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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.

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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:

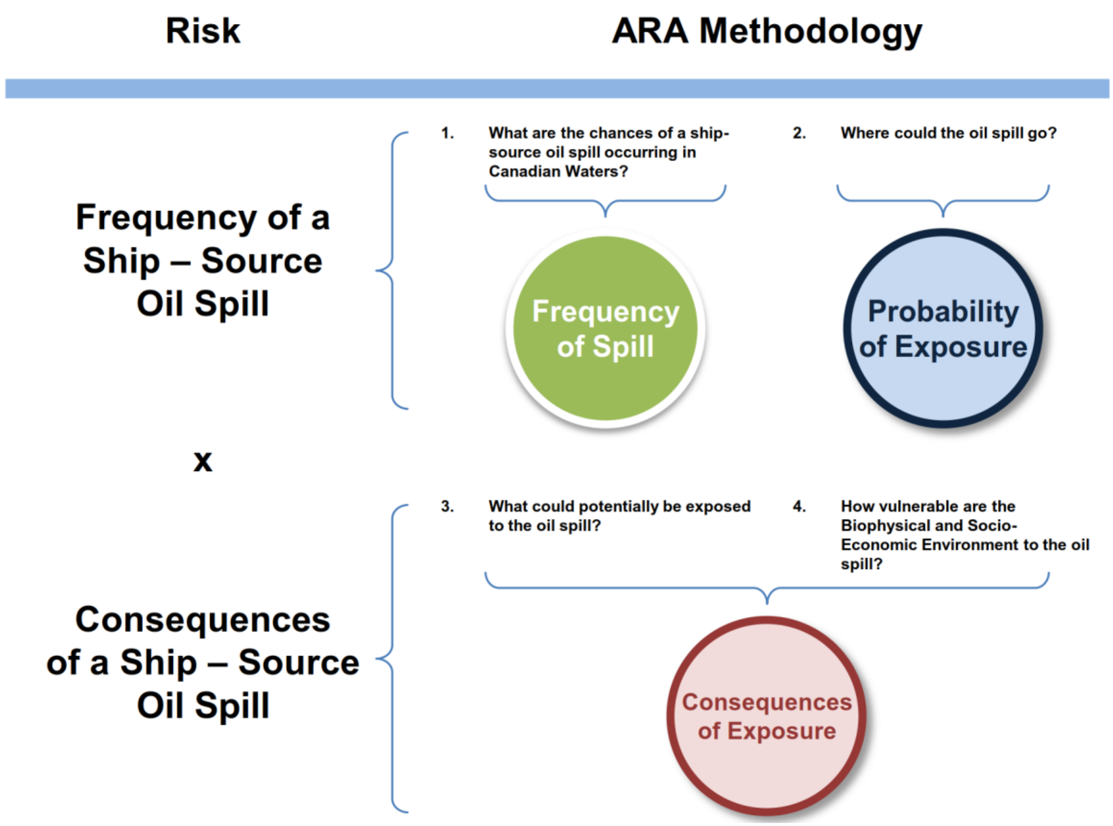

Figure 2-1: How the ARA Methodology Defines Risk

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**).

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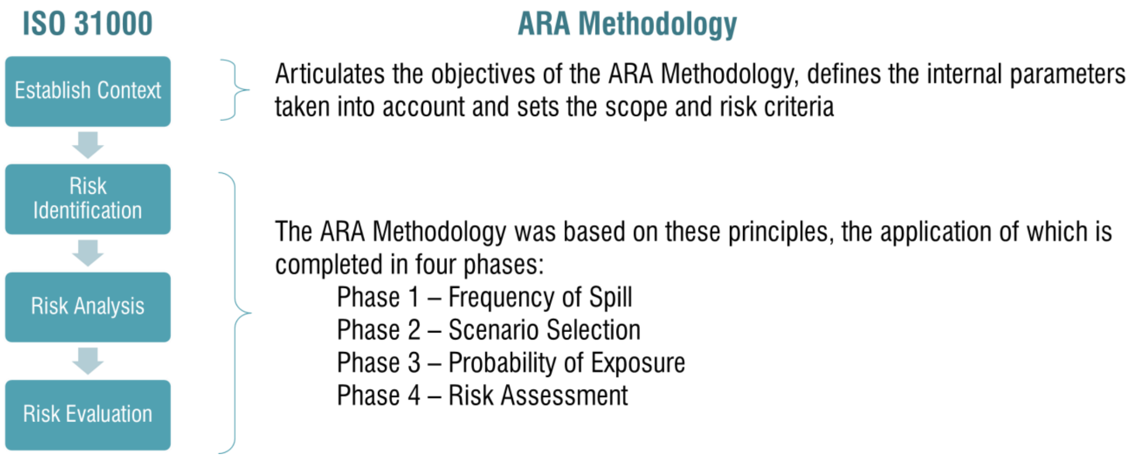


Figure 2-2: ARA Methodology – Principles Based on CAN/CSA-ISO 31000-10

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**.

