TERMPOL 3.15 – GENERAL RISK ANALYSIS AND INTENDED METHODS OF REDUCING RISKS

Trans Mountain Expansion Project

Prepared for:

TRANS MOUNTAIN

Prepared by:

DNV

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REPORT

Termpol 3.15 General Risk Analysis and Intended Methods of Reducing Risks

TRANS MOUNTAIN PIPELINE EXPANSION PROJECT

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PP061115	**167ITKV-9/PP061115**	**Termpol 3.15 General Risk Analysis and Intended Methods of Reducing Risks**

Task and Objective:

This report describes the marine transport Quantitative Risk Analysis (QRA) completed as part of the Termpol review process for the Trans Mountain Expansion Project (TMEP). The QRA fulfils a number of the requirements described in Section 3.15 of Termpol.

Termpol 2001 recommends examining the probability of certain events occurring en route to the marine terminal or during marine terminal transhipment and the likelihood of an event causing an uncontrolled release of oil or bunker fuel. Incident scenarios considered in the QRA include:

- a ship to ship collision;
- a ship grounding (powered and drift);
- a ship striking a fixed object (e.g. marine structures during berthing);
- an incident resulting from improper cargo transfer;
- a fire or explosion on board the vessel, or
- foundering due to structural failure

In addition this QRA also examines the risk of a tanker at the berth being struck by a passing vessel and the risk of a tug boat striking and damaging a tanker.

- As requested in Termpol 2001 the QRA examines:
- the probabilities of credible incidents that could breach a ship's cargo containment system;
- the risks associated with navigation to and from Westridge Marine Terminal;
- the probabilities of cargo transfer incidents at one of the three berths at Westridge Marine Terminal;
- the consequences of an incident occurring, and
- the probability that an incident becomes "uncontrollable".

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EXECUTIVE SUMMARY

Trans Mountain Pipeline ULC (Trans Mountain) proposes to increase the capacity of the Trans Mountain Pipeline system from the current 300,000 bbls/day to an estimated 890,000 bbls/day (the Project). This will result in an increased number of tankers calling the Westridge Marine Terminal (Westridge terminal) to load crude oil cargo. As a result, Trans Mountain expects that tanker traffic to the Westridge terminal shall increase from about 60 per year to around 408 per year if the terminal and pipeline system is developed as planned. Trans Mountain will work to minimize the potential effect from the Project, specifically the increase in tanker traffic and to manage and mitigate accidental risk related to the loading and transit of the tankers. As part of this and to meet the Termpol guidelines, Trans Mountain has assigned DNV to conduct a marine traffic and cargo handling risk assessment and identification of potential risk reducing measures.

The sailing route from Westridge terminal to high seas outside the mouth of Juan de Fuca Strait is a relatively uncomplicated route. The most challenging part is the start of the route from the terminal through the Second and First Narrows in the Vancouver harbour area, which is a Movement Restricted Area (MRA). The transit of laden oil tankers is strictly regulated with requirement of two pilots until the Juan de Fuca Strait and use of tethered tug escort in the harbour area and through the Boundary Pass and Haro Strait. The whole sailing route has a traffic separation scheme (TSS) and is monitored and guided by the Canadian Coast Guard MCTS and U.S. Coast Guard VTS. Thus it can be concluded that the sailing route is well managed and has a high level of risk control in place.

The oil tankers that transit the terminal, now and in the future, are modern high standard double hull vessels that are operated by qualified and competent mariners. The tankers have to meet strict acceptance standards set by Trans Mountain prior to calling at the terminal. The tankers are loaded under supervision of a Trans Mountain Loading Master and checked prior to departing laden from the terminal in order to confirm that all safety conditions onboard the tanker will be met during her passage to sea.

An overview of traffic patterns and traffic details in the study area was obtained by analysing AIS data records for 2012. A growth forecast was developed and applied to the 2012 data to estimate traffic for 2018 and 2028 for use in the risk assessment. Based on this forecast, if the project proceeds, in 2018 Trans Mountain tankers will represent only 3.3% of the distance sailed by all vessels in the AIS data set for the study area.

Oil tankers that call Trans Mountain's Westridge terminal are and will be modern double hull vessels of Aframax size (80,000 - 120,000 DWT) and in the majority of these vessels the bunker oil tanks will be protected by a double hull. So only the most severe impacts from an incident like a high-energy collision or grounding is expected to cause an oil spill. ITOPF data on accidental oil spills show a clear decrease in both the number and the volume of oil spill in recent decades. The average total oil spill volume per year has decreased with a factor of 18 from the 1970s until the last decade. The number of accidental oil spills has decreased with a factor of 5 in the same period

The hazards and risks related to a sailing route are prevented and mitigated by implemented risk control measures. The study area sailing routes are well managed and important risk controls have been established for all traffic and for oil tankers in particular. These controls are in line with global best practices. These risk controls will continue to reduce the frequency of critical situations (e.g. the traffic separation scheme will reduce the frequency of encounters (the critical situation for collision)) and reduce the probability of an incident given a critical situation (e.g. pilotage will reduce the probability of collision given an encounter). The following risk reducing measures have been taken into account in the risk assessment: VTS, Traffic Separation Scheme, Pilotage, PPU, ECDIS/ENC, Ship vetting, escort tugs (tethered and non-tethered tugs), one-way traffic. Some of the risk reducing measures are only applicable for specific vessel types and for specific areas. Compared to other traffic tankers have more risk reducing measures applied.

The assessment considers the effect on incident risk of traffic growth from Trans Mountain tanker traffic as well as from overall traffic growth in the study area (Chapter 7). The increase in traffic resulting from the Project (going from 60 to 408 tankers per year) is found to have a negligible effect on the total incident frequency for the region. With or without the Project, tanker traffic remains a small part of total traffic in the region.

For the purposes of the assessment the oil cargo spill risk (Chapter 10) is the combination of the oil cargo spill accident frequency (Chapter 7 and 8) and the oil cargo spill consequence (Chapter 9). Oil cargo spill accident frequency is calculated for Trans Mountain tanker traffic and for all tanker and oil barge traffic in the area. Only ships with oil as cargo are included. For the purpose of the assessment "consequence" refers to the volume of cargo that may be released. Oil outflow in this study has been modelled for a partially laden Aframax tanker.

For in-transit Trans Mountain tanker traffic in 2018:

- Without the Project the frequency of accidents resulting in an oil cargo spill of any size is estimated to be 1 in every 309 years. Post implementation of the Project, if no additional risk reducing measures are implemented, the frequency will be 1 in every 46 years. If all the risk reducing measures discussed in this report are implemented the frequency will be 1 in every 237 years.

- The consequence of an oil cargo spill accident depends on the extent of the damage to the vessel's hull and the amount of oil that can spill from a ship. The damage severity and oil outflow modelling shows that the 90th percentile worst case scenario is the loss of the entire contents of two cargo oil tanks to the sea, which gives an oil outflow of approximately 16,500 m3. Such an event is considered the credible worst case oil spill.

- Without the Project in 2018 the risk of a credible worst case oil spill is estimated to be 1 in every 3093 years. Once the Project is implemented, if no additional risk reducing measures are implemented, the frequency will be 1 in every 456 years. If all the risk reducing measures discussed in this report are implemented the frequency will be 1 in every 2366 years.

- This means that after the Project enters service provided all current and future proposed risk control measures are implemented, the increased risk of a credible worst case oil spill in the study area from the Trans Mountain tanker traffic will be only 30% higher than the risk of such an occurrence if the Project did not take place.

With effective implementation of risk reducing measures most of the incremental risk resulting from the Project can be eliminated. The additional risk reducing measures identified by DNV for laden Trans Mountain tankers include; extending tug escorts to cover the entire sailing route from the terminal to the mouth of Juan de Fuca, and implementing a moving exclusion/safety zone around the tankers during transit. The extended tug escort will lead to reduction in the grounding likelihood while the exclusion zone will reduce the likelihood of a collision. If implemented, these measures will further increase the safety of the already well-managed sailing route.

Oil spill risk for Westridge terminal activities was also calculated. Without the Project the frequency of a $<10m^3$ spill is estimated to be 1 every 234 years while a spill $<100\ m^3$ is estimated to be a 1 every 1,655 years event. With the Project the frequency of a $<10m^3$ spill is estimated to be 1 every 34 years while a spill $<100\ m^3$is estimated to be a 1 every 234 years occurrence. The basic frequencies of a release during cargo transfer activities are derived from European terminal accident statistics and modified to account for site specific risk reducing measures that will be implemented at the new Westridge terminal. A credible worst case oil spill during loading is calculated as 103 m^3 based upon damage to one loading arm during cargo loading at one of the berths at the future Westridge terminal. The return period of such an occurrence is calculated as a 1 in every 234 years event. The preventative booms deployed around the berths are expected to have an oil containment capacity of more than 1500 m3 oil. The return period for a 16,500 m^3 size oil spill for tankers berthed at Westridge terminal or at anchor east of the Second Narrows is estimated as 1 in every 227,270 years if the Project did not proceed and 1 in every 50,000 years if the Project proceeds. The historical oil spill data shows that the probability for an accident with total loss of containment is so low that it does not represent a credible worst case scenario involving modern tankers of the type proposed for this project. Thus a total loss of containment is not considered as credible worst case scenario for this risk assessment nor for the oil spill response capacity assessment.

Spill response in the region is currently the subject of review by the Federal and Provincial governments of Canada. Based on information from the risk assessment enhanced planning standards for spill response describe a regime that will be able to deliver 20,000 tonnes of capacity within 36 hours from dedicated resources staged within the study area. This represents a response capacity that is double and a delivery time that is half the existing planning standards. These enhancements will reduce times for initiating a response to two hours for the harbour and six hours for the remainder of the study area and parts of the West Coast of Vancouver Island. These reduced times will be achieved by creating new base locations along the tanker route. Meeting the response capacities within the designated times requires redundancy of equipment, as a result the overall capacity of dedicated response equipment available in the area will be in excess of 30,000 tonnes. WCMRC also has mutual aid agreements in place with several oil spill response organizations in Canada and the US. The standard for cleaning of oiled shoreline is also improved significantly from 500 m/day to 3,000 m/day.

The Westridge Marine Terminal, which will be rebuilt and modernized as a part of the Project, has been in operation since 1953. The sailing route has a well-established navigational safety regime and is not heavily trafficked compared to other oil terminal sailing routes in the world and Trans Mountain plans to implement further enhancements to the already high standard risk reducing measures in place. At the same time Trans Mountain is proposing significant improvements to the oil spill response regime for the area, which will be further modified in accordance with any future Canadian Federal regulations and standards. Taking all of the above into consideration, **DNV concludes that the regional increase in oil spill risk caused by the expected increase in oil tanker traffic to Trans Mountain Westridge Marine Terminal is low, and that the region is capable of safely accommodating the additional one laden crude oil tanker per day increase that will result from the Project.**

1. INTRODUCTION

Trans Mountain Pipeline ULC (Trans Mountain) proposes to expand the capacity of the Trans-Mountain Pipeline system, which will result in increased number of tankers calling the Westridge Marine Terminal (Westridge terminal) to load crude oil (including diluted bitumen) cargo. The number of tankers is expected to increase from an average of 5 partly loaded double hull Aframax size tankers per month to 34 similarly loaded tankers per month. The tankers will navigate Canadian and US waters on passage through Juan de Fuca Straits and the Salish Sea.

DNV has been engaged by Trans Mountain to conduct a marine transport Quantitative Risk Assessment (QRA) of the effect of the increased tanker traffic. The outcome of the QRA provides the probability for accidental oil discharges and the potential amount of oil discharges, which in turn will provide input to oil drift modelling and to the environmental consequence and risk analysis. The consequences estimated in this report are also used in the environmental and, socio-economic assessment provided to the National Energy Board (NEB) and in developing oil spill response methodology and techniques that are discussed in the Termpol study.

1.1 Objective

This report describes the marine transport Quantitative Risk Analysis (QRA) completed as part of the Termpol review process for the Trans Mountain Expansion Project (TMEP, the Project). The QRA fulfils a number of the requirements described in Section 3.15 of the Termpol Review Process (TP743E, Transport Canada 2001).

Termpol 2001 recommends examining the probability of certain events occurring en route to the marine terminal or during marine terminal transhipment and the likelihood of an event causing an uncontrolled release of oil. Incident scenarios considered in the QRA include:

- a ship to ship collision;
- a ship grounding (powered and drift);
- a ship striking a fixed object (e.g. marine structures during berthing);
- an incident resulting from improper cargo transfer;
- a fire or explosion on board the vessel, or
- foundering due to structural failure

In addition this QRA also examines the risk of a tanker at the berth being struck by a passing vessel and the risk of a tug boat striking and damaging a tanker. As requested in Termpol 2001 the QRA examines:

- the probabilities of credible incidents that could breach a ship's cargo containment system;
- the [hazards] associated with navigation to and from Westridge Marine Terminal;
- the probabilities of cargo transfer incidents at one of the three berths at Westridge Marine Terminal;
- the consequences of an incident occurring, and
- the probability that an incident becomes "uncontrollable".

1.2 Abbreviations and units

ABBREVIATIONS

AIS	Automatic Identification System
API	American Petroleum Institute
ASD	Azimuth Stern Drive
ATC	Air Traffic Control
BC	British Columbia
BCCP	British Columbia Coast Pilots Ltd
BRM	Bridge Resource Management
CCG	Canadian Coast Guards
CN	CN Rail
DNV	Det Norske Veritas
ECDIS	Electronic Chart Display and Information System
ECS	Electronic Chart System
ENC	Electronic Navigational Chart
ERTV	Emergency Response Towing Vessel
ERV	Emergency Response Vessel
ETV	Emergency Towing Vessel
HAZID	Hazard Identification
HECOM	The Baltic Marine Environment Protection Commission, also known as the Helsinki Commission
IHS	IHS Fairplay incident database
IMO	International Maritime Organisation
ITOPF	International Tanker Owners Pollution Federation
JRCC	Joint Rescue Coordination Center
KMC	Kinder Morgan Canada
LR2	Long Range 2 (Product Tankers)
MARCS	Marine Accident Risk Calculation System
MARPOL	The International Convention for the Prevention of Pollution from Ships
MCTS	Marine Communications and Traffic Services, a Canadian Coast Guard specific term for Vessel Traffic Service (VTS)
MEPC	Marine Environment Protection Committee
MMSI	Maritime Mobile Service Identity
MRA	Movement Restriction Area
NAPA	Naval Architecture Package

ABBREVIATIONS

NEB	National Energy Board
PMV	Port Metro Vancouver
PPU	Portable Pilot Units
QRA	Quantitative Risk Analysis
QRMH	Quick Release Mooring Hook
SIRE	Ship Inspection Report
SOLAS	International Convention for Safety of Life at Sea
TM	Trans Mountain
TMEP	Trans Mountain Expansion Project
TSS	Traffic Separation Scheme
UKC	Under Keel Clearance
USCG	United States Coast Guards
VHF	Very High Frequency
VTS	Vessel Traffic Service, a general term for the Canadian Coast Guard Marine Communication and Traffic Services

UNITS

bbls	Barrels
DWT	Dead Weight Tons (metric tons)
kts	Knots (nautical miles per hour)
m	Meters
m^3	Cubic meters
m/s	Meters per second
Min	Minutes
nm	Nautical miles
Yr	Years

1.3 Report structure

Chapter 2 presents a brief methodology applied for the QRA, while Appendix A gives a more detailed description of the applied model. Chapter 3 describes the routes taken by the tankers, berthing procedures and important characteristics of the tankers. In addition, it presents some metocean data (meteorological and current data) and environmental inputs that will be used in the risk assessment.

Chapter 4 of the QRA identifies hazards to laden tankers travelling in Canadian waters and during cargo transfer at the Westridge terminal. Local knowledge of potential hazards was incorporated through a HAZID workshop and through riding the marine route from Westridge terminal to the pilot de-boarding station outside Victoria, BC. Chapter 5 provides information on the traffic data used in the analysis, and Chapter 6 discusses the risk controls taken into consideration in the model.

The likelihood for a marine incident during transit is estimated in Chapter 7 using the Marine Accident and Risk Calculation System (MARCS), DNV's proprietary risk management tool. Frequency assessment for incidents at the terminal is estimated in Chapter 8, and the probable consequences of accidents are examined in Chapter 9, which includes a discussion on credible worst case. Consequences are defined as the potential damage to tankers and / or the marine terminal, as well as the volume of cargo or bunker fuel that may be released. The consequences developed in this report are used in the environmental and, socio-economic assessment provided to the National Energy Board (NEB) and in developing spill response methodology and techniques that are also discussed in Termpol. The risks of accidents occurring and accidents causing a release of oil cargo are calculated in Chapter 10.

Chapter 11 includes a sensitivity discussion of the MARCS model applied to estimate the incident frequencies and in Chapter 12 of this report there is a more qualitatively discussion on the tanker traffic risk. Existing and additional identified risk reducing measures are summed up in Chapter 13 with recommendation for improved risk controls related to the project. The report provides recommendations to Termpol in Chapter 14 along with conclusions of the study in Chapter 15.

2 METHODOLOGY

2.1 Method Overview

The QRA evaluates quantitatively the increase in risk posed by the Project. The incident frequencies are calculated for both inbound tankers in ballast and outbound laden tankers as an incident can happen in both sailing directions. However, the cargo oil spill accident frequencies are estimated based on the incident frequency for outbound laden tankers only. The QRA also assesses the risk of an oil spill from a tanker's loading activities at the Westridge terminal. All results should therefore be read with this in mind; i.e. the various percentages of contribution to frequency and risk when discussing all incidents such as collision and grounding includes contribution of the unladen Project tankers in ballast, but when discussing oil spill risk only focuses on the laden Project tankers. Any Project related tanker is described as a Trans Mountain tanker in the QRA.

The risk model used in this work is called the Marine Accident Risk Calculation System (MARCS). MARCS was developed by DNV to support its consultancy navigational risk services. MARCS was first used in the 1990s and has been continually used and updated since that time. MARCS combines data on shipping traffic (e.g. ship types, sizes, routes, transit frequencies, etc.) with data to describe the marine environment (e.g. location of shallow water, visibility data, wind data, sea state data, etc.) and with data that describe operational aspects of shipping operations (e.g. pilotage, escort tugs, etc.) to predict the frequency of the navigational incidents as collision, powered and drift grounding, foundering, fire and explosion. A more detailed description of MARCS is found in Appendix 1.

The risk assessment is based on an analysis and description of the routes and existing traffic patterns obtained by use of AIS and the results of the navigational and terminal HAZIDs. The expected future traffic pattern is extrapolated from the existing traffic pattern based on a forecast of traffic growth for vessel categories. The traffic forecast is described in Termpol 3.2. From that information, a quantification of the incident frequencies and consequences for vessels is estimated, using two different models:

- MARCS is used to quantify the incident frequencies with and without oil spill as a result of the incident.
- The cargo oil spill volumes and related probability are estimated from a separate model that is based on IMO Res. MEPC. 122(52)[1] for collision and grounding events.

The basic frequencies of a release during cargo transfer operations are derived from European terminal incident statistics and modified to account for site specific risk reducing measures that will be implemented at the new Westridge Marine Terminal.

Once the frequencies and consequences are estimated, the risk is then a combination of these two factors.

For this analysis a marine incident is defined as an event that can lead to an oil cargo spill accident. **The majority of incidents will be of a nature that will not lead to an oil cargo spill accident.** The incident frequencies are calculated for the following events:

- Collision;
- Powered Grounding;
- Drift Grounding;
- Structural failure; and
- Fire and Explosion.

In a few cases an incident will cause so severe damage to the tanker that it will lead to a breakage of the cargo tanks and thus lead to an oil spill accident. The probability that an incident leads to an oil spill accident is estimated in MARCS based on:

[1] International Maritime Organization resolution for Marine Environmental Protection Program; IMO Res. MEPC. 122(52) "Explanatory notes on matters related to the accidental oil performance under regulation 23 of the revised MARPOL Annex I". A software package called NAPA (Naval Architecture Package, by NAPA Ltd.) is used

- Ship Structure, whether it is single or double hull (all Trans Mountain tankers are double hull).
- The probability of grounding on rocky shore versus soft bottom shore. This probability distribution is equal to the presence of distribution of rocky shoreline versus soft bottom shoreline; grounding on rocks will increase the likelihood of a loss of containment.
- Wave and wind affects the probability that a grounding incidents leads to an oil spill. Wave height also affects the probability for a structural failure leading to foundering.
- In case of collision, the momentum of a colliding ship affects whether the incident becomes an oil spill accident.

If an incident is estimated to cause an oil cargo spill accident, then the oil cargo spill volumes and their probability are estimated from a separate model that is based on IMO Res. MEPC. 122(52) for collision and grounding event. The method applies detailed design drawings for an example vessel, in this case an Aframax. The probability distribution functions of oil spill from Aframax tankers have been established by performing Monte Carlo simulations on the Aframax example vessel. The Monte Carlo simulations are based on the probability distributions for damage extent from collision and grounding as presented in IMO Res. MEPC. 122(52) "Explanatory notes on matters related to the accidental oil performance under regulation 23 of the revised MARPOL Annex I". The same assumptions as in MARPOL have been applied in the calculations. For side damages all cargo oil is assumed lost, while for the bottom damages the oil outflow is calculated based on the assumption of hydrostatic balance to the sea at zero trim. For the bottom damage cases additional calculations are carried out for 2.5 m tidal difference as corresponding to the MARPOL regulations. The Monte Carlo simulations are based on a generated number of 10,000 damage cases which have been repeated 5 times. The estimated outflow volume for a P50 scenario (the 50 % worst case outflow) and a P90 scenario (the 90 % worst case outflow) are used in the risk assessment.

3 SYSTEM DEFINITION

3.1 Route Description

This is a high level description of the sailing route for Trans Mountain tankers sailing from the Westridge terminal; sailing routes of other traffic are not described. A detailed description of the route is given in Termpol 3.5, *Route Analysis, Approach Characteristics and Navigability Survey*. The sailing route description here is based on the Termpol 3.5, information from the HAZID workshop and a ride along the route from Westridge terminal to Brotchie Ledge Pilot Station outside Victoria, BC. The sailing route ride was conducted by a DNV mariner as part of the hazard identification exercise. The HAZID report in Appendix 2 provides more details from the sailing route ride.

The Trans Mountain tankers will have pilotage in the area between the Westridge terminal and the Brotchie Ledge Pilot Station, both on inbound and outbound route. The sailing routes to and from the Westridge terminal to the open sea are well established and familiar to the BC Coast Pilots Ltd. (BCCP). The whole sailing route from the English Bay to the Juliet Buoy outside the Strait of Juan de Fuca has a Traffic Separation Scheme (TSS) with outbound traffic north and west of the traffic separation and inbound traffic east and south of the separation. The traffic separation is jointly supervised by the Canadian Coast Guard Marine Communications and Traffic Services (MCTS) in Vancouver and Victoria and by the US Coast Guard Puget Sound Vessel Traffic Service. The three traffic service stations will be mutually described as Vessel Traffic Service (VTS) for the remaining of this document.

For purpose of the analysis the sailing route is divided into 7 segments as shown in Figure 1. The segments are briefly described below. For a detailed route description please refer to the combined Termpol 3.5/3.12 study.

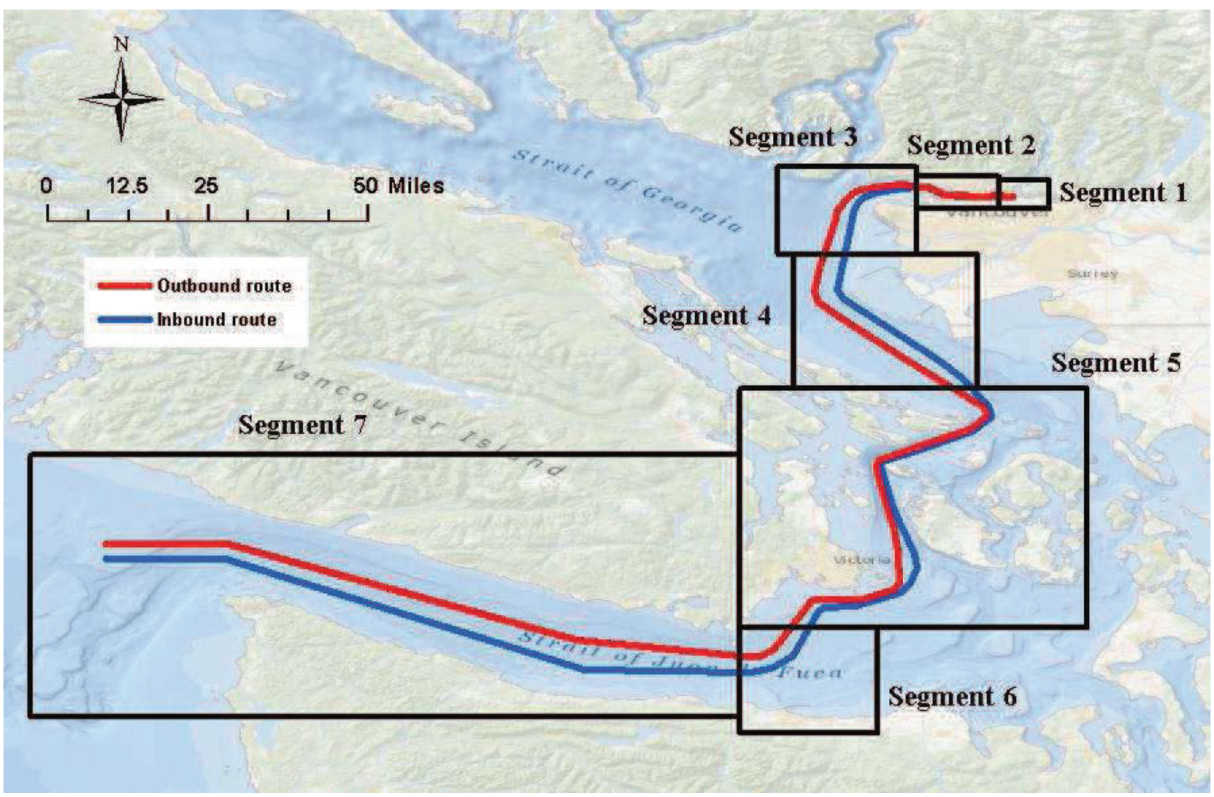

Figure 1 - Trans Mountain tanker route to and from Westridge terminal

3.1.1 Description of segments

Segment 1: Westridge Terminal to Berry Point

The sailing route from Westridge terminal starts at the terminal in Burnaby east of Second Narrows in the Burrard inlet and goes to Berry Point right before the Second Narrows. The channel is 900 - 1,600 meter wide. There are four designated anchoring locations in the Burrard Inlet east of the Second Narrows. The closest anchoring area is about 800 meters from the existing terminal.

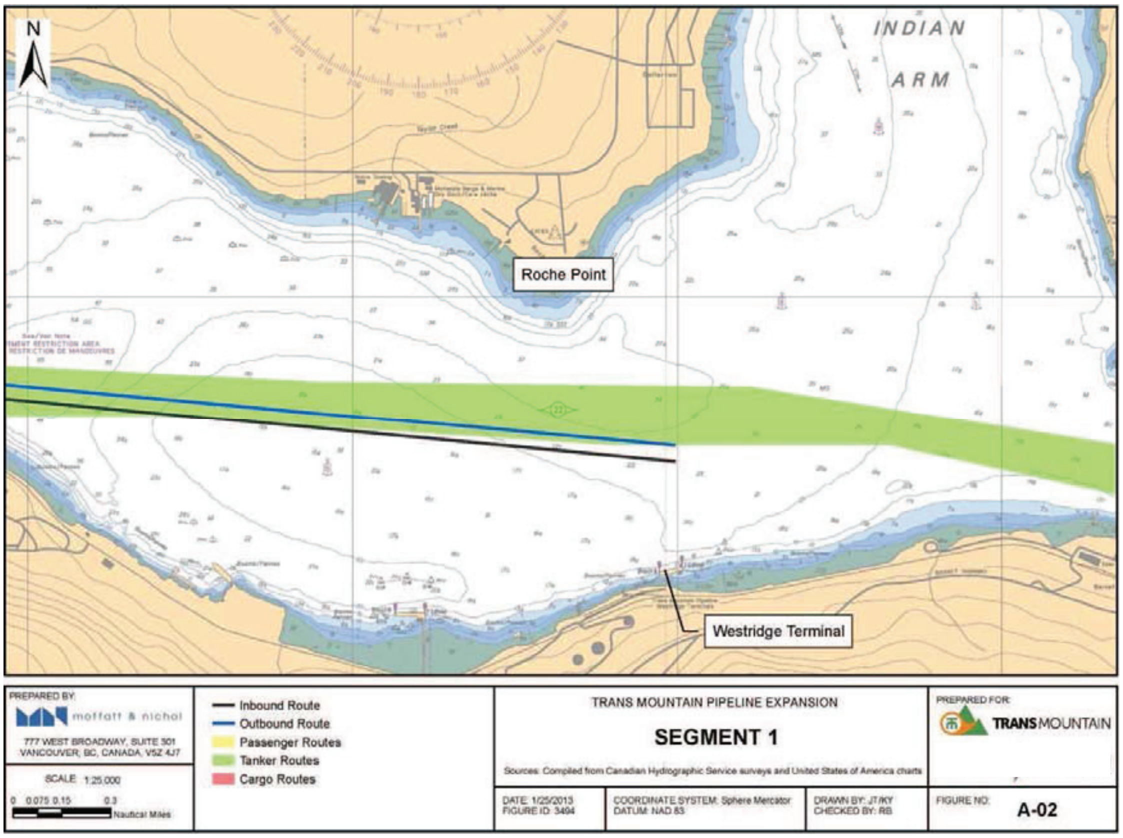

Figure 2 - Segment 1: Westridge terminal to Berry Point

Segment 2: Vancouver Harbour Area

In Segment 2 the route goes through the Second Narrows, harbour area and through the First Narrows out to the English Bay. The Second Narrows is a Movement Restricted Area (MRA) enforced by Port Metro Vancouver (PMV). In addition PMV also requires a "Clear Narrows" during the passage of large vessels through First Narrows. There are seven designated anchorage locations between the First and Second Narrows. PMV requires that laden tankers are escorted by 2-4 tethered tugs whilst transiting the Vancouver Harbour area (segment 2). Two bridges cross the channel at Second Narrows; a fixed road bridge (Iron Workers Memorial Bridge) and a lifting railway bridge operated by Canadian National Railway. The Lion's Gate Bridge, which is a fixed road bridge, crosses the First Narrows.

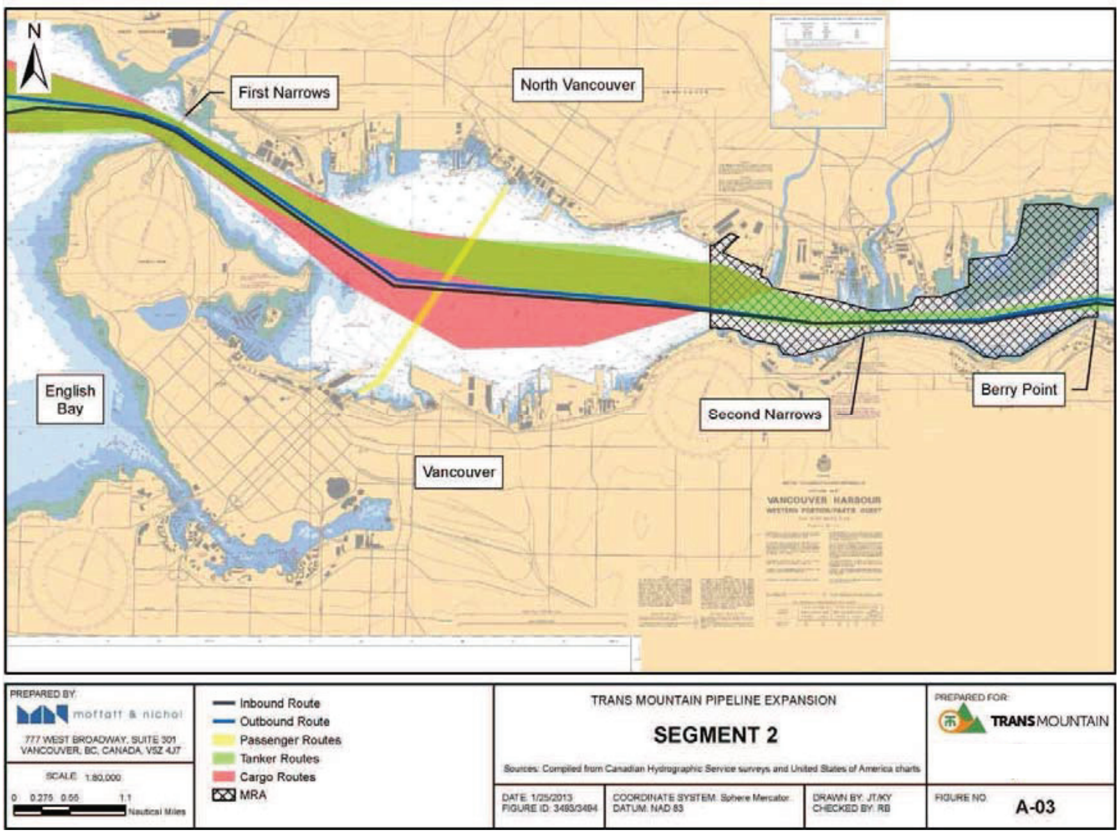

Figure 3 - Segment 2: Vancouver Harbour Area

Segment 3: English Bay and out into Strait of Georgia

The segment goes from west of First Narrows in English Bay out into the Strait of Georgia west of the Fraser River delta. It is an open and wide area with some crossing traffic from the north arm and main arm of the Fraser River. There are 16 dedicated anchoring locations in the English Bay. The entire coastline around the Fraser River delta is a shallow area with a soft sediment seabed.

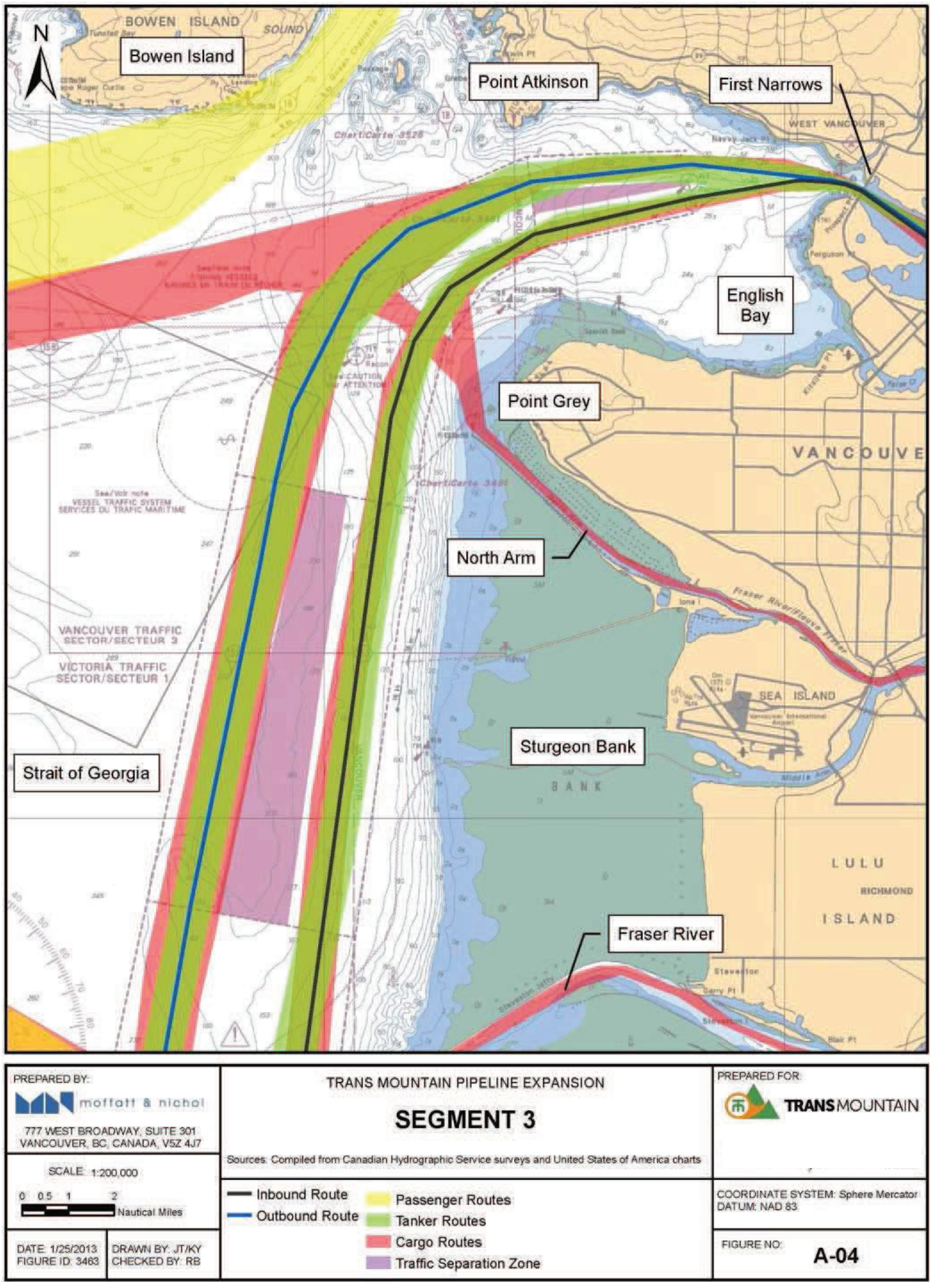

Figure 4 - Segment 3: English Bay into Strait of Georgia

Segment 4: Strait of Georgia

In segment 4 the sailing route runs South-Southeast through the Strait of Georgia. It is a wide strait with relatively low traffic density and minimum navigational challenges. The sailing route crosses two major ferry routes from Tsawwassen Ferry Terminal to Vancouver Island as well as deep sea and coastal traffic entering or leaving Fraser River, plus deep sea traffic (coal and container) moving to and from the Roberts Bank coal and container terminals. Traffic from the Puget Sound (U.S.) connects to the Strait of Georgia traffic lanes.

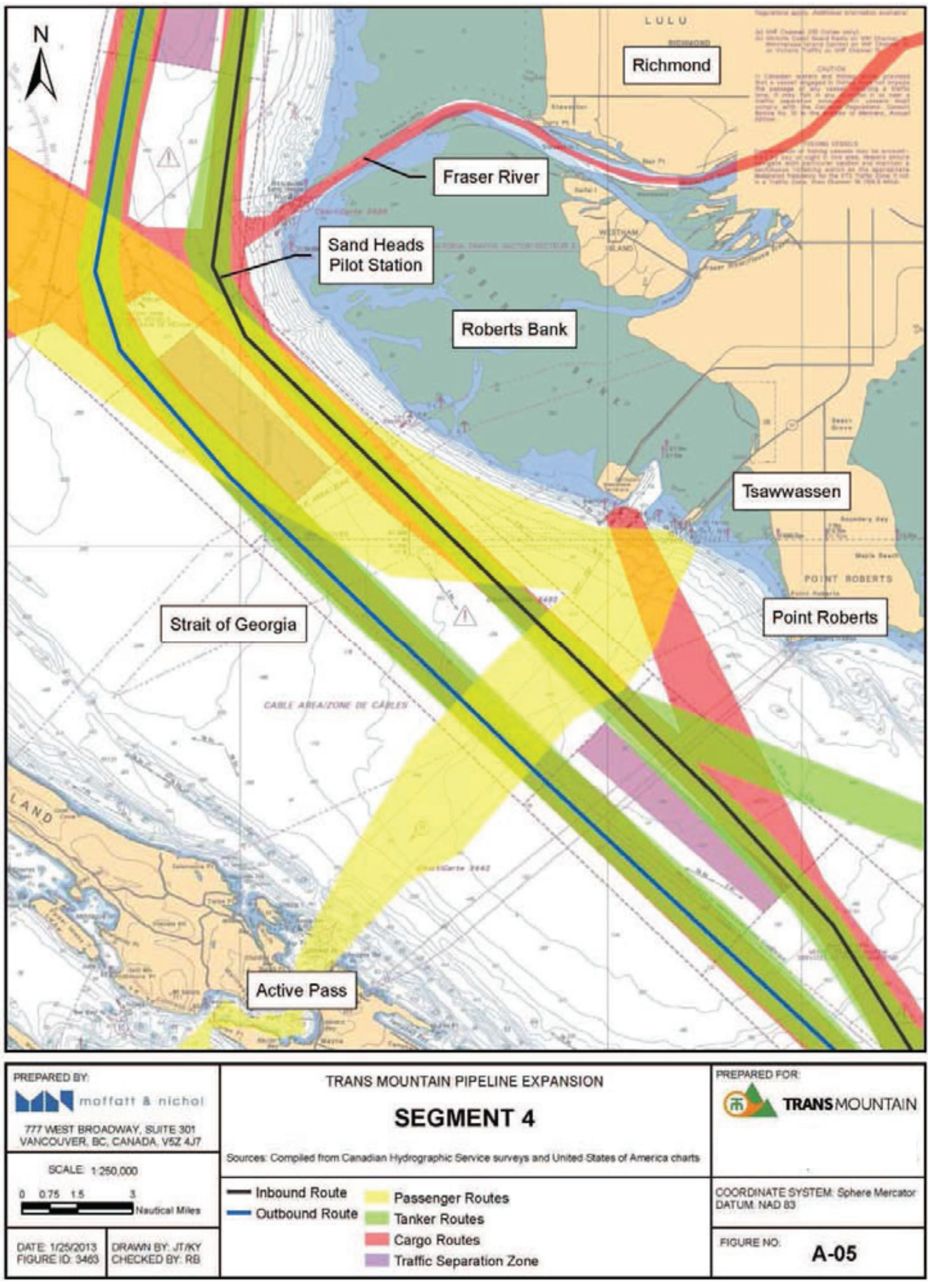

Figure 5 - Segment 4: Strait of Georgia

Segment 5: Boundary Pass and Haro Strait

In segment 5, the route passes through Boundary Pass and Haro Strait. At the East Point, Saturna Island, the route turns more westerly and enters Boundary Pass. Boundary Pass connects to Haro Strait at Turn Point. The route transitions across the Canadian/US border. The area, from approximately 3.0 nm North of East Point, Saturna Island to abeam of Race Rocks, Vancouver Island requires a number of alterations of course involving relatively tight turns implemented in otherwise restricted waters. Laden tankers are escorted by a tethered tug through Boundary Pass and Haro Strait. The area bounded by approximately 2.0 nm north and south of Turn Point is covered by a Special Operating Area (SOA) where MCTS Victoria facilitates a one way traffic policy.

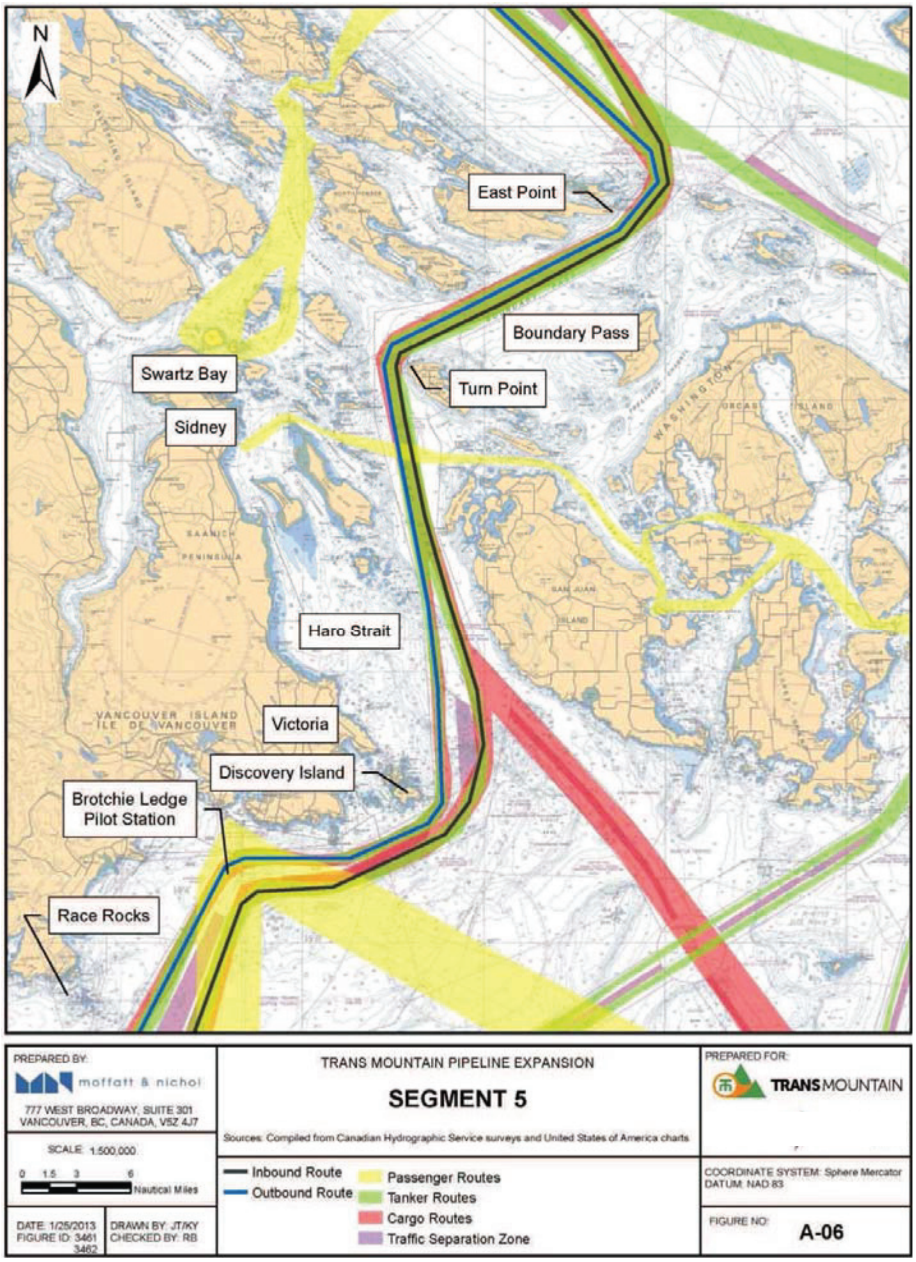

Figure 6 - Segment 5: Boundary Pass and Haro Strait

Segment 6: Race Rocks

Segment 6 is a short segment that constitutes the traffic crossing area with traffic to and from the U.S. Race Rocks is a shallow reef area which often generates relatively higher wave action due to wind and current conditions.

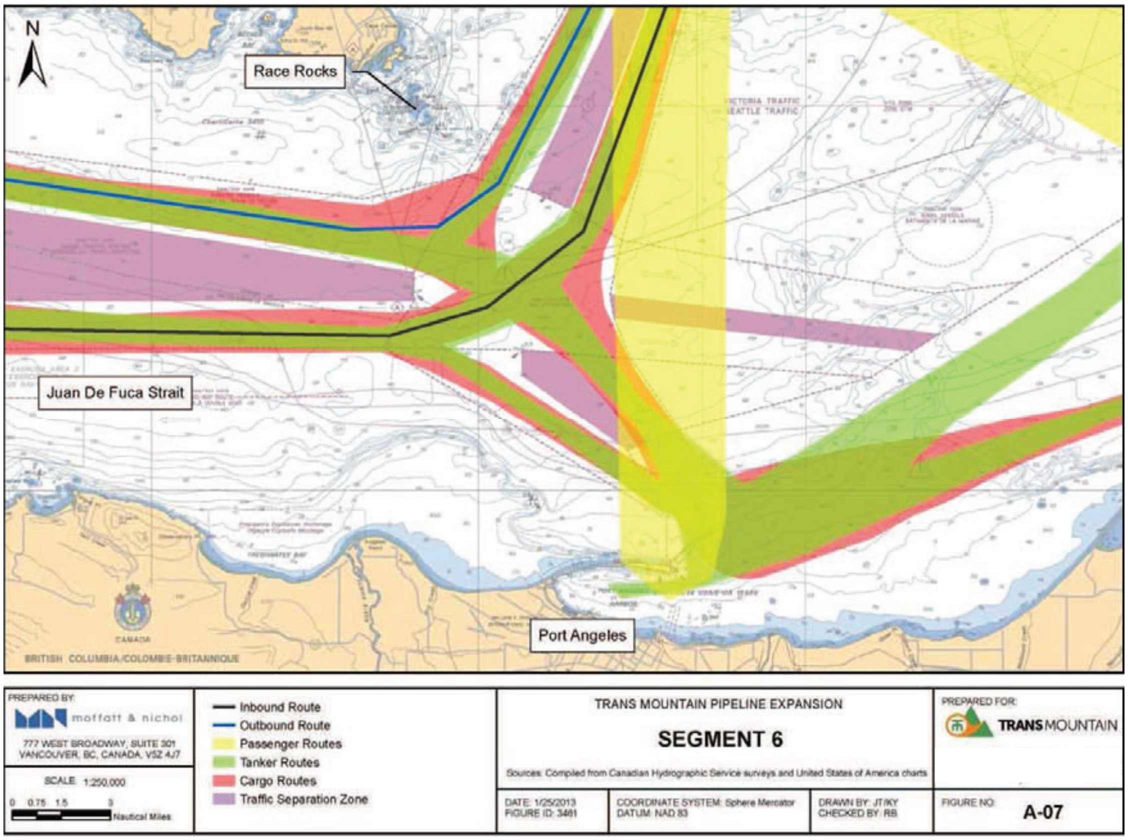

Figure 7 - Segment 6 : Race Rocks

Segment 7 : Juan de Fuca Strait

From Race Rocks there is a wide, open and straight passage through Juan de Fuca Strait to the Juliet Buoy. The outbound traffic uses the TSS lane in the Canadian side of the Juan de Fuca Strait and the inbound traffic uses the TSS lane on the U.S. side. The traffic lanes are widely separated.

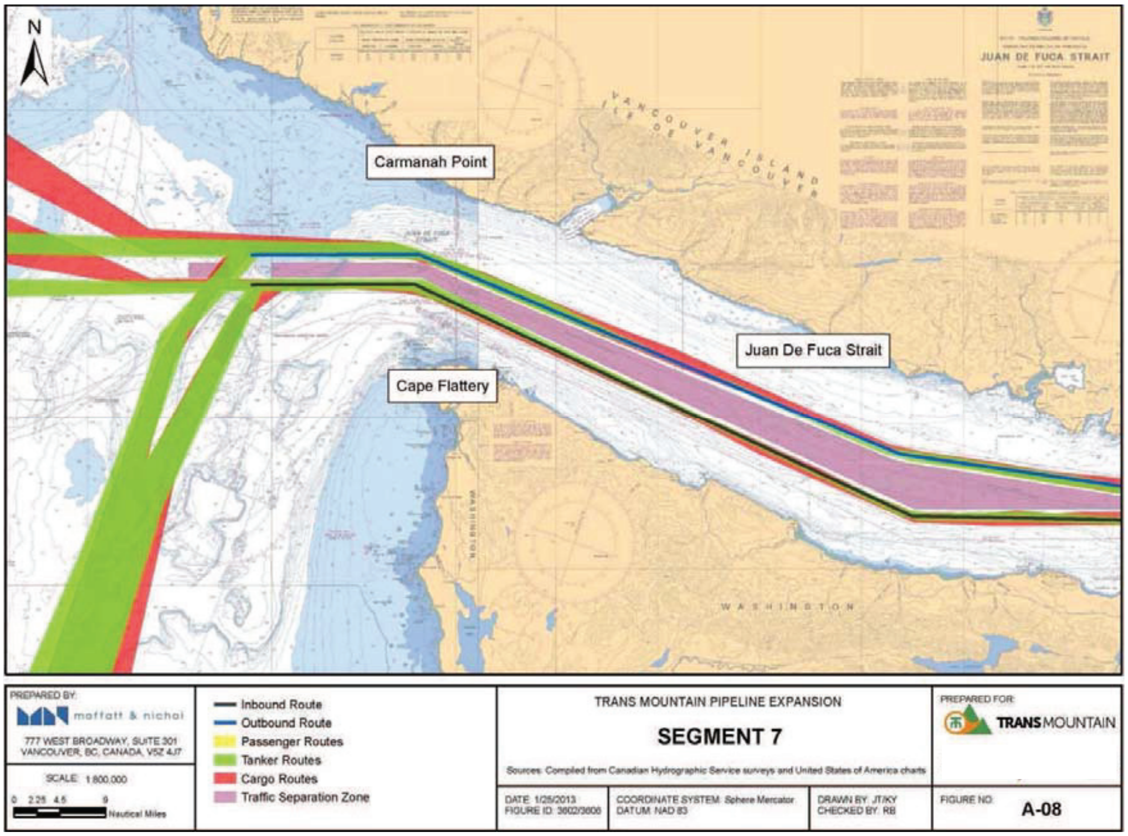

Figure 8 - Segment 7 : Juan de Fuca Strait

3.2 Vessel handling, support and escort

This section describes the actual process of a tanker arriving at the Westridge terminal and subsequently departing to sea. It outlines the various contributions of Federal and other agencies involved in ensuring that the navigational safety regime is exercised fully through all portions of the vessel's travel within Canadian waters. This section should be read in conjunction with Termpol 3.2.

According to Canadian Shipping Act 2001 all tank vessel operators that are sailing in Canadian waters must have an arrangement with a certified oil spill response organization, in British Columbia this is Western Canada Marine Response Cooperation (WCMRC). Upon arrival in Canadian waters, tankers must follow strict communications and guidance protocols with the Vessel Traffic Service stations. The CCG and US Coast Guard (USCG) monitor ship traffic through the Salish Sea. Four VTS stations monitor the traffic:

- CCG MCTS Tofino - traffic entrance to Juan de Fuca Strait,
- USCG Puget Sound VTS - traffic in Juan de Fuca Strait and further in Puget Sound
- CCG MCTS Victoria - traffic in Salish Sea including Strait of Georgia
- CCG MCTS Vancouver - traffic in Vancouver Harbour

All ships over 20 m length are required to participate in VTS and remain in communication with Marine Communications and Traffic Services (MCTS) and their positions are monitored by either CCG or USCG depending on jurisdiction over the sector. There is a system of handing off between traffic zones as ships move from one sector to the other. A combination of radar, automatic information system and direct radio communication is used to co-ordinate safe conduct of the ship with other masters and pilots. Currently, there is no US or Canadian pilotage requirement for transit through the Juan de Fuca Strait. CCG proposes to consolidate the monitoring and oversight of both Victoria and Vancouver traffic at the Victoria MCTS center. That is scheduled to take place in 2014 and is not expected to have any effect on the quality of service.

The PPA or Pacific Pilotage Authority is the federal organization responsible for the administration of the Pilotage Act on the West Coast. The BC Coast Pilots Ltd. is the organization of coastal pilots who are licenced under the Pilotage Act. All vessels over 350 GT are required to have a licensed pilot when in pilotage waters as defined in the Pilotage Act. When loaded, tankers are required to have two pilots. The pilot advises the vessel's master on safe navigation and is responsible for safe conduct of the vessel while in pilotage waters.

Vessels sailing to and from the Westridge terminal transit the Juan de Fuca Strait, Haro Strait and Boundary Pass, Strait of Georgia and Burrard Inlet as described above. Empty tankers headed for the Westridge terminal pick up a pilot at the Victoria pilot station near Brotchie Ledge. Under the pilot's guidance, and with supervision from VTS, the ship continues to navigate through established shipping lanes to PMV.
Once a ship enters into PMV's jurisdictional area (east of a North/South line between Point Atkinson and the US border), a series of protocols apply:

- The PMV rules for conduct of shipping within its jurisdictional area are documented in the Harbour Operations Manual.
- Inbound empty tankers are escorted by tugs through the Second Narrows to Westridge where they could either go directly alongside or else anchor in the vicinity of the berth awaiting cargo readiness.
- The Harbour Master's office assigns an anchorage for the vessel based on availability and operational requirements. A vessel may anchor at designated locations in English Bay or designated locations off the Westridge terminal, depending on timing of tides, the Westridge terminal loading schedule and the ship's own requirements for provisioning or maintenance. In some cases, the ship might proceed directly to the berth.
- Pilots leave the ship after it anchors or berths, but are aboard anytime it moves, which includes shifting from anchor to dock or back.
- The ship is inspected by Transport Canada on its first arrival in Canada and once per year after that. This might occur at anchor or alongside at Westridge terminal. Canada is a signatory to both the Paris and Tokyo memorandums of understanding (MOU) and has adopted the MOU requirements into the Canada Shipping Act. Under these MOUs, Transport Canada has access to inspection records from inspections by

other signatory jurisdictions and shares Canadian results. Convention entities publish annual reports ranking performance of flag states, which are used as a basis to accept or deny entry of vessels.
- The tanker is assisted by docking tugs during her approach to Westridge terminal and whilst she is making fast to the dock.
- The Trans Mountain Loading Master boards the tanker and carries out necessary checks and inspections of the vessel prior accepting here for loading at the berth. The Loading Master acts as the primary point of contact between the tanker and Westridge terminal and provides guidance and oversight of the tanker's operation while she is alongside.
- Oil spill containment booms are always deployed around the tanker during cargo handling.

Post loading the tanker's departure is as described below:

- The loading master checks with the master to ensure vessel readiness and remains on board until pilots board to move the vessel away from the dock.
- The tanker is cast off and could either go to an assigned anchorage location to wait for tide for the Second Narrows transit, as required by the PMV's *Harbour Operations Manual,* or sail directly out. The PPA requires loaded tankers to have two BC Coast Pilots on board, one to ensure safe conduct of the vessel and one to monitor the bridge crew and ship's systems.
- Two BCCP pilots assist the tanker to safely navigate out of the immediate vicinity of Westridge terminal, through 2nd Narrows, Vancouver Harbour and subsequently through Boundary Pass and Haro Strait.
- The PMV's *Harbour Operations Manual* defines the Second Narrows MRA and the rules for MRA transits, including tanker size restrictions, tug escort requirements and speed restrictions. Only one vessel at a time is allowed in the Second Narrows MRA and First Narrows. VTS monitors the tanker's progress and other vessel traffic in the harbour.
- Before the transit begins, VTS declares a clear narrows and the Canadian National Railway bridge operator is contacted to raise their rail bridge.
- PMV rules require escort tugs to be tethered to the tanker when transiting the Second Narrows MRA. For transit of an Aframax tanker it includes two tugs at the stern and at least one tug on the bow. The tug requirements are defined in the PMV Harbour Operation Manual. Only the two large tugs tethered to the stern are required for the transit through the remainder of the harbour.
- After clearing the First Narrows, the escort tugs fall away and one escort tug rejoins the vessel as it approaches Boundary Pass.
- The PPA has established escort requirements for the Salish Sea (Boundary Pass and Haro Strait). The PPA requires a single large tug tethered from a position 2.0 nautical miles north of East Point until Victoria Pilot Station and then in close attendance until the vessel passes Race Rocks.
- The two onboard BC Pilots disembark at the Victoria Pilot Station (Brotchie Ledge) and the tug is untethered.
- The escort tug remains in close (but untethered) escort of the vessel till she clears Race Rocks and enters the Juan de Fuca Strait.
- No pilotage or escort is required through the Juan de Fuca Strait. However, as with inbound transits, the tanker and all other traffic are monitored by the MCTS.

The tanker transits the vessel traffic separation scheme, which is jointly managed between Canada and USA. U.S. industry funds a rescue tug at Neah Bay, which, upon request, is available to assist a vessel requiring assistance in the Juan de Fuca Strait, although that cannot be taken as a certainty at this time.

3.3 Tanker Specification

The existing tankers used for exporting oil from Trans Mountain's Westridge terminal are of the Aframax class (80,000 - 120,000 DWT) and Panamax class (50,000 - 80,000 DWT), all double hulled tankers. The tankers using the facility are restricted to a maximum draft, when transiting Second Narrows in order to obtain a minimum Under Keel Clearance (UKC) of 10% of the loaded draft (Termpol 3.6) within the prescribed safe channel width of 2.85 x beam through the MRA to a current maximum of 13.0 meters, which is in the process of being revised to 13.5 m.

All tankers arriving at the Westridge terminal undergo a strict vetting and inspection process prior to being accepted by Trans Mountain. Part of the vetting process and superintendence is to establish that the vessel and crew meet equipment and performance requirements. Consequently, the tankers and crew using the Westridge terminal are typically of a high industry standard.

3.3.1 Hull and Cargo Tank Components

All Trans Mountain tankers are double hull. The implementation of double hull construction using special shipbuilding grade steel offers increased protection to the cargo tanks against breaches during collisions and grounding. Furthermore, within the tanker's inner hull there are a number of individually segregated cargo tanks, so if a breach of a cargo tank does occur the potential leak can be limited to the product within the affected cargo tank only and further contained within the inter-hull space. It will necessitate the breaching of both hulls for cargo oil to escape to the sea. A typical number of cargo tanks in an Aframax is 10-14 tanks, which gives approximate 10,000 m^3 (63,000 bbls) of crude oil in each tank.

IMO requires that all tankers built after August 2010 are designed with protected bunker tanks and with individual bunker tank size not exceeding 2,500 metric tons. The average age of the global Aframax and Panamax size tanker fleet is 9 years. Based on this it is expected that 40 % of the tankers will have protected bunker tanks in 2018 and 100 % in 2028.

Crude oil Aframax tankers have a few meters of each cargo tank's inner bottoms and tops coated with high quality epoxy paint. All cargo tanks are inspected at regular intervals as part of their mandated and normal maintenance and survey schedules, overseen by the operator, Class and Flag. Ballast tanks and spaces adjacent to cargo tanks are fully coated with high quality epoxy paints and inspected regularly as part of maintenance and survey schedules. These treatments and regular inspections and surveys ensure the ships and cargo tanks are protected against corrosion.

3.3.2 Navigational Equipment

The general purpose of the IMO's Safety of Life at Sea (SOLAS) convention is to ensure that a ship is safe and fit for the service for which it is intended. Transport Canada requires that all tankers calling Canada must satisfy SOLAS requirements. This is also noted in Termpol 3.9 which contains a detailed description of ship specifications.

Tankers carry sophisticated navigation aids mandated by SOLAS, Chapter V, Regulation 19, and the Canada Shipping Act. The requirements include certified charts, position monitoring and anti-collision devices such as: precise GPS, redundant compasses, echo sounder to measure depth of water, speed log, and other devices. The tankers must also satisfy the navigation bridge visibility requirements set out in Regulation 22. All tankers must have two radar systems, one of which must be a specialised collision-avoidance radar. Additionally, ships must be equipped with AIS which broadcasts the vessel's coordinates and other information for use by traffic services and other vessels to help avoid collision.

All tankers will have an Electronic Charts System (ECS) and Electronic Chart Display and Information System (ECDIS) that in combination with AIS and GPS displays the position of the tanker and other vessels in the area.

3.3.3 Fire Prevention and Fire Fighting

As described in Termpol 3.9, tankers must be equipped with fire prevention and firefighting systems that meet international rules and regulations, i.e. SOLAS. This requires specific fire protection, fire detection and firefighting equipment to be part of the vessel's design standards and the tanker's crew has to meet international training standards for this purpose. The tanker's inert gas system maintains cargo tanks in an inert condition (oxygen content must be less than 8% volume), which removes any danger of fire or explosion in the cargo tanks. All electrical equipment in designated areas must be intrinsically safe. Appropriate means of dowsing or smothering a fire, e.g. water, foam, chemicals, etc. are provided depending on the type of space to be protected. Foam system is provided to fight fire on the deck of the tanker.

Cargo transfer at Westridge terminal is always conducted under closed loading conditions, the ships vapour collection system is used to collect and transfer vapour ashore for treatment. This ensures that there are no flammable vapours emitted or accumulated on the deck of the vessel.

Tanker terminals, including Westridge Marine Terminal, have the capacity to apply water, foam and chemicals to the tanker's decks using fixed monitors on the dock. This is further described in Chapter 3.4.

3.3.4 Trends in Tanker Fleet

DNV has assessed the global Panamax/Aframax sized fleet development since 1980 and the expected development over the next 10 years (Figure 9). The global Aframax and Panamax crude oil tanker fleet of today has an average vessel age of 9 years. It is expected that the average age for the fleet will be the same or younger in 2018.

In 2012 the world fleet consisted of 247 Panamax and 742 Aframax crude tankers, giving a total of 989 tankers between 60,000 and 120,000 DWT. In addition there were 315 Panamax size product tankers. The forecasted size of the Aframax/Panamax crude tanker fleet in 2018 is estimated at 1,048 vessels. DNV has no reliable data on the forecasted distribution between the two tanker size classes, but given the same ratio between Aframax and Panamax as in 2012, it estimates there will be 260 Panamax crude tankers and 788 Aframax crude tankers in 2018. In addition to the crude oil tanker fleet, DNV also estimates there will be approximately 427 product tankers of Panamax size in 2018, which may also be used by certain shippers, depending on need and availability, to carry crude oil.

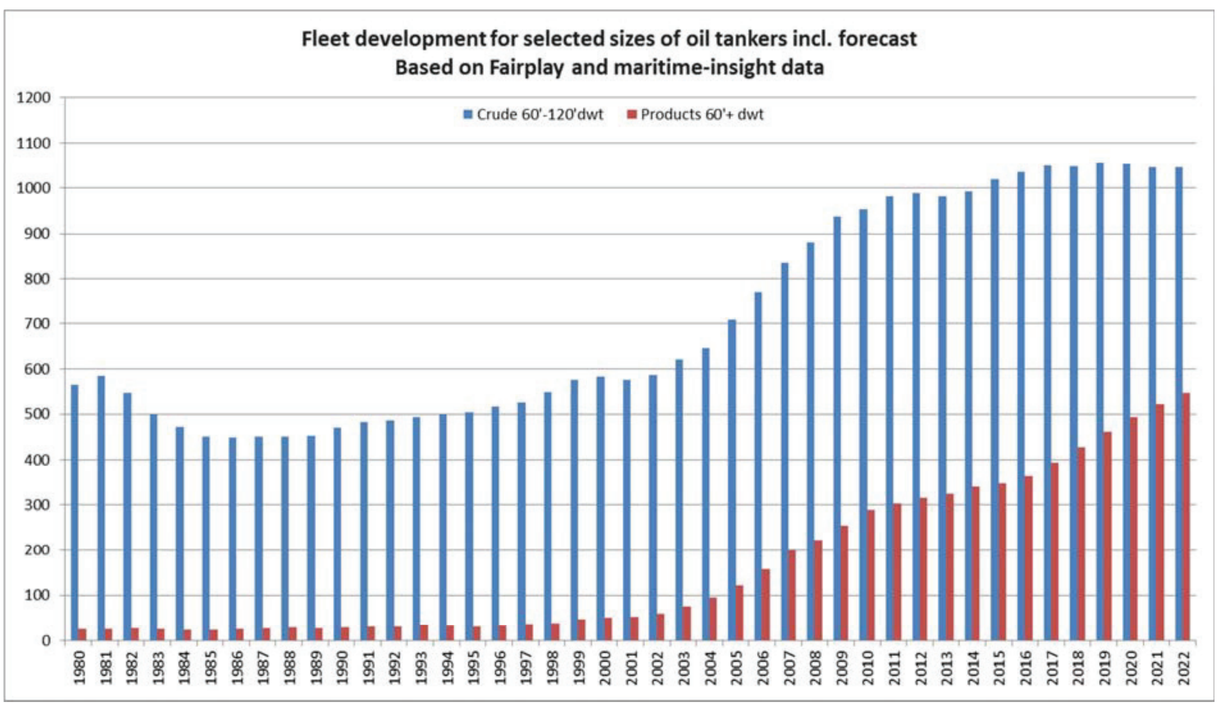

Figure 9 - Estimated fleet development of crude oil tankers in the size range 60,000 - 120,000 DWT (Panamax and Aframax size) and of product tankers > 60,000 DWT (mostly Panamax size)

3.4 Westridge Terminal Specification

Batches of oil destined for Westridge terminal will be collected in the storage tanks at Burnaby Terminal and delivered via two new 762.0 mm (NPS 30) pipelines and the existing 609.6 mm (NPS 24) pipeline. Each pipeline line will have a capacity of 4,635 m^3/hour (700,000 bbl/d), except that the existing line will only be capable of this flow rate when delivering light oil. The three delivery lines will terminate at receiving traps located at Westridge terminal. Interconnecting piping and a valve manifold will allow any of the three pipelines to deliver to any of the three berths. The pipelines will be operable simultaneously.

Moffatt & Nichol developed several design options for the expanded Westridge Marine Terminal (Moffatt & Nichol 2012). A combination of three Aframax berths consisting of a double berth finger pier to the west and a single berth to the east has been chosen as the preferred option (Figure 10). The three berths are accessed by a single common access trestle, approximately 70 meters long. In addition, one floating utility dock with gangway to shore is incorporated to the dock design. The design provides good alignment and access/egress for all sizes of vessels up to Aframax size. All berths shall be Aframax capable and be outfitted with three cargo chicksan loading arms each.

The access trestle will include a roadway with pipe racks on both sides. Pipe racks will be provided on each side of the roadway serving separate berths on either side of a finger pier. The pipe rack structure will be independent of the access roadway structure.

Loading platforms are designed to accommodate equipment and piping. This includes cargo transfer arms for crude oil and vapour recovery from the vessel. The platform will have a containment area where cargo transfer arms and supplemental process equipment such as stripping pumps (for draining inboard portions of the arms) and hydraulic control stations will be situated. Vapour recovery process equipment will also be situated in the containment area.

Westridge terminal currently receives jet fuel from barges and stages it in tanks at Westridge for onward transfer via a separate pipeline to the Vancouver International Airport. Approximately one barge a month is received for this purpose. This activity is not expected to change as a result of the project. Therefore, at least one berth shall be equipped with dedicated equipment to receive jet fuel.

Foam trailer and controls shall be provided on the shore side. The deck of the loading platform will be sloped for adequate drainage. Any seepage or spills from the containment area will be directed into a containment tank situated below deck. It is assumed that storm water which collects in the tank will be pumped to shore for treatment and disposal. Before a tanker berths, the contents of the containment tank are to be pumped to shore. Runoff from the remaining non-process areas of the deck will be deposited directly into the sea through a system of drains and drain pipes. Non-process areas shall be maintained in a clean and without any taint by oil for this purpose.

Three cargo transfer arms of 406 mm (16 inch) diameter will be used to load crude oil on to tankers on Berths 1, 2 and 3. At Berth 1 there will also be a 305 mm (12 inch) arm for receiving jet fuel as described previously. Vapour return arms will be 305 mm. The number and size of the cargo arms are such that each vessel can be loaded at the rate of approximately 4,635 m^3/hour. The total berth time will include any time spent on hoteling, cargo sampling, clearing the vessel in/out with authorities as well as mooring and unmooring. A total of 6 hours is assumed dedicated for these operations.

Custody transfer meters, located just downstream of the manifold, will be provided on each of the loading lines. A control valve will also be provided on each loading line to modulate the loading flow rate.

