenarios were generated by SAMSON, that have corresponding Individual Frequencies (f) between 8.70 x 10^{-17} (or 1 in 5 sextillion years) and 5.57 x 10^{-7} (or 1 in 1.7 million years). The scenarios are sorted with the highest oil spill volume selected as the scenario to bring forward for analysis in Phase 3. In this specific example, the following scenario was identified:

Oil Spill Volume Scenario
Incident Type: Foundering of vessel 200,000 DWT Tanker
Oil Category: Medium Evaporator (Crude Oil)
Volume: 122,359 m^3
Individual Frequency (f) = 2.23 x 10^{-8} or 1 in 44 million years

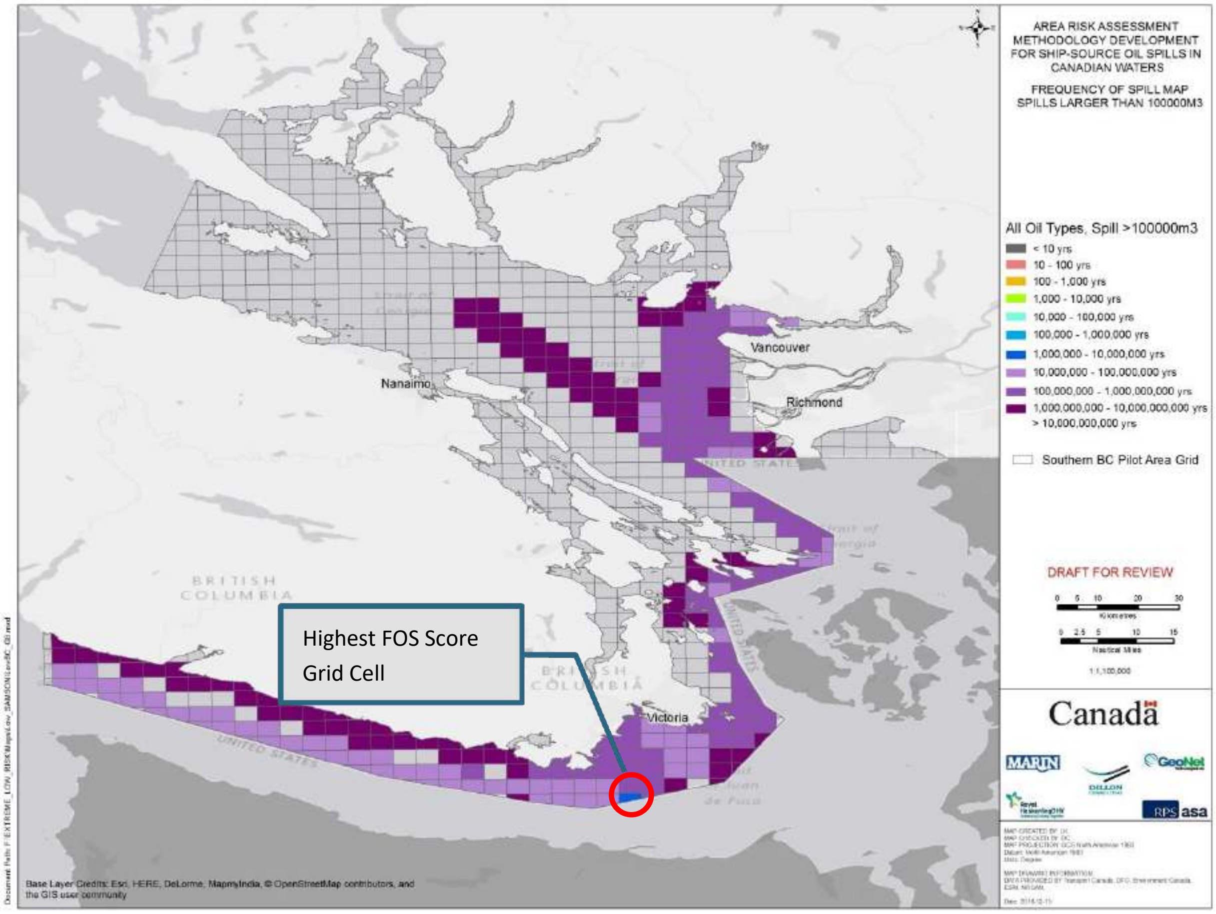


Figure 4-2: Identification of Largest Oil Spill Volume Scenarios

5.0 Phase 3 – Probability of Exposure

The Probability of Exposure (POE) represents the probability of oil being present within each grid cell in the Study Area above a measurable threshold across each grid layer using an oil spill model. The main inputs to the oil spill model are from Phase 1 and Phase 2, specifically:

1. Location of Spill;
2. Volume of Spill and Oil Category;
3. Oil Thresholds;
4. Other Parameters; and
5. Spill Response.

A general overview is provided in the subsequent sections. **Appendix E** provides additional details on the oil spill model including detailed descriptions on the inputs required to define the spill scenarios and characterize the environment. It explains how the model is applied and how the model results are used in the overall risk calculation.

5.1 Location of Spill

The specific geographic locations (grid cells) identified in Phase 2 are inputs into the SIMAP Model.

5.2 Volume of Spill and Oil Category

The grid cells identified in Phase 2 detail the volume of spill and type of oil as determined by the SAMSON Model completed in Phase 1.

5.3 Oil Thresholds

Minimum oil thickness and concentration thresholds are used in the SIMAP Model to determine the probability of oil exposure for each of the three Risk Receptor Categories – Biological Sensitivities, Physical Environment and Socio-Economic Factors. The thresholds are Risk Receptor specific and are used to determine if oil is present in a quantity sufficient to cause a particular impact.

5.4 Other Parameters

Other parameters summarized in **Table 5-1** are User inputs into the SIMAP Model.

Table 5-1: SIMAP Model inputs

SIMAP Model Inputs	Description
Wind Data	Multi-year record of observed winds or a multi-year hindcast model that varies both temporally and spatially across the Study Area.
Currents	Multi-year or cyclical current record that is generated by a hydrodynamic model that covers the entire Study Area.
Ice	Multi-year historical ice records (percent coverage) for areas in the Study Area with ice.
Water parameters	Temperature, salinity and suspended particulate matter concentration throughout the Study Area.
Bathymetry	The Canadian Hydrographic Service provides digital navigation charts for navigable waters in Canada. The best approach is to assemble depth data from multiple sources and merge them into single bathymetry coverage

5.5 Spill Response

The oil spill model simulates oil spill response techniques during the oil spill fate and trajectory modelling. For the ARA Methodology, the User can choose from the following options:

- **Unmitigated** –spill scenario assumes no spill response measures are in place.
- **Encounter Rate** –spill scenario includes source control using booms and using an encounter rate calculation to estimate the volume of oil recovered using advancing skimming system. The encounter rate calculation includes limitations of primary storage of recovery vessels and the time required to discharge to secondary storages. The encounter rate can be modified to include in-situ burning and dispersant application.

The oil spill trajectory modeling of an oil spill scenario is based upon hundreds of random variations of individual parameters in order to provide a statistical representation of environmental conditions over a ten year period. As such, the performance of specific oil spill response equipment is not possible within the ARA Methodology – only the simulation of a specific oil spill event (sometimes called a "deterministic model") would enable the performance of specific equipment to be modeled.

5.6 Calculation of the POE Scores in Each Grid Cell

The oil spill model calculates the probability of exposure to oil on the sea surface, shoreline, in the water column and on seabed sediment within each grid cell covering the spill footprint. When oil from a spill is present in a grid cell in excess of the defined threshold, this constitutes a "hit".

Each stochastic scenario generated by the oil spill model results in a series of probability maps showing the probability of oil exceeding the thresholds. These maps will show the exceedances per cell and in all four vertical layers of the Pilot Area grid. The POE Score will be based on the mid-range of each POE probability range, as presented in **Table 5-2**.

Table 5-2: Probability of Exposure (POE) Categories, Scoring, Description, Definitions and Colour Code

POE Category	POE Score	Description[8]	Definition	Colour Code
POE-5	0.9	81% to 100%	Very High	
POE-4	0.7	61% to 80%	High	
POE-3	0.5	41% to 60%	Medium	
POE-2	0.3	21% to 40%	Low	
POE-1	0.1	5% to 20%	Very Low	

Note: Values less than 5% were excluded due to statistical variability within the oil trajectory model outputs

Each POE Score is a representation of the probability of the hundreds of scenarios run in stochastic mode. For example, POE-5 Category (POS Score = 0.9) would mean that 81-100% of the hundreds of random scenarios had oil exceeding the specified threshold of a specific Risk Receptor in a specific grid layer.

Within the ARA Methodology, the User has the ability to generate specific POE maps by selecting one attribute from each column listed in **Table 5-3**. To calculate the Risk$_S$ in a specific grid cell, all Grid Layers and Risk Receptors are selected, but only one Season and one Spill Response attribute can be selected by the User for the specific scenario.

Table 5-3: List of Attributes Available to the User to Generate a POE Map

Grid Layer	Risk Receptor	Season	Spill Response
✓ Water Surface ✓ Water Column ✓ Seafloor	**Biological Sensitivities** ✓ Species at Risk ✓ PAIH	✓ Summer or ✓ Winter	✓ Unmitigated or ✓ Basic Response or ✓ Enhanced Encounter Rate
	Socio-Economic Factors ✓ Commercial Fishing ✓ Tourism Employment ✓ Freight Tonnage ✓ Water Resources Extraction ✓ First Nations ✓ Population Density ✓ Parks and Cultural Areas		
✓ Seafloor ✓ Shoreline	**Physical Environment** ✓ Shoreline ✓ Seafloor		

An example POE map of a Level 2 oil spill in Active Pass on the Water Surface for a Species at Risk in the Summer for Unmitigated scenario is provided in **Figure 5-1**.

[8] The lower limit of POE -1 was chosen to be 5% below which is considered to be statistically insignificant.

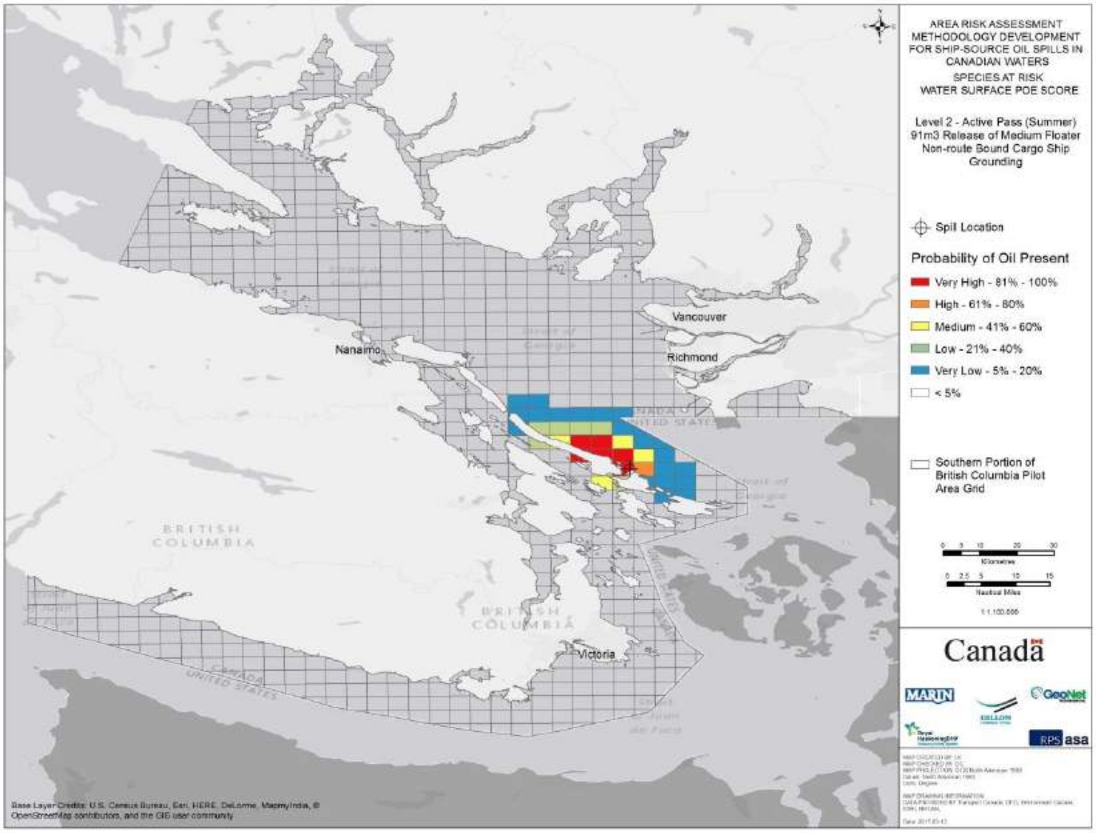


Figure 5-1: Example POE Map for a Level 2 oil Spill near Active Pass – Species at Risk on the Water Surface – Summer (unmitigated)

6.0 Phase 4 – Risk Assessment

The final step of the ARA Methodology involves calculating the $Risk_S$ associated with a specific oil spill scenario by incorporating the outputs from Phase 1 through 3 into two primary elements, one of which is further built upon two sub-elements, as illustrated below and in **Figure 6-1**:

1. **Frequency of Exposure (FOE)** – Combines the outputs from Phase 1 - FOS with Phase 3 – POE. Further details are provided in **Section 6.1**.
2. **Consequences of Exposure (COE)** – Consequences based on the impact to biological, physical and socio-economic *Risk Receptors* that are present in each grid layer where oil is present. The methodology used to calculate the impact of oil to the various *Risk Receptors* is explained in **Section 6.2**.

The methodology to combine all three (3) elements to calculate $Risk_S$, as illustrated below, is provided in **Section 6.3**.

Figure 6-1: ARA Methodology – Calculation of Risk Score

6.1 Frequency of Exposure (FOE)

The FOE represents the combination of the FOS and POE Scores. They are provided as real units – "Total Frequency - FOS" and "Percentage – POE", resulting in a "Total Frequency" of exposure to oil that is estimated within each grid layer of all grid cells within the Study Area. The FOE is utilized in the $Risk_S$ calculation. The categories, scoring scheme, description and colour code for the FOE are provided in **Table 6-1**.

Table 6-1: Frequency of Exposure (FOE) Categories, Scoring, Description and Colour Code

FOE Category	FOE Score (Frequency of Exposure per Year)	Description	Colour Code
FOE-9	2.846×10^{-1}	Very High	
FOE-8	2.214×10^{-2}	High	
FOE-7	1.581×10^{-3}	Medium	
FOE-6	9.487×10^{-4}	Low	
FOE-5	3.162×10^{-5}	Very Low	
FOE-4	2.214×10^{-7}	Extremely Low	
FOE-3	1.581×10^{-8}	Marginal	
FOE-2	9.487×10^{-10}	Negligible	
FOE-1	3.162×10^{-11}	Improbable	

It is important to note that the FOE scores are specific to each Risk Receptor within each grid layer because of the receptor/grid layer specific oil thresholds used to calculate the POE (refer to **Appendix E** for additional details).

6.2 Consequence of Exposure (COE)

The next step is to calculate the consequences of the oil spill – within the ARA Methodology it is called "Consequences of Exposure" (COE). The User has the ability to determine the consequences of an oil spill for the following three (3) categories of *Risk Receptors*:

1. **Biological Sensitivities** - Refers to biological species at risk[9] and habitats that could be affected by an oil spill. If species specific data is available, it can be incorporated into the methodology.
2. **Physical Environment** - Refers to the main physical attributes of the water surface, column and bottom including shoreline.
3. **Socio-Economic Factors** - Refers to human-use resources like commercial fishing, First Nations, water usage, tourism and other important sites/activities in coastal communities.

[9] For a complete listing of Biological Sensitivities considered in this framework refer to Table F-2 in **Appendix F**.

If a specific Risk Receptor is deemed to be present within the corresponding grid layer of a grid cell, a COE Score is calculated. The COE Score reflects the presence and type of risk receptor within a specific grid layer – in essence, the sensitivity of the risk receptor to oil. **It does NOT reflect the level of impact to oil**.

The consequence of exposure scoring scheme is based upon the principle of equal distribution of importance using a 5-step scale ranging from Very Low to Very High, which resulted in the generation of the COE scoring scheme presented in **Table 6-2**.

Table 6-2: Consequence of Exposure (COE) Categories, Scoring, Description and Colour Code

COE Category	COE Score	Description	Colour Code
COE-5	16	Very High	
COE-4	8	High	
COE-3	4	Medium	
COE-2	2	Low	
COE-1	1	Very Low	

The scale of the COE Score equates to an equal distribution of importance. For example, as you go from COE-1 to COE-2 that translates to (2-1)/1 = 100% increase in importance. Similarly, as you go from COE-4 to COE-5 that translates to (16-8)/8 = 100% increase in importance.

6.3 Risk Score ($Risk_S$)

As illustrated in **Figure 6-1**, the $Risk_S$ is calculated by multiplying the FOE Score with the corresponding COE Score. To calculate the Risk Score within each grid cell, a roll up of the grid layers must be done for the final calculation. To ensure the three Risk Receptors equally contribute to the Risk Score within a specific grid cell, individual Risk Scores within the various Risk Receptor categories that are present in the grid layers are rolled up as illustrated in **Figure 6-2** for a grid cell with no shoreline and in **Figure 6-3** for a grid cell that has a shoreline.

Another reason that the Risk Scores are rolled up in the manner illustrated in **Figure 6-2** and **Figure 6-3** is due to the varying oil threshold sensitivities amongst the Risk Receptors.

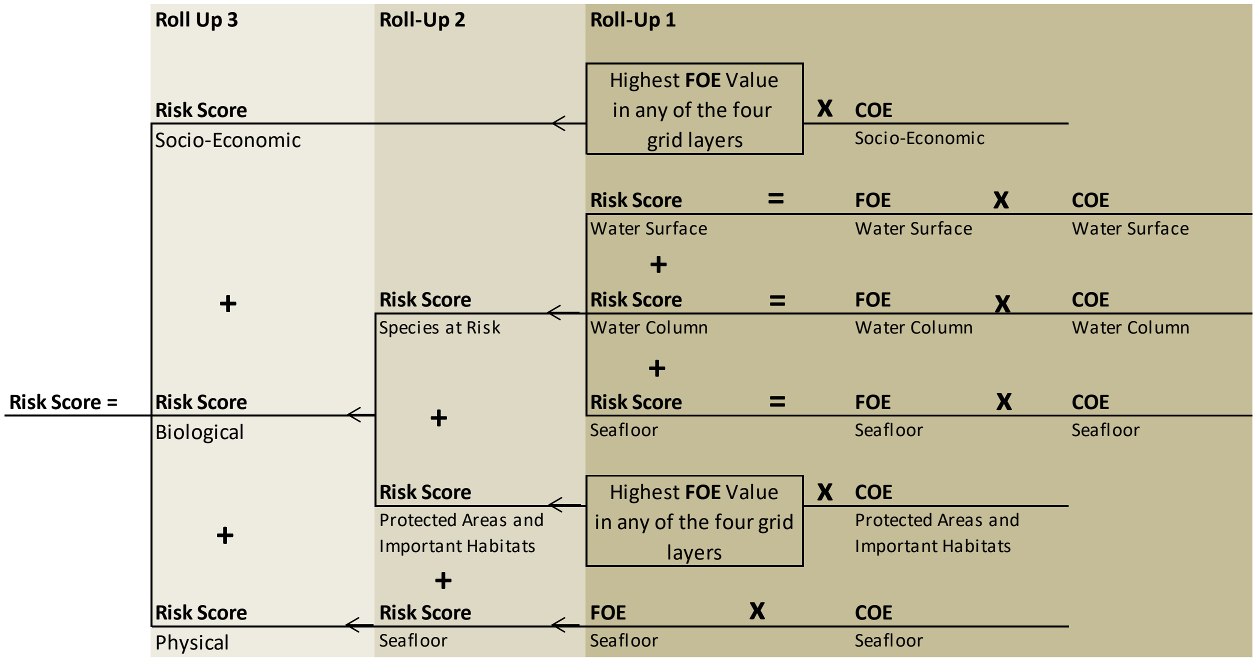


Figure 6-2: Risk Score Roll-Up Scheme - Grid Cell with No Shoreline

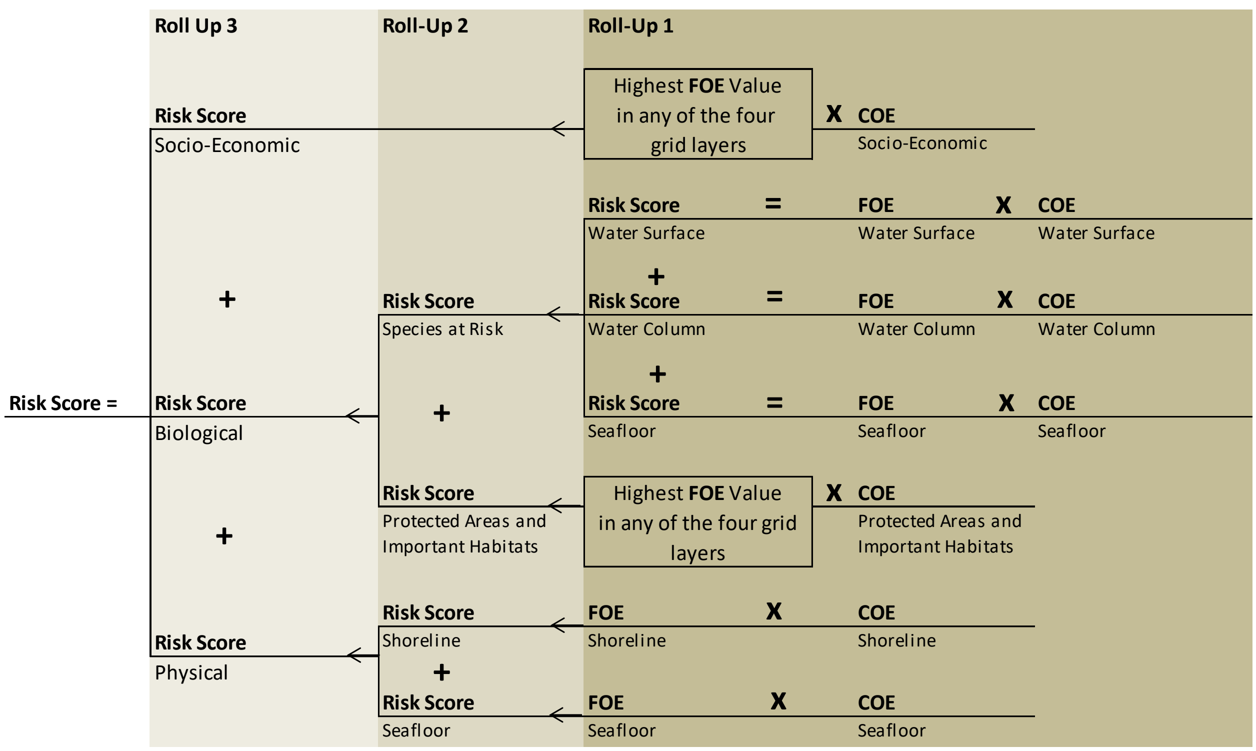


Figure 6-3: Risk Score Roll-Up Scheme - Grid Cell with Shoreline

The $Risk_S$ within each grid cell is rated with a corresponding colour code as shown in **Table 6-3**. An example $Risk_S$ map for the Level 2 oil spill in Active Pass in the Summer for Unmitigated scenario is provided in **Figure 6-4**.

Table 6-3: Risk$_S$ Category, Description and Colour Code

Risk$_S$ Category	Description	Colour Code
Risk$_S$-8	Very High	
Risk$_S$-7	High	
Risk$_S$-6	Medium	
Risk$_S$-5	Low	
Risk$_S$-4	Very Low	
Risk$_S$-3	Extremely Low	
Risk$_S$-2	Marginal	
Risk$_S$-1	Negligible	

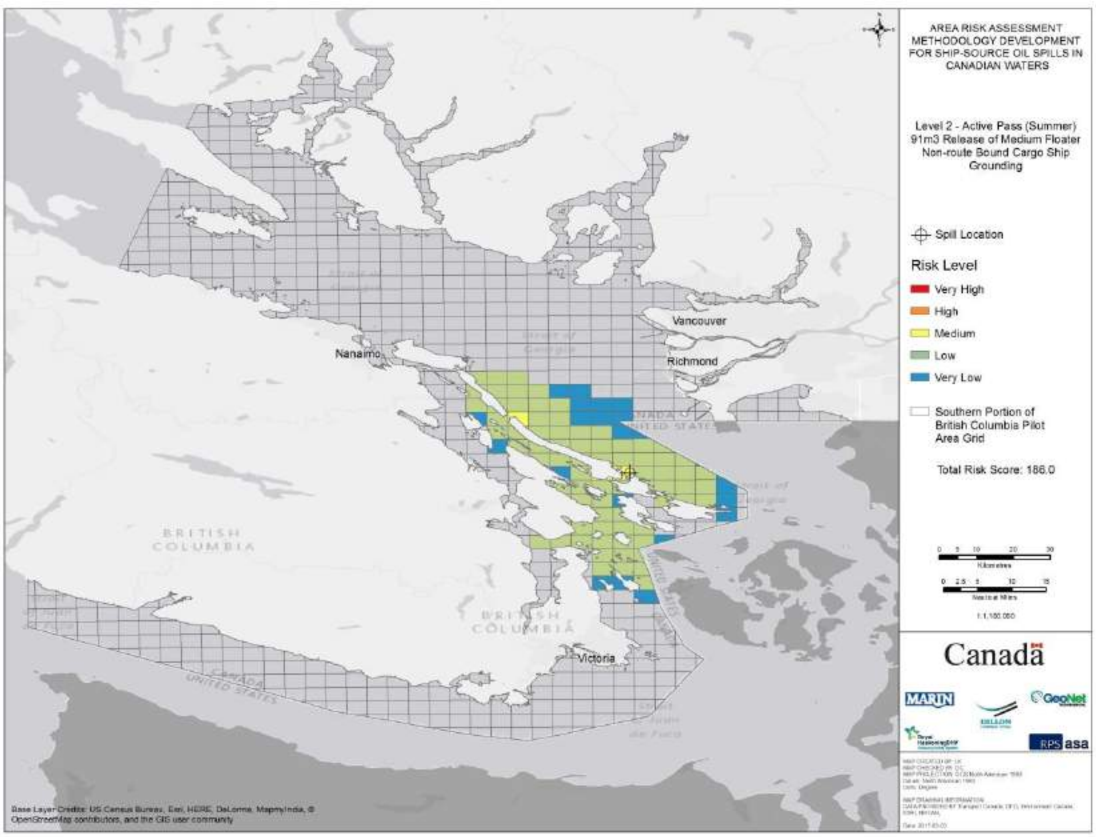


Figure 6-4: Example Risk$_S$ Map - Level 2 oil Spill near Active Pass – Summer (Unmitigated)

7.0 References

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Appendix A

Glossary

Term	Definition
Accident	An accident resulting directly from the operation of a ship other than a pleasure craft, where the ship sinks, founders or capsizes, is involved in a collision [includes strikings and contacts], sustains a fire or an explosion, goes aground, sustains damage that affects its seaworthiness or renders it unfit for its purpose, or is missing or abandoned. Reference: http://www.tsb.gc.ca/eng/stats/marine/2015/ssem-ssmo-2015.asp#3.0
Admission Policy	Policy which dictates which vessels and vessel types can enter Canadian waters.
Aids to Navigation	Are devices or systems, external to a vessel, which area provided to assist mariners in determining position and course, to warn of dangers or obstructions or to advise of the location of the best or preferred route.
Allision	The running of one vessel upon another vessel that is stationary (berthed or at anchor).
Anchoring Area	Areas that are identified in local charts, sailing instructions and Notice to Mariners that have been designated as places to anchor vessels while waiting to enter or leave a port, channel, canal or waterway.
Approach and Mooring Procedures	A measure to prevent oil spills at cargo handling. Generally, not port specific.
Atmosphere	Processes and phenomena of the atmosphere (e.g. cloud cover, weather, climate, atmospheric conditions, climate change, precipitation).
Automatic Identification System (AIS and S-AIS)	A shipboard broadcast system for identifying significant vessels within very high frequency (VHF) radio range, as well as their names, positions (with GPS or differential GPS accuracy), actual size, speed and heading. AIS electronically exchanges data with other nearby ships, AIS base stations, and satellites. Satellite AIS (S-AIS) indicates satellites are used to detect AIS signatures.
Barriers	Also known as controls. Barriers help prevent or reduce the impact of a Top Event (e.g. firefighting tug can help extinguish a vessel fire (preventative barrier), Incident Response Plan can help reduce the impact of a ship oil spill (reactive barrier)).
Boundaries	Legal land description (e.g. political and administrative boundaries, marine boundaries, international boundaries).
Bunker Oil	The petroleum product used and/or stored during transportation by the ship for its own function.
Buoy / Jetty Areas	Areas located alongside waterways including zones around Single Point Mooring buoys and jetties but excluding jetties and offloading areas within harbours.
Cargo Oil	The petroleum product that a ship is transporting as cargo.
Casualty Rate	Variable in the SAMSON model which represents the probability that an exposure will lead to an accident.
Collision	Collision in the SAMSON Model denotes a ship on ship collision.
Consequences	A potential event resulting from the loss of control of the hazard. Can be

Term	Definition
	triggered by the Top Event (e.g. collapse of local aquaculture facilities due to a ship oil spill).
Converging Waterway	Where two or more water bodies meet, also referred to as a confluence. Term can be used to describe the meeting of tidal or other water bodies (such as two canals) or the meeting of two or more rivers.
Countermeasures Requiring Approvals	Any technique that requires approval and is subject to various specific criteria to ensure success. The approval process typically requires a NEBA (Net Environmental Benefit Assessment) protocol and specialized equipment, such as, fire-proof boom, lighting mechanism, spreading mechanisms, dispersant stockpiles etc.
Danger Miles	The total distance of the main traffic routes on which a contact with an object occurs due to navigation error or engine failure.
Degradation	Oil changed either chemically or biologically into other compounds.
Dispersants	Chemical agents added to the spill to promote the physical and/or chemical breakdown of a product, distributing it into the water column.
Dissolution	Water soluble components of the oil dissolve in the water.
Double Hull	A ship hull design and construction method where the bottom and sides of the ship have two complete layers of watertight hull surface: one outer layer forming the normal hull of the ship, and a second inner hull which is some distance inboard, typically by a metre or two, which forms a redundant barrier to seawater in case the outer hull is damaged and leaks.
Dynamic Positioning System	A computer-controlled system to automatically maintain a vessel's position and heading by using its own propellers and thrusters. Position reference sensors, combined with wind sensors, motion sensors and gyrocompasses, provide information to the computer pertaining to the vessel's position and the magnitude and direction of environmental forces affecting its position.
Electronic Chart Display and Information System (ECDIS)	A computer-based navigation information system which with adequate back-up arrangements can be accepted as complying with International Maritime Organization regulations by displaying selected information from a system electronic navigation chart (SENC) with positional information from navigation sensors to assist the mariner in route planning and route monitoring, and if required display additional navigation-related information. Can be used as an alternative to paper nautical charts.
Electronic Navigation (ENAV)	Electronic Navigation is the harmonized collection, integration, exchange and presentation of maritime information onboard vessels and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment.
Elevation	Height above or below sea level (e.g. altitude, bathymetry, digital elevation models, slope, derived products, DEMs, TINs).
Emergency Anchoring	When an engine failure occurs one of the emergency procedures will be lowering the anchor. By lowering the anchor the drift path of a vessel can be stopped to prevent the ship from drifting against a fixed object of other sailing vessel.

Term	Definition
Emergency Towing Vessel (ETV)	A seagoing tug capable of operation in the worst environmental conditions within the area of her deployment, capable of providing towage to shipping casualties during marine emergencies.
Emulsification	Water is mixed with the oil forming a matrix of oil and embedded water droplets.
Encounters	Occurs when a ship domain is entered by another ship.
Entrainment	Oil from the surface slick is broken up into small droplets and driven into the water by breaking waves.
Environmental Conditions	Currents and wind conditions (within context of SAMSON Model).
Escalation Factor	Circumstance or event that will likely result in an impact on the effectiveness of any barriers applied to modify the consequences (e.g. adverse weather conditions which inhibit proper emergency response to an oil spill).
Evaporation	Volatile components leave the surface slick as vapour.
Fire/Explosion	Event which occurs on a vessel.
Fire Fighting Tug	A specialized vessel specifically designed to fight fires. The vessel is equipped with pumps and nozzles designed for fighting shoreline and shipboard fires.
Founder	Fill with water and sink without interference from outside the ship.
Frequency	The number of occurrences of a repeating event per unit time (e.g. the total expected number of spills (accidents) per year).
Habitat Vulnerability	The sensitivity of a habitat to potential impacts from a Top Event.
Hazard	An activity, which is required to conduct business, and has the potential to cause harm to people, environment, property damage, social and/or economic disruption (e.g. oil in itself is a hazard since it has the ability to cause harm, however it is a requirement for an oil company to conduct business).
Heavy Floaters	Oils with an API number between 10 and 17. Includes heavy crude oils like Inglewood crude oil as well as heavy refined oils like Bunker C and IFOs. Minimal evaporation expected, up to 10% maximum and minimal weathering expected or weathering occurs over long period of time. Highly vicious heavy floaters (like Bunker C) will break up into patches and form tar balls instead of slicks. Heavy oiling and contamination expected to intertidal areas and sediments as well severe negative effects to marine birds and fur-bearing mammals expected to occur. Very difficult to cleanup shorelines that are oiled under any condition.
Heavy Sinkers	Oils with an API number less than 10. May include very heavy crude oils like Boscan, undiluted bitumen and diluted bitumen after the condensate has evaporated (generally 24 hours after release). Density of heavy sinkers is close to seawater and there is a good probability they could sink. Heavy oiling and contamination expected in the sediments of the seafloor and in the intertidal region. Extremely difficult to collect and clean up once sunk and often cleanup techniques can be as damaging to the environment as the oil itself.

Term	Definition
Hull Failure	Failure of the hull which can result in a discharge of oil or cargo.
Ice Breaker	Means any ship whose operational profile may include escort or ice management functions, whose powering and dimensions allow it to undertake aggressive operations in ice-covered waters.
Ice Regime	Ice Regime provides the most timely and accurate information regarding ice in Canada's navigable waters through a series of products including: Ice and Iceberg Bulletins, Ice and Iceberg Charts, Ice Images and Reference Maps. These products assist mariners in route planning and identifying areas where there are heavy concentrations of ice. Ice Regime helps the Canadian Coast Guard (CCG) to optimize the deployment of its icebreaking fleet by allowing prepositioning of ice breakers at critical areas to prevent ice jams that could block navigational channels.
Incident	1) The ship makes unforeseen contact with the bottom without going aground; fouls a utility cable or pipe, or an underwater pipeline; is involved in a risk of a collision; sustains a total failure of: a) the navigation equipment if the failure poses a threat to the safety of any person, property or the environment, b) the main or auxiliary machinery, or c) the propulsion, steering, or deck machinery if the failure poses a threat to the safety of any person, property or the environment. 2) All or part of the ship's cargo shifts or falls overboard; or 3) The ship is anchored, grounded or beached to avoid an occurrence. 4) There is an accidental release on board or from the ship consisting of a quantity of dangerous goods or an emission of radiation that is greater than the quantity or emission levels specified in Part 8 of the Transportation of Dangerous Goods Regulations. Reference: http://www.tsb.gc.ca/eng/stats/marine/2015/ssem-ssmo-2015.asp#3.0
In-situ Burning	The controlled burning of oil on scene or site.
Inherent Risk	Risk which exists before applying barriers (controls) to reduce or eliminate it.
Light Evaporators	Oils with an API number greater than 45 and include gasoline and jet fuels. Oils are highly volatile and will likely evaporate with 1-2 days. Localized, significant impacts to water column and intertidal area. Generally, no response/cleanup possible.
Machinery Failure	Failure of the steering system of the engines on a vessel.
MARCOL	A quantitative risk analysis tool for analyzing collision events (developed by Marin).
Marine Occurrence	a) any accident or incident associated with the operation of a ship and b) any situation or condition that the TSB has reasonable grounds to believe could, if left unattended, induce an accident or incident described above. Reference: http://www.tsb.gc.ca/eng/stats/marine/2015/ssem-ssmo-2015.asp#3.0

Term	Definition
Marine Safety Info	Marine or Maritime Safety Information (MSI) is an internationally co-ordinated network of broadcasts of maritime safety information. The information contains navigational warnings (e.g.: buoys out of position), meteorological information (e.g.: forecasts and warnings) and distress alerts. MSI is part of the Global Maritime Distress and Safety System (GMDSS).
Mechanical Containment and Diversion	Any barrier (floating or stationary boom, dike, pneumatic system) constructed or installed to confine, prevent from spreading or remobilizing and/or diverting oil to a recovery area or away from a sensitivity or resource at risk.
Medium Evaporators	Oils with an API number between 17 and 45 and with a Reid vapour pressure greater than 3 kPa. Includes light and medium crude oils with large percentage of light ends like Bakken; synthetic crude oils like Syncrude and Husky Synthetic. Approximately, 30% to 60% of oil will evaporate. Contain significant concentrations of toxic compounds that are soluble in water and may lead to oiling of intertidal zone and waterfowl with the potential to cause long-term impacts. Response activities can be very effective at recovering the oil and limiting environmental impact.
Medium Floaters	Oils with an API number between 17 and 45 and with a Reid vapour pressure less than or equal to 3 kPa. Includes light and medium crude oils like Arab Light and Lloydminister as well as Diesel and Fuel Oils. Approximately, 30% of oil will evaporate within 24 hours of release. Oiling of intertidal area can be very significant causing long-term effects. Significant negative effects to marine birds and fur-bearing mammals. Response is effective if mobilization and response occurs rapidly after the release.
Natural Recovery	A proactive decision process where conditions such as: little or no movement shoreward is expected, no important resources are threatened, or if the oil is breaking up or dispersing naturally or if the conditions are such that response actions do more harm than good or are fundamentally impractical, a “no-action required” tactic is recommended.
Non-Route Bound Traffic	Vessels that have a mission at sea like fishing vessels, supply vessels and tugs that don’t follow a defined network
Ocean, Sea, Lake, River – Water Bed Recovery	Related to sunken oils, this recovery technique typically requires pumping or dredging activities or in small shallow circumstances, physical recovery. Pumping and dredging is also somewhat limited to shallower applications, due to high product viscosity, and mechanical limitations (i.e. suction, bucket reach etc.).
Oil Spreading	Spreading and thinning of surface slicks from gravity forces and surface tension.
Oil Types (“Hazard Classification”)	Oil types include light evaporators, medium evaporators, medium floaters, heavy floaters, and heavy sinkers.
On Water or Surface Recovery	Mechanical recovery, including use of sorbent materials, of floating product in open water.
Open Waterway	An artificial waterway constructed to transport water, to irrigate or drain land, to connect two or more bodies of water, or to serve as a waterway

Term	Definition
	for watercraft. As referred to as a Canal or Ditch.
P50 Scenario	The statistical median (i.e. 50th percentile or P50) of OHF spill sizes.
P90 Scenario	The statistical upper 90th percentile of an OHF spill size. Represents the upper threshold of credible spill size.
Pilotage	The services of a marine pilot to direct movements of a vessel through pilot waters using knowledge of channels, aids to navigation, dangers to navigation, etc. in a particular area for which the pilot is licensed.
Risk	The uncertainty of outcomes that can either be negative or positive.
Residual Risk	Risk that remains even after all barriers are applied.
Risk Receptor	Areas/entities which the Top Event can affect (public, environment, economy, animals etc.).
Risk Score	Determined as Probability multiplied by Severity.
Risk Tolerance	The amount of risk an organization/entity is willing accept to reach its objectives.
Route-bound Traffic	Marine traffic which follows a specific route.
Safe Haven of Refuge	Places of refuge for ships, intended for use when a ship is in need of assistance but the safety of life is not involved.
Safety Distances	An minimum area of sea space established around a vessel or object into which no other traffic is permitted to enter.
SAMSON Model	The Safety Assessment Model for Shipping and Offshore on the North Sea (SAMSON) model that through the use of AIS data and marine accident statistics calculates the probability of a marine accident occurring as well as calculates the probability that the accident causes oil to be released from the vessel. The model also determines the quantity of oil that would be released from the vessel.
Absorption into Sediment	Oil adsorbed to suspended particulate matter deposit on the seabed.
Severity	The measurable level of impact of an event. In risk management severity is typically calculated on a scale ranging from low to high.
Severity Score	Score which ranks the severity of a particular consequence or factor to a Risk Receptor.
Ship Quality	The competency of the crew and reliability of the systems on board of the ship.
Shoreline (Area)	Shoreline is determined as the area from the lower low water larger tide (LLWLT) to the higher high water larger tide (HHWLT). Lower low water large tide (LLWLT) is the average of the lowest low waters from each year over the 19 years of tidal predictions. On Canadian Charts it is also chart datum and serves as the reference point for depths and in tidal waters it is the lowest height waters will reach. Higher high water larger tide (HHWLT) is the average of the highest high water form each year over the 19 years of tidal predictions, in tidal waters it is the maximum height water levels will reach.
Shoreline Recovery	Provides for the return to pre-spill conditions but is highly subject to

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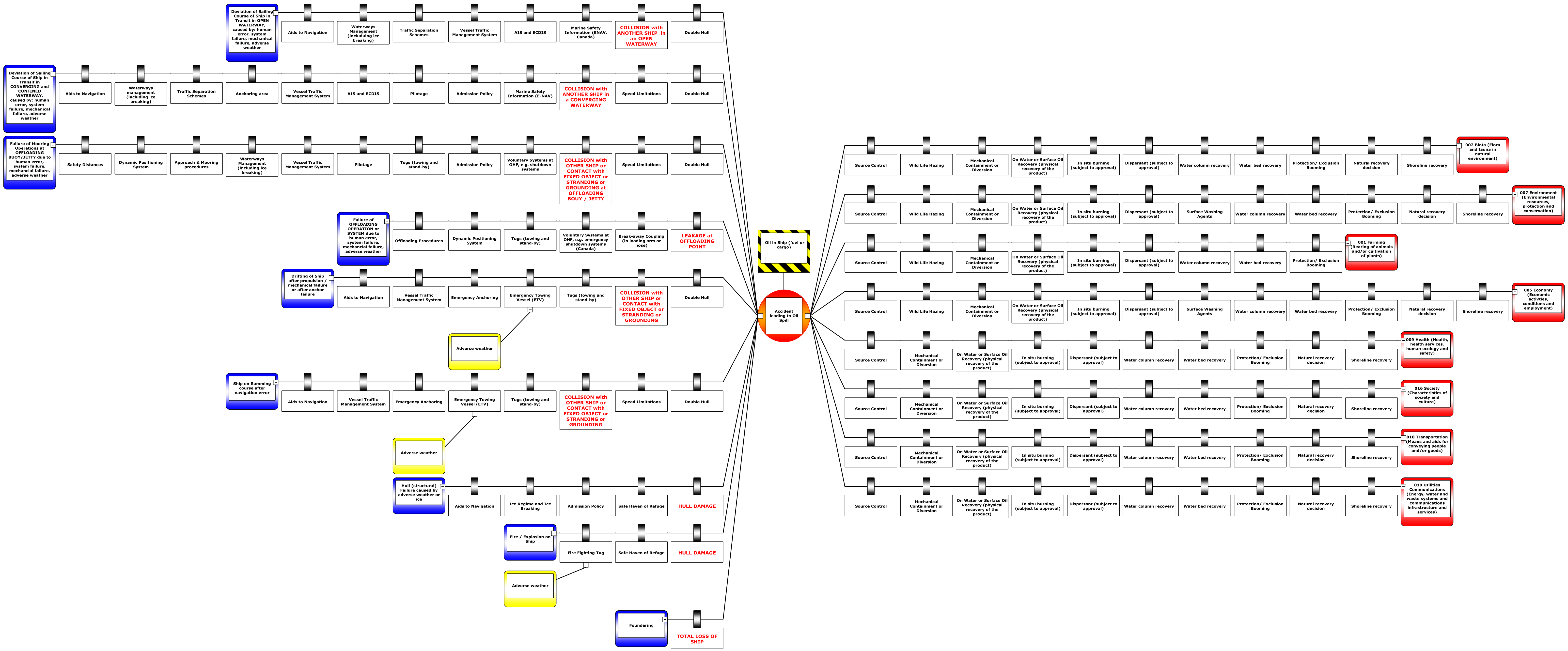
Term	Definition
	shoreline type.
SIMAP	A computer modeling software application that estimates physical fates and biological effects of releases of oil.
Socio-Economic	Relates to the human-use of resources for social and economic benefits. e.g. Commercial fishing.
Source Control	Best first action designed to "prevent" product from continuously entering the environment. This activity includes decision processes related to harbours or places of refuge or any decision which alters the source location to one facilitating a response or protection of an important resource.
Spill Size Class	Volume ranges of outflow class cargo or bunker oil (cubic meters). Class 1: 0.01-20 / 0.01-20 Class 2: 20-150 / 20-50 Class 3: 150-750 / 50-150 Class 4: 750-3000 / 150-500 Class 5: 3000-10000 / 500-750 Class 6: 10000-30000 / 750-1500 Class 7: 30000-100000 / 1500-3000 Class 8: 100000-999999 / 3000-999999
Stochastic model	A tool for estimating probability distributions of potential outcomes by allowing random variation in one or more inputs over time. e.g. multiple runs of an oil spill trajectory with varying environmental conditions (currents and wind conditions) at different, randomly selected spill start times
Surface Washing Agents ("Surfactants")	Chemical treating agents, differentiated from dispersants, which act to release oil from surfaces to ease the process of recovery for shorelines.
Threats ("Incident")	Factors which can cause the Top Event. (e.g. fire or explosion on a vessel).
Top Event ("Accident")	Event which causes loss of control over a hazard. The undesired characteristics of the hazard are now in the open; however, impacts to Risk Receptors have not yet manifested themselves (e.g. accident leading to an oil spill).
Total Return Period	The average number of years between spills of a certain size is the return period or recurrence interval.
Traffic Separation Schemes (TSS)	A scheme which aims at reducing the risk of collision in congested and/or converging areas by separating traffic moving in opposite, or nearly opposite, directions.
Tugs	A small, powerful boat that is used for towing (pulling and pushing) ships especially into harbours or up rivers. A tug can be operated for stand-by, meaning the lines are already fixed, in most cases, but the vessel is still moving/steering itself, in case an incident occurs.
Vessel Traffic Management System ("Vessel Traffic Services")	Shore-side systems which range from the provision of simple information messages to ships, such as position of other traffic or meteorological hazard warnings, to extensive management of traffic within a port or waterway.

Term	Definition
Volatilization	Dissolved oil enters the atmosphere in gaseous phase.
Voluntary Measures at Oil Handling Facilities	Various voluntary measures in place at individual Oil Handling Facilities (OHFs) that include, but are not limited to maximum ages of vessels allowed to berth at OHF, vetting of vessels, mandatory navigation routes, and meteorological restrictions for berthing and cargo transfer operations.
Vulnerability	Inability to withstand the effects of an accident.
Water Column Recovery (“Sub-surface Recovery”)	Mechanical or physical removal of product in the water column, involving fine sieves or courser implements to sift or catch degraded oils (tar balls, mats). Typically this method is only used in limited circumstances and shallow waters.
Waterways Management	Monitoring and maintenance services provided by the Waterways Management program that enables the Canadian Coast Guard (CCG) to help ensure safe, economical, and efficient movement of ships in Canadian waterways. These services also contribute to the maintenance of specific navigable channels, reduce marine navigation risks, and support environmental protection.
Wildlife Hazing	The suite of reactive (e.g. sound devices scaring wildlife away) and proactive (e.g. baiting with food to alternative sites) tactics that can be used to “prevent” wildlife contact with surface oil. While these techniques are predominately used for waterfowl (avian), there may be application for marine mammals and/or shoreline based wildlife (reptiles).
Wrecked/Stranding	Within the SAMSON Model, this defines a ship to object collision or a ship grounding.

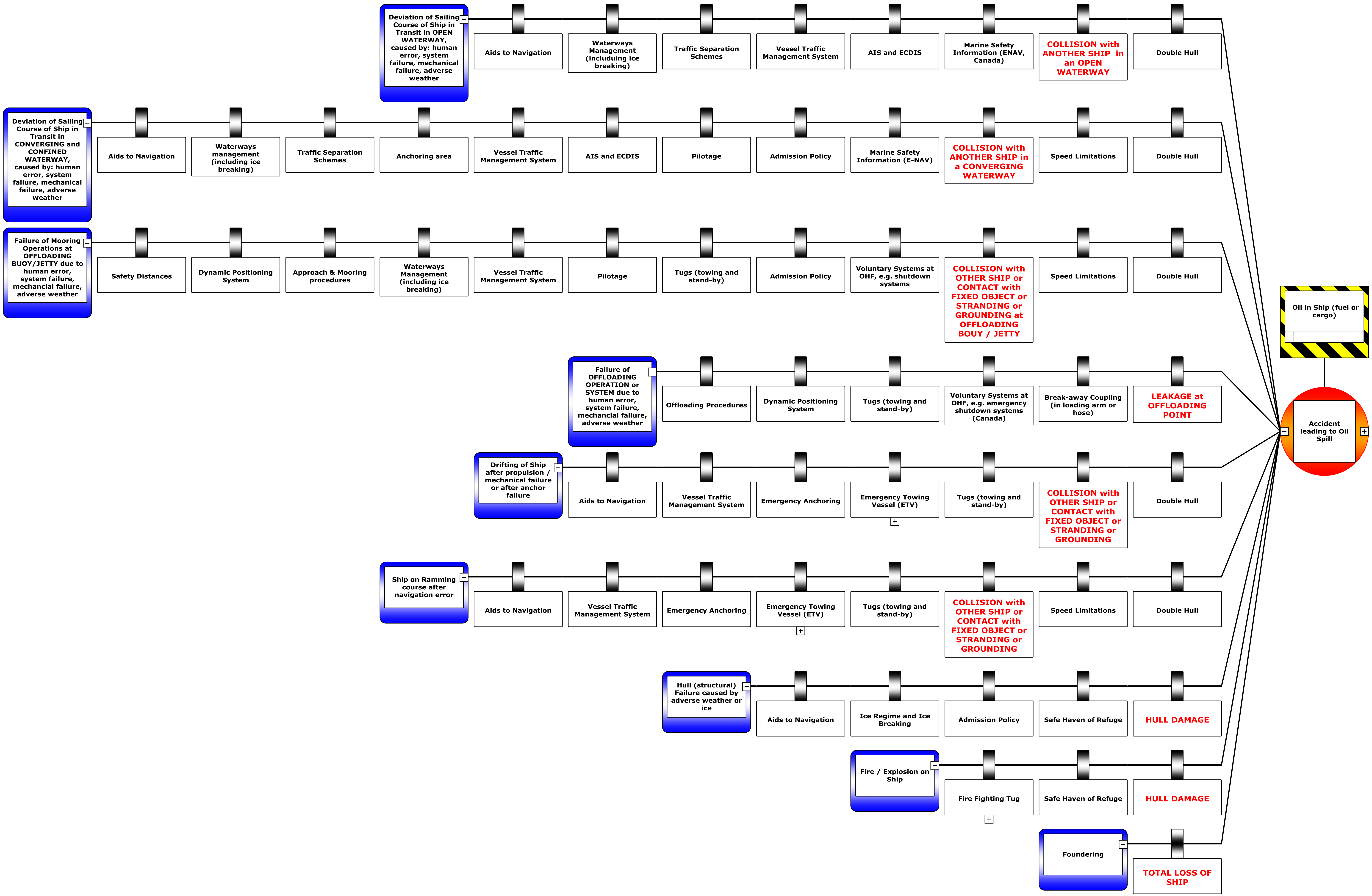
Appendix B

ARA BowTie

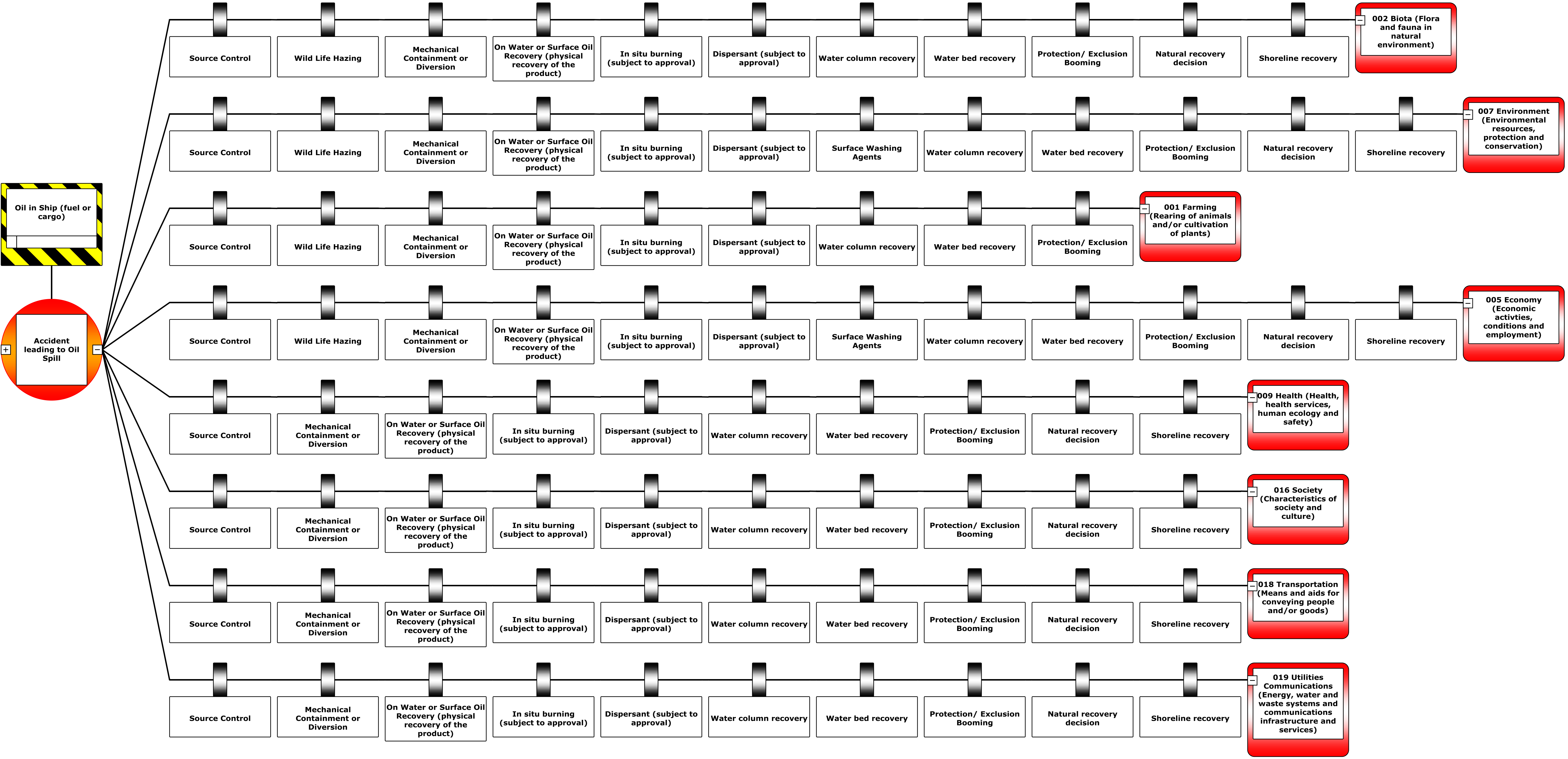
Full Bowtie


Deviation of Sailing Course of Ship in Transit in OPEN WATERWAY, caused by: human error, system failure, mechanical failure, adverse weather
Aids to Navigation
Waterways Management (includuing ice breaking)
Traffic Separation Schemes
Vessel Traffic Management System
AIS and ECDIS
Marine Safety Information (ENAV, Canada)
COLLISION with ANOTHER SHIP in an OPEN WATERWAY
Double Hull
Deviation of Sailing Course of Ship in Transit in CONVERGING and CONFINED WATERWAY, caused by: human error, system failure, mechanical failure, adverse weather
Aids to Navigation
Waterways management (including ice breaking)
Traffic Separation Schemes
Anchoring area
Vessel Traffic Management System
AIS and ECDIS
Pilotage
Admission Policy
Marine Safety Information (E-NAV)
COLLISION with ANOTHER SHIP in a CONVERGING WATERWAY
Speed Limitations
Double Hull
Failure of Mooring Operations at OFFLOADING BUOY/JETTY due to human error, system failure, mechancial failure, adverse weather
Safety Distances
Dynamic Positioning System
Approach & Mooring procedures
Waterways Management (including ice breaking)
Vessel Traffic Management System
Pilotage
Tugs (towing and stand-by)
Admission Policy
Voluntary Systems at OHF, e.g. shutdown systems
COLLISION with OTHER SHIP or CONTACT with FIXED OBJECT or STRANDING or GROUNDING at OFFLOADING BOUY / JETTY
Speed Limitations
Double Hull
Failure of OFFLOADING OPERATION or SYSTEM due to human error, system failure, mechancial failure, adverse weather
Offloading Procedures
Dynamic Positioning System
Tugs (towing and stand-by)
Voluntary Systems at OHF, e.g. emergency shutdown systems (Canada)
Break-away Coupling (in loading arm or hose)
LEAKAGE at OFFLOADING POINT
Drifting of Ship after propulsion / mechanical failure or after anchor failure
Aids to Navigation
Vessel Traffic Management System
Emergency Anchoring
Emergency Towing Vessel (ETV)
Tugs (towing and stand-by)
COLLISION with OTHER SHIP or CONTACT with FIXED OBJECT or STRANDING or GROUNDING
Double Hull
Adverse weather
Ship on Ramming course after navigation error
Aids to Navigation
Vessel Traffic Management System
Emergency Anchoring
Emergency Towing Vessel (ETV)
Tugs (towing and stand-by)
COLLISION with OTHER SHIP or CONTACT with FIXED OBJECT or STRANDING or GROUNDING
Speed Limitations
Double Hull
Adverse weather
Hull (structural) Failure caused by adverse weather or ice
Aids to Navigation
Ice Regime and Ice Breaking
Admission Policy
Safe Haven of Refuge
HULL DAMAGE
Fire / Explosion on Ship
Fire Fighting Tug
Safe Haven of Refuge
HULL DAMAGE
Adverse weather
Foundering
TOTAL LOSS OF SHIP
Oil in Ship (fuel or cargo)
Accident leading to Oil Spill
Source Control
Wild Life Hazing
Mechanical Containment or Diversion
On Water or Surface Oil Recovery (physical recovery of the product)
In situ burning (subject to approval)
Dispersant (subject to approval)
Water column recovery
Water bed recovery
Protection/ Exclusion Booming
Natural recovery decision
Shoreline recovery
002 Biota (Flora and fauna in natural environment)
Source Control
Wild Life Hazing
Mechanical Containment or Diversion
On Water or Surface Oil Recovery (physical recovery of the product)
In situ burning (subject to approval)
Dispersant (subject to approval)
Surface Washing Agents
Water column recovery
Water bed recovery
Protection/ Exclusion Booming
Natural recovery decision
Shoreline recovery
007 Environment (Environmental resources, protection and conservation)
Source Control
Wild Life Hazing
Mechanical Containment or Diversion
On Water or Surface Oil Recovery (physical recovery of the product)
In situ burning (subject to approval)
Dispersant (subject to approval)
Water column recovery
Water bed recovery
Protection/ Exclusion Booming
001 Farming (Rearing of animals and/or cultivation of plants)
Source Control
Wild Life Hazing
Mechanical Containment or Diversion
On Water or Surface Oil Recovery (physical recovery of the product)
In situ burning (subject to approval)
Dispersant (subject to approval)
Surface Washing Agents
Water column recovery
Water bed recovery
Protection/ Exclusion Booming
Natural recovery decision
Shoreline recovery
005 Economy (Economic activties, conditions and employment)
Source Control
Mechanical Containment or Diversion
On Water or Surface Oil Recovery (physical recovery of the product)
In situ burning (subject to approval)
Dispersant (subject to approval)
Water column recovery
Water bed recovery
Protection/ Exclusion Booming
Natural recovery decision
Shoreline recovery
009 Health (Health, health services, human ecology and safety)
Source Control
Mechanical Containment or Diversion
On Water or Surface Oil Recovery (physical recovery of the product)
In situ burning (subject to approval)
Dispersant (subject to approval)
Water column recovery
Water bed recovery
Protection/ Exclusion Booming
Natural recovery decision
Shoreline recovery
016 Society (Characteristics of society and culture)
Source Control
Mechanical Containment or Diversion
On Water or Surface Oil Recovery (physical recovery of the product)
In situ burning (subject to approval)
Dispersant (subject to approval)
Water column recovery
Water bed recovery
Protection/ Exclusion Booming
Natural recovery decision
Shoreline recovery
018 Transportation (Means and aids for conveying people and/or goods)
Source Control
Mechanical Containment or Diversion
On Water or Surface Oil Recovery (physical recovery of the product)
In situ burning (subject to approval)
Dispersant (subject to approval)
Water column recovery
Water bed recovery
Protection/ Exclusion Booming
Natural recovery decision
Shoreline recovery
019 Utilities Communications (Energy, water and waste systems and communications infrastructure and services)

Left Hand Side – Bowtie

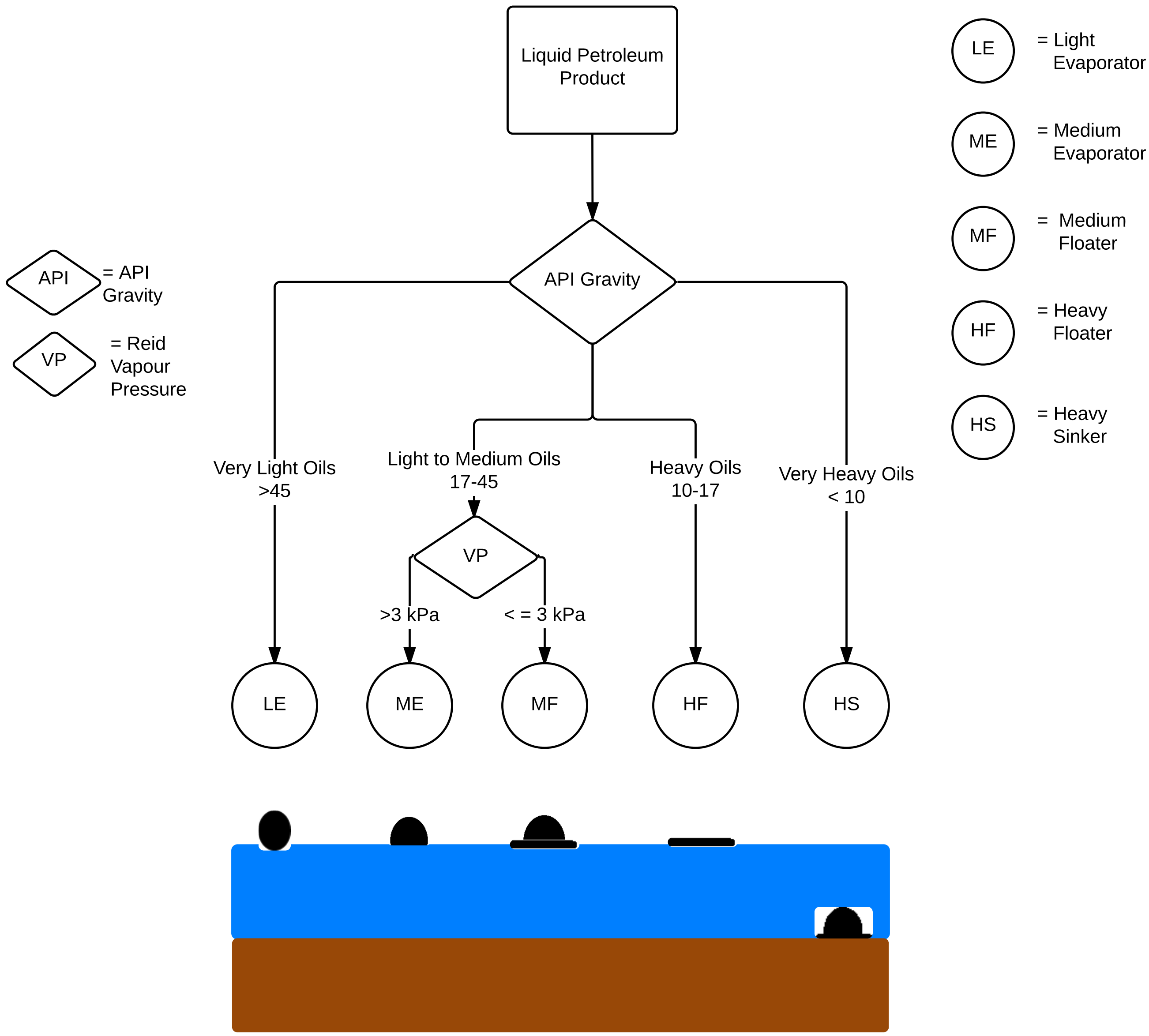


Right Hand Side – Bowtie



Appendix C

Oil Categories


Liquid Petroleum Product
API Gravity
Very Light Oils >45
Light to Medium Oils 17-45
Heavy Oils 10-17
Very Heavy Oils < 10
VP
>3 kPa
< = 3 kPa
LE
ME
MF
HF
HS
API = API Gravity
VP = Reid Vapour Pressure
LE = Light Evaporator
ME = Medium Evaporator
MF = Medium Floater
HF = Heavy Floater
HS = Heavy Sinker

Appendix D

Frequency of Spill (FOS) Model

Table of Contents

Figures

Tables

1.0 Introduction

The Area Risk Assessment (ARA) Methodology is completed in four phases. This will allow the User to first determine the frequency of a ship-source oil spill for each of the eight (8) oil spill classes (Phase 1) within the prescribed Study Area, thereby focusing efforts to identify the oil spill volume and type (Phase 2) at specific locations. Before the final phase, the Frequency of Exposure is determined (Phase 3). This enables the risk assessment to be completed (Phase 4) to better understand and evaluate the risks for the selected oil spill volume types at specific locations within the Study Area. A graphical illustration of the ARA Methodology application is presented below in **Figure D-1** – taken from **Figure 2-7** of the Guidance Document.

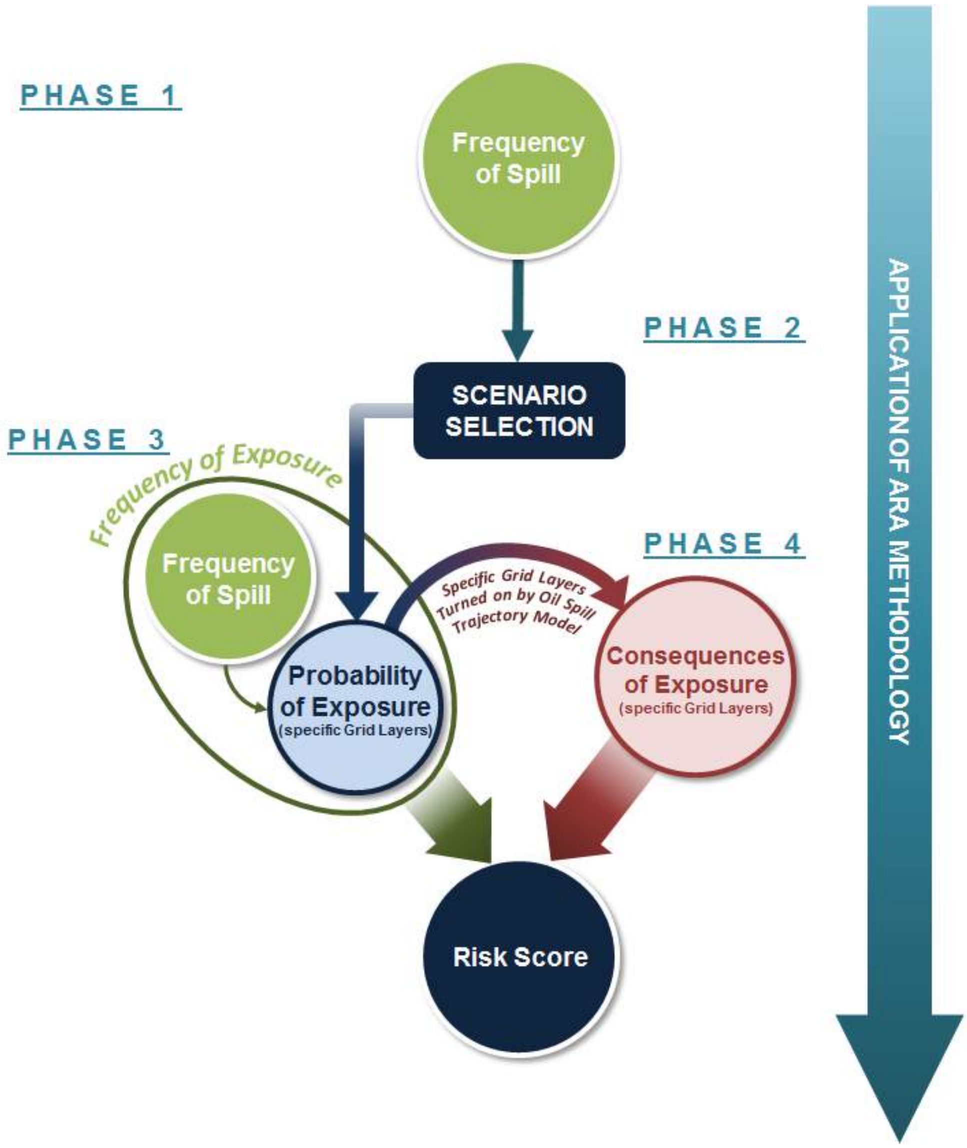


Figure D-1: ARA Methodology Decision Flow Chart

The Frequency of a Spill was designed to answer one question:

Table D-1: Frequency of Spill – Answers to Question 1 in Figure 2-1 of Guidance Document

Question	Response
1. What are the chances of a ship-source oil spill occurring in Canadian Waters?	The frequency of ship-source oil spills in Canadian Waters is based on: a) Marine traffic present in Canadian Waters and the likelihood of an incident leading to an oil spill occurring; and b) The failure of transfer operations at an Oil Handling Facility (OHF) leading to an oil spill.

The left side of the simplified ARA BowTie presented in Section 2.2 of the Guidance Document and repeated below as **Figure D-2** highlights the specific threats which are evaluated in the SAMSON model to determine the frequency of an oil spill occurring.

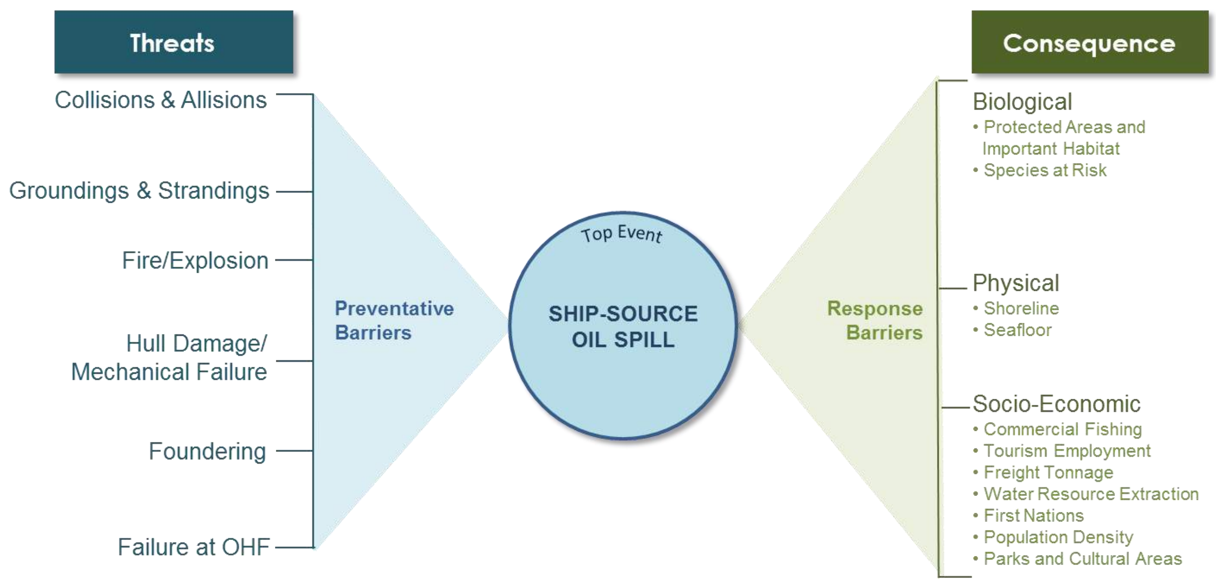


Figure D-2: Simplified ARA Bowtie with Specific Risk Receptor Groups

Once the Frequency of a Spill and the Probability of Exposure (see **Appendix E**) are determined, the ARA Methodology will calculate the $Risk_S$ in both a horizontal (grid cell 'j') and vertical (grid layer 'k') perspective as illustrated in **Figure D-3**. The horizontal grid cells are selected to provide adequate spatial resolution for assessing the risk of oil spills and vertically there will be the following four grid layers where oil can manifest itself:

- Shoreline;
- Water Surface;
- Water Column; and
- Seafloor.

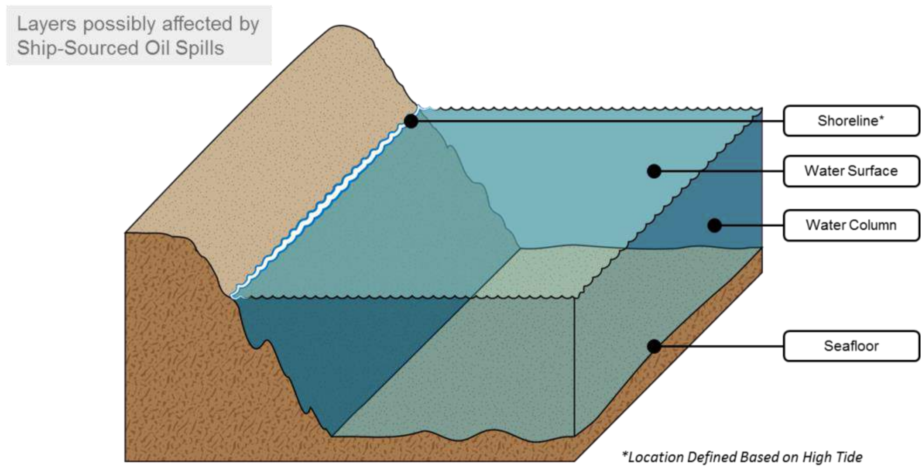


Figure D-3: Grid Layers that Compose a Grid Cell

This Appendix provides the technical details for the User to understand how the Frequency of a Spill is determined utilizing the SAMSON Model. In **Section 2** information on the details of the SAMSON Model will be provided. Finally, in **Section 3**, SAMSON Model outputs will be discussed.

1.1 Overall Approach

To determine the Frequency of a Spill, the ARA Methodology integrates the findings from the BowTie assessment with the SAMSON Model. The SAMSON Model was developed by MARIN over 25 years ago to assess the frequency of ship-source oil spills and during that time it has undergone extensive validation and testing. The SAMSON Model calculates the frequency, volume, location, and oil type of a potential ship-source oil spill. As discussed in the BowTie methodology, several causes or threats can lead to the top event (see **Figure D-2**). Since a ship-source oil spill is the top event for the ARA Methodology, the probability of it occurring is influenced by a number of barriers. Both the threats as well as the barriers are included in the SAMSON Model as they influence the frequency of a ship-source oil spill.

2.0 The SAMSON Model

The SAMSON Model utilizes specific inputs in order to calculate the frequency of incidents that could lead to an oil spill. This Section will describe the model inputs and the calculation process which the SAMSON Model undertakes to determine its outputs. The outputs will be described in **Section 3.0**.

SAMSON stands for **S**afety **A**ssessment **M**odels for **S**hipping and **O**ffshore in the **N**orth Sea. With the model, various risk assessment calculations can be performed regarding maritime safety. Using a good maritime traffic database, environmental conditions such as wind and currents and different mathematical models, the frequency of different types of incidents can be determined.

To determine the frequency of an incident occurring, the number of potentially dangerous situations is determined first. For example, a potentially dangerous situation can occur when a collision between vessels is possible because of their proximity. The potentially dangerous situation occurs when one ship enters within a certain domain around the other ship.

To help determine the frequency of potentially dangerous situations occurring, maritime traffic is integrated into the Model.

The SAMSON Model also calculates the frequency of incidents by incorporating different barriers (preventative measures). Some of these barriers are integrated as a part of the model and run for every simulation while others can be adjusted and removed. This allows for the impact of barriers to be evaluated.

The final step in calculating the frequency of incidents, is multiplying the calculated potentially dangerous situations, with the incident rate corresponding to the type of potentially dangerous situation. An incident rate defines the frequency of a potential dangerous situation leading to an actual accident. The incident rates are based on the worldwide data from the International IHS Fairplay Collision database, collected between 1990 and 2010.

The results of the SAMSON Model allow the User to not only determine the frequency of an oil spill but also to identify specific locations within a study area that have a higher risk for oil spills. This can allow the User to adjust their response plans for these areas. The SAMSON model allows the User to adjust or add additional preventative measures that could reduce the frequency of an oil spill.

2.1 SAMSON Model Inputs

For the SAMSON Model to be able to calculate the frequency, volume, location and oil type of a potential ship-source oil spill, it needs a number of data inputs as presented in **Figure D-4**. These inputs can be grouped into six categories: Traffic, Environmental Data, Preventive Barriers, Incident Statistics, Ship Classes and Volumes and Types of Oil. Each of these inputs consists of several elements, of which a more detailed description is provided in the sections below.

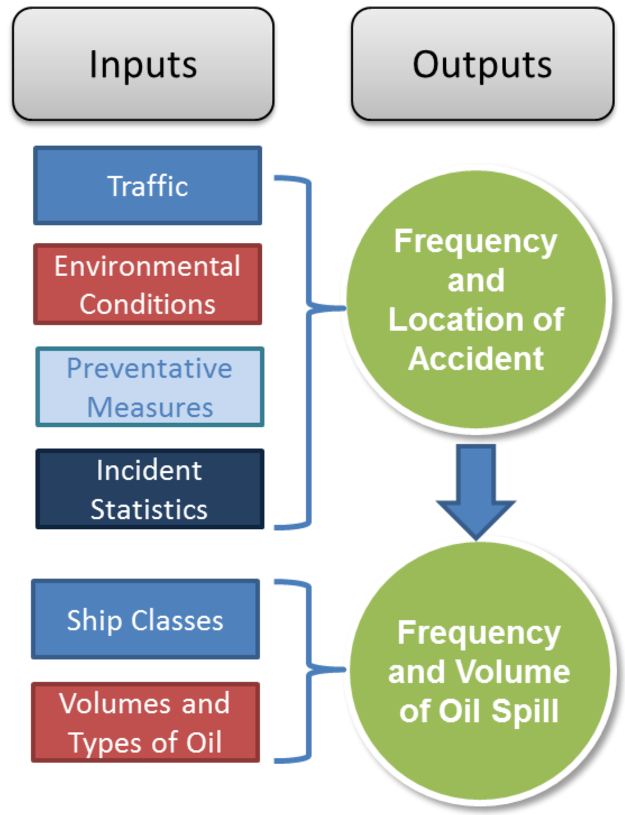


Figure D-4: SAMSON Model Inputs and Outputs

2.1.1 Traffic

The Automated Identification System (AIS) data is an important input for the SAMSON Model. This data provides information on the shipping intensity and movements in a specific area over a period of one year (for the Pilot). AIS data can be utilized for multiple years and even specific seasons. The data forms the basis on which the the frequency of an incident is being calculated. AIS data is provided by the Canadian Coast Guard for each study area.

2.1.2 Environment Data

Within the context of the SAMSON Model, environmental information is used to determine the trajectory and speed of drifting vessels as well as to determine potential ship damage from extreme weather. Therefore wind and current data are included as environmental data in the SAMSON Model.

Wind Data

Historical wind data from an appropriate meteorological model is used as input for the SAMSON Model. The same wind data is also used for the oil spill trajectory modelling and is further discussed in **Appendix E of the Guidance Document**.

Currents Data

Simulating the drifting of a disabled vessel requires definition of the current over the entire Study Area. In order to have adequate spatial resolution of the current, a hydrodynamic model is used for each Study Area. The same hydrodynamic model is used for the oil spill trajectory modelling and is further discussed in **Appendix E of the Guidance Document**.

2.1.3 Preventive Barriers

Preventive Barriers include the navigational aids and measures that assist in reducing the frequency of an incident. **Table D-2** provides an overview of the preventative barriers which are built into SAMSON, adjustable, and excluded. Several preventative barriers are also included indirectly in the SAMSON Model and not as separate parameters or factors, those include barriers such as: ice regime and ice breakers, approach and mooring procedures, and electronic navigation (ENAV). Descriptions of each preventative barrier can be found in the glossary (**Appendix A – Guidance Document**). The information on these measures is provided by Electronic Nautical Charts (ENC), which are obtained from the Canadian Hydrographic Service.

Table D-2: Preventative Barriers for SAMSON Model

Built into the Model	Adjustable Elements	Not in the Model
Admission Policy	Pilotage	Dynamic Positioning System
AIS & Electronic Chart Display and Information System (ECDIS)	Traffic Separation Schemes	Fire Fighting Tug
Aids to Navigation	Vessel Traffic Management System (VTMS)	Safe Haven of Refuge
Anchoring Areas	Tugs (Tethered and Escort)	Emergency Anchorage
Marine Safety Info.		Emergency Tow Vessel
Waterways Management		
Safety Distances		

Built into the Model

These barriers are built into the SAMSON Model by only using incident statistics that have these barriers included.

Adjustable Elements

The four barriers are defined below.

Pilotage Areas

The location of mandatory pilotage areas is obtained from the ENC charts, Annual Notice to Mariners (CCG, 2015), Port Information Books, Sailing Directions and local port authorities. The zones in each area that require pilots, including where the pilots embark and disembark are used in the SAMSON Model calculations. The effect pilots have on reducing the risk of an incident occurring is presented in **Table D-3**.

Traffic Separation Schemes (TSS)

The location of TSS is obtained from the ENC Charts. In areas where TSS are in place they act to reduce the number of encounters which reduces the number of incidents as traffic is separated laterally from each other. In the SAMSON Model there is no percent reduction assigned to TSS.

Vessel Traffic Management System (VTMS) Areas

The location of VTMS areas is obtained from the ENC Charts, Annual Notice to Mariners (CCG, 2015) and Sailing Directions. In areas where there is VTMS, vessel movements are being monitored and navigational safety is provided. VTMS is used in the SAMSON Model calculations and the percentage effect it has on reducing the risk on an incident is presented in **Table D-3**.

Tugs

In some areas it could be mandatory to have escort and tethered tugs. The locations where escort and tethered tugs are required, is obtained from the appropriate port authority, sailing directions and liaising with the OHFs in the Study Area. In addition to the locational requirement, the number and positioning of the tugs is obtained as well as the size and types of vessels that require tugs. Modelling of tugs in the SAMSON Model calculations is dependent on area characteristics. The percentage effect that both escort and tethered tugs have on reducing the risk of an incident is presented in **Table D-3**.

Table D-3: Reduction Percentages for Adjustable Elements

Element	Incident Type					
	Allision/Contact (Drift/Ramming)		Collision	Stranding		Other*
	Drift	Ramming	Ramming	Drift	Ramming	
Pilotage	0%	62%	62%	0%	62%	0%
TSS	Reduces the number of encounters so therefore reduces the number of incidents					
VTMS	0%	0%	30%	0%	0%	0%
Tugs-Escort	90%	0%	0%	90%	0%	0%
Tugs-Tethered	99%	50%	0%	99%	50%	0%

*Other incidents include Fire/Explosion, Foundering, and Hull Failure.

Not in the Model

The four preventative barriers, identified in **Table D-2** are not included in the SAMSON model, and the rationale for not including them is as follows:

- Dynamic Positioning System – Can be included in the SAMSON Model as a preventative barrier if vessels use the system during loading/unloading at OHFs. At the time of the pilot study none of the pilot areas had OHFs that used Dynamic Positioning Systems where vessels called.
- Fire Fighting Tugs – Can be included in the SAMSON Model to look at the reduction in damage to a vessel from fire with a fire fighting tug present. Not used in the pilot study as it does not alter the risk of an oil spill.

- Safe Haven of Refuge – Can be included in the SAMSON Model but not included in the pilot study, as there are currently no designated places of refuge in the pilot areas.
- Emergency Anchorage – Designated emergency anchorage locations can be included in the SAMSON Model once these areas have been designated.

2.1.4 Incident Statistics

The SAMSON Model also uses several collision databases to calculate the frequency of vessel incidents when a vessel enters the domain of another vessel or object. The databases used in this study, and the information these databases provide is further detailed below.

International Database

The SAMSON Model uses incident statistics available from the international IHS Fairplay collision database from 1990 to 2012 The international statistics obtained from the IHS Fairplay Database are filtered to include maritime countries in the North Sea with similar regimes to Canada. The countries selected were Germany, France, Netherlands, Norway, and UK.

Canadian Database

Canadian incident statistics, obtained from the Transportation Safety Board of Canada website from 2004 to September 2015 (TSB, 2015), are compared to the international statistics to confirm that the international statistics are representative of Canadian data.

2.1.5 Ship Classes

In order to adequately represent the various ships that travel through Canadian waters, the SAMSON Model distinguishes 42 different ship classes, divided over two main groups of ships: route bound ships and non-route bound ships (see **Tables D-3** and **D-4**). Each of the 42 ship classes is further divided into 8 size classes ranging from 100 tonnes to 100,000 tonnes. Furthermore, there are multiple ship types obtained from the Lloyd's registry. This results in over 3,000 different ships being modelled in the SAMSON Model. The route bound ships consist of merchant vessels and ferries sailing along the shortest route from one port to another. The non-route bound ships consist of vessels that mainly have a mission at sea such as fishing, supply, towing and recreation. This large number of classes is required for subsequent calculations, such as for the calculation of the kinetic energy when a ship strikes another vessel or runs aground.

Table D-3: Ship Types (Classes) for Route Bound Traffic

No.	Ship Type	No.	Ship Type
1	Oil / Bulk / Combination Tanker	19	LNG
2	Oil/ Bulk/ Ore Combination Tanker DH	20	LPG Refrigerated
3	Chemical Tanker IMO 1	21	LPG Semi Pressured
4	Chemical Tanker IMO 1 DH	22	LPG Pressured
5	Chemical Tanker IMO 2	23	LPG Remaining
6	Chemical Tanker IMO 2 DH	24	Bulkers
7	Chemical Tanker IMO 3	25	Unitized Container
8	Chemical Tanker IMO 3 DH	26	Unitized Roro
9	Chemical Tanker	27	Unitized Vehicle
10	Chemical Tanker DH	28	General Dry Cargo
11	Chemical Tanker Water/Wine/Replenishment	29	General Dry Cargo with Containers
12	Chemical Tanker Water/Wine/Replenishment DH	30	General Dry Cargo Reefer
13	Oil Tanker, Crude Oil	31	Passenger
14	Oil Tanker, Crude Oil DH	32	Passenger Roro
15	Oil Product Tanker	33	Ferries
16	Oil Product Tanker DH	34	High Speed Ferries
17	Oil Remaining	35	Miscellaneous
18	Oil Remaining DH	36	Tugs

Note:

IMO – International Maritime Organization number

LNG – Liquefied Natural Gas carrier

LPG – Liquefied Petroleum Gas carrier

Table D-4: Ship Types (Classes) for Non-route Bound Traffic

No.	Ship Type	No.	Ship Type
1	Work Vessels	4	Chemical Tanker
2	All route-bound ships outside route network, excluding oil and chemical tankers	5	Oil Tanker
3	Fishing from/to	6	Recreation

2.1.6 Volumes and Types of Oil

In the event of an accident, the frequency and volume of oil outflow is calculated by the SAMSON Model. Therefore information is required on the volume and type of oil carried as cargo by each vessel. A vessel can carry oil as cargo, but also as bunker oil. The cargo oil data is not provided by one set of data, but can be determined by combining AIS Data with data from OHFs (see **Figure D-5**). How the volumes and type of oil are determined for both cargo and bunker oil is provided below.

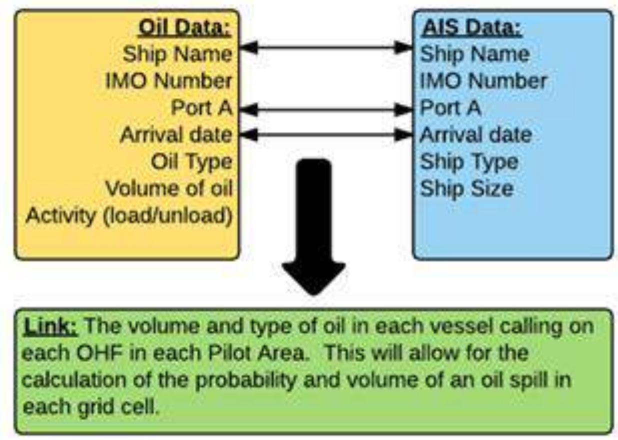


Figure D-5: Linkage between the AIS Data and the Oil Data from an OHF

Determining Volumes and Types of Cargo Oil

To determine the volumes and types of cargo oil, data needs to be obtained from the OHFs in the Study Area. When combining this data with the data on vessel names, designation and ship type originating from the AIS Data, the volume and type of oil carried by a vessel can be determined.

The data from the OHF therefore needs to include cargo records such as:

1. Ship Name;
2. Ship IMO Number;
3. Arrival Date;
4. OHF Name;
5. Oil Type (detailed name, API number and Vapour Pressure, crude or refined not detailed enough);
6. Volume of Oil Loaded/Unloaded; and
7. Activity (loading or unloading).

Determining Volumes and Types of Bunker Oil

Based on the average layout of the various ship type and ship size combinations, the amount of bunker oil on board is estimated from MARIN’s nautical database. The method for calculating the frequency of the outflow of oil is performed using the following steps:

1. Calculation of the frequency of the different exposures (possible dangerous situations) for the different type of accidents.
2. Calculation of the frequency of the different accident types, by multiplying the exposures with the associated casualty rate.
3. Calculation of the (annual) number of ships that are damaged in such a way that the cargo/bunker oil flows out because the cargo tanks are penetrated.

4. Calculation of the frequency of outflow of oil by multiplying the frequency of a cargo tank penetration with the frequency that the cargo tank is loaded with oil.
5. Calculation of the amount of oil that can flow out based on the size of the cargo tanks and the location of the hole in the tank.

2.2 Calculation Process of the SAMSON Model

As illustrated in the previous section, the SAMSON Model depends on several data inputs in order for it to be able to calculate the frequency, volume, location and oil type of a potential ship-source oil spill. First of all it is important to understand how the marine traffic is modelled, since this is the basis of all further calculations. The SAMSON Model calculates the incident frequency first, followed by the frequency of penetrating the ship's hull, then the frequency of an outflow and the volume of outflow. This Section focusses on the calculation processes for each of the aforementioned steps as presented in **Figure D-6**. The outputs of this set of calculations will be presented in **Section 3.0**.

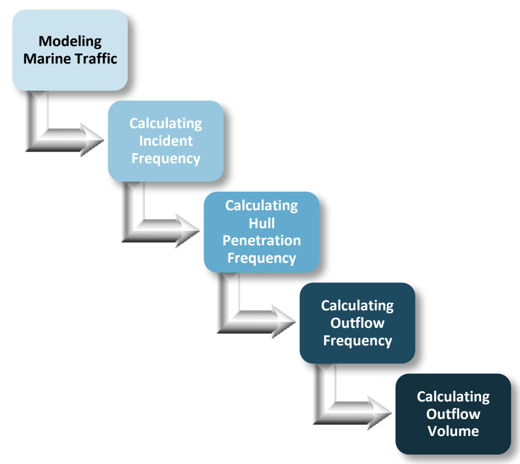


Figure D-6: SAMSON Model Calculation Process

2.2.1 Modelling Marine Traffic

As stated above, the SAMSON Model distinguished two main groups of ships: route bound ships and non-route bound ships. Each of these groups is modelled in a different way: The route bound traffic is modelled based on shipping routes, while the non-route bound traffic is modelled using vessel density.

Modelling Route Bound Traffic

Most of the route bound ships sail on a large network of links, comparable to a road network on land. This is a result of the location of various ports and TSS in a specific area. It is assumed that ships sail along the shortest possible route to reach their destination. Moreover, ships have to comply with the rules and regulations that are in place in a specific area, such as Traffic Separation Schemes. The shipping intensity on the different links is determined based on AIS data. The traffic database contains waypoints and links connecting these waypoints. On each link, the traffic (in number of movements per year) is known for each of the 36 route bound ship types and eight ship size classes.

Modelling Non-Route Bound Traffic

The non-route bound traffic database in generally constructed from three datasets. The first dataset is to assign any route bound traffic that could not be assigned a network to a density. The second dataset consist of the typical vessels found in the non-route bound database, vessels that have a mission at sea like fishing vessels, supply vessels and tugs that don't follow a defined network. The final dataset is to assign unknown vessels to the non-route bound database. Unknown, vessels are AIS signals that don't provide any information on the type, size or mission of the vessel. Using the AIS signals of these three datasets, the non-route bound database is created which assigns a vessel density to each grid of the study area that is then subsequently used to calculate the frequency of an incident.

2.2.2 Calculating Incident Frequency

The frequency of incidents is calculated on the basis of exposures for the different type of incidents as presented in **Table D-5**. Exposures can be described as "*possible dangerous situations that could lead to an incident*".

Table D-5: Relationship between Incident Type and Exposure

Incident Type	Exposure
Collision	Encounters
Allision	Stranding Opportunity
Wreck/Stranding	Stranding Opportunity (powered) and Danger miles (unpowered)
Foundering	Nautical Miles (ship miles)
Fire/Explosion	Nautical Miles (ship miles)
Hull/Machinery Failure	Nautical Miles (ship miles)

The exposure for a collision between two ships is an encounter. Ships can only collide when they are within a certain range of each other. An encounter occurs when a ship enters the domain of another ship. This domain is defined as a circle with a radius of 0.125 nm around a ship. Only a small part of all encounters will actually result in a collision. The casualty rate, the relation between the number of exposures and the number of accidents, depends on the type and size of the ship.

The two main causes for the incident types, allisions and wrecks/stranding, are navigational error and a technical failure, which causes the ship to be uncontrollable. The exposure measure for an allision or wreck/stranding caused by a navigational error is called the stranding opportunity. An allision or wreck/stranding caused by a navigational error can only occur when the ship is located close enough to the stranding line or fixed object. Only then, can a navigational error be critical. The stranding opportunity is based on the location, sailing direction, speed and length of the ship and the location of the stranding line or fixed object.

An allision and wreck/stranding caused by a technical failure will only take place when the failure occurs near the stranding line or fixed object and when the ship drifts in the direction of the stranding line or object. In addition, the repair time and the probability of successful anchoring are important factors. The exposure for this type of accident is called "danger mile".

2.2.3 Calculating the Frequency of the Penetration of a Ship's Hull

Even if an incident occurs, this does not automatically mean that an oil spill will occur. Oil can only be released from a vessel if the hull and the cargo or fuel tanks are penetrated. Therefore the next step is to calculate the frequency that the hull of a ship is penetrated. The probability that a hole in a cargo or fuel tank of a ship will occur as a result of an incident, is determined in the SAMSON Model by:

1. The tank layout of the ship (for each ship type and size some layouts are given); and
2. Damage (penetrating) functions derived from casualty statistics combined with MARCOL Model (quantitative tool for analysing collision events) analysis.[1]

2.2.4 Calculating the Frequency of an Outflow

Penetration of the hull of a ship and the cargo/fuel tanks during an incident does not automatically lead to an oil spill. For an oil spill to occur the tanks need to be loaded with oil. The frequency of an oil spill is determined by multiplying the frequency of penetration of a ship's tank with the frequency that the tanks are loaded. The probability of the cargo tanks being loaded and the volume of the oil in each tank is obtained from the traffic database and is calculated based on the ship class and from the data provided by the OHFs. In the SAMSON Model fuel oil is present in each ship, it is assumed that half of the fuel tanks are fully loaded and the other half of the fuel tanks are empty. The outflow of fuel tanks is determined by calculating the probability that a loaded fuel tank of the ship is holed.

2.2.5 Calculating the Volume of Outflow

When an incident will result in an outflow, the SAMSON Model also calculates the volume of the outflow. The volume of oil that flows out of a penetration of a ship's hull depends on the location of the hole in the tank. When a hole in a cargo tank is located above the waterline, only the oil above the hole will flow out. If a hole in the cargo tank is located below the waterline, the model assumes that the entire volume of the tank is released. The volume of oil outflow can be calculated from the following simplified equations:

$$N_{accidents} = N_{exposures} * CasRat$$

$$N_{outflow} = N_{accidents} * F_{hole\_in\_tank} * F_{oil\_in\_tank}$$

$$V_{outflow} = N_{outflow} * V_{tank}$$

[1] The MARCOL Model (Maritime Collision Model of MARIN) was a model developed to easily analyze the penetration frequency of various ship hulls. Additional information on the MARCOL Model can be found at www.marin.nl.

Where:

$N_{accidents}$	Number of accidents per year
$N_{exposures}$	Number of exposures (possible dangerous situations)
$CasRat$	Casualty Rate (frequency that an exposure ends up in an accident)
$N_{outflow}$	Number of outflows per year
$F_{hole\_in\_tank}$	Frequency of a hole in the cargo tank
$F_{oil\_in\_tank}$	Frequency of oil the cargo tank
$V_{outflow}$	Volume of the oil spill
V_{tank}	Volume of the damaged cargo tank

The outflow classes used in the SAMSON Model is summarized in **Table D-6**. The classes were derived based on typical vessel types and the capacities and locations of their associated bunker tank and cargo tank (tankers only).

Table D-6: Outflow Classes and Associated Vessel Types used in the SAMSON Model

Spill Volume Class	Outflow - Spill Class		Vessel Type	Typical Spill Volume from Bunker or Cargo Tank (m^3)	Spill due to Total loss (m^3)
	From (m^3)	To (m^3)			
1	0	30	Fishing, Recreation	Bunkertank <30	Fishing, Recreation (<150)
2	30	150	Small commercial	Bunkertank <150	
3	150	1,000	Medium commercial	Bunkertank <1k	Small commercial (<1k)
4	1,000	5,000	General purpose Med. range tanker	Bunkertank <5k 1x Cargo side 5k	Medium commercial (<10k)
5	5,000	15,000	Long range 1 tanker Panamax	1x Cargo side 12k	
6	15,000	30,000	Aframax	1x Cargo side 10k + 1x Cargo centre 17k	General purpose (<30k) Med. range tanker (<30k)
7	30,000	100,000	New Panamax Suezmax VLCC ULCC	1x Cargo side 17k + 1x Cargo centre 40k	Long range tanker (<60k) Panamax (<60k) Aframax (<100k)
8	> 100,000			NA (Spill exceeds volume of 2 largest) tanks)	New Panamax (100k+) Suezmax (100k+) VLCC (100k+) ULCC (100k+)

Notes:
NA – Not Applicable
VLCC – Very Large Crude Carriers
ULCC – Ultra Large Crude Carriers

2.2.6 Oil Handling Facilities

Next to oil spills resulting from collisions, groundings, mechanical failure, foundering, and hull damage for route bound and non-route bound traffic, ship-source oil spills might also occur at OHFs. An OHF spill is most likely to occur during ship loading and off-loading operations at a single buoy mooring (SBM) point loading facility or at a jetty / quay loading facility.

Spill scenarios due to failure of a (subsea) pipeline are not considered. Spill sizes from loading/off-loading operations fall in Class 1 and 2 of the spill size class for cargo oil, ranging from 0.01 to 150 m^3 (IAOGP, 2010).

Calculating the Frequency of a Spill from Single Buoy Mooring

The following assumptions and variables are considered for determining the frequency and volume of an oil spill at a SBM:

- One (1) event (tanker breakout or surge event) every 3,518 operating days without Marine Breakaway Coupling (MBC; IAOGP, 2010);
- One (1) event every 5,621 operating days with MBC (IAOGP, 2010);
- Number of operating days (i.e. actual loading days/berth occupancy) per year (OHF loading records);
- Type of loading arm (fixed loading arm or flexible hose);
- Presence of MBC; i.e., If a loading arm is equipped with MBC, the spill volume is reduced by a factor of 1/35; Spill volume reduction in case a loading facility is equipped with MBC is factor 1/35; and
- Presence, effectiveness and timing of Emergency Shutdown (i.e. valve closure and pump stop).

Note that ‘operating days’ refers to the number of days a tanker is moored at the SBM. Typically a shuttle tanker loading operation lasts less than 24 hours; it is suggested that operating days be used as a surrogate for the number of cargos loaded.

Calculating the Frequency of a Spill from Jetties or Quays

The following assumptions and variables are considered for determining the frequency and volume of an oil spill at jetties or quays:

- Number of operating days (i.e. actual loading days/berth occupancy) per year (jetty/quay loading records);
- Each loading arm has a failure frequency resulting in a guillotine break 12 times in 1 million transfer operations (UKHSE, 2012);
- Smaller leaks (10% of diameter of arm) occur almost three (3) times more frequently, however these failures are not used in the SAMSON Model as the associated spill is considered too small for the study scope (UKHSE, 2012);
- Type of loading arm (fixed loading arm or flexible hose);
- If a loading arm is equipped with MBC, the spill volume is reduced by a factor of 1/35; and

- Presence, effectiveness and timing of Emergency Shutdown (i.e. valve closure and pump stop).

P50 and P90 calculation methodology

For OHFs, two scenarios are taken into account: a typical small spill (the 50th percentile – P50) and a typical large spill (Upper 90th percentile – P90). The spill volume ranges from $0.1m^3$ to $150m^3$ in worst case conditions.

In case risk mitigation measures are active, the spill volume is reduced with a reduction factor. For example: if MBC's couplings are present, the spill volume is reduced by 1/35th of the maximum spill size. The following assumptions are made, as related to OHF type category III en IV i.e. compliance with Best Practices regarding Emergency Response capacity:

Description	Assumptions
Loading arms	Fixed loading arms (no flexible hoses)
MBC	Present (activated on tensile forces exceeding predetermined tolerance)
ESD	Present (pump stopped and valves closed within < 2 minutes)
Pump capacity	Maximum 2.000 m^3/h (one-way outflow)
Oil data	Total volume per year (oil data)
Number operations	Number of ships per year (frequency)
Number operating days (days at berth)	Largest of either the number of ships per year (minimum) or the total Volume/pump capacity
Without MBC	One event (tanker breakout or surge event) every 3,518 operating days
With MBC	One event every 5,621 operating days
P50/P90 factor	P50 occurs 3 times more often than P90

For Mooring Buoys the frequency depends on the number of operating days, the presence of a MBC and on the spill size and is presented as a number of occurrences per days operating.

This leads to the following basic assumptions for Mooring Buoys:

	Volume $[m^3]$	Frequency [per operating day per year]	Volume $[m^3]$	Frequency [per operating day per year]
MBC	0.0029	1.33×10^{-4}	4.29	4.45×10^{-5}
No MBC	0.1	2.13×10^{-4}	150	7.11×10^{-5}

For jetties and quays the frequency depends on the number of operations and the spill size and is given as a number of occurrences per operation. The frequency for (un)loadings is 12×10^{-6}. This leads to the following basic assumptions for Jetties and Quays:

	Volume [m^3]	Frequency [per operation per year]	Volume [m^3]	Frequency [per operation per year]
MBC	0.0029	9.0 x 10^{-6}	4.29	3.0 x 10^{-6}
No MBC	0.1	9.0 x 10^{-6}	150	3.0 x 10^{-6}

Input

For each OHF the input is:

- OHF name and location
- OHF type (Mooring Buoy or Jetty/Quay)
- Oil types transferred (Light/Medium Evaporator, Medium/Heavy Floater, Heavy Sinker)
- Volume per year per oil type
- Number of operating days per year (days at berth), operations per year

Output

For each OHF, the results per oil type (5x) is:

- (5x) P50 (with MBC), including related Volume (V50) and return period
- (5x) P90 (with MBC), including related Volume (V90) and return period

3.0 SAMSON Model Outputs

The modelling and calculation processes of the SAMSON Model generate several outputs. The outputs of the model are presented in table format and/or visually in maps.

3.1 Marine Traffic Output

The output of the marine traffic model is best presented on maps, showing the main transport routes of oil in a specific area and providing information on the volumes of oil carried by ships in a specific area. An example of the AIS signals for the Saint John and Bay of Fundy Study Area for 2014, with a time interval of 5 minutes, is shown in **Figure D-7**. The traffic that was considered to be route bound traffic is shown in **Figure D-8**.

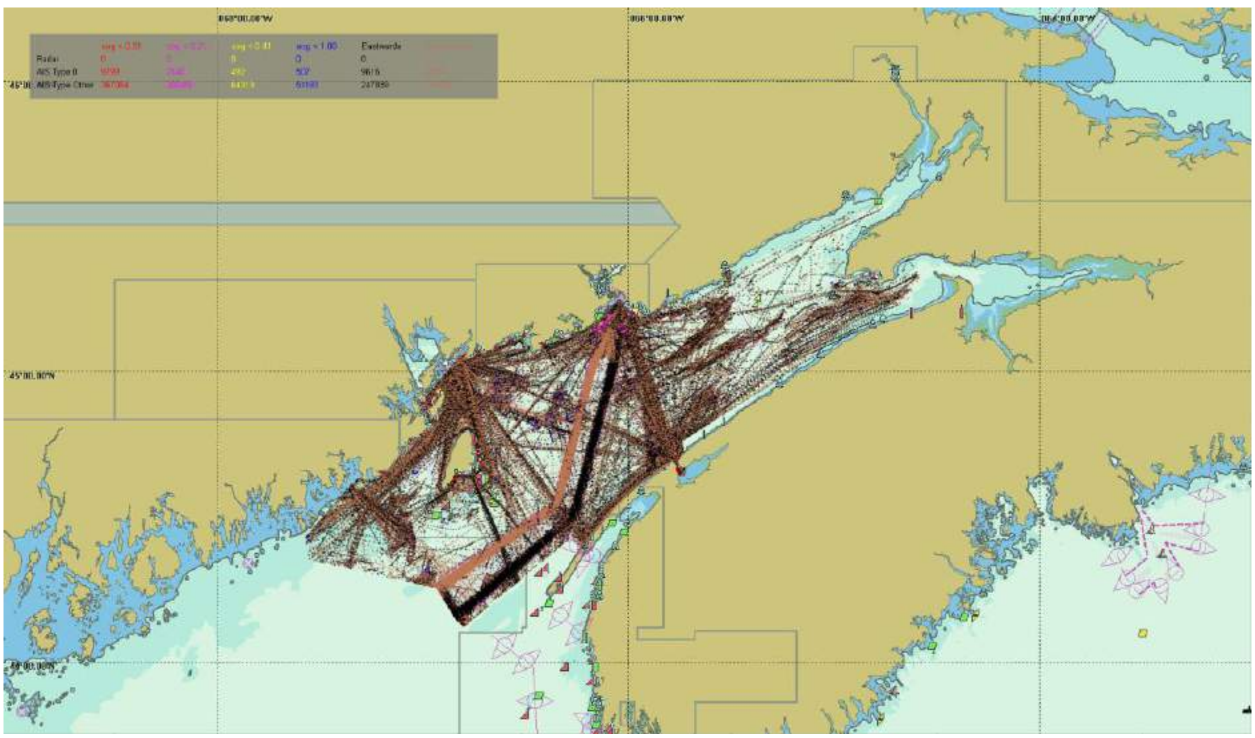


Figure D-7: Saint John and Bay of Fundy Study Area AIS Signals for 2014 at 5 Minute Time Interval

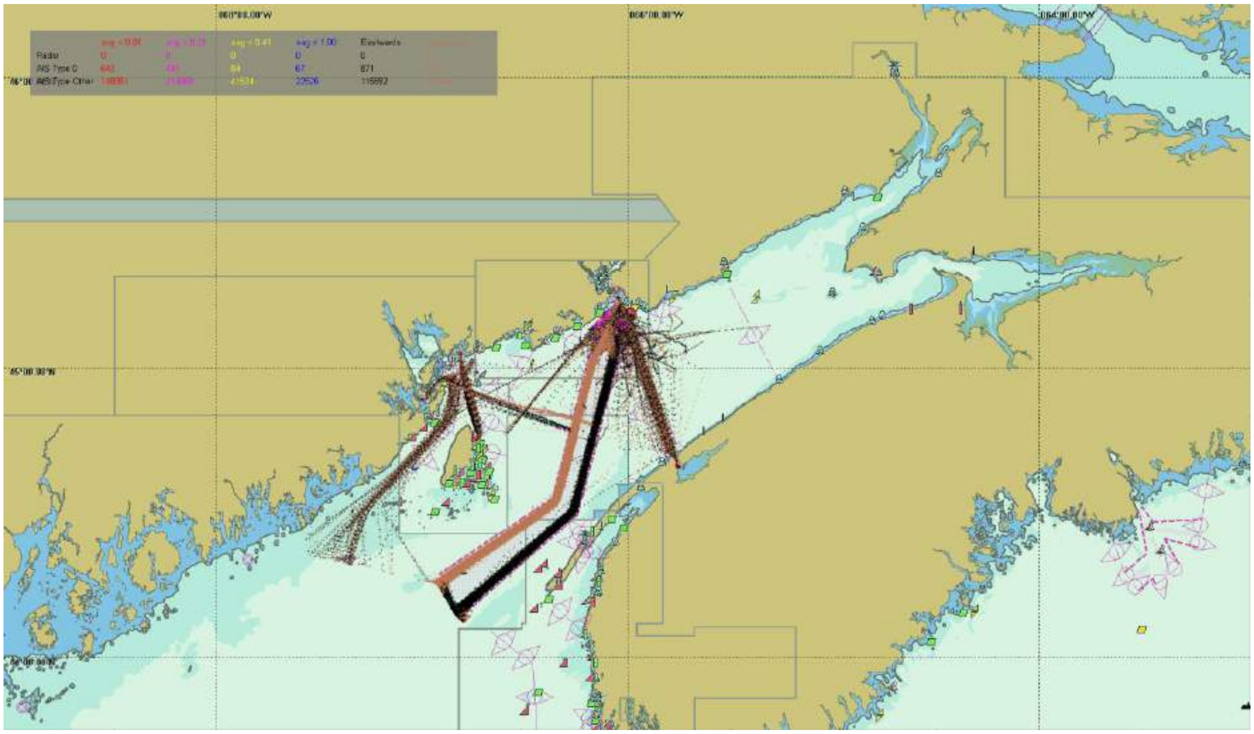


Figure D-8: Saint John and Bay of Fundy Study Area AIS Signals Route Bound Traffic for 2014

3.2 Frequency of Incidents, Accidents and Volumes of Outflow Output

The calculations of the incident frequency, the frequency of the penetration of a ship's hull, the frequency of an outflow, and the volume of outflow together result in the main output of the SAMSON Model. The outputs of the frequency calculations are used to determine the frequency of an oil spill (FOS) in a specific grid cell or location, which is then normalized on a probability scale. A ten step scale is used to represent the Extremely Low (=1) to Very High (=10) frequency ranges as presented in **Table D-7**. The output is presented both in table format and visually on maps.

Table D-7: FOS Categories, Scoring, Description, Definitions and Colour Code

FOS Category	FOS Score (Annual Total Frequency)	Description	Definition[2] (Total Return Period)	Colour Code
FOS-10	3.16×10^{-1}	Very High	<1:10 years	
FOS-9	3.16×10^{-2}	High	1:10 - 1:99 years	
FOS-8	3.16×10^{-3}	Medium	1:100 - 1:999 years	
FOS-7	3.16×10^{-4}	Low	1:1,000 - 1:9,999 years	
FOS-6	3.16×10^{-5}	Very Low	1:10,000 - 1:99,999 years	

[2] The Total Return Periods defined in **Table D-7** cannot be used to represent the frequency of individual ship-source oil spill accidents.

FOS Category	FOS Score (Annual Total Frequency)	Description	Definition[2] (Total Return Period)	Colour Code
FOS-5	3.16×10^{-6}	Extremely Low	1:100,000 - 1:999,999 years	
FOS-4	3.16×10^{-7}		1:1,000,000 - 1:9,999,999 years	
FOS-3	3.16×10^{-8}		1:10,000,000 - 1:99,999,999 years	
FOS-2	3.16×10^{-9}		1:100,000,000 - 1:999,999,999 years	
FOS-1	3.16×10^{-10}		1:1,000,000,000 - 1:9,999,999,999 years	

Visualisation of the Output in Tables

The results can be presented in output tables. The results are generated on a per grid cell or per area basis, per oil type and per accident type. **Table D-8** provides an example of a standard output table for the Saint John and Bay of Fundy Study Area, which contains the results of the various spill classes for a total area in 2014.

Table D-8: Saint John and Bay of Fundy Outflow Frequencies per Oil Spill Size Class for 2014

Outflow Class (m^3)		Total Area; Cargo Oil (all accident types)			
From	**To**	**Freq./Year**	**Once in . year**	**m^3 /year**	**Average m^3**
0.01	30	0.083879	11.9	0.237	3
30	150	0.001406	711	0.134	95
150	1,000	0.004227	237	1.673	396
1,000	5,000	0.002664	375	7.294	2,738
5,000	15,000	0.001833	545	16.377	8,932
15,000	30,000	0.000668	1,498	13.700	20,524
30,000	100,000	0.000436	2,294	22.059	50,614
>100,000		0.000154	6,481	24.053	155,892
Total		**0.095267**	**10.5**	**85.527**	**898**

Visualisation of the Output on Maps

The results can be visualized for grid cells on a map of a specific area. **Figure D-9** illustrates an example of the return period of oil spills greater than 30 m^3 in the Saint John and Bay of Fundy Study Area.

For each grid cell the following information is provided as an output of the SAMSON Model:

- Latitude (or grid number in northern direction);
- Longitude (or grid number in eastern direction;
- Ship Type i;
- Ship Size Class j;

- Accident Type a;
- Spill Size Class k (0 is no spill);
- Substance of Spill s (crude, refined oil, fuel oil (bunker);
- Frequency of Spill F_{ijaks}; and
- Volume of Spill V_{ijaks}.

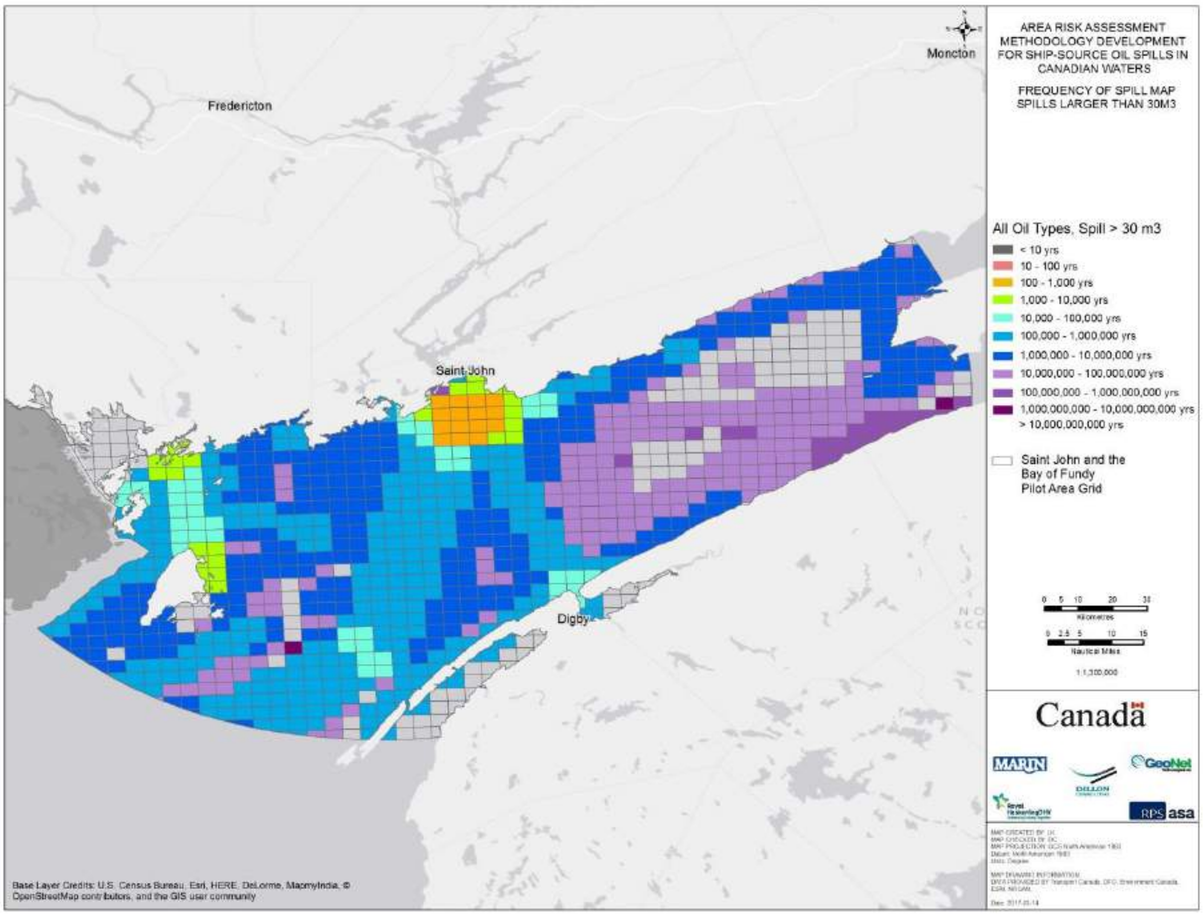


Figure D-9: Saint John and Bay of Fundy Recurrence Period for Bunker Oil plus Cargo Oil Spills >30 m^3

4.0 Conclusion

The Frequency of Spill is determined by the SAMSON Model using the methodology discussed in this appendix. Utilizing the SAMSON Model and determining the FOS in Phase 1, allows us to determine hot spots in the study area where scenarios can be selected to run the oil fate and trajectory modelling to determine the Probability of Exposure, discussed in further detail in **Appendix E**.

Flexibility of the SAMSON Model

It is important to note that the SAMSON Model also offers flexibility within its parameters. The model can be built to help determine impacts of future traffic by entering ghost ships into the traffic databases. This can allow for the ability to examine the risks surrounding proposed projects which would increase tanker traffic, as an example.

The model can also be used to test preventative barriers by adding or changing existing barriers and testing their impact on the FOS in the area.

5.0 References

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Appendix E

Probability of Exposure (POE) Model

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Figures

Tables

1.0 Introduction

The Area Risk Assessment (ARA) Methodology is completed in four phases. This will allow the User to first determine the frequency of a ship-source oil spill for each of the eight (8) oil spill classes (Phase 1) within the prescribed Study Area, thereby focusing efforts to identify the oil spill volume types (Phase 2) at specific locations. Before the final phase, the Frequency of Exposure is determined (Phase 3). These phases enable the risk assessment to be completed (Phase 4) to better understand and evaluate the risks for the selected oil spill volume types at specific locations within the Study Area. A graphical illustration of the ARA Methodology application is presented below in **Figure E-1**– taken from **Figure 2-7** of the Guidance Document.

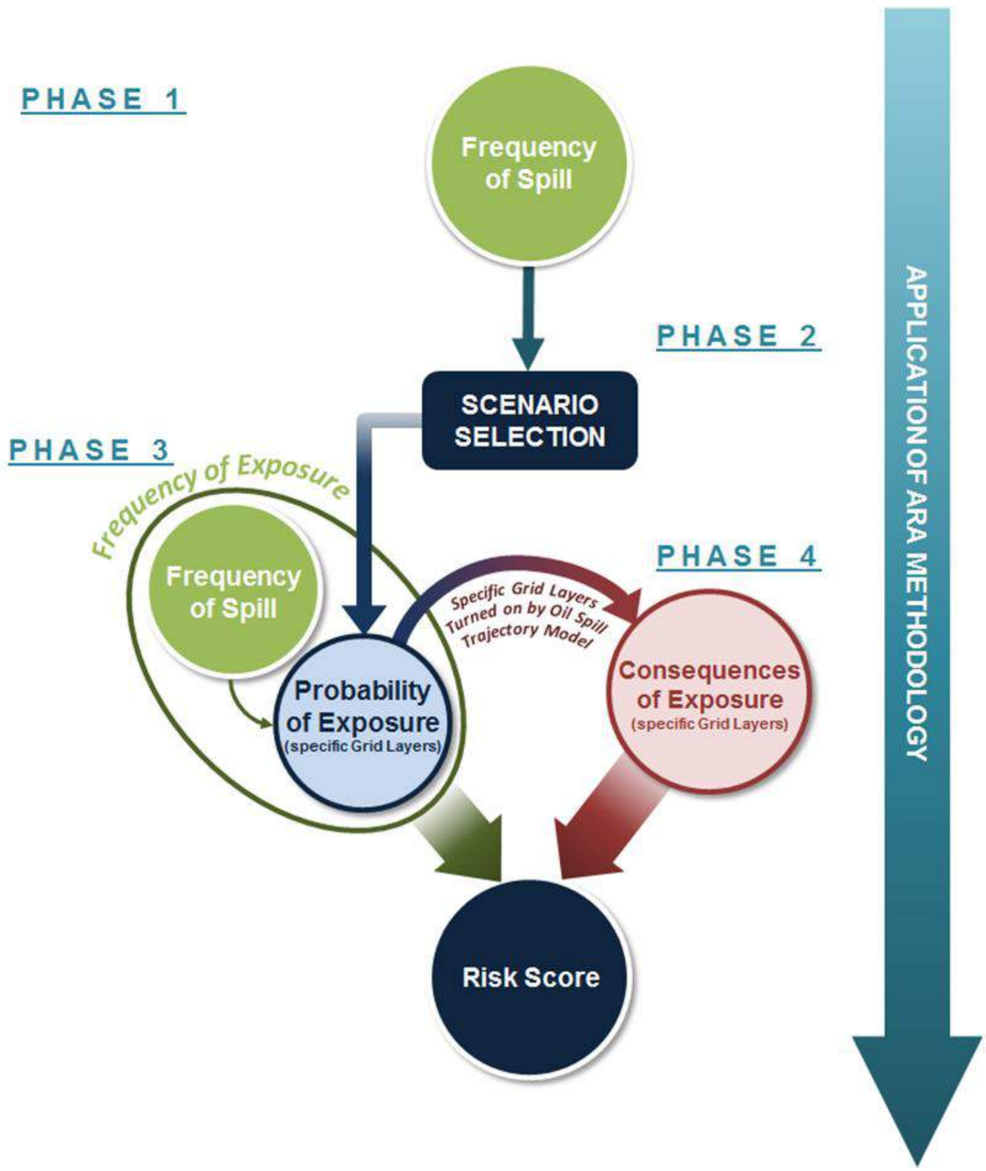

Figure E-1: ARA Methodology Decision Flow Chart

The Probability of Exposure was designed to answer one question:

Table E-1: Probability of Exposure – Answer to Question 2 in Figure 2-1 of Guidance Document

Question	Response
1. Where could the oil spill go?	The oil fate and trajectory modeling conducted using the SIMAP Model will be able to determine where the oil spill will take place in the selected scenarios from Phase 2.

The right side of the simplified ARA BowTie presented in Section 2.2 of the Guidance Document is further expanded to highlight all three Risk Receptors and the specific Risk Receptor groups that are incorporated within the ARA Methodology (see **Figure E-2**). The Probability of Exposure will help us determine the consequences by showing us which risk receptors will be exposed to oil in the selected scenarios.

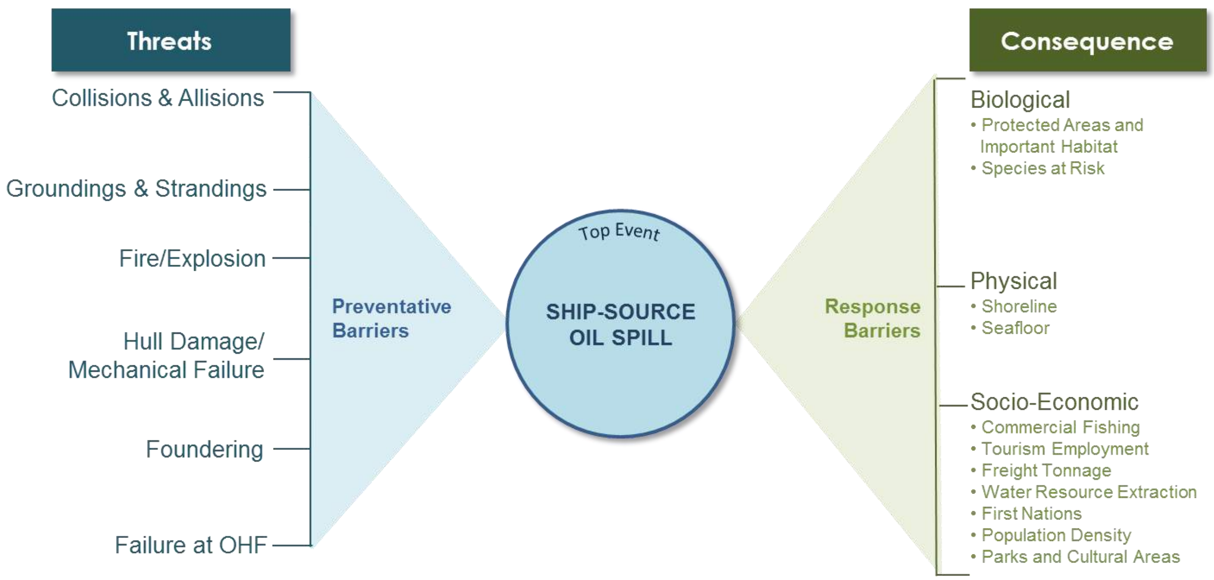

Figure E-2: Simplified ARA Bowtie with Specific Risk Receptor Groups

The ARA Methodology will calculate the Risk Score ($Risk_S$) in both a horizontal (grid cell 'j') and vertical (grid layer 'k') perspective as illustrated in **Figure E-3**. The horizontal grid cells are selected to provide adequate spatial resolution for assessing the risk of oil spills and vertically there will be the following four grid layers where oil can manifest itself:

- Shoreline;
- Water Surface;
- Water Column; and
- Seafloor.

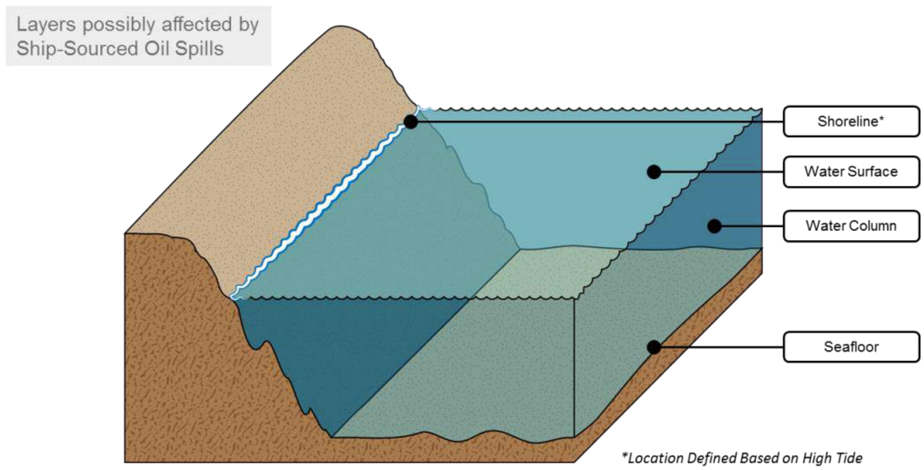

Figure E-3: Grid Layers that Compose a Grid Cell

This Appendix provides the technical details of the Spill Impact Model (SIMAP) which allows the User to determine where the oil will go within the grid cells of the study area and therefore which layers will be affected. The following sections will discuss the SIMAP Model (**Section 2**), Spill Mitigation Measures (**Section 3**), the Probability of Exposure (**Section 4**) and finally the SIMAP Model Outputs (**Section 5**).

1.1 Overall Approach

Determining the Probability of Exposure (POE) is done by performing oil spill fate and trajectory model simulations for ship-source and Oil Handling Facility (OHF) spill scenarios. The output from a spill model simulation is a map of the probability of exposure to oil within sea surface, subsurface and shoreline environments.

Oil spill trajectory and fate models are used to predict the spatial distribution of the probability that spilled oil will contaminate the environment. When determining probabilities, it is not sufficient to simulate the trajectory and fate of a single spill event because the spill trajectory will be different depending on the environmental conditions on a given day of the year. Imagine the difference between a spill trajectory during the summer when a low speed wind is blowing from the south and one during a strong easterly wind as a storm passes. Each will result in a different spill trajectory but each is likely to occur in a given season or within a period of many years.

What is required for calculating probabilities is a method for simulating hundreds of individual spill events, each one occurring on a different day and transported by different winds and currents. For oil spill risk assessments, oil spill models are typically applied using a Monte Carlo approach where hundreds of individual spill events are simulated with the input parameters (winds and currents) for each spill event taken from the range of possible conditions in the region of interest. The Monte Carlo method, also referred to as a stochastic approach, makes it possible to simulate multiple spills, each with a different, but possible, wind condition. With this approach, the model samples the range of possible wind conditions and the resulting trajectories, when overlaid, provide a map showing the probability of where a spill will go.

This Appendix to the ARA guidance document describes how an oil spill model is used to quantify the probability of exposure to spilled oil.

2.0 The SIMAP Model

Spill models use a "scenario" to define the location, volume, oil type and other parameters of a spill event as inputs to a spill simulation. For a risk assessment of spills from vessels, the details of the scenario are typically supplied by output from a probability analysis of vessel incidents and the likelihood of a subsequent spill. The probability analysis of vessel traffic identifies the most probable spill locations, spill volumes and oil types, and the spill model quantifies the probability of exposure to the spilled oil in the different parts of the environment. The spill model is applied to the risk assessment using the stochastic approach described in this section of the Appendix.

The SIMAP stochastic model is used to determine the likelihood of various risk receptors being exposed to oil when spills occur. The stochastic approach is a statistical analysis of results generated from many different individual trajectories of the same spill event with each trajectory having a different spill start time selected at random from a multi-year period. **Figure E-4** illustrates the random selection method where the simulation of each trajectory uses winds and currents from a different time within a multi-year dataset. The random start times allow for the same spill scenario to be analyzed under varying wind and current conditions. In order to capture the natural variability of winds and currents, the model requires both spatially (multiple points) and temporally (changing with time) varying wind and current datasets covering a multiple year period so that variability within the year (seasonal) and from year-to-year is captured.

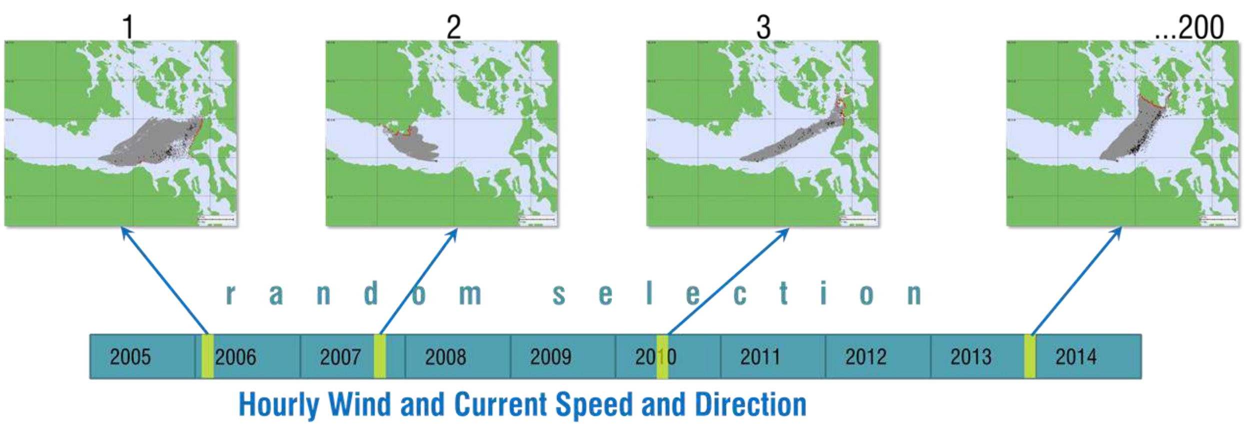

Figure E-4: Illustration of the Random Sampling of Wind and Current Data that is used in the Stochastic Modeling Approach

The trajectories from multiple individual spill events are overlain to generate a map depicting the probability that oil will reach a particular location within the region of the spill (see **Figure E-5**).

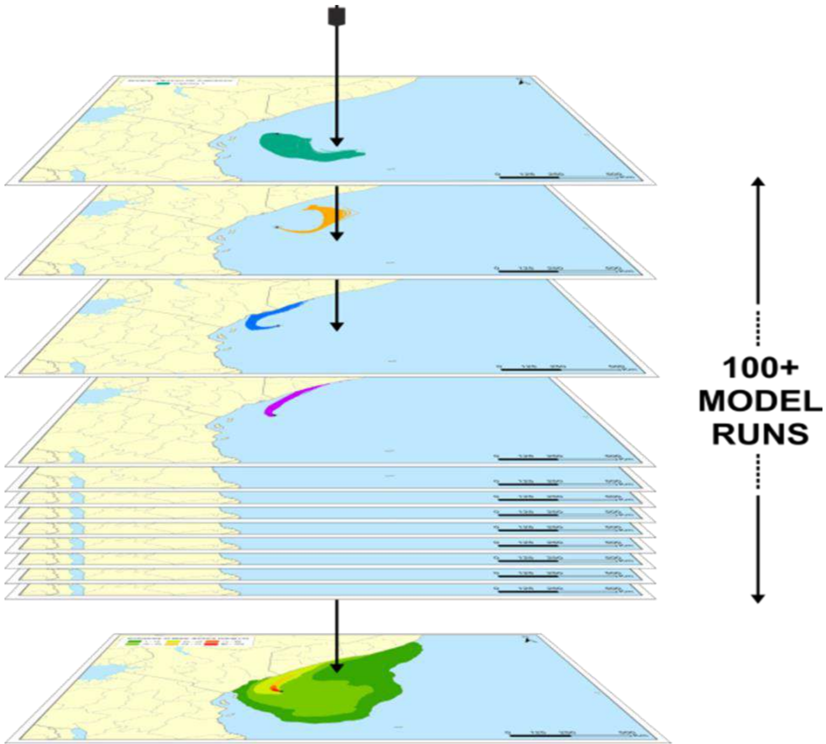

Figure E-5: Overlay of Spill Trajectories from Multiple Spill Events Produces a Map Depicting the Probability of Oil Reaching Anywhere in the Region of the Spill

The oil spill model used in the stochastic modeling approach needs to be capable of simulating the trajectory of the spilled oil and the fate of the oil as it moves through the environment. The trajectory of the oil is determined primarily by the currents and winds, which are the primary forcing mechanisms for oil transport. Wind blowing over the water surface moves the surface water and surface oil slicks, and it generates waves that can drive the oil beneath the surface. Currents are of particular importance in surface and subsurface oil transport and must capture the different flow processes present within the region of interest. The model must also simulate oil fate processes that change the physical and chemical properties of the oil as it interacts with elements of the environment.

SIMAP is a three-dimensional physical fates model that calculates the distribution (as mass and concentration) of whole oil and oil components on the water surface, on shorelines, in the water column, and in sediments. The model utilizes a spatially and temporally varying definition of winds and currents to transport the spill on the surface, in the subsurface and on the shoreline. Oil fate processes included are oil spreading (gravitational and by shearing), evaporation, transport, randomized dispersion, emulsification, entrainment (natural and facilitated by dispersant), dissolution, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended sediments, adsorption of soluble and sparingly-soluble aromatics to suspended sediments, sedimentation, and degradation.

In the SIMAP Model, the mixture of hydrocarbons of varying physical, chemical, and toxicological characteristics is represented by component categories, and the fate of each component is tracked separately. The "pseudo-component" approach (Payne et al., 1984; French et al., 1996; Jones, 1997; Lehr et al., 2000) is used, where chemicals in the oil mixture are grouped by physical-chemical properties, and the resulting component category behaves as if it were a single chemical with characteristics typical of the chemical group. This approach provides a more precise means of calculating the potential effects of the oil on biological resources.

The SIMAP Model is derived from the NRDAM/CME model, which was developed as the basis of the CERCLA Natural Resource Damage Assessment (NRDA) regulations for Type A assessments (French et al., 1996). The most recent version of the Type A models, the NRDAM/CME (Version 2.4, April 1996) was published as part of the CERCLA Type A NRDA Final Rule (Federal Register, May 7, 1996, Vol. 61, No. 89, p. 20559-20614). The technical documentation for the NRDAM/CME is in French et al. (1996 a-c). This technical development involved several in-depth peer reviews, as described in the Final Rule.

Since the development of the NRDAM/CME model, SIMAP has been used in multiple risk assessments and validated with more than 20 case histories, as well as test spills designed to verify the model's transport and fate algorithms.

The schematic in **Figure E-6** depicts oil fates processes simulated in open water conditions, while the schematic in **Figure E-7** depicts oil fates processes that are simulated at and near the shoreline. Because oil contains many chemicals with varying physical-chemical properties that influence its behavior, and because the environment is highly variable across space and in time, the oil separates into different phases or parts of the environment:

- Surface oil;
- Emulsified oil (mousse) and tar balls;
- Oil droplets suspended in the water column;
- Oil adhering to suspended particulate matter in the water;
- Dissolved lower molecular weight components (MAHs, PAHs, and other soluble components) in the water column;
- Oil on and in the sediments;
- Dissolved lower molecular weight components (MAHs, PAHs, and other soluble components) in the sediment pore water; and
- Oil on and in the shoreline sediments and surfaces.

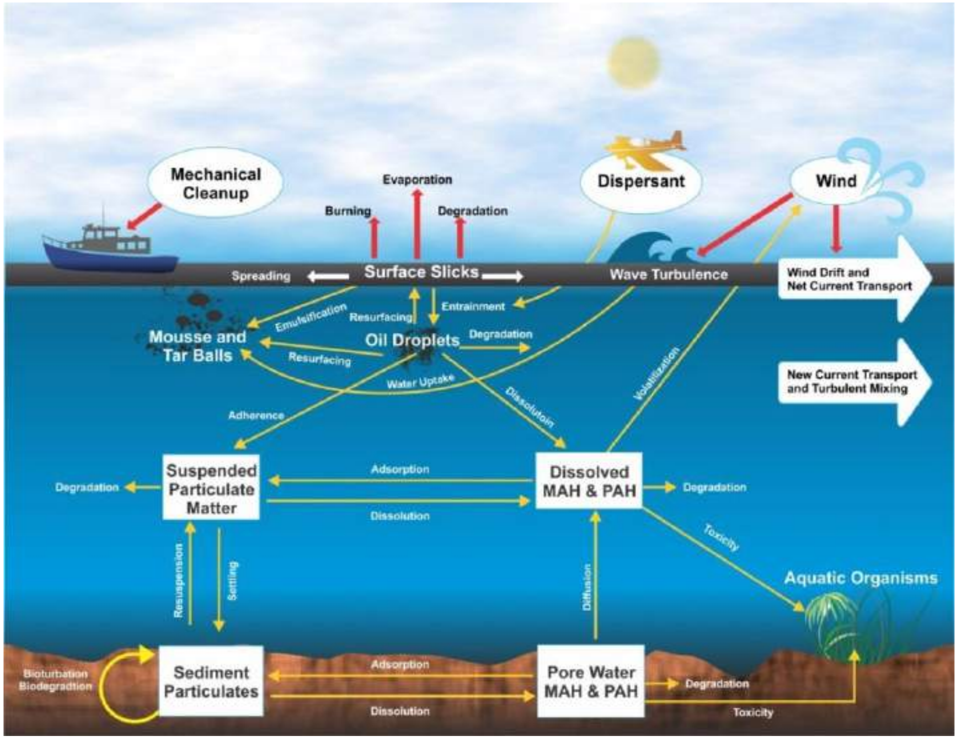

Figure E-6: Oil Fate Processes Simulated in Open Water within the SIMAP Model

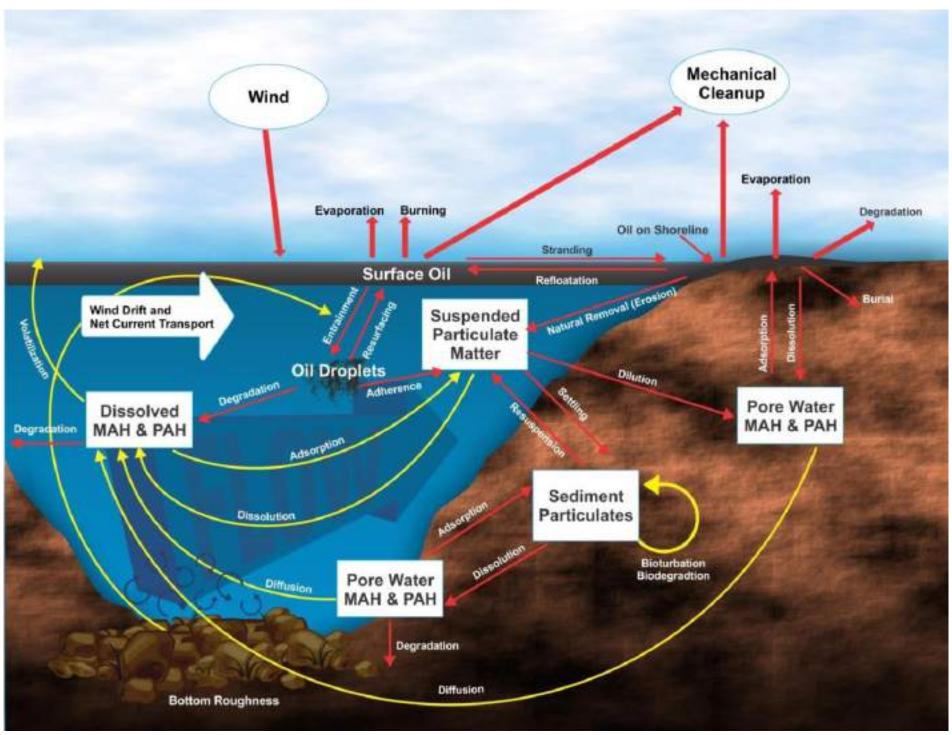

Figure E-7: Oil Fate Processes Simulated near Shorelines within the SIMAP Model

There are several interactions that can occur when oil is released in the presence of sea ice. These include oil deposition onto the surface of the ice; oil absorption into surface snow; oil encapsulation into the ice; oil becoming trapped in leads or in open water fields between floes; under the ice in ridges and keels; building up along and becoming trapped in landfast ice edges (**Figure E-8**) (Drozdowski et al., 2011).

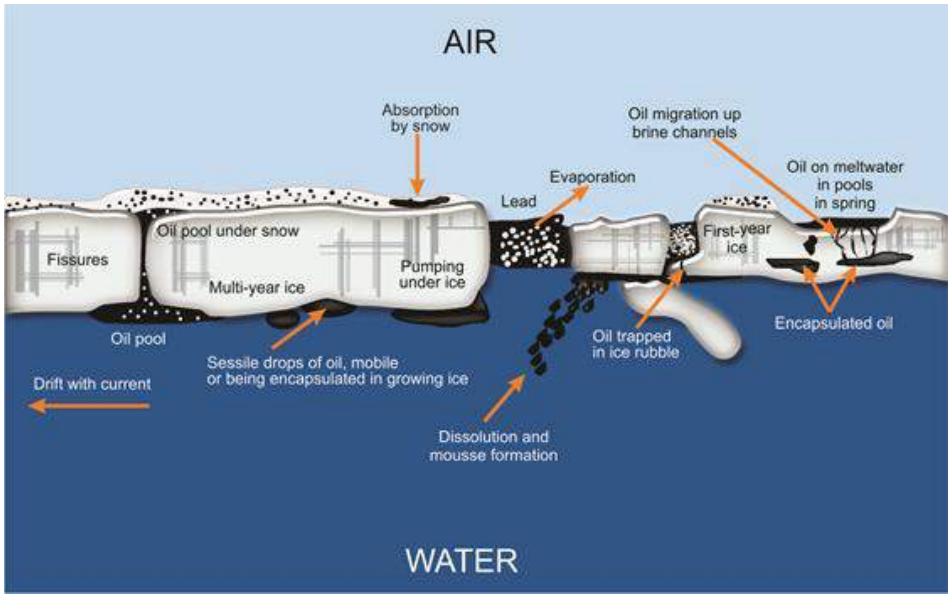

Figure E-8: Oil and Ice Interactions

Many of these interactions and processes occur at small scales that are too fine to be captured in hydrodynamic and ice models, and are often not included or accounted for in oil spill trajectory modeling. Any improvement in modeling these processes lies in the ability to model the behaviour of the ice itself at the necessary spatial scales, which can be on the order of meters. Oil spill trajectory models such as SIMAP simulate the large scale effects that ice has on oil transport and fate processes based on observations from laboratory and field studies.

The degree to which oil is transported by ice is dependent on the ice coverage. The approach used in spill modeling studies where the fine scale characteristics of ice are not defined and only ice coverage is known, is to modify the transport and fate of the oil as follows:

- Advection – reduced with increasing percent ice cover
- Evaporation – reduced due to shielding from wind/waves
- Entrainment – reduced due to reduced wave energy
- Spreading – slowed by cold, presence of ice, herding and containment effects

2.1 SIMAP Inputs

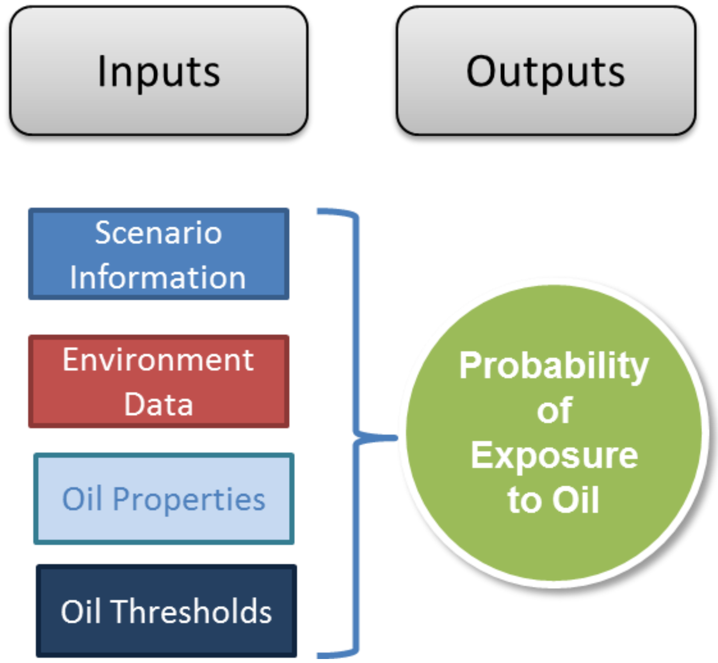

Figure E-9: Inputs and Outputs of the SIMAP Model

Inputs to the spill trajectory and fate analysis define the physical and biological environment used by SIMAP, but they also define the spill scenarios that are to be modeled, the properties of the spilled oil and multiple criteria used to calculate the effects of oil in the environment inputs (see **Figure E-9**). Much of the required data are fairly specialized and require understanding of complex file formats and scientific conventions, as well as some preparation. When utilizing an oil spill model as part of a spill risk assessment, the majority of the effort is often applied to obtaining, understanding and formatting the input data required to run the spill simulations. The descriptions of model inputs in the following sections of this report are intended to give a high level understanding of each input dataset. The discussion uses examples from the Bay of Fundy.

2.1.1 Scenario Information

In the SIMAP oil spill model, a scenario contains a definition of all of the inputs and outputs for a spill simulation. In the context of the risk assessment of ship-sourced oil spills, scenarios are developed using information generated by model simulations performed by the SAMSON Model.

2.1.2 Environmental Data

Environmental data are used by the trajectory and fate model to define the physical and biological environment. The datasets describe environmental parameters that change rapidly in time such as winds, currents, waves and water column properties, but also more static elements of the environment like water depth and habitat type. This section describes the data needed to define all aspects of the environment required by the oil spill model.

Winds

Simulating the trajectory and fate of oil spills requires a definition of a highly dynamic and variable wind field over the entire area where oil may potentially travel. There are public sources for wind data maintained by Canadian and U.S. government agencies that provide the necessary inputs for the spill modeling required in a risk assessment. The data come from buoys or fixed instruments where wind speed and direction have been recorded over multiple years or from output from meteorological models that generate wind speed and direction on a regular grid from a multiple year simulation. **Figure E-10** shows an example of a wind field generated by a meteorological model for the Bay of Fundy region extracted from the North American Mesoscale Forecast System (NAM) run by the NOAA National Centers for Environmental Prediction (NOAA-NCEP).

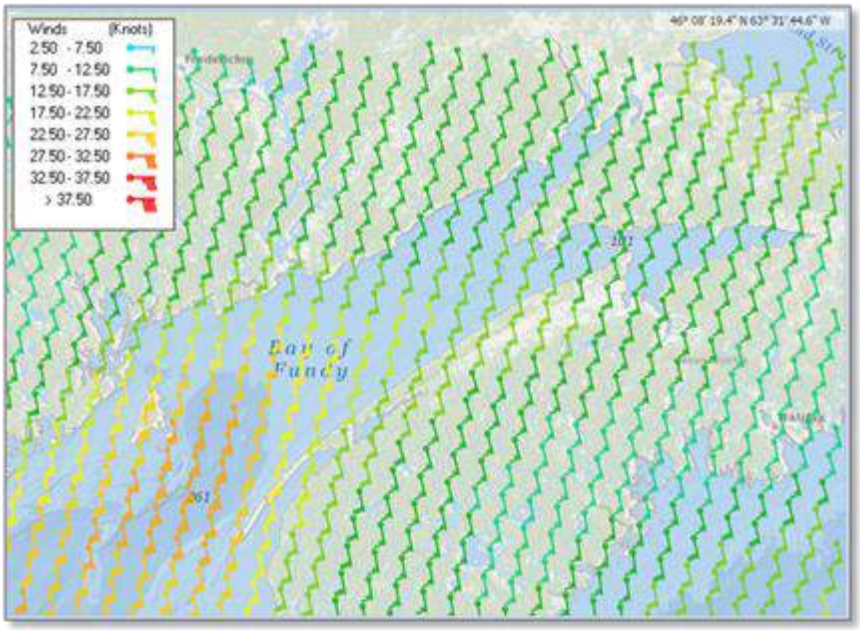

Figure E-10: Example Wind Field over the Bay of Fundy

Canadian and U.S. government agencies provide wind data in both forms. Wind data for oil spill risk assessments needs to have adequate spatial coverage to capture the spatial variability present in a region and it must cover a sufficient number of years (10 years is ideal) to capture the year-to-year variability.

Currents

Simulating the trajectory and fate of oil spills requires a definition of the currents over the entire area where oil may potentially travel. Current observations such as those collected by instruments deployed in the field do not have sufficient spatial coverage to adequately drive an oil spill model. In addition to complete spatial coverage, when a stochastic approach is used for modeling oil spills, a current field extending over a long time period is required in order to capture the variability that occurs on monthly, seasonal, annual or decadal time scales. A hydrodynamic model applied to the area of interest is the best solution for meeting the spatial and temporal requirements of the spill modeling tasks.

One common approach in hydrodynamic modeling is to hindcast a recent multi-year period and use current data collected by instruments in a data assimilation process to improve the hydrodynamic model accuracy. These types of hydrodynamic model products are not readily available for many parts of the world. Another approach to modeling the hydrodynamics in a region, particularly where tides or strong seasonal freshwater inflows are important drivers, is to use a hydrodynamic model to simulate currents for a one-year period based on tides and river inflows. This approach is more easily achieved than the long-term model hindcast and it provides hydrodynamics well suited to the stochastic modeling approach because they vary by month and seasonally and have contiguous spatial coverage.

Other oceanographic processes that drive currents in a region may be important and should be included in the hydrodynamic model if possible. An example of this kind of process is a current generated by the difference in density of water masses where density differences drive the water movements. If currents from this type of flow play a role in transporting spilled oil then they should be incorporated into the hydrodynamic model.

Temperature/Salinity

The temperature and salinity of the water are important parameters that are used by oil spill models in the various oil fate calculations. Oil entrained in the water column in the form of oil droplets is carried upward by buoyant force on each individual droplet, and density (calculated from temperature and salinity) is a critical parameter in that calculation.

The SIMAP oil spill model uses a characterization of the water column using temperature and salinity values at discrete depths along a vertical profile. **Figure E-11** shows an example of temperature and salinity vertical profiles. The temperature and salinity values are used to calculate a water density profile throughout the water column. Temperature and salinity may be obtained from a number of sources. The World Ocean Atlas 2013 (Locarnini, et al., 2013; Zweng, et al., 2013) provides a source for seasonal temperature and salinity profiles for the globe. Temperature and salinity data are also available from government sources on a regional or local basis. A single set of values can be used to define the water column in the oil spill model, or if seasonal variability occurs, seasonal or monthly profiles may be defined.

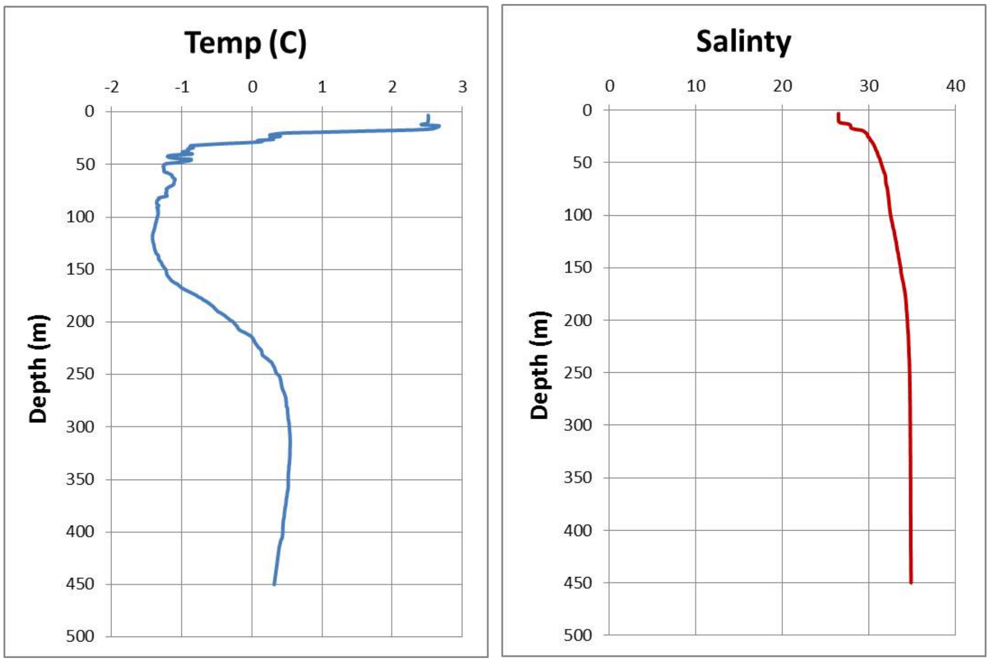

Figure E-11: Example Temperature and Salinity used to Define the Properties of the Water Column in SIMAP

Waves

Waves breaking on the sea surface are important in oil spill modeling because they can drive the oil contained in a surface slick into the water column in the form of small droplets. Depending on the size of the oil droplets generated by this entrainment process, the oil can remain submerged in the water for some time where it may undergo dissolution. Entrained oil also will not evaporate so that volatile oils may be more persistent when they are below the surface thereby causing more impact on water column organisms. The SIMAP Model generates sea surface waves using the wind data specified as input to the model and a methodology developed by the U.S. Army Corps of Engineers (USCOE) as described in USCOE, 2002. If available, a wave model hindcast of the study area may be used for generating significant wave heights for use in the oil spill model.

Ice

The presence of sea ice has a direct effect on the transport and weathering of spilled oil. Sea ice can be defined in a spill model as a percent cover, such as the map in **Figure E-12**, or on a grid system similar to that generated from a hydrodynamic model only the ice grid contains ice movement instead of currents.

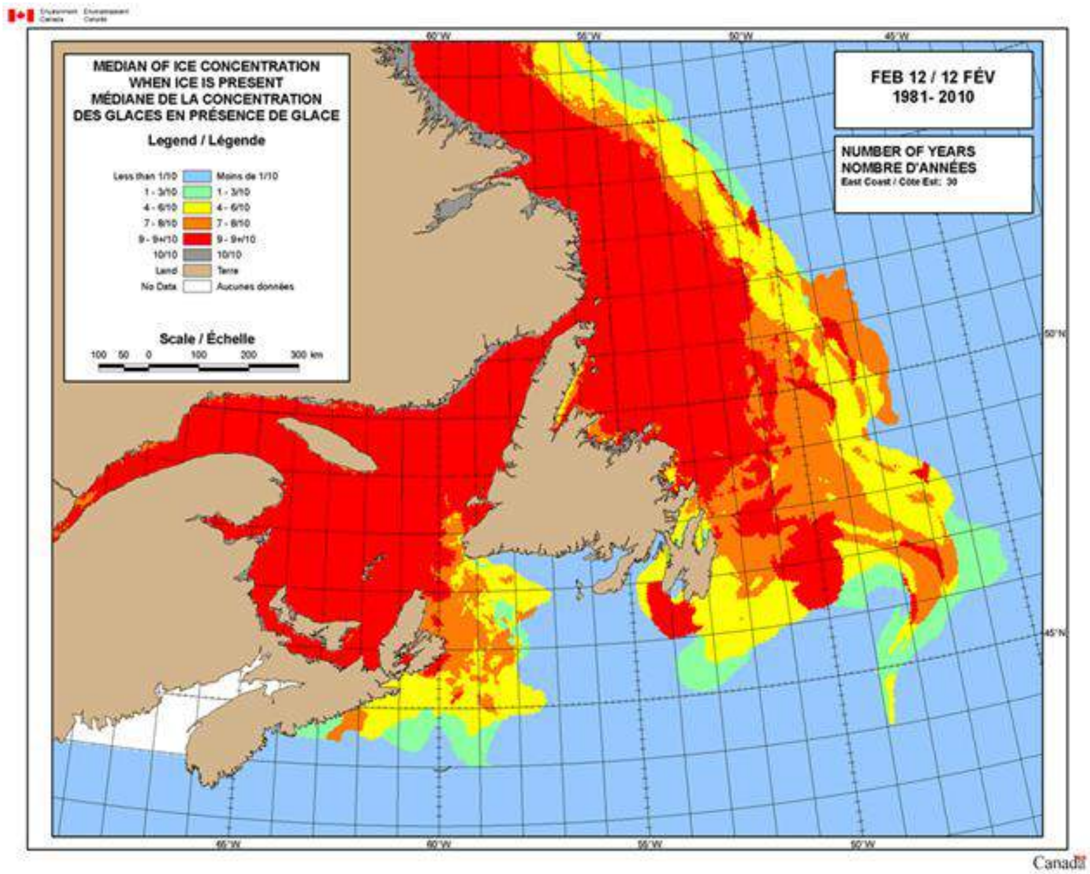

Figure E-12: Median Ice Concentration on February 12 when Ice is Present. Provided by the Canadian Ice Service using Data from 1981 through 2010

Physical and Biological Habitats

The SIMAP Model uses a definition of the physical and biological environment by defining a habitat type for all areas where oil may be transported by the model. A habitat type describes shoreline, intertidal and subtidal environments, and the species that inhabit them. The oil spill model reads the habitat designations from a grid that covers the model domain. Each of the grid cells is assigned a depth and a habitat type. Information associated with each type designation includes a listing of the biological species which are known to inhabit these habitats for the area under study. A model grid may contain up to 21 ecological habitat types. Habitat types are defined consistent with the approach of Cowardin et al. (1979).

Habitats are designated as landward or seaward. Landward portions are the rivers, streams, estuaries and inlets off the main water body of interest. The seaward portion is the more oceanic or main part of the water body. This designation allows different biological abundances to be simulated in landward and seaward zones of the same habitat type (e.g., open water with sand bottom within a large estuary versus in a coastal lagoon). Appropriate biological data is used to assign a type to each grid cell and whether it is landward or seaward. In freshwater, landward is equivalent to littoral and seaward is equivalent to limnetic.

In tidal waters (either estuarine or freshwater), ecological habitat types are broadly categorized into two zones: intertidal and subtidal. Intertidal habitats are those above spring low water tide level, with subtidal defined as all water areas below that level. Intertidal areas may be “extensive”, such that they are wide enough to be represented by more than a single grid cell. Extensive intertidal habitats are typically either mud flats or wetlands. All other intertidal habitats are typically narrower than the size of a grid cell, and these fringing intertidal types have typical widths assigned to them in the model. Boundaries between land and water are fringing intertidal habitat types. On the waterside of fringing intertidal grid cells, there may be extensive intertidal grid cells if the intertidal zone is extensive. Otherwise, subtidal habitats border the fringing intertidal. For the purposes of the biological database, extensive and fringing mudflats are identical, as are extensive and fringing wetlands. These habitats differ only by the width of the intertidal zone. Public sources for these kinds of data are varied. Individual provinces provide data such as the British Columbia Shore-Zone described in Howes, et al., 1994.

Bathymetry

Water depth over the entire region of the simulated spill is important for calculating the subsurface transport and concentration of any entrained oil. The SIMAP Model defines the water depth in each habitat grid cell using the best available data. There are multiple bathymetry datasets that have global coverage that are suitable for offshore areas but lack resolution in nearshore environments. For nearshore depths, soundings and depth contours from navigation charts can be used. The Canadian Hydrographic Service provides digital navigation charts for navigable waters in Canada. The best approach is to assemble depth data from multiple sources and merge them into single bathymetry coverage.

2.1.3 Properties of Spilled Products

Specifying the physical and chemical properties of the oils used in the SIMAP spill model is critical to achieving accurate and reliable oil fate predictions. Some of the oil properties required by the model can be difficult to find and so the system contains a database of oil properties for a range of commonly produced crudes and refined oil products. The best single source for physical and chemical parameters describing crude and refined oil products is maintained by Environment Canada and made available on-line: http://www.etc-cte.ec.gc.ca/databases/oilproperties/. The EC oils database currently contains properties for 450 products. Recent studies of the fate and behavior of oil have been published by Fisheries and Oceans Canada, Center for Offshore Oil, Gas and Energy Research.

2.1.4 Product Oiling Thresholds

Thresholds of either oil thickness or concentration are used in oil spill models to determine if the amount of oil present in the environment is sufficient to cause an impact or if it is sufficient for applying different spill response operations. Impact thresholds are used for determining either ecological or socioeconomic impacts. Spill response related thresholds consider, for example, whether floating oil thickness is sufficient to effectively employ mechanical recovery.

Surface oil thickness is often expressed in units of g/m^2, where 1 g/m^2 corresponds to an oil layer that is approximately 1 micron (µm) thick. **Table E-2** lists approximate thickness ranges for surface oil of varying appearance. Dull brown sheens are about 1-4 µm thick. Rainbow sheen is about 0.2-0.8 µm thick and silver sheens are 0.05-0.2 µm thick (NRC, 1985). Crude and heavy fuel oil that is greater than 1mm thick appears as black oil. Light fuels and diesel that are greater than 1mm thick are not black in appearance, but appear brown or reddish. Floating oil will not always have these appearances, as weathered oil would be in the form of scattered floating tar balls and tar mats where currents converge.

Table E-2: Oil Thickness (µm) and its Appearance on the Water Surface (NRC, 1985)

Minimum (µm)	Maximum (µm)	Appearance on Water Surface
0.05	0.2	Colourless and silver sheen
0.2	0.8	Rainbow sheen
1	4	Dull brown sheen
10	100	Dark brown sheen
1,000	10,000	Black oil

Determination of which thresholds to apply depends on the intended purposes of the modeling. Socio-economic thresholds are appropriate for determining the degree of impact to socio-economic resources. For example, oil accumulating on an amenity beach at a thickness exceeding the threshold would be closed to swimming. Ecological thresholds are used to determine the effect to biological resources. For example, the ecological threshold for sea surface oiling has been observed to mortally impact birds and other marine wildlife (fur-bearing mammals, sea turtles). Response thresholds are relevant for determining if various response techniques can be utilized and will be effective. For example, mechanical recovery is not considered effective for surface oil less than 8 g/m^2 (8 µm) thick. The SIMAP Model can apply multiple thresholds within a single stochastic scenario.

To analyze the probability or likelihood of potential effects, the SIMAP Model uses different thresholds for surface oil thickness, in-water concentration, and shoreline oiling. Thresholds can also be specified for determining the probability of oiling effects for individual species groups found within these environmental compartments. Data used to define the various thresholds is limited and it is best to take a conservative approach when defining a threshold for determining the effects from exposure to oil. Spill simulations performed as part of the ARA will use an oil thickness or concentration threshold to calculate the probability of oiling that is appropriate for the subsequent risk calculations that take the oil spill model outputs as input. The thresholds used for the SIMAP modeling in the ARA are presented in **Table E-3**. The thresholds were obtained from a review and analysis study (French McCay, 2016) that examined over 90 previously published peer reviewed articles on oil thresholds that could cause biological and socio-economic effects.

Table E-3: Oil Thickness Thresholds for Sea Surface, Shoreline, Water Column and Sea Floor Sediments (French McCay, 2016)

Grid Layer	Threshold (thickness or concentration)	Description
Sea Surface	0.01 g/m^2 (0.01 µm)	Oil thickness for socio-economic effects
	1 g/m^2 (1 µm)	Oil thickness for sub-lethal effects to marine mammals, birds and reptiles impacted by surface oil slicks
	8.0 g/m^2 (8 µm)	Minimum oil thickness for which response equipment can skim/remove oil from the surface, surface dispersants are effectively applied or oil can be boomed/collected for in-situ burning
Shoreline	1 g/m^2 (1 µm)	Oil thickness for socio-economic effects
	10 g/m^2 (10 µm)	Oil thickness for sub-lethal effects to shore birds and wading birds
Water Column	0.1 µg/L	PAH concentration for sub-lethal effects in Protected Areas and Important Habitats
	1.0 µg/L	PAH concentration for sub-lethal effects to fish and invertebrates
	100.0 µg/L	THC concentration for effect to general water column biota
Sea Floor Sediment	200 g/m2	Sub lethal effects to invertebrates in sediment.

3.0 Spill Mitigation Measures

The oil spill model can incorporate spill mitigation measures into the simulations so that their effectiveness can be measured. This is useful for comparing the potential effects from a spill with and without response measures such as booming, mechanical recovery, dispersant application and in-situ burning. Response measures are incorporated into the model simulations based on estimates of the capabilities, capacities and deployment logistics of response resources available in each geographic location.

The selected spill scenario is first modelled assuming no response occurs as this provides the necessary information required for the incorporating spill response measures. Scenarios can then be modelled using an encounter rate method that can include various response methods (including: booms, mechanical recovery, dispersant application and in-situ burning0 and then compare and the effectiveness of the different response options assessed to the no response option. The encounter rate response is a stochastic simulation which is the combination of 200 different scenarios that are combined to yield a probability of where oil is likely to go. It does not represent a specific spill event and the results of the encounter rate response should only be used as part of the ARA framework and not for response planning.

3.1 Deflection Boom

Booms are defined as polylines that represent their position and characteristics. In the model simulation, the boom performs according to thresholds for current speed, wave height and wind speed. The boom fails if any of the thresholds are exceeded during the simulation. Model output of the oil trajectory will reflect the deployment, and failure of boom sections.

3.2 Collection Boom

Boom locations are defined as polygons that represent a collection region and the boom characteristics. In the model simulation, the boom performs according to thresholds for current speed, wave height and wind speed. The boom fails if any of the thresholds are exceeded during the simulation. Model output of the oil trajectory will reflect the deployment, oil recovery, and failure of boom sections.

3.3 Mechanical Recovery

Oil removal by skimmers is defined for the model within regions described as polygons. Each removal region represents an active skimmer who's logistical and operational characteristics have been defined such that oil removal can be calculated for surface oil within the region. Characteristics of the skimmer include a start time and an end time for application; the amount of oil to be removed per hour. For details on how to determine the volume of oil to be removed per hour refer to Dillon's Technical Memo titled "SIMAP Oil Spill – Enhanced Encounter Rate Response Memo" dated November 21, 2016.

Thresholds define the limits on recovery including minimum oil thickness, maximum current speed and maximum wave height for skimming to occur.

When a spill simulation is run, oil will be removed from that area at the rate specified during the time window defined. All logistical parameters such as deployment and transit times, daylight hours and other operational constraints associated with operating vessels are accounted for in the model calculations.

3.4 Dispersant Application

Dispersant regions outline where dispersant is to be applied by a single vessel or aircraft. Multiple dispersant regions can be defined and used in a model simulation. Each region has a start time and an end time for dispersant application and a defined dispersion rate, in metric tons per hour, at which oil is removed from the water's surface by the dispersant. Oil is removed from the water surface and dispersed as small droplets into the water column. Oil removed cannot exceed the amount present within the region. Thresholds are defined for each region that may restrict the dispersant application: minimum oil thickness, minimum wind speed, maximum wind speed, minimum water depth, maximum oil viscosity. All logistical parameters such as deployment and transit times, daylight hours and other operational constraints associated with operating vessels and aircraft are accounted for in the model calculations.

3.5 In-Situ Burning

In-situ Burning regions outline where in-situ burning operations take place. Multiple burn areas can be defined and used in a model simulation. Each burn area has a start time and an end time for burning and a defined burning rate, in metric tons per hour, at which oil is removed from the water's surface through combustion. Oil removed cannot exceed the amount present within the region. Thresholds are defined for each area that may restrict the burning rate: minimum oil thickness, minimum wind speed, maximum wind speed and maximum oil viscosity. All logistical parameters such as deployment and transit times, daylight hours and other operational constraints associated with operating vessels and burning equipment are accounted for in the model calculations.

4.0 Probability of Exposure

The Probability of Exposure (POE) is in essence the probability of oil contamination occurring above the defined threshold(s) for sea surface, shoreline, water column and seafloor environments. The POE values are calculated by the SIMAP Model on a grid covering the entire extent of the spill trajectories and expressed by values between 0 (no probability of oil contamination) and 1 (100% probability of oil contamination).

Grids containing the probability that sea surface oiling, shoreline oiling, seafloor oiling and water column contamination are expected to exceed the specified thresholds are produced for each stochastic model scenario. The probability of oiling is based on a statistical analysis of the resulting ensemble of individual trajectories calculated as part of each spill scenario. The probability grids do not provide any information on the quantity of oil in a given grid cell, they simply denote the probability of oil exceeding the given threshold over the entire ensemble of runs at each point. Because the thresholds applied in the calculation of oil exposure probabilities are defined as oil quantities shown to cause impact and injury to biological resources, the probabilities are a measure of the potential for impact. As an example, a surface oil slick greater than the 10 micron thickness threshold is shown to mortally impact birds and other marine wildlife (fur-bearing mammals, sea turtles), so the probability of exposure is a measure of the likelihood of mortality. Thresholds appropriate for sub-lethal effects may also be applied to determine the probability of exposure.

The POE Score in each grid cell can be determined and normalized on a risk-based scale for each of the four zones (shoreline, surface water, water column and seafloor). A five-step scale is used to represent the Very Low (=1) to Very High (=5) probability range, as presented in **Table E-4**.

Table E-4: Relative Scoring of the Probability of Oil Contamination to Define Probability of Exposure (POE)

POE Category	POE Score	Description[1]	Definition	Colour Code
POE-5	0.9	81% to 100%	Very High	
POE-4	0.7	61% to 80%	High	
POE-3	0.5	41% to 60%	Medium	
POE-2	0.3	21% to 40%	Low	
POE-1	0.1	5% to 20%	Very Low	

Note: Values less than 5% were excluded due to statistical variability within the oil trajectory model outputs

[1] The lower limit of POE -1 was chosen to be 5% below which is considered to be statistically insignificant.

5.0 SIMAP Model Outputs

Each stochastic scenario results in a map of the probability of exposure to oil on the sea surface (see example in **Figure E-13**), on the shoreline and in the water column. Calculation of the probabilities is based on oil present in a quantity exceeding a specified thickness or concentration threshold. Thresholds are specified based on the type of spill effects to be assessed as discussed in **Section 2.1.4**.

It should be noted that when applying an oil spill model stochastically, the many individual trajectories generate an area of probability that describes the possible area of oil contamination from the entire suite of modeled conditions. Stochastic footprints are therefore much larger than the expected effects from any single incident.

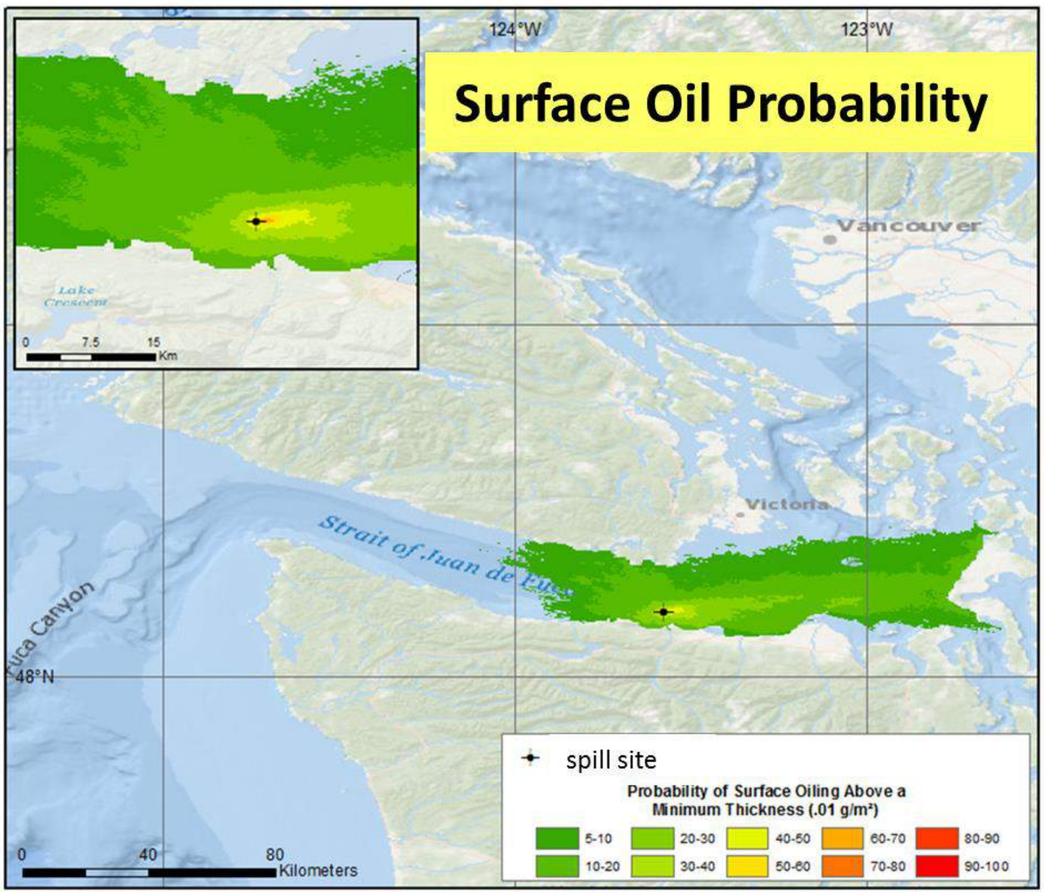

Figure E-13: Map Showing the Probability of Oil Reaching the Sea Surface in Excess of a 0.01 g/m^2 Thickness Threshold

6.0 Conclusion

The Probability of Exposure, determined by the use of the SIMAP Model, allows for the calculation of the Frequency of Exposure (FOE) – refer to **Section 6.1** of the Guidance Document for additional details. Utilizing the SIMAP Model, we can calculate the Consequences of Exposure by utilizing the methodology described in **Appendix F of the Guidance Document**.

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Appendix F

Consequence of Exposure (COE) Model

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Figures

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DILLON CONSULTING

Appendices

1.0 Introduction

The Area Risk Assessment (ARA) Methodology, as illustrated in **Figure 2-2** of the Guidance Document, is completed in four phases. This will allow the User to first determine the probability of a ship-source oil spill for each of the eight (8) oil spill classes (Phase 1) within the prescribed Study Area, thereby focusing efforts to identify the oil spill volume types (Phase 2) at specific locations. Before the final phase, the Frequency of Exposure is determined (Phase 3). This enables the risk assessment to be completed (Phase 4) to better understand and evaluate the risk for the selected oil spill volume types at specific locations within the Study Area. A graphical illustration of the ARA Methodology application is presented below – taken from **Figure 2-7** of the Guidance Document.

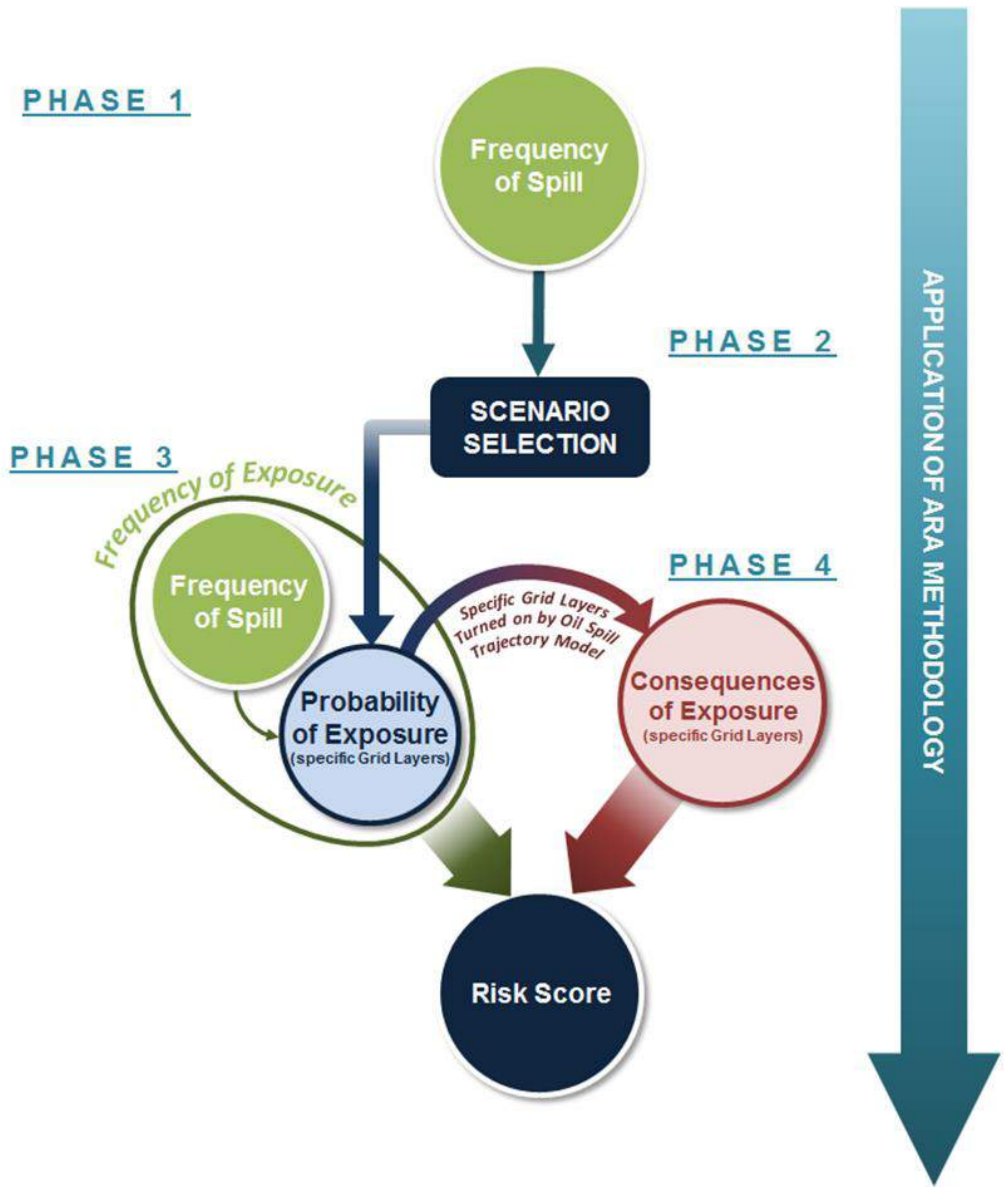

Figure F-1: ARA Methodology Decision Flow Chart

As illustrated in **Figure 2-1** of the Guidance Document, the Consequences of Exposure (COE) answers Questions 3 and 4:

Table F-1: Consequences of Exposure – Answers to Questions 3 and 4 in Figure 2-1 of Guidance Document

Question	Response
3. What could potentially be exposed to the oil spill?	Two conditions must be met in order to answer Question 3 and proceed to Question 4: • A Risk Receptor must be present – Biological, Physical and/or Socio-Economic; and • Oil must be present.
4. How vulnerable are the Biophysical and Socio-Economic Environment to the oil spill? 	The COE Score reflects the presence and type of the following three categories of Risk Receptors – in essence, the sensitivity of the Risk Receptor to oil. **It does NOT reflect the level of impact to oil.** **Biological Sensitivities** - Refers to biological species at risk[1] and habitats that could be affected by an oil spill. If species specific data is available, it can be incorporated into the methodology. **Physical Environment** - Refers to the main physical attributes of the water surface, column and bottom including shoreline. **Socio-Economic Factors** - Refers to human-use resources like commercial fishing, First Nations, water usage, tourism and other important sites/activities in coastal communities.

The right side of the ARA BowTie (as presented in **Section 2.2** of the Guidance Document) highlights the three Risk Receptor categories and the specific Risk Receptor groups that are incorporated within the ARA Methodology (see **Figure F-2**).

[1] For a complete listing of Biological Sensitivities considered in this framework refer to **Table F-2** in **Appendix F**.

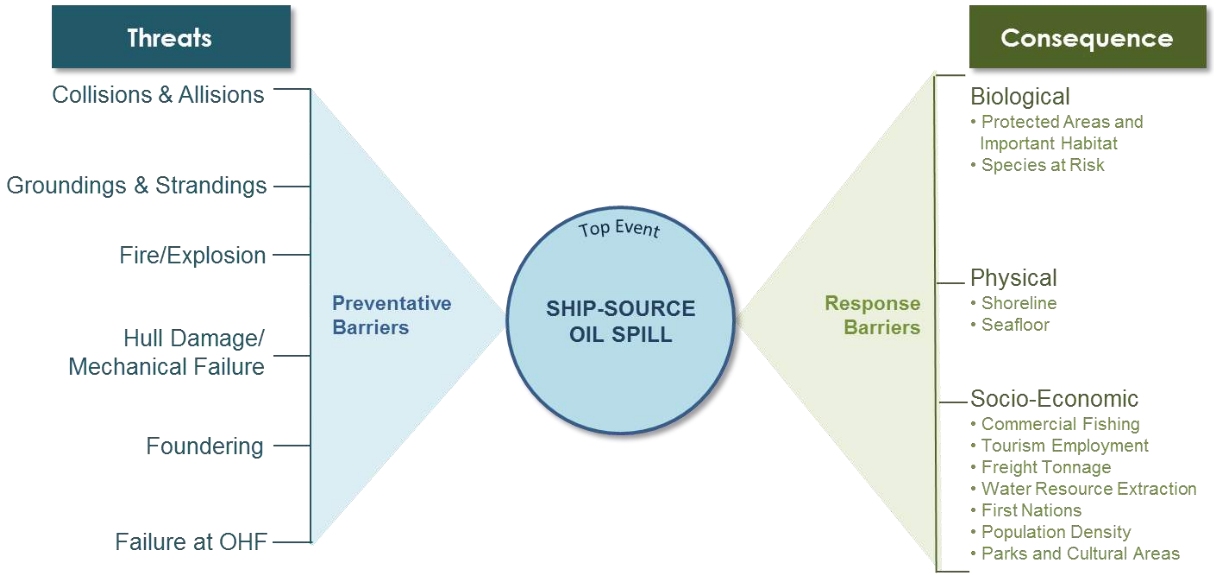

Figure F-2: Simplified ARA Bowtie with Specific Risk Receptor Groups

The ARA Methodology will determine the COE in both a horizontal (Grid Cell 'j') and vertical (Grid Layer 'k') perspective as illustrated in **Figure F-3**. The horizontal grid cells are selected to provide adequate spatial resolution for assessing the risk of oil spills and vertically there will be the following four grid layers where oil can manifest itself:

- Shoreline;
- Water Surface;
- Water Column; and
- Seafloor.

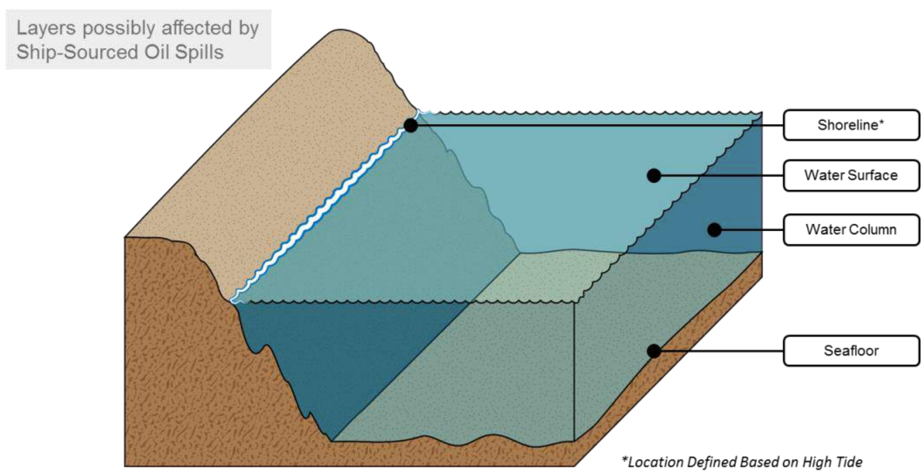

Figure F-3: Grid Layers that Compose a Grid Cell

If a specific Risk Receptor is deemed to be present within the corresponding grid layer of a grid cell, a COE Score is calculated. The COE Score reflects the presence and type of Risk Receptor within a specific grid layer – in essence, the sensitivity of the Risk Receptor to oil. **It does NOT reflect the level of impact to oil.**

The COE scoring scheme is based upon the principle of equal distribution of importance using a 5-step scale ranging from Very Low to Very High, which resulted in the generation of the COE scoring scheme presented in **Table F-2**.

Table F-2 : Consequence of Exposure (COE) Categories, Scoring, Description and Colour Code

COE Category	COE Score	Description	Colour Code
COE-5	16	Very High	
COE-4	8	High	
COE-3	4	Medium	
COE-2	2	Low	
COE-1	1	Very Low	

The scale of the COE Score equates to an equal distribution of importance. For example, as you go from COE-1 to COE-2 that translates to (2-1)/1 = 100% increase in importance. Similarly, as you go from COE-4 to COE-5 that translates to (16-8)/8 = 100% increase in importance.

Appendix F provides the technical details for the User to determine the COE as part of Phase 4 of the ARA Methodology. The following sections will discuss the Biological Sensitivities (**Section 2**), the Physical Environment (**Section 3**), and the Socio-Economic Factors (**Section 4**).

2.0 Biological Sensitivities

2.1 Overview

The methodology used to calculate the Protected Areas and Important Habitats and Species at Risk Score is described in the subsequent sections. The data sources for each of these biological Risk Receptors are found in the Data Standards and Management Document and a brief description of each is provided in **Table F-3**.

Table F-3: Species Groups and Sub-categories Selected for Use in the ARA Methodology

Risk Receptor (ESI)	Risk Receptor Sub-Category	Description
Biological	Protected Area and Important Habitats (PAIH)	Protected Areas – Provided by DFO and EC as well as a GIS layer obtained from World Database on Protected Areas. This includes areas protected by legislation (Legislated Protected Areas) and areas that have status through legislation or regulations (Status Areas). Important Habitats – Provided by DFO and EC as GIS polygons of critical habitat and important habitat. The multiple layers are then converted in GIS to the following classifications: Legislated Protected Areas and Habitats, Status Areas and Important Habitats.
	Species at Risk (SAR)	Species at Risk– Provided by DFO and EC. The multiple Species at Risk are provided in a GIS layer for a Study Area and are sorted into six Species Groups: Marine Mammals, Birds, Reptiles, Fish, Invertebrates and Marine Plants.

Each of the Environmental Sensitivities Risk Receptor sub-categories is given equal weighting in the calculation of the Risk Score for the Biological Sensitivities. The methodology used to calculate the Shoreline and Seafloor Scores is described in the subsequent sections.

2.2 Protected Areas and Important Habitats (COE_{PAIH})

The COE_{PAIH} is calculated based on the presence and type of a Protected Areas and Important Habitats within a specific grid cell. This means that, regardless of whether oil is present within one or in all four grid layers, the corresponding COE remains the same within a specific grid cell.

Three main protected areas and habitats that are considered in the COE_{PAIH} are 1) Legislated Protected Areas, 2) Status Areas and 3) Important Habitats. The sensitivity of a Protected Area or Important Habitat, if exposed to oil, will be a function of its designation (e.g. marine protected area, essential fish habitat).

The COE_{PAIH} for each Grid Cell 'j' will be calculated as follows:

$$COE_{PAIH,j} = \sum \left(\frac{Area_o}{Area_j}\right) PAIHS_o \times PW$$

Where:

$PAIH_o$	Protected Areas and Important Habitats Exposure Index for each Protected Area and Important Habitat Type 'o' in Grid Cell 'j'
$Area_o$	Area of Protected Area and Important Habitat Type 'o' in Grid Cell 'j'
$Area_j$	Total area of Grid Cell 'j'
PW	Factor to account for active (1) or inactive (0) exposure pathways

The types of Protected Areas and Important Habitat are based on the status of the Protected Area and are assigned a score ranging from 4 for Important Habitats to 16 for Legislated Protected Areas. It is important to note that the Protected Area or Important Habitat is designated in large part to their biological values (e.g. critical spawning habitats, important bird areas). The description of the Protected Areas and Important Habitat are presented in **Table F-4**.

Table F-4: Protected Areas and Important Habitat Exposure Index

Protected Areas and Important Habitats Type 'o'	Description	Exposure Index[2]
Legislated Protected Areas	Areas that are protected either by international, national or provincial laws and/or regulations. (e.g. Marine Protected Areas, SAR Critical Habitats, and Protected Areas)	16
Status Areas	Areas that have a status through regulations or laws but are not considered protected. (e.g. Important Bird Areas, Marine Important Areas, RAMSAR Wetlands)	8
Important Habitats	Habitats that have been identified as important to certain species or groups of species. (e.g. seal haul out areas, critical fish habitat, Ecological/Biological Significant Areas.)	4
Not Currently Defined[3]		2
		1

The last factor in the COE_{PAIH} Impact Score is the Pathway Factor (PW) that activates (1) or deactivates (0) the COE_{PAIH}. The pathway is only activated if the oil comes into contact with the Protected Area or

[2] The Exposure Index values correspond to the COE categories defined in **Table F-2**.

[3] As legislation and policies change that expand the definition of Protected Areas and Important Habitats, additional categories can be utilized within the ARA Methodology.

Important Habitat above the defined threshold on the water surface, water column, seafloor and shoreline Grid Layer 'k'.

2.3 Species at Risk (COE_{SAR})

Given the wide variety and importance of Species at Risk across Canada, it is critical that they be included in the COE calculation. This component only applies to the actual species as the species habitat is included in the COE_{PAIH}. A number of international studies (French et. al., 1996; SL Ross, 2007; Schmidt, 2009; WSP, 2013; DNV, 2001; Stevens and Aurand, 2008; Cole and Hasselström, 2013 DNV, 2010; DNV, 2011) and approaches to assess environmental sensitivities to oil spills were reviewed and considered for applicability in the ARA Methodology.

From the review of these studies, it was determined that the Species at Risk Score (COE_{SAR}) would be a simple score based on the status of any designated Species at Risk in Grid Cell 'j' and Grid Layer 'k' as stipulated in the Species at Risk Act (SARA, 2002). In order to provide a common method to classify the various Species at Risk they were broken down into six (6) Species Groups that were further sub-divided into specific Species Subgroups as presented in **Table F-5**.

Table F-5: Species Groups and Subgroups Selected for Use in the ARA Methodology

Risk Receptor (ESI)	Risk Receptor Sub-Category	Species Group 'y'		Species Subgroup 'x'
Biological	Species at Risk Score = Max of (COE_{SAR})	Marine Mammals (COE_{SAR_MMS})	= Max of	Whales ($COE_{SAR\_MMS\_Whales}$) Fur-Bearing Pinnipeds ($COE_{SAR\_MMS\_FBP}$) Other Pinnipeds ($COE_{SAR\_MMS\_OP}$) Other Fur Bearing Mammals ($COE_{SAR\_MMS\_OFM}$)
		Birds (COE_{SAR_BS})	= Max of	Waterfowl ($COE_{SAR\_BS\_WF}$) Seabirds – Aerial Divers ($COE_{SAR\_BS\_SAD}$) Seabirds – Surface Divers ($COE_{SAR\_BS\_SSD}$) Shorebirds/Wading Birds ($COE_{SAR\_BS\_SWB}$) Raptors ($COE_{SAR\_BS\_RAP}$)
		Reptile (COE_{SAR_RS})	= Max of	Turtles ($COE_{SAR\_RS\_TUR}$)
		Fish (COE_{SAR_FS})	= Max of	Pelagic ($COE_{SAR\_FS\_PEL}$) Demersal ($COE_{SAR\_FS\_DEM}$) Anadromous/Catadromous ($COE_{SAR\_FS\_AC}$) Sharks ($COESAR_{\_FS\_SHK}$)
		Invertebrates (COE_{SAR_IS})	= Max of	Benthic ($COE_{SAR\_IS\_BEN}$) Demersal ($COE_{SAR\_IS\_DEM}$) Sponges and Corals ($COE_{SAR\_IS\_SAC}$)
		Marine Plants (COE_{SAR_MPS})	= Max of	Seagrass ($COE_{SAR\_MPS\_SGR}$) Kelps ($COE_{SAR\_MPS\_KLP}$)

The definition of what is considered an endangered species, threatened species and species of concern is presented in **Table F-6**.

Table F-6: Species at Risk Designation

Species at Risk Designation	Description	Exposure Index[2]
Endangered Species	A wildlife species that is facing imminent extirpation or extinction (SARA, 2002).	16
Threatened Species	A wildlife species that is likely to become an endangered species if nothing is done to reverse the factors leading to its extirpation or extinction (SARA, 2002).	8
Species of Concern	A wildlife species that may become threatened or an endangered species because of a combination of biological characteristics and identified threats (SARA, 2002).	4
Species Vulnerable to Oiling	A wildlife species that does not meet any of the above three categories, but is present and vulnerable to impact from oiling.	2
Absence of Designated Species	Due to uncertainty in the presence/absence of species, there is potential for a species to be present and oiled.	1

Given that the Provinces and the Federal Government do not use the same SAR designations, a Federal/Provincial SAR Crosswalk is used and presented at the end of this Appendix. For the purpose of the analysis, any provincially designated SAR is converted to the Federal designation.

The COE_{SAR} is determined for Species Subgroup 'x' of Species Group 'y' based on the presence of a single status species, in any of the Species Subgroups, in Grid Cell 'j' and Grid Layer 'k' as outlined below:

$$COE_{SAR,x,y,j,k} = MAX(PES \times ESEI, PTS \times TSEI, PSC \times SCEI, PSV \times SVEI, ADS \times ADSEI)$$

Where:

PES Presence of Endangered Species. The factor is either a 0 or 1 depending on the presence of a single species.

PTS Presence of Threatened Species. The factor is either a 0 or 1 depending on the presence of a single species.

PSC Presence of Species of Concern. The factor is either a 0 or 1 depending on the presence of a single species.

PSV Presence of Species Vulnerable to Oiling. The factor is either a 0 or 1 depending on the presence of a single species.

ADS Absence of Designated Species. The factor is considered 1 only if the lack of a designated SAR cannot be explicitly verified.

EI Refers to Exposure Index.

MAX Returns the maximum value of the Endangered Species, Threatened Species, Species of Concern, Species Vulnerable to Oil or Absence of Designated Species. Therefore, in the event that a Species Subgroup has more than one category of Species at Risk, only the highest designation species will be scored.

The COE_{SAR} for each Species Group 'y' is the maximum score from each Species Subgroup 'x', as follows:

$$COE_{SAR,y,j,k} = MAX(COE_{SAR,x,y,j,k})$$

For example, COE_{SAR} for marine mammals within Grid Cell 'j' and Grid Layer 'k' would be calculated as:

$$COE_{SAR\_MMS,j,k} = MAX\ (COE_{SAR\_MMS\_Whales,j,k}, COE_{SAR\_MMS\_FBP,j,k}\ , COE_{SAR\_MMS\_OP,j,k}, COE_{SAR\_MMS\_OFM,j,k})$$

Finally, the COE_{SAR} for each Grid Cell 'j' and Grid Layer 'k' is calculated as the maximum score from each Species Group 'y', as follows:

$$COE_{SAR,k} = MAX(COE_{SAR\_MMS,j,k}, COE_{SAR\_BS,j,k}, COE_{SAR\_RS,j,k}\ , COE_{SAR\_FS,j,k}, COE_{SAR\_IS,j,k}, COE_{SAR\_MPS,j,k})$$

Where:

$COE_{SAR\_MMS,\ j,\ k}$	Marine Mammals Species Group Score in Grid Cell 'j' and Grid Layer 'k'
$COE_{SAR\_BS,\ j,\ k}$	Bird Species Group Score in Grid Cell 'j' and Grid Layer 'k'
$COE_{SAR\_RS,\ j,\ k}$	Reptile Species Group Score in Grid Cell 'j' and Grid Layer 'k'
$COE_{SAR\_FS,\ j,\ k}$	Fish Species Group Score in Grid Cell 'j' and Grid Layer 'k'
$COE_{SAR\_IS,\ j,\ k}$	Invertebrate Species Group Score in Grid Cell 'j' and Grid Layer 'k'
$COE_{SAR\_MPS,\ j,\ k}$	Marine Plant Species Group Score in Grid Cell 'j' and Grid Layer 'k'

3.0 Physical Environment

3.1 Overview

The COE for the Physical Environment (COE_{PE}) focuses on key physical attributes that if exposed to oil, would result in impacts that need to be taken into consideration. There are two mechanisms of oil that can impact the physical environment:

1. Oil washes up onto the shoreline; and
2. Oil sinks in the water column and accumulates along the seafloor.

Oil that impacts these features will translate to an associated impact that needs to be identified and quantified within the ARA Methodology.

Two main physical environment groups considered in the COE_{PE} are the 1) shoreline, and 2) seafloor. Each of these two physical groups is given equal weighting in the calculation of the Risk Score for the Physical Environment. The methodology used to calculate the Shoreline and Seafloor Scores is described in the subsequent sections. The data sources for each of these physical environments are found in the Data Standards and Management Document and a brief description of each is provided in **Table F-7**.

Table F-7: Physical Environment Groups

Risk Receptor (ESI)	Group	Description
Physical	Shoreline	EC Shoreline Classifications – Provided by EC's National Environmental Emergencies Centre. A GIS layer that divides the entire Canadian Coastline (south of 60° latitude) into eleven (11) shoreline types.
	Seafloor	Seafloor Substrate Layer – Provided by DFO. The multiple substrate types provided in a GIS layer for a Study Area is converted into three (3) seafloor types: soft bottom, mixed bottom and hard bottom.
	Combined Shoreline & Seafloor	There will be grid cells that contain both shoreline and seafloor that could be exposed to oil, which requires the Consequence of Exposure Score to be combined based on equal weighting between the two Risk Receptor sub-categories.

3.2 Shoreline ($COE_{Shoreline}$)

The COE for the shoreline ($COE_{Shoreline}$) is determined by the relative percentage of the Shoreline Score (SS) within a grid cell.

$$COE_{Shoreline,j} = \sum \left(\frac{LOS_m}{LOS_j}\right) SS_m$$

Where:

SS_m	Shoreline Score for shoreline type 'm' in Grid Cell 'j'
LOS_m	Length of shoreline type 'm' in Grid Cell 'j'
LOS_j	Total length of shoreline in Grid Cell 'j'

The SS for each shoreline type 'm' includes the Shoreline Classification Score, Shoreline Cleanup Method Sensitivity Modifier and the Exposure Pathway Function. Given the numerous factors that make up the $COE_{Shoreline}$ the score is normalized on a 1 to 16 scale prior to calculating the COE_{PE}.

The SS will be calculated for each shoreline segment as follows:

$$SS_m = (SCS_m \; x \; MF_{SCMS} \; x \; PW)$$

Where:

SCS	Shoreline Classification Score for each individual shoreline segment in a given Grid Cell
MF_{SCMS}	Modifier to account for sensitivity of the shoreline to various cleanup methods which is dependent upon the shoreline classification
PW	Factor to account for active (1) or inactive (0) exposure pathways

The Shoreline Classification Score (SCS) is determined by the eleven (11) Environment Canada Shoreline Types (Owens and Sergy, 2000; Wynja *et al*, 2015) and their sensitivity to oiling. The eleven (11) Shoreline Types and their associated SCS are presented in **Table F-8**.

Table F-8: Shoreline Types and Associated Classification Score

Shoreline Type 'm'	Description	Shoreline Classification Score
Bedrock Cliff/Vertical	Impermeable outcrops of native rock with slopes greater than 35°, regular exposure to high wave energy or tidal conditions, attached organisms are hardy and accustomed to wave energy.	1
Man-Made Solid	Anthropogenic structures composed of impermeable materials. Include docks, wharves, breakwaters and seawalls. Habitat is not as rich as bedrock shores given the steep vertical nature of the structures.	2
Bedrock Platform	Impermeable outcrops of native rock with nearly horizontal platforms with slope of less than 5°.	4
Bedrock Sloping/Ramp	Impermeable outcrops of native rock with ramp slopes from 5° to 35°. Generally, provides good habitat for algae and attached organisms.	8
Man-Made Permeable	Anthropogenic structures composed of permeable materials. Include docks, wharves, breakwaters and seawalls. Habitat is not as rich as bedrock shores given the steep vertical nature of the structures.	16
Not Classified	Shoreline has not been classified so it is scored in the mid-range of the Shoreline Classification Score.	32

Shoreline Type 'm'	Description	Shoreline Classification Score
Mixed and Coarse Sediment Tidal Flat	Dominant geological material is coarse sediment including pebbles and/or cobbles. Pebbles have diameter of 4-64 mm while cobbles have diameter of 65-256 mm. Permeable to all but heavy sinkers and have mobile surface layers. Supports little habitat due to constant reworking of the geology.	32
Mixed Sediment Beach or Bank	Composed of sands, granules, pebbles, cobbles and boulders. Supports little habitat in exposed shorelines due to wave energy. Habitat can be more prevalent in sheltered waters.	64
Sand Beach or Bank	Beach is composed of sand with a grain-size diameter of 0.0625 to 2.0 mm. Beaches may also contain small amounts of granules, pebbles and cobbles. Permeable for medium evaporator and medium floater. Have a very dynamic, mobile and unstable surface layer of sand. Presents very little habitat due to the unstable environment.	128
Sand Tidal Flat	Wide flat surface (slope less than 5^{o}) with the dominant substrate being sand. Permeable for medium evaporator and medium floater. Generally present in sheltered areas and provide important habitats, especially to birds.	256
Mud Tidal Flat	Wide flat surface (slope less than 5^{o}) with the dominant substrate being silt and clay (grain-size less than 0.0625 mm). Can include organic detritus and small amounts of sand. Water saturated and not permeable to oil. Generally present in sheltered areas and provide important habitats, especially to birds. Very productive biological habitats contain many different organisms at varying trophic levels.	512
Marsh	Shoreline periodically or permanently under water, and has strong presence of vegetation. Permeable for medium evaporator oils. Extremely productive habitats in terms of plants, small organisms and birds.	1,024

The SCS is based on the principle of equal distribution of importance, starting with the Bedrock Cliff/Vertical having the lowest sensitivity to oil exposure – with a corresponding SCS of “1”. The doubling of the SCS results in the shoreline type Marsh having the highest SCS of “1,024”.

The SCS was determined based on each individual shoreline type’s geology, exposure to wave and tidal energy, slope, substrate permeability for oil penetration and burial and biological productivity and sensitivity (NOAA, 2002; NOAA, 2013a; Genivar, 2013). The shoreline types are provided in a GIS layer to the User from Environment Canada’s National Environmental Emergencies Centre.

The Shoreline Cleanup Method Sensitivity Modifier (MF_{SCMS}) accounts for the impact that shoreline cleanup methods have on the various shoreline types and types of oil. The Shoreline Cleanup Sensitivity Score evaluates the environmental damage the shoreline cleanup techniques could have (e.g. difference between natural recovery through to steam cleaning) on the shoreline and biological receptors known to be present on the shoreline considering the five (5) oil types (Owens, 1998 and NOAA, 2013b). The Shoreline Cleanup Sensitivity Score includes the generally accepted shoreline cleanup techniques recommended by Environment Canada (Owens, 1998).

The MF_{SCMS} is selected from the matrix, presented in **Annex F-1** based on the eleven (11) types of shorelines and the five (5) oil categories. The matrix will not be used to select a shoreline cleanup method as that is beyond the scope of the ARA Methodology, but will instead be used as a surrogate to evaluate the potential environmental impact shoreline cleaning could have on specific shoreline types.

The matrix evaluates the environmental impact of the cleanup technique on the shoreline and classifies it into the five (5) categories presented in **Table F-9**. Each of the five (5) categories is assigned a numeric weighting value between 1 and 16. The numeric weighting value is summed for each shoreline and oil category and then normalized to yield a MF_{SCMS} for each shoreline and oil type.. The shoreline cleanup environmental impact score matrix is presented in **Annex F-2** of this Appendix.

Table F-9: Numeric Weighting Value based on Environmental Impact of Shoreline Cleanup Methodology

Environmental Impact Category	Description	Exposure Index[2]
A	The least adverse habitat impact	1
B	Some adverse habitat impact	2
C	Significant adverse habitat impact	8
D	The most adverse habitat impact	16
I	Insufficient information – impact or effectiveness is not known	4

The last factor in the COE for the shoreline ($COE_{Shoreline}$) is the Pathway Factor (PW) that activates or deactivates the COE using a 1 or 0 respectively. The pathway is only activated if the segment of the shoreline Grid Layer is oiled above the defined threshold. If oil on the shoreline grid layer doesn't exceed the threshold then the pathway remains inactive and a value of 0 is used.

3.3 Seafloor ($COE_{Seafloor}$)

The COE for the seafloor ($COE_{Seafloor}$) is a function of the sensitivity of the seafloor to the type of oil based on the geological and potential biological productivity characteristics of the seafloor (Reich *et. al.,* 2014) grouped into the following three (3) categories:

1. Hard Bottom - Areas that are predominated by hard substrates that include: continuous and discontinuous bedrock and boulders.
2. Mixed Bottom - Areas that have a mixture of hard and soft substrate and include: gravels, mixed sediment and, sand and gravel.
3. Soft Bottom - Areas that are predominated by soft substrates including: muds, sand, and mud and sand.

The $COE_{Seafloor}$ for each Grid Cell 'j' will be calculated as follows:

$$COE_{Seafloor\_j} = \sum \left(\frac{Area_n}{Area_j} \right) SFEI_n \times PW$$

Where:

$SFEI_n$	Seafloor Exposure Index for seafloor type 'n' in Grid Cell 'j'
$Area_n$	Area of seafloor type 'n' in Grid Cell 'j'
$Area_j$	Total area of Grid Cell 'j'
PW	Factor to account for active (1) or inactive (0) exposure pathways

The Seafloor Exposure Index (SFEI) for each type of seafloor was determined based on the substrate type, its sensitivity to oiling and its biological productivity, ranked from 1 to 16, with 1 being the least sensitive and 16 being the most sensitive to oil (see **Table F-10**).

Table F-10: Seafloor Exposure Index

Seafloor Type 'n'	Description	Exposure Index[2]
Hard Bottom	Continuous and discontinuous bedrock and boulders	1
Mixed Bottom	Gravels, mixed sediment and, sand and gravel	4
Soft Bottom	Muds, sand, and mud and sand	16

The last factor in the $COE_{Seafloor}$ is the Pathway Factor (PW) that activates (1) or deactivates (0) the COE. The pathway is only activated if the seafloor area comes into contact with oil above the defined threshold in the seafloor grid layer.

4.0 Socio-Economic Factors

4.1 Overview

Socio-economic value relates to human-use of resources for social and economic benefits. Assessing the socio-economic impact of a ship-source oil spill within a Study Area is a complex task for which no simple indicator exists (WSP, 2013). Furthermore, available data further limits the ability to accurately measure socio-economic impacts. The ARA Methodology builds on work done by others in Canada, which adapted earlier work done for Australia (DNV, 2011) with modifications to reflect the Canadian economy (WSP, 2013).

The ARA Methodology builds on previous Canadian assessments (WSP, 2013; WSP, 2014) by adding an indicator for the presence of First Nations land and communities and by adding a factor to account for population density in the vicinity of the shoreline. Additionally, the freshwater use intensity factor is replaced by a water resource extraction indicator to account for presence of infrastructure that relies on extraction of either saltwater or freshwater.

In total, there are seven (7) sub-categories of Socio-Economic Factors Risk Receptors, as shown in **Table F-11** with further details provided in the subsequent sections.

Table F-11: ARA Methodology Socio-Economic Factors Risk Receptor Sub-Categories

Socio-Economic Factors	
There are seven sub-categories to the Socio-Economic Risk Receptor, which requires the Consequence of Exposure Score within a specific grid cell to be combined based on equal weighting.	• Commercial Fishing Intensity; • Tourism Employment Intensity; • Freight Tonnage Index; • Water Resource Extraction Indicator; • First Nations; • Population Density Indicator; and • Parks and Cultural Areas Indicator.

The COE for the Socio-Economic Factors (COE_{SEF}) is calculated based on the presence and type of each of the seven (7) Risk Receptor sub-categories within a specific grid cell. This means that, regardless of whether oil is present within one or in all four grid layers, the corresponding COE value for each Risk Receptor sub-category remains the same within a specific grid cell.

4.2 Commercial Fishing Intensity (CFI)

The Commercial Fishing Intensity indicator (CFI) represents the socio-economic value of commercial fishing in the Study Area. The commercial fishing component will vary depending on the region and the data which is available in that region. Available data on seaweed harvesting and First Nations commercial fisheries is also included in this metric. Data sources include DFO and Provincial Governmental departments.

Commercial fishing is examined using one of the data sets outlined in **Table F-12** in order of preference from top to bottom (top being the highest value data), so the User can select the specific method to suit the data set that is available in the specific Study Area.

Table F-12: Commercial Fishing Intensity Scoring Methods

Data Set and Input	Justification of Hierarchy
Catch Totals per Grid Cell 'j'	Data will allow for specific locations and abundance figures for regions and therefore is the most accurate data available.
Commercial Monetary Value per Grid Cell 'j'	Data is not as accurate as catch totals per unit area but provides the next best data set which is commercial value per unit area.
Commercial Monetary Fishing Port Value	Data is based on ports and therefore does not encompass a specific unit area. It is not as accurate as the two data sets mentioned above.
Known Port in Study Area	Data is based on local knowledge and should only be used when the other data sets are unavailable or incomplete.

Each of the data sets for each Study Area will be scored using the natural break (Jenks function) of ArcGIS. The natural break function divides the data set into five (5) groups that are based on natural grouping of the data as shown in **Table F-13**.

Table F-13: Commercial Fishing Intensity (CFI) Categories, Scoring, Description, Definition and Colour Code

CFI Category	CFI Score	Description	Definition (based on Total Catch per grid cell in Study Area)	Colour Code
CFI – 5	16	Very High	Highest Catch Total within a Grid Cell	
CFI – 4	8	High	Calculated using Natural Break	
CFI – 3	4	Medium		
CFI – 2	2	Low		
CFI – 1	1	Very Low	Lowest Catch Total within a Grid Cell	

The breaks are developed that best group similar values together and maximize the differences between the groups (de Smith et. al., 2015). Therefore, grid cells that report the largest catch totals or largest monetary value caught will be scored higher than grid cells that report the lowest catch totals by weight or monetary value. The natural break function was used as it allows the User to easily observe the fishing locations in each Study Area that have the most harvesting.

4.3 Tourism Employment Intensity (TEI)

As in the WSP (2013) methodology, the relative importance of tourism in each Study Area is a ratio of tourism industry employment, compared to total employment. Data is obtained from Statistics Canada's most recent (2011) National Household Survey and from Environics for 2015 at the dissemination geographic level. Dissemination area polygons are selected that fall along the coast of the particular Study Area. Although dissemination areas can go far inland in rural areas, it is not expected to skew the data as previous studies have shown that rural areas as a whole tend to have relatively the same total of tourism employment as urban areas (Statistics Canada, 2005). Where more than one dissemination area abuts the shoreline, a weighted average is used for the Study Area.

Accommodation and food services employment data are used as a proxy for overall tourism employment data. The Tourism Employment Intensity (TEI) indirectly accounts for tourism industry activities for which data is insufficient or inconsistent, such as marine tourism (e.g. whale watching), recreational land use (e.g. beaches, surfing), and passenger vessel traffic. National parks and other tourist landmarks are also indirectly accounted for since they impact overall tourism employment in the surrounding areas. This approach allows for a consistent, repeatable method for determining the relative importance of tourism related activities in the Study Area.

The calculation of the TEI for each Grid Cell 'j' commences by determining which distance zone each grid cell sits in. This distance zone is used to determine which dissemination areas are used when calculating the tourism industry employment and total employment for each grid cell. The whale watching layer acts as an override for the Distance Modifier (MF_{TEI}) and considers all whale watching areas to be in the "Coastal Zone" regardless of their actual distance from shore. The TEI is then calculated as follows:

$$TEI_j = \left(\frac{\sum Tourism\ Industry\ Employment\ in\ each\ dissemination\ area}{\sum Total\ Employment\ in\ each\ dissemination\ area}\right) \times MF_{TEI} \times PW$$

Where:

MF_{TEI} Distance Modifier to account for the impacts oil could have on tourism based on the distance from the shoreline and whale watching areas

The Distance Modifier (MF_{TEI}) will factor in the distance from the shoreline as a decreasing factor, specifically:

- Coastal zone / Whale Watching Areas = 1.0
- Meso zone = 0.8
- Nearshore zone = 0.5
- Intermediate zone = 0.2
- Deep-sea zone = 0.05

The results of the TEI is a score that varies from 0 (no tourism present or no oil present) to a maximum value of 1 (100% tourism employment in grid cell). However, the maximum value is predominately less than 1, as tourism is generally not 100% of the employment in a dissemination area. The account for this, the TEI is normalized on a 1 to 16 scale using five (5) equally distributed breaks from zero to the maximum score for each Study Area. An example of the scoring for the Southern Portion Study Area is presented in **Table F-14**.

Table F-14: Tourism Employment Intensity (TEI) Categories, Scoring, Description, Definition and Colour Code

TEI Category	TEI Score	Description	Definition[1] (contribution of tourism to total employment within Study Area)	Colour Code
TEI – 5	16	Very High	0.12241 – 0.15300	
TEI – 4	8	High	0.09181 – 0.12240	
TEI – 3	4	Medium	0.061121 – 0.09180	
TEI – 2	2	Low	0.03061– 0.061120	
TEI – 1	1	Very Low	0.00 – 0.03060	

Note: 1) Results from the Southern Portion of British Columbia Study Area

4.4 Freight Tonnage Index (FTI)

Port industry activity is scored if there is a designated port as defined under the *Canadian Marine Act* (1998) present in the Study Area. The Freight Tonnage Index (FTI) is based on the presence of oil in a designated port as presented in **Table F-15**.

Table F-15: Freight Tonnage Index Values

Location	Description	FTI
Port	Grid Cells that are located in the defined boundaries of a Canada Port Authority defined in the *Canadian Marine Act*, 1998.	16
Open Water	Areas that are not federally regulated ports.	0

4.5 Water Resource Extraction Indicator (WREI)

The Water Resource Extraction Indicator (WREI) accounts for the presence of saltwater and freshwater intakes within a Study Area used for: drinking water, power generation plant cooling, fish processing plants, aquariums, aquaculture sites and lobster/crab holding facilities. In the event of an oil spill, usage would be suspended, resulting in an associated economic impact. The presence of intakes in the Study Area was determined from area mapping, local knowledge and provincial operating approvals.

The score is based on the presence of oil near water resource extraction infrastructure. WREI is calculated per Grid Cell 'j' as follows:

$$WREI_j = (P_{WREI} \times MF_{WREI} \times PW)$$

Where:

- P_{WREI} Factor to account for presence of water resource extraction site in Grid Cell 'j' (1) or not present (0)
- MF_{WREI} Distance Modifier to account for the impacts oil could have on the extraction of water based on the distance from the point of extraction
- PW Factor to account for presence of oil (1) or no oil (0) in Grid Cell 'j'

The Distance Modifier goes out to 8 nm from the identified grid cell with the water resource extraction site. The Water Resource Extraction Distance Modifiers used for the ARA Methodology are:

- 0-4 nm from intake = 16
- 4-8 nm from intake = 4
- > 8 nm from intake = 0

4.6 First Nations Indicator (FNI)

The First Nations Indicator (FNI) accounts for the presence of First Nations communities and important First Nations cultural sites being present along the shoreline. The presence of First Nations resources in the Study Area is determined from area mapping, as well as provincial sources. The FNI is calculated per Grid Cell 'j' as follows:

$$FNI_j = (P_{FNI} \times MF_{FNI} \times PW)$$

Where:

P_{FNI}	Factor to account for the presence of First Nations in Grid Cell 'j' (1) or not present (0)
MF_{FNI}	Distance Modifier to account for the impacts oil could have on the First Nations
PW	Factor to account for presence of oil (1) or no oil (0) in Grid Cell 'j'

The Distance Modifier goes out to 8 nm from the identified grid cell with the First Nations community. The First Nations Distance Modifiers used for the ARA Methodology are:

- 0-4 nm from First Nation = 16
- 4-8 nm from First Nation = 4
- > 8 nm from First Nation = 0

4.7 Population Density Indicator (PDI)

Population Density Indicator (PDI) accounts for the correlation between risk and the level of scrutiny that the public pays to an oil spill. To take this into consideration, each grid cell is assigned a distance zone value (8 nm). This distance zone is used to aggregate the population statistics for all dissemination areas that are within that distance zone to calculate population density for each grid cell. Population density is used as a proxy to measure the level of public scrutiny.

Specifically, the PDI uses the population density per dissemination area obtained from Statistics Canada and Environics in the Study Area. Each grid cell is then assigned a value from 1 to 5 based on the grid cell's population density compared to a natural break population density of the Study Area. The natural break tries to maximize the difference between the five (5) groups while attempting to distribute the values equally across the five (5) values. The PDI is calculated per Grid Cell 'j' as follows:

$$PDI_j = (PD_{PDI} \times MF_{PDI} \times PW)$$

Where:

PD_{PDI}	Value to account for population density in Grid Cell 'j'
MF_{PDI}	Distance Modifier to account for the decrease impact from shoreline
PW	Factor to account for presence of oil (1) or no oil (0) in Grid Cell 'j'

The Distance Modifier goes out to 8 nm from the identified Grid Cell 'j'. The Population Density Distance Modifiers used for the ARA Methodology are:

- 0-4 nm from Grid Cell, 'j' = 1.0
- 4-8 nm from Grid Cell, 'j' = 0.5
- > 8 nm from Grid Cell, 'j' = 0.0

The results of the PDI is a score that varies from 0 (no human population within the dissemination area) to a maximum value based on the Study Area. The maximum value varies from each Study Area based on the population density in the Study Area. The PDI is then normalized from 1 to 16 based on an ARCGIS natural break calculation for the data range in each Study Area.

An example of the values for each break in the Southern Portion of British Columbia Study Area can be seen below in **Table F-16**. A key attribute of the PDI is that it is a Study Area comparison; it identifies the high population density and low population density areas within each Study Area. It does not compare the population density of the Study Area to national levels.

Table F-16: Population Density Intensity (PDI) Categories, Scoring, Description, Definition and Colour Code

PDI Category	PDI Score	Description	Definition[1] (Total Population Per Dissemination Area)	Colour Code
PDI – 5	16	Very High	2089.447 – 3655.302	
PDI – 4	8	High	1191.970 – 2089.446	
PDI – 3	4	Medium	552.854 – 1191.969	
PDI – 2	2	Low	158.117 – 552.853	
PDI – 1	1	Very Low	0.00 – 158.116	

Note: 1) Results from the Southern Portion of British Columbia Study Area

4.8 Parks and Cultural Areas Indicator (PCAI)

The Parks and Cultural Areas Indicator (PCAI) accounts for the presence of National, Provincial and Municipal Parks as well as important cultural areas along the shoreline. The presence of parks and important cultural areas in the Study Area is determined from area mapping, as well as Provincial sources. The PCAI is calculated per Grid Cell 'j' as follows:

$$PCAI_j = (P_{PCAI} \times MF_{PCAI} \times PW)$$

Where:

P_{PCAI}	Factor to account for the presence of a park or cultural area in Grid Cell 'j' (1) or not present (0)
MF_{PCAI}	Distance Modifier to account for the impacts oil could have on the parks and cultural areas
PW	Factor to account for presence of oil (1) or no oil (0) in Grid Cell 'j'

The Distance Modifier goes out to 8 nm from the identified grid cell with the park or cultural area. The Parks and Cultural Areas Distance Modifiers used for the ARA Methodology are:

- 0-4 nm from park or cultural area = 16
- 4-8 nm from park or cultural area = 4
- > 8 nm from park or cultural area = 0

5.0 References

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Annex F-1

Shoreline Cleanup Method Sensitivity Modifier (MFSCMS)

Transport Canada
Area Risk Assessment Methodology Development for Ship-Source Oil Spills in Canadian Waters
March 2017

DILLON CONSULTING

Annex F-1: Shoreline Cleanup Method Sensitivity Modifier (MF_{SCMS})

Final Version 1.0 - Dated August 2, 2016

		Natural Recovery	Barriers/Berms	Manual Oil Removal	Mechanical Oil Removal	Passive Sorbents	Vacuums	Debris Removal	Mechanical Tilling/Aeration	Vegetation Removal	Flooding	Low-Pressure, Cold Water Wash	High-Pressure, Cold Water Wash	Low-Pressure, Warm/Hot Water Wash	High-Pressure, Warm/Hot Water Wash	Steam Cleaning	Sand Blasting	Solidifiers	Shoreline Cleaners	Nutrient Enrichment	Bioremediation (Natural Microbe Seeding)	In-situ Burning	Shoreline Cleanup Method Sensitivity Modifier
Bedrock Cliff/Vertical	Light Evaporators	A																					1.00
	Medium Evaporators	A				B	A					A	B										1.40
	Medium Floaters	A		B		A	A			C		A	B	C	C	D	D		C				6.00
	Heavy Floaters	A		B		A	A			C		B	B	C	C	D	D		C				6.08
	Heavy Sinkers			B		A	A			C		B	B	C	C		D		C				5.60
Man-made Solid	Light Evaporators	A																					1.00
	Medium Evaporators	A				B						A	B										1.50
	Medium Floaters	A		B		A				B		A	B	C	C	D	D		B				5.36
	Heavy Floaters	A		B		A				B		B	B	C	C	D	D		B				5.45
	Heavy Sinkers	A		B		A				B		B	B	C	C	D	D		B				5.45
Bedrock Platform	Light Evaporators	A																					1.00
	Medium Evaporators	A		B		B	A	A			A	A	B	D	D			C		I		D	5.46
	Medium Floaters	A		B		A	A	A		C	A	A	B	C	C	D	D	C	C	I		D	6.00
	Heavy Floaters	A		B		A	A	A		C	B	B	B	C	C	D	D		C	I		D	6.00
	Heavy Sinkers	A		B		A	A	A		C	B	B	B	C	C	D	D		C	I			5.33
Bedrock Sloping/ramp	Light Evaporators	A																					1.00
	Medium Evaporators	A				B	A	A			A	A	B	D	D			C		I		D	5.75
	Medium Floaters	A		B		A	A	A		C	A	A	B	C	C	D	D	C	C	I		D	6.00
	Heavy Floaters	A		B		A	A	A		C	B	B	B	C	C	D	D		C	I		D	6.00
	Heavy Sinkers			B		A	A	A		C	B	B	B	C	C	D	D		C	I			5.64
Boulder Beaches or Bank	Light Evaporators	A									A	A	A										1.00
	Medium Evaporators	A		A		A		A		C	A	A	A	C	C			B		A	I		2.92
	Medium Floaters	B		A	C	A	A	A		C	B	B	B	C	C	D	D	B	B	A	I	D	5.32
	Heavy Floaters	B		A	C	B	A	A		B	C	C	B	C	C	D	D		B	B	I	D	5.94
	Heavy Sinkers	B		A	C	B	A	A		B	C	C	C	C	C	D	D		B	B	I		5.71
Pebble-cobble Beach or Bank	Light Evaporators	A		D	D				D		A	A											8.50
	Medium Evaporators	A	B	C	D	A		A	B	D	A	A								A	I		4.50
	Medium Floaters	B	B	B	C	A	B	A	B	C	B	A	B	C	C	D		B	B	A	I	C	4.10
	Heavy Floaters	B	B	B	C	B	B	A	B	C	C	B	B	B	C	D			B	A	I	C	4.32
	Heavy Sinkers	B	B	A	C	B	B	A	B		C	C	B	B	C	D			B	A	I	C	4.39
Mixed Sediment Beach or Bank	Light Evaporators	A	C	D	D				D		A	B											8.57
	Medium Evaporators	B	C	C	C	A		A	B	C	A	A								A	I		3.75
	Medium Floaters	B	C	B	B	A	B	A	B	C	B	A	C	C	D	D		B	C	A	I	C	5.10
	Heavy Floaters	C	B	B	B	B	B	A	B	C	C	B	D	C	D	D			C	B	I	C	6.16
	Heavy Sinkers		B	B	B	B	B	A	B	C	C	C	D	C	D	D			C	C	I	C	6.72
Sand Beach or Bank	Light Evaporators	A	B	D	D				D		A	B											7.71
	Medium Evaporators	B	B	B	B	B		A	B	C	A	B								A	I		2.42
	Medium Floaters	B	B	A	B	A	B	A	B	C	A	B		C				B	C	A	I	C	3.24
	Heavy Floaters	C	B	A	B	A	A	A	B	C	B	B		C					C	B	I	C	3.75
	Heavy Sinkers	C	B	A	B	B	A		B	C	C	C		C					C	B	I	C	4.80
Sand Tidal Flat	Light Evaporators	A	B																		I		2.33
	Medium Evaporators	A	B	C	D	A	C	B		D	A	B						C		C	I		5.92
	Medium Floaters	A	B	B	C	A	B	B	C	D	A	B						C		C	I		4.64
	Heavy Floaters	A	B	B	C	A	B	B	C	D	A	C								I	I		4.54
	Heavy Sinkers	A	B	B	C	A	B	B	C	D	A	C								I	I		4.54
Mud Tidal Flat	Light Evaporators	A	B																		I		2.33
	Medium Evaporators	A	B	C	D	A	C	B		D	A	B						C		C	I		5.92
	Medium Floaters	A	B	B	C	A	B	B	C	D	A	B						C		C	I		4.64
	Heavy Floaters	A	B	B	C	A	B	B	C	D	A	C								I	I		4.54
	Heavy Sinkers	A	B	B	C	A	B	B	C	D	A	C								I	I		4.54
Marsh	Light Evaporators	A	B	D	D				D	D	B	B									I		8.33
	Medium Evaporators	A	B	D	D	A	B	B	D	D	B	B						C		A	I	B	6.07
	Medium Floaters	B	B	C	D	A	B	B	D	C	B	B						C	B	B	I	B	4.94
	Heavy Floaters	B	B	C	D	A	B	B	D	C	B	B							B	B	I	B	4.73
	Heavy Sinkers	B	B	C	D	B	B	B	D	C	B	B							I	B	I	C	5.33

A = The least adverse habitat impact	A =	1
B = Some adverse habitat impact.	B =	2
C = Significatn adverse habitat impact.	C =	8
D = The most adverse habitat impact.	D =	16
I - Insufficient information - impact or effectiveness is not known.	I =	4
blank = not applicable	Blank =	0

Annex F-2

Federal and Provincial Species at Risk Crosswalk

Transport Canada
Area Risk Assessment Methodology Development for Ship-Source Oil Spills in Canadian Waters
March 2017

DILLON CONSULTING

Annex F-2: Federal and Provincial Species at Risk Crosswalk

Federal	COSEWIC	NB/PEI/ON	NS	NF	QC	MB	SK	AB	BC
Endangered	Endangered	Endangered	Endangered	Endangered		Endangered	Endangered	Endangered	Endangered
Threatened	Threatened	Threatened	Threatened	Threatened	Threatened	Threatened	Threatened	Threatened	Threatened
Special Concern	Special Concern	Special Concern	Vulnerable	Vulnerable	Vulnerable		Vulnerable	Special Concern	
No Status	Not at Risk / Data Deficient								