

**APPENDIX 30-A**  
**Marine Vessel Incidence Prediction Inputs**  
**to the Quantitative Risk Assessment**

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# **ROBERTS BANK TERMINAL 2 TECHNICAL REPORT**

## **Marine Vessel Incidence Prediction Inputs to the Quantitative Risk Assessment**

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## **Technical Report/Technical Data Report Disclaimer**

The Canadian Environmental Assessment Agency determined the scope of the proposed Roberts Bank Terminal 2 Project (RBT2 or the Project) and the scope of the assessment in the [Final Environmental Impact Statement Guidelines](#) (EISG) issued January 7, 2014. The scope of the Project includes the project components and physical activities to be considered in the environmental assessment. The scope of the assessment includes the factors to be considered and the scope of those factors. The Environmental Impact Statement (EIS) has been prepared in accordance with the scope of the Project and the scope of the assessment specified in the EISG. For each component of the natural or human environment considered in the EIS, the geographic scope of the assessment depends on the extent of potential effects.

At the time supporting technical studies were initiated in 2011, with the objective of ensuring adequate information would be available to inform the environmental assessment of the Project, neither the scope of the Project nor the scope of the assessment had been determined.

Therefore, the scope of supporting studies may include physical activities that are not included in the scope of the Project as determined by the Agency. Similarly, the scope of supporting studies may also include spatial areas that are not expected to be affected by the Project.

This out-of-scope information is included in the Technical Report (TR)/Technical Data Report (TDR) for each study, but may not be considered in the assessment of potential effects of the Project unless relevant for understanding the context of those effects or to assessing potential cumulative effects.

## EXECUTIVE SUMMARY

This technical report discusses an incidence prediction (IP) for marine vessel accidents due to the incremental increase in ship movements and port activities associated with the Roberts Bank Terminal 2 Project (RBT2). The IP is the probability assessment component of the Quantitative Risk Assessment (QRA) being completed to satisfy the needs of the Environmental Assessment process.

The proposed capacity for RBT2 is 2.4 million twenty foot equivalent containers (TEU). In 2030 these are projected to be carried on container ships ranging in size from less than 5,000 TEUs up to 18,000 TEUs. In 2030, 260 ship calls are projected at RBT2. Concurrently, there are projected to be 312 container ship calls at Deltaport Terminal, also with a container throughput of 2.4 M TEUs, for a total of 572 container ships calling at Roberts Bank servicing a total of 4.8 M TEUs. Thus, the RBT2 container ship traffic represents an 83% increase in the number of container ship calls and a doubling of the number of containers throughput. During this period, the coal shipments at the Westshore Terminals located at Roberts Bank are projected to reach 35 M tonnes shipped on approximately 313 bulk carriers.

The scope of the IP includes developing predictions regarding types and probabilities of accidents related to shipping, berthing, loading, and unloading of container ships. It focuses on the expected immediate consequences of these accidents (for example, types and volume or mass of materials released to the environment), associated with the expected incremental increase in container ship activity associated with RBT2. The IP performed in this component of the QRA provides input to subsequent components that evaluate the secondary consequences of the events in terms of human and environmental receptors. Together these results will be used to assess the incremental risk of accidents and malfunctions associated with the increase in container ship movements.

The IP process includes the following steps that are based on the structure of a risk assessment as outlined in the Pilotage Risk Management Methodology (PRMM) by Transport Canada:

- Identification of the Study Area;
- Definition of the Temporal Scope of the IP;
- Hazard Identification and Release Material Characterization;
- Identification of Existing Risk Mitigation Approaches;
- Development of the Vessel Traffic Affected;
- Development of Accident Rates;
- Incidence Prediction and Associated Release Amounts; and
- Frequency Assessment and Metrics for Future Predictions.

The Study Area includes the immediate terminal area where the container ships engage in maneuvering, berthing and cargo loading and unloading, referred to as the In-Port area, plus the adjacent waters where the increased container ship traffic interacts with other vessels transiting the area, referred to as the In-Transit area. The extent of the In-Transit Study Area is limited to the area where container ship traffic bound for Roberts Bank is distinguishable from other traffic in that their routes deviate from other regional traffic.

The IP uses Automatic Identification System (AIS) data and Port Metro Vancouver ship call data to establish the existing vessel traffic in 2012. Future vessel traffic projections are primarily based on the year 2030 in order to assess the changes in marine vessel accident incidence once RBT2 is fully operational and at peak throughput, and other reasonably foreseeable marine facilities are also functioning. Regulatory requirements influencing ship construction, particularly international requirements for protective location of fuel tanks, play an important role in incidence of accidents with the potential to damage the environment. To assess this, an interim year, 2025, is included when the full projected number of ships calling at RBT2 is expected to be reached, but fewer of these ships would have been constructed in consideration of the fuel tank protection requirements.

The IP includes predictions with and without RBT2. Vessel traffic in the region, and thus, accident incidence, is also a function of the existence of potential marine facilities other than RBT2. The influence that the addition of RBT2 has on accident incidence is dependent upon the background level of traffic assumed. For this reason, four future (2030) projections for vessel traffic are made in addition to the year 2012 to enable comparisons against different background vessel traffic levels. The vessel traffic scenarios evaluated are:

1. Year 2012;
2. Increases in vessel traffic due to growth consistent with existing marine facilities, without RBT2;
3. Increases in vessel traffic due to growth consistent with existing marine facilities, with RBT2;
4. Increases in vessel traffic due to growth consistent with foreseeable new marine facilities, without RBT2; and
5. Increases in vessel traffic due to growth consistent with foreseeable new marine facilities, with RBT2.

Hazard and accident types have been identified based upon interrogation of incident, accident and casualty databases, review of literature including other QRAs, and professional experience of PMV, stakeholders, experts and the study authors. Container shipping has also been the subject of a Formal Safety Assessment (FSA) by the International Maritime Organization (IMO). Accident types identified for consideration for RBT2 include: allisions, collisions, groundings (drift and powered), fires and explosions (F/E), and container mishandling accidents. Potential spill materials and their characteristics for consequence assessment have been identified. These include a range of Hazardous and Noxious Substances (HNS) as these are commonly carried in containers in addition to petroleum products including fuel oils, crude oils and operational lubricants.

The southern British Columbia coast is a mature marine vessel traffic area that is regularly used by deep sea vessels. Traffic in the region applies many marine risk mitigation approaches including a vessel traffic management system and pilotage requirements. Existing mitigation practices at the Roberts Bank terminals include, among others: one way, one ship at a time, traffic at a terminal, and prohibition of bunkering at the terminal. Design of container ships includes mitigation through the installation of fire detection and extinguishing systems, reduced use of heavy fuel oil, and, for ships constructed since 2010, protective location of fuel oil tanks.

Accident rates for the Vancouver region were developed on the basis of incident and casualty data from several sources, including the Transportation Safety Board, Canadian Coast Guard, Pacific Pilotage Authority, and Sea-Web databases. In this analysis, an event is classified as an incident when there is the possibility of damage to life, environment or property; and if such an incident does result in damage to life, environment or property then it is also an accident. Local incident rates have been compared to regional and worldwide data to assess the applicability of worldwide data to the Vancouver region. In particular, use has been made of data developed for the IMO FSA of container vessels - including recent updates by Germanischer Lloyd in 2013. These are referred to as the “updated IMO rates”. The key findings include:

- Vancouver region incident rates are low, such that there is wide variability over the years, introduced by small numbers of incidents;
- Comparison of Vancouver region incident rates with regional and global rates should be done on the basis of all ships for the entire region as there are too few incidents to assess on an individual terminal or ship types basis;
- Vancouver region incident rates are consistent with global rates;
- The most relevant comparison is with updated IMO rates for container ship accidents;
- The raw updated IMO rates were adjusted for an exposure factor that accounts for the portion of a ship-year when an accident type is possible; and
- Comparison of Vancouver region accident rates with the adjusted, updated IMO rates indicating the latter were appropriate to use as a basis in subsequent analyses.

IP for the In-Port area involved the evaluation of the incidence and amounts of released materials associated with container handling accidents, ship impact related accidents, and discharges of stern tube lubricants during normal ship operations. **Return periods** for container handling accidents resulting in spills into the water at RBT2 are estimated to be over 400 years, and over 50,000 years for spills involving HNS. Return periods for impact spills (allisions, collisions and groundings) are predicted to increase in 2030 from those in 2012 with or without RBT2. This is attributed to the implementation of fuel tank protection by 2030 on all container ships calling at RBT2. Mean return periods in 2030 (95% confidence limit value) are all greater than 1000 years. Incidence of spills is directly related to the number of ships calling. Thus, the incidence for a spill resulting from container ship movements at Roberts Bank terminals is 83% greater with RBT2 than that without RBT2. Incidence of collisions with fishing and

recreational vessels is projected to be small based upon information indicating the density of such vessels on a daily basis in the waters adjacent to Roberts Bank is small. Return periods for collisions with fishing vessels and for recreational vessels are estimated to be approximately 50 years. The increase due to RBT2 is approximately 3%.

IP for the In-Transit area involved the evaluation of the loss of containers overboard in transit, and the incidence of spills from collisions and groundings during the transit through the Study Area. Voyage times within the In-Transit study area (to and from) for RBT2-bound container ships are approximately 3 hours. Loss rates for containers overboard based upon global data indicate this risk is negligible in the semi-protected and protected waters of this voyage. Return periods (95% confidence limit) for spills associated with collisions and groundings are all over 1000 years, and again closely proportional to the number of ships. Thus, the incidence for a spill resulting from a container ship travelling to and from Roberts Bank terminals is 83% to 87% greater with RBT2 than that without RBT2. Return periods for collisions involving container ships striking a laden crude tanker are over 800,000 years.

Return periods associated with F/E accidents are the shortest, at approximately 60 years with RBT2 and nearly double that without RBT2. F/E accidents can be associated with container contents or machinery operations. Rates for the former are expected to be proportional to numbers of containers while the rates for the latter are expected to follow ship numbers.

Return periods for all accident types are considered Improbable following the assessment methodology of the Transport Canada PRMM.

In planning for response capabilities, the concept of worst-case discharge is usually taken as the total capacity of the cargo and/or fuel tanks of the vessel involved. In assessing risk, this is not necessarily the appropriate amount if the probability of such a spill is minute, on the order of  $1 \times 10^{-6}$  per annum. Scenarios that would result in total loss would almost invariably take time long enough for a response to be initiated. In the event of a spill, a clean-up would be mounted, whether the spill consisted of containers, or their contents, and whether the spill originated from the container ship or another ship involved in a collision. Evaluation of the exposure of the environment to the maximum credible spill should take these factors into account. On the other hand, planning for the response should take into account the amount that would need to be removed from being in a position to cause environmental damage, i.e., the worst-case discharge.

This study recommends that the maximum credible spill sizes be as follows:

- Fuel oil spill from a container ship in a collision In-Transit or any cause In-Port: 2,500 m<sup>3</sup>;
- Fuel oil spill from a grounding In-Transit: 7,500 m<sup>3</sup>;
- Oil spill from a laden crude tanker due to a collision with a container ship: 40,000 m<sup>3</sup>; and
- Maximum number of HNS containers lost or spilt overboard: 1 container carrying up to 26 m<sup>3</sup> of liquid contents.

Note that the estimates above for maximum credible spill size are not different for RBT2 than for current container ship traffic to Deltaport and other PMV terminals

Metrics are provided for adjusting this IP if estimates of vessel traffic or numbers of containers throughput change. The recommended metrics are:

- Number of ship calls for incidence scaling of allision, collision and grounding accidents;
- Number of containers throughput in TEUs for container handling and F/E accidents; and
- Time en route: for scaling of collision and grounding accident incidence for voyages of different distances.

IP for In-Port impact spills in the year 2025 produces similar results to the IP for 2030. Spill probabilities are 8% to 9% larger and spill amounts are 2% to 4% smaller for 2025. The increase in spill probability is attributable to the lower level of fuel tank protection while the reduction in spill amount is attributable to the smaller average size of the ships in 2025. Similar trends are expected for In-Transit incidences. Overall these differences are small in comparison to the overall uncertainty in the IP analysis.

The consequences of a spill are controlled in large part by the location relative to sensitive and vulnerable ecosystem components. Allisions, in-port collisions and operational spills will occur adjacent to or near the berth face. In contrast to Deltaport, which is influenced by two causeways, the Roberts Bank causeway to the north-east and the BC Ferries causeway to the south-east, the RBT2 berth face is exposed to the Strait of Georgia.

Collisions and subsequent spills in the In-Transit study area will have the highest probability of occurrence where the encounter probability is highest. The spill locations are most likely near the ferry terminal and approaches to Roberts Bank terminals, near East Point on Saturna Island at the entrance to Boundary Pass, and near Turn Point on Stewart Island at the entrance to Haro Strait. Groundings are expected to occur most frequently along Boundary Pass due to the narrowness of the channel and prevailing wind directions.

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## ACRONYMS

AIS	Automatic Identification System
BC MOE	BC Ministry of Environment
Bbl	Barrel
CCG	Canadian Coast Guard
CCIP	Container Capacity Improvement Program
Cedre	Centre of Documentation, Research and Experimentation of Accidental Water Pollution (France)
CI	Confidence interval
CSC	International Convention for Safe Containers
CVTS	Cooperative Vessel Traffic Service
DFO	Fisheries and Oceans Canada
DTRRIP	Deltaport Terminal, Road, and Rail Improvement Project
DNV	Det Norske Veritas (ship classification organization)
DWT	Deadweight tonnage
EA	Environmental Assessment
F/E	Fire or Explosion
FSA	Formal Safety Assessment
GL	Germanischer Lloyd (ship classification organisation)
GOALDS	Goal-Based Damage Stability
GT	Gross tonnage
HEC	Herbert Engineering Corp.
HFO	Heavy fuel oil
HNS	Hazardous and Noxious Substances
IACS	International Association of Classification Societies
IHS	Information Handling Services hosts the Sea-web database (formerly Lloyd's Fairplay database)
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
IMTE	Institute of Marine Traffic Engineering
IP	Incidence Prediction
KM	Kinder Morgan
LR	Lloyd's Register (ship classification organisation)

MARIN	Maritime Research Institute Netherlands
MARPOL	IMO International Convention for the Prevention of Pollution from Ships
MCTS	Marine Communication and Traffic Services
NM	Nautical mile
PMV	Port Metro Vancouver
PRMM	Pilotage Risk Management Methodology
QRA	Quantitative Risk Assessment
RBT2	Roberts Bank Terminal 2 Project
Ro Ro	Roll-on / Roll-off vessel
SOLAS	IMO Safety of Life At Sea convention
STCW	International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers
TC	Transport Canada
TEU	Twenty foot equivalent unit, an industry standard measure of container ship capacity
TFN	Tsawwassen First Nation
TSB	Transportation Safety Board of Canada
TSI	Terminal Systems Incorporated
UCL	Upper confidence limit of the mean
USCG	United States Coast Guard
WP	WorleyParsons Canada
WSC	World Shipping Council
YVR	Vancouver International Airport

## GLOSSARY

**Accident:** a sudden event that is not planned or intended and that causes damage to life, environment or property.

**Aframax Tanker:** a tanker with a oil carrying capacity between 80,000 and 120,000 DWT

**Allision:** an event in which a moving object strikes a stationary object (e.g., a vessel hitting a pier or a moored vessel).

**Automatic Identification System (AIS):** an automatic tracking system used on ships and by vessel traffic services for identifying and locating vessels by electronically exchanging data with other nearby ships and AIS base stations. While the purpose of these communications is primarily for vessel traffic control, collision avoidance, and other maritime safety and security applications, the aggregate data of vessel traffic also provides an extremely detailed history of vessel traffic movements that can be used in determining patterns of vessel movement and establishing numbers of vessels in traffic lanes, port areas, and regions by vessel type.

**Barrel (bbl):** the equivalent of 42 US gallons, 35 Imperial gallons, 159 L or 0.159 cubic metres. There are 6.29 barrels of oil per cubic metre.

**Bulker:** bulk carrier.

**Bunkering:** the process of refueling a deep-sea vessel (typically heavy fuel oil or diesel)

**Case:** analysis case corresponding to a Vessel Population Scenario.

**Casualty:** an incident reported to a marine authority.

**Chemical Tanker:** category of tank ship (tanker) that carries HNS rather than petroleum products and is generally between 9,000 and 80,000 DWT.

**Collision:** an event in which two moving objects strike each other (e.g., two vessels in transit or maneuvering striking each other).

**Crude Tanker:** category of tank ship (tanker) that is generally over 90,000 DWT and usually carries crude oil.

**Deadweight tonnage (DWT):** the maximum amount of weight a ship or vessel can safely carry as expressed in metric tonnes.

**Deltaport Terminal:** the existing container terminal at Roberts Bank.

**Drift grounding:** an incident in which a vessel makes contact with the bottom because of mechanical failure or other factors not attributable to human error.

**Equipment failure:** the failure in any of a vessel's systems that may lead to the spillage of oil or other pollutants.

**Exposure factor:** a correction factor applied to incident rates in probability per ship-year to account for the portion of a year when the accident type under consideration is possible.

**Fuel capacity:** the maximum bunker fuel capacity of a vessel, including distillate and/or residual fuels.

**Foundering:** sinking as a result of heavy weather, vessel springing leaks or breaking in two.

**Gross tonnage (GT):** a measure of a ship's overall internal volume.

**Heavy fuel oil:** Heavy fuel oil (HFO) is a residual oil from distillation and/or the cracking system of natural gas processing and serves as fuel for marine diesel engines with primary oil combustion. The international trading description of such oil is: Marine (Residual) Fuel Oil (MFO) sometimes also the US description Bunker C.

**Incident:** an unexpected event involving a vessel or facility that could potentially result in damage to life, environment or property.

**Incident rate:** the number of incidents per vessel transit or ship call.

**Monte Carlo simulation:** a mathematical modelling technique used to approximate the probability of certain outcomes by running multiple trial runs, called simulations, using random variables.

**Non-piloted vessels:** vessels that would not ordinarily be required to transit the study area with pilots, including tugs, barges, fishing vessels, ferries, and other vessels.

**Operational pollutant input:** the release of fuel and/or cargo into the marine environment as part of normal operations of the vessel, including lubricant discharges from stern tube leakage.

**Outside force:** an incident cause, including damage by wake, wave, storm, or an object hitting a vessel (e.g., crane at dock).

**Outside Study Area:** area within the limits of Canadian and/or relevant US (Puget Sound) waters, but not in the Vancouver region, where selected incidents were reviewed due to their relevance for containerships.

**Piloted vessels:** vessels that would be required to transit with pilots, including bulk carriers, container ships, cruise ships, tankers, fish factories, and vehicle carriers.

**Powered grounding:** an incident in which the vessel makes contact with the bottom generally due to a human error in navigation, steering, or piloting.

**PMV Navigation jurisdiction:** refers to the area in which Port Metro Vancouver (PMV) has been delegated authority regarding marine navigation. Navigation Jurisdiction extends from Point Roberts at the Canada / U.S. border through Burrard Inlet to Port Moody and Indian Arm, excluding False Creek, and from the mouth of the Fraser River, eastward to Kanaka Creek, north along the Pitt River to Pitt Lake, and includes the north and middle arms of the Fraser River.

**Product Tanker:** category of tank ship (tanker) that usually carries refined petroleum products rather than crude oil and is between 20,000 and 90,000 DWT.

**Return period:** the inverse of the expected number of occurrences in a year.

**Roberts Bank:** the intertidal mudflats, marshes and surrounding waters located west of Delta B.C., ranging from Canoe Passage to the north to Point Roberts to the south.

**Roberts Bank terminals:** the container and coal terminals at Roberts Bank, including Deltaport Terminal, Westshore Terminals, and potentially, Roberts Bank Terminal 2.

**Serious:** incidents are defined by the International Association of Classification Societies (IACS) as “serious” based on these criteria: total loss (vessel ceasing to exist after casualty due to it being unrecoverable or being broken up); breakdown resulting in the ship being towed or requiring assistance from ashore; flooding of any compartment; or structural, mechanical, or electrical damage requiring repairs before the ship can continue trading.

**Ship year:** one ship operating for one year, or a combination of ships operating for shorter time periods, all of which add up to one year.

**Split service:** one container line operates a service where the unloading and loading at Deltaport is split between two vessel calls that are separated by a round trip to the Seattle-Tacoma port. On the first arrival the vessel unloads, then it travels to Seattle-Tacoma, then it loads containers outbound on its second call at Deltaport.

**Stern tube:** The stern tube is a hollow tube passing at the lower stern part of the ship carrying tail shaft and connecting it to the propeller out at sea, the bearing for the tail shaft, the lubrication arrangement, and the sealing arrangements.

**Structural failure:** an event in which the structural integrity of a vessel's hull, bunker tanks, or cargo tanks is compromised causing the potential for pollutant leakage or actual leakage. Damage can cause the vessel to sink.

**Tender:** a ship is considered tender if it is prone to heel or roll noticeably if subjected to relatively small roll moments such as those introduced by wind or turning manoeuvres.

**Transit:** a round trip voyage through the region of interest.

**Updated IMO rates:** accident rates for container ships based upon Germanischer Lloyd (GL) updates of IMO statistics (GL 2013).

**Vancouver region:** Vancouver ports and other nearby Canadian ports south of Latitude 50 degrees N and the adjacent waters where the majority of ships transiting those waters are travelling to or from those ports.

**Vessel failure:** a consolidation of cause types, including equipment failure, propulsion loss, and steering loss.

**Westshore Terminals:** the existing coal terminal at Roberts Bank.

**Worst-Case Discharge:** the spill volume based on US Coast Guard regulations as the total capacity of the cargo and/or bunker fuel tanks of the vessel. This volume varies from 10 barrels (bbl) for small recreational vessels to 1.9 million bbl for fully-loaded crude tankers.

**Zone:** one of the four subareas within the Vancouver region.

## 1.0 INTRODUCTION

### 1.1 PROJECT BACKGROUND

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new multi-berth container terminal intended to provide additional container shipping capacity on the west coast of Canada. The Project is part of the Container Capacity Improvement Program (CCIP), Port Metro Vancouver's long-term strategy to deliver projects to meet anticipated growth and demand for container capacity in the coming decades.

Port Metro Vancouver (PMV) has retained Herbert Engineering Corp. (HEC) to undertake this technical study related to the Project. This technical report describes the results of the Marine Vessel Incidence Prediction Inputs to the Quantitative Risk Assessment study.

### 1.2 QUANTITATIVE RISK ASSESSMENT OVERVIEW

A Quantitative Risk Assessment (QRA) is being completed in order to provide analysis and information that will be used for other assessments as part of the environmental assessment (EA) required for RBT2.

Risk in this EA process is defined as *Risk = Probability X Consequence* where varying levels of risk are produced by the products of a range of probabilities of events and their consequences. A popular format for presenting risk in qualitative terms is the risk matrix shown in **Figure 1-1**. Once quantitative information is available, risk can be evaluated using more precise numerical comparisons.

LEVEL OF RISK					
	EXTREME	VERY HIGH	HIGH	MEDIUM	LOW
Highly Probable					
Probable					
Possible					
Unlikely					
Improbable					

**Figure 1-1 Risk as a Product of Probability times Consequence**

The QRA has been further divided into two components of which this report discusses the Probability Assessment component of the QRA.

- Component 1 – Probability Assessment, or Incidence Prediction (The focus of this report); and
- Component 2 – Fate of Releases to the Environment (see RPS ASA 2014).

### 1.2.1 Marine Vessel Incidence Prediction Inputs to the Quantitative Risk Assessment

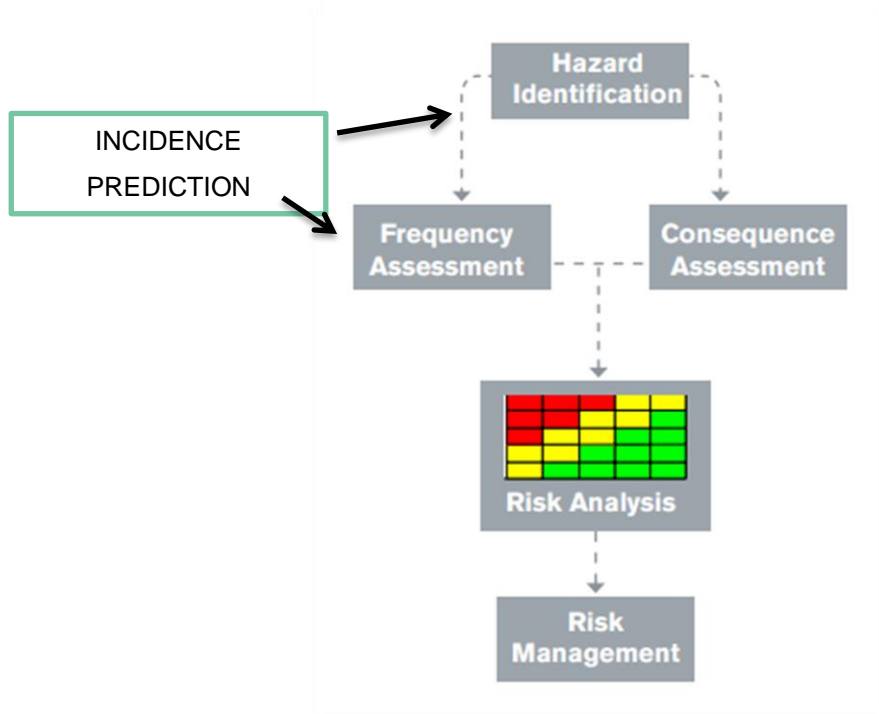
Component 1 of the QRA consists of the prediction of incidents due to the incremental increase in ship movements and port activities associated with RBT2. This component is termed the “Marine Vessel Incidence Prediction Inputs to the Quantitative Risk Assessment”, and subsequently referred to in this document as the “Incidence Prediction” or “IP”. The scope of the IP includes developing predictions regarding types and probabilities of **accidents** related to shipping, berthing, loading and unloading of container ships. It focuses on the expected immediate consequences of these accidents (for example, types and volume or mass of materials released to the environment) associated with the expected incremental increase in container ship activity associated with RBT2. The IP performed in this component of the QRA provides input to subsequent components that evaluate the consequences of the events (**Figure 2-1**). Together these results will be used to assess the incremental risk of accidents and malfunctions associated with the increase in container ship movements.

The IP process includes the following steps that are based on the structure of a risk assessment as outlined in the Pilotage Risk Management Methodology (PRMM) by Transport Canada (TC) (2010):

- Identification of the Study Area;
- Definition of the Temporal Scope of the IP;
- Hazard Identification;
- Identification of Existing Risk Mitigation Approaches, i.e. Current Defences;
- Development of the Vessel Traffic Affected;
- Development of Accident Rates;
- Incidence Prediction and Associated Release Amounts;
- Frequency Assessment; and
- Release Material Property Characterization.

This report is organized into three primary sections:

1. Methods – the analysis approach is described;
2. Results – the probabilities of accidents and amounts of releases are presented; and
3. Discussion – the results are placed in the context of the incremental change in ship movements and terminal activities associated with the Project.



**Figure 1-2 Incidence Prediction in the Risk Management Process**

## **2.0 METHODS**

### **2.1 STUDY AREA**

The Study Area is based upon the risk of spills from vessels or shore-side facilities due to the incremental increase in ship movements and port activities if the Project is approved. The study area includes two sub-areas; one is the immediate vicinity of the existing and proposed Roberts Bank Terminals, referred to as the In-Port evaluation region, outlined in green in **Figure 2-1**, and the second is the waters adjacent to the terminal including the vessel traffic lanes, referred to as the In-Transit evaluation region, outlined in red in **Figure 2-1**.

#### **2.1.1 In-Port Evaluation**

The In-Port evaluation sub-area is predicated on the different operational risk factors that come into play once a vessel has left the traffic lanes to approach and berth at RBT2, while at the berth, and when departing from the berth prior to entering the traffic lanes. The vessels are assisted by tugs and no longer interact with passing traffic. Spills of the contents of containers are considered. Oil spills are limited to fuel and lubricants carried by the vessels visiting Roberts Bank terminals. Fuel could be heavy fuel oil, diesel oil and, in the future, LNG. Crude oil and diluted bitumen are not included as part of the In-Port scenario, since these are not carried by tankers in the immediate vicinity of RBT2 or in containers. The vessel traffic lanes are approximately 3 NM (5 km) from the berth face.

In this approach, the IP is based upon the number of ship calls at the terminal or the number of containers, expressed in TEUs involved.

#### **2.1.2 In-Transit Evaluation**

The In-Transit evaluation is based on the potential impact on the regional vessel traffic of additional vessels calling at RBT2. These vessels will enter the vessel traffic lanes approximately 3 NM (5 km) southwest of the Roberts Bank terminals. From here, they will interact with ships calling at Vancouver region facilities including those in Burrard Inlet (including the potential additional tanker traffic from the Trans Mountain Pipeline (Kinder Morgan Canada Project), the Fraser River, the BC Ferries Terminal at Tsawwassen, other Canadian ports in the region, and may interact in the future with vessels calling at the proposed Gateway Pacific Bulk Terminal and the existing tanker terminal, both located near Cherry Point, WA. As the vessels travel to/from the Pacific following normal traffic patterns, they travel within vessel traffic lanes in Boundary Pass, in Haro Strait and in the lanes adjacent to Alden Bank shown in **Figure 2-1**. Once in traffic lanes, the container ships bound for Roberts Bank would no longer introduce any additional risks from other container vessels in the traffic lanes. Boundary Pass has been included because the northeast entrance to this pass is part of the transition for Roberts Bank vessel traffic into and out of normal traffic patterns. The northwestern boundary is based upon the assumption that the vessel traffic beyond this boundary is not impacted by Roberts Bank traffic.

### 2.1.3 Zones Used for Incident Rate Analysis

Analysis of accident rates was performed over a region larger than the Study Area and includes the other terminals and ports in the Vancouver region in order to access a larger database of potentially relevant **incidents**. Four zones in the Vancouver region were considered in the analysis to evaluate differences within the region (see **Figure 2-2**). They are representative of different types of vessel operations and are used to determine if it is possible to distinguish incident and accident rates between them. The four zones are:

- PMV Main: includes Burrard Inlet and its entrance (including English Bay);
- Fraser: includes both arms of the Fraser River;
- RBT: includes the immediate area around the Roberts Bank terminals and the BC Ferry Terminal at Tsawwassen; and
- Transit: includes the adjacent waters as shown in **Figure 2-2**.

### 2.1.4 Location and Layout of Proposed Roberts Bank Terminal 2

The Project's terminal will be located immediately west of the existing Roberts Bank terminal facilities, approximately 5.5 km from the east shore end of the causeway. The terminal will be oriented parallel to the shoreline (perpendicular to the causeway) and will extend approximately 600 metres (m) further offshore than the edge of the existing terminal at Roberts Bank. The terminal will be rectangular in shape with a berth face length of 1,300 m to accommodate the mooring of three ships. The terminal width will be 700 m to support terminal components. The total marine footprint of the terminal will be approximately 116 ha.

The orientation of the new terminal has been designed to facilitate the berthing of container ships.

**Figures 2-3 to 2-5** illustrate the location and orientation of the Project terminal.

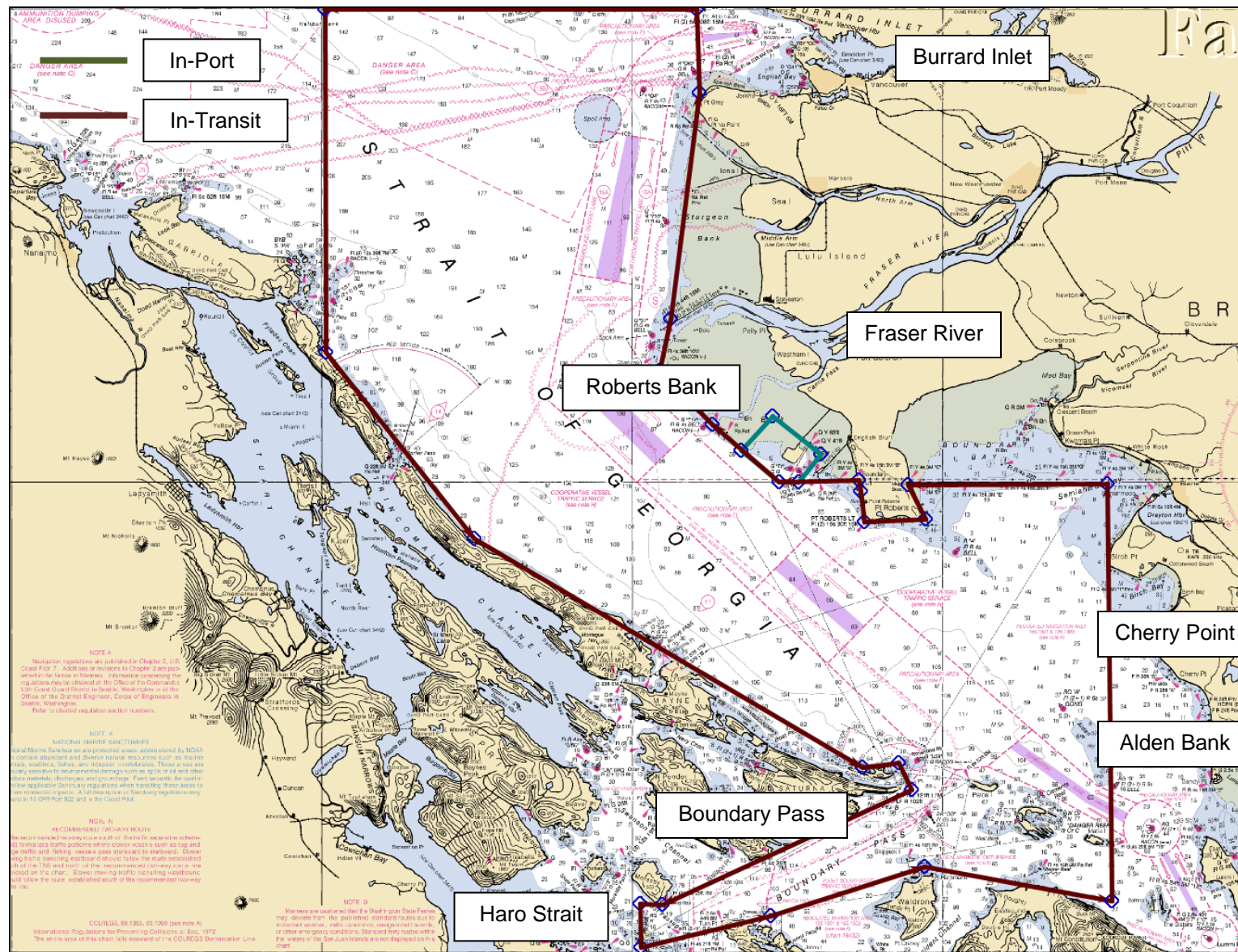


Figure 2-1 Project Study Area Showing In-Port and In-Transit Evaluation Regions



Figure 2-2 Zones Within the Vancouver Region

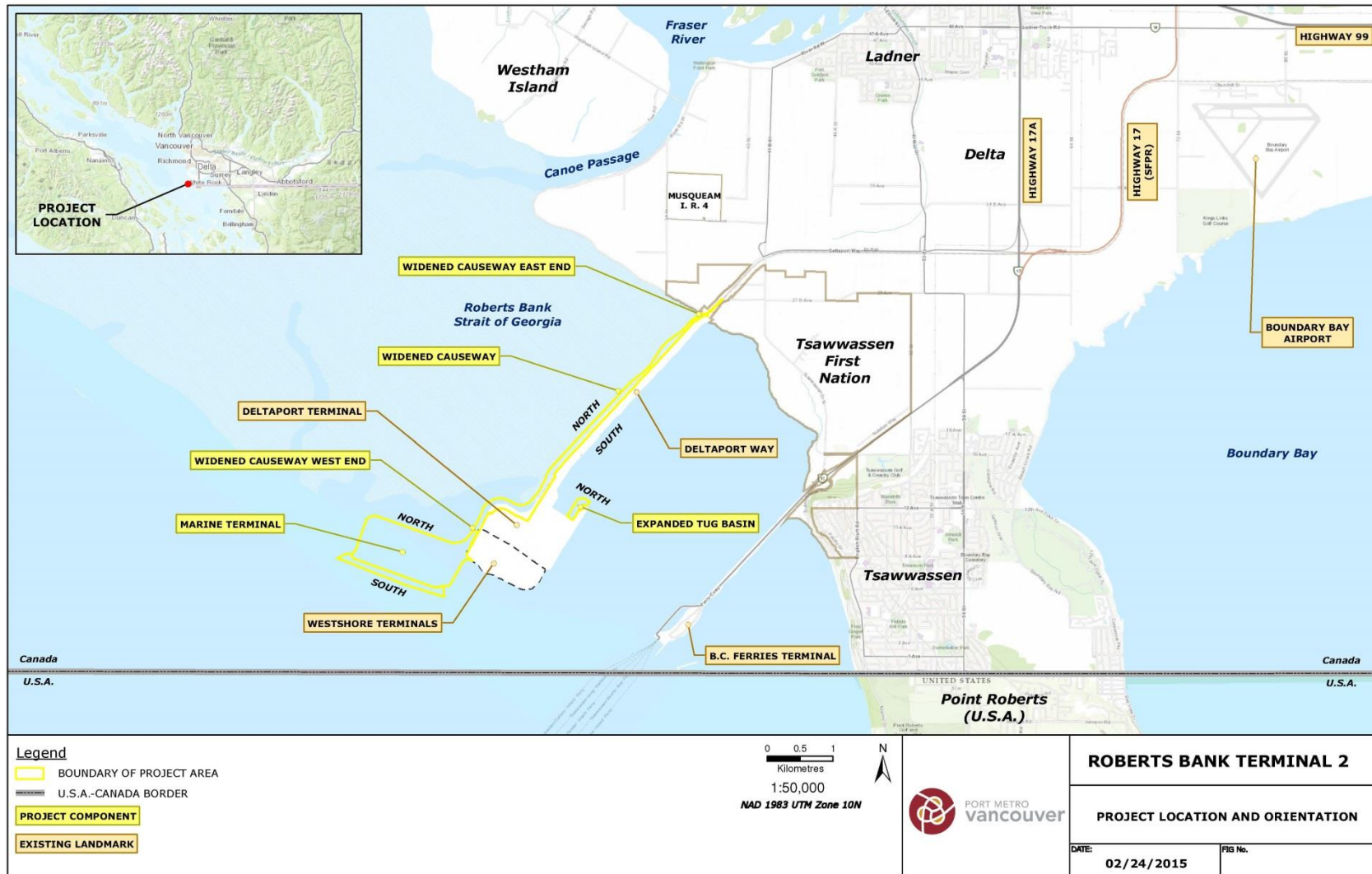


Figure 2-3 Project Location



Figure 2-4 RBT2 Artist's Rendering

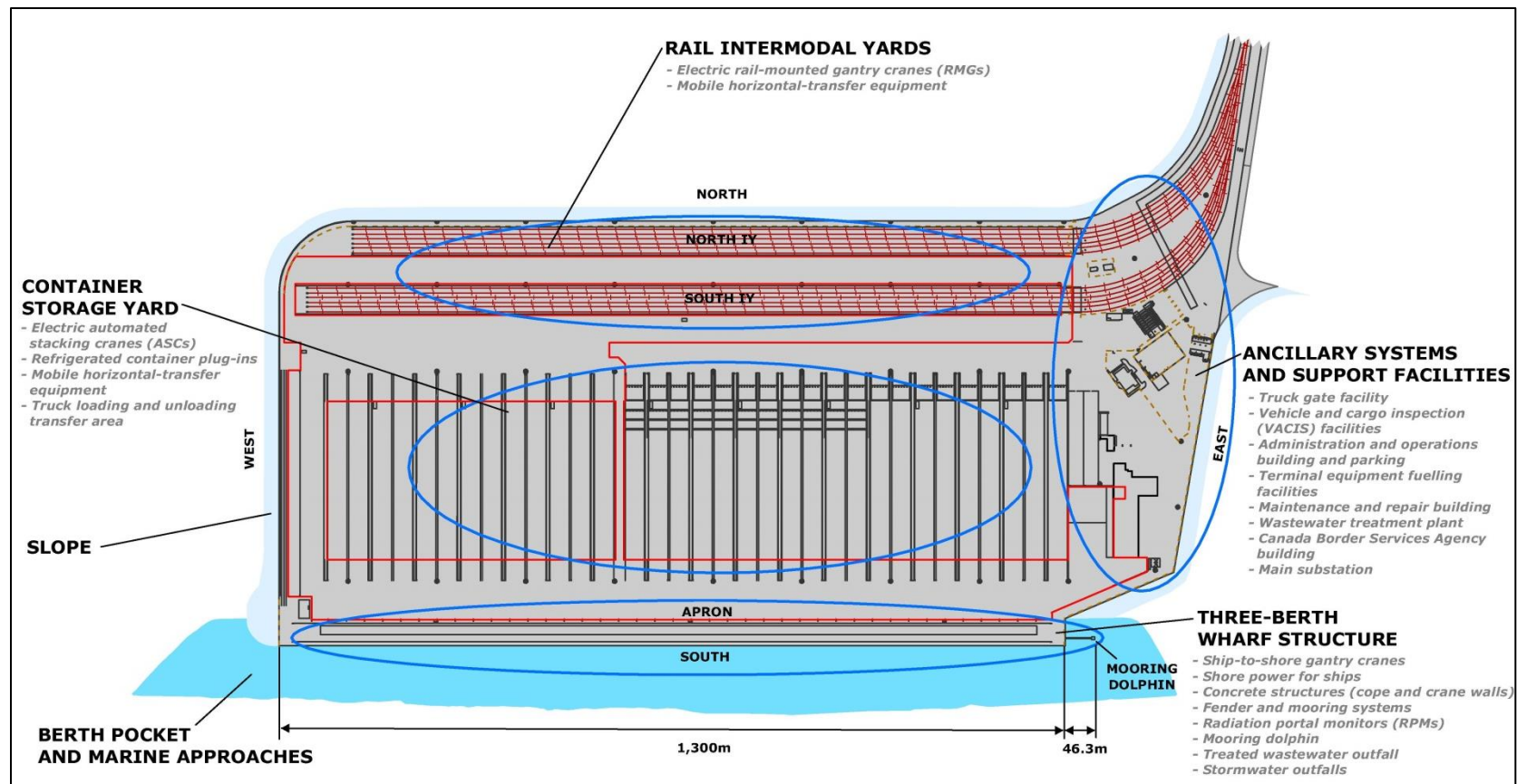


Figure 2-5 RBT2 Berth Arrangement

### 2.1.5 Route Description and Approach Characteristics

Deep sea vessels, including container ships bound for RBT2, enter and exit the Strait of Juan de Fuca north of Cape Flattery, see **Figure 2-6**. The route to RBT2 follows the main route for deep sea vessels travelling to Vancouver and other regional ports. The main restriction on vessel navigation is sufficient draught. While potential new container ships are some of the longest vessels in the world, even very large container ships have relatively low draughts (12 m to 15 m) compared to large tankers and bulk carriers (17 m to 18 m). Container ships travelling at normal transit speeds have good manoeuvrability compared to bulk carriers and tankers and will not have difficulty navigating these routes. Container ships travelling to Roberts Bank along these routes will not create nor be exposed to hazards different from other vessels in the region.

Once in the Strait of Juan de Fuca, inbound ships proceed eastward, travelling in vessel traffic lanes under the management of the Canadian Coast Guard operated Cooperative Vessel Traffic Service (CVTS), until they are south of Race Rocks at the southern end of Vancouver Island. There they separate from US-bound traffic and head north towards Victoria, again in lanes managed under the CVTS. South of Victoria, at the Brothie Ledge pilot station, inbound ships pick up a BC Coast Pilot for the onward journey. The ships travel east, then north through Haro Strait, turn northeast at Turn Point, again a Precautionary Area<sup>1</sup> where tidal currents are considerable, into Boundary Pass where they travel approximately 12 NM to enter the southern Strait of Georgia between East Point on Saturna Island in Canada and Patos Island to the south in the United States. The voyage is primarily in protected waters as ships pass through the channels of the Canadian Gulf Islands and American San Juan Islands. Wind and wave conditions are generally mild, but tidal currents - especially near Race Rocks and in the vicinity of Turn and East Points - are large enough to influence deep sea vessel operations (Pacific Pilotage Authority 2010).

Once past East Point, the waters open up and container ships bound for Roberts Bank start to deviate from the general deep sea vessel traffic bound for terminals in the Fraser River, Burrard Inlet and points north and west. Historical Automatic Identification System (AIS) data (MarineTraffic 2012) shows that containerships typically head straight towards Roberts Bank terminals while other vessels align with the vessel traffic lanes.

Similar patterns are found for vessels departing Roberts Bank. Utilising a direct route to Boundary Pass permits a more gentle turn as the pass is entered, which is preferred by masters of relatively **tender** container ships to minimise heel (PMV 2013e). After entering Boundary Pass, outbound vessels travel a parallel route to the inbound vessels, located on the northern and western sides of the traffic lanes. This puts them closer to Canadian shores in general than the inbound vessels.

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<sup>1</sup> In the CVTS definitions a precautionary area is a routing measure comprising an area within defined limits where ships must navigate with particular caution and within which the direction of traffic flow may be recommended.

As the container ships bound for RBT2 or Deltaport and the bulk carriers bound for the Westshore Terminals approach Roberts Bank, they pass the BC Ferries Terminal at Tsawwassen. BC Ferries operates on routes that travel southwest to Active Pass and northwest to Duke Point on Vancouver Island. Once past the ferry traffic, the container ships and bulk carriers are met by tugs approximately 1 NM (1.85 km) offshore to begin berthing manoeuvres.

Vessels not bound for Roberts Bank continue northwest past Sand Heads under management of CVTS in the traffic lanes centred about 3 NM (5 km) off the existing terminal.

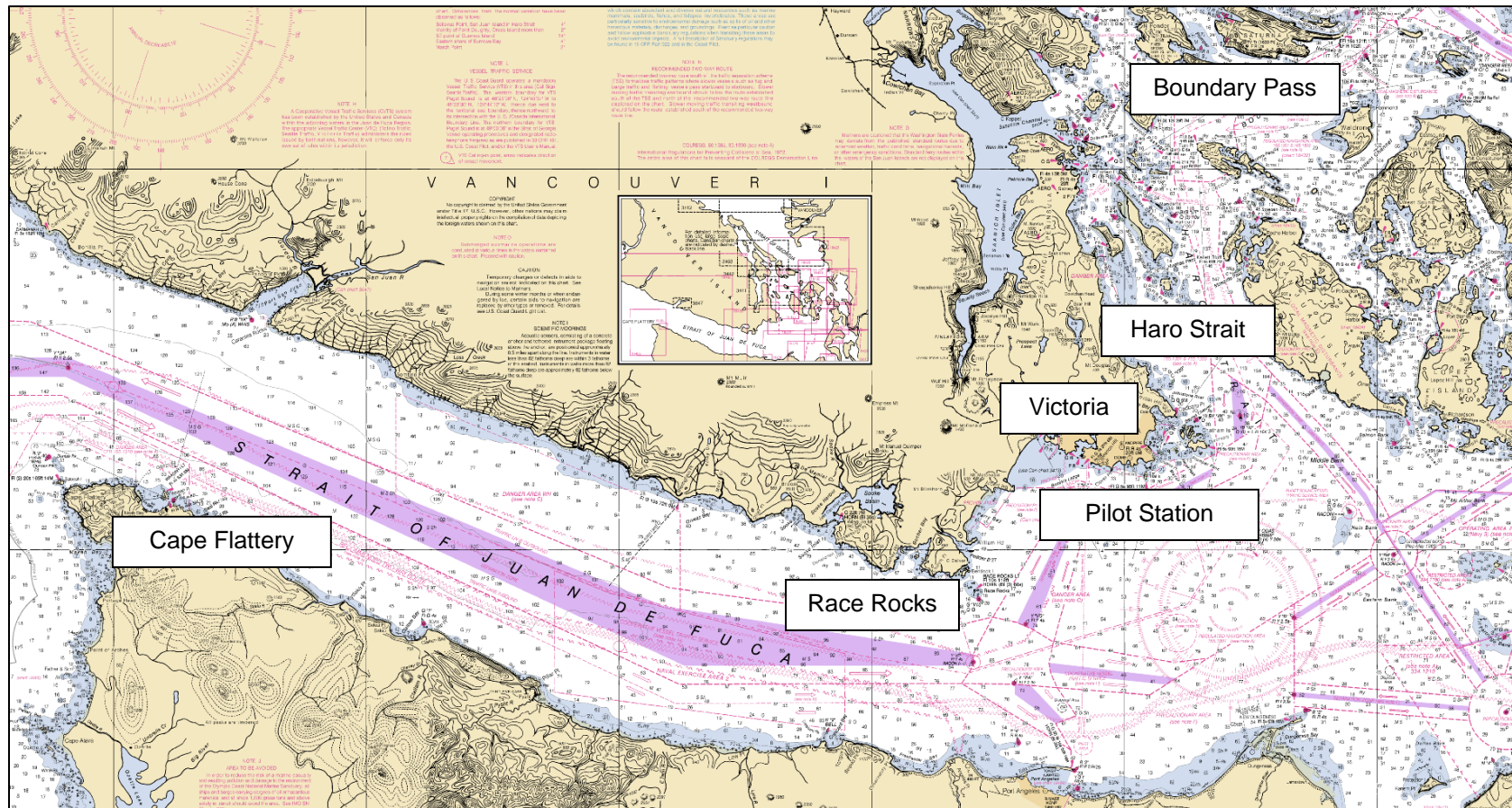


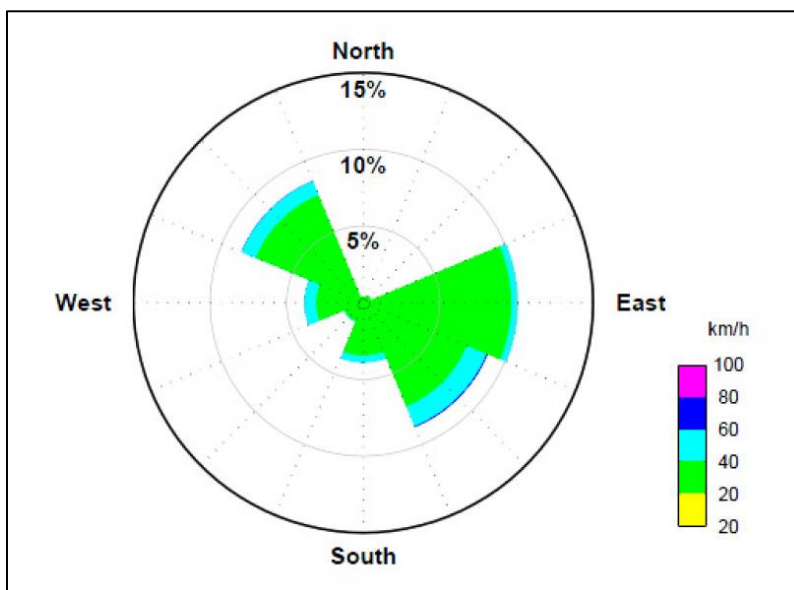
Figure 2-6 Strait of Juan de Fuca Approach

### 2.1.5.1 Description of Shore in the Southern Strait of Georgia and Approaches

The Roberts Bank terminals consist of a man-made structure constructed on the sand and mud banks of the Fraser River estuary. The shoreline of the southwest side of the Strait of Georgia and the shores of Boundary Pass and Haro Strait are primarily rocky, often with submerged or partially submerged reefs. Soft-substrate beaches, minor deltas, and sandbars occur as small, geographically isolated features that comprise a very small portion of the overall length of shoreline.

### 2.1.5.2 Winds, Waves and Currents

The winds in the southern Strait of Georgia are dominated by two wind directions as shown in **Figure 2-7** (WorleyParsons 2014). These wind directions are aligned with the berth face at RBT2 whereas for Deltaport they are perpendicular to the berth.



**Figure 2-7** Wind Speed and Direction Rose for Sand Heads, 01-May-1967 to 02-Feb-2011

Tidal currents at RBT2 also align with the berth face as shown in **Table 2-1** (AECOM 2012).

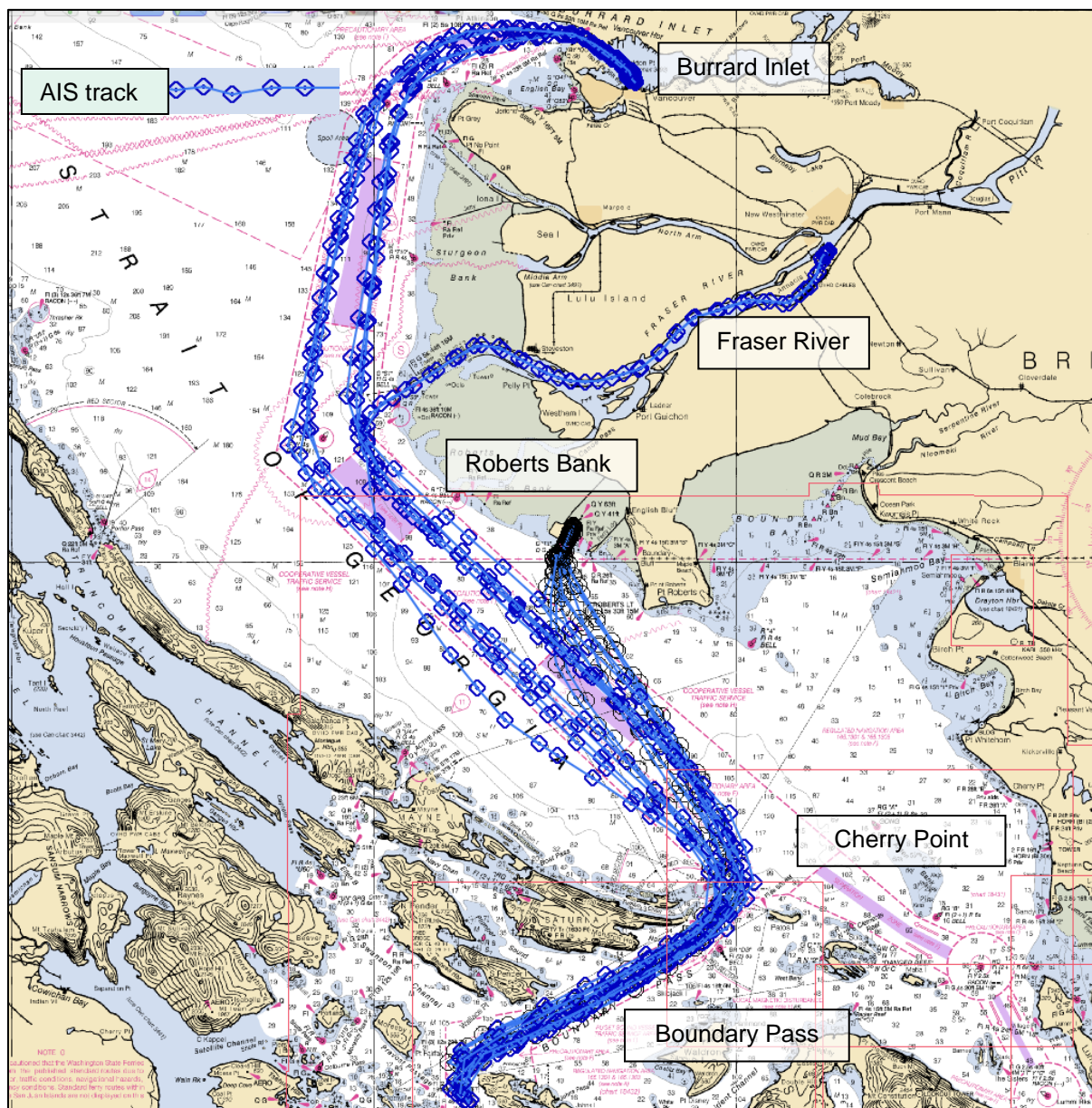
**Table 2-1** Tidal Current at RBT2

Phase	Velocity (knots)	Velocity (m/s)	Direction
Flood	2.0	1.03	WNW, aligned to berth face
Ebb	1.5	0.77	ESE, aligned to berth face

Tidal currents in the southern Strait of Georgia, especially in the vicinity of East Point and Turn Point at the eastern and western ends of Boundary Pass respectively (see **Figure 2-8**), play a role in vessel manoeuvring.

### 2.1.5.3 Container Ship Routes in Region

Container ships travel not only to Roberts Bank terminals, but also to other terminals within PMV Navigation jurisdiction (**Figure 2-8**). All share the approach through Boundary Pass. In 2012, container ships bound to Roberts Bank terminals represent between 2 to 3% of the large vessel traffic in the waterway. In the period 2021 to 2030 with RBT2, this is predicted to increase to between 4 and 5%. Container ship routes to and from Roberts Bank terminals and other terminals are not tightly bound by traffic lanes in the southern Strait of Georgia.



**Figure 2-8 Sample Container Ship Routes to Roberts Bank, Fraser River and Burrard Inlet Terminals in 2012<sup>2</sup>**

<sup>2</sup> [www.MarineTraffic.com](http://www.MarineTraffic.com), AIS data for 2012

#### **2.1.5.4 Sailing Strategy at Roberts Bank**

The Fast-time Ship Navigation Simulation Study (AECOM 2012) outlines the normal operational procedures for arrival or departure of a vessel to or from RBT2. Based on the information provided by local pilots, the potential sailing strategy for RBT2 is summarised as follows.

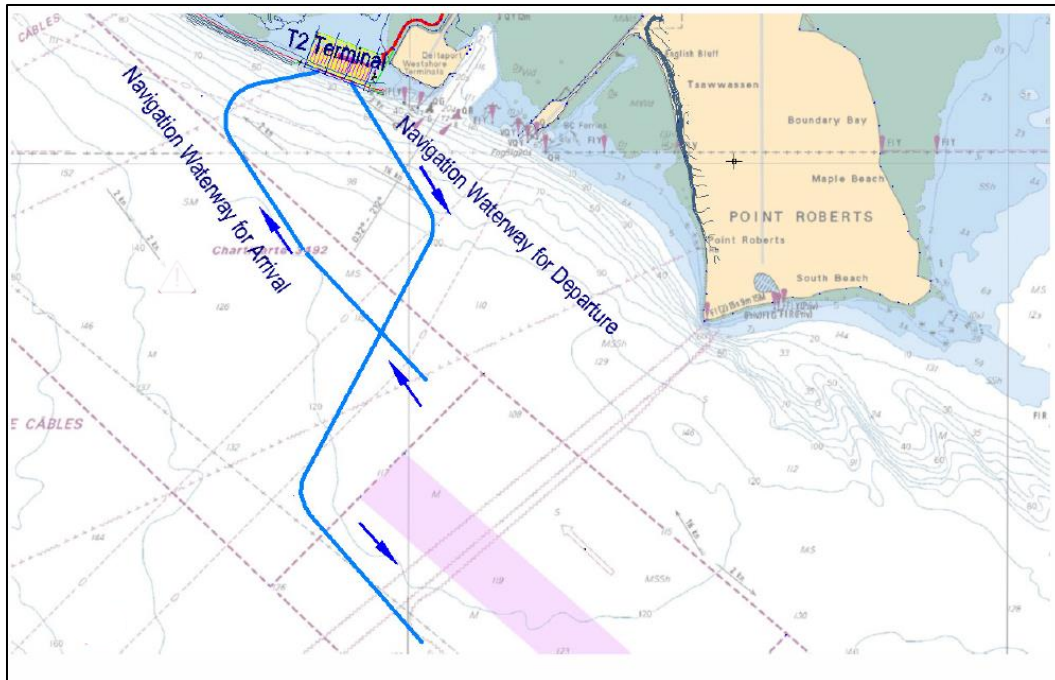
##### Arrivals:

The container ship starts arrival maneuvering while still in existing vessel traffic lanes, (**Figure 2-9**). For its next maneuver, the vessel moves out of the existing main waterway and makes a slow turn into the arrival area accompanied by tugs. The arrival maneuvering starts approximately a mile or more offshore where tugs (with bollard pull capacity of 75 tonnes to 80 tonnes each) meet the vessel, positioning one each at the forward and aft, starboard quarters. The tugs are connected to the vessel and slow it down. The tugs remain connected to the vessel and proceed up the vessel traffic lanes to the northwest of the terminal, and in the second maneuver, make the turn and move the vessel into position for berthing. In this last stage, the vessel is almost completely under control of the tugs. The general approach path and actual number of tugs would vary, depending on the ship size, current, wind, and wave conditions.

##### Departures:

Vessel departure is relatively simple considering the shipping lanes are very accessible from the site. However, the actual departure path is dependent on the ship size, current, wind, and wave conditions. Once the vessel is pulled clear of the berth by tugs, it can start to accelerate to a safe maneuvering speed. The tugs are released soon after the vessel reaches a safe maneuvering speed for the conditions, and the vessel then proceeds to sea under its own power. The only foreseen restrictions would be the limitations imposed by the tug's operational capabilities and severity of the environmental conditions. In severe environmental conditions, a tug escort may be required for a longer duration and distance.

For both arrival and departure maneuverings, safety margins for related operations are typically defined that allow enough time and/or clearances to respond to unforeseen situations.



**Figure 2-9 Proposed Initial Navigation Waterways for Terminal Vessel Arrival and Departure (AECOM 2012)**

Although the Fast-time Ship Navigation Simulation Study suggests that departing ships will head offshore to enter the traffic lanes (**Figure 2-9**), historical AIS data and pilot input indicate that they will likely head more directly to Boundary Pass, similarly to vessels using Deltaport. This is the assumption made in subsequent simulations, however details of the approach do not impact the results of the study.

#### **2.1.5.5 Comparison to Deltaport**

RBT2 would be located on the same artificial peninsula as Deltaport, yet these two terminals have some distinct differences. The RBT2 berth face would have an open approach that is relatively exposed compared to Deltaport and thus, would be subjected to more wave action. This negatively impacts the weather-related restrictions on operations. Wind and tidal currents are largely aligned with the RBT2 berth face, which helps in manoeuvring. In contrast, Deltaport is located at the end of a narrow approach that is perpendicular to the prevailing wind and current directions. High windage vessels such as container ships are more difficult to handle in cross winds. Furthermore, in times of high current, the entrance to the narrow approach requires careful navigation.

## **2.2 TEMPORAL SCOPE**

As noted in the definition of the study area, this study's main focus is the potential change in incidence of accidents associated with the incremental increase in ship movements and port activities related to RBT2. A basis of comparison is necessary to assess these changes. Thus, existing conditions representing current vessel traffic is used to establish current accident incidence and the immediate consequences of these accidents. A horizon year must also be designated that defines when the new terminal is fully operational so the changes can be assessed in the context of a future year with and without the Project, to determine the incremental change that can be attributed to RBT2.

The IP in this analysis relies heavily on vessel traffic tracked via AIS data. At the time of this study, 2012 represented the most recent complete year for AIS data for establishment of existing conditions.

Changes to marine risk related to RBT2 are predicted and characterized for the year 2030, the horizon year selected to assess the changes once RBT2 is fully operational. Although RBT2 would have full container capacity by 2024, other projects in the Vancouver region will be completed in the 2028 to 2030 period (PMV 2013a). As the incidence of accidents is related to not only to RBT2 bound traffic, but also to the impact of changes in other traffic, the year 2030 was chosen as it is anticipated that all foreseeable improvements and expansions to marine facilities would be functioning by then.

To assess the incremental increase in risk, it is necessary to have projections of accident incidence with and without the existence of RBT2. Vessel traffic in the region, and thus, accident incidence, is also a function of the existence of potential marine facilities other than RBT2. The influence that the addition of RBT2 has on accident incidence is dependent upon the background level of traffic assumed. For this reason, four future projections for vessel traffic are made in addition to the year 2012 to enable comparisons against different background vessel traffic levels. These five scenarios are described in the following section.

### **2.2.1 Vessel Population Scenarios for Projection Year 2030**

The five vessel population scenarios provide the information necessary to assess the incremental risk associated with increased container ship traffic due to RBT2, in comparison to the risks associated with existing vessel traffic and traffic increases through 2030 from facilities other than RBT2. The scenarios are:

- The first scenario is the year 2012 which represents existing conditions for the vessel traffic study;
- The second scenario represents a case without RBT2 in the year 2030. This scenario has no new facilities other than Deltaport and Westshore Terminals volume increases, including Deltaport volume increases associated with the Delta Terminal Road and Rail Improvement Project (DTRRIP);

- The third scenario adds the RBT2 container ship traffic to the preceding second scenario in the year 2030;
- The fourth scenario is without RBT2 but includes the addition of all reasonably foreseeable future marine facilities in the area and associated vessel traffic in the year 2030; and
- The fifth scenario adds the RBT2 container ship traffic to the preceding fourth scenario in the year 2030.

Based on these scenarios, the incremental risk associated with the addition of container ship traffic at RBT2 can be computed for the two background levels of vessel traffic, and also compared to the existing level of risk. Since not all potential new facilities included in the high level background are certain, the actual incremental change associated with completion of RBT2 is likely to be between the incremental change estimated for the low and high estimates

### 2.2.2 Temporal Influence of Key Regulations

Over time, the incidence of accidents from vessel traffic is also influenced by regulations affecting the shipping industry. In particular, two International Maritime Organization (IMO) regulations have had or should have an impact on accident rates, and on the probability of a spill from a ship fuel oil tank. The first is the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) which sets qualification standards for masters, officers, and watch personnel on seagoing merchant ships. STCW first entered into force in 1984, with extensive amendments introduced in 1995 that entered into force in 2002; and additional amendments that entered into force in 2012 (IMO 1995). The influence of this regulation is seen in the accident rates developed in this study. The second IMO regulation is the protective location of fuel tanks requirements (IMO 2010) that became mandatory for ships constructed after January 2010. This amendment to the IMO Marine Pollution Prevention Regulations (MARPOL) (IMO 2008) provides requirements for protection of fuel tanks from impact accidents and is largely complied with by the use of double hull structures around fuel tanks. In addition, the regulation sets maximum fuel tank size to 2,500 m<sup>3</sup>. The further in the future the year chosen for risk assessment is, the greater the proportion of the vessel fleet that will have been built in compliance with this regulation. In 2030, twenty years after the MARPOL amendments came into force; virtually all container ships calling at RBT2 would be in compliance. Earlier years would have lower compliance ratios. The same number of container ships could call at RBT2 in 2025 as in 2030, however, with a different size and age breakdown. In 2025, a greater proportion of the container ships calling at RBT2 would not have protected fuel tanks. This is discussed further in **Section 3.5.2.1, Year 2025 Incidence and Release Amounts of Impact Spills In-Port.**

## 2.3 STUDY METHODS

Development of the IP and the corresponding prediction of spill amounts and locations involved several steps as listed in **Section 1.2.1**, Marine Vessel Incidence Prediction Inputs to the Quantitative Risk Assessment including:

1. Identification of Hazards and Accident Types;
2. Identification of Existing Risk Mitigation Practices;
3. Development of Vessel Traffic Affected;
4. Development of Accident Rates;
5. In-Port Accident Incidence Prediction, including resulting spill amounts; and
6. In-Transit Accident Incidence Prediction, including resulting spill amounts.

The methods used in these steps are described in the following sections.

### 2.3.1 Identification of Hazards and Accident Types and of Existing Risk Mitigation Practices

Hazard and accident type identification is a key part of risk management methodologies. The sources used to identify the hazards associated with the incremental increase in ship movements and port activities due to RBT2 include:

- Analysis of historical events via interrogation of incident, accident and **casualty** databases. Key sources for this included the Transportation Safety Board of Canada (TSB 2013) and Information Handling Services (IHS) Sea-web database (IHS 2013);
- Review of literature and other QRAs including the Aleutian Islands comprehensive risk assessment special report (Transportation Research Board of the National Academies 2008), the Fraser River Tanker Traffic Study (Det Norske Veritas, (DNV) 2012a), the Prince Rupert Marine Risk Assessment (DNV 2012b), the Enbridge Northern Gateway Project (DNV 2010b) and a regulatory assessment of the use of tugs to protect against oil spills in the Puget Sound area (HEC 1999); and
- Professional experience of PMV, stakeholders, experts and the study authors, solicited at a Regulators and Stakeholders workshop (PMV 2013f), a Navigational Expert Panel web meeting (PMV 2013e), and through personal communication.

Root causes of shipping accidents include events such as severe weather, mechanical failure or human error. These result in incidents that may lead to an accident. This IP evaluates the rate of container shipping accidents, not the root causes of these accidents.

Hazard identification in container ship operations has been performed formally at an international level by the Marine Safety Committee of the International Maritime Organization (IMO) in their Formal Safety Assessment (FSA) of Container Vessels (IMO 2007). The FSA identified the following accident categories; collision, contact (allision), grounding, fire/explosion, machinery damage, hull damage,

foundering, and miscellaneous. Accidents are categorised by end result, thus, accidents leading to grounding for example are classified as such even if machinery damage was possibly a contributing factor. Machinery damage was only reported when it did not lead to another accident category. In the FSA, the miscellaneous entries are mostly related to container losses and pollution, often coupled with bad weather conditions. These categories have been used as the basis of this analysis. Some accidents of the various types are reviewed in the following section.

Addressing root causes is an approach for reducing probabilities of accidents, leading to mitigation of risk. Mitigation also occurs through addressing the consequences of accidents. These root causes are addressed in the European Union project SAFEDOR (2005).

Identification of existing risk mitigation practices (Current defences in the PRMM) helps place the operations of container ships in the context of global operations for comparing local and regional accident rates to global rates. Similar procedures to identifying hazards have been used including:

- Review of navigational procedures e.g., Fast-time Ship Navigation Simulation Study (AECOM 2012);
- Interrogation of Regulators and Stakeholders and Experts (see above);
- Review of other QRAs (see above);
- Professional experience of commercial naval architects involved in the design and modification of container ships.

### 2.3.2 Projection of Vessel Traffic Affected

The increased demand for containerised trade introduces new vessels into the marine vessel traffic in the region. This impact is felt not only immediately by the other Roberts Bank terminals traffic, but also by the marine vessel traffic travelling to and from other terminals and ports in the Vancouver region. The steps in the projection of the vessel traffic affected were:

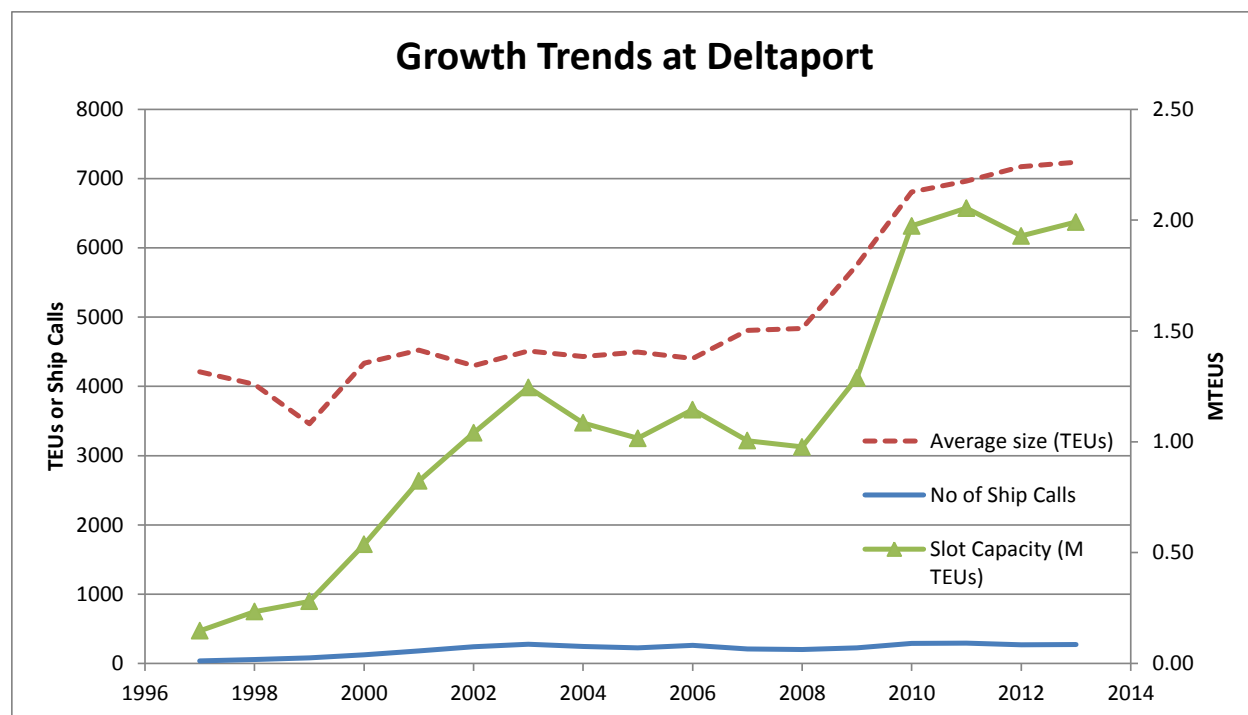
1. **Projection of Container Ship Traffic at Roberts Bank Terminals.** This step used information gathered from PMV ship call data, world fleet developments and projections for the CCIP to develop the container ship traffic associated with RBT2. This projection is described in **Section 2.3.2.1** below;
2. **Projection of Bulk Carrier Traffic at Westshore Terminals.** This step used information provided by Westshore Terminals (2013) to develop coal throughput and resulting vessel sizes;
3. **Definition of Vessel Types of Interest.** AIS data and PMV ship call (PMV 2013b) data were used to determine the vessel types interacting with RBT2 containership traffic;
4. **Development of 2012 Existing Conditions Traffic.** AIS and PMV ship call data provided the basis for the 2012 existing conditions traffic. This includes vessel types, times in the region, and location in the waterway; and

5. **Prediction of Vessel Traffic in 2030.** This step involved the projection of historical vessel traffic volumes, along with incorporation of predictions of future vessel traffic associated with potential marine facilities and activities. A screening process, see **Section 2.3.3** Development of Vessel Population Scenarios, was used to evaluate which new marine facilities to include in the projected 2030 traffic.

#### ***2.3.2.1 Projection of Container Ship Traffic at Roberts Bank Terminals (Deltaport and RBT2)***

The existing container ship terminal at Roberts Bank, Deltaport Terminal (Deltaport), has the container capacity of approximately 1.8 million twenty foot equivalent container units (TEU) (PMV 2015a). Container ship capacity is typically given in quantity of TEUs that can be carried. In practice most containers are 40 ft. in length and are the equivalent of two TEUs. One component of the Container Capacity Improvement Program, the Deltaport Terminal Road and Rail Improvement Project (DTTRIP) to increase capacity to 2.4M TEUs is anticipated to be completed in 2017. The proposed container capacity for RBT2 in 2030 is also 2.4M TEUs. In 2012, there were 269 container ship arrivals at Deltaport (PMV 2013b). Of these, 202 ships were in the 8,000 to 10,000 TEUs range, the remaining were below 8,000 TEUs.

Worldwide, and within the Vancouver region, economies of scale have led to an increase in container ship size. These larger ships are more efficient in both container handling and in terms of fuel cost per container shipped. The average container ship capacity at Deltaport was about 7,000 TEUs in 2012 in comparison with approximately 4,500 TEUs in 2000 (PMV 2013b). Slot capacity (ship capacity multiplied by number of calls) has also increased dramatically (**Figure 2-10**).



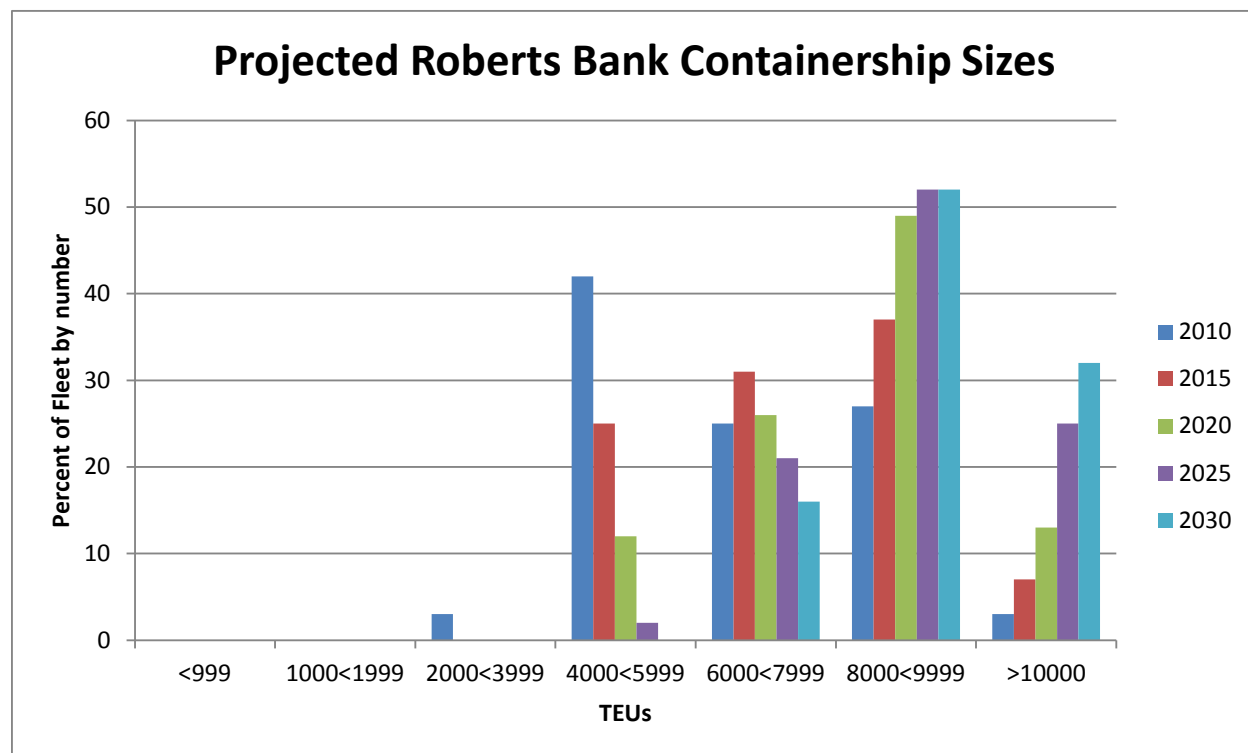
**Figure 2-10 Growth Trends at Deltaport Terminal**

The maximum vessel size that could call at RBT2 is based upon the Maersk “Triple-E” size which can hold approximately 18,000 TEUs, while currently typical ships calling at Deltaport are 8,000 to 10,000 TEUs, characteristic of the larger end of the Post Panamax Plus size range (see **Appendix A: Figure A-1**) (PMV 2015b).

Based on historical trends in fleet management, it is expected that - as the newest, largest ships (18,000 TEUs) get put into service on the Asia/Europe routes - the next ship size down (12-15,000 TEUs) will begin to visit the mid-size ports, such as Vancouver. Container ships travelling to RBT2 are generally calling at other ports on the North American west coast, so constraints on vessel sizes from these ports also influence ship sizes at RBT2.

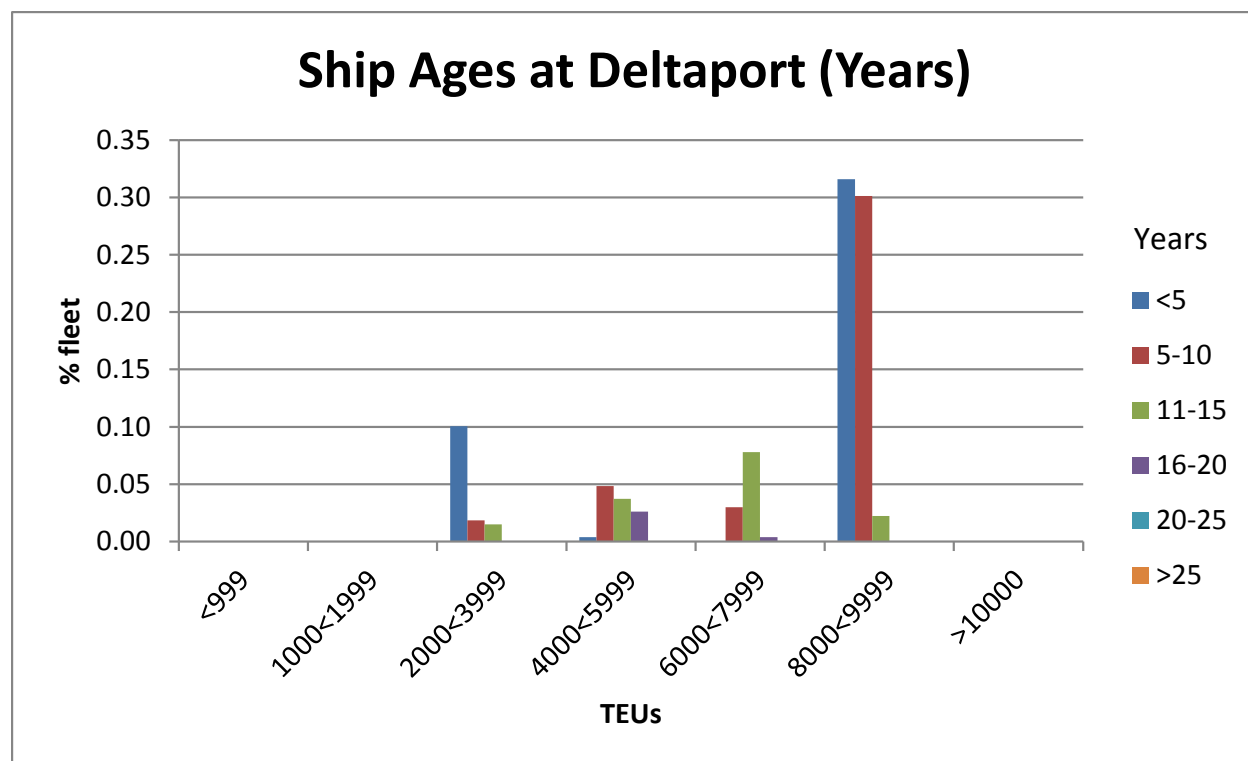
As part of pre-planning for CCIP, the estimated number of ship calls and size breakdown for Deltaport was evaluated (WorleyParsons 2011). This estimate also forms the basis for the projected number of ship calls at RBT2 (see **Section 3.3.6**, 2012 Existing Conditions and 2030 Vessel Traffic Projections for Westshore Terminals and Roberts Bank Container Terminals). Projection of ship types and populations 15 to 20 years into the future is uncertain. Twenty years ago the advent of 18,000 TEU ships was not foreseen. The uncertainty in these projections is further discussed in **Section 2.4.5**, Approaches to Assessing Data Sparseness, Uncertainty and Sensitivity. Variability in these numbers is included in the uncertainty modelling. Projections for Deltaport to 2030, and thus, for RBT2, are shown in **Figure 2-11**.

The container ship fleet currently calling at Deltaport is relatively young: the average age in 2012 was 6.1 years. The average age of container ships globally in 2007, according to the IMO FSA, was 11.6 years old, which is considered young compared to other vessel types. The distribution of ship ages by vessel size category is illustrated in **Figure 2-12** which shows that all ships were less than 20 years old. This study makes the assumption that this will also be true in 2030 and thus, all container ships calling at RBT2 will be subject to IMO Bunker Tank<sup>3</sup> protection requirements that became mandatory in 2010. Maximum fuel tank size under the IMO requirements is 2,500 m<sup>3</sup>.



**Figure 2-11 Projected Roberts Bank Container Ship Sizes**

<sup>3</sup> IMO, Regulation 12A to MARPOL Annex I. 2010



**Figure 2-12 Container Ship Ages by Vessel Size Category at Deltaport**

Container ships are generally sized in terms of TEU. There is a good correlation between vessel displacement (i.e. the actual weight of water the vessel displaces) and TEU. This is shown in **Appendix A: Figure A-2**.

### 2.3.3 Development of Vessel Population Scenarios

Vessel type categories and general usage, based upon PMV traffic data and adapted from Aleutians Islands Risk Assessment Phase A Traffic Study (Det Norske Veritas (DNV) 2010a), are shown in **Appendix B: Table B-1**.

Container ship traffic related to RBT2 will interact with other traffic in the region. Vessel population projections for the five scenarios are made in the context of vessel traffic related to new marine facilities projects and projected growth in the region. These projections are used in the IP to estimate the increased interaction with other vessels and to estimate the rates of accidents with and without RBT2 to put the risks associated with RBT2 in context of overall marine vessel traffic risk.

The screening criteria for including the effects of other marine facilities were:

- Documented additional cargo amounts or ship calls available – Included;
- Documented information indicating that additional ship traffic is not anticipated – not Included; and
- Information on cargo amounts or ship calls or project feasibility incomplete or not available – not Included.

The potential marine facilities projects that are considered to have potential impact on the marine vessel traffic and are selected for inclusion in the vessel population scenarios are listed in **Appendix B: Table B-1**. A net of 1,191 additional ship calls per year is associated with these facilities. Details of the selection rationale are provided following the table. The projects selected for inclusion are:

- Fraser Surrey Docks Direct Coal Transfer;
- Richardson Grain Elevator;
- Neptune Terminals Coal Expansion;
- Vancouver Airport Fuel Delivery Project;
- Kinder Morgan Trans-Mountain Pipeline Expansion Project;
- Gateway Pacific Bulk Terminal; and
- Pacific Coast Terminals.

#### **2.3.4 Development of Accident Rates**

Rates of accidents of various types are necessary to evaluate the incidence of accidents with the potential to damage the environment.

Accident rates for the Vancouver region were developed on the basis of incident and casualty data from several sources, including the TSB, Canadian Coast Guard, Pacific Pilotage Authority and IHS Sea-Web databases. Local incident rates have been compared to regional and worldwide data to assess the applicability of worldwide data to the Vancouver region. RBT2 traffic will only be container ships and thus, the most relevant comparison is to worldwide rates for container ships.

In particular, use has been made of hazard identification and accident rates developed for the IMO FSA of container vessels (IMO 2007) - including recent updates (GL 2013). These are referred to in this report as the **updated IMO rates**.

The steps in the development of the accident rates used in the analysis were:

1. **Collection of local incident data** and conversion into incident rates, as described in Data Analysis **Section 2.4.1**, Analysis of Incident and Accident Data for the Vancouver Region and **Appendix C**, Vessel Incident Analysis for Vancouver Region. This step included developing post-STCW incident rates for the Vancouver region;
2. **Collection of global container ship accident rates**, see **Appendix D**, Update of IMO FSA Container Ship Accident Rates. This step used the GL update to the IMO data to develop lower bound, mean, and upper bound accident rates for container ship accidents for the post-STCW period;
3. **Conversion of local incident rates into accident rates utilizing globally based relationships**. This step used factor from the original IMO FSA to convert incident rates into accident rates as described in **Section 2.3.4.1** below;
4. **Adjustment of global accident rates based on ship years to account for exposure factors**. This step adjusted the global rates that are based upon ship years to account for the fact that not all accident types are possible throughout a year of ship operations. This adjustment is described in **Section 2.3.4.2** below;
5. **Comparison of local to global accident rates**. In this step, the Vancouver regional rates were compared to the updated IMO rates. This comparison is made in Results **Section 3.4.2**, Comparison to World and Regional Rates; and
6. **Selection of accident rates to implement in subsequent analysis**.

#### ***2.3.4.1 Conversion of Local Incident Rates into Accident Rates***

In this analysis, the Vancouver region incident rates are for all **piloted** vessels rather than just container ships because of the relatively small sample set of container ships. Further, the raw incident rates in the Vancouver region include serious and non-serious events, whereas the GL update to the IMO data includes only serious accidents. Accidents are defined by the International Association of Classification Societies (IACS) as “serious” based on these criteria: total loss (vessel ceasing to exist after casualty due to it being unrecoverable or being broken up); breakdown resulting in the ship being towed or requiring assistance from ashore; flooding of any compartment; or structural, mechanical, or electrical damage requiring repairs before the ship can continue trading.

For comparison with the GL updated rates, the Vancouver region post-STCW incident rates were adjusted by the percentages in **Table 2-2**, from the original IMO FSA, by incident type to reflect the rate of “serious” incidents to total incidents. The incident rates scaled by the seriousness factor are considered accident rates for comparison to the updated IMO rates.

**Table 2-2 Reported Serious Incidents with Container Ships Worldwide 1993 to 2004**

Incident Type	Total Number	Serious Number	% Serious
Collision	493	78	16%
Allision	112	15	13%
Grounding	210	64	30%
Fire/Explosion	109	44	40%
Foundering	2	2	100%
Total	926	203	22%

#### **2.3.4.2 Adjustment of Ship Year Based Rates for Exposure Factor**

The updated accident frequency rates for container ships are based on ship-years and have been developed by dividing the number of reported accidents by the number of ship-years in the study. To compare to rates in the Vancouver region, a correction for exposure time must be made. Further, since the possibility of certain accident types is not uniformly distributed throughout the ship's voyage, the annual rates must factor in the period per year when the accident is possible. For example, an allision is almost impossible at sea. Thus, this study has adjusted the annual rates by the ratio of time the accident type is possible (referred to as **exposure factor** in subsequent sections). All adjustments are subject to uncertainty and are treated as random variables. The adjustment amounts are as follows:

- Allisions – IMO in their FSA estimate that 99% of allisions occur in port or restricted waters. PMV ship call data (PMV 2013b) shows that container ships spend about 1% of a year at the berth or maneuvering during berthing for each arrival at a PMV terminal. Typical container routes include several ports, typically 8 to 10, as indicated in the PMV container service maps (PMV 2013c) indicating a port time ratio of about 10%. Container shipping to PMV is primarily trans-Pacific service and thus has a relatively low port time percentage. It is assumed that more general container ship operations have 20% port time. This is supported by IHS Sea-Web data for fires and explosions (F/E). This study makes the assumption that F/E events are caused by factors that are largely independent of whether the ship is at sea or in port. Thus, assuming the rate of F/E is constant; the number of in-port F/E accidents is proportional to the time in port. The IHS Sea-web container ship casualty data for F/E for 1995 to 2013 shows that this rate is 22%. This is consistent with the choice of 20% port time. This study assumes this to be uncertain with a range of 15% to 25% in subsequent IPs;
- Collisions – An exposure ratio of 20% for tankers based upon correcting for voyages including congested has been accepted in a previous TERMPOL submittals to Transport Canada (DNV 2010b). Container ships and tankers spend similar amounts of time in port per voyage, but container ships are roughly 1.5 times as fast in transit. Further, this report assumes container ship traffic includes more short duration voyages. This is based in part upon the average number of port calls per year for container ships being larger than that for tankers<sup>4</sup>. Thus, it is estimated that the exposure ratio for container ships is 30%. This study assumes this to be uncertain with a range of 20% to 40% in subsequent IPs;

<sup>4</sup> The PMV service container maps and Gkonis and Psaraftis (2009) both indicate about seven calls per voyage for container ships whereas crude oil tankers more typically make two to three based upon HEC review of crude oil tanker routes.

- Groundings – Exposure ratios of 10% for powered groundings and 15% for drift groundings have been accepted by previous TERMPOL submittals to Transport Canada (DNV 2010b). Groundings are assumed to be 80% powered groundings, 20% drift groundings<sup>5</sup> resulting in a combined exposure factor of 11%. This report assumes these to be uncertain with a range of +/-10% of the base value in subsequent IPs;
- Fire/Explosion – The exposure ratio for F/E accidents is assumed to be 100%; and
- Foundering – the assumption is made that primary causes of ship foundering are associated with heavy seas and thus, foundering does not occur in port or semi-protected waters.

The GL updates to the IMO rates and exposure factors are shown in **Table 2-3**.

**Table 2-3 Updated IMO Container Ship Accident Rates (GL 2013) and Assumed Exposure Factors**

Global Container Ship Accident Rates (per 1000 ship years) and Exposure Factor				
Incident Type	GL Estimated Lower Bound	GL Estimated Mean	GL Estimated Upper Bound	Exposure Factor
Collision	3.00	8.3	11.50	0.30
Allision	0.30	2.3	4.50	0.20
Grounding	1.70	5.4	7.20	0.11
Fire/Explosion	1.00	1.9	3.30	1.00
Founder	0.00	0.1	0.50	0.80

Once the updated IMO rates are adjusted for the exposure rate, they can be compared to Vancouver regional rates per transit by scaling by the time in ship-years per transit. Based on AIS data and PMV ship call data (PMV 2013b), this is determined to be 1% of a ship-year per transit for comparison with local data derived for the four zones described in **Section 2.1.3**, and **Figure 2-2**.

For incident prediction within the Study Area the portion of a ship year is typically shorter and rates are correspondingly smaller. These adjustments are described as they are applied in **Section 3**, Results.

#### **2.3.4.3 Development Fires and Explosions Rates**

Global fire or explosion event rates (GL 2013) are presented in terms of accidents per ship year. However, this implicitly includes the size of the vessels carrying the containers in the rates. As container ships get larger they will carry the same container volume on relatively fewer ships. If the risk is assumed to be associated primarily with the container not the ship itself, then utilising rates based upon number of containers is considered appropriate for future projections. However, there is also risk associated with machinery operations, so the rates are probably influenced by both number of containers and number of ships. Accident rates developed using both approaches are compared in this study.

<sup>5</sup> This is a common approach, most recently used by DNV in the Vancouver International Airport (YVR) QRA for PMV (DNV 2012a).

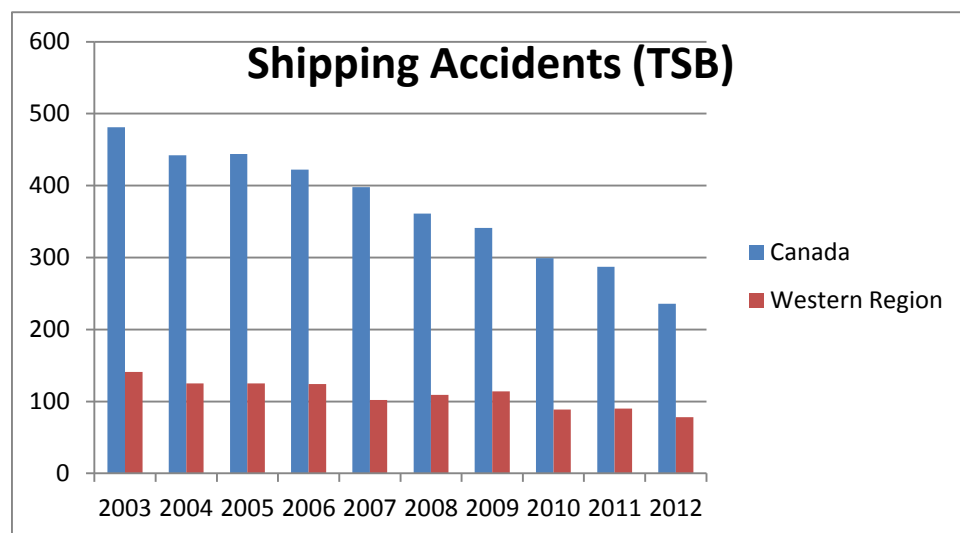
#### 2.3.4.4 Special cases

Two special cases are considered; one case is fishing and recreational vessels and the other is accidents associated with tugs during berthing and maneuvering operations at RBT2. The approaches taken are described in **Section 3.4**, Accident Rates As Implemented in Analysis.

#### 2.3.4.5 Projection of Rate Changes to 2030

The TSB (2012) has found that there has been a statistically significant reduction over time in the number of marine accidents including shipping accidents and accidents aboard ships in Canada. This trend is also clear for shipping accidents alone (**Figure 2-13**). If this linear trend were to continue, there would be no shipping accidents at all in 2022. This seems unlikely, and instead the number might drop to a level that is considered negligible. On the other hand, data for the TSB Western Region shows the reduction in the number of vessels in accidents is largest in accidents involving small ships, i.e. all other than cargo ships, bulk carriers and tankers. For large ships, the number of vessels involved in shipping accidents is small (<15 per year), but there is no clear trend indicating an increase or decrease (**Figure 2-14**).

Further, as illustrated by **Figure 2-15**, the rates for serious incidents for container ships have not decreased recently. On this basis the current accident rates for projections to 2030 are used by this study.



**Figure 2-13 Shipping Accidents (TSB 2012)**

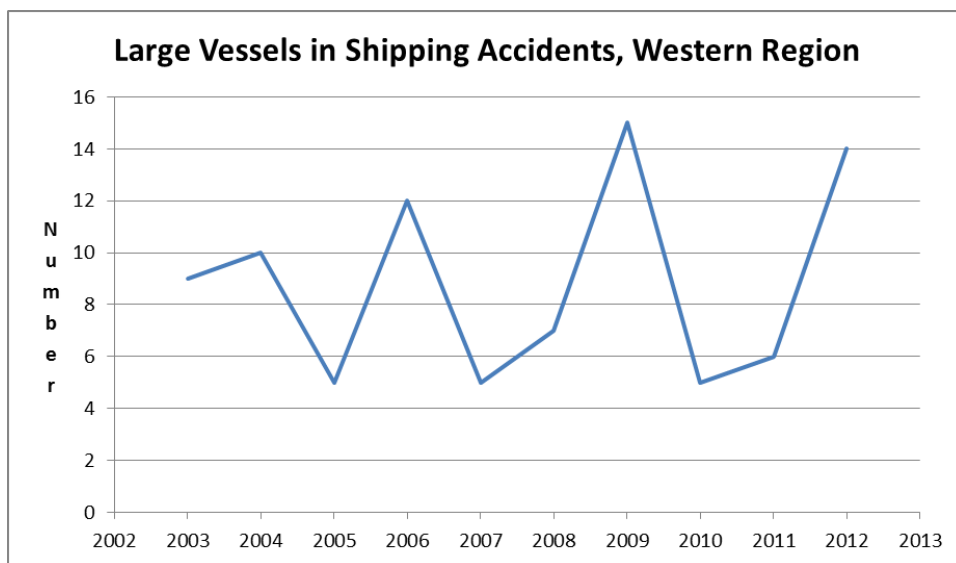


Figure 2-14 Number of Large Vessels Involved in TSB Western Region Shipping Accidents

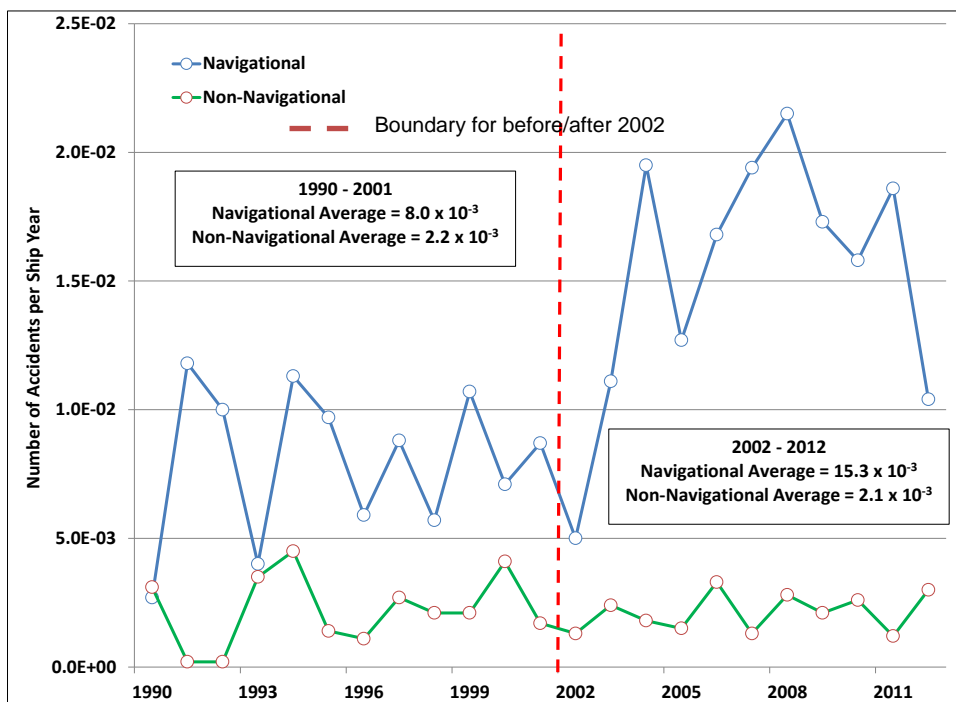


Figure 2-15 Container Ship Navigational and Non-Navigational Serious Accident Frequency

### 2.3.4.6 Changes in Incidence of Accidents Due to RBT2 Bound Container Ships

The incidence of accidents is expected to increase as the number of container ships arriving at Roberts Bank terminals increases. Some accident incidence numbers will increase in proportion to the increasing number of ships. This approach has been used for determining the number of powered groundings, allisions and structural failures. Collisions are expected to increase more rapidly than the rate of increase

in ship numbers, approximately as the square of the relative increase in ship movements (HEC 1999). However, other factors including changes in traffic patterns/destinations and the speed of additional vessels affect this increase. This study simulated the increased vessel traffic by modifying existing, and adding new AIS based vessel tracks, in order to calculate the increased number of encounters and thus, collision incidence rates, see **Section 2.4.3**, Use of AIS Data to Model Vessel Traffic.

The increase in drift grounding is influenced not only by the number of ships, but also by the availability of rescue capable tugs. With the addition of RBT2, the number of rescue capable tugs at Roberts Bank will double. This factor has been evaluated in a simplified drift grounding analysis and found to have a small impact on drift grounding rates.

Incidents involving small craft such as fishing vessels and recreational vessels are assumed to increase with the density of the vessels in a particular area, and the number of container ships transiting the area.

Other accidents, such as loss of containers or their contents during loading and offloading operations, are proportional to the number of containers handled. This study evaluated these incidences on the basis of containers handled.

### **2.3.5 In-Port Incidence Prediction Methods**

In this section, the methods used to evaluate the incidence of accidents In-Port are described. These include methods to evaluate accidents associated with container handling, impacts of ships with other ships or with shore-side facilities, and also releases of oil associated with normal operations.

#### ***2.3.5.1 Modelling Loss Overboard of Containers or Their Contents at the Terminal***

Two approaches to modelling loss overboard due to container handling accidents have been used. Both are based upon the container throughput at the terminal and are independent of the number of ships. The details of the methods are developed below.

#### **Container Losses Based Upon Global Container Loss Rates**

There are various estimates as to the number of containers that fall off of container ships. For example, the Monterey Bay Research Institute claim that 10,000 containers are lost each year – about one every hour (Singularity University 2011). On the other hand, the World Shipping Council (WSC) (2013), a trade organization representing over 90% of the liner shipping industry, and the non-profit National Cargo Bureau (2013) state this figure is a gross exaggeration and that “there have been no comprehensive statistics kept as to the number of containers lost overboard”. Based on their survey, an estimated 350 containers are lost each year, not counting catastrophic events in which 50 to several hundred containers are lost in a single incident. These events are rare, but adding these losses, the average loss per year is approximately 675 containers. Each year, approximately 100 million TEUs are transported worldwide

according to the WSC. A loss of 675 containers would constitute 0.0007% of loaded containers transported. Many of these incidents occur in heavy seas where ships are subject to significant rotational and linear motions. Such heavy seas are not physically possible in the study port or transit area due to the regional topography.

The Maritime Research Institute Netherlands (MARIN) (Koning 2009, 2010) summarised the causes of lost or damaged containers (see **Table 2-4**). The incident types that could conceivably occur in ports during transit or loading/unloading operations are indicated with asterisks (\*).

**Table 2-4 Causes of Container Losses and Damages (adapted from Koning, 2009, 2010)**

Cause	Percentage of Total Incidents	
	All Incidents	Port-Specific Incidents <sup>6</sup>
Speed/Weather	23%	0%
Weather Head/Follow	21%	0%
Twistlocks Failed or Open*	11%	0.11%
Deck Fitting Failure*	11%	0.11%
Internal Shift	9%	0.09%
Crane Operator Error*	9%	9%
Poor Stowage or Planning*	7%	0.07%
Overweight Containers*	6%	0.06%
Roll Motions Follow Sea	3%	0%
Total	100%	9.44%

Given the following assumptions, the likelihood of a container loss at RBT2 was estimated:

- There is a 0.0007% chance per year of a particular individual container being lost;
- Container ships calling at RBT2 spend 1% of their time there per vessel call;<sup>7</sup>
- 1% of the container loss and damage incidents caused by failed twistlocks, deck fitting failure, poor stowage, and overweight containers, are assumed to occur in port;
- Crane operator errors are assumed to occur only in port;
- Overall, only 9.44% of incident causes are applicable to ports; and
- The probability is the product of the overall rate and the percent that occur in port.

<sup>6</sup> Since container vessels spend approximately 1% of their time in port at Roberts Bank, incident types that could happen in port are assumed to occur in 1% of time. The exception is crane operator error, assumed to only happen in port.

<sup>7</sup> Rounded up from a range of 0.5% to 0.63% for berth times at the Deltaport Terminal.

There is therefore, a  $6.6 \times 10^{-7}$  probability of loss or damage of an individual container while at RBT2. The vast majority of container lifts occur on the shore side of the ship or over the ship. Most will not go in the water, but some will spill into the ship or water. Professional opinion (see Clark 2003) indicates that the chance of rupture of a dropped container is 1 in 100 (0.01 probability) per container loss or drop.

### Container Losses Based Upon Risk Assessment for UK Container Terminal

This estimate is based upon a study performed in the UK for a new container terminal (Clark 2003). The rate for a HNS spill is developed using the cargo damaging accident rate (accidents per container handled) and professional opinion from that study, plus the Terminal Systems Incorporated (TSI) data for HNS percentage (see **Appendix B: Table B-4, Composition and Number of HNS Containers at Deltaport in 2012**). This approach indicates a return period of over 50,000 years (**Table 2-5**).

**Table 2-5 Return Period for Container Spill due to Handling HNS Containers at RBT2**

Item	Value	Notes
Number of lifts per year	$1.27 \times 10^6$	Laden containers at RBT2
Cargo damaging Accident Rate	$1.30 \times 10^{-6}$	Accidents per container handled (Clark 2003)
Containers damaged per year	1.65	
Probability of breach	0.01	Professional opinion (Clark 2003)
Breached containers per year	$1.65 \times 10^{-2}$	
Probability of spill entering water	0.1	HEC estimate
Spills into water per year	$1.65 \times 10^{-3}$	
Return period	607	Years
HNS ratio	0.007	
HNS spills in water	$1.15 \times 10^{-5}$	
HNS spill in water return periods	86719	Years

This study has extended this approach using Monte Carlo simulation assuming a +/-20% uniform distribution for the cargo damaging rate, probability of breach and HNS ratio. A 0.01, 0.1, 0.15 triangular distribution was assumed for the 'spill entering water' estimate.

### 2.3.5.2 Impact spills from Container Ships at RBT2

Spills resulting from maneuvering and berthing operations of container ships at Roberts Bank terminals are evaluated for the five vessel population scenarios. These include the possibility of a berthed ship being struck by an incoming or departing vessel, i.e. an allision. Vessels approaching the tug-assist region are considered in the In-Transit analysis.

The evaluations are based upon Monte Carlo simulations of spill events using incident rates and conditional spill probabilities. The approach and assumptions are outlined here. Uncertainty is included in the use of probability distributions for key parameters.

## Probability of Hull Penetration and Bunker Tank Penetration

The probability of impact-related incidents (allisions, collisions, and groundings) resulting in spillage depends on the likelihood of hull and bunker tank penetration leading to leakage. The likelihood of penetration is dependent on the velocity of the vessel(s) at the time of the incident. An allision, collision, or grounding en route is likely to occur at a much higher velocity increasing the likelihood of penetration of the hull and subsequent oil leakage, than an impact-related incident that occurs at a terminal or in more limited waters.

In the Goal-Based Damage Stability (GOALDS) model (Papanikolaou et al. 2013), the probabilities for water ingress (i.e., hull penetration) were noted to depend on the velocity of the vessels at the time of the impact accident. As vessel speeds are lower at terminals, the probability of hull penetration is lower. The average probabilities obtained from the Papanikolaou et al. statistical survey show this (**Table 2-6**). The probability of bunker spillage for collisions, allisions, and groundings is adjusted to reflect the potential for penetration (and water ingress and oil leakage) with differing vessel speeds.

**Table 2-6 GOALDS Model Water Ingress Probabilities**

Operational State	Water Ingress Probability with Impact
En Route or Limited Waters	$P_{wi_e} = 0.423$
Terminal	$P_{wi_t} = 0.118$

The probabilities of bunker spillage can be based on bunker tank outflow modelling conducted for the IMO (Michel and Winslow 1999, 2000; Barone et al. 2007) and studies conducted on US oil spills (Etkin and Michel 2003, HEC et al. 2003). For general shipping a bunker tank for a single hulled vessel is assumed to have a 5% chance of being hit, for a double hulled vessel or one with other protective locations the assumption is 2% (Etkin and Michel 2003). However, there is more specific information on probability of hitting a bunker tank available for container ships within the above studies as described below.

In 2013, 6% of ships calling at Deltaport were built after 2010 and would have bunker tank protection. In 2030, this study assumes all will comply with the requirements.

In preparation for the adoption of the protective fuel tank location regulations, immediate spill consequences of container ships with and without protective locations were evaluated (Michel and Winslow 1999, 2000). The following configurations were considered as illustrated in **Appendix A: Figure A-6**:

- Configurations C1 and C2 represent typical arrangements currently in use without protective location of fuel oil tanks; and

- Configurations C3 and C4<sup>8</sup> represent configurations with regulation compliant protective location of fuel oil tanks.

The difference in probability of puncturing or rupturing a fuel oil tank as a result of an allision or collision is large for the different tank configurations as shown in **Table 2-7** (Michel and Winslow, 1999). The average from **Table 2-7** of C1 and C2 has been applied for the year 2012 and the average of C3 and C4 for 2030.

**Table 2-7 Probability of Fuel Oil Tank Penetration for Container Ship Configurations**

Configuration	Probability of Fuel Oil Tank Penetration Side Impact	Probability of Fuel Oil Tank Penetration Bottom Impact
C1	0.427	0.043
C2	0.36	0.034
C3	0.08	0.085
C4	0.042	0.108

#### **Bunker Spill Amount Conditional Probability**

Spill volume is derived by multiplying the oil outflow percentage times the capacity. The probability distribution of percentage of outflow for all vessels (except tank barges, which have no bunker fuel) involved in impact accidents is as shown in **Table 2-8**. Note that there is no difference between double- and single-hulled vessels in regard to oil outflow percentage; rather, the probability that a spill will occur is reduced by the presence of a double hull as addressed in the previous section. The probabilities for percentage outflow were derived from the oil outflow modelling conducted for the IMO in the studies referenced above, and verified by analyses of US and international data on oil spillage using actual spillage versus adjusted capacity (Etkin and Michel 2003; Etkin 2001, 2002; Herbert Engineering and Designers & Planners Inc. 2003; Michel and Winslow 1999, 2000; Barone et al. 2007; Yip et al. 2011).

<sup>8</sup> Configuration C4 evaluated for this project using HEC software used for prior evaluations.

**Table 2-8 Bunker Conditional Outflow Probability Functions for Oil Release Amount given Fuel Tank Penetration from All Vessel Impact Accidents**

% Bunker Outflow ( $O_b$ ) (normalised by capacity)	Probability $P(O_b)$	Cumulative density function
0.01%	0.23	0.2300
0.03%	0.17	0.4000
0.15%	0.14	0.5400
1.6%	0.10	0.6400
4.3%	0.09	0.7300
10%	0.08	0.8100
16%	0.06	0.8700
33.3%	0.05	0.9200
59%	0.04	0.9600
100%	0.04	1.0000

For the evaluation of spill sizes, three sizes of container ships are considered; less than 8,000 TEUs, 8,000 to 10,000 TEUs, and over 10,000 TEUs. This study has used the typical fuel oil capacity for container ships with 5,400 TEUs, 9,000 TEUs and 12,500 TEUs respectively to represent these three ship classes in the oil release analysis (Table 2-9).

**Table 2-9 Container Ship Fuel Oil Capacity (combined HFO and Diesel)**

Container ship size	Fuel Oil Capacity (m <sup>3</sup> )
Small < 8,000 TEUs	7,800
Medium 8,000 - 10,000 TEUs	11,800
Large > 10,000 TEUs	12,950

### Key Parameters

In-port spill probabilities and amounts were modelled considering the factors listed below as uncertain parameters (i.e. as random variables with probability distributions as indicated).

For collisions and allisions, the following are considered:

- $C_r$ : Collision rate (Triangular using GL (2013) study rate variability, peak value  $8.3 \times 10^{-3}$  per year). This is adjusted by the following exposure factor;
- $C_{ef}$ : Collision exposure factor, portion of ship-year exposed to accident type, see **Section 2.3.4.2** (Uniform, 0.2 to 0.4);
- $Y_{rs}$ : Years in manoeuvres in port where ship is exposed to collision risk (Uniform, +/- 15% around mean of 2 hours per arrival);

- $P_{ship}$ : Probability of another ship being in the waterway while maneuvering (Uniform, +/- 15% around mean of .05 based upon normal berthing protocols);
- $A_r$ : Allision rate (Triangular using GL (2013) study rate variability, peak value  $2.3 \times 10^{-3}$  per year). This is adjusted by the following exposure factor:
  - $A_{ef}$ : Allision exposure factor, portion of ship-year exposed to accident type (Uniform, 0.15 to 0.25);
- $Y_{rb}$ : Years at berth (Uniform, +/- 15% around mean of 0.01 year per arrival);
- $P_{bs}$ : Bunker tank impact probability for side impacts (Uniform, +/- 15% around mean of 0.394 for side impact ships without protective fuel tank locations in 2012, 0.061 for ships with protective fuel tank locations in 2030, see **Table 2-7**); and
- $P_p$ : Probability of hull penetration in collision or allision (Uniform, +/- 15% around mean of 0.118).

For groundings, the following are considered:

- $G_r$ : Grounding rate (Triangular using GL (2013) study rate variability, peak value  $6.6 \times 10^{-4}$  per year). This is adjusted by the following exposure factor;
- $G_{ef}$ : Grounding exposure factor, portion of ship-year exposed to accident type (Uniform, +/- 15% around mean of 0.11 for combined drift and powered grounding);
- $Y_{rs}$ : Years in manoeuvres in port where ship is exposed to grounding risk (Uniform, +/- 15% around mean of 2 hours per arrival);
- $P_{bg}$ : Bunker tank impact probability for bottom impacts (Uniform, +/- 15% around mean of 0.0385 for 2012, 0.0965 for 2030, see **Table 2-7**); and
- $P_{pg}$ : Probability of hull penetration in grounding (Uniform, +/- 15% around mean of 0.05 for soft, slow groundings).

Thus, the probability of a spill in a collision  $P_{cs}$  is given by:

$$P_{cs} = \frac{C_r}{C_{ef}} \cdot Y_{rs} \cdot P_{ship} \cdot P_{bs} \cdot P_p$$

The probability of a spill from an allision  $P_{as}$  is given by:

$$P_{as} = \frac{A_r}{A_{ef}} \cdot Y_{rb} \cdot P_{bs} \cdot P_p$$

The probability of a spill from a grounding  $P_{gs}$  is given by:

$$P_{gs} = \frac{G_r}{G_{ef}} \cdot Y_{rs} \cdot P_{bg} \cdot P_{pg}$$

For spill amounts, this study considers:

- Bunker tank fill level (uniform, +/- 15% around mean of 70%<sup>9</sup>); and
- Spill amount given a penetration (uses conditional probability distribution described above).

The in-port penetration rate accounts for the fact that ships are moving slowly in port (see **Table 2-6**).

A ship involved in an allision can be one that has struck a stationary object or was the stationary object that was struck. In the former case, allision damages to the striking ship can be anywhere on the ship. This is different than the case for collisions for which it is assumed that the striking ship makes contact on its bow and suffers no damage that would put its oil tanks at risk (unless the collision in turn results in sinking or other secondary events). Thus, in both roles the ship is assumed to act as a struck ship and appropriate damage penetration statistics are applied.

In this analysis a 5% chance of another ship being maneuvered in the waterway while the assessed ship is approaching or departing the berth is assumed. Expert judgment and berthing practice indicates this is a conservative assumption.

### **2.3.5.3 Operational spills**

In addition to spillage of cargo or bunker fuel that might occur from vessels, there are also operational discharges and inputs that may occur from larger vessels, including stern tube lubricants. This study considered an estimated annual amount of stern tube oil discharges in the study area (**Appendix F**, Operational Pollutant Inputs – Lubricant Discharges).

Estimates for amounts are based on vessel traffic for PMV including Roberts Bank terminals for the years 1995 to 2013, and for the years 2008 to 2013 for the Fraser River (PMV 2013b), and scaled linearly for the increase in container ship traffic associated with RBT2.

### **2.3.6 In-Transit Incidence Prediction Methods**

In this section the methods used to evaluate the incidence of accidents In-Transit are described. These include methods to evaluate incidence associated with collisions and groundings of container ships while travelling to and from Roberts Bank terminals.

#### **2.3.6.1 Encounter Modelling**

Encounters are events where the projected paths of two ships will cross within a certain distance of each other. The probability of encounters was modelled for vessel traffic travelling to/from Roberts Bank terminals and transiting the waterway nearby.

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<sup>9</sup> Assuming 70% is at the upper end of levels assumed in similar studies, but is consistent with container ships calling at Roberts Bank bunkering in Asia and thus, requiring fuel for the voyage to Asia.

Encounters are classified into three categories, each with a different collision risk associated with it:

- Overtaking, where two vessels are moving in the same direction and the vessel behind is moving faster, so that it is projected to pass the other vessel within a certain distance;
- Crossing, where the paths of two vessels are crossing and both ships are projected to cross within a certain time of each other; and
- Head-on, where the vessels are heading toward each other and their projected paths will cross within a certain distance.

The vessel traffic in the region is modelled using information generated from AIS data, as described in **Appendix E**, Encounter Modelling. Vessel routes for container ship traffic and other vessel traffic in the Study Area are developed for the 2012 and 2030 years. The route information provides the location and speed of all vessels at five minute increments. The number of encounters is calculated using criteria based upon distance, relative heading, and speed and distributed into the three categories above. Each encounter also includes information on type and destination of the ships involved, permitting separation of encounters into groups identified by these properties. Simulations are performed for five one-year periods to capture the effects of variability included in the AIS derived vessel routes.

In each of the modelled vessel population scenarios, routes of the vessels were analysed to check for these types of encounters. With each encounter there is risk of a collision. Highest risk is associated with crossings, followed by head-on and then overtaking. An example of encounter location plot is shown in **Figure 3-6**.

Encounter modelling is used to apportion the rate of collision accidents developed as described in **Section 2.3.4**, Development of Accident Rates above amongst vessel types and locations of interest.

Further details of the modelling approach are provided in **Appendix E**, Encounter Modelling. The appendix also provides information on the relative rate of encounters for the vessel population scenarios.

#### ***2.3.6.2 Application of Encounter Modelling and Accident Rates to Collisions In-Transit***

Collision rates are based upon the updated IMO rates (GL 2013) as adjusted for exposure factor as described in **Section 2.3.4.2** and for the transit time of  $3.2 \times 10^{-4}$  years per transit (approximately 3 hours) representing a voyage from Turn Point to Roberts Bank and return.

In this analysis the spill analysis is restricted to collisions between container ships and collisions where a RBT2 bound container ship strikes a laden crude tanker. This study modelled collision spill amounts considering the following factors as uncertain parameters:

- $C_r$ : Collision rate (Triangular using GL (2013) study rate variability, peak value  $8.3 \times 10^{-3}$  per year). This is adjusted by the following exposure factor;

- $C_{ef}$ : Collision exposure factor, portion of ship-year exposed to accident type, see **Section 2.3.4.2** above (Uniform, 0.2 to 0.4);
- $C_p$ : Container ship collision percentage (Normal, 10% standard deviation, based upon encounter modelling);
- $P_{bs}$ : Bunker tank impact probability (Uniform, +/- 15% around mean of 0.394 for 2012, 0.061 for 2030); and
- $P_p$ : Probability of hull penetration (Uniform, +/- 15% around mean of 0.423).

Thus, the probability of a spill in a collision  $P_{cs}$  is given by: 
$$P_{cs} = \frac{C_r}{C_{ef}} \cdot C_p \cdot P_{bs} \cdot P_p$$

For spill amounts the following was considered:

- Bunker tank fill level (Uniform, +/- 15% around mean of 70%); and
- Spill amount given a penetration (uses conditional probability distribution described in **Section 2.3.5.2** above for container ships, for tanker see below).

For collisions where a RBT2 bound container ship strikes a laden tanker the following additional factors are applied:

- Percentage of container ships bound for Roberts Bank terminals that are calling at RBT2: 45%;
- Percentage of collisions where the crude tanker is the struck ship: 50%;
- Percentage of crude tankers being laden: 50%; and
- Spill amount given a penetration uses a conditional probability distribution based on an analysis of oil outflow amounts for a 90% full, double hull, **Aframax tanker** damaged in accordance with IMO probability distributions for accidental oil outflow assessment (IMO 2010).

### **2.3.6.3 Application of Accident Rates to Groundings In-Transit (Drift and Powered)**

Grounding incidences are estimated based upon the updated IMO rates (GL 2013) as adjusted for exposure factor as described in **Section 2.3.4.2** and for the transit time of  $3.2 \times 10^{-4}$  years per transit (approximately 3 hours) representing a voyage from Turn Point to Roberts Bank and return.

For drift grounding it is assumed that for 15% of the ship year that the vessel travels in regions where drift grounding can occur, and adjusts the updated IMO annual rates of grounding accordingly, as described in **Section 2.3.4.2**. The grounding rate is simulated using triangular probability distributions for both grounding rate and number of ships.

Powered groundings are also estimated based upon the GL rates for the exposure time of  $3.2 \times 10^{-4}$  years per transit. Powered groundings can only occur when travelling near shore. This study assumes that for 10% of the ship year that the vessel travels in regions where powered grounding can occur, and adjusts the updated IMO annual rates of grounding accordingly. Powered groundings are a consequence

of human error. In a piloted vessel this is expected to be extremely low, although this has not been explicitly accounted for. The grounding rate and number of ships have been simulated using triangular probability distributions.

Typically groundings in transit are split 20% / 80% between drift and powered groundings. Once a ship grounds there are further events that must happen before a spill happens. For the route travelled by container ships bound for RBT2, it is assumed that 75% of the transit is bounded by rock and the rest by soft bottoms. For rock bottoms it is assumed that the probability of hull penetration is 80% per grounding. For soft bottoms the penetration rate is assumed to be 10%. These are typical values used in similar analyses (e.g. HEC 1999, DNV 2010b). Spill quantities are estimated for bunker spills using conditional spill probability functions given a penetration.

Spill amounts have been modelled considering the following factors as uncertain parameters:

- $G_r$ : Grounding rate (Triangular using GL (2013) study rate variability, peak value 5.4E-3 per year). This is adjusted by the following exposure factor;
- $G_{ef}$ : Grounding exposure factor, portion of ship-year exposed to accident type, see **Section 2.3.4.2** (Uniform, +/- 15% around mean of 0.11 for combined drift and powered grounding);
- $Y_{rs}$ : Years at risk;
- $P_{bg}$ : Bunker tank impact (Uniform, +/- 15% around mean of 0.0385 for 2012, 0.0965 for 2030); and
- $P_{pg}$ : Probability of hull penetration (Uniform, +/- 15% around mean of 0.62 based upon 75% rock, 25% soft bottom).

The probability of a spill from a grounding  $P_{gs}$  is given by:

$$P_{gs} = \frac{G_r}{G_{ef}} \cdot Y_{rs} \cdot P_{bg} \cdot P_{pg}$$

For spill amounts this study considers:

- Bunker tank fill level (Uniform, +/- 15% around mean of 70%); and
- Spill amount given a penetration (uses conditional probability distribution described previously).

### 2.3.7 Fishing and Recreational Vessels

One approach to collision probability is based on the concept that vessel density (the number of vessels in a given area) is the driving factor, since vessel density affects the potential encounter rate. This approach is useful for determining the likelihood of collisions with fishing and recreational vessels.

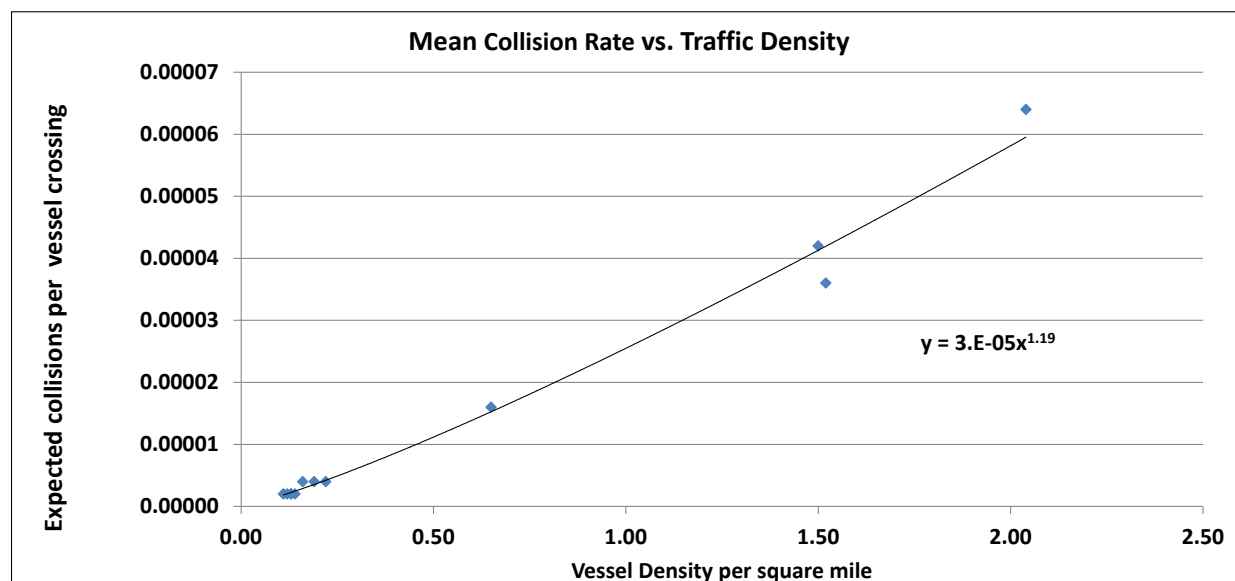
Based on an analysis conducted on vessel collisions and vessel density in the Puget Sound, the following relationship between vessel density and expected collisions was developed<sup>10</sup>:

$$CR_d = 0.00003d^{1.19}$$

Where:  $d$  = vessel density (number of vessels per square mile)

$CR_d$  = collision rate (expected collisions per vessel crossing of the area) at vessel density,  $d$

The data are based on offshore fishing and would not account for reduced risk for interactions with tug assisted vessels or highly monitored areas such as Roberts Bank. Thus, this rate could be considered an upper bound on the incident rate. The incident rate vs. vessel density using this approach for Puget Sound fishing vessels is shown in **Figure 2-16**.



**Figure 2-16 Mean Collision Rates vs. Regional Fishing Vessel Densities**  
(adapted from Judson, 1992)

On any given call at Roberts Bank terminals the risk of collision will be small. This is consistent with pilot experience (see PMV 2013e) and TSB incident data (TSB 2013). The TSB incident data includes one incident where a fishing vessel collided with a container ship or other large deep sea vessel in southwestern B.C. waters (south of Latitude 50 deg. N) since 1995.

Information from Fisheries and Oceans Canada (Fisheries and Oceans Canada 2014) for five years from 2008 through 2012 has been used to develop fishing vessel densities for the region transited by container ships bound for Roberts Bank terminals. This region is represented by DFO subareas 18-1, 18-11, 29-6, 29-7 plus an area of U.S. waters adjacent to DFO subarea 18-1 (see **Figures A-6 and A-7**). It has been

<sup>10</sup> Equation developed from data on vessel density and collision rates extrapolated from Judson 1992.

assumed that the fishing vessel operations in the U.S. waters are similar to those in the adjacent Canadian waters. The DFO data indicates that this region is not heavily fished, the largest number of vessels in any one subarea on a given day was six, occurring once in the largest subarea, 18-1. The most active subarea, based upon fishing vessel days per unit area is DFO subarea 29-7. The DFO data indicates that most days there are no fishing vessels in the area; see Figures A-8 for DFO subarea 18-1 which is typical of all the subareas.

Preliminary information from TFN indicates approximately 1,000 fishing vessel hours per year (TFN 2011, 2012) adjacent to Roberts Bank, concentrated over 2 to 3 weekends per year. For example, the busiest weekend in 2011 or 2012 accounted for 314 vessel hours. Assuming 48 hours for the busiest weekend, the 314 vessel hours result in about seven vessels continuously operating for that period. It is not known how the vessels would cluster while fishing. If the vessels were all within a 2 NM (3.7 km) radius of Roberts Bank then the density would be about one vessel per  $\text{NM}^2$  leading to a rate of  $2.5 \times 10^{-5}$  collisions per ship call or one in 4,000 ship calls. This density would only be achieved once or twice a year however, according to the TFN data. Thus the contribution to the overall incidence of fishing vessel collision with a container ship or other large vessel from TFN fishing operations is considered negligible.

## **2.4 DATA SOURCES AND ANALYSIS**

To perform the IP using the methods described in the preceding section, data analysis has been performed. The data analysis includes:

- Obtaining and analyzing incident and accident data for the Vancouver Region;
- Analyzing vessel call data provided by PMV to establish several characteristics of the vessel fleet calling both at Roberts Bank terminals and other PMV terminals; and
- Development of routing information and other vessel traffic characteristics using AIS data.

Additional data analysis includes:

- Evaluation of underreporting of incidents and accidents;
- Modification of results based upon limited data using expert judgment; and
- Accounting for sparseness and uncertainty in key databases and the use of experts.

### **2.4.1 Analysis of Incident and Accident Data for the Vancouver Region**

This section describes the collection of incident data and subsequent analysis to determine local incident and accident rates. These rates provide a basis for comparing incident and accident rates for the Vancouver region with global rates.

In this analysis an event is classified as an incident when there is the possibility of damage to life, environment or property, and thus, is reported to various authorities. Worldwide databases, such as the

IHS Sea-web database, classify these events as casualties. If an incident does result in damage to life, environment or property then it is also an accident. Unfortunately the use of these terms is not consistent within the industry and thus some judgment in interpretation of the terms incident and accident must be exercised. Further, the use of the term **serious** is sometimes applied to incidents, casualties and accidents to eliminate those for which no significant disruption in vessel operations occurs. Ultimately this study's analysis is focused on predicting the rates of spills into the environment, and thus, accidents are the relevant events. However, accident occurrences for local regions or individual ship types can be so rare as to make comparisons difficult, while incidents are more numerous and can provide a basis for comparison between regions or ship types.

Collection of data for vessel-related incidents that have occurred within PMV Navigation jurisdiction and the general area since 1995 provided the basis for estimating first incident and the accident rates for the Vancouver region. Four zones in the Vancouver region were considered in the analysis to evaluate differences within the region (see **Figure 2-2**). They are representative of different types of vessel operations and are used to determine if it is possible to distinguish incident rates between them. The incidents are analysed with respect to:

- Annual incident rates by vessel type (and size category), pilotage (piloted vs. non-piloted vessels), incident type (cause of incident), and study area zone;
- Incident rates per vessel transit or port visit by vessel type (and size category), pilotage (piloted vs. non-piloted), incident type (cause of incident), and study area zone;
- Incident rates pre- and post-**STCW** standards;
- Likelihood of spillage with incidents; and
- Potential spill volumes associated with incidents by vessel type and size.

Incident rates in Roberts Bank terminals and the Vancouver region were compared with incident rates in other regional areas (e.g. Puget Sound), other ports, and worldwide to provide a benchmark for the Roberts Bank Terminals and Vancouver region rates.

**Appendix C**, Vessel Incident Analysis for Vancouver Region provides background data on incidents and transits used to develop rates in this analysis.

### 2.4.1.1 Incident Types

Incidents were classified into the categories shown in **Table 2-10**.

**Table 2-10 Incident Types Evaluated**

Incident Types
Allision
Allision – Near <sup>11</sup>
Broke Mooring
Broke Tow
Cargo Loss Overboard
Collision
Collision – Near
Equipment Failure
Explosion/Fire
Grounding
Grounding – Near
Outside Force
Propulsion Loss
Sinking <sup>12</sup>
Steering Loss
Structural Failure
Transfer Error
Other/Miscellaneous

The incidents were analysed with respect to annual occurrence and per-transit rates by vessel type, incident type, and study region to derive incident rates for further analysis.

### 2.4.1.2 Incidents in the Vancouver Region

Fortunately, marine incidents and accidents near Roberts Bank are relatively rare. Reported incident numbers for vessels over 300 GT for the four zones combined are shown in **Appendix C; Table C-6** for the period 1995 through June 2013. During that period, there were 389 incidents and approximately 650,000 transits (round trip voyages) for an average incident rate of one in 1,670 transits. Only 17 of these incidents occurred in the Roberts Bank terminals zone. Details of the Roberts Bank Terminals incidents are also presented in **Appendix C**, Vessel Incident Analysis for the Vancouver Region.

<sup>11</sup> A near allision, collision or grounding is a reported incident because there was potential risk to life, property, or the environment.

<sup>12</sup> Sinking includes taking-on water and foundering.

**Table 2-11 Consolidated Incidents by Type in Study Area Zones – All Vessels 1995 to June 2013**

Incident Type	Zone				
	Roberts Bank Terminals	PMV Main	Fraser	Transit	Total
Allision	6	43	31	1	81
Allision - Near	0	2	2	0	4
Collision	0	15	6	2	23
Collision - Near	1	41	26	15	83
Grounding	2	13	14	2	31
Grounding - Near	0	11	0	0	11
Vessel Failure <sup>13</sup>	7	23	10	23	63
Structural Failure/Sinking	0	9	11	6	26
Other/Explosion/Fire/Outside Force	1	23	11	11	46
Broke Mooring/Tow	0	4	10	2	16
Transfer Error/Cargo Loss	0	4	1	0	5
<b>Total</b>	<b>17</b>	<b>188</b>	<b>122</b>	<b>62</b>	<b>389</b>

During this period container ships were involved in 35 incidents as shown in **Table 2-12**. Details of these incidents are included in **Appendix C**, Vessel Incident Analysis for Vancouver Region.

**Table 2-12 Container Ship Incidents in Study Area Zones - 1995 to June 2013**

Vessel Type	Total Incidents	Total Port Visits (Transits <sup>14</sup> )	Incidents per Transit
Container <8,000 TEUs	34	11,715	0.0029
Container 8,000 to 10,000 TEUs	1	618	0.0016
Container >10,000 TEUs	0	12	0.0000

#### **2.4.1.3 Incident Rates after Implementation of Standards of Training, Certification, and Watchkeeping**

There are various studies, along with ample anecdotal evidence, that have shown a decrease in the likelihood of vessel casualties as a result of improvements in the training of marine vessel crews and an associated reduction in the incidence of human errors (Wang and Zhang 2000, Grabowski 2013). The most noteworthy changes in vessel crew training came with the implementation of STCW. This convention, which set qualification standards for masters, officers, and watch personnel on seagoing merchant ships, first entered into force in 1984, with significant amendments in 1995 that entered into force in 2002 (IMO 1995). Additional amendments entered into force in 2012.

<sup>13</sup> Includes equipment failure, propulsion loss and steering loss

<sup>14</sup> Transits are round trip voyages, thus there is a one-to-one relationship with port visits.

The incident data for piloted vessels were analysed to determine incident rates pre-STCW 1995 amendments, and post-STCW 1995 amendments to evaluate the hypothesis that incident rates would have been affected by the degree of training in crews. Since the STCW 1995 amendments entered into force in 2002, the data were separated into 1995 to 2001 and 2002 to 2013. Note that for the Fraser zone, only the period 2008 to 2013 was included in the initial analysis, which covers only the post-STCW time period.

In **Appendix C: Table C-12** the pre- and post-STCW incident rates for piloted vessels by incident type are compared. This comparison shows that for the study area, incident rates have dropped from 0.0015 incidents per transit to 0.00117 incidents per transit, a 22% overall reduction in the incident rate since STCW went into effect. In incidents most likely attributable to human errors, the rate changes from 0.00111 incidents per transit to 0.00102 incidents per transit, a reduction of 8% post-STCW. It was not possible to distinguish trends for individual zones or incident types in pre- and post-STCW incident rates, in part due to the very small sample sizes.

#### **2.4.2 Use of Ship Call Data to Establish Vessel Population Characteristics**

PMV ship call data (2013b) for the period 1995 to June 2013 combined with ship population data contained in that database and the IHS Sea-Web database provided the ability to determine historical patterns of:

- Vessel types and sizes;
- Vessel ages;
- Arrival and departure time distributions; and
- Berth times.

Vessel type and size information provided the basis for numbers of ships in the background traffic in subsequent encounter modelling described in **Section 2.3.6.1**, Encounter Modelling.

Vessel age distributions were determined for several ship types. The age distribution of container ships that have called at Deltaport, where the entire population is less than 20 years old, forms the basis of the assumption that the projected traffic in 2030 will contain an insignificant number of older ships.

Analysis of the arrival times established that the arrivals into the Study Area followed a Poisson process and thus, the intervals between ship arrivals followed an exponential probability distribution. This permitted adjusting arrival times in subsequent analyses based upon increased numbers of vessels and thus, shorter mean arrival intervals.

Arrival times, berth times and departure times were used in combination with vessel speeds and route lengths to determine the amount of time a vessel spent per ship call in the Vancouver region.

### 2.4.3 Use of AIS Data to Model Vessel Traffic

AIS data was obtained from [www.MarineTraffic.com](http://www.MarineTraffic.com) (2013) for vessel traffic from April 2011 to June 2013 in a one degree, latitude and longitude, square centred on Roberts Bank. The AIS data was interrogated to provide several forms of data. A key component of this was extracting routes for various vessel types to all terminals in the Vancouver region, in order to model existing and potential traffic in the year 2030 to Roberts Bank terminals and other terminals.

AIS data includes many erroneous data points due to a number of factors and thus, requires screening and removal of bad data points. To facilitate its use in encounter modelling, the tracks for vessels were manipulated to provide location, speed, and vessel characteristics at common time stamps; every five minutes throughout the approximately two year period covered by the data.

Further manipulation and use of the AIS data is described in **Appendix E**, Encounter Modelling.

### 2.4.4 Underreporting of Incidents and Accidents

Marine shipping incidents are widely considered to be underreported; for example, Hassel (2010) concluded that real rates are higher than those reported. The Hassel study states that underreporting is proven to occur in particular because some casualty data are exclusively in only one database. Evaluation of the incident data for the Vancouver region, where multiple data sources have been used, supports this conclusion. Reasons for this discrepancy include the differing goals and interests of those recording the data. However, the study also notes that Canada was the best flag state in the study, missing approximately 25% of all accidents occurring in its area of responsibility. The authors of this report agree with the conclusion of the study that use of statistical data should assume a certain amount of underreporting. Options to include this effect include using a correction factor, safety margins and relying more heavily on expert judgment.

Recent updates of IMO FSA container ship accident rates have evaluated the issue of underreporting for serious accidents in the fully cellular container ship fleet. Reported serious accident rates have increased since 2002 as indicated in **Figure 2-15**. Investigations of the reported data by GL and the National Technical University of Athens (Eliopoulou et al. 2013) indicate that this is in part due to more accident types being considered serious. Secondly, the issue of underreporting for IACS classed container ships has been investigated and is considered small. Confidence intervals (CI) on the accident rates were developed. In **Table 2-13** the reported 95% confidence intervals are reproduced and converted into ratios of the base rate. The 95% confidence bounds average +/-15%.

**Table 2-13 Worldwide Frequency of Serious Events, Time Period 1990 to 2012**

Frequency of occurrence		Low CI	High CI	Low CI Ratio	High CI Ratio
<b>Collision</b>	$7.04 \times 10^{-3}$	$6.33 \times 10^{-3}$	$7.82 \times 10^{-3}$	0.90	1.11
<b>Contact</b>	$2.21 \times 10^{-3}$	$1.81 \times 10^{-3}$	$2.66 \times 10^{-3}$	0.82	1.20
<b>Grounding</b>	$4.70 \times 10^{-3}$	$4.11 \times 10^{-3}$	$5.34 \times 10^{-3}$	0.87	1.14

Assessment of Vancouver regional rates established that the local rates are generally consistent with the low end of worldwide rates. Further, large vessel traffic in the region is exclusively under the supervision of a pilot, unlike global traffic where piloted operations represent a smaller portion of overall operations. For this reason, this study assumes that the underreporting for the region and vessels of interest is lower than the Canadian average. In application of accident rates to estimate the number of accidents expected, this study has modelled the rates as uncertain values with bounds that are based upon the variability in worldwide rates. This study has also used the average variability as a basis for ranges of uncertainty for parameters for which statistical data are not available.

#### 2.4.5 Approaches to Assessing Data Sparseness, Uncertainty and Sensitivity

The incidence of accidents evaluated here are low and this is reflected in the low numbers of incidents over extended time periods recorded both locally and globally. In developing the incidence predictions, therefore, it was necessary to use sparse data and to further make assumptions based on expert judgment.

This study has made use of consultation with marine experts to inform the analysis team about local marine traffic and risk issues. Such consultations included a web-based panel including pilots and tug operators (PMV 2013e), feedback from stakeholders at a workshop (PMV 2013f), and direct communication<sup>15</sup>. As prior data analysis sections indicate, local incident and accident rates are consistent with worldwide rates. Thus, this report avoided the use of expert judgment to adjust incident rates from worldwide rates, but rather relied on their judgment to confirm assessments of local data. An example of this is:

- One of the existing risk mitigation approaches identified in **Section 3.2** is a restriction on number of ships being moved at one time in a terminal. This is confirmed by discussions with the pilots that indicate that two ships at a time are rarely moving in the tug-assist area off Roberts Bank. This is further confirmed by interrogating AIS data for concurrent ship movements. This information is used to largely discount the risk of a collision with a large vessel during berthing operations.

<sup>15</sup> Personal communications have been documented where applied.

Uncertainty is accounted for explicitly through the use of probability distributions for key variables in the analyses. Monte Carlo simulation is used to develop results that provide not just nominal rates, but also results associated with specific probabilities of exceeding prescribed thresholds.

This study has also explicitly modelled a key assumption about the number of new container ships arriving at RBT2. This sensitivity analysis is described as part of the encounter simulation. Further, the key parameters in the estimate of the most likely spill scenario have been identified and the sensitivity to these assumptions has been evaluated.

#### ***2.4.5.1 Uncertainty in Roberts Bank Vessel Population***

This study's estimate for Westshore Terminals assumes that the current bulk carrier vessel size distribution will apply in the future, based on recommendations from Westshore Terminals (2013). Interpretation of the Westshore Terminals historical data suggests that this estimate of the number of calls is closer to an upper bound. Average deadweight both locally and globally is steadily increasing. Ships much larger than those currently calling at Westshore Terminals exist in the coal trade, and the Westshore Terminal Berth 1 is not limited in size, whereas there is some limitation on the Berth 2 in draught (PMV 2013e). Dredging is always a possibility to eliminate some of this restriction. The uncertainty is estimated to be in the range of +5% to -15%.

For container ships arriving at Deltaport and RBT2 much the same holds true. The estimate for number of container ships is based upon a combination of worldwide data and interviews with operators. WorleyParsons (WP) (2011) noted that their estimate for Deltaport is subjective, since there is no clear statistical basis for estimating the number of future ship calls. An estimate of ship size can be developed through use of the 2012 order book for container ships provided by the Institute of Shipping Economics and Logistics (ISEL 2012). Using a weighted average for the larger container ships of 11,500 TEUs (these ships would be close to average world fleet age by 2030), at a 99% utilization rate (WorleyParsons 2011), results in an estimate of about 210 container ships calling at RBT2 and 260 at Deltaport (down from 260 and 312 respectively). As the newest, largest ships (18,000 TEUs now) get put into service on the Asia/Europe routes the next size smaller (12,000 to 15,000 TEUs) ships will call more frequently in Vancouver. Note that the British Columbia Ministry of Environment report (BC MOE 2013) estimates 140 to 180 container ships calling at RBT2, but notes that their estimate is highly speculative. This study thus, considers that the WP numbers for container ships are also close to being upper bounds with an even bigger potential for fewer ships. The uncertainty is estimated to be +5% to -25% for container ships, especially if the split service were to stop.

#### ***2.4.5.2 Uncertainty in Vessel Population for Vessels Not Calling at Roberts Bank Terminals***

Ship movement estimates for 2030 for the vessels not calling at Roberts Bank terminals, but transiting the waters near it, are more uncertain in comparison with estimates for Roberts Bank terminals vessels. This is part of the rationale for comparing Scenarios 2 and 3, and 4 and 5. These two pairs of scenarios represent approximate lower and upper bounds to the vessel populations. Even within these bounds, the estimates are approximate. The estimates with the least uncertainty, however, are those for tanker traffic associated with the potential Trans Mountain Pipeline expansion as the number of tankers required can be estimated directly from the pipeline and tanker capacities.

### 3.0 RESULTS

This section presents the main findings of the IP and the corresponding spill amounts and locations utilising the methods described in **Section 2.0** including:

1. **Identification of Hazards and Accident Types:** where the accident types relevant to container shipping at RBT2 are defined;
2. **Identification of Existing Risk Mitigation Practices:** where current defences that reduce the incidence and consequence of spills are noted. This establishes that shipping in the Vancouver region utilises current best practice in these areas;
3. **Vessel Traffic Affected:** where the projections of the container ship traffic to RBT2, and traffic to other terminals and ports in the Vancouver region, in the 2012 and 2030 years are detailed;
4. **Development, Comparison and Selection of Accident Rates:** where accident rates for use in subsequent analyses are presented;
5. **In-Port Accident Incidence Prediction**, including resulting spill amounts is presented; and
6. **In-Transit Accident Incidence Prediction**, including resulting spill amounts is presented.

The results are described in the following sections.

#### 3.1 IDENTIFICATION OF ACCIDENT TYPES

In this analysis an event is classified as an incident when there is the possibility of damage to life, environment or property; and if such an incident does result in damage to life, environment or property then it is also an accident.

The following broad categories of accidents based upon hazard identification done by IMO, and other sources as described in **Section 2.3.1**, were considered:

- Allisions;
- Collisions;
- Fire/Explosions;
- Drift groundings;
- Powered groundings;
- Foundering and Structural failures;
- Vessel failures; and
- Container Mishandlings.

### 3.1.1 Representative Historical Container Ship Accident Scenarios

There have been a number of high profile container loss events since the advent of containerised shipping approximately 50 years ago. Some involved hundreds of containers. In 1998, for example, the APL China lost nearly 800 containers overboard in the NE Pacific (France et al. 2003). Most container loss events were motion related accidents occurring in storm conditions in open oceans or channels. There have been no containers reported lost overboard in the protected and semi-protected waters of the Strait of Georgia and surrounding passages. In the case of the APL China, the ship rolled severely in a storm where the significant wave height was over 14 m, whereas the 100 year return period, significant wave height in the Strait of Georgia is 3.3 m (WorleyParsons 2011). The incidence of these events in the protected waters near RBT2 is considered negligible.

More recently, the grounding of the MV Rena off the north coast of New Zealand in 2012 led to the eventual loss of the ship and many of its containers, and also portions of its fuel. This accident occurred on an exposed reef and most of the container loss was associated with the ship breaking up in heavy weather encountered over a period of weeks. Approximately 360 of the 1,368 containers onboard were lost (Maritime New Zealand 2013). The vessel was not under the control of a pilot or vessel traffic management system at the time of grounding.

In mid-2013, the MOL Comfort buckled in waves in the Indian Ocean, subsequently broke in two, caught on fire, and then both halves eventually sunk (Lloyd's List 2013). Again this occurred in the open ocean in heavy weather. The incidence of such foundering events in the protected waters near RBT2 is considered negligible.

Another potential container loss scenario for protected and semi-protected waters is loss overboard as a result of a collision. An example is the collision of the container ship MSC Chitra and the bulk carrier Khalijia off Mumbai. The MSC Chitra eventually listed heavily to port, causing a number of containers to slide overboard and also caused an oil spill. Information on the number of containers lost in collisions is generally not available but the number can be a large part of the cargo. Visual inspection of the photographs in this case indicates about 25% of the on-deck cargo was lost. The vessel was carrying 1,219 containers (2,440 TEUs). Assuming an on-deck ratio of 60% this would lead to a loss overboard of approximately 180 containers.

More commonly there is the potential for an allision. Minor allisions in port are a relatively common occurrence as a hard berthing can be considered an allision. There have been six reported allisions at Roberts Bank terminals since 1995. Descriptions of these allisions are provided in **Appendix C**.

Serious allision accidents also occur. A high profile allision was the COSCO Busan allision with a pier of the San Francisco Bay Bridge while under pilotage with tug assistance in fog in 2007<sup>16</sup>. The damage caused a bunker tank to be penetrated and lose its entire contents. The spill amount was approximately 200 cubic metres ( $2 \times 10^5$  L). This is an especially relevant case as it sheds light on the influence on releases of the protective location of bunker tanks. If the bunker tank had been inside a double hull, then there would have been no spill for this amount of damage. Two relatively high energy events have occurred at Roberts Bank, one involving two large vessels contacting each other without causing a spill and another in December 2012 where a bulk carrier damaged shore side facilities (a conveyor belt and load out structure) leading to a coal spill.

Container ships have capsized in port due to loss of stability when loading. This has been confined to ships much smaller than those calling at Roberts Bank: typically multi-purpose vessels less than 200 m compared to the fully cellular container ships of 275 m to 350 m length expected to call at Deltaport and RBT2.

### 3.1.2 Container Handling and Other Accidents at Berth

Container handling accidents while the vessel is berthed (e.g. **Appendix A: Figure A-4**) are a potential source of spills into the water or container losses. In practice, the close proximity of the ship to the quay limits the possibility of a container falling into the water since container loading at Roberts Bank will rarely involve suspension over the water.

Bulk liquids can be carried aboard container ships in drums within a standard container or in large format tanks, as illustrated in **Appendix A: Figure A-5**. The large format tanks represent the largest volume that could be spilled from a single container. Liquid volumes range from 20,000 to 26,000 litres ( $26 \text{ m}^3$ ), depending on the cargo, with a working pressure rating of 3 to 4 bar (Stolt-Nielsen 2013).

The SAFEDOR (2005) study performed hazard identification for loading and unloading at a berth. Hazards associated with these operations that passed their threshold criteria for risk to the environment included the following two hazards:

#### **Environment**

Cargo related	Pollution by wrongly declared dangerous goods
Human Error	Pollution due to communication problems

It is noted that neither of these hazards directly consider failure during handling of the container by the gantry crane system, meaning that the IMO panel perceived it as low risk. This study considered it reasonable to include such events to extend the hazards associated with human error. A container that is

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<sup>16</sup> IHS Sea-web database, Casualty No. 9818000, retrieved November 25, 2013.

dropped may rupture and its contents may spill into the water. No accident of this nature has been recorded at Deltaport. An evaluation of the rate of container loss or spill based upon worldwide rates is made in **Section 3.6.1**, Loss Overboard of Containers from Ships in Transit or Maneuvering in Semi-protected Waters.

Pollution risk due to wrongly declared goods is associated with fire/explosion accidents. An evaluation of the rate based upon worldwide rates is provided in **Section 3.7**, Fire and Explosion Accidents.

### **3.1.3 Marine Vessel Related Risk during Terminal Construction**

The main contributions to incidence of spill from marine vessels during terminal construction are associated with the movement of dredging and construction barges by tugs and from spills during barge operations including refueling equipment onboard the barges.

### **3.1.4 Catastrophic Risk**

A catastrophic event has been defined as “an event that is believed to have a very low probability of materializing, but if it does materialise will produce harm so great and sudden as to seem discontinuous with the flow of events that preceded it” (Posner 2004). An example of such an event would be a spill that permanently destroys the livelihood of a local community.

Container ship traffic to RBT2 will be similar in operational practices, ship types and cargoes carried to other container ship operations including those at Deltaport. This study’s assessment is that the container ship traffic to RBT2 does not introduce new types of accidents that might lead to catastrophic event risks.

## **3.2 IDENTIFICATION OF EXISTING RISK MITIGATION PRACTICES**

The southern British Columbia coast is a mature marine vessel traffic area that is regularly used by deep sea vessels. Traffic in the region applies many marine risk mitigation approaches including:

- **Vessel traffic management system including radar surveillance and traffic separation zones:** The Canadian Coast Guard (CCG) Marine Communication and Traffic Services (MCTS) maintains a vessel traffic management system that includes mandatory vessel reporting requirements, monitoring of radio communication, radar tracking and a vessel traffic separation scheme;
- **Pilotage for all vessel moves within the region:** The Pacific Pilotage Authority Canada is a federal Crown corporation which administers pilotage service in the Canadian waters off the coast of British Columbia. All vessels over 350 Gross Tonnage (GT) are required to have a pilot onboard from the pilot station at Brothie Ledge off Victoria to their final destination in the Vancouver region, including Roberts Bank terminals. Approximately 12,000 vessel moves are made each year;
- **Navigational Aids:** Aids to Navigation are placed at critical areas along the waterway and in the vicinity of Roberts Bank; and

- **Precautionary areas and special operating instructions:** At key locations along traffic route, such as approaching East Pt. for outbound tankers, and approaching Turn Pt. at the junction of Haro Strait and Boundary Pass, special operating instructions are imposed.

Further, the marine operations at and near Roberts Bank include additional measures:

- **Radio communication with BC Ferries:** The pilots onboard the vessels calling Roberts Bank terminals and the BC Ferries masters have established effective radio communication protocols;
- **Tug assistance while maneuvering to/from berth:** As ships approach within approximately 1 NM (1.85 km) of Roberts Bank they slow and are assisted by tugs. While the slowing reduces the ability of the large ship to maneuver this is compensated for by the assistance of tugs. The slow vessel speeds and additional eyes and ears reduce risk;
- **One way, one ship at a time traffic arriving/departing Roberts Bank terminals:** Ship traffic and tug availability restrict berthing operations at each terminal to one ship at a time, thus, reducing the risk of collision;
- **Weather restrictions for berthing:** The port is closed during severe weather conditions limiting the risk of accidents during maneuvering or tug assistance;
- **Exclusion zones for crabbing adjacent to Roberts Bank:** Commercial and Recreational crabbing in the waters immediately adjacent to Roberts Bank terminals is restricted. This reduces the risk for interaction with crabbing vessels; and
- **Bunkering at Roberts Bank prohibited.** Bunkering of vessels introduces the risk of spills during transfer operations and increases the risk of collisions or allisions (PMV 2012a). Prohibiting these operations removes these risks.

Additionally, container ship operations routinely implement risk controls and operating practices including the following:

- **Fire detection and extinguishing system in the cargo holds of container ships:** Container ship cargo holds are required to be outfitted with a fixed fire detection and alarm system. Typically a smoke detection system is provided and is combined with CO<sub>2</sub> extinguishing system piping;
- **Reduced use of heavy bunker fuel in favor of diesel oil:** As a result of implementation of Special Emission Control Areas off the West Coast, the use of **heavy fuel oil** as a primary fuel source is restricted. As such, container ships carry less heavy fuel in such areas; and
- **Fuel tank protection (IMO 2010):** All ships delivered on or after 1 August, 2010, with an aggregate oil fuel capacity of 600 m<sup>3</sup> and above are required to have fuel tank protection designed to minimise outflow of oil from fuel tanks. The requirements include a protected location of the fuel tanks and performance standards for accidental oil fuel outflow. In practice, this is mostly implemented by double hulling the fuel tanks and will be implemented in virtually the entire fleet by 2030.

### 3.3 VESSEL POPULATION SCENARIOS

Five vessel population scenarios were developed. These provide the information necessary to assess the incremental risk associated with increased container ship traffic due to RBT2, in comparison to the risks associated with existing vessel traffic and traffic increases through 2030 from facilities other than RBT2. The scenarios are described in the following sections.

#### 3.3.1 Scenario 1 Existing Conditions in 2012

The purpose of this Scenario is to establish existing conditions against which future vessel traffic can be compared. This Scenario:

- Uses AIS data to establish number of ships and encounters, based on 2012 data;
- Uses PMV ship call data (PMV 2013b) to estimate container ship makeup. Cross checked against WorleyParsons (WorleyParsons 2011) data; and
- Westshore Terminals coal shipments were approximately 26 million tonnes and 270 bulk carrier ship calls (Westshore Terminals Investment Corporation 2013).

#### 3.3.2 Scenario 2 Traffic Growth to 2030 without New Facilities

The purpose of this Scenario is to establish a basis for comparing the incremental risk associated with RBT2 if no other new marine facilities are constructed other than Deltaport and Westshore Terminals volume increases. Changes in marine vessel traffic consistent with changes in fleet makeup are included. This Scenario:

- Assumes no new marine terminals;
  - Projects container throughput to meet maximum capacity of existing terminals at or before 2030.
- The assumed container capacity is shown in **Table 3-1**.

**Table 3-1 Container Capacity (Million TEUs) at PMV Terminals**

Year	2013 (Million TEUs)	2030 without RBT2 (Million TEUs)	2030 with RBT2 (Million TEUs)
<b>Total PMV TEU Capacity</b>	3.7	4.9	7.3
<b>Centerm</b>	0.9	1.3	1.3
<b>Deltaport</b>	1.8*	2.4	4.8
<b>Fraser Surrey Dock</b>	0.2	**	**
<b>Vanterm</b>	0.8	1.2	1.2

\* Deltaport 2013 capacity does not include DTRRIP improvements, 2030 capacity does.

\*\* Navigational constraints limit the economic viability of Fraser Surrey Docks. Although current container handling operations involving smaller container vessels may be maintained for some time, for planning purposes, Fraser Surrey Docks is not expected to be a reliable source of container capacity beyond 2018.

- Assumes tanker traffic will reflect existing fleet makeup, essentially no change to existing traffic; 40 tankers per year of which 80% are partially loaded Aframax, 20% are smaller (60,000 to 80,000 DWT);
- Assumes container ship traffic adjusts to changing sizes; sizes at Deltaport to follow 'large' size model, others to follow 'small' size model reflecting population makeup in other regions of the port;
- Assumes Westshore Terminals coal shipments to be 35 million tonnes, 313 bulker ship calls (PMV 2015a);
- Assumes no change to BC Ferries traffic at the Tsawwassen Terminal; and
- Projects sizes for other vessel sizes from 2009 to 2013 growth rates (see **Section 3.3.7** where size and number breakdowns are provided).

### **3.3.3 Scenario 3 Traffic Growth to 2030 without New Facilities but with RBT2**

The purpose of this Scenario is to assess the impact of the new container ship traffic on projected traffic without the addition of new marine facilities. This Scenario:

- Adds RBT2 container throughput (2.4 million TEUs) to Scenario 2 (PMV 2015a); and
- Uses projected 'large' container ship fleet size for RBT2 taken from the projection in container vessel size and traffic.

### **3.3.4 Scenario 4 Traffic Growth to 2030 with All Potential New Facilities, without RBT2**

The purpose of this Scenario is to establish a basis for comparing the incremental risk associated with RBT2 if all reasonably foreseeable other new marine facilities are constructed and operating at expected capacity. Changes in marine vessel traffic consistent with changes in fleet makeup are included. Scenario 2 is adjusted for the all foreseeable new facilities including:

- KM Trans-Mountain Pipeline Expansion; oil exports to be increased from 300,000 barrels per day (bpd) to 890,000 bpd carrying dilbit (a mixture of bitumen and condensate). Tankers are partially loaded Aframax tankers (KM 2013);
- Gateway Pacific coal/bulk terminal in Washington State to accommodate 54 million metric tonnes per year, 48 million of which would be coal; 490 ships per year based upon Capesize bulkers (similar to the majority at Westshore Terminals, average size 110,000 DWT) would call at the terminal. Most would enter and exit via Rosario Strait to the south (State of Washington 2013); and
- PMV projects including the Richardson Grain Terminal, Neptune Coal, Texada Coal and others, see **Section 3.3.7**.

### 3.3.5 Scenario 5 Traffic Growth to 2030 With All Potential New Facilities, with RBT2

The purpose of this Scenario is to assess the impact of the new RBT2 container ship traffic on projected traffic with the addition of new marine facilities. The additional ships in Scenario 4 (approximately 900) appreciably increase the size of the vessel population in the area. This Scenario:

- Adds RBT2 container throughput (2.4 million TEUs) to Scenario 4; and
- Uses projected 'large' container ship fleet size for RBT2.

Using Scenario 2 as a basis for comparison may lead to a larger relative increase in risk due to RBT2 than using Scenario 4 as a basis.

### 3.3.6 2012 Existing Conditions and 2030 Vessel Traffic Projections for Westshore Terminals and Roberts Bank Container Terminals

Marine vessel traffic data for the IP is based upon a combination of recorded vessel arrivals for the year 2012, and projections under four scenarios for the year 2030. **Table 3-2** presents the vessel traffic at Roberts Bank Terminals for the five scenarios including the breakdown in numbers of container ships and bulk carriers of different sizes.

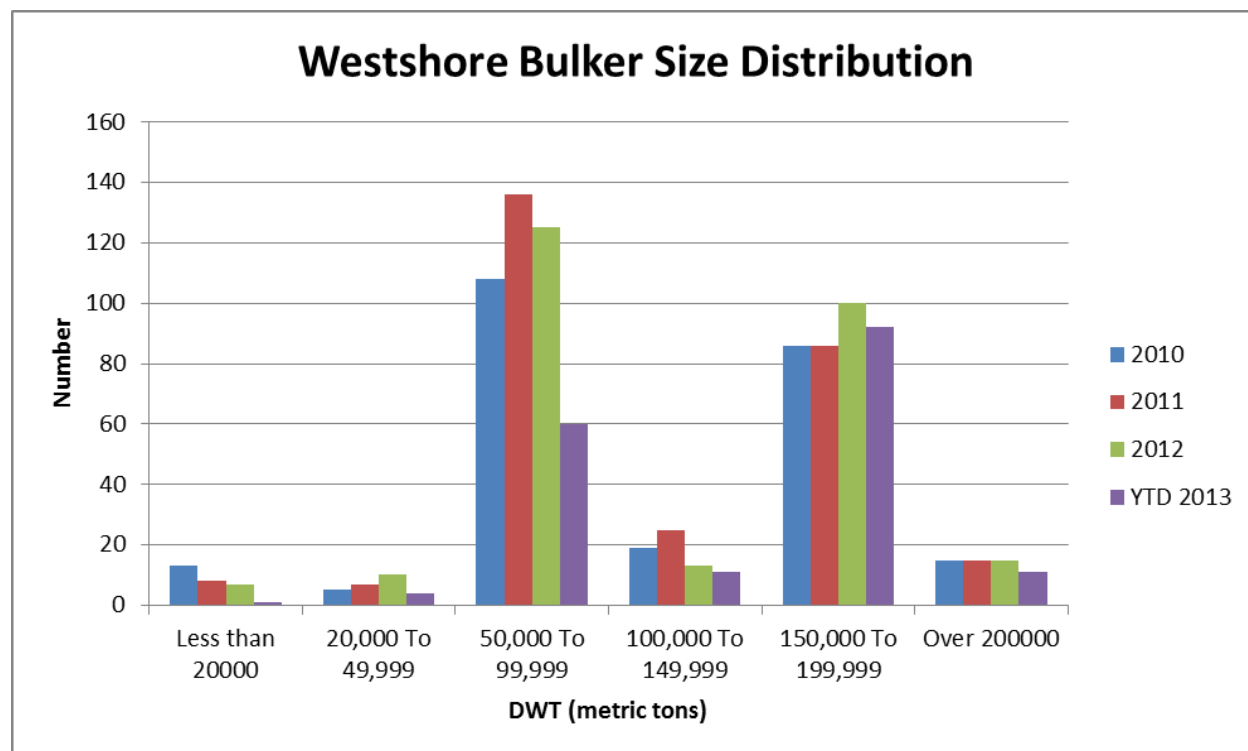
**Table 3-2 Vessels arriving at Roberts Bank Terminals in 2012 and 2030**

Vessel Population Models	Current 2012 No. of Ship Calls	Projected No. of Ship Calls in 2030			
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
Vessel Type	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
<b>Container Ships at Roberts Bank terminals</b>	1.8 MTEUs Capacity	2.4 MTEUs Capacity	4.8 MTEUs Capacity	2.4 MTEUs Capacity	4.8 MTEUs Capacity
<8,000 TEUs	67	42	84	42	84
8,000-10,000 TEUs	202	187	322	187	322
>10,000 TEUs	0	83	166	83	166
Total container ships	269	312	572	312	572
<b>Bulk Carriers at Westshore Terminals</b>	26.09 Mtonnes shipped	35.0 Mtonnes Capacity			
<=100,000 DWT	142	114	114	114	114
>100,000 DWT	128	199	199	199	199
Total bulk carriers	270	313	313	313	313

\* Assumes the successful approval, construction and operation of future projects listed in **Appendix B: Table B-2**.

Information and assumptions pertaining to marine vessel traffic for 2012 and 2030 are as follows:

- Roberts Bank container capacity refers to Deltaport only for the year 2012 and scenarios without RBT2 (PMV 2015a). RBT2 container capacity is assumed to be 2.4 MTEUs. Vessel traffic for the year 2012 is not derived from terminal capacity, but is obtained from PMV vessel arrival data (PMV 2013b);
- Container ship size breakdown for the year 2012 was developed by cross referencing the PMV vessel arrival data with the IHS Sea-Web database;
- Coal shipments and ship calls in 2012 reflect actual amounts and number of arrivals (Westshore Terminals, personal communication);
- Scenario 2 reflects vessel traffic assuming no additional marine facilities, but does include Deltaport operating at its sustainable operating capacity. Westshore Terminals coal shipments are assumed to be operating at expected 35 Mtonnes capacity (PMV 2015a). Container ship traffic is as projected by WorelyParsons (2011). Ship calls are derived by dividing ship movements by two to include the double call from a **split service**;
- Bulker traffic at Westshore Terminals for Scenarios 2 to 5 was based on the shipment tonnage and breakdown in vessels sizes recorded by Westshore Terminals in 2013 through August, and then extrapolated to 35 Mtonnes total capacity. Vessel sizes at Westshore Terminals have been steadily increasing with the major change being the elimination of very small vessels. The vessel population shows two distinct humps, as illustrated in **Figure 3-1**. The bulk carrier size distribution is driven in part by the requirements of the destination ports; and
- Container ship traffic at RBT2 was assumed to be the same as at Deltaport except that the split service that creates an additional 52 calls per year was assumed not to occur at RBT2. Container ships that call at Deltaport and Vancouver are typically part of liner trades involving several ports in Asia and generally more than one in North America (PMV 2013c). Although planned dredging at RBT2 permits the 18,000 TEU container ships to berth (PMV 2015b), the number of ships of this size that might call at this berth is assumed to be small enough because liner services restrictions in other ports are likely to limit the use of the maximum size vessels and thus, based upon the study authors' knowledge of the ports included in the liner trades, to have a minimal impact on ship call numbers. The general size breakdown at Deltaport is also assumed to be applicable to RBT2.



**Figure 3-1 Westshore Fleet Numbers and Sizes**

### 3.3.7 2012 Existing Conditions and 2030 Projections for other Marine Facilities including Cumulative Effects of Other Potential Marine Projects

Container ship traffic to RBT2 will interact with other traffic in the region. Vessel population projections for the five scenarios are made on the basis of cumulative effects of reasonably foreseeable new marine facilities projects and projected growth in the region as discussed in **Section 2.3.3**, Development of Vessel Population Scenarios. Combining these known potential new marine facilities with general marine traffic changes leads to the projections for marine vessel traffic transiting the waters adjacent to Roberts Bank shown in **Appendix B: Table B-3**.

### 3.4 ACCIDENT RATES AS IMPLEMENTED IN ANALYSIS

The methods used to develop the rates of accidents of various types necessary to evaluate the incidence of accidents with the potential to damage the environment are described in **Section 2.3.4**, Development of Accident Rates where the use of incident data and accident data are described. This section presents the results of that development. The key findings include:

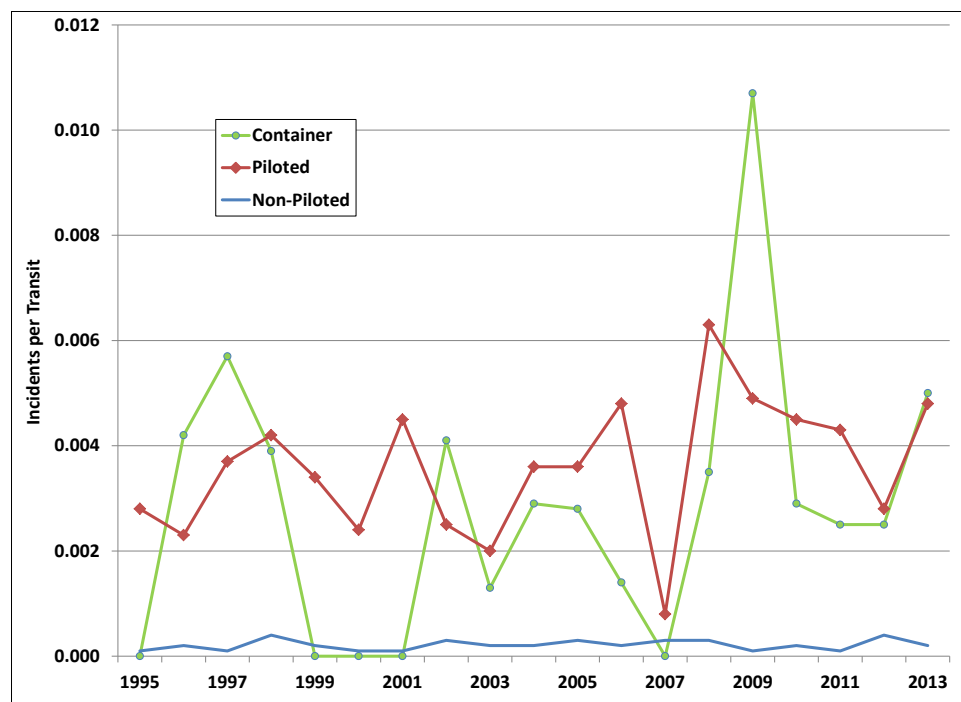
- Vancouver region incident rates are low, such that there is wide variability over the years introduced by small numbers of incidents;
- Comparison of Vancouver region incident rates should be done on the basis of all ships for all zones as there are too few incidents to assess on an individual zone or ship types basis;
- Vancouver incident rates are consistent with global rates;

- The most relevant comparison is with updated IMO rates for container ship accidents;
- The raw updated IMO rates need to be adjusted for exposure factor; and
- Comparison of Vancouver region accident rates with the updated IMO rates indicates the latter are appropriate to use as a basis in subsequent analyses.

Two special cases are also presented: collision rates for fishing and recreational vessel near the Roberts Bank terminals, and the risk associated with tugs during berthing and maneuvering operations.

### 3.4.1 Incident Rates in the Vancouver Region

The incident rate per transit for all reported incidents for container ships, piloted (i.e. large deep sea vessels) and non-piloted vessels is shown in **Figure 3-2**. The trends for piloted vessels and container ships show similar averages over time. As noted earlier, container ships are perceived to have lower incident rates than other vessels worldwide. The similarity in trends is likely a function of the highly managed vessel traffic including the use of pilots on nearly all large vessels. The small number of incidents, typically 2 to 3 per year, means that single events or lack of events cause large spikes in the effective rates. In 2007, for example, there were no container ship incidents and in 2009 there were eight.



**Figure 3-2 Annual Incidents per Transit (all types) for Container Ships, Piloted Vessels and Non-Piloted Vessels in the Vancouver region**

### 3.4.2 Comparison to World and Regional Rates

In the IMO FSA it is stated that -

“Generally, within the maritime industry and the public, container vessels have a reputation of being well designed, constructed, maintained, manned and operated with a high focus on safety. In addition to this, accident statistics suggest a safety record above the average of the merchant fleet today.”

Further the FSA assumes

“that the established baseline risk level implicitly reflects the current safety level of rules and regulations related to container vessels, despite the fact that specific vessels may have an even lower risk level due to commercial considerations. While many regulations pertain to all ship types, the International Convention for Safe Containers (CSC), the International Maritime Dangerous Goods Code (IMDG), and the Interim Guidelines for Open-top Container Ships apply to container vessels specifically. Both the IMDG code and the CSC code are mandatory under the SOLAS Convention.”

Evaluation of the **incident rates** in the vicinity of Roberts Bank supports the conclusion that the above applies to this region in particular. The basis of this assessment is outlined in this section.

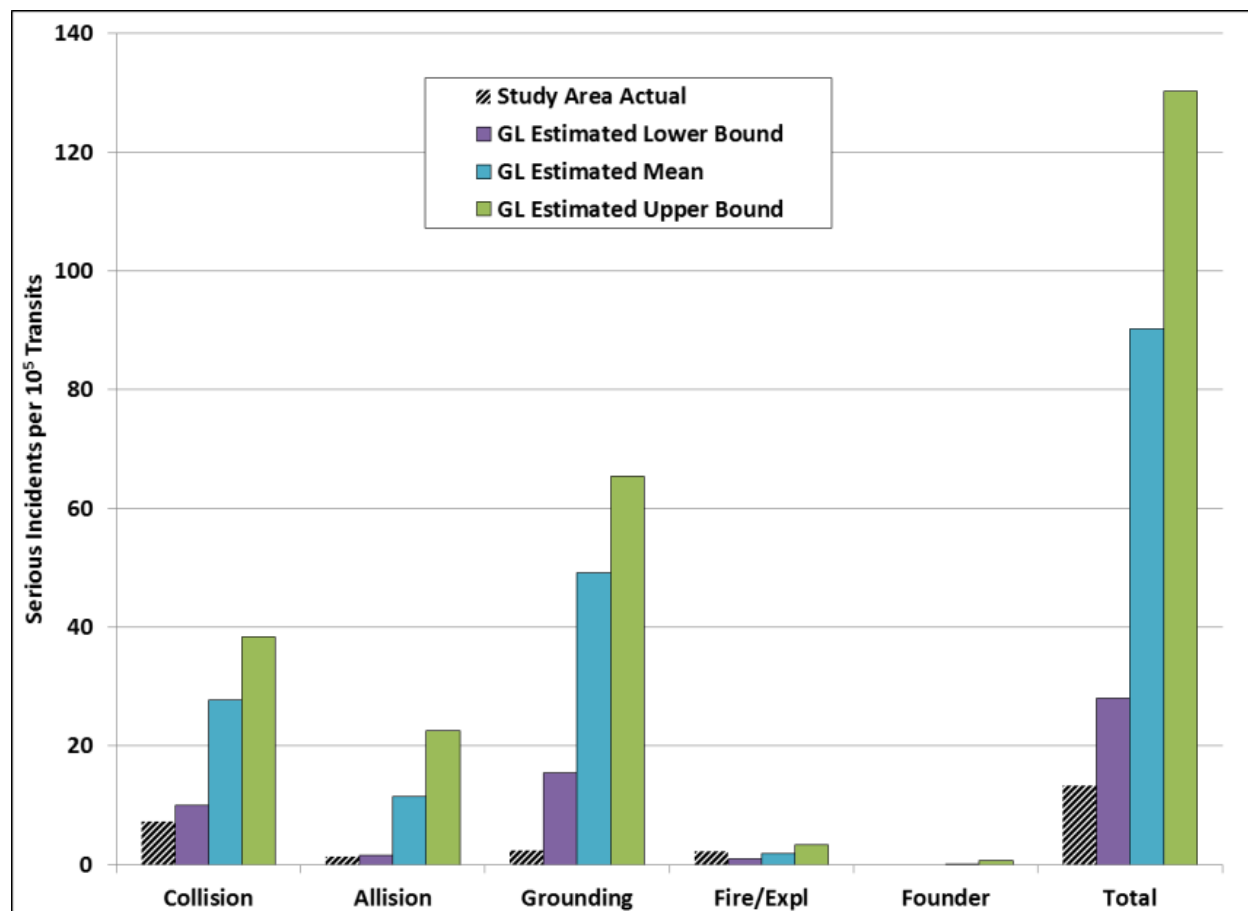
The comparison to world and regional rates shown in **Appendix C: Table C-13** indicate that the incident rates associated with vessel traffic in the Roberts Bank vicinity, and the incident study zones, are neither unusually high nor unusually low. This study has chosen to make this assessment based upon the full study region for all vessels, as the number of incidents in any one zone or for any one vessel type is considered to be too small to be statistically significant.

RBT2 traffic will be container ships. Thus, the most relevant comparison is to worldwide rates for container ships. The post-STCW incident rates for container ships in the Vancouver region are compared with the post-STCW accident rates derived in the GL updates to IMO accident rates (GL 2013) in **Table 3-3**.

**Table 3-3 Comparison of Adjusted GL Updates of IMO Rates to Vancouver Regional Rates**

Accident Type	Updated IMO Post-STCW Expected Container Adjusted Accident Rate			Vancouver Region Post-STCW		
	per Transit in Vancouver Region			Rate per Transit		
	Mean	Lower Bound	Upper Bound	Actual Incident Rate	% Serious	Estimated Accident Rate
<b>Collision</b>	$2.77 \times 10^{-4}$	$1.00 \times 10^{-4}$	$3.83 \times 10^{-4}$	$4.60 \times 10^{-4}$	16%	$7.36 \times 10^{-5}$
<b>Allision</b>	$1.15 \times 10^{-4}$	$1.50 \times 10^{-5}$	$2.25 \times 10^{-4}$	$1.10 \times 10^{-4}$	13%	$1.43 \times 10^{-5}$
<b>Ground</b>	$4.91 \times 10^{-4}$	$1.55 \times 10^{-4}$	$6.55 \times 10^{-4}$	$8.00 \times 10^{-5}$	30%	$2.40 \times 10^{-5}$
<b>F/E</b>	$1.90 \times 10^{-5}$	$1.00 \times 10^{-5}$	$3.30 \times 10^{-5}$	$5.60 \times 10^{-5}$	40%	$2.24 \times 10^{-5}$
<b>Founder</b>	$1.25 \times 10^{-6}$	0.00	$6.25 \times 10^{-6}$	0.00	100%	0.00
<b>Total.</b>	$9.03 \times 10^{-4}$	$2.80 \times 10^{-4}$	$1.30 \times 10^{-3}$	$6.10 \times 10^{-4}$	22%	$1.34 \times 10^{-4}$

**Figure 3-3** shows the comparison between the mean, lower-bound, and upper-bound accident rates calculated for the Vancouver region from the updated IMO rates, based on the incident rate analysis from actual incident data as presented earlier in this report. Overall the comparison to world rates indicates that the Vancouver regional rates are similar to the lower end of global container ship rates. However, it must be recognised that even when accounting for all piloted vessels the Vancouver regional data are still sparse.



**Figure 3-3 Comparison Between Adjusted Updated IMO Rates and Regional Accident Rates**

### 3.4.3 Implemented Accident Rates per Ship Year

The accident rates shown in **Table 3-4** are used to develop accident incidences and associated spill amounts in subsequent sections. The historical variability in these rates is used as a basis for the uncertainty in the rates. This variability is illustrated in **Figure 2-15**. Plots of the variability for individual accident types are presented in **Appendix D**, Update of IMO FSA Container Ship Accident Rates.

These accident rates, in adjusted ship years, are then multiplied by the actual time In-Port or In-Transit to get the rate per ship call or transit.

**Table 3-4 Implemented Accident Rates**

Implemented Accident Rates per Ship Year			
Accident Type	Lower Bound	Mean	Upper Bound
Collision	$10.0 \times 10^{-3}$	$27.7 \times 10^{-3}$	$38.3 \times 10^{-3}$
Allision	$1.5 \times 10^{-3}$	$11.5 \times 10^{-3}$	$22.5 \times 10^{-3}$
Grounding	$15.5 \times 10^{-3}$	$49.1 \times 10^{-3}$	$65.5 \times 10^{-3}$
Fire/Explosion	$1.0 \times 10^{-3}$	$1.9 \times 10^{-3}$	$3.3 \times 10^{-3}$
Founder	0.0	$0.1 \times 10^{-3}$	$0.6 \times 10^{-3}$

In application of accident rates to estimate the number of accidents expected, this study has modelled the rates as uncertain values with bounds that are based upon the variability in worldwide rates. This study has also used the average variability as a basis for ranges of uncertainty for parameters such as the exposure rate for which statistical data are not available.

### 3.4.4 Fishing and Recreational Vessels

Using the fishing vessel density data, see **Section 2.3.7** Fishing and Recreational Vessels, the collision probability per ship call, and the number of crossings of the fishing subareas by large vessels (including ferries), the probability of a collision between a fishing vessel and a container ship or other large vessel transiting the area is computed. Each large vessel crosses several DFO fishing subareas during each call to the region. The DFO data does not provide information about how the vessels might cluster while fishing. The mildly nonlinear effect of increased fishing vessel density on the collision rate is largely offset by the lower probability of encountering a cluster of fishing vessels in a given area. The effect of this assumption is considered negligible in comparison to the other assumptions in the model. In **Table 3-5** the probabilities and return periods for the five vessel scenarios are presented, showing a small increase of approximately 3% in the probability of a collision of a large vessel with a fishing vessel with the inclusion of RBT2. Collision return periods, which decrease slightly with RBT2, are consistent with the TSB incident data considering the much larger region covered by the TSB data and the lack of collisions near Roberts Bank.

**Table 3-5 Modelled Encounter Ratios and Collision Incidence for Selected Ship Types**

	Vessel Population Scenario				
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
	1	2	3	4	5
Container ship crossings of DFO fishing subareas	3120	3120	5720	3120	5720
Other vessel crossings of DFO fishing subareas	66260	67068	67084	75860	75876
Total vessel crossings of DFO fishing subareas	69380	70188	72804	78980	81596
Annual probability of collision with a fishing vessel	$1.75 \times 10^{-2}$	$1.77 \times 10^{-2}$	$1.83 \times 10^{-2}$	$1.94 \times 10^{-2}$	$2.00 \times 10^{-2}$
Return period of collision with a fishing vessel	57	56	55	51	50

\* Assumes the successful approval, construction and operation of future projects listed in **Appendix B: Table B-2**.

An uncertain issue is the role of crab fishing in collision rates. Entanglement with crab pot lines poses a small risk for tugs assisting large vessels. Currently there are off-limit areas for crab pots that are largely, but not uniformly obeyed. However, should RBT2 come on line, the navigational area will expand requiring a larger off-limit area or else a larger risk to tugs will be introduced. There is a small chance that tug assistance of a container ship would be curtailed. In 2012, the TFN expended about 15,000 hours of effort on crab fishing (definition of hours of effort is not known) and had about 65,000 trap days.

Recreational vessels are also not perceived to be a significant risk by pilots in the waters adjacent to RBT2. Numbers of recreational vessels in these waters are small compared to other points in the route to PMV terminals, including Roberts Bank terminals. Based upon this information the return periods for collisions with recreational vessels are estimated to be of the same order of magnitude as for fishing vessels.

### 3.4.5 Tug Boats at RBT2

DNV (2010b), based on an energy assessment, discounted the probability of a tug striking a tanker in berthing operations with sufficient force to damage the tanker enough to result in a spill. This is due to the added protection of the tanks for double hulled tankers. This would also apply to container ships calling at RBT2 in 2030 which would have double hull protection of fuel oil tanks.

A review of the IHS Sea-web database returned approximately 150 tug collision from 1995 through 2013 worldwide. These are based upon casualties reported for tugs with IMO numbers, and many tugs do not have IMO numbers. However, based upon the small number of incidents reported and the hundreds of thousands of tug assists yearly, the rate of such incidents that damage the tug to the point of causing pollution is considered negligible.

### 3.5 IN-PORT ACCIDENT INCIDENCE AND RELEASE AMOUNT PREDICTION

Using the methods described in **Section 2.3.5**, In-Port Incidence Prediction Methods the incidence of accidents leading to spills and the spill release amounts are estimated for container mishandling accidents, ship impact accidents and operational spills. Incidence of fire and explosion accidents is also estimated.

Spills during loading and unloading accidents and from ships can include fuel oils, crude oils, oil products and a variety of other bulk liquids, some of which are considered Hazardous and Noxious Substances (HNS) materials. **Appendix G**, Spill Materials and Properties, describes these materials.

#### 3.5.1 Incidence of Loss Overboard of Containers or Contents at Berth from Container Handling

Losses of this nature are very rare, especially those that result in loss of containers into the water. For example there have been none recorded at Deltaport (TSI 2013). As there is little data with which to evaluate this accident type, this study has taken two approaches to assess the incidence, see **Section 2.3.5.1**.

Container ships carry many different kinds of cargo. This includes HNS cargoes. **Appendix B: Table B-4** Composition and Number of HNS Containers at Deltaport in **2012** provides the distribution of HNS cargoes at Deltaport in 2012 and indicates both the wide range of HNS cargoes and the small percentage of containers carrying those cargoes. These HNS containers represent 0.7% of the container throughput at Deltaport in 2012 (TSI 2013). If a container or its contents were to be lost overboard there is a small chance it would be HNS cargo.

#### Container Losses Based Upon Global Container Loss Rates

Based upon this information developed in **Section 2.3.5.1**, the estimated probability of a spill is shown in the following **Table 3-6**.

**Table 3-6 Estimated Probability of a Spill from a Container, In Port**

Item	Value	Notes
Rate per laden container	$6.61 \times 10^{-7}$	Probability of a container loss per laden container
TEUs	$2.40 \times 10^6$	TEUs handled at RBT2
Laden ratio	0.88	Based upon PMV 2012b, not an empty container
Containers	$1.27 \times 10^6$	Laden containers at RBT2 (60% of TEUs)
No./year	0.84	Containers lost at RBT2
Years	1.2	Return period on container loss
Rupture/spill	0.01	Expert opinion estimate (Clark 2003)
No./year	.008	Spills from containers per year
Years	119	Return period on container spill

The probability of the spill from a container accident consisting of HNS material is approximately 0.007 based upon Deltaport container statistics for 2012 (TSI 2013). On this basis, the spill rate of HNS materials is  $0.59 \times 10^{-4}$  spills per year, or a return period over 17,000 years. This return period would be similar for Deltaport or RBT2 in 2030 also, as the number of containers handled at each terminal will be approximately the same.

### **Container Losses Based Upon Risk Assessment for UK Container Terminal**

This estimate is based upon a study performed in the UK for a new container terminal (Clark 2003), see **Section 2.3.5.1**. This study has extended this approach using Monte Carlo simulation. Using this, the return period associated with mean rate for a spill into the water increases to 700 years, and the HNS spill return period to 100,000 years based upon a container throughput of 2.4 MTEUs.

#### ***3.5.1.1 Loss of Containers Due to Ship Capsizing at Berth***

Small container and Ro Ro ships that may be carrying partial container cargoes have capsized while loading and unloading at berth. The probability of this type of event for fully cellular container ships of the size that will call at RBT2 and Deltaport is considered negligible. All recorded instances are for smaller vessels or multi-purpose vessels.

### **3.5.2 Incidence and Release Amounts of Impact Spills In-Port**

Spill probabilities and the estimated release volumes along with associated probability of being exceeded are provided in **Table 3-7**. The key result from this analysis is that both spill probability and spill size is expected to decrease from 2012 to 2030 with or without RBT2. This can be directly attributed to the requirements for protection of bunker tanks that came into force in 2010. The relative rate of bunker tank penetration is approximately 20%. This reduction in relative rates of bunker tank compromise, in association with projected changes in fleet compositions, will more than offset the increased spill probability associated with an increase in the number of ships as a result of Project completion. In 2030, the spill incidence and amounts are predicted to be proportional to the number of ships, so the completion of RBT2 would lead to an approximate doubling of the rate and amount of spills for container traffic at Roberts Bank.

Spill incidence is most sensitive to the assumptions on collision rate as well as the probability of hitting a bunker tank, while predictions about spill amounts are most sensitive to the bunker spill amount conditional probability.

In 2030, the mean spill sizes represent about  $1 \times 10^{-5}$  percent of the fuel oil carried by the container ships that would be calling at Deltaport and RBT2.

**Table 3-7 In-Port Bunker Tank Spill Occurrence and Expected Annual Amounts**

	Vessel Population Scenario				
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
	1	2	3	4	5
<b>No. of container ships</b>	269	312	572	312	572
Bunker spill conditional probability	0.394	0.061	0.061	0.061	0.061
<b>Mean spill probability</b>	$1.7 \times 10^{-3}$	$3.2 \times 10^{-4}$	$5.9 \times 10^{-4}$	$3.2 \times 10^{-4}$	$5.9 \times 10^{-4}$
Std. dev. of spill probability	$5.6 \times 10^{-4}$	$8.5 \times 10^{-5}$	$1.5 \times 10^{-4}$	$8.5 \times 10^{-5}$	$1.5 \times 10^{-4}$
95% confidence bound	$2.7 \times 10^{-3}$	$4.7 \times 10^{-4}$	$8.6 \times 10^{-4}$	$4.7 \times 10^{-4}$	$8.6 \times 10^{-4}$
<b>Mean annual spill amount (m<sup>3</sup>)</b>	1.42	0.29	0.52	0.29	0.52
Std. dev. of spill size	2.85	0.20	0.80	0.20	0.80
90% percentile size	4.10	0.81	1.50	0.81	1.50
95% percentile size	7.14	1.19	2.18	1.19	2.18
99% percentile size	14.73	2.26	3.96	2.26	3.96
<b>Return Period on Spill (years)</b>	586	3102	1691	3102	1691
<b>Mean annual spill amount (barrels)</b>	8.9	1.8	3.3	1.8	3.3
<b>100 year spill (barrels)</b>	93	14	25	14	25

\* Assumes the successful approval, construction and operation of future projects listed in **Appendix B: Table B-2**.

### 3.5.2.1 Year 2025 Incidence and Release Amounts of Impact Spills In-Port

In 2025, it is projected that the same number of ships will call as in 2030, but with a different size distribution. Also it will have been only 15 years since the IMO requirements for protective location of fuel tanks (IMO 2010) came into force, not 20 years as in 2030. In 2025 a small percentage of the container ships will be older than 15 years and thus, constructed before the requirements came into force. The same historical data above shows that 8 of the 97 (8.2%) container ships under 8,000 TEUs were older than 15 years, and that none over 8,000 TEUs were over 15 years in age. The following **Table 3-8** presents results for the impact spill assessment assuming this percentage also applies to ships under 8,000 TEUs in 2025.

The results for 2025 are very similar to those of 2030 as expected since the number of ships not implementing protective location of fuel tanks is relatively small. Spill probabilities are 8% to 9% larger and spill amounts are 2% to 4% smaller for 2025. The increase in spill probability is attributable to the lower level of fuel tank protection while the reduction in spill amount is attributable to the smaller average size of the ships in 2025. Similar trends are expected for In-Transit incidences. Overall these differences are small in comparison to the uncertainty in the predictions.

**Table 3-8 In-Port Bunker Tank Spill Occurrence and Expected Annual Amounts for Year 2025**

Comparison of Years 2025 and 2030	Container Ship Size Breakdown At Roberts Bank Terminals			
	2025		2030	
	Without RBT2	With RBT2	Without RBT2	With RBT2
	Scenario 4	Scenario 5	Scenario 4	Scenario 5
<b>Container Ships at Roberts Bank terminals</b>	2.4 MTEUs Capacity	4.8 MTEUs Capacity	2.4 MTEUs Capacity	4.8 MTEUs Capacity
<8,000 TEUs	60	120	42	84
8,000-10,000 TEUs	187	322	187	322
>10,000 TEUs	65	130	83	166
Total container ships	312	572	312	572
<b>Mean spill probability</b>	$3.5 \times 10^{-4}$	$6.4 \times 10^{-4}$	$3.2 \times 10^{-4}$	$5.9 \times 10^{-4}$
Std. dev. of spill probability	$8.9 \times 10^{-5}$	$1.6 \times 10^{-4}$	$8.5 \times 10^{-5}$	$1.5 \times 10^{-4}$
95% confidence bound	$5.1 \times 10^{-4}$	$9.3 \times 10^{-4}$	$4.7 \times 10^{-4}$	$8.6 \times 10^{-4}$
<b>Mean annual spill amount (m<sup>3</sup>)</b>	0.29	0.54	0.29	0.52
Std. dev. of spill size	0.20	0.79	0.2	0.8
90% percentile size	0.80	1.49	0.81	1.5
95% percentile size	1.17	2.09	1.19	2.18
99% percentile size	2.20	3.82	2.26	3.96

<b>Return Period on Spill (years)</b>	2865	1552	3102	1691
<b>Mean annual spill amount (barrels)</b>	1.8	3.4	1.8	3.3
<b>100 year spill (barrels)</b>	14	24	14	25

### 3.5.3 Operational Spills

Estimated operational stern tube lubricant inputs are shown in **Table 3-9**. Estimates for container ships alone are shown in **Table 3-10**. The amounts for 2030 are shown in **Table 3-11** assuming a linear increase with number of container ships. These tables use barrels of oil (6.29 bbls of oil per cubic metre). Converting to cubic metres leads to 3 m<sup>3</sup> from container ships and 5 m<sup>3</sup> in total at Roberts Bank in 2030.

**Table 3-9 Estimated Annual Lubricant Oil Discharges in 2012, all Vessel Types**

Port Area	Annual Bbl of Input
	Stern Tube
PMV Main	86
Roberts Bank Terminals	20
Fraser River	13
Transit	132
<b>Total</b>	251

**Table 3-10 Estimated Annual Lubricant Oil Discharges in 2012 from Container Ships Only**

Port Area	Annual Bbl of Input
	Stern Tube
PMV Main	17
Roberts Bank Terminals	9
Fraser River	5
Transit	34
Total	65

**Table 3-11 Estimated Annual Lubricant Oil Discharges in 2030, Container Ships vs. all Vessels at Roberts Bank Terminals**

Port Area	Annual Bbl of Input
	Stern Tube
Container ships at Roberts Bank Terminals 2030	19
All Vessels - Roberts Bank Terminals 2030	30

### 3.6 IN-TRANSIT ACCIDENT INCIDENCE AND RELEASE AMOUNT PREDICTION

Incidence of In-Transit accidents leading to loss of containers or liquids from ships is considered in this section. Where there is a non-negligible probability of an accident causing a spill the annual expected amount is also presented.

#### 3.6.1 Loss Overboard of Containers from Ships in Transit or Maneuvering in Semi-protected Waters

Loss of containers overboard in semi-protected or protected waters is assumed to result from a collision or grounding. Risk of loss from foundering or loss overboard from ship motions in semi-protected water is considered negligible. This is based on the WSC (2013) estimate that there are 350 containers lost per year from non-catastrophic events associated with ship seaway motions. There are typically about 100 million containers moved per year (WSC 2013) of which RBT2 would represent 2.4%. Thus, the loss rate is less  $1 \times 10^{-7}$  per year for container movements to RBT2. This incidence is considered negligible.

Numbers of containers lost overboard from collision are estimated in **Section 3.8.3**, Maximum Credible Number of Containers Lost.

### 3.6.2 Spill Incidence from Collisions In-Transit

The incidence of collisions in the In-Transit study area for container ships bound for Roberts Bank Terminals is based on a combination of the encounter modelling described in **Section 2.3.6.2** and the collision rates per ship year in **Table 3-4**.

The encounter model also permits classification of the other vessel types involved in encounters with container ships bound for Roberts Bank terminals. Four types of marine vessels have been selected for evaluation based upon possible consequence or largest number of encounters: crude tankers, other tankers (product and chemical), bulk carriers, and other container ships. BC Ferries from Tsawwassen have not been included on the basis of their high maneuverability and established risk avoidance and communication practices at Roberts Bank terminals. In **Table 3-12** the rates for these vessel types for each of the five vessel population scenarios are compared showing that of the four types, container ships have the highest encounter rate and crude oil tankers the lowest. This is expected given the relative numbers of vessels in the routes leading to most encounters.

The collision rate (collisions per transit) is computed from the accident rates given in **Table 3-4** in **Section 3.4**, adjusted for the transit period for a container ship travelling to RBT2 from the west end of Boundary Pass. This is a voyage of 56 NM miles round trip at an average speed of 20 knots. This is approximately 2.8 hours ( $3.2 \times 10^{-4}$  years) transit time for the round trip. In **Table 3-12** the collision rate per transit is distributed amongst the ship types in proportion to their relative encounter ratio to develop a collision rate for each ship type per transit, which is then multiplied by the number of transits to get the number of collisions per year.

**Table 3-12 Modelled Encounter Ratios and Collision Incidence for Selected Ship Types**

	Vessel Population Scenario				
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
	1	2	3	4	5
<b>Ratio of Encounters by Type</b>					
Crude tankers	0.1%	0.1%	0.2%	0.3%	1.2%
Other tankers	0.6%	0.2%	0.6%	0.7%	0.4%
Dry bulk carriers	3.4%	7.8%	4.9%	9.5%	6.7%
Other container ships	50.8%	51.3%	51.0%	50.6%	51.7%
All ships	100.0%	100.0%	100.0%	100.0%	100.0%
<b>Collision Rate per Transit</b>	$8.84 \times 10^{-6}$				
Container ships heading to RB	269	312	572	312	572
Collisions per year	$7.6 \times 10^{-5}$	$8.8 \times 10^{-5}$	$1.6 \times 10^{-4}$	$8.8 \times 10^{-5}$	$1.6 \times 10^{-4}$
<b>Collisions per Year by Type</b>					
Crude tankers	$1.1 \times 10^{-7}$	$1.2 \times 10^{-7}$	$2.5 \times 10^{-7}$	$2.6 \times 10^{-7}$	$1.9 \times 10^{-6}$

	Vessel Population Scenario				
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
	1	2	3	4	5
Other tankers	$4.6 \times 10^{-7}$	$1.3 \times 10^{-7}$	$1.0 \times 10^{-6}$	$6.2 \times 10^{-7}$	$6.9 \times 10^{-7}$
Dry bulk carriers	$2.6 \times 10^{-6}$	$6.9 \times 10^{-6}$	$8.0 \times 10^{-6}$	$8.3 \times 10^{-6}$	$1.1 \times 10^{-5}$
Other container ships	$3.9 \times 10^{-5}$	$4.5 \times 10^{-5}$	$8.2 \times 10^{-5}$	$4.5 \times 10^{-5}$	$8.4 \times 10^{-5}$
All ships	$7.6 \times 10^{-5}$	$8.8 \times 10^{-5}$	$1.6 \times 10^{-4}$	$8.8 \times 10^{-5}$	$1.6 \times 10^{-4}$
<b>Collision Return Period by Type</b>					
Crude tankers	$9.2 \times 10^6$	$8.0 \times 10^6$	$4.0 \times 10^6$	$3.9 \times 10^6$	$5.1 \times 10^5$
Other tankers	$2.2 \times 10^6$	$7.5 \times 10^6$	$9.6 \times 10^5$	$1.6 \times 10^6$	$1.5 \times 10^6$
Dry bulk carriers	$3.9 \times 10^5$	$1.4 \times 10^5$	$1.2 \times 10^5$	$1.2 \times 10^5$	$9.2 \times 10^4$
Other container ships	$2.6 \times 10^4$	$2.2 \times 10^4$	$1.2 \times 10^4$	$2.2 \times 10^4$	$1.2 \times 10^4$
All ships	$1.3 \times 10^4$	$1.1 \times 10^4$	$6.2 \times 10^3$	$1.1 \times 10^4$	$6.2 \times 10^3$

\* Assumes the successful approval, construction and operation of future projects listed in **Appendix B: Table B-2**.

RBT2 bound ships are not distinguished in this table from general Roberts Bank container ships including those that go to Deltaport. RBT2 container ships represent 83% increase in the number of ships (from 312 to 572 in 2030). The collision rate with RBT2 is 83% larger than without RBT2. The difference is effectively proportional to the potential increase in number of ships. This is true whether other marine facilities are included (Scenario 4 vs. Scenario 5) or not (Scenario 2 vs. Scenario 3). The difference between these two comparisons is well within the uncertainties in the modelling.

The collision rate has some variability. This study has modelled it as a random variable, centred on the implemented rate with lower and upper bounds based upon the collision rate bounds in **Table 3-4** Implemented Accident Rates **Table 3-13**. Utilising a Monte Carlo simulation for this, a standard deviation of 30% on the rate including the variability in the base updated IMO rates (GL 2013) and the exposure ratio assumption is obtained. The impact on return periods for RBT2 container ships under Scenario 5 which has the highest rate is shown in **Table 3-13**. That shows the minimum return period, for a collision with another container ship, or any ship, is approximately 7000 years, see cells highlighted in red in **Table 3-13**.

Minimum return periods for collisions with crude tankers, other tankers and bulk carriers are all over 50,000 years with bulk carriers being the lowest. This is consistent with the similarity in traffic routes for Roberts Bank terminals bound bulk carriers and container ships. Tanker return periods are all over 290,000 years and those for laden crude oil tankers are lower due to the fact that only southbound crude oil tankers are expected to be laden with crude oil.

**Table 3-13 Return Periods for RBT2 Bound Container Ship Collisions with Selected Ship Types**

Ship Type	Collision Return Periods (years)				
	Crude Tankers	Other Tankers	Dry Bulk Carriers	Other Container Ships	All Ships
Mean	$1.0 \times 10^6$	$2.9 \times 10^6$	$1.8 \times 10^5$	$2.4 \times 10^4$	$2.4 \times 10^4$
Standard Deviation	$3.1 \times 10^5$	$8.9 \times 10^5$	$5.5 \times 10^4$	$7.1 \times 10^3$	$7.1 \times 10^3$
Minimum	$2.9 \times 10^5$	$8.1 \times 10^5$	$5.4 \times 10^4$	$7.0 \times 10^3$	$7.0 \times 10^3$
Maximum	$2.0 \times 10^6$	$5.5 \times 10^6$	$3.5 \times 10^5$	$4.4 \times 10^4$	$4.4 \times 10^4$

Annual probabilities of spills in collisions between container ships bound for Roberts Bank terminals and other container ships, based upon the methodology in **Section 2.3.6.2**, Application of Encounter Modelling and Accident Rates to Collisions In-Transit are shown in **Table 3-14**. Note most collisions will not result in spills due to the protective location of fuel oil tanks. The mean annual probability of a spill drops from  $1.9 \times 10^{-4}$  in 2012 to  $3.4 \times 10^{-5}$  in 2030 without RBT2, and  $6.4 \times 10^{-5}$  with RBT2. This is attributed to the improved fuel tank protection. Return periods associated with mean spill probabilities range from 5,000 years to nearly 30,000 years. Maximum credible spill sizes from collisions where the container ship is struck are discussed in **Section 3.8.1**, Maximum Credible Fuel Oil Spill Size from a Container Ship.

As shown in **Table 3-13**, the minimum return period for collisions where a RBT2 bound container ship collides with a crude tanker is 290,000 years. However, the potential oil release from a collision where the container ship strikes a laden crude tanker is tens of thousands of cubic metres. In recognition of this combination of rare but high consequence event this event was assessed. The approach uses the same method as for container ship to container ship collisions with the adjustments for application to laden crude tankers described in **Section 2.3.6.2**. In that approach the crude tanker is laden half the time and is the struck ship half the time. Maximum credible spill sizes from collisions where the container ship is struck are discussed in **Section 3.8.2**, Maximum Credible Spill Size from a Crude Oil Tanker Involved in a Collision with a RBT2 Bound Container Ship.

**Table 3-14 Annual Probabilities of Spills from Collisions of RBT2 Bound Container Ships in the In-Transit Study Area with Container Ships**

	Vessel Population Scenario				
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
	1	2	3	4	5
	269	312	572	312	572
<b>Container ships</b>					
<b>Spill Probability</b>					
Mean	$1.9 \times 10^{-4}$	$3.5 \times 10^{-5}$	$6.3 \times 10^{-5}$	$3.4 \times 10^{-5}$	$6.4 \times 10^{-5}$
Standard Deviation	$6.7 \times 10^{-5}$	$1.2 \times 10^{-5}$	$2.2 \times 10^{-5}$	$1.2 \times 10^{-5}$	$2.3 \times 10^{-5}$
50%	$1.8 \times 10^{-4}$	$3.3 \times 10^{-5}$	$6.0 \times 10^{-5}$	$3.3 \times 10^{-5}$	$6.2 \times 10^{-5}$
75%	$2.3 \times 10^{-4}$	$4.2 \times 10^{-5}$	$7.6 \times 10^{-5}$	$4.2 \times 10^{-5}$	$7.8 \times 10^{-5}$
90%	$2.8 \times 10^{-4}$	$5.1 \times 10^{-5}$	$9.4 \times 10^{-5}$	$5.1 \times 10^{-5}$	$9.5 \times 10^{-5}$
95%	$3.2 \times 10^{-4}$	$5.7 \times 10^{-5}$	$1.1 \times 10^{-4}$	$5.7 \times 10^{-5}$	$1.1 \times 10^{-4}$
99%	$3.9 \times 10^{-4}$	$7.1 \times 10^{-5}$	$1.3 \times 10^{-4}$	$6.8 \times 10^{-5}$	$1.3 \times 10^{-4}$

\* Assumes the successful approval, construction and operation of future projects listed in **Appendix B: Table B-2**

**Table 3-15 Annual Probabilities of Spills from Collisions of RBT2 Bound Container Ships in the In-Transit Study Area with Laden Crude Tankers**

	Vessel Population Scenario				
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
	1	2	3	4	5
	269	312	572	312	572
<b>Container ships</b>					
<b>Crude Tankers</b>	55	49	49	399	399
<b>Spill Probability</b>					
Mean	$4.16 \times 10^{-8}$	$4.75 \times 10^{-8}$	$9.65 \times 10^{-8}$	$9.79 \times 10^{-8}$	$7.39 \times 10^{-7}$
95%	$6.92 \times 10^{-8}$	$7.79 \times 10^{-8}$	$1.61 \times 10^{-7}$	$1.61 \times 10^{-7}$	$1.22 \times 10^{-6}$
99%	$8.30 \times 10^{-8}$	$9.31 \times 10^{-8}$	$1.95 \times 10^{-7}$	$1.99 \times 10^{-7}$	$1.50 \times 10^{-6}$
<b>Spill</b>	m <sup>3</sup>	m <sup>3</sup>	m <sup>3</sup>	m <sup>3</sup>	m <sup>3</sup>
Mean	$4.16 \times 10^{-4}$	$4.75 \times 10^{-4}$	$9.62 \times 10^{-4}$	$9.92 \times 10^{-4}$	$7.47 \times 10^{-3}$
95%	$1.04 \times 10^{-3}$	$1.07 \times 10^{-3}$	$2.16 \times 10^{-3}$	$2.28 \times 10^{-3}$	$1.70 \times 10^{-2}$
99%	$1.39 \times 10^{-3}$	$1.43 \times 10^{-3}$	$3.01 \times 10^{-3}$	$3.01 \times 10^{-3}$	$2.24 \times 10^{-2}$

\* Assumes the successful approval, construction and operation of future projects listed in **Appendix B: Table B-2**.

### 3.6.3 Spill Incidence from Groundings In-Transit (drift and powered) for RBT2 Bound Container Ships

Grounding incidence from drift and powered groundings utilising the approach described in **Section 2.3.6.3**, Application of Accident Rates to Groundings In-Transit (Drift and Powered) is presented in **Table 3-16** and **Table 3-17**. Following that the probability of a spill associated with grounding is presented for each of the five vessel population scenarios in **Table 3-18**, showing the relative increase in spill probability with the addition of RBT2.

**Table 3-16 Drift Grounding Incidence for RBT2 Bound Container Ships**

Item	Peak	Lower	Upper
Grounding Rate	$2.30 \times 10^{-6}$	$7.25 \times 10^{-7}$	$3.07 \times 10^{-6}$
No. of ships	260	195	273
	Mean Standard Deviation 50% 75% 90% 95% 99%	<b>Groundings per year</b>	<b>Return Period years</b>
		$4.9 \times 10^{-4}$	2028
		$1.3 \times 10^{-4}$	
		$5.0 \times 10^{-4}$	2001
		$5.9 \times 10^{-4}$	1705
		$6.5 \times 10^{-4}$	1529
		$7.0 \times 10^{-4}$	1437
		$7.6 \times 10^{-4}$	1307

**Table 3-17 Powered Grounding Incidence for RBT2 Bound Container Ships**

Item	Peak	Lower	Upper
Grounding Rate	$1.38 \times 10^{-5}$	$4.35 \times 10^{-6}$	$1.84 \times 10^{-5}$
No. of Ships	260	195	273
	Mean Standard Deviation 50% 75% 90% 95% 99%	<b>Groundings per year</b>	<b>Return Period years</b>
		$3.0 \times 10^{-3}$	338
		$7.6 \times 10^{-4}$	
		$3.0 \times 10^{-3}$	334
		$3.5 \times 10^{-3}$	284
		$3.9 \times 10^{-3}$	255
		$4.2 \times 10^{-3}$	239
		$4.6 \times 10^{-3}$	218

The rate of grounding is predicted to be proportional to the number of arrivals. As RBT2 represents a potential 83% increase in container ship traffic over predicted traffic to Deltaport the increase in drift grounding incidence is a factor of 1.83 higher than the estimated incidence for 2030 without RBT2.

Estimated probabilities of spills in groundings of container ships In-Transit are shown in **Table 3-18**. The mean annual probability of a spill increases from  $8.89 \times 10^{-5}$  in 2012 to  $2.74 \times 10^{-4}$  in 2030 without RBT2, and  $4.73 \times 10^{-4}$  with RBT2. The increase from 2012 values depends on two factors; one, the increases in number of ships and the second, the relocation of bunker tanks that is optimised around avoiding penetration from collisions rather than groundings. In this case the improvement due to protective location of fuel tanks is not enough to offset the increase in numbers. Return periods associated with mean spill probabilities range from 2,000 years to 11,000 years.

The estimated expected annual amounts ( $0.21 \text{ m}^3$  to  $0.40 \text{ m}^3$ , see **Table 3-19**) in 2030 increase from 2012 as a function of the same two factors as above. Differences between Scenario 3 and 5 are due to the variability in the Monte Carlo simulation.

**Table 3-18 Annual Probabilities of Spills from Groundings of Container Ships In-Transit**

	Vessel Population Scenario				
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
	1	2	3	4	5
	269	312	572	312	572
<b>Container ships</b>					
<b>Spill Probability</b>					
Mean	$8.9 \times 10^{-5}$	$2.6 \times 10^{-4}$	$4.7 \times 10^{-4}$	$2.6 \times 10^{-4}$	$4.7 \times 10^{-4}$
Standard Deviation	$2.4 \times 10^{-5}$	$7.1 \times 10^{-5}$	$1.3 \times 10^{-4}$	$7.1 \times 10^{-5}$	$1.3 \times 10^{-4}$
75%	$1.1 \times 10^{-4}$	$3.1 \times 10^{-4}$	$5.6 \times 10^{-4}$	$3.1 \times 10^{-4}$	$5.6 \times 10^{-4}$
90%	$1.2 \times 10^{-4}$	$3.5 \times 10^{-4}$	$6.4 \times 10^{-4}$	$3.5 \times 10^{-4}$	$6.4 \times 10^{-4}$
95%	$1.3 \times 10^{-4}$	$3.8 \times 10^{-4}$	$6.9 \times 10^{-4}$	$3.8 \times 10^{-4}$	$6.9 \times 10^{-4}$
99%	$1.4 \times 10^{-4}$	$4.2 \times 10^{-4}$	$7.7 \times 10^{-4}$	$4.2 \times 10^{-4}$	$7.7 \times 10^{-4}$

**Table 3-19 Annual Spill Amounts from Grounding of Container Ships In-Transit**

	Vessel Population Scenario				
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
	1	2	3	4	5
	269	312	572	312	572
<b>Container ships</b>					
<b>Spill</b>	$\text{m}^3$	$\text{m}^3$	$\text{m}^3$	$\text{m}^3$	$\text{m}^3$
Mean	0.07	0.21	0.40	0.22	0.40
Standard Deviation	0.13	0.34	0.61	0.35	0.62
75%	0.07	0.26	0.47	0.25	0.48
90%	0.20	0.62	1.19	0.63	1.19
95%	0.36	0.93	1.75	0.97	1.74
99%	0.66	1.65	2.87	1.69	2.90

\* Assumes the successful approval, construction and operation of cumulative effects projects listed in **Appendix B: Table B-2**.

### 3.7 FIRE AND EXPLOSION ACCIDENTS

The IHS Sea-web database was searched for F/E casualties worldwide in container ships. These events can be some of the most catastrophic for container ships; an example is the Hyundai Fortune<sup>17</sup>. Most are minor and extinguished quickly. As noted earlier in Existing Risk Management Approaches (**Section 3.2**), container ships are required to have fire detection and suppression capabilities in the holds.

Since 1995, there have been 148 F/Es recorded for container ships worldwide (IHS 2013), of which 33 were in port; three of these were on the West Coast of North America, including two in Seattle and one in Los Angeles / Long Beach. Of the worldwide F/Es, twelve were in the cargo holds, three were in unspecified locations, and the rest were in accommodation, engine or machinery spaces. Two of the West Coast F/Es were in the cargo holds. The most common cause of F/Es in holds is incorrect storage of incorrectly labelled containers.

There have been about 1 billion ( $1 \times 10^9$ ) laden TEUs moved globally since 1995. For 2.4 MTEU each at Deltaport and RBT2, then the return period for each facility is about 600 years, and for both slightly under 300 years for a fire in a cargo hold. Although only a fraction of containers will contain HNS, it is likely that most ship hold fires will involve a container that should have been classified HNS.

Another source for F/E rates is the updated IMO rates (GL 2013), see **Section 3.4.3**, Implemented Accident Rates. Using this information the rate for RBT2 is evaluated as shown in **Table 3-20**. This study has assumed triangular probability distributions for the incident rate and the number of ships. The rate with a 95% confidence level is 140 years assuming 260 for the mean number of ships.

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<sup>17</sup> According to the Centre of Documentation, Research and Experimentation of Accidental Water Pollution (Cedre), in 2006, en route from China to Europe the Hyundai Fortune suffered an explosion of unknown origin in a hold causing 60 to 90 containers to fall into the ocean. The explosion caused a fire that spread through the stern of the ship, including the accommodation and container stacks in front of the accommodation. Secondary explosions followed as seven containers of fireworks also ignited. Firefighting efforts took several days.

**Table 3-20 Fire/Explosion Incidence**

Item	Peak	Lower	Upper
Fire/Explosion	$1.90 \times 10^{-5}$	$1.00 \times 10^{-5}$	$3.30 \times 10^{-5}$
No. of Ships	260	195	273

		F/E per year	Return Period years
	Mean	$5.0 \times 10^{-3}$	199
	Standard Deviation	$1.2 \times 10^{-3}$	
	50%	$4.9 \times 10^{-3}$	202
	75%	$5.9 \times 10^{-3}$	171
	90%	$6.7 \times 10^{-3}$	149
	95%	$7.1 \times 10^{-3}$	140
	99%	$7.9 \times 10^{-3}$	127

Both approaches indicate that the rate of F/E events will approximately double with the addition of RBT2 because the number of containers doubles. Most of these events will be of short duration and controlled by the ship crew.

### 3.8 MAXIMUM CREDIBLE SPILL SIZES

In planning for response capabilities the U.S. Coast Guard (USCG) uses the concept of **worst-case discharge**. This spill volume, based on USCG regulations, is the total capacity of the cargo and/or bunker fuel tanks of the vessel. This volume varies from 10 barrels for small recreational vessels to 1.9 million barrels ( $300,000 \text{ m}^3$ ) for fully-loaded, very large, crude tankers.

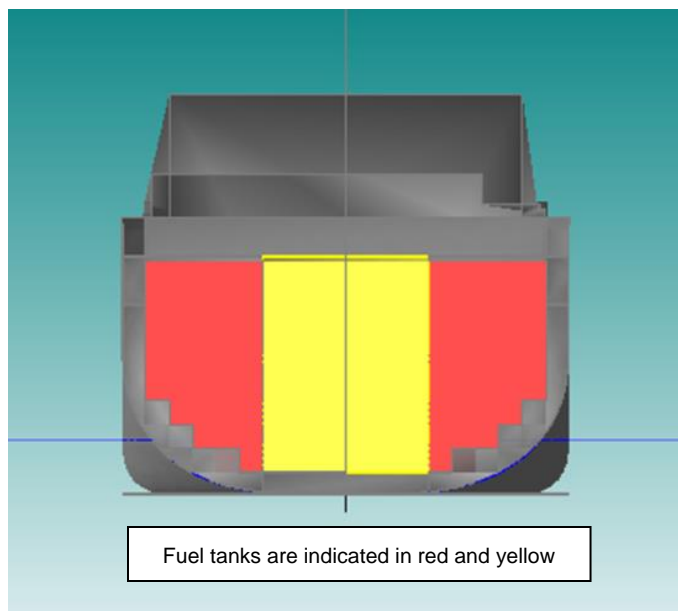
In planning for response capabilities, the concept of worst-case discharge is usually taken as the total capacity of the cargo and/or fuel tanks of the vessel involved. In assessing risk, this is not necessarily the appropriate amount if the probability of such a spill is minute, on the order of  $1 \times 10^{-6}$  per annum. Scenarios that would result in total loss would almost invariably take time long enough for a response to be initiated. In the event of a spill, a clean-up would be mounted, whether the spill consisted of containers, or their contents, and whether the spill originated from the container ship or another ship involved in a collision. Evaluation of the exposure of the environment to the maximum credible spill should take these factors into account. On the other hand, planning for the response should take into account the amount that would need to be removed from being in a position to cause environmental damage, i.e., the worst-case discharge.

Note that the estimates below for maximum credible spill size are not different for RBT2 than for current container ship traffic to Deltaport and other PMV terminals as the maximum fuel oil tanks sizes for container ships calling at all terminals is the same.

### **3.8.1 Maximum Credible Fuel Oil Spill Size from a Container Ship**

Fuel tanks on container ships are usually widely distributed throughout the vessel, and the chance of damage causing all to lose all their contents is minute given the accident rates and types for the region, see **Sections 3.5** and **3.5.2.1**. For this assessment, the largest assumed oil spill release was based upon one or two of the largest fuel tanks losing their contents. IMO statistics used to formulate the fuel tank protective locations show no damage penetrations beyond 0.3 times ship beam, including all side penetrations, from impacts at all speeds. In port, the penetrations would be due to low speed collisions or allisions. Bunker tanks on container ships meeting the requirements for protective location are designed such that the boundary into a second tank is beyond the limit of the IMO distribution, and the tanks are not located adjacent to one another longitudinally. **Figure 3-4** and **Appendix A: Figure A-6** show the widely longitudinal separation and three-across arrangement of the fuel tanks of a modern container ship. Fuel tanks are indicated in red and yellow. Each tank is less than or equal to 2,500 m<sup>3</sup> in size as limited by IMO. Thus, this study recommends that the maximum credible spill for a collision, allision or soft grounding would be the size of the largest single fuel tank allowed under the regulation.

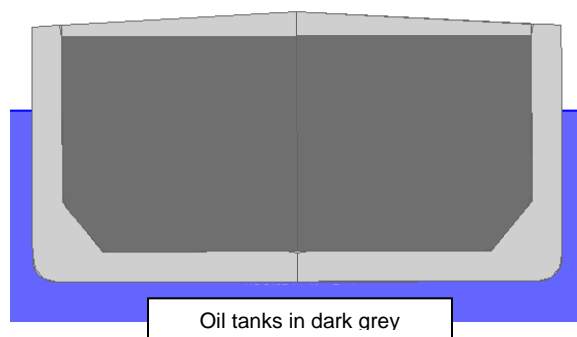
Simulation of grounding damage analysis using the IMO probability distributions via the HEC software indicates a greater probability of hitting three tanks across. For grounding scenarios therefore, it is assumed that the maximum credible spill size for a hard grounding is three times the maximum tank size, or 7,500 m<sup>3</sup>.



**Figure 3-4 Three Across Fuel Tank Arrangement for 12,500 TEU Container Ship**  
(see also C4 in Appendix A: Figure A-6)

### **3.8.2 Maximum Credible Spill Size from a Crude Oil Tanker Involved in a Collision with a RBT2 Bound Container Ship**

Analysis of collisions where a container ship strikes a 90% full laden Aframax tanker similar to the current and proposed tanker traffic from the KM terminal in Burrard Inlet using the IMO Accidental Oil Outflow damage probability distributions (IMO 2010) has been done. A double hulled tanker will have a cross section such as shown in **Figure 3-5** where the oil tanks are surrounded by an envelope typically 2.5 m in thickness. This analysis indicates that the tanker will always survive the collision. For collisions that cause hull penetration, the probability of striking an oil tank (whether fuel or cargo) is 0.292 using this approach. The IMO statistics used show no damage penetrations beyond 0.3 times ship beam, including all side penetrations, from impacts at all speeds thus, limiting the amount of oil possibly spilled. The maximum amount of oil spill in a damage scenario under these assumptions is just under 40,000 m<sup>3</sup>.



**Figure 3-5 Aframax Crude Oil tanker midship cross-section at 90% loading**

### **3.8.3 Maximum Credible Number of Containers Lost**

In the absence of any established procedure for determining maximum numbers of containers lost in protected waters, the IHS Sea-web casualty database was reviewed for containers lost in collisions in or near ports. Of the 19 events provided in the database, 12 events did not involve a reported loss overboard of containers. The largest number of overboard containers reported was 290 containers from the MSC Chitra (2,314 TEUs capacity) in 2010, about 25% of the capacity based upon typical 40 ft. containers.

In the case of the MV Rena grounding accident, there was a loss of 360 of 1,368 containers, representing 26% of the containers onboard.

The APL China incident occurred in a storm at sea, resulting in the overboard loss of 800 containers, representing approximately 30% of the vessel capacity. The sea states involved in this accident are impossible in the Strait of Georgia, thus, this is not considered a credible event.

Collisions that have caused the largest numbers of container loss have occurred in transit rather than during maneuvering in port. In port, one might imagine an incident where a few containers were dislodged during an allision incident. Conceivably, some containers could end up in the water. However, the incidence of such containers carrying HNS is proportional to the ratio of HNS containers to total containers moved. The combination of these factors suggests that the most credible maximum HNS container loss in a collision or container handling accident would be one.

Container handling operations between the ship and pier are almost exclusively single container operations. Thus, during in port container handling operations, the most credible maximum predicted loss into the water is a single container. This could amount to 26,000 L of liquids from a twenty foot bulk liquid container.

### 3.9 SPILL LOCATIONS

The consequences of a spill are controlled in large part by the location relative to sensitive and vulnerable ecosystem components. Allisions, in-port collisions and operational spills will occur adjacent to or near the berth face. In contrast to Deltaport, which is influenced by two causeways, the Roberts Bank causeway to the north-east and the BC Ferries causeway to the south-east, the RBT2 berth face is exposed to the Strait of Georgia. For Deltaport, in the event of a spill it would be possible to boom off the exit to the main waterway. On the other hand RBT2's exposure means that a spill will be more difficult to contain. Conversely, a spill in the vicinity of Deltaport would place it in closer proximity to ecologically productive foreshore and intertidal areas, while a spill in the vicinity of RBT2 would be farther removed initially from marine substrate-water interface areas. The impact of this difference is the subject of Component 2 of the QRA.

Collisions and subsequent spills in the In-Transit study area will have the highest probability of occurrence where the encounter probability is highest. The most likely encounter, and thus, possible collision and resulting spill locations, are illustrated by **Figure 3-6** and shown in more detail in **Figure 3-7** for Vessel Scenario 5 which has the highest vessel traffic. The spill locations are most likely near the ferry terminal and approaches to Roberts Bank terminals, near East Point on Saturna Island at the eastern entrance to Boundary Pass, and near Turn Point on Stewart Island at the entrance to Haro Strait at the southwest end of Boundary Pass, based on the relative risk of overtaking, head-on and crossing encounters. Groundings are expected to occur most frequently along Boundary Pass due to the narrowness of the channel and prevailing wind directions.

The encounters maps produced from route modelling include not just RBT2 incremental ship movements, but also all projected traffic for Deltaport and surrounding areas. Therefore, the maximum density of encounter tends to occur south of the location of the proposed RBT2 berth face, as occurs at present. The encounter maps are potentially useful for identifying general areas of higher spill probability – albeit very low overall, for the purpose of consequence analysis.

Note that the actual probability of collision is extremely small as described in **Section 3.6.2**, Spill Incidence from Collisions In-Transit.

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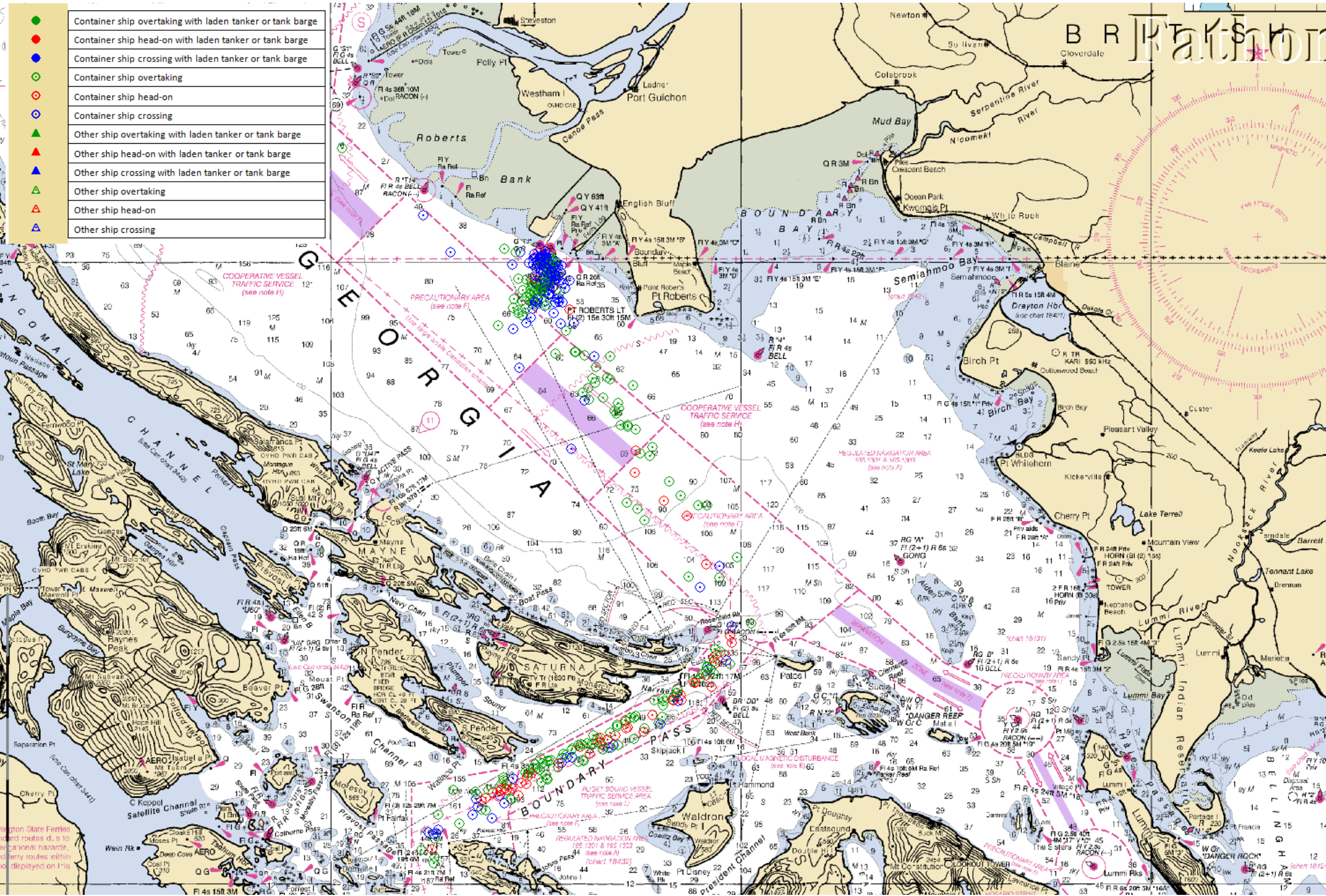
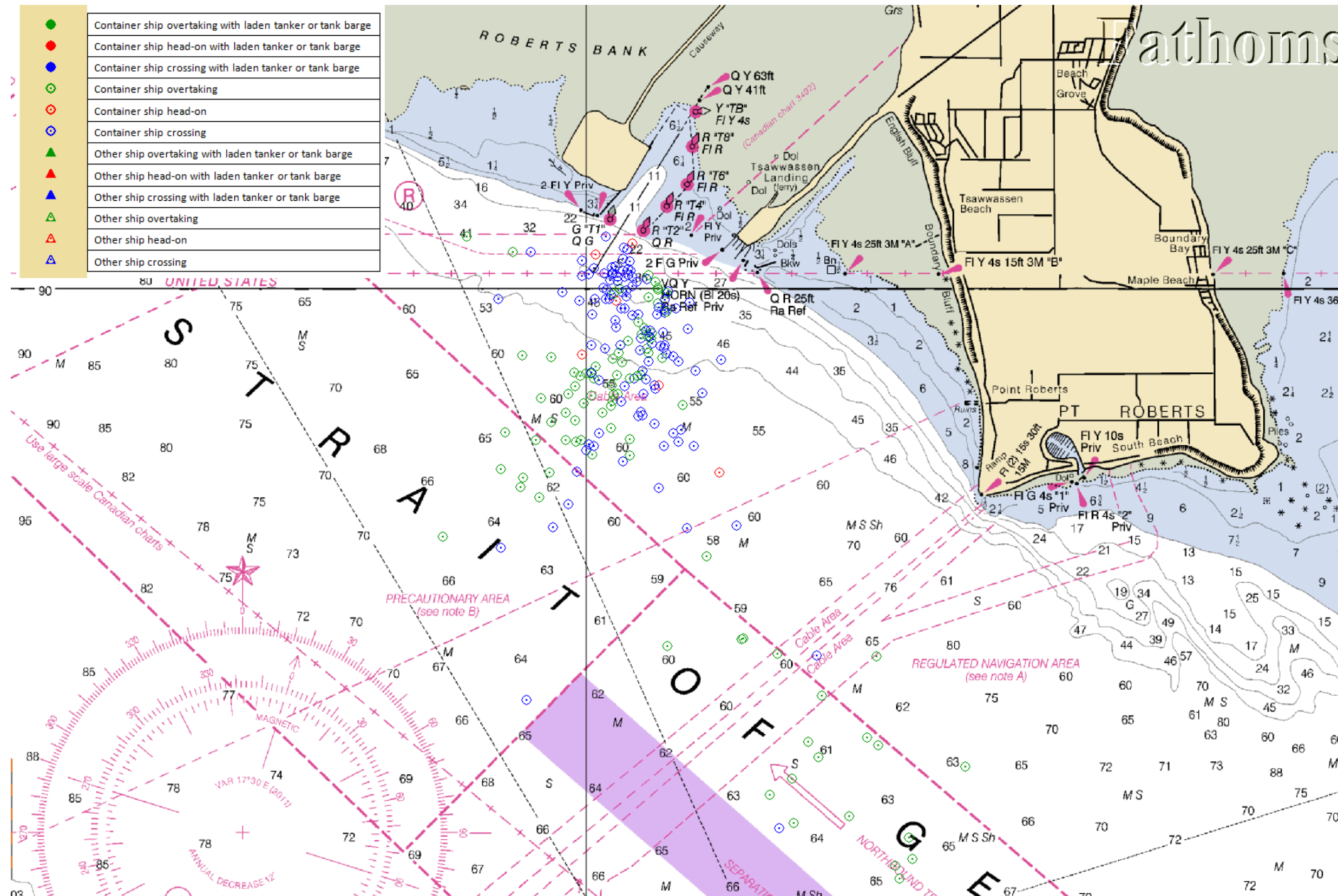


Figure 3-6 Encounter Locations for Roberts Bank Terminals Bound Container Ships, Scenario 5



**Figure 3-7 Encounter Locations for Roberts Bank Terminals Bound Container Ships, Scenario 5 near Roberts Bank**

## 4.0 DISCUSSION

A discussion of the major results arising from the Marine Vessel Incidence Prediction Inputs to the QRA study is provided below. The key items are:

- An assessment of the frequency of events potentially leading to adverse consequences in the context of the Transport Canada PRMM where the frequencies are identified as improbable;
- A discussion of the sensitivity to key assumptions where it is shown that the frequency assessment is not sensitive to the assumptions;
- Recommendations for metrics upon which to base future incidence predictions if projections of vessel populations or container throughput at RBT2 change; and
- A discussion of the changes in incidence associated with the incremental increase in ship movements and port activities associated with RBT2.

A brief note about a data gap associated with fishing and recreational vessel data in the vicinity of Roberts Bank is provided.

### 4.1 FREQUENCY ASSESSMENT

The Transport Canada PRMM provides guidance for frequency assessment of events leading to adverse consequences. This study has utilised the interpretation included in the Vancouver International Airport (YVR) fuel facility QRA (DNV 2012a) to translate these into approximate return periods (see **Table 4-1**). The interpretations emerge directly from the definitions from the PRMM with the exception of the “Improbable” category, where an assumption has been made. In practice the shipping related incidence for accidents and malfunctions associated with RBT2 are considered highly improbable, as shown below, so classification of frequency is not sensitive to this assumption.

**Table 4-1 PRMM Frequency Assessment Interpretation**

Probability of Event Occurring		Accident Return Period Project Interpretation
<b>Highly Probable</b>	Almost certain that the event will occur OR at least once over a period of one year	Less than or equal to 1 year
<b>Probable</b>	Expected that the event will occur OR at least once over a period of three years	Between 1 and 3 years
<b>Possible</b>	The event could occur over a period of 10 years	Between 3 and 10 years
<b>Unlikely</b>	It is not expected that the event will occur over a period 10 years	Between 10 and 25 years
<b>Improbable</b>	It is not expected that the event will occur over any defined period.	Assume greater than 25 years

**Table 4-2** provides the incidence predictions for spills from allisions, collisions and groundings, and for F/E from container ships bound for Roberts Bank terminals, showing that return periods and 95% upper confidence limit estimates for all these events are in the “Improbable” category. The lowest return periods are for F/E events. Return periods for events other than F/E are generally more than one order of magnitude longer than the interpretation used for the Improbable category.

**Table 4-2 Annual Incidence of Pollution Causing Events for Container Ships Bound for Roberts Bank Terminals**

Annual Incidence and 95% Upper Confidence Limit (UCL) of Pollution Causing Events for Container Ships Bound for Roberts Bank Terminals								
	Collision with Container ship In- Transit		Grounding In-Transit		In-Port Combined Collision, Allision and Grounding		In-Port Fire/Explosion	
	Without RBT2	With RBT2	Without RBT2	With RBT2	Without RBT2	With RBT2	Without RBT2	With RBT2
<b>Mean rate</b>	$3.45 \times 10^{-5}$	$6.45 \times 10^{-5}$	$2.58 \times 10^{-4}$	$4.73 \times 10^{-4}$	$3.22 \times 10^{-4}$	$5.91 \times 10^{-4}$	$6.04 \times 10^{-3}$	$1.11 \times 10^{-2}$
<b>95% UCL rate</b>	$5.70 \times 10^{-5}$	$1.07 \times 10^{-4}$	$3.76 \times 10^{-4}$	$6.88 \times 10^{-4}$	$4.74 \times 10^{-4}$	$8.61 \times 10^{-4}$	$8.57 \times 10^{-3}$	$1.57 \times 10^{-2}$
<b>Ratio 95 UCL/Mean</b>	1.65	1.66	1.46	1.45	1.47	1.46	1.42	1.42
<b>Ratio with /without RBT2 based upon Mean</b>	n/a	1.87	n/a	1.83	n/a	1.84	n/a	1.83
<b>Return Period 95% UCL (years)</b>	17544	9346	2660	1453	2110	1161	117	64

For collisions in the In-Transit study area, only other container ships were included in the table as the rate for collisions with other ship types such as tankers are much smaller. Return periods for a spill from a laden crude tanker from a collision with a RBT2 bound container ship are over 800,000 years. Details of these rates can be found in 3.6.2, Spill Incidence from Collisions In-Transit.

Accident incidence associated with container handling is described in **Section 3.5.1**. Two approaches have been used to develop rates in lieu of the availability of detailed, credible data. Both approaches lead to expected return periods for HNS container spills of over 10,000 years thus, being considered improbable.

F/E incidence is presented for the prediction based upon utilizing the updated IMO rates as using this approach allows development of the 95% UCL rate. Utilising an approach based upon number of containers throughput leads to similar results, see **Section 3.7**.

Return periods for collisions with fishing vessels and for collisions with recreational vessels are approximately 50 years. The addition of RBT2 container vessels increases the incidence by approximately 3%.

#### 4.2 SENSITIVITY TO KEY ASSUMPTIONS

The frequency assessment conducted indicates that all shipping related accidents can be considered improbable, with or without RBT2. This study has explicitly included uncertainty in analyses and utilised 95% confidence bounds to make that assessment. Uncertainty in the number of new container ships associated with RBT2 has been explicitly included. In practice, the nominal numbers are closer to upper bounds on number of new ships.

Monte Carlo simulations indicate that, aside from the number of ships, the variance in the estimates is most sensitive to the accident rate assumed. The accident rate estimates that were utilised were based on the GL (2013) rates for a ship-year, combined with an estimate of the proportion of the ship-year the ship is exposed to that accident risk. To evaluate the impact of these assumptions this study has taken the In-port combined spill analysis and applied extreme value estimates for the accident rate and exposure ratio. Specifically, the upper 95% confidence bound for the accident rate and the lowest exposure ratio was used. This is a combination that leads to higher accident rate estimates. The assumptions for variability for other parameters were kept the same as in the prior analysis.

For this set of assumptions the 95% return period value for a spill occurring without RBT2 decreases from 2,110 years to 1,974 years. For the scenario with RBT2 the decrease is from 1,161 to 1,080 years. All remain well above the improbable event threshold.

#### 4.3 METRICS FOR FUTURE FREQUENCY PREDICTION

There are three metrics that can be used to scale future predictions of container shipping accident and malfunction incidence. These are:

- **Number of ship calls:** the incidence estimates for vessel traffic related accidents are largely independent of ship size at this time. Further, the largest bunker tank size is limited by regulation so will not change for ships built after 2010. This metric is suggested for incidence scaling of allisions, collisions and groundings;
- **Number of containers throughput in TEUs:** Container handling accident incidence is considered independent of the ship being loaded or unloaded. This metric is suggested for incidence scaling of container handling accidents and also F/E accidents. Although the IP used both ship calls and number of containers to evaluate the incidence of F/E events this approach is recommended for future prediction because the F/E of concern are most likely to be associated with containers carrying HNS cargoes. The number of these containers will be proportional to the total number of containers, not number of ship calls; and

- **Time in transit:** the incidence of collisions and groundings in transit is essentially linear with time in transit. The time per transit in the study area for a Roberts Bank bound container ship is about 3 hours for an average vessel speed of 20 knots. Estimates for longer times and thus, correspondingly longer transits, such as including Haro Strait or beyond, can be made by linearly scaling incidence for these accident types.

The number of ships to handle a particular container throughput is a function of the effective utilisation of a ship slot capacity. For RBT2 in 2030 the container throughput is modelled at 2.4 M TEUs carried on 260 container ships. This is an effective average slot capacity utilization of 9,230 TEUs per arrival. This study's assessment of vessel population uncertainty suggests that future ship sizes may be larger than the mean estimate. An estimated 10,000 TEU throughput per ship call seems reasonable.

#### 4.4 CHANGES IN INCIDENCE AND SPILLS DUE TO RBT2

The potential RBT2 project would introduce transshipment of 2.4 M TEUs of containers. To handle this traffic, approximately 260 container ships will arrive at RBT2 in addition to the projected 312 container ships at Deltaport and 313 bulk carriers at Westshore Terminals. This is an increase of 1.83 on container ships calling at RBT2 or increase of 1.29 for all large vessels calling Roberts Bank terminals. Incidence of collisions, contacts and groundings is approximately proportional to number of vessels. Thus, the projected incidence for Roberts Bank bound ships would increase by 83% for containers ships and 29% for all vessels. Incident rates remain improbable for all A&M under Transport Canada's PRMM classification systems with or without RBT2.

Expected spill release rates and sizes are influenced by numbers of vessels and especially by the influence of fuel tank protective location on vessel design. This is particularly relevant for container ships as older vessels have been built with fuel tanks in relatively exposed locations immediately adjacent to hull plating. Expected spill rates will decrease from 2012 to 2030. The expected spill rate is projected to drop to 20% of the 2012 rate for Deltaport without RBT2. The expected return period on a spill is projected to increase from 600 years to over 3,000 years in 2030 without RBT2 and over 1,600 years with RBT2. The addition of RBT2 will still cause a higher release rate due to more ships. The ratio is the same as above, 1.83.

Expected spill size (i.e. the mean average spill sizes) is also projected to decrease for container ships at Roberts Bank in 2030 from the expected release size in 2012. The expected annual spill amount for the In-Port area drops from  $1.42 \text{ m}^3$  in 2012 to  $0.29 \text{ m}^3$  without RBT2 and to  $0.52 \text{ m}^3$  with RBT2 in 2030. As noted earlier, expected spill sizes are a weighted average of different size spills. Some years can be expected to have no spills, others a larger spill or more than one spill. The expected amount is projected to drop to one-third of the existing expectation. The addition of RBT2 will still cause a higher release amount due to more ships. The ratio is the same as above, 1.83. However, maximum credible spill sizes at Roberts Bank remain the same with or without the construction of RBT2.

Incidence of container or container contents loss, or of fire and explosion, are found to follow the number of containers handled. Since RBT2 will double the number of containers handled, the incidence of such events will also double. Thus, the return period of a fire or explosion onboard a container ship while in port will drop from approximately 120 years to 60 years with the addition of RBT2. Most of these will not be serious and can be handled by the onboard fire suppression equipment. Incident rates for loss of HNS containers or contents due to mishandling will continue to lead to return periods in the tens of thousands of years.

In terms of the overall marine traffic in the waters adjacent to Roberts Bank in the southern Strait of Georgia, the increase in vessels is from approximately 11,250 in 2012 to 12,445 without RBT2 and 12,705 with RBT2 in 2030. The percentage of the population represented by container ships rises from 2.4% in 2012 to 2.5% and 4.5% without and with RBT2 respectively, in 2030. Container ships are generally thought to be safer than the general shipping traffic. However, a quantitative assessment of this improved safety is not available because of the lack of direct comparisons in casualty databases. Thus, a reasonable estimate of increased incidence is the relative increase in number of ships.

This assessment is most sensitive to the estimated number of ships calling at Roberts Bank terminals, and at other facilities in the region, and uncertainty exists in these estimates. The rapid expansion in container ship size was unforeseen fifteen years before it happened. There is the possibility of other major unforeseen changes in the marine industry in the fifteen years covered in this projection. However, there is a long term trend in growth in size of ships. The estimates in this analysis are probably biased toward the high end of number of ships calling at RBT2 thus, representing an upper end estimate for incident rates.

Finally, it should be stressed that this analysis considers only incidence prediction and does not include a consequence assessment. In particular this applies to the consequence of spills resulting from collisions or groundings In-Transit, where the consequences of an accident involving a laden oil or chemical tanker are likely to dwarf those of an accident involving a container ship, unless the container ship is involved in the collision for which the incidence is highly improbable.

#### **4.5 DATA GAPS AND LIMITATIONS**

Accident rates for container ships are low, thus data sets are small and sometimes non-existent for specific regions. Thus a number of assumptions have been made in this study.

## 5.0 CLOSURE

Major authors and reviewers of this technical report are listed below, along with their signatures.

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## **7.0 STATEMENT OF LIMITATIONS**

This report was prepared by Herbert Engineering Corp., (HEC) based on analysis conducted by HEC, for the sole benefit and exclusive use of Port Metro Vancouver. The material presented reflects HEC's best judgment in light of the information available to it at the time of preparing this Report. Any use that a third party makes of this Report, or any reliance on or decision made based on it, is the responsibility of such third parties. HEC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this Report.

HEC has performed the work as described above and made the findings and conclusions set out in this Report in a manner consistent with the level of care and skill normally exercised by members of the naval architecture profession practicing under similar conditions at the time the work was performed.

This Report represents a reasonable review of the information available to HEC within the established Scope, work schedule and budgetary constraints. The conclusions and recommendations contained in this Report are based upon applicable legislation existing at the time the Report was drafted. Any changes in the legislation may alter the conclusions and/or recommendations contained in the Report. Regulatory implications discussed in this Report were based on the applicable legislation existing at the time this Report was written.

In preparing this Report, HEC has relied in good faith on information provided by others as noted in this Report, and has assumed that the information provided by those individuals is both factual and accurate. HEC accepts no responsibility for any deficiency, misstatement or inaccuracy in this Report resulting from the information provided by those individuals.

## **APPENDIX A - FIGURES**

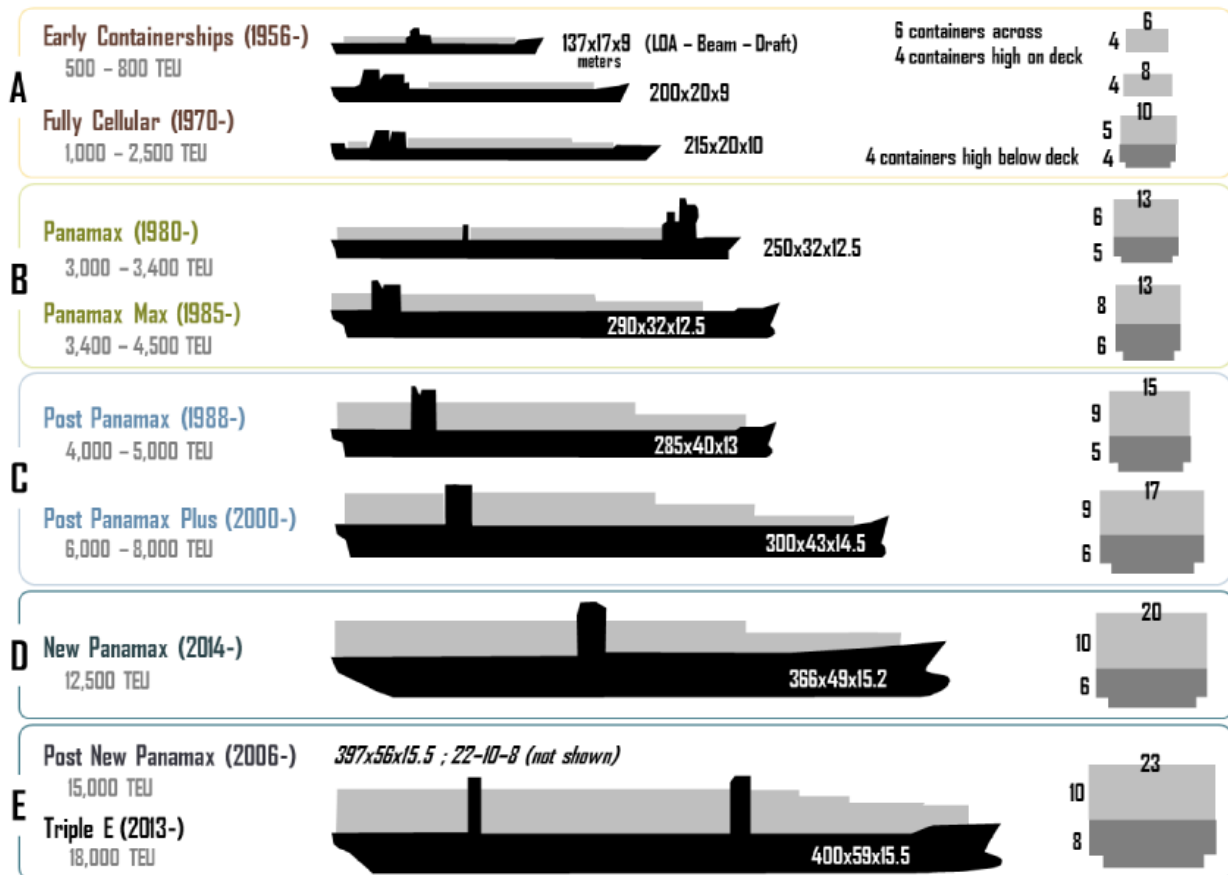


Figure A-1 The Evolution of Container Ship Sizes (Ashar and Rodrigue 2012)

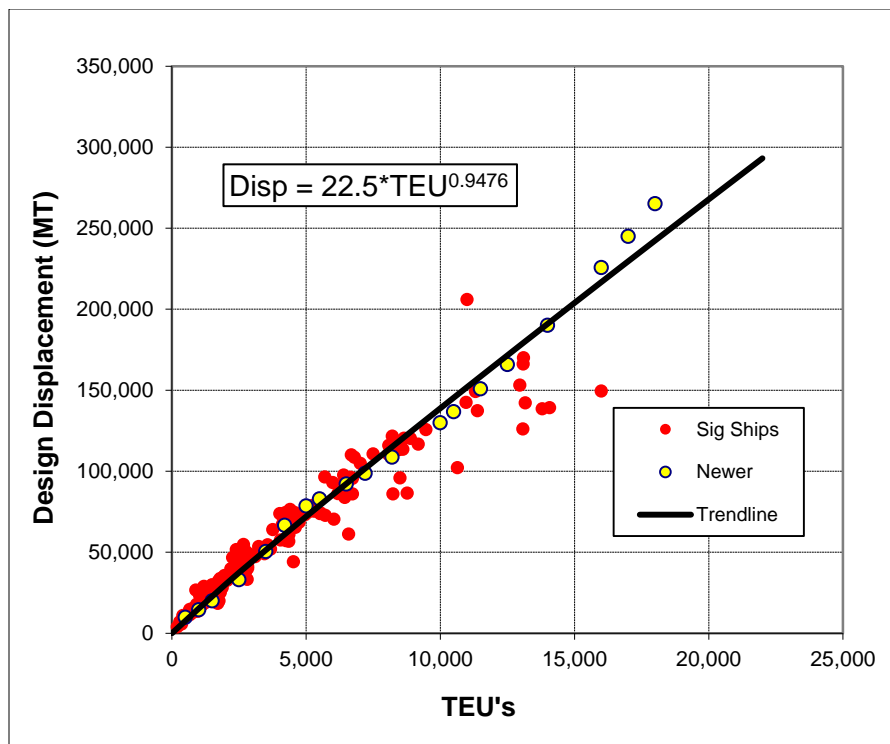


Figure A-2 Vessel Displacement vs. TEUs (Source: HEC database)

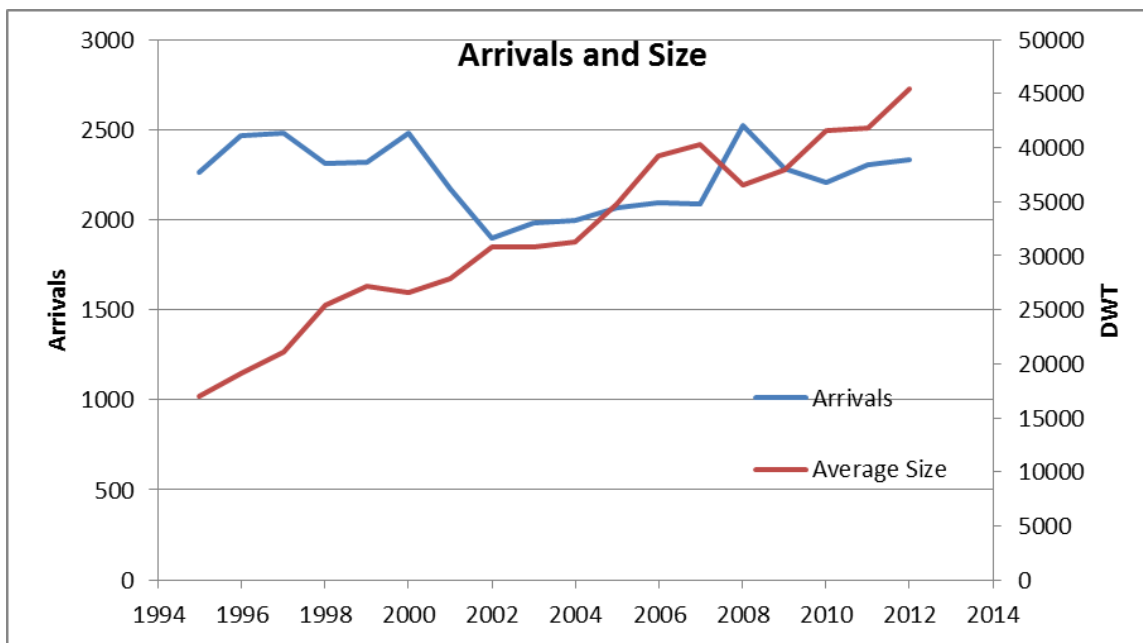


Figure A-3 Trends in Arrivals and Vessel Size for PMV Terminals not at Roberts Bank



**Figure A-4 An Example of a Container Handling Accident with Potential Loss Overboard (Koning 2010)**



**Figure A-5 Large Format Bulk Liquid Tank in 20 ft. Frame (Hoover Container Solutions 2013)**

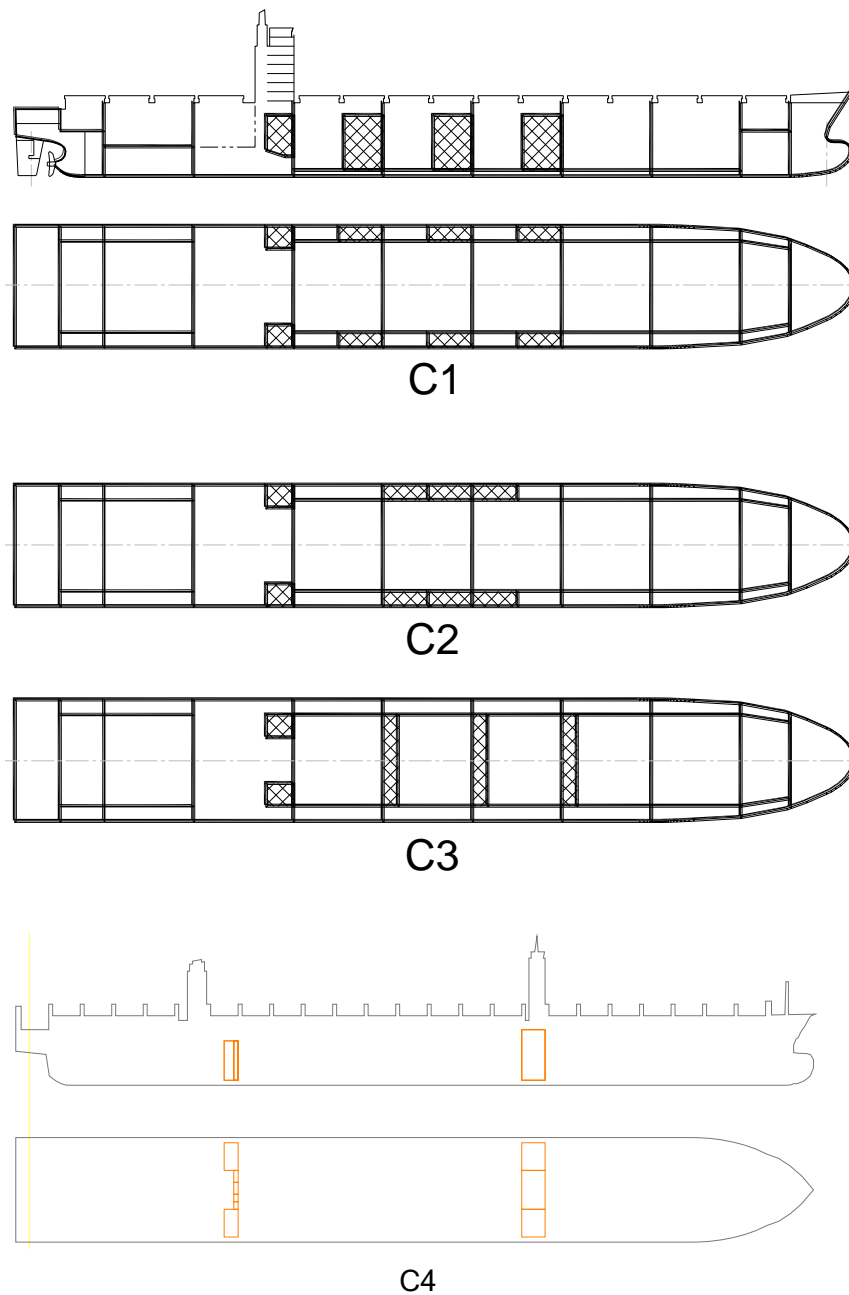


Figure A-6 Container Ship Fuel Oil Tank Arrangements

## **APPENDIX B - TABLES**

**Table B-1 Vessel Type and General Usage**

Vessel Type	Description
1.	Container ships of less than 8,000 20-ft equivalent units (TEU) Refers to vessels designed to carry their entire load in intermodal containers, in this case less than 8,000 TEUs. This size is the most common size for container ships calling at PMV terminals other than Deltaport.
2.	Container ships of greater than 8,000 TEUs and less than 10,000 TEUs Refers to vessels designed to carry their entire load in intermodal containers, in this case from 8,000 to 10,000 TEUs. This is the dominant (~80%) size range for container ships calling at Deltaport.
3.	Container ships of greater than 10,000 TEUs Refers to vessels designed to carry their entire load in intermodal containers, in this case greater than 10,000 TEUs. This represents the size range dominating new construction orders of container ships as of 2012.
4.	Bulk carriers of less than 60,000 tonnes deadweight tonnage (DWT) Refers to ocean-going vessels used to transport bulk cargo items such as ore or food staples (rice, grain, etc.) and similar cargo including bulk cargos such as iron ore, coal, bauxite/alumina, phosphate, steel products, cement, petcoke, forest products, fertilisers, sulphur and other dry bulk cargos. This size, known as <i>Handymax</i> and <i>Handy-size</i> bulkers, dominates (>65%) PMV bulker traffic not calling at Roberts Bank terminals.
5.	Bulk carriers of 60,000 to 100,000 tonnes DWT This size, known as <i>Panamax</i> bulkers, is a growing percentage of PMV bulker traffic.
6.	Bulk carriers of greater than 100,000 tonnes DWT This size, known as <i>Capesize</i> bulkers, dominates (approaching 55%) PMV bulker traffic calling at Roberts Bank. A typical average size is 160,000-180,000 tonnes DWT.
7.	General cargo vessels (includes breakbulk vessels) Refers to ocean-going multi-purpose vessels, designed to handle and stow a variety of freight. This may include forest products, manufactured goods, heavy equipment, vehicles, machinery, bagged goods, steel, food products, and containers. Some specialised vessels combine general cargo with refrigerated cargo, specialised cargo and heavy lift capabilities for transporting large, awkwardly shaped components to refinery, chemical processing and other plant construction projects.
8.	Roll-on/Roll-off vessels (Ro Ro) and pure car carriers Refers to vessels designed to carry wheeled cargo such as automobiles, trucks, semi-trailer trucks, trailers or railroad cars that are driven on and off the vessel on their own wheels.
9.	Cruise ships Refers to vessels designed to carry large numbers of passengers for pleasure voyages.
10.	Crude oil carriers (laden and in ballast) Refers to vessels designed for the bulk transport of unrefined crude oil.
11.	Product tankers (laden and in ballast) Refers to vessels designed for the bulk transport of refined petrochemicals (Gasoline, diesel, etc.). Product tankers are generally smaller than crude oil carriers.
12.	Chemical carriers Refers to vessels designed for the bulk transport of chemicals.
13.	Tank barges (laden and in ballast) Refers to non-self-propelled vessels designed to transport liquid cargo such as petrochemicals and that need be towed or pushed by tugboats.
14.	Liquefied natural gas (LNG) carriers and gas carriers Refers to vessels built for the dedicated carriage of Liquefied Natural Gas (LNG) and, other vessels dedicated to the carriage of liquefied, compressed or pressurised gases.

Vessel Type	Description
15.	Cargo barges Refers to non-self-propelled vessels designed to transport dry cargo such as woodchips, ore or food staples (rice, grain, etc.) and that need be towed or pushed by .
16.	Fishing vessels (open ocean) Refers to vessels used to catch fish in the open ocean. For the purpose of this study, fish factory vessels are included in this definition. Typically have AIS transponders and IMO numbers.
17.	Fishing vessels (local) Refers to vessels used to catch fish in local waters, not typically having AIS transponders nor IMO numbers.
18.	Tugs Refers to vessels designed to maneuver other vessels by pushing or towing them.
19.	Government vessels Refers to governmental owned vessels not in the commercial trade (Canadian, US, etc.)
20.	Other vessels Refers to other vessels not categorised above (research, drill ships, pleasure craft, etc.)

**Table B-2 Future Projects of Interest Outside Roberts Bank Terminals (as of 1 October 2013)**

Project	Affected Cargo Amount	Ship Type	Vessel Capacity (tonnes)	No. ships
Fraser Surrey Docks Direct Coal Transfer - Barges	8.0 Mtonnes	cargo barge	16,000	500
Fraser Surrey Docks Direct Coal Transfer - Ships from Texada Island	8.0 Mtonnes	bulker	100,000	80
Richardson Grain Elevator	2.0 Mtonnes	bulker	70,000	29
	3.0 Mtonnes	bulker		-17
Neptune Terminals Coal Expansion	6.0 Mtonnes	bulker	100,000	60
Vancouver Airport Fuel Delivery Project		tanker	60,000	12
		barge	4,200	48
KinderMorgan Trans-Mountain Pipeline Expansion Project		tanker	120,000	350
Gateway Pacific Bulk Terminal	54 Mtonnes	bulker	110,000	25
Pacific Coast Terminals/Other Chemical carrier facilities		chemical carrier		104
TOTAL				1191

A net of 1,191 additional ship calls is associated with these facilities. Information and assumptions pertaining to marine vessel traffic from these facilities for 2030 in **Table B-1** are as follows:

- Fraser Surrey Docks Direct Coal Transfer would involve taking coal from the Fraser River by barge to a transfer facility on Texada Island, where it would be subsequently loaded onto bulk carriers. Tonnage is taken from the PMV project website (PMV 2013d). Tank barges of 8,000 DWT would be single towed to Sand Heads where they would be doubled up for the tow to Texada Island. Outbound bulk carriers are assumed to average 100,000 tonnes effective capacity, similar to those calling at other facilities in the region (PMV 2013b); This project is currently under permit review by PMV.
- The Richardson Grain Elevator expansion of 2.0 Mtonnes was taken from the PMV On-going Projects website (PMV 2013d). The expansion is being accompanied by an increase in the average size of the vessels handling the existing 3.0 Mtonne capacity, resulting in fewer ships. The assumed new average size is based upon project information and results in a net increase of 12 vessels;
- The Neptune Terminals Coal Expansion is anticipated to be 6.0 Mtonnes, taken from the PMV On-going Projects website (PMV 2013d). At an average effective capacity of 100,000 tonnes similar to those calling at other facilities in the region (PMV 2013b), this equates to 60 ships;
- The Vancouver Airport Fuel Delivery data were taken from the project QRA (DNV 2012a). A British Columbia Environmental Assessment Certificate was issued for this project on December 12, 2013;
- The KM Trans-Mountain Expansion Project data were taken from the KM submission to the Tanker Expert Safety Panel (KM 2013). Approximately 350 partially loaded Aframax tankers are foreseen. Existing tank barge traffic is not affected;
- The Gateway Pacific Bulk Terminal at Cherry Point tonnage figures are from the State of Washington Dept. of Ecology project website (State of Washington 2013). It is assumed that the majority of the bulk carrier traffic will enter and exit the terminal from the south via Rosario Strait. This is the case with tanker traffic calling at Cherry Point also. However, AIS data indicates that a small number of tankers enter or exit via Boundary Pass. Expert opinion indicates that this is due to constrictions in Rosario Strait and/or tide/weather effects (PMV 2013e). Based upon the AIS data, this study has assumed that similarly, 5% of the Gateway Pacific bulk carriers will do the same. The assumed effective capacity of the bulk carriers is assumed to be 110,000 tonnes based upon being consistent with the similar Westshore Terminals fleet capacity, based upon actual ship call data and historical fleet makeup (PMV 2013b, Westshore Terminals 2013); and
- Details of the planned expansion of the Pacific Coast terminals are not available on-line. PMV ship call data (PMV 2013b) shows a steady increase in size and number of chemical carriers calling at the port. This projection is based upon the five year trend in the PMV arrival data.

The following potential actions or facilities were considered, but found to have negligible effects:

- Lehigh Hanson Aggregate Facility (PMV On-going Projects website, PMV 2013d);
- Neptune Phosphate Rock Handling (PMV On-going Projects website, PMV 2013d); and

- Tilbury Island - LNG fueling – Currently there is no LNG marine fuel planning information available for this facility. Further, a report by Lloyd's Register (LR 2012) forecasting LNG use as a marine fuel indicates that the number of ships berthing at PMV terminals that are LNG capable will be small (<3%) by 2030.

The following potential actions or facilities were not considered because insufficient information was available to make reasonable projections:

- Texada Island LNG facility– no documented evidence of project proceeding;
- Campbell River (Duncan Bay) LNG facility– no documented evidence of project proceeding; and
- Southern Strait of Georgia National Marine Conservation Area – The impact on marine traffic is unforeseeable as all deep-sea vessels berthing at PMV terminals and entering or exiting via Boundary Pass travel through or immediately adjacent to this proposed conservation area.

**Table B-3 Vessels Transiting the Waters near Roberts Bank in 2012 and 2030 not berthing at Roberts Bank Terminals**

Vessel Population Models	Current 2012 No. of Ship Calls	Projected No. of Ship Calls in 2030			
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
Vessel Type	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
<b>Container ships not at RB</b>	1.9 MTEUs Capacity	2.5 MTEUs Capacity			
under 6,000 TEUs	375	352	352	352	352
6,000-10,000 TEUs	146	151	151	151	151
>10,000 TEUs	0	0	0	0	0
<b>Bulkers at PMV</b>					
Handy	586	529	529	529	529
Panamax	201	265	265	265	265
Capesize	95	88	88	88	88
<b>Bulkers at Gateway Pacific Bulk Terminal</b>					
Capesize	0	0	0	25	25
<b>Bulkers at New PMV Projects</b>					
Neptune Coal	0	0	0	60	60
Texada Coal (Fraser Surrey Docks)	0	0	0	80	80
Richardson Grain	0	0	0	12	12
<b>General Cargo</b>	262	239	239	239	239

Vessel Population Models	Current 2012 No. of Ship Calls	Projected No. of Ship Calls in 2030			
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
Vessel Type	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
<b>Ro Ro</b>					
BC Ferries at Tsawwassen	7274	7274	7274	7274	7274
Other	311	272	272	272	272
<b>Cruise Ships</b>	190	190	190	190	190
<b>Crude Oil Tankers</b>					
KM related	42	36	36	386	386
Other & Cherry Point	13	13	13	13	13
<b>Product Tankers</b>					
PMV existing facilities	19	16	16	16	16
Jet Fuel to YVR	0	0	0	12	12
<b>Chemical Carriers</b>					
Pacific Coast Terminals	161	265	265	265	265
<b>Tank Barges</b>					
KM related	36	36	36	48	48
Jet Fuel to YVR	0	0	0	48	48
<b>Cargo Barges</b>					
Texada Coal	0	0	0	500	500
<b>Gas Carriers (LNG &amp; LPG)</b>	0	0	0	0	0
<b>Fishing Vessels</b>					
open ocean	188	188	188	188	188
<b>Tugs</b>					
At RB	2	2	4	2	4
<b>Other Large Vessels</b>	804	804	804	804	804
<b>Sum (includes RB)</b>	11244	11345	11607	12444	12706
<b>Without Ferries</b>	3970	4071	4333	5170	5432
<b>Difference from Scenario 1</b>		101	363	1200	1462
<b>Difference from Scenario 2</b>			262	1099	1361
<b>Difference from</b>				837	1099

Vessel Population Models	Current 2012 No. of Ship Calls	Projected No. of Ship Calls in 2030			
		Without New Marine Facilities		With New Marine Facilities*	
	Year 2012	Without RBT2	With RBT2	Without RBT2	With RBT2
Vessel Type	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Scenario 3					
Difference from Scenario 4					262

\* Assumes the successful approval, construction and operation of future projects listed in **Appendix B: Table B-2**.

Information and assumptions pertaining to marine vessel traffic transiting the waters adjacent to Roberts Bank for the year 2012 and for 2030 are as follows:

- Ship calls for the year 2012 were from PMV ship call data (PMV 2013b) unless noted;
- Projections to 2030 for general traffic were based upon the assumption that vessel sizes are increasing while there will be no trend towards an increase in numbers of vessels. This is supported by PMV arrival data (PMV 2013b), see **Appendix A: Figure A-3**;
- Container ship arrivals and size breakdown were based upon PMV ship call data (PMV 2013b);
- BC Ferries calling at Tsawwassen for 2012 were based upon AIS data for the year 2012. Projections are based upon personal communication with BC Ferries personnel (BC Ferries 2013) indicating that there were no publically available projections and the *status quo* was a reasonable estimate. This estimate is thus, highly uncertain;
- There are a large number of tugs movements in the region. Tug movements that could be considered individual voyages are numerous and difficult to define. The AIS data was used to define a tug transit at Roberts Bank based upon a 60 minute absence from the immediate vicinity of Roberts Bank terminals. This can mean the AIS transponder is turned off or the tug has left the region under consideration. Using the 60 minute screening, the number of transits for Roberts Bank in 2012 is 1,500 which are 3.6 per day or about three transits per ship call. Some of these transits will be ship assist voyages and others are voyages to the Fraser River or other regional ports;
- Historical data (PMV 2013b) shows that cruise ships visiting PMV are getting larger and numbers are decreasing. The size of cruise ships visiting PMV is already limited by air draughts under the Lion's Gate Bridge. Based upon these competing factors, this study has assumed effectively no change in number of cruise ships. The majority of cruise ship traffic is north of Roberts Bank terminals; and
- Other large vessels numbers were derived from AIS data vessel counts. This includes a wide variety of vessel types making projection to 2030 uncertain. As these could increase or decrease, it is assumed that the number does not change out to 2030.

**Table B-4 Composition and Number of HNS Containers at Deltaport in 2012 (TSI 2013)**

Dangerous Goods Class	Export	Import	Total	Dangerous Goods description	
1.3	5	5	10	Explosives	1.3 Explosives with a fire, blast or projection hazard, but not a mass explosion hazard.
1.4		99	99		1.4 Minor fire or projection hazard (includes ammunition and most consumer fireworks).
1.4G		6	6		
2	1	1	2	Gases	Gases
2.1	47	242	289		2.1 Flammable Gas: Gases which ignite on contact with an ignition source, such as acetylene and hydrogen.
2.2	125	262	387		2.2 Non-Flammable Gases: Gases which are neither flammable nor poisonous. Includes the cryogenic gases/liquids (temperatures of below -100°C) used for cryopreservation and rocket fuels, such as nitrogen and neon.
2.3	6	1	7		2.3 Poisonous Gases: Gases liable to cause death or serious injury to human health if inhaled; examples are fluorine, chlorine, and hydrogen cyanide.
3	666	1,254	1,920	Flammable Liquids	Flammable Liquids, Fuels
3.3		1	1		
4.1	67	581	648	Flammable Solids	4.1 Flammable Solids: Solid substances that are easily ignited and readily combustible (nitrocellulose, magnesium, safety or strike-anywhere matches).
4.2	5	383	388		4.2 Spontaneously Combustible: Solid substances that ignite spontaneously (aluminum alkyls, white phosphorus).
4.3	6	39	45		4.3 Dangerous when Wet: Solid substances that emit a flammable gas when wet or react violently with water (sodium, calcium, potassium, calcium carbide).
5.1	13	401	414	Oxidizing Agents	5.1 Oxidizing agents other than organic peroxides (calcium hypochlorite, ammonium nitrate, hydrogen peroxide, potassium permanganate).
5.2		5	5		5.2 Organic peroxides, either in liquid or solid form (benzoyl peroxides, cumene hydroperoxide).
6.1	71	994	1,065	Toxic & Infectious Substances	6.1a Toxic substances which are liable to cause death or serious injury to human health if inhaled, swallowed or by skin absorption (potassium cyanide, mercuric chloride).
7	4	1	5	Radioactive Substances	Radioactive substances comprise substances or a combination of substances which emit ionizing radiation (uranium, plutonium).
8	596	3,213	3,809	Corrosive Substances	Corrosive substances are substances that can dissolve organic tissue or severely corrode certain metals:
9	1,212	1,693	2,905	Misc.	Hazardous substances that do not fall into the other categories (asbestos, air-bag inflators, self-inflating life rafts, dry ice).
<b>Total</b>	<b>2,824</b>	<b>9,181</b>	<b>12,005</b>		

## **APPENDIX C - VESSEL INCIDENT ANALYSIS FOR VANCOUVER REGION**

## C. VESSEL INCIDENT ANALYSIS FOR VANCOUVER REGION

This appendix provides information upon which the local incident rates are based, and includes:

- A listing of reported incidents at Roberts Bank;
- A listing of reported container ship incidents in the region. Note there is some duplication with the prior list due to the occurrence of some container ship incidents at Roberts Banks;
- Incident data consolidated by accident type, ship type and year. These data permit independent reconstruction of the local incident rates presented in the analysis;
- Comparison of rates prior to and after the introduction of STCW;
- Comparison of incident rates with worldwide data; and
- A description of accident rates resulting from the GL 2013 update of the IMO FSA for container ships.

### C-1 Roberts Bank Terminal Incidents

The reported incidents that occurred in the Roberts Bank Terminal (RBT) zone during 1995 through 2013 are shown **Table C-1**.

**Table C-1 Roberts Bank Terminal Incidents**

Incident Date	Vessel	Incident Type	Incident Details
12/11/2001	Ocean Cosmos Bulk Carrier IMO 9218179 85,868 GT 171,191DWT	Allision while maneuvering at dock	Vessel struck shore crane while docking at Roberts Bank Terminal. No pollution reported.
4/10/2002	Katsuragi Container ship IMO 8910419 50,437 GT 59,418 DWT 3,613 TEUs	Propulsion failure while maneuvering at dock	Vessel suffered engine failure with loss of propulsion due to a faulty fuel injector at Westshore Terminals, Roberts Bank. No pollution reported.
1/3/2003	Ming Cultivation Bulk Carrier IMO 9159189 35,905 GT 69,163DWT	Outside force damage at dock	Vessel struck by wind-damaged crane at Berth 2 Westshore Terminals. Minimal damage reported to rail in way of hatch 4. Crane brought down by 100-kmh winds injuring two shore employees. Vessel reported to have sailed. No pollution reported.

Incident Date	Vessel	Incident Type	Incident Details
8/7/2004	Yuehe Container ship IMO 9120750 65,140 GT 69,285 DWT 5,618 TEUs	Equipment failure in transit	Vessel suffered electrical failure (blackout) while enroute leaving Deltaport. No pollution reported.
8/31/2004	Seaspan Discovery Tug IMO 8315827 435 GT	Allision while assisting vessel at dock	Vessel struck bulk carrier Hyundai Prosperity (77,650 GT; 151,257 DWT; IMO 8821632) while assisting with unberthing at Roberts Bank Terminal. No pollution reported.
9/30/2004	Genmar Spirit Product Tanker IMO 8920232 55,790 GT 98,929 DWT	Equipment failure while in transit	Vessel reported to have broken down near Roberts Bank. <sup>18</sup> No pollution reported.
10/13/2004	Bunga Orkid Dua Bulk Carrier IMO 9070785 25,498 GT 43,246 DWT	Allision from another vessel while moored at dock	Vessel was struck by container ship Ever Unific (69,246 GT; 63,216 DWT; 5,652 TEUs; IMO 9168843) while berthed at Roberts Bank Terminal. Vessel sustained minor damage to forecastle area, was subsequently inspected, and continued on its voyage. The tug Seaspan Discovery was also involved. No pollution reported. [See following two incidents.]
10/13/2004	Ever Unific Container ship IMO 9168843 69,246 GT 63,216 DWT 5,652 TEUs	Allision with another vessel while berthing	Vessel struck bulk carrier Bunga Orkid Dua (25,498 GT; 43,246 DWT; IMO 9070785) while berthing at dock. Bunga Orkid Dua was moored at the time. Vessel sustained minor damage to bow area, was subsequently inspected, and continued on its voyage. The tug Seaspan Discovery was also involved. No pollution reported. [See previous and subsequent incident.]
10/13/2004	Seaspan Discovery Tug IMO 8315827 435 GT	Allision while assisting berthing vessel.	Tug was involved in allision between container ship Ever Unific (69,246 GT; 63,216 DWT; 5,652 TEUs; IMO 9168843) with bulk carrier Bunga Orkid Dua (25,498 GT; 43,246 DWT; IMO 9070785) while berthing at dock. No pollution reported. [See two previous incidents.]
9/17/2007	Fraser Titan Hopper/Dredger IMO 6913596 3,289 GT 5,080 DWT	Near collision when in transit.	Tug reported a near collision with F/V Sandra Rose near Deltaport. No pollution reported.
11/12/2007	LPG 3 Tank Barge	Grounding while in transit.	Barge LPG 3 broke free from tow in storm and ran aground near Deltaport Causeway. No pollution reported.

<sup>18</sup>Canada TSB records report that the vessel Genmar Spirit was a bulk carrier. This is incorrect according to records in other sources based on the vessel name and IMO number.

Incident Date	Vessel	Incident Type	Incident Details
2/25/2010	Global Partnership Bulk Carrier IMO 9311282 89,726 GT 176,967 DWT	Steering loss while in transit.	Vessel reported to have had steering loss while in transit near Roberts Bank Terminal. No pollution reported.
9/8/2010	Unique Carrier Bulk Carrier IMO 9374832 91,384 GT 177,876 DWT	Propulsion loss while in transit.	Vessel, while under pilotage, experienced temporary loss of auxiliary and main propulsion power off Roberts Bank Terminal. Power was restored and vessel proceeded to English Bay Anchorage without incident. No pollution reported.
7/20/2011	Nathan E. Stewart Tug IMO 8968210 302 GT	Steering loss while in transit.	Vessel suffered partial steering loss while in transit off Roberts Bank Terminal. No pollution reported.
11/13/2012	BC Ocean Dragon Fishing Vessel	Propulsion loss while maneuvering.	Fishing vessel disabled due to engine problems off Roberts Bank Terminal and reported to be a hazard to other vessels in the area. Towed to Steveston by another fishing vessel. No pollution reported.
12/7/2012	Cape Apricot Bulk Carrier IMO 9311828 90,091 GT 180, 310 DWT	Allision while maneuvering.	Vessel struck jetty while maneuvering and approaching Berth 2 at Westshore Terminals while under pilotage. The vessel failed to make a starboard turn approaching Berth 2 and went through the causeway to Berth 1, which was loading another ship at the time. Subsequently repaired and returned to service. Vessel sustained damage to bulbous bow. About one-third of a coal car or 30 tonnes of coal spilled into the water. No injuries reported. The jetty sustained severe damage with 400 feet of trestle and conveyor damaged. The vessel proceeded to berth for inspection and subsequently arrived in Yura, Japan for repairs.

## C-2 Container Ship Incidents At or In Transit to/from Roberts Bank

Incidents involving container ships that occurred from 1995 through 2013 are summarised in **Table C-2** through **Table C-5** by Study Area zone. There were no container ship incidents in the Transit zone during this time period. Two container ship incidents that occurred just outside the Study Area with vessels en route to the Vancouver port are summarised in **Table C-7**.

**Table C-2 Container Ship Incidents: Roberts Bank Terminal**

Incident Date	Vessel	Incident Type	Incident Details
4/10/2002	Katsuragi Container ship IMO 8910419 50,437 GT 59,418 DWT 3,613 TEUs	Propulsion failure while maneuvering at dock	Vessel suffered engine failure with loss of propulsion due to a faulty fuel injector at Westshore Terminals, Roberts Bank. No pollution reported.
8/7/2004	Yuehe Container ship IMO 9120750 65,140 GT 69,285 DWT 5,618 TEUs	Equipment failure in transit	Vessel suffered electrical failure (blackout) while en route leaving Deltaport. No pollution reported.
10/13/2004	Ever Unific Container ship IMO 9168843 69,246 GT 63,216 DWT 5,652 TEUs	Allision with another vessel while berthing	Vessel struck bulk carrier Bunga Orkid Dua (25,498 GT; 43,246 DWT; IMO 9070785) while berthing at dock. Bunga Orkid Dua was moored at the time. Vessel sustained minor damage to bow area, was subsequently inspected, and continued on its voyage. The tug Seaspans Discovery was also involved. No pollution reported.

**Table C-3 Container Ship Incidents: PMV Main**

Incident Date	Vessel	Incident Type	Incident Details
2/20/1998	CSCL Oceania Container ship IMO 9286009 90,645 GT 101,810 DWT 8,468 TEUs	Near collision in transit.	Vessel reported in a near-collision with tug Swan towing a barge. No pollution was reported.
7/19/2002	CCNI Arica Container ship IMO 9144158 16,801 GT 23,106 DWT 1,730 TEUs	Near collision in transit.	Near-collision and close quarters reported for vessel and fishing vessel Katlyn. No pollution was reported.
11/8/2003	Cielo del Canada Container ship IMO 9138290 25,361 GT 34,041 DWT 2,470 TEUs	Grounded	Vessel grounded in Fraser River near Sand Heads. Refloated later the same day and proceeded to Fraser Surrey Docks for inspection. Subsequently returned to service. No pollution was reported.
7/31/2005	Canmar Dynasty Container ship IMO 9062984 23,540 GT 30,621 DWT 2,070 TEUs	Near allision in transit.	Vessel reported to be in close quarters and near allision with fishing vessel Nite Rider near Steveston on Fraser River.

Incident Date	Vessel	Incident Type	Incident Details
1/4/2012	Brattingsborg Container ship IMO 9488035 9,627 GT 12,705 DWT 665 TEUs	Allision while maneuvering at dock.	Vessel in allision with bulk carrier Orient Hope (IMO 9385166; 19,828 GT; 32,165 DWT) while docking at Fraser Surrey Docks. Both vessels sustained damage. No pollution was reported.
2/13/2012	Cape Manila Container ship IMO 9571313 35,708 GT 41,534 DWT 2,758 TEUs	Outside force damage while docked.	Vessel's gangway was struck by a shore crane while at Fraser Surrey Dock. No injuries or pollution reported.

**Table C-4 Container Ship Incidents: PMV Main**

Incident Date	Vessel	Incident Type	Incident Details
1/15/1996	OOCL Fidelity Container ship IMO 8407319 40,980 GT 40,560 DWT 3,161TEUs	Near collision while in transit.	Vessel in close quarters and near collision with fishing vessel Viking Moon one mile west of First Narrows Bridge. Fishing vessel allegedly cut across bow while changing from the outbound to inbound lane. No pollution was reported.
7/9/1996	OOCL Frontier Container ship IMO 7224318 67,393 GT 47,838 DWT 2,952 TEUs	Allision while maneuvering at dock.	Vessel bumped dock while berthing at Vanterm wharves causing minor bow damage. No pollution was reported.
4/2/1997	Columbus Valparaiso Container ship IMO 7384168 17,640 GT 15,550 DWT 807 TEUs	Allision while maneuvering at dock.	Vessel struck container crane while berthing at Vanterm. No pollution was reported.
5/4/1997	Hanjin Seattle Container ship IMO 9461477 91,621 GT 102,529 DWT 8,586 TEUs	Caused outside force damage to vessel moored at dock.	Bow wave vessel broke four mooring lines on bulk carrier Lok Pragati (IMO 7503855; 16,040 GT; 26,926 DWT) berthed at Vancouver wharves. This resulted in vessel moving 20 m off berth and assistance of tug was required to re-secure alongside. No pollution was reported.
12/28/1997	Yunhe Container ship IMO 9120750 65,140 GT 69,285 DWT 5,618 TEUs	Outside force damage while passing another vessel moored at dock.	While passing, wake from vessel caused mooring line of tug Pantodynamos (IMO 7038642; 859 GT; 754 DWT) to part. No pollution was reported.

Incident Date	Vessel	Incident Type	Incident Details
10/21/1998	P&O Nedlloyd Chicago Container ship IMO 9161297 37,579 GT 56,902 DWT 3,424 TEUs	Engine failure in transit.	Vessel experienced engine failure while in transit leaving Port of Vancouver. The vessel dropped two anchors at Burnaby Shoal. Repairs effected by crew while vessel steadied by tugs and sailed for Portland the same day. No pollution reported.
5/17/2002	MOL Wisdom Container ship IMO 9101601 41,114 GT 39,814 DWT 2,852 TEUs	Equipment failure while at dock.	Vessel reported that seacock initially failed to seat properly during maintenance allowing water into engine room while moored at Centerm 6. Problem fixed in a few minutes and vessel advised situation under control. No pollution reported.
1/6/2005	APL England Container ship IMO 9218650 65,792 GT 67,987 DWT 5,510 TEUs	Outside force damage while in transit.	Sustained puncture forward of double bottom tank in way of No. 4 hold when a 40 foot container fell from its gantry and struck the tank top. No injuries reported. No pollution reported.
2/26/2006	Ym Ibiza Container ship IMO 9128192 31,730 GT 34,894 DWT 2,758 TEUs	Allision while maneuvering at dock.	Vessel struck dock gantry crane when approaching Berth 6, Vanterm and sustained holing damage to bow area. Subsequently repaired and returned to service. No pollution was reported.
6/27/2008	Hanjin Berlin Container ship IMO 9115743 66,403 GT 67,298 DWT 5,302 TEUs	Allision while maneuvering at dock.	Vessel struck mooring line of docked container ship OOCL Los Angeles (IMO 9211169; 66,289 GT; 67,737 DWT; 5,762 TEUs) while berthing. No injuries or pollution reported. Caused minor damage to OOCL Los Angeles. [See subsequent incident listing.]
6/27/2008	OOCL Los Angeles Container ship IMO 9211169 66,289 GT 67,737 DWT 5,762 TEUs	Allision while docked.	Vessel was struck by container ship Hanjin Berlin (IMO 9115743; 66,403 GT; 67,298 DWT; 5,302 TEUs) while at dock. No injuries or pollution reported. Minor damage to vessel. [See previous incident listing.]
12/29/2008	OOCL France Container ship IMO 9103697 51,931 GT 60,348 DWT 4,507 TEUs	Near grounding while maneuvering.	Vessel reported dragging anchor in high winds, and in danger of running aground in English Bay. Vessel repositioned by pilots. Several other vessels involved. No pollution was reported.
3/20/2009	OOCL Shanghai Container ship IMO 9198111 66,289 GT 67,584 DWT 5,762 TEUs	Propulsion loss while in transit.	Vessel outbound for Japan sustained engine failure whilst transiting Second Narrows Bridge. Effected repairs at anchorage No. 6 and subsequently continued on voyage. No pollution was reported.

Incident Date	Vessel	Incident Type	Incident Details
4/24/2009	Cosco Tanjin Container ship IMO 9300324 66,380 GT 67,209 DWT 4,632 TEUs	Allision while maneuvering at dock.	Struck the dock whilst berthing with the assistance of tug Tiger Sun; subsequently repaired and returned to service. Sustained 10 cm cracks in the starboard quarter above the waterline. No injuries or pollution reported. Vessel proceeded for inspection and repairs.
5/16/2009	Hanjin Madrid Container ship IMO 9248150 65,918 GT 50,703 DWT 5,752 TEUs	Outside force damage to another vessel while maneuvering at dock.	The wake from vessel while passing Vancouver Wharves berth 4, B.C., at a reported speed of 15 kts, parted one mooring line of bulker Ystwyth (IMO 7922178; 43,576 GT; 77,673 DWT) causing it to drift 30-40' from its berth. No vessel damage or pollution was reported.
5/27/2009	Kota Lambang Container ship IMO 9351036 39,906 GT 50,596 DWT 4,250 TEUs	Collision while maneuvering in port.	Vessel in collision whilst departing harbor with container ship Cosco Tianjin (IMO 9300324; 66,380 GT; 67,209 DWT; 4,632 TEU) Subsequently continued on voyage after an inspection. No damage, injuries or pollution reported. [See subsequent incident listing.]
5/27/2009	Cosco Tianjin Container ship IMO 9300324 66,380 GT 67,209 DWT 4,632 TEUs	Collision while maneuvering in port.	Vessel in collision whilst departing harbor with container ship Kota Lambang (IMO 9351036; 39,906 GT 50,596 DWT; 4,250 TEU). Subsequently continued on voyage after an inspection. No damage, injuries or pollution reported. [See previous listing.]
5/28/2009	Hyundai Republic Container ship IMO 9215830 74,373 GT 80,596 DWT 8,003 TEUs	Transfer error while docked.	Vessel operators noticed a container aboard leaking toxic nitrous oxide while loading at Centerm No. The container was patched and loading resumed. Leakage of nitrous oxide was reported.
5/31/2009	APL Atlanta Container ship IMO 9345972 43,071 GT 55,482 DWT 4,250 TEUs	Allision while maneuvering at dock.	Vessel reported damage to the fairlead and deck plating (ripped off) while berthing with assistance from tug Smit Mississippi; proceeded for inspection and repairs. No pollution was reported.
8/22/2009	Hanjin Washington Container ship IMO 9111395 65,643 GT 67, 272 DWT 5,302 TEUs	Allision while maneuvering at dock.	Vessel struck the wharf whilst berthing with two tugs assisting at Vanterm #6 at high tide. Vessel made contact with the brackets of the fendering system and punctured the ship's plating starboard side. Vessel subsequently repaired and returned to service. Sustained a hole to the ship's plating starboard side. No injuries or pollution reported.
11/5/2010	Hyundai Republic Container ship IMO 9215830 74,373 GT 80,596 DWT 8,003 TEUs	Allision while moored at dock.	Vessel was contacted by container ship APL Garnet (IMO 9077460; 53,519 GT; 66,618 DWT; 4,729 TEU) while it was leaving berth from Centerm. No damage or pollution was reported. See following incident listing.

Incident Date	Vessel	Incident Type	Incident Details
11/5/2010	APL Garnet Container ship IMO 9077460 53,519 GT 66,618 DWT 4,729 TEUs	Allision while maneuvering at dock.	Vessel contacted container ship Hyundai Republic (IMO 9215830; 74,373 GT; 80,596 DWT; 8,003 TEUs) while leaving berth from Centerm. No damage or pollution was reported. See previous listing.
9/3/2011	Hanjin Washington Container ship IMO 9111395 65,643 GT 67,272 DWT 5,302 TEUs	Allision while maneuvering at dock.	Vessel made heavy contact with steel lugbolts of the fender system while coming alongside at Vanterm Berth 6. Vessel sustained 2-3 inch crack to starboard bow hull structure. Inspection and repairs effected at Vancouver. No injuries or pollution reported.
11/15/2011	Hanjin Newport Container ship IMO 9404194 40,542 GT 50,274 DWT 4,253 TEUs	Allision while maneuvering at dock.	Vessel struck shore crane while berthing (coming alongside) at Vanterm Berth No. 5. No pollution was reported.
4/27/2013	Ever Ethic Container ship IMO 9241293 76,067 GT 75,898 DWT 6,332 TEUs	Allision while maneuvering at dock.	Vessel struck the quay while berthing with tug assistance at Vanterm Berth No. 5 while under pilotage. Two starboard fresh water tanks were holed just aft of accommodation. Subsequently repaired and returned to serve. No injuries or pollution reported.
8/20/2013	MOL Mission Container ship IMO 9475650 78,316 GT 79,491 DWT 6,724 TEUs	Propulsion failure while maneuvering in port.	Vessel lost propulsion approaching Centerm Terminals. Vessel dropped both anchors and required tug assistance to stop the ship. No damage, injuries or pollution reported.

**Table C-5 Container Ship Incidents: Outside Study Area**

Incident Date	Vessel	Incident Type	Incident Details
12/13/1996	Trinity Container ship IMO 9367944 9,549 GT 12,582 DWT 907 TEUs	Propulsion loss in transit.	Vessel suffered main engine failure in the Strait of Juan de Fuca and was unable to restart main engines due to problems with fuses for air compressors. Vessel escorted back to Constance Bank anchorage and held until repairs approved by TC Ship Safety. No pollution was reported.
1/31/1998	Sea-Land Tacoma Container ship IMO 8419154 20,965 GT 20,668 DWT 1,712 TEUs	Steering loss while in transit.	Vessel experienced problems with the variable pitch propeller control drifting towards land 10 miles south of Estevan Point, B.C. Anchor deployed while waiting for assistance from tugs. Vessel towed to Esquimalt Drydock for repairs. No pollution reported.
11/25/1998	Aristotelis Container ship IMO 9625530 52,467 GT 63,105 DWT 5,023 TEUs	Propulsion loss in transit.	Main engine shut down to change a burnt exhaust valve west of Cape Flattery. Vessel drifted towards shore and had to anchor to prevent grounding. Two Canadian DND ships assisting. Engine repaired and vessel proceeded to Vancouver. No pollution reported.
2/10/1999	Hyundai Explorer Container ship IMO 8511299 39,892 GT 43,567 DWT 3,016 TEUs	Propulsion loss in transit.	Container ship reported main engine failure with propulsion loss 2 NM south of Turn Point, B.C. Assistance requested and vessels tasked to assist. Repairs effected onboard and container ship proceeded under own power to Delta Port. No pollution reported.
9/1/1999	Pretty River Container ship IMO 9043005 22,746 GT 33,548 DWT 1,923 TEUs	Propulsion loss while maneuvering.	While getting underway from anchorage with pilot at Constance Bank, vessel experienced loss of engine control air with loss of propulsion. Vessel re-anchored, repaired problem and within minutes proceeded underway. No pollution reported.
4/6/2000	APL Philippines Container ship IMO 9077276 64,502 GT 65,642 DWT 5,108 TEUs	Allision while maneuvering.	Allision reported to US Coast Guard at 49.333, -124.000. Vessel reported to be maneuvering. No pollution reported.

### C-3 Consolidated Incident data for the Vancouver region

The number of incidents only at Roberts Bank or only involving container ships in the region is too small to provide meaningful statistical data. In this section incident data for all vessels are presented to enable the development of incident rates for comparison to worldwide data. The tables below contain:

- Incidents for all vessels in the region (**Table C-6**);
- Incidents for piloted vessels in the region. All vessels other than tugs calling at Roberts Bank are piloted vessels (**Table C-7**);
- Number of arrivals (transits) by vessel type and year. Transits are generally round trip voyages. Incident rates are developed on a per transit basis by dividing the number of incidents by number of transits (**Table C-8**);
- Number of incidents by vessel type and year (Table C-9);
- Vessel incident rates by vessel type and year (**Table C-10**). A comparison of rates showing that container ship rates are similar to rates for all piloted vessels is shown in **Figure C-1**;
- Incident rates by accident type (including near accidents) that form the basis for comparison to worldwide rates are presented in **Table C-11**; and
- Incident rates prior to and after STCW are presented in **Table C-12**.

**Table C-6 Consolidated Incident Types in Study Area Zones – All Vessels**

Incident Type	Zone				
	RBT	PMV Main	Fraser	Transit	Total
Allision	6	43	31	1	81
Allision - Near	0	2	2	0	4
Collision	0	15	6	2	23
Collision - Near	1	41	26	15	83
Grounding	2	13	14	2	31
Grounding - Near	0	11	0	0	11
Vessel Failure <sup>19</sup>	7	23	10	23	63
Structural Failure/Sinking	0	9	11	6	26
Other/Explosion Fire/Outside	1	23	11	11	46
Broke Mooring/Tow	0	4	10	2	16
Transfer Error/Cargo Loss	0	4	1	0	5
<b>Total</b>	<b>17</b>	<b>188</b>	<b>122</b>	<b>62</b>	<b>389</b>

**Table C-7 Consolidated Incident Types in Study Area Zones – Piloted Vessels**

Incident Type	Zone				
	RBT	PMV Main	Fraser	Transit	Total
Allision	4	35	5	0	44
Allision – Near	0	2	2	0	4
Collision	0	7	2	1	10
Collision – Near	0	19	14	8	41
Grounding	1	4	4	0	9
Grounding – Near	0	9	0	0	9
Vessel Failure	5	20	5	3	33
Structural Failure/Sinking	0	2	0	0	2
Other/Explosion Fire/Outside	1	14	2	3	20
Broke Mooring/Tow	0	2	1	0	3
Transfer Error/Cargo Loss	0	3	0	0	3
<b>Total</b>	<b>11</b>	<b>117</b>	<b>35</b>	<b>15</b>	<b>178</b>

<sup>19</sup> Includes equipment failure, propulsion loss and steering loss.

**Table C-8 Vessel Arrivals in Port Metro Vancouver**

Type	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Container <8,000 TEUs	343	473	529	519	593	715	669	729	744	690	702	707	662	807	700	582	629	616	306
Container Medium	0	0	0	0	0	0	0	0	0	0	0	0	1	46	43	100	158	175	95
Container >10,000 TEUs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	7	1	0	0
Tanker Crude	106	89	61	60	46	48	36	55	69	31	31	45	61	56	73	55	31	42	18
Tanker Product	23	19	22	23	34	21	21	14	12	10	16	35	20	28	31	39	15	10	11
Tanker Chemical	55	82	91	93	80	85	106	93	100	143	143	134	160	155	154	177	161	161	90
Bulker <60,000DWT	1,210	1,170	1,151	1,059	982	992	830	532	585	703	602	539	520	577	542	662	704	621	321
Bulker Medium	106	144	157	167	183	208	207	179	204	225	268	280	213	244	225	224	254	236	149
Bulker >80,000DWT	48	66	75	86	95	87	96	92	79	70	71	101	135	122	135	184	208	246	128
Vehicle Carrier	28	19	19	6	20	19	16	14	21	15	24	23	31	278	238	243	244	295	139
Cruise ship	268	276	288	294	309	334	330	342	306	282	268	250	277	254	258	182	199	190	97
Tug <sup>20</sup>	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000
Gen. Cargo	271	317	327	314	334	391	365	313	349	317	384	389	362	312	246	229	203	216	98
Other <sup>21</sup>	39	44	40	22	44	41	39	35	58	45	45	58	47	57	43	37	50	30	13
Fishing-Ocean	4	10	10	7	7	13	6	1	0	4	0	0	0	0	0	0	0	5	0
Military	1	1	3	1	0	0	1	2	0	2	1	1	0	1	1	0	0	0	0
Ferry	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600	14,600
Totals	34,102	34,310	34,373	34,251	34,327	34,554	34,322	34,001	34,127	34,137	34,155	34,162	34,089	34,537	34,293	34,321	34,457	34,443	33,065

<sup>20</sup> Tug transits are based upon assumptions on duration of voyage and interrogation of AIS data, see Section 3.3.7

<sup>21</sup> "Other" is assumed to include all vessels not in other categories with the exception of tank barges, or cargo barges for which there are no arrival data.

**Table C-9 Vessel Incidents in Study Area**

Type	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Container <8,000 TEUs	0	2	3	1	0	0	0	3	1	2	2	1	0	3	8	2	2	2	2
Container Medium	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Container >10,000 TEUs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crude Tanker	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Product Tanker	1	0	0	1	1	0	1	0	0	2	0	1	0	1	1	3	2	0	0
Chemical Tanker <sup>22</sup>	2	0	2	1	2	0	1	1	0	0	1	0	0	1	0	0	0	0	0
Bulker <60,000DWT	4	3	4	4	5	4	5	1	1	3	4	7	2	8	2	5	3	2	2
Bulker Medium	0	0	0	2	0	0	2	0	2	1	2	1	0	5	1	0	3	1	1
Bulker >80,000DWT	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	2	1	2	0
Vehicle Carrier	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0
Cruise ship	0	1	0	1	0	1	1	0	1	0	0	1	0	0	1	0	0	1	1
Tug	0	0	0	0	0	1	2	0	2	4	0	0	2	2	1	0	2	3	2
Gen. Cargo	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Other	0	0	1	1	1	0	0	0	0	2	0	0	2	0	0	1	2	0	0
Fishing-Ocean	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0
Military	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Ferry	0	4	1	2	2	2	6	3	13	4	2	4	7	6	6	9	4	6	5
Totals	7	10	12	14	12	10	20	9	20	19	11	18	13	28	20	22	20	17	14

<sup>22</sup> Vessels classified as Product/Chemical Tanker were assumed to be chemical tankers.

**Table C-10 Vessel Incidents per Vessel Arrival in Study Area**

Type	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Container <8,000 TEUs	0.0000	0.0042	0.0057	0.0019	0.0000	0.0000	0.0000	0.0041	0.0013	0.0029	0.0028	0.0014	0.0000	0.0037	0.0114	0.0034	0.0032	0.0032	0.0065
Container Medium	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Container >10,000 TEUs	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Crude Tanker	0.0000	0.0000	0.0164	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Product Tanker	0.0435	0.0000	0.0000	0.0435	0.0294	0.0000	0.0476	0.0000	0.0000	0.2000	0.0000	0.0286	0.0000	0.0357	0.0323	0.0769	0.1333	0.0000	0.0000
Chemical Tanker	0.0364	0.0000	0.0220	0.0108	0.0250	0.0000	0.0094	0.0108	0.0000	0.0000	0.0070	0.0000	0.0000	0.0065	0.0000	0.0000	0.0000	0.0000	0.0000
Bulker <60,000DWT	0.0033	0.0026	0.0035	0.0038	0.0051	0.0040	0.0060	0.0019	0.0017	0.0043	0.0066	0.0130	0.0038	0.0139	0.0037	0.0076	0.0043	0.0032	0.0062
Bulker Medium	0.0000	0.0000	0.0000	0.0120	0.0000	0.0000	0.0097	0.0000	0.0098	0.0044	0.0075	0.0036	0.0000	0.0205	0.0044	0.0000	0.0118	0.0042	0.0067
Bulker >80,000DWT	0.0000	0.0000	0.0000	0.0000	0.0000	0.0115	0.0104	0.0000	0.0000	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	0.0109	0.0048	0.0081	0.0000
Vehicle Carrier	0.0000	0.0000	0.0000	0.0000	0.0000	0.0526	0.0625	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0041	0.0000	0.0000
Cruise ship	0.0000	0.0036	0.0000	0.0034	0.0000	0.0030	0.0030	0.0000	0.0033	0.0000	0.0000	0.0040	0.0000	0.0000	0.0039	0.0000	0.0000	0.0053	0.0103
Tug	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0002	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	0.0002	0.0001
General Cargo	0.0000	0.0000	0.0000	0.0000	0.0030	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0026	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0102
Other	0.0000	0.0000	0.0250	0.0455	0.0227	0.0000	0.0000	0.0000	0.0000	0.0444	0.0000	0.0000	0.0426	0.0000	0.0000	0.0270	0.0400	0.0000	0.0000
Fishing-Ocean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Military	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ferry	0.0000	0.0003	0.0001	0.0001	0.0001	0.0001	0.0004	0.0002	0.0009	0.0003	0.0001	0.0003	0.0005	0.0004	0.0004	0.0006	0.0003	0.0004	0.0003
Totals <sup>23</sup>	0.0002	0.0003	0.0003	0.0004	0.0003	0.0003	0.0006	0.0003	0.0006	0.0006	0.0003	0.0005	0.0004	0.0008	0.0006	0.0006	0.0006	0.0005	0.0004

<sup>23</sup> The Totals rate is the total number of incidents divided by the number of arrivals, not the sum of the individual ship types.

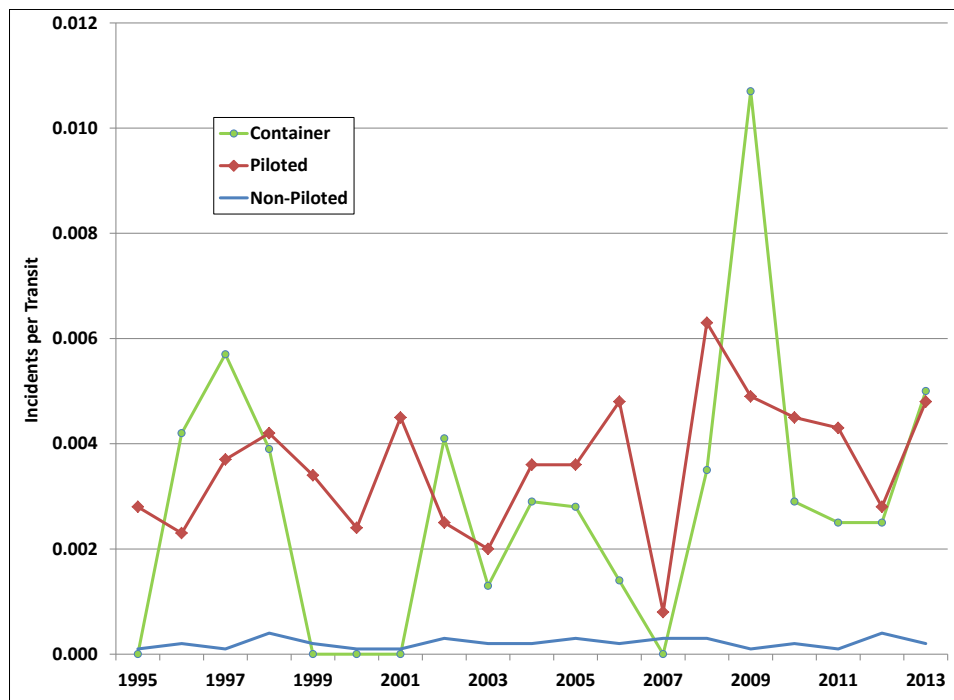


Figure C-1 Annual Incident Rates for Container Ships, Piloted Vessels and Non-piloted Vessels in the Vancouver region

Table C-11 Incident Rates and Consolidated Incident Type – Piloted Vessels: All Zones

Incident Type	Port Zones			Transit Zone			All Zones		
	#	Visits	Rate	#	Visits	Rate	#	Visits	Rate
Allision	44	48,757	0.00090	0	56,944	0.00000	44	105,701	0.00042
Allision – Near	4	48,757	0.00008	0	56,944	0.00000	4	105,701	0.00004
Broke Moor/Tow	3	48,757	0.00006	0	56,944	0.00000	3	105,701	0.00003
Collision	9	48,757	0.00018	1	56,944	0.00002	10	105,701	0.00009
Collision – Near	33	48,757	0.00068	8	56,944	0.00014	41	105,701	0.00039
Vessel Failure	30	48,757	0.00062	3	56,944	0.00005	33	105,701	0.00031
Grounding	9	48,757	0.00018	0	56,944	0.00000	9	105,701	0.00009
Grounding – Near	9	48,757	0.00018	0	56,944	0.00000	9	105,701	0.00009
Other/Misc.	17	48,757	0.00035	3	56,944	0.00005	20	105,701	0.00019
Structural Failure	2	48,757	0.00004	0	56,944	0.00000	2	105,701	0.00002
Transfer Error	3	48,757	0.00006	0	56,944	0.00000	3	105,701	0.00003
<b>Total</b>	<b>163</b>	<b>48,757</b>	<b>0.00334</b>	<b>15</b>	<b>56,944</b>	<b>0.00026</b>	<b>178</b>	<b>105,701</b>	<b>0.00168</b>

**Table C-12 Pre- and Post-STCW 1995<sup>24</sup> Incident Rates (per Transit) by Zone and Incident Type – Piloted Vessels**

Incident Type <sup>25</sup>	RBT		Fraser		PMV Main		Transit		Total Study Area	
	Pre-STCW	Post-STCW	Pre-STCW	Post-STCW	Pre-STCW	Post-STCW	Pre-STCW	Post-STCW	Pre-STCW	Post-STCW
Allision*	0.00031	0.00060	n/a	0.00012	0.00111	0.00106	0.00000	0.00003	0.00040	0.00031
Near-Allision*	0.00000	0.00000	n/a	0.00003	0.00008	0.00010	0.00000	0.00009	0.00003	0.00007
Collision*	0.00000	0.00000	n/a	0.00000	0.00024	0.00035	0.00000	0.00000	0.00008	0.00008
Near-Collision*	0.00000	0.00000	n/a	0.00009	0.00111	0.00055	0.00018	0.00003	0.00047	0.00016
Grounding*	0.00000	0.00020	n/a	0.00000	0.00024	0.00020	0.00000	0.00000	0.00008	0.00005
Near-Grounding*	0.00000	0.00000	n/a	0.00000	0.00000	0.00045	0.00000	0.00000	0.00000	0.00010
Vessel Failure	0.00000	0.00100	n/a	0.00009	0.00055	0.00055	0.00005	0.00006	0.00021	0.00023
Structural Failure	0.00000	0.00000	n/a	0.00000	0.00008	0.00000	0.00000	0.00000	0.00003	0.00000
Broke Mooring	0.00000	0.00000	n/a	0.00000	0.00000	0.00010	0.00000	0.00000	0.00000	0.00002
Transfer Error*	0.00000	0.00000	n/a	0.00000	0.00016	0.00005	0.00000	0.00000	0.00005	0.00001
Other	0.00000	0.00020	n/a	0.00006	0.00032	0.00050	0.00009	0.00000	0.00016	0.00014
All Incidents	0.00031	0.00200	n/a	0.00040	0.00388	0.00393	0.00032	0.00020	0.00150	0.00117
*Human Error Incidents	0.00031	0.00180	n/a	0.00037	0.00293	0.00338	0.00018	0.00020	0.00111	0.00102

<sup>24</sup> STCW 1995 entered into force in 2002, the data were separated into 1995 to 2001 and 2002 to 2013.

<sup>25</sup> Incidents that have large human error components while in transit are marked with asterisks (\*) and are analyzed separately in the bottom row of the table.

#### C-4 Comparison of Local Incident Rates to Worldwide Rates

**Table C-13** provides a comparison of Vancouver area incident rates with regional and worldwide rates. A complete listing of other data rates considered is available.

**Table C-13 Comparison with Regional and Worldwide Incident Rates (piloted vessels)**

Incident Type <sup>26</sup>	Incident Rates per Transit or Port Visit <sup>27</sup>							
	Vancouver region (Post-STCW Rates)					Regional		Worldwide <sup>28</sup>
	Roberts Bank Terminals	PMV Main	Fraser	Transit	All <sup>30</sup>	Puget Sound <sup>31</sup>	Other	(Port Areas) Low/High <sup>29</sup>
All Incidents <sup>32</sup>	$3.17 \times 10^{-3}$	$2.32 \times 10^{-3}$	$7.17 \times 10^{-4}$	$3.0 \times 10^{-5}$	$6.84 \times 10^{-4}$	$1.19 \times 10^{-3}$	$1.09 \times 10^{-2}$ Prince Rupert <sup>33</sup>	$1.91 \times 10^{-4}$ $7.00 \times 10^{-3}$ per transit
Allision	$6.0 \times 10^{-4}$	$1.06 \times 10^{-3}$	$1.2 \times 10^{-4}$	$3.0 \times 10^{-5}$	$3.1 \times 10^{-4}$	$4.99 \times 10^{-5}$	-	$2.03 \times 10^{-4}$ per transit  $9.90 \times 10^{-4}$ per ship-yr
Collision	0	$3.5 \times 10^{-4}$	0	0	$8 \times 10^{-5}$	$1.94 \times 10^{-5}$	-	$6.9 \times 10^{-6}$ $1.62 \times 10^{-2}$ per transit  $3.6 \times 10^{-3}$ per ship-yr
Grounding	$2.0 \times 10^{-4}$	$2.0 \times 10^{-4}$	0	0	$5 \times 10^{-5}$	$2.77 \times 10^{-6}$	$5.0 \times 10^{-2}$ Fraser River <sup>34</sup>	$1.19 \times 10^{-4}$ $6.84 \times 10^{-3}$ per transit  $1.92 \times 10^{-3}$ per ship-yr

<sup>26</sup> Combined piloted vessel types. There is variation in the definitions of incident types between the different studies.

<sup>27</sup> All values are per-transit rates unless otherwise noted.

<sup>28</sup> Global estimates or range of port-specific estimates for ports outside the Vancouver region.

<sup>29</sup> Per ship-year calculations require an estimate of transits per year per ship to convert to per-transit rates.

<sup>30</sup> Incident rates for all zones are not the sum of incidents per zone. All incidents that occurred in all the zones were divided by the total transits for all the zones.

<sup>31</sup> Based on The Glosten Associates et al. 2013 data for Puget Sound. Note that data are in transit-days.

<sup>32</sup> Includes allisions, collisions, groundings, fire/explosion, propulsion failure, steering failure, structural failure, other non-impact (which includes fire/explosion, which is also tracked separately in this table), and transfer errors. Note that totals do not include near-allisions, near-collisions, and near-groundings, or broke mooring/tow incidents which are included in totals in Tables 85 – 90.

<sup>33</sup> Det Norske Veritas 2012b.

<sup>34</sup> Det Norske Veritas 2012a.

Incident Type <sup>26</sup>	Incident Rates per Transit or Port Visit <sup>27</sup>							
	Vancouver region (Post-STCW Rates)					Regional		Worldwide <sup>28</sup>
	Roberts Bank Terminals	PMV Main	Fraser	Transit	All <sup>30</sup>	Puget Sound <sup>31</sup>	Other	(Port Areas) Low/High <sup>29</sup>
Fire/Explosion	0	$7.8 \times 10^{-5}$	0	0	$2.8 \times 10^{-5}$	-	$5.0 \times 10^{-5}$ Fraser River <sup>35</sup>	$2.12 \times 10^{-5}$ $1.44 \times 10^{-4}$ per transit $1.4 \times 10^{-2}$ $1.51 \times 10^{-3}$ per ship-yr
Structural Failure <sup>36</sup>	0	0	0	0	0	-	$2.0 \times 10^{-5}$ Fraser River <sup>37</sup>	$3.04 \times 10^{-6}$ per transit
Other Non-Impact <sup>38</sup>	$2.0 \times 10^{-3}$	$5.0 \times 10^{-4}$	$6.0 \times 10^{-5}$	0	$1.4 \times 10^{-4}$	$8.67 \times 10^{-4}$	-	$2.74 \times 10^{-5}$ per transit
Transfer Error <sup>39</sup>	0	$5.0 \times 10^{-5}$	0	0	$1.0 \times 10^{-5}$	$2.11 \times 10^{-4}$	-	$1.5 \times 10^{-4}$ per transfer $4.6 \times 10^{-3}$ per transfer
Propulsion Failure	$2.44 \times 10^{-4}$	$1.29 \times 10^{-4}$	0	0	$6.6 \times 10^{-5}$	-	-	$7.72 \times 10^{-4}$ per transit <sup>40</sup>
Steering Failure	$1.22 \times 10^{-4}$	$2.6 \times 10^{-5}$	$5.37 \times 10^{-4}$	0	$2.8 \times 10^{-5}$	-	-	$1.61 \times 10^{-4}$ per transit <sup>41</sup>
Propulsion or Steering Failure	$3.66 \times 10^{-4}$	$1.55 \times 10^{-4}$	$5.37 \times 10^{-4}$	0	$9.5 \times 10^{-5}$	-	-	

<sup>35</sup> Det Norske Veritas 2012a.

<sup>36</sup> Includes structural failure, sinking, and foundering.

<sup>37</sup> Det Norske Veritas 2012a.

<sup>38</sup> Includes all incidents other than impact-related incidents (allisions, collisions, and groundings) or transfer errors.

<sup>39</sup> Includes bunkering incidents.

<sup>40</sup> The hourly rate of propulsion failure ( $1.39 \times 10^{-4}$ ) as per Dong et al. 2013 was converted to a per-transit rate based on the usual speeds and miles of transit from Turn Point to English Bay in the study area.

<sup>41</sup> The hourly rate of propulsion failure ( $2.9 \times 10^{-5}$ ) as per Glosten et al. (2004) was converted to a per-transit rate based on the usual speeds and miles of transit from Turn Point to English Bay in the study area.

## **APPENDIX D - UPDATE OF IMO FSA CONTAINER SHIP ACCIDENT RATES**

## D. UPDATE OF IMO FSA CONTAINER SHIP ACCIDENT RATES

Germanischer Lloyd (GL 2103) performed an update to the FSA on container ships presented to IMO (IMO 2007). GL analysed data on container ship accidents worldwide for the years 1990 through 2012. The data in the latter study were more comprehensive than the earlier FSA study and also included data for the years after 2005 to reflect the change in the container ship fleet. Between 2004 and 2012, the worldwide container ship fleet grew by 60% with regard to the number of vessels. In addition, the TEU capacity grew by 128%. The annual frequencies of serious container ship incidents by type and time period are shown in **Table D-1** and **Figure D-1** through **Figure D-7** (GL 2013).

While some of the other studies mentioned in **Table D-1** include container ships as part of the vessels studied or even specifically analyse incident rates in container ships for certain locations or time periods, the GL study is the most comprehensive.

**Table D-1 Worldwide Container Ship Serious Incidents (GL 2013)**

Serious Incident Type	Frequency 1990 – 2012 (per ship-year)	Pre-STCW	Post-STCW
		Frequency 1990 – 2001 (per ship-year)	Frequency 2002 – 2012 (per ship-year)
<b>Collision</b>	$7.04 \times 10^{-3}$	$3.37 \times 10^{-3}$	$8.28 \times 10^{-3}$
<b>Contact (Allision)</b>	$2.25 \times 10^{-3}$	$2.09 \times 10^{-3}$	$2.30 \times 10^{-3}$
<b>Grounding</b>	$4.70 \times 10^{-3}$	$2.73 \times 10^{-3}$	$5.36 \times 10^{-3}$
<b>Fire</b>	$1.48 \times 10^{-3}$	$1.28 \times 10^{-3}$	$1.54 \times 10^{-3}$
<b>Explosion</b>	$0.47 \times 10^{-3}$	$0.72 \times 10^{-3}$	$0.38 \times 10^{-3}$
<b>Foundering</b>	$0.12 \times 10^{-3}$	$0.16 \times 10^{-3}$	$0.11 \times 10^{-3}$
<b>Total</b>	$16.05 \times 10^{-3}$	$10.36 \times 10^{-3}$	$17.97 \times 10^{-3}$

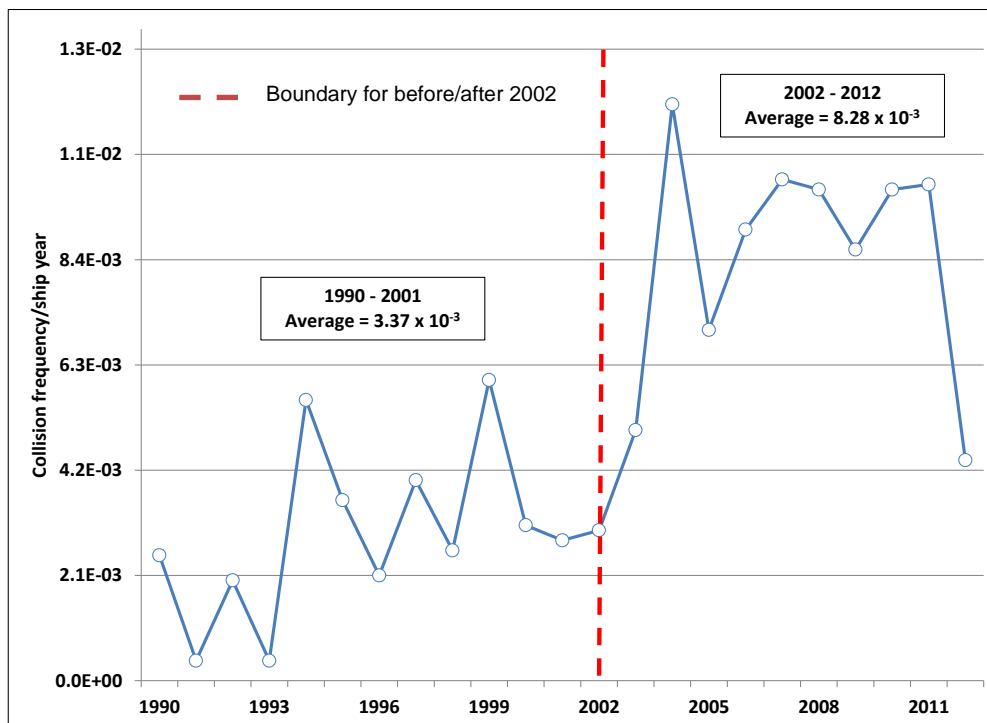


Figure D-1 Annual Serious Collision Frequency per Ship Year for Container Ships

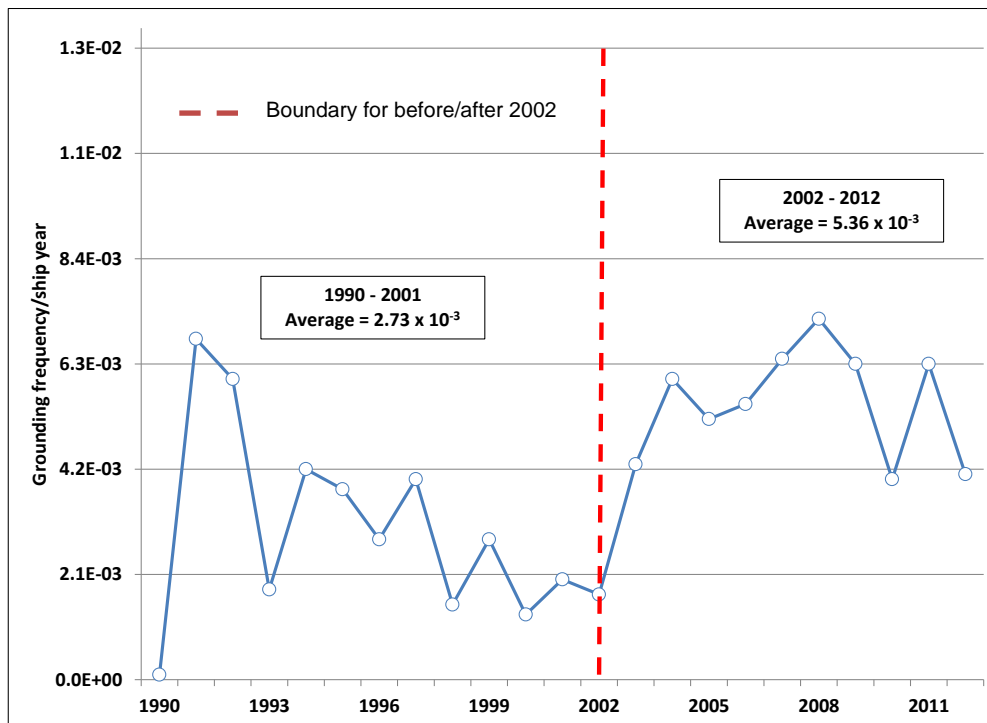


Figure D-2 Annual Serious Grounding Frequency per Ship Year for Container Ships

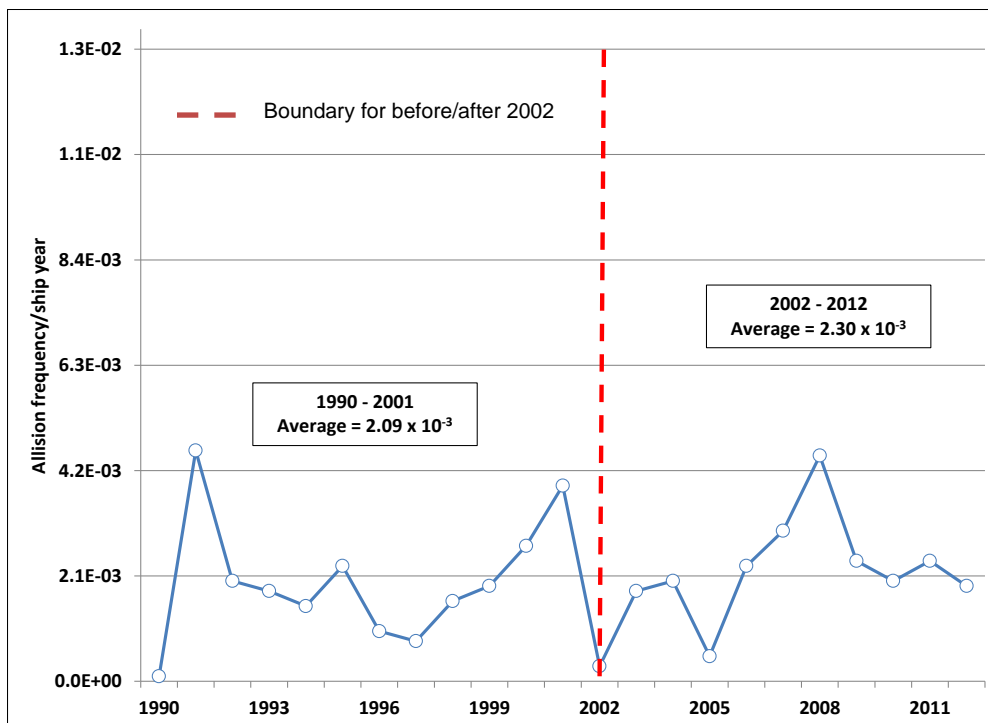


Figure D-3 Annual Serious Allision Frequency per Ship Year for Container Ships

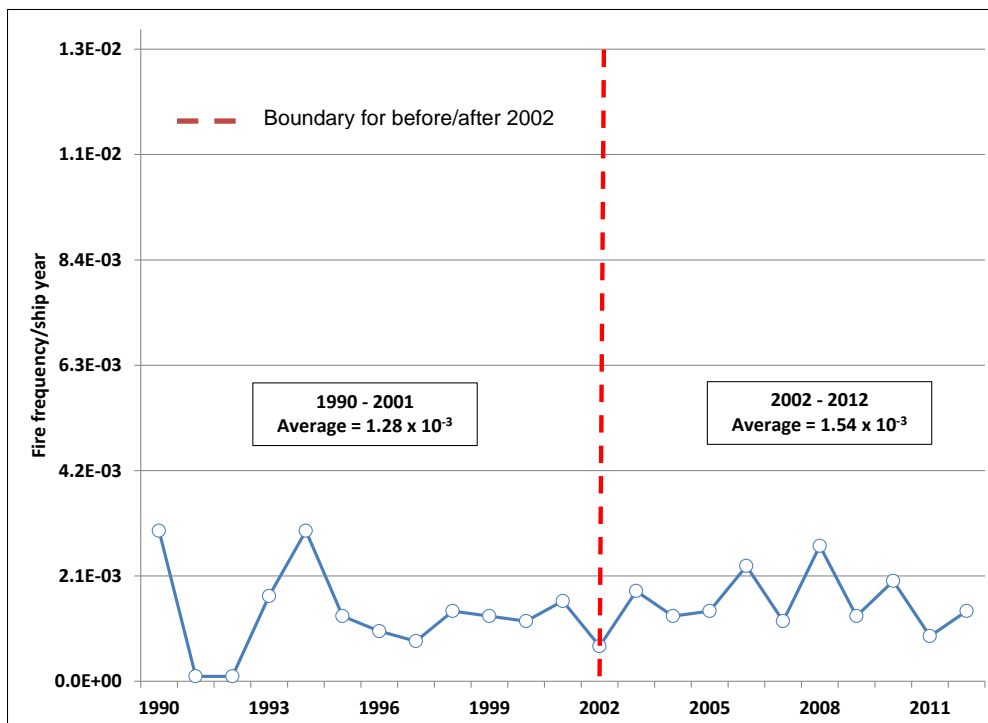


Figure D-4 Annual Serious Fire Frequency per Ship Year for Container Ships

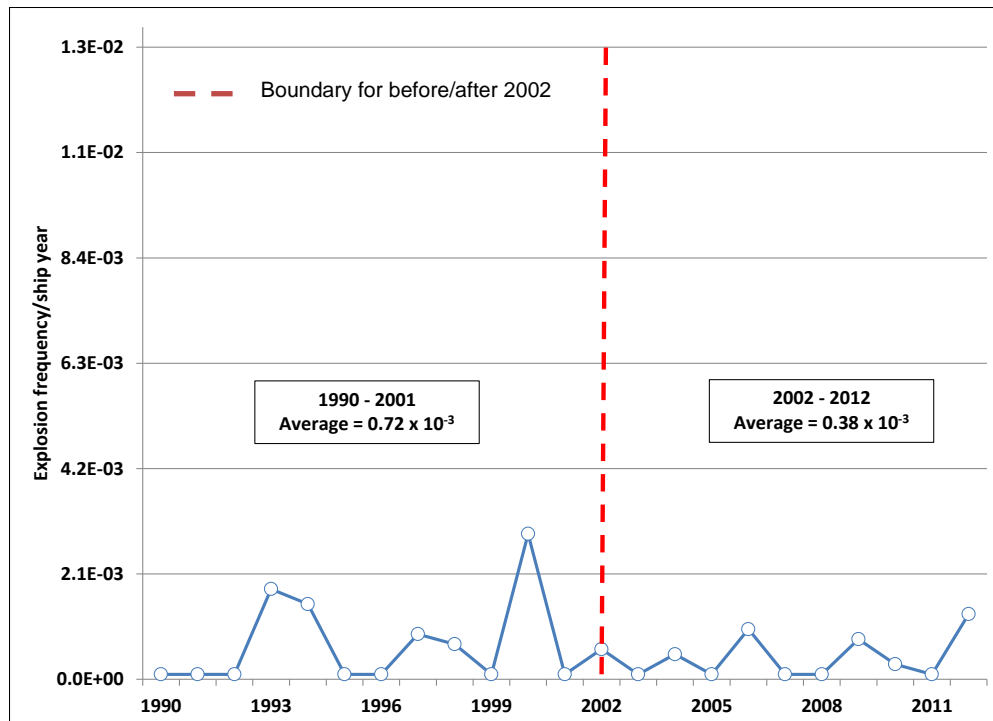


Figure D-5 Annual Serious Explosion Frequency per Ship Year for Container Ships

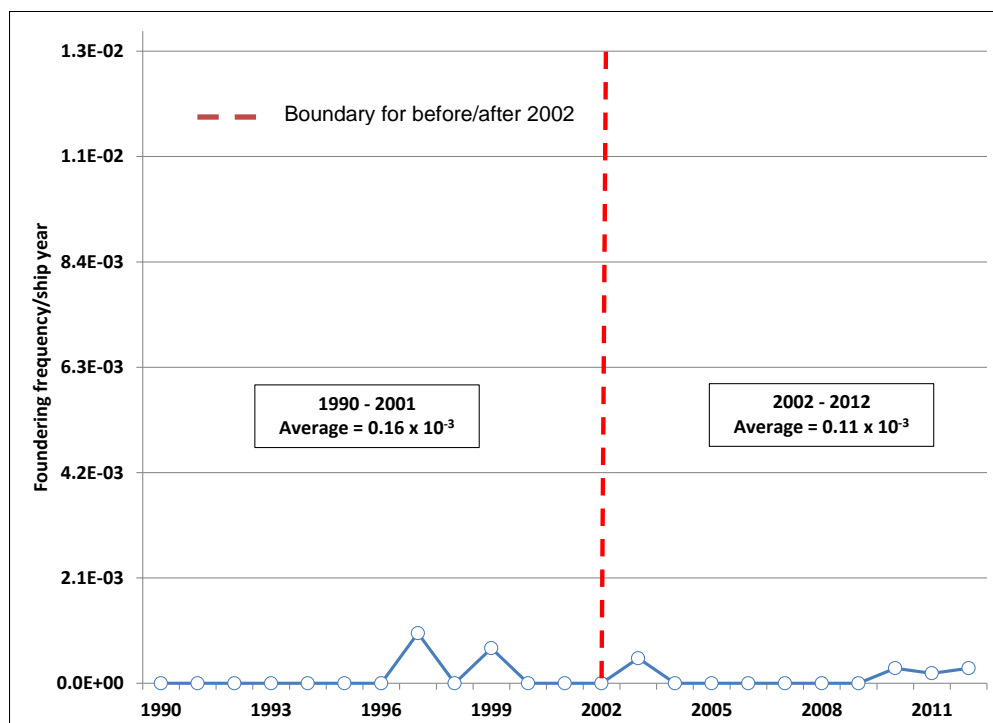
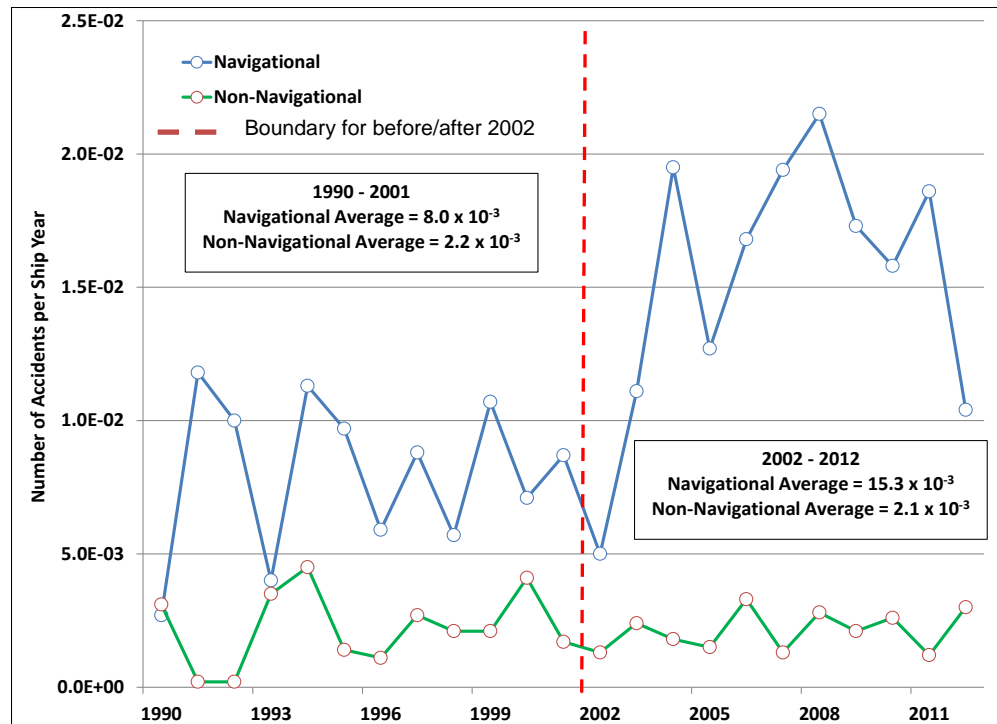


Figure D-6 Annual Serious Foundering Frequency per Ship Year for Container Ships



**Figure D-7 Container Ship Navigational/Non-Navigational Serious Incident Frequency**

## **APPENDIX E - ENCOUNTER MODELLING**

## **E. ENCOUNTER MODELLING**

To effectively model the vessel traffic, a basis of the current vessel traffic was established. The current traffic data were based on information collected on the vessel's AIS. Most commercial vessels have an AIS transponder which broadcasts information on vessel GPS location, speed, heading, and a unique vessel identifier called the Maritime Mobile Service Identity (MMSI). These data are broadcasted every 3 to 6 minutes. MMSI numbers within the AIS data were cross-referenced with a database of vessel information that included the vessel's type, dimensions, and capacity.

### **E-1 AIS Data Processing**

AIS data is collected and stored in a database by [www.MarineTraffic.com](http://www.MarineTraffic.com). As the information is received, a time and date is added to the database. This database includes all the AIS transmissions within the region of study from April 2011 to June 2013.

Before creating the model of the existing vessel traffic, it was necessary to screen the AIS database and remove all erroneous data. AIS data could be incorrectly reported for a variety of reasons, including malfunctioning equipment on the ship, simultaneous transmission of data from two ships, or weather (lightning and fog can interfere with the VHF signals used by the AIS transponders). By sorting the data by MMSI number and time, the GPS positions provided a track of the ship's route. Each route was checked for continuity by making sure that the dead reckoning calculation, using the reported heading and speed, was close to the vessel's GPS position. Any points that could not be verified in this manner were removed from the database.

The next process was to create a uniform time interval among all the AIS data. This was necessary in order to compare the position of two ships at an instant in time. A time interval of 5 minutes was chosen because it was close to the average time interval of the original AIS data. At fixed time intervals, each ship's position was calculated by estimating the ship's position from the locations and headings reported before and after the fixed time.

### **E-2 Identifying Voyages**

The vessel routes were analysed for any period of time that the vessel was stopped for a prolonged period in one place. This location was classified as a port or an anchorage. By running this process for all the container ships, bulkers, and tankers in the AIS database, a list of voyages with arrival and departure times at the ports and anchorages was created. This list of arrivals was compared to the list of arrivals provided by PMV to ensure that the AIS data was accurately representative of the vessel traffic in the region.

**Figure 2-8** shows some sample routes extracted from the AIS data. These routes show container ship round trip voyages to terminals at Roberts Bank, Fraser River, and Burrard Inlet.

### **E-3 Creating a Background Data Set**

Every type of ship seen in the AIS database was analysed to determine if the vessel population was expected to change in the 2030 projections. Vessel populations that were expected to change were extracted from the AIS database and new vessel populations were modelled. Populations that were not projected to change significantly created a database of background ship routess.

### **E-4 Modelling Vessel Populations**

Vessel populations were modelled to represent the current vessel traffic as well as six different scenarios for the expected traffic in 2030. The first four added scenarios represent scenarios 2 through 5 of the Vessel Population Scenarios (see main report). Two additional scenarios representing a 25% reduction in the number of container ships calling at RBT2 were also evaluated to assess the sensitivity to this effect. For each scenario, five different vessel populations were created to show the variations that can be found in each model. For the scenarios without RBT2 this represents approximately 1560 container ship roundtrip voyages. With RBT2 the modeling includes approximately 2860 container ship roundtrip voyages. Annual numbers are taken by averaging the five populations.

Traffic entering the region through Boundary Pass was analysed to determine the distribution of time separating the arriving ships to each port. This distribution was then used to build a new vessel arrival list. For the traffic models where more traffic was expected, the average time between arrivals needed to be reduced, but the overall distribution of times was modelled with the same shaped distribution.

Each of the arriving ships in the model was assigned a random round trip voyage from the AIS data associated with a ship of the same type going to the same port. The existing voyage data gave the new arrival model a route, a time at port, and a time of departure from the region. In some cases, when the vessel prediction showed that larger vessels would be serving the ports, the time at the port was extended to represent the increased time needed to handle a larger vessel.

Traffic within Boundary Pass is regulated by the Victoria branch of Canada's Marine Communications and Traffic Services to maintain a minimum separation time between vessels. The separation time of arriving vessels was set when creating the arrival distributions, but by assigning random voyages to the vessels, the exit times needed to be checked for minimum separation time. If the exit time of two vessels was found to be too close, a delay time was added to one of the vessels, keeping it at the port for longer until the exit time met the minimum requirement.

## E-5 Encounters

Encounters are events where the projected paths of two ships will cross within a certain distance of each other. Encounters are classified into three categories, and each category has a different risk associated with it:

- Overtaking, where two vessels are moving in the same direction and the vessel behind is moving faster, so that it is projected to pass the other vessel within a certain distance.
- Crossing, where the paths of two vessels are crossing and both ships are projected to cross within a certain time of each other.
- Head-On, where the vessels are heading toward each other and their projected paths will cross within a certain distance.

In each of the modelled vessel populations, routes of the vessels were analysed to check for these types of encounters. The paths were checked against the background existing traffic and the other ships present in that scenario model. **Figure E-1** shows a plot of the encounters as calculated from the existing ships in the 2012 AIS data. Green marks are overtaking encounters, blue is crossing and red is head-on. Solid icons are encounters with laden tankers or tank barges.

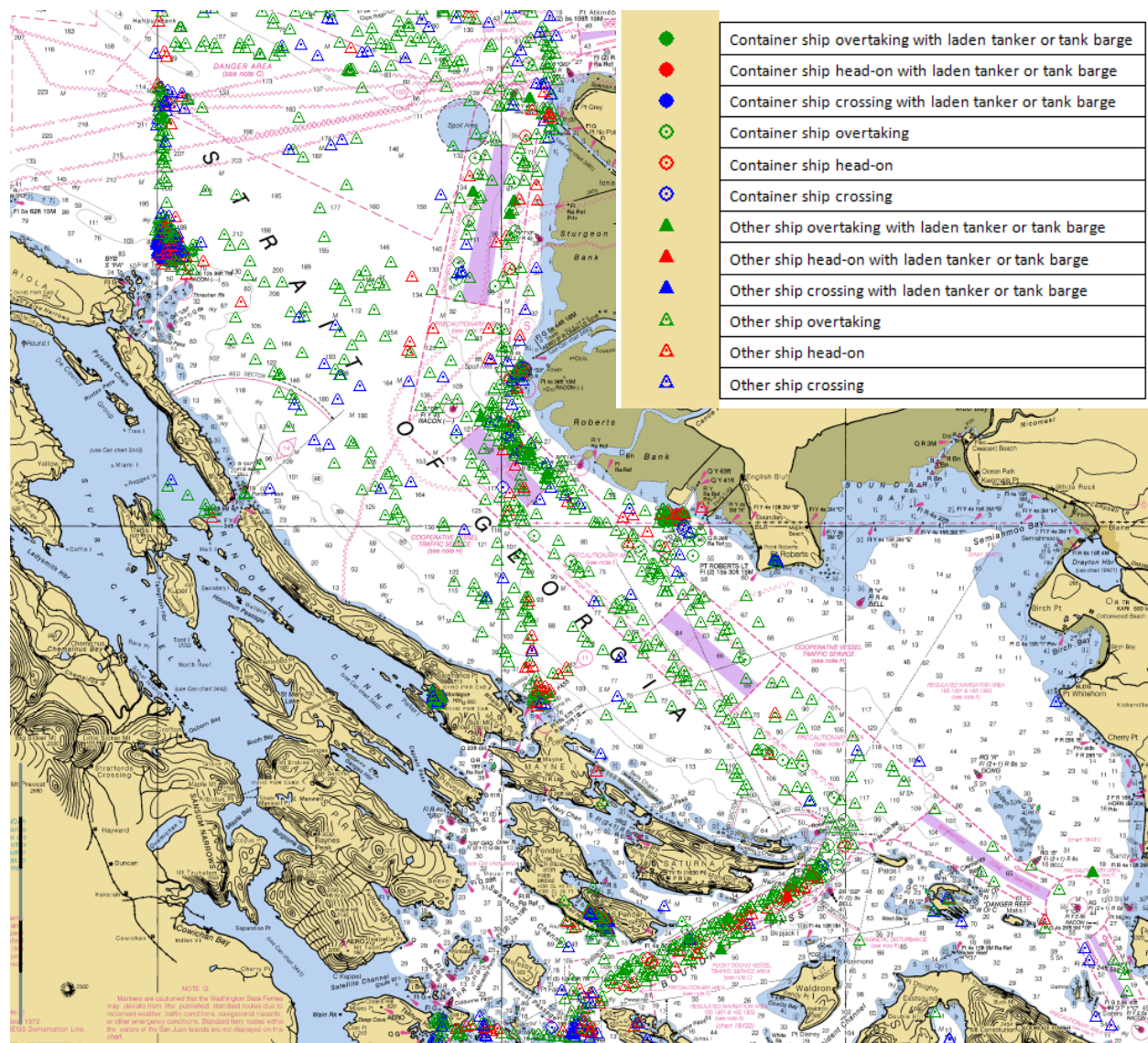


Figure E-1 Encounters in the Study Area from 2012 AIS Data

Encounters and thus, collision rate increase with the number of vessels. **Table E-1** shows the increase in key ship numbers over Scenario 1.

Table E-1 Ship population numbers and ratios

		Scenario						
		1	2	3	4	5	6	7
Containerships heading to RB	No.	269	312	572	312	572	522	522
	Ratio	1.00	1.16	2.13	1.16	2.13	1.94	1.94
Large Ships in waterway	No.	11244	11345	11607	12444	12706	12394	12656
	Ratio	1.00	1.01	1.03	1.11	1.13	1.10	1.13

One of the reasons for performing this encounter analysis was to show the relative increases associated with new container ships at RBT2 in the context of general traffic increase. First note that the number of large ships does not increase very much from 2012 to 2030, about 1% without any new facilities. This is a result of increasing average size. The addition of RBT2 container ships is about a 2% increase (compare Case 3 vs. Case 2, or Case 5 vs. Case 4). Similarly the addition of traffic to foreseeable new facilities leads to about a 10% increase in vessel traffic.

Ratios comparing the number of encounters for each future scenario relative to Scenario 1 (the existing conditions in the year 2012) number have been derived. **Table E-2** shows data extracted for selected sub-populations. Here the number of encounters is weighted by the contribution to collision risk for each encounter type from the Institute of Marine Traffic Engineering (IMTE) model<sup>42</sup> so that the number is proportional to overall collision risk. C\_rate is the collision rate based upon the IMTE model and Ratio is the ratio to Scenario 1. The IMTE Collision Model estimated collision probabilities per encounter as shown in **Table E-1**. The criterion for an encounter is 0.75 NM (1.4 km), approximately 5 ship lengths for large container ships.

**Table E-2 Collision Probability (IMTE Model)**

Type of Encounter	% Cases	Probability of Collision per Encounter
Head-On	40%	$3.1 \times 10^{-6}$
Overtaking	40%	$3.3 \times 10^{-6}$
Crossing	20%	$8.9 \times 10^{-6}$
Weighted Mean	-	$4.3 \times 10^{-6}$

<sup>42</sup> Przywarty 2009a, 2009b based on: HELCOM 2006; 2007; 2008.

**Table E-3 Encounter data using 0.75 NM (1.4 km) criteria**

Encounter Data Selection		Vessel Population Scenario						
		1	2	3	4	5	6	7
Container ships heading to RB	No.	44	45	89	50	89	83	84
	C_rate	$6.7 \times 10^{-4}$	$6.9 \times 10^{-4}$	$1.4 \times 10^{-3}$	$7.6 \times 10^{-4}$	$1.4 \times 10^{-3}$	$1.3 \times 10^{-3}$	$1.3 \times 10^{-3}$
	Ratio	1	1.03	2.04	1.14	2.04	1.89	1.92
Bulk Carriers heading to RB	No.	93	98	102	102	101	104	107
	C_rate	$1.4 \times 10^{-3}$	$1.5 \times 10^{-3}$	$1.6 \times 10^{-3}$	$1.6 \times 10^{-3}$	$1.6 \times 10^{-3}$	$1.6 \times 10^{-3}$	$1.6 \times 10^{-3}$
	Ratio	1	1.06	1.10	1.10	1.09	1.12	1.16
All ships excluding tugs, only with laden tankers*	No.	3	3	3	22	25	3	25
	C_rate	$4.9 \times 10^{-5}$	$4.4 \times 10^{-5}$	$4.1 \times 10^{-5}$	$3.3 \times 10^{-4}$	$3.9 \times 10^{-4}$	$3.9 \times 10^{-5}$	$3.8 \times 10^{-4}$
	Ratio	1	0.91	0.85	6.80	7.99	0.80	7.81
All ships excluding tugs **	No.	1230	2	1270	1320	1360	1270	1350
	C_rate	$1.9 \times 10^{-2}$	$1.9 \times 10^{-2}$	$1.9 \times 10^{-2}$	$2.0 \times 10^{-2}$	$2.1 \times 10^{-2}$	$1.9 \times 10^{-2}$	$2.1 \times 10^{-2}$
	Ratio	1	1.02	1.03	1.07	1.10	1.03	1.09
All ships	No.	4090	4130	4160	4440	4500	4150	4480
	C_rate	$6.3 \times 10^{-2}$	$6.3 \times 10^{-2}$	$6.4 \times 10^{-2}$	$6.8 \times 10^{-2}$	$6.9 \times 10^{-2}$	$6.4 \times 10^{-2}$	$6.9 \times 10^{-2}$
	Ratio	1	1.01	1.02	1.09	1.10	1.02	1.10

\* The collision rate for laden tankers does not include any reduction for escort tugs; however this is estimated at only a 5% reduction based upon DNV estimation.

\*\* The exclusion of tugs is to eliminate tug-vessel interactions in tug-assist maneuvering.

Comparing ratios of encounters to ratios of ship numbers shows:

- The number of encounters for all ships excluding tugs grows slightly less than the number of ships;
- Vessel speed plays a role in number of encounters. Container ships have fewer encounters than bulk carriers because they are in the waterway for a shorter time;
- Comparing the ratio for Case 3 vs. Case 2 for container ships shows a ratio of  $2.04/1.03 = 1.98$ . Similarly the ratio for Case 5 vs. Case 4 ( $2.04/1.14$ ) is 1.79 or a 10% reduction from the preceding ratio. Thus, the increase in collision rate and thus, ultimately collision risk with RBT2 compared to that without RBT2 is about 10% less when measured against the larger background traffic compared to the lower assumption for background traffic. However this 10% reduction is less than the uncertainty associated with the combination of population, and the encounter numbers (which show a coefficient of variation in the 4%-8% range for 5 simulations of a year's traffic). Thus, this reduction does not affect collision rate comparisons for with and without RBT2; and
- Encounters with laden tankers for all ships increase by a factor of about 7-8, compare Case 2 and Case 3 vs. Case 4 and Case 5, for the row 'All ships excluding tugs, only with laden tanker' if the KM Trans Mountain Pipeline Expansion happens but this does not strongly influence the container ship encounter numbers in the first row. This indicates the vessel routes and timing for the two vessel types do not overlap extensively as expected.

## E-8 Encounter Locations

The following figures show the locations of encounters for container ships bound for Roberts Bank for Vessel Scenarios (Cases) 4 and 5. These are the cases with the most encounters because both contain the additional traffic associated with other potential marine facilities. The difference is illustrative of the existence of RBT2.

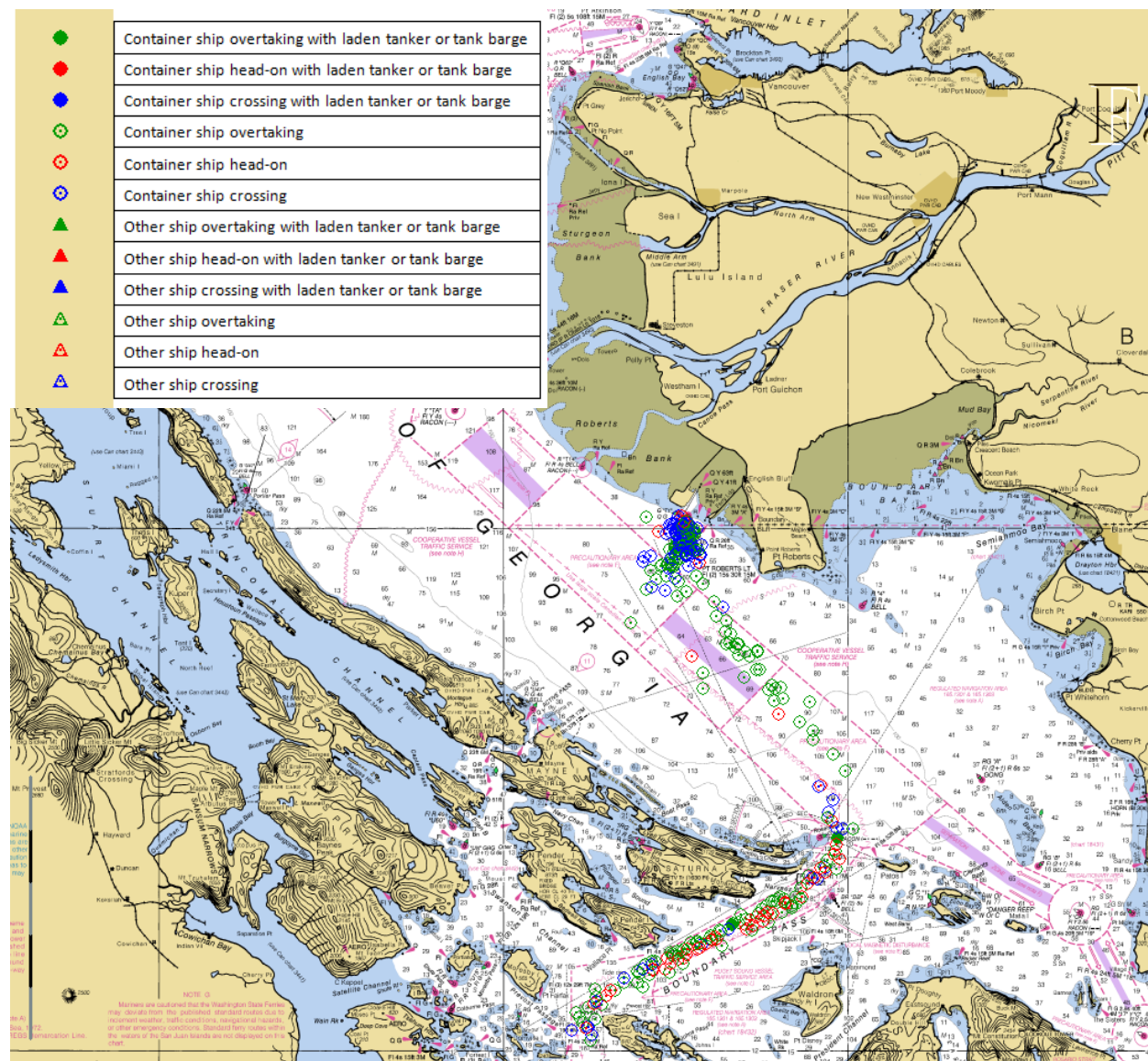


Figure E-2 Encounters for Case 4

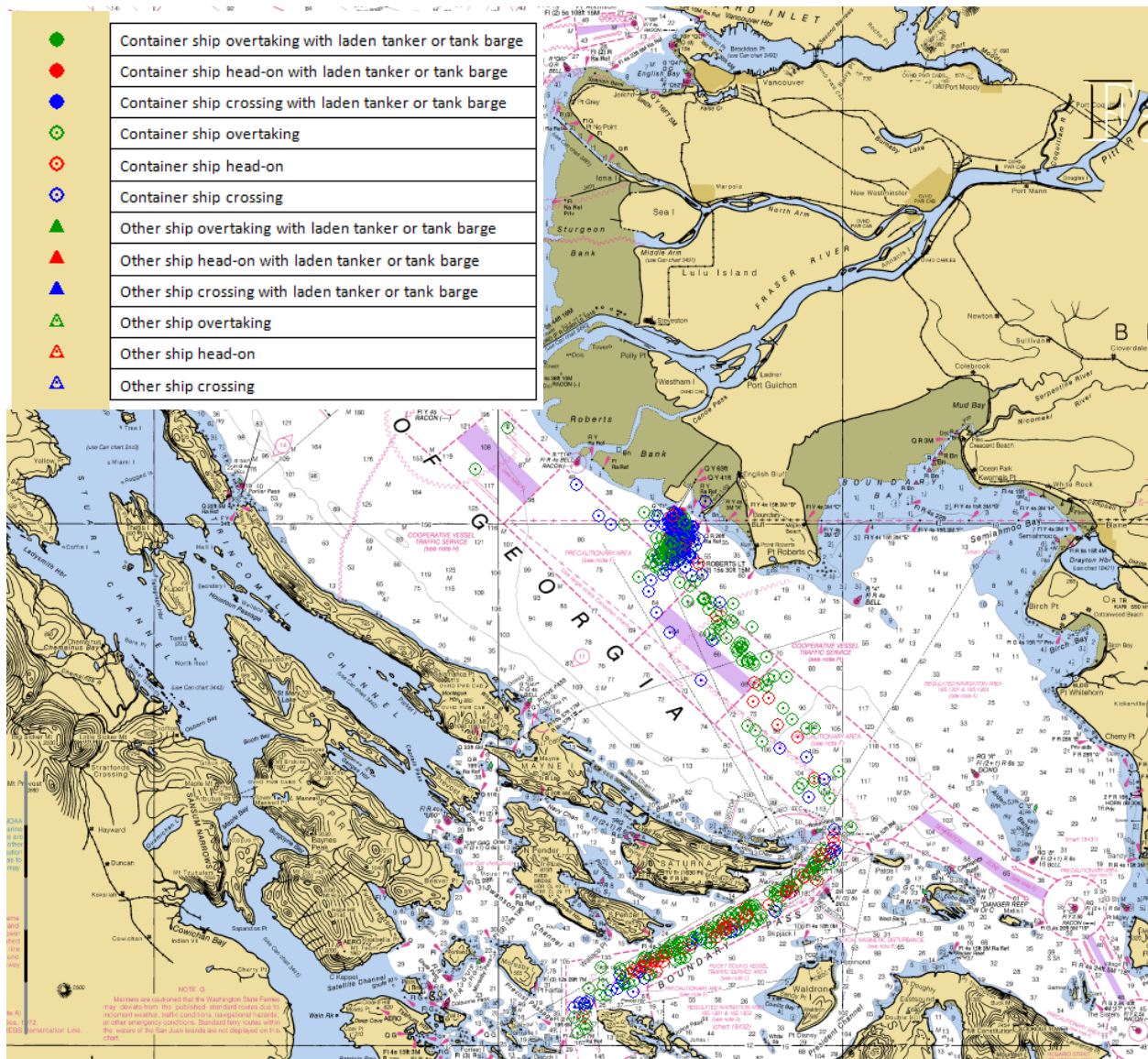


Figure E-3 Encounters for Case 5

## **APPENDIX F - OPERATIONAL POLLUTANT INPUTS**

## F. OPERATIONAL POLLUTANT INPUTS – LUBRICANT DISCHARGES

The majority of ocean-going ships operates with oil-lubricated stern tubes and uses lubricating oils in a large number of applications in on-deck machinery and in-water (submerged) machinery. **Table F-1** shows the average daily consumption (i.e., loss) of stern tube lubricants by vessel type.

**Table F-1 Average Daily Consumption of Stern Tube Lubricants**

Vessel Type(s) <sup>43</sup>	Daily Consumption <sup>44</sup>
Barge Carrier	20 litres
IWW Oil Tanker	11 litres
Navy Ships	10 litres
General Cargo Ship	7 litres
Bulker; Passenger/Ro-Ro Cargo Ship	6 litres
Container ship; Tender; Live Stock Carrier	5 litres
Heavy Load Carrier; Research Vessel; Crude Oil Tanker; Refrigerated Cargo Ship; Chemical Tanker; Container Ro-Ro Cargo Ship; Trawler	4 litres
Pusher Tug; Hopper Dredger; Palletised Cargo Ship; Oil Products Tanker; Wood Chips Tanker; HNS/Oil Products Tanker; Vehicles Carrier; LPG Tanker	3 litres
Offshore Supply Ship; Passenger Ferry; Self-Discharging Bulker; Offshore Tug/Supply Ship; Fish Carrier; Fishing Vessel; Sail Training Ship; Passenger Cruise Ship; Standby Safety Vessel; Cement Carrier; Asphalt/Bitumen Tanker	2 litres
Offshore Support Vessel; Bulk/Oil Carrier; LNG Tanker	1 liter
Buoy/Lighthouse Vessel; Cable Layer; Crane Ship; Dredger; Fishery Support Vessel; Live Fish Carrier; Motor Hopper; Offshore Processing Ship; Ore Carrier; Passenger/General Cargo Ship; Patrol Vessel; Pipe Layer; Platform; Pollution Control Vessel; Pontoon; Stone Carrier; Trans-Shipments Vessel; Water Tanker; Well Stimulation Vessel; Work/Repair	0 litres

Based on vessel traffic for Port Metro Vancouver and Roberts Bank Terminal for the years 1995 - 2013, and for the years 2008 – 2013 for Fraser, estimates of operational stern tube lubricant inputs were calculated as shown in **Table F-2**. Estimates for container ships alone are shown in **Table F-3**.

<sup>43</sup> Note that vessels such as barge carriers and inland waterway (IWW) oil tankers may be consuming larger amounts of stern tube lubricants due to the degree to which the vessels are submerged. Port Metro Vancouver notes that while there is some operational loss of oil from the stern tube of all vessels, the actual amount varies from vessel to vessel. Deep sea ships calling Port Metro Vancouver meet stringent international standards and are inspected regularly to ensure compliance. In North America it is standard practice, and it is law in US waters such as the approaches to Port Metro Vancouver through the Cooperative Vessel Traffic Services (CVTS) agreement, to use only lubricants that meet the requirements of a Vessel General Permit (VGP). This requirement ensures that all lubricants used are Environmentally Acceptable Lubricants (EALs) and means that they are biodegradable, minimally toxic and not bio accumulative. EALs are required to be used in stern tubes, stabilizers, rudders, thrusters, azipods, wire ropes and any other mechanical equipment subject to immersion.

<sup>44</sup> Etkin 2009 (IMO MEPC 60 submittal); Etkin 2010.

**Table F-2 Estimated Annual Stern Tube Lubricant Oil discharges in Study Area 2012**

Port Area	Annual Bbl of Input
	Stern Tube
PMV Main	86
Roberts Bank Terminal	20
Fraser River	13
Transit	132
<b>Total</b>	251

**Table F-3 Estimated Annual Stern Tube Lubricant Oil Discharges from Container ships in Study Area 2012**

Port Area	Annual Bbl of Input
	Stern Tube
PMV Main	17
Roberts Bank Terminal	9
Fraser River	5
Transit	34
<b>Total</b>	65

## **APPENDIX G - SPILL MATERIALS AND PROPERTIES**

## G. SPILL MATERIALS AND PROPERTIES

### G-1 Spill Impact Based on Pollutant Type

The importance of the pollutant type is that it determines the impacts or consequences of the spill in that particular location (environment) and at that particular time. The volume of the spill will also be a factor in determining the magnitude of impact.

The impact of the pollutant depends on its toxicity, its persistence in the environment, and its propensity for adherence and mechanical injury (e.g., smothering or sticking to bird feathers). These factors are, in turn, dependent on the chemical and physical characteristics of the substance under those particular environmental conditions (e.g., temperature, water salinity, hydrodynamics). The degree to which a substance is actually toxic to organisms in the environment is dependent on its solubility, volatility, and other factors. A further factor is the “bioavailability” of the substance once it is in the environment, that is, the degree to which the chemical components of the substance are actually absorbed by an organism (i.e., the chemical crosses the organism’s cellular membranes). The length of time that the organisms are exposed to the substances will also affect toxicity. The length of time that passes after a spill occurs also affects the toxicity of the substance because of chemical and physical changes related to evaporation and dilution. Different organisms also vary with respect to their sensitivity and toxic response.

### G-2 Spill Impact Based on Oil Type

While there are chemical and physical differences between the hundreds or thousands of oil types, there are certain general characteristics that allow for grouping of oils into five major categories. **Table G-1** shows the relative effects of these different oil types.<sup>45</sup>

- Volatile distillates (e.g., gasoline, jet fuel, kerosene)
- Light fuel (e.g., diesel)
- Crude oil<sup>46</sup>
- Heavy fuel (HFO) (e.g., bunker fuel, residual fuel oil, intermediate fuel oil)
- Vegetable oil (e.g., canola oil)

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<sup>45</sup> French-McCay et al. 2008, 2009.

<sup>46</sup> Light crude oil may behave more like light fuels in the environment, because of the higher proportion of lighter volatile components, while heavy crude oil may behave more like heavy fuel due to the higher proportion of heavier, persistent components.

**Table G-1 Environmental Effects of Oil Types**

Oil Category	Acute Toxicity	Mechanical Injury/Adherence	Persistence
Crude	Low	Moderate	High (5 – 10 years)
Heavy	Moderate	High	High (5 – 10 years)
Light	Moderate	Moderate	Lower (1 month – 1 year)
Volatile Distillate	High	Low	Low (days to weeks)
Vegetable	Lower	Lower	Low (days to weeks)

There is a “tradeoff” (or inverse relationship) between persistence and toxicity in oils, because the substances that are the most toxic are also the most likely to evaporate and disperse and not persist. The heavier components of oil will persist longer in the environment, but are not as chemically toxic.

The oil types that are likely to spill in the Study Area are dependent on the type of oil being transported and consumed. The oil being transported as cargo by tanker and tank barges may be crude or refined products. Crude oil may be transported to the refinery, but most of the transported oil is refined petroleum, which may include jet fuel, diesel, heavy fuel oil, and other products.

Oil used as fuel for vessels will vary from diesel fuel to heavy fuel oil (Bunker C or intermediate fuel oil IFO). Smaller recreational vessels may run on gasoline. Due to international regulations aimed at reducing air pollution from ships in port areas,<sup>47</sup> there has been and will continue to be a gradual shift from the use of heavy fuel oil to diesel fuel in port areas, which reduces sulfur oxide (SO<sub>x</sub>) and nitrogen oxide (NO<sub>x</sub>) emissions. Vessels will likely continue to use heavy fuel oil while en route at sea due to lower costs. The proportion of diesel fuel to HFO is expected to increase in future, increasing the probability that spills will involve diesel rather than heavier fuel.

### **G-3 Spill Impact Based on HNS Type**

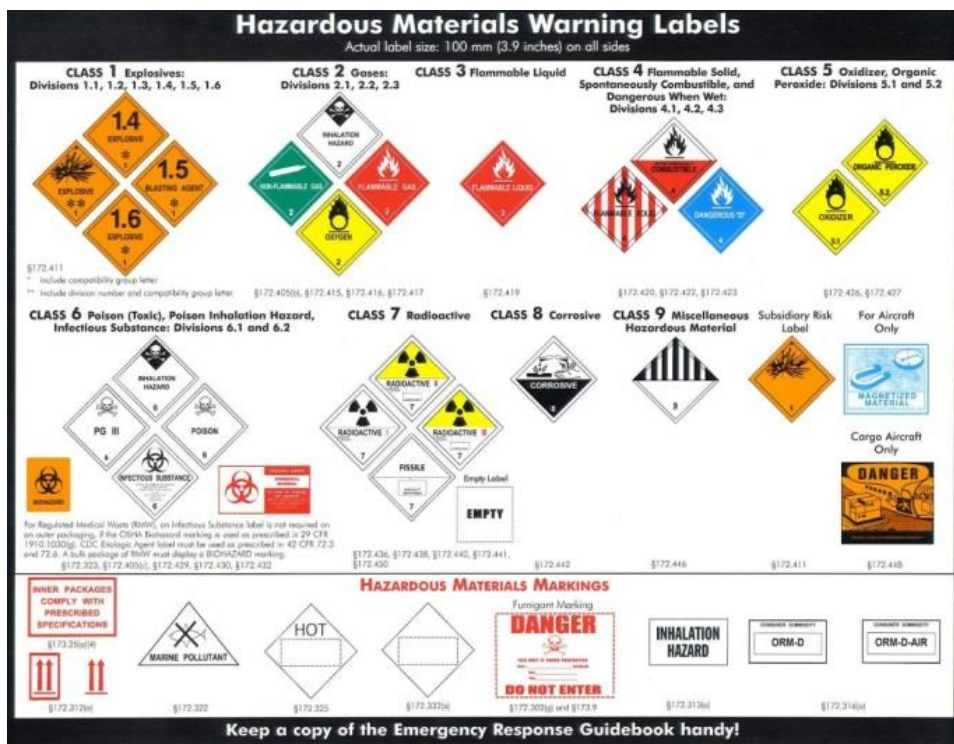
With respect to HNS, there are even more differences between substances with respect to the chemical and physical behavior of the substances. The IMO convention Protocol on Preparedness, Response, and Co-operation to Pollution Incidents by Hazardous and Noxious Substances, 2000 (OPRC-HNS Protocol), adopted 2000 and entered into force 14 June 2006 established measures for dealing with pollution incidents related to HNS. Another IMO Convention, the 2010 HNS Convention also covers HNS from the perspective of financial considerations with respect to compensation for incidents. The two conventions classify substances slightly differently. The descriptions used by the OPRC-HNS Protocol are shown in **Table G-2**.

<sup>47</sup> MEPC.176(58) Amendments to the Annex of the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (Revised MARPOL Annex VI), adopted October 2008.

**Table G-2 Worldwide HNS Vessel Incidents by Product Behavior Category (2006 – 2011)**

Behavior of Substance	Abbreviation	Number of Incidents	% Incidents
Dissolver	D	39	16.7%
Dissolver-Evaporator	DE	18	7.7%
Evaporator	E	9	3.8%
Floater	F	3	1.3%
Floater-Dissolver	FD	1	0.4%
Floater-Evaporator	FE	12	5.1%
Floater-Evaporator-Dissolver	FED	1	0.4%
Persistent Floater	Fp	16	6.8%
Gas	G	16	6.8%
Gas-Dissolver	GD	2	0.9%
Sinker	S	8	3.4%
Sinker-Dissolver	SD	2	0.9%
Unknown	Unknown	107	45.7%
<b>Total</b>		<b>234</b>	<b>100.0%</b>

The International Maritime Dangerous Goods (IMDG) Code<sup>48</sup> classifies substances according to nine categories (Figure G-1).



**Figure G-1 IMDG Code Classifications**

<sup>48</sup> For more information on IMDG code classifications, see Transport Canada, Transportation of Dangerous Goods (TDG) Regulations.

The 2012 container throughput for Deltaport (RBT) and by IMDG substances are shown in **Table G-3**.

**Table G-3 Dangerous Good TEUs Transported through Deltaport (RBT) in 2012**

IMDG Category	IMDG Class	IMDG Description	Number of Containers Handled <sup>49</sup>	% Total IMDG	% Total TEUs
Explosives	1.3	Explosives with a fire, blast or projection hazard but not a mass explosion hazard.	10	0.08%	0.0006%
	1.4	Minor fire or projection hazard (includes ammunition and most consumer fireworks).	99	0.82%	0.0058%
	1.4G		6	0.05%	0.0004%
Gases	2		2	0.02%	0.0001%
	2.1	Flammable Gases: Gases which ignite on contact with an ignition source, such as acetylene and hydrogen.	289	2.41%	0.0170%
	2.2	Non-Flammable Gases: Gases which are neither flammable nor poisonous. Includes the cryogenic gases/liquids (temperatures of below -100°C) used for cryopreservation and rocket fuels, such as nitrogen and neon.	387	3.22%	0.0228%
	2.3	Poisonous Gases: Gases liable to cause death or serious injury to human health if inhaled; examples are fluorine, chlorine, and hydrogen cyanide.	7	0.06%	0.0004%
Flammable Liquids	3		1,920	15.99%	0.1129%
	3.3		1	0.01%	0.0001%
Flammable Solids	4.1	Flammable Solids: Solid substances that are easily ignited and readily combustible (nitrocellulose, magnesium, safety or strike-anywhere matches).	648	5.40%	0.0381%
	4.2	Spontaneously Combustible: Solid substances that ignite spontaneously (aluminium alkyls, white phosphorus).	388	3.23%	0.0228%
	4.3	Dangerous when Wet: Solid substances that emit a flammable gas when wet or react violently with water (sodium, calcium, potassium, calcium carbide).	45	0.37%	0.0026%
Oxidizing Agents	5.1	Oxidizing agents other than organic peroxides (calcium hypochlorite, ammonium nitrate, hydrogen peroxide, potassium permanganate).	414	3.45%	0.0244%
	5.2	Organic peroxides, either in liquid or solid form (benzoyl peroxides, cumene hydroperoxide).	5	0.04%	0.0003%
Toxic & Infectious Substances	6.1	Toxic substances which are liable to cause death or serious injury to human health if inhaled, swallowed or by skin absorption (potassium cyanide, mercuric chloride).	1,065	8.87%	0.0626%
Radioactive Substances	7	Radioactive substances comprise substances or a combination of substances which emit ionizing radiation (uranium, plutonium).	5	0.04%	0.0003%

<sup>49</sup> Includes imports and exports.

IMDG Category	IMDG Class	IMDG Description	Number of Containers Handled <sup>49</sup>	% Total IMDG	% Total TEUs
Corrosive Substances	8	Corrosive substances are substances that can dissolve organic tissue or severely corrode certain metals.	3,809	31.73%	0.2241%
Miscellaneous	9	Hazardous substances that do not fall into the other categories (asbestos, air-bag inflators, self-inflating life rafts, dry ice).	2,905	24.20%	0.1709%
Total IMDG	-		12,005	-	0.7062%
Non-DG	-	All materials not included in the above categories. (Not part of IMDG Code.)	1,687,995	n/a	99.2938%
Total			1,700,000		

Of the 1.7 million TEUs handled at the Deltaport Terminal in 2012, less than 1% (0.7062%) involved goods that could be classified as Dangerous Goods under the IMDG Code.

The IMDG Code was developed primarily for safe transportation rather than to determine the impacts of these substances if and when spilled into the marine environment. For each of the HNS substances transported in containers, in bulk carriers, or by tank vessel, the toxicity and behavior varies considerably. The volume of spillage is not indicative of the magnitude of impacts when comparing differing substances. A small volume of a particularly toxic substance may create more environmental damage than a much larger quantity of another less toxic substance. The HNS that have the highest ecological consequences after a spill are those that disperse readily (are soluble), are not highly volatile (i.e., they do not evaporate readily), and are most toxic to aquatic biota. The chemicals that present the highest hazard to aquatic biota per unit mass in decreasing order of hazard are:<sup>50</sup>

- Phenol
- Formaldehyde
- Ammonia
- Chlorobenzene
- Tetraethyl lead
- Acetaldehyde
- Xylene
- Ethylbenzene
- Styrene
- Carbon Tetrachloride

<sup>50</sup> French-McCay et al. 2006.

The least hazardous are:<sup>51</sup>

- Ethylene glycol
- Hydrochloric acid (solution)
- Sodium hydroxide (solution)
- Methanol
- Methyl ethyl ketone (MEK)

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<sup>51</sup> Least hazardous of the chemicals analyzed in: French-McCay et al. 2006.

**APPENDIX 30-B**  
**Estuarine/Marine Fate of Spill-type Accidents**

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# **ROBERTS BANK TERMINAL 2 TECHNICAL REPORT Quantitative Risk Assessment Component 2 – Estuarine/ Marine Fate of Spill-type Accidents**

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December 2014

## **Technical Report/Technical Data Report Disclaimer**

The Canadian Environmental Assessment Agency determined the scope of the proposed Roberts Bank Terminal 2 Project (RBT2 or the Project) and the scope of the assessment in the [Final Environmental Impact Statement Guidelines](#) (EISG) issued January 7, 2014. The scope of the Project includes the project components and physical activities to be considered in the environmental assessment. The scope of the assessment includes the factors to be considered and the scope of those factors. The Environmental Impact Statement (EIS) has been prepared in accordance with the scope of the Project and the scope of the assessment specified in the EISG. For each component of the natural or human environment considered in the EIS, the geographic scope of the assessment depends on the extent of potential effects.

At the time supporting technical studies were initiated in 2011, with the objective of ensuring adequate information would be available to inform the environmental assessment of the Project, neither the scope of the Project nor the scope of the assessment had been determined.

Therefore, the scope of supporting studies may include physical activities that are not included in the scope of the Project as determined by the Agency. Similarly, the scope of supporting studies may also include spatial areas that are not expected to be affected by the Project.

This out-of-scope information is included in the Technical Report (TR)/Technical Data Report (TDR) for each study, but may not be considered in the assessment of potential effects of the Project unless relevant for understanding the context of those effects or to assessing potential cumulative effects.

## EXECUTIVE SUMMARY

Port Metro Vancouver (PMV) retained RPS Applied Science Associates, Inc (RPS ASA) to conduct an assessment of the “Estuarine/Marine Fate of Spill-type Accidents” for the Roberts Bank Terminal 2 Project (RBT2), a proposed new three-berth marine terminal at Roberts Bank in Delta, B.C. The study herein was the second component of the Quantitative Risk Assessment (QRA), and was based on the spill incidence prediction results presented in the assessment titled “Marine Vessel Incidence Prediction Inputs to the Quantitative Risk Assessment” conducted by Herbert Engineering Corporation (Herbert Engineering Corp. et al. 2014). Due to the conclusions of the Component 1 Assessment that spill incidents were very improbable, and that maximum possible volumes spilled were relatively small, RPS ASA conducted a qualitative evaluation of the physical fate and transport of potential spill incidents associated with RBT2 vessel traffic and activities.

The major objectives of the study were to:

- (i) Review and characterise the general environmental conditions in the study area (e.g., wind and current circulation),
- (ii) Review and characterise chemical physical properties of the oil types considered and their fate when spilled in the marine environment, and
- (iii) Qualitatively evaluate the general transport and behaviour of possible spill events and identify the physical environmental compartment(s) (i.e., water column, water surface, shoreline) potentially vulnerable to spill events.

Herbert Engineering Corp. 2014 identified the “In Port” region of their study area to be the locality of highest spill probability (recognising that there is a low probability of occurrence overall). The “At berth” region discussed in this study encompasses vessel arrival and departure routes to the existing Roberts Bank terminals, including the area 1.5km seaward of the proposed RBT2 berth face within PMV jurisdiction. The “At-Berth” region was assumed to be the location of a hypothetical spill for a subsequent spill transport evaluation.

The physical chemical properties of the two oil types potentially released in a spill event, light fuel oil and heavy fuel oil, were reviewed and summarised. Light oils have a greater proportion of the lower molecular weight and more volatile fraction, making them more evaporative and also more soluble in the water column. Light fuel oil is more likely to break up into small droplets that become entrained in the water column due to wind and wave forcing, as compared to heavier fuel oils or crudes. Marine light fuels contain a substantial amount of lower-molecular-weight aromatics (e.g., BTEX and naphthalenes) that could be dissolved in the water column and cause toxicity and biological exposure. Overall, spilled light fuel oil is less persistent in the environment and dissipates faster than heavier oils. Heavy fuel oils are highly viscous and mostly insoluble. They have minimal fraction of volatiles, and hence are less dispersible in the water and may be more persistent in the environment at the water surface and

shorelines. Weathered heavy fuel oil may also become incorporated in near shore sediments in estuaries, where sufficiently high amounts of suspended particulate matters are present. The lighter fractions of heavy fuels may evaporate to the atmosphere or dissolve in water.

Potential releases of oil in the “At Berth” region in the spring would be heavily influenced by the Fraser River freshet and be transported with the strong surface currents to the southwest. A release in the summer through early fall would be less influenced by the Fraser River outflow and transport would become less southerly and more dependent upon wind direction. Winds out of the northwest would likely increase the chance of shoreline oiling near RBT2, Point Roberts, and the shorelines along the eastern side of the Strait of Georgia. Winds out of the southeast could potentially cause oiling along the shorelines of Galiano, Mayne, and Saturna Islands. Spills during the winter would likely be influenced by easterly to southeasterly winds and transport would be towards the western shoreline of the Strait of Georgia.

In general, some light fuel oil released in a potential spill could impact the shorelines due to the close confines of the southern Strait of Georgia. However, the bulk of the light oil should spread to its minimum thickness and evaporate within a few days. Turbulent conditions resulting in high entrainment of light fuel oil types may cause short-lived acute water column contamination, especially in shallower waters. The persistence of heavy fuel oil on the sea surface means it would likely travel further than light fuel oils resulting in more sea surface area affected and shoreline oiling. Water column contamination is less likely from heavy fuel oils; however, it is possible in very turbulent conditions.

The maximum credible discharge (MCD) volumes associated with container vessel traffic and activity associated with RBT2, as predicted by the Component 1 Assessment (Herbert Engineering Corp. et al. 2014), were relatively low (2,500 and 7,500 m<sup>3</sup>).

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## LIST OF ACRONYMS

ASTM	American Society for Testing and Materials (now ASTM International)
AWAC	Acoustic wave and current meter
BTEX	Benzene, toluene, ethylbenzene, and xylene
CLWB	Cold lake water blend
ERC	Environmental Research Consulting
HEC	Herbert Engineering Corporation
MAH	Monocyclic aromatic hydrocarbon
MCD	Maximum credible discharge
MDF	Marine diesel fuel
MDO	Marine diesel oil
MGO	Marine gas oil
IFO	Intermediate fuel oil
ISO	International Standardisation Organisation
PAH	Polycyclic aromatic hydrocarbon
QRA	Quantitative risk assessment
RBT2	Roberts Bank Terminal 2
RPS ASA	RPS Applied Science Associates, Inc.
SIMAP	Spill Impact Model Application Package

## GLOSSARY

<b>Adherence</b>	Entrained oil droplets combine with solid particles in the water column.
<b>Adsorption</b>	The process by which dissolved chemical components of oil adhere to suspended sediments without penetrating their internal structure.
<b>Advection</b>	Movement of oil with the flow of water caused by wind drift and currents.
<b>Aliphatic hydrocarbon</b>	Category of organic compounds in which carbon atoms form open chains, that includes alkanes, alkenes, and alkynes.
<b>Allision</b>	An event in which a moving object strikes a stationary object (e.g., a vessel hitting a pier or a moored vessel).
<b>API gravity</b>	A measure of how heavy or light a petroleum liquid is compared to water. If >10, it is lighter and floats on water; if <10, it is heavier and sinks. Mathematically, it is unitless but is referred to as being in 'degrees'.
<b>Aromatic hydrocarbon</b>	Category of organic compounds in which carbon atoms form planar ring systems, that includes benzene and toluene.
<b>Biodegradation</b>	The chemical dissolution (see <b>Dissolution</b> ) of materials by bacteria or other biological means.
<b>Bioturbation</b>	The disturbance of sedimentary deposits by living organisms.
<b>Brackish</b>	A slightly salty mixture of fresh river water and seawater in estuaries.
<b>Category 1 engine</b>	An engine that requires < 5 litres fuel per cylinder.
<b>Category 2 engine</b>	An engine that requires 5 to 30 litres fuel per cylinder.
<b>Category 3 engine</b>	An engine that requires ≥ 30 litres fuel per cylinder.
<b>Collision</b>	An event in which two moving objects strike each other (e.g., two vessels in transit or maneuvering striking each other).
<b>Cracking</b>	The process whereby complex organic molecules (heavy hydrocarbons) are broken down into simpler molecules (light hydrocarbons) by breaking carbon-carbon bonds.
<b>Crest</b>	The point on a wave with the maximum upward displacement (highest point) within a cycle.
<b>Diffusion</b>	The intermingling of substances by the natural movement of their particles.
<b>Dispersion</b>	The distribution of spilled oil into the water column by natural wave action or application of chemical dispersants.
<b>Dissolution</b>	The act or process of dissolving one substance in another.
<b>Distillation</b>	The act of purifying a liquid through heating and cooling.
<b>DMA</b>	Fuel grade; also called marine gas oil; general purpose marine distillate free from residual fuel traces used in Category 1 engines.
<b>DMB</b>	Fuel grade; also called marine diesel oil; can contain traces of residual fuel used in Category 2 and 3 engines.
<b>DMC</b>	Fuel grade; may contain residual fuel and is often a blend that can be used in Category 2 and 3 engines.
<b>DMX</b>	Fuel grade; special light distillate intended for use in emergency engines.
<b>Emulsification</b>	The process whereby one liquid is dispersed into another liquid in the form of small droplets. Water-in-oil emulsions can be referred to as 'mousse'.
<b>Entrainment</b>	The movement of one fluid by another.

<b>Environmental compartment</b>	Different sections of the environment including biota, air, water, land, and aquatic sediments.
<b>Evaporation</b>	The process whereby a substance is converted from a liquid state and becomes part of the surrounding atmosphere in the form of a vapor.
<b>Fetch</b>	The distance traveled by wind or waves across open water.
<b>Freshet</b>	The flood of a river from heavy rain or melting snow.
<b>Hard grounding</b>	A grounding occurring at higher speeds (e.g., at normal operating speeds) or on rocky shorelines likely to cause damage to more than one tank.
<b>Heavy fuel oils</b>	Examples include bunker fuel, residual fuel oil, and intermediate fuel oil comprised of residuals left over from distillation process.
<b>Lateral shear</b>	The pulling force of a fluid moving in one direction as it passes by a fluid or object moving in another direction due to the horizontal velocity gradient.
<b>Light fuel oils</b>	Examples include marine diesel and distillate-derived fuels.
<b>Maximum credible discharge</b>	The largest spill that has a probability of occurrence that is not minute based upon engineering judgment for the particular event being considered.
<b>Olefinic hydrocarbon</b>	Category of unsaturated organic compounds containing one or more pairs of carbon atoms linked by a double bond, such as alkenes.
<b>Percolation</b>	The process during which oil is carried into the spaces within shoreline sediments by receding waves and tides.
<b>Photolysis</b>	The decomposition or separation of molecules by the action of light.
<b>Photo-oxidation</b>	Sunlight-promoted chemical reaction between oxygen in the air and oil.
<b>Polycyclic</b>	An organic compound having several rings of atoms in the molecule.
<b>Pour point</b>	The pour point of a liquid is the temperature at which it becomes semi-solid and loses its flow characteristics.
<b>Rip</b>	A strong current.
<b>Soft grounding</b>	A grounding occurring at lower speeds (e.g., at maneuvering speeds in port) or on soft (sand, mud) shorelines likely to cause damage to no tanks or only one tank.
<b>Sedimentation</b>	The process by which oil compounds become incorporated into the sediment.
<b>Shoaling</b>	The creation of a shallow sandy elevation of the bottom of a body of water, constituting a hazard to navigation; a sandbar or sand bank.
<b>Significant wave height</b>	The mean wave height (trough to crest) of the third highest waves valid for the indicated period.
<b>Trough</b>	The point on a wave with the minimum upward displacement (lowest point) within a cycle.
<b>Turbulent dispersion</b>	is the mixing caused by “sub-scale” currents (not included in the current data), also known as turbulent eddies, that move oil and mix it both horizontally and vertically.
<b>Weathering</b>	The processes by which crude oil is broken down in the environment, includes spreading, evaporation, dispersion, emulsification, dissolution, oxidation, sedimentation, and biodegradation.

## 1.0 INTRODUCTION

### 1.1 PROJECT BACKGROUND

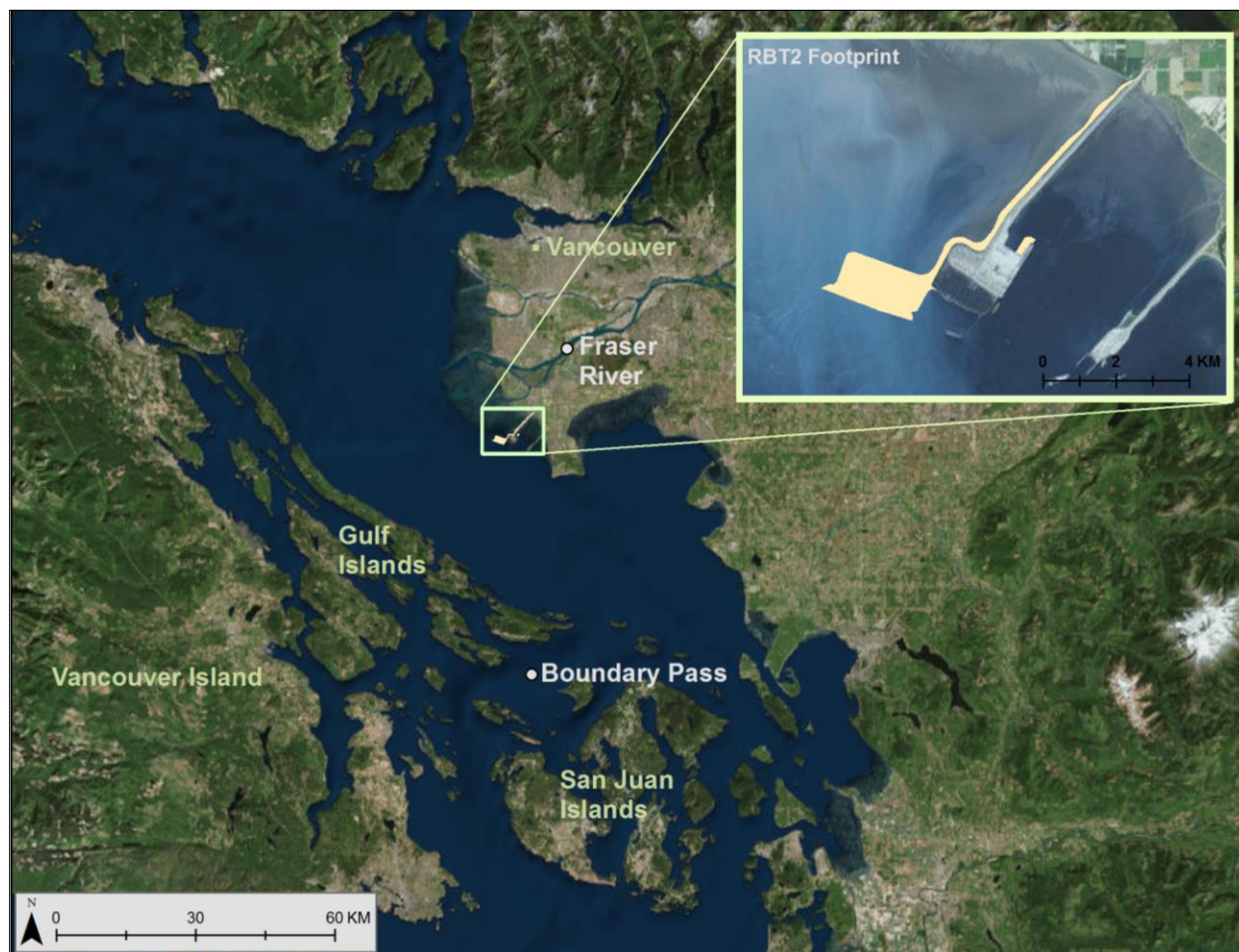
The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new three-berth marine terminal at Roberts Bank in Delta, B.C. that could provide 2.4 million TEUs (twenty-foot equivalent unit containers) of additional container capacity annually (**Figure 1-1** and **Figure 1-2**). The project is part of Port Metro Vancouver's Container Capacity Improvement Program, a long-term strategy to deliver projects to meet anticipated growth in demand for container capacity to 2030.

This technical report describes the results of the Quantitative Risk Assessment, Component 2 – Spill Assessment Study, subsequently referred to in this document as the “QRA Component 2 Spill Assessment”.

**Figure 1-1      Artist's Impression of Proposed RBT2**



**Figure 1-2 Roberts Bank Terminals Location and Proposed RBT2 Footprint**



## 1.2 QRA COMPONENT 2 SPILL ASSESSMENT OVERVIEW

Port Metro Vancouver retained RPS Applied Science Associates, Inc (RPS ASA) to conduct the QRA Component 2 Spill Assessment for RBT2. This study was the second component of the QRA, and was based on the spill incidence prediction results presented in the assessment titled “Marine Vessel Incidence Prediction Inputs to the Quantitative Risk Assessment” conducted by Herbert Engineering Corporation (HEC) with subcontractor Environmental Research Consulting (ERC) (Herbert Engineering Corp. et al. 2014).

Major outcomes of the Component 1 Assessment included:

- i. Serious incidents either under current operating conditions or in 2030 were predicted to be very improbable, generally with return periods of greater than 1,000 years to 100,000 years [i.e., it is predicted based on Roberts Bank-related ship movements, allied activities, and contemporary global incidence rates for groundings, **collisions** and **allisions** that an incidence has a probability of occur of less than 1 incidence in 1,000 years (for an internal ship fire or explosion that would be controlled prior to an environmental release) to 1 in 100,000 years (e.g., for a collision)];

- ii. The predicted incremental changes in serious incidents associated with additional container ship traffic as facilitated by completion of RBT2 is lower still; and
- iii. In the event of an incident, the maximum possible volumes released to the adjacent marine environment of products such as bunker fuel and marine diesel were relatively small (**Table 1-1**).

Due to the conclusions of the Component 1 Assessment, RPS ASA conducted a qualitative evaluation of the physical fates and transport of oil spills in the marine environment from potential marine accidents and malfunctions associated with container shipping traffic and activity associated with RBT2. The major objectives of the study were to:

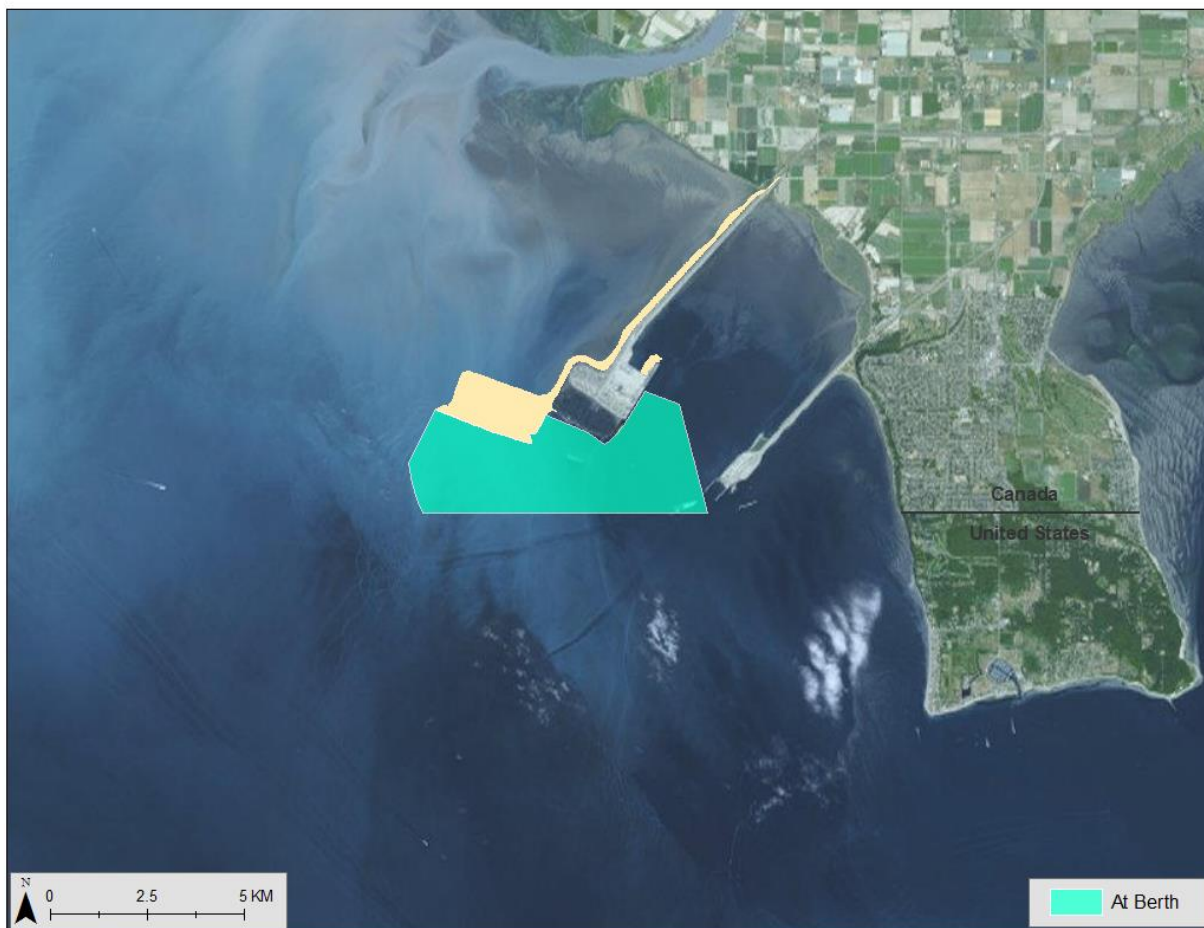
- i. Review the general environmental conditions that would affect the **weathering** and transport of spilled oil in the study area (water column structure, wind and current circulation, seasonal trends);
- ii. Provide a general characterisation for each oil type and review its important chemical properties and physical fate processes in the marine environment; and
- iii. Qualitatively evaluate the general transport and behaviour of possible spill events considering site specific environmental conditions, seasonality, and predicted oil types and quantities released, and identify the physical **environmental compartment(s)** (i.e., water column, water surface, and shoreline) potentially vulnerable to spill events.

The potential spill scenarios evaluated in this study were based on the locality of higher probability areas (recognising that there is a low probability of occurrence overall), spill volumes (**maximum credible discharge** (MCD)), oil types, and incident types as identified in the Component 1 Assessment. This study focuses on an area within PMV jurisdiction that encompasses vessel arrival and departure routes to the existing Roberts Bank terminals, including the area 1.5km seaward of the proposed RBT2 berth face (here after referred to as the “At Berth” region). The “At-Berth” region was assumed to be the location of a hypothetical spill for a subsequent spill transport evaluation (**Figure 1-3**).

The “At Berth” region of interest encompasses the generalised higher probability area where accidental releases may occur or originate. Spills originating from this region may travel outside of the delineated area.

It is important to note that the areas of higher probabilities of a collision, allision or grounding that may result in a spill may not be the higher environmental risk areas. Evaluations may also be suggested for geographic locations where a spill might affect at-risk species or sensitive and unique habitats, even if the local probability of an incidence is lower than for other portions of the “At Berth” region study area.

**Figure 1-3 “At Berth” Region of Interest for the Component 2 Spill Assessment**



The Component 1 Assessment stated that an MCD of 2,500 m<sup>3</sup> was associated with one fuel hold on a Post-Panamax container ship rupturing (Herbert Engineering Corp. et al. 2014). This spill volume could result from a collision, allision or **soft grounding** during activities in the “At Berth” region. A MCD of 7,500 m<sup>3</sup> represents up to 3 ruptured fuel tanks resulting from a **hard grounding** (Herbert Engineering Corp. et al. 2014).

Oil types evaluated included light (e.g., marine diesel) and **heavy fuel oils** (e.g., bunker fuel and intermediate fuel oil). These oil products were found to be the most common fuel types carried by container and other vessels associated with potential incidents involving container shipping traffic and activity associated with RBT2. Most ocean-going container ships carry both heavy and **light fuel oils** (Herbert Engineering Corp. et al. 2014). Currently, overall heavy fuel oil usage is higher as compared to light, and is burned while offshore. Typically most of the fuel on board a container vessel is a heavy fuel type. The remaining portion is a marine diesel or light fuel which is used when traveling in an environmentally regulated area to meet air quality standards. Ships that frequent environmentally

regulated areas more often will most likely carry more light fuel. It was projected in the Component 1 Assessment that, due to increasing international regulations aimed at reducing air pollution from ships in port areas, the proportion of diesel fuel to heavy fuel oil carried by a vessel is expected to increase in the future. Due to current and future trends in container ship fuel usage, spill incidents of both oil types (heavy and light) were assessed and assumed to be equal in probability of occurrence.

The potential spill scenario results from the incident prediction Component 1 Assessment are summarised in **Table 1-1**.

**Table 1-1 Oil Spill Incident Types as Identified in the Component 1 Assessment (Herbert Engineering Corp. et al. 2014)**

Oil Type	Assumed Discharge Quantity	Incident Type(s)	Probability of Spill Incident
Light (marine diesel)	2,500 m <sup>3</sup>	Collision, Allision or Soft Grounding	1200 year return period
Heavy (bunker fuel, residual fuel oil, intermediate fuel oil)	2,500 m <sup>3</sup>	Collision, Allision or Soft Grounding	1200 year return period

This report presents a review of the available literature and data on the marine environmental conditions of the study area (**Section 2.0**). A literature review of important physical and chemical properties and on the fate and weathering of both light and heavy fuel oils is presented in **Section 3.0**. The potential transport and fate of spilled substances was qualitatively evaluated for each oil type, season, and for releases originating from each region of interest, as summarised in **Section 4.0**. **Section 5.0** provides study conclusions and recommendations.

## 2.0 REVIEW OF AVAILABLE LITERATURE AND DATA ANALYSIS: ENVIRONMENTAL CONDITIONS

To predict and evaluate the potential fate and behaviour of oil releases in the “At Berth” region, it was necessary to establish a fundamental understanding of both the meteorological and oceanographic conditions. Wind and currents, especially in coastal areas, are the primary driving forces that dictate the transport of spilled pollutants. Currents that are wind, tidal, or density (freshwater discharge) driven can affect where spilled fuels or chemicals go and how long they may persist in the environment. In addition to transport, wind stress, wind/wave induced water mixing, and suspended sediment have major influence over fate processes such as **evaporation**, **entrainment**, **dissolution**, **emulsification** and **sedimentation**. Several fates processes are also dependent on the temperature and salinity in the water column.

The following sections present a review of existing published articles and technical reports addressing the environmental conditions (winds, currents, tides, waves, and water column structure) in the vicinity of the study area (**Figure 1-3**). In addition to review of literature, RPS ASA acquired publicly available data records (e.g., wind, tide, and wave) to determine the existing environmental conditions in the study area. Evaluating long-term records was essential for assessing general seasonal and annual trends used to qualitatively predict the general outcomes of spills (**Section 0**) occurring in the higher incident probability region (**Figure 1-3**).

### 2.1 GEOGRAPHIC LOCATION AND ENVIRONMENTAL DATA STATIONS

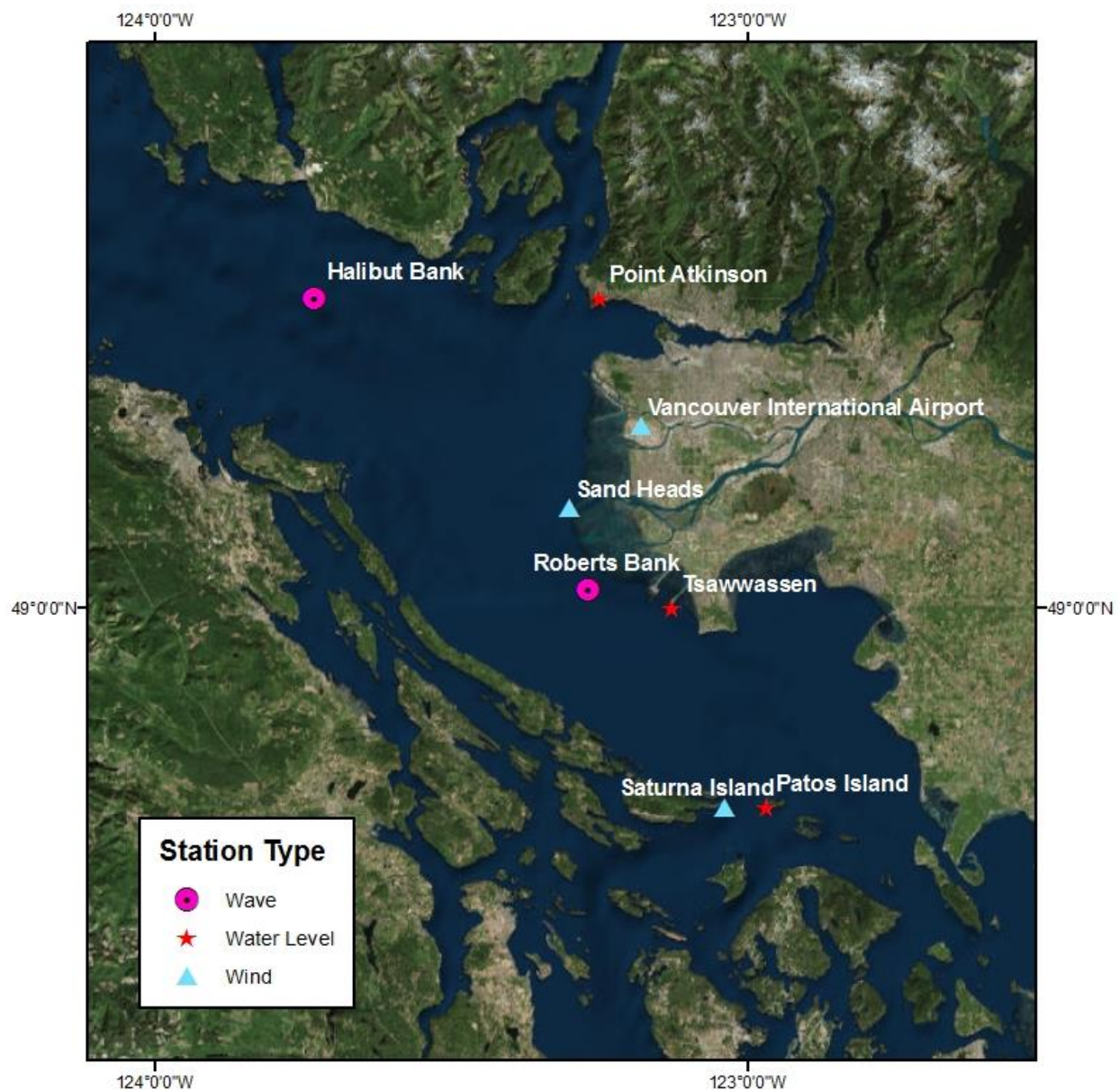
Roberts Bank is located on the eastern shore of the Strait of Georgia in Delta, B.C., south of Vancouver. The Strait of Georgia lies between the Coast Mountains of mainland B.C. to the east and Vancouver Island to the west. The Strait of Georgia is linked to the Pacific Ocean via several narrow, long channels at the northern end and via the Juan de Fuca Strait at the southern end. The eastern shore is characterised by deep and long fjords, while the western shoreline is less dynamic and contains several inlets. The Strait of Georgia is 222 km long and 28 km wide with an average depth of 155 m and maximum depths greater than 400 m in the central basin (Stronach 2006).

The Fraser River is the largest river in B.C. and the largest freshwater discharge into the Strait of Georgia. The main channel splits into several arms 35 km from the river mouth, with the southernmost arm discharging directly into the northern Roberts Bank tidal flats (Northwest Hydraulic Consultants 2014). The Fraser River estuary is an example of a river-dominated estuary, which means that the river deposits sediment at a deposition rate that overwhelms the rate of re-working and removal due to marine processes (Northwest Hydraulic Consultants 2014).

Data for the environmental conditions analysis were collected from several Environment Canada and National Oceanic and Atmospheric Administration stations in the study area (**Figure 2-1**). Long-term wind

data records were obtained from the Vancouver International Airport, Sand Heads and Saturna Island stations (**Table 2-1, Figure 2-1**). Wave data were obtained from Halibut Bank and Roberts Bank buoys (**Table 2-2, Figure 2-1**). Water level data were collected at the Point Atkinson, Tsawwassen, and Patos Island stations (**Table 2-3, Figure 2-1**).

**Figure 2-1**      **Locations of Stations from which Wave, Water Level, and Wind Data were Collected**



**Table 2-1 Wind Buoy Location and Time Period of Data Gathered and Analysed**

Wind Station	Station Number	Time Period	Location	Elevation (m)
Vancouver International Airport	1108447	Hourly; January 2012 to June 2013	49.20N, 123.18W	4.3
Sand Heads	1107010	Hourly; January 2012 to December 2013	49.11N, 123.30W	11
Saturna Islands	1017101	Hourly; January 2012 to December 2013	48.78N, 123.04W	24.4

**Table 2-2 Wave Buoy Location and Time Period of Data Gathered and Analysed**

Wave Station	Station Number	Time Period	Location
Halibut Bank	c46146	March 1992 to March 2014	49.34N, 123.73W
Roberts Bank	meds108	February 1974 to April 1976	49.02N, 123.27W

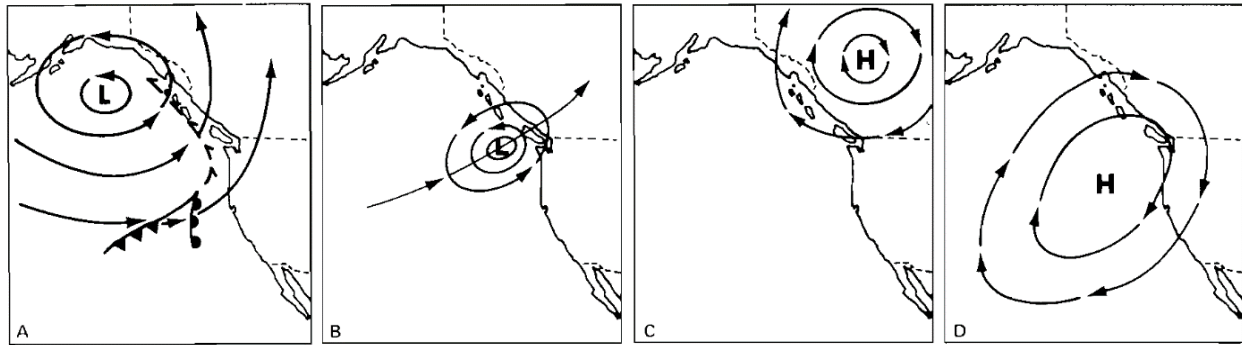
**Table 2-3 Water Level Station Location and Time Period of Data Gathered and Analysed**

Water Level Station	Station Number	Time Period	Location
Tsawwassen	7590	Hourly; September 1967 to December 1977	49.00N, 123.13W
Point Atkinson	7795	Hourly; January 2000 to December 2009	49.34N, 123.25W
Patos Island	7505	Hourly; December 1967 to May 1969	48.78N, 122.97W

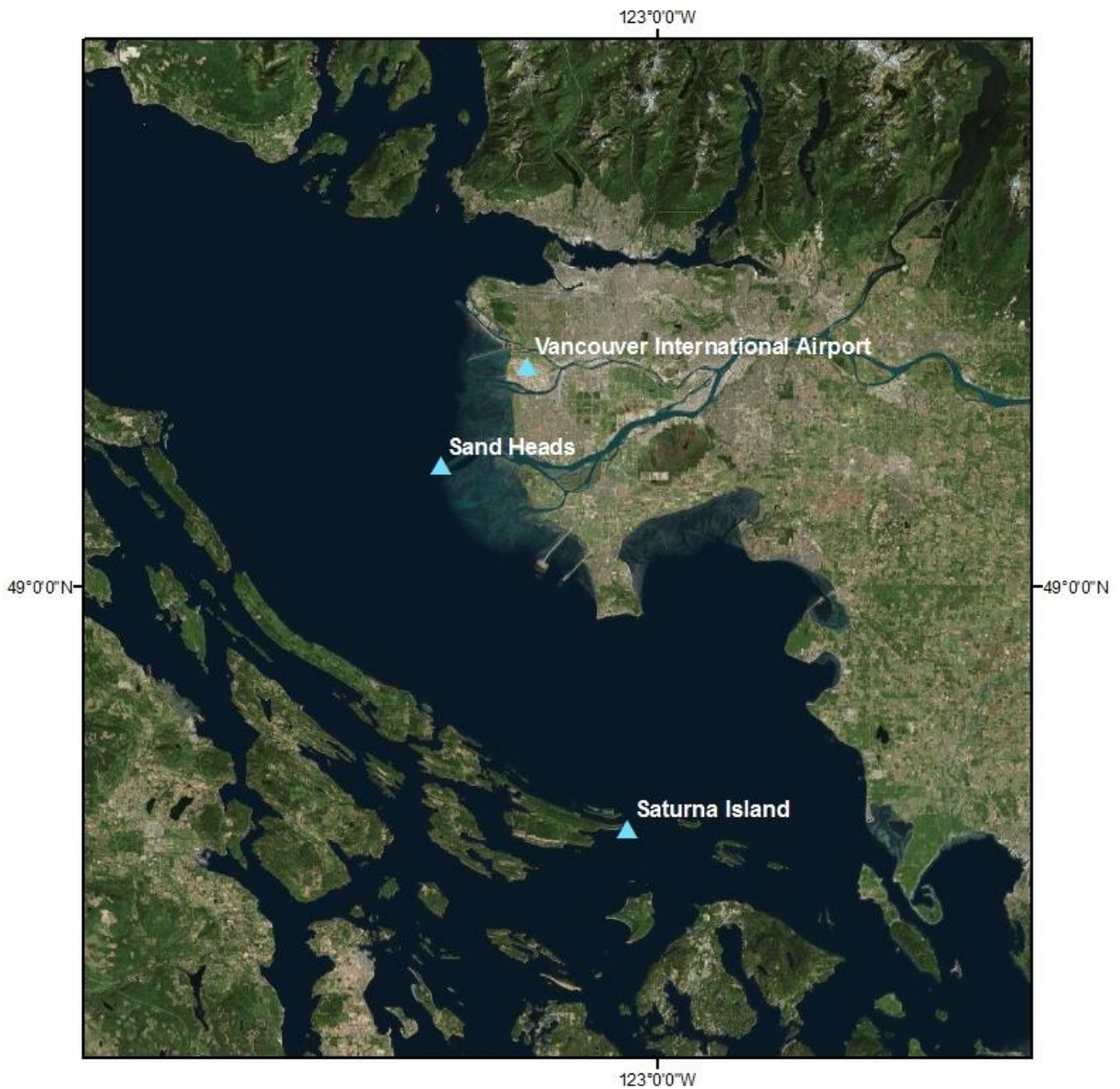
## 2.2 WINDS

The prevailing winds in the main channel of the Strait of Georgia are predominantly from the northwest in summer and from the southeast in winter (Davenne and Masson 2001). However, overall wind patterns in the Strait of Georgia are affected by the surrounding topography in the Juan de Fuca Strait, Puget Sound, and Fraser Valley. For example, southeasterly prevailing winds could become easterlies off the Fraser River (Davenne and Masson 2001). In general, easterly (seaward) winds are predominant in winter, while westerly (landward) winds are more frequent in summer (Cannon et al. 1978). The winter season (December to February) is dominated by cyclonic storms moving over the region that are typically associated with the anticyclone in southern Alaska (**Figure 2-2, Panel A**). Another common storm type (**Figure 2-2, Panel B**) with strong westerly components has disturbances that form in the central Pacific with an east-northeasterly trajectory and make landfall over Vancouver Island. Typically, an upper level ridge of high pressure will develop over northwest Canada in between low pressure systems (**Figure 2-2, Panel C**) and corresponds with easterly winds that increase in magnitude from east to west (Cannon et al. 1978). Summer is typically characterised by the offshore build-up of the eastern Pacific high pressure system (**Figure 2-2, Panel D**). These high pressure systems lead to a dry season with prevailing winds from the west to northwest (Cannon et al. 1978).

**Figure 2-2 Typical Storm Patterns Affecting the Northwest Coast (source: Cannon et al. 1978)**



**Figure 2-3 Locations of Wind Stations Analysed**



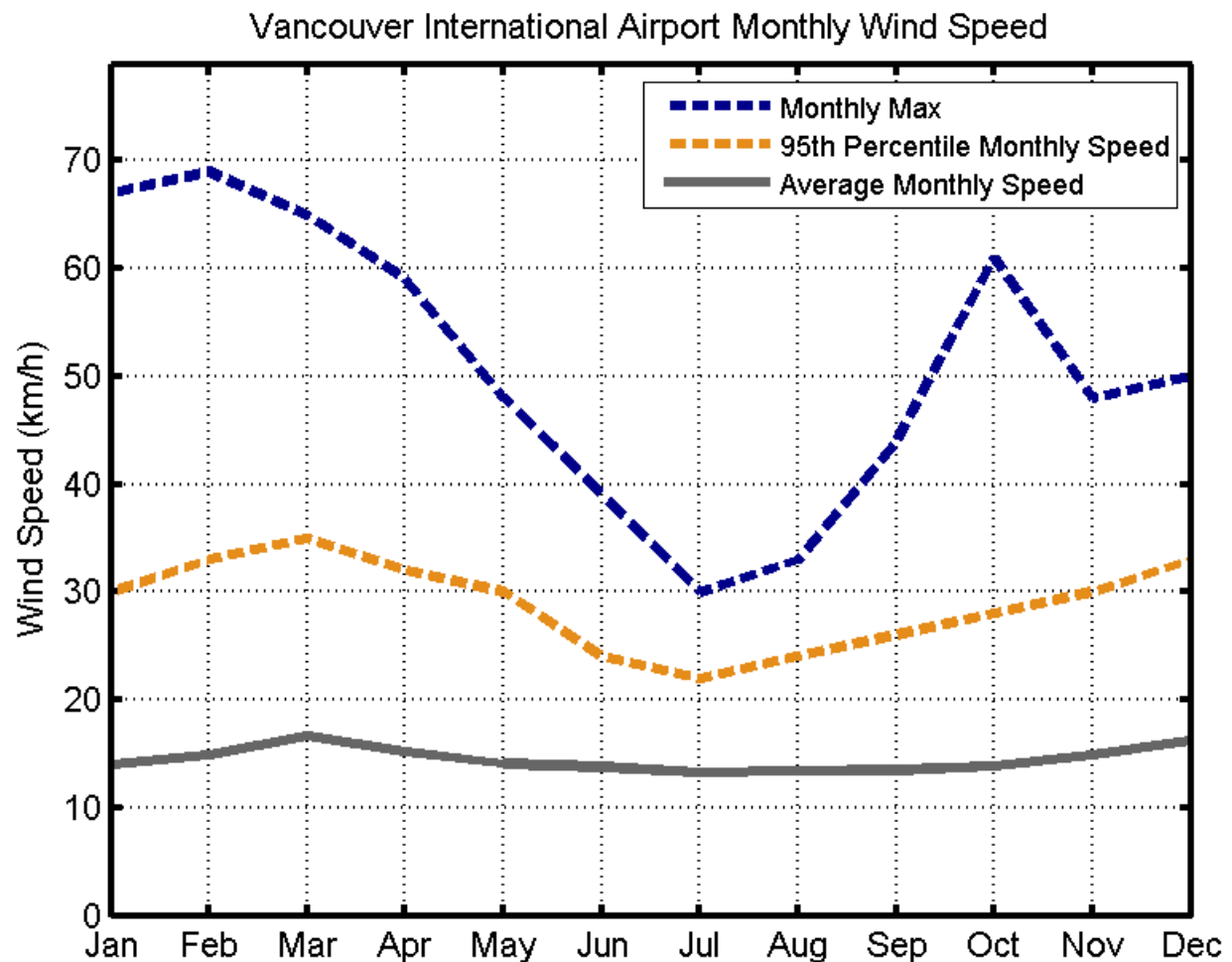
Based on data analysis from three wind stations (**Figure 2-3, Table 2-1**), winds are variable in both direction and magnitude throughout the year. Monthly wind speed statistics (average, maximum, and 95<sup>th</sup> percentiles) for 2012 and 2013 (average of both years) at Vancouver International Airport are provided in **Figure 2-4**. Monthly mean wind speeds were relatively consistent; ranging from 12 to 16 km/h. Maximum monthly speeds near 70 km/h occurred in February and subsequently decreased to a minimum near 30 km/h in July. Monthly wind direction and amplitudes are shown in **Figure 2-5**. Although, the predominant direction was from the east for the majority of the year, there was seasonality in the regime. From October through February, winds are primarily easterly with mean speeds of 15 km/h. From April through September, wind direction was primarily from the northwest and southeast.

Monthly wind speed statistics (average, maximum and 95<sup>th</sup> percentile) for 2012 and 2013 (average of both years) at the Sand Heads wind station, closest to the “At Berth” region, are provided in **Figure 2-6**. This site showed average monthly wind speeds from 15 to 22 km/h with peak speeds in March and minimum speeds in June. Wind speeds were weaker in the summer and autumn (late May to October) than in winter and spring. Monthly wind roses for years 2012 and 2013 (average of both years) at Sand Heads indicated some seasonality in the wind regime (**Figure 2-7**). The wind direction throughout the year was primarily from the northwest and southeast with an average speed of 10 knots (19 km/h). The strongest winds occurred in late autumn through spring (November to March with a peak monthly maximum of 42 knots (78 km/h)). Winds weakened during the summer and exhibited variable flow from both the northwest and southeast, though were predominantly southeasterly. Winds were from the southeast during December and began to have a northwesterly component again in late spring.

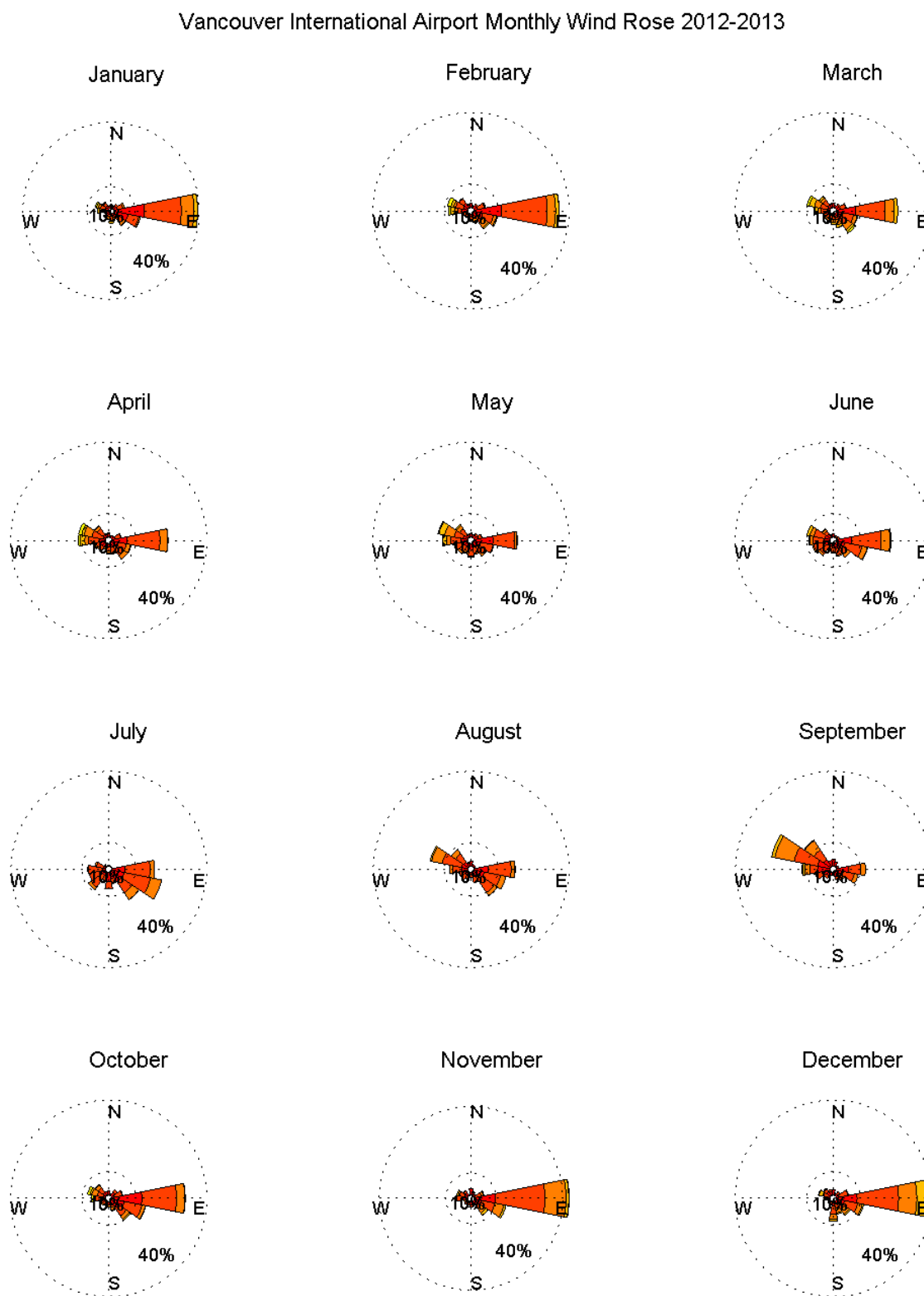
Monthly wind speed statistics were also compiled from data collected at Saturna Island wind station. Monthly wind speed statistics (average, maximum, and 95<sup>th</sup> percentile) for 2012 and 2013 (average of both years) are provided in **Figure 2-8**. The wind speed patterns were similar to those at the Sand Heads station where May through October had slower speeds (11 to 14 km/h) and November through March exhibited faster wind speeds (16 to 22 km/h). The average monthly wind speed was highest (over 20 km/h) in December, while the minimum monthly wind speed occurred in May (12 km/h). Monthly wind roses for years 2012 and 2013 (average of both years) for Saturna Island showed that wind direction throughout the year was primarily from the southwest with a yearly mean speed of 8 knots (15 km/h) (**Figure 2-9**). The strongest winds occurred in late autumn with a peak maximum of 48 knots (89 km/h) in December. During winter, winds had an easterly flow and were more variable.

For each of the three weather stations winds less than 30 km/h were removed from the analysis in order to gain a better understanding of the stronger winds occurring in the region. Vancouver International Airport winds were primarily from the west-northwest, while at Sand Heads winds were primarily northwesterly and southerly, and Saturna Island showed predominantly southerly winds. Plots showing yearly wind speed and direction >30 km/h at each station are presented in **Appendix A**.

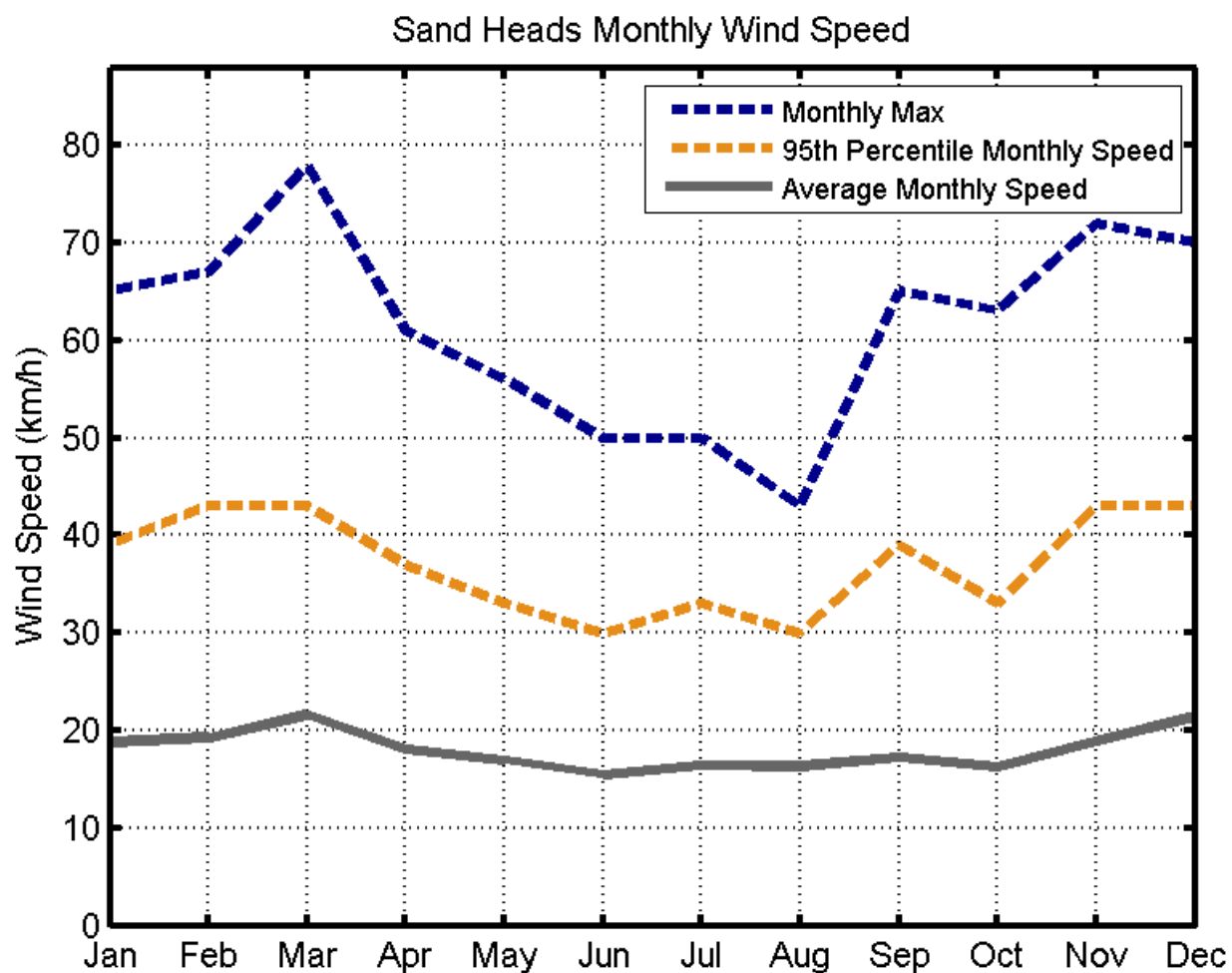
**Figure 2-4 Wind Station Speed Statistics: Average Monthly Speed, 95th Percentile, and Monthly Maximum Wind Speeds at Vancouver International Airport wind station for 2012 and 2013 (average of both years)**



**Figure 2-5 Monthly Wind Roses at Vancouver International Airport for 2012 and 2013 (average of both years). Wind Direction is in the Traditional Convention (coming from). Units are in km/h**



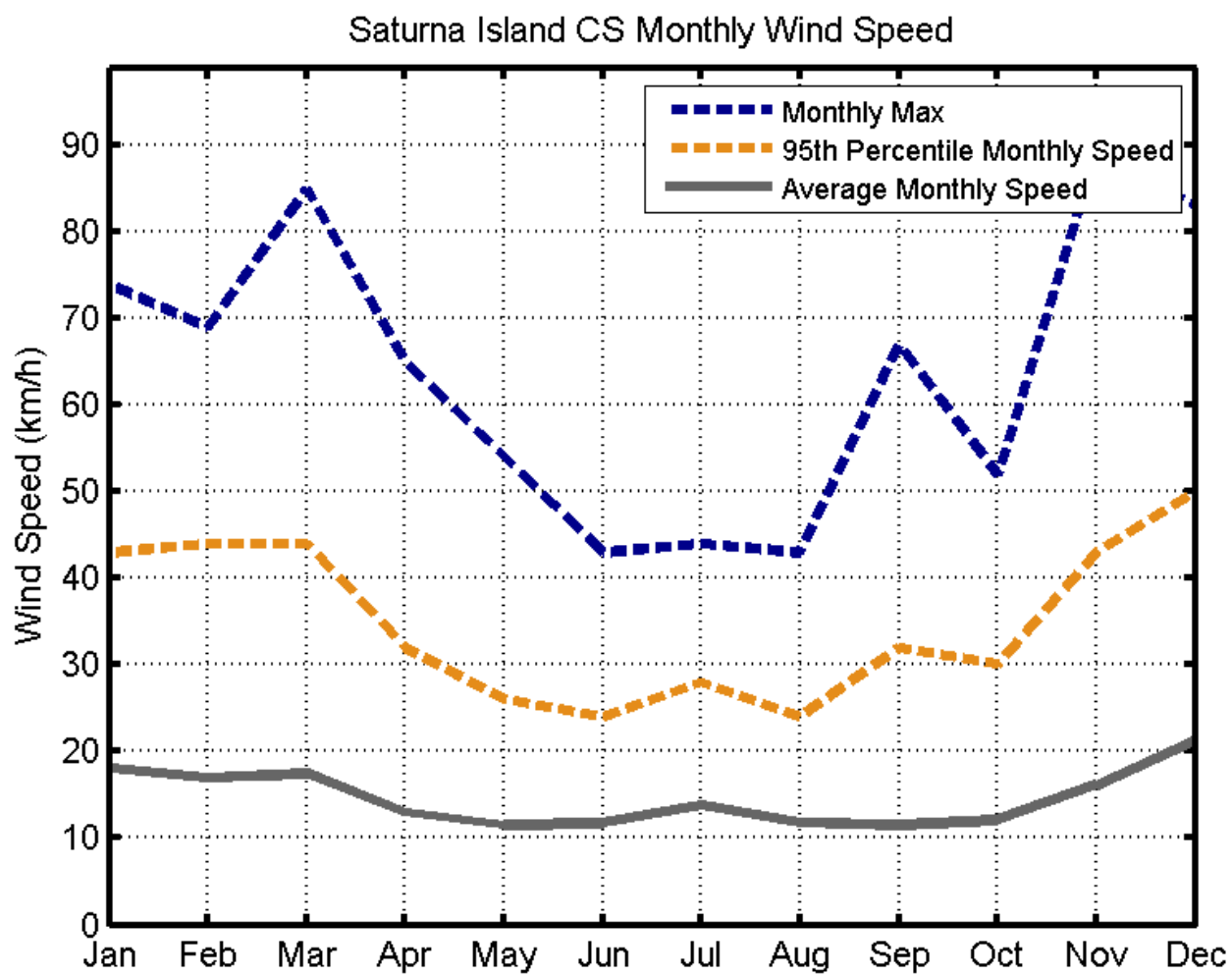
**Figure 2-6 Wind Station Speed Statistics: Average Monthly Speed, 95th Percentile, and Monthly Maximum Wind Speeds at Sand Heads Wind Station for 2012 and 2013 (average of both years)**



**Figure 2-7 Monthly Wind Roses at Sand Heads for 2012 and 2013 (average of both years). Wind Direction is in the Traditional Convention (coming from). Units are in km/h**

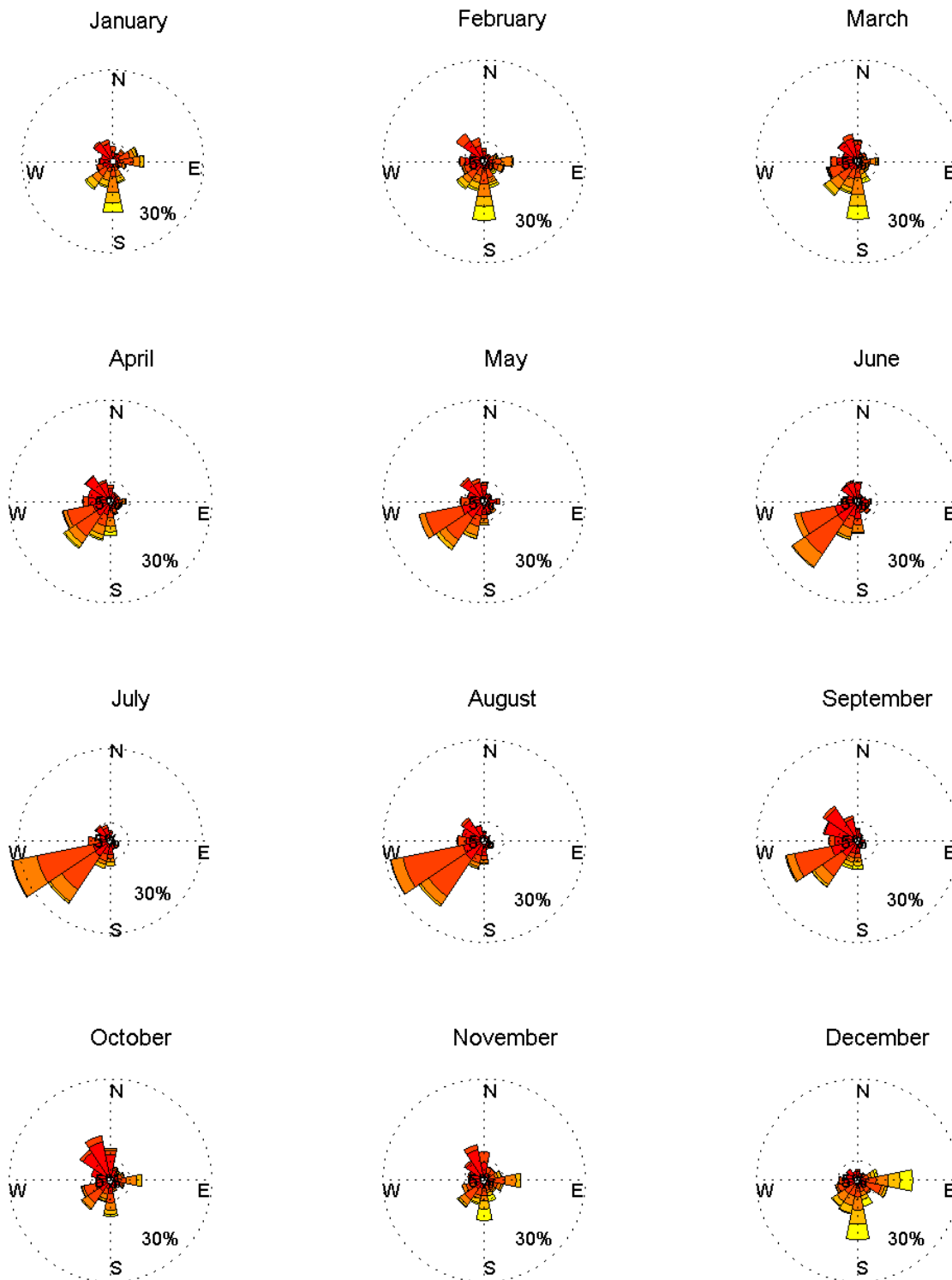


**Figure 2-8 Wind Station Speed Statistics: Average Monthly Speed, 95th Percentile, and Monthly Maximum Wind Speeds at Saturna Island Wind Station for 2012 and 2013 (average of both years)**



**Figure 2-9 Monthly Wind Roses at Saturna Island for 2012 and 2013 (average of both years). Wind Direction is in the Traditional Convention (coming from). Units are in km/h**

Saturna Island CS Monthly Wind Rose 2012-2013



## 2.3 PHYSICAL OCEANOGRAPHY OF THE REGION

### 2.3.1 Circulation and Currents

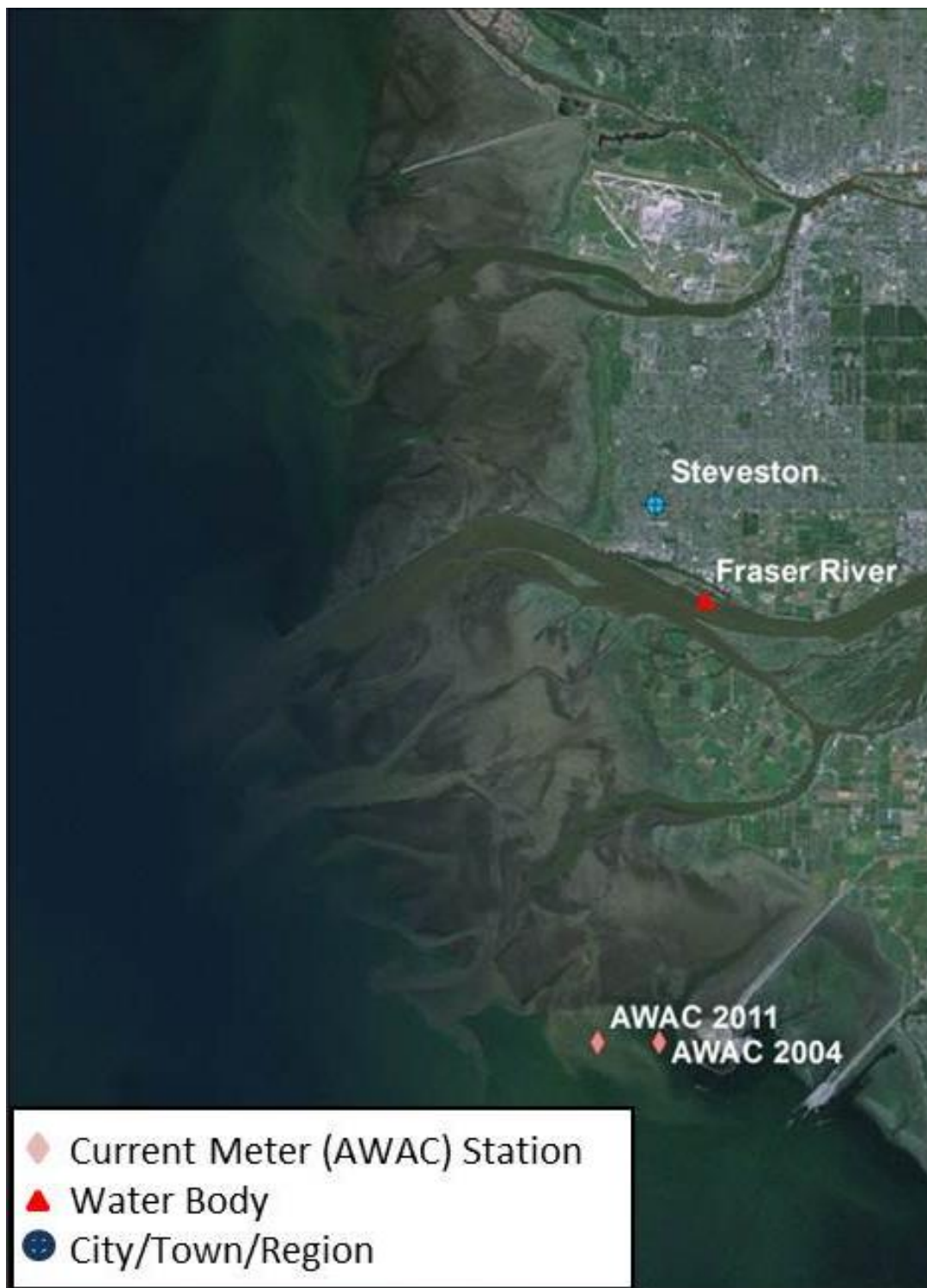
The marine environment of the Strait of Georgia is influenced by several dominant physical characteristics, such as wind, tidal currents and freshwater discharge. The northern basin of the Strait of Georgia exhibits a mean anticlockwise circulation, driven largely by the winds from the northwest. The mean currents in the southern part of the Strait of Georgia are influenced by both the wind and buoyancy flux of freshwater input, with currents circulating in a clockwise direction (Victoria Experimental Network Under the Sea 2014). The mean currents are slow (0.1 to 0.2 m/s) with stronger, mainly semi-diurnal tides superimposed upon them. The flood tides, entering primarily from the south (Boundary Pass), drive currents northward, while ebb tides drive currents southward (Victoria Experimental Network Under the Sea 2014). On the shallower eastern side of the Strait of Georgia, surface waters show a weaker mean current flowing northwestward with a well-mixed water column (Cannon et al. 1978).

The Fraser River is the largest freshwater discharge into the Strait of Georgia which flows approximately perpendicular to the direction of tidal currents and winds in the Strait of Georgia. Consequently, the wave field in the vicinity of the river mouth is changed considerably due to wave-current interactions. The largest discharge occurs in the beginning of summer (May to June), and minimum discharge occurs during winter (December to March) (**Figure 2-11**). During the **freshet** period of river flood due to heavy rain or melted snow (May to June), the river discharges as a “jet” near Steveston (located near the mouth of the Fraser River) and causes the current to flow in a south-westward direction. Currents near the river mouth can reach 2.5 m/s during freshet conditions and low tides, and average 1 m/s during mean tide conditions (Northwest Hydraulic Consultants 2014).

The mean flow during late winter and early spring on the western side of the Strait of Georgia is predominantly driven by the Fraser River discharge (Cannon et al. 1978). The discharge is strong enough to cross the Strait and flows along the western side in a southeast direction. North of the Boundary Pass (between Saturna and Patos Islands), bathymetry causes a portion of the less saline surface waters to bifurcate, where one portion flows east-southeastward along the San Juan Archipelago and the remainder flows seaward through Boundary Pass and the Haro Strait. On the eastern side of the Strait of Georgia, winds play a dominant role in circulation. Cannon et al. (1978) found that 71% of the variation in the current velocity could be accounted by the wind field when winds exceeded 10 m/s. The western side of the Strait of Georgia is influenced by strong estuarine flow, thus reducing the relative impact of the winds on circulation.

Two Acoustic Wave and Current Meter (AWAC) data collection devices were deployed near the project area during 2004 and 2011 (**Figure 2-10**) (WorleyParsons Canada 2011). **Table 2-4** lists the site location, time and currents data collected during these periods. The maximum flood current between March 2004 and March 2005 was 2.5 knots (1.3 m/s) west-northwestward, and a maximum ebb current southward at 1.8 knots (0.9 m/s). From January to March 2011, the maximum flood current was westward at 1.9 knots (1.0 m/s), and maximum ebb current southward at 1.5 knots (0.8 m/s).

**Figure 2-10** Site Locations of AWAC Instruments (Pink Diamonds) deployed by WorleyParsons Canada (2011) and General Area near Steveston where Fraser River Discharges forms a “Jet” during the Summer Freshet



**Table 2-4 Measured Maximum Tidal Currents from WorleyParsons Canada (2011)**

Device Identifier	Location	Depth	Time Period	Max Flood Current-Direction (deg) and Speed (knots)	Max Ebb Current-Direction (deg) and Speed (knots)
AWAC 2004	49.02 N, 123.18 W	7 m	3/13/2004- to 3/14/2005	290°, 2.5 knots	170°, 1.8 knots
AWAC 2011	49.02 N, 123.20 W	16 m	1/18/2011 to 3/7/2011	270°, 1.9 knots	90°, 1.5 knots

Where the Fraser River plume meets the saline water, there is an abrupt change marked by a visible edge between the river water and darker sea water (**Figure 2-12**). The water masses separated by this frontal surface also have differing velocities, thus where the surface velocities are convergent, there is downward movement at the front (Cannon et al. 1978). Baker et al. (1978) studied the Fraser River plume using remotely-sensed LANDSAT images from 1972 to 1977. They found that during summer the southward flows of the Fraser River were so strong that the resultant plume maintained its identity for a considerable distance and, in some instances, traversed the length of the Strait of Georgia. The plume extended southeast or southwest from the mouth of the river, depending on the changes in tidal currents. The tidal effects on the **dispersion** of the river plume were also studied using satellite images. Results indicated that during the ebb tide, distinct sediment plumes originating from the main arm flowed to the southwest and were then diverted to the southeast by the ebb flow in the Strait of Georgia.

**Figure 2-11 Seasonal Variation of the Fraser River Discharge in 2000 (source: Davenne and Masson 2001)**


**Figure 2-12 LANDSAT Image of the Strait of Georgia Illustrating the Extent of the Fraser River Plume during a Summer Ebbing Tide in 1999 (source: Northwest Hydraulic Consultants 2014)**

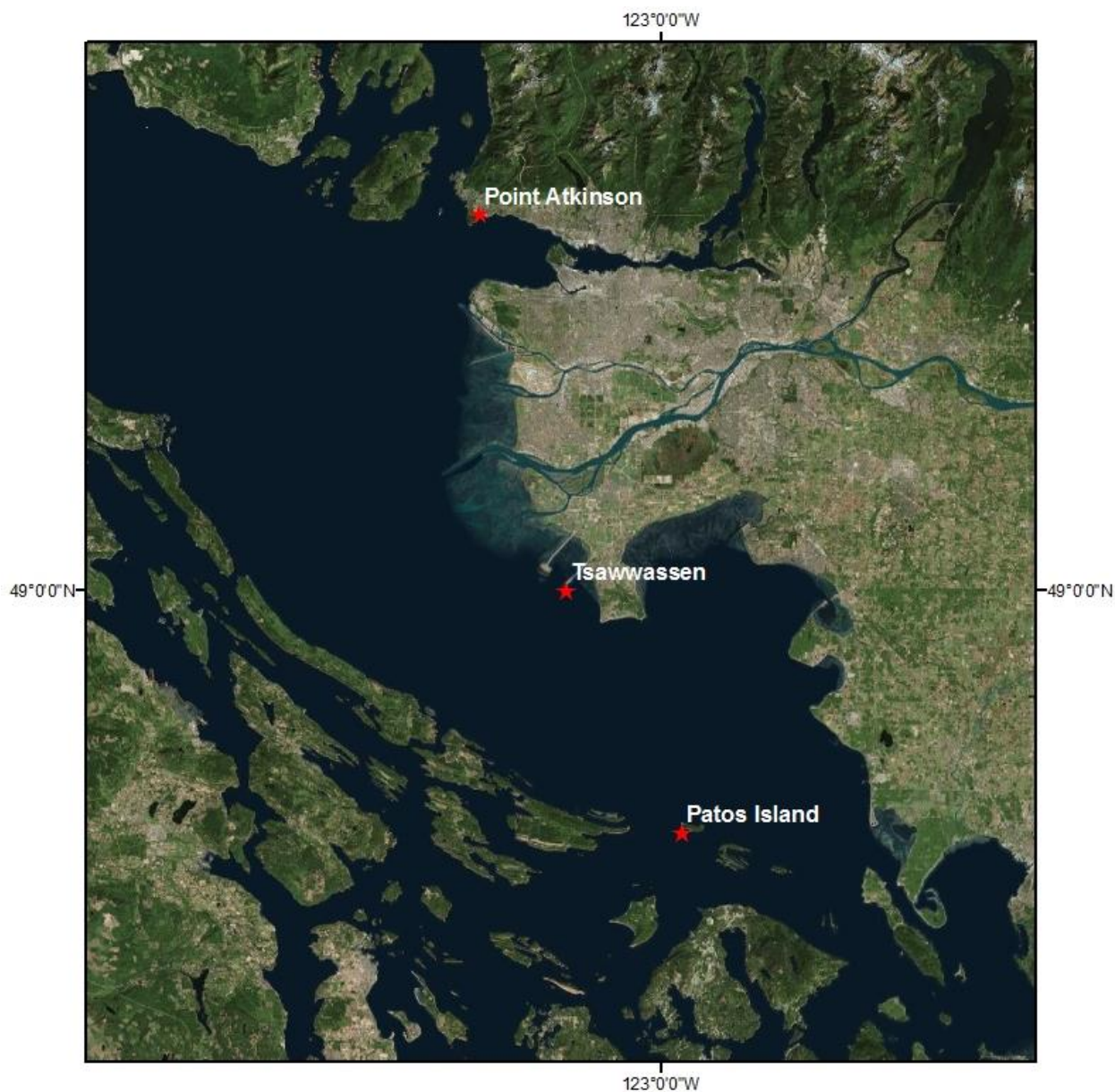


### 2.3.2 Tides

Tides in the Strait of Georgia are primarily driven by forcing and resonance with the tide cycles of the Pacific Ocean, which are mixed but mainly semi-diurnal (Northwest Hydraulic Consultants 2014). Except in passes and narrows, the tidal streams in the Strait of Georgia are typically weak, with the more dominant circulation forces being wind-generated currents, river runoff, and internal tidal effects (Stronach 2006). A mixed tidal system, diurnal and semi-diurnal, exists around the area of interest. The main direction of the inflow is towards the northwest, more or less parallel to the coast, with speeds of 75 to 130 cm/s attained during spring tides (Davenne and Masson 2001). The Fraser River freshwater input induces a flow of surface water towards the west in the Juan de Fuca Strait and towards the southeast in the Strait of Georgia, causing a weaker, reverse current in deep water (Davenne and Masson 2001). The resulting westward near-surface current in the Juan de Fuca Strait has typical speeds of 10 to 20 cm/s, but during summer can reach speeds of 40 cm/s concentrated in the middle of the channel. In deep water, the reverse current flows toward the east, predominantly on the sides of the channel, with slower

speeds around 10 cm/s (Davenne and Masson 2001). In the central Strait of Georgia, the tidal stream is predominantly northwest to north during the flooding tide, and south to southeast during the ebbing tide (Northwest Hydraulic Consultants 2014). Typically, the maximum flood velocity occurs 2 to 4 hours before high water, while the maximum ebb velocity occurs 2 to 4 hours before low water (Northwest Hydraulic Consultants 2014). Speeds of offshore currents generally reach 60 cm/s during flooding and ebbing conditions. Cannon et al. (1978) found the ebb current to be stronger with increased **lateral shear**. The water levels from several stations were obtained from Environmental Canada to examine tidal currents around the study area (**Table 2-3, Figure 2-13**).

**Figure 2-13 Water Level Station Locations Used in Analysis**



The tidal ranges at the Pt. Atkinson station are four to five metres and vary seasonally. The largest difference in sea water height occurs typically during the summer and winter months. The two high tides are more pronounced from September to December, with the height difference increasing. During January to March and June to August, a single high and low tide is more noticeable.

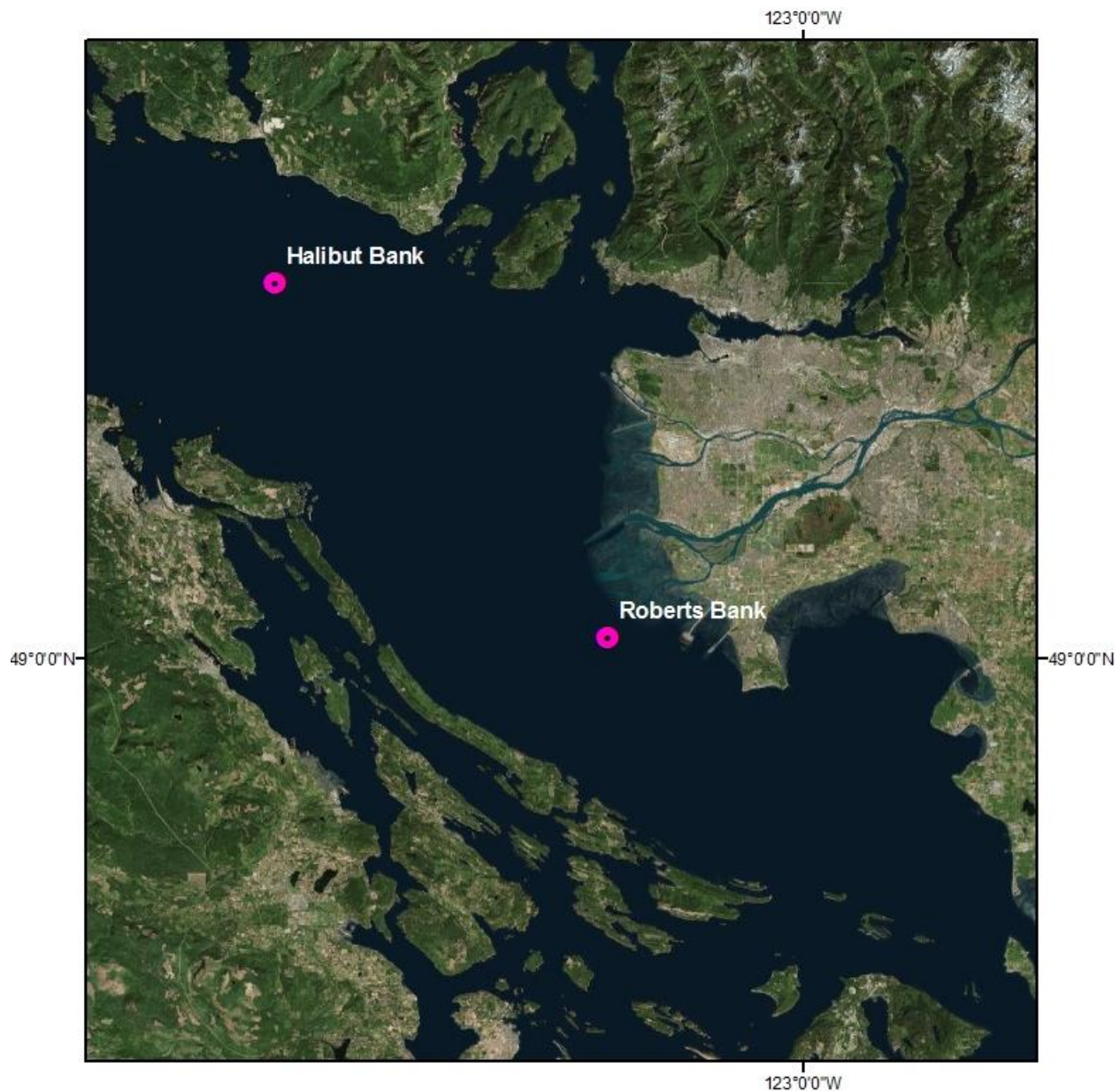
The Tsawwassen water station located closest to the existing Roberts Bank terminals station had historic data available from 1967 to 1977 only. The tidal range is 4 m with larger changes in the summer and winter months, a pattern consistent with the Pt. Atkinson station. The daily tides show a different pattern at the Tsawwassen station as compared with the Pt. Atkinson station. There is a more noticeable semi-diurnal tide throughout the year, with May showing the largest difference. To look at tidal ranges in the Boundary Pass area, data were also obtained from the Patos Island station. Similar to the Tsawwassen Station, the data is older but covered a shorter time frame (1968 to early 1969). The daily and monthly tidal ranges are very similar in magnitude and pattern to the Tsawwassen station. Figures of water level plots from each station are in **Appendix A** of this report.

### 2.3.3 Waves

The wave heights in the Strait of Georgia are more limited by **fetch** than by wind strength and duration. There was a program north of Roberts Bank in Burrard Inlet to gather wave statistics for the area near Point Atkinson (Stronach 2006). **Significant wave height** is traditionally defined as the mean wave height (**trough to crest**) of the third highest waves valid for the indicated period. Significant wave heights and trends have been evaluated in the study area. Significant wave heights greater than 2 m are typically indicative of turbulent or storm-like conditions. During 26 months of observations, the significant wave height never exceeded 2.1 m off Roberts Bank, while maximum wave heights were between 3.3 m and 4.0 m. The majority of the waves in the open Strait of Georgia off the Fraser River had periods in the range of 2 to 4 s (Thompson 1981). Previous studies have found that the largest offshore waves were generated by winds from the southeast, south, and northwest directions, with the majority from the southeast (Northwest Hydraulic Consultants 2014). The highest and steepest waves in the Strait of Georgia occurred where strong currents opposed waves generated by gale force winds over long fetches. One such **rip** occurred seaward of Steveston Jetty and North Arm Jetty off the Fraser River during west to northwest gales. In addition, extremely dangerous rips were created during the summer freshet or near low tide when river currents could reach 2.5 m/s in the main channel. **Shoaling** further amplified wave heights near the river mouth, creating rougher conditions than in adjacent waters (Thompson 1981).

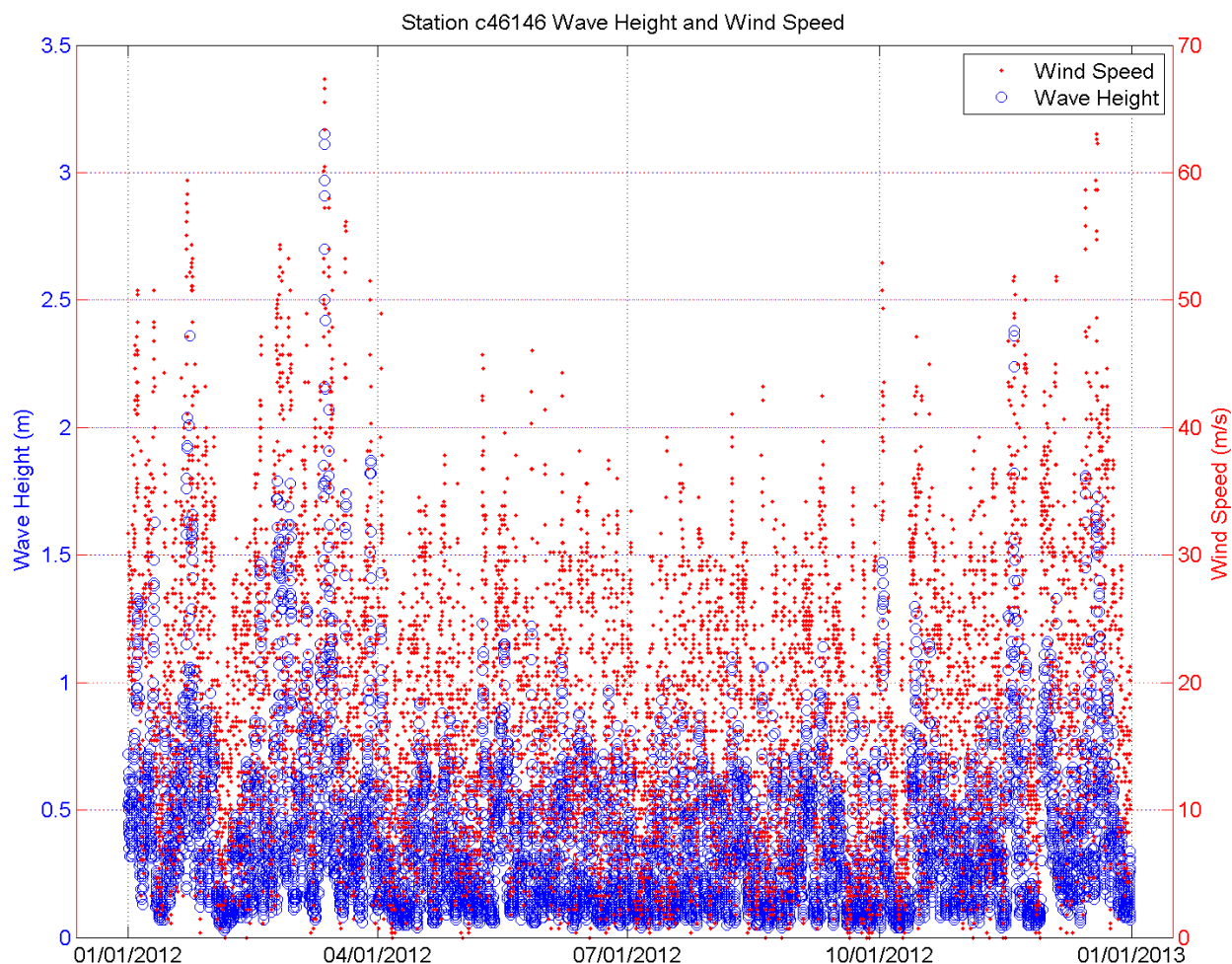
Significant wave height data from Halibut Bank and Roberts Bank (buoys c46146 and meds108, respectively), were obtained for analysis (**Table 2-2, Figure 2-14**).

**Figure 2-14 Wave Data Locations Used in Analysis**



Data available for February 1974 to April 1976 from the Roberts Bank buoy was used in this analysis. Time series of wind and wave from Halibut Bank (**Figure 2-15**) were plotted for 2012. In general, wave height and wind speed correlated, with higher wind speeds resulting in larger wave heights. Wind speeds were higher during winter and early spring at this station.

**Figure 2-15 Wind Speed and Wave Height at Halibut Bank, 2012**



The most frequent significant wave heights fall in the 0.1 m to 0.3 m bin for all stations (**Table 2-5**). Significant wave height is defined as the mean wave height (trough to crest) of the third highest waves valid for the indicated period. Halibut Bank had a higher maximum wave height, with significant wave heights recorded over 5 m. For Halibut Bank, over 79 percent of significant wave heights fell between 0 and 0.5 m, with percentages decreasing as heights increase. The same trend was seen at Roberts Bank, with over 79 percent of significant wave heights in the 0 to 0.5 m range. The maximum heights were 2.2 m at Roberts Bank and 5.0 m at Halibut Bank. Both stations had mean heights slightly over 0.3 m.

In order to look at more substantial wave events, significant wave heights equal to or exceeding 2 m during the time period were evaluated. From 1992 to 2014, there were 169 instances of wave heights exceeding 2 m at Halibut Bank and only one instance recorded at Roberts Bank. For Halibut Bank, the most common time for higher wave height was during late fall and winter, with the highest frequency of events recorded in December. No wave heights over 2 m occurred during May through August.

Conversely, Roberts Bank only showed one instance of recorded wave heights over 2 m in its older and shorter dataset. This wave event occurred during May and its duration was less than 1 hour. When data were analysed with events lesser than 2 hours duration removed, only 34 significant events at Halibut Bank and none at Roberts Bank remained. Additional figures (**Figure A-17** through **Figure A-19**) showing wave height distribution and monthly frequency of significant wave heights for each station are provided in **Appendix A**.

**Table 2-5 Significant Wave Height Distribution for Halibuts Bank (1992 to 2014)**

Halibut Bank, Hourly data 1992 to 2014 (0.5 m bins)	Percentages	# of Occurrences in Bin
0 to 0.5	79.4	130395
0.5 to 1	17.7	29065
1 to 1.5	2.5	4075
1.5 to 2	0.4	622
2 to 2.5	0.1	121
2.5 to >5	<0.1	42

**Table 2-6 Significant Wave Height Distribution for Roberts Bank (1974 to 1976)**

Roberts Bank, Hourly data 1974 to 1976 (0.25 m bins)	Percentages	# of Occurrences in Bin
0 to 0.25	53.0	2171
0.25 to 0.5	26.7	1094
0.5 to 0.75	11.3	462
0.75 to 1	5.4	219
1 to 1.25	2.2	88
1.25 to 1.5	1.1	45
1.5 to 1.75	0.3	11
1.75 to 2	0.1	3
>2	<0.1	1

### 2.3.4 Water Column Structure

The temperature and salinity in the Strait of Georgia are primarily governed by the Fraser River and other freshwater inputs as well as oceanic water from the Pacific. The Fraser River also dominates surface circulation, particularly in the summer months. From December to April, there is typically low river discharge and frequent strong wind mixing, which results in the salinity of the upper layer increasing with depth from 27 or 28 ppt to 29.5 ppt near 50 m depth. The Fraser River freshet in late May creates a layer of **brackish** water with salinity less than 15 ppt in the top few metres in most of the central and southern

Strait of Georgia (Stronach 2006). Surface temperatures warm from 5 or 6°C during winter to 15°C in May. The increased stability created by the brackish layer which forms during the freshet allowed further warming so that water temperatures in the Strait of Georgia can exceed 20°C in July. By the end of summer, the Fraser River runoff decreases and subsequently, the salinity values increase again. As the Fraser River plume spreads predominantly to the north, it mixes with the adjacent underlying water which forms an intermediate layer. This layer shows preferential seaward movement which carries water of intermediate salinity (~29 ppt or less) south. This flow opposes the saline inflow from Juan de Fuca, thus causing a salinity maximum in the lower waters in July (Crean et al. 1988).

Water temperature data was analysed for the Halibut Bank wave buoy (c46146). There was an evident seasonal trend in water temperature from 1992 to 2014 at Halibut Bank. Temperatures reached a maximum from July to August at over 20°C, and were at a minimum of 5°C from December to January. Temperatures increased in March and decreased in September.

### 3.0 REVIEW OF AVAILABLE LITERATURE: PROPERTIES AND FATE OF SPILLED SUBSTANCES

#### 3.1 OILS

The oil types that might be spilled in the study area depend on the type of oil being transported and used as a ship fuel. Fuel oils are the most common spills in marine environments due to their frequent transportation as cargo and their widespread use as fuels in marine diesel engines. In the maritime industries, fuel oils are generally classified as “light oil” and “heavy oil” according to their densities. The light oils in marine systems commonly include marine gas oil (MGO) or marine diesel oil (MDO). MGO is a high-quality distillate diesel fuel that contains no residual oil blending components--roughly equivalent to No. 2 fuel oil, and is made from distillate only (**Table 3-1**). MDO is a blend of gas oil and residual oil, but still has relatively low kinematic viscosity ( $\leq 12$  cSt or  $\text{mm}^2/\text{s}$  at  $40^\circ\text{C}$ ), so it can be used in the internal combustion engine without the pre-heating required for pumping and handling purposes. The heavy oils most commonly used in maritime industry are intermediate fuel oil 180 (IFO180) and 380 (IFO 380), names referring to their permissible maximum viscosities of 180 and 380 cSt at  $50^\circ\text{C}$ , respectively. The nomenclature system of “bunker fuel” has been commonly used in the maritime industry. In this naming system, Bunker A is generally equivalent to No. 2 fuel oil and Bunker B is synonymous with No.4 fuel oil. Both Bunker A and B are “light” oil. Bunker C is essentially No. 6 “heavy” fuel oil.

**Table 3-1 Common Diesel Fuel Types for Commercial Marine Use**

Fuel type	Fuel grades	Other Common Industry Names
Light (Distillate-derived)	DMX, DMA, DMB, DMC	Gas Oil (GO) or Marine Gas Oil (MGO)
Heavy (Comprised substantially of residuals left from distillation process)	IFO 180, IFO 380	Marine Diesel Fuel (MDF) or Intermediate Fuel Oil (IFO)

Most of the transported oil in the marine waters surrounding RBT2 would be refined petroleum products (Herbert Engineering Corp. et al. 2014), which may include jet fuel, diesel, and heavy fuel oil. Oil used as fuel for vessels will vary from diesel fuel to heavy fuel oil (Bunker C or intermediate fuel oil IFO) and smaller recreational vessels may run on gasoline. In general, heavy fuel oil usage in the marine industry is currently higher than light fuel usage. It was projected in the Component 1 Assessment that due to international regulations aimed at reducing air pollution from ships in the port area, there would be a gradual shift from the use of heavy fuel oil to diesel fuel in port areas; the proportion of diesel fuel to heavy fuel oil is expected to increase in the future, increasing the possibility that spills will involve diesel rather than heavier fuel oils (Herbert Engineering Corp. et al. 2014). Vessels would likely continue to use heavy fuel oil while en route at sea due to lower costs.

The Component 1 Probability Analysis stated that the MCD for a collision, allision, or soft grounding would be the size of the largest single fuel tank allowed by the regulation (i.e., less than or equal to 2,500 m<sup>3</sup>) (Herbert Engineering Corp. et al. 2014). The MCD for a hard grounding would be three times the maximum tank size (i.e., 7,500 m<sup>3</sup>), or three tanks rupturing (Herbert Engineering Corp. et al. 2014).

The next two sub-sections provide a review of the physical and chemical properties of light and heavy fuels oil types, along with their fate and behaviour in the marine environment. The review in **Section 4.0** provides contextual information for the fate and transport of these products in the marine waters surrounding RBT2, including the Fraser River estuary and the Strait of Georgia.

### 3.1.1 Light Fuels

#### 3.1.1.1 Physical and Chemical Properties of Light Fuels

Light fuels have slightly different physical properties within each category of fuel specifications from different organisational standards. Most of the major producers of marine fuel manufacture to International Standardization Organization (ISO) standards. The present standards (ISO 2010: 8217) recognise four distillate (light fuel) grades: **DMX**, **DMA**, **DMZ**, and **DMB**, and 11 residual (heavy fuel) grades (see **Section 3.1.2**). In these standard fuel grades, DMX is a special light distillate intended mainly for use in emergency engines. DMA (also called marine gas oil, MGO) is a general purpose marine distillate that must be free from traces of residual fuel. DMX and DMA fuels are primarily used in Category 1 marine engines (< 5 litres per cylinder). DMB (marine diesel oil, MDO) can have traces of residual fuel typically used for Category 2 (5 to 30 litres per cylinder) and Category 3 (≥ 30 litres per cylinder) engines. **DMC** is a grade that may contain residual fuel and is often a residual fuel blend and can be used in Category 2 and Category 3 marine diesel engines. Vessel operators and fuel suppliers tend to use an ASTM standard (D975) for diesel fuel and add requirements for sulfur content, stabilisers, and adjustment of the fuel for temperature conditions. ASTM D975 standard covers three grades of diesel: No1-D, No2-D, and No4-D.

Most of the physical and chemical properties of the common marine light fuel refinery products (**Table 3-2**) are maintained to meet the standardised specifications that are required for their onboard engine performance. Nevertheless, several of these properties (i.e., density, viscosity and **pour point**, vapor pressure, and aqueous solubility) are especially important when considering the fate and behaviour of these petroleum products in the marine environment (National Research Council 2003).

Density of oil is measured in mass per unit volume and is reported in kg/m<sup>3</sup> at 15°C at fuel oil standard specifications. It is often expressed in dimensionless specific gravity (SG) or American Petroleum Institute (API) gravity (API G). The specific gravity of oil is the ratio of the density of oil to the density of pure water at 60°F (~15.5°C). The **API gravity** is calculated from the specific gravity of oil by using the formula (API G = 141.5/SG – 131.5). The density of pure water is 1,000 kg/m<sup>3</sup> and the density of seawater is

approximately 1,030 kg/m<sup>3</sup>. Thus, most oils, which range in density from 700 to 990 kg/m<sup>3</sup>, will float on water. In API gravity, the value is scaled such that oil with API gravity greater than 10 will float on water, and less than 10 will sink. Lower API gravity values indicate heavier oils. Typical API gravity ranges are defined as heavy (<22.3), medium (22.3 to 31.1), and light (>31.1).

**Table 3-2 Physical Chemical Properties of Common Marine Light Fuel Oils**

Characteristics	MGO (DMX, DMA, DMZ)	MDO (DMB, DMC)
Density (g/ml @ 15°C)	0.83 to 0.90	0.85
API gravity (dimensionless)	26 to 38	34
Viscosity @ 40°C (mPa·s)	1.4 to 5.5	2 to 11
Surface Tension (mN/m)	27	27
Pour Point (°C)	- 42 to - 6	- 36

**Note:** Data from Environment Canada Oil Property Database (available online at [http://www.etc-cte.ec.gc.ca/databases/OilProperties/oil\\_prop\\_e.html](http://www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html)), and ISO 2101:8217.

Density of oil plays an important role in the fate of spilled oil. The density difference between oil and water determines: 1) the extent to which the oil slick is submerged; and 2) the residence time of the oil droplets that may be entrained in the water column. Density of spilled oil increases as evaporation process removes the lighter constituents. Light fuel oils, however, do not have substantial density increases as a result of evaporation (usually one percent [%] increase in density with 20% loss of oil mass during evaporation). More substantial density increases of oil slicks are attributable to either the formation of water-in-oil emulsion ("mousse") or association with suspended sediments (mineral fines or organic matter) to form oil-mineral aggregates.

Viscosity is the resistance of a liquid to flow. Kinematic viscosity of oil relates the shear stress and strain rate of oil; it is reported in units of mm<sup>2</sup>/s (or cSt) at a certain temperature and shear in (s<sup>-1</sup>). Viscosity of oil is an important fluid property as it directly measures the fluidity (i.e., pumping and handling capability of the product) at different temperatures and operational conditions. When spilled in the marine environment, viscosity of oil controls the spreading rate of surface slicks in the gravity-viscous regime and the minimum sheen thickness as it spreads under surface tension-viscous regime. It is also a key factor determining the entrained oil droplet size distribution under breaking waves and therefore the natural and chemical dispersion. The viscosity of spilled oil increases with the weathering processes and decreases as temperature rises. Weathering processes, such as evaporative removal of light constituents and formation of water-in-oil emulsification, tend to increase the viscosity dramatically for crude oil and heavy fuel oils. The viscosities of light fuels are much lower than most crude oil and other heavy fuel oils; they are highly dispersible in the water column as dissolved components and dispersed small droplets. The increase of viscosity of light fuels is not as strongly influenced by evaporation. Due to the particularly low concentrations or non-existence of residual oil fractions (e.g., resins and asphaltenes), light fuels usually do not form water-in-oil emulsion; therefore, the increase of viscosity due to uptake of water is also at a minimum.

Fuel oils No. 1 and No. 2 are distillate fuels which consist of distilled process streams. Residual fuel oils such as fuel oil No. 4 are residues remaining after **distillation** or **cracking**, or blends of such residues with distillates. All fuel oils consist of complex mixtures of aliphatic and **aromatic hydrocarbons**. Fuel oil No. 1 (straight run kerosene) is a light distillate which consists primarily of hydrocarbons in the C9 to C16 range; fuel oil No. 2 is a heavier, usually blended, distillate with hydrocarbons in the C9 to C25 range. Diesel fuel No. 2 is similar in chemical composition to fuel oil No. 2, with hydrocarbons in the C9 to C27 range, but with additional additives. Diesel fuels predominantly contain a mixture of C10 through C19 hydrocarbons, which include approximately 64% **aliphatic hydrocarbons**, 35% aromatic hydrocarbons, and 1 to 2% **olefinic hydrocarbons**. All of the above fuel oils contain less than 5% **polycyclic aromatic hydrocarbons**. Fuel No. 4 (marine diesel fuel) is less volatile than diesel fuel No. 2 and may contain up to 15% residual process streams, in addition to more than 5% polycyclic aromatic hydrocarbons.

Boiling distribution of marine fuel oils has direct impact on two other critical properties that affect the fate and behaviour of fuel oils spilled in the marine environment: 1) vapor pressure; and 2) water solubility. These two properties are critically important to the primary weathering processes of evaporation and dissolution and affect the chemical composition of spilled oil from hours to days following an oil spill.

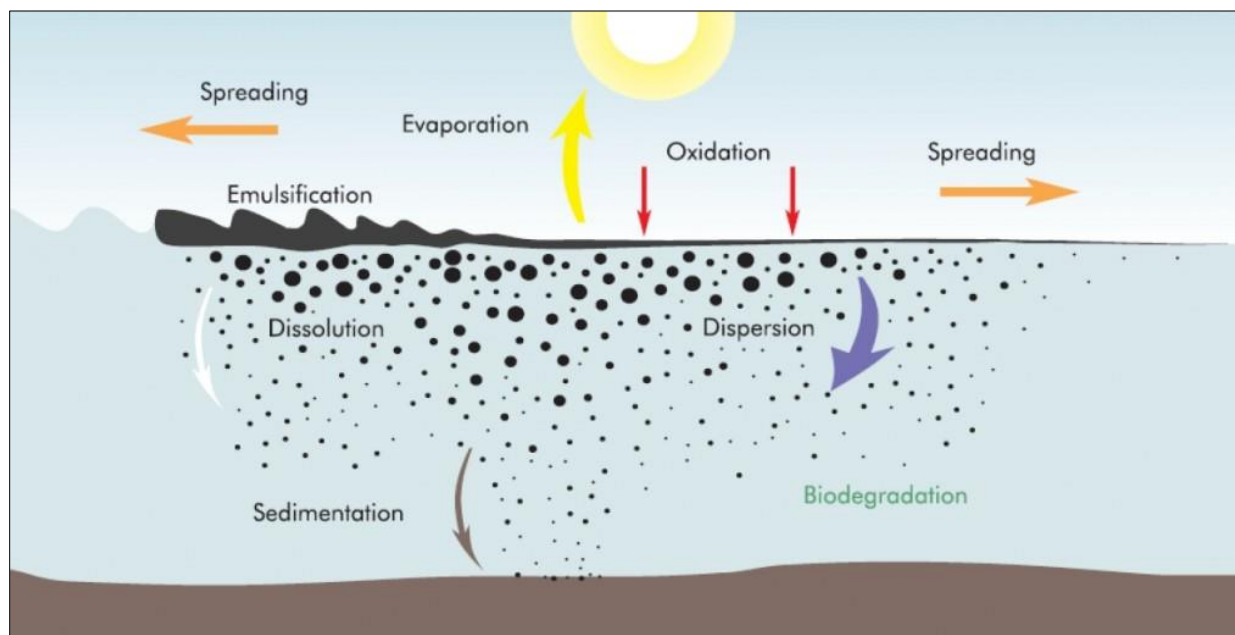
Vapor pressure controls the rate and ultimate extent of hydrocarbon evaporation in oil, although other spill site-specific conditions such as water and air temperature, wind speed, and turbulent conditions also affect the evaporation rate of hydrocarbons. Petroleum compounds that boil at temperatures below 270°C, or have vapor pressures greater than 0.1 mm Hg (or 13.3 Pa), tend to evaporate rapidly from the surface slick of spilled oil. Compounds within these ranges include alkanes up to n-C15 and one- to two-ring aromatics ranging from benzene through alkyl naphthalenes. In general, compounds with boiling points below 200°C (~C12) tend to evaporate within 24 hours, with additional semi-volatiles evaporating within 48 hours. Marine light fuels have high rates and extents of evaporative loss once spilled into the marine environment. Most of the No. 1 fuels can evaporate within one or two days after their spill into the environment; diesel oils lose 30 to 40% of their mass within a couple of days, as well. Heavy fuel oils (IFO180 and IFO 380), however, are very limited in their mass of evaporation (see **Section 3.1.2**).

In summary, the physical chemical properties of fuel oils are highly relevant to their fate, behaviour, and subsequent transport and dispersion in the environment. In the next section, the fate and transport of marine light fuels will be reviewed and discussed.

### **3.1.1.2 Fate and Transport of Light Fuels in the Marine Environment**

Major processes that determine the fate and behaviour of oil in the marine environment include those involving physical transport within a given environmental compartment (spreading of free-phase mixtures, entrainment, **advection**), transfers between environmental compartments (evaporation, dissolution, sedimentation), changes in physical-chemical properties (emulsification (water-in-oil emulsion or mousse formation)) and destruction/degradation (**photolysis** and **biodegradation**) (**Figure 3-1**). Each of these is defined and described in more detail below.

**Figure 3-1 Fate, Transport, and Dispersion Processes of Oil in the Environment (source: International Tanker Owners Pollution Federation 2011)**



Following an initial free-phase introduction, oil would move via spreading and surface transport due to tidal and wave currents. Spreading is the thinning and broadening of surface oil slicks caused by gravitational forces and surface tension that occurs rapidly after oil is spilled. For a spill on the water surface, the gravitational spreading occurs within hours to a minimum thickness. The spreading rate of marine light fuels is fast because the oil viscosity is low. The minimum thickness of marine light fuels, according to the estimation based on their low viscosity, can be as thin as 0.01 to 0.10  $\mu\text{m}$ , visible as rainbow or silver-gray sheens in the calm open water. The area exposed to evaporation is high relative to the oil volume.

As the oil spreads and transported at the surface, the volatile fractions of oil partition into air (evaporation) and soluble fraction partitions into the water (solubilisation and entrainment). Evaporation is the process by which volatile components of the oil diffuse from the oil and enter the gaseous phase in the atmosphere. Evaporation from surface and shoreline oil increases as the oil surface area, temperature, and wind speed increase. As lighter components evaporate off, the remaining “weathered” oil becomes more viscous. For light oils, since a large fraction of oil is volatile and semi-volatile, evaporation plays a very important role in the removal of spilled light fuel oil. The rate of evaporation increases as the wind speed increases. However, above wind speeds of 6 m/s, white caps form and the breaking waves entrain oil as droplets into the water column. The higher the wind speed (and turbulence), the more entrainment and the smaller the droplet sizes. Dissolution is the process by which water-soluble components diffuse from the oil phase into the water column. The dissolution rate increases with higher surface area of the oil relative to its volume; the smaller the spherical droplets, the greater the surface area to oil ratio and the

higher the dissolution rate. Dissolution from entrained small droplets is much faster than from flat surface slicks due to the greater surface area of small droplets in contact with ambient water. Surface slicks are in maximum contact with ambient air which has much higher mass transfer coefficients than those in ambient water. Light fuel oils have a large portion of components that are both soluble components and volatile, and evaporation from their surface slicks is faster than dissolution into the underlying water. Thus, the processes of evaporation and dissolution are competitive, with evaporation as the dominant process for the light fuel oil spilled at the surface. Evaporation proceeds faster than dissolution. Thus, most of the volatiles and semi-volatiles evaporate, with a smaller fraction dissolving into the water.

Advection is the process by which oil moves with the flow caused by wind drift and currents. Currents are generated by several forces, including tidal, river (freshwater) flow, wind, waves, pressure gradients, etc. Advection transport is a vector sum of all current components affecting the oil. Empirical studies have determined that subsurface oil will move as the bulk water moves, and surface oil moves at about 2.5 to 4% of the wind speed. A common value is 3.5 %, assuming light winds and no breaking waves.

**Turbulent dispersion** is the mixing caused by “sub-scale” currents (not included in the current data), also known as turbulent eddies, that move oil and mix it both horizontally and vertically. Numerous causes may exist in near shore and estuarine environments that introduce turbulent mixing, such as: wind blowing over a basin of variable depth causing rotational current, friction of tidal flow running over the channel bottom generating turbulence, interaction of the tidal wave with the bathymetry generating larger scale currents, the shear effect in estuaries and tidal rivers, tidal pumping and trapping, and mixing caused by a river outflow (Fischer et al. 1979). Turbulent dispersion will have a greater effect on the dissolved and dispersed components of light fuel oils through acceleration of their dilution rates. Dilution occurs when water of lower concentration is mixed into water with higher concentration by turbulence, currents, or shoreline groundwater.

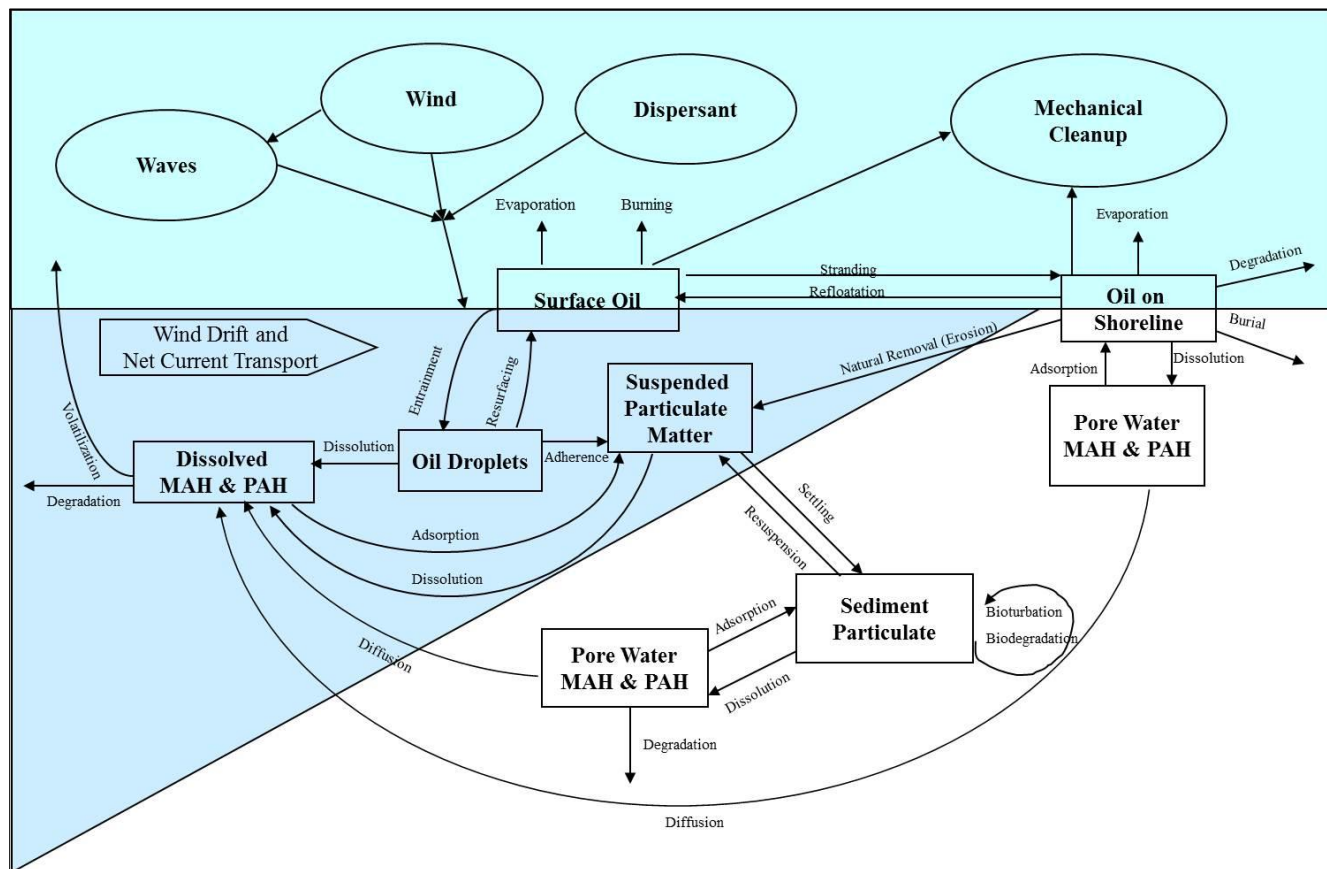
Entrainment (dispersion) occurs when waves break over surface oil and carry it as droplets into the water column. Entrainment becomes increasingly important (higher rate of mass transfer to the water column) at higher wind speeds because higher speeds increase wave height and wave breaking. As wind and turbulence increase, the oil droplet sizes become smaller. Application of chemical dispersant increases the entrainment rate of oil and decreases droplet size at a given level of turbulence. Some wave energy is required for dispersant-treated oil to actually entrain. Light fuel oils are easier to break up into small droplets than crude oil and heavy fuel oil because of their relatively low viscosity and greater volatile and soluble fractions. Dispersant application is often unnecessary because the natural dispersion of light fuel oils is sufficient to cause significant entrainment and dispersion after evaporative loss of the bulk of oil.

Resurfacing of entrained oil rapidly occurs for larger oil droplets. Smaller droplets resurface when the wave turbulence decreases. The smallest droplets do not resurface, as typical turbulence levels in the water keep them in suspension indefinitely. Resurfaced oil typically forms sheens. As surface slicks are usually blown downwind faster than the underlying water, resurfacing droplets come up behind the leading edge of the oil, effectively spreading the slicks in the downwind direction. Light fuel oils tend to form thin sheens very fast, which in turn enhances the formation of small droplets in the water column with subsequent entrainment under breaking waves.

Emulsification is the process by which water is mixed into the oil, such that the oil makes a matrix with embedded water droplets. The resulting mixture is commonly called mousse and is technically referred to as a water-in-oil emulsion. The rate of emulsification increases with increasing wind speed and turbulence on the surface of the water. Viscosity increases as oil emulsifies and the relative water concentration increases. For the light fuel oils, emulsification is unlikely to occur due to the lack of residual oil components such as resins and asphaltenes.

In near shore and estuarine environments, transport and dispersion of oil becomes much more complex due to the additional processes that affect the fate and transport of oil (**Figure 3-2**). Besides the major processes that affect fate and transport of oil in open water, other processes that must be considered in the near shore environment include: **adsorption**, **adherence**, sedimentation, **diffusion**, **bioturbation**, burial, and **percolation**.

**Figure 3-2 Fate, Transport, and Dispersion Model of Processes of Oil in the Estuarine and Near Shore Environment (RPS ASA 2010)**



Adsorption of dissolved components to suspended sediments in the water column occurs particularly when the organic carbon content of the suspended particulate matter is high.

Entrained oil droplets may also combine with particles in the water through adherence process. If the particles are suspended sediments, and the combined oil/suspended sediment agglomerate is heavier than the water, the oil-sediment agglomerates may settle to the sediment phase. Adherence and sedimentation can be an important pathway of oil in near shore areas when waves are strong and subsequently subside. Re-suspension of settled oil-sediment particles and diffusion of the adsorbed semi-soluble components may occur if current speeds and turbulence exceed threshold values where adhesive forces can be overcome.

Other natural attenuation processes of oil in near shore environment include percolation, flushing, stranding, erosion, and degradation. Percolation is the process by which oil is carried into shoreline sediments by receding waves and tides. Shoreline sediments may be mixtures of a range of particle sizes from silt to cobbles and boulders.

Flushing of shoreline sediments occurs naturally by freshwater flow (rivers, streams, rain runoff, and groundwater) and by tidal and wave activity.

Stranding of oil on shorelines occurs when incoming tides and waves bring floating oil ashore that is not subsequently flushed. Re-floatation occurs when an incoming tide or waves wet the shoreline where stranding had previously occurred and where the oil is sufficiently mobile to be floated off. Erosion by waves and currents can remove oiled sediments from shorelines. The oiled sediment may remain in suspension and be transported some distance or be deposited in the near shore subtidal habitat.

Degradation is the process through which oil components are changed either chemically or biologically (biodegradation) into another compound. It includes breakdown to simpler organic carbon compounds by bacteria and other organisms, **photo-oxidation** by solar energy, and other chemical reactions. Higher temperature and higher light intensity (particularly ultraviolet wavelengths) increase the rate of degradation.

### **3.1.2 Heavy Fuels**

#### ***3.1.2.1 Physical and Chemical Properties of Heavy Fuels***

Heavy fuel oils, or marine residual fuel oils, are a group of high viscosity, high density oils containing residuals from various refining processes blended with a distillate fraction in order to obtain a required viscosity.

Heavy fuel oils (**Table 3-1**) are classified according to IFO grade system, where the viscosity is specified at 50°C, as an indicator of the oil pumping capability and handling properties during storage. For example, an IFO-180 has a specified kinematic viscosity ( $\leq 180$  cSt) at 50°C, while IFO-380 should have a specified viscosity ( $\leq 380$  cSt). At ambient temperature, however, the viscosities of these oils are dramatically increased. At 15°C, the IFO 180 viscosity ranges from 1500 to 3000 cSt, and the IFO 380 viscosity may range between 5,000 and 30,000 cSt (International Tanker Owners Pollution Federation 2011).

The physical and chemical properties of various residual fuel oils within the same IFO grade may therefore differ due to differences in the refining processes, the quality of the feed oil in the refining process, and variable addition of distillate to give a viscosity at 50°C in accordance with the specifications. This variation in physicochemical properties influences the properties of the heavy fuel oil at realistic spill temperatures.

The principle features that distinguish the 11 grades of residual marine fuel oils (**Table 3-3**) include density, viscosity, pour point, sulfur, residual carbon, and metals residual content (ISO 2010: 8217). In practice, only 5 of the 11 residual grades of marine fuels are commonly used for marine transportation (Uhler et al. 2007). These five commonly-used residual fuels are classified in two groups: 1) intermediate fuel oil 180 (IFO180s); and 2) intermediate fuel oil 380 (IFO380s).

**Table 3-3 Physical Chemical Properties of Common Marine Heavy Fuel Oils**

Characteristics	RME-180	RMG-180	RMG-380	RMK-380
Density (g/ml @ 15°C)	0.99	0.99	0.99	1.01
API gravity (dimensionless)	11	11	11	9
Viscosity @ 50°C (mPa·s)	180	180	380	380
Surface Tension (mN/m)	25 to 30	25 to 30	25 to 30	25 to 35
Pour Point (°C)	30	30	30	30
Water content (max vol %)	0.5	0.5	0.5	0.5
Carbon residual (mass %)	15	18	18	20
Vanadium (max mg/kg)	150	350	350	450

**Note:** Data from Environment Canada Oil Property Database (available online at [http://www.etc-cte.ec.gc.ca/databases/OilProperties/oil\\_prop\\_e.html](http://www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html)), and ISO 2101:8217

### 3.1.2.2 Fate and Transport of Heavy Fuels in the Marine Environment

Heavy fuel oils spilled at sea may go through the same weathering processes as those processes affecting light oils, including: spreading, evaporation, emulsification, natural and chemical dispersion, dissolution of water soluble components, photo-oxidation, and biodegradation. The extent of the various processes depends on the oil properties, including specific gravity, distillation characteristics, vapor pressure, viscosity, and pour point. While many refined products (light oils) tend to have well-defined properties irrespective of the original crude oil from which they are derived, heavy fuel oils, which contain varying proportions of the residuals of the refining process blended with lighter refined products, may vary considerably in their properties.

When heavy fuel oils are spilled into the marine environment, the lighter fractions (< C20) of heavy fuels may evaporate to the atmosphere or dissolve in water. Heavy fuel oils may undergo little evaporation because of the low constituents of light fractions.

Heavy fuel oils typically have low API gravity and densities approaching, and sometimes exceeding, that of water (National Research Council 1999, Neff et al. 2003). Therefore, heavy fuels may float on water, sink, or resurface after they sink, depending on meteorological and oceanographic conditions (Michel and Galt 1995, National Oceanic and Atmospheric Administration 1997). It is possible for heavy fuel oil to submerge beneath the sea surface under appropriate conditions, including: 1) the density of oil (or emulsion) close to the ambient water; 2) the viscosity of oil (or emulsion) low enough so that it breaks into mm to m patches or mats; and 3) the energy of waves sufficiently high to submerge the oil. When a dense oil mass is weathered to the extent that its density approaches that of the ambient water, the oil becomes suspended under the water surface and subject to appreciable over-washing as a result of wind-driven waves, buoyancy-driven cross-shore currents, and along-shore geostrophic currents in the near surface region. Weathered oil may also become incorporated into near shore sediments in estuaries, where sufficiently high amounts of suspended particulate matters are present to cause oil to sink. Although oil sedimentation is one of the key long-term processes leading to the accumulation of spilled oil

in the marine environment, sinking of bulk oil is rarely observed beyond areas of near shore shallow waters, and only occurs primarily as a result of shoreline interaction. The interaction of stranded oil with shorelines depends primarily on the levels of energy to which the shoreline is exposed and the nature and size of the shoreline substrate (Michel and Hayes 1992).

At lower atmospheric and sea water temperatures, it is typical to see reduced fluidity for heavy fuel oils. For example, IFO 180 has viscosity ranging from 1,500 to 3,000 cSt, and IFO 380 typically has viscosity between 5,000 and 30,000 cSt at 15°C. With high viscosity at low temperature, semi-solid or highly viscous heavy fuel oils may fragment into millimetre to centimetre thick patches which move apart, rather than spreading as a thin, continuous layer over the surface.

As heavy fuel oils experience weathering at sea, their properties such as viscosity can change considerably. For example, during the *Prestige* incident (Cedre 2006), oil samples that were taken at sea during the three-month oil spill response operation were systematically characterised. The sea temperature during the time period was 12 to 15°C. After one month at sea, the viscosity at 15°C was approximately 100,000 cSt (at 10 s<sup>-1</sup>), after two months it was approximately 200,000 cSt, and after three months it was approximately 300,000 cSt. These very high viscosities explain the increasing difficulty of recovering and handling the emulsified oil during the response operation period.

Several important processes contribute to natural attenuation of oil spilled in the environment, including photo-oxidation and biodegradation. Some compounds can be transformed through direct photolytic reactions if they receive sufficient irradiation from sunlight to affect the photo-oxidation chemical reactions. Others may undergo indirect photo-degradation with photo-sensitised light absorbers such as the chromophores present in dissolved organic material (Schwarzenbach et al. 1993). Biodegradation rates are related to molecular weight and structural conformation, with the lower molecular weight fractions being used first by microbes due to their relatively higher bioavailability. The biodegradation rates are also influenced by temperature, dissolved oxygen, and available nutrients. Although biodegradation is clearly not capable of removing bulk oil accumulations, it is one of the main long term mechanisms for the natural removal of the final traces of oil from shorelines that are frequently over-washed by tidal or wind-driven action.

## 4.0 POTENTIAL TRANSPORT OF SPILLED SUBSTANCES IN THE STUDY AREA

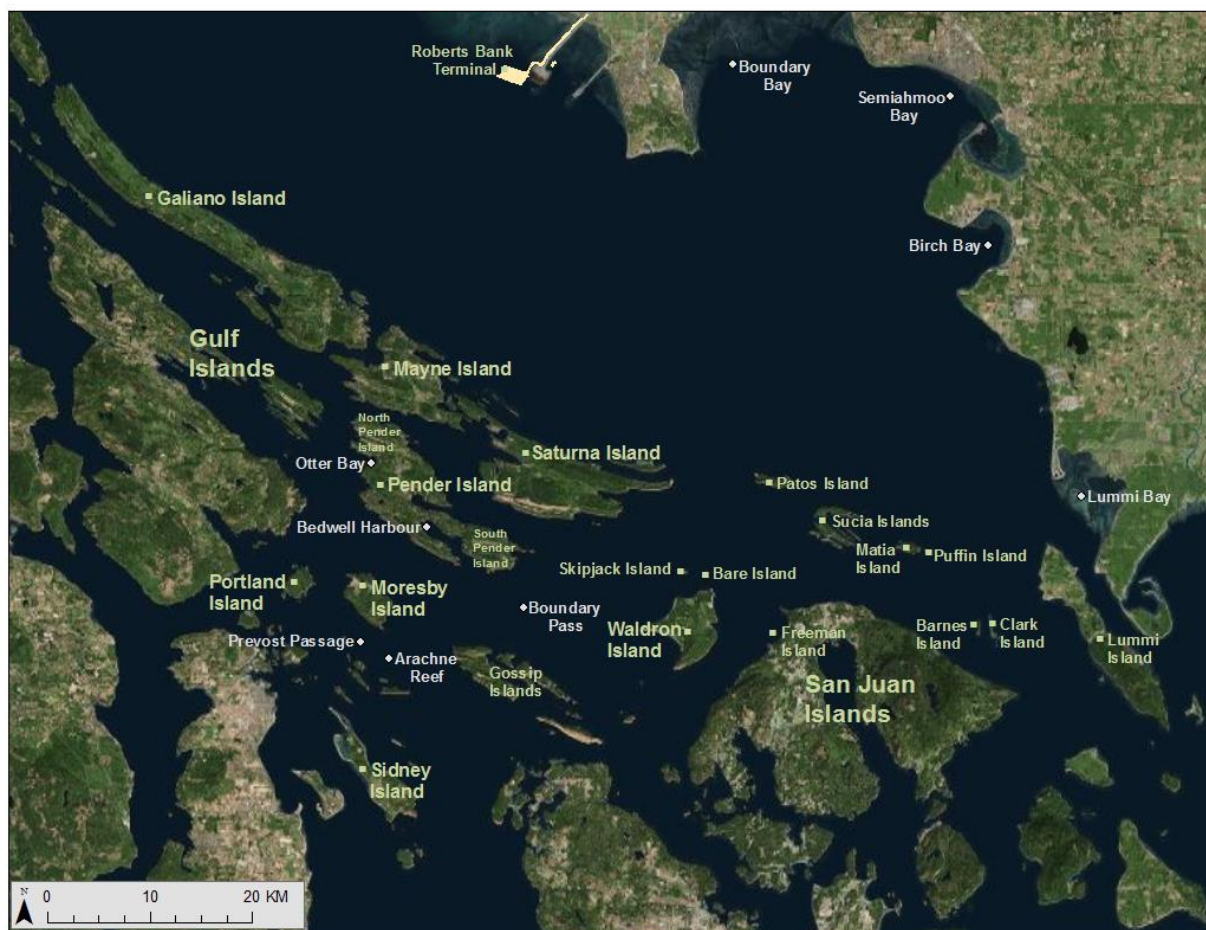
The following sections qualitatively evaluate the potential transport and fates of spilled substances for releases originating from the “At Berth” region, **Figure 1-3**) in different seasons. Findings and conclusions from the analysis of environmental conditions (**Section 2.0**) and from the review of the oil properties and fate (**Section 3.0**) were used to predict general fate and transport of spills originating from this region. The fate and transport of any light or heavy fuel oil spilled in this region will depend on the specific environmental conditions present at the time of the release and in the subsequent hours and days. The analysis provided in this section is meant as a general guide as to where the oil would *most likely* go in the event of a release, and was evaluated in the context of the seasonal forcing trends reviewed in **Section 2.0**. Actual transport and fate may differ from what is predicted or suggested herein due to uncertainties associated with the independent variables and interactions.

**Figure 4-1** provides a reference map for locations and water bodies mentioned in the transport evaluation in the following sections.

**Figure 4-1**      **Locations and Water Bodies Referred to in the Spill Transport Evaluation for the Study Area**



**Figure 4-2**      **Locations and Water Bodies Referred to in the Spill Transport Evaluation for the Study Area, Close-up of the Gulf Islands and San Juan Islands**



Oil fate and transport in the marine environment is primarily controlled by the environmental conditions and the physical properties of the spilled product. Based on the Component 1 Probability Analysis, light and heavy fuel oils were the two groups of petroleum products most likely to be discharged into the marine environment from RBT2 shipping traffic and activity. **Section 3.0** reviewed the physical properties of “light fuel oils”, including MGO and MDO; and “heavy fuel oils”, including RME-180, RMG-180, 380, and RMK-380.

The Component 1 Assessment concluded that the MCD volume for a collision, allision or soft grounding at berth was 2,500 m<sup>3</sup>. It was assumed that this MCD was suitable for both light and heavy fuel oil types, as both fuel types are used or carried by vessels associated with RBT2 traffic (Herbert Engineering Corp. et al. 2014).

In general, the bulk of the light oil products potentially released from RBT2 should spread to its minimum thickness and evaporate within a couple of days throughout the year. In particular, warm temperatures in summer would likely further speed up evaporation rates relative to other times of the year. Similarly, colder temperatures during winter would likely slow evaporation rates relative to other times of the year. If the spill occurred during a period of high winds, wave action would likely entrain the oil and disperse it throughout the wave mixed layer, increasing the dissolution and/or dispersion of oil in the water column. The peak concentration and amount of dissolved hydrocarbon contaminants in the water column would depend on how wide the oil spreads horizontally and how deep the oil penetrates into the water column. Given the circulation potential of the region and the MCD volumes, it is expected that residence time of any resulting in-water contamination would be relatively short (hours to days) for light fuel oils.

The environmental compartment most likely to be affected by a spill of light fuel oil will depend on the environmental conditions at the time of the spill. High waves would potentially increase hydrocarbon concentration in the water column, while light winds would cause an increased concentration of volatile organic compounds in the immediate vicinity of the ambient air of the spill site. However, the impacts to air quality are expected to be localised given the tremendous dilution capacity under the ambient meteorological conditions.

The bulk of the heavy fuel oil products that could potentially be released from the “At Berth” region would have limited removal through evaporation, and would likely form either emulsions or wash ashore. Degradation (biodegradation and photo-oxidation) would occur in this area given sufficient dissolved oxygen and nutrient supply, and bioavailability of part of the oil compounds. If a spill occurred during a period of high winds, then wave action would cause some entrainment and dispersion, and potentially formation of water-in-oil emulsions and/or oil-sediment agglomerates if a spill occurred in the areas of high load of suspended particulate material such as the estuary of the Fraser River.

#### **4.1 PAST MODELLING STUDY NEAR THE STUDY AREA**

A past oil spill modelling study conducted near the “At Berth” region, was reviewed and incorporated where applicable into the fate and transport evaluation and analysis herein. Due to the conclusions of the Component 1 Assessment that spill incidents were very improbable (Herbert Engineering Corp. et al. 2014), and that maximum possible volumes spilled were relatively small, the analysis herein is a qualitative evaluation of potential spill incidents associated with RBT2 vessel traffic and activities as opposed to the quantitative modelling studies reviewed. The reviewed report will be referenced in the following sections as Study 1 (EBA 2013, Stantec 2013). Study 1 consisted of two reports building off the same modelling effort. The first, entitled “Modelling the Fate and Behavior of Marine Oil Spill for the Trans Mountain Expansion Project Summary Report”, was prepared by EBA in November 2013 for Stantec (EBA 2013). EBA (2013) discussed the modelling methodology and provided some results. The second, entitled “Ecological Risk Assessment of Marine Transportation Spills”, was prepared by Stantec in

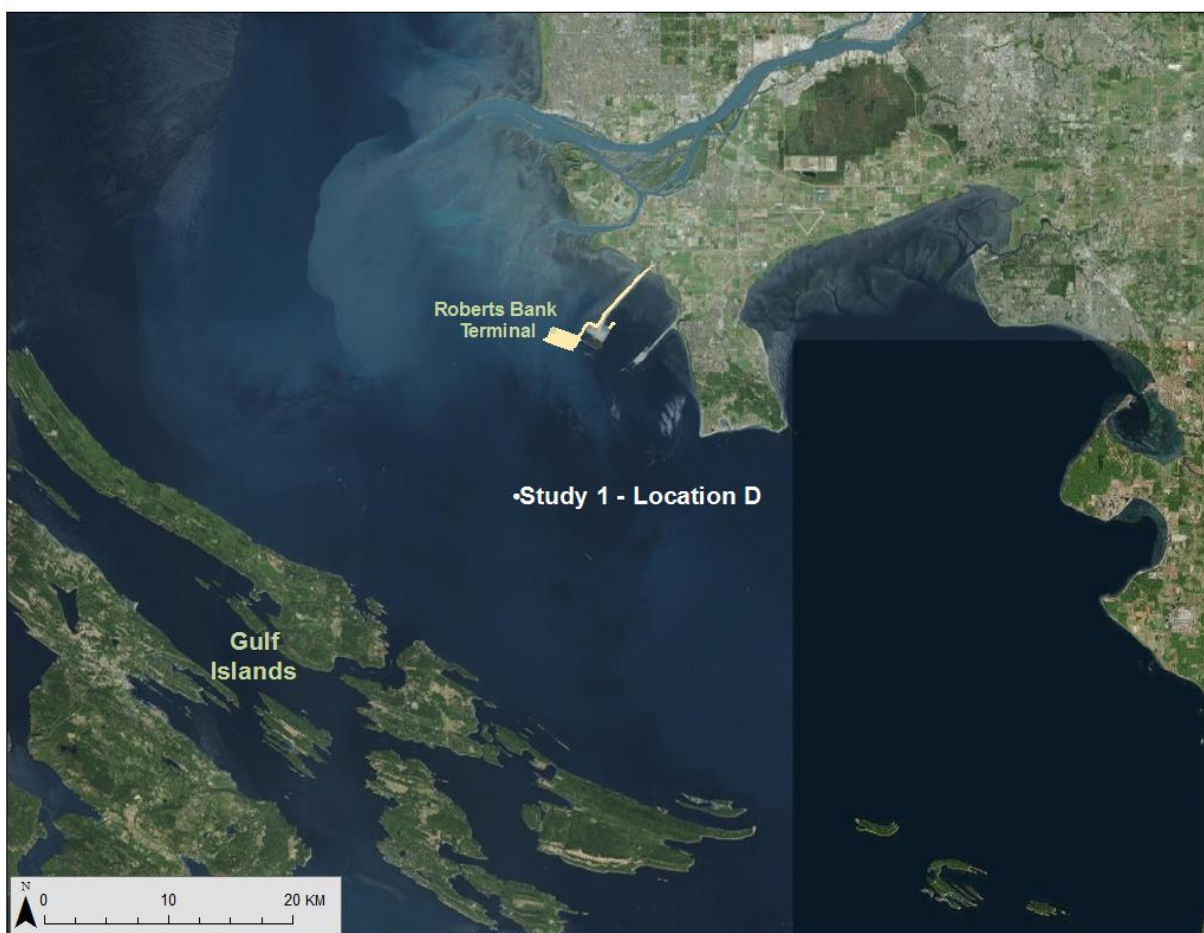
December 2013 for Trans Mountain Pipeline expansion project (Stantec 2013). Stantec (2013) focused on two release sites in the RBT2 region of interest: Location D near RBT2 in the Strait of Georgia; and Location E at Arachne Reef at the western end of Boundary Pass (**Figure 4-1**). Of these two sites, Location D is a close site to the present "At Berth" region, while E is not. Therefore, only the study of Location D was considered for this assessment. Study 1 (EBA 2013, Stantec 2013) used surface currents derived from the three-dimensional hydrodynamic model H3D, wind data gathered from the Meteorological Service of Canada, the National Oceanic and Atmospheric Administration, Metro Vancouver, and B.C. Ministry of Environment moored buoys and stations, and wave data from the wave model SWAN. Inputs from these three sources were fed into the Oil Spill Model SPILLCALC. These simulations used Cold Lake Winter Blend Bitumen as the spilled oil. Stochastic simulations predicting the probability of oiling were run for four seasons: winter, spring, summer, and autumn.

Study 1 (EBA 2013, Stantec 2013) found for spills originating at Location D that there was a high to very high probability that shoreline oiling would occur. It is important to note that the oil used for the modelling in Study 1 (EBA 2013, Stantec 2013) was heavier and potentially more persistent than the light fuel oil discussed regarding RBT2; thus, the overall extents of the light fuel oil releases for RBT2 are expected to be smaller than shown in Study 1. On the other hand, the oil used for the modelling in Study 1 (EBA 2013, Stantec 2013) has similar physical chemical properties as heavy fuel oils considered in this analysis (**Section 3.1.2**), and thus the extents of the heavy fuel oil releases in the RBT2 study area are expected to be similar if the same amount of oil were released in the environment. Overall, the Study 1 (EBA 2013, Stantec 2013) release volumes modelled were higher than the MCDs predicted for RBT2 (16,500 m<sup>3</sup> versus 2,500 or 7,500 m<sup>3</sup>). Study 1 found that the potential for contamination of the water column was low due to low dissolved polycyclic aromatic hydrocarbon (PAH) concentrations. Since the chemical composition of the oil type (diluted bitumen cold lake winter blend or CLWB) in Study 1 and the heavy fuel oils (IFO180 and IFO380) have similar level of aromatic composition (Environment Canada, Fisheries and Oceans Canada, and Natural Resources Canada 2013), it is predictable that the potential contamination to the water column would also be low in the RBT2 vessels in the study area.

The review of spill modelling results from Study 1 (EBA 2013, Stantec 2013) Location D (nearest to the RBT2 study area) showed that the bulk of the transport during the spring and autumn months (April, October, November, December) would be to the south. More transport to the north was observed in winter months than during the summer months, most likely due to the increased occurrence of southeasterly winds. Oil would most likely travel to the south and southeast towards the eastern shores of southern Strait of Georgia and the northern shorelines of the San Juan Islands in the summer months, but there would also be an increased chance of oil reaching the western shores of the Strait of Georgia.

The stochastic simulations showing probability of oiling performed in Study 1 (EBA 2013, Stantec 2013) at Location D during the winter months (January, February, March) demonstrated a significant amount of transport to the northwest, coinciding with the predominantly southeasterly winds observed and previously discussed. Transport to the south and southeast was still observed, but with less likelihood during this time period. Shoreline oiling was most likely on the western and eastern shores of the Strait of Georgia north of RBT2 during this time period, coinciding with both the northwesterly winds and the low flow rate from the Fraser River. If oil moved south during this time period, it was expected to affect Point Roberts and the shorelines near Birch Bay.

**Figure 4-3**      **Locations of Release Sites from Study 1, a Previous Oil Spill Modelling Study in the Area. Study 1 refers to EBA (2013) and Stantec (2013)**



## **4.2 SPILLS ORIGINATING FROM THE “AT BERTH” REGION**

The environmental conditions analysis (**Section 2.0**), with a focus on the wind data for the Sand Heads site (**Figure 2-1**) and the available circulation data, identified two distinct seasons during which possible oil spills originating from the “At Berth” region (**Figure 1-3**) could be characterised.

The first season (season 1) was defined as May through October, and comprised the late spring, summer, and early autumn months of the region. The circulation in the area during the beginning of May through early July is characterised by large discharges from the Fraser River which deflects the tidal and wind-driven currents to the southwest across the Strait of Georgia. Throughout the remainder of the season (August – October), tidal and wind-driven circulation dominates the surface waters. Winds are predominantly out of the southeast throughout the season. Northwest winds are also observed and are more frequent towards the end of the season. Water temperatures range from approximately 10°C in May to approximately 20°C in July and August, before falling to approximately 12°C in October.

The second season (season 2) was defined as November through April, and comprised the late autumn, winter, and early spring months of the region. Circulation near RBT2 is controlled by the tidal movement and wind forcing during this period as the discharge from the Fraser River is at its lowest. East and east-southeast winds dominate from December through February, with northwest winds less likely than during the summer and autumn months. Southeast and northwest winds are observed in November, March, and April, though again, northwest winds are not as prevalent as during other times of the year. Water temperatures range from approximately 10°C in November to approximately 6°C in December, January, and February, before rising to approximately 10°C in April.

The spill incidence probability predicted for the “At Berth” region for collisions, allisions, and soft groundings was a 1200 year return period (**Table 1-1**) (Herbert Engineering Corp. et al. 2014). The overall consequences (e.g., shoreline oiling, surface oil concentrations, water column contamination, persistence in the environment) of spills originating from the “At Berth” region is dependent on oil type and season.

### **4.2.1 Light Fuel Oil**

#### **4.2.1.1 Season 1 (May through October)**

A release in May or June in the “At Berth” region would be strongly influenced by the Fraser River discharge which is at its peak flow rate during these months. This outflow would most likely carry oil to the southwest with the strong surface currents that could reach 2.5 m/s during this period and potentially result in oiling on the eastern shorelines of Saturna and Mayne Islands. Winds out of the southeast during this time period could cause some deflection to the north, while winds out of the northwest could cause some deflection to the south, but overall the transport would be dominated by the river discharge. Deflections to the north could increase or cause shoreline oiling on Galiano Island, while deflections to

the south could transport the oil into Boundary Pass and potentially onto the northern shores of Patos Island. During this time period, wave heights between 3.3 m and 4.0 m were observed in the immediate vicinity of the discharge (**Section 2.3.3**), especially where the wind or tide was going against the discharge. This wave action would enhance the entrainment of spilled oil as small oil droplets in the wave mixed layer, following the evaporative loss and rapid spreading of oil immediately after the spill. Increased entrainment of smaller oil droplets would result in higher dissolution rate of petroleum hydrocarbons into the water column, causing increased water column concentration of oil and other potentially toxic constituents. The volatile fractions of light oils, however, would volatilise to the atmosphere from the upper mixed layer soon after their dissolution in the water column.

A release from July through October would be less strongly influenced by the Fraser River discharge as the freshet ends; thus the bulk of the transport would become less southerly and more dependent upon wind direction. Tidal currents would cause the oil to move northwest during the flood tide and southeast during the ebb tide. The winds at the time of the spill would intensify this movement if they are in the same direction as the tidal flow. If the winds were opposite to the tidal flow, then the movement would slow until the tides changed. Winds out of the northwest would likely increase the chance of shoreline oiling near RBT2, Point Roberts, and the shorelines along the eastern side of the Strait of Georgia. Depending on wind strength, the oil could travel as far as the northern San Juan Islands, although it would most likely be comprised of the non-evaporative fractions only after the weathering processes. Winds out of the southeast could potentially cause oiling along the shorelines of Galiano, Mayne, and Saturna Islands. Regardless of wind direction, some shoreline oiling would occur in the vicinity of RBT2 and the western shore of Point Roberts.

Depending on the exact spill location in the “At Berth” region, some light fuel oil could reach the shorelines. This was seen in Study 1 (EBA 2013, Stantec 2013) due to the close confines of the region. However, as stated in **Section 4.1**, the bulk of the light oil should spread to its minimum thickness in appearance of silver or rainbow sheens and evaporate within a few days. Eventually, the rest of the spilled hydrocarbon compounds would either be removed via natural attenuation such as photo-oxidation and biodegradation processes or sequestered in geosorbents including marine and shoreline sediments.

#### **4.2.1.2 Season 2 (November through April)**

Spills in the “At Berth” region during the months of early spring (March and April) and late autumn (November) should show similar characteristics to those during season 1 due to the same tidal transport (e.g. to the northwest on flood time and southeast on ebb tide). This transport would be magnified by a wind moving in the same direction and dampened by a wind moving in the opposite direction. If winds were out of the northwest, the shorelines near Point Roberts, the eastern coastline of the Strait of Georgia below RBT2, and the northern shorelines of the San Juan Islands (including Lummi and Patos Island) could potentially be oiled. A southeast wind would drive transport to the western shore of the Strait of Georgia, specifically Valdes, Galiano, Mayne, and Saturna Islands. Regardless of the wind direction, some shoreline oiling would occur in the vicinity of RBT2 and the western shore of Point Roberts.

The winter months of December, January, and February were dominated by easterly to southeasterly winds, with much less variation observed at the Sand Heads station than during other months. Spills during this time period would most likely be influenced by winds from this direction and transport would be towards the western shoreline of the Strait of Georgia. Valdes, Galiano, Mayne, and Saturna Island could also experience some shoreline oiling if winds were persistently from the southeast.

Similar to season 1 and as seen in Study 1 (EBA 2013, Stantec 2013) some light fuel oil could reach the shorelines due to the close confines of the region. However, again, the bulk of the light oil should spread to its minimum thickness and evaporate within a few days. Evaporation of oil might be under a slower rate in Season 2 (winter months) than in Season 1 (summer months) due to the lower temperature. However, the stronger wind conditions may speed up the evaporative and dispersive loss of oil due to the reduced mass transfer barriers. Low temperature would not affect the photo-oxidation of hydrocarbons but the reduced length of irradiation time in winter month would reduce the photo-degradation rate. Although biodegradation of hydrocarbons would normally be expected to be slower in winter than in summer (Atlas and Bartha 1972), recent studies have shown that biodegradation could be significant in cold marine environments (Brakstad et al. 2006; McFarlin et al. 2014).

#### **4.2.2 Heavy Fuel Oil**

##### ***4.2.2.1 Season 1 (May through October)***

A release of heavy fuel oil in May or June in the “At Berth” region would be strongly influenced by the Fraser River discharge, while at its peak flow rate. This outflow would most likely carry oil to the southwest with the strong surface currents that can reach up to 2.5 m/s, with shoreline oiling likely reaching the Saturna and Mayne Islands. Winds out of the southeast during this time period would cause some deflection to the north, while winds out of the northwest would cause some deflection to the south, but overall the transport would be dominated by the river discharge. Deflections to the north would increase shoreline oiling along the western shores of the Strait of Georgia, with oiling likely along Galiano, Mayne, and Saturna Islands. Deflections to the south would increase shoreline oiling along Saturna Island, and would likely cause shoreline oiling along Patos Island, the Sucia Islands, and Puffin Island. Due to the relative low volatility of heavy fuel oil, it is likely that the majority of the northern shorelines of the San Juan Islands would see some oiling during these months. Oiling along the western shores of Roberts Point would also be expected from a spill during this time period; though potentially not as heavy as oiling along the western side of the Strait of Georgia. Regardless of wind direction, some shoreline oiling would occur in the vicinity of RBT2 and the western shore of Point Roberts.

As the freshet ends, the bulk of the transport would become more dependent on wind and less so on river discharge. Tidal currents would cause the oil to move to the northwest during the flood tide and the southeast during the ebb tide. The winds at the time of the spill would either magnify this movement if they were in the same direction as the tidal flow or slow it until the tide changed if they opposed the tidal

flow. Northwest winds would increase shoreline oiling near RBT2, Point Roberts, and the shorelines along the eastern shore of Strait of Georgia. If the spill occurred near the berth and oil was forced to the landward side of the proposed structure, oil could become trapped against the Roberts Bank causeway. The persistence of heavy fuel oil on the sea surface means it could travel as far as the northern San Juan Islands during a period of northwest winds, causing shoreline oiling along the northern coastlines of the Sucia Islands, Lummi Island, and Patos Island. Oiling would be possible along the shorelines of Birch Bay, Lummi Bay, and the land between the two water bodies. Winds out of the southeast during this time period would likely push the spilled oil northwest up the Strait of Georgia. Shoreline oiling would be expected along Galiano, Valdes, and Gabriola Islands. Due to the persistence of the heavy fuel oil, it is possible that oil could reach the shorelines past Gabriola Island, potentially reaching the coastline between Nanaimo and Parksville.

Regardless of the exact spill location at or near the RBT2 berth face, there is expected to be substantial shoreline oiling from a heavy fuel oil spill in this area. Shoreline oiling was predicted to occur in Study 1 (EBA 2013, Stantec 2013) due to the close confines of the region. However, the warmer temperatures observed during this season would reduce the viscosity of the heavy fuel products and therefore increase their efficiency to be dispersed (Li et al. 2010; Srinivasan et al. 2007). The high flow rate and maximum wave heights between 3.3 m and 4.0 m (**Section 2.3.3**) during the first two months of this season would likely increase the amount of entrainment compared to the latter months of the season, which would in turn cause more entrainment and water column contamination, and possibly result in oil-sediment flocculants that could be deposited on the seafloor. In contrast, if oil remains viscous and not easily entrained, heavy wind and wave action may form water-in-oil emulsion or thick mousse at the surface. Any increase in dispersion and entrainment would enhance the amount of biodegradation as the amount of surface area available for the consumption of hydrocarbons through microbial degradation would be increased by the formation of smaller droplets.

#### ***4.2.2.2 Season 2 (November through April)***

Spills in the “At Berth” region during the months of March, April, and November would show similar characteristics (in terms of the fate and transport of oil) to those during season 1 due to the same tidal transport (e.g., to the northwest on flood tide and southeast on ebb tide). This transport would again be magnified by wind moving in the same direction and decreased by wind moving in the opposite direction. Northwest winds would likely cause shoreline oiling near Point Roberts, along the shorelines of Boundary Pass, Semiahmoo, Birch, and Lummi Bays, and potentially along the northern shores of the northern San Juan Islands, including Lummi, Clark, Barnes, and Puffin Islands. If the spill were to occur on the landward side of the proposed structure, these winds could also force oil to become trapped around the piers at RBT2. A southeast wind would drive transport into the western side of the Strait of Georgia, specifically Valdes, Galiano, Mayne, and Saturna Islands. Unlike during the summer months, shoreline oiling on the eastern shores of the Strait of Georgia north of RBT2 would be possible during this period as the river outflow would not deflect the spill away from the coastline.

The winter months of December, January, and February were dominated by easterly to southeasterly winds, with much less variation observed at the Sand Heads station than during other months. Spills during this time period would likely result in shoreline oiling along the western shores of the Strait of Georgia from Mayne Island to Nanoose Bay, with oil possibly reaching as far north as Parksville and Qualicum Beach. Overall, transport during this period would be to the northwest into these shorelines unless a period of anomalous northwest winds occurred, a few of which were observed in the Sand Heads data. If the spill occurred near the berth and oil was forced to the landward side of the proposed structure, oil could become trapped against the Roberts Bank causeway. Similar to other months in which northwest winds were observed, shorelines to the south would also be at risk of oiling.

Regardless of the spill location, some shoreline oiling would be expected from a spill of heavy fuel oil during this time period, as seen in Study 1 (EBA 2013, Stantec 2013), due to the close confines of the region and the comparable physical chemical properties of these heavy fuel oils to the oils in these studies, but to a lesser extent since the maximum spilled volume of oil would be at least two-times smaller. The colder temperatures observed during this season would further increase the viscosity of these heavy fuel oils and therefore decrease their tendency to spread. However, the period of high wave action (greater than 2.0 m) (**Section 2.3.3**) observed during these months would increase dispersion and entrainment and subsequently increase the amount of oil in the water column. The increase in dispersion and entrainment would enhance the amount of biodegradation as the amount of surface area available for consumption of hydrocarbons by microorganisms would be increased by the formation of smaller droplets.

## 5.0 CONCLUSIONS

A discussion of the major results and conclusions from the Component 2 Spill Assessment study are provided in this section.

### 5.1 DISCUSSION OF KEY FINDINGS AND CONCLUSIONS

#### 5.1.1 Summary of the Analysis of Environmental Conditions

In addition to reviewing existing meteorological and oceanographic literature, wind, wave, and tidal data were synthesised from several Environment Canada and National Oceanic and Atmospheric Administration mooring stations for the environmental conditions analysis of the study area. Wind direction throughout the year is variable in direction and magnitude. The northern stations (Sand Heads and Vancouver International Airport) (**Figure 2-3**) have a more easterly wind field. The most prevalent winds at the Sand Heads station, closest to RBT2, are southeasterly, though a significant percentage is from the northwest. Trends in wind data across all stations are summarised in **Table 5-1**. Overall, the review of environmental conditions data showed that wind changes in direction and strength over the seasons, with stronger winds in winter, and weaker winds from spring to autumn.

**Table 5-1 Summary of General Trends in Seasonality of Wind Data Across all Stations**

Season/Period	Winds
Summer (June to August)	Generally weaker winds, 12 to 20 km/h Dominant directions are southwesterly and southeasterly
Fall (September to November)	Variable speed and direction, 12 to 20 km/h Most frequently northwesterly and east-southeasterly
Winter (December to February)	Stronger winds, 18 to 22 km/h Variable, but predominantly easterly/southeasterly
Spring (March to May)	Variable speed and direction, 12-22 km/h Most frequently southeasterly and southwesterly

Wave stations nearest to RBT2 are located at Roberts Bank and Halibut Bank to the north. Significant wave height events at these stations occurred 34 times over 20 years. The majority of wave heights are less than 0.5 m, averaging 0.33 overall. The wave heights are generally moderate, and the storm events are scarce in the study region. Water levels were examined for tidal effects at three stations in the region, Pt. Atkinson, Tsawwassen, and Patos Island. Semi-diurnal is the dominant tidal pattern. Tidal ranges at all stations were between 3 to 5 m, the most northern stations having the largest ranges.

The mean water flow in the northern basin of the Strait is anticlockwise circulation driven largely by the winds from the northwest, and the buoyancy flux of freshwater input. The mean currents are slow (0.1 to 0.2 m/s) with stronger, mainly semi-diurnal tides superimposed upon them. The flood tides, entering primarily from the south (Boundary Pass), drive currents northward, while ebb tides drive currents

southward (Victoria Experimental Network Under the Sea 2014). The Fraser River is the largest freshwater discharge into the Strait of Georgia and flows approximately perpendicular to the direction of tidal currents and winds in the Strait of Georgia. During the freshet period of river flood and due to heavy rain or snow melt (May to June), the river discharges as a “jet” near Steveston and causes the current to flow in a south-westward direction.

### **5.1.2 Summary of Oil Properties and Fate**

The physical chemical properties of the two most common products, namely light fuel oil and heavy fuel oil, have been reviewed and summarised. Light oils were found to have more volatile fraction making more evaporative and also more soluble in the water column. Light fuel oils evaporate from their surface slicks faster than dissolution into the underlying water. Thus, the processes of evaporation and dissolution are competitive, with evaporation as the dominant process for the surface oil. Light fuel oil is more likely to break up into small droplets that entrain in the water column due to wind and wave forcing, as compared to heavier fuel oils or crudes. In turbulent conditions, this can lead to high concentrations of water column contamination, although usually short-lived. Marine light fuels contain a substantial amount of lower-molecular-weight aromatics (e.g., BTEX and naphthalenes) that could be dissolved in the water column and cause toxicity and biological exposure. Gas oil and diesel oil are among the list of oils that are most likely to cause water column toxicity when spilled in shallow water and create high concentrations of aromatics in localised areas. Overall, spilled light fuel oil is less persistent in the environment and dissipates quicker than heavier oils. The bulk of the light oil products released into the marine environment should spread to its minimum thickness and evaporate relatively quickly.

While many refined products tend to have well-defined properties irrespective of the original crude oil from which they are derived, heavy fuel oils may vary considerably in their properties. Heavy fuel oils contain varying proportions of the residuals of the refining process blended with lighter refined products. Polycyclic aromatic hydrocarbons (PAHs) are the primary soluble constituents of oil that can dissolve into the water column and cause toxicity and biological exposure, PAH concentration and composition among the heavy fuel oils can vary greatly. When heavy fuel oils are spilled, different weathering processes alter the properties of the oil depending on the time period and weather conditions. These processes include: spreading, evaporation, emulsification, natural and chemical dispersion, dissolution of water soluble components, photo-oxidation, and biodegradation. The extent of the various processes depends on the oil's properties, including specific gravity, distillation characteristics, vapor pressure, viscosity, and pour point.

Heavy fuel oils are highly viscous and mostly insoluble. They have minimal fraction of volatiles, and hence are less dispersible in the water and may be more persistent in the environment (water surface and shorelines). The heaviest fractions of the oil may float or sink, depending on the density relationships with the ambient water. Weathered heavy fuel oil may also become incorporated into near shore sediments in

estuaries, where sufficiently high amounts of suspended particulate matters are present. The lighter fractions of heavy fuels may evaporate to the atmosphere or dissolve in water. Some heavy residual fuel oils may undergo little or no evaporation because of the low constituents of light fractions. The thick patches of viscous oils on the water surface may show little tendency to disperse even with the addition of dispersants.

### **5.1.3 Summary of Transport of Spilled Substances in the Study Area**

The general transport and behaviour of potential spills in the study areas was qualitatively evaluated considering site specific seasonality of environmental conditions. For this study the year was broken up into two “seasons”.

Based on wind data from the Sand Heads station, closest to the “At Berth” region, season 1 was defined as May through October. The circulation in the area during the beginning of May is characterised by large discharges from the Fraser River which deflects the tidal and wind-driven currents to the southwest across the Strait of Georgia. Throughout the remainder of the season, tidal and wind-driven circulation dominates the surface waters. Winds are predominantly out of the southeast throughout the season. Northwest winds are also observed and are more frequent towards the end of the season.

Season 2 was defined as November through April. Circulation near RBT2 is controlled by the tidal movement and wind forcing during season 2 as the discharge from the Fraser River is at its lowest. East and east-southeast winds dominate from December through February. Southeast and northwest winds are observed in November, March, and April, though northwest winds are not as prevalent as during other times of the year.

Releases of oil in the “At Berth” region in the spring would be heavily influenced by the Fraser River freshet and be transported with the strong surface currents to the southwest. A release in the summer through early fall would be less influenced by the Fraser River and transport would become less southerly and more dependent upon wind direction. Winds out of the northwest would likely increase the chance of shoreline oiling near RBT2, Point Roberts, and the shorelines along the eastern side of the Strait of Georgia. Winds out of the southeast could potentially cause oiling along the shorelines of Galiano, Mayne, and Saturna Islands. Spills during the winter would most likely be influenced by easterly to southeasterly winds and transport would be towards the western shoreline of the Strait of Georgia.

In general, some light fuel oil could affect the shorelines due to the close confines of the southern Strait of Georgia. However, the bulk of the light oil should spread to its minimum thickness and evaporate within a few days. Turbulent conditions resulting in high entrainment of light fuel oil types may cause short-lived acute water column contamination, especially in shallower waters.

The persistence of heavy fuel oil on the sea surface causes it to likely travel further than light fuel oils resulting in more sea surface area affected and shoreline oiling. Water column contamination is less likely from heavy fuel oils, but is possible in very turbulent conditions. Marine organisms most vulnerable to a heavy fuel oil spill are those that interact with the sea surface (e.g., marine mammals, seabirds, and neuston) and are found along shorelines and in intertidal zones.

A modelling study for another development project in the region (EBA 2013, Stantec 2013) found that there was a high to very high probability that shoreline oiling would occur based on past modeling study of release at location D of the Study Area (Fig. 4-3). The oil used for the modelling study had similar physical chemical properties as heavy fuel oils considered in this analysis, although release volumes were higher than the MCDs predicted for RBT2 (16,500 m<sup>3</sup> versus 2,500 or 7,500 m<sup>3</sup>). The modelling study found that the potential for negative impacts to the water column was low due to low dissolved polycyclic aromatic hydrocarbon (PAH) concentrations.

The MCD volumes associated with RBT2 traffic and activity, as predicted by the Component 1 assessment (Herbert Engineering Corp. et al. 2014), were relatively low (2,500 and 7,500 m<sup>3</sup>).

## 6.0 CLOSURE

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## **8.0 STATEMENT OF LIMITATIONS**

This report was prepared by RPS ASA for Port Metro Vancouver, based on other studies conducted by Hemmera and other subcontractors, for the sole benefit and exclusive use of Port Metro Vancouver. The material in it reflects RPS ASA's best judgment in light of the information available to it at the time of preparing this Report. Any use that a third party makes of this Report, or any reliance on or decision made based on it, is the responsibility of such third parties. RPS ASA accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this Report.

RPS ASA has performed the work as described above and made the findings and conclusions set out in this Report in a manner consistent with the level of care and skill normally exercised by members of the environmental science profession practicing under similar conditions at the time the work was performed.

This Report represents a reasonable review of the information available to RPS ASA within the established Scope, work schedule and budgetary constraints. The conclusions and recommendations contained in this Report are based upon applicable legislation existing at the time the Report was drafted. Any changes in the legislation may alter the conclusions and/or recommendations contained in the Report. Regulatory implications discussed in this Report were based on the applicable legislation existing at the time this Report was written.

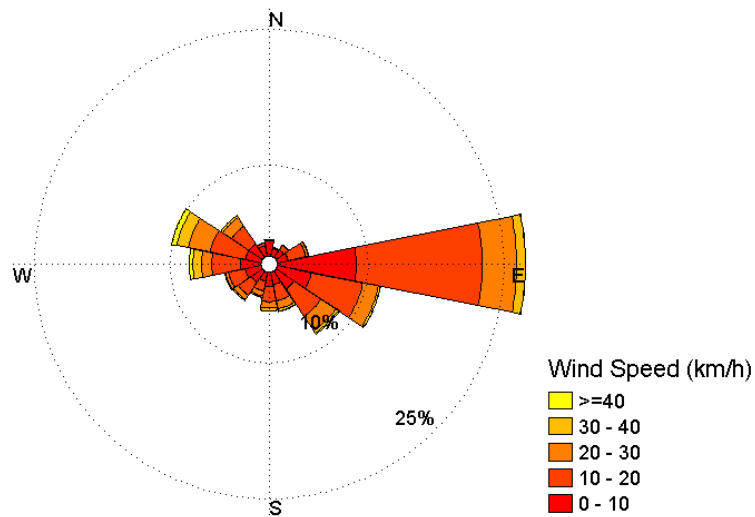
In preparing this Report, RPS ASA have relied in good faith on information provided by others as noted in this Report, and has assumed that the information provided by those individuals is both factual and accurate. RPS ASA and Hemmera accept no responsibility for any deficiency, misstatement or inaccuracy in this Report resulting from the information provided by those individuals.

# **APPENDIX A**

## **Additional Environmental Conditions Analysis Figures**

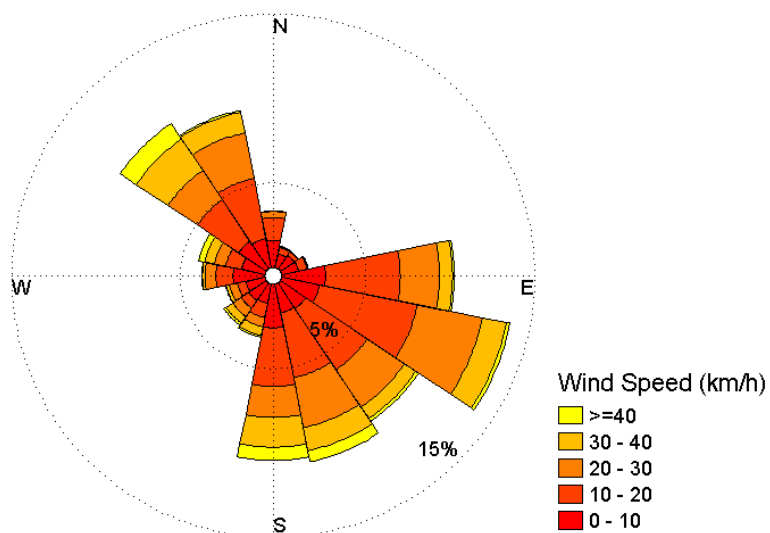
**Figure A-1**      **Yearly Wind Rose at Vancouver International Airport for 2012 and 2013 (average of both years). Wind Direction is in the Traditional Convention (coming from)**

**Vancouver International Airport Yearly Wind Rose 2012-2013**



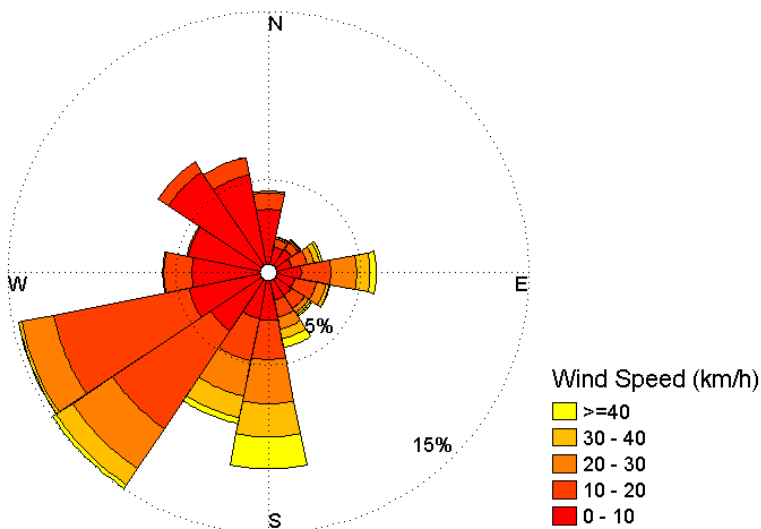
**Figure A-2**      **Yearly Wind Rose at Sand Heads for 2012 and 2013 (average of both years). Wind Direction is in the Traditional Convention (coming from)**

**Sand Heads Yearly Wind Rose 2012-2013**



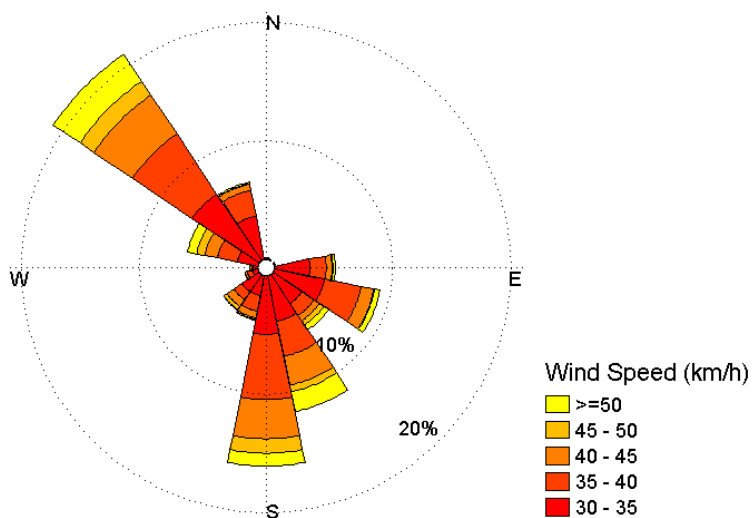
**Figure A-3**      **Yearly Wind Rose at Saturna Island for 2012 and 2013 (average of both years).**  
**Wind Direction is in the Traditional Convention (coming from)**

**Saturna Island CS Yearly Wind Rose 2012-2013**



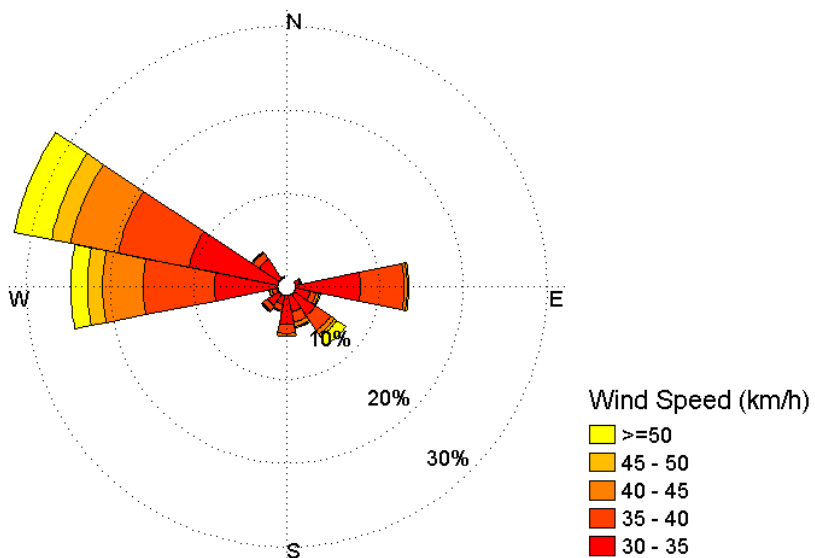
**Figure A-4**      **Wind Speed and Direction for Speeds >30 km/h at Sand Heads for 2012 and 2013 (average of both years)**

**Sand Heads Yearly Wind Rose 2012-2013**



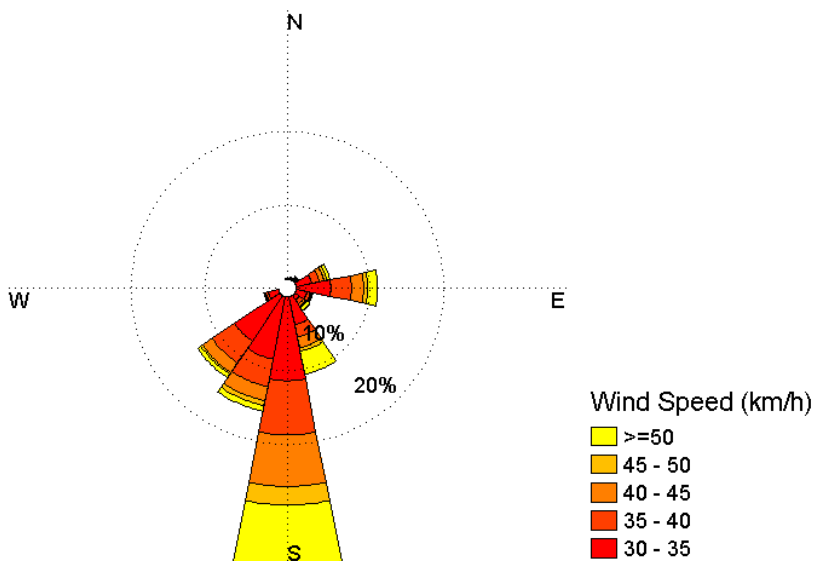
**Figure A-5** Wind Speed and Direction for Speeds >30 km/h at Vancouver Int'l Airport for 2012 and 2013 (average of both years)

**Vancouver International Airport Yearly Wind Rose 2012-2013**

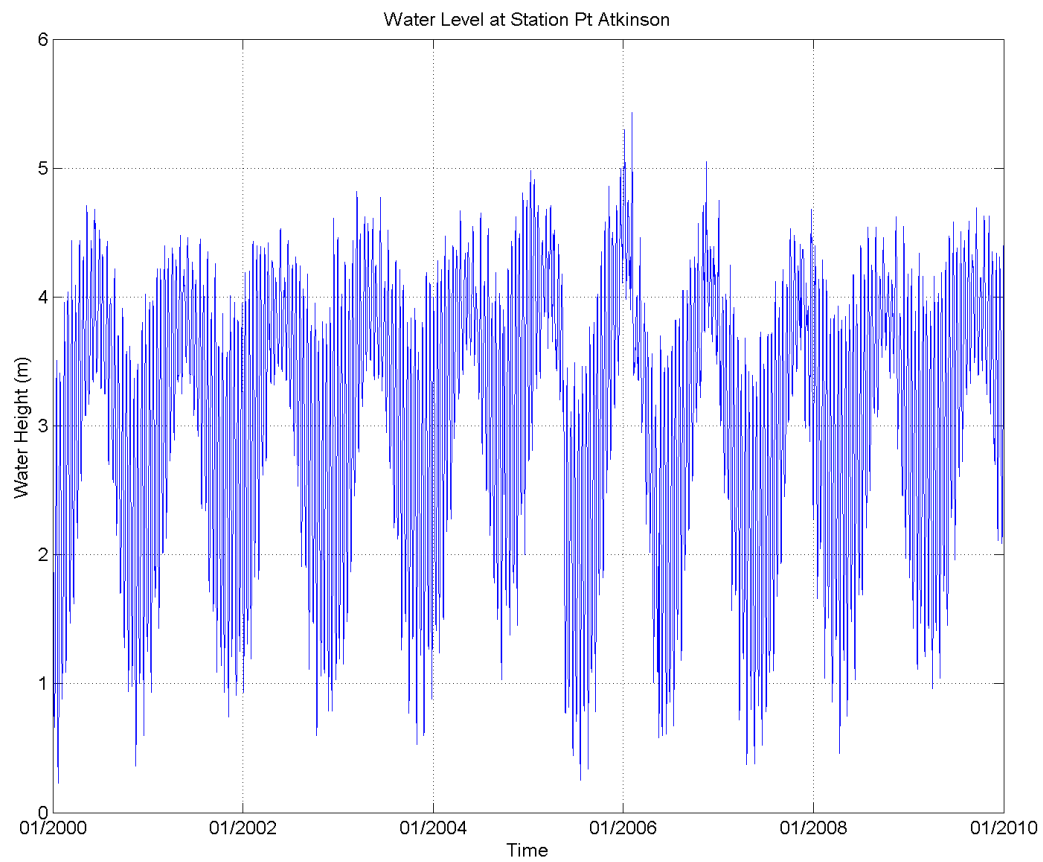


**Figure A-6** Wind Speed and Direction for Speeds >30 km/h at Saturna Island for 2012 and 2013 (average of both years)

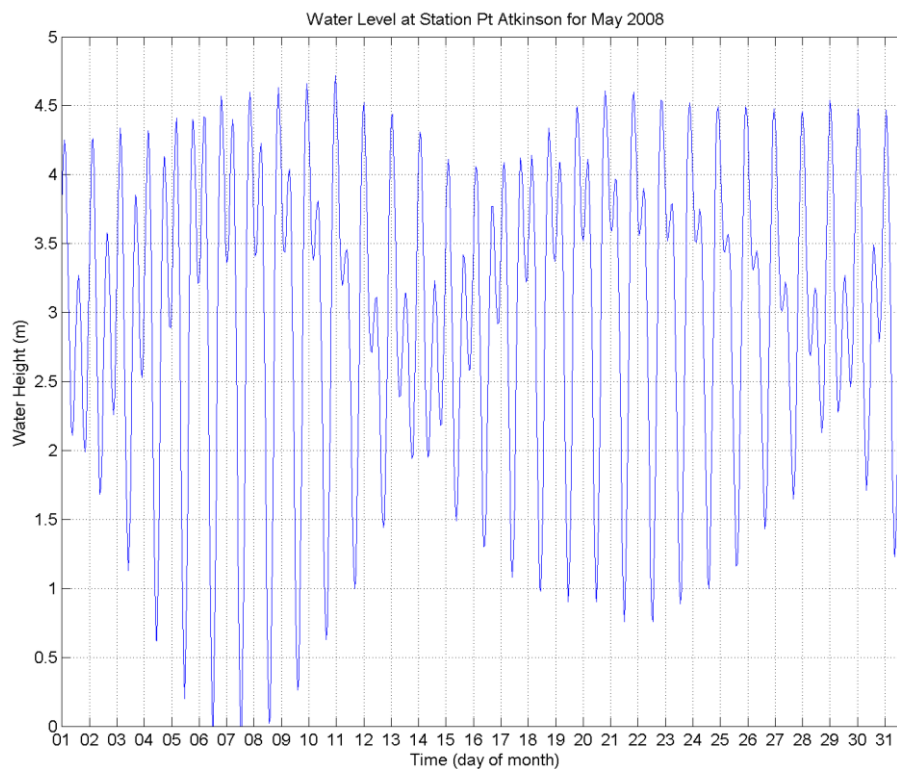
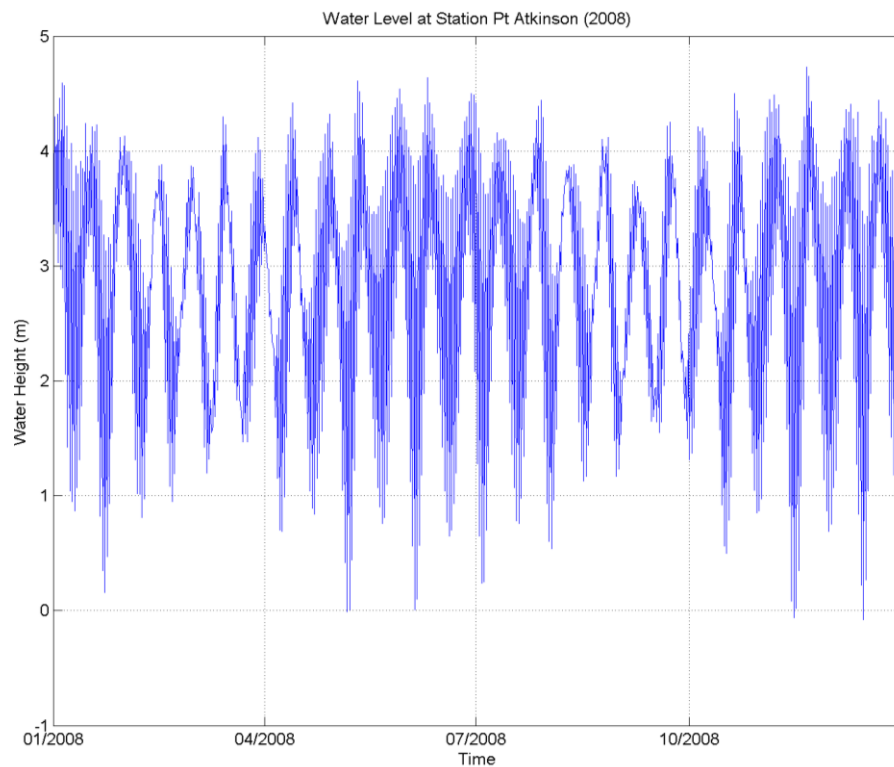
**Saturna Island CS Yearly Wind Rose 2012-2013**



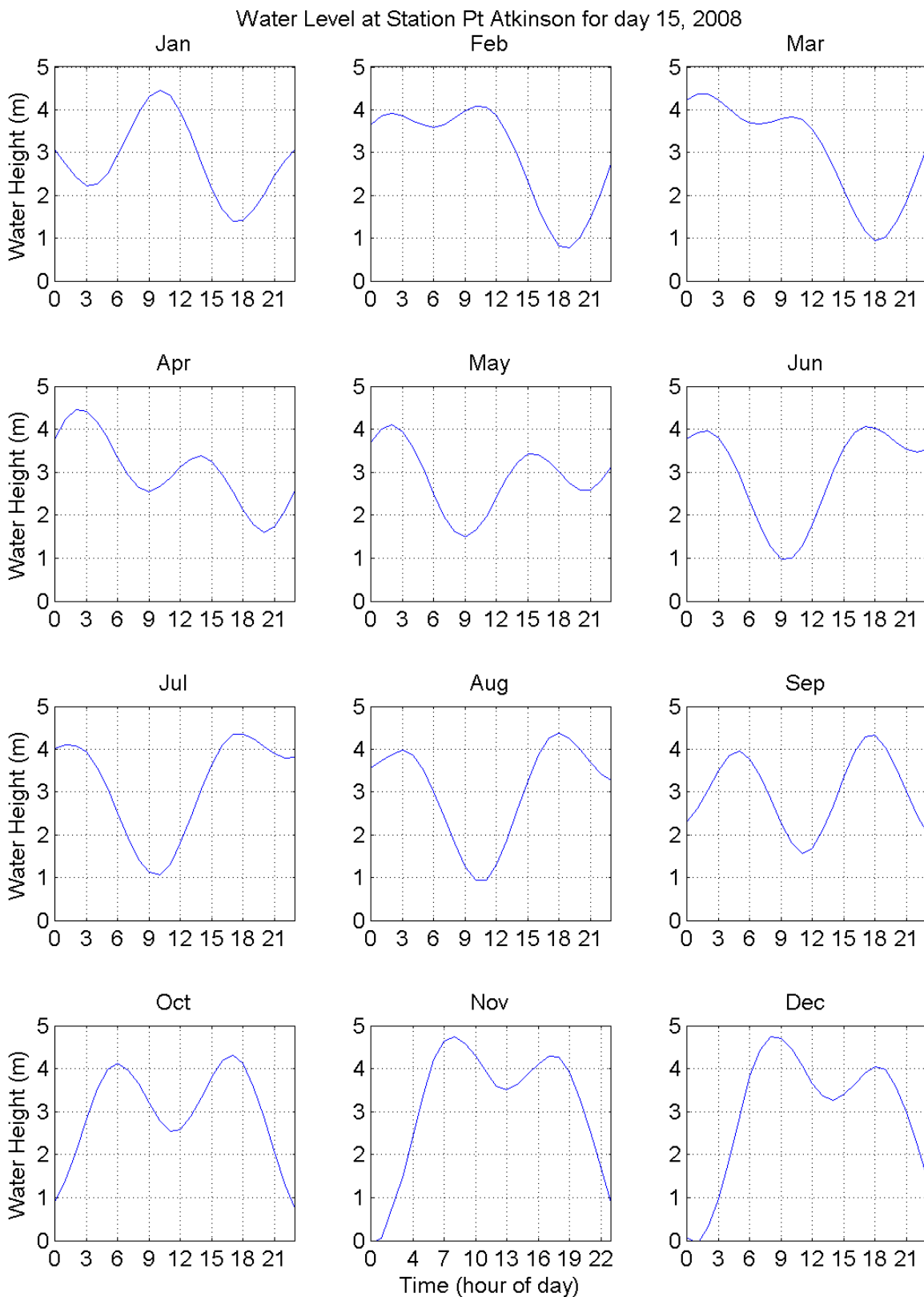
**Figure A-7 Water Level Data at the Pt. Atkinson Station for 2000 to 2010**



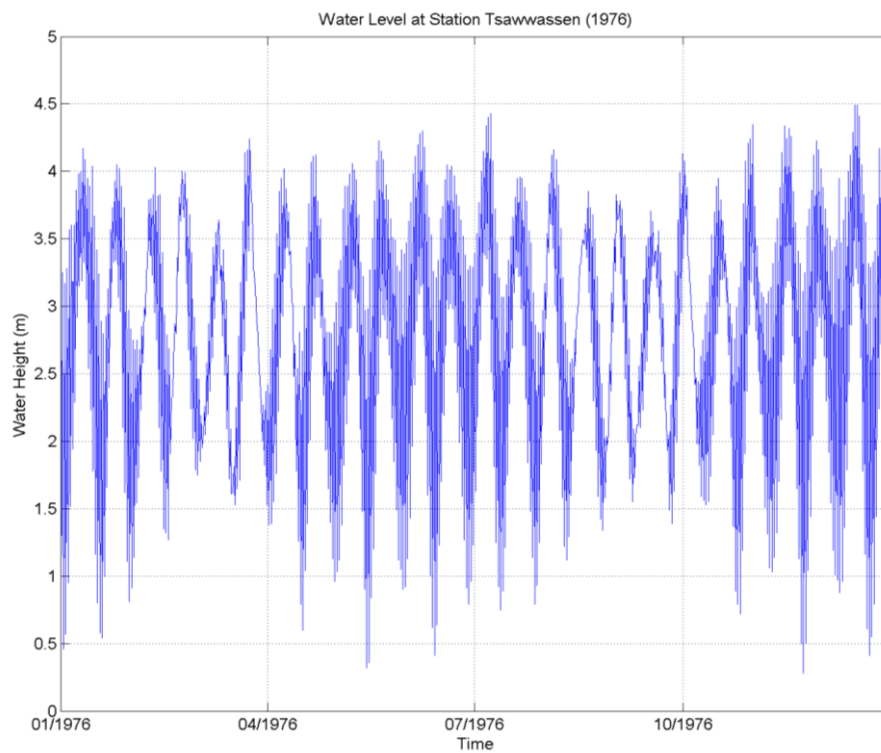
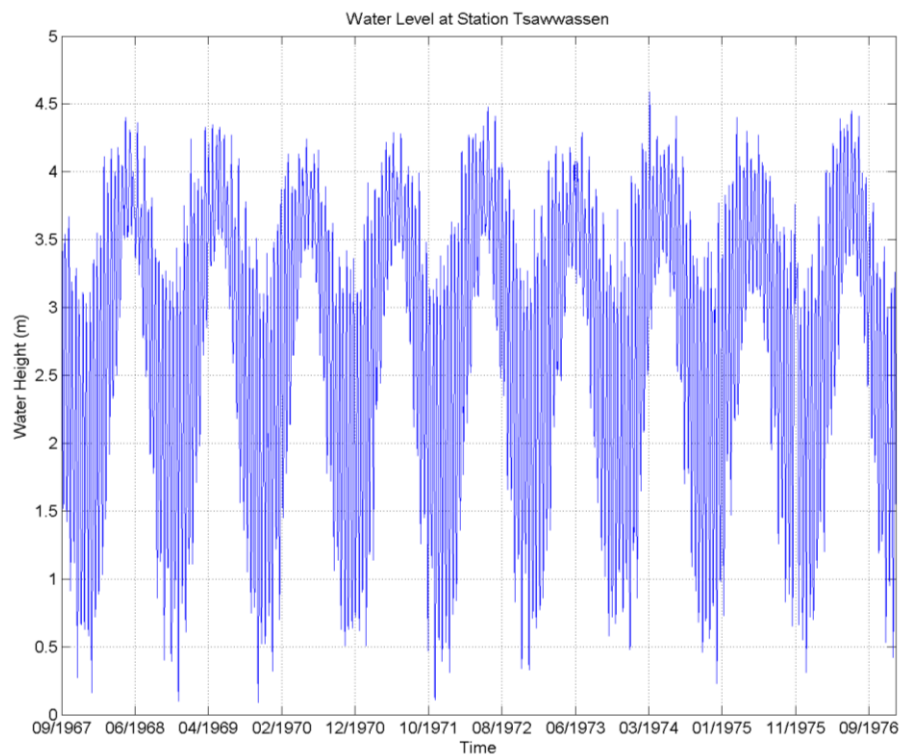
**Figure A-8 Water Level Data at the Pt. Atkinson Station for 2008 (top) and Daily for May 2008 (bottom)**



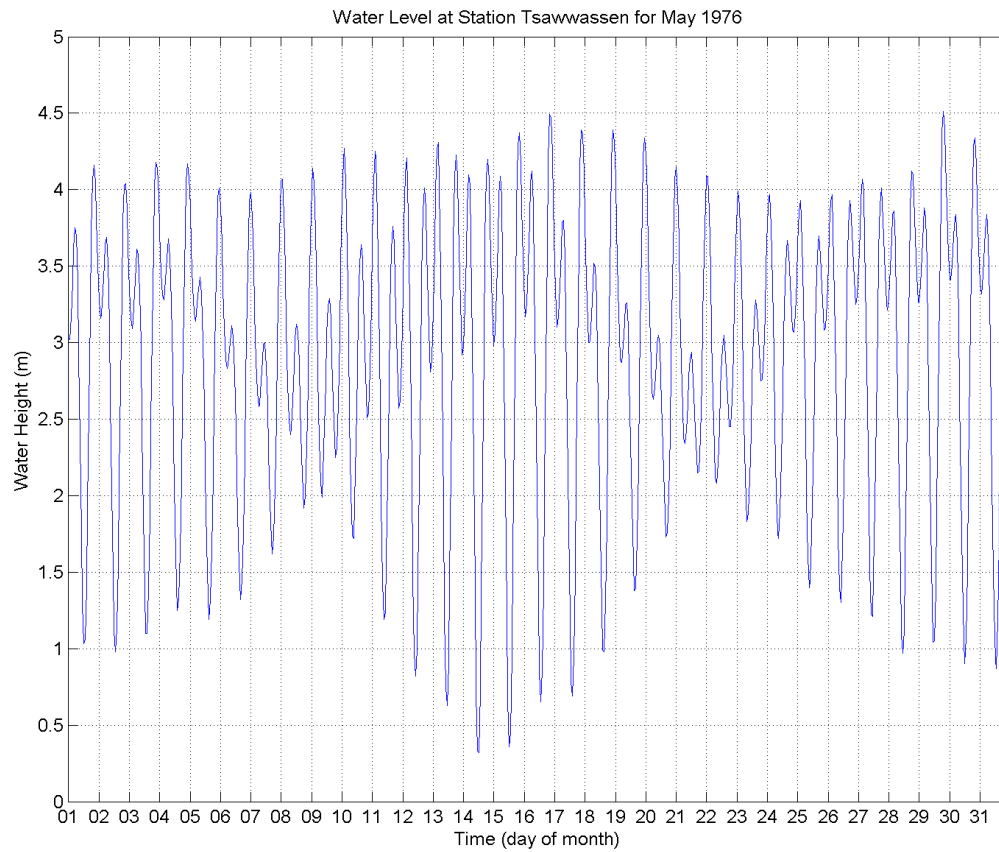
**Figure A-9 Monthly Water Level for a Specific Day (shown is the 15th) at Pt. Atkinson Station (2008)**



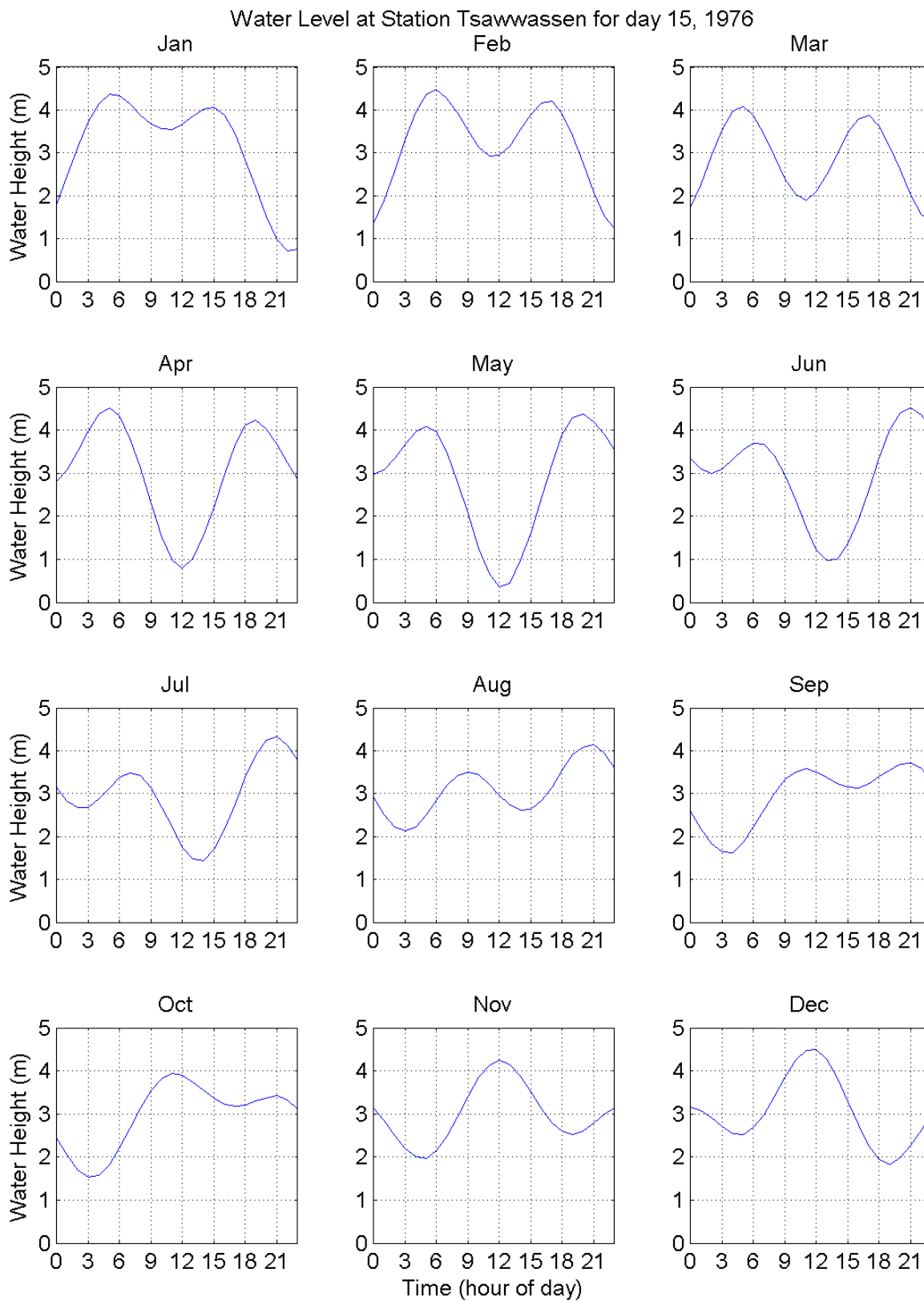
**Figure A-10 Water Level Data at the Tsawwassen Station for 1967 to 1977 (top) and 1976 (bottom)**



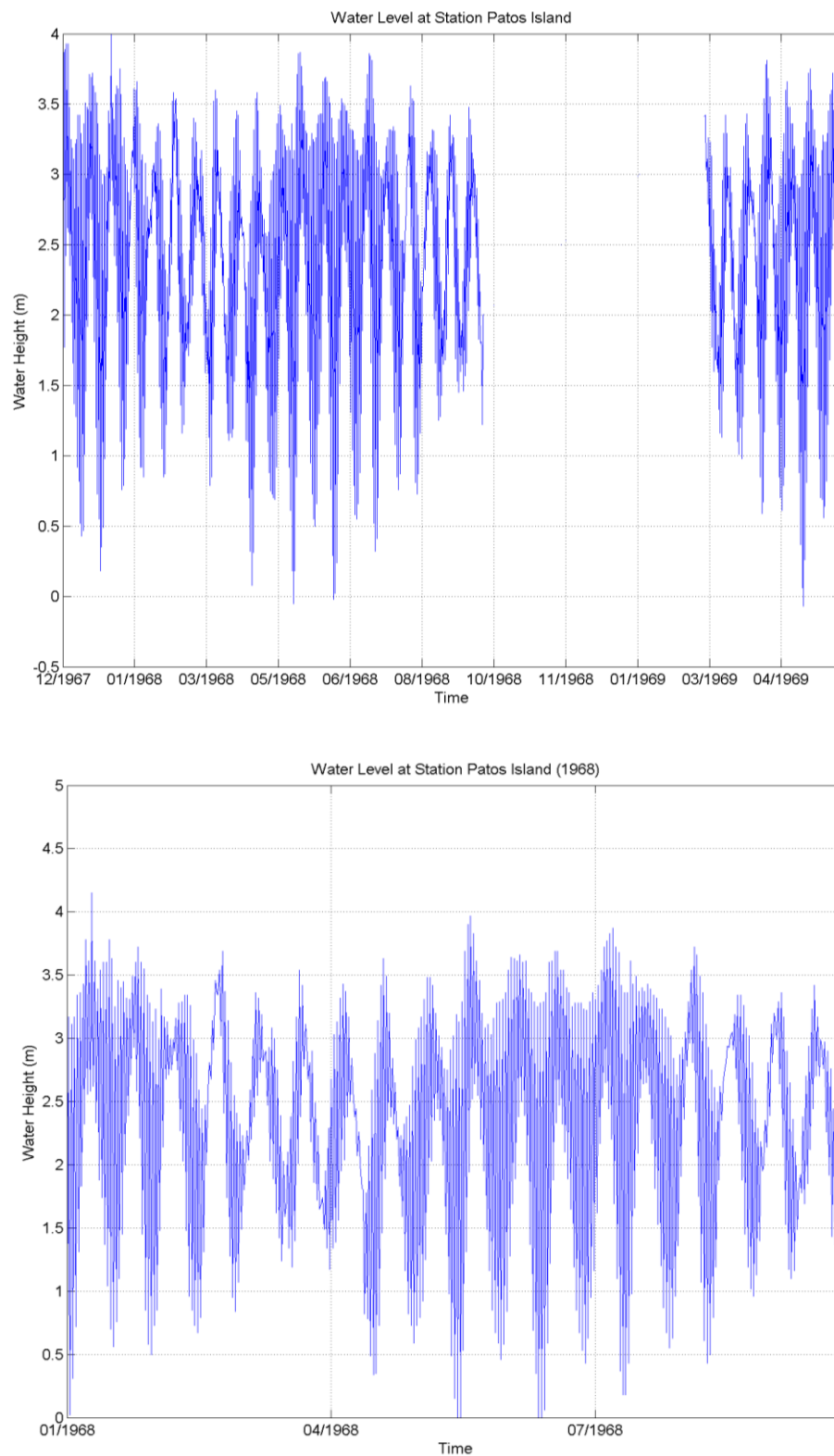
**Figure A-11 Water Level for Tsawwassen for May 1976**



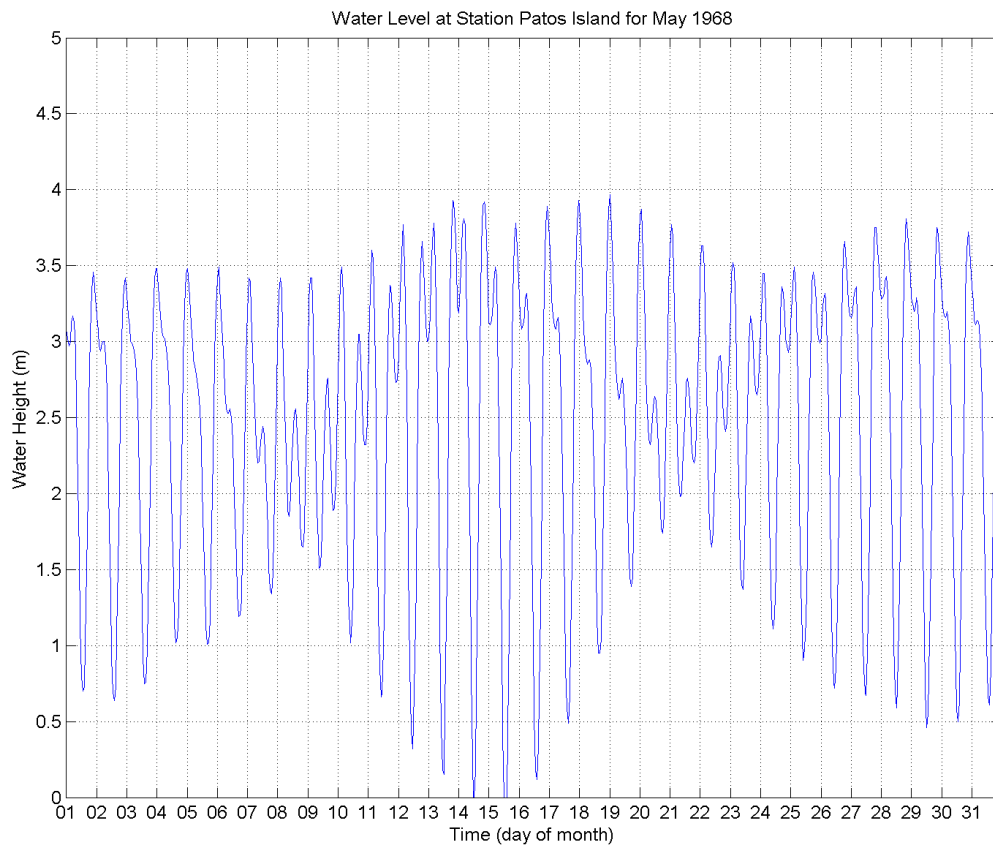
**Figure A-12 Monthly Water Level for a Specific Day (shown is the 15th) at Tsawwassen Station (1976)**



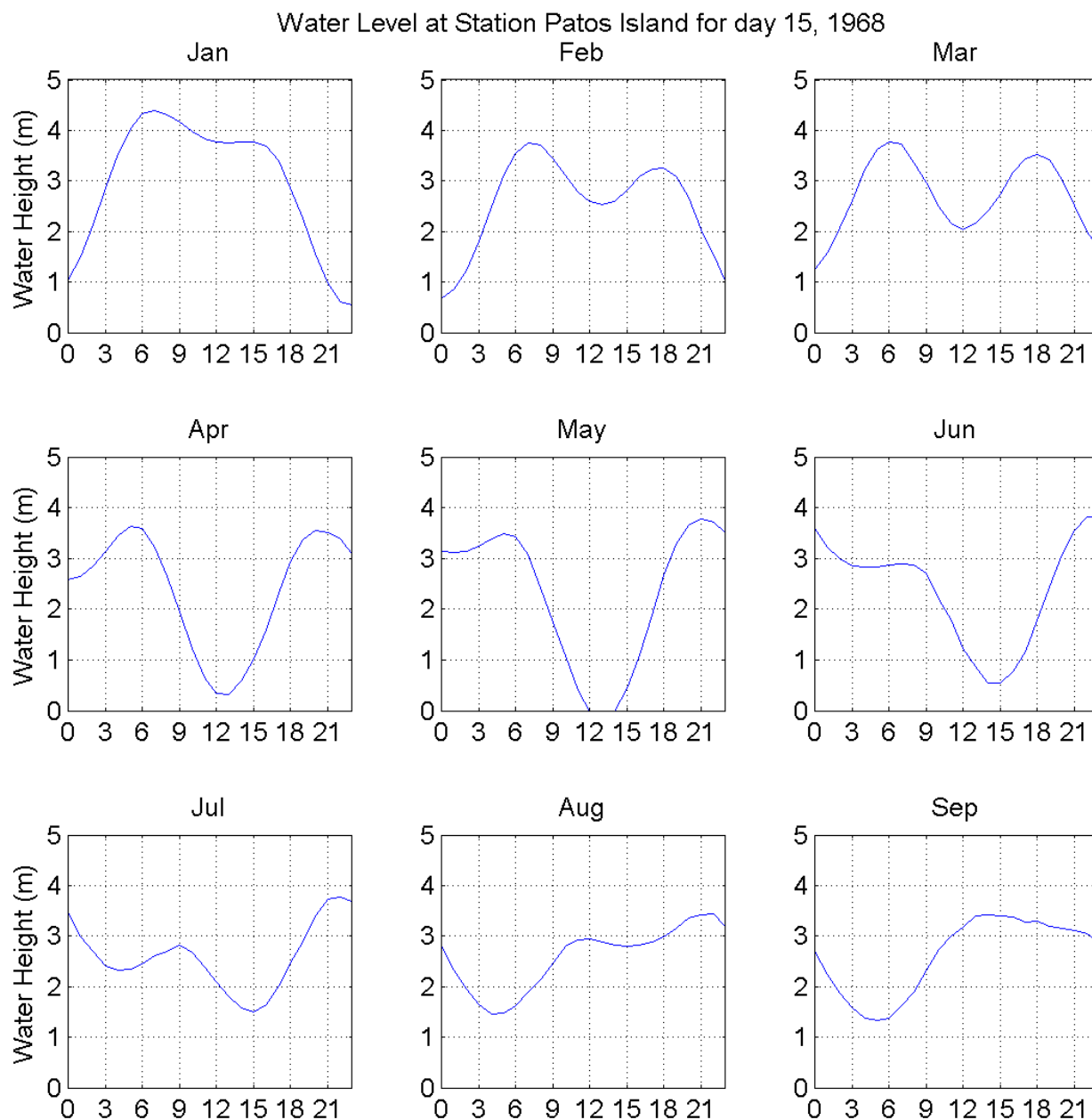
**Figure A-13 Daily Water Level Data at the Patos Island Station for 1967 to 1969 (top) and 1968 (bottom)**



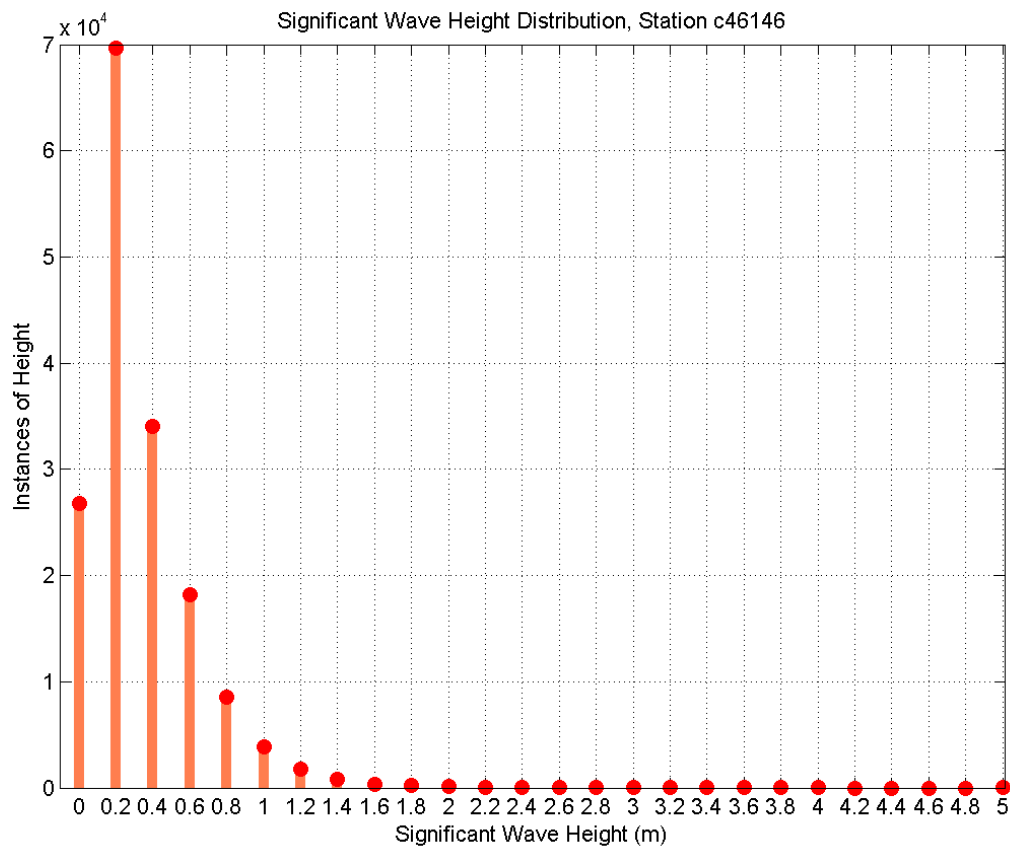
**Figure A-14 Water Level for Patos Island for May 1968**



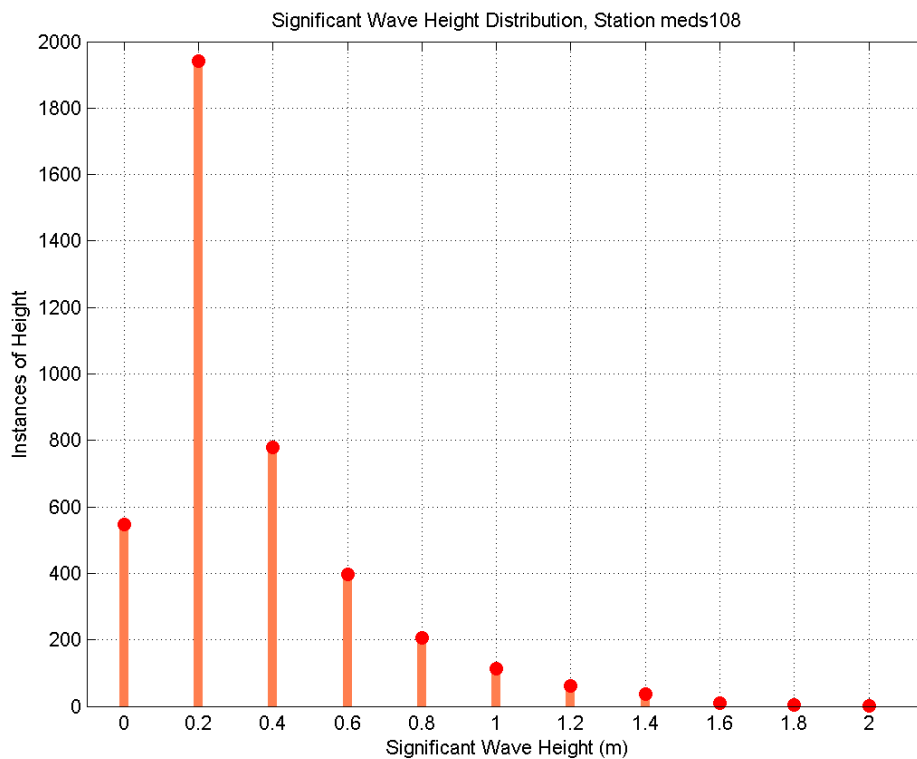
**Figure A-15 Monthly Water Level for a Specific Day (shown is the 15th) at Patos Island Station (1968)**



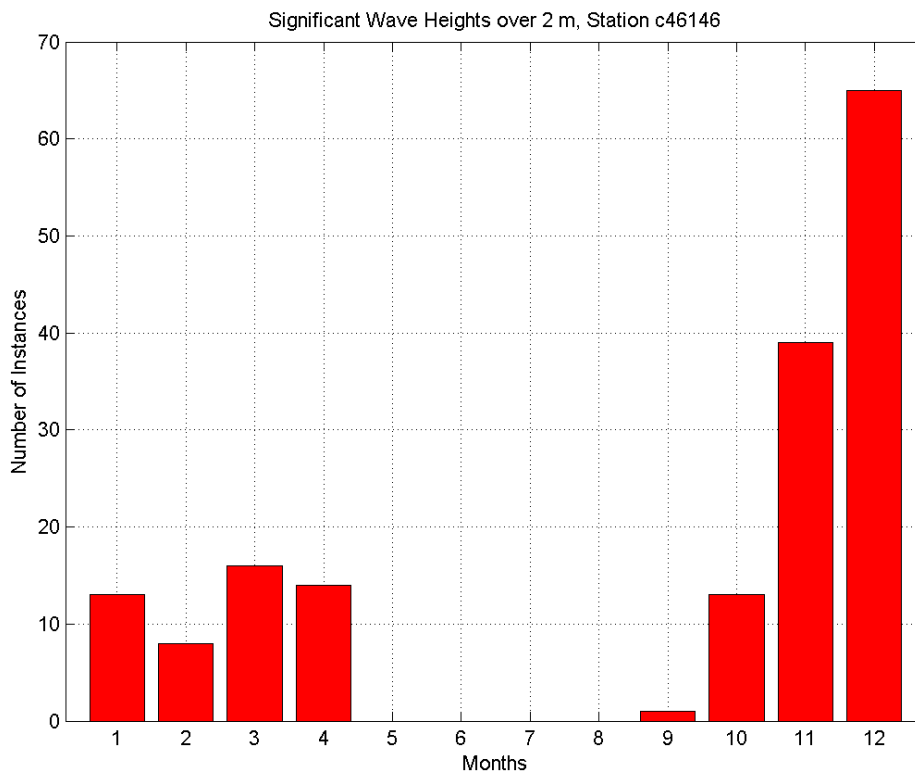
**Figure A-16 Significant Wave Height Distribution for Halibut Bank, 2010 to 2013**



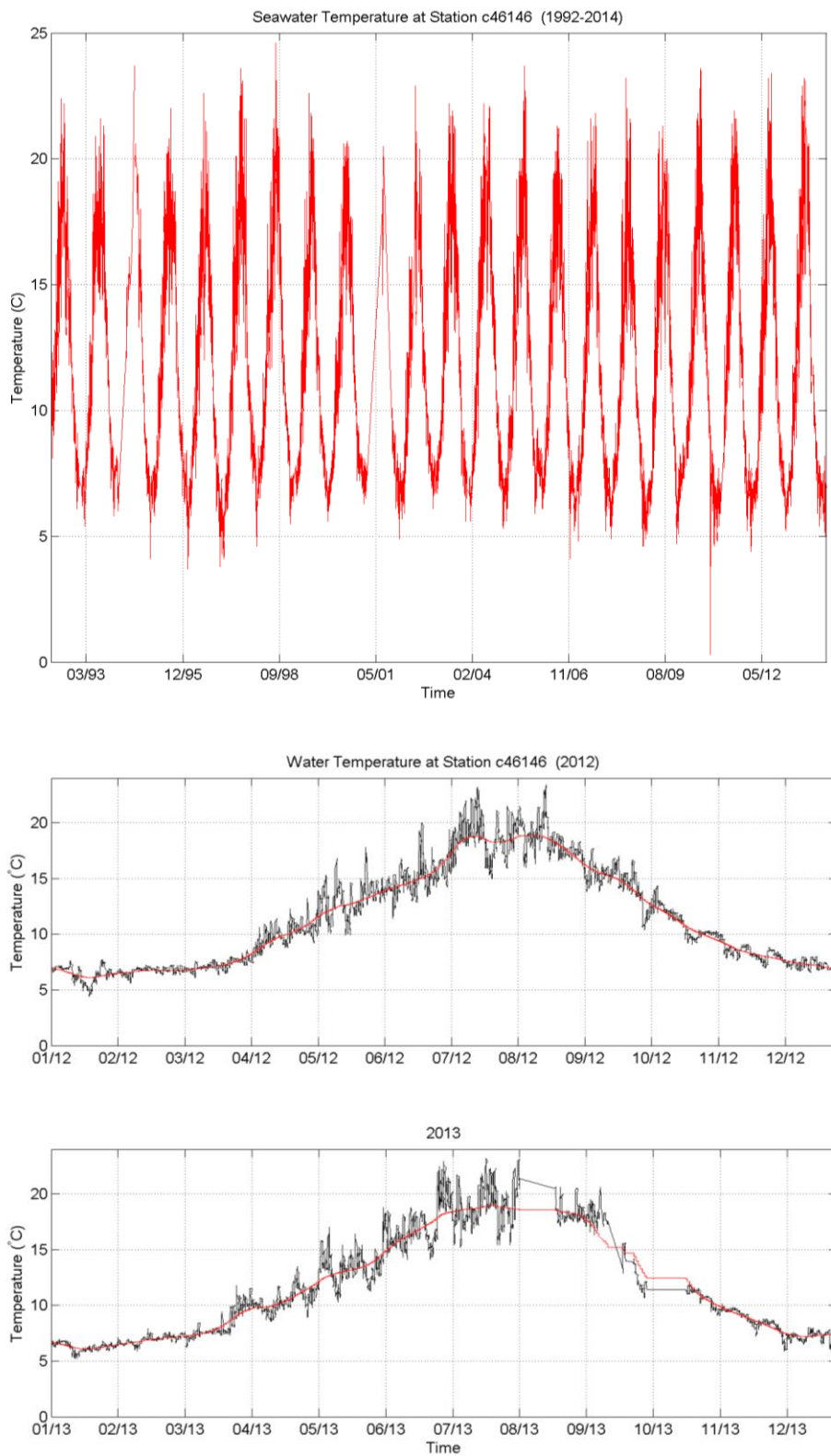
**Figure A-17 Significant Wave Height Distribution for Roberts Bank, 1974 to 1976**



**Figure A-18 Monthly Frequency of Significant Wave Heights Over 2 m for Halibut Bank, 1992 to 2014**



**Figure A-19 Temperature Data from Halibut Bank, (Buoy c46146) from 1992 to 2014 (top). Yearly Averages Shown in the Bottom Two Panels**



**APPENDIX 30-C**  
**Supplemental Information Regarding**  
**Traffic Safety on Roberts Bank Causeway and**  
**Deltaport Way Overpass**

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### Appendix 30-C Supplemental Information Regarding Traffic Safety on Roberts Bank Causeway and Deltaport Way Overpass

**Table 30-C1** shows 2012 traffic levels for the existing Roberts Bank terminals. In 2012, over half (56%) of the total vehicles that travelled along the Roberts Bank causeway were trucks, while the remaining 44% were passenger vehicles (**Appendix 4-D Roberts Bank Traffic Data Matrix**).

**Table 30-C1 Annual Inbound and Outbound Traffic Levels Along Roberts Bank Causeway (2012)**

Trucks	Personal Vehicles	Total Vehicles
Deltaport Terminal only	Deltaport Terminal and Westshore Terminals	Deltaport Terminal and Westshore Terminals
634,000	498,000	1,132,000

**Table 30-C2** shows the number of collisions and associated injuries on the Roberts Bank causeway for the 10-year period from 2004 to 2013, based on information provided by the Insurance Corporation of British Columbia (ICBC) and collected from police data. The term casualty refers to crash incidents resulting in injury or fatality; the term property damage refers to crash incidents resulting in material damages to vehicles with no injuries or fatalities. Based on this data, an average of 3.4 collisions per year occurred on Roberts Bank Road and the Deltaport Way overpass from 2004 to 2013. During this time, the number of casualty crashes averaged 1.1 per year. The number of people injured is unknown, but may be higher than 1.1 per year as a collision may result in injuries to more than one person. There were no fatal crashes along Roberts Bank Road and the Deltaport Way Overpass corridor in Delta within the 10-year period from 2004 to 2013.

**Table 30-C2 Traffic Collision Data for Roberts Bank Road and Deltaport Way Overpass**

Years	Accident Severity		Total Accidents
	Casualty	Property damage only	
2004	0	3	<b>3</b>
2005	0	0	<b>0</b>
2006	0	4	<b>4</b>
2007	1	2	<b>3</b>
2008	1	1	<b>2</b>
2009	0	3	<b>3</b>
2010	1	4	<b>5</b>

Years	Accident Severity		Total Accidents
	Casualty	Property damage only	
2011	2	5	7
2012	4	1	5
2013	2	0	2
<b>Total</b>	<b>11</b>	<b>23</b>	<b>34</b>

**Source:** ICBC

Since the majority of construction-related traffic will not travel on the paved areas of the existing causeway during construction, the Project is not expected to affect traffic levels along Deltaport Way during its construction phase. Project traffic will be limited to the north part of the new causeway section as it is filled in. As a result, the number of traffic-related injuries is not expected to increase during the construction phase as a result of the Project.

**Table 30-C3** identifies projected RBT2 operations traffic for 2025, a year in which the new terminal would have attained its design capacity. Overall traffic levels are expected to increase by approximately 191% from 2012 levels, including a 203% increase in container truck traffic and a 177% increase in service and personal vehicles (considering increases in traffic associated with Deltaport Terminal, Westshore Terminals, and RBT2).

**Table 30-C3 Projected Annual Inbound and Outbound Operational (2025) Traffic Levels Along the Roberts Bank Causeway**

Year	Container Trucks			Service and Personal Vehicles			Total Vehicles
	Deltaport Terminal	RBT2	Total	Deltaport Terminal and Westshore Terminals	RBT2	Total	With RBT2
2012	634,000	-	634,000	498,000	-	498,000	<b>1,132,000</b>
2025	959,000	959,000	1,918,000	753,000	627,000	1,380,000	<b>3,298,000</b>
<b>Increase (%)</b>			<b>203%</b>			<b>177%</b>	<b>191%</b>

**Source:** see **Appendix 4-D – Roberts Bank Traffic Data Matrix**

Traffic along the Roberts Bank causeway will increase during Project operation, and this may result in a proportional increase in motor vehicle accidents. Based on this assumption, the number of accidents may increase from the current annual average of 3.4 accidents to 6.5 accidents, including an average of 2.1 casualty accidents per year.