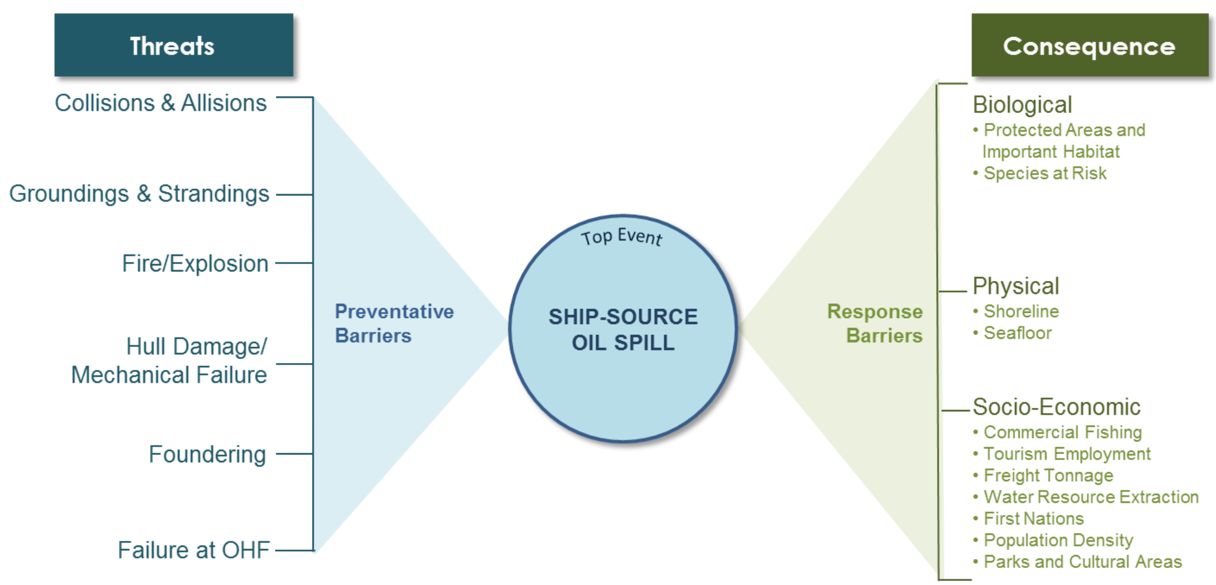


Figure 2-3: Simplified ARA BowTie Diagram

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

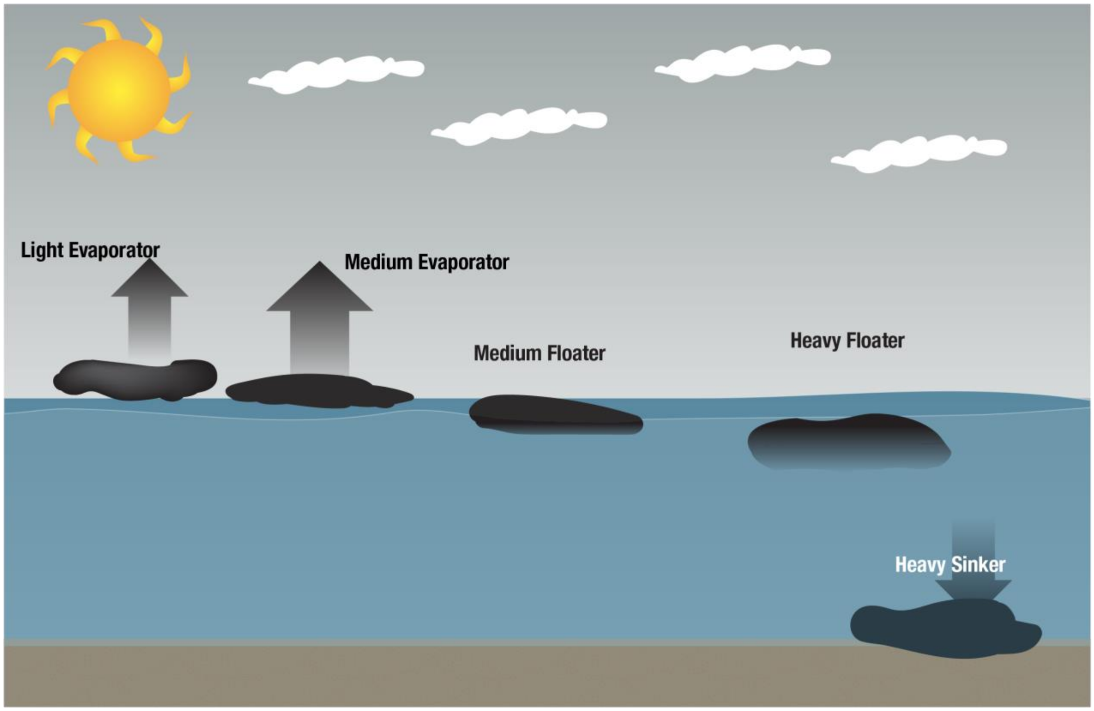


Figure 2-4: Oil Categories Included in ARA Methodology

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.

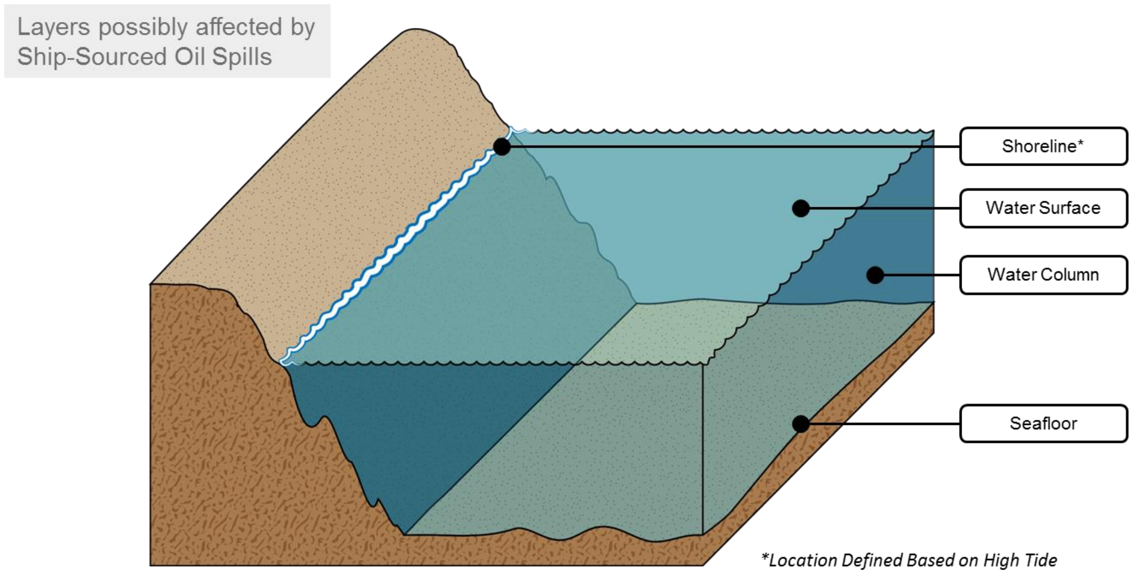


Figure 2-5: Grid Layers That Compose a Grid Cell

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.

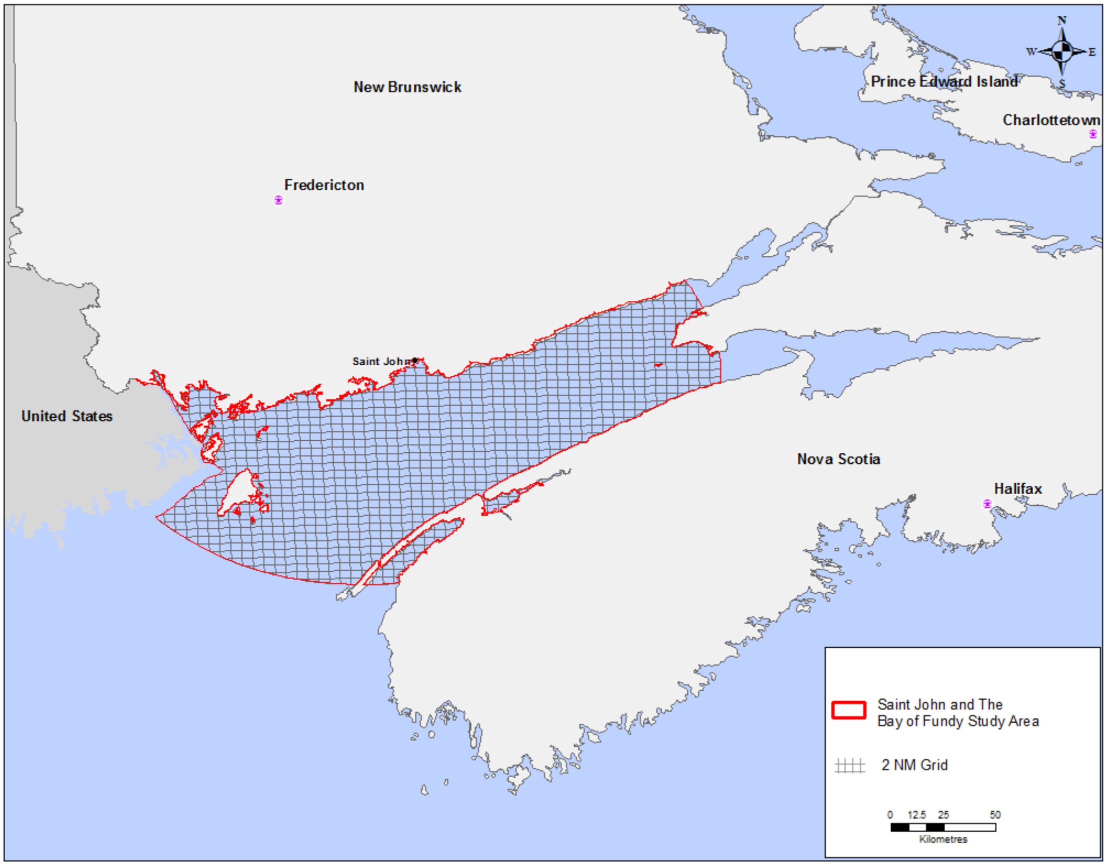


Figure 2-6: Bay of Fundy Grid Cell Map

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.

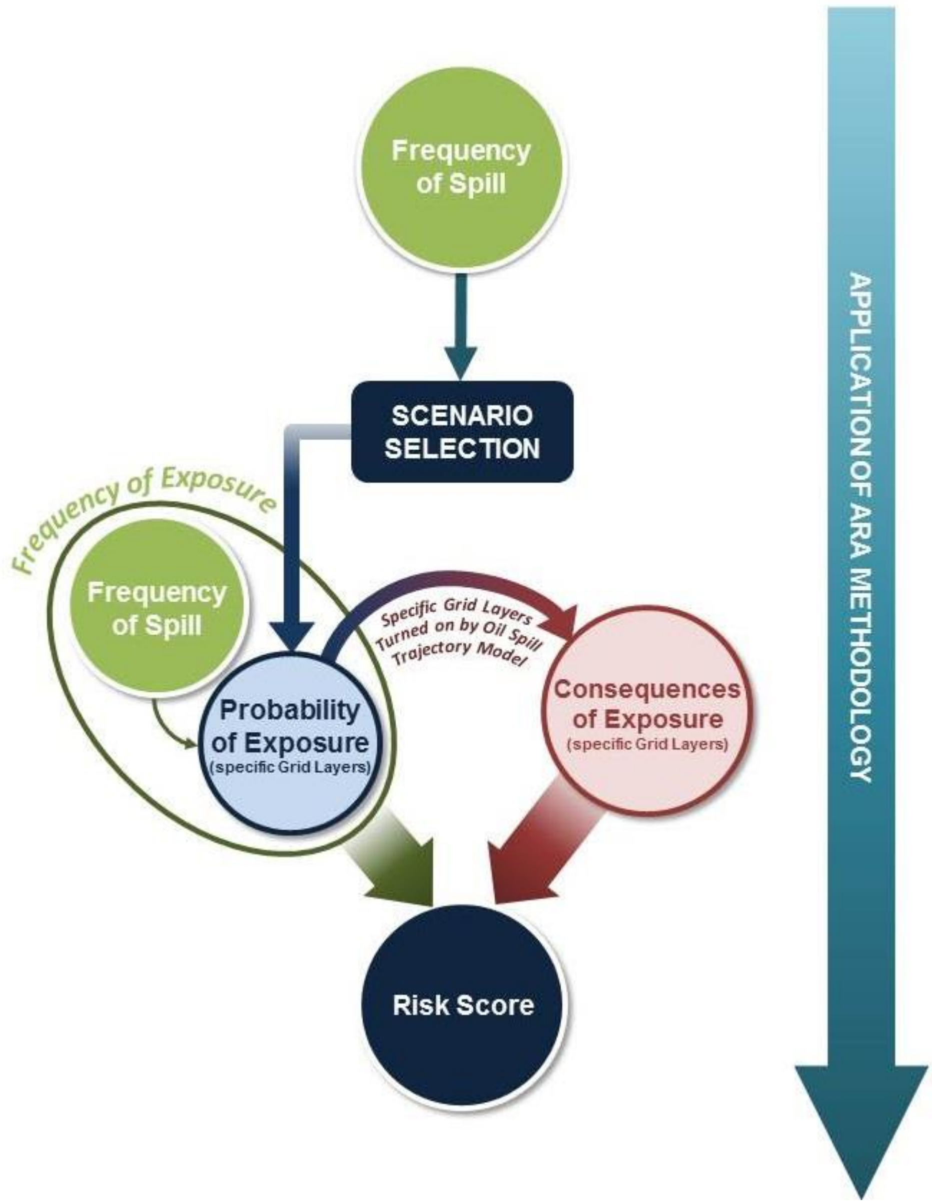


Figure 2-7: ARA Methodology Decision Flow Chart

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.

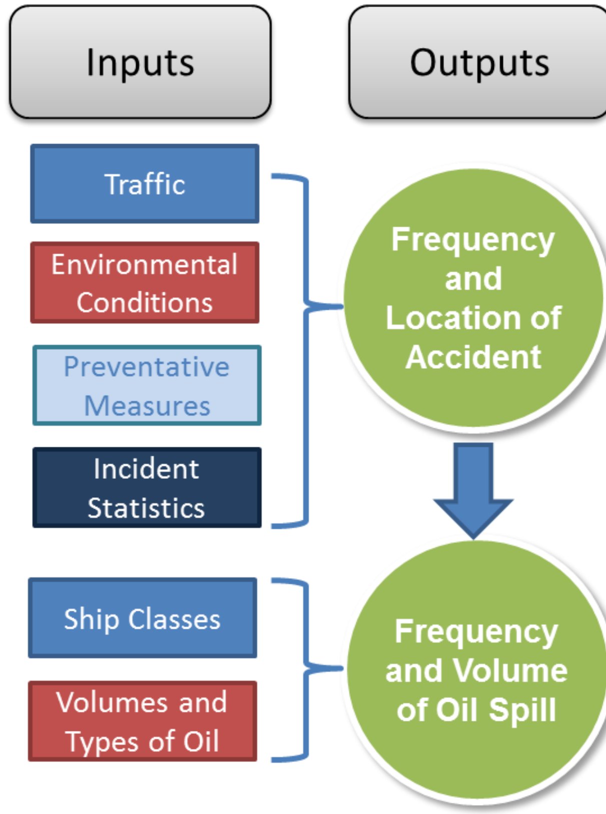


Figure 3-1: SAMSON Model Inputs and outputs

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.**

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.

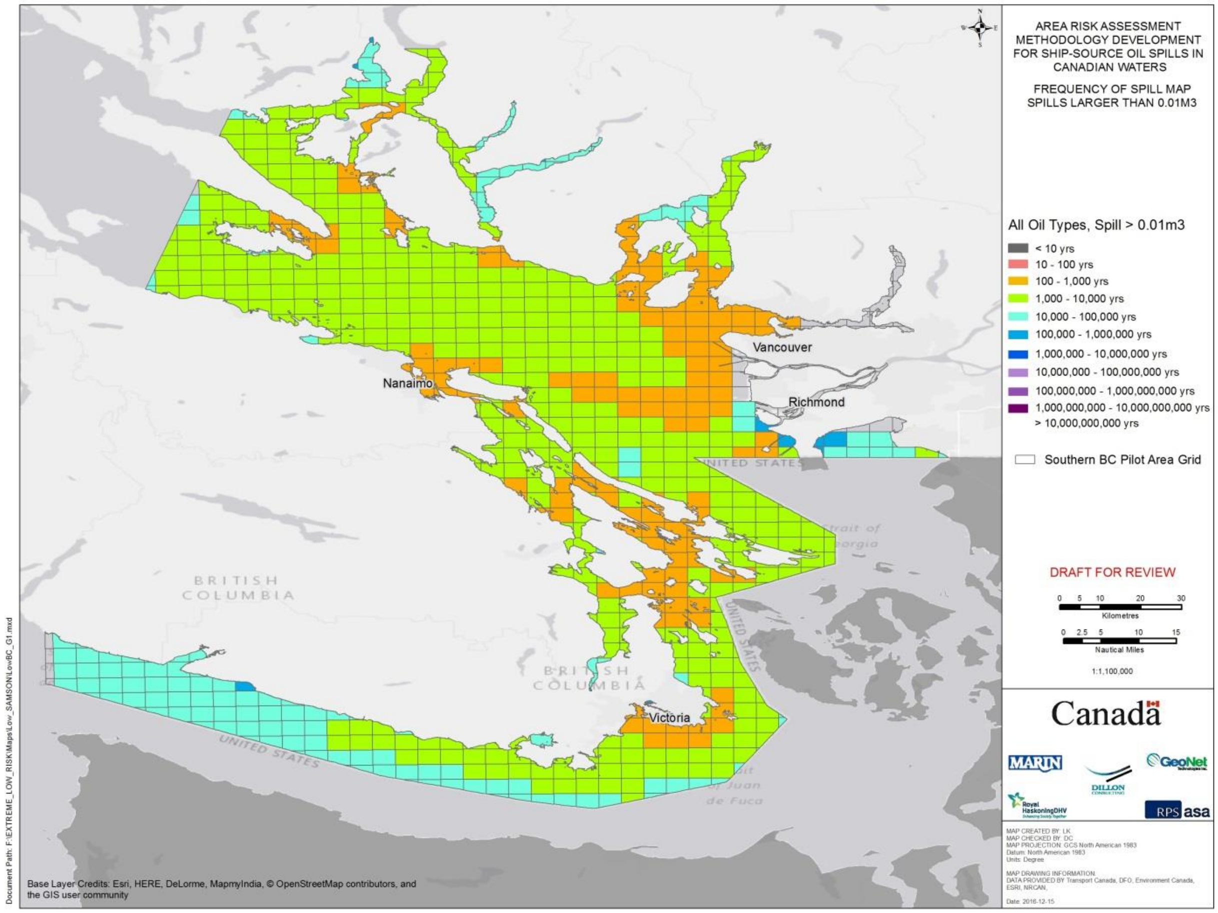


Figure 3-2: Example FOS Map for Spills >0.01 m^3 – Southern Portion of BC Pilot Area

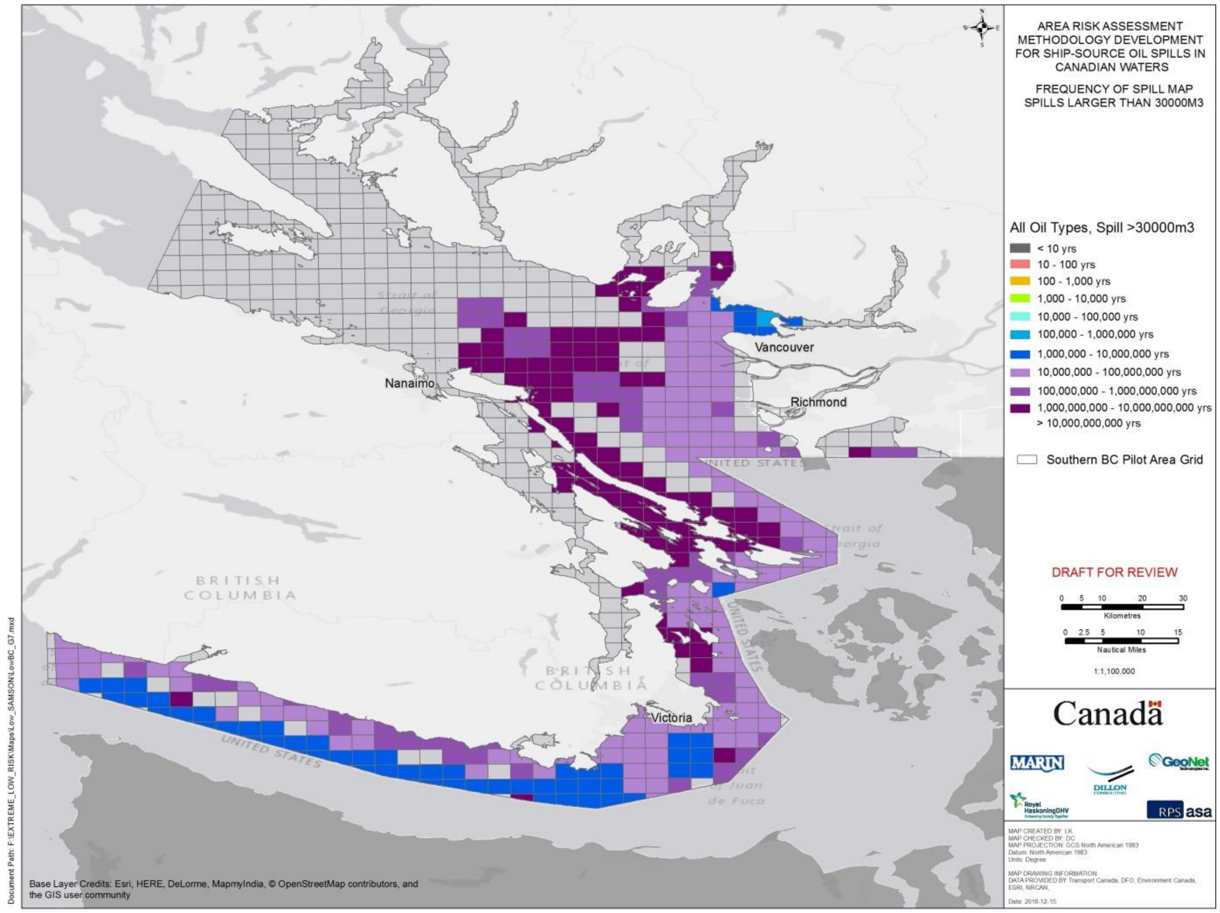


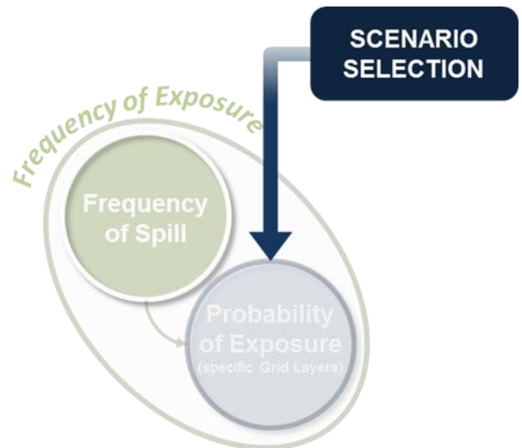
Figure 3-3: Example FOS Map for Spills >30,000 m^3 – Southern Portion of BC Pilot Area

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.

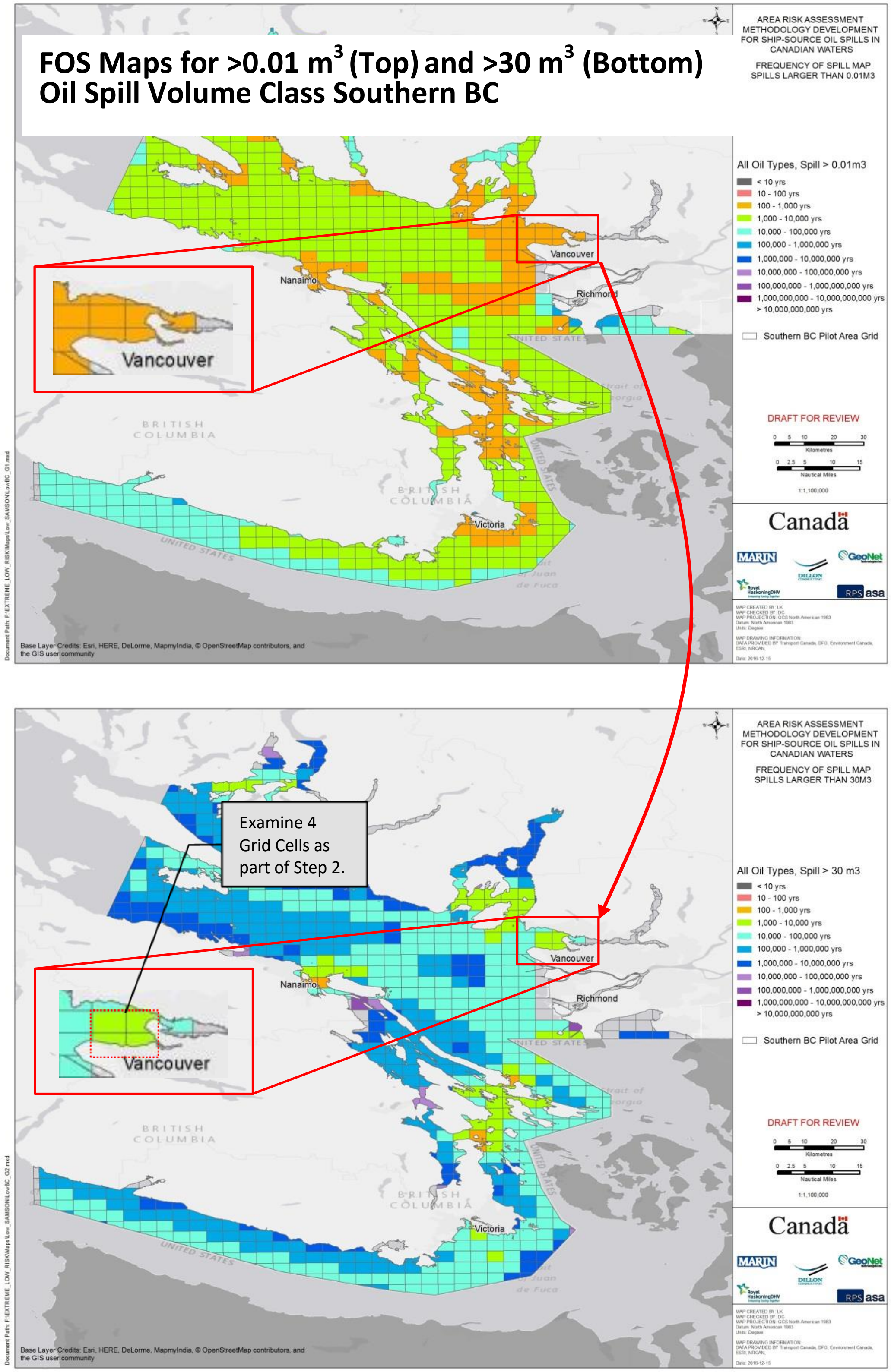


Figure 4-1: Step 2 of Scenario Selection - Comparison of FOS Maps

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	716	2.48×10^{-28}	1.43×10^{-7}	1.01×10^{-6}	1.07×10^{-6}	or	993,755
8	>100,000		Suezmax VLCC ULCC	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 8.70×10^{-17} (or 1 in 5 sextillion years) and $5.57 \times 10^{--7}$ (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)** = 2.23×10^{-8} or 1 in 44 million years

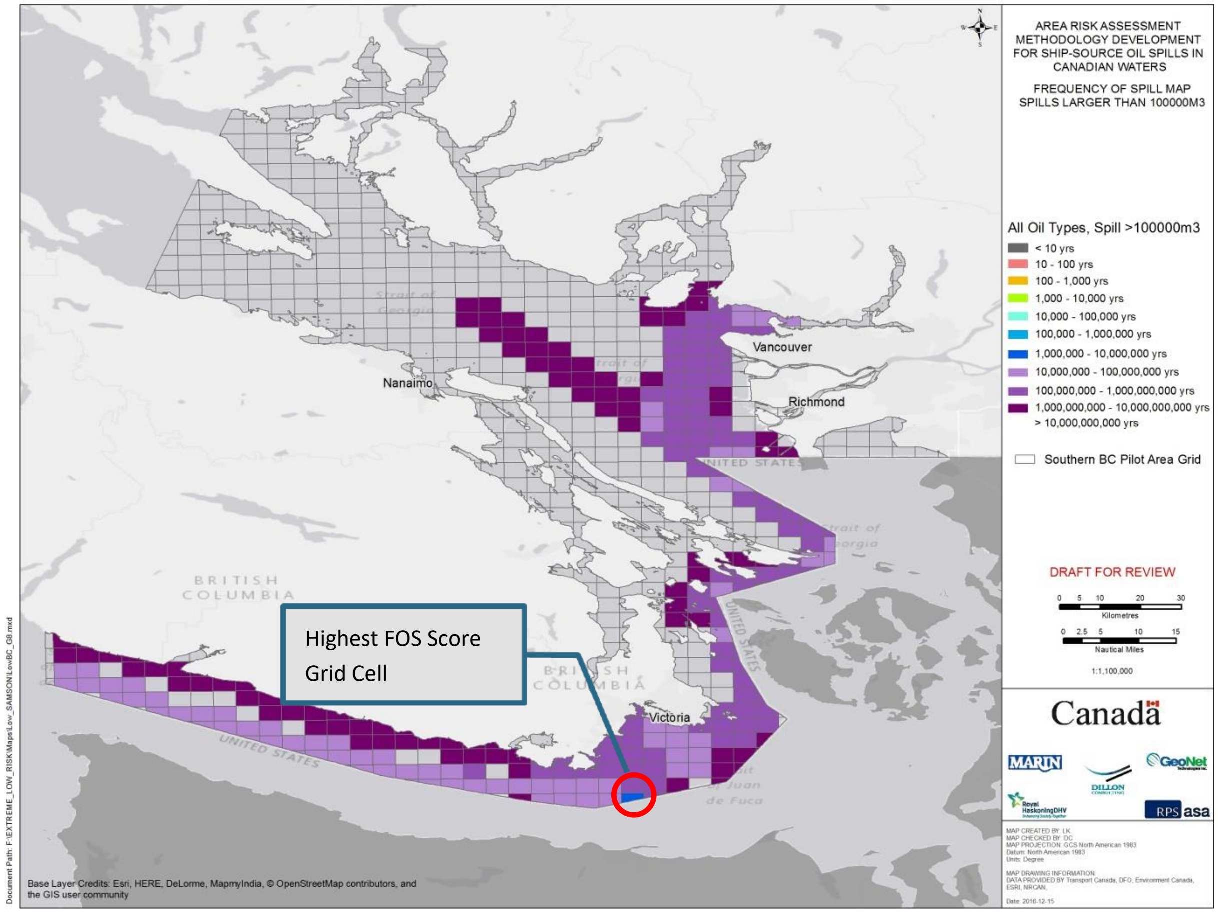


Figure 4-2: Identification of Largest Oil Spill Volume Scenarios

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.

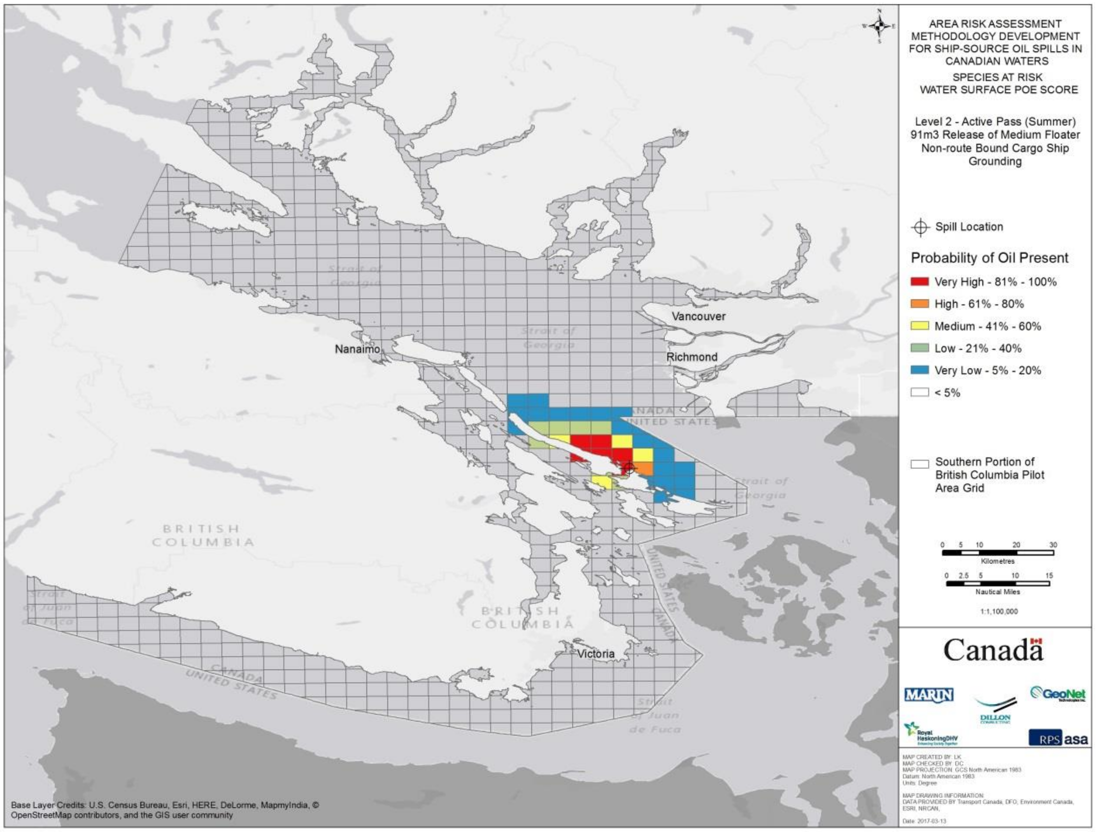


Figure 5-1: Example POE Map for a Level 2 oil Spill near Active Pass – Species at Risk on the Water Surface – Summer (unmitigated)

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.

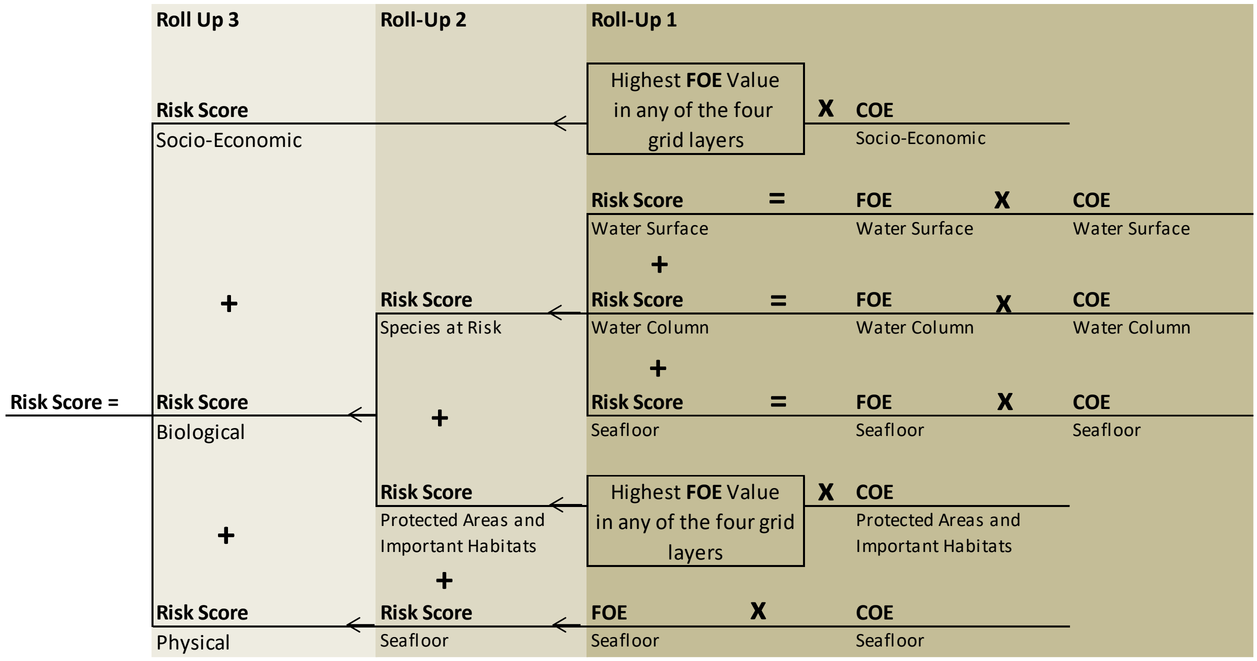


Figure 6-2: Risk Score Roll-Up Scheme - Grid Cell with No Shoreline

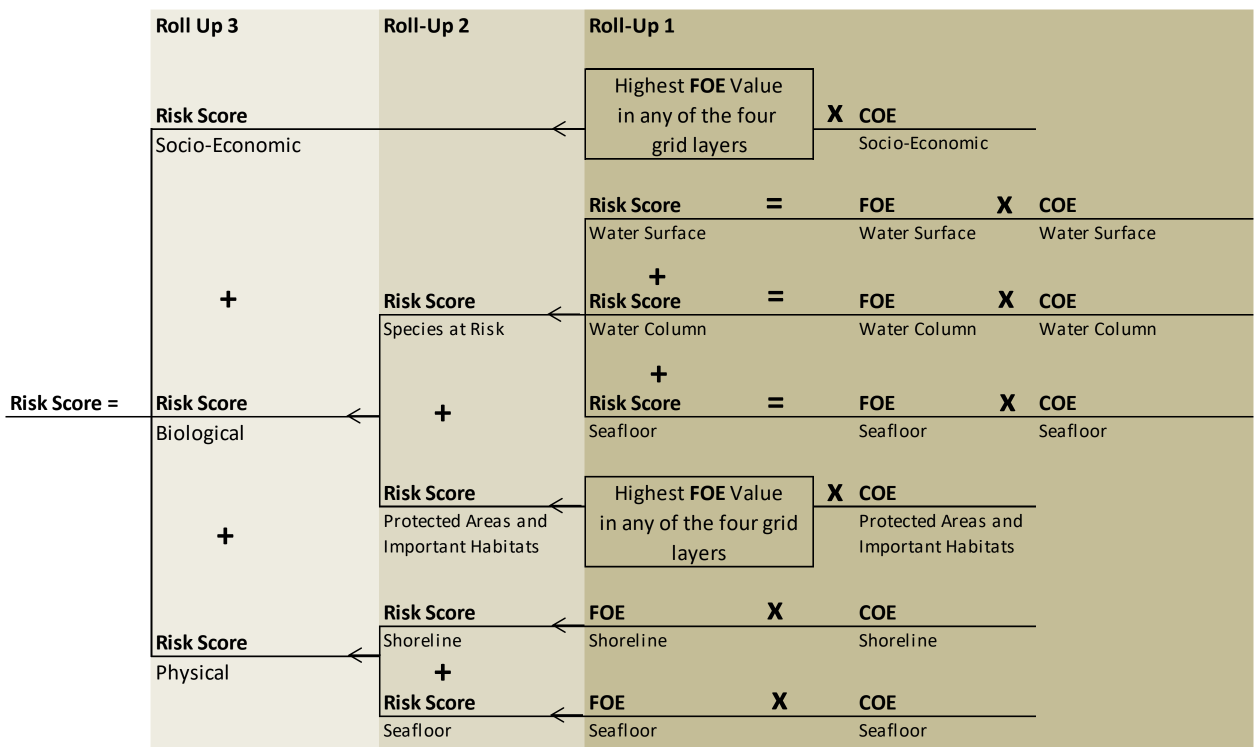


Figure 6-3: Risk Score Roll-Up Scheme - Grid Cell with Shoreline

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	

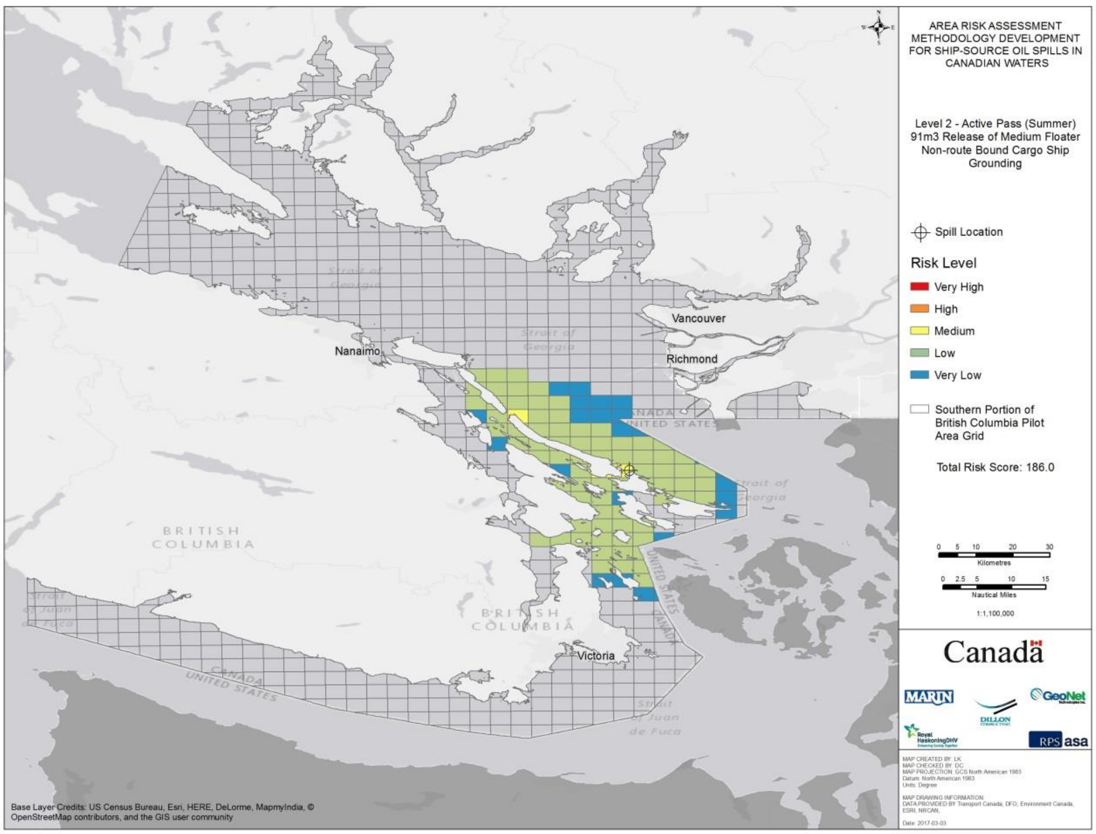


Figure 6-4: Example Risk$_S$ Map - Level 2 oil Spill near Active Pass – Summer (Unmitigated)

7.0 References

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