Two (2) vapour recovery units (VRUs) and one (1) a vapour combustion unit (VCU) will be located at Westridge terminal. The vapour streams displaced from the vessels during loading will normally go to the VRUs, which will remove odorous components and capture the majority of the hydrocarbon vapours for reinjection onto the vessels being loaded or future vessels. During periods when one of the VRUs is shut down for maintenance or repair the VCU will be used. The VCU will also be used if three vessels are being loaded simultaneously, which is expected to be less than 5% of the time. One of the VRU designs under consideration requires two small tanks for synthetic crude used as part of the capture and reinjection cycle. The design of the VRU/VCU system will be finalized during the Detailed Engineering and Design Phase.

Table 1 - Dock and berth overview

Dock	Berth	Product	Trestle length	Total pipe length	Pipe dimension inner diameter
1	1	Crude oïl export + Jet Fuel import	250 meters	290 meters	Crude : 762 mm (30”) Jet Fuel: 305 mm (12”)
2	2	Crude oil export	250 meters	280 meters	Crude 914 mm (36”)
	3	Crude oil export	290 meters	320 meters	Crude 914 mm (36”)
3	4	NA - Utility Dock	Gangway	NA	NA

Figure 10 - Terminal Design Layout (Moffatt & Nichol 2013)

3.4.1 Marine Terminal Berthing Procedures

The following is an extract from Westridge terminal berthing procedures and the preliminary design description from Moffatt & Nichol (2012). Prior to a tanker arriving at the berth, a mooring plan shall be agreed between the ship's officers and Pilot. The Loading Master shall act as liaison between the vessel and Westridge terminal personnel so that appropriate preparations can be made.

- Tankers are brought through the Second Narrows by escort tugboats. They may be brought to temporary anchorage or directly to the dock.
- The tanker initially approaches the terminal at a very low speed, below 5kts. Once within 200 m the approach velocity is reduced with the assistance of tugs in order to gently land the vessel on the dock fenders.
- At least two tethered tugboats are required when berthing a tanker. Another smaller tug assists in passing the vessel’s mooring lines to the mooring dolphins and can also assist as required by the Pilot. The tugs hold the vessel against the dock until she is securely moored.

- Tankers may be moored from either side, i.e. port or starboard side. This will depend on various requirements including the state of the tide and environmental conditions, the particulars of the vessel (e.g. alignment of the manifold connections between the vessel and the dock) and any special requests of Westridge terminal, vessel or pilot.
- The eyes of the tanker's mooring lines are placed over the quick release hooks on the berth and then tensioned by winches on board the vessel. The hook mechanism allows mooring lines to be released quickly in normal operation and also if required during an emergency.

The sea and harbour area are protected from potential spills by a boom deployed around the vessel prior to loading or offloading of petroleum taking place. The tanker shall operate in accordance with international and local regulations and in keeping with any special requirements of PMV and Westridge terminal. This includes the discharge of bilge and ballast water. Canadian regulations require all ballast water to be exchanged mid ocean prior arrival in order to avoid the introduction of non-indigenous species or other contamination into the local environment. Spot inspections to ensure compliance are carried out by the Harbour Master's Office and Transport Canada inspectors. The Trans Mountain Loading Master and Technicians shall note any discharges that do not appear to be in accordance with regulations and try to verify with the vessel. The Terminal is obliged to inform requisite Authorities whenever any discharge is considered to be not in accordance with regulations.

3.4.2 Westridge Safety and Monitoring

The Westridge terminal is an existing facility and is already equipped with safety and monitoring equipment. These will be upgraded or replaced in keeping with industry best practices in order to ensure the safe cargo transfer operations. A brief description of some of the safety systems are provided below (for more details, see Termpol 3.10 and Termpol 3.11).

Loading Master

Trans Mountain allocates a Loading Master to all arriving vessels. This person has knowledge of tanker operations and is designated by the Terminal to liaise and communicate with a vessel prior to and during her stay at the terminal about operations at the dock; the Loading Master acts as the Terminal's Representative.

The Loading Master witnesses operations and confirms that safety and tanker and terminal best practices are being followed. The Loading Master has the authority to immediately stop or abort cargo transfer operations take immediate actions to safeguard the terminal and the environment if necessary. The Loading Master provides local knowledge and prompt on-scene guidance to the vessel and Terminal during an emergency, however, the Loading Master's authority does not extend to the vessel or her crew.

The Loading Master updates information in the Terminal's files about the performance of the vessel.

Gas Monitoring

Gas alarms to detect hydrocarbon, H2S and other vapours will be installed throughout the terminal to detect gas well before a dangerous condition can develop.

Fire Detection and Firefighting

Suitable fire detection and firefighting systems shall be fitted in and around Westridge terminal depending on the need. Examples of areas that will be provided with such equipment include the control room/s, areas where process equipment such as places vapour processing units are fitted, any oil storage tanks, etc. Independently driven fire pumps shall be available to provide required amount of seawater (or foam) for firefighting purposes.

Firefighting systems will be provided at all tanker berths to extinguish a fire within the area of the berth platforms and on the deck of the tanker in the vicinity of the ship's manifold area. Firefighting equipment includes water and foam monitors located on the main loading platforms. Each berth will have two dedicated rotating fire monitors with foam and water capability. In addition, certain harbour tugs are equipped with fire monitors and local marine firefighting capability is expected to be available with local fire departments.

Control Room Monitoring

The Westridge terminal control center will be located onshore near the water and will monitor and control the cargo transfer operations at the marine terminal. This control centre will also provide primary oversight of the entire terminal including the reception and monitoring of all operating data; it will have the capability of controlling valves and the monitoring of all security systems. A system redundancy back-up plan will be evaluated during detailed design.

Ship-to-shore communications will be maintained throughout all cargo transfer operations. CCTV monitoring will be available.

Quick Release and Load Monitoring of Mooring Lines

- Breasting and mooring dolphins will be equipped with 100-tonne, double quick release mooring hooks (QRMH) and an electric motor-driven capstan.
- There will be one unit on each dolphin and two on the dock (eight in total). The mooring hooks can be operated manually or through electrical release via remote control from a central monitoring system.
- The load on each hook must be capable of being monitored from a central monitoring station. The load monitoring system will provide the facility operator with real-time information on the loads in all mooring lines.

Metocean Monitoring System

Meteorological and oceanographic monitoring equipment will be installed at the Westridge terminal. These sensors will provide real time data on wind speed, wind direction, barometric pressure, temperature, visibility, tidal changes, wave height, wave direction, current speed, and current direction.

The information gathered by the sensors will be used to guide decision making for both vessel and terminal operators Westridge terminal shall set environmental limits and parameters for conducting hydrocarbon transfer activities as well as environmental conditions during which mooring/unmooring operations shall not take place. The conditions include times when a vessel may be required to vacate her berth because of prevailing or expected weather events. Real time tide and current data is also available at the Second Narrows Rail Bridge.

Aids to Navigation

In consultation with PMV and CCG suitable aids to navigation shall be installed on the dock complex. These will be designed to meet the requirements of vessels calling at the dock as well as any passing vessels.

Docking Monitoring System

The Westridge terminal will be equipped with a docking monitoring system to assist in docking and undocking tankers. This system provides feedback information to the pilot and ship's crew in order to facilitate the safe berthing of the vessel.

The docking system assists pilots and terminal operators during the final 200 to 300 metres of the approach to the berth. Laser sensors measure the vessel's approach speed, distance and angle with respect to the berth structures. The vessel's distance and speed data are typically displayed on a large outdoor display board located on one of the berth structures. The data can also be transmitted and displayed to the pilots and ship personnel in real time via carry-on laptops or hand-held monitors.

The system improves the safety of the berthing operation by helping the pilot and ship's crew manage the vessel's speed and approach vectors and verify that the approach procedure is within the specified terminal limits.

The system will be designed to perform three major functions including:

- Monitoring the vessel as it approaches and is manoeuvred towards the berth;
- Monitoring the vessel's approach immediately prior to docking as it makes contact with the fender(s); and

- Monitoring the drift movements and position of the vessel while it is moored at the berth.

All sensor information is sent to the control centre for display and logging.

3.5 Environmental Data

In the risk assessment model MARCS uses several environmental parameters as inputs to the model: visibility, wind characteristics, shoreline types and seabed types. All the data used in the risk assessment has been provided by EBA Engineering Consultants Ltd. (EBA), a consultant engaged by Trans Mountain to develop spill modelling for Termpol studies. This information can be found attached to Termpol 3.1.

The fraction of time with poor visibility, defined by DNV as less than a 2 nm visibility, as a function of location is shown in Table 2. Within the study area, the outer part of Juan de Fuca Strait has the highest percentage of low visibility annually. In this area the visibility is less than 2 nm for 14% of the year, caused primarily by fog.

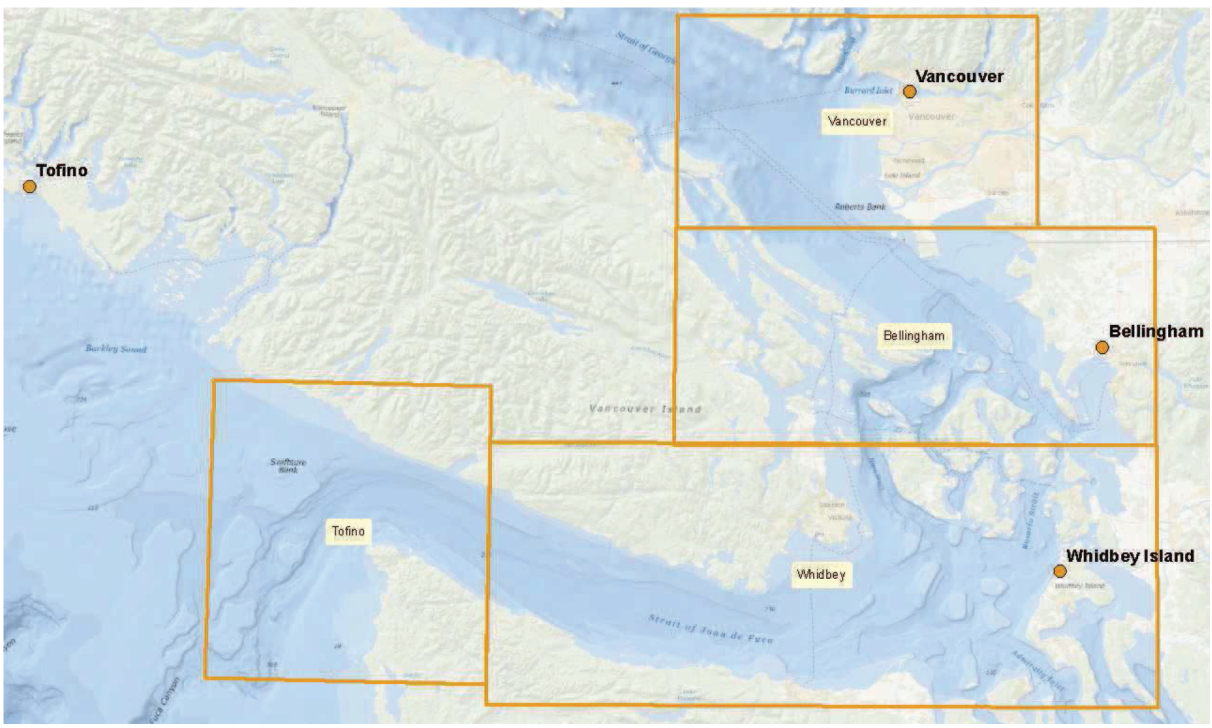

Figure 11 - Visibility Stations used for the various part of the study area

Table 2 - Percentage of time with low visibility

Station	Percentage of time with low visibility
Tofino	14 %
Whidbey Island	5 %
Bellingham	4 %
Vancouver	1.5 %

Several different wind roses are defined in the study area as shown in Figure 12 and in Table 3. The wind data indicated in Table 3 shows that winds are most of the time calm or fresh.

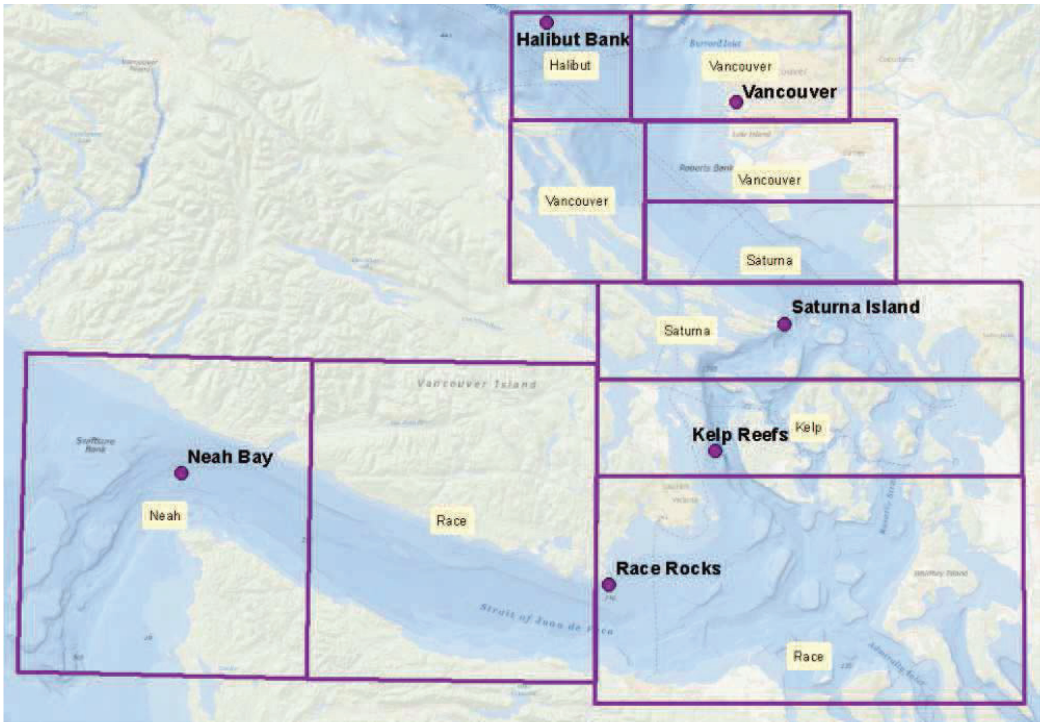

Figure 12 - Wind Stations used for various parts of the study area

Figure 12 also shows the areas where the sea state is evaluated to be sheltered (sub-area Vancouver, Halibut Bank and Saturna Island), semi-sheltered (sub-area Kelp Reefs) and exposed (sub-area Neah Bay and Race Rocks). The exposure level influences the sea state that again has effect on the tug performance and the structural failure/ foundering incident likelihood.

Table 3 - Wind Rose Data Used in the Analysis

Vancouver

	knots	m / s	N	NE	E	SE	S	SW	W	NW
Calm	0 - 20	0 - 10	0.0355	0.0456	0.3706	0.1095	0.0833	0.0562	0.1636	0.0782
Fresh	20 - 30	10 - 15	0.0000	0.0000	0.0057	0.0066	0.0060	0.0052	0.0122	0.0061
Gale	30 - 45	15 - 23	0.0000	0.0000	0.0000	0.0050	0.0000	0.0000	0.0057	0.0050
Storm	> 45	> 23	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Halibut Bank

	knots	m / s	N	NE	E	SE	S	SW	W	NW
Calm	0 - 20	0 - 10	0.0671	0.0326	0.1966	0.2244	0.0689	0.0371	0.1726	0.1564
Fresh	20 - 30	10 - 15	0.0006	0.0005	0.0219	0.0106	0.0007	0.0003	0.0034	0.0050
Gale	30 - 45	15 - 23	0.0002	0.0000	0.0005	0.0003	0.0000	0.0000	0.0000	0.0003
Storm	> 45	> 23	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Saturna Island

	knots	m / s	N	NE	E	SE	S	SW	W	NW
Calm	0 - 20	0 - 10	0.0591	0.0467	0.0807	0.0669	0.1778	0.2596	0.0675	0.1659
Fresh	20 - 30	10 - 15	0.0008	0.0069	0.0069	0.0102	0.0250	0.0043	0.0000	0.0000
Gale	30 - 45	15 - 23	0.0006	0.0025	0.0012	0.0052	0.0098	0.0009	0.0000	0.0000
Storm	> 45	> 23	0.0000	0.0000	0.0000	0.0006	0.0009	0.0000	0.0000	0.0000

Kelp Reefs

	knots	m / s	N	NE	E	SE	S	SW	W	NW
Calm	0 - 20	0 - 10	0.1588	0.1037	0.0506	0.1122	0.2775	0.0823	0.0921	0.0328
Fresh	20 - 30	10 - 15	0.0031	0.0054	0.0042	0.0201	0.0141	0.0043	0.0093	0.0021
Gale	30 - 45	15 - 23	0.0000	0.0031	0.0029	0.0085	0.0059	0.0023	0.0026	0.0000
Storm	> 45	> 23	0.0000	0.0000	0.0000	0.0000	0.0021	0.0000	0.0000	0.0000

Race Rocks

	knots	m / s	N	NE	E	SE	S	SW	W	NW
Calm	0 - 20	0 - 10	0.0954	0.1308	0.0870	0.0466	0.0357	0.0637	0.2716	0.0194
Fresh	20 - 30	10 - 15	0.0078	0.0147	0.0048	0.0016	0.0010	0.0098	0.1619	0.0003
Gale	30 - 45	15 - 23	0.0009	0.0038	0.0025	0.0006	0.0001	0.0031	0.0364	0.0000
Storm	> 45	> 23	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0003	0.0000

Neah Bay

	knots	m / s	N	NE	E	SE	S	SW	W	NW
Calm	0 - 20	0 - 10	0.0278	0.0378	0.2460	0.1168	0.0828	0.1441	0.1731	0.0956
Fresh	20 - 30	10 - 15	0.0002	0.0004	0.0170	0.0168	0.0126	0.0056	0.0079	0.0094
Gale	30 - 45	15 - 23	0.0000	0.0000	0.0007	0.0005	0.0026	0.0005	0.0010	0.0008
Storm	> 45	> 23	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Figure 13 defines the probability of encountering a rocky hard shoreline if a vessel grounds during its transit of the sailing route. The figure shows the probability of the hull being penetrated as a result of grounding as incorporated in the MARCS model. This is not the same as the probability of an oil spill because not all tankers are laden, not all hull damage occurs adjacent to oil tanks and as all tankers are double hulled, and a penetration of the hull adjacent to an oil tank may not result in the penetration of that oil tank. The potential damage to a tanker's cargo tanks is modeled and described in greater detail in Chapter 9.

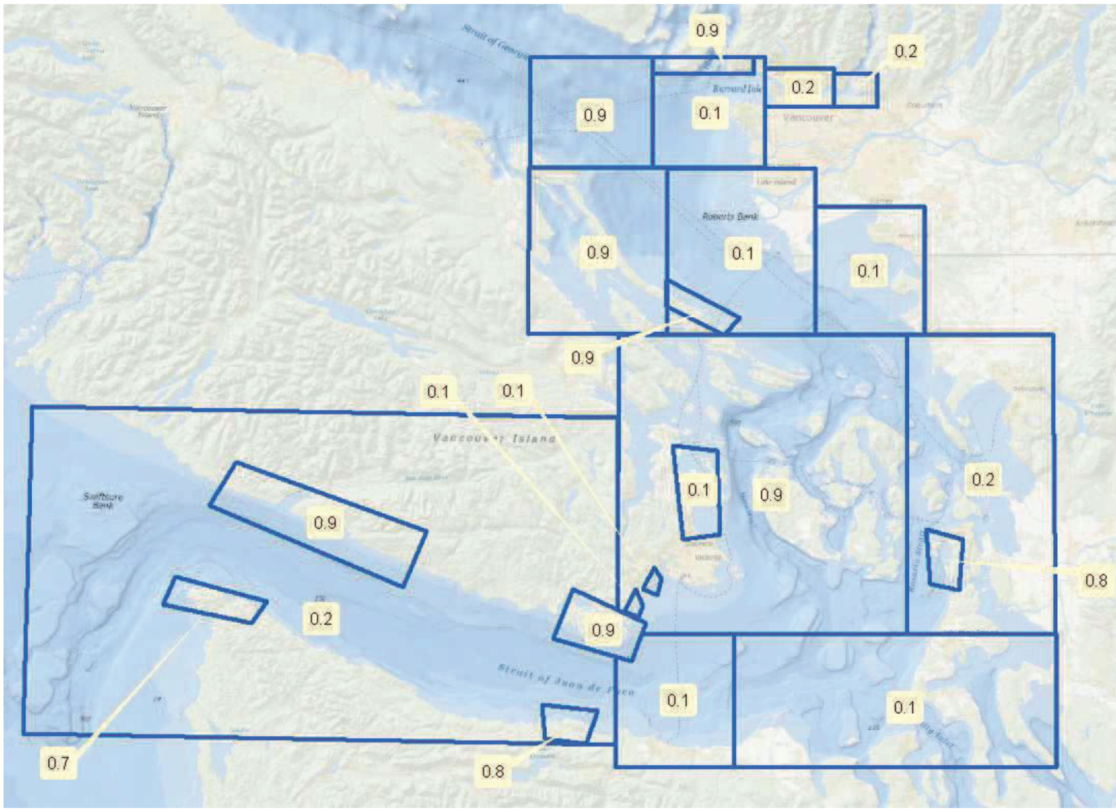

Figure 13 - Probability of hitting a Rocky Shoreline if a grounding occurs

3.6 Emergency Anchorage

A drifting ship can save itself from grounding if the location is suitable and if the ship's crew can safely deploy the ship's anchors, which as per their design, can be used when the vessel is a 'deadship' or without power.

Not all locations are suitable for emergency anchoring. In general, shallow sea areas with gentle gradient sea beds with a soft sea bottom, such as mud, provide the best holding ground and will allow a drifting ship to regain control by deploying its anchors thereby preventing a drift-grounding from taking place. The thresholds applied in MARCS are that the anchorage has to be less than 60 meter deep and more than 500 meters from land. The likelihood of success is highest for soft bottom and lowest for hard (rock) bottom. The model also assumes that the crew understand how to perform this procedure correctly and they are able to do it (e.g. in the absence of main engine power).

The areas in the study area where an emergency anchoring is suitable are shown in Figure 14, areas with less than 60 meter deep more than 500 meter from land. The dominating seabed types for the areas are indicated in the figure. Different anchor-save probabilities are applied for different wind conditions (Calm, Fresh, Gale, and Storm) and for different sea bottom types (soft or hard), see the MARCS methodology in Appendix 1 for detailed description of these probability distributions.

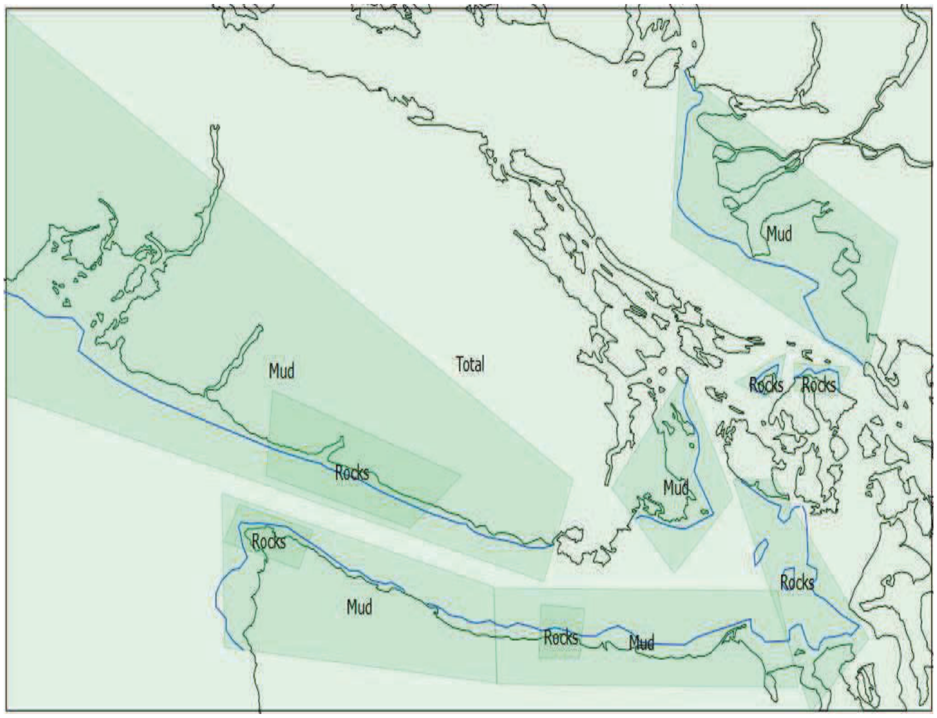

Figure 14 - Emergency Anchoring Areas Characteristics

4 HAZARD IDENTIFICATION

A HAZID workshop is a systematic, multidisciplinary, team-oriented exercise involving a group of experts who evaluate the hazards involved in an operation and the relevant safeguards and other mitigation measures used to address these hazards.

4.1 Navigational HAZID Workshop

A one day HAZID workshop was conducted to evaluate navigational hazards related to the sailing route for loaded tankers departing Westridge terminal. The HAZID first asked participants to identify credible causes of marine incidents based on local knowledge of historical events, weather, bathymetry, navigation routes, local aids to navigation and other infrastructure. The team was then asked to evaluate the adequacy of safeguards to prevent incidents from occurring or mitigate the consequences should an incident occur. The results from the Navigational HAZID are reported in Appendix 2.

4.1.1 Hazard Evaluation of Route by Expert Mariner

As part of the hazard evaluation DNV attended a sailing of a Panamax in the sailing route from Westridge terminal to the pilot debarking area south of Victoria, BC. The ride was undertaken by an experienced Master Mariner and widely experienced former ship captain who has conducted similar evaluations globally. The description of the sailing can be found in Appendix 2.

4.2 Westridge Terminal HAZID Workshop

A second one day HAZID workshop was conducted to evaluate hazards related to cargo loading operations at the Westridge terminal. Again participants were asked to identify credible causes of incidents based on local knowledge of weather, traffic and terminal operation. The team was then asked to evaluate the adequacy of safeguards to prevent incidents from occurring or mitigate the consequences should an incident occur. The results from the terminal HAZID are reported in Appendix 3.

5 VESSEL TRAFFIC

5.1 Traffic input to model

In order to accurately assess the frequency in which Project tankers may be exposed to collisions or other incidents it is necessary to model all traffic movement along the route these tankers travel (see Chapter 7 Frequency Assessment). For ease of extrapolation, the region has been divided into 12 segments (see Figure 15) Segments 1 and 2 comprise the in-port section of the route, Segments 3 – 7 comprise the normal transit section of the region, Segments 8-12 comprise those waters and shore that are adjacent to the normal tanker route.

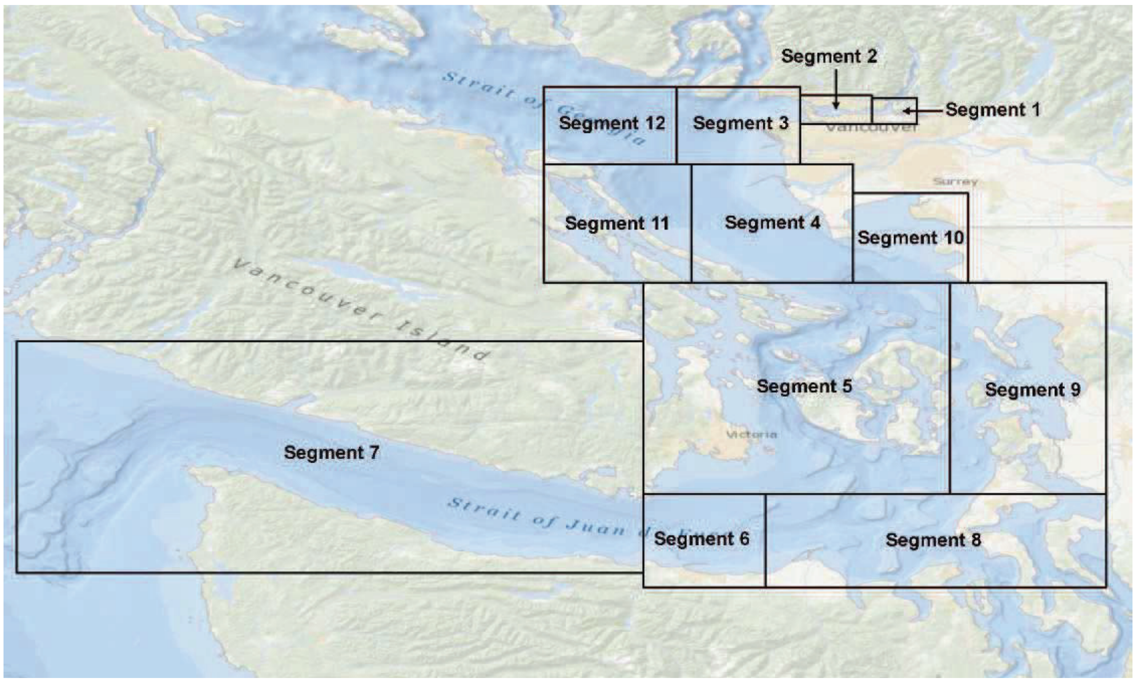

Figure 15 - Study area and segments defined in MARCS

The traffic from the AIS data that is loaded into MARCS is divided into 8 vessel categories (Table 4) for the purpose of being able to analyse the incident risk for the various vessel types. The traffic is also divided into vessel size categories for input to the MARCS model (Table 5).

Table 4 - Vessel Type Categories Used in MARCS

Number	Vessel category	Vessel types
1	Trans Mountain tanker	The oil tankers sailing to and from Westridge Terminal
2	Other crude oil tanker	Crude oil tankers that are not carrying crude from the Westridge Terminal
3	Other product tanker	Petroleum product tankers and chemical tankers sailing in the study area
4	Towing long and wide	Tugs with long and/or wide tow, mostly barges
5	Cargo	All dry bulk vessels, container vessels and RoRo cargo vessels
6	Passenger	Ferries and cruise vessels
7	Fishing	Commercial fishing vessels
8	Other	Military vessels, service vessels, vessel handling tugs, scientific vessels etc.

Table 5 - Vessel Size Categories Used in MARCS

Number	Deadweight category (DWT)		
1	0	-	10
2	10	-	500
3	500	-	14,000
4	14,000	-	32,000
5	32,000	-	50,000
6	50,000	-	65,000
7	65,000	-	80,000
8	80,000	-	210,000

The vessel type category "Towing long and wide" shown in category 4 in Table 4 is the AIS category for tugs with barge tow and is recorded without any manner to identify how many long and wide tows transport oil. Based on information gathered during the HAZID workshop, it has been assumed that the oil barge traffic is 15% of the "Towing long and wide" traffic.

AIS data for 2012 from the Marine Exchange of Puget Sound[2] was used to provide data on vessel traffic movements in the Salish Sea. AIS is an automatic tracking system used on ships that allow them to identify and locate other traffic vessels. The International Convention for the Safety of Life at Sea (SOLAS) requires AIS to be fitted aboard all vessels of 300 GT or more. As AIS can be a key tool in incident avoidance a large number of local smaller vessels have fitted AIS on a voluntary basis.

A holistic picture of all the traffic routes in the area needs to be inserted into MARCS for the modelling to reflect the actual and forecasted traffic level and hence potential collision and grounding frequencies. Figure 16 shows the geographical traffic lanes of the main ship movements in the study area. The AIS data was used to identify and establish the main traffic lanes that cover the majority of the traffic movement in the area plus all tanker and large vessel movement. Based on the AIS data the MARCS model determines the number, type and size of vessels within each traffic lane.

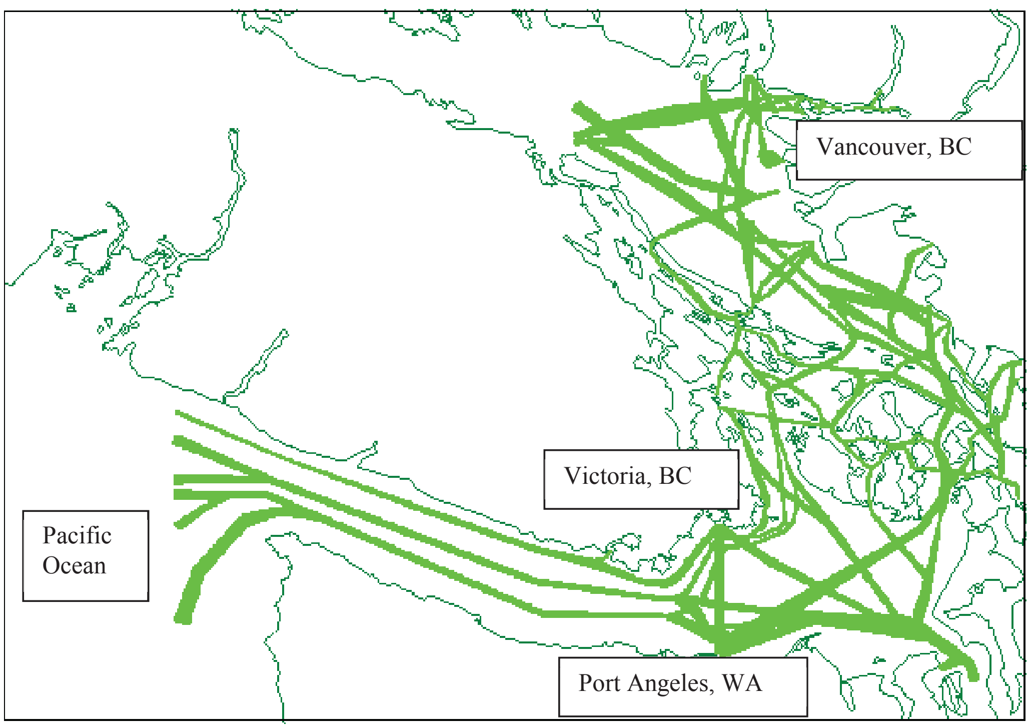

Figure 16 - Main traffic lanes applied in the MARCS modelling

[2] The Marine Exchange was founded in 1981 and is governed by a board of directors made up of members. Based in Seattle, WA, it serves as an information clearinghouse for its members providing a wide range of services. The Exchange has implemented an Automated Identification System (AIS) network covering all of Puget Sound, Vancouver BC and the Columbia River and off the Washington Coast for 150 miles.

5.1.1 Use of AIS data by MARCS

AIS raw data is treated and analysed prior to being used in the MARCS model. The process for use of AIS data as input to MARCS is as follows:

- The AIS position report data is manually evaluated and faulty position reports (e.g. positions shown on land) are removed from the dataset.
- Individual ships tracks (successive AIS position reports for a specific ship) are extracted from the AIS dataset and defined by vessel (see Table 4) type and vessel size category (see Table 5).
- Each individual vessel track is transferred from the AIS data to the MARCS route structure that is shown in Figure 16.
- The number of vessel-miles in each route element for each vessel type and vessel size category is calculated based on the AIS data.
- Finally, the route frequency data is obtained by dividing the ship-miles by the route element length.

This analysis generates a transit frequency per year along each route as a function of vessel type and vessel size. This data is then used as an input into the MARCS calculations.

5.2 Evolution of the vessel traffic

5.2.1 Traffic in 2018 and 2028

The risk assessment outlined in this report aims to compare the risk of tanker traffic to and from Westridge terminal under three scenarios of forecasted traffic:

Case 0 (Base case – without the Project, forecast traffic in 2018):

- Trans Mountain tanker traffic in 2018 without the Project (i.e. 60 tankers per year)[3] plus other traffic escalated to 2018 levels as described below. For the purpose of the risk assessment it is assumed that all tankers are Aframax size.

Case 1 (Project proceeds, forecast traffic in 2018)

- Trans Mountain tanker traffic in 2018 with the Project implemented (i.e. 408 tankers per year)[3] plus other traffic escalated to 2018 as for Case 0. The model assumption is that all of the tankers are Aframax size.

Case 2 (Project proceeds, forecast traffic in 2028)

- Trans Mountain tanker traffic with the Project (i.e. 408 tankers per year)[3] plus other traffic escalated to 2028 as described below. The model assumption is that all of the tankers are Aframax size.

[3] The number of transits are the double of the number of vessels as they are inbound in ballast and outbound laden. However, incidents that lead to an oil cargo spill accident can only happen to the laden outbound tankers.

5.2.2 Traffic Escalation

Traffic growth factors were obtained from the Termpol 3.2 study and are outlined in Table 6 and Table 7.

Table 6 - Traffic Growth Factors used to escalate traffic from 2012 to 2018

Vessel Type	Segments 1 to 5	Segments 6 to 12
	Growth factor (percent per year)	
Cargo/Carrier	1	1
Tug	1	1
Service	1	1
Passenger	1	1
Tanker (not Trans Mountain tanker)	4	2
Fishing	0	0
Ferry	0	0
Unknown	1	1
Other	1	1

Table 7 - Traffic growth rates for 2018 - 2030

Projected Growth Rates (percent per year) All Segments			
Vessel Type	**2018 - 2020**	**2020 - 2025**	**2025 - 2030**
Cargo/Carrier	1	1	1
Tug	1	1	1
Service	1	1	1
Passenger	1	1	1
Tanker (not Trans Mountain tanker)	2	2	2
Fishing	0	0	0
Ferry	0	1	1
Unknown	1	1	1
Other	1	1	1

To estimate the traffic volume for 2018 and 2028 the 2012 traffic data has been extrapolated in the MARCS model based on the forecasted annual growth showed in the tables above. The estimated number of vessel-miles for Case 0, Case 1 and Case 2 are shown in Table 8 (Figure 17), Table 9 (Figure 18) and Table 10 (Figure 19) respectively. As MARCS is using the main traffic lanes as shown in Figure 16 there will be some minor traffic outside these lanes that is not covered by the MARCS modelling. Thus there will be slightly less total sailed nautical miles registered in the MARCS model than the actual 2012 traffic registered by all vessels in the AIS data. However, this does not affect the risk results for the tankers sailing to and from Westridge terminal as their sailing lanes and also their crossing sailing lanes are all well defined in the model. It will only show a slight difference in the total sailed nautical miles between the MARCS model and the AIS data registrations for the total study area.

The MARCS model divides the traffic into vessel size categories for the risk analysis as shown in Table 5. The vessel category “Other” includes tugs that are not towing barges, which are predominantly escort tugs and harbour tugs that assist large vessels. There are a high number of these tugs in the area and they perform a high level of activity. This is the main reason for such a large number of sailed nautical miles in this category. The risk analysis results are not biased because the potential effects from collision with these vessels are also included in evaluating the risk model.

Table 8 - Predicted Vessel Nautical Miles Data in the Study Area in 2018 by Vessel Type and Vessel Size for Case 0 (without Project)

In Vessel-miles	Vessel Size Category								
Vessel Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Trans Mountain Tanker	-	-	-	-	192	613	3,967	14,372	**19,143**
Crude Tanker	-	-	-	-	6,254	5,754	11,450	73,000	**96,458**
Product Tanker	-	-	1,648	38,030	50,400	1,168	-	-	**91,246**
Towing long and wide	3,433	97,620	179	-	-	-	-	-	**101,232**
Cargo	-	-	110,700	202,100	189,300	168,700	218,400	157,400	**1,046,600**
Passenger	-	60,900	633,900	63,670	852	-	-	-	**759,322**
Fishing	-	36,360	34,540	539	-	-	-	-	**71,439**
Other	113,600	1,375,000	73,930	4,193	546	-	-	40,160	**1,607,429**
Total	**117,033**	**1,569,880**	**854,897**	**308,532**	**247,543**	**176,235**	**233,817**	**284,932**	**3,792,869**

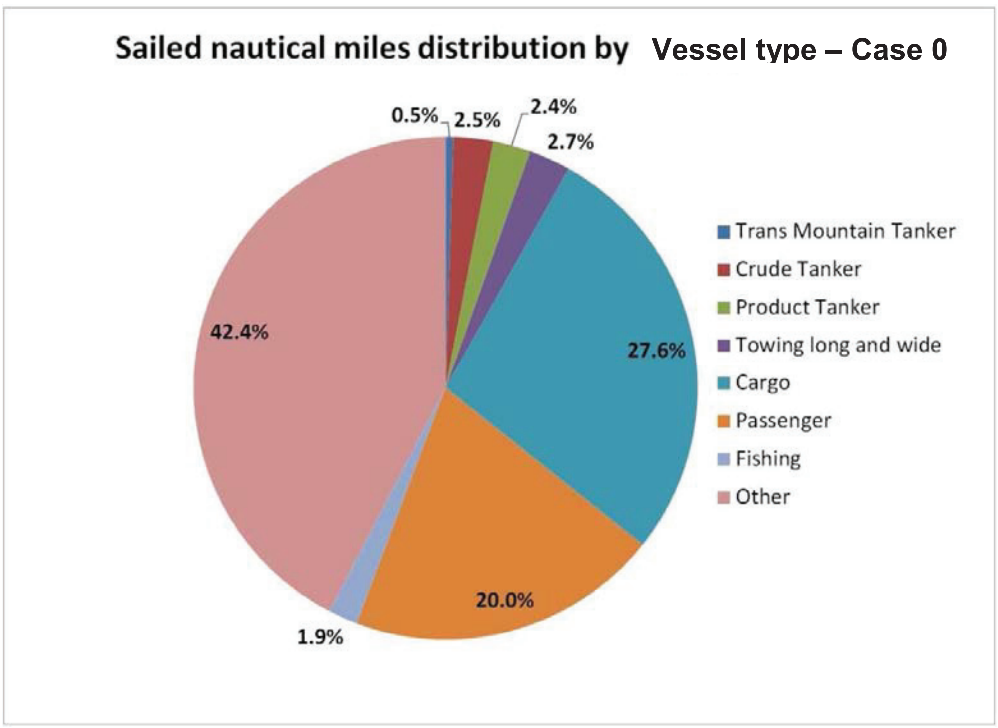

Figure 17 - Distribution of the sailed miles by vessel type for Case 0

For Case 0, the Trans Mountain tanker traffic is more than 9 times less frequent than the other tanker traffic. A much lower incident frequency for the Trans Mountain tankers than for the other tankers can be expected from this fact. The majority of the miles sailed are due to the following vessel types: “Other” (42%), “Cargo” (28%) and “Passenger” (20%). The Trans Mountain tankers represent 0.5% of the entire number of nautical miles sailed.

Table 9 - Predicted Vessel Nautical Miles Data in the Study Area in 2018 by Vessel Type and Vessel Size for Case 1 (with Project)

In Vessel-miles	Vessel Size Category								
Vessel Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Trans Mountain Tanker	-	-	-	-	1,303	4,170	26,970	97,720	**130,163**
Crude Tanker	-	-	-	-	6,254	5,754	11,450	73,000	**96,458**
Product Tanker	-	-	1,648	38,030	50,400	1,168	-	-	**91,246**
Towing long and wide	3,433	97,620	179	-	-	-	-	-	**101,232**
Cargo	-	-	110,700	202,100	189,300	168,700	218,400	157,400	**1,046,600**
Passenger	-	60,900	633,900	63,670	852	-	-	-	**759,322**
Fishing	-	36,360	34,540	539	-	-	-	-	**71,439**
Other	113,600	1,375,000	73,930	4,193	546	-	-	40,160	**1,607,429**
Total	**117,033**	**1,569,880**	**854,897**	**308,532**	**248,654**	**179,792**	**256,820**	**368,280**	**3,903,889**

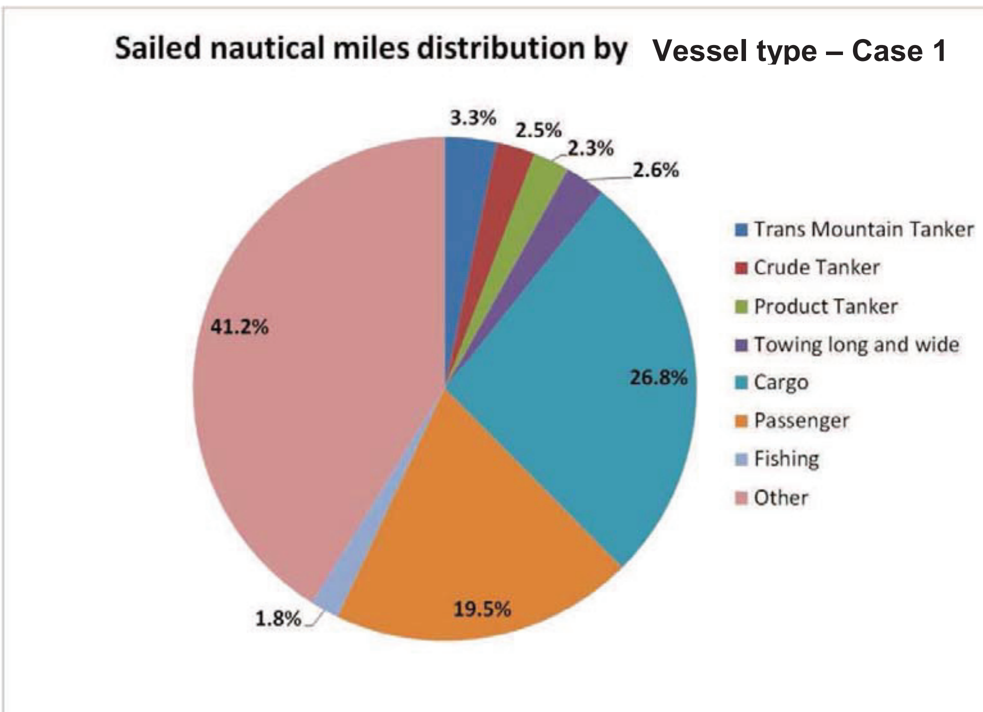

Figure 18 - Distribution of the sailed miles by vessel type for Case 1

For Case 1, the Trans Mountain tanker traffic represents 41% of the nautical miles sailed by a tanker in the study area, instead of 9% for Case 0. That means that the Trans Mountain tanker traffic will constitute less than half of the tanker traffic in the study area if the Project goes ahead. However, Trans Mountain tankers will constitute only 3.3% of the entire number of nautical miles sailed. The majority of the estimated miles sailed are by the following vessel types: “Other” (41.2%), “Cargo” (26.8%) and “Passenger” (19.5%).

Table 10 - Predicted Vessel Nautical Miles Data in the Study Area in 2028 by Vessel Type and Vessel Size for Case 2 (with Project)

In Vessel-miles	Vessel Size Category								
Vessel Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Trans Mountain Tanker	-	-	-	-	521	1,694	10,810	117,300	**130,325**
Crude Tanker	-	-	-	-	7,622	7,013	13,960	88,980	**117,575**
Product Tanker	-	-	2,008	46,360	61,440	1,424	-	-	**111,232**
Towing long and wide	3,792	107,800	198	-	-	-	-	-	**111,790**
Cargo	-	-	122,300	223,200	209,100	186,300	241,300	173,900	**1,156,100**
Passenger	-	66,610	693,300	69,640	932	-	-	-	**830,482**
Fishing	-	36,360	34,540	539	-	-	-	-	**71,439**
Other	125,500	1,519,000	81,660	4,631	603	-	-	44,360	**1,775,754**
Total	**129,292**	**1,729,770**	**934,006**	**344,370**	**280,217**	**196,431**	**266,070**	**424,540**	**4,304,697**

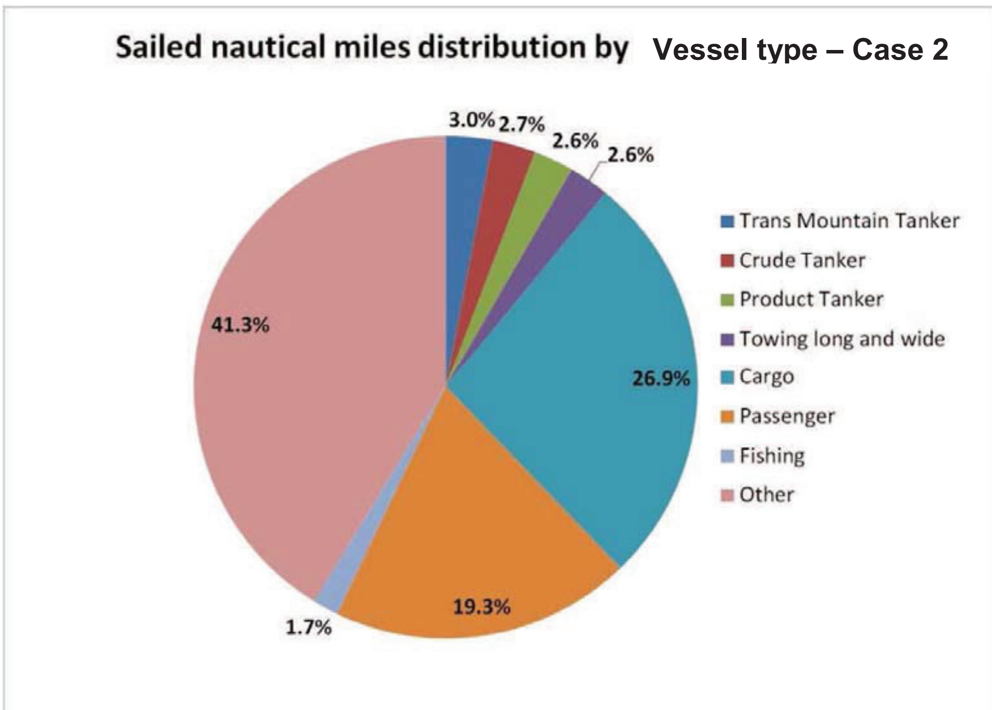

Figure 19 - Distribution of the sailed miles by vessel type for Case 2

For Case 2, the forecasted traffic growth shown in Table 6 and Table 7, shows that in 2028 the Trans Mountain tanker traffic will only represent 3.0% of the miles sailed considering the entire traffic, and 36% of the total tanker traffic.

Figure 20 shows the geographic distribution of total overall ship movements in the study area for Case 1. The highest number of movements is in the ferry routes and in the main routes of the Strait of Juan de Fuca as well as in the Strait of Georgia. The Trans Mountain tankers sail in the well-defined inbound and outbound routes, and constitute less than 0.4 movements per day for Case 0 and slightly more than 2 movements per day for Case 1 and Case 2.

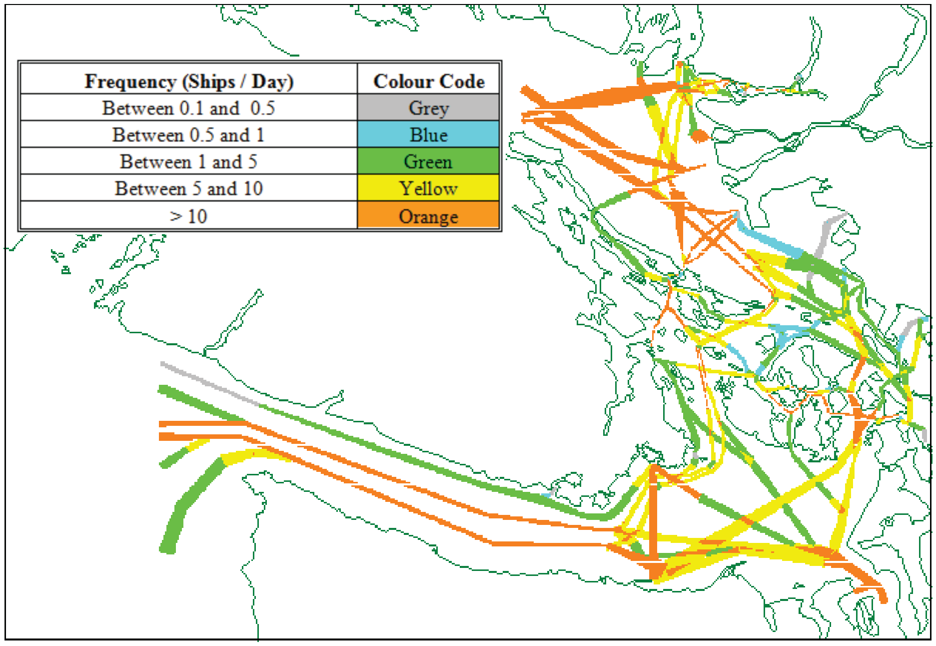

Figure 20 - Geographical Distribution of all Vessel Movements in the Study Area for Case 1

6 RISK CONTROLS TAKEN INTO CONSIDERATION IN THE ANALYSIS

The MARCS model estimates the probability for incidents based on the traffic pattern, sailing route navigability and meteorological parameters. The hazards and risks related to a sailing route are prevented and mitigated by implementing risk control measures. The study area's sailing routes are well managed and have well established important risk controls for the traffic and for oil cargo transport in particular. This section describes the risk controls that have been taken into account in the risk analysis and discusses the risk reducing effect of the risk controls as applied in the MARCS model.

The table below summarizes the risk controls applied as a function of case, traffic type, and location. All controls are assumed to apply for both transit direction (inbound and outbound) and loading condition (in-ballast or laden) unless otherwise stated (e.g. escorting controls outside Segments 1 and 2 are applied to laden tankers only). Any risk controls not described have not been implemented in the risk model. Significant traffic are those vessels that may pose a hazard to Trans Mountain tanker traffic, it is assumed to be all traffic larger than 500 DWT, which is size category 3-8 as shown in the MARCS vessel size categories (Table 5). Vessels that are small and not posing a threat to Trans Mountain tanker traffic is not considered significant for this purpose.

Table 11 - Overview of risk controls taken into account in the risk assessment

Traffic and segments	Case 0, Case 1 and Case 2
All significant traffic in all segments	VTS
All significant traffic in all segments	Traffic Separation Scheme (TSS)
All non-local significant traffic All segments except 6 and 7	Pilotage
TM tankers and in all segments	ECDIS/ ENC Ship vetting
All Tankers in Segment 1	Pilotage and PPU - 2 pilots laden, 1 in ballast (applies to all pilot segments) Tethered tugs Non-tethered tugs
All Tankers in Segment 2	Pilotage and PPU Tethered tugs Non-tethered tugs
TM Tankers in Segment 3 and 4	Pilotage and PPU
Other Tankers in Segment 3 and 4	Pilotage and PPU
All Tankers in Segment 5	Pilotage and PPU Tethered tug (laden only & >40,000 DWT) One-way traffic for 2 nm South and North of Turn Point (defined SOA)
Laden TM Tankers in Segment 6	Requirement for min 40 ton bollard pull (BP) escort tug, 0.5nm from tanker, 100% available; Actual tugs used for TM tankers have BP in range of 50-70 tons
All Tanker Traffic	For laden tankers, over 40,000 DWT, escorted and tethered as shown in Figures below One-way traffic in Rosario Strait

The many different sailing routes modeled in MARCS with tug escort for laden oil tankers were incorporated in MARCS and are shown in Figure 21; the pale blue lines represent tanker routes with untethered tug escort and the darker blue lines represent tanker routes with tethered tug escort. The red lines represent parts of the tanker routes with no required escort and/or sailing routes with no tanker traffic.

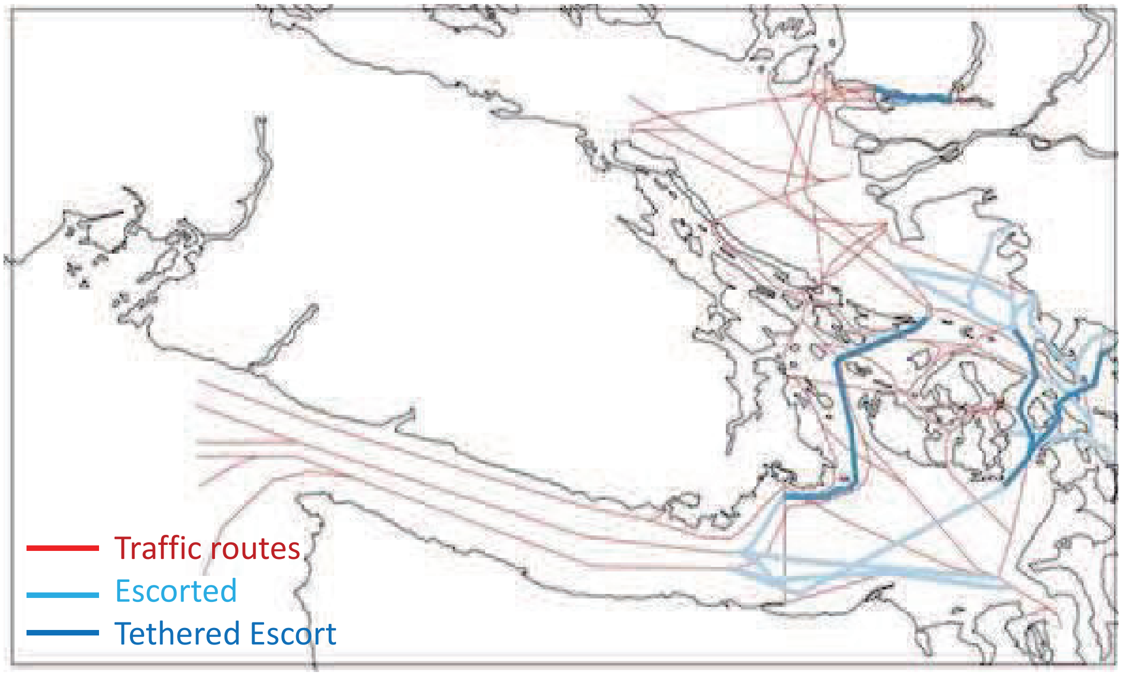

Figure 21 - Level of Escorting for Case 0, Case 1 and Case 2 - Pale blue lines indicate escorted but not tethered. Dark blue lines indicate a tethered escort

6.1 Effect of the Risk Controls Applied in MARCS

This is a summary of the discussion about the effect of the risk controls which is provided in full in Appendix 4.

All the incident frequency models used in MARCS function by a two-step process:

1. MARCS first calculates the frequency of critical situations from the ship traffic data and the data that describes the navigation. The definition of the critical situation depends on the incident type.
2. MARCS then applies a probability of an incident given a critical situation to calculate the frequency of incidents.

All risk controls must either reduce the frequency of critical situations (e.g. a traffic separation scheme will reduce the frequency of encounters (the critical situation for collision) and/ or reduce the probability of an incident given a critical situation (e.g. pilotage will reduce the probability of collision given an encounter).

The base case performance parameters (such as the probability of human error leading to a collision) were derived in previous work by DNV, such as the EU research projects on Safety of Shipping in Coastal Waters (SAFECO I and SAFECO II[4]). This was done by reference to historical incident rates. The effect of different risk controls on the base case performance parameters was derived by a mixture of methods; including historical data were available as well as reference to fault trees and expert judgment as required.

Tethered Tugs, Escort Tugs and Tugs of Opportunity

In the risk model, the presence of tugs affects the frequency of drift grounding incidents. Some may argue that the presence of tugs also reduces the frequency of powered grounding, but DNV has considered only a tethered tug as having the response capability to reduce the powered grounding incident frequency. In combination with VTS and

[4] http://www.transport-research.info/Upload/Documents/200310/safeco.pdf

pilotage, DNV does not allocate any additional reduction in collision frequency merely by having a tug present (either tethered or untethered).

A tethered escort tug is immediately available to respond to a mechanical failure on the tanker (drift grounding hazard). In the risk model, this modifies the rate of mechanical failure on the tanker. DNV is unaware of a grounding incident which has occurred with a tethered tug in attendance, so a reduction factor of 100 times reduction is applied to the mechanical failure rate of tethered tankers. It is assumed that the escort tug is capable of controlling the tanker in the event of a tanker mechanical failure. Tugs are tethered to the outbound tanker in Segments 1, 2 and 5 and thus benefits from it (Trans Mountain and other tankers (vessel types 1, 2 and 3)) in these segments.

A tethered escort tug may also respond to prevent a powered grounding incident. In previous work, DNV has assessed the benefit of this as a reduction by a factor of 2. This is applied to the powered grounding failure frequencies for Trans Mountain and other tankers, vessel types 1, 2 and 3 in segments 5. Additional risk reduction benefits are assigned to the tethered tugs in segments 1 and 2 due to the low tanker speed through the harbour and MRA, and in berth approach operations.

The presence of a powerful escort tug tethered to the tanker also introduces additional failure modes associated with incorrect actions on the tug leading to vessel grounding. DNV assumes that good coordinated command and control structures exist in the tanker-tug combination that reduces the frequency of occurrence of such additional failure modes to insignificant levels.

Escort tugs navigate with the laden outbound tanker but are not tethered to it. In the event of a tanker failure, the escort tug needs to connect a line and exert a saving force on the vessel. This must be done before the tanker drifts aground so the time for the escort to reach the tanker (usually short when escorting, but will be longer for tugs of opportunity, see below) and the time to connect the line must be compared to the time to drift to shore to determine if the escort tug can prevent the grounding. So the effective risk reduction provided by an untethered escort will, among other factors, be dependent on the proximity of the vessel from a possible grounding location in the event of a propulsion failure. The escort tug must also be capable of controlling the tanker in the wind and wave conditions.

For escort tugs, DNV assumes a tug with a bollard pull of about 40 tons and a length of about 40 m. The tug is dedicated to escort duty (100% available) and navigates within 0.5 nm of the tanker it is escorting. In the case of Trans Mountain tankers, the actual capacity of the escort tugs used in practice are at least 50 tons or more.

In addition, tugs of opportunity and emergency response tugs may be able to provide assistance to a drifting tanker. Such tugs may have limited availability (assigned to other duties) or limited capability in open waters (typical small harbour tugs). Tugs of opportunity are not included in the risk model. Neither is the risk reduction from the rescue tug stationed in Neah Bay, although it will have an effect on the drift grounding risk in the Strait of Juan de Fuca. This was not included because it cannot be confirmed with any certainty that this facility will be available to Trans Mountain tankers for the duration of the Project, as well because the rescue tug is primarily provided to safeguard US bound traffic, including loaded tankers bound US port, there is no certainty at this time that even if the tug is available it will be made available to use for a Trans Mountain tanker requiring its assistance.

Tankers over 20,000 DWT are required to be provided with a suitable Emergency Towing Arrangement (ETA) at the stern that can be deployed quickly in the event of the tug being unable to connect to the vessel through normal means due to stress of weather or other reasons. The capacity of the ETA for an Aframax tanker is 200 tons.

7 FREQUENCY ASSESSMENT OF MARINE TRAFFIC INCIDENTS DURING TRANSIT

As discussed in the previous chapter, the frequency assessment has been made for 3 different cases:

Case 0 (Base case – without Project, forecast traffic in 2018):
- Trans Mountain tanker traffic in 2018 without the Project (i.e. 60 tankers per year)[5] plus other traffic escalated to 2018 levels.

Case 1 (With Project, forecast traffic in 2018)
- Trans Mountain tanker traffic in 2018 with the Project (i.e. 408 tankers per year)[4] plus other traffic escalated to 2018 as for Case 0.

Case 2 (With Project, forecast traffic in 2028)
- Trans Mountain tanker traffic with the Project (i.e. 408 tankers per year)[4] plus other traffic escalated to 2028.

The frequency reducing measures that have been taken into account are defined in Chapter 6.

For each case, the calculated incident frequencies (both total incident frequencies and oil cargo spill accident frequencies) for the Trans Mountain tankers have been estimated by using the MARCS model, and are given for each study segment (Segments 1 to 12), for the total study area. For this analysis a marine incident is defined as an event that can lead to an oil cargo spill accident. The majority of incidents will be of a nature that will not lead to an oil cargo spill accident. The incident frequencies are calculated for the following events:

- Collision;
- Powered Grounding;
- Drift Grounding;
- Structural failure; and
- Fire and Explosion.

In a few cases an incident will cause so severe damage to the vessel that it will lead to a breakage of the cargo tanks and thus lead to an oil spill accident. The probability that an incident leads to an oil spill accident is estimated in MARCS based on:
- Ship Structure, whether it is single or double hull (all Trans Mountain tankers are double hull).
- The probability of grounding on rocky shore versus soft bottom shore. This probability distribution is equal to the presence of distribution of rocky shoreline versus soft bottom shoreline (as shown in Figure 13), grounding on rocks will increase the likelihood of a loss of containment.
- Wave and wind affects the probability that a grounding incidents leads to an oil spill. Wave height also affects the probability for a structural failure leading to foundering.
- In case of collision, the momentum of a colliding ship affects whether the incident becomes an oil spill accident.

If an incident is estimated to cause an oil cargo spill accident, then the oil cargo spill volumes and their probability are estimated based on IMO probability distribution and NAPA stability modelling; this approach is described in Chapter 2 and the results are shown in Chapter 9.

[5] The number of transits are the double of the number of vessels as they are inbound in ballast and outbound laden. However, incidents that lead to an oil cargo spill accident can only happen to the laden outbound tankers.

The incident frequency and oil spill accident frequency are estimated in this chapter by first carrying out the frequency assessment for all incidents, including those not leading to an oil spill (Section 7.1). Then the oil cargo spill accident frequency is estimated for Case 0 and Case 1 (Section 7.2). The potential reduction in frequency for an oil cargo spill due to implementation of new risk reducing measures is estimated in Section 7.3. Section 7.4 summarises the incident frequency and oil cargo spill frequency result, while Section 7.5 compares the oil cargo accident spill frequencies with historical spill data from other areas.

7.1 Total Incident Frequency

This section outlines the **Total Incident Frequency** and **Return Period** estimated for the Trans Mountain tankers transiting to and from the Westridge terminal in 2018, Case 0 (without Project) and Case 1 (with Project), and tanker transit to and from the terminal in 2028, Case 2 (with Project).

The Total Incident Frequency is the annual frequency that an incident (collision, powered/drift grounding, fire/explosion and structural failure) occurs without considering its consequence. It therefore includes non-spilling incidents and oil cargo spill accidents for all traffic. The final outcome of the risk assessment is the frequency for cargo oil spill accidents, the total incident frequency results are shown in order to show the process of the risk analysis.

A Return Period is mathematically the inverse of an annual frequency. It means that an incident whose annual frequency is 0.01 is likely to happen once every 100 years. Its return period is 100 years. The lower the frequency is the higher the return period will be.

The total incident frequency is calculated for all traffic recorded in the AIS database and within the traffic lanes defined in MARCS in the study area. Trans Mountain tanker traffic is affected by the surrounding traffic and vice versa. Incident frequencies for Trans Mountain tankers are compared with the total incident frequency to give a better understanding of the Trans Mountain tanker traffic's contribution to the incident frequency in the study area.

Figure 22 shows that the highest incident frequencies are at the coast line. This is caused by the chance of grounding. The frequencies in the sailing lanes are caused by the chance of collision, fire and explosions and structural failure. The increase in the total incident frequency for all traffic is negligible between Case 0 and Case 1, the reason being that the other traffic overshadows the relative frequency increase from increasing the number of Trans Mountain tankers from 60 to 408 vessels a year. There is only a slight increase in the total incident frequency for all traffic from Case 0 to Case 2. The forecasted increase in the total traffic from 2018 to 2028, together with the increase in Trans Mountain tanker traffic, is the reason for this slight increase in total incident frequency, however, the relative contribution from the increase in Trans Mountain tanker traffic remains small.

The total incident frequencies, expressed as return periods, for the Trans Mountain tankers are extracted and shown in Table 12 and Table 13.

Table 12 presents the total incident return periods for the Trans Mountain tankers and for the total traffic. The same results are shown as total incident frequencies in Figure 22 for all traffic and for the Trans Mountain tankers in Figure 23. The results are split into; Inner Harbour, Trans Mountain tanker transit lanes and that for the total study area (sum of all segments). The analysis shows that although the total incident frequency increases by 6.8 times for Trans Mountain tankers if the Project takes place (Case 1 compared to Case 0), the effect of the increased Trans Mountain tanker traffic on the incident frequency for all traffic is marginal. The total incident return period for all traffic changes from once every 0.07 year (approximate 14 incidents a year) to once every 0.06 year (approximate 16.5 incidents a year). The forecasted increase in the total traffic in 2028 only gives a slight increase in the total incident frequency shown as a change in the incident return period from 4.8 for Case 1 to 4.7 for Case 2. This is due to increased collision risk caused by increased total traffic density.

Termpol 3.8, Casualty Data Study, shows that there have been, on average, 134 vessel incidents per year for the last 10 years on the west coast of Canada. The majority of these incidents are with fishing vessels. Fishing vessel traffic, and hence incidents, are underestimated in the MARCS modelling because the traffic data from AIS does not include small fishing vessels that are without AIS transponder.

Only one incident with a tanker is registered in the database for the last ten years on the west coast of Canada, which gives a return period on 1 incident in every 10 years. Since 1993 there have been 6 incidents with tanker vessels in this region, which equates to a return period of 1 incident in every 3.3 years. This is for the entire west coast of Canada and when compared with output of MARCS shows that the MARCS modelling results provides equivalent and valid incident frequency levels. It is important to note that both the MARCS results shown here and the historical casualty data referred to include all types of incidents, including also those not leading to an oil spill. The results of frequency/return period for oil spill incident are described in Section 7.2 of this report.

Table 12 - Total incident return periods by Case and Segment Area, including those that do not lead to oil spills

Total incident return period (1 in every x years)			
Segment Area	**Case #**	**Trans Mountain Tanker**	**All Traffic**
Inner Harbour (Seg 1-2)	**Case 0**	129.5	0.11
	Case 1	19.0	0.11
	Case 2	18.6	0.10
Trans Mountain tankers sailing lanes (Seg 3-7)	**Case 0**	49.9	0.27
	Case 1	7.3	0.26
	Case 2	7.2	0.23
Total Study area (Seg 1-12)	**Case 0**	32.6	0.07
	Case 1	4.8	0.06
	Case 2	4.7	0.06

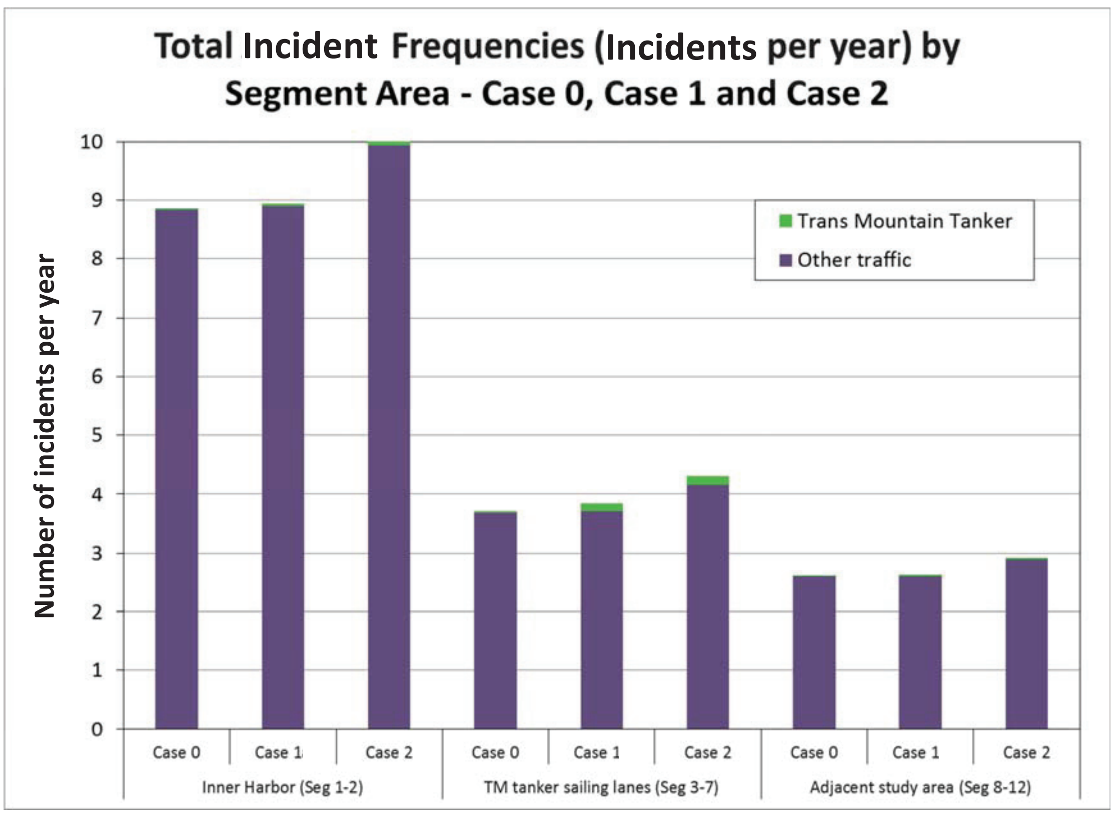

Figure 22 - Incident frequencies by Case and Segment Area for the entire traffic, including incidents that do not lead to oil spills

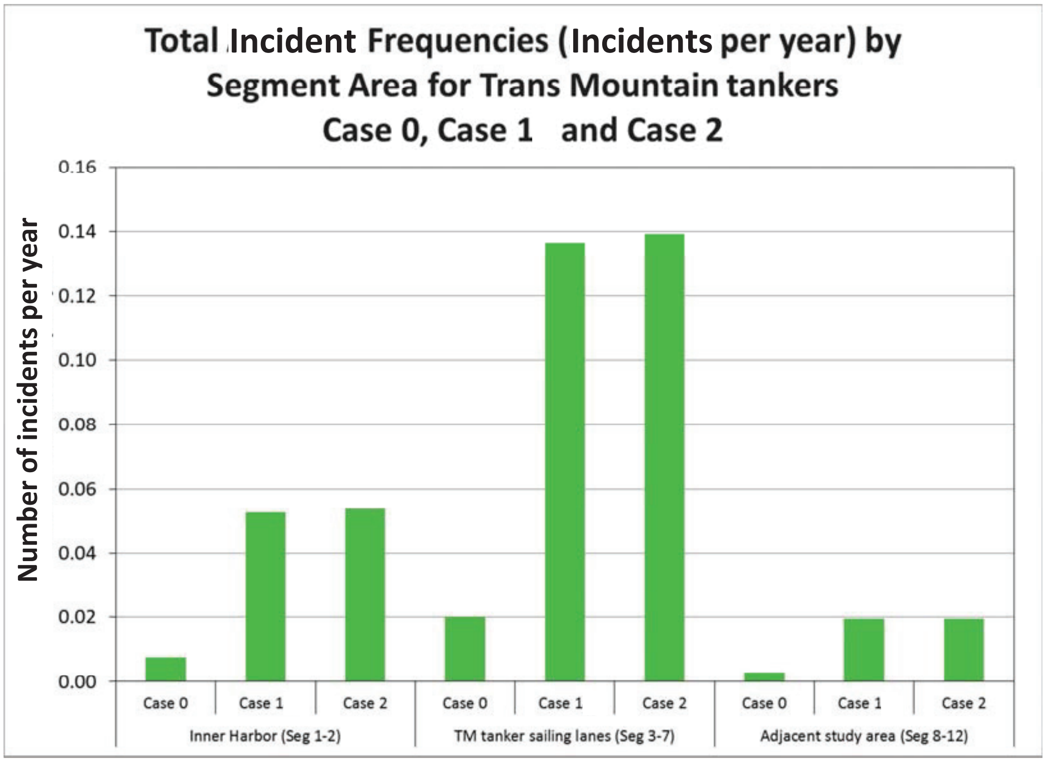

Figure 23 - Total Incident frequencies by Case and Segment Area for the <u>Trans Mountain tanker traffic only</u>, including incidents that do not lead to oil spills.

Table 13 shows the total incident return periods for the Trans Mountain tankers in each of the segments of the sailing route. The return periods are split into the various incident types, also the total return periods for each case and segment are shown.

The results show that Segment 2 (Vancouver Harbour Area), Segment 5 (Boundary Pass and Haro Strait) and Segment 7 (Juan de Fuca Strait) have the highest incident likelihood with a return period of 141, 141 and 135 years respectively for Case 0. It is important to remember that this shows the return period for all incidents including those that do not lead to oil spill accidents. For more information on historical casualties please refer to Termpol 3.8, which has also been prepared by DNV.

The powered grounding likelihood in Segment 2 (once every 190 years for Case 0) is expected to be overestimated in the model due to the nature of the narrow channel, which gives some overestimation for powered grounding in the applied model. However, the speed of the tankers is low in this area and they are assisted by multiple tethered tugs, so a powered grounding that leads to an oil spill is considered highly unlikely. This is discussed further in the oil spill section (Section 7.2). The likelihood results for grounding in segment 2 have not been adjusted despite the identification of the overestimation. Segment 7 is the segment with the highest likelihood for an incident at one in every 135 years for Case 0, one in every 20 years for Case 1 and one in every 19 years in Case 2. Drift grounding is the most likely incident type in Segment 7 due to the absence of tug escort for inbound and outbound tankers. Note that the potential risk reduction effect from the rescue tug in Neah Bay is not included in the analysis as it cannot be predicted with any certainty if it will be available for the life of the Project or that it will be made available in case a Trans Mountain tanker requests its assistance. The second highest incident frequency type is calculated to be collision and it is seen from the results that Segments 2, 5 and 7 have higher collision frequencies.

Table 13 - Incident return periods (in years) by Segment and Incident Type for Trans Mountain tankers

Total incident return period (years)								
		Inner harbour		Trans Mountain tankers sailing lanes				
Case #	**Incident type**	**Seg 1**	**Seg 2**	**Seg 3**	**Seg 4**	**Seg 5**	**Seg 6**	**Seg 7**
Case 0	Collision	18,603	597	2,692	1,826	1,109	5,094	717
	Structural failure	302,086	49,216	49,938	30,234	14,698	75,543	10,734
	Fire / Explosion	202,557	32,998	34,254	20,740	10,488	57,783	7,948
	Powered grounding	1,895	190	1,278	N*	793	N*	N*
	Drift grounding	54,909	7,133	797	671	209	1,343	173
	Overall	**1,645**	**141**	**407**	**472**	**141**	**1,029**	**135**
Case 1	Collision	2,736	88	392	267	161	737	104
	Structural failure	44,427	7,238	7,331	4,437	2,159	11,090	1,574
	Fire / Explosion	29,787	4,853	5,030	3,043	1,540	8,482	1,165
	Powered grounding	279	28	188	N*	117	N*	N*
	Drift grounding	8,075	1,049	117	99	31	198	25
	Overall	**242**	**21**	**60**	**69**	**21**	**151**	**20**
Case 2	Collision	2,399	80	355	242	145	665	94
	Structural failure	44,427	7,238	7,326	4,431	2,157	11,079	1,572
	Fire / Explosion	29,787	4,853	5,030	3,043	1,540	8,482	1,165
	Powered grounding	279	28	188	N*	117	N*	N*
	Drift grounding	8,075	1,049	117	99	31	197	25
	Overall	**239**	**20**	**59**	**67**	**20**	**148**	**19**

Note: N* = Negligible frequency

7.2 Oil Cargo Spill Accident Frequency

This section outlines the **accidental oil cargo spill frequency** and **return period** estimated for the Trans Mountain tankers transiting to and from the Westridge Marine Terminal in 2018, Case 0 and Case 1, and tanker transit to and from Westridge terminal in 2028, Case 2.

In a few cases an incident will cause so severe damage to the vessel that it will lead to a breakage of the cargo tanks and thus lead to an oil spill accident. The probability that an incident leads to an oil spill accident is estimated in MARCS based on:

- Ship Structure, whether it is single or double hull (all Trans Mountain tankers are double hull).
- The probability of grounding on rocky shore versus soft bottom shore. This probability distribution is equal to the presence of distribution of rocky shoreline versus soft bottom shoreline (as shown in Figure 13), grounding on rocks will increase the likelihood of a loss of containment.
- Wave and wind affects the probability that a grounding incidents leads to an oil spill. Wave height also affects the probability for a structural failure leading to foundering.
- In case of collision, the momentum of a colliding ship affects whether the incident becomes an oil spill accident.

If an incident is estimated to cause an oil cargo spill accident, then the oil cargo spill volumes and their probability are estimated based on IMO probability distribution and NAPA stability modelling; this approach is described in Chapter 2 and the results are shown in Chapter 9.

The accidental oil cargo spill frequency is the estimated frequency at which an incident could occur where the consequence will be an oil discharge coming from the tanker's cargo tanks. Only tankers with oil as cargo have a risk of an oil cargo spill accident. Please see Appendix 1 for more details on how this is estimated.

A return period is mathematically the inverse of an annual frequency. The accidental oil cargo spill frequency includes any potential accidental oil spills regardless of the size of the spill. The size of oil spill and its associated likelihood is discussed in Chapter 9.

Table 14 presents the in transit accidental oil cargo spill return periods for the Trans Mountain tankers and for the total tanker and oil barge traffic. The same results are shown as total incident frequencies in Figure 24 for all traffic and in Figure 25 for Trans Mountain tankers only. The results are split into; Inner Harbour (segment 1-2), Trans Mountain tanker transit lanes (segment 3-7) and the total study area (segment 1-12). The analysis shows that the oil spill accident frequency increases by 6.8 times for Trans Mountain tankers if the Westridge Marine Terminal is expanded in 2018 (Case 1) compared to 2018 without the Project (Case 0). This is shown in the table as a reduction of return period from one accidental oil spill per 304 years to one accidental oil spill per 46 years for the entire study area. The forecasted increase in the total traffic in 2028 only gives a slight increase in the accidental oil spill frequency shown as a change in the oil spill return period from once per 46 years for Case 1 to once per 45 years for Case 2. This is due to an increased collision risk caused by increased traffic density.

Comparing the oil spill accident return period between the Trans Mountain tankers and all oil cargo transport in the study area (segment 1-12) shows that the potential oil spill accident from Trans Mountain tankers constitute 20 % of the potential oil spill accidents in Case 0 and 63 % in Case 1.

However this estimation is for any size oil spill and should not be misinterpreted with the main purpose of this study, which is to calculate the risk of an incident that can lead to an uncontrolled oil outflow from a Trans Mountain tanker, i.e. causes a large oil spill. This topic will be addressed further in Section 7.2.

Table 14 presents the cargo spill return periods by segment area. Table 15 shows them by the various incident types modelled in MARCS for the Trans Mountain tankers and for segments 1 to 7.

Table 14 – In transit Oil Cargo Spill return periods (in years) by Case and Segment Area

In transit Oil cargo spill accident return period (years)			
Segment Area	**Case #**	**Trans Mountain tanker**	**Overall tanker and oil barge traffic**
Inner Harbour (Seg 1-2)	**Case 0**	3,697	361
	Case 1	580	231
	Case 2	530	196
Trans Mountain tankers sailing lanes (Seg 3-7)	**Case 0**	410	106
	Case 1	60	42
	Case 2	59	40
Study area (Seg 1-12)	**Case 0**	309	62
	Case 1	46	29
	Case 2	45	27

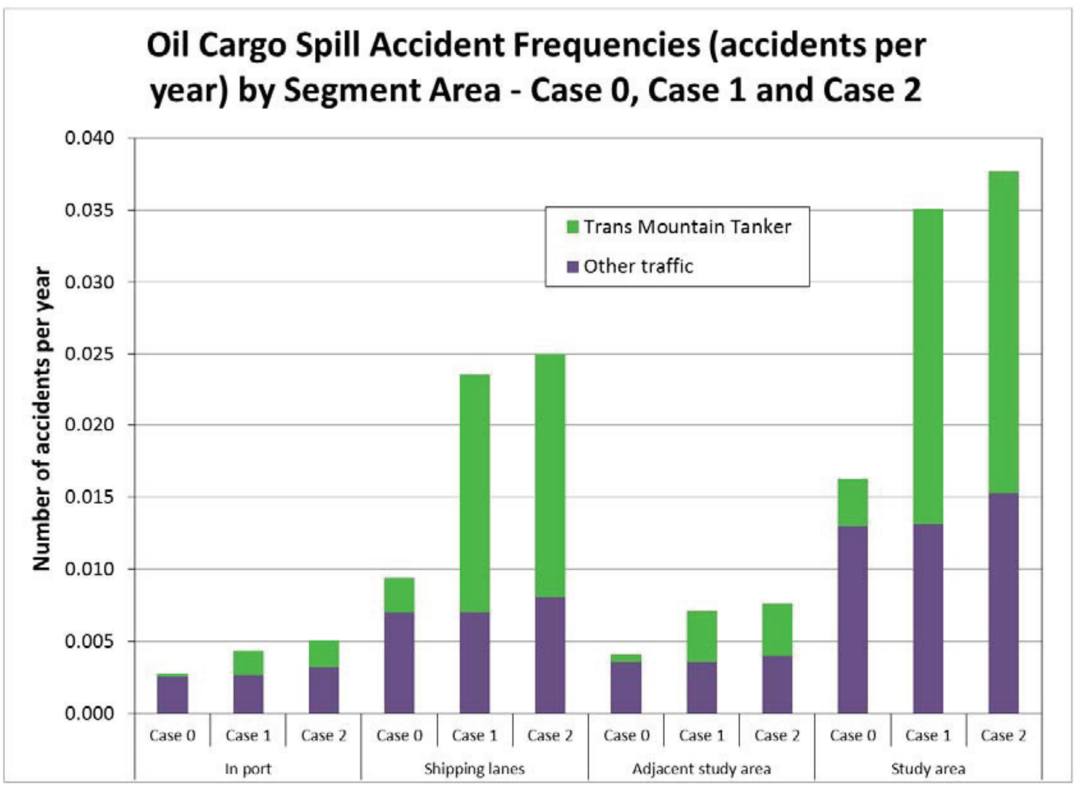

Figure 24 – In transit Oil Cargo Spill Accident frequencies by Case and Segment Area for the entire traffic

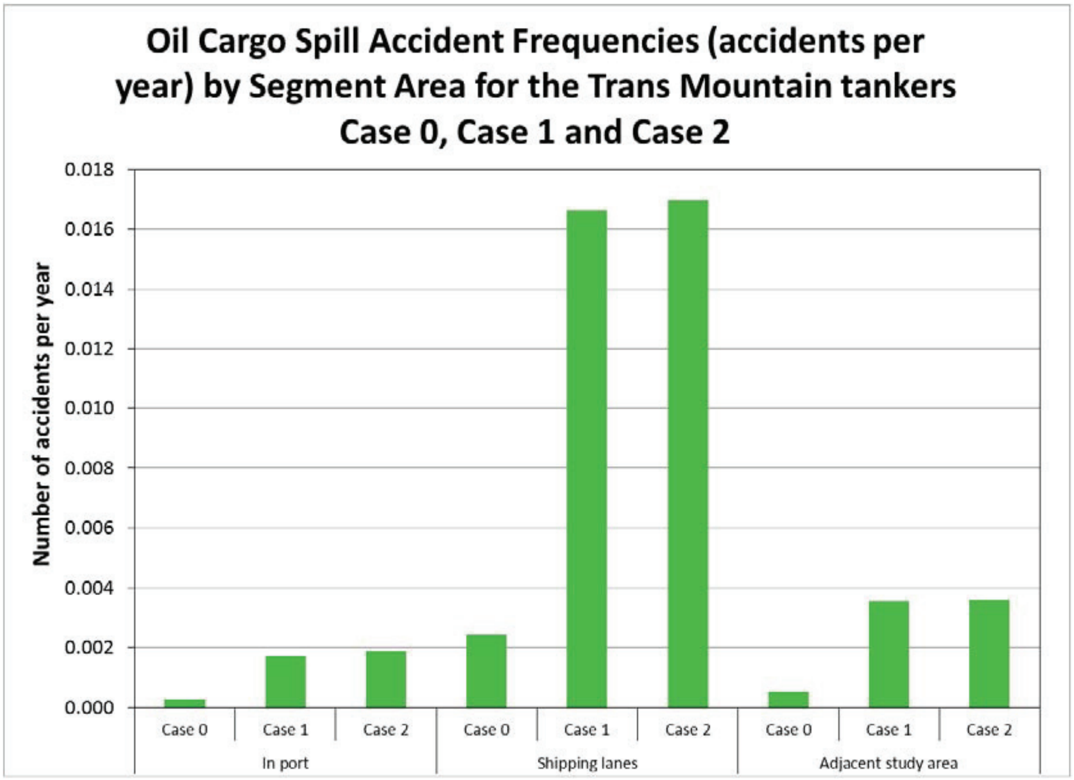

Figure 25 – In transit Oil Cargo Spill Accident frequencies by Case and Segment Area for Trans Mountain tankers

It is evident from Figure 25 and Figure 26 that there is a higher probability of accidental oil cargo spill in the shipping lanes. Table 15 shows the in transit accidental oil cargo spill return periods for the Trans Mountain tankers in each of the segments of the sailing route and by accident type. Figure 26 shows the same results in terms of oil cargo spill accident frequencies.

The results show that Segment 5 (Boundary Pass and Haro Strait) and Segment 7 (Juan de Fuca Strait) have the highest in transit oil cargo spill accident likelihood with a return period of 1,236 and 921 years respectively for Case 0. Segment 7 is the segment with highest likelihood for an oil spill accident, likelihood is one in every 921 years for Case 0, one in every 135 years for Case 1 and one in every 133 years in Case 2. The most likely accident types are drift grounding and collision in Segment 5, and drift grounding in Segment 7. The oil spill probability from drift grounding in Segment 5 is mainly caused by the probability for non-tethered tankers to drift from Segment 4 and 6 into Segment 5.

Table 15 – In transit Accidental Oil Cargo Spill return periods (in years) by Segment and Accident Type for Trans Mountain tankers

In transit Accidental oil cargo spill return period (years)								
Case #	**Accident type**	**Seg 1**	**Seg 2**	**Seg 3**	**Seg 4**	**Seg 5**	**Seg 6**	**Seg 7**
Case 0	Collision	137,973	4,528	148,768	80,020	3,780	165,375	7,860
	Structural failure	1,007,240	169,770	1,172,161	745,921	40,115	2,318,841	135,192
	Fire / Explosion	506,489	85,367	808,081	512,821	28,666	1,748,634	100,063
	Powered grounding	1,263,823	319,840	54,091	N*	10,895	N*	N*
	Drift grounding	8,268,734	1,122,807	5,299	3,566	2,545	38,356	1,063
	Overall	**89,870**	**4,124**	**4,629**	**3,376**	**1,236**	**30,192**	**921**
Case 1	Collision	20,289	666	21,556	11,671	548	24,010	1,147
	Structural failure	148,104	24,965	172,712	109,890	5,894	337,838	19,806
	Fire / Explosion	74,477	12,554	118,624	75,415	4,210	258,398	14,667
	Powered grounding	185,874	47,030	7,949	N*	1,605	N*	N*
	Drift grounding	1,212,121	165,153	779	524	374	5,640	156
	Overall	**13,215**	**607**	**680**	**496**	**181**	**4,429**	**135**
Case 2	Collision	17,779	603	19,406	10,566	494	21,529	1,023
	Structural failure	148,104	24,965	172,712	109,769	5,880	336,700	19,763
	Fire / Explosion	74,477	12,554	118,483	75,358	4,206	258,398	14,652
	Powered grounding	185,874	47,030	7,943	N*	1,602	N*	N*
	Drift grounding	1,212,121	165,153	778	523	374	5,631	156
	Overall	**12,102**	**554**	**677**	**493**	**174**	**4,331**	**133**

Note: N* = Negligible frequency

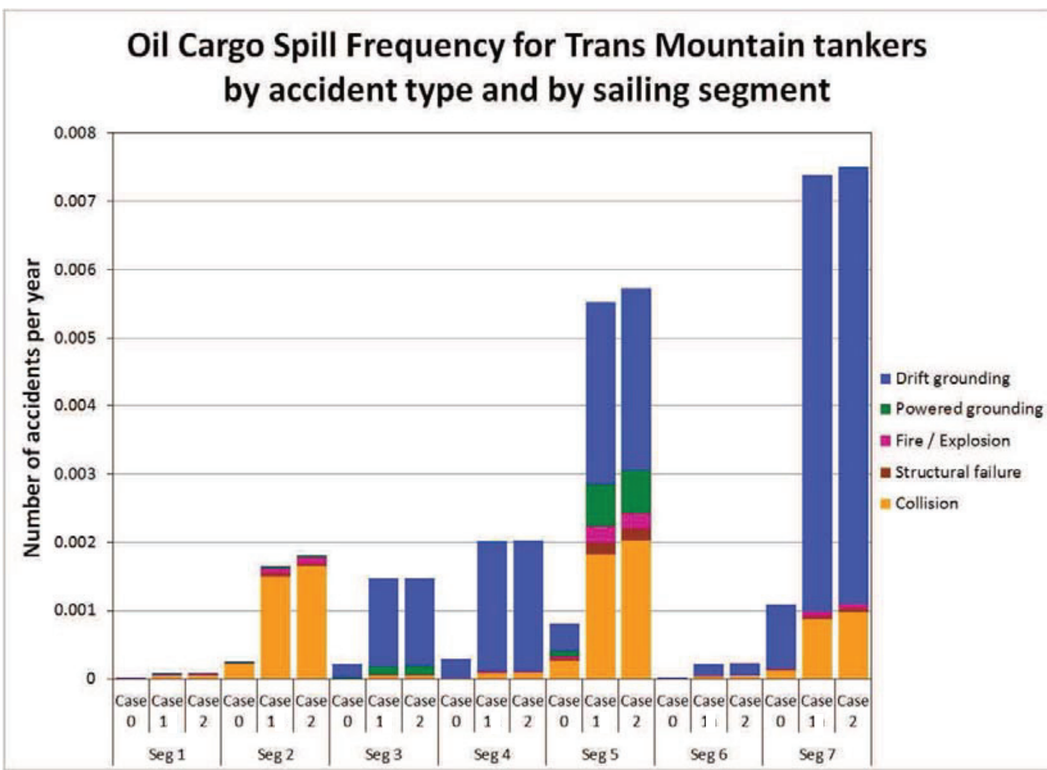

Figure 26 – In transit Accidental Oil Cargo Spill frequencies for Trans Mountain tankers by Segment and by Accident Type for Case 0, Case 1 and Case 2

7.3 Possible Improved Risk Control Measures for Case 1

Trans Mountain requested DNV to assess Case 1 and identify methods to reduce the chances of oil cargo spill accidents from Trans Mountain tanker traffic to as low as reasonably practicable. The focus of these efforts was to identify improvements in the risk control measures for the sailing route. In doing so **DNV acknowledges that the existing risk controls for the sailing route are considered to be state of the art compared to other coastal sailing routes worldwide.**

In order to estimate the benefit of more risk controls in the sailing route, Case 1 was remodelled with enhanced risk controls applied. The total incident results show that the highest incident frequency is for grounding, thus a potential enhancement can be to extend the tug escort to the entire sailing route. The second highest incident frequency is collisions with other vessels; so a potential enhancement can be to create a traffic exclusion zone around the tanker during transit, in other words a moving exclusion/safety zone. Both have been tested in the model:

- Case 1a – With Project, forecast traffic in 2018 with extended tug escort for the entire sailing route out to the Juliet Buoy (results in Section 7.3.1)
- Case 1b – With Project, forecast traffic in 2018 with extended tug escort and moving exclusion (safety) zone for the entire sailing route out to the Juliet Buoy (results in Section 7.3.2)

7.3.1 Case 1a - Marine Traffic in 2018 with Project and Extended Tug Escort

This section presents the results of in transit total incident and oil spill accident frequencies if the use of escort tugs provided for Trans Mountain tankers were extended to cover the entire route out to the Juliet Buoy.

Case 1a (With Project - forecast traffic in 2018):

- Trans Mountain tanker traffic in 2018 with the Project in service (408 tankers per year) plus other traffic escalated to 2018 as for Case 0.
- Level of tug escorting is increased to provide an escort for outbound laden Trans Mountain tankers for the full length of the study area (see Figure 27).

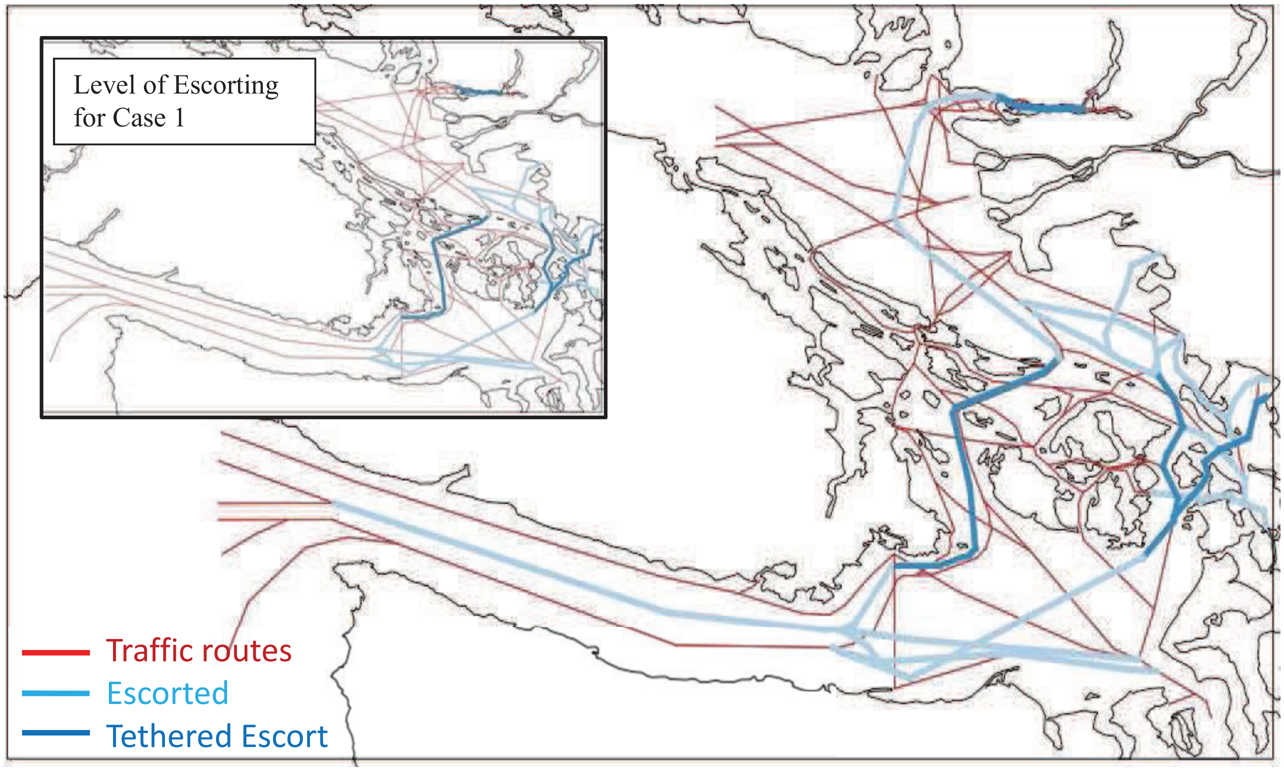

Figure 27 - Level of Escorting for Case 1a - Pale blue lines indicate tug escorted but not tethered. Dark blue lines indicate a tethered escort tug

The oil cargo spill accident frequency will be significantly reduced by introducing tug escort for the entire sailing route. Figure 29 shows the comparison of the oil cargo spill accident frequency between Case 1 and Case 1a. The largest reduction in oil cargo spill frequency is for the part of the sailing route that did not have any dedicated tug escort in the original Case 1, which constitutes Segment 3, 4 and 7. The oil cargo spill frequency is also reduced in Segment 5 even though this segment already had tug escort for laden tankers. The reason for this is that a drifting tanker from the following or previous roué segment can lead to drift grounding in Segment 5 if she does not have tug escort in the other segments. Table 16 presents the same results as in transit oil cargo spill accident return period for Case 1a within Segments 1 to 7. The values that have changed relative to Case 1 are shown in bold.

Table 16 – In transit Accidental Oil Cargo Spill return periods (in years) by Segment and Accident Type for Trans Mountain Tankers - Case 1a (2018 with Project)

Return period (years)	Seg 1	Seg 2	Seg 3	Seg 4	Seg 5	Seg 6	Seg 7
Collision	20,289	666	21,556	11,671	548	24,010	1,147
Structural failure	148,104	24,965	172,712	109,890	5,894	337,838	19,806
Fire / Explosion	74,477	12,554	118,624	75,415	4,210	258,398	14,667
Powered grounding	185,874	47,030	7,949	N*	1,605	N*	N*
Drift grounding	1,212,121	165,153	**15,408**	**15,267**	**7,463**	**31,546**	**782**
Overall	13,215	607	**3,979**	**5,762**	**335**	**12,472**	**441**

Note: N* = Negligible frequency

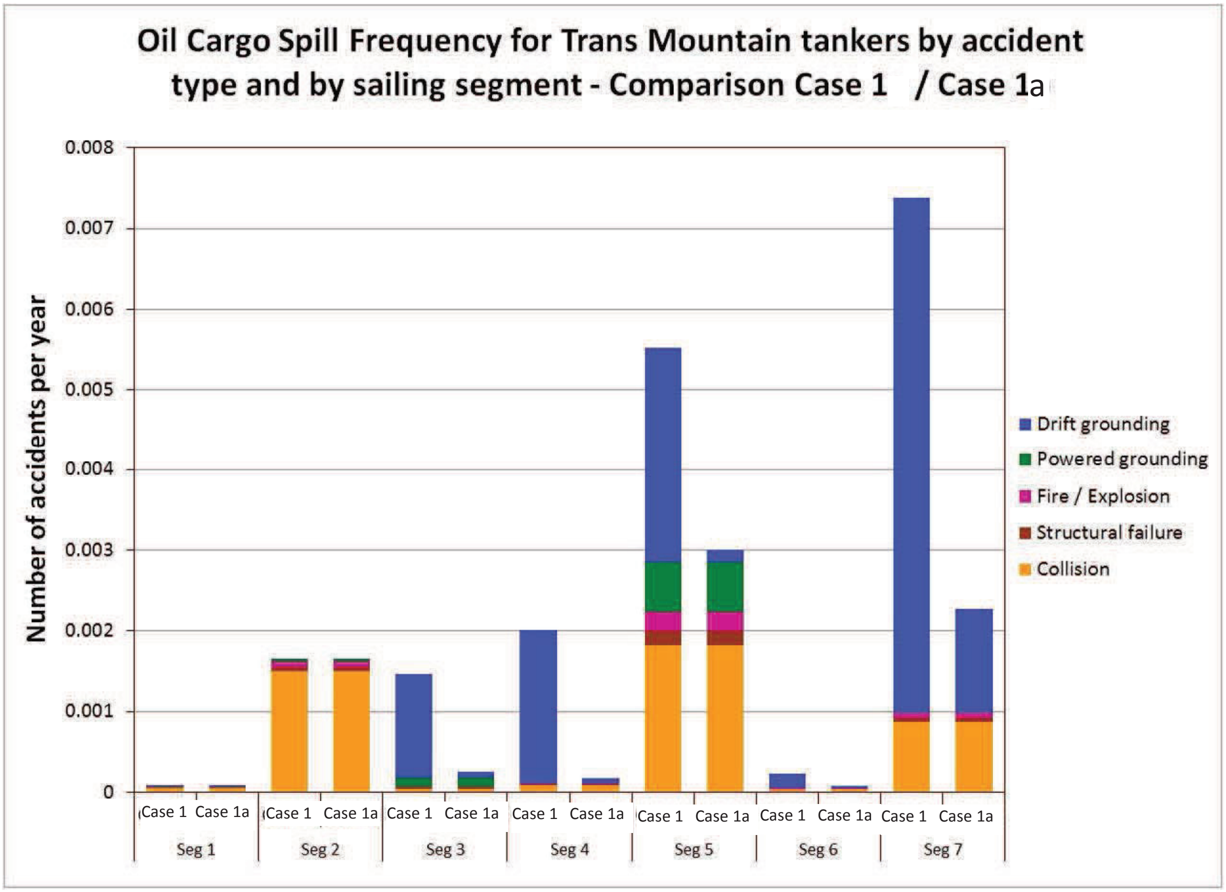

Figure 29 - Comparison of the accidental oil cargo spill frequency between Case 1 and Case 1a

Table 17 shows that the increased level of tug escort in Case 1a decreases the incident frequency for the Trans Mountain tanker traffic by 12% - 38% for the various shipping lane segments (Seg. 3-7).

More importantly, for the oil cargo spill accident frequency, the frequency reduction resulting from the tug escort change is much more pronounced: with reduction achieved between 46% (Seg. 5) and 91% (Seg. 4) for the shipping lanes (Seg. 3-7).

It is clear that the increase in tug escort will significantly reduce both frequencies, especially in Segments 3, 4 and 7.

Table 17 - Comparison of the in transit incident and accidental oil cargo spill frequency levels between Case 1 and Case 1a

	Incident Frequency Reduction (%)						
	Seg 1	**Seg 2**	**Seg 3**	**Seg 4**	**Seg 5**	**Seg 6**	**Seg 7**
Drift grounding	0%	0%	37%	54%	17%	27%	38%
Overall	0%	0%	19%	38%	12%	21%	30%
	Accidental Oil Cargo Spill Frequency Reduction (%)						
	Seg 1	**Seg 2**	**Seg 3**	**Seg 4**	**Seg 5**	**Seg 6**	**Seg 7**
Drift grounding	0%	0%	95%	97%	95%	82%	80%
Overall	0%	0%	83%	91%	46%	64%	69%

The frequency reduction effectiveness is larger for oil cargo spill accidents for two reasons. First, only laden tankers are escorted and can spill cargo oil. Second, the extension of tug escort through the Strait of Juan de Fuca provides better support to prevent drifting tankers from going aground on the rocky northern shoreline. Tankers that ground on hard rock are more likely to spill cargo oil than tankers that ground on soft shorelines.

7.3.2 Case 1b - Marine Traffic in 2018 with the Project, Extended Tug Escort and Moving Exclusion (Safety) Zone

Case 1b is an additional case in order to review the risk reduction by adding a moving exclusion zone around the laden Trans Mountain tankers. So, this case is identical to Case 1a, but it includes the extended tug escort and also makes provision of moving exclusion zones for laden tankers. A moving exclusion zone is a zone of no entrance for other vessels around the tanker that is in effect during transit, in other words moves with the tanker.

Case 1b (With Project, forecast traffic in 2018):

- Trans Mountain tanker traffic in 2018 with Project (408 tankers per year) plus other traffic escalated to 2018 as for Case 0.
- Level of tug escorting is increased to provide an escort for outbound laden Tran Mountain tankers for the full length of the study area (see Figure 27).
- Moving exclusion zones enacted round the laden Trans Mountain tankers.

The effect of VTS mandating a moving exclusion zone around laden outbound Trans Mountain tankers is estimated to reduce the frequency of encounters with commercial shipping by 90% or more, assuming the measure is applied in a professional way. In the risk model, this will, in turn, reduce the collision frequency by the same ratio. The effectiveness of reducing encounters with smaller fishing vessels and recreational vessels (under 20 m length) are expected to be lower, perhaps only 50%. The reason for this is that these vessels are not required to carry AIS transponder and thus cannot be monitored by the VTS as efficiently as vessels with AIS transponders. Smaller vessels, however, are less likely to cause a cargo oil spill from a tanker during collision with a large double hulled tanker.

The introduction of moving exclusion zones between frequency results of Case 1a and Case 1b will reduce the collision frequency. The reduction factor of the collision frequency is estimated to be at least 75%. Therefore a coefficient of 0.25 is applied to the collision frequency of Case 1a for the laden Trans Mountain tankers in order to obtain the frequencies of Case 1b. Table 18 presents the accidental oil cargo spill frequency for Case 1b for Segments 1 to 7. The values that have changed relative to Case 1 are shown in bold.

Table 18 - Accidental Oil Cargo Spill return periods (in years) by Segment and Accident Type for Trans Mountain Tankers - Case 1b (2018 with Project)

Return period (years)	Seg 1	Seg 2	Seg 3	Seg 4	Seg 5	Seg 6	Seg 7
Collision	**81,157**	**2,664**	**86,225**	**46,685**	**2,192**	**96,038**	**4,586**
Structural failure	148,104	24,965	172,712	109,890	5,894	337,838	19,806
Fire / Explosion	74,477	12,554	118,624	75,415	4,210	258,398	14,667
Powered grounding	185,874	47,030	7,949	N*	1,605	N*	N*
Drift grounding	1,212,121	165,153	**15,408**	**15,267**	**7,463**	**31,546**	**782**
Overall	**25,836**	**1,914**	**4,619**	**9,151**	**617**	**20,432**	**619**

Note: N* = Negligible frequency

Table 19 shows that the moving exclusion zone around the Trans Mountain tankers in Case 1b further decreases the incident frequency for the Trans Mountain tanker traffic by 3% - 16%, for Segments 1 to 7. For the oil cargo spill accident frequency, the frequency reduction is more pronounced: between 14 - 68% for Segments 1 to 7. Trans Mountain has written to CCG and USCG requesting that they jointly implement such a measure for all tankers in this area. Transport Canada has been included in this discussion and Trans Mountain intends to recommend both the additional tug escort as well the provision of a moving exclusion zone to the Termpol Review Committee.

Table 19 - Comparison of the in transit incident and accidental oil cargo spill frequency levels between Case 1a and Case 1b

	Incident Frequency Reduction (%)						
	Seg 1	**Seg 2**	**Seg 3**	**Seg 4**	**Seg 5**	**Seg 6**	**Seg 7**
Collision	37.5%	37.5%	37.5%	37.5%	37.5%	37.5%	37.5%
Overall	3%	9%	7%	16%	5%	10%	10%
	Accidental Oil Cargo Spill Frequency Reduction (%)						
	Seg 1	**Seg 2**	**Seg 3**	**Seg 4**	**Seg 5**	**Seg 6**	**Seg 7**
Collision	75%	75%	75%	75%	75%	75%	75%
Overall	49%	68%	14%	37%	46%	39%	29%

The risk reduction effectiveness is larger for oil cargo spill accidents because only laden tankers are considered as having a moving exclusion zone applied.

7.4 Vessel Transit Oil Cargo Spill Accident Result Summary

The Trans Mountain tanker traffic will increase from 60 tankers a year to 408 tankers a year in 2018 if the Westridge terminal is expanded. The results in this chapter have shown an increase in the likelihood for an oil cargo spill accident by 6.8 times compared to before Project implementation. However, enhanced risk control measures have the potential to reduce the oil cargo spill accident frequency significantly. By introducing additional tug escorts for the entire route and a moving exclusion zone for the loaded tanker, it has been estimated that the increase in oil cargo spill accident frequency for the transit will only be approximately 1.3 times the same frequency without expanding the terminal and existing risk controls, or an increase of 0.3 times when comparing Case 1 with Case 0. These results are summed up in the following.

The different cases are summarized below:

- Case 0: Traffic in 2018 without TMEP (60 Trans Mountain tankers)
- Case 1: Traffic in 2018 with TMEP (408 Trans Mountain tankers)
- Case 1a: Same as Case 1 but with higher tug escort level for loaded Trans Mountain tankers
- Case 1b: Same as Case 1a but with moving exclusion zone for loaded Trans Mountain tankers.
- Case 2: Traffic in 2028 with TMEP (408 Trans Mountain tankers)

Table 20 - Accidental Oil Cargo Spill Frequency Distribution between Trans Mountain tanker traffic and Other Oil Cargo Traffic for all cases for the entire study area

	Trans Mountain tanker		Other Oil Cargo traffic		Total	
	Frequency (/Year)	**%**	**Frequency (/Year)**	**%**	**Frequency (/Year)**	**%**
Case 0	0.00323	20%	0.01301	80%	0.01624	100%
Case 1	0.02191	63%	0.01313	37%	0.03505	100%
Case 1a	0.00754	36%	0.01313	64%	0.02067	100%
Case 1b	0.00423	24%	0.01313	76%	0.01736	100%
Case 2	0.02243	59%	0.01527	41%	0.03770	100%

Table 21 - Comparison of Accidental Oil Cargo Spill Frequency Cases for Trans Mountain tanker traffic in all cases for the entire study area

	Frequency (/Year)	Return period (Year)	Increase from Case 0 (%)
Case 0	0.00323	309	-0%
Case 1	0.02191	46	578%
Case 1a	0.00754	133	133%
Case 1b	**0.00423**	**237**	**31%**
Case 2	0.02243	45	594%

The results considering the entire oil traffic show that:

- If no changes are made to the current application of risk mitigation measures in 2018, after Project implementation the Trans Mountain tankers will be involved in 63% of any oil cargo spill accidents instead of 20% as for 2018 without the Project.
- By increasing the tug escort level as defined in Case 1b, only 36% of any oil cargo spill accidents will involve a Trans Mountain tanker. If a dynamic exclusion zone around Trans Mountain tankers is implemented, the Trans Mountain tankers' involvement in oil cargo spill accidents will be close to Case 0: 24% for Case 1b (with Project) versus 20% for Case 0 (without Project).

The conclusion of these results is:

- With the Trans Mountain Expansion Project, the Trans Mountain tanker traffic will increase by about 580% and so will the in transit oil cargo spill accident frequency related to the Trans Mountain tanker traffic if further mitigation measures are not implemented.
- With additional risk mitigation measures, i.e. increasing the escort tug level and implementing a moving safety zone as described in Case 1b, the in transit oil cargo spill frequency will only increase by 31%.

The next figures present these results graphically.

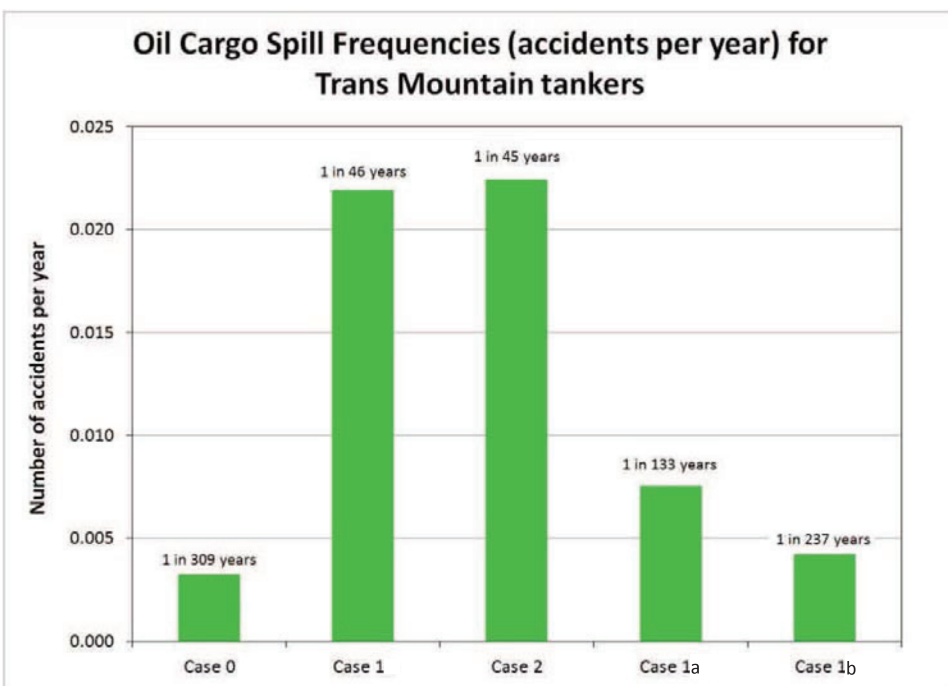

Figure 28 – In transit Accidental Oil Cargo Spill Frequency for the Trans Mountain tankers by case, showing effect of additional mitigation

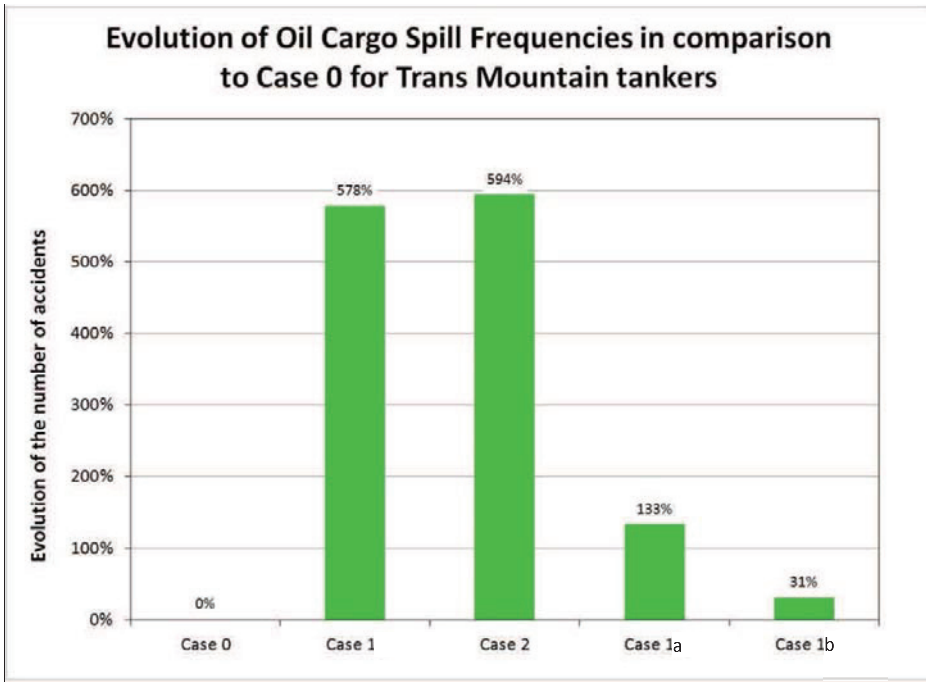

Figure 29 - Percentage increase of in transit Accidental Oil Cargo Spill Frequency for the Trans Mountain tankers compared with Case 0

7.5 Comparison with Traffic in Other Areas

This section provides a comparison of vessel traffic and incident frequencies in the study area with other regions.

7.5.1 Traffic data for relevant congested straits

As can be seen in Figure 30, the commercial vessel traffic at key locations in the study area, i.e. Haro Strait and Juan de Fuca Strait, is far less when compared with vessel traffic in other straits in the world. Because of that it is also expected that the incidental frequency is lower in the study area compared with these other example areas.

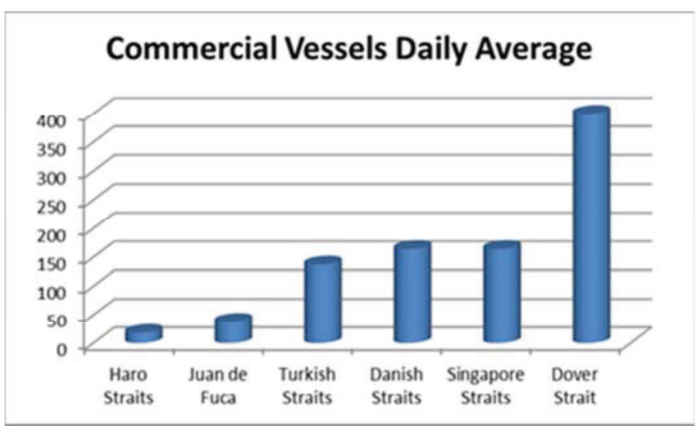

Figure 30 - Comparison of daily average movements in some busy straits around the world

7.5.2 Global tanker oil spill data

In Termpol 3.8, it was estimated that based on the ITOPF data for the last 10 years the global frequency of accidental oil spills over 7 tons is 0.0016 per shipyear. This frequency will vary in each area depending on the risk reducing measures in place, weather and current conditions, and navigability of the sailing route.

DNV's standard assumptions are that total sailed distance for an oil tanker per year is 74,000 nautical miles. Only 20 % of that distance is assumed to be sailed near land and in trafficked areas. Thus a shipyear is assumed to be equal to 14,800 nautical miles, or approximate 15,000 NM, sailed in areas where collisions and grounding may occur. Based on this assumption, the accidental oil spill frequency from ITOPF can be estimated as approximately 0.0016 accidents per 15,000 NM sailed in coastal waters.

If the Project was to proceed, the Trans Mountain tankers will sail 130,000 NM in the study area per year and have an oil cargo spill accident frequency of 0.0045 accidents per year (Case 1b).That equates to 0.0005 accidents per 15,000 NM (or shipyear). This calculation thus highlights that the likelihood for an oil cargo spill from the Trans Mountain tankers is significantly lower than the last 10 years historical data from ITOPF. This comparison also shows that the likelihood for an in transit oil cargo spill is low compared to other areas. This is further confirmed by comparison with Baltic Sea - Kattegat in the next section.

7.5.3 The Danish Strait

The Danish Strait, Kattegat, between Denmark and Sweden serves all traffic to and from the Baltic Sea (Figure 31). It is selected for comparison with the incident frequency level estimated in this study because the sailing route is relatively similar to the Trans Mountain tanker sailing route. The Danish Strait has a total sailing distance of about 230 NM from the Baltic Sea to the Skagerrak with some narrow straits down to 2 NM wide and other parts of the route with wide open passages. The risk controls in place in the Danish Strait are comparable with the risk controls in place for the Trans Mountain tanker sailing route. However, the traffic through the Danish Strait is much greater.

Figure 31 - Overview map of the Danish Strait.

Data from HELCOM's AIS database show that there are approximate 60,000 movements per year in the main sailing route of the Danish Strait. On average there are 15 significant collisions and 25 groundings annually in the area (Figure 34)

In 2011 tankers were involved in 13 % of the incident in the whole Baltic Sea (Figure 33). Assuming the same distribution of vessel types in the South West area of the Baltic gives an average of 2 tanker collisions and 3.25 tanker grounding per year.

The HELCOM data shows that 9% of such incidents led to pollution of the marine environment. The data does not specify what kind of pollution was occurring, or the amount of pollution that results from oil tanker accidents. Thus the HELCOM data can only be used to compare with the total incident frequency for the Trans Mountain risk assessment.

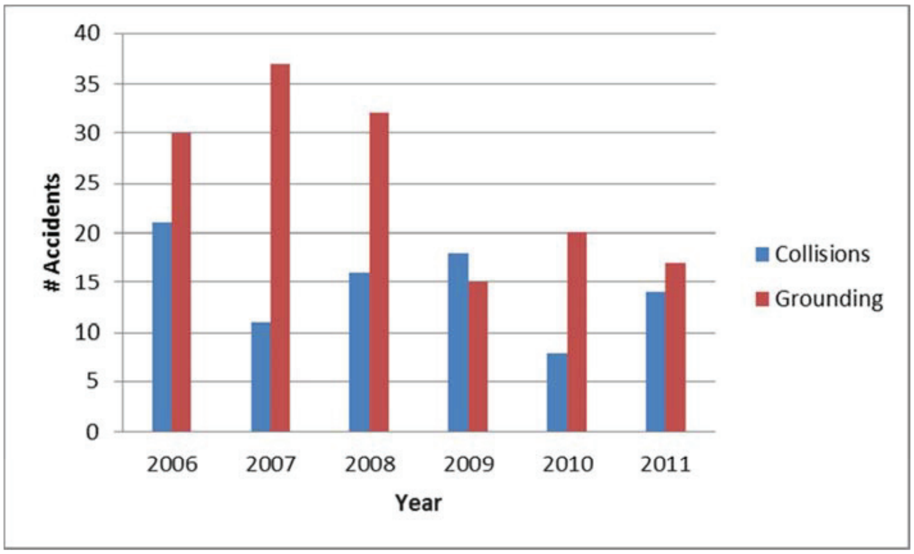

Figure 32 - Number of incidents per year in the Danish Strait (Kattegat)

The incident frequency for tankers in the Danish Strait is 32 times higher for collision and 8 times higher for grounding than the annual number of potential incident from all tankers (Trans Mountain and others) in the whole study area for the Trans Mountain risk assessment, given the Project goes ahead (Case 1). This shows that the future incident risk is relatively low in the Trans Mountain sailing route, even under existing risk reducing measures. **Implementing extra risk controls as is being proposed by the Project raises the level of care and safety in the study area to well above globally common practice.**

The conclusion of these comparisons with global oil spill accident frequencies, marine incidents frequencies in a comparable well organized waterway (the Danish Strait) and with traffic densities of other busy straits worldwide, is that the traffic density in the study area is relatively low and it will remain low, compared with busy straits worldwide, even after 2018 with the Project in operation. The likelihood for a marine transit incident and the likelihood for an oil cargo spill accident are therefore considered relatively low compared with other well established sailing routes.

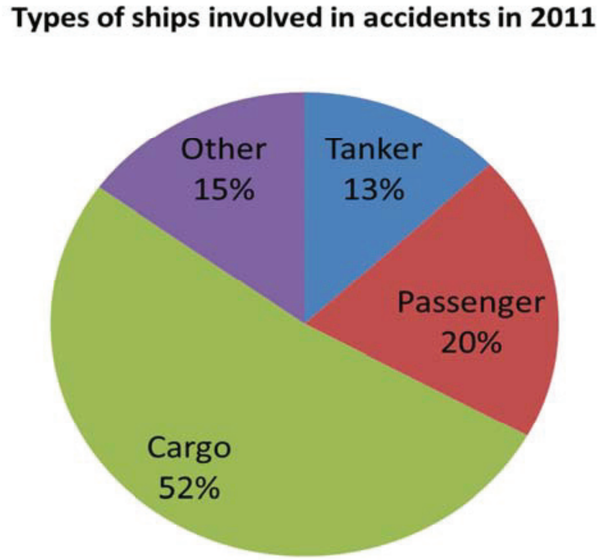

Figure 33 - Types of vessels involved in accidents in the Baltic Sea in 2011

8 FREQUENCY ASSESSMENT FOR INCIDENT FOR VESSELS AT BERTH AND CARGO TRANSFER OPERATIONS

This chapter will assess the frequencies for oil spills during cargo transfer operations and for incidents with the tank vessel at berth and during berthing or unberthing.

8.1 Cargo transfer operations

Typical causes of oil spills during cargo transfer operations at oil and condensate handling facilities include:

- Overfilling of cargo tanks (e.g. caused by technical failures or operator error)
- Damage to loading arms/hoses or piping from external effects (e.g. caused by excessive vessel movements, mooring failure, operator error, etc.)
- Leaks from loading arms/hoses or piping from internal damages (e.g. caused by wear and tear, corrosion, fatigue, etc.)

The basic frequencies of a release during cargo transfer operations are derived from European terminal accident statistics and modified to account for site specific risk reducing measures that will be implemented at the new Westridge Marine Terminal. The basic frequencies of a release during cargo transfer operations are based on DNV's internal QRA handbook and are derived from European terminal accident statistics (DNV 2000) which are shown in Table 22.

Table 22 - Frequency and return period of accidental cargo oil release incidents per loading operation (DNV 2000)

Cause	Frequency of release per operation	Return period per operation (1 incident per x operations)
Release of oil from defect in loading arm	5.1E-05	19,608
Failure of cargo control equipment	5.1E-06	196,078
Failure of the vessel's piping system or pumps	7.2E-06	138,889
Human failure	7.2E-06	138,889
Mooring failure causing breakaway from berth	3.8E-06	263,158
Overfilling of cargo tank	1.2E-04	8,333

The frequencies from the Table 22 do not take into account site specific risk reducing measures such as technological and operational barriers put in place. There is a wide variety of risk controls that will be implemented at the new Westridge terminal, majority of which are already in place:

- Oil booms deployed around the vessel during cargo transfer activities.
- Loading platform at the berths drained to sloop tanks and treated at shore.
- Emergency Release Couplers at the loading arms
- Emergency shutdown (ESD) valves at flow pipelines by the manifold at the loading platform and at landfall, all ESD can be activated from the control room.
- Overfilling detection at the tanker vessel.
- Leak detection at the pipeline
- Operational procedures to assure that all systems works adequately prior to cargo transfer.
- Operational procedure for safe cargo transfer activities both onboard the ship and at the terminal
- A Loading Master assigned to each loading tanker.

- Assigned exclusion zone using oil spill prevention booms around the terminal during cargo transfer operations.
- Use of tethered tugs and passing at reduced speed for passing large commercial vessels.
- Fire prevention and protection both onboard the vessel and at the marine terminal.
- Marine Terminal personnel who are trained for the purpose.
- Oil spill management

Table 23 therefore shows adjusted global basis frequencies for accidental oil spill which are used in this analysis. The frequencies are adjusted due to an expected improvement of the accident barriers and spill control caused by the risk controls mentioned above and by the fact that all equipment at the terminal will be of top modern standard. The large reduction of mooring failure frequency comes from the very calm weather conditions at the terminal in combination with the strict weather restrictions for loading operations. Overfilling of cargo tanks will be avoided by use of overloading detectors in combination with a dedicated loading master at the vessel during loading operations. The frequency for overloading is further reduced because the cargo tanks at the vessels will be less than full compared with other jurisdictions in order to meet the draft limitations of the sailing route.

Table 23 - Adjusted frequency and return period of accidental cargo oil release incidents per loading operation (DNV 2000)

Cause	Reduction factor	Frequency of release per operation	Return period per operation (1 incident per x operations)
Release of oil from defect in loading arm	20%	4.08E-05	24,510
Failure of cargo control equipment	20%	4.08E-06	245,098
Failure of the vessel's piping system or pumps	20%	5.76E-06	173,611
Human failure	20%	5.76E-06	173,611
Mooring failure causing breakaway from berth	80%	7.60E-07	1,315,789
Overfilling of cargo tank	80%	2.40E-05	41,667
Sum all causes	58%	8.12E-05	12,321

8.2 Impact and Striking Incident Frequency

8.2.1 Impact at Berth (Impact During Berthing Operations)

Impact at Berth is defined as an incident whereby a Trans Mountain tanker hits the berth with excessive force when approaching or departing. The frequency of impact incidents is proportional to the annual frequency of Trans Mountain tanker berthing operations.

Despite the fact that the incident frequency of an impact is higher than zero, the oil cargo spill frequency is estimated to be zero because all tankers approach the berth in-ballast. Therefore no oil cargo spill can occur. Departing laden tankers may be involved in such incidents as well, but again these will be very low energy events that will not lead to a breach of the inner hull of a double hull tanker.

8.2.2 Striking at Berth (Impact on Tanker while at Berth)

Striking at Berth is defined as an incident whereby another vessel (including other Trans Mountain tankers) strikes the Trans Mountain tanker while the Trans Mountain tanker is stationary at the berth. The frequency of striking incidents is proportional to the frequency of Trans Mountain tanker loading operations, the average time that each operation takes (24 hours) and the frequency of passing of significant vessels (i.e. vessels with sufficient size and structural rigidity to penetrate a Trans Mountain tanker). The frequency of striking does not reflect the frequency for an oil spill as most of the striking incidents will have low energy and will thus not cause a cargo tank breakage. The frequencies in this section are the total striking frequencies, while the frequency for an oil spill is shown in Chapter 10.4.

While a tanker is moored at Westridge terminal there is a possibility that passing vessels transiting to and from other terminals in the vicinity of Westridge terminal strike the Trans Mountain tanker due to an error in navigation or mechanical failure. The probability depends on the number of passing vessels and the width of the passage.

In 2006, DNV performed a study that estimated the annual striking frequency for ports in various coastal fairway types, as shown in Table 24. The Westridge terminal is situated where Burrard Inlet is approximately 0.7 NM wide, so a base frequency applicable to fjords or channels is used; frequency of 9×10^{-6} per transit.

Table 24 Striking probabilities (DNV, 2006)

Port Type	Description	Striking Frequency	Striking return period (1 per x transit)
Narrow river	rivers; under ¼ nm mean width	4.2 E-5	23,810
Fjord	fjords or narrow channels; ¼ to 1 ¼ nm mean width	9.0 E-6	111,111
Wide estuary	estuary; over 1 ¼ nm mean width	4.0 E-6	250,000
Open sea	lock or breakwater approach	4.0 E-6	250,000

The data summarized in Table 24 is from world ports with high traffic, many terminals and frequent manoeuvring operations. During manoeuvring in port there is a higher probability a vessel will lose power due to frequent load variations on the machinery and steering systems. This loss of power could lead to a vessel drifting and colliding with a berth or another vessel.

The limited amount of traffic forecast to pass the marine terminal in the very well monitored and managed Vancouver Harbour leads to a further reduction of the base frequency by 50% (DNV 2006) in the probability of a vessel striking another vessel at berth with sufficient energy to cause a spill.

The average time for loading operations at the Westridge terminal (including berthing and unberthing) is approximately 24 hours. It is during this time at berth that tankers will be exposed to the possibility of a striking incident. Furthermore one of the berths (Berth 1) is sheltered from the passing traffic as it is positioned at the south side of the western finger pier.

Based on the forecast traffic passing by the Westridge terminal approximately 420 vessels of sufficient size to damage a tanker will pass Westridge terminal each year.

The terminal design is such as one of the berths is 100% protected for striking by a passing vessel. DNV assume that the tankers are equally distributed between the three berths at the terminal, thus protection of one of the berths is reflected in the frequency calculations by reducing the annual number of tankers by 1/3 for Case 1.

Based on the above reduction factors, the time each tanker will be at the berth, and the forecast passing traffic, the frequency for a tanker being struck while at berth can be determined as follows:

$F_{striking}$= 9E-06 * 0.5 * 24h / (365 * 24h) * 420 = $5.2x10^{-06}$ per vessel berth.

The estimated striking frequency for Case 0, with a total of 60 tankers loading at the Westridge terminal per year, is $3.1 x10^{-4}$ per year (60 x $5.2x10^{-06}$) or once in 3225 years.

The estimated striking frequency for Case 1, with a total of 408 tankers loading at the Westridge terminal per year, is $1.4 x10^{-3}$ per year (408 x 2/3 x $5.2x10^{-06}$) or once in 707 years.

8.2.3 Striking of the Tanker at Anchorage

The risk model to estimate incident risks for Trans Mountain tankers at the anchorage is identical to that for it being struck at the berth, except that the number of tankers that go to anchorage at one of the 4 anchorage locations near the terminal is set as a proportion of the number of tankers that visit the berth. Assumption:

- 50% of ballast tankers go to anchorage;
- 35% of laden tankers go to anchorage

The average time at anchorage is assumed to be 24 hours. The frequency of striking incident at the anchorage is proportional to the frequency that Trans Mountain tanker go to anchorage, the average time that each tanker spends at the anchorage and the frequency of passing of significant vessels (i.e. vessels with sufficient size and structural rigidity to penetrate a Trans Mountain tanker).

The estimated striking frequency for Case 0, with a total of 21 laden tankers anchoring per year, is $1.1x10^{-4}$ per year (21 x $5.2x10^{-06}$) or once every 9090 years.

The estimated striking frequency for Case 1, with a total of 143 laden tankers anchoring per year, is $7.4x10^{-4}$ per year (143 x $5.2x10^{-06}$) or once every 1351 years.

Table 25 summarises the incident return periods for striking a Trans Mountain tanker while berthed at Westridge terminal or at anchorage for Case 0 and Case 1.

Table 25 - Incident Return Periods for Impact and Striking

Cause	Return Period (1 per x Years)	
	Case 0	**Case 1**
Striking of Trans Mountain Tanker at berth	3,225	707
Striking of Trans Mountain tanker at Anchorage	9,090	1,351

9 CONSEQUENCE ASSESSMENT

This chapter describes the consequences that could result from relevant incidents. For the purposes of the QRA the term consequence refers to vessel damage and volume of cargo oil that may be released. The consequence assessment is divided into two parts:

- Consequences from an incident involving tankers travelling to and from Westridge terminal (i.e. in transit).
- Consequences resulting from an incident during berthing or cargo transfer operations at Westridge terminal.

9.1 Tankers in Transit

9.1.1 Model basis

The conditional spill probability and spill size distribution for bottom and side damages are estimated for an Aframax size tanker. It uses detailed design drawings of the hull and tanks for an Aframax tanker classed by DNV as the basis for the oil outflow (spill) modelling. The sample vessel applied is a tanker of modern design with double hull and single continuous centreline oil tight longitudinal bulkhead. The vessel characteristics are summarized in Table 26. The method calculates spill quantities based on vessel damage information provided in IMO's MARPOL regulations. A software package called NAPA (Naval Architecture Package, by NAPA Ltd.) is used to simulate damage to the sample tanker's outer and inner hulls for various damage penetration depths and sizes of openings. The penetration depths and opening sizes are randomly picked from probability distribution curves generated by IMO's MARPOL. The spill sizes are calculated based on the number of tanks that can be damaged given the various penetration depths and hole sizes. The model uses a Monte Carlo simulation and applies 50,000 random computer generated damages (penetration depth and hole sizes) to estimate the conditional probability for different spill sizes.

Table 26 - Characteristics of the sample vessel applied in the analysis

Parameter	Sample Tanker of Aframax size
Deadweight tons (DWT)	105,278 mt
Length	235 m
Breadth	42 m
Depth	21.3 m
Max draft	14.8 m
Cargo tank capacity	120263 m^3
Number of cargo tanks	12
Number of slop tanks	2

Two loading conditions have been investigated to reflect the variations in cargo. As there is a draft limitation of 13.5 meters, the Aframax class tankers cannot be loaded to their maximum capacity. The heavy crude oil cargo (diluted bitumen) has a density close to API 20 (0,934 tons/m^3), but it does vary and also lighter oils up to API 26 can be transported from Westridge terminal (see more about the Trans Mountain oil characteristics in Chapter 13). For API 20, the corresponding density is 0.934 tons/m^3 while for API 26 the density is 0.898 tons/m^3. To be conservative the less dense oil has been applied to estimate the maximum cargo volume for a partially laden Aframax tanker. Details regarding the tank loading volumes are shown in Table 27. This size of Aframax tanker is considered as the current average size from within the 80,000 mt to 120,000 mt DWT range of tankers in service.

Table 27 - Aframax sized tanker, loading particulars

Cargo tank	Max volume (m^3)	Loaded volume (API 20) (m^3)	Loaded volume (API 26) (m^3)
CT1P	7514	6011	6214
CT1S	7514	6011	6214
CT2P	10110	8110	8361
CT2S	10110	8110	8361
CT3P	10138	8110	8384
CT3S	10138	8110	8384
CT4P	10138	8110	8384
CT4S	10138	8110	8384
CT5P	10138	8110	8384
CT5S	10138	8110	8384
CT6P	9773	7818	8082
CT6S	9773	7818	8082
SLOPP	2318	1854	1917
SLOPS	2318	1854	1917

The calculations have been based on the assumption that oil outflow will occur only from those tank compartments that are breached and opened to sea. A total loss of the vessel is not considered as that is not considered to be a credible scenario; DNV's rationale for this is discussed in Chapter 9.1.5.

9.1.2 Grounding

The results of the Monte-Carlo simulations (according to IMO's MARPOL regulations as outlined in MEPC 49/22/Add.2) for grounding (bottom damage) are shown in Figure 34. In this assessment a mean outflow is calculated as the 50% largest outflow (P50) given an accident that causes an oil spill. An extreme outflow or credible worst case scenario has been defined as the 10 % highest outflow (P90) given an accident that causes an oil spill.

Figure 34 shows the probability for an outflow volume given an accident that causes a spill. The mean outflow volume (P50) is 5,700 m^3 given a bottom impact that leads to an oil spill. The credible worst case outflow considered to be (P90) is 15,750 m^3 given bottom impact that leads to an oil spill.

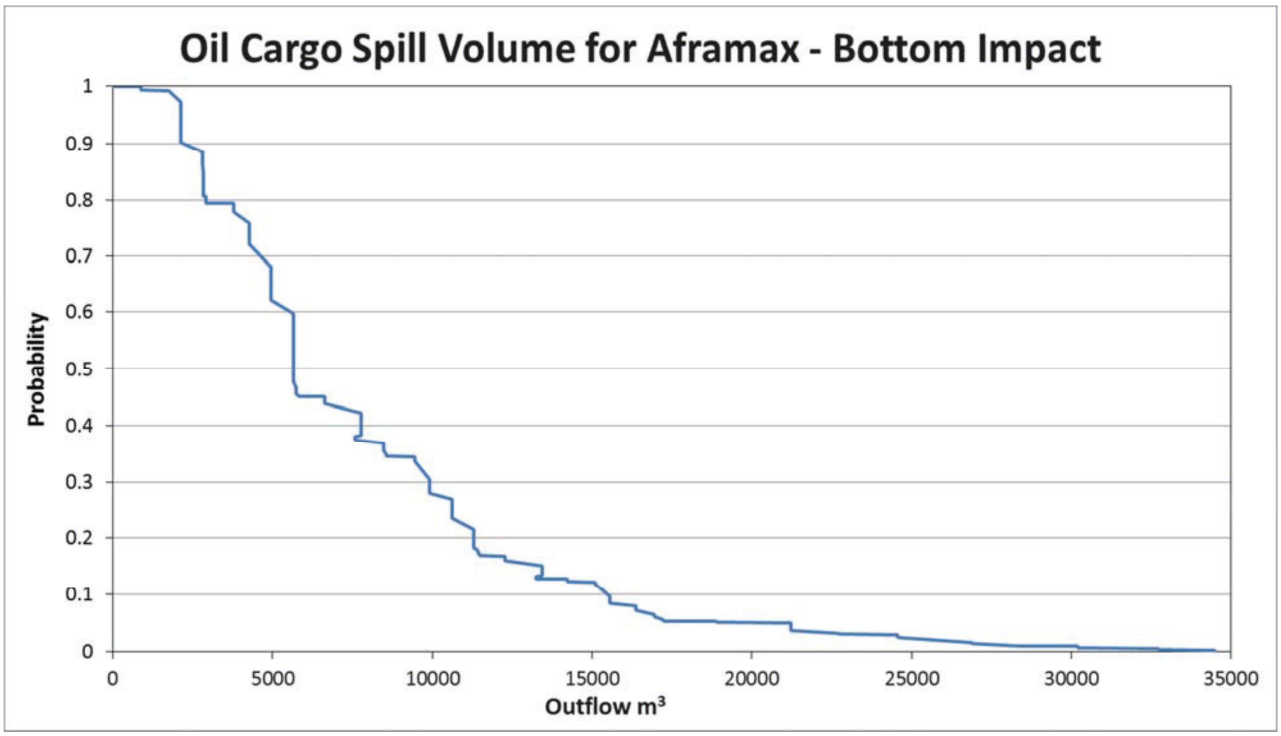

Figure 34 - Conditional probability for oil spill volume for Aframax bottom impact given a grounding incident that leads to a spill

9.1.3 Collision

The collision oil spill volume and the conditional probability for the spill volume given a collision that leads to an oil spill are estimated here. The oil spill volume is estimated for a side impact, i.e. for another vessel colliding into the side of the oil tanker.

The probability distribution of consequences given a collision that leads to oil spill is provided in Figure 35 below. Conservative assumptions have been made given that the exact nature of the collision will have great effect on whether a spill occurs and what size of spill occurs. The mean outflow volume (P50) is 8,250 m^3 given a side impact that leads to an oil spill. The credible worst case outflow considered to be (P90) is 16,500 m^3 given side impact that leads to an oil spill.

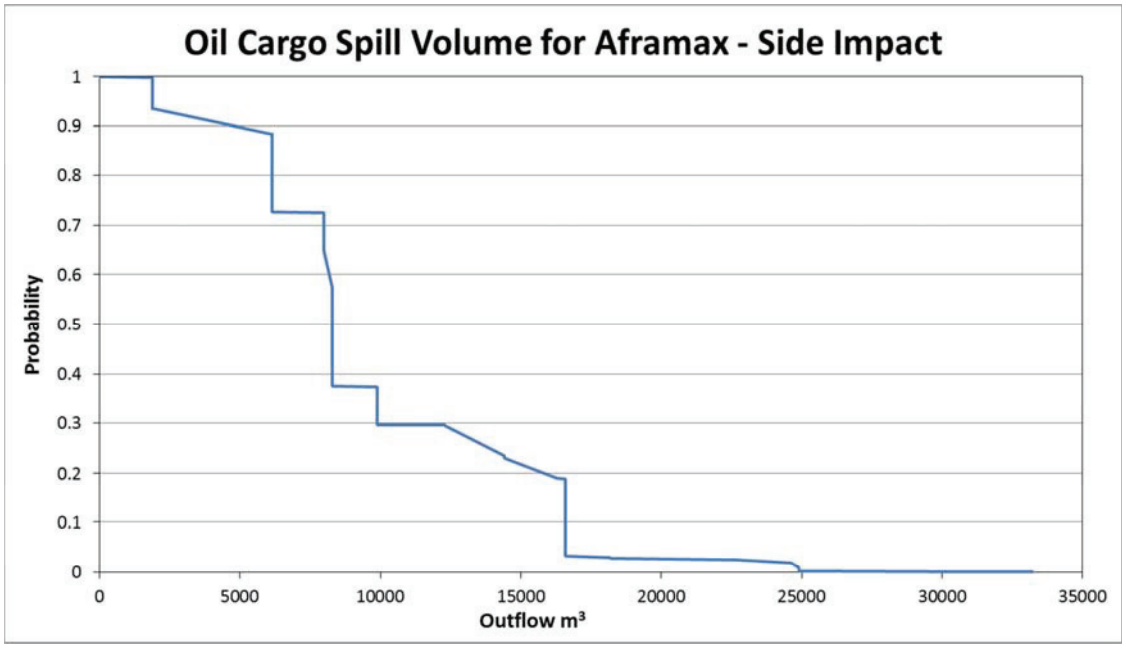

Figure 35 - Conditional probability for oil spill volume for Aframax side impact

9.1.4 Foundering, Fire and Explosions

Foundering describes an accident where a vessel usually sinks due to a structural failure of the hull. The structural failure is usually attributed to harsh weather and structural fatigue or defects. Structural failure and foundering incidents are not related to incidents caused by collision, grounding, fire or explosion. Foundering and total loss of a well-founded tanker such as that proposed by the Project is an extremely improbable event and therefore not considered a credible event. The contribution of foundering, fire and explosion to the calculation of overall low probability of an accidental oil spill event is extremely low. The next section discusses this with more detail.

Based on an analysis of historical accident data, it is assumed that if a structural failure/ foundering does occur on a double hull tanker, then the probability of total loss is 40%. It is further assumed that a total loss accident will result in the release of all cargo (if laden) and all bunker fuel onboard. It should be noted that the historical data does not readily distinguish between constructive total loss (vessel remains afloat but is damaged beyond economic repair) and actual total loss (vessel sinks or is wrecked on the shoreline), but only in the latter case will all the oil onboard be lost, if the tanker was laden at the time of her loss.

In MARCS, a fire or explosion accident assumes one of sufficient severity which could cause, or escalate to cause, a cargo or bunker fuel oil spill. Accommodation or galley fires are not usually in this category.

Most fires or explosions occur in mechanical rooms and do not necessarily effect cargo or bunker fuel tanks. Cargo tanks on modern tankers are protected by inert gas systems, so that a fire or explosion is highly unlikely in an intact cargo tank. However, external fires or explosions could damage cargo or bunker fuel oil tanks and if this occurs escalation could result, although this is a very low probability event. Bunker fuel tanks are often located near the mechanical rooms, but are typically separated for safety by an empty compartment (cofferdam) under Class rules.

Based on an analysis of historical accident data it is assumed that if a fire/ explosion occurs to a double hull tanker, then the probability of total loss is 20%. It is further assumed that a total loss accident will result in the release of all cargo (if laden) and all bunker fuel onboard. It should be noted that the historical data does not readily distinguish between constructive total loss (vessel remains afloat but is damaged beyond economic repair) and actual total loss (vessel sinks or is wrecked on the shoreline), but only in the latter case is all the oil onboard spilled, but only if the tanker is laden at the time. Thus these assumptions are considered overly conservative.

9.1.5 Analysis of Past Oil Spills for Determining Credible Worst Case Oil Spill

The definition of a credible worst case scenario is not provided in Termpol 2001 and is left to the risk assessor to determine. DNV recommends that **Credible worst case scenario** should be defined as representing a scenario whose likelihood of occurrence is remote, but not out of the realm of possibility, which will, if the event were to occur, cause significant impact. This could then be used in evaluating the quantitative risk assessment scoring and also for further risk scenario development. Based upon the fact that there has not been any total loss of containment scenarios involving a double hull tanker, ever, to date a credible worst case scenario does not include total loss of tanker with complete loss of cargo. A 90^{th} percentile event causing uncontrolled outflow from a tanker's cargo oil tanks has therefore been recommended as the Project's definition of a credible worse case. Such determination is further discussed below.

There are historical records of total loss of tankers leading to complete loss of cargo oil; however those past circumstances when these events took place were very much different when compared with modern tankers and their operating practices.

Only very few incidents reported involved a large oil tanker breaking and foundering. The largest cargo losses have however, been due to such accidents that all involved single hull tankers over past decades; e.g. Atlantic Empress caught fire after a collision and sank with 287,000 tonnes of crude oil in 1979, not all cargo was initially spilt. Castillo de Bellver was another large oil tanker that sank after a fire and explosion accident in 1983. The vessel broke in two and sank with most of the cargo still in the tanks. Approximate 50 - 60,000 tonnes of a total of 252,000 tonnes were spilt. Also ABT Summer sank after a fire and explosion accident in 1991; there are no data on the amount of oil spilt. All these fire and explosion accidents took place prior to the SOLAS design requirements for Inert Gas (IG) systems as mandatory fire and explosion protection for tanker vessels.

Sea Empress sank in 1996 after a grounding accident in the UK. Erika and Prestige, both these single hull tankers suffered structural failure and foundering due to heavy weather that allegedly aggravated existing poor structural conditions in 1999 and 2002 respectively. All these vessels were single hull tankers. As mentioned, there have been no double hull tankers that have suffered a total loss of cargo. As an example, the effect of the modern double hull versus single hull can be illustrated by the groundings of Exxon Valdez in 1989 and HS Elektra in 2009. Indeed, the single hull tanker, Exxon Valdez, spilled 37,000 tons of oil in Prince William Sound, due to a hard grounding on Bligh Reef. On the contrary, when the laden double hull Aframax tanker, HS Elektra, hit an uncharted rock and suffered large damage close to the Chilean coast, the tanker did not spill any of the cargo oil at all.

The historical trend in oil spill volume shown in the ITOPF data in Figure 36and Figure 37 clearly show that there has been a decreasing trend in the total quantity of oil spilled per year from an average of more than 300,000 m^3 in the seventies, more than 100,000 m^3 per year in the eighties to less than 20,000 m^3 per year since 2000 until 2012. Table 28 shows that the number of oil spills has decreased from decade to decade. In the 1970s it was on average 24.6 oil spills per year over 700 tonnes (ITOPF data), 9.3 spills per year on average in the 1980s, 7.8 in the 1990s and as low as 2.9 spills over 700 tonnes per year in the 2000-2012 period. The spill sizes however do not show the same stable decreasing trend from decade to decade. The average spill volume per spill over 7 tonnes was 4,084 tonnes in the 1970s; 2,590 tonnes in the 1980s; 3,153 tonnes in the 1990s and 1,123 tonnes per spill during 2000-2012. What the data clearly shows is that the oil spill volumes per spill have been significantly lower in the 2000s compared to earlier years, which DNV believes reflects the improvements in shipping regulations, tanker design, construction, applied technology, operating practices and crew training.

By comparing the historical data with the analysis data in the sections above it shows that the average calculated spill volume results for grounding and collisions of a Trans Mountain tanker are most likely overestimated and thus very conservative. **The historical oil spill data shows that the probability for an accident with total loss of containment is so low that it does not represent a credible worst case scenario involving modern tankers of the type proposed for this project. Thus a total loss of containment is not considered as credible worst case scenario for this risk assessment nor for the oil spill response capacity assessment.**

The estimated credible worst case spill sizes at 16,500 m^3 and 15,750 m^3 based upon the 90^{th} percentile loss of cargo oil resulting from for a collision or grounding respectively are therefore seen as clearly well within the definition of a credible worst case scenario. For purpose of providing oil spill response capacity and resources the higher figure should be used.

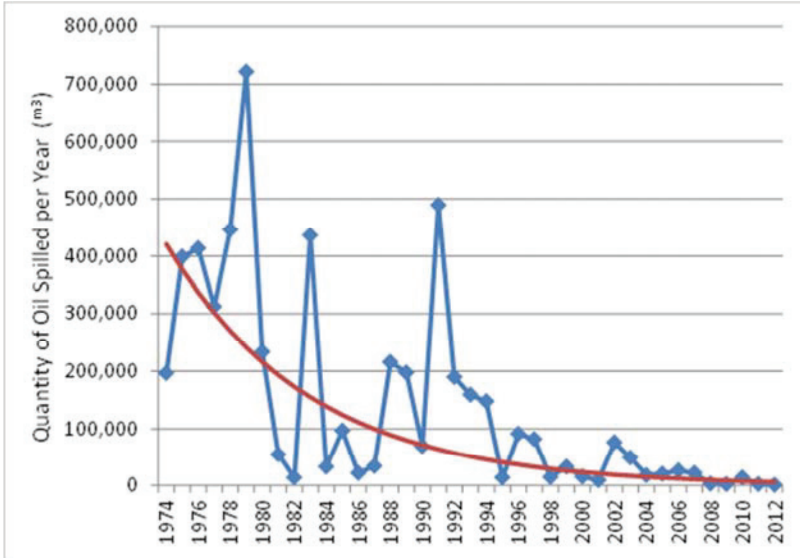

Figure 36 - Quantity of Oil Spilled from Tank Vessels Worldwide (ITOPF, 2013)

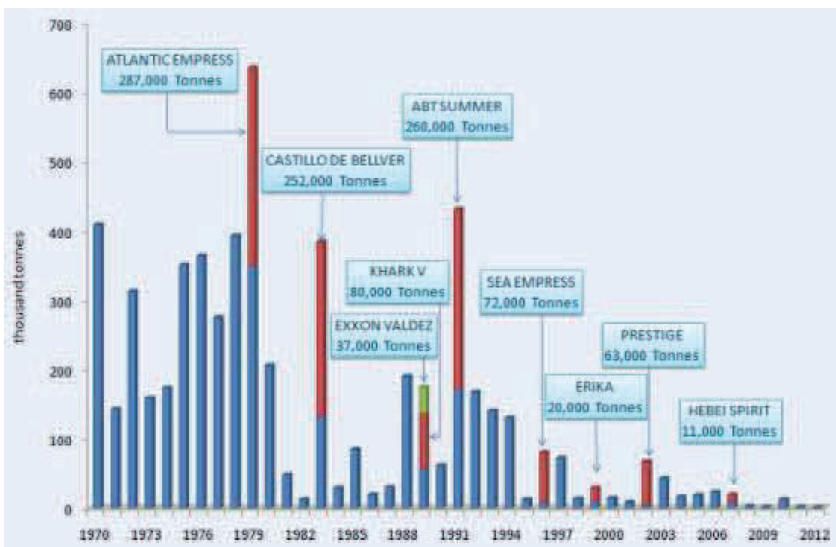

Figure 37 - Quantity of Oil Spilled > 7 tons (ITOPF, 2013)

Table 28 - Annual Quantity of oil spilt (ITOPF 2013)

Year	Quantity (tonnes)	7-700 tonnes	>700 tonnes	average spill volume	Year	Quantity (tonnes)	7-700 tonnes	>700 tonnes	average spill volume
1970	409,000	7	30	11,054	1980	206,000	52	13	3,169
1971	143,000	18	14	4,469	1981	48,000	54	7	787
1972	313,000	48	27	4,173	1982	12,000	46	4	240
1973	159,000	28	31	2,695	1983	384,000	52	13	5,908
1974	173,000	90	27	1,479	1984	29,000	26	8	853
1975	351,000	96	20	3,026	1985	85,000	33	8	2,073
1976	364,000	67	26	3,914	1986	19,000	27	7	559
1977	275,000	69	16	3,235	1987	30,000	27	10	811
1978	393,000	59	23	4,793	1988	190,000	11	10	9,048
1979	636,000	60	32	6,913	1989	174,000	33	13	3,783
1970s Total	**3,218,000**	**542**	**246**	**4,084**	**1980s Total**	**1,176,000**	**361**	**93**	**2,590**
Year	Quantity (tonnes)	7-700 tonnes	>700 tonnes	average spill volume	Year	Quantity (tonnes)	7-700 tonnes	>700 tonnes	average spill volume
1990	61,000	51	14	938	2000	14,000	21	4	560
1991	431,000	30	7	11,649	2001	8,000	17	3	400
1992	167,000	31	10	4,073	2002	67,000	12	3	4,467
1993	140,000	31	11	3,333	2003	43,000	19	4	1,870
1994	130,000	26	9	3,714	2004	16,000	17	5	727
1995	12,000	20	3	522	2005	18,000	22	3	720
1996	80,000	20	3	3,478	2006	23,000	13	5	1,278
1997	72,000	28	10	1,895	2007	19,000	13	4	1,118
1998	13,000	25	5	433	2008	3,000	8	1	333
1999	29,000	20	6	1,115	2009	2,000	7	1	250
1990s Total	**1,135,000**	**282**	**78**	**3,153**	2010	12,000	4	4	1,500
					2011	2,000	5	1	333
					2012	1,000	7	0	143
					2000 - 2012 Total	**228,000**	**165**	**38**	**1,123**

9.2 Cargo Transfer Operations

The technical parameters shown in Table 29 have been used to calculate potential leak volumes related to cargo transfer operations (Moffatt & Nichol, 2012).

Table 29 - Technical parameters for calculation of oil spill volume from loading operations

Technical parameter	Value	Unit	Comment
Loading time	About 24	Hours	
Vessel capacity Aframax	660,000	bbls	104,930 m3
Vessel capacity Panamax	400,000	bbls	63,595 m3
# Loading arms per berth	3		3 berths with 3 loading arms each
Diameter	16	inch	400 mm ND
Peak rate	1545	m^3/hr	
Detection and shutdown time	4	Min	Assumption is in line with similar projects

Typical causes of hydrocarbon releases during cargo transfer operations at oil terminals include:

- Overfilling cargo tanks (e.g. caused by technical failures or operator errors)
- Damage to loading arms/hoses or piping from external effects (e.g. caused by excessive vessel movements, mooring failure, operator errors, etc.)
- Leaks from loading arms/hoses or piping from internal damages (e.g. caused by wear and tear, corrosion, fatigue, etc.)

Table 30 - Distribution of spills from loading incidents (DNV 2000)

Event	Distribution of medium/small spill	
	Medium spill (%)	Small spill (%)
Release from loading arm	10	90
Failure in equipment	100	0
Failure in the vessels piping system or pumps	10	90
Human failure	10	90
Mooring failure	100	0
Overloading of cargo tank	0	100

Situations where mooring lines break and vessels are forced from the berth by wind or waves are rare and are usually the result of an extreme weather event, earthquake or tsunami. In the case of conditions that may lead to a failure of the mooring lines, cargo transfer operations will be stopped, the loading arms drained and tug boats will be readied to provide assistance to the tankers as required. Therefore the probability of a mooring failure contributing to an oil spill is assumed to be negligible.

The size of the spill will depend on the transfer rate, spill detection time, and shut down time of the loading or discharge process. The spill volumes are based on forecast loading and discharge rate for Westridge terminal. The actual rates, as well as expected detection and shut down time will be finalized during detailed design. A typical maximum detection and shutdown time of 4 minutes was suggested by Trans Mountain and this is in accordance with other studies (DNV 2006). Using this assumption the likely size of a spill has been calculated using the following formula:

Volume of spill = Transfer rate * (Detection time + Emergency Shutdown Time)

The oil spill volume from a large break in one loading arm lasting for 4 minutes until the leak is isolated is calculated to be 103 m^3. This is within the same range of oil spill size from loading operations at other terminals and is considered a credible worst case oil spill at Westridge terminal.

If there is a release caused by leakage rather than rupture of the loading arm/system, the estimated spill volume has typically been found to be less than 10 m^3, which is considered a small spill in QRA best practice methods.

The pre-deployed oil boom will be an important mitigating measure for the oil spill accidents at the terminal. The oil containment boom shall, according to the oil spill contingency plan for the terminal, have the capacity to contain a spill of more than 1500 m^3 oil. DNV has not carried out any capability assessment of the oil spill containment and recovery system at the terminal, such evaluation to be part of later detailed design engineering.

9.2.1 Impact at Berth

All Trans Mountain tankers will approach the berth in ballast, thus the probability of cargo spill is zero and the risk of cargo spill is also zero.

9.2.2 Striking at Berth

The probability of a spill given that a Trans Mountain tanker is struck by a passing large vessel is estimated by the same method as for collisions in Section 9.1.3 (the NAPA model). The potential oil spill volumes are lower than for a collision under transit because the tanks are not loaded to planned capacity until right before the vessel leaves the berth. Therefore, it is assumed that Trans Mountain tankers at the berth are on average 50% laden.

The risk model to estimate accident risks for Trans Mountain tankers at the anchorage is identical to that for a regular collision modeled in Section 9.1.3.

Figure 38 shows the conditional probability for an oil spill volume given a striking of a Trans Mountain vessel that leads to an oil spill.

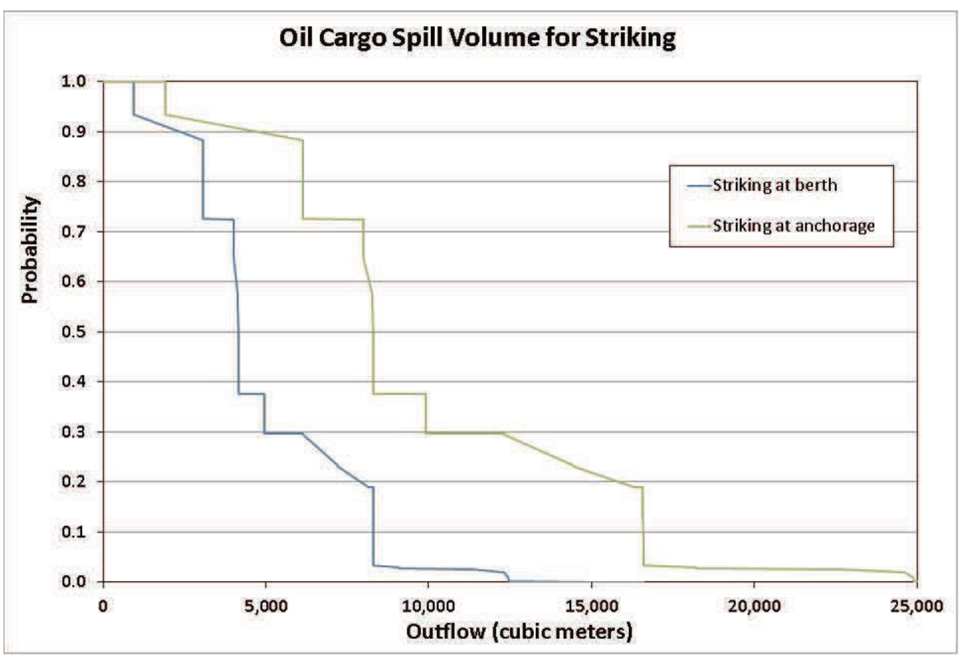

Figure 38: Conditional probability for oil spill volumes if a Trans Mountain tanker at berth or anchorage is struck by another vessel and leads to an oil spill

10 OIL SPILL RISK RESULTS

10.1 Oil Spill Accident Locations

A number of locations were identified by the navigational risk assessment team as possible accident locations, of which a few were selected as viable oil spill accident locations.

Figure 39 and Table 31 below show the five locations of hypothetical accidents where it was assumed that an oil spill could occur. These locations were arrived at after joint agreement between the navigational risk assessment team and the oil spill modeling team.

Stochastic oil drift modelling has been carried out for the five locations. The oil drift modelling has been used to assess oil spill response and for developing appropriate spill responses to both credible worst case and smaller spills at locations D, E, G and H. As a conservative approach and to ensure consistency the smaller spill volume for locations D, E, G and H have been fixed as 8,250 m3, i.e. P50. A large oil spill of 160 m3 and a smaller spill volume of 10 m^3 have been modelled at location A, see Table 31 for more details.

Locations A and E have been selected for detailed deterministic and 3D spill modelling for the Environmental and Socio-Economic Assessment submitted to the National Energy Board.

The spill rates and durations applied in the oil spill modelling are derived from the estimated spill volumes in Chapter 9. The rates for a credible worst case discharge scenario and average case discharge scenario are calculated based on DNV assumption that 25 % of the cargo in the breached tank flows out within the first hour in case of a collision and that 20 % of the cargo flows out within the first hour in case of a grounding, and that the rest of the volume flows out during the next 12 hours.

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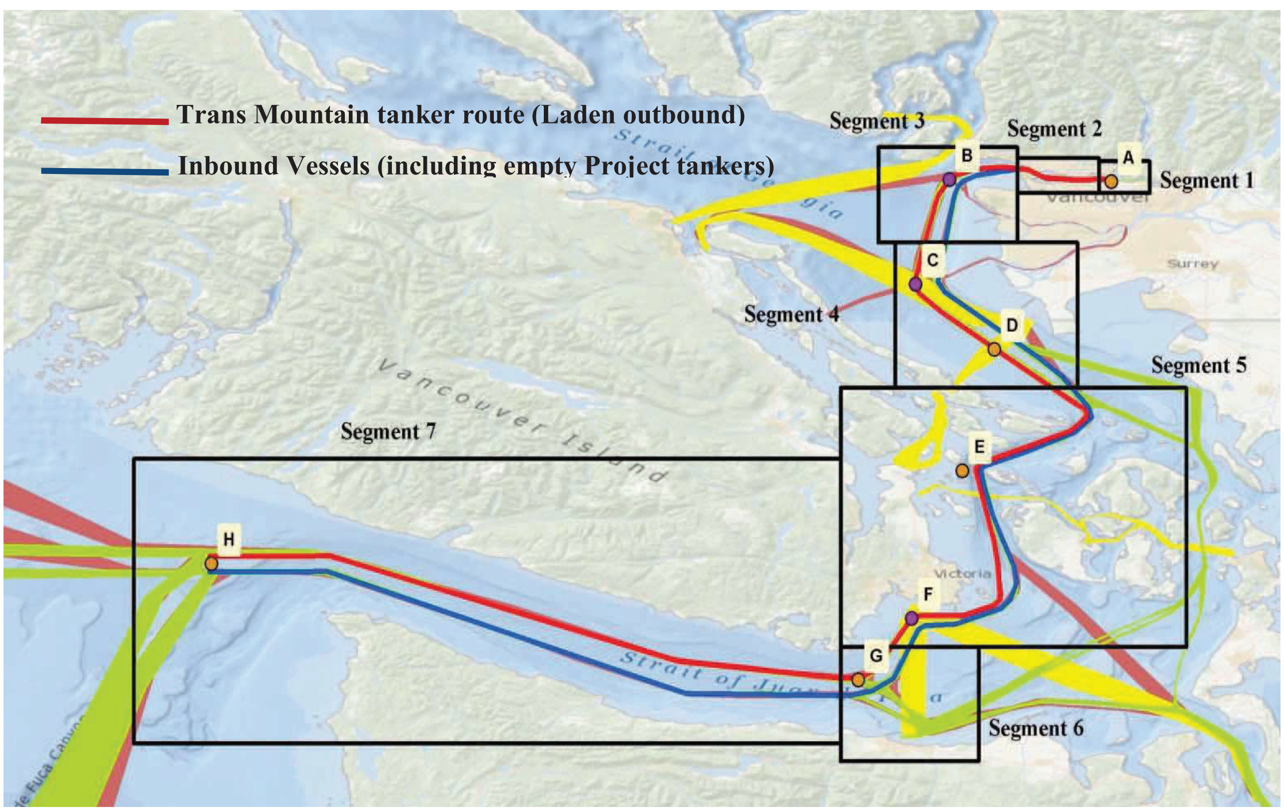

Figure 39 - Hypothetical Accident Locations – assumed oil spill locations in orange

Table 31 describes the oil spill locations and indicates in which study segment they are. Note for spill modeling consistency the oil outflows due to side impact have been used. These are considered as conservative assumptions.

The credible worst case oil spill during loading has been estimated to be 103 m^3 (see Chapter 9.2). However, the spill volume applied in the oil drift modeling for spill location A is 160 m^3. The reason for the higher volume in the spill modeling is because it was conducted before the dock optimization and risk assessment were complete. Therefore the value of 160 m^3 reflects a conservative estimate that was assumed for the spill modeling analysis. Thus optimization of the terminal design, among other outcomes, also mitigates oil spill risk at the future Westridge terminal.

Table 31 - Oil Spill Locations

ID	Study Segment	Possible location of Accident with possibility of Oil Spill	Representative hypothetical incident	Identified Hypothetical Spill Scenario (Latitude/Longitude: North / West)
A	1	Westridge Terminal	Oil spill from loading operation or flow line damage.	160 m3 large spill at berth with 20% escaping the pre-deployed oil spill boom (Lat/Long: 49.29150/ -122.95050)
B	3	English Bay	Possible collision with ships at anchor in English Bay and traffic from Fraser river is low probability	Not considered as viable spill location due to relatively low frequency for an accidental oil cargo spill
C	4	Roberts Bank	Possible collision with crossing traffic from Fraser river and other crossing traffic is low probability	Not considered as viable spill location due to relatively low frequency for an accidental oil cargo spill
D	4	Main ferry route crossing	Possible collision with crossing traffic from Fraser River and ferries is a low probability event, but considered because of higher number of crossings per day	Collision (Lat/Long: 48.94303/ -123.21739)
E	5	Turn Point SOA – Arachne Reef	Possible powered grounding is a low probability event due to pilots and tethered tug but this location is rated with greatest level of navigation complexity for the entire passage. Location also has high environmental values.	Powered grounding (Lat/Long: 48.6850/ -123.2930)
F	5	Brotchie Pilot Boarding Area	Possible collision with other vessel is a low probability event.	Similar to Location G. Chose Location G.
G	6	Juan de Fuca Strait - South of Race Rocks	Possible collision with crossing traffic from Puget Sound and Rosario Strait or grounding at Race Rock is a low probability event, but considered because not all vessels in this location will have pilot onboard	Collision (Lat/Long: 48.25257/ -123.52687)
H	7	Bouy Juliet	Possible collision between vessels approaching the confluence of the TSS at the entrance to Juan de Fuca Strait. It is a low probability event due to high oversight by MCTS and well established TSS,	Collision (Lat/Long: 48.49401/ -124.99440)

Note: All in-transit hypothetical spill locations have been modelled for both CWC and smaller spill size (8,250 m3)

The reduction of locations with potential oil spill from 8 to 5 locations has been done based on the accident oil cargo spill frequency for the various locations. Location B and C have relatively low frequency for an accidental oil cargo spill, location D is selected as the location in Georgia Strait as it is where the route crosses the frequently used ferry route. Location F has also relatively low frequency for accidental oil cargo spill and location G is more relevant as it is at the weather exposed Race Rocks.

10.2 Transit Oil Cargo Spill Risk

The oil cargo spill risk is the combination of the oil cargo spill frequency and the oil cargo spill consequence. The determination of the oil cargo spill frequencies for Cases 0, 1, 1a and 1b were detailed in Chapter 7 and the oil cargo spill consequence was described in Chapter 10.

The mean volume outflow (P50) and the credible worst case outflow (P90) developed in Chapter 10 have been selected for comparison in this Section. The volumes used for each are based on the most conservative volume consequences between grounding and collision.

The next two tables summarize the oil cargo spill return periods for a P50 volume outflow (Table 32) and a P90 volume outflow (Table 33), for Case 0, Case 1, Case 1a and Case 1b by accident type, within the Trans Mountain tanker shipping lane segments (Seg. 1-7). The tables also show the total P50 in transit oil cargo spill return periods for Trans Mountain tankers in the study area.

Table 32 - P50 Return Periods (in years) by accident type for Cases 0, 1, 1a and 1b

Oil Cargo Spill Return Periods for Trans Mountain tankers within the shipping lanes (Seg. 1 - 7)				
Accident Type	**Case 0**	**Case 1**	**Case 1a**	**Case 1b**
Collision	3,100	452	452	1,809
Structural failure	47,809	7,022	7,022	7,022
Fire / Explosion	32,089	4,713	4,713	4,713
Powered grounding	17,515	2,579	2,579	2,579
Drift grounding	1,093	161	1,265	1,265
Oil Cargo Spill Return Periods for Trans Mountain tankers within the study area (Seg. 1-12)				
Study Area	619	91	265	473

Table 33 - P90 (CWC) Return Periods (in years) by accident type for Cases 0, 1, 1a and 1b

Oil Cargo Spill Return Periods for Trans Mountain tankers within the shipping lanes (Seg. 1 - 7)				
Accident Type	**Case 0**	**Case 1**	**Case 1a**	**Case 1b**
Collision	15,500	2,261	2,261	9,046
Structural failure	239,045	35,111	35,111	35,111
Fire / Explosion	160,447	23,565	23,565	23,565
Powered grounding	87,576	12,896	12,896	12,896
Drift grounding	5,465	804	6,325	6,325
Oil Cargo Spill Return Periods for Trans Mountain tankers within the study area (Seg. 1-12)				
Study Area	3,093	456	1,326	2,366

Table 34 and Figure 40 summarises the oil cargo spill risk for credible worst case oil spill volume (P90) and average case oil spill volume (P50).

If all the mitigation measures taken into consideration in Case 1b are correctly implemented, it will lead to a fivefold decrease in the oil spill risk compared to Case 1 (Project proceeding without additional risk reducing measures). **In other words by implementing the additional risk reducing measures the accidental oil spill risk will only increase by 31% compared to Case 0, which is the estimated risk level in 2018 without the Project.**

Table 34 - Oil Spill Risk for Credible Worst Case and Mean Case

		Frequency (per year)				Return periods (years)			
	Oil Spill Volume (m^3)	Case 0	Case 1	Case 1a	Case 1b	Case 0	Case1	Case1a	Case1b
Credible Worst Case	16,500	0.00032	0.00219	0.00075	0.00042	3,093	456	1,326	2,366
Mean Case	8,250	0.00162	0.01096	0.00377	0.00211	619	91	265	473
Any oil spill	> 0	0.00323	0.02191	0.00754	0.00423	309	46	133	237

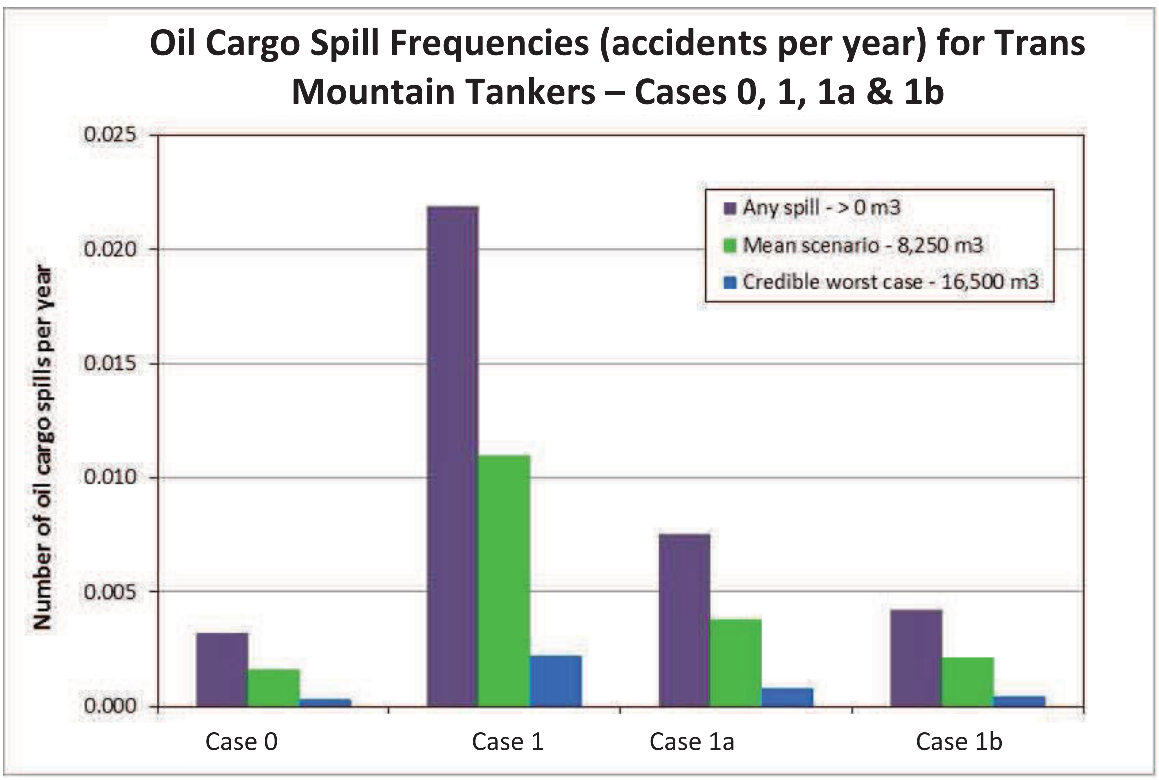

Figure 40 - Oil Spill Risk for various spill volumes

Figure 41 shows the in transit oil cargo spill risk in terms of frequency for oil spill volume, which the P50 and P90 risk results above are derived from. The Figure clearly shows that the oil spill risk from Case 1b is only slightly higher than for the base case (Case 0). The same risk results are shown as return periods for oil spill volumes, Figure 42 shows the results with 2000 years return period as cut-off, while Figure 43 shows the same result with 5000 years as return period cut-off.

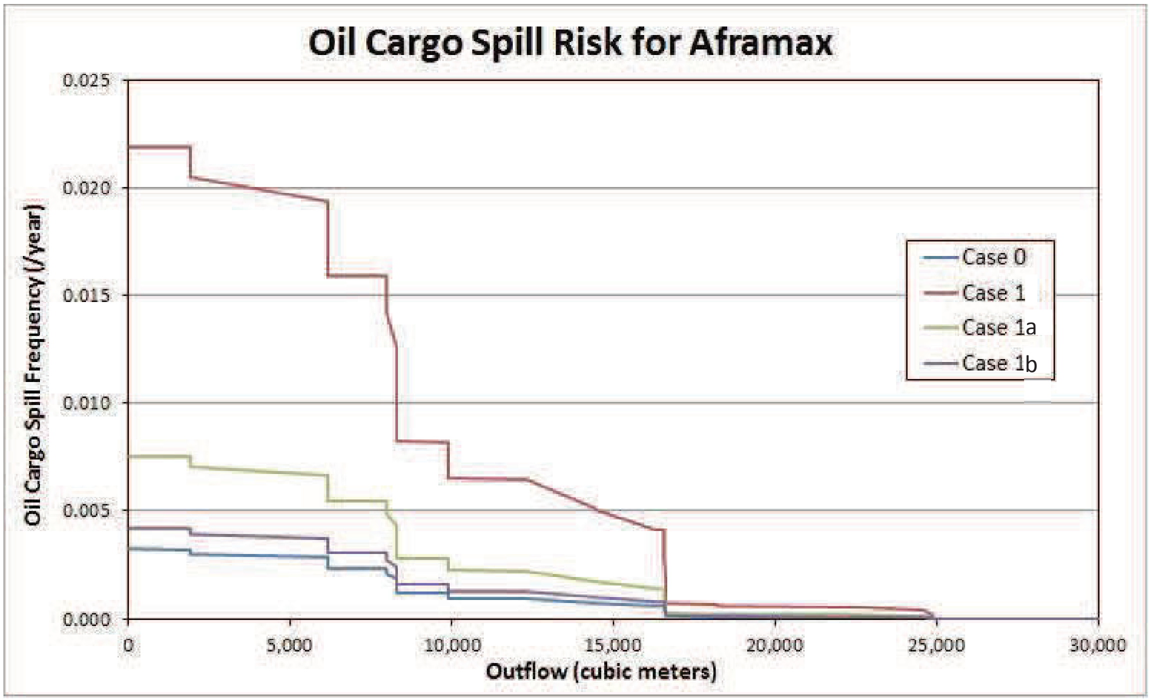

Figure 41 - Oil Cargo Spill Risk - Frequency for Oil Cargo Spill Volume

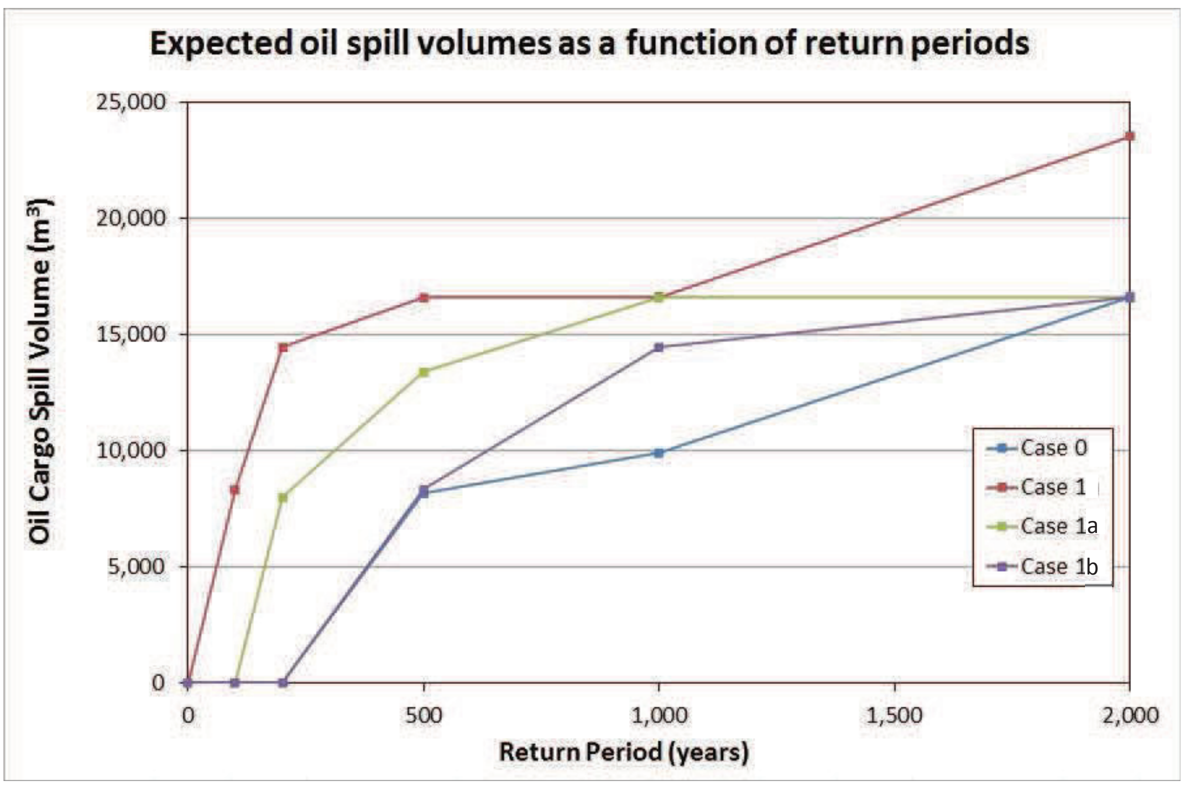

Figure 42 - Oil Cargo Spill Risk - Expected oil cargo spill volumes, up to 2,000 years return period

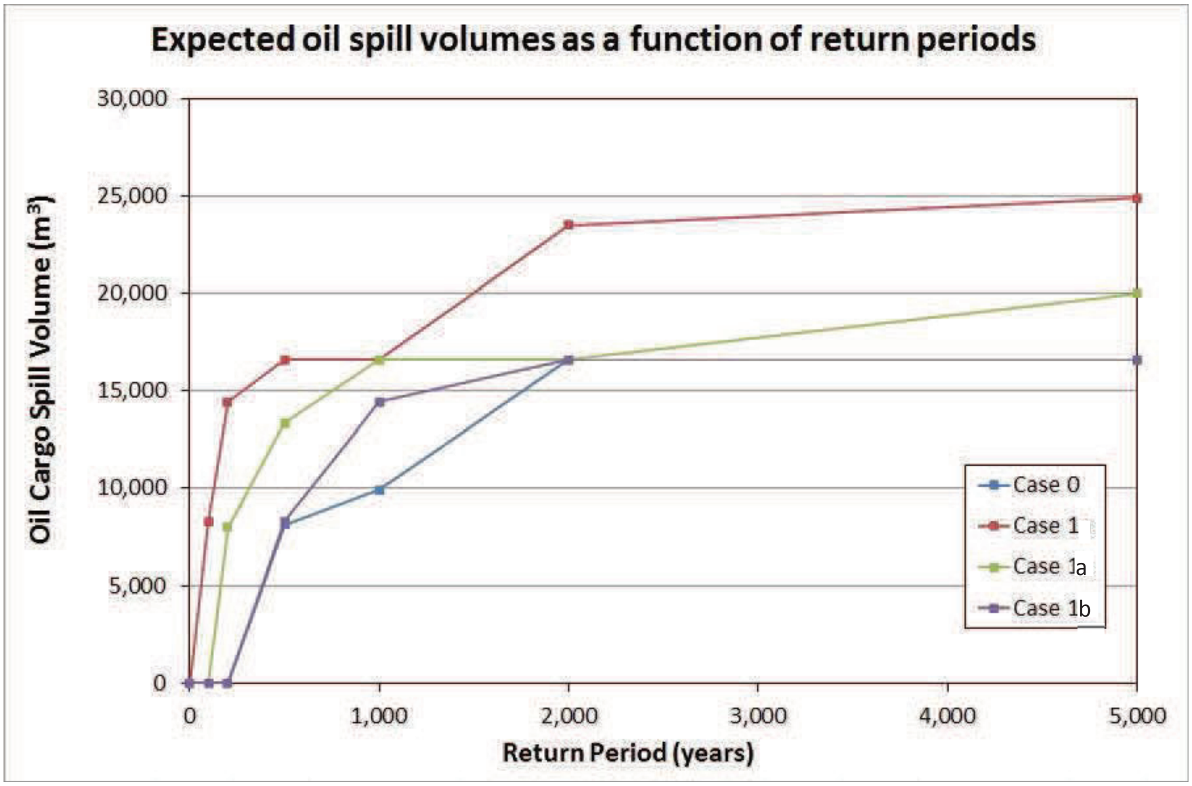

Figure 43 - Oil Cargo Spill Risk - Expected oil cargo spill volumes, up to 5,000 years return period

10.3 Cargo Transfer Operations Oil Spill Risk

The annual oil spill frequencies for a spill <10 m^3 and a <100 m^3 spill are calculated based on the base frequencies (Table 23) and expected number of loading operations, 60 per year for Case 0 and 408 per year for Case 1.

Table 35 shows that for Case 0 a <10 m^3 spill is estimated to occur once every 234 years while a <100 m^3 spill is estimated to occur once every 1,655 years. For Case 1 a <10 m^3 spill is estimated to occur once every 34 years while a <100 m^3 spill is estimated to occur once every 234 years. The basic frequencies of a release during cargo loading activities are derived from European terminal accident statistics and modified to account for site specific risk reducing measures that will be implemented at the new Westridge Marine Terminal, the majority of which are already in place

Table 35 - Annual oil spill frequencies and return periods (Source: DNV 2000)

Case 0 - 60 operations annually	**Annual spill frequency**	**Return period**
Spill size < 10 m^3	4.3E-03	234 years
Spill size < 100 m^3	6.0E-04	1,655 years
Case 1 - 408 operations annually	**Annual spill frequency**	**Return period**
Spill size < 10 m^3	2.9E-02	34 years
Spill size < 100 m^3	4.1E-03	234 years

Trans Mountain has an oil spill incident database for the Westridge terminal. The database has maintained records since as far back as 1961.

The list of spills in the database shows three spills, all small, for Westridge terminal of which two can be allocated to cargo transfer.

- April 1982 – 0.045 m3 – operations related
- March 1990 – 0.005 m3 – not operations related
- March 1998 – 0.04 m3 – operations related

Therefore the spill frequency for a small spill at the Westridge terminal is calculated as 0.04 spills per year or one spill every 25 years. The spill volume was much lower than oil spill volume threshold considered as small in the global database. Thus it is expected that the frequency for a <10m^3 spill at Westridge terminal will be even lower.

A credible worst case oil spill volume during loading is calculated as 103 m^3 based upon damage to one loading arm during cargo loading at one of the berths at the future Westridge terminal (Chapter 9). The return period of such an occurrence is calculated as a 1 in every 234 years event.

10.4 Striking Tanker at Berth or Anchorage Oil Spill Risk

Figure 44 and Figure 45 show the risk for oil spill related to striking a Trans mountain tanker at the berth or at anchorage. The frequency of striking a tanker at the berth is higher than at the anchorage, but the potential spill volumes are lower.

The return period for a 16,500 m3 oil spill for tankers at the terminal or anchorage area is estimated to 1 in every 227,270 years for Case 0 and 1 in every 50,000 years for Case 1.

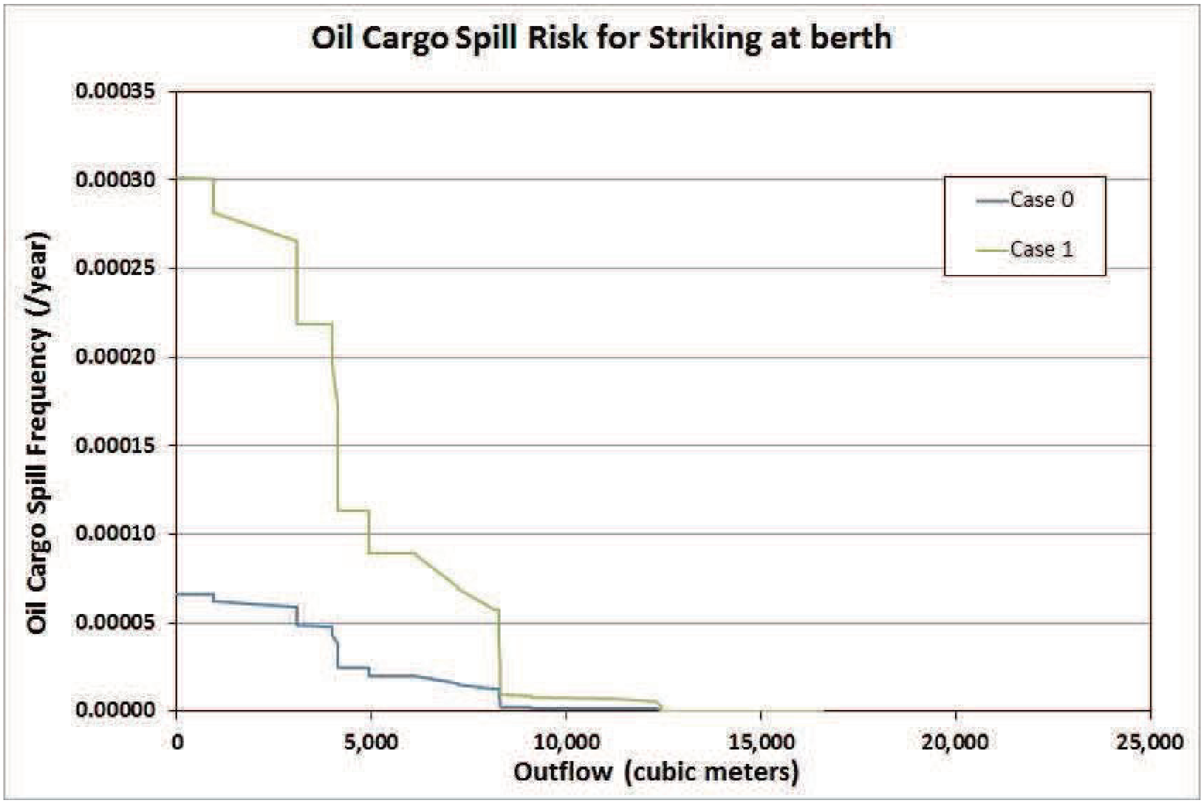

Figure 44 Oil Cargo Spill Risk for Striking Trans Mountain Tankers at the Berth

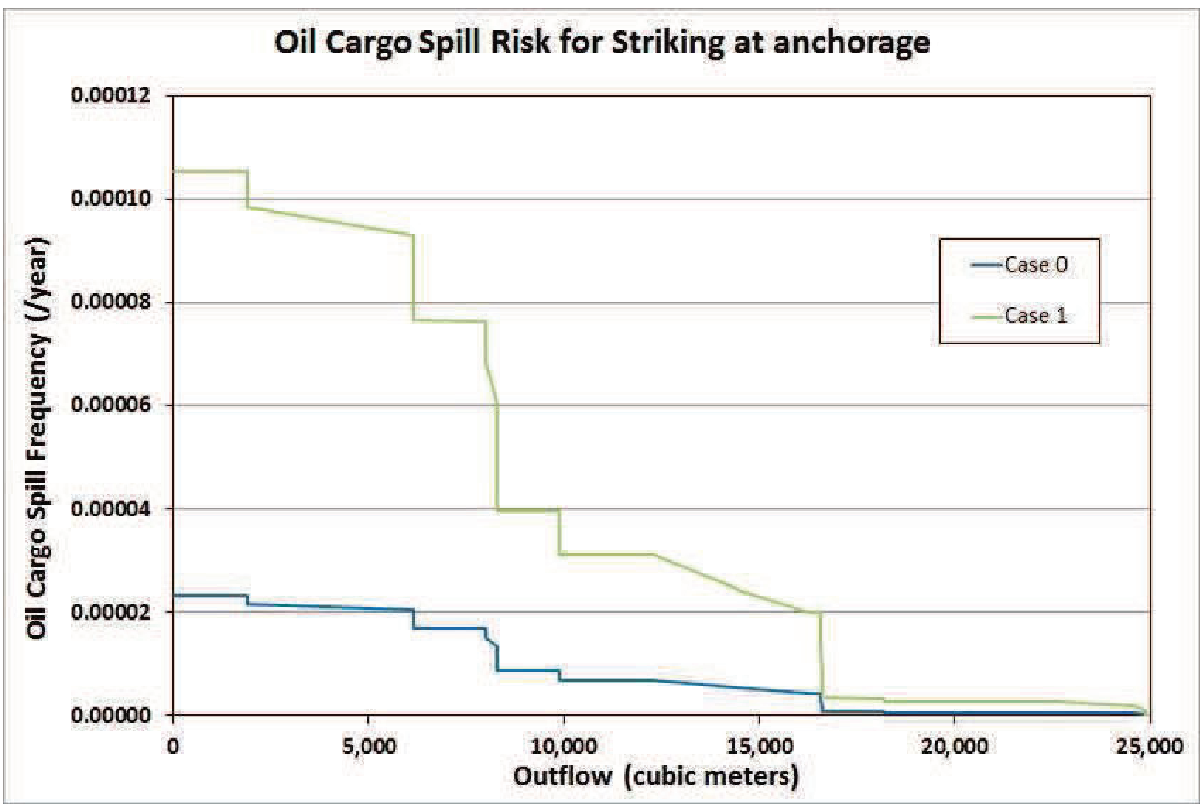

Figure 45 Oil Cargo Spill Risk for Striking Trans Mountain Tankers at the Anchorage

11 SENSITIVITY OF METHOD

11.1 Discussion of Accident Model Performance

Previous projects have shown that the collision, structural failure/ foundering and fire/ explosion accident frequency models used in this QRA all normally give good agreement with good quality historical accident data.

The powered grounding accident frequency model also generally gives good agreement with historical accident frequencies provided that the traffic input data is carefully reviewed and clear conflicts between vessel tracks and land (e.g. due to faulty AIS records) are eliminated.

However, experience has shown that MARCS tends to over-predict drift grounding accident frequencies compared to historical data. Some reasons for this are:

- The basis of the self-repair function and the vessel breakdown frequency may not be fully consistent.
- MARCS assumes a straight line drift track from the breakdown location to the grounding location. This is a conservative assumption, but is likely to be overly so in many situations.
- The MARCS model does not include all tugs of opportunity. Within a study area it is possible that powerful sea-going tugs may be available by chance and may be able to assist a drifting vessel. Such good fortune is not included in the risk model results.
- Most often when a vessel suffers issues with propulsion it may still be possible to maintain power for a period of time in order to stop in a safer location (e.g. an anchorage). Based on expert judgement, only 20% of breakdowns are "sudden, no-choice" breakdowns, but the MARCS model assumes all breakdowns to be "sudden, no-choice" breakdowns. This factor alone could reduce the modelled drift grounding frequency by a factor of 5.

In DNV's view, these are plausible reasons why the MARCS model over-predicts the drift grounding accident frequency.

Overall, DNV believes that the MARCS model makes risk predictions that are reasonable given the level of data available and are sufficient and suitable to support informed decision making.

11.2 Discussion on Model Validation

Demonstrating that a risk model is validated and that its results are verified is not a straightforward process. Like other computer models, risk models may reference 100s or 1,000s of parameters and probably contain 1,000s of lines of computer code. It is not practical, efficient or even desirable to validate such a model by manually checking input parameters or lines of code. DNV's response to this issue is described here.

The models are subject to manual checking and validation when the models are coded, and after any significant modifications. This includes checking the outputs from simple systems against analytical solutions (where possible) or against estimates. Discrepancies are understood and either eliminated or documented. Following significant updates the outputs of the new model are checked against the old model and any discrepancies are understood and either eliminated or documented.

Models which have been used regularly over a longer period of time gain additional credibility. Different types of applications generate different issues which are then resolved through the work performed. Thus models that have been used extensively over a period of time gain credibility and hence validation. MARCS was first developed in the early 1990s. It has been used extensively since then by many different types of projects. As part of two different projects in the US in 1996 and 2010, the methods and results of MARCS have been subjected to third party academic peer review by the US National Academy of Sciences.

Risk models, like MARCS, often generate aggregate risk numbers (e.g. over an entire study area) and apportioned risk numbers (e.g. for different operations within a study area). Analysts perform check-sums to ensure that numbers derived by different parts of the calculation tool that should agree do in fact agree. This type of test is applied within a calculation case.

Risk models are also often applied to multiple cases where each case may be similar to each other but not identical. Often it is possible to estimate from the input parameters the relative magnitude of the results. Even if this is not possible, the analyst will have an expectation of how the model results should vary and these variations across case results are checked and understood.

The absolute predictions of risk models should be checked against historical accident experience. This can be subject to significant uncertainties, but nevertheless this is an important verification step for any risk model. Care should be taken with understanding these types of checks as some models are calibrated with historical data, thus for some models this may be a circular process. MARCS results are compared to historical accident data but the MARCS algorithms are not calibrated with historical data.

Finally, it is DNV's view that the majority of the benefit of a risk model is derived from building the model and examining how its relative results vary with the inputs used. This promotes understanding of the key risk drivers and hence allows the identification of the more appropriate risk reduction options.

12 QUALITATIVE ASSESSMENT OF THE TANKER TRAFFIC RISK

There is a long history of marine transportation of crude oil and refined petroleum products within this region. Therefore, for most parts the transport risk factors associated with the Trans Mountain Expansion Project already exist in the region, whether as part of current ongoing operations at Westridge terminal or as a result of other tanker activity in this region, which includes the movement into the study area of large quantities on crude oil in parcel sizes to neighbouring refinery terminals that are slightly larger than what is proposed as the average export parcel size from Westridge terminal. The existing risk factors relate to both the probability for an accident to occur as well as the potential consequences of a spill. As this analysis shows, as a result of the increase in tanker traffic to and from Westridge Terminal, there will be an increase in the probability of a tanker incident. As the risk assessment gives absolute frequency values for accidents and its related consequences to occur it is important to remember the limitations of any model that aims to simulate the "real world" and in addition forecast potential incidents. The absolute risk values are thus more suited for comparison within the study than with other studies that have applied different models. The strength of the model is that it gives a good geographical distribution of the accidental frequencies and is able to reflect the risk reduction effect of implemented risk controls. This study has aimed to analyse a variety of risk controls, already implemented and potential new risk controls. By this the project has been able to identify adequate additional risk controls that can bring the oil spill risk down to as low level as reasonably practicable. As will be explained in a following section, the probability of an oil spill shall remain low. Also, current mitigation steps and processes, which are well established and tested in this region, are expected to be capable of safely managing the predicted increase in tanker traffic.

The primary risk related to the Project is increased threat of an oil spill due to the increase in tanker traffic and due to increase in number of cargo transfer activities at Westridge terminal. The most relevant causes for such a threat are:

- Systemic failure from within the global tanker industry leading to poor physical quality of the tanker or poor competence amongst a tanker's operating staff and supervisors,
- Any lack of oversight and monitoring by those responsible amongst regulators and within industry
- Any breakdown within Trans Mountain's tanker acceptance process,
- Navigation failure and/or Pilot error
- Collision with other vessels
- Striking terminal trestle or berth
- Inclement weather
- Fire and explosion
- Security intrusion
- Earthquake and/or Tsunami

The following is a qualitative discussion of the threats and the risk controls that shall minimize the risk.

Systemic failure from within the global tanker industry leading to poor physical quality of the tanker or poor competence amongst a tanker's operating staff and supervisors

As described in previous sections of this document and in Termpol 3.8 and 3.9, there is evidence that the safety standards of global tanker industry have vastly improved over the past three decades, both design standards and operational procedures. The reduction in severe incidents in general and in oil spill accidents in particular is a good indicator of safety improvement of the industry. The modern tanker fleet that is available to the shippers of oil from Westridge Marine Terminal consists of safe and modern tankers manned by well trained and competent seafarers who are governed by high common global standards.

Any lack of oversight and monitoring by those responsible amongst regulators and within industry

As described in previous sections of this document and in Termpol 3.9 there are reasons to believe that governmental and non-governmental regulators remain highly active in their monitoring of the tanker industry to ensure strict compliance with rules and regulations. In addition, various initiatives from oil companies, industry, class societies, insurers, etc. support continuous improvement initiatives in the areas of technical and procedural advancement. These initiatives and the industries interest for improved safety performance support a continuous focus in these subjects together with a focus on continuous improvements to the levels and standards of crew training.

Any breakdown within Trans Mountain's tanker acceptance process

Trans Mountain applies Kinder Morgan Canada's procedures and is committed to their company internal Environment, Health and Safety Policy, which requires every employee to comply with all health, safety, security and environmental laws, and promote best practice. Trans Mountain believes that based upon their experience, their historical records and the established contractual ability to decline any unsuitable or unsafe vessel from calling at Westridge terminal, the chance of accepting a tanker in poor physical condition or one that is poorly managed is low.

Despite the industry and regulators monitoring and enforcement of design and maintenance codes and regulations as well as strict vessel acceptance and selection processes, errors and malfunctions could occur.

Navigation failure and/or Pilot error

The mandated use of pilots and escort tugs has been described elsewhere in this document. Pilots are highly trained, experienced, tested for local knowledge and certified by the PPA. Two pilots are assigned to all loaded tankers and they maintain a combined oversight of the vessel's bridge and her movements; they each carry a PPU. The PPA plays an active part in ensuring the pilotage practices are reviewed and any navigation incident reported onboard a vessel with pilot is investigated and followed up appropriately. Ongoing and refresher training programs for pilots ensure they maintain their skills. The track records of incidents related to vessels under PPA pilotage, as shown in Termpol 3.8, are excellent when it comes to oil spill accidents. Both pilots who board a laden tanker to depart a tanker from Westridge terminal are provided an orientation by the tanker's bridge team and then become part of the team. Of the two pilots assigned to the vessel, only one shall have the con at any time and the other shall provide backup and consultation to the pilot having the con as well as continue to keep the vessel's bridge team informed and involved in the progress of the vessel. The pilots discuss the passage with the Master and the Bridge Team and also confirms that the main engines and steering system have been tested and working satisfactorily. As well, it is confirmed that the engine room is manned and shall remain so for the entire duration of the transit; however the engines shall be operated directly from the tanker's bridge.

Collision with other vessels

As Trans Mountain tankers form only a small proportion of the marine traffic that comprises the regional marine network, a threat for collision with another network vessel exists. However, there are a number of safeguards against such an occurrence, like the MRA regime within PMV that regulates the movement of tankers and other vessels whenever a tanker transits the confined waters the harbour. The traffic separation scheme with proactive and joint management of the shipping lanes between Canada and USA separates inbound and outbound traffic as well as enforces rules for crossing vessels so as to highly reduce the possibility of collisions. Increase in the overall traffic intensity for the region has been considered and factored into the quantitative navigation risk assessment described in this document.

Inclement weather

The coastal climate and weather patterns of Southern BC are relatively benign when compared with many other parts of the world. A Metocean study has been completed by EBA and its report is a key input to the navigational risk assessment reported in this document as well as in many of the studies and evaluations.

Fire and Explosion

Since implementation of mandatory use of inert gas to all crude oil tankers, the threat of fire and explosion onboard a tanker related to her cargo has been almost eliminated. However, external fires or explosions could damage cargo or bunker fuel oil tanks and if this occurs escalation could result. The advent of double hull tankers has further reduced such threats as a result of collisions or other high energy impacts. Tanker crews are trained to maintain an onboard environment free of ignition threats and various prevention and detection elements are designed into the construction of the tanker.

Security intrusion

Security threats have not been a part of the QRA. Port Metro Vancouver works closely with other federal agencies to apply security measures for standardized Marine Security (MARSEC) response levels. The Port continuously reviews security standards in consultation with its tenants, customers, labor and regulatory agencies. These standards reflect the local operational requirements for the secure movement of cargo and passengers during times of normal and elevated levels of security. To support on-water security requirements, PMV operates a number of harbour patrol vessels.

In January 2004, the Government of Canada established the National Risk Assessment Centre (NRAC) within the Canada Border Services Agency (CBSA). The NRAC operates 24/7 as a focal point and interface between intelligence agencies at the international, national, and local levels to protect Canadians against current and emerging threats. The NRAC uses sophisticated intelligence gathering techniques and information sharing and analysis to detect and stop the movement into the country of high-risk individuals and goods. The NRAC distributes this information to its law enforcement partners who can then act appropriately. Under the Smart Border Declaration, Canada and the United States have agreed to combine their efforts to detect persons or goods that pose a threat to national security.

There have been no threats to marine security recorded in this region. All vessels at the Westridge Marine Terminal follow the requirements of the ISPS Code (International Ship and Port Security Code) and establish onboard security levels to reduce chances of being boarded by hostile elements.

Earthquake and/or Tsunami

A tsunami is a wave, or a series of waves, that occurs in an ocean or other large body of water caused by some sudden activity on the seabed or at the surface. Most tsunamis result from submarine earthquakes, volcanoes and landslides, but in extremely rare instances, they may also be caused by asteroid or meteorite impact. It has the potential to cause large-scale damage and devastation to people and the environment. Recent global and regional earthquakes and tsunamis have raised awareness of such incidents. However these are low frequency events and are not usually significant influences on the risk profile of a port or country.

The Emergency Management BC website indicates those coastal areas on the West coast of Canada that could experience a damaging tsunami generated in conjunction with either a close or distant earthquake. Port Metro Vancouver and terminals in the Burrard Inlet have not been identified as at risk locations.

Well founded ocean going vessels such as the tankers that call Westridge terminal should not face any specific challenges when at sea from a tsunami. In fact because of the nature of the tsunami, which is usually a long wavelength, low amplitude wave, a vessel at sea may not even notice the wave.

13 EXISTING AND ADDITIONAL RISK REDUCING MEASURES

13.1 Navigational and sailing route risk controls

The risk reducing measures that have been taken into account in the accident frequency estimation of the sailing route are shown in Table 36. The risk controls that are identified for all the segments are controls that already are in place in the sailing route. The additional risk controls for Case 1a and Case 1b are only indicative to estimate the risk reduction of them.

Table 36 - Overview of Risk Controls Taken Into Account for the Various Cases in the Risk Assessment

Traffic and segments	Case 0, Case 1, Case 1a, Case 1b and Case 2	Case 1a	Case 1b
All significant traffic in all segments	VTS		
All significant traffic in all segments	Traffic Separation Scheme (TSS)		
All non-local significant traffic All segments except 6 and 7	Pilotage		
TM tankers and in all segments	ECDIS/ ENC Tanker vetting		moving exclusion zone around laden tankers
All Tankers in Segment 1	Pilotage and PPU - 2 pilots outbound, 1 inbound (applies to all pilot segments) Tethered tugs Non-tethered tugs		
All Tankers in Segment 2	Pilotage and PPU Tethered tugs Non-tethered tugs		
TM Tankers in Segment 3 and 4	Pilotage and PPU	Tug escort for laden tankers	Tug escort for laden tankers
Other Tankers in Segment 3 and 4	Pilotage and PPU		
All Tankers in Segment 5	Pilotage and PPU Tethered tug (laden only & >40,000 DWT) One-way traffic for +/- 1 nm round turn point		
TM Tankers in Segment 6	Requirement for min 40 ton bollard pull escort tug, 0.5 nm from tanker, 100% available; Actual tugs used for TM tankers have BP in range of 50-70 tons		
All Tanker Traffic	For laden tankers, over 40,000 DWT, escorted and tethered as shown in Figure 21 One-way traffic in Rosario Strait		
TM Tankers in Segment 7		Extended tug escort to the mouth of Juan de Fuca Strait for outbound laden tankers	Extended tug escort to the mouth of Juan de Fuca Strait for outbound laden tankers

13.2 Westridge Marine Terminal Risk Controls

It is a wide spectrum of risk controls that will be implemented at the new Westridge terminal, majority of which are already in place. This section describes the risk controls that reduce risk for oil spill to sea during the berthing operations, cargo transfer activities and de-berthing operations:

- Tethered tugs and standby tugs to assist the tanker during berthing at the terminal.
- Oil booms deployed around the vessel during cargo transfer activities.
- Loading platform at the berths drained to sloop tanks and treated at shore.
- Emergency Release Couplers at the loading arms
- Emergency shutdown (ESD) valves at flow pipelines by the manifold at the loading platform and at landfall, all ESD can be activated from the control room.
- Overfilling detection at the tanker vessel.
- Leak detection at the pipeline
- Operational procedures to assure that all systems works adequately prior to cargo transfer.
- Operational procedure for safe cargo transfer activities both onboard the ship and at the terminal
- A Loading Master assigned to each loading tanker.
- Using oil spill prevention booms around the terminal during cargo transfer operations creates an exclusion zone around the loading tanker.
- Typically passing large commercial vessels use tethered tugs and pass at reduced speed.
- Fire prevention and protection both onboard the vessel and at the marine terminal.
- Marine Terminal personnel who are trained for the purpose.
- Emergency Response Plans that are already developed and in place for current operations at Westridge terminal, which will be further adjusted for the increased future activities.

13.3 Oil Spill Management

13.3.1 Oil Cargo Characteristics

The increased Trans Mountain pipeline system shall have the capability to transport a variety of oils that will include both light and heavy crude oils, including those oils often termed as dilbit. The following is a list of the various generic streams of oils that may be offered for transportation by shippers of the pipeline system and loaded on tankers at Westridge terminal.

Table 37 - Crude Comparison - From Sept. 01, 2011 to Sept. 01, 2013
(Source: Crudemonitor.ca and KMC Annual Crude Properties) Format is: Average ± std. dev.

Basic Analysis	Light Sour	Light Sweet	Synthetic	High TAN Dilbit	Dilbit	Synbit	Dilsynbit
Density (kg/m3)	829.5 ± 6.8	828.7 ± 3.9	844.9 ± 18.4	874.2 ± 48.4	928.0 ± 5.2	931.9 ± 6.1	933.2 ± 6.8
Gravity (deg. API)	39.0 ± 1.4	39.1 ± 0.8	35.9 ± 3.6	30.7 ± 9.0	20.9 ± 0.9	20.2 ± 1.0	20.0 ± 1.1
Viscosity cSt) @ 5 deg.C	10.6	12.1	10.7	Blended to meet < 350 cSt at Reference Temperature			
Viscosity cSt) @ 10 deg. C	8.0	8.0	8.9				
Viscosity cSt) @ 15 deg. C	6.9	6.4	7.5				
Reid Vapour Pressure (kPa)	68.9	74.9	31.7	62.9	51.7	20	62.7
Sulphur (wt%)	0.69 ± 0.18	0.42 ± 0.07	0.29 ± 0.12	2.08 ± 1.78	3.78 ± 0.08	3.42 ± 0.38	3.11 ± 0.70
Hydrogen Sulphide (ppm)	< 250	< 10	< 1	< 10	< 10	< 10	< 10
MCR (wt%)	2.13 ± 0.44	1.92 ± 0.18	0.94 ± 0.89	6.06 ± 4.55	10.42 ± 0.30	8.93 ± 1.55	11.50 ± 1.47
Sediment (ppmw)	-	-	-	136 ± 113	123 ± 92	92 ± 38	378 ± 341
TAN (mgKOH/g)	-	-	-	1.72 ± 0.09	0.98 ± 0.08	1.20 ± 0.24	0.75 ± 0.27
Salt (ptb)	-	-	-	6.2 ± 1.7	10.4 ± 2.3	7.5 ± 3.2	10.7 ± 1.9

The maximum relative density of petroleum transported on the Trans Mountain system is 0.94 kg/m3. This means that all the petroleum will float if spilled in water. However, once released into the environment petroleum begins to "weather" and this process could lead to an increase in both density as well as viscosity. Increased density can cause the petroleum to be submerged or begin to sink. When petroleum is released into water lighter components will begin to evaporate, some will dissolve into the water column, and the remainder will float as long as its density is less than the ambient seawater. Wave action can cause water-in-oil emulsions which will drive the mixture towards neutral buoyancy. Adhesion to bottom sediment (beaches, riverbeds) or other sinking material can cause the oil to be submerged.

The crude bitumen contained in the Canadian oil sands can be described as naturally occurring petroleum that exists in the semi-solid or solid phase in natural deposits. The extracted bitumen being of longer chain hydrocarbons result in denser more viscous crude oil will not flow unless heated or diluted with lighter hydrocarbons. At room temperature, it is much like cold molasses. The World Energy Council (WEC) defines natural bitumen as "oil having a viscosity greater than 10,000 centipoises under reservoir conditions, and an API gravity of less than 10° API". In order to transport it through pipelines, a diluent is added to the bitumen. Bitumen mixed with the diluent produces a homogeneous blend that has considerably lower density and viscosity with good pumping and flow properties. This product is often referred to as Diluted Bitumen or Dilbit. The diluent used could be lighter crude oils, synthetic crude oils or natural gas condensates.

While many of the base bitumens are denser than water the diluents are not and when blended the dilbits transported by the Trans Mountain system have a relative density less than 0.94. Properties of both the base bitumens and the diluted bitumens are regularly reported on www.crudemonitor.ca.

On behalf of Trans Mountain, Witt O'Briens together with Polaris Applied Science and WCMRC conducted a meso-scale study of the fate and behaviour of typical dilbit oils transported on the Trans Mountain system[6]; Cold Lake Winter Blend (CLB), and Access Western Blend (AWB). The study also tested effectiveness of conventional skimming equipment for mechanical recovery of fresh and weathered dilbit (CLB) as well as effectiveness of in-situ burning, dispersants, and beach cleaning agents as alternatives to mechanical recovery. The tests were run over a 10 day period and were conducted on brackish water with a salinity similar to that of Burrard Inlet and the Salish Sea (relative density of ~1.015, fresh water=1.0).

Each type of oil (CLWB and AWB) was exposed to three similar types of weathering conditions:

- Static Conditions - No agitation. Wind exposure was minimized as far as was practical.
- Mild Agitation - Low imposed wind and wave conditions; induced by simple mechanical means through intrinsically safe fans and a paddle mechanism.
- Moderate Agitation - Greater induced wind and wave agitation using the same means.

Samples of both the affected water and the weathered oil were taken over the 10 day test period to assess the changing properties of both. During the test period probes were employed to determine whether any oil had sunken to the bottom of the tanks. No evidence of sunken oil was found from these probes nor was oil observed on the bottom of the tanks at the conclusion of testing when the tanks were emptied.

The density of samples taken during the test show that it took 8-10 days for oil to reach the density of fresh water (1000 kg/m3) if it occurred at all. The meso-scale tests showed that the weathering patterns between CLB and AWS are similar and that oil physical and chemical properties are consistent with other heavy crude oil.

The test have shown dilbits to have physical properties similar to many intermediate fuel oils and heavy crude oils, which are not characterized under the USCG system as nonfloating oils

13.3.2 Oil Drift Modelling

EBA has conducted oil drift modelling and their report[7] will be part of Termpol 3.1 as an attachment. The results show that oil spilled in the water will, depending on the environmental conditions prevailing at the time, quite quickly reach the shorelines in the vicinity of the spill location. On a mass-balance basis, if no response took place, then depending on the actual conditions at the time, a credible worst case oil spill will result in extensive shoreline oiling with approximately 60% – 70% of the oil affecting shorelines. As the entire region has a number of marine parks and sensitive areas, those will also be affected by any oil spill.

A key takeaway from spill modelling is further knowledge of the probable spreading of the oil over time, which indicates that early and adequate response is required in order to carry out an effective response. The spill modelling also indicates that there is need in the response planning standards to have the ability to deal with much more shoreline cleaning than what is currently required as per the existing planning standards. These items have been considered in developing plans for a spill response regime suitable to the project's needs.

13.3.3 Oil Spill Response

The regulation of marine oil spill response is primarily defined in the *Canada Shipping Act, 2001* and administered by Transport Canada. The Act defines the requirement for oil spill Response Organizations to be certified by the Minister, the requirement for all large vessels and oil handling facilities to have an arrangement with a certified Response Organization as a condition of operating in Canadian waters, and establishes planning standards that define minimum levels of capacity to be maintained by the Response Organization.

Western Canada Marine Response Corporation (WCMRC) is the Response Organization for the West Coast. Current planning standards require capacity to respond to oil spills of up to 10,000 tonnes in specified time frames

6 A Study of Fate and Behaviour of Diluted Bitumen Oils on Marine Water Dilbit experiments, Gainford, Alberta (Witt O'Briens, Polaris Applied Science and WCMRC, 2013)

7 Modelling the Fate and Behaviour of Marine Oil Spills for the Trans Mountain Expansion Project (Summary Report) (EBA, 2013)

which in some cases allow up to 72 hours plus travel time to deliver response equipment. WCMRC currently maintains capacity significantly in excess of the minimum planning standard requirements.

Relative to the existing planning standards the credible worst case oil spill volume calculated by DNV (16,500 m3 or 15,500 tonnes) suggests the need for increased spill response capacity and EBA's fate and behaviour study shows the benefit of reduced response times in the study area. Trans Mountain therefore engaged WCMRC to review this work and to describe enhancements to the existing planning standards that will better accommodate the Project.

The WCMRC study (WCMRC 2013)[8] describes an enhanced response regime that will be capable of delivering 20,000 tonnes of capacity within 36 hours with dedicated resources staged within the study area. This represents a response capacity that is double and a delivery time that is half the existing planning standards. These enhancements will reduce times for initiating a response to two hours for the harbour and six hours for the remainder of the study area and parts of the West Coast of Vancouver Island. These reduced times will be achieved by creating new base locations along the tanker route. Meeting the response capacities within the designated times requires redundancy of equipment, as a result the overall capacity of dedicated response equipment available in the area will be in excess of 30,000 tonnes. Also, based on the increased shoreline oiling identified by the spill modelling, the recommendation from WCMRC is to have the means to deal with more shoreline cleaning, i.e. increase the existing shoreline cleaning standard from 500 m/day to 3,000 m/day for this region.

The WCMRC report is available as a supplementary report supporting the Termpol 3.1 submission and was used in the spill response discussion that forms part of Termpol 3.15.

The effectiveness of the enhanced response was exercised under simulated conditions by EBA with input from WCMRC for a credible worst case oil spill event. The results of these simulations[9] are included in Termpol 3.1.

The WCMRC study serves as a practical example of how response capacity could be enhanced to accommodate the Project. Implementation of the plan will be subject to a number of factors and requires knowledge that will be gained through the outcome of the Federal and Provincial reviews of marine spill response, the NEB review of TMEP, and further consultation with Aboriginal groups and other marine communities.

While recognizing that there are alternative means to achieve similar results, Trans Mountain is supportive of the enhanced capacity and the general means of implementation described by WCMRC.

This proposal for enhanced planning standards shall be modified in order to meet any changes to regulations and standards through the ongoing Federal review process. The final oil spill contingency plan will be tested and practiced through oil spill response exercises.

Mutual Aid Agreements have been formed between WCMRC and three other organizations:

- Southeast Alaska Petroleum Response Organization (SEAPRO)
- Eastern Canada Response Corporation (ECRC)
- Marine Spill Response Corporation (MSRC)

Mutual Aid is a formal agreement among responders to lend assistance across jurisdictional boundaries when required. As a result of these agreements, organizations train and exercise together, ensure equipment is compatible, share communication frequencies as well as best management practices. In addition to WCMRC's agreements, there are Joint Marine Contingency plans that exist between Canada and the US, France and Denmark.

Based on information provided in the WCMRC report Figure 45 shows the location of spill response bases and equipment recommended to meet the proposed planning standards. Table 37 shows the distance of potential base locations to locations used in the Drift Modelling. Table 38 provides an example of how the total response capacity in the region could be distributed on a risk informed basis, subject to further development of geographic response plans.

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8 Future Oil Spill Response Approach Plan, Tran Mountain Expansion Project (WCMRC, 2013)

9 Trans Mountain Expansion Project Oil Spill Response Simulation Study, Arachne Reef & Westridge Marine Terminal (EBA, 2013)

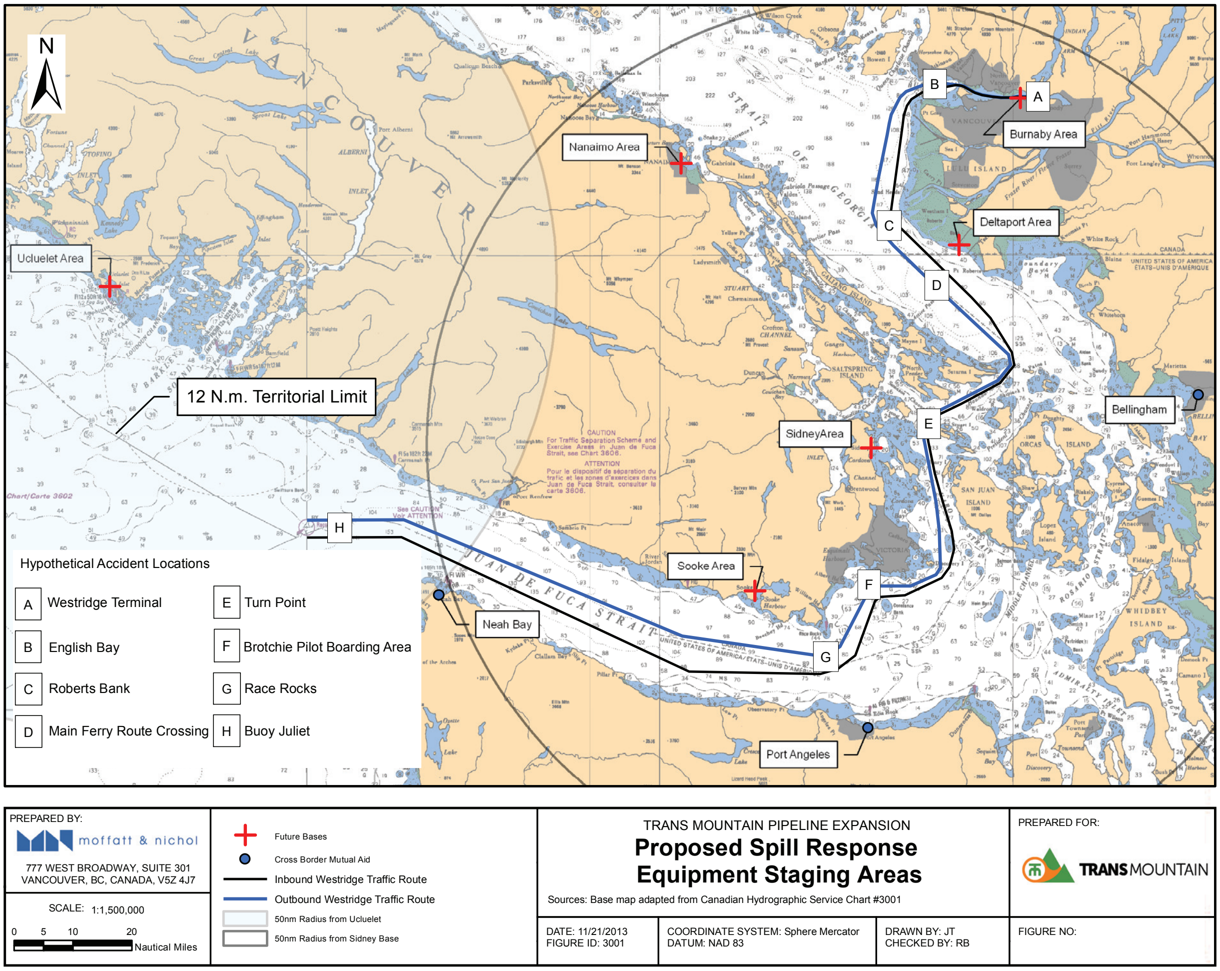

Figure 46 Existing and Proposed Spill Response Equipment Staging Areas

Table 38 – Distance by water from Proposed Response Base Areas to Accident sites (in NM)

Distance by water from Proposed Response Base Areas to Hypothetical Accident Locations (in NM)								
	Hypothetical Accident/Spill Location							
Various Response Bases	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Burnaby	2	10	25	35	50	75	80	130
Nanaimo area	40	30	25	35	45	70	75	125
Deltaport area	35	25	8	5	25	50	55	105
Sidney area	55	45	30	20	8	25	30	80
Sooke area	95	85	70	65	45	20	10	45
Ucluelet area	180	170	155	150	130	110	100	40

Table 39 – Proposed Response Base Capacity for Future Oil Spill Equipment Staging Areas

Example of Distribution of Proposed Equipment to Staging Areas	Response Capacity	
	m^3	tonnes
Burrard Inlet (Burnaby) [A]	9550	9000
Delta Port area [A]	1350	1250
South Vancouver Island (Nanaimo – Chemainus area)	2800	2650
North Saanich Peninsula (Sidney area) [A]	11900	11200
South Vancouver Island (Victoria – Sooke area)	4700	4400
Southwest coast of Vancouver Island (Port Renfrew – Ucluelet area)	1600	1500
Total Capacity at Bases	31900	30000
[A] These locations will require full-time staff, 24-hours/day, 7-days/week.		
In addition, Community response packages will be allocated (150 tonnes) × ten locations	1600	1500

14 RECOMMENDATIONS TO TERMPOL

Mitigation of risks is an essential consideration in Trans Mountain's submissions, both in terms of avoiding accidents and reducing their consequences should they occur. The existing tanker safety regime is based on local experience and international best practices. It is comprehensive, well established, and has proven to be effective.

- Tethered tugs and standby tugs to assist the tanker during berthing at the terminal.
- Oil booms deployed around the vessel during cargo transfer activities.
- Loading platform at the berths drained to sloop tanks and treated at shore.
- Emergency Release Couplers at the loading arms
- Emergency shutdown (ESD) valves at flow pipelines by the manifold at the loading platform and at landfall, all ESD can be activated from the control room.
- Overfilling detection at the tanker vessel.
- Leak detection at the pipeline
- Operational procedures to assure that all systems works adequately prior to cargo transfer.
- Operational procedure for safe cargo transfer activities both onboard the ship and at the terminal
- A Loading Master assigned to each loading tanker.
- Fire prevention and protection both onboard the vessel and at the marine terminal.
- Marine Terminal personnel who are trained for the purpose.
- Emergency Response Plans that are already developed and in place for current operations at Westridge terminal, which will be further adjusted for the increased future activities.

However, to further mitigate the effects of the existing and proposed tanker traffic that will result from the Project Trans Mountain recommends the Termpol Review Committee consider the following measures:

- Potential improvements to the Aids to Navigation system as described in Termpol 3.5 / 3.12.
- Potential extension of the zone of Pilotage (e.g. to a location west of Race Rocks) and traffic scheduling / management protocols in congested areas, Termpol 3.5/3.12.
- Additional untethered tug escort for laden tankers through Strait of Georgia and Juan de Fuca Strait as described in Termpol 3.15.
- Introduction of a laden tanker moving exclusion zone, Termpol 3.15. On October 8, 2013, Trans Mountain wrote to the Canadian Coast Guard and the United States Coast Guard, the managers of the Joint Cooperative Vessel Traffic System, requesting for such measures to be introduced for all laden tankers in the region as part of continuous improvement of waterways management practices.
- Facilitate the development of a "shipping channel" in the eastern section of PMV between Second Narrows and Port Moody, Termpol 3.5/3.12.
- Assign the area demarcated by the oil spill prevention booms surrounding the tankers loading at Westridge terminal as exclusion zones, Termpol 3.5/3.12.
- Formalize the existing practice of using tethered tugs and passing at reduced speed for large commercial vessels passing the Westridge terminal, Termpol 3.5/3.12.
- Encourage fitting and use of AIS equipment and radar reflectors by more vessels on a voluntary basis, Termpol 3.5/3.12. Today the International Convention for the Safety of Life at Sea (SOLAS) requires AIS to be fitted aboard all vessels of 300 GT or more. As AIS has been proven to be a key tool in accident avoidance a large number of smaller vessels have fitted AIS on a voluntary basis. Consider making the provision of AIS mandatory for all powered vessels exceeding 12 m length. Until such time as such mandatory regulations can be enacted, consider promoting the voluntary use of AIS on smaller vessels. Trans Mountain will assist an expedited rollout of AIS on smaller vessels by supporting fitting those small craft that enroll in WCMRC's Fishermen's Oil Spill Emergency Team (FOSET) program.

- That risk based planning standards for spill response is adopted for the Salish Sea. These planning standards should be established based on consideration of probability and consequence, with particular consideration to credible worst case spill volumes, material fate and behavior, as well as the geographic setting and sensitivities. The regime should be modified to provide a means to identify and sanction risk based response planning standards for areas requiring enhanced response. Whether through the private response organizations such as WCMRC, or through the public efforts, where new investment in response capacity is required opportunities to maximize the benefit to Aboriginal and other communities affected by the possible risks with marine traffic should be sought. Termpol 3.15 and the supporting studies provide an example of how risk based planning standards could enhance the spill response capacity and response times for the study area. Trans Mountain is willing to actively support efforts in this regard.

15 CONCLUSION

There is a long history of marine transportation of crude oil and refined petroleum products within this region. Therefore, for most parts the transport risk factors associated with the Trans Mountain Expansion Project already exist in the region. The safety regime in place today for both the existing tanker traffic and the operation of the Westridge terminal has been developed and continually improved since the terminal entered service in 1953. The regime is based on regulatory requirements, local experience and international best practices. It is comprehensive, well established, and has proven to be effective.

The sailing route from Westridge terminal to high seas outside the mouth of Juan de Fuca Strait is a relatively uncomplicated route. The most challenging part is the start of the route from the terminal through the Second and First Narrows in the Vancouver harbour area, which is a Movement Restricted Area (MRA). The transit of laden oil tankers is strictly regulated with requirement of two pilots until the Juan de Fuca Strait and use of tethered tug escort in the harbour area and through the Boundary Pass and Haro Strait. The whole sailing route has a traffic separation scheme (TSS) and is monitored and guided by the Canadian Coast Guard MCTS and U.S. Coast Guard VTS. Thus it can be concluded that the sailing route is well managed and has a high level of risk control in place.

The oil tankers that transit the terminal, now and in the future, are modern high standard double hull vessels that are operated by qualified and competent mariners. The tankers have to meet strict acceptance standards set by Trans Mountain prior to calling at the terminal. The tankers are loaded under supervision of a Trans Mountain Loading Master and checked prior to departing laden from the terminal in order to confirm that all safety conditions onboard the tanker will be met during her passage to sea.

An overview of traffic patterns and traffic details in the study area was obtained by analysing AIS data records for 2012. A growth forecast was developed and applied to the 2012 data to estimate traffic for 2018 and 2028 for use in the risk assessment. Based on this forecast, if the project proceeds, in 2018 Trans Mountain tankers will represent only 3.3% of the distance sailed by all vessels in the AIS data set for the study area.

Oil tankers that call Trans Mountain's Westridge Marine Terminal are and will be modern double hull vessels of Aframax size (80,000 - 120,000 DWT) and in the majority of these vessels the bunker oil tanks will be protected by a double hull. So only the most severe impacts from an incident like a high-energy collision or grounding is expected to cause an oil spill. ITOPF data on accidental oil spills show a clear decrease in both the number and the volume of oil spill in recent decades. The average total oil spill volume per year has decreased with a factor of 18 from the 1970s until the last decade. The number of accidental oil spills has decreased with a factor of 5 in the same period

The hazards and risks related to a sailing route are prevented and mitigated by implemented risk control measures. The study area sailing routes are well managed and important risk controls have been established for all traffic and for oil tankers in particular. These controls are in line with global best practices. These risk controls will continue to reduce the frequency of critical situations (e.g. the traffic separation scheme will reduce the frequency of encounters (the critical situation for collision)) and reduce the probability of an incident given a critical situation (e.g. pilotage will reduce the probability of collision given an encounter). The following risk reducing measures have been taken into account in the risk assessment: VTS, Traffic Separation Scheme, Pilotage, PPU, ECDIS/ENC, Tanker vetting, escort tugs (tethered and non-tethered tugs), one-way traffic. Some of the risks reducing measures are only applicable for specific vessel types and for specific areas. Compared to other traffic tankers have more risk reducing measures applied.

The assessment considers the effect on incident risk of traffic growth from Trans Mountain tanker traffic as well as from overall traffic growth in the study area (Chapter 8). The increase in traffic resulting from the Trans Mountain tanker traffic (60 to 408 tankers per year - each sailing direction) is found to have a negligible effect on the total incident frequency for in the region. With or without the Project Trans Mountain tanker traffic remains a small part of total traffic in the region.

For the purposes of the assessment the oil cargo spill risk (Chapter 11) is the combination of the oil cargo spill accident frequency (Chapter 8) and the oil cargo spill consequence (Chapter 10). Oil cargo spill accident frequency is calculated for Trans Mountain tanker traffic and for all tanker and oil barge traffic in the area. Only tankers with oil as cargo are included. For the purpose of the assessment "consequence" refers to the volume of cargo that may be released. Oil outflow in this study has been modelled for a partially laden Aframax tanker.

For in-transit Trans Mountain tanker traffic in 2018:

- If the Project was to not proceed the frequency of accidents resulting in an oil cargo spill of any size is estimated to be 1 in every 309 years. If the Project goes ahead then, if no additional risk reducing measures are implemented, the frequency will be 1 in every 46 years. If all the risk reducing measures discussed in this report are implemented the frequency will be 1 in every 237 years.

- The consequence of an oil cargo spill accident depends on the extent of the damage to the vessel's hull and the amount of oil that can spill from a vessel. The damage severity and oil outflow modelling shows that the 90th percentile worst case scenario is the loss of the entire contents of two cargo oil tanks to the sea, which gives an oil outflow of approximately 16,500 m3. Such an event is considered the credible worst case oil spill.

- Without the Project the risk of a credible worst case oil spill is estimated to be 1 in every 3093 years. Post 2018, with TMEP, if no additional risk reducing measures are implemented, the frequency will be 1 in every 456 years. If all the risk reducing measures discussed in this report are implemented the frequency will be 1 in every 2366 years.

- This means that after the Project is implemented, provided all current and future proposed risk control measures are implemented, the increased risk of a credible worst case oil spill in the study area from the Trans Mountain tanker traffic will be only 30% higher than the risk of such an occurrence if the Project did not take place.

With effective implementation of risk reducing measures most of the incremental risk resulting from the Project can be eliminated. The additional risk reducing measures identified by DNV for laden Trans Mountain tankers include; extending tug escorts to cover the entire sailing route from the terminal to the mouth of Juan de Fuca, and implementing a moving exclusion safety zone around the tankers during transit. The extended tug escort will lead to reduction in the grounding likelihood while the exclusion zone will reduce the likelihood of a collision. If implemented, these measures will further increase the safety of the already well-managed sailing route.

Oil spill risk for Westridge terminal activities was also calculated. Without the Project the frequency of a $<10m^3$ spill is estimated to be 1 every 234 years while a spill $<100\ m^3$ is estimated to be a 1 every 1,655 years event. With the Project the frequency of a $<10m^3$ spill is estimated to be 1 every 34 years while a spill $<100\ m^3$is estimated to be a 1 every 234 years occurrence. The basic frequencies of a release during cargo transfer activities are derived from European terminal accident statistics and modified to account for site specific risk reducing measures that will be implemented at the new Westridge terminal. A credible worst case oil spill during loading is calculated as 103 m^3 based upon damage to one loading arm during cargo loading at one of the berths at the future Westridge terminal. The return period of such an occurrence is calculated as a 1 in every 234 years event. The preventative booms deployed around the berths are expected to have an oil containment capacity of more than 1500 m3 oil. The return period for a 16,500 m^3 size oil spill for tankers berthed at Westridge terminal or at anchor east of the Second

Narrows is estimated as 1 in every 227,270 years if the Project did not proceed and 1 in every 50,000 years if the Project proceeds. The historical oil spill data shows that the probability for an accident with total loss of containment is so low that it does not represent a credible worst case scenario involving modern tankers of the type proposed for this project. Thus a total loss of containment is not considered as credible worst case scenario for this risk assessment nor for the oil spill response capacity assessment.

Spill response in the region is currently the subject of review by the Federal and Provincial governments. Based on information form the risk assessment enhanced planning standards for spill response describe a regime that will be able to deliver 20,000 tonnes of capacity within 36 hours from dedicated resources staged within the study area. This represents a response capacity that is double and a delivery time that is half the existing planning standards. These enhancements will reduce times for initiating a response to two hours for the harbour and six hours for the remainder of the study area and parts of the West Coast of Vancouver Island. These reduced times will be achieved by creating new base locations along the tanker route. Meeting the response capacities within the designated times requires redundancy of equipment, as a result the overall capacity of dedicated response equipment available in the area will be in excess of 30,000 tonnes. WCMRC also has mutual aid agreements in place with several oil spill response organizations in Canada and the US. The standard for cleaning of oiled shoreline is also improved significantly from 500 m/day to 3,000 m/day.

The Westridge Marine Terminal, which will be rebuilt and modernized as a part of the Project, has been in operation since 1953. The sailing route has a well-established navigational safety regime and is not heavy trafficked compared to other oil terminal sailing routes in the world and Trans Mountain plans to implement further enhancements to the already high standard risk reducing measures in place. DNV opines that **implementing extra risk controls (as is being proposed by the Project) raises the level of care and safety in the study area to well above globally accepted shipping standards.** At the same time Trans Mountain is proposing significant improvements to the oil spill response regime for the area, which will be further modified in accordance with any future Canadian Federal regulations and standards. Taking all of the above into consideration, **DNV concludes that the regional increase in oil spill risk caused by the expected increase in oil tanker traffic to Trans Mountain Westridge Marine Terminal is low, and that the region is capable of safely accommodating the additional one laden crude oil tanker per day increase that will result from the Project.**

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Appendix 1
Description of the MARCS Model

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1 INTRODUCTION: DESCRIPTION OF THE MARCS MODEL

Transportation by sea using conventional shipping operations results in both economic benefits and associated ship accident risks, which can result in safety and environmental impacts. Analysis of historical ship accident data indicates that almost all open-water shipping losses (excepting causes such as war or piracy) can be categorised into the following generic accident types:

- Ship-ship collision;
- Powered grounding (groundings which occur when the ship has the ability to navigate safely yet goes aground, such as the *Exxon Valdez*);
- Drift grounding (groundings which occur when the ship is unable to navigate safely due to mechanical failure, such as the *Braer*);
- Structural failure/ foundering whilst underway;
- Fire/ explosion whilst underway;
- Powered ship collision with fixed marine structures such as platforms or wind turbines (similar definition to powered grounding);
- Drifting ship collision with fixed marine structures such as platforms or wind turbines (similar definition to drift grounding).

These generic accident types effectively represent the results of a high level marine transportation hazard identification (HAZID) exercise and are applicable for most marine transportation systems.

Marine transport risk analysis can be performed by assessing the frequency of the above accident types, followed by an assessment of the accident consequences, typically in terms of cargo spill, lives lost or in financial terms. DNV has developed the MARCS model (Marine Accident Risk Calculation System) to perform such marine transport risk analyses in a structured manner. The risk analysis results can then be assessed to determine if the estimated risks are acceptable or if risk mitigation is justified or required (risk assessment).

2 INTRODUCTION TO MARCS

2.1 Overview

The Marine Accident Risk Calculation System (MARCS) was developed by DNV to support our marine risk management consultancy business. The MARCS model provides a general framework for the performance of marine risk calculations. A block diagram of the model is shown in Figure 2.1.

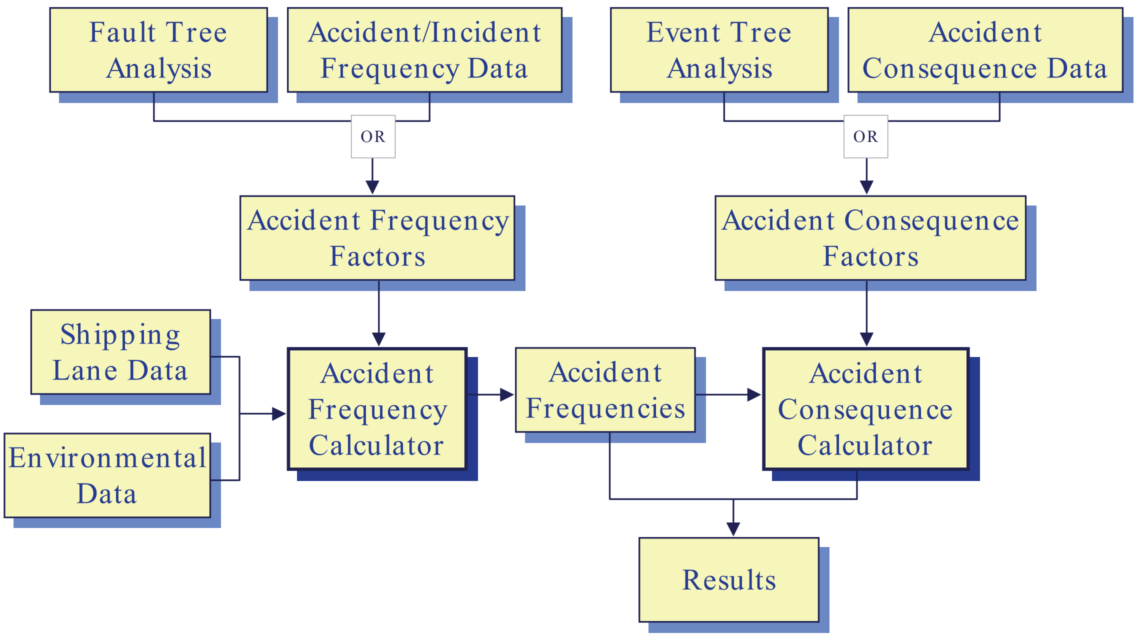


Figure 2.1 Block Diagram of MARCS

The MARCS model classifies data into 4 main types:

- Shipping lane data describes the movements of different marine traffic types within the study area;
- Environment data describes the conditions within the calculation area, including the location of geographical features (land, offshore structures etc.) and meteorological data (visibility, wind rose, water currents and seastate);
- Internal operational data describes operational procedures and equipment installed onboard ship – such data can affect both accident frequency and accident consequence factors;
- External operational data describes factors external to the ship that can affect ship safety, such as VTS (Vessel Traffic Systems), TSS (Traffic Separation Schemes), and the location and performance of emergency tugs – such data can affect both accident frequency and accident consequence factors.

As indicated in Figure 2.1, accident frequency and consequence factors can be derived in two ways. If a coarse assessment of accident risk is required, the factors may be taken from worldwide historical accident data. Alternatively, if a more detailed study is required, these factors may be derived from generic fault trees or event trees which have been modified to take account of specific local factors.

2.2 Critical Situations

MARCS calculates the accident risk in stages. It first calculates the location dependent frequency of critical situations (the number of situations which could result in an accident –"potential accidents" – at a location per year; a location is defined as a small part of the study area, typically about 1 nautical mile square, but dependent on the chosen calculation resolution). The definition of a critical situation varies with the accident mode, see Section 4. MARCS then assesses the location dependent frequency of serious accidents for each accident mode via "probability of an accident given a critical situation" parameters. A "serious accident" is defined by Lloyds as any accident where repairs must be made before the ship can continue to trade. Finally, the location dependent accident consequence, and hence risk, is assessed.

Analysis of these results for a specified area or trade enables the derivation of conclusions and recommendations on topics such as risk acceptability, risk reduction measures and cost-benefit analysis of alternative options.

2.3 Fault Tree Analysis

Fault tree analysis (see, for example, Henley E.J. and Kumamoto H., 1981 or Cooke R.M., 1995) can be described as an analytical technique, whereby an undesired state of a system is specified, and the system is then analysed in the context of its environment and operation to find all credible ways in which the undesired event can occur. This undesired state is referred to as the top event of the fault tree. It expresses the frequency or probability for the occurrence of this event or incident.

The basic events of a fault tree are those events that make up the bottom line of the fault tree structure. To perform calculations of the top frequency or probability of a fault tree, these basic events needs to be quantified.

The fault tree structure is built up by basic events, and logical combinations of these events which are expressed by AND and OR gates. The outputs of these gates are new events, which again may be combined with other events/ basic events in new gates. The logic finally results in the top event of the fault tree. For example, fire occurs if combustible material AND air/oxygen AND an ignition source is present.

The different symbols in the fault tree are defined in Figure 2.2.

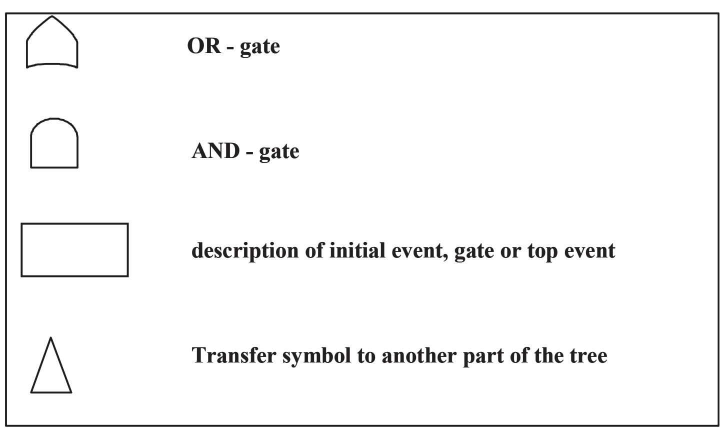


Figure 2.2 Fault tree symbols

The OR gate, see Figure 2.3, expresses the probability of occurrence of event 1 or event 2, and is calculated as the sum minus the intersection of the two events:

$$P(\text{event 1 OR event 2}) = P1 + P2 - P1*P2$$

Usually the intersection probability can be neglected, as it will be a very small number (if $P1 = P2 = 10^{-2}$, then $P1*P2 = 10^{-4}$).

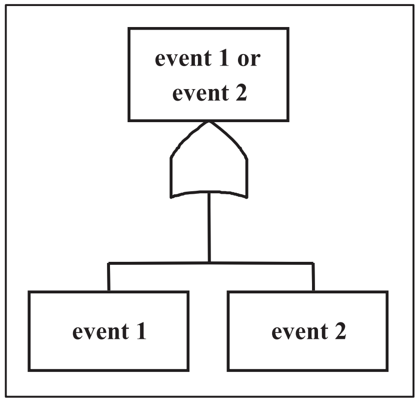


Figure 2.3 OR–Gate

The AND gate, see Figure 2.4, expresses the probability that event 1 and event 2 occur simultaneously, and is calculated as the product of the two events:

$$P(\text{event 1 AND event 2}) = P1*P2$$

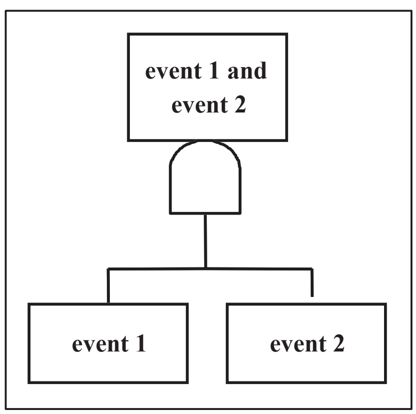


Figure 2.4 AND-Gate

It should be emphasised that the quality of the results produced by fault tree analysis is dependent on how realistically and comprehensively the fault tree model reflects the causes leading to the top event. Of course, it is never possible to fully represent reality, and therefore the models will always only represent a simplified picture of the situation of interest. The top event frequencies will generally be indicative, and hence relative trends are more secure than the absolute values.

Fault tree models have been constructed to assess a number of parameters within MARCS, including collision per encounter probabilities (collision model) and failure to avoid a powered grounding given a critical situation probabilities (powered grounding model) (SAFECO I; SAFECO II).

3 DATA USED BY MARCS

3.1 Traffic Image Data

The marine traffic image data used by MARCS is a representation of the actual flows of traffic within the calculation area. Marine traffic data is represented using lane data structures. Different traffic types are divided into separate marine databases in order to facilitate data verification and the computation of different types of risk (for example, crude oil spill risk versus human safety).

A typical traffic lane is shown in Figure 3.1. The following data items are defined for all lanes:

- The lane number (a unique identifier used as a label for the lane);
- The lane width distribution function (e.g. Gaussian or truncated Gaussian);
- The lane directionality (one-way or two-way);
- The annual frequency of ship movements along the lane;
- A list of waypoints, and an associated lane width parameter at each waypoint;
- The vessel size distribution on the lane.

Additional data may be attached to the lane, such as: the hull type distribution (single hull, double hull, etc.) for tankers; the loading type (full loading, hydrostatic loading) for tankers; ship type etc.

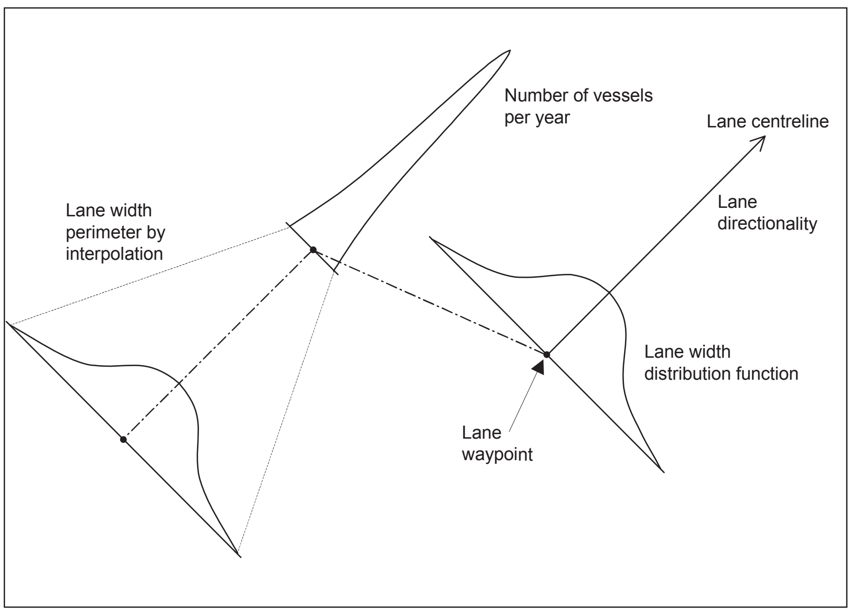


Figure 3.1 Shipping Lane representation used in MARCS

Detailed surveys of marine traffic in UK waters in the mid-1980s (e.g. HMSO, 1985) concluded that commercial shipping follows fairly well defined shipping lanes, as opposed to mainly random tracks of individual ships. Further detailed analysis of the lanes showed that the lateral distribution across the lane width was approximately Gaussian, or truncated Gaussian for traffic arriving in coastal waters from long haul voyages (e.g. from Europe or Asia). The shipping lane distributions used in MARCS are shown in Figure 3.2.

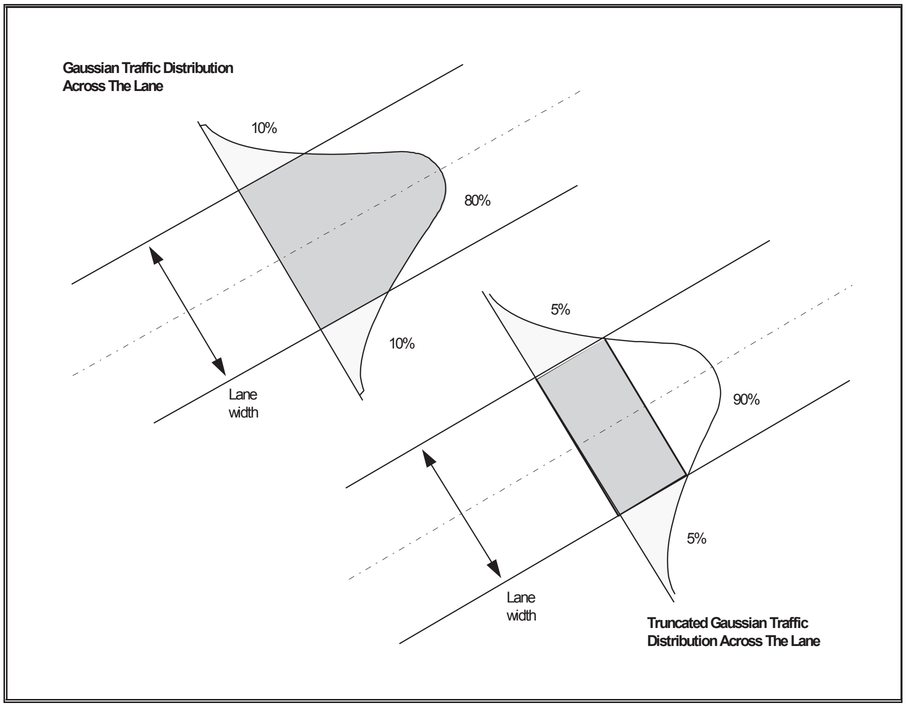


Figure 3.2 Shipping Lane Width Distribution Functions used in MARCS

The marine traffic description used by MARCS is completed by the definition of four additional parameters for each type of traffic:

1. Average vessel speed (generally 8 to 18 knots);
2. Speed fraction applied to faster and slower than average vessels (generally plus/minus 20%);
3. Fraction of vessels travelling faster and slower than the average speed (generally plus/minus 20%);
4. Fraction of vessels that exhibit "rogue" behaviour (generally set to 0%, though historical accident data in many geographical areas shows a small proportion of (usually) smaller vessels undergo accidents through lack of watch keeping (bridge personal absent or incapacitated)).

A rogue vessel is defined as one that fails to adhere (fully or partially) to the Collision Avoidance Rules (Cockcroft, 1982). Such vessels are assumed to represent an enhanced collision hazard. These four parameters can be specified as a function of location within the study area for each traffic type.

The marine traffic image is made up by the superposition of the defined traffic for each contributing traffic type.

3.2 Internal Operational Data

Internal operational data is represented within MARCS using either worldwide data or frequency factors obtained from fault tree analysis or location specific survey data. Fault tree parameters take into consideration factors such as crew watch-keeping competence and internal vigilance (where a second crew member, or a monitoring device, checks that the navigating officer is not incapacitated by, for example, a heart attack). Examples of internal operational data include:

- The probability of a collision given an encounter;
- The probability of a powered grounding given a ship's course is close to the shoreline;
- The frequency (per hour at risk) of fires or explosions.

Internal operational data may be defined for different traffic types and/ or the same traffic type on a location specific basis.

3.3 External Operational Data

External operational data generally represents controls external to the traffic image, which affect marine risk. In MARCS it relates mainly to the location of VTS zones (which influence the collision and powered grounding frequencies by external vigilance, where external vigilance means that an observer external to the ship may alert the ship to prevent an accident) and the presence and performance of emergency towing vessels (tugs) which can save a ship from drift grounding.

3.4 Environment Data

The environment data describes the location of geographical features (land, offshore structures etc.) and meteorological data (visibility, wind rose, sea currents and sea state).

Poor visibility arises when fog, snow, rain or other phenomena restricts visibility to less than 2 nautical miles. It should be noted that night-time is categorised as good visibility unless fog, for example, is present.

Wind rose data is defined within 8 compass points (north, north-east, east etc.) in 4 wind speed categories denoted: calm (0 to 20 knots, Beaufort 0 to 4); fresh (20 to 30 knots, Beaufort 5 to 6); gale (30 to 45 knots, Beaufort 7 to 9); and storm (greater than 45 knots, Beaufort 10 to 12). Seastate (wave height) within MARCS is inferred from the wind speed and the nature of the sea area (classified as sheltered, semi-sheltered or open water).

Sea currents are represented as maximum speeds in a defined direction within an area.

4 DESCRIPTION OF ACCIDENT FREQUENCY MODELS

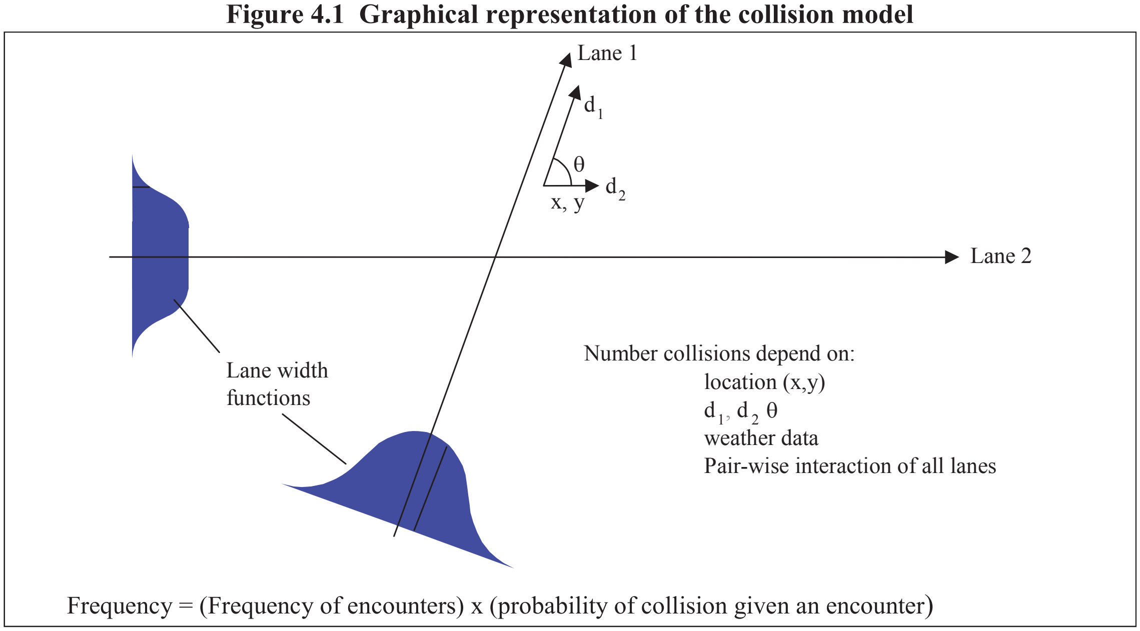
The section describes how MARCS uses the input data (traffic image, internal operational data, external operational data and environment data) to calculate the frequency of serious accidents in the study area.

4.1 The Collision Model

The collision model calculates the frequency of serious inter-ship powered collisions at a given geographical location in two stages. The model first estimates the frequency of encounters (critical situations for collision - when two vessels pass within 0.5 nautical miles of each other) from the traffic image data using a pair-wise summation technique, assuming no collision avoiding actions are taken. This enables the calculation of either total encounter frequencies, or encounter frequencies involving specific vessel types.
The model then applies a probability of a collision for each encounter, obtained from fault tree analysis, to give the collision frequency. The collision probability value depends on a number of factors including, for example, the visibility or the presence of a pilot.

Figure 4.1 shows a graphical representation of the way in which the collision model operates.

Figure 4.1 Graphical representation of the collision model



In Figure 4.1, d_1 refers to the density of traffic associated with lane 1 at the location (x, y). The frequency of encounters at location (x, y) through the interaction of lanes 1 and 2 is proportional to the product of d_1, d_2 and the relative velocity between the lane densities.

4.2 The Powered Grounding Model

The powered grounding frequency model calculates the frequency of serious powered grounding accidents in two stages. The model first calculates the frequency of critical situations (sometimes called "dangerous courses" for powered grounding accidents). Two types of critical situation are defined as illustrated in Figure 4.2. The first critical situation arises when a course change point (waypoint) is located such that failure to make the course change would result in grounding within 20 minutes navigation from the planned course change point if the course change is not made successfully. The second critical situation results when a grounding location is within 20 minutes navigation of the course centreline. In this case crew inattention combined with wind, current or other factors could result in a powered grounding.

The frequency of serious powered groundings is calculated as the frequency of critical situations multiplied by the probability of failure to avoid grounding.

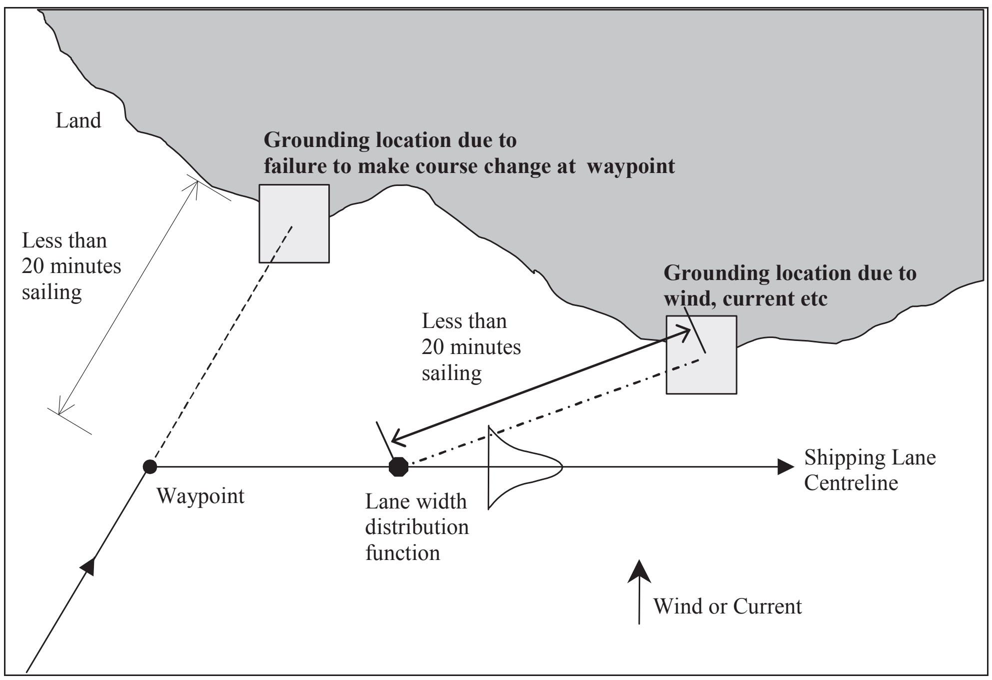


Figure 4.2 Graphical representation of the powered grounding model

The powered grounding probabilities are derived from the fault tree analysis of powered grounding. The powered grounding fault tree contains 2 main branches:

- Powered grounding through failure to make a course change whilst on a dangerous course. A dangerous course is defined as one that would ground the vessel within 20 minutes if the course change were not made.
- Powered grounding caused by crew inattention and wind or current from the side when the ship lane runs parallel to a shore within 20 minutes sailing.

Both these branches are illustrated in Figure 4.2. The powered grounding frequency model takes account of internal and external vigilance, visibility and the presence of navigational aids (radar) in deducing failure parameters.

4.3 The Drift Grounding Model

The drift grounding frequency model consists of two main elements as follows: first, the ship traffic image is combined with the ship breakdown frequency factor to generate the location and frequency of vessel breakdowns; second, the recovery of control of drifting ships can be regained by one of 3 mechanisms:

- Repair;
- Emergency tow vessel assistance;
- Anchoring.

Those drifting ships that are not saved by one of these three mechanisms (and do not drift out into the open sea) contribute to the serious drift grounding accident frequency results.

The number and size distribution of ships which start to drift is determined from the ship breakdown frequency, the annual number of transits along the lane and the size distribution of vessels using the lane. The proportion of drifting vessels which are saved (fail to ground) is determined from the vessel recovery models. The drift grounding frequency model is illustrated in Figure 4.3.

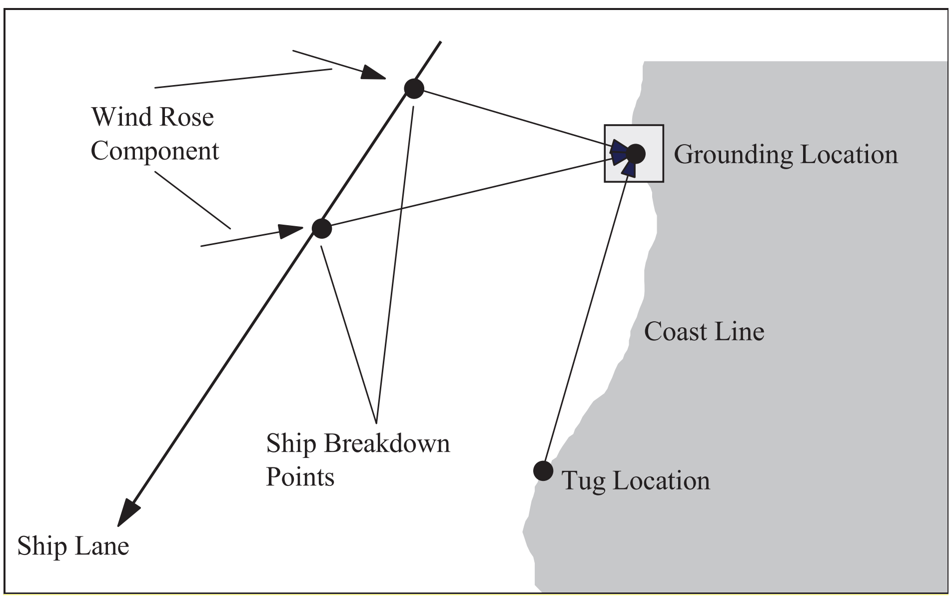


Figure 4.3 Graphical representation of the drift grounding model

Implicit in Figure 4.3 is the importance of the time taken for the ship to drift aground. When this time is large (because the distance to the shore is large and/ or because the drift velocity is small) then the probability that the ship will recover control before grounding (via repair or tug assistance) will be increased.

4.3.1 Repair Recovery Model

Vessels which start to drift may recover control by effecting repairs. For a given vessel breakdown location, grounding location and drift speed there is a characteristic drift time to the grounding point. The proportion of drifting vessels which have recovered control by self-repair is determined from this characteristic drift time and the distribution of repair times.

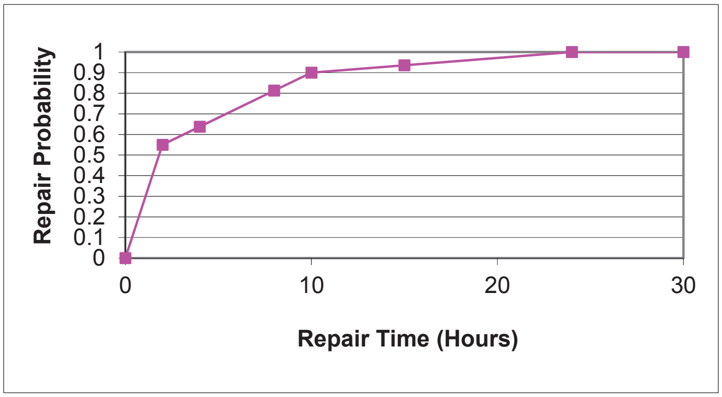


Figure 4.4 Graphical representation of the self-repair save mechanism

4.3.2 Recovery of Control by Emergency Tow

Drifting vessels may be brought under control (saved from grounding) by being taken in tow by an appropriate tug. It should be noted that the tug save model assumes a save is made when the ship is prevented from drifting further towards the shoreline by the attachment of a suitable tug. In practice, two or more tugs would be required to complete the ship save, by towing the vessel to a safe location, but this aspect of the save is not modelled in MARCS.

Two types of tug can be represented within MARCS. Close escort tugs move with ships through their transit, thus their time to reach a drifting ship is always small. Pre-positioned tugs are located at strategic points around the study area. The model works by calculating for each tug:

- If the tug can reach the drifting vessel in time to prevent it grounding. This time consists of the time to reach the ship (almost zero when close escorting) and the time to connect and take control of the ship (which is a function of seastate);
- If the tug can reach the ship before it grounds, then the adequacy of the tug with regard to control of the ship is evaluated. (The presence of several tugs of differing power is assumed to be represented by the presence of one tug of the largest power. This is because only one tug is usually used to exert the main "saving" pull. Other tugs present are used to control the heading of the disabled ship, and to bring the ship to a safe location.)
- When several tugs of various capabilities can reach the drifting ship in time, then the tug with the best performance is assumed to be connected to the ship and takes control of the largest proportion of the drifting vessels.

The tug model contains parameters to take explicit account of:

- The availability of the tug (some tugs have other duties);
- The tugs response time (delay before assistance is summoned);
- The tug speed (as a function of sea state);
- The time to connect a line and exert a controlling influence on the ship (as a function of sea state);
- The performance of the tug (identified as the maximum control tonnage for the tug) as a function of wind speed and location (since the wind speed and the fetch control sea state).

Tug performance parameters can take account of ship wind and wave resistance, tug wind and wave resistance and tug length and propulsion arrangement (open versus nozzle) which influences the propulsion efficiency.

4.3.3 Recovery of Control by Anchoring

The anchor save model is derived with reference to the following reasoning:

- Anchoring is only possible if there is a sufficient length of suitable water to prevent the ship running aground. Suitable water is defined as a depth of between 30 fathoms (about 60 m - maximum for deployment of anchor) and 10 fathoms (about 20 m - minimum for ship to avoid grounding). Sufficient length is calculated as 100m for anchor to take firm hold of the seabed + 300 m to stop ship + 300 m for length of ship + 100 m for clearance = 800 m, or 0.5 nautical miles (to be slightly conservative).
- If such a track exists, then the probability that the anchor holds is calculated as a function of the wind speed and the sea bottom type (soft sea beds consist predominantly of sands, silts and muds). If the anchor hold, then an anchor save is made.

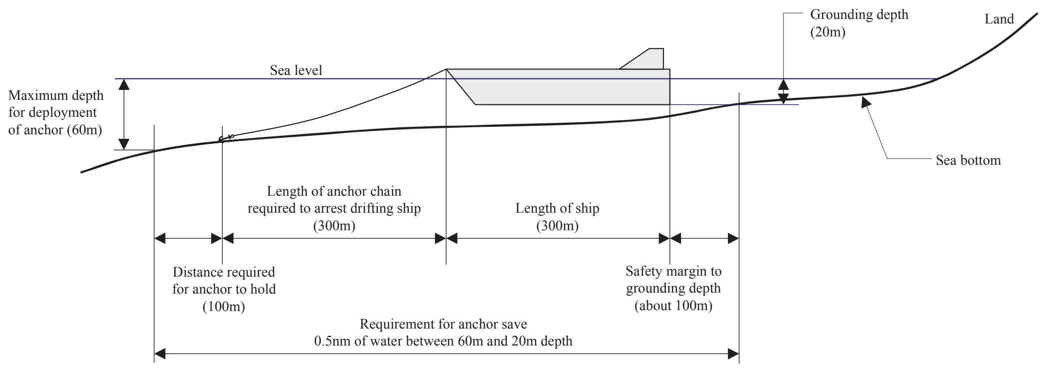


Figure 4.5 Graphical representation of the Anchor save mechanism

The anchor save model is conservative in that it under-predicts the effectiveness of this save mechanism for average and smaller ships.

For this work in the Great Barrier Reef the drift grounding model was also altered slightly in order to be able to estimate powered grounding risk without having to perform a very high resolution calculation (very small calculation locations). The alteration made was that any drift track less than 2NM in length results in zero drift grounding frequency.

4.4 The Structural Failure Model

The structural failure/foundering accident frequency model applies accident frequency parameters derived from accident data or fault tree analysis with calculations of the ship exposure time to obtain the serious accident frequency. The structural failure/foundering parameters take account of the greater structural strength of some hull designs, such as double hulled vessels.

The total ship exposure time (number of vessel hours) in any area for a given wind speed category (used by MARCS to infer the seastate) can be calculated from the traffic image parameters (locations of lanes, frequencies of movements and vessel speeds) and the local wind speed parameters. The serious structural failure/foundering frequency is then obtained by multiplying these vessel exposure times by the appropriate structural failure frequency factor for the wind speed (sea state) category.

4.5 The Fire and Explosion Model

The fire/explosion accident frequency model applies the accident frequency parameters derived from accident data or fault tree analysis with calculations of the ship exposure time to obtain the serious accident frequency. The total ship exposure time (number of vessel hours) in any area can be calculated from the traffic image parameters (locations of lanes, frequencies of movements and vessel speeds). The fire/explosion serious accident frequency is then obtained by multiplying these vessel exposure times by the appropriate fire/explosion frequency factor (accidents per ship-hour). It should be noted that fire/explosion frequency factors assumed to be independent of environmental conditions outside the ship.

5 DESCRIPTION OF ACCIDENT CONSEQUENCE MODELS

5.1 Introduction

MARCS evaluates the consequences of an accident in terms of, for example, the loss of containment of any fluid stored within a ship. This loss of containment can be in the form of either a bunker (fuel) oil spillage, a loss of liquid cargo stored in atmospheric tanks (tanks at the same pressure as the atmosphere), or a loss of gas cargo from pressurised or refrigerated tanks. It should be noted that MARCS does not calculate any consequences based upon the dispersion of fluid that might result from a loss of containment, though DNV are able to assess such consequences using other DNV tools.

Marine accident consequences are typically expressed in terms of cargo spilled, lives lost or financial loss. They are used with the frequency of a marine accident to estimate the resulting marine accident risk(s).

5.2 Factors affecting Cargo Loss Risk

There are various factors or events that can affect the probability of loss of containment following an accident ranging from those that relate to accident frequencies to those that relate to accident locations. Listed below are the factors which may be referenced by MARCS, depending on the situation, when evaluating the consequence(s) of a particular scenario.

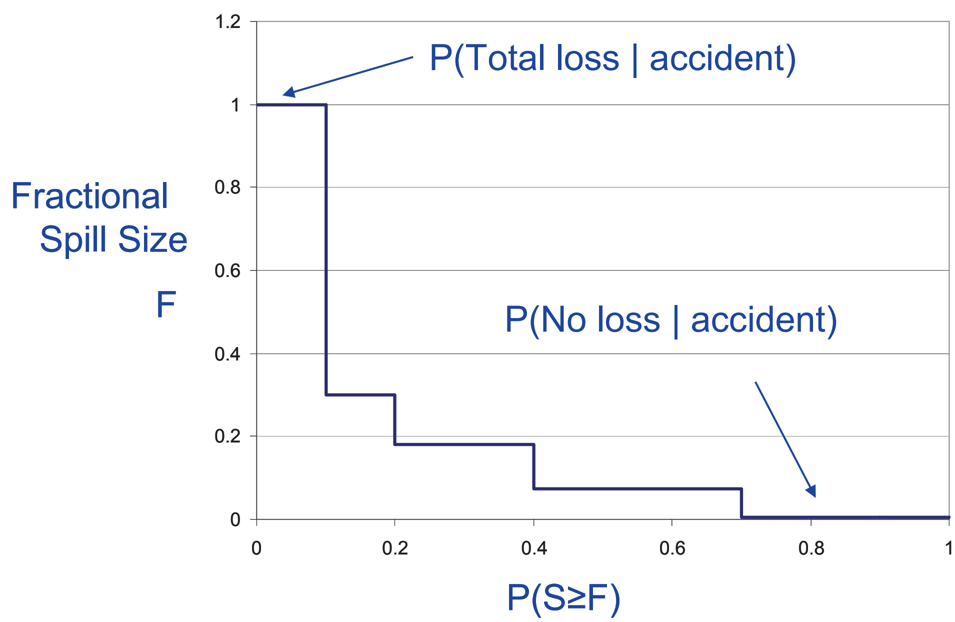
- Frequency of serious accidents. This is taken from the accident frequency models based upon historical accident data, as described in Section 4 above, and is one of the main factors that affect risk.
- The probability of loss of containment given a serious accident. This could be a function of:
  - Ship Type. A laden crude tanker has both cargo and bunker oil that could spill compared with, for example, a container ship that has only bunker oil.
  - Ship Structure. Ships may be single or double hulled, or a variation of either.
  - Probability of grounding on rocks. Grounding on rocks will increase the likelihood of a loss of containment.
  - Severity of accident. For example, an increase in the momentum of a colliding ship will increase the severity of an accident because of the resulting increase in energy that needs to be dissipated.
  - Location of accident. For example, grounding on high wave energy shorelines lead to an increased probability of ship damage and hence increased probability of loss of containment and an increased probability of total loss of the ship.
- Probability of outflow of a specific quantity given a serious accident. This is the probability that there is a spillage of certain mass following a serious accident.
- Probability of the total loss of a ship given a serious accident. This assumes a total loss of cargo, though in practice some cargo may be recovered without spillage.

5.3 Generic Spill Model

The spill models developed for use by MARCS are based upon one or more of 3 main sources of information. These are historical accident analysis, engineering calculations, and judgements based upon other sources of data. Historical accident analysis, where available, can provide information on the number of accidents per ship category and the size of spillage in each case. This is usually the most robust source of data and is often complemented by further calculations to obtain spill models. In certain cases it is necessary to make judgements where relevant data is lacking; this can be the least robust method available.

Previous projects performed by DNV have developed crude oil outflow models for different accident types (collision, fire/explosion etc.) and different hull configurations (single hull, double hull etc.). These models (normalised cumulative probability distributions) take the generic form shown in Figure 5.1. This shows a typical spill model as used by MARCS. The fractional spill size is defined as the size of the spillage divided by the total cargo capacity of the ship in DWT and the value on the x-axis is the probability that an actual spill (as a fraction of the total capacity) is greater than a certain defined fractional spill size.

Figure 5.1 Generic MARCS Spill Model



DNV has also developed bunker fuel oil spill models for all ship types, using a similar form to that shown in Figure 5.1.

5.4 MARCS Spill Model Parameters

There are various parameters that MARCS utilises to reference a particular spill model in order to correctly estimate the marine accident risks. These are listed below along with examples:

- Accident Type. For example, collision, powered grounding, etc.
- Vessel Type and Size. For example, oil tanker with a cargo capacity of 100,000 DWT.
- Accident Severity. For example, collision energy.
- Accident Location. For example, high wave energy shoreline.
- Hull Type. For example, single hull, double hull, double bottom, double side.
- Loading Type. For example, fully laden, empty (contains bunker oil only).
- Probability of vessel being laden for each cargo type. For example, a vessel might be laden 50% of the time and empty the other 50% of the time resulting in the vessel having a 0.5 probability of being laden.

These parameters are used by MARCS to calculate the risks from marine traffic accidents.

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Appendix 2
Navigational HAZID Workshop

Table of Contents

1 INTRODUCTION

1.1 Background

Trans Mountain Pipeline ULC proposes to expand the capacity of the Trans-Mountain Pipeline system. This will result in increased number of tankers calling the Westridge Marine Terminal (Westridge) to load crude oil (including diluted bitumen) cargo. The numbers of tankers are expected to increase from an average of 5 tankers per month to 34 partly loaded tankers per month of the partly loaded Aframax sized double hull tanker. The tankers will navigate Canadian and US waters on passage through Juan de Fuca Straits and the Salish Sea.

DNV has been retained by Trans Mountain to conduct a navigation risk assessment of the impact of the increased tanker traffic.

The outcome of the navigational risk assessment will provide the probability for accidental oil discharges and the potential amount of oil discharges, which in turn will provide input to oil drift modelling and to the environmental consequence and risk analysis.

2 HAZID WORKSHOP

A Hazard Identification Study (HAZID) is the process of identifying hazards in order to plan for, avoid, or mitigate their impacts. Hazard identification is an important step in risk assessment and risk management.

Therefore the Navigational HAZID workshop forms a key step and provides risk assessors important local knowledge about the sailing route, highlighting particular navigational and any operational challenges along the sailing route and approaches to the Terminal.

Berthing and unberthing manoeuvres at the Terminal were considered but not the cargo transfer operation.

Results of the Navigation HAZID helps establish relevant probability values for accidental incidents along the sailing route and at the terminal

A HAZID workshop was held in Vancouver, January 22nd, 2013 with local maritime experts to identify local hazards to the proposed routes and to assess how the hazards could influence risk.

The geographic boundary for the HAZID workshop was from 12 nautical miles offshore (Buoy J) to the existing Westridge Marine terminal through the Juan de Fuca Strait and Salish Sea. Also considered were the anchorages relevant to tankers and defining of areas where tug escort are used.

The following Incident types where considered as part of the workshop:

- Collision with Marine Terminal Jetty
- Collision. An accidental contact with or without damage between two ships whilst both are underway.
- Powered grounding. These are groundings that may occur when the ship has the ability to navigate safely yet goes aground, for example due to human error.
- Drifting grounding. These are groundings that may occur when the ship is unable to navigate safely, mostly due to mechanical failure and is forced onto the shoreline by the action of wind or waves.

2.1 HAZID participants

A group of local 43 experts (full details appendix 6.1) knowledgeable of the study area was assembled. Members of the team had experience of piloting, escorting and conning vessels to and from the Vancouver Harbour and working on marine projects in the Vancouver and BC coast areas.

3 HAZID FINDINGS

The sailing route had been predefined into sailing route segments and sailing route traffic and type information was provided for each segment. Each segment was discussed potential hazards identified noting any segment specific causes. (See appendix 6.4)

Segments

- Berth to Second Narrows Movement Restricted Area (MRA)
- Second Narrows MRA to Burrard Inlet (English Bay)
- English Bay to Strait of Georgia, Sturgeon Bank
- Strait of Georgia, Fraser River to 3 miles north of East Point
- Boundary Pass, Haro Strait to Victoria Pilot Boarding station
- Victoria Pilot Boarding station to Race Rocks
- Race Rocks, Juan de Fuca Strait to Sea

Based on the causes each segment, in terms of the perceived likelihood of a hazard leading to a grounding or collision incident was assigned a rating based on:

Much higher than average -	H-3
Higher than average -	H-2
average -	A-1
lower than average -	L-2
much lower than average -	L-3

3.1 General

The following issues were raised as part of general discussions across various segments:

- It was noted that Aframax Tankers routinely undertake the voyage to and from the Westridge berth today and many mitigations are already in place developed from experience of these voyages and lessons learnt, for instances the MRA for Second Narrows and active escorting with purpose-designed escort tugs. Pilots and Tugs had also gained experience in the handling and manoeuvring of these vessels.
- It was noted that Pilots carry Portable Pilot Units and Electronic Charts (PPU's) and as such had independent means of monitoring the vessels position and were not only reliant of the ships navigation team.
- The shipping lanes and common waterways in this area are jointly managed by the Canadian and US Coast Guards.

- International shipping requirements mandate that all ships MUST produce a passage plan from the berth to sea, such a plan should identify hazards and navigational restriction thereby ensuring the ships bridge team is fully informed before arrival or departure.
- The differences between an inbound Aframax tanker in ballast and a partially loaded Aframax tanker sailing were that for inward passage in ballast only one pilot would be used, tethered escorting tugs were not used in Haro Strait area, draft restrictions were not relevant..
- All Aframax tankers arriving at the Westridge terminal have been pre-vetted by Trans Mountain and will also have been inspected under the OCIMF - SIRE regime by Oil Majors before being chartered by them.
- Trans Mountain places a Loading Master on board the ship during the complete stay of the vessel at their facility, who would bring to the attention of the relevant authorities any concerns about the vessels condition or of crew competence before it was allowed to sail.
- It was noted that the anchorages off Roche Pt. Anchorage K, L, M & N are for four vessels and could become congested in the future with increased vessels calls. It was also noted that loaded ship could be anchored awaiting the correct circumstances to sail (tide, fog)
- Whilst the shipping tracks and densities being reviewed as part of this workshop were based on actual data it is noted that they may not necessarily reflect the impact of future increased traffic from other potential projects in the area being considered.
- Further traffic density work was requested as it was felt that traffic from the North Arm was not sufficiently shown. In addition large tows of logs might not have been necessarily captured as they might not have AIS fitted.
- Further traffic data for traffic in the area of first and second narrows was requested as it was felt the local traffic volumes were not sufficiently captured.
- The Pilotage authority performed 13,000 calls per annum in previous years and only 11,000 last year therefore an increase in traffic was considered to be within the capabilities of the organisation.
- Whilst VTS is responsible for monitoring the traffic and identifying failures to comply with requirements it has no enforcement responsibility.
- There is no formal process in place to review the capacity of VTS with increases in traffic forecast.
- The Escort Tugs operating within the Port are modern ASD state of the art Escort Tugs designed for such services and equipped with in built redundancy for critical equipment to prevent failures. The masters of the escort tugs and Pilots have been trained in escorting techniques.
- It was noted that two VTS and Pilotage Authorities were operating and controlling within the certain segments were crossing and convergence of traffic occurred. Close co-operation was essential to ensure navigational safety.
- Various segments were identified as areas where whale watching takes places, the collision effect with the vessels was considered in the segments. However, the issue of potential noise from propellers on the whales was raised and whilst little is known about the effect of shipping noise at some stage recommendation on overall traffic management, which might affect the transit could be a possibility and should be considered; this could affect the 8 hr. transit time seen at present. It was further noted that whale strikes whilst not prevalent were a possibility.
- Present safe speeds were 6 knots within MRA, outside 10-12 knots
- Various segments were also noted to have high densities of recreational craft at certain times of the day and year. Recreational craft effect on the hull of an Aframax tanker in any collision would be minimal. However the tanker might manoeuvre to avoid such boats and put itself into danger

by deviating from the approved track. Within Burrard inlet the CCG, Harbour Master, and Vancouver Police operate craft to clear the way for deep draft ships.

- It was noted that numerous ferry routes cross the traffic segments at various points. These ferries do not have pilots, but have crews with good local knowledge on-board. They are also monitored by VTS. The competence and professionalism of the bridge teams on these ferries is of paramount importance.
- The sector lights, on the first and second narrows and navigational aids are maintained by the CCG. However private lights used for navigation on the rail bridge are maintained by the rail road.
- Roles and responsibilities of PMV and CN for second narrows bridge visibility need clarification, the go no go lights from bridge operator are based on his assessment of visibility and are a potential for concern.
- Bridge should be up 30 mins prior to transit. If train on bridge then pilots able to hold vessel with available tugs, whilst awaiting clearance.
- The MRA Vessel transit safety standards (/1/) requirements can be found in detail in the attached link however the principal issue were as follows:
    - Tug escort requirements, number and size (bollard Pull) based on DWT of Tanker
    - Pilotage requirements: two pilots for loaded outbound but one pilot for inbound
    - Transit windows - daylight requirements loaded and in ballast for Aframax class. In ballast Panamax is allowed inbound at night.
    - Visibility requirements but no specific limits of wind speeds
    - Tidal requirements
    - “Clear Narrows” requirements - whilst loaded Aframax tankers are transiting the MRA all other vessels must remain clear.
- All references to vessel collision are assumed to mean with vessels underway, berthed or at anchor and applies equally for recreational craft as well as commercial shipping.

3.2 Segment 1

#	Hazard/description	Cause	Mitigation	R#	Comments
1	Collision with Marine Terminal Jetty - Berth Departure	Tug failure	Two tugs of sufficient horsepower utilised - in the event of a failure third tug standing by	L-2	
2	Collision with Marine Terminal Jetty - Berth Arrival	Tug failure	Two tugs of sufficient horsepower utilised - in the event of a failure third tug standing by	L-2	
3	Collision with Marine Terminal Jetty - Berth Departure	Human Error - Lack of Bridge team competence	2 pilots, competent and trained, unrestricted licenses , 7 years training at least, both will be senior pilots	L-2	work hours requirements for long runs
4	Grounding	Insufficient depth of water	UKC requirements 10%, freshet criteria predicted tides may not be same	A-1	Intent is to have real time AIS feed but presently not in place.
5	Grounding after dragging anchor from anchorage off berth	Lack of Crew attention or Crew incapacitated after outbreak of disease	unlikely, safe manning should allow for sufficient personnel , Shipping company and crew responsibility	A-1	Vessel can and do bunker at anchorage, as not allowed at the terminal. procedures in place for the port
6	Grounding	Failure of bollards leading to Escort Tug becoming detached	Bollard strength pre checks, The pilotage database updated so ship identified as OK,	L-2	Tugs have strain gauges, rating set to bits strength, pre arrival checks consider that vessels have bollards etc. OK for outbound transit, system in place PMV.
7	Collision at anchorage	failure of other ships to keep clear	sheltered area, well-spaced anchorages,	H-1	no defined exclusion zones - with increase in number of Tankers will present anchorage be sufficient?
8	Collision or Grounding during transit	Vessel manoeuvrability & equipment condition	Checks in place - Pilot will report things he notices including BRM to Traffic. All tankers will have been through pre-vetting requirement, and have undergone SIRE inspections etc.	L-2	Terminal has loading Master on board who will ensure meet all requirements before casting off.
9	Collision or Grounding during transit	Human Error - Lack of Bridge team competence	2 pilots, competent and trained, unrestricted, 7 years training at least, work hours requirements for long runs, both will be senior pilots. Tankers have established alcohol limits for staff.	L-2	Inebriation, alcohol limit in Canadian waters? Not under marine law but criminal law

3.3 Segment 2

#	Hazard/description	Cause	Mitigation	R#	Comments
1	Collision/grounding	Loss of Control - Seymour river outflow, Freshet	Notified by District about high flow, pilotage informed, visibility regulations PMV.	H-2	VTS is active, radar at Berry Point, redundancy built in to systems.
2	Collision with fixed object	collision with first or second narrows bridges, loss of control	2 tugs tethered off berth by pilots. Prior to MRA 3rd tug tethered by 2nd narrows, maybe 2 more if required.	H-2	41m air draft for road bridge, rail bridge when opened locked in position
3	Collision	congestion of traffic in the channel	MRA kept clear by traffic, continual monitoring, pilot makes a decision for transit (visibility etc.), no discretionary window managed by pilots and MCTS. No traffic will be allowed when tanker transiting MRA,	H-2	In or out bound traffic, off centre of the MRA in holding areas (clear narrows requirement).
4	Collision	pilot dispensation vessels not aware of MRA requirements	only smaller vessels, American tugboats, recreational craft - not considered a risk to Aframax tanker	A-1	Announcement made to restrict commercial traffic, harbour regs apply.
5	Collision with Seaplane	Seaplane operation, no communication with MCTS/ATC	Seaplanes under ATC control not considered an issue as have gained enough height by channel	A-1	Not stopped during tanker transit
6	collision with small craft	High density of fishing vessels during the season, Capilano River. High density of recreational craft in summer months in Segments 1,2,3,4,5	Loudhailer on bridge, camera keeping track, and harbour + police boat will ensure channel is clear. Mainly during cruise ship season,	H-2	CCG will go in and escort out.
7	Grounding	Insufficient water depth	10% UKC applies - Least UKC in 1st narrows, unlike anywhere else, 15m depth. At 2nd Narrows, harbour requirement to maintain water depth of 10% in excess of vessel's maximum draft across 2.85 times the vessel's beam.	A-1	Pilot checks prior to leaving berth
8	Collision with vessel at anchorage within harbour	Machinery failure	tethered escort tugs	H-2	sometimes full anchorages in harbour

3.4 Segment 3 & 4

#	Hazard/description	Cause	Mitigation	R#	Comments
1	Collision	ferry traffic, traffic in out of sand heads, congested	VTS monitoring considered adequate	A-1	
2	Grounding	Machinery failure	No formal ERV tugs but general assets in the area - tugs stationed at Roberts Bank, 30 mins current direction drive off shore - sufficient sea room	H-2	No formal response unless asked to respond but JRCC would assess whatever assets were in the area and coordinated by the JRCC - structured.
3	Collision	fishing vessels when gill net opening (august)	VTS	A-1	
4	Collision	vessels dumping in spoil ground	do not affect the pilots if vessel is dumping	A-1	
5	Collision	Ferry crossing traffic	annual meeting between pilots and BC Ferries, regular review in cooperation with BCIT, dramatic reduction in incidents	H-2	Is there knowledge experience of the ferry captains, - 4-5 ferry collisions in past
6	Collision	Crossing traffic in out of Fraser river	VTS, ships radar and Collision regulations. However It was stated by several that they considered collision with traffic in/out Fraser river as a higher risk than collision with the ferries	H-2	Surface outflow from river, nothing noticed by pilots. effect only 3-5 m depth of surface
7	Collision	Crossing traffic small tug tows north arm	VTS, ships radar and Collision regulations	A-1	
8	Collision	Log tows from Howe sound or Vancouver Island	Sufficient sea room to go around them.	A-1	Typically 400 x 70m tow but 1/4 mile / 1.8 knot long time crossing, could be challenge to pick up on the radar

3.5 Segment 5

#	Hazard/description	Cause	Mitigation	R#	Comments
1	Grounding	Escort Tug - failure or lack of availability	Tugs made fast three miles north of passage. If no tugs available transit not undertaken and ship will remain north of the strait. No formal emergency tugs available, although general assets in the area. tugs stationed at Vancouver or Roberts Bank, 3 tugs in Victoria not escort type	A-1	JRCC would assess whatever assets were in the area and coordinate. Roberts Bank to Haro Strait entrance is approximately 45 nm.
2	Grounding	proximity to land, powered grounding, engine failure	Escort tugs for boundary pass / harrow strait, (1 tug, 65 T bollard pull tug,) Passage never undertaken without Escort Tugs	A-1	Testing done both live and simulation, escort tug will be able to stop ship within 2.5 cable offset, well within the navigable area. Transit 6 Cables off shoreline
3	Collision	Vessels pass each other at Turn Point Stuart Island; vessel radar blind spots	Special Operating Area regulations in place. VTS can see special operating area. pilots communicate, self-regulated, requirement for separation not less than 1/2 cable, no ship coming up etc., south / north not allowed to meet at this point, understand that traffic is monitoring, they monitor but not enforce	H-2	This area is restricted passing. Simultaneous passing has taken place once about 4 years ago. Not practical to be reducing speed on north bound container ship, work out controlled by pilots
4	Collision	Traffic congestion	Communications between 2 VTS services, - most pilots switch between stations. Seattle / Victoria Traffic handover point, different frequency between traffics	H-2	harmonised practices, agreements in place, US traffic mainly uses Rosario straits, not expected to change to this preference
5	Grounding/collision	single Escort tug failure	Good seamanship, local anchorages close by, emergency anchorages (Plumper sound) , depending on sea room steam out	H-2	No safe or soft grounding points
6	Grounding	Inbound tankers loaded - no escort tugs required		H-2	industry study to identify mitigation + procedures to treat out and in same
7	Collision/Grounding	Issues with escort tug at the Pilot Boarding or Departing area. Bad sea states when strong winds blowing and a falling tide, making it difficult for escort tugs to operate.	Use different tugs or don't do transit.	H-2	tugs may not behave exactly, study was done under benign conditions, further work in progress, - identified issues being researched

3.6 Segment 6

#	Hazard/description	Cause	Mitigation	R#	Comments
1	Collision	Poor oversight from VTS	Harmonised practices, agreements in place, VTS monitoring adequate. Considered traffic channels wide enough plus sufficient sea room	A-1	Increase in Traffic volumes. Will VTS coverage be sufficient? More resources can be bought in on temporary basis. No special requirements for tanker traffic specifically. MCTS reviewing after traffic increase - more on a case-by case basis based on workload.
2	Grounding -	Once Pilot has departed ship at Discovery Island the Captain is reliant on his charts and normal navigation practices augmented with any local experience	Untethered escort tugs assigned (under service to the vessel) until race rocks.	A-1	Only VHF communication between tugs and ship
3	Collision	fog, reduced visibility	open area, traffic routes well defined, good confidence,	H-2	High traffic volumes in the area
4	Grounding	Engine Failure	tugs stationed at Vancouver or Westshore terminal, 3 tugs in Victoria not escort type	A-1	Concerns voiced about effect of tsunami debris etc. None reported but a possibility
5	Grounding	Engine Failure	Anchorage area at Pilot station	A-1	
6	Grounding - Human factors	crew competence	vetting processes, general experience is good, adequate standard of crew, generally reported, communication with Tanker crews good	A-1	However some comments were received about language difficulties, not specific to tankers
7	Grounding	Loss of Control due to Strong currents at race rocks up to 6 knots	Increase in speed to sea speed, less direct current effect	H-2	Master should be aware as part of the passage plan requirements; part of pilot exchange during handover of the con
8	Collision with Naval Traffic	Poor Communications	Controlled and reporting same as Merchant ships	A-1	
9	Grounding	equipment failure	All ships must undertake manoeuvring trails of main engine before entering Canadian waters		Few ship reports of breakdowns. If occurred mainly inbound.
10	Grounding/Collision	caused by confusion over instructions from two separate VTS and Pilotage authorities	harmonised practices, agreements in place	A-1	

11	Grounding/Collision	Lack of Control due to escort tugs being unable to function in heavy seas		H-2	potential for delays as tankers unable to transit

3.7 Segment 7

#	Hazard/description	Cause	Mitigation	R#	Comments
1	collision - small craft	Commercial Fishing activity at the exit of the traffic separation scheme (Buoy J)	International rules of the road for collision avoidance. Vessels showing correct lights and shapes, radar	H-2	
2	collision - large vessel	Converging traffic into traffic separation scheme - spacing of ships into this channel?	Canada MCTS Tofino controls first 10 miles to 120 40' W for approach & departure	H-2	Incident of collision in 1991
2	collision - large vessel	Large vessels not complying with separation scheme - spacing of ships into this channel?	Canada MCTS Tofino controls first 10 miles to 120 40' W for approach & departure. Seattle traffic govern 102 40'w to race rocks. Seattle traffic more directive and controls order of shipping.	A-1	Robust procedures for hand over from Tofino traffic to Seattle traffic including checking vessel has registered with new traffic service before leaving the other
3	collision - large vessel	Fog	Vessel under control of VTS. Operating in a Traffic separation scheme Radar Reduced speed	A-1	
4	Grounding	Loss of Power - equipment failure (steering gear)	Sufficient sea room, Emergency Tug (ERTV) - Contracted by Fos Marine, stationed at Neah Bay	A-1	Area with potentially strong wind and high waves
5	Grounding	Loss of Power - equipment failure (steering gear)	Constants Bank and Royal Roads emergency anchorage areas	A-1	Area with potentially strong wind and high waves

4 HAZID CONCLUSION

The Seven segments were rated overall based on route hazards and navigation complexity as follows.

- Segment 1. Lower than average due to reduced traffic in this area and tugs available
- Segment 2. Above average due to draft and tidal restriction obstructions from the first and second narrows and the high density of traffic within the harbour area.
- Segment 3/4 Average for this area - benign navigational challenges overall
- Segment 5 Above average, limited sea room navigational channel restricted
- Segment 6 Average - benign navigational challenges overall
- Segment 7 Average - benign navigational challenges overall

The Key observations from the HAZID are as follows

- Well established vessel traffic mechanisms in place with high degree of involvement of the Federal Authorities and Pilots; although it is somewhat self-regulated.
- There is no clear process in place to review/audit the overall traffic system and its capacity/resources at regular intervals.
- Close coordination required between PMV, Pilots and CN for rail bridge opening in second narrows.
- Daylight restriction for tankers at 2nd Narrows does not appear to add significant degree of additional risk mitigation.
- No escort tug redundancy in the Haro Straits.
- No established emergency tugs assist in the region, although normally there are several tugs available in the vicinity. Although there is a ETV sponsored by US station at Neah Bay
- There is a voluntary tanker exclusion zone off the west coast of Vancouver Island pertaining to north-south traffic to and from Alaska. However there is no monitoring of the area to ensure adherence.

5 REFERENCES

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/2/ Pacific Pilotage Authority - Interim Operating Rules for Loaded Crude Oil Tankers in excess of 40, 000 Dead Weight tonnage -Boundary pass & Haro strait

http://www.ppa.gc.ca/text/notice/Web_Notice_to_Industry_05-2010-e.pdf

/3/ Canadian Coastguard Marine communication and Traffic services http://www.ccg-gcc.gc.ca/eng/CCG/MCTS_General_Information

/4/ PACIFIC PILOTAGE AUTHORITY - General Information for Agents

6 APPENDIX

6.1 Workshop Participants

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6.2 Generic List of Hazards used in Navigation HAZID workshop

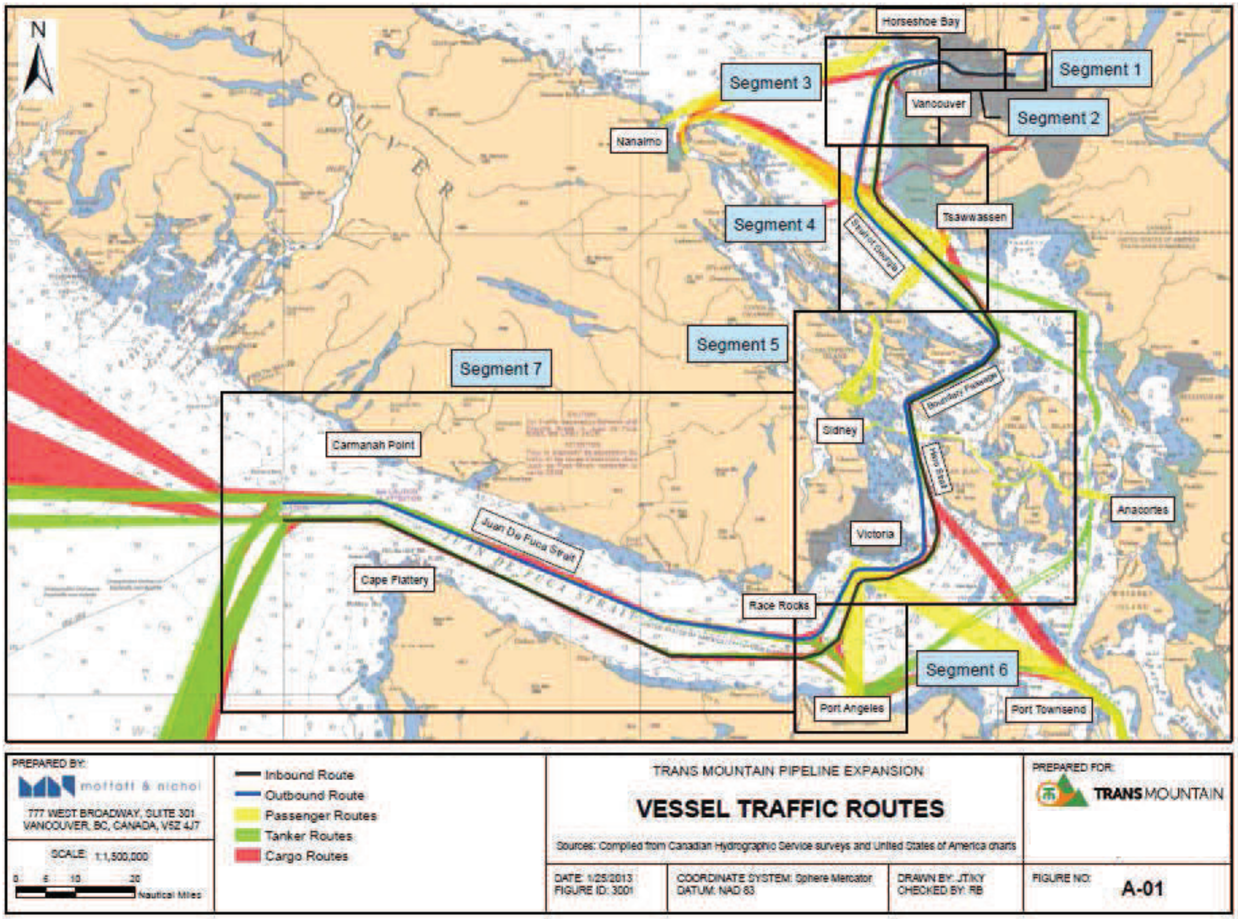
#	Hazard	Specifics	Guidance
1	Human error (ship / pilot)	Response time / sequence Action taken Information	*Focus on the operating role and navigational or cooperative errors in particular.* *Errors are generally as a result of inadequate training or poorly written instructions.*
	Human error (tug)	Response time / sequence Action taken Information	
2	Steering failure (ship)	Centred During manoeuvre	*Consider the steering angle, vessel position and speed. Consider interaction with environmental forces.*
	Steering failure (tug)	Centred During manoeuvre	
3	Propulsion failure (ship)	Steady course During manoeuvre	*Consider the steering angle, vessel position and speed. Consider interaction with environmental forces.*
	Propulsion failure (tug)	Steady course During manoeuvre	
4	Comms / Nav failure (ship)	Radio Radar	*Highly dependent on the activities being undertaken in the transit section.*
	Comms / Nav failure (tug)	Radio Radar	
5	Mech / Elec failure (ship)	Blackout Deck machinery	*Severity may vary in different transit sections*
	Mech / Elec failure (tug)	Blackout Deck machinery	
6	Environmental conditions	Wind Tide Fog Extreme events?	*Environmental forces or scenarios that could have a hazardous effect on the vessel while in transit.*
7	Shipboard emergency	Fire Explosion Redundancy / Safety fails	*Escalation of minor incidents during emergencies should also be evaluated.*
8	External influence	Other ship N.U.C. Other ship R.A.M. Other ship emergency	

6.3 Important considerations when identifying Hazard

External/physical conditions	Already established mitigation
Wind direction and strength	International rules and regulations
Wave direction and intensity	Port and Traffic rules
Current direction and intensity/ Effect of tide	Traffic monitoring
Route geometry (depth, width, turns)	Pilotage rules
Route marking (lights, marks, boys, day/night/winter/summer navigation)	Use of escort tugs
Fog/snow/reduced visibility	International rules and regulations
Accident prone areas (bends and turns)	
Power cables (subsea/air)	

Tanker characteristics	Potential Hazards
Limitations on draughts, summer/winter	Number and types of vessels in the fair ways
Air draughts (ballast)	Fixed objects
Length, turning characteristics, manoeuvrability (machinery, rudder)	Hazardous cargo
Emergency anchor	Manoeuvring areas (meeting/crossing)
Stopping distance	Human factors (competence, charts, fatigue, language, quality/availability of pilots)
Visibility from bridge	Potential grounding sites
Main/aux engine, steering machinery	

6.4 Route Segments



6.5 Route Analysis

6.5.1 Introduction

As part of the Hazid study DNV undertook a navigational route analysis on board the Panamax Motor tanker Antipolis on the 23rd February, sailing from the Trans Mountain Berth at Westridge Marine Terminal to the pilot at Brotchie Ledge Pilot Station, via segment 1 - 5 as defined in the Trans Mountain Pipeline Expansion, Vessel Traffic Routes dated 01/25/2013 (appendix 6.4).

Figure 1 - Motor Tanker Antipolis (Picture is not taken at Westridge Marine Terminal)

Vessels Details

Ship Type: Oil products tanker
Year Built: 2006
Length x Breadth: 229 m X 33 m
Gross Tonnage: 42,096 metric tons, Deadweight: 74,543 metric tons
Speed recorded (Max / Average): 13.2 / 11.7 knots
Flag: Greece [GR]
Call Sign: SWCA
IMO: 9311361, MMSI: 240516000

6.5.2 Towage

Tugs were available to unberth and guide the vessel through Second Narrows in accordance with current Port Metro Vancouver requirements as described in the table below:

Vessel Dimensions (meters)		Number of Tugs		Bollard Pull (tonnes)		
Draught	LOA / LOA+B	Bow	Stern	Bow	Stern	Total
> 12	LOA > 200 m	1	2	30	110	140
> 10 <12	LOA > 200 m	1	1 or 2	30	80	110
<10	(LOA+B) > 265 m	1	1 or 2	30	65	95
> 8 <10	LOA > 200m; (LOA+B) < 265m	1	1 or 2	30	65	95
< 8	LOA > 200m; (LOA+B) < 265m	1	1 or 2	30	50	80
> 10	LOA < 200 m	1	1 or 2	30	50	80
> 8 <10	LOA < 200 m	1	1 or 2	30	40	70
< 8	LOA < 200 m	1	1	20	30	50

Two tugs from Smit were used for the manoeuvre off the berth, as tethered escort tugs for the MRA second narrows transit through to clearing first narrows and one tug for the escort duties in Boundary Pass and Haro Strait.

Figure 2 - SMIT TIGER SUN - IMO 8953540 - 95 Tons Bollard Pull

Figure 3 - SMIT ORLEANS - IMO 9424998 - 85 Tons Bollard Pull

6.5.3 Pilotage

Two Pilots both equipped with Portable Pilotage Units (PPU) fitted with external GPS receivers and independent rate of turn indicators joined the ship at the berth for the transit to English Bay where the pilots were exchanged for two new pilots to take the ship to the Victoria pilot station.

Prior to departure the Master Pilot exchange of information was comprehensive, with the master passing all details of the vessel with regard to dimensions, draft and air draft to the pilots and confirming all equipment was in full working order. The pilots took the master through the intended passage on the bridge charts. A similar detailed exchange was observed when pilots changes at English Bay.

The Pilots confirmed with Vancouver traffic the passing time for the second narrows, which was confirmed as 1100 which meant a 1030 passing of Berry Point.

Prior to the ship leaving the berth the tug Smit Tiger Sun was made fast forward and the tug Smit Orleans made fast aft.

6.5.4 Segment 1 - From the berth to second narrows rail bridge

The anchorage K which lies to the north of the berth had a vessel anchored which lying 3.6 cables off the Antipolis; this section of water is routinely navigated by Tankers and Bulkers coming from Burrard Inlet therefore whilst at the berth ships which are of an equal size and without tethered escort tugs may pass tankers at the Terminal of a distance of less than 2 cables (400 feet).

Figure 4 - Southern Anchorage K off berth

The ship let go her mooring at 0950 and moved off the berth, at this time a transit speed of 2.6 Knots was required to make the 1100 transit of the second narrows.

Figure 5 - Clearing Westridge Berth

The passage to Berry Point was undertaken mainly with the assistance of the tugs, due to the low speed required. Regular updates were made with Vancouver Traffic and information sought on the tidal flows at Second Narrows. It should be noted that the pilots reported that the automated system giving tidal readouts to the pilots was not functioning correctly and had not done so for some time. In addition the pilots noted that automated data on outflows from the Seymour River (adjacent to the second narrows bridge) were neither available nor were they planned to be. The Seymour River outflows when heavy melt water is coming down can have a direct influence on the bow of a tanker as she approaches the second narrows.

Figure 6 - Seymour River outflow

The passage to Berry Point passes close to the anchorage N, which at this time had no ship anchored. However, with the increase in traffic for the Westridge Terminal in the future ships may be anchored which would mean passing at a distance of less than 2 cables however at the stage the tankers are tethered and can be assumed to be under full control.

During the HAZID workshop little was discussed about the potential for having ships anchored in anchorage N and K both of which are relatively close to the track from and to Westridge Marine Terminal. Also large ships passing close to the Westridge berth to the south of anchorage K and north of the berth a gap of approximately 3.5 cables, without tethered tugs and the potential for loss of control of these ships and having a collision whilst a tanker was on the berth. This should be reviewed as part of the terminal risk analysis, also taking into consideration any extension of the future berths further seaward of the current facility.

Once clear of Berry Point at approx. 1030 the speed was increased to approximately 5 knots for the second narrows transit to assist with the ships steerage and manoeuvrability. It was noted that the bridge was fully lifted and locked at least 40 minutes before second narrows transit time. During the passage routine communications were maintained by the pilots with other traffic in the area and Vancouver Traffic, to assess the optimum time for second narrows transit. At 1040 Vancouver traffic broadcast a second narrows clearing requirement for Antipolis to all ships in the harbour.

Figure 7 - Approach to Second Narrows

The approach to second narrows whilst restricted did not pose any major navigational challenges, there was no outflow from the Seymour River and the pilots with only limited assistance from the tugs maintained the ship position in the centre of the channel. It should be noted that visibility was excellent for the whole of the transit and the winds within the harbour were very low.

Clearing second narrows was recorded at 1104.

6.5.5 Segment 2 - Passage between second narrows and first narrows

Figure 8 - Segment 2 Ferry crossing

The passage through the harbour was without anything of note, the routine ferry traffic between the North and South shores did not impeded the passage of Antipolis at any time, pilots reported that they had never experienced any difficulties with the ferries. There were ship anchored to the north and south of the transit line but were well clear of the track, similarly the ships moored at the berths both north and south of the track gave little concern. Contact was maintained with Vancouver traffic and the Antipolis was kept informed of all ship movements within the harbour.

Figure 9 - Approach to First Narrows

The approach to First Narrows was straight forward and transit took place at 1145, Vancouver traffic having requested first narrows clearing for Antipolis.

6.5.6 Segment 3 - First Narrows, English Bay to Fraser River

Once clear of the First Narrows, 1120, both tugs were let go and given clearance to depart, the Smit Orleans heading for a later rendezvous for the Boundary Pass tethered escort duties. It was noted that approximately 13 ships were anchored in English Bay as well as two off point Atkinson, these would not pose a direct risk to the transit but ships manoeuvring to anchor or getting underway might create a close quarter's situation. Ships arriving northwards would be well separated by the traffic separation scheme in place form off Point Atkinson to the QB buoy.

The Antipolis was required to undertake a compass swing and moved from the normal track to manouver in the waters north of the QA buoy and south of Bowen Island, The ship spent approximately 90 minutes manoeuvring and steaming on courses covering all the magnetic cardinal and half points - basically undertaking a stages 540 degree turn. Whilst the importance of maintaining the magnetic compass is fully appreciated from a risk perspective having a laden tanker manoeuvring in such a fashion in relatively high density traffic area, where the steering gear is in constant usage and without assistance available might lead to an unnecessary close quarters situations. The compass swing was completed at approximately 1345 and Antipolis manoeuvred back to the QB buoy to exchange pilots for the passage to Victoria.

Pilots were exchanged at 1410 and the passage to outward resumed, full manoeuvring speed of 10+ knots was requested by the pilots with the proviso that immediate manoeuvring of the main engine was available. A speed of 12.6 Knots was achieved though segments 3 and 4.

The passage through segment 3 was uneventful no inward shipping was experienced nor any crossing traffic encountered. Sea room for manoeuvring was more than sufficient. Passing of the QA buoy was recorded at 1445

Figure 10 - Segment 3 Good Visibility No Traffic

6.5.7 Segment 4 - Strait of Georgia

Sand Heads Pilot Station was passed at 1543; no ships were manoeuvring in the area and the visibility of Point Roberts Container terminal was very good. One ship was passed inward bound at the stage but the passing distance was well over one mile.

The BC ferries that operate across the strait in this area were clearly visible both visually and on radar and passed well clear of Antipolis, Pilots reported that they kept well clear of traffic and the pilots had not experienced any problems with close quarters situation.

Figure 11 - Segment 4 Ferry Crossing

6.5.8 Segment 5 - Boundary Pass and Haro Straight

The rendezvous with the escort tug Smit Orleans was made 2.5 miles north of East Point at 1707. The ship's speed had been reduced to 10 Knots over the ground and the Tug made fast to a centre lead on Antipolis on a 203ton bit.

No traffic either Inbound, Outbound or crossing was experienced whilst in Boundary pass and Haro Straight. Although it was noted that the one mile clearance for Turn Point SOA was in force no traffic was in the vicinity. Pilots reported that although outward bound it was normally uneventful inward coming around Turn Point ships could be faced with high density leisure traffic in Boundary Pass.

Visual navigational marks are limited in this area but the approach to East Point was made with the aid of the pilots PPU, lights on Aldon and East Points the ships radar gave a good picture of the land formations so distances off were easily measured. The Pilot maintained a wide angle of turn off East Point as the cross currents in this area can lead to the ship being swept closer to the land.

The turn for Turn Point was given as all clear by Victoria traffic who had supplied information with regard to incoming traffic.

Figure 12 - Boundary Pass

Figure 13 - Approach to Turn Point

The passage through Boundary Pass and Haro Strait was uneventful from a navigation risk perspective, the land formations were such that the ship's position could easily be fixed and at no time did the ship get closer to the land than was prudent, and always remained within the charted channel boundaries. An engine failure or steering gear failure in this area would be well mitigated by the tethered escort tug.

The passage of Boundary pass and Haro Strait was from 1727 until clear of Discovery Island at 1945.

The approach to Victoria pilot station was uneventful, no incoming traffic manoeuvring for the pilot, the escort tug was let go before pilot leaving but was required to stay with Antipolis until Race Rocks.

DNV, together with attending TMEP personnel, left the ship with the Pilots at approximately 2020.

6.5.9 Segment 6&7

These segments were not reviewed as part of the route analysis this being completed at Brotchie Ledge Pilot Station where DNV left the ship

6.5.10 Route Analysis Summary and Observations

The onboard route analysis in most cases mirrored with what was described in the HAZID Workshop, e.g.

- The pilots PPU was fully operational, the Master Pilot exchange prior to leaving the berth fully covered the International shipping requirements for proper passage planning, the Trans Mountain loading Master on board Antipolis while she was at the terminal had evidently maintained close liaison with the ship's staff. In addition the Tugs utilised were of a modern ASD type with sufficient bollard pull and demonstrated a close liaison with the pilot and were manoeuvred in a fashion consistent with good harbour towing practices. The communications between the various pilots, VTS and tugs was clear and unambiguous; the VTS made the correct transmissions about clearing narrows and kept the pilots informed about other movements within the harbour and inward and outward traffic.
- It was also apparent, but always subject to any detailed review if considered necessary, that given the scale of control over the tanker maintained by pilots, tugs and VTS, a tanker (both empty and loaded) can navigate Port Metro Vancouver, including 2nd Narrows, during all hours of the day or night, again subject to suitable environmental conditions being available.
- When Antipolis was under her own way with no escort tugs tethered there was sufficient sea room to manoeuver should she have been required to do so.

The following items appeared to be at variance with what was described in the HAZID Workshop,

- During the workshop a lot of discussion had been held with regard to traffic density both commercial and recreational, during the route analysis there were three occasions where the Antipolis encountered crossing traffic, all ferries and none of which required the ship to alter her course. Despite being very good weather conditions and a weekend no more than about ten leisure craft were observed for the whole transit and these remained at considerable distance. Inward traffic to the port was two ships and outward one.
- Also, during the workshop, some discussion had taken place about ready availability of tugs to be called upon in case of a vessel emergency. This was not readily apparent based upon the traffic encountered during this passage.

The following are additional observations or specific items from the onboard route analysis.

- It was felt by the DNV representative that the practice of having loaded tankers manoeuver off the port to complete a compass swing was a risk that should be considered unnecessary and system put in place to ensure that departing loaded tankers were not required to undertake a compass swing.
- When approaching Turn Point, the possibility of smaller vessels without AIS not being visible by sight or radar was acknowledged by the Bridge Team and pilots. An expanded shore radar network interacting with MCTS/VTS has been utilized in other nautical jurisdictions to address this type of situation. The author acknowledges that he does not have knowledge himself on the extent of local radar coverage available.
- Also when approaching Turn Point, from conversations with pilots, it was not clear as to whether there were any special passing instructions provided by MCTS/VTS when a tanker was approaching Stuart Island.
- An overall port/terminal tanker movement plan taking into account the increase in post-expansion tanker traffic would improve efficiency of tanker movements.

Also following the onboard route analysis and witnessing current tug escort and towing practices involving a loaded tanker departing Westridge Marine Terminal for sea, it was felt that the practices may be further tailored to suit specific time and location requirements, e.g.

- Providing pilots the option of asking for an additional bow tug, especially during times of the year when possibility of Seymour River freshets exist.
- A recommendation that post-expansion, all vessel movements (tankers and other vessels) east of 2nd Narrow, take place with tug attendance. This would address the very low probability of interaction between passing vessels and vessels at anchor at designated anchorages east of 2nd Narrows or berthed in the future Westridge Marine Terminal.
- Untethered tug escort during passage from English Bay to Saturna Island, especially during periods of reduced visibility, and times during the year when the Fraser River freshets occur.
- Extending a single tug escort (untethered) seaward from Race Rocks for a further distance, to be determined. This would address the very low probability of interaction between an outward bound loaded tanker and traffic joining from the US.

Appendix 3: HAZID for Westridge Terminal Expansion

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CONCLUSIVE SUMMARY

DNV has been engaged by Trans Mountain Pipeline ULC to conduct a quantitative risk analysis of the impact of both increased tanker traffic and increased terminal operations related to the proposed expansion of the Trans-Mountain Pipeline system. As a part of DNV's engagement a hazard and hazardous event identification for the Westridge Marine Oil Terminal was conducted. The HAZID was performed on the 29th of April in Vancouver, Canada.

The objective of the HAZID session was to identify and gain awareness of the hazard scenarios associated with the operation of Westridge Marine Oil Terminal. The focus was on hazardous events that can cause oil spill to the environment, and the mitigating safeguards that can reduce the probability and the consequences of an oil spill.

The marine terminal HAZID workshop forms a *key* step in the risk assessment and provides risk assessors important local knowledge about the marine terminal highlights particular operational challenges for the terminal and highlights potential accidental events related to the terminal.

1 INTRODUCTION

1.1 Scope

DNV has been engaged by Trans Mountain ULC to conduct a quantitative risk analysis of the impact of both increased tanker traffic and increased terminal operations related to the proposed expansion of the Trans-Mountain Pipeline system. As a part of DNV's engagement a hazard and hazardous event identification for the Westridge Marine Oil Terminal was conducted.

1.2 Objective

The objective of the HAZID session was to identify and gain awareness of the hazard scenarios associated with the operation of Westridge Marine Oil Terminal. The focus was on hazardous events that can cause oil spill to the environment.

The marine terminal HAZID workshop forms a *key* step in the risk assessment and shall provide risk assessors important local knowledge about the marine terminal, highlight particular operational challenges for the terminal and highlight potential accidental events related to the terminal.

The outcome of the marine terminal risk assessment shall provide probability for accidental oil discharges and potential amount of oil discharges. The risk assessment will provide input to oil drift modelling and to environmental consequences and risk analysis.

This report is limited to the description and documentation of the HAZID workshop with focus on hazardous events that can cause oil spill to the environment.

1.3 Background and basis documentation

The following documentation formed the basis for the HAZID:

/1/ PHA Study – Central Control Operation Project, Burnaby/Westridge

/2/ TRANS MOUNTAIN Expansion Project Westridge Berth Concept Study 7773-03, rev.B

/3/ Presentation given by Trans Mountain Expansion Project during the HAZID session.

/4/ Preliminary dock complex design consists of two (2) Aframax berths and one (1) Panamax berth, this is currently under review.

1.4 HAZID team

The composition of the HAZID workshop is reflected in key personnel that attended the workshop. The participants of the HAZID study are listed in Table 2.

Table 1 - HAZID participants

Contact	Company
Chris Doudican	Aquaguard
Harry King	Ausenco
Shaolin Tsui	Ausenco
Tony Steele	BC Coast Pilots
Daniel Ried	Canadian Coast Guard
Jamie Toxopeus	Canadian Coast Guard
Martin Jenner	Canadian Coast Guard
John Abbot	CH2MHill
Stephen Brown	COSBC
Mark Homeyer	Crowley Petroleum
Ole Øystein Aspholm	DNV
Sunil Kale	DNV
Arnt-Ove Blytt-Tøsdal Kolås	DNV
Albert Drinovz	Fire Department, City of Vancouver
Richard Johnson	Fire Department, City of Vancouver
Daniel Reid	Fisheries and Oceans Canada
Christine Mcfarland	Intrinsik HRA Lead
John Staynor	Island Tug and Barge Ltd.
Bruce Jamer	KMC
Captain Robert Scott	KMC
Lee Glenn	KMC
Jay Boyce	KMC - Van Wharf
Ralph Drew	Mayor of Belcarra
Ron Byres	Moffat Nichol Engineering
James Traber	Moffat Nichol Engineering
Captain John Swamm	Moffatt Nichol Engineering
Aaron Wilson	Musqueam Indian Band
Leona M Sparrow, Director	Musqueam Indian Band
Norm Webster	Police Deptment, City of Vancouver
Neil Gillespie	Police Deptment, City of Vancouver
Andrea Heba	Port Metro Vancouver
Dave Hart	Port Metro Vancouver
Gary Sergy	S3 Environmental
Terry Antoniuk	Salmo Consulting Inc/ TERA Env
Dick Lauer	Sause Bros. Inc.

Contact	Company
Colin Eckford	Seaspan
Rob Armstrong	SeaSpan
Frank Skinner	Shell
John Armstrong	SMIT Marine
John Henderson	Stantec HRA Lead
Stefan Dick	Stantec Marine Lead
April Maestras	Suncor
Greg Bryant	TERA Facilities Lead
Bikramjit Kanjilal	TMEP
Chris Badger	TMEP
Chris Tupper	TMEP
Lizette Parson Bell	TMEP
Dean Monterey	TMEP
Margaret Mears	TMEP
Michael Davies	TMEP
Stephanie Snider	TMEP
Max Knock	TMEP
Lexa Hobenshield	TMEP/ KMC
Trevor Davis	WCMRC
Marc Fellis	Westward Shipping

2 HAZID PHASES

The HAZID review was split into the following nodes:

1. Berthing operations
2. Cargo transfer - Jetty & Vessel
3. Upland Components (Pipes from Burnaby terminal to trestle/jetty)
4. Leaving berth operations
5. Others – Process loss and delays

3 METHOD

A HAZID study is a systematic approach used to identity hazards associated with a facility or an activity.

A short introduction to the HAZID methodology was given at the start of the HAZID session. By use of guide words, and the HAZID participants' knowledge and experience of the system under review, the facilitator and scribe guided the discussion.

Each HAZID phase as described in Chapter 2 was discussed and reported with regard to the following:

- Potential hazardous events relevant for the installation activity
- Causes for the incident
- Existing risk reducing measures

3.1 HAZID guide words

Guide words were used in a general manner throughout the HAZID in order to identify potential hazards. The list of guide words used for the various activities is shown below:

Table 2 – Guide words

Guide words	Guide words
▪ Striking the jetty ▪ Striking tanker at berth ▪ Rupture/leakage in a flange or valve ▪ Corrosion ▪ Human error in loading operation ▪ Overfilling tank ▪ Loading wrong tank ▪ Error in loading arm draining operation ▪ Leak detection	▪ Utility failure ▪ Extreme metocean ▪ Slope tank draining ▪ Loss of stability ▪ Loss of mooring ▪ Structural failure ▪ Mechanical failure ▪ Fire or Explosion ▪ External threats

The HAZID discussion was not constrained to the above mentioned guidewords or HAZID phases.

4 REPORTING

The main findings from the HAZID discussions are reported in the work sheets as presented in the HAZID log given in Appendix 1 to this report. Relevant deviations and potential hazards, including causes and consequences are reported together with comments.

APPENDIX
1
HAZID LOG

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Node	Hazardous event	Cause	Mitigation	Comments
Node 1. Berthing operations				
1.1	Striking the jetty during berthing			
1.1.1		Loss of power on one tug. Loss of communication with tugs.	There will be two tugs leading vessel into berth. A third tug is also present to run a line if needed. A back up communication plan between pilots and Tugs is required	C1: Tug utilization plan to be confirmed during simulation and vessel trials with new dock design
1.1.2		Currents, weather, visibility outflow winds up to 30kts can be experienced	24-48 hrs weather forecasts are used during moorage planning including number of lines to be used. Tide and Current issues will be minimized by aligning berths in an east/west direction. Maximum wind criteria for operations will be established.	C2: Additional wind and current monitoring are planned for the area? TMP expects there will be an anemometer located at the facility.
1.1.3		Line parting, SWL of bits and fairleads	A copy of the mooring and escort plan is provided to the tugs. Minimum bollard pull requirements for tugs set by port authority minimum SWL of vessels Bitts confirmed in mooring plan and inspected by berthing master.	C3: SWL of bits and fairleads has been in question. Towline could part, but very low possibility. More than one tug tethered to vessel.
1.1.4		Insuffisient mooring plan/training	There are ongoing standardized training for pilots, tug crews and dock crews.	C4: Generally standard mooring plan, but some vessels are different.
1.1.5		Unfamiliarity of new berths that will protrude further into the navigable channel	simulator and live trial training for pilot, and tug crews	C5: Berthing method and orientation is still uncertain. This should be simulated and lot of it is still work in progress. Berthing method to be confirmed once berth orientation is established
1.1.6		Ships engines stopping, fuel change over HO-DO, air starting systems, after long voyages.	There will be appropriate tug package to deal with vessel main engine failure.	

Node	Hazardous event	Cause	Mitigation	Comments
1.2	Striking the jetty with a tug	Tugs losing power	There will be tugs equipped with twin power packs. Tug package to allow for redundancy	C6: Will a black out cause complete failure of propulsion for a tug? Do tugs have emergency preparedness training and has a risk assessment been carried out to confirm the failure modes. Will there be redundancy requirements for tugs? C7: Evaluate if this needs to be captured in a best practice.
1.3	Striking the vessel with a tug		Tugs are small and do not have the potential to penetrate the double hull. They have low speed / low energy and are well operated and well fendered.	
1.4	Striking the jetty with passing traffic	New berths will protrude further into the navigable channel and be closer to passing traffic	slow bell and tug escort requirements will be reviewed by pilots and port authority	C8: How far out does the trestle go? Does it extend into the shipping lane heading to the PCL etc? Kilo (K) anchorage has been moved out due to lack of room for vessels to move. Maybe the additional anchorages will not be needed. This will depend upon the Utilization of anchorages. These will become a residing area for vessels waiting to berth / load. Ausenco study is looking into this.
1.4.1				
Node 2. Cargo transfer - Jetty & Vessel				
2.1	Oil spill to inlet	See sub nodes below	Booms provided around the vessel and jetty. Prior to all loading ops except gasoline. Centralized control of monitoring and shut down systems, (expected), < 1 min to initiate shut down, 2-3 mins to shut flow. Check valves in lines.	C9: Check valves would be included with the flow control and isolation valves, and could be located as close as practical to the loading arms. The check valve locations would be finalized during detailed engineering design.

Node	Hazardous event	Cause	Mitigation	Comments
2.2	Striking vessel at berth	Other vessels transiting the area or proceeding to anchorages	There is established practice of communication with VTS / MCTS – based on any conditions laid on vessel. VTS will provide pilots with traffic situational awareness and information. However there is no control over / of vessels under 20 m - these include recreational crafts. There should be communication and discussions with the terminals to the east and west of TMPL for maintaining traffic and consistent control procedures. (terminals are generally not involved in traffic control procedures, however an understanding of potential traffic increases to other terminals should be undertaken) Control of speed of passing vessels to other berths and the need for slow bells to be reviewed by pilots and port authority harbor tugs can respond within 20-40 minutes.	C10: Tugs may not remain with the vessel while she transits. Currently there is no requirement for tugs to be present for all deep draft vessels transiting the Westridge terminal. Tug and barges transiting will be without pilots onboard. Currently there are no operational requirements that mandate a pilot or tug escort. Under correct circumstances a barge could have enough energy to penetrate the double hull. Speed restrictions could mitigate this aspect. Recreational boating traffic – control of such vessels is difficult. Bulk carriers and other ships passing by the terminal have single screw without tugs. These are more likely failure mode.
2.3	Striking jetty during loading operations	Other vessels transiting the area or proceeding to anchorages	Terminal emergency plan to be exercised	C11: Are there any procedures at the terminal should such an event occur, has a risk assessment been carried out or will this be incorporated into an emergency preparedness plan and will be exercised?
2.4	Break in flange, break in valve at jetty	Human error on loading Accident due to vehicular traffic on trestle	Types of valves, Process piping etc not yet designed. Typically there would be valves close to the manifolds. The following are in place wrt break in flange or valve: • Integrity management programs, • Periodical Inspections (incl. valves), • Stable temperatures therefore no chances of thermal cracks, It is not clear whether the good practices are incorporated into best practices and documented procedures.	C12: Although there is a minimal risk of vehicular accident- traffic barriers, are speed limitations, reflected in procedures. C13: Automatic leak detection: There is a leak detection system between Burnaby tank farm and the terminal. It may be beneficial to continue this up to very close to the loading arms.
2.4.1		Thermal expansion	PSVs on the docklines.	
2.5	Leak at ship's manifold during startup.	Open drain, leakage between vessel and loading arm (poor connection)	The leak will be collected in drip pan. Initial startup rate is low in order to verify that all the lines are secured and properly lined up and that the loading arm connection is secure. People on dock inspecting the transfer at first start up.	

Node	Hazardous event	Cause	Mitigation	Comments
2.6	Error in loading arm - break of loading hose/arm	Strain on the loading arm due to high wind speed or vessel surging on dock	The wind speed is monitored. A high wind speed will result in a shutdown. There are loading arm movement alarms and vibration monitoring alarm on the dock. Slow bell for passing vessels to be reviewed	C14: Wind speed can be checked in control room. Possible procedural requirements could be (winds) 30 kts stop, 40 kts consult / consider calling tugs etc, 45 kts depart jetty. High vibration loading arm procedures? What are the acceptable loading arm tolerances?
2.7	Break in connection between vessel and loading arm	Is time an issue when draining? Is it possible a vessel departs berth in a hurry and accident happens due to loading arm being full or not properly disconnected? Wash from tugs operating panamax berth when there is an aframax tanker at the west berth?	Containment area under loading arm. Vessel's scuppers are plugged prior to oil transfer operations	C15: Current procedure for load arm draining is as follows: • drain down. • Induce air , • check vent etc before disconnection. The Capt of the vessel is always in charge during this operation. Loading master is the advisor for the specific terminal. Master decides when the vessel is ready for departure.
2.8	Leakage in swivel joint at the loading arm	Dripping and leaking does occur	Increasing rates usually solves the problem of gland leakages and valve dripping. People on dock inspecting the transfer at first start up Personnel are present 24hrs at the manifold including during night time periods to monitor leaks, there is adequate lighting. Operators for the terminal – At present there are 2 persons on watch. The best would be to have continuous manning and a standby arrangement. Change management process to consider for changes in Westridge – training, manning, instrumentation, monitoring.	C16: Future staffing has not been considered. There are 4 Loading masters at west ridge. These are all Master Mariners, tanker men doing a 12-on / 12-off routine. Overflows are the main cause of typical outflows. Only about 9 % due to break in flange or the manifold (John Swann).
2.9	Loss of mooring - breakway from berth	Interaction from passing vessels or excessive wind speeds	Transiting procedures to be reviewed by pilots and port authority. mooring plan to allow for high winds	

Node	Hazardous event	Cause	Mitigation	Comments
2.10	Loading wrong tank	Failure of communication	Communications between ship shore as follows: • Formal check list form exchanged every 4 hrs, • VHF communications, • 3 –radios provided – 1 each to loading master / chief mate / dock person.	
2.11	Overfilling tank on vessel		Multiple means to confirm levels (batch meter, etc), 98% filling usually mandated. The pumps can be stopped and the remaining inventory can be slowly filled.	C17: West ridge prefer full or empty tanks on the ship and this is normally the case at present. Procedures
2.11.1		Loading too fast	Apparently there is no chance of this at present loading rates. In future could be. Alarm for over pressure is set at 1 psi (Vapor line?) – Shut down would operate at 2 psi - it would help to define max. Loading rates and set alarms and shut down protocols accordingly.	
2.12	Leakage in dock vault	Overfilling of vault while it is full	Vault is emptied prior to loading. Rain water is removed. Spills are cleaned and not washed down in vault.	C18: Is there any high level monitoring on the vault? Redundancy?
2.12.1		Damage to dock vault e.g. due to vessel that collides with dock.	Design	
2.13	Error in loading arm venting operation	Human error	Dock operator procedures, training.	
2.14	Error in draining operation - vessel		Spill trays would take care of that. There is a 14" spill bar which should hold about 100 barrels of oil? The loading arm can be drained to vacuum truck, even when not connected to vessel. Could not be done if there is bad weather, but will be done prior loading. The presentation flange is required to be within the spill tray.	C19 This has happened. However' the draining of these by mistake into water has not happened.
2.15	Error in draining operation - vacuum truck	Vacuum truck overfilling	Procedures, training of operators/drivers, vacuum truck safety check list.	
2.15.1		Vacuum truck collides with objects on dock.	Procedures, training of operators/drivers.	C20: Verify that the dock is designed for vehicle traffic. Evaluate if vacuum truck procedures should include vacuum truck accidents. Can a vacuum truck accident result in a marine oil spill? Related to Node 2.4.

Node	Hazardous event	Cause	Mitigation	Comments
2.16	Fire/explosion in vessel	Smoking on vessel	Fire suppression systems, G58. Smoking regulations enforced onboard vessels	
2.17	Fire/explosion at land that can impact cargo transfer components and vessel	Fire/explosion	Firefighting systems to be incorporated in terminal design. It is assumed that fire water for the dock will be obtained from the Burrard Inlet. The City of Burnaby municipal supply may not be capable of providing the required volume and flow rate. This will need to be evaluated during detailed engineering design. A fire foam system is also included in the current scope for the dock. Fire water will probably be sea water. Today it is fresh water from municipal supply.	C21: Internationally the use of fire wires is being questioned If the fire is deemed dangerous and out of control – identified procedures, laid down in emergency procedures for the dock should define what next steps should be. The terminal to decide through risk analysis if necessary. It is acknowledged that this is a way to connect with the vessel if there is no crew onboard. OCIMF wants to do away with it. There is a question regarding its usefulness – eg., • can tugs get close enough, • is length of line effective etc. Likely to be removed from ISGOTT in future– even though the current edition still retains this requirement.
2.17.1				C22 Considerations: • Where will tugs come from? • How many relevant tugs will be available and free? • Are there Quick release hooks, line loads in control room, and means to monitor these? If considered unsafe could additional mooring + tugs be considered / ordered. Calling in larger tugs may need railway bridge to be lifted (2nd narrows).

Node	Hazardous event	Cause	Mitigation	Comments
2.17.2			By SOLAS compliance, ships self-sufficient for their FiFi. Port and terminal emergency plans to address shipboard fires. Plans to be exercised Tugs will have FiFi. Requirements and positioning not defined yet. Right now only newer tugs have FiFi (Seaspan) FiFi1- Class Notation = 2400 CUM of water/hr . There are 5 in the harbor – may not be readily available if tasked elsewhere or unable to cross bridge or not on standby. Specific requirements to have them available is being discussed with stakeholders (Fire departments + PMV + COSBC) convening the "the tanker panel". Some operational models have been explored but not resolved. There is confidence that something will be decided that is practical and serve to raise the level of comfort. The idea of getting in a 'Red Adair' kind of emergency response team from elsewhere is also being explored as is the thought of maintaining dedicated equipment on or off site The Harbour has 3 FiFi boats in service – their future is political. However these are small vessels and it is not sure how effective these would be in case of the fire. How many will be actually available or planned to keep stand by during terminal operations is also not clear. Deficit in training, from shore 13 epts. Has been suggested (VFD).generally these are comments not specific mitigation	C23: Existing jet fuel system – this project does envisage changes to those units. The product is Jet-B which is low volatile
2.17.3		Lightning strikes	Protection by way of lightning conductors which are built in.	C24: Lightning procedures?
2.18	Hazards due to extreme metocean events - eg, Tsunami not sure what this means are we talking storm surges?	tsunami	Containment systems do not work very good during wave action causing slop over. Ship traffic movement to be considered - thought to be given to the design of the boom - typically ¾ kts design. Not very effective when waves etc. (this is a comment not mitigation) Berth designed for extreme tidal range.	

Node	Hazardous event	Cause	Mitigation	Comments
2.19	Bunkering operation at the terminal	bunker spill causes shut down of terminal	COSBC has done a risk assessment for bunkering in inner harbor. PMV has no restrictions for bunkering along side. TM should consider a risk assessment for bunkering tankers at the terminal jetty. This does not reflect hazard being considered Safe bunkering procedures and emergency planning procedures to be implemented	C25: Currently no bunkering operations are taking place at at Westridge. However they may happen in future and most probably will be required for faster turn around of vessels. Due to demand on anchorages and vessel time at berth it would be prudent to consider bunkering alongside. This is usually a separate activity to the cargo loading and thought to be given whether this is kept separate and mandated by port and/or terminal procedures. Bunkering operation + barge coming along side is then a possibility. The Port should consider procedural steps – or prohibit bunkering. Operating procedures will be required if this activity is implemented.
2.20	Loss of stability during loading or debalasting		Loading plan to be confirmed between vessel crew and shore crew. Loading master to confirm bending moments and GM during loading operation	
2.21	Terrorist Attack at terminal from external threat	External threats and sabotage. External issue. ISPS compliance. Attack from water side.	Terminal to maintain PFSP compliance and to exercise plan	C26: Should be considered in terminal security (PFSP – Port Facility Security Plan). C27: Any notifying procedure if other vessels come within a security / safety cordon? At present this is not enforceable – It is of concern and there is room for improvement.

Node	Hazardous event	Cause	Mitigation	Comments
Node 3. Upland Components (Pipes from tankfarm to trestle/jetty)				
3.1	Leak in pipe/flange		Pipelines set up: 24" dia existing piping + 2x 30". These are built to code CSA 662– which is also adopted / accepted by NEB. These are laid few feet underground. Integrity checks in place will include – • construction phase, mill certs for piping materials, joining procedures and monitoring controls, coating requirements (corrosivity), cathodic protection etc. • Scraper pigs will be used for cleaning. • Equipment available to check pits and pitting. • Repair means will be in place. • Geo-hazards program to monitor the pipeline. • Also a 3rd party damage prevention program – i.e., to prevent un-controlled damage due to e.g., digging. BC One call system method (is this proactive?). It is assumed pipeline warning signs will be installed at various locations along the right-of-way (i.e. road crossings). Any person digging requires to apply for the permit and clearance by registering at BC one Call. • Consideration for Ground patrols etc for monitoring the piping. • VOC's emanating from area could be an indication of leak. Will be part of enhanced ERP • Landslip geo-hazard area (also this is considered a seismic area). The terminal is understood to be in the path of an older landslip. TM states that it has been looking into this aspect - but no concrete answers at this time. • All Current building codes will be applied. In this context pipelines are considered least susceptible due to their flexibility and hence the pollution risk would be low? • Are there means to take action if things go wrong? – Emergency procedures shut down equipment and protocols will be in place. • KMC has risk algorithms (QRA) for the existing pipelines. Integrity, management plans, maintenance of this by periodic assessments to confirm risks.	C28: There will be an increase in personnel traffic– on to berth / to the ship; e.g., stores, and other personnel. Future and planned road ways and associated controls looked at.

Node	Hazardous event	Cause	Mitigation	Comments
3.2	Fire	Vapor recovery unit has a mix of volatiles and air – potential danger.	All berths shall be away from the shoreline (c.f. Schema of the general arrangement of the trestle in Appendix 2) and shall be Aframax capable and carry 3 chiksans each. The number of proposed vapor recovery units is 2 and is based on the amount of time that a third berth is expected to be used. The proposed new vapor combustion unit would be utilized when the third berth is used. Process details will be determined during detailed engineering design. If a vapor recovery unit fails it will be backed up by the second vapor recovery unit or the vapor combustion unit. Operation of the vapor recovery units would require two 25,000 bbl (approx.) crude tanks.	
3.3	Derailment, rail accident		There are rail lines close by (about 100 m away). These include trains carrying hazmat and passengers (risk to passengers in passing train or escalation of damage due to a hazmat train on track affected due to fire explosion at the jetty). There is a plan to keep the access road clear. They (CN/CP) will clear the rail line for access if required. This can be arranged between CP and CN. Procedural requirement for communication when vessels at the berth? Bridge carrying piping across the tracks will have to be upgraded or replaced. They have met with CP rail, who had no concern.	
Node 4. Leaving berth operations				
4.1	Striking the jetty with a tug	Covered in node 1		
4.2	striking vessel during un-berthing	Covered in node 1		

Node	Hazardous event	Cause	Mitigation	Comments
Node 5. Process Loss and Delays				
5.1		Bad weather, e.g. fog, etc		C29: There have been some isolated cases of fog in anchorages. These can last for a while - if movements shut down for say 10 days, what will be the range of options - shutting down pipeline? The rates, tankage etc is being designed for 34 ships but that many are not expected. The Ausenco model assumes weather delays, including some delays into the filling of tanks at Burnaby. The options would be to: • Start by slowing down, • hold longer in tanks, • but may need to shut down after that.

APPENDIX 2
SCHEMA OF THE GENERAL ARRANGEMENT OF THE BERTH - OPTION D10

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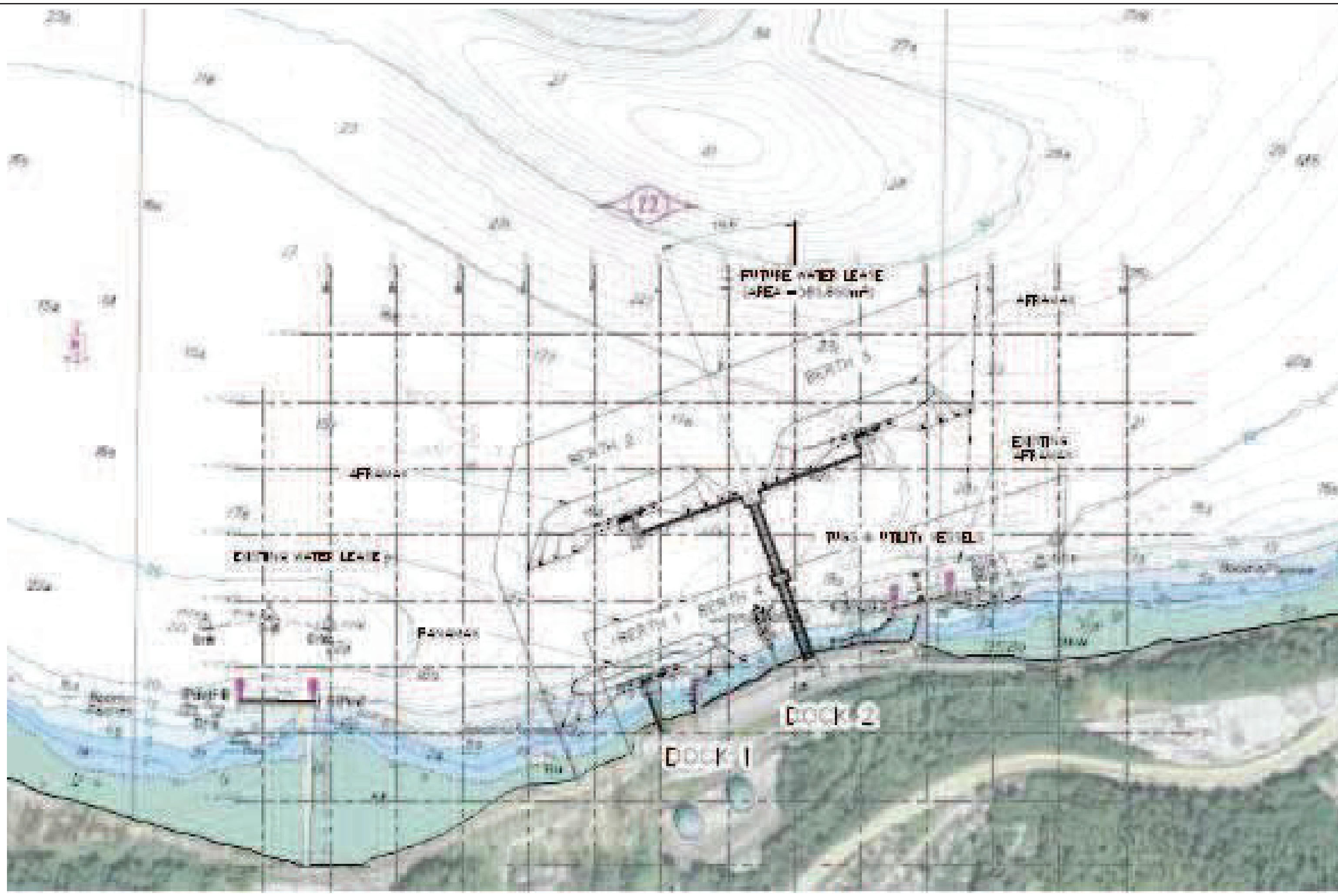
DOCK 1
DOCK 2

Appendix 4: Effectiveness of Risk Reduction Options

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1 INTRODUCTION: EFFECTIVENESS OF RISK REDUCTION OPTIONS

Several important risk control measures were identified through the risk assessment. The process of identifying these risk control measures included discussions with marine experts and local stakeholders during the navigational HAZID and through communication with the Trans Mountain Expansion Project (TMEP), Port Metro Vancouver (PMV), Canadian Coast Guard (CCG) and Pacific Pilotage Authority (PPA).

2 MODELLING THE RISKS OF NAVIGATION

2.1 Incident Types and Causal Chains

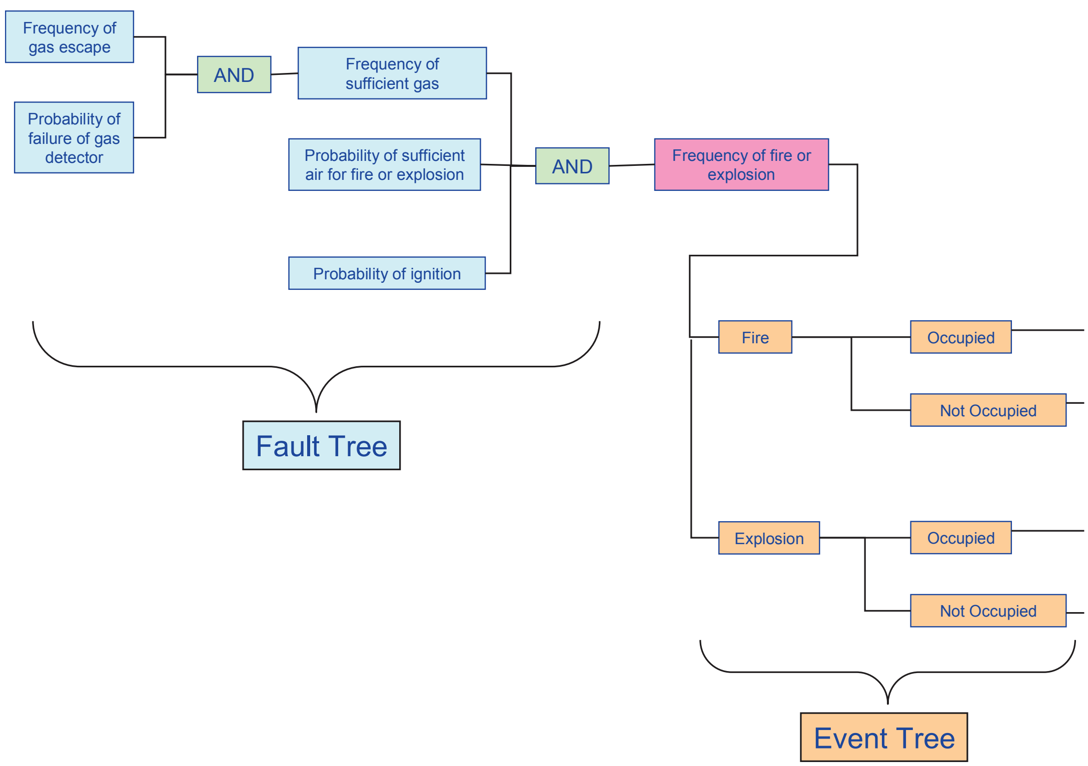
The navigational risk model for this project estimates the incident frequencies for the following incident types:

- Collision. A collision between two ships when both are underway.
- Powered grounding. These are groundings that occur when the ship has the ability to navigate safely yet goes aground (often due to human error), such as the *Exxon Valdez*.
- Drift grounding. These are groundings that occur when the ship is unable to navigate safely (often due to mechanical failure) and is forced onto the shoreline by the action of wind or waves, such as the *Braer*.
- Structural failure or foundering whilst underway.
- Fire or explosion whilst underway.

In case an incident should lead to an oil spill accident, the consequence can be evaluated by an estimate of the quantity of oil (tonnes) lost into the water as a result of the accident. Both cargo oil and bunker fuel oil spills are estimated.

The risk model for each incident type is conceptually represented as a causal chain that links basic causes to incident consequences by a fault tree and an event tree (or bow-tie). An example bow-tie is shown in Figure 2.1.

Figure 2.1 Example Bow-Tie Model of Incident Causal Chain



In the navigational risk model the generic fault tree model is shown in Figure 2.2 and the generic event tree model is shown in Figure 2.3.

Figure 2.2 Generic Incident Frequency Fault Tree Used in the Navigational Risk Model

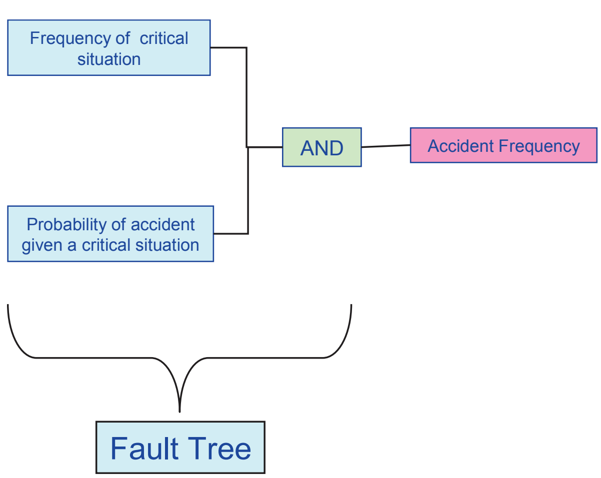
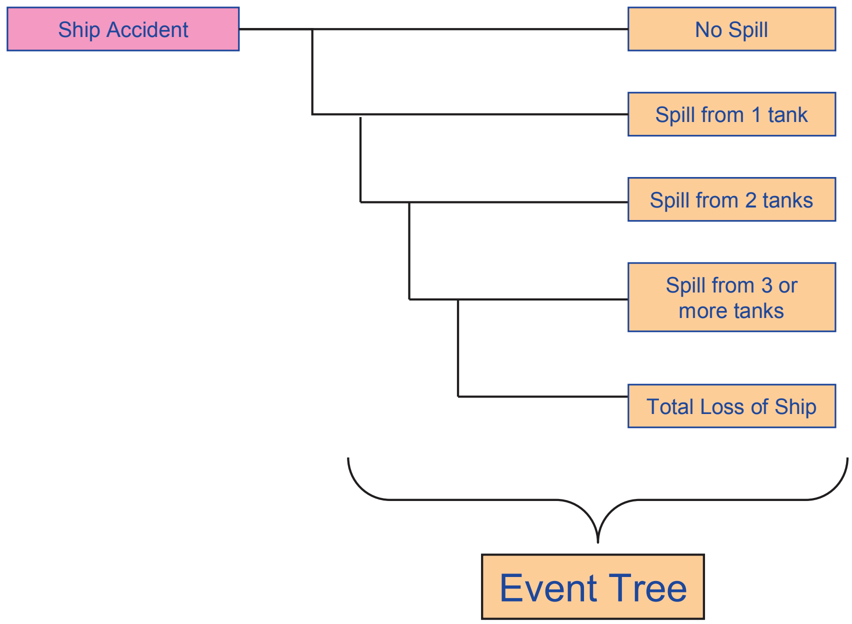


Figure 2.3 Generic Incident Frequency Event Tree Used in the Navigational Risk Model (including oil spill accidents)



In both Figure 2.2 and Figure 2.3 the ship incident is one of the 5 incident types described above. Thus the risk model estimates both frequencies of accident with spill and frequencies of incident without spill (spill risk equals zero, but such incidents may also have other impacts such as ship damage or reputation impacts).

2.2 Fault Tree Models for Navigational Incidents

The generic incident event tree (Figure 2.3) is applicable to all the incident types, thus this section will focus on the fault tree side of the bow-ties.

2.2.1 Collision

For collision the critical situation considered is if two ships will navigate to within 0.5 nm of each other in the absence of avoidance measures. This is also called a "close encounter" or an "encounter".

Figure 2.4 Collision Fault Tree

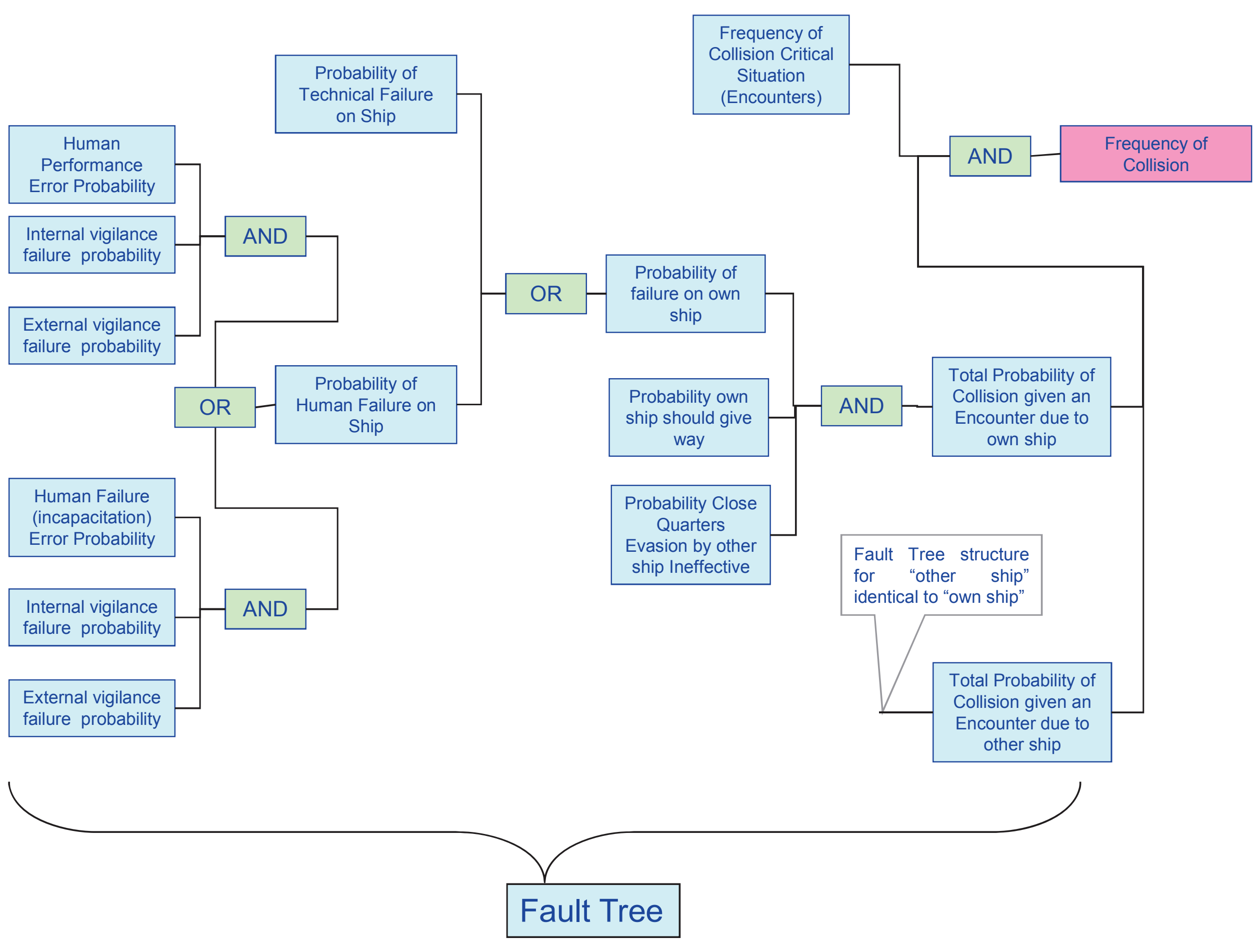


Table **2.1** defines the terms used in Figure 2.4 (and Figure 2.5 below).

Table 2.1 Definition of Terms used in the Collision and Powered grounding Fault Tree

Term	Definition
Human Performance (human error)	Inadequate planning of voyage, substandard use of navigational equipment, lack of experience, poor judgement of conditions, etc.
Internal Vigilance with respect to Human Performance	Failure in internal vigilance of the navigating office on the ship with respect to detecting sub-standard human performance.
External Vigilance with respect to Human Performance	Related to efforts by others to warn or divert a vessel on dangerous course.
Incapacitation (human reliability)	Officer on board is absent, absorbed, injured, asleep/ sleepy or intoxicated.
Internal Vigilance with respect to Incapacitation	Failure of internal vigilance of the deck officer with respect to detection of incapacitation.
External Vigilance with respect to Incapacitation	Related to efforts by others to warn or divert a vessel on dangerous course.

Risk reduction options typically influence collision risk by either:

- Reducing the probability of a collision given an encounter, usually by modifying the probability of human failure (performance and/ or incapacitation).
- Reducing the frequency of encounters by modifying the traffic pattern.

This is further discussed in Section 2.3 and Section 3 below.

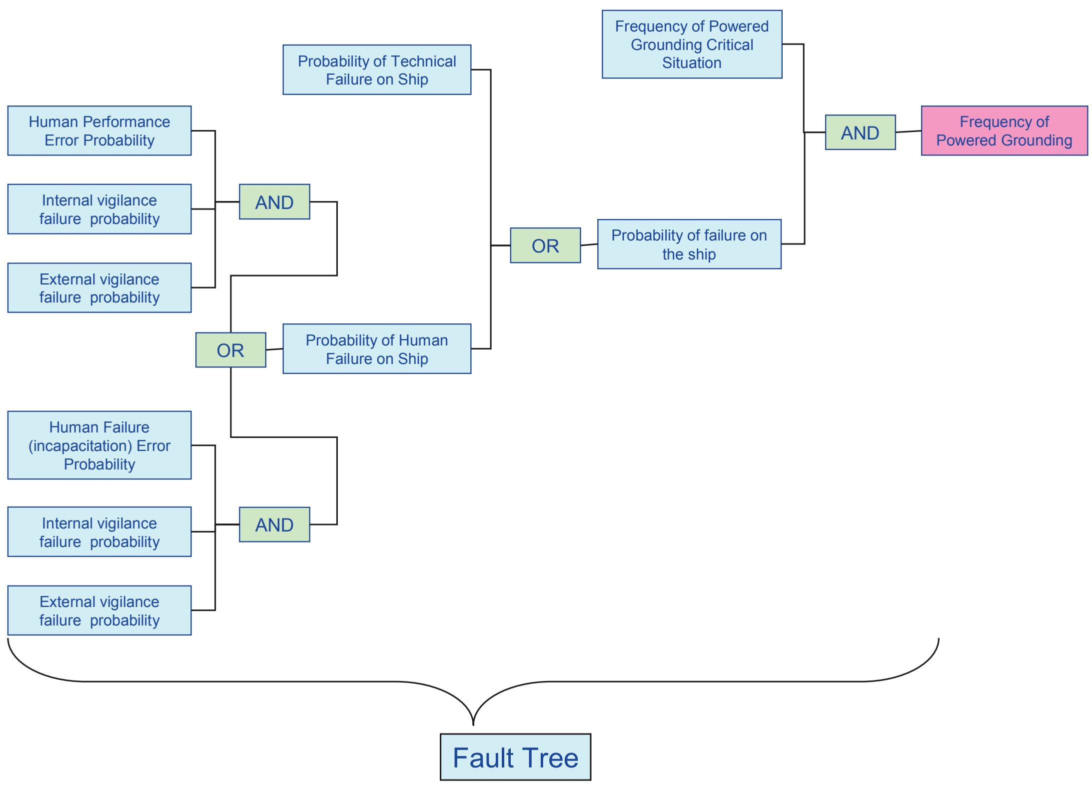
2.2.2 Powered Grounding

For powered grounding there are presently two critical situations:

- The frequency of critical course change points within 20 minutes navigation of a shore line.
- The frequency of navigation parallel to a shore line with wind and waves from the side and within 20 minutes navigation of the shore line.

Figure 2.5 shows the main parts of the fault tree used for powered grounding.

Figure 2.5 Powered Grounding Fault Tree



Risk reduction options typically influence powered grounding risk by either:

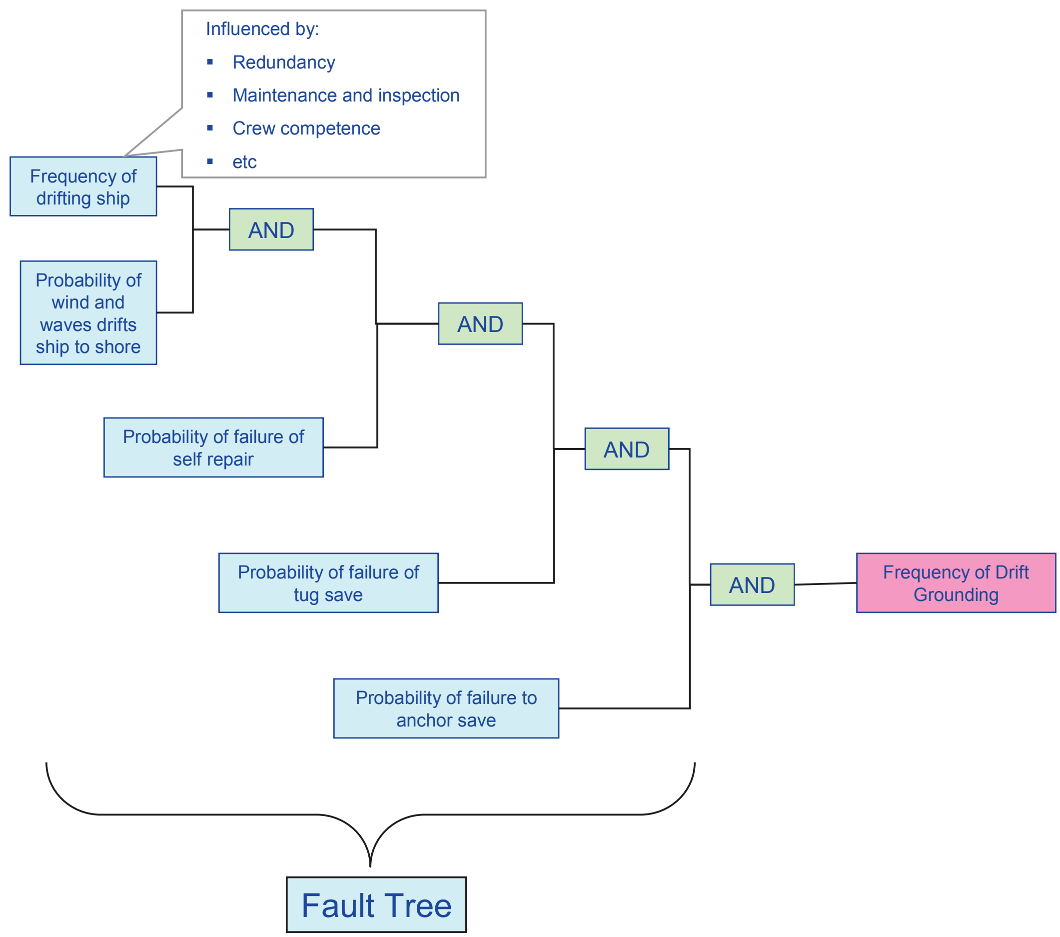
- Reducing the probability of a powered grounding given a critical situation, usually by modifying the probability of human failure (performance and/ or incapacitation).
- Reducing the frequency of critical situations by modifying the traffic pattern.

This is further discussed in Section 2.3 and Section 3 below.

2.2.3 Drift Grounding

For drift grounding the critical situation is the frequency of breakdown of the ship's main systems (propulsion and steering). Figure 2.6 shows a generic fault tree for the drift grounding incident type.

Figure 2.6 Drift Grounding Fault Tree



Risk reduction options typically influence drift grounding risk by either:

- Reducing the probability of a drift grounding given a critical situation, usually by modifying the probability of technical failure or by introducing measures that enhance the probability that a drifting ship is controlled prior to grounding.
- Reducing the frequency of critical situations by modifying the traffic pattern (typically by ensuring shipping maintains sufficient sea room from prevailing downwind shorelines when this is feasible).

This is further discussed in Section 2.3 and Section 3 below.

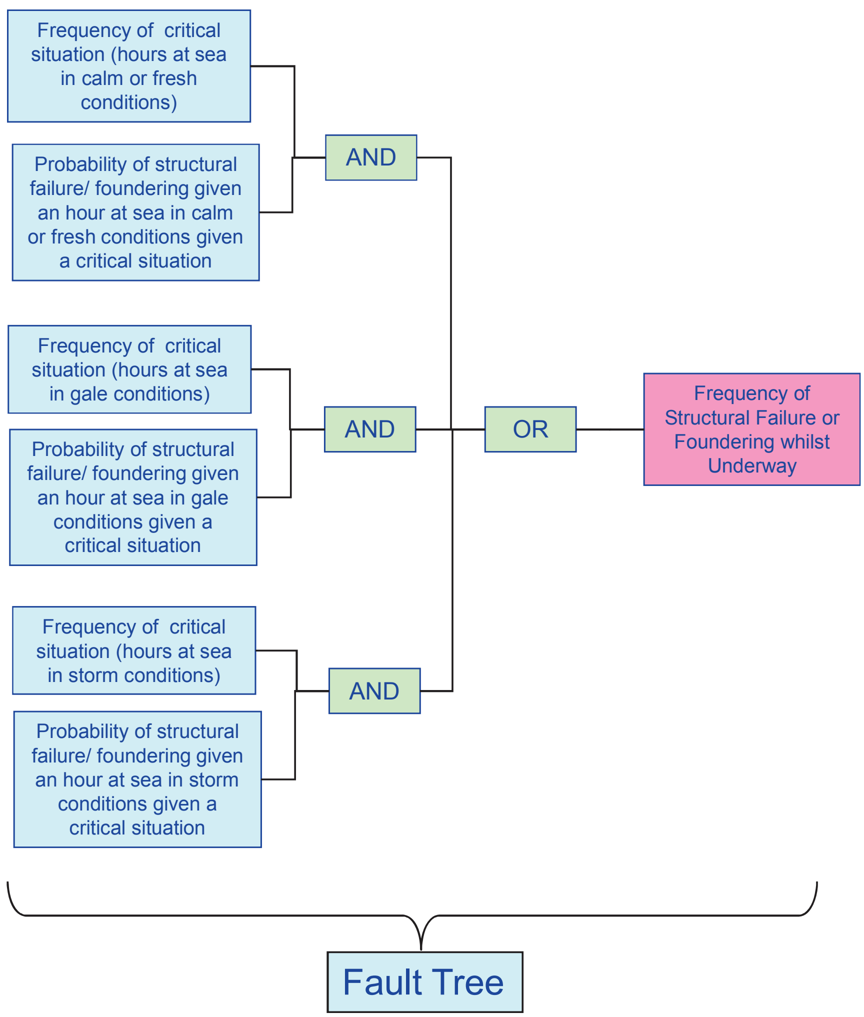
2.2.4 Structural Failure or Foundering Whilst Underway

For this incident type there are three critical situations:

- One hour underway in calm or fresh wind conditions and associated low seastates.
- One hour underway in gale wind conditions and associated moderate seastates.
- One hour underway in storm wind conditions and associated high seastates.

Figure 2.7 shows the fault tree used for structural failure or foundering whilst underway.

Figure 2.7 Structural Failure or Foundering Whilst Underway Fault Tree



Risk reduction options typically influence structural failure or foundering risk by either:

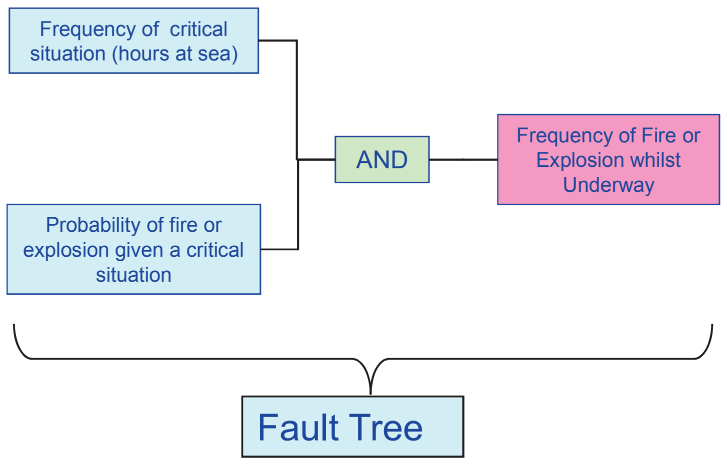
- Reducing the probability of a structural failure/ foundering given a critical situation.
- Reducing the frequency of critical situations by modifying the traffic pattern (weather routing).

This is further discussed in Section 2.3 and Section 3 below.

2.2.5 Fire or Explosion Whilst Underway

For this incident type the critical situation considered is an hour at sea. Figure 2.8 shows the fault tree used for structural failure or foundering whilst underway.

Figure 2.8 Fire or Explosion Whilst Underway Fault Tree



Risk reduction options typically influence fire or explosion risk by reducing the probability of a fire/ explosion given a critical situation (though reducing the hours at risk will also reduce the risk from fire/ explosion within a specified area).

This is further discussed in Section 2.3 and Section 3 below.

2.3 Adapting the Navigational Risk Model to the Study Area

The fault and event trees described in Section 2.2 have been previously quantified by internal DNV research work and project work performed under contract to clients. Thus DNV has estimates of how these many probabilities depend on ship type, risk reduction options applied, the quality of operational management and other factors that influence risk. Base case parameters were derived mainly from work in the North Sea (for incident probabilities) and from worldwide oil spill incident data (for oil spill event tree parameters). DNV believes that because shipping is a predominantly international business, parameters derived from the North Sea are applicable worldwide. This assumption has been made for many of our international navigational risk assessments.

In order to address the risk reduction options specific for the Trans Mountain tanker traffic and for the study area as such it will be necessary to use this prior knowledge and, in some cases, to extend it for this project. For each risk reduction option it is necessary to specify exactly how the option will influence the incident causal chains described in Section 2.2 above.

3 ESTIMATION OF EFFECTIVENESS OF RISK REDUCTION OPTIONS

This section describes and evaluates each risk reduction option in turn. Each discussion is concluded by a statement of how the risk reduction option was included in the risk model. Possible overlaps of risk reduction options are then discussed.

The effect of each option on the frequency of various incidents is measured in the following ways:

- Percentage reduction = (R0 – R1)/R0 x 100%
- Relative risk = R1/R0

Where:
R0 = frequency of incident without risk reduction option
R1 = frequency of incident with risk reduction option

When representing the effects in a risk model, the various model parameters are modified according to Performance Shaping Factors (PSFs), defined as:

- PSF = P1/P0

Where:

- P0 = probability of model parameter without risk reduction option
- P1 = probability of model parameter with risk reduction option

The risk parameters (R0, R1) are related to the probability factors (P0, P1) by the traffic pattern which may or may not vary before and after the application of the risk reduction option. If the traffic pattern does not change as the risk reduction option is applied and if the fault tree consists only of AND gates then the PSFs are identical to the relative risks. This equivalence will be *assumed* for the risk reduction options described below. In general, the effect of this assumption will be to *under-estimate* the risk reduction benefit due to the risk reduction option. The advantage is that it reduces the complexity of the analysis and increases the clarity of the discussion.

As discussed in Section 2.3 above, the basic parameters in MARCS represent North Sea average shipping operations in the mid to late 1990s. This study requires us to estimate changes in safety performance, which are represented as changes in numerical risk model parameters, for the GBR today without a specified risk reduction option and in the GBR today (or in the future) with the risk reduction option applied. In order to maintain the project scope within reasonable constraints, it is assumed that North Sea average conditions in the 1990s correspond to GBR operations today without the specified risk reduction option. In practice this may lead to some over-estimation of risks in the GBR area.

3.1 Coastal VTS

VTS is expected to influence the frequency of collision and of powered grounding.

A European study (CEC 1988) estimated that radar-based VTS would produce a relative risk for collisions and groundings of 0.6 (i.e. a 40% risk reduction).

Other similar studies (summarised by Larsen 1993) have found relative risks of 0.5 to 0.33 (i.e. risk reduction by 50% to 67%). Data on the Dover Strait (Lewison 1980) indicated that the main effect of VTS was in thick fog. As an example in the case of crossing encounters with 99% clear and 1% thick fog, the relative risk was 0.43 (or a 57% reduction).

The SAFECO study (DNV 1998) quoted data for the Western Scheldt estuary that indicated relative risks of 0.6 for collisions and 0.8 for powered groundings. Based on this, DNV's MARCS model uses performance shaping factors (PSFs) for external vigilance of 0.8 with respect to human performance and incapacitation, which give an overall relative risk of 0.8 (i.e. a 20% reduction) for collisions (assuming both ships in the encounter participate in the VTS) and for powered grounding.

An Australian study (DNV 1999) used relative risks of 0.16 for collisions and 0.8 for groundings in a "supervised traffic separation scheme", interpreted more recently (DNV 2011) as equivalent to VTS, but in fact combining elements of a traffic separation scheme which also reduces the frequency of encounters (critical situations).

SSPA (2012) reports various studies in the Baltic area obtaining relative risks in the range 0.2 to 0.45 (i.e. 55% to 80% reduction).

The progressive adoption of VTS may be one reason for the decline in world-wide collision and grounding frequencies. However most sea areas are not covered by VTS, so it is not possible to estimate what fraction of the reduction could be due to VTS.

The effects of other background changes in shipping safety can be quantified by subtracting worldwide trends in grounding and collision risk. The underlying trend has been approximately a 5.5% annual reduction in grounding risk (

Figure **3.1**) and a 3.5% annual reduction in collision risk (from comparable data, not shown). This assumes that the observed trends in total loss frequency represent real risk while the changes in serious casualty frequency result from changes in reporting standards. Over the 10 year period between the mid-points of the 2 data periods, these are equivalent to a relative risk of 0.57 for groundings and 0.70 for collisions.

In the MARCS model it is assumed a PSF of 0.8 (see Table 3.1), which gives a reduction of 20% in groundings and collisions.

3.1.1 Representation in Incident Models

VTS and pilotage reduce the frequency of collision and powered grounding via similar mechanisms. The effects are discussed and quantified together in Section 3.2.3.

3.2 Pilotage

3.2.1 Effects on Safety

Pilots have two main generic benefits:

- Their navigational expertise and familiarity with local conditions reduces the chance of error due to unfamiliarity with the navigation or poor performance by the officer of the watch.
- Their presence increases the number of people on the bridge, so reducing the chance of incidents due to omission or incapacitation. In principle, confusion over responsibility for the ship may offset this benefit, but this hazard should be managed through correct bridge resource management.

There is also an additional risk to pilots associated with embarking/ disembarking from the ship.

Several factors are considered that might modify the benefits of pilotage:

- The navigational complexity and uniqueness of the route. In the open sea, a pilot would have smaller benefit, as local familiarity would have little value. Most areas with mandatory pilotage are assumed to have significant navigational complexity.
- The navigational expertise and local knowledge of the ship's crew. If the bridge team is already well managed and knowledgeable, the pilot's expertise would have relatively less benefit. This is acknowledged by pilotage exemptions for some ship's masters.
- The navigational expertise and local knowledge of the pilot. In the Salish Sea sailing area competency standards are well established, both on Canadian and U.S. side, and pilots are assumed to have a high degree of navigational expertise.

A PPU can be seen as a support tool to enhance the pilot's navigational performance, because pilots are more familiar with their own equipment. The PPU also provides some additional redundancy against ship navigational equipment failure or incorrect calibration, and in some cases a greater degree of accuracy than from the ship's own equipment.

3.2.2 Quantification of Effects of Pilotage

Pilotage is expected to influence the frequency of collision and powered grounding. The personal incident risk from embarking/disembarking is not modelled in the study.

Where a pilot is optional, Japanese data (reported by Larsen, 1993) indicated that a pilot on board reduced the incident frequency by 83%.

An Australian study (DNV 1999) used a relative risk of 0.51 (i.e. a 49% reduction) for "compulsory pilotage for majority of ships". Given the extension of compulsory pilotage since then, this has been re-interpreted more recently (DNV 2011) as a relative risk of 0.5 for "non-compulsory pilotage".

SSPA (2012) reports various studies using reduction reductions in the range of 50% to 97% reduction, with the Australian one being the smallest and a Danish study being the largest. However, no data is provided to support the factors.

DNV's MARCS model uses performance shaping factors (PSFs) for internal vigilance of 0.5 with respect to human performance and 0.25 with respect to incapacitation, which give an overall relative risk of 0.74 (i.e. a 26% reduction) for collisions and 0.49 (i.e. a 51% reduction) for powered grounding. The collision result assumes pilotage on one ship only. If both the encountering ships carry pilots then the reduction in collision risk is 53%.

3.2.3 Representation of VTS and Pilotage in Incident Models

When the discussion in Sections 3.1 and 3.2 were first compared it was noticed that the analysis predicted that VTS is a more effective risk reduction option than the presence of a pilot on the bridge. This observation is inconsistent with the parameters in MARCS derived from SAFECO. It is also inconsistent with the expert judgement of 2 ex-navigating officers employed by DNV. Taking into account all the available evidence, DNV has made the decision to favour the MARCS parameters, and these have been further amended to represent all important influences as described below.

The effect of VTS, the various levels of pilotage and the PPU discussed above is summarised in Table 3.1.

Table 3.1 Performance Shaping Factors for VTS, Pilotage and the PPU

	Basic Operations	VTS	1 Pilot,	2 pilots	PPU
Collision – Human Error	1.00	0.80	0.50	0.54	1.00
Collision – Incapacitation	1.00	0.80	0.25	0.27	1.00
Powered Grounding – Human Error	1.00	0.80	0.50	0.54	0.90
Powered Grounding - Incapacitation	1.00	0.80	0.25	0.25	1.00

The figures in Table 3.1 assume that both ships in the encounter (collision critical situation) participate in the VTS and/ or carry pilots at the specified level. The main contributing factors to these results are:

- The presence of a VTS provides external vigilance to reduce human error and incapacitation error on the bridge.
- The presence of a pilot reduces the human performance error probability and provides internal vigilance to help reduce incapacitation errors on the bridge.
- The effect of pilotage in a long transit is better than without a pilot, but not as good as a piloted short transit or using 2 pilots on a long transit. Using 2 pilots on a long transit is almost as good as using a single pilot on a short transit.
- In the absence of any data, it is provisionally assumed that a PPU will improve the pilot's human error performance with respect to powered groundings by a further 10%. The effect on collisions is assumed to be negligible in comparison. This is modelled by an additional PSF (see Section 3.7) of 0.90 applied to human performance errors in powered groundings when at least one pilot is present.

In the future, a Traffic Organisation Service (TOS) may be provided by the VTS to smooth the flow of traffic or segregate it in a way that reduces encounters. The reduced frequency of encounters could be represented by changes in the traffic input data (e.g. by a traffic separation scheme) or by an additional PSF applied in some areas. A 10% reduction was judged possible, that is a TOS is assigned an additional PSF of 0.9 in areas where the TOS is implemented. This factor is mainly an assumption.

3.3 Aids to Navigation

3.3.1 Description of Current Measures

Aids to Navigation (AtoN) include:

- Conventional visual and radio aids such as lights, beacons, racons, buoys etc..
- (Differential) Global Position System ((D)GPS).
- Automatic Identification System (AIS), including its use as an AtoN.

3.3.2 Differential Global Positioning Systems (DGPS)

3.3.2.1 Effects of DGPS on Safety

The use of GPS is ubiquitous and it has become the primary means of navigation worldwide. GPS signals allow a receiver to calculate its position based on signals received from the constellation of GPS satellites. The GPS Standard Positioning Service Performance Standard states that GPS receivers operating in a stand-alone mode will provide positions to within approximately 9 metres (95% probability) of the true position. This is more than adequate for the navigation of commercial shipping.

However, it is also widely accepted that relatively weak GPS signals are vulnerable to space and ground segment failures, atmospheric disturbances and intentional and unintentional interference. Also, GPS is not infallible and it is possible for large errors caused by an “unhealthy” satellite to go undetected for several hours.

Thus the main concerns with using GPS as a means of navigation are:

- Reliance on a system beyond the control of the shipping industry or the Australian government.
- Integrity of the signals received and resultant determination of position.
- Vulnerability of the signal to interference.

These concerns become more acute if ships rely solely on GPS signals for navigation. Differential (D) GPS aims to improve GPS performance by providing:

- Greater accuracy of the position calculated. This is significant in some applications (e.g. aviation) but is perhaps less important for coastal marine navigation.
- An assessment of the integrity of the GPS signals. This is valuable to coastal marine navigation.

The advantage of GPS over conventional AtoN is that it provides a very accurate and continuously updated calculation of the ship’s position in all weather conditions. DGPS provides greater accuracy and reliability. This is beneficial against powered grounding, which may result from inaccurate positional knowledge. Hereafter DGPS will refer to the composite of GPS and DGPS systems.

DGPS has the additional benefit that it requires less time than conventional navigation, and hence reduces bridge workload (e.g. by plotting on a conventional chart). However, this benefit may be offset by additional duties or reduced watchkeepers.

Possible disadvantages of DGPS include:

- Reliance on DGPS-based navigation may reduce mariners ability in conventional navigation ("de-skilling"), which is needed if the equipment fails. Failure modes may not be obvious (especially for GPS), and navigators may be slow to detect partial failures.

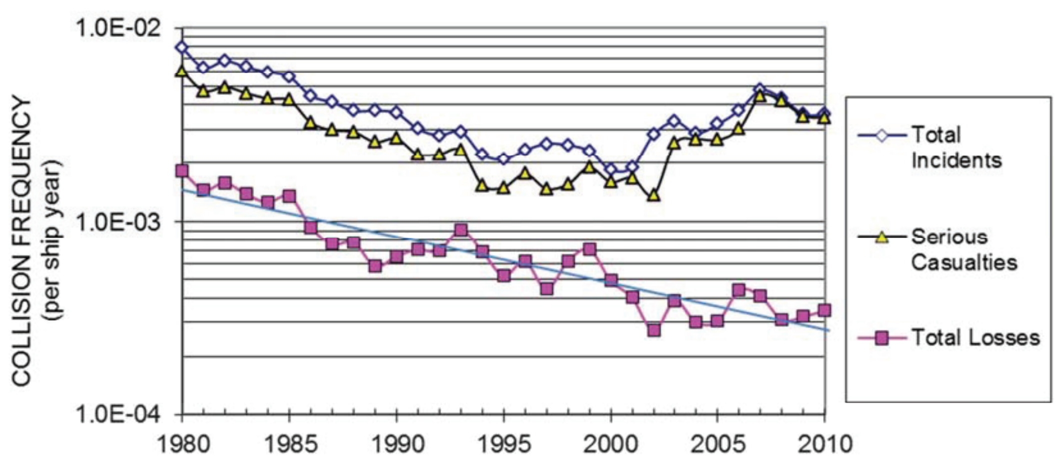
Over-confidence in the accuracy of DGPS may encourage mariners to reduce normal safety margins. The *Costa Concordia* incident indicates the danger of reducing safety margins.

3.3.2.2 Quantification of Effects of DGPS

Although DGPS is widely believed to make a major contribution to the safety of navigation, there are no known studies that provide a comparison between incident rates with DGPS, stand-alone GPS and conventional (non-GPS) navigation.

Figure 3.1 shows the historical trend in the frequency of groundings in the world-wide fleet, most of which are powered groundings. The frequency of total losses has declined at an average rate of approximately 5.5% per year. However, when serious casualties and non-serious incidents are included, the frequency appears to have increased during 2002-07. The causes are not entirely clear, but the effect is that the historical trend does not show any clear decline that could be apportioned into its various causes, including aids to navigation, but also including changes in operating procedures and safety management.

Figure 3.1 Grounding Frequency Trends, 1980-2010



The potential benefit of DGPS may be indicated by causal data prior to its introduction. An analysis of the causes of grounding incidents on Norwegian registered ships over 1600 GRT during 1970-78 (Drager et al 1981) gave the main causal areas as shown in Table 3.2. Errors in conventional navigation, which might be prevented by DGPS, are represented by "misinterpretation of lights/marks", and amounted to 8.4% of incidents. DGPS would not necessarily prevent all such errors, and indeed may have some negative impacts that would not be visible in data from this period. However, DGPS might have indirect benefits on all navigational errors. Therefore a reduction in groundings by 8.4% might be justified by this data. However, in the absence of a direct estimate of the benefits, this is very uncertain, and so it is rounded to 8%.

Table 3.2 Causal Factors in Groundings, 1970-78

CAUSAL FACTOR	CONTRIBUTION	
External conditions	39.9%	
Channel and shallow water		18.9%
Reduced visibility		12.6%
Fault/deficiency of lights, marks etc.		6.4%
Other external conditions		2.0%
Technical failure	8.8%	
Fault in the ship's technical systems		5.7%
Other technical failures		3.1%
Inadequate navigational factors	18.9%	
Bridge manning/organisation		8.4%
Error/deficiency in charts/publications		8.1%
Other navigational factors		2.4%
Navigational error	22.9%	
Navigation and manoeuvring factors		11.7%
Misinterpretation of lights/marks		8.4%
Other navigational error		2.8%
Non-compliance	8.1%	
Inadequate coverage of the watch		5.7%
Other non-compliance		2.4%
Other ship	1.4%	1.4%
Total	100.0%	100.0%

3.3.3 Automatic Identification System (AIS)

3.3.3.1 Effects of AIS on Safety

AIS data transmitted to shore-based receivers does not directly affect safety onboard, but may be seen as enabling effective VTS (covered above), and assisting management of conventional AtoN (considered below).

In principle, AIS data exchanged between ships may assist collision avoidance. It highlights and identifies other vessels, enabling collision avoidance action, and provides accurate measurements of Closest Point of Approach (CPA) and Time of Closest Point of Approach (TCPA). However, when DNV discussed this use of AIS with a number of mariners, it was not clear that AIS is in fact used in this way.

Virtual AIS AtoNs can make mariners promptly aware of hazards and route features that cannot be otherwise physically marked (or would require extra time and resources to mark). This may help prevent powered grounding by ensuring that information on hazards to navigation is continually updated.

3.3.3.2 Quantification of Effects of AIS

There are no known studies that show the effect of AIS coverage on incident rates, apart from those on VTS above.

AIS has been required under SOLAS on ships over 300GT since 2000. The progressive adoption of AIS may have influenced overall collision frequencies, but no clear decline is visible in the data from this period.

No causal data has been found suitable to show the potential effects of AIS on collision avoidance, because a very high proportion of collisions are due to failure to identify the other vessel and to understand its movements in close quarters, but it is not evident what proportion of these could be eliminated by AIS.

The benefit of AIS on collision avoidance is expected to be small compared to the other risk reduction options considered here. In the absence of any useful data, it is judged that AIS coverage in an area could reduce the collision frequency on ships with AIS receivers by about 2%. This small reduction is, however, not included in the risk model because mariners do not seem to use the AIS in this way.

The potential benefit of AIS AtoNs may be indicated by causal data on groundings. However, available data such as Table 3.2 does not identify groundings due to lack of marking of hazards.

The benefit of AIS AtoNs on grounding is expected to be larger than its benefit on collisions. In the absence of any useful data, it is judged that use of AIS AtoNs in addition to AIS coverage in an area may reduce the powered grounding frequency on ships with AIS receivers by 5%.

3.3.4 Electronic Navigation Charts and ECDIS

3.3.4.1 Effects of ECDIS and ENC on Safety

An Electronic Chart Display and Information System (ECDIS) is a navigation aid that can be used instead of paper charts and publications to plan and display a ship's route, and to plot and monitor its position throughout the voyage. Electronic Navigational Charts (ENC) are a standardised database of chart information, including supplementary information considered necessary for safe navigation, issued for use by ECDIS.

ECDIS provides a continuous display of a vessel's position in relation to land, charted objects, aids to navigation and possible unseen hazards. Compared to conventional paper charts, it provides an improved representation of the vessel's position, and reduces the workload due to position plotting. It can be located where convenient on the bridge, so as to enable the watch-keeper to maintain a good lookout, instead of needing a screened chart table. It allows charts to be updated in a more efficient way by inserting a CD into the ECDIS computer, instead of manually annotating paper charts. ECDIS also allows route planning and continuous monitoring.

ECDIS can provide improved functionality, such as:

- Location polygons can be defined and alarms set if the ship exits defined safe areas.
- AIS data can be displayed.
- Radar targets can be superimposed on the ECDIS.

ECDIS can also operate with scanned copies of conventional paper charts (raster charts) for areas of the world where ENC are not available. This is known as Raster Chart Display System (RCDS) mode. This is mode provides less information (and limited interactivity) to navigators than the full ECDIS.

3.3.4.2 Quantification of Effects of ECDIS

A formal safety assessment (FSA) was submitted to IMO MSC in 2006 in connection with a proposal for ECDIS carriage requirements. The assessment investigated three cargo ship types using a Bayesian network model. It concluded that ECDIS reduced grounding risk by approximately 36%. This was due to a combination of more time available on the bridge for situational awareness, more efficient plotting of the ship's position and more efficient updating routines. A subsequent study (MSC 2007) that took account of 11 different routes and a mix of ship types found reductions in grounding risk between 11% and 38% due to variations in ENC coverage. Where ENC coverage was 100% the reduction in grounding risk was 38%.

3.3.5 Quantification of Effects of Improving Conventional AtoN

Conventional aids to navigation are a key enabler for spatial awareness, leading to safe navigation,. There is no obvious baseline (i.e. risk without AtoN) that could be used for comparison. However, it is possible to consider the benefits of improvements in conventional AtoN.

The potential benefit of improving conventional AtoN may be indicated by causal data on groundings. In the absence of recent data, the older data in Table 3.2 is used. Causes that might be prevented by improved conventional AtoN are represented by "fault/deficiency of lights/marks", and amounted to 6.4% of incidents. Improving conventional AtoN would not necessarily prevent all such incidents, but might have indirect benefits on other navigational errors. Therefore a reduction in groundings by 6.4% might be justified by this data.

In reality, improving conventional AtoN is a continuous process, which can be undertaken with varying degrees of commitment. It is therefore assumed that a 6.4% reduction in grounding risks might be obtained over a decade from a comprehensive programme of review and improvement, compared to a policy of simply maintaining the current AtoNs. However, in the absence of a direct estimate of the benefits, this is very uncertain, so it is rounded to 6%.

It would be impractical to estimate the benefits of improving the specific AtoN that that are in place in the study area. No methodology exists for this, and so the only viable approach would be an extensive set of expert judgements. The above approach based on causal data in effect assumes the AtoN have the same range of strengths and weaknesses as elsewhere in the world. If the standard of conventional AtoN is relatively high in the study area, the available improvement would be lower than estimated. On the other hand, there are many grounding hazards in the study area, which might justify retaining the original figure.

3.3.6 Representation in Incident Models

This section summarises the effect on powered grounding frequency of:

- Differential Global Position Systems (DGPS).
- Virtual Automatic Identification System (vAIS).
- Raster Chart Display System (RCDS).
- Electronic Navigation Charts (ENC).

- Enhanced conventional Aids to Navigation (cAtoN).

Successful navigation requires:

- Accurate and up to date knowledge of where a ship can be placed. This is obtained by accurate charts and can be supported in near real time by the use of vAIS. As discussed in Section 3.3, if this data is deficient there is little that the navigator can do to avoid a powered grounding.
- Accurate positioning of the ship away from known hazards.

Thus improved charts and vAIS contribute to the "error 4" branch of the powered grounding fault tree discussed in Section 2.2.2 above. This branch has not yet been quantified by DNV and is presently excluded from consideration. Quantification of this branch could be achieved by counting the number of ship-hours per year in shallow water relative to the ship's draught and weighting these hours by a probability of grounding due to an unidentified grounding hazard. This probability will be very uncertain and is likely to be very low. It is expected that the "error 4" branch contribution to the total frequency of powered grounding will be less than 1%, perhaps much less than 1%.

The effect of ECDIS is a 38% reduction in powered grounding. This risk benefit arises by various mechanisms, including the ability to set limits to safe navigation and alarms if the ship crosses these limits. This provides a safety barrier against incapacitation in addition to human error. The effect of ENC alone is assumed to be one third the effect of ECDIS and excluding the incapacitation benefit.

Some representative performance shaping factors for enhanced aids to navigation are shown in Table 3.3. These results are directly comparable to those shown in Table 3.1.

Table 3.3 Performance Shaping Factors for Aids to Navigation

	Basic Operations	DGPS	cAtoN	ECDIS	ENC
Powered Grounding – Human Error	1.00	0.92	0.94	0.62	0.87
Powered Grounding - Incapacitation	1.00	1.00	1.00	0.62	1.00

Comparing the results in in Table 3.1 and Table 3.3 indicates that enhanced aids to navigation are less effective at reducing incident frequency than pilotage (even a single pilot on a long transit) and VTS. A fully integrated ECDIS is predicted to be the most effective single aid to navigation.

3.4 Ship Routing Measures

3.4.1 Description of Current Measures

Ship routing measures that are approved by the International Maritime Organization (IMO) include (but are not limited to):

- Traffic Separation Scheme (TSS) - a routeing measure aimed at separating opposing streams of traffic by establishing separate traffic lanes.
- Two Way Route (TWR) - a route within defined limits inside which two-way traffic is established, aimed at providing safe passage of ships through waters where navigation is difficult or dangerous.
- Traffic lane - an area of one-way traffic typically around natural obstacles.
- Recommended route - a route of undefined width, for the convenience of ships in transit, which is often marked by centreline buoys.
- Deep-water route - a route within defined limits which has been accurately surveyed for clearance of sea bottom.
- Area to be avoided - an area within defined limits in which either navigation is particularly hazardous or which should be avoided by all ships, or by certain classes of ships.

3.4.2 Effects of Ship Routing on Safety

The effects of ship routing measures include reducing the complexity of traffic flow, increasing the separation between ships on opposing tracks, and between ships and navigational hazards. They are expected to reduce the frequency of collision, powered grounding and possibly drift grounding.

3.4.3 Quantification of Effects and Representation in Risk Models

An Australian study (DNV 1999) used relative risks of 0.40 for “unsupervised traffic separation scheme”, and 0.16 for “supervised traffic separation scheme”, i.e. TSS combined with VTS.

A key effect of TSS is to reduce the frequency of head-on encounters. This is best represented in the traffic data used in the collision model. No data is available on any additional effects due to regularising the traffic flow.

A key effect of DSA is to increase separation of traffic from grounding hazards. This is best represented in the traffic data used in the powered and drift grounding models (that is, it does not change the probability of an incident given a critical scenario, but does change the frequency of critical scenarios as reflected in the traffic pattern).

TWRs may be subject to surveillance by VTS or not. DNV assume that VTS surveillance will increase the effectiveness of a TWR.

Ideally the TWR should be represented in the risk model by an amended traffic pattern. As an approximation, DNV assumes that in the area where a TWR is defined the collision and powered grounding human error PSF is set to 0.95 (with VTS) and 0.975 (without VTS).

3.5 Port State Control

3.5.1 Description of Current Measures

Port State Control (PSC) is the inspection of foreign ships in national ports to verify that the condition of the ship and its equipment comply with the requirements of international regulations and that the ship is manned and operated in compliance with these rules.

3.5.2 Effects of PSC on Safety

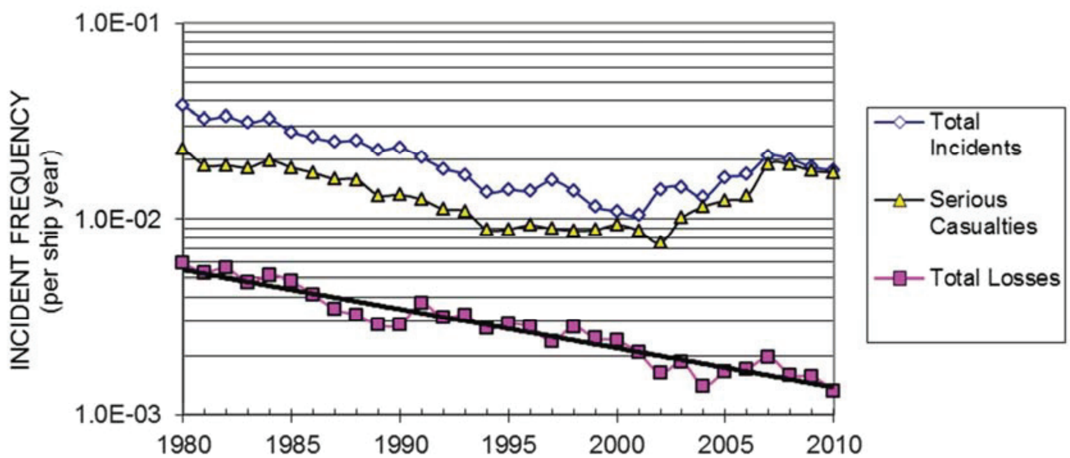
The effects of PSC are generally considered to be increased compliance with international regulations, including rest periods, and a reduction in sub-standard ships. This is expected to affect ship safety for all incident types.

3.5.3 Quantification of Effects of PSC

PSC has been progressively adopted world-wide since the first implementation in Europe through the Paris Memorandum of Understanding (MOU) in 1982. It may therefore account for some of the reduction in incident frequencies since then.

Figure 3.2 shows the historical trend in the frequency of all types of losses, casualties and incidents in the world-wide fleet. The frequency of total losses has declined at an average rate of approximately 5.2% per year. However, when serious casualties and non-serious incidents are included, the frequency appears to have increased during 2002-07. The causes are not entirely clear, but the effect is that the historical trend does not show any clear decline that could be apportioned into its various causes, including PSC, but also including changes in operating procedures and safety management.

Figure 3.2 Overall Ship Incident Frequency Trends, 1980-2010



There are no reliable regional incident rates for ships, due to lack of regional exposure data, so it is not possible to show any effects from the staggered adoption of PSC in different regions.

There is evidence that the PSC detention rate is correlated with ship incident rate.

Figure **3.3** shows an association of this type (Spouge 2003). In principle, trends in detention rate could be combined with this data to indicate the benefits of PSC. However, the PSC detention rate in Australia has not shown any consistent trend (
Figure 3.4). The increases are believed to result from improved targeting of inspections towards sub-standard ships. In contrast, the PSC detention rate in the Paris MOU region has shown a substantial reduction. This was attributed to the migration of sub-standard shipping away from Europe. As a result, it is difficult to use this data to show the benefits of PSC. However, it is possible that the detention rate might have reduced by a factor of 2 (from about 8% to 4%) in the absence of targeting or ship migration, and that this might have reduced the loss rate by a factor of 2 (i.e. a 50% reduction). However, this is very speculative.

Figure 3.3 Comparison of Detention Rate and Total Loss Rate for Selected Ship Types

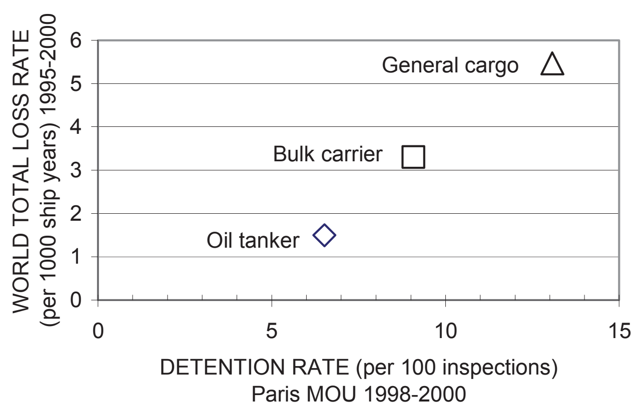
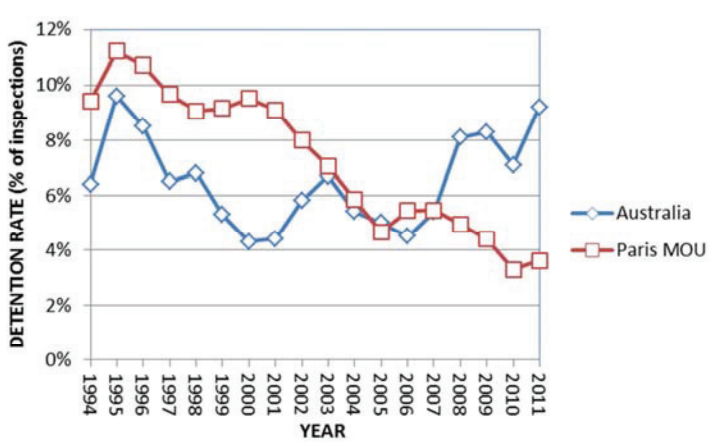


Figure 3.4 Trends in Detention Rate in PSC Inspections



Knapp et al (2011) estimated the survival gains for different ship types in the years 2003-07 based on individual ship loss experience and PSC inspections in Australia and the USA. PSC inspections were associated with ship survival gains of 0.1% to 0.5% on base risk rates of 1-3%. Combining the data for 4 cargo ship types over 5 years, the average gain was 12% of the risk of total loss. The average benefit may be smaller because not all ships are inspected. On the other hand, the benefit may be increased through the targeting of inspections on high-risk ships, and the possibility that any ship may be inspected and detained if not compliant. Overall, this analysis is considered to provide the best estimate of the benefit of PSC.

3.5.4 Representation in Incident Models

The effect of PSC is represented by:

- Applying a PSF of 0.88 for all the technical failure rates in the risk model. This directly affects the frequency of drift grounding, fire/ explosion and structural failure/ foundering. It also has a very minor impact on collision and powered grounding (which are dominated by human error and human incapacitation).
- Applying a human error and human incapacitation PSF of 0.88 in the collision and powered grounding incident models. This represents the emphasis placed on ISM issues by PSC inspections and should help ensure reduce the likelihood of excessively fatigued navigating officers.

3.6 Emergency Towing Vessels (ETV)

No Emergency Towing Vessel has been taken into consideration in this study. MARCS can include ETVs in its model, but it needs very detailed information about the ETVs' behaviour according to the seastate and the winds.

3.7 Risk Reduction Option Overlaps

The sections above have estimated the effect of implementing each risk reduction option in isolation on the basis of data (where available) and expert judgement. A number of these risk reduction options function by adjusting the same immediate causes in the incident fault trees. In this case the effect of the risk reduction options together could be less than the sum of the effects individually. These overlaps, which mainly apply to collision and powered grounding, are discussed and evaluated here.

The effect of DGPS and of enhanced cAtoN on reduced powered grounding frequency is via a similar mode of action. They both assist the navigator to determine the ship's position. DNV therefore assumes that these risk reduction options are not additive if applied together.

The effect of ECDIS and ENC on reduced powered grounding frequency is via a similar mode of action. They both support the navigation process. DNV therefore assumes that these risk reduction options are not additive if applied together.

The benefit of the PPU can only be applied if one or more pilot is present.

Thus the 13 distinct risk reduction options evaluated above fall into 9 logical groups as follows:

1. DGPS and enhanced cAtoN.
2. ECDIS and ENC.
3. Pilotage and PPU.
4. VTS (which may or may not be applied with TWRs).
5. TWR which may or may not be applied with VTS).
6. PSC.
7. ETV, noting that emergency tugs affect only drift grounding and their effect is completely separate from the other risk reduction options.
8. VTS and TOS.

DNV considers that these risk reduction options can be combined according to the following rules:

- All options are fully additive, unless specified otherwise below. Fully additive means that if option 1 has PSF1 and option 2 has PSF2 then the PSF of the two options applied together equals PSF1*PSF2, or in general is equal to the product of the PSFs from each of the above 9 groups.
- The effect of pilotage (group 3) and enhanced navigation (group 1) overlap because of the pilots' local knowledge. This is because a pilot is more familiar with the navigation in the area and has less need for enhanced AtoN. If one or more pilots are present then the benefit from group 1 is halved.
- The effect of pilotage (group 3) and ECDIS (from group 2) overlap because of the pilots' presence on the bridge and the ECDIS both provide a means of alerting an inattentive navigator (incapacitation error). The effect of ECDIS is halved if one or more pilots is present.
- The effect of pilotage (group 3) and PSC (group 7) overlap because the benefit of PSC in the collision and powered grounding model is that it ensures that navigators are fit for duty (not fatigued). The effect of PSC on human error and on human incapacitation is halved if one or more pilots are also present.

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An Evaluation of Local Escort and Rescue Tug Capabilities in Juan de Fuca Strait

Project 213-063 Revision 3 November 27, 2013

Prepared for:

Trans-Mountain Pipeline ULC
Calgary, AB

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An Evaluation of Local Escort and Rescue Tug Capabilities in Juan de Fuca Strait

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Prepared For: **Trans-Mountain Pipeline ULC** **Calgary, AB**	*Client's Reference:* **Master Contract No. 69346**
Prepared By: **Mike Phillips, P. Eng.** **Robert G. Allan, P. Eng.**	*Professional Engineer of Record:* **Robert G. Allan, P. Eng.**

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An Evaluation of Local Escort and Rescue Tug Capabilities in Juan de Fuca Strait

EXECUTIVE SUMMARY

Robert Allan Ltd. was retained by Trans Mountain Pipeline ULC to conduct a review of the capabilities of the local Canadian tug fleet to secure and control a fully laden Aframax tanker (120,000 t DWT), assumed to have suffered an engine failure and drifting in the Strait of Juan de Fuca.

Conditions at Neah Bay in the winter are the limiting case for defining imposed wind and wave loads on a ship and hence the tug performance requirements. The 99th and 93rd winter season percentiles were selected as important conditions for evaluation of wave forces. These same percentiles can be selected for wind and current, although this is likely conservative.

The following are the approximate overall percentiles of Met-Ocean data used to calculate the required tug forces:

- **99th percentile (Neah Bay, winter) - Waves 6 m, Winds 34 knots, Current 1.5 m/s**
- **93rd percentile (Neah Bay, winter) - Waves 4 m, Winds 21 knots, Current 1.3 m/s**

For those environmental conditions of interest, force components were calculated using several different methods and referencing published data for a variety of tanker sizes. Once overall forces on the tanker were determined, adjustments were made for the increase in required towing force due to the effect of tanker yawing while under tow, as well as for the reduction in bollard pull for the tug operating in a seaway.

Accounting for the towing efficiency of a tug in a seaway, as well as the tendency of a tanker to yaw under influence of wind and waves, the individual force components were summed to obtain a total required Bollard Pull (maximum thrust at zero speed) for the tugs, as follows:

Component	**93rd Percentile (4 m H_s, 21 knots wind, 1.3 m/s current)**	**99th Percentile (6 m H_s, 34 knots wind, 1.5 m/s current)**
Wind Force	8 tonnes	18 tonnes
Current Force	18 tonnes	24 tonnes
Wave Force	28 tonnes	42 tonnes
Subtotal	54 tonnes	84 tonnes
Tug Efficiency	80%	76%
Bollard Pull Required	**68 tonnes**	**110 tonnes**

There are currently approximately **1,200 tugs** registered in the Canadian "Pacific Region", however almost half of that large number are very small tugs used in support of the logging industry. Another large number are small tugs working in the small ports and rivers of the coast, and which measure under 15 GT in order to avoid inspection by Transport Canada. Another group, which measure between 15 and 150 GT and which are typically under 24 metres in length with between 900 and 1,350 kW (1,200 and 1,800 bhp), are primarily used in coastal log and barge towing. That leaves a small cadre of tugs which are engaged principally in the business of towing barges along the BC coast, the majority of which are quite small (under 30 metres in length) and some of which, engaged in towing larger barges are considerably larger and exceed 500 GT. The latter two groups, 32 tugs in total, are the total pool from which escort and rescue tugs can be selected.

Pacific Region	
Vessel Size	**Number of Tugs**
< 5 GT	607
5 < GT < 15	430
15 < GT < 150	181
150 < GT < 500	29
GT > 500	3

Of these, only a handful have the size and power necessary to be considered seriously for a rescue tug role in the exposed waters of Juan de Fuca Strait and even fewer are properly equipped for and capable of performing ship escorting. In order to examine a more logical sample, those tugs under 150 GT were eliminated from consideration. Those tugs are typically too small and of limited power to be useful or even safe in the intended role. <u>All further analysis and discussion considered only those Canadian registered tugs in BC waters which are above 150 GT, which is selected as a reasonable indicator of tug size (typically more than 24 metres in length)</u>. That left the sample of only 32 tugs to consider, of which there is a smaller sub-set of 14 which are dedicated ship assist and/or escort tugs.

Although not part of the study mandate it was considered important to at least identify the approximate number of US registered tugs which could be in the vicinity of North Puget Sound or Juan de Fuca Strait. According to Owner websites, there are at least 55 tugs of a size that could be considered capable of rendering rescue towing capability, and 25 of those have more than 60 tonnes of Bollard Pull (BP). In BC there are only 11 tugs with this much thrust capability.

The International Tug of Opportunity System (ITOS) cited in the West Coast Spill Response Study (for BC Department of the Environment) has not existed for more than a decade. Most tugs operating in any specific geographic area can be readily identified through the international Automatic Identification System (AIS), but their towing capabilities are not identifiable in that system. To enable rapid identification of tugs with adequate capability, an extension of the AIS system must be created which can quickly identify the real escort and rescue towing capabilities of any tugs located in the vicinity of an incident. That system is currently NOT in place and will not be for several years.

There is an industry-funded Rescue Tug permanently stationed at Neah Bay in Washington State. However there is "no specific mechanism" for any cross-border cooperation regarding its potential use in response to an incident in Canadian waters. Should this tug be deployed to support an incident in Canadian waters it leaves the Washington coast unguarded, which suggests that it would be highly unlikely that the Neah Bay tug would be deployed unless there was a direct threat to the US coastline.

The Canadian fleet sample was broken down according to the primary functional role of each tug, and then finally those with a BP below 60 tonnes were eliminated due to insufficient power, as per Table ES1 below. Those with less than 70 tonnes BP were identified as only suitable for response in the summer months.

Table ES-1 Sample of BC Tugs suitable for Escort and Rescue Towing by Type Category

Vessel Name	Owner	BP (tonnes)	Length (metres)	*Coastal Towing*	*Ship-Assist*	*Escort*	*Rescue Capable*
SMIT MISSISSIPPI	SMIT HARBOUR TOWAGE VANCOUVER INC	65	30.6				summer only
SMIT CLYDE	SMIT HARBOUR TOWAGE VANCOUVER INC	65	30.6				summer only
SMIT HUMBER	SMIT HARBOUR TOWAGE VANCOUVER INC	65	30.6				summer only
SEASPAN RAVEN	SEASPAN ULC	71	28.2				
SEASPAN EAGLE	SEASPAN ULC	71	28.2				
SEASPAN KESTREL	SEASPAN ULC	81	28.2				no aft winch
SEASPAN OSPREY	SEASPAN ULC	81	28.2				no aft winch
SEASPAN RESOLUTION	SEASPAN ULC	82	30.0				no aft winch
SEASPAN COMMODORE	SEASPAN ULC	82	43.3				
SMIT ORLEANS	SMIT MARINE CANADA INC.	85	29.3				
SEASPAN ROYAL	SEASPAN ULC	93	40.6				

From this list, there are only six (6) BC-based tugs which have a clearly definable escort capability. Of that group, three are not fitted with aft towing winches and hence are incapable of rescue towing. That leaves only three tugs in BC which have the combined capability of performing escort and rescue towing in Juan de Fuca Strait. There are a total of 8 tugs in the sample which could be considered capable of performing rescue tows, but the two largest tugs in that group are most often engaged on longer tows and hence cannot be assured of being in the vicinity. Those tugs identified as escort capable are already part of the existing escort tug regime of risk-reducing measures, escorting laden tankers from Westridge Terminal to Race Rocks.

70 tonnes BP has been identified as the thrust necessary to provide about 93% of the rescue towing requirement in winter. It can then be reasonably argued that two tugs of that capability could satisfy the 99th percentile condition requirement of 110 tonnes, but that leaves a small margin of performance.

Based on the information available and the analysis performed, the following are recommended as <u>the minimum criteria</u> to be used for nominating a tug as suitable for either an escort or a rescue tug role in Juan de Fuca Strait:

- > **150 GT** - essentially identifies an absolute minimum size of tug which could handle the weather and sea state conditions in the Strait
- **BP** =/> **70 tonnes** - the minimum (calm water) thrust which should be available to enable rescue towing in winter (93rd percentile conditions)
- **Indirect Steering Force (F_s) at 10 knots** - the indirect steering force of any tug at 10 knots should be at least equal to its BP. However the assessment of the actual F_s requirement to prevent a tanker grounding anywhere along the tethered escort route is not part of this study and must be identified before proper conclusions can be drawn
- **Towline Size and Strength:**
  - **UTS** > **200 tonnes** - requires the towline breaking strength to be rated at approx. 3 x BP
  - **Length** > **610 metres** - suitable for deep sea towing

Based on the criteria above, the list of tug candidates which can be considered capable of rendering assistance to an Aframax size tanker in Juan de Fuca Strait is as follows:

A. <u>Escort Only – All Seasons</u>:

- ***Seaspan Kestrel***
- ***Seaspan Osprey***
- ***Seaspan Resolution***

B. <u>Rescue Only - Summer Only</u>:

- ***SMIT Mississippi***
- ***SMIT Clyde***
- ***SMIT Humber***

C. Rescue Only- All Seasons:

- ***Seaspan Commodore***
- ***Seaspan Royal***

D. Combined Escort and Rescue – All Seasons:

- ***Seaspan Raven***
- ***Seaspan Eagle***
- ***SMIT Orleans***

Particulars of all of these eligible tugs are summarized in Table ES-2 below:

Table ES-2 Escort Capable and Rescue Towing Capable Tugs in BC

Vessel Name	*Company*	*Length (m)*	*Beam (m)*	*Power (kW)*	*BP (tonnes)*	*Propulsion Type*	*Aft Towing Winch Details*
SMIT MISSISSIPPI	SMIT HARBOUR TOWAGE VANCOUVER INC	30.6	10.6	3660	65	Z-Drive	Hydraulic, single drum
SMIT CLYDE	SMIT HARBOUR TOWAGE VANCOUVER INC	30.6	10.6	3660	65	Z-Drive	Hydraulic, single drum
SMIT HUMBER	SMIT HARBOUR TOWAGE VANCOUVER INC	30.6	10.6	3660	65	Z-Drive	Hydraulic, single drum
SEASPAN RAVEN	SEASPAN ULC	28.2	12.6	3728	71	Z-Drive	Rolls-Royce single drum
SEASPAN EAGLE	SEASPAN ULC	28.2	12.6	3728	71	Z-Drive	Rolls-Royce single drum
SEASPAN KESTREL	SEASPAN ULC	28.2	12.6	4698	81	Z-Drive	no aft winch fitted
SEASPAN OSPREY	SEASPAN ULC	28.2	12.6	4698	81	Z-Drive	no aft winch fitted
SEASPAN RESOLUTION	SEASPAN ULC	30.0	12.2	4476	82	Z-Drive	no aft winch fitted
SEASPAN COMMODORE	SEASPAN ULC	43.3	10.9	4290	82	Twin Screw	Burrard Iron Works double drum type HK-D, 1280m wire port & 1158m wire starboard, tow pins c/w hold down blocks
SMIT ORLEANS	SMIT MARINE CANADA INC.	29.3	12.2	5050	85	Z-Drive	John Rie Series 525, capacity of 792m of 57mm wire
SEASPAN ROYAL	SEASPAN ULC	40.6	11.89	4623	93	Twin Screw	Burrard Iron Works double drum type HK-D, 914m wire port & 1158m wire starboard, tow pins

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Project 213-063
November 27, 2013
Rev. 3

An Evaluation of Local Escort and Rescue Tug Capabilities in Juan de Fuca Strait

For: Trans-Mountain Pipeline ULC
Calgary, AB

1.0 TERMS OF REFERENCE

Robert Allan Ltd. was retained by Trans Mountain Pipeline ULC to conduct a review of the capabilities of the local Canadian tug fleet to control a fully laden Aframax tanker, assumed to have suffered an engine or steering failure and drifting in the Strait of Juan de Fuca.

The agreed scope of work was as follows:

- Identify the range of environmental conditions (wind, wave, current) in the area of proposed tanker traffic
- Determine empirically the forces required to hold the nominated tanker in position in the identified range of environmental conditions (Note: No computer-based simulations were proposed.)
- Analyze the capability of existing Canadian tugs in the region against the determined forces when operating in those same sea states (i.e. factoring in a reduction in tug performance due to environmental conditions)

This report describes the work done and the findings of this study.

2.0 METHODOLOGY

Trans Mountain Pipelines provided Robert Allan Ltd. with a report by EBA Engineering Consultants Ltd. [1] on Met-Ocean conditions in areas relevant to the tanker route, including through Juan de Fuca Strait. That report provides information which was used to determine magnitudes and associated probabilities of occurrence of individual components of wind, waves, and current. These individual components were then evaluated together to obtain overall combined conditions expressed in terms of percentiles of occurrence. This analysis is summarized in Section 3.0 of this report.

For those environmental conditions of interest, force components were calculated using several different methods and refer to published data for a variety of tanker sizes.

Once overall forces on the tanker were determined, adjustments were made for the increase in required towing force due the effect of tanker yawing while under tow, as well as for the reduction in bollard pull due to tug motions in a seaway. This yields the overall requirement for tug "static" bollard pull for each environmental condition. These results are described in further detail in Section 4.0.

3.0 MET-OCEAN DATA

Information on the wind, waves and current in the study area was by taken from the report by EBA Engineering Consultants Ltd. [1]

The study area is illustrated in Figure 1 below:

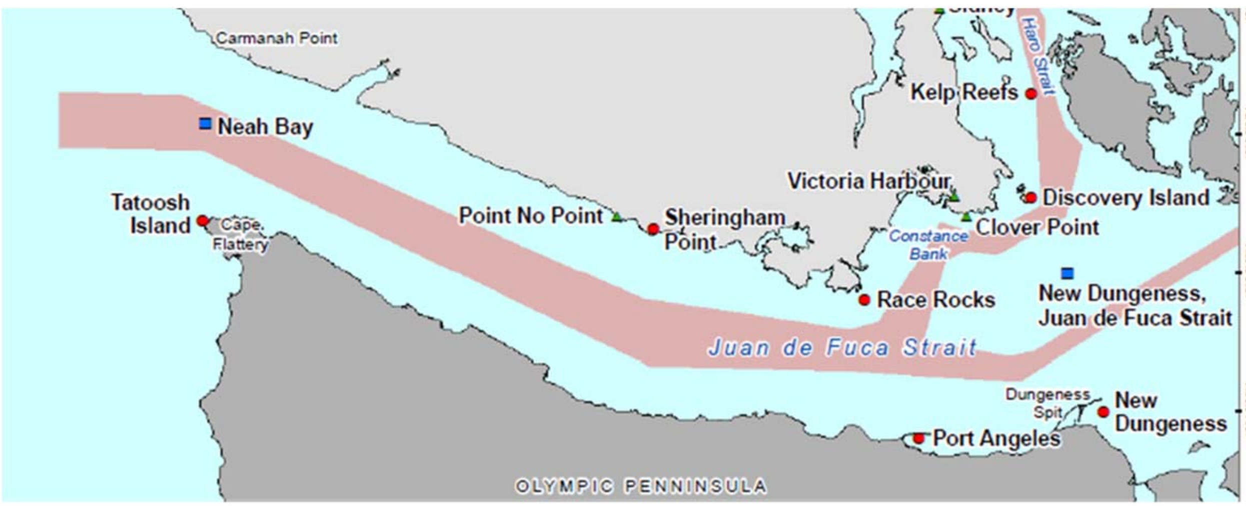

Figure 1 Juan de Fuca Strait

3.1 Wave Conditions

Presently there are wave buoys located near both extremities of Juan de Fuca Strait; one at Neah Bay (near Cape Flattery) and one at New Dungeness.

- **New Dungeness:**

  This buoy is located in a location protected from Pacific swells and as a result sees relatively calm water. The following statistics describe the waves in the area:

Winter	Summer
98.70% less than 2 m H_s	99.87% less than 2 m H_s

  Waves at New Dungeness are primarily from the West in summer. There is some scatter in the direction of the waves in the winter, but the magnitudes are small.

- **Neah Bay:**

  Being close to the open Pacific, Neah Bay logically presents the more challenging conditions. The following are values for waves from the West (SW to NW). These are predominant, and waves from other directions make up very small percentages.

Winter	Summer
99.96% less than 8 m H_s	99.97% less than 6 m H_s
99.44% less than 6 m H_s	99.71% less than 4 m H_s
93.39% less than 4 m H_s	97.18% less than 3 m H_s
77.44% less than 3 m H_s	81.72% less than 2 m H_s
99th percentile: < 6 m H_s	99th percentile: < 4 m H_s
93rd percentile: < 4 m H_s	97th percentile: < 3 m H_s

This clearly establishes the obvious, that there are more challenges in the winter than in the summer, although conditions more severe than 6 m significant wave height are only likely to occur on an average of one day per year. Given the infrequency of such conditions, it is likely possible to avoid transits through the Strait when waves at Neah Bay are in excess of 6 m significant wave height. The 99th percentile waves in winter are therefore a logical condition to consider as an extreme case within the Strait.

Waves of more than 4 m significant wave height are also quite rare, with 93% less than this height in winter at Neah Bay, and nearly all smaller than 4 m in summer. Wave drift loads on a vessel decrease very quickly with reductions in wave height, so it becomes much more realistic for a single moderately powerful tug to perform a rescue in such conditions. Conditions requiring a more powerful tug, or possibly a second tug, would only occur approximately 13 days per year. Therefore, the 93rd percentile winter wave condition (also the 99.7th percentile condition in summer) represents an interesting condition for evaluating tug bollard pull requirements for the vast majority of the year.

Waves are still less than 3 m significant height for the majority of the winter, and in fact nearly all of the summer, but the relative frequency of larger waves in the winter means that any tug just powerful enough for these conditions would frequently need help. Therefore, this condition was not investigated any further.

As there is no buoy in the middle of the Strait, it is difficult to estimate how quickly the waves dissipate on their way to the east end of the Strait. The wave buoy at New Dungeness is partially sheltered so any interpolation would be quite questionable. Therefore, this study only considers waves reported by the buoy at Neah Bay, which adds a degree of conservatism for areas which are significantly east of the buoy.

The following conditions were thus selected for calculation of wave forces:

- 99^{th} percentile winter waves: 6 m H_s
- 93^{rd} percentile winter waves: 4 m H_s

3.2 Wind Conditions

There are weather stations recording wind at Tatoosh Island (west entrance), Sheringham Point (mid-Strait), and Race Rocks (east entrance). Although there is some scatter in the wind directions at these stations, westerly winds are very common (in some cases predominant), and have the potential to be additive to the wave loads from the west. Therefore, the following statistics are for westerly winds only (NW to SW) rather than overall, since these have an impact on the required bollard pull of the tugs.

- **Tatoosh Island:**

  This station is positioned at the tip of Cape Flattery and may be affected as a result (there appears to be a blind spot north of the station). Taken at face value, winds are predominantly from the south in the winter, although westerlies are common. In the summer, easterlies are the most common, but some strong winds do come from the west. Data compiled for westerly winds (NW to SW) are as follows:

Winter	Summer
99.27% below 35 knots	99.80% below 35 knots
98.26% below 29 knots	99.51% below 29 knots
96.04% below 23 knots	98.75% below 23 knots
92.41% below 17.5 knots	96.92% below 17.5 knots

- **Sheringham Point:**

  In the summer, nearly all wind is from the west (or WNW). In winter, there is some scatter, but most of the high winds come from the west. The following statistics are compiled for the westerly winds:

Winter	Summer
99.58% below 35 knots	99.95% below 35 knots
98.63% below 29 knots	99.68% below 29 knots
97.06% below 23 knots	96.41% below 23 knots
92.96% below 17.5 knots	82.86% below 17.5 knots

- **Race Rocks:**

  In the summer, nearly all wind at Race Rocks is from the west. In winter, there is quite a bit of scatter, but the most common direction for the high winds is also from the west. The statistics for those westerly winds are as follows.

Winter	Summer
99.24% below 35 knots	99.54% below 35 knots
97.51% below 29 knots	95.89% below 29 knots
93.34% below 23 knots	84.04% below 23 knots
87.70% below 17.5 knots	63.74% below 17.5 knots

Unlike with the waves, there is generally no relaxation in winds in the eastern end of the Strait, when compared to the west.

3.3 Current

Currents in Juan de Fuca Strait are rather logically mostly west to east and east to west, and may be summarized as follows:

Winter	Summer
99th percentile: 1.5 m/s	99th percentile: 1.9 m/s
93rd percentile: 1.3 m/s	93rd percentile: 1.6 m/s

3.4 Overall Met-Ocean Statistics

As discussed in Section 3.1, it is clear that conditions at Neah Bay in the winter are the limiting case for defining imposed wind and wave loads on a ship and hence the associated tug requirements. The 99th and 93rd winter season percentiles were selected as important conditions for evaluation of wave forces. These same percentiles can be selected for wind and current, although this is likely conservative. For example, there is no guarantee that the 99th percentile high winds or current will occur simultaneously with the 99th percentile waves. Nonetheless, assuming simultaneous wind, wave, and current loads at the same percentiles is a convenient approach, and one that likely results in some conservatism for the cases being considered.

The following are therefore the approximate overall percentiles:

- 99th percentile (Neah Bay, winter) - Waves 6 m, Winds 34 knots, Current 1.5 m/s
- 93rd percentile (Neah Bay, winter) - Waves 4 m, Winds 21 knots, Current 1.3 m/s

The latter condition is also quite close to the 100th percentile in summer. A tug which can handle a disabled tanker in the 93rd percentile winter condition will also be able to handle virtually all conditions in the summer.

<u>Conclusion 1</u>: The following are deemed appropriate as the limiting conditions in which a rescue tug ought to be able to effect control over a tanker in Juan de Fuca Strait:

- **99th percentile (Neah Bay, winter):**
  - **Waves 6 m, Winds 34 knots, Current 1.5 m/s**
- **93rd percentile (Neah Bay, winter):**
  - **Waves 4 m, Winds 21 knots, Current 1.3 m/s**

4.0 FORCES ON TANKERS

4.1 Design Case Tanker

The defined requirement was to identify the required tug capabilities with respect to an Aframax tanker, which is defined as a tanker of more than 80,000 tonnes but less than 120,000 tonnes DWT. For the purposes of this study, a large Aframax tanker of 120,000 tonnes DWT is assumed, which represents a "worst-case" scenario. The following principal dimensions are used as representative, and are approximately equal to those of the large Aframax tanker ***Erik Spirit***:

- Deadweight - 120,000 tonnes
- Length OA - 249.9 metres
- Beam - 43.9 metres
- Load Draft - 14.9 metres

It should be noted that the forces derived, as discussed below, will vary somewhat according to vessel size and load state; smaller or more lightly laden tankers will require less tug power and larger vessels will require more. A detailed matrix of tug power vs. tanker size and weather conditions is beyond the terms of reference of this study.

4.2 Forces

For each climactic condition of interest (Section 3.4), forces for current, wind, and waves were individually calculated using separate methods prior to summation of the overall forces on the tanker.

The most authoritative source of information for wind and current forces is the Mooring Equipment Guidelines, published by OCIMF [2]. This publication provides individual force coefficients for current and wind derived from model tests, which are specifically for oil tankers and LNG gas carriers. These coefficients were then be used in standard formulae to obtain overall current and wind loads in the longitudinal direction on the design case Aframax tanker.

It is important to note that the summation of forces in the longitudinal direction is not equal to the tug's required towline force to overcome the wind, wave, and current forces on the tanker. When towed, especially at very low speeds, a tanker yaws, which introduces a transverse force component which adds to the tug's total towline tension. For the purposes of this report, this effect is called the "Y-factor", and it is different for the various force components due to the difference in the tanker's geometry above and below the waterline. In the case of current and waves, the transverse component of each force on the tanker can be equal to the longitudinal force component due to tanker yaw, which effectively increases the tug's required towline force by up to 41%.

By using the recommended wind and current coefficients from the Mooring Equipment Guidelines [2], and applying a representative Y-factor, the following wind and current loads are calculated, expressed in terms of required towline tension:

- Wind force (at zero speed of advance):
  - 34 knots - 18 tonnes
  - 21 knots - 8 tonnes
- Current force (at zero speed of advance):
  - 1.5 m/s - 24 tonnes
  - 1.3 m/s - 18 tonnes

Wave force coefficients are not published in OCIMF's Mooring Equipment Guidelines. However, another OCIMF publication [3] on tanker drift studies provides some combined wind and wave forces for a VLCC in various sea states, based on experimental results and numerical models. Some manipulation of this data was necessary to remove the wind component, as well as some scaling to suit an Aframax tanker.

Robert Allan Ltd. has also previously performed computational fluid dynamics (CFD) simulations in order to determine wave loads on VLCCs. These can be scaled as well in order to obtain approximate wave forces on an Aframax tanker in the sea states of interest. Results from this method compare very well with those based on OCIMF's drift studies described above.

A publication of the National Academy of Sciences (USA) [4] provides wave forces for a range of tanker sizes, based on the results from a program named OCMOTA, developed by the Maritime Research Institute of the Netherlands (MARIN) for OCIMF. These results can be extracted quite easily for the design case Aframax tanker.

After adjustment for the Y-factor, these three methods converge towards the following wave forces, expressed in terms of required towline tension:

- Wave Forces (at zero speed of advance):
  - 6 m H_s - 42 tonnes
  - 4 m H_s - 28 tonnes

When added together, the three force components (wind, waves and current) equal the required <u>effective towline force</u> that a tug must provide in order to simply hold station against the defined environmental forces. However, when operating in the sea states considered in this study, the tug's effective towline pull is reduced due to tug motions (and potentially propeller emergence), as well as the relative motions between the tug and the tanker. The Marine Salvage Study of the National Academy of Sciences [4] provides guidance on these losses in efficiency, which can be summarized as:

- Tug Efficiency Ratings:
  - 6 m H_s - 76%
  - 4 m H_s - 80%

It should be noted that these tug efficiencies are generally valid for conventional twin screw and azimuthing stern drive (ASD) tug configurations, which currently accounts for virtually the entire tug fleet in BC, there being only a very few much older single screw tugs still in service. Tug propulsion configurations with more deeply submerged propellers will likely have somewhat higher efficiencies, but no reference on this topic considers anything above 80%.

With these values for efficiency, the individual force components can now be summed, per Table 4.1 below, to obtain a total required "calm water" Bollard Pull (BP) value for the tugs.

Table 4.1 Required Tug Bollard Pull vs. Met-Ocean Conditions

Component	**93rd Percentile (4 m H_s, 21 knots wind, 1.3 m/s current)**	**99th Percentile (6 m H_s, 34 knots wind, 1.5 m/s current)**
Wind Force	8 tonnes	18 tonnes
Current Force	18 tonnes	24 tonnes
Wave Force	28 tonnes	42 tonnes
Subtotal	54 tonnes	84 tonnes
Tug Efficiency	80%	76%
Bollard Pull Required	**68 tonnes**	**110 tonnes**

Conclusion 2: The Bollard Pull ratings required of a rescue tug (or tugs) in Juan de Fuca Strait are as follows:

- **93rd percentile (winter) = 68 tonnes**
- **99th percentile (summer) = 68 tonnes**
- **99th percentile winter = 110 tonnes**

It should be noted again that the forces defined above relate solely to those required to control a 120,000 t DWT. Aframax tanker in the defined percentile conditions. Smaller vessels, or more lightly laden tankers will require less tug power.

5.0 THE WEST COAST TUG FLEET

5.1 The Canadian Tug Fleet

There are currently approximately **1,200** tugs registered in the Canadian "Pacific Region" (according to the Transport Canada Vessel Registry), however that large number is extremely misleading in the context of tugs capable of working at sea in a rescue or escort towing mode. The data is also somewhat unreliable as there were a number of vessels included in the registry which are either not tugs, or which operate in other locales such as the Mackenzie River. The majority of those anomalies however have been weeded out in the course of this analysis. As shown in Table 5.1 below, almost half of those are very small tugs used in the logging industry to organize log booms and do small "yarding" tasks (Figure 5.1). These tugs invariably measure under 5 Gross Tons (GT) and hence are not subject to any rules of design or construction under Transport Canada. Another large number are small tugs working in the small ports and rivers of the coast which measure under 15 GT in order to avoid inspection by Transport Canada. These tugs are almost exclusively under about 15 metres in length and cannot be considered as "sea-going" in any context. (Figure 5.2). Vessels which do fall under Transport Canada's purview form another group, which measure between 15 and 150 GT. The latter hurdle is the threshold above which vessels are subject to annual inspections rather than quadrennial inspections. Tugs or 15 to 150 GT are typically under 24 metres in length, would typically have propulsive power between 900 and 1,350 kW (1,200 and 1,800 bhp), and would primarily be used in coastal log and barge towing. That leaves a much smaller cadre of only about 32 tugs (> 150 GT) which are engaged principally in the business of towing barges along the BC coast, the majority of which are quite small (under 30 metres in length) (Figure 5.3) and some of which, engaged in towing larger barges and often on the exposed West Coast, are considerably larger and are close to or exceed 500 GT (Figure 5.4).

Table 5.1 Active Vessels in Canada's Pacific Region Registry by GT Categories

Pacific Region	
Vessel Size	**Number of Tugs**
< 5 GT	607
5 < GT < 15	430
15 < GT < 150	181
150 < GT < 500	29
GT > 500	3

There is a much smaller group of tugs whose primary function is ship-handling, and even fewer that are properly equipped for and capable of performing ship escorting. These purpose-designed tugs (Figure 5.5) tend to be congregated in the Port of Vancouver and environs, and to a much lesser degree in Prince Rupert.

Obviously not all of the tugs registered can be considered as capable of providing tanker support in Juan de Fuca Strait. In order to examine a more logical sample those tugs under 150 GT have been eliminated from consideration. Those tugs are typically too small and of limited power to be useful or even safe in the intended role. <u>All further discussion in this report therefore considers only those Canadian registered tugs in BC waters which are above 150 GT, which is selected as a reasonable indicator of tug size (typically more than 24 metres in length)</u>.

Table 5.2 lists the names of tugs and their Owners, and shows the particulars of those Canadian West Coast tugboats which are in excess of 150 GT. It is a modest list of only 32 tugs distributed along the entire BC coast.

Table 5.3 lists and shows the particulars of the much smaller sub-set of 14 West Coast tugs, extracted from the set shown in Table 5.2, which are dedicated ship assist or escort tugs. It should be noted that occasionally some of the other more conventional tugs in Table 5.2 will also be used for ship-handling, but in general those tugs are not designed for, nor well-equipped for that service.

<u>Conclusion 3</u>: Although there are more than 1,200 tugboats registered in BC, only about 32 of these are of a size which can even remotely be considered suitable for operation in a rescue tug role, being more than 150 GT. Of that total only a handful have the size and power necessary to be considered seriously for a rescue tug role in the exposed waters of Juan de Fuca Strait.

<u>Conclusion 4</u>: Only 14 tugs > 150 GT in BC have been specifically designed and equipped to operate as ship-handling tugs, and of that number only 6 could be considered as serious tanker escort tugs.

Figure 5.1 Typical small yarding tugs like the one at left make up half of the BC tug fleet.

Figure 5.2 Tugs under 15 GT, such as the vessel to right, avoid Inspection by Transport Canada.

Figure 5.3 (below) Coastal tugs < 150 GT, as shown below, are typical for towing barges on the BC coast.

Figure 5.4 Tugs of 500 GT and larger are more typical for larger coastal tows, and on the exposed West Coast.

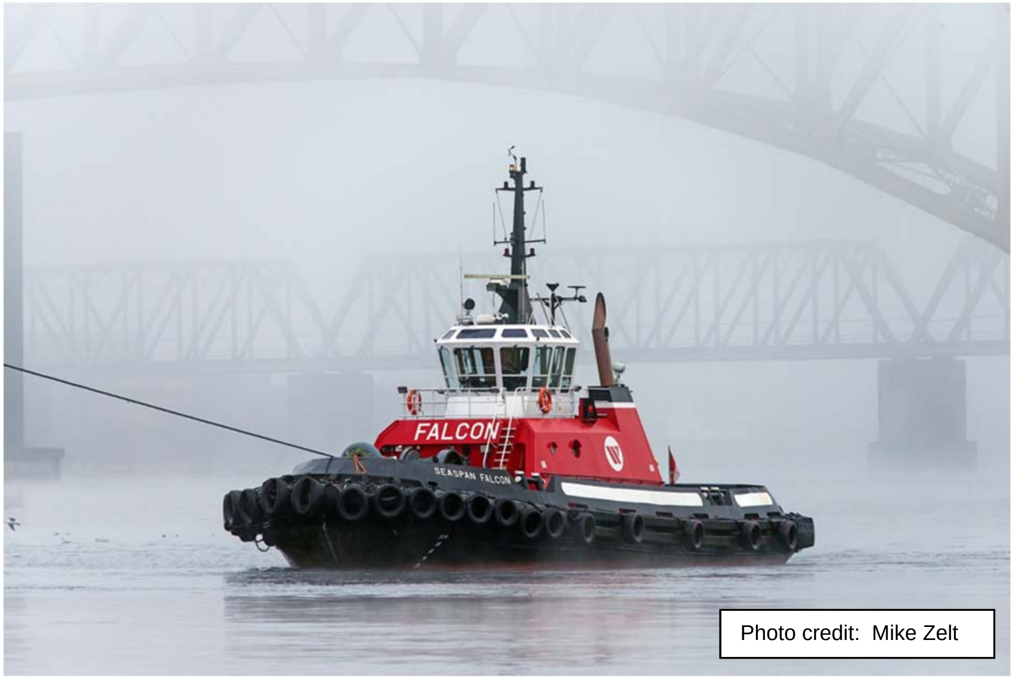

Figure 5.5a Typical Vancouver Harbour Z-Drive Ship-Assist Tug, 50 Tonnes BP

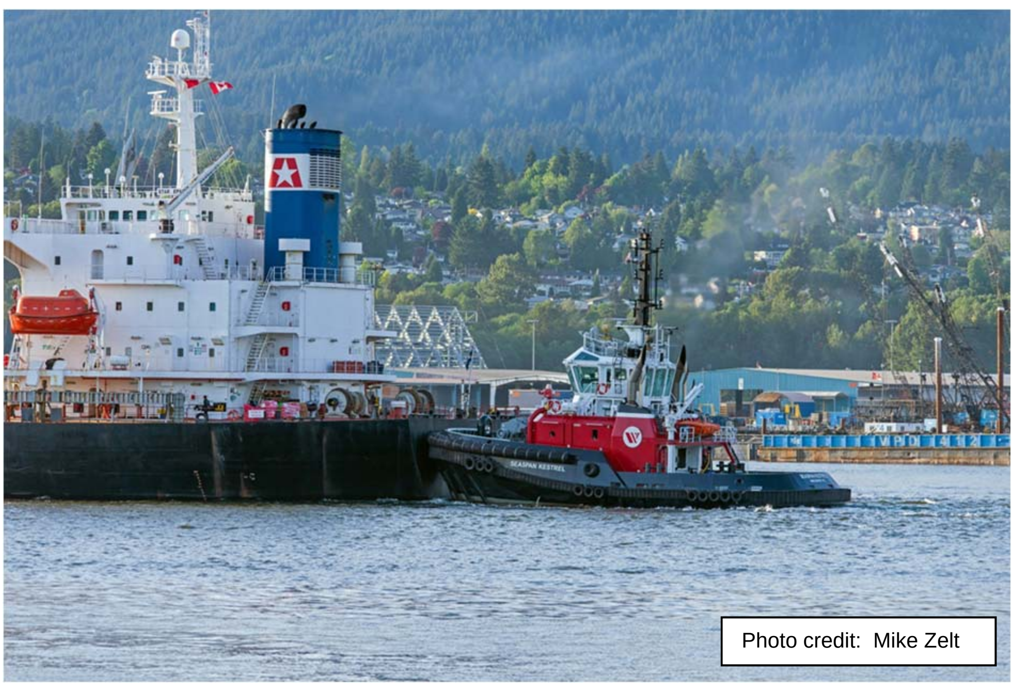

Figure 5.5b Dedicated Terminal Support/Escort Tug, 28 metres, 70-80 tonnes BP. Vessels of this class are the largest and most powerful tugs of this type on the BC coast.

Table 5.2 BC Coastal Tugs > 150 GT

Vessel Name	Company	Year Built	Length (m)	Beam (m)	Power (kW)	BP Ahead (t)	Propulsion Type	Aft Towing Winch Details
NEVA STRAITS	SEA-LINK MARINE SERVICES LTD.	1962	26.4	7.6	984	18	Single Screw	aft winch fitted: details unknown
JOSE NARVAEZ	LAFARGE CANADA INC.	1969	24.6	7.3	1081	20	Single Screw	aft winch fitted: details unknown
SEA WARRIOR	SEA-LINK MARINE SERVICES LTD.	1959	27.6	8.0	1141	21	Single Screw	aft winch fitted: details unknown
PACIFIC RANGER II	PACIFIC TOWING SERVICES LTD.	1975	25.1	8.1	1268	23	Twin Screw	aft winch fitted: details unknown
OCEAN CLIPPER	PACIFIC CACHALOT LTD.	1965	26.5	8.3	1342	24	Single Screw	aft winch fitted: details unknown
ISLAND SCOUT	ISLAND TUG AND BARGE LTD.	2001	23.9	7.5	1268	25	Twin Screw	Burrard Iron Works HF,single drum, 823 m of 45 mm wire 80 ton capacity, tow pins c/w hold down block
SEASPAN QUEEN	SEASPAN ULC	1964	29.0	8.0	1275	26	Twin Screw	Burrard Iron Works HF - single drum, 549m capacity, tow pins c/w hold down block
ARCTIC TAGLU	SEA-LINK MARINE SERVICES LTD.	1976	31.5	10.4	1678	31	Twin Screw	aft winch fitted: details tbd
ARCTIC HOOPER	SEA-LINK MARINE SERVICES LTD.	1976	31.1	10.4	1678	31	Twin Screw	aft winch fitted: details tbd
SEASPAN PACER	SEASPAN ULC	1967	29.0	7.9	1676	34	Twin Screw	Burrard Iron Works HJL - single drum, 549m capacity, tow pins c/w hold down block
SEASPAN MONARCH	SEASPAN ULC	1977	34.8	9.1	1940	39	Twin Screw	Burrard Iron Works HJL - 792m capacity, tow pins c/w hold down block
SEASPAN FALCON	SEASPAN ULC	1993	24.6	9.8	2312	40	Z-Drive	no aft winch fitted
SEASPAN HAWK	SEASPAN ULC	1993	24.6	9.8	2312	40	Z-Drive	no aft winch fitted
ISLAND TUGGER	ISLAND TUG AND BARGE LTD.	1981	35.9	10.4	2274	41	Twin Screw	Burrard Iron Works HF-D double drum, 823 m of 45 mm wire on each drum 80 ton capacity, towing pins c/w hold down hooks
ISLAND MONARCH	ISLAND TUG AND BARGE LTD.	1966	41.5	9.8	2237	41	Twin Screw	Burrard Iron Works HID double drum, 790 m of 51 mm wire on each drum 120 ton capacity, towing pins c/w hold down hooks
SEA COMMANDER	SEA-LINK MARINE SERVICES LTD.	1945	43.5	10.1	2282	42	Single Screw	aft winch fitted: details unknown
SMIT NASS	SMIT MARINE CANADA INC.	1979	30.2	11.0	2655	45	Z-Drive	no aft winch fitted
SMIT SKEENA	SMIT MARINE CANADA INC.	1979	30.3	11.0	2655	45	Z-Drive	no aft winch fitted
SEASPAN KING	SEASPAN ULC	1968	40.2	9.8	2684	49	Single Screw	Burrard Iron Works HJS - 1158m capacity, tow pins c/w hold down block
SMIT TIGER SUN **	SMIT MARINE CANADA INC.	1999	21.7	10.7	4027	53	Z-Drive	no aft winch fitted
SMIT MISSISSIPPI	SMIT HARBOUR TOWAGE VANCOUVER INC	1999	30.6	10.6	3660	65	Z-Drive	Hydraulic, single drum
SMIT CLYDE	SMIT HARBOUR TOWAGE VANCOUVER INC	2000	30.6	10.6	3660	65	Z-Drive	Hydraulic, single drum
SMIT HUMBER	SMIT HARBOUR TOWAGE VANCOUVER INC	2000	30.6	10.6	3660	65	Z-Drive	Hydraulic, single drum
SEASPAN RAVEN	SEASPAN ULC	2009	28.2	12.6	3728	71	Z-Drive	Rolls-Royce single drum
SEASPAN EAGLE	SEASPAN ULC	2011	28.2	12.6	3728	71	Z-Drive	Rolls-Royce single drum
SEASPAN KESTREL	SEASPAN ULC	2011	28.2	12.6	4698	81	Z-Drive	no aft winch fitted
SEASPAN OSPREY	SEASPAN ULC	2011	28.2	12.6	4698	81	Z-Drive	no aft winch fitted
SEASPAN RESOLUTION	SEASPAN ULC	2008	30.0	12.2	4476	82	Z-Drive	no aft winch fitted
SEASPAN COMMODORE	SEASPAN ULC	1974	43.3	10.9	4290	82	Twin Screw	Burrard Iron Works double drum type HK-D, 1280m wire port & 1158m wire starboard, tow pins c/w hold down blocks
SMIT ORLEANS	SMIT MARINE CANADA INC.	2007	29.3	12.2	5050	85	Z-Drive	John Rie Series 525, capacity of 792m of 57mm wire
SEASPAN ROYAL	SEASPAN ULC	1981	40.6	11.9	4623	93	Twin Screw	Burrard Iron Works double drum type HK-D, 914m wire port & 1158m wire starboard, tow pins

<u>Note</u>: BP values shown in red are estimated based on known power and propulsion type.
SMIT Tiger Sun is just < 150 GT but is included here as one of the more powerful tugs in Vancouver Harbour

Table 5.3 Dedicated Ship-Handling and/or Escort Tugs in BC > 150 GT

Vessel Name	Company	Length (m)	Beam (m)	Power (kW)	BP Ahead (t)	Propulsion Type	Towing Winch Details
SEASPAN FALCON	SEASPAN ULC	24.6	9.8	2312	40	Z-Drive	no aft winch fitted
SEASPAN HAWK	SEASPAN ULC	24.6	9.8	2312	40	Z-Drive	no aft winch fitted
SMIT NASS	SMIT MARINE CANADA INC.	30.2	11.0	2655	45	Z-Drive	no aft winch fitted
SMIT SKEENA	SMIT MARINE CANADA INC.	30.3	11.0	2655	45	Z-Drive	no aft winch fitted
SMIT TIGER SUN **	SMIT MARINE CANADA INC.	21.7	10.7	4027	53	Z-Drive	no aft winch fitted
SMIT MISSISSIPPI	SMIT HARBOUR TOWAGE VANCOUVER INC	30.6	10.6	3660	65	Z-Drive	Hydraulic, single drum
SMIT CLYDE	SMIT HARBOUR TOWAGE VANCOUVER INC	30.6	10.6	3660	65	Z-Drive	Hydraulic, single drum
SMIT HUMBER	SMIT HARBOUR TOWAGE VANCOUVER INC	30.6	10.6	3660	65	Z-Drive	Hydraulic, single drum
SEASPAN RAVEN	SEASPAN ULC	28.2	12.6	3728	71	Z-Drive	Rolls-Royce single drum
SEASPAN EAGLE	SEASPAN ULC	28.2	12.6	3728	71	Z-Drive	Rolls-Royce single drum
SEASPAN KESTREL	SEASPAN ULC	28.2	12.6	4698	81	Z-Drive	no aft winch fitted
SEASPAN OSPREY	SEASPAN ULC	28.2	12.6	4698	81	Z-Drive	no aft winch fitted
SEASPAN RESOLUTION	SEASPAN ULC	30.0	12.2	4476	82	Z-Drive	no aft winch fitted
SMIT ORLEANS	SMIT MARINE CANADA INC.	29.3	12.2	5050	85	Z-Drive	John Rie Series 525, capacity of 792m of 57mm wire

Note: BP values shown in red are estimated based on known power and propulsion type.

5.2 U.S. Tug Fleet

The terms of reference for this study did not include any review of the US tug fleet operating in proximity to Juan de Fuca Strait, however it is too important to ignore. The presence of major oil refineries in Northern Washington State, specifically at Cherry Point and in Anacortes, dictated that some quite significant tugs had to be built to support those operations and to provide a highly capable system of terminal support and escort tugs. In addition there is a fairly sizeable fleet of larger, powerful tugs routinely engaged in towing barges to Alaska, almost exclusively travelling through the Inside Passage waters of BC.

Table 5.4 identifies the fleet of US tugs which are, according to their Owner's web-sites, based in Puget Sound and which are described as "Ocean-Going". The table also highlights those tugs which are dedicated to oil terminal support and tanker escort service and the latter group includes two significant dedicated tanker escort tugs, the ***Garth Foss*** (Figure 5.6) and ***Lindsey Foss***, both serving North Puget Sound.

Figure 5.6 79 Tonne BP VSP Escort Tug *Garth Foss*

It is critically important in the context of this study to understand any restrictions or commitments which may exist with respect to the potential deployment of any of these US registered tugs in the event of an emergency on the Canadian side of the border. Their fleet is in general larger and more capable for escort and rescue towing than are almost any Canadian tugs. That evaluation was not however a part of the current limited tasking covered by this study.

Among the US fleet are many large and capable tugs. Many of these routinely tow barges between Washington and Alaska and hence cannot reliably be said to regularly be "in the vicinity". However there are quite a number of very large and powerful escort capable tugs, dedicated to the support of tanker movements and terminal operations in North Puget Sound, whose capabilities to execute emergency response manoeuvres would greatly influence the number of available tugs in this study.

Conclusion 5: Any regulatory or industry cooperative agreements which are in place with respect to US registered tugs acting in Canadian waters in an emergency response role need to be identified and clarified.

Table 5.4 Major US "Ocean-Going" Tugs Located in Puget Sound and Alaska Waters

Tug Name	Company	Type	Power		Length		BP	Location per AIS - Nov 25, 2013
			bhp	kW	ft	metres	tonnes	
Keegan Foss	Foss Maritime	TS	3900	2909	110.0	33.5	33	Oakland, CA
Pacific Escort	Foss Maritime	ASD	3000	2238	100.2	30.5	35	Columbia River, OR
Western Mariner	Western Towboat Co.	TS	3000	2238	90.0	27.4	41	Unkown position
Daniel Foss	Foss Maritime	ASD	3300	2462	95.2	29.0	41	Portland, OR (assigned to Valdez area according to Crowley website)
Stacey Foss	Foss Maritime	TS	2800	2089	102.4	31.2	42	Seattle, WA
Ocean Navigator	Western Towboat Co.	TS	3100	2313	83.7	25.5	42	Port McNeill, BC
Western Navigator	Western Towboat Co.	TS	3100	2313	94.0	28.6	42	Inside Passage, BC
Ocean Mariner	Western Towboat Co.	TS	3200	2387	94.0	28.6	44	Seattle, WA
Arthur Foss	Foss Maritime	VSP	4000	2984	107.0	32.6	44	Long Beach, CA
Tioga	Crowley Maritime Corp.	ASD	4400	3282	N/A	N/A	46	Seattle, WA
Henry Foss	Foss Maritime	VSP	5000	3730	100.0	30.5	47	Seattle, WA
Western Ranger	Western Towboat Co.	TS	3420	2551	N/A	N/A	47	Seattle, WA
Justine Foss	Foss Maritime	TS	4300	3208	126.0	38.4	49	Gulf of Alaska
Andrew Foss	Foss Maritime	*Tractor-plus = 2 x VSP plus 1 Z-drive*	4290	3200	106.7	32.5	49	Tacoma, WA
Chief	Crowley Maritime Corp.	VSP	4800	3581	N/A	N/A	51	Tacoma, WA
Guide	Crowley Maritime Corp.	VSP	4800	3581	N/A	N/A	51	Tacoma, WA
Weddel Foss	Foss Maritime	VSP	5000	3730	100.0	30.5	52	Anacortes, WA
Brynn Foss	Foss Maritime	VSP	4700	3506	100.0	30.5	52	Los Angeles, WA
Protector	Crowley Maritime Corp.	VSP	5500	4103	N/A	N/A	54	Port Angeles, WA
Alaska Mariner	Western Towboat Co.	TS	4000	2984	108.8	33.1	54	Seattle, WA
Ocean Ranger	Western Towboat Co.	TS	4200	3133	117.0	35.6	57	Seattle, WA
Pacific Titan	Western Towboat Co.	ASD	4500	3357	108.0	32.9	58	Seattle, WA
Western Titan	Western Towboat Co.	ASD	4500	3357	108.0	32.9	58	Prince Rupert, BC
Gulf Titan	Western Towboat Co.	ASD	4500	3357	120.0	36.6	58	Gulf of Alaska
Barbara Foss	Foss Maritime	TS	4300	3208	118.7	36.2	60	Seattle, WA
Guardian	Crowley Maritime Corp.	TS	5750	4290	N/A	N/A	61	Alaska (assigned to Valdez area according to Crowley website)
Goliath	Crowley Maritime Corp.	ASD	4400	3282	N/A	N/A	63	Seattle, WA (assigned to San Francisco Bay area according to Crowley website)
Jeffrey Foss	Foss Maritime	TS	4300	3208	120.0	36.6	64	*on station at Neah Bay, WA*
Alaska Titan	Western Towboat Co.	ASD	5000	3730	120.0	36.6	65	Seattle, WA
Ocean Titan	Western Towboat Co.	ASD	5000	3730	120.0	36.6	65	Seattle, WA
Arctic Titan	Western Towboat Co.	ASD	5000	3730	120.0	36.6	65	Juneau, AK
Bulwark	Crowley Maritime Corp.	TS	7200	5371	N/A	N/A	68	Prince Rupert (assigned to Valdez area according to Crowley website)
Invader	Crowley Maritime Corp.	TS	7200	5371	N/A	N/A	68	Portland, OR (assigned to Valdez area according to Crowley website)
Hunter	Crowley Maritime Corp.	TS	7200	5371	N/A	N/A	68	Gulf of Alaska
Stalwart	Crowley Maritime Corp.	TS	7200	5371	N/A	N/A	68	Valdez, AK
Response	Crowley Maritime Corp.	VSP	7240	5401	N/A	N/A	70	Anarcortes, WA
Marshall Foss	Foss Maritime	ASD	6250	4663	98.0	29.9	76	Oakland, CA
Lynn Marie	Foss Maritime	ASD	6250	4663	98.0	29.9	77	San Francisco, CA
Garth Foss	Foss Maritime	VSP	8000	5968	155.0	47.2	79	Anacortes, WA
Lindsey Foss	Foss Maritime	VSP	8000	5968	155.0	47.2	79	Anacortes, WA
America	Foss Maritime	ASD	6610	4931	98.0	29.9	80	Berkeley, CA
Endurance	Crowley Maritime Corp.	TS	5750	4290	N/A	N/A	82	Juneau, AK (assigned to Valdez area according to Crowley website)
Pacific Star	Foss Maritime	ASD	6610	4931	98.0	29.9	82	Seattle, WA
Vigilant	Crowley Maritime Corp.	ASD	6700	4998	N/A	N/A	83	Anacortes, WA (assigned to Cook Inlet, AK area according to Crowley website)
Valor	Crowley Maritime Corp.	ASD	6772	5052	N/A	N/A	83	San Francisco, CA (assigned to Valdez according to Crowley website)
Delta Lindsey	Foss Maritime	ASD	6850	5110	100.0	30.5	85	Berkeley, CA
Pacific Explorer	Foss Maritime	ASD	4400	3282	99.0	30.2	85	Juneau, AK
Nanuq	Crowley Maritime Corp.	VSP	10192	7603	153.0	46.6	94	permanently stationed in Valdez AK
Tan'erliq	Crowley Maritime Corp.	VSP	10192	7603	153.0	46.6	94	permanently stationed in Valdez AK
Corbin Foss	Foss Maritime	TS	8000	5968	149.8	45.6	97	Panama
Lauren Foss	Foss Maritime	TS	8000	5968	149.8	45.6	98	Seattle, WA
Sea Voyager	Crowley Maritime Corp.	TS	7200	5371	N/A	N/A	109	Alaska (assigned to Valdez area according to Crowley website)
Alert	Crowley Maritime Corp.	ASD	10192	7603	140.0	42.7	125	permanently stationed in Valdez AK
Attentive	Crowley Maritime Corp.	ASD	10192	7603	140.0	42.7	125	permanently stationed in Valdez AK
Aware	Crowley Maritime Corp.	ASD	10192	7603	140.0	42.7	125	permanently stationed in Valdez AK

Note: BP values shown in red are estimated based on known power and propulsion type.

5.3 Tug of Opportunity System

In about 1997 the USCG endorsed an industry coordinated "International Tug of Opportunity System" (ITOS) which identified those tugs with some rescue towing capability, and equipped each of those vessels with a transponder unit, enabling the rapid locating of any of those tugs in the event of an incident. At the time of its initiation the system involved both US and Canadian tugs.

The West Coast Spill Response Study, Volume 1 [5] states the following:

> *"BC currently relies on a tug-of-opportunity system for rescue services. A tug-of-opportunity system provides a less costly but also less certain rescue tug response capacity by relying on nearby commercial tugs to provide rescue services, if needed. The Canadian and US vessel traffic services track tug availability as part of the International Tug of Opportunity System (ITOS), which allows for a quick assessment of nearby tugs in the event of an emergency. There is no guarantee that appropriately sized or capable tugs-of-opportunity will be available or proximate to the vessel in need of assistance. If a tug-of-opportunity already has a vessel or barge in tow, there may be additional delays associated with safely releasing the primary tow so that the tug can respond to the emergency. Tugs-of-opportunity can be an effective prevention measure for certain types of accidents (i.e. drift groundings), but would not be as effective as an escort tug in preventing collisions or powered groundings. (USCG, 1999)*

The statement "*if a tug of opportunity already has a vessel or barge in tow…*" indicates a distinct lack of understanding of the nature of marine traffic on the BC coast. There are VERY few tugs which are ever going anywhere on this coast without something in tow; that is the nature of maritime commerce in this Province.

However telephone and email contacts with both the Council of Marine Carriers in BC (representing the majority of tug owners in the Province), and with the Marine Exchange of Puget Sound (MEPS) confirmed that the ITOS has not existed for about 10 years. The assumptions of the West Coast Spill Response Study are clearly inaccurate. With the advent of the International Maritime Organization (IMO) regulated shipboard "Automatic Identification System" (AIS) and with the implementation of the dedicated standby/rescue tug at Neah Bay (Ref. Section 5.4) the ITOS system was made effectively redundant. However AIS is only required on ships over 300 GT engaged on international voyages, and so many tugs in local waters would not necessarily have this equipment fitted. Although the AIS system can quickly identify the participating vessels in any geographic area, at present it does not have the capability to identify the specific characteristics of the vessel identified. MEPS advised that they are working on the development of a system which could have that ability, but that is more than a couple of years away in terms of its potential implementation.

<u>Conclusion 6</u>: The ITOS system cited in the West Coast Spill Response Study has not existed for more than a decade. Participating tugs operating in any specific geographic area can be readily identified through the newer AIS system, but the towing capabilities of those tugs are not identifiable in AIS. To enable rapid identification of tugs with adequate towing capability, an extension of the AIS system must be in place which can quickly identify the real escort and rescue towing capabilities of any tugs located in the vicinity of an incident. That system is currently NOT in place and will not be for several years.

5.4 Neah Bay Rescue Station Tug

Since about 1997 Washington State has mandated the deployment of a designated "Emergency Response Towing Vessel" (ERTV), or rescue tug, at Neah Bay, near the western entrance to Juan de Fuca Strait. The cost of maintaining this tug capability has been rather hotly debated since its inception, but is now currently paid for by a levy on all ships entering state waters. A report from the Washington State Department of Ecology in 2010 [6] states the following.

> *"The emergency response tug stationed at Neah Bay is an important safety net to prevent disabled ships and barges from grounding in the western Strait of Juan de Fuca or off our outer coast.*
>
> *Funding for the Neah Bay tug has successfully transitioned from Washington State management to private maritime industry financed and managed operations. The maritime shipping industry established an ERTV contract (vessel under charter to the Washington State Maritime Cooperative) to maintain an industry funded standby towing capability at Neah Bay. As required by statute the U.S. Coast Guard and Ecology may separately contract for the services of the ERTV stationed at Neah Bay to respond to an emerging maritime casualty, or as a precautionary measure.*
>
> *Since 1999, the tug has deployed to stand by or directly assist 46 vessels that were either completely disabled or had reduced maneuvering ability. On 11 of these responses the tug had to take the disabled vessels in tow to prevent them from drifting onto the rocks and spilling oil. The actions taken in those 11 cases helped prevent a combined spill potential of nearly 5 million gallons of oil."*

The West Coast Oil Spill Response Study [5] states that:

> *"There are no rescue tugs stationed in BC, but there is a rescue tug stationed just over the US border in Neah Bay, Washington (Figure 3.2) that could provide some emergency towing support to an incident in BC waters, if the State of Washington allows the tug to be released, though there is no specific mechanism designed to facilitate this."*

The fact that there is "no specific mechanism" for such cross-border cooperation speaks volumes. Should the Neah Bay tug be deployed to support an incident in Canadian waters it leaves the Washington coast unguarded. Since incidents are either most likely to occur in bad weather or the risks from any incident will become greater in bad weather, it is highly unlikely that the Neah Bay tug would be deployed unless there was a direct threat to the US coast. At the present time the tug stationed at Neah Bay is the 36.6 metre, twin-screw, 3,207 kW (4,300 bhp) tug ***Jeffrey Foss***, with a BP of 64 tonnes. A data sheet describing the basic particulars of this tug is attached as Annex A.

Conclusion 7: The ability or likelihood of the Washington State Emergency Response Towing Vessel, stationed at Neah Bay, to respond to any incident in Canadian waters requires detailed examination and clarification.

6.0 TUGBOAT SERVICES AND PERFORMANCE

This section of the report will briefly describe the general configuration of tugs designed for the various major roles in which they are engaged along the BC coast.

6.1 Coastal Towing

Tugs engaged in coastal towing are typically twin screw with conventional propulsion systems and rudders. Towing is performed from a large winch on the main deck aft, relatively close to amidships. These tugs are designed to tow barges at moderate speeds 6–9 knots, and their propellers are pitched accordingly, rather than to maximize thrust at zero speed (Bollard Pull (BP)). The majority of these tugs are in the 20–30 metre length range and typically have total power ranging from 750-1,500 kW (1,000 bhp to 2,000 bhp) (Figure 6.1). These tugs are generally not equipped to conduct any rescue towing other than they have usually about 600–750 metres of steel towline, the breaking strength of which will correspond to 2.5–3 times the BP. As a very typical power is about 1,350 kW (1,800 bhp), corresponding to a BP of say 25 tonnes, the ultimate towline strength may be about 75 tonnes.

Figure 6.1 Typically Coastal Barge Towing Tug (Foreground)

There are a few tugs in the 30–40 metre length range on this coast (Figure 6.2) principally engaged in towing large log barges and larger deck cargo barges on longer coastal tows or on the open West Coast, or on voyages to Oregon or California. Their power is typically in the 1,900-3,000 kW (2500-4,000 bhp) range, so towline ultimate strengths will be in the range of 100–150 tonnes. Some of these larger tugs have dual winches and towlines, making them more suitable for rescue towing operations.

Figure 6.2 Larger Type of Coastal Barge Towing Tug; 35 metres length, 1,940 kW, Dual Winch

6.2 Ship-Handling

Ship-handling is the business of guiding ships into and out from their berths within the ports. This is typically a quite slow speed operation and involves smaller but more high-powered tugs whose function is to push or pull on the command of the Pilots in order to safely berth the attended ships. In Vancouver and most BC ports tugs engaged in this activity are much smaller than found in other parts of the world. Accordingly these tugs are too small to work in more than the sort of relatively calm conditions found within the confines of a sheltered harbour. Although there are still a few twin-screw tugs doing this work in the Port of Vancouver, the majority of these tugs have Z-Drive propulsion in an "azimuthing stern drive" (ASD) configuration. These tugs are exceptionally manoeuvrable and controllable and exert essentially uniform thrust through 360°. They typically do their work over the bow from a winch with a synthetic, relatively short towline (200 metres max). Very few of this class of tug have any towing gear aft.

Figure 6.3 Typical Ship-Handling Tugs; 25 metres length, 2,300 kW, single hawser winch forward, no towing winch aft.

6.3 Escorting

Escorting with tugs is a relatively new game in world terms, essentially created after the Exxon Valdez incident in 1989. It is generally defined in the industry as the activity of providing a specially designed tug to accompany a large vessel (usually tankers), which can control the ship as effectively as its own steering and propulsion system in the event of a propulsion or steering system failure, when operating at relatively high speeds, in the region of 8–10 knots. The critical distinction between ship-handling and escorting is the speed at which these operations take place, and thus the manner in which the tugs must operate in order to perform these tasks safely and most effectively. Escorting is distinguished by the tug operating in what is known as the "Indirect" mode, (Figure 6.4) whereby the combination of hydrodynamic forces generated by the hull and its appendages and the direct thrust of the propellers work in combination to generate towline forces considerably higher than can be generated by the propellers alone. Total towline forces 30–50% higher than the BP are common.

Escort tugs most typically work with synthetic lines on a winch on the fore deck (in the case of ASD tugs), or on the aft deck in the case of tractor tugs. Many ASD escort tugs also have conventional steel wire towing gear aft. That facility is less common on tractor tugs as it is a challenge to work with both steel wire and synthetic hawsers in the same area. The expensive synthetic hawsers are very susceptible to damage from the nicks and grooves which steel lines will inevitably inflict on the bitts and bulwark rails, so it is critically important to keep the two towline mediums isolated from one another.

Figure 6.4 Large escort tug working in "indirect" mode at an oblique angle to the attended ship.

Ref. [5] cites the following with respect to tanker escorting in BC waters:

> ### 3.3 *Escort and Rescue Tugs*
>
> The use of escort and rescue tugs for oil tankers in transit is a recognized spill prevention practice used in many jurisdictions.
>
> #### 3.3.1 Escort Tugs
>
> Tug escort requirements currently exist for two geographic areas in southern BC (Figure 3.1). Escort tugs accompany vessels, typically laden oil tankers, through high-risk transit areas. Escort tugs assist with navigation and are available to immediately respond or assist in the event of an emergency.
>
> In Haro Strait and Boundary Pass, all laden tankers of over 40,000 DWT must be escorted by an escort tug that meets minimum specifications established in a 2010 Notice to Industry. The tug is to be tethered for two miles of the transit, and is required to adhere to speed restrictions. (PPA, 2010)
>
> The Vancouver Fraser Port Authority requires a minimum of two escort tugs to accompany laden tankers in excess of 40,000 DWT while transiting the First and Second Narrows, both inbound and outbound. The requirements specify minimum bollard pull, tug package configuration, and escort configuration. Three tugs are required for certain tankers based on their length overall plus breadth. (Port Metro Vancouver, 2010)
>
> There are no escort tug systems currently in place in British Columbia waters north of the Vancouver area, and there are no federal or provincial statues or regulations that compel tanker escorts in BC waters.

However, notable by omission in this document is any mention of the actual required escort capability of the tugs to perform this critical work. The escort capability must be defined by (a) minimum Bollard Pull, (b) Indirect Escort Force generation capability (steering and braking) at speeds of up to 10 knots, and (c) the winch specification necessary to deal with the associated forces.

6.4 Rescue Towing

Rescue towing is the act of taking a disabled vessel under tow in whatever the prevailing weather and sea conditions might be. As the risks of a vessel grounding are obviously higher in the more severe conditions, almost by definition rescue towing will take place in high wind and wave conditions.

Tugs engaged in rescue towing must have suitable towing gear and almost as critically, have crews who are well-trained to handle the heavy and often dangerous gear associated with making towing connections in bad weather. The very basic towing gear required for this role should include:

- Towing winch (preferably dual winches)
- Stern towline roller and tow pins
- Main steel wire rope (SWR) towline
- Possible use of a synthetic emergency towline/hawser
- Synthetic spring line element in SWR system
- Lead chain or wire pendant
- Chain bridle/chafing gear
- Connecting "jewelry" (shackles, etc.)
- Spare components; secondary towline

A larger tug equipped for heavier coastal towing (Figure 6.5) is likely to be equipped with dual winches, and thus most capable of satisfying this rescue towing requirement.

Figure 6.5 Large coastal towing tug, equipped with heavy duty towing gear and dual winch system.

In this context it is also important to understand how tankers are equipped to handle an emergency tow. The standard international requirements for towing fittings on tankers are defined by the "Mooring Equipment Guidelines" [2] (the "Guidelines") published by OCIMF, which reflect the requirements of SOLAS, which are in turn reflected in the vast majority of Flag State Regulations. The basic equipment requirements are as shown in Figure 6.6 below:

3.4 Requirements for Emergency Towing, Escorting and Pull-Back

Regulation Ch V/15-1 (Ch II-1/3-4 from 1/7/98) of SOLAS adopted by IMO in 1994, contains the following provisions:

- All 'tankers' of 20,000 DWT and above are to be provided with an emergency towing arrangement at both ends
- the term 'tankers' includes oil tankers, chemical tankers and gas carriers
- the minimum components for an emergency towing arrangement are to comprise of the following:

Component	Forward	Aft
Towing pennant	Optional	Required
Pick-up gear	Optional	Required
Chafing gear	Required	Dependent on design
Fairlead	Required	Required
Strong point	Required	Required
Roller pedestal lead	Required	Dependent on design

- the forward arrangement of strong point, fairlead, chafing gear and roller pedestal lead reflects the guidance previously contained in IMO Assembly Resolution A.535(13), which on many oil tankers may be accommodated by the fittings recommended to facilitate mooring at SPMs (see Appendix E)
- the arrangement aft contains a major new provision introduced since IMO Assembly Resolution A.535 (13) was developed, i.e. the requirement for the ship to carry a pre-rigged towing pennant incorporating pick-up gear. The pick-up gear must be capable of being deployed manually by one person and the pennant must be demonstrated to be capable of full deployment within 15 minutes under harbour conditions.

Figure 6.6 Extract from OCIMF "Mooring Equipment Guidelines" defining tanker shipboard emergency towing fitting requirements.

The presence of this "pick-up" gear on a tanker makes an emergency connection a great deal safer and faster than if it were necessary for the tug to get a line up to the deck of the ship and then have the tanker crew make it fast.

Rescue towing is more likely to take place in severe conditions than in calm, as sometimes failures are initiated by the actions of a ship in a seaway As tug motions are directly linked to their size and weight, and as crew safety on deck is directly linked to the amplitude of motions and the associated accelerations, larger tugs are considerably safer for rescue towing than are smaller tugs. Figure 6.7 illustrates the motions of a typical mid-sized coastal towing tug in a gale off Cape Mudge; one can get a sense of the motions aboard this tug in what are probably about 2-2.5 metre seas. There are conditions far more severe that will be encountered in Juan de Fuca Strait, emphasizing that rescue towing is a role for the biggest possible tug, not the typical West Coast barge towing tug. Size is almost as important as power, as that has a direct impact on the ability of a tug to exert forces in a more continuous manner, and has a significant bearing on the ability of the crew to work safely on deck.

Figure 6.7 Motions of tugs are very directly related to their size relative to the prevailing sea conditions. Tugs such as the one illustrated here (< 30 m length) will be very "active" in sea-states more than 2 metres H_s. Crew effectiveness and safety is greatly affected by these motions.

7.0 EVALUATION OF THE BC COASTAL FLEET FOR TANKER ESCORT OR RESCUE

Based on the functional distinctions described in Section 6.0 above, Table 7.1 below indicates the all the specific tugs in the >150 GT sample in each primary functional category, namely:

- Coastal towing
- Ship-handling
- Escort rated

In addition Table 7.1 identifies those tugs which by virtue of their size, power and towing configuration are deemed capable of rescue towing in the broad sense (before consideration of the actual towing force requirements).

Table 7.1 BC Tugs > 150 GT: Description by Service Category

Vessel Name	Owner	BP Ahead (tonnes)	Length (metres)	*Coastal Towing*	*Ship-Assist*	*Escort*	*Rescue Capable*
NEVA STRAITS	SEA-LINK MARINE SERVICES LTD.	18	26.4				
JOSE NARVAEZ	LAFARGE CANADA INC.	20	24.6				
SEA WARRIOR	SEA-LINK MARINE SERVICES LTD.	21	27.6				
PACIFIC RANGER II	PACIFIC TOWING SERVICES LTD.	23	25.1				
OCEAN CLIPPER	PACIFIC CACHALOT LTD.	24	26.5				
ISLAND SCOUT	ISLAND TUG AND BARGE LTD.	25	23.9				
SEASPAN QUEEN	SEASPAN ULC	26	29.0				
ARCTIC TAGLU	SEA-LINK MARINE SERVICES LTD.	31	31.5				
ARCTIC HOOPER	SEA-LINK MARINE SERVICES LTD.	31	31.1				
SEASPAN PACER	SEASPAN ULC	34	29.0				
SEASPAN MONARCH	SEASPAN ULC	39	34.8				
*SEASPAN FALCON **	SEASPAN ULC	40	24.6				
*SEASPAN HAWK **	SEASPAN ULC	40	24.6				
ISLAND TUGGER	ISLAND TUG AND BARGE LTD.	41	35.9				
ISLAND MONARCH	ISLAND TUG AND BARGE LTD.	41	41.5				
SEA COMMANDER	SEA-LINK MARINE SERVICES LTD.	42	43.5				
*SMIT NASS **	SMIT MARINE CANADA INC.	45	30.2				
*SMIT SKEENA **	SMIT MARINE CANADA INC.	45	30.3				
SEASPAN KING	SEASPAN ULC	49	40.2				
*SMIT TIGER SUN ***	SMIT MARINE CANADA INC.	53	21.7				
SMIT MISSISSIPPI	SMIT HARBOUR TOWAGE VANCOUVER INC	65	30.6				
SMIT CLYDE	SMIT HARBOUR TOWAGE VANCOUVER INC	65	30.6				
SMIT HUMBER	SMIT HARBOUR TOWAGE VANCOUVER INC	65	30.6				
SEASPAN RAVEN	SEASPAN ULC	71	28.2				
SEASPAN EAGLE	SEASPAN ULC	71	28.2				
*SEASPAN KESTREL **	SEASPAN ULC	81	28.2				
*SEASPAN OSPREY **	SEASPAN ULC	81	28.2				
*SEASPAN RESOLUTION **	SEASPAN ULC	82	30.0				
SEASPAN COMMODORE	SEASPAN ULC	82	43.3				
SMIT ORLEANS	SMIT MARINE CANADA INC.	85	29.3				
SEASPAN ROYAL	SEASPAN ULC	93	40.6				

*Note: ** SMIT Tiger Sun is just < 150 GT, but is included here as one of the more powerful tugs in Vancouver Harbour*

*Note: * Tugs without any aft winch are deemed unsuitable for rescue towing*

As identified in Section 4 the proposed tanker escort / rescue service demands tugs of about 70 tonnes BP., Given that number, (rather rarified territory in the BC tug fleet), it is perhaps prudent to identify all tugs with more than 60 tonnes of BP, a lower threshold which enables identification of those marginal vessels which in more moderate conditions may also be suitable. Table 7.2 below segregates this select group of tugs from the larger group of > 150 GT tugs.

Table 7.2 Escort and Rescue Towing Capable Tugs in BC

Vessel Name	Owner	BP (tonnes)	Length (metres)	*Coastal Towing*	*Ship-Assist*	*Escort*	*Rescue Capable*
SMIT MISSISSIPPI	SMIT HARBOUR TOWAGE VANCOUVER INC	65	30.6				summer only
SMIT CLYDE	SMIT HARBOUR TOWAGE VANCOUVER INC	65	30.6				summer only
SMIT HUMBER	SMIT HARBOUR TOWAGE VANCOUVER INC	65	30.6				summer only
SEASPAN RAVEN	SEASPAN ULC	71	28.2				
SEASPAN EAGLE	SEASPAN ULC	71	28.2				
SEASPAN KESTREL	SEASPAN ULC	81	28.2				no aft winch
SEASPAN OSPREY	SEASPAN ULC	81	28.2				no aft winch
SEASPAN RESOLUTION	SEASPAN ULC	82	30.0				no aft winch
SEASPAN COMMODORE	SEASPAN ULC	82	43.3				
SMIT ORLEANS	SMIT MARINE CANADA INC.	85	29.3				
SEASPAN ROYAL	SEASPAN ULC	93	40.6				

It can be seen from Table 7.2 that there are only six (6) BC-based tugs which have a clearly definable escort capability. The escort ratings according to Classification Society standards for the five (5) Seaspan ASD tugs are known, as those vessels were designed by this office. The escort rating of the SMIT Orleans is at present not known, but has reportedly been determined through some direct tests with the BC Coast Pilots. Only these six tugs should be considered for the demanding escort towing service, and ideally the actual indirect steering and braking capabilities required to affect a recovery from a steering or propulsion failure on a tanker should be identified through a careful analysis or simulation, after which the precise escort capabilities of these six (6) tugs should be reassessed.

It should be noted that those tugs identified above as escort capable are already part of the existing escort tug regime of risk-reducing measures, escorting laden tankers from Westridge Terminal to Race Rocks.

<u>Conclusion 8</u>: The actual indirect steering and braking capabilities required to affect a recovery from a steering or propulsion failure on a tanker anywhere on the intended route should be identified through a careful analysis or simulation, after which the precise escort capabilities of the six (6) escort-rated tugs should be reassessed.

Of that group of six (6), three are not fitted with aft towing winches, hence are incapable of rescue towing. That leaves only three tugs in BC which have the combined capability of performing escort and rescue towing in Juan de Fuca Strait.

There are a total of eight (8) tugs in the above list which could be considered capable of performing rescue tows. That includes the three (3) escort/rescue-capable tugs identified above, plus three relatively large 65 tonne BP ASD harbour tugs owned by SMIT Canada Ltd which have reasonable towing gear aft, and two large twin screw coastal towing tugs with reasonable power and heavy duty towing gear. These latter two tugs are typically engaged in long distance barge tows to the US or the BC North Coast/Gulf of Alaska, hence their availability in event of an emergency is moot.

Conclusion 9: The following numbers of BC-based tugs are capable of conducting tethered escorts or performing rescue tows of an Aframax tanker in Juan de Fuca Strait:
- **Tethered Escorts - 6**
- **Tethered Escort and Rescue Tows - 3**
- **Rescue Tows – Summer Conditions - 8**
- **Rescue Tows – Winter 93rd Percentile - 5**
- **Rescue Tows – Winter 99th Percentile - 0 (if acting alone)**

Section 4 of this report identified the towing force requirements necessary to affect rescue tows in Juan de Fuca Strait in a range of weather conditions. Summarizing that data:

- 99th percentile winter condition (6 m H_s, 34 knots wind, 1.5 m/s current): 110 t BP required
- 93rd percentile winter condition (4 m H_s, 21 knots wind, 1.3 m/s current): 68 t (say 70 t) BP required

As 70 tonnes BP is necessary to provide about 93% of the requirement in winter, then it could be argued that two tugs of that capability could satisfy the 99th percentile condition of 110 tonnes, but that leaves a small margin of error. There are also some risks associated with a tandem rescue tow, principally the risk of the tugs interfering with each other and getting their towing gear entangled. The use of tandem tugs however is not unusual and does offer the advantage of redundancy.

8.0 INCIDENT RISK

The risk of any incident involving tankers has been analyzed by Det Norske Veritas [8]. That report provides the comments in italics below regarding the use of support tugs in the tanker voyages. Some elements of this discussion have been highlighted for further comment:

> *"In the risk model, the* presence *of tugs affects the frequency of drift grounding incidents. Some may argue that the presence of tugs also reduces the frequency of powered grounding, but DNV has considered only a tethered tug as having the response capability to reduce the powered grounding incident frequency. In combination with VTS and pilotage, DNV does not allocate any additional reduction in collision frequency merely by having a tug present (either tethered or untethered).*
>
> *A tethered escort tug is immediately available to respond to a mechanical failure on the tanker (drift grounding hazard). In the risk model, this modifies the rate of mechanical failure on the tanker. DNV is unaware of a grounding incident which has occurred with a tethered tug in attendance, so a reduction factor of 100 times reduction is applied to the mechanical failure rate of tethered tankers.* ***It is assumed that the escort tug is capable of controlling the tanker in the event of a tanker mechanical failure.*** (Robert Allan Ltd. emphasis) *Tugs are tethered to the outbound tanker in Segments 1, 2 and 5 and thus benefits from it (Trans Mountain and other tankers (vessel types 1, 2 and 3)) in these segments.*
>
> *A tethered escort tug may also respond to prevent a powered grounding incident. In previous work, DNV has assessed the benefit of this as a reduction by a factor of 2. This is applied to the powered grounding failure frequencies for Trans Mountain and other tankers, vessel types 1, 2, and 3 in segments 5. Additional risk reduction benefits are assigned to the tethered tugs in segments 1 and 2 due to the low tanker speed through the harbour and MRA, and in berth approach operations.*
>
> *The presence of a powerful escort tug tethered to the tanker also introduces additional failure modes associated with incorrect actions on the tug leading to a vessel grounding. DNV assumes that good coordinated command and control structures exist in the tanker-tug combination that reduces the frequency of occurrence of such additional failure modes to insignificant levels.*

Escort tugs navigate with the laden outbound tanker but are not tethered to it. In the event of a tanker failure, the escort tug needs to connect a line and exert a saving force on the vessel. This must be done before the tanker drifts aground so the time for the escort to reach the tanker (usually short when escorting, but will be longer for tugs of opportunity, see below) and the time to connect the line must be compared to the time to drift to shore to determine if the escort tug can prevent the grounding. So the effective risk reduction provided by an untethered escort would, among other factors, be dependent on the proximity of the vessel from a possible grounding location in the event of a propulsion failure. ***The escort tug must also be capable of controlling the tanker in the wind and wave conditions.***

For escort tugs, ***DNV assumes a tug with a bollard pull of about 40 tons and a length of about 40 m****. The tug is dedicated to escort duty (100% available) and navigates within 0.5 nm of the tanker it is escorting. In the case of Trans Mountain tankers, the actual capacity of the escort tugs used in practice are at least 50 tons or more.*

In addition, tugs of opportunity and emergency response tugs may be able to provide assistance to a drifting tanker. Such tugs may have limited availability (assigned to other duties) or limited capability in open waters (typical small harbour tugs). Tugs of opportunity are not included in the risk model. Neither is the risk reduction from the rescue tug stationed in Neah Bay, although it will have an effect on the drift grounding risk in the Strait of Juan de Fuca. ***This was not included because it cannot be confirmed with any certainty that this facility will be available to Trans Mountain tankers for the duration of the Project,*** *as well because the rescue tug is primarily provided to safeguard US bound traffic, including loaded tankers bound US port, there is no certainty at this time that even if the tug is available it will be made available to use for a Trans Mountain tanker requiring its assistance.*

Although the current probability of an actual oil spill (as opposed to any marine "incident") without tug escort measures in place for laden tankers in Juan de Fuca Strait has been analyzed in the DNV study, and estimated as a once in every 921 year event, DNV analyzed the impact on spill probabilities of extending the escort tug area of operation further out into Juan de Fuca Strait, with the following results:

"… shows that the increased level of tug escort in Case 1a [i.e. a case extending tug escorts to include Juan de Fuca Strait] *decreases the <u>incident frequency</u> for the Trans Mountain tanker traffic by 12%— 38% for the various shipping lanes (Seg. 3-7).*

More importantly, for the <u>oil cargo spill accident frequency</u>, the frequency reduction resulting from the tug escort change is much more pronounced: with reduction achieved between 46% (Seg. 5) and ***91%*** *(Seg. 4) for the shipping lanes (Seg. 3-7).* {<u>Note</u>: Segment 7 is Juan de Fuca Strait.}

It is clear that the increase in tug escort would significantly reduce both frequencies, especially in Segments 3, 4, and 7."

The elements of the DNV report [8] which have been **bold** emphasized above deserve further comment:

a. The assumption that the escort tug is capable of controlling the tanker in the event of a mechanical breakdown is valid for the type of study, but the precise indirect escort forces required of the escort tugs have not been defined. These force requirements MUST be thoroughly analyzed and defined; it cannot be assumed that just because there are some "escort tugs" in BC waters that those specific tugs have all the capabilities required to be fully effective when needed.

b. DNV state that the escort tugs "*must also be capable of controlling the tanker in the wind and wave conditions*". The DNV Study used the same reference source [1] for Met Ocean Data as did Robert Allan Ltd. in this study, hence it is assumed that the same effects have been considered.

c. *"DNV assumes a tug with a bollard pull of about 40 tons and a length of about 40 m"*. There is no substantiation of the above assumptions regarding power and size, and a review of the tug sample (Table 4.2) shows clearly that in fact there are only 5 tugs in BC which satisfy both these criteria, and all of those are coastal towing tugs. All of the more powerful escort-rated tugs are less than 30 metres in length. It is reasonable to assume that DNV identified the larger size in order to ensure a reasonably safe tug in the predicted sea-states, however that must be confirmed by them.

d. It is also noted that DNV did not assume (correctly, in our estimation) that the Neah Bay tug would be available to respond to an incident in Canadian waters

The DNV report certainly highlights the significant benefit of a well-founded escort tug system as a serious and effective oil spill risk mitigation measure. It remains however to clearly define the specific escort tug performance capabilities required along the entire tanker route. At the present time it appears that precise capability has not been clearly defined, and more critically it also appears that it might be assumed that it does exist, simply by the presence of the existing tug fleet.

Conclusion 10: It is clear from the General Risk Analysis Study conducted by DNV that the use of tethered escort tugs is a highly effective tool by which to reduce the risk of a tanker grounding and an associated oil spill incident. The precise force-generating capacity required for escort tugs at various stages along the route however does not appear to be clearly defined. The assessment of the present tug fleet against those force requirements is a critical missing link in defining safe procedures for tanker escort in BC waters.

9.0 CONCLUSIONS

9.1 Met-Ocean Conditions

It is virtually impossible to define a capability suitable for 100% of all conditions, especially when the worst conditions are reasonably detectable and predictable, and a ship can delay its outbound voyage for a relatively short duration and avoid the more severe sea conditions at the outer portions of the Strait. Therefore the following are deemed appropriate as the limiting Met-Ocean conditions in which a rescue tug should be able to effect control over a tanker in Juan de Fuca Strait:

- 99^{th} percentile (Neah Bay, winter) - Waves 6 m, Winds 34 knots, Current 1.5 m/s
- 93^{rd} percentile (Neah Bay, winter) - Waves 4 m, Winds 21 knots, Current 1.3 m/s
- 99^{th} percentile (Neah Bay, summer) - Waves 3.5 m, Winds 26 knots, Current 2.0 m/s

9.2 Tanker Size

This analysis has focussed on the forces required to control a fully laden 120,000 t DWT Aframax tanker. The tug forces defined herein therefore would be overly conservative as the minimum required for a smaller or more lightly laden ship, and similarly would be insufficient to control a larger vessel. To properly assess the overall capability of the BC coastal tug fleet, the matrix of analysis should be extended to a broader size range of tankers and through a broader spectrum of Met-Ocean conditions.

9.3 Tug Performance

Based on the information available and the analysis performed, the following are recommended as <u>the minimum criteria</u> to be used for nominating a tug as suitable for either an escort or a rescue tug role in Juan de Fuca Strait, in support of the largest Aframax tankers:

- **> 150 GT** - essentially identifies an absolute minimum size of tug which could handle the weather and sea state conditions in the Strait. This also ensures that the tug would at least fall under the scrutiny of Transport Canada's inspection regime on an annual basis and therefore meet some minimum standard of quality.

- **BP =/> 70 tonnes** - the minimum (calm water) thrust which should be available to enable rescue towing in winter (93^{rd} winter percentile conditions). In more severe conditions two tugs of this class would be required to effect full control over the tanker. It is important to understand that this power is that which is sufficient to simply hold against the environmental forces. Another 10 tonnes of BP would ensure that the tug could actually make some headway against those conditions

- **Indirect Steering Force (F_s) at 10 knots** - the indirect steering force capability of any tug at 10 knots should at the very least be equal to its BP However the assessment of the actual F_s requirement to prevent a tanker grounding anywhere along the tethered escort route is not part of this study and must be identified before proper conclusions can be drawn

- **Towline Size and Strength:**
  - **UTS > 200 tonnes** - requires the towline breaking strength to be rated at approx. 3 x BP
  - **Length > 610 metres** - suitable for deep sea towing

10.0 SUMMARY

The conditions at Neah Bay in the winter are the limiting case for defining Met-Ocean forces imposed on a ship. The following are approximate overall percentiles of conditions used in this analysis:

- 99th percentile (Neah Bay, winter) - Waves 6 m, Winds 34 knots, Current 1.5 m/s
- 93rd percentile (Neah Bay, winter) - Waves 4 m, Winds 21 knots, Current 1.3 m/s
- 99th percentile (Neah Bay, summer) - Waves 3.5 m, Winds 26 knots, Current 2.0 m/s

Although there are more than 1200 tugs boats registered in BC, only about 32 of these are of a size which could even remotely be considered as suitable for operation in any rescue tug role. Of that total only a handful have the size and power necessary to be considered seriously for a rescue tug role in the exposed waters of Juan de Fuca Strait.

Only 6 tugs in BC have been designed and equipped to operate as serious tanker escort tugs, but three of these are not equipped with aft towing winches, hence are not capable of rescue towing, leaving only three tugs capable of both tasks. There are a total of 8 tugs in the list of BC tugs which could be considered capable of performing rescue tows, but the two largest tugs are most often engaged on longer tows and hence cannot be assured of being in the vicinity.

The US fleet operating in the vicinity of North Puget Sound is in general larger and more capable for escort and rescue towing roles than almost any Canadian tugs. Although the major US tugs believed to be based in Puget Sound have been identified, the evaluation of the escort and rescue capability of those tugs was not a part of the current study.

Any regulatory or industry cooperative agreements which are in place with respect to US registered tugs acting in Canadian waters in an emergency response role need to be identified and clarified.

The ITOS system cited in the West Coast Spill Response Study [5] has not existed for more than a decade. Tugs operating in any specific geographic area can be readily identified through the AIS system, but their specific towing capabilities are not identifiable in AIS. To enable rapid identification of tugs with adequate capability, an extension of the AIS system must be created which can quickly identify the real escort and rescue towing capabilities of any tugs located in the vicinity of an incident. That system is currently NOT in place and will not be for several years.

The ability or likelihood of the Washington State Emergency Response Towing Vessel, stationed at Neah Bay, to respond to any incident in Canadian waters requires detailed examination and clarification.

The actual indirect steering and braking capabilities required of an escort tug to affect a recovery from a steering or propulsion failure on a tanker anywhere on the intended route should be identified through a careful analysis or simulation after which the precise escort capabilities of the six escort-rated tugs identified in this report should be reassessed.

It is clear from the General Risk Analysis Study conducted by DNV that the use of tethered escort tugs is a highly effective tool by which to reduce the risk of a tanker grounding and an associated oil spill incident. The precise force-generating capacity required for escort tugs at various stages along the route however does not appear to be clearly defined. The assessment of the present tug fleet against those force requirements is a critical missing link in defining safe procedures for tanker escort in BC waters.

The following are recommended as the minimum criteria to be used for nominating a tug as suitable for either an escort or a rescue tug role in Juan de Fuca Strait:

- **> 150 GT** - essentially identifies an absolute minimum size of tug which could handle the weather and sea state conditions in the Strait
- **BP =/> 70 tonnes** - the minimum thrust which should be available to enable rescue towing in winter (93rd percentile conditions)
- **Indirect Steering Force (F_s) > 70 tonnes at 10 knots** - assumes that a tug must at least be able to generate an indirect steering force at 10 knots at least equal to its BP
- **Towline Size and Strength:**
  - **UTS > 200 tonnes** - requires the towline breaking strength to be rated at approx. 3 x BP
  - **Length > 610 metres** - suitable for deep sea towing

Based on the criteria above, the list of tug candidates which can be considered capable of rendering assistance to an Aframax size tanker in Juan de Fuca Strait is as follows:

A. **Escort Only – All Seasons:**

- ***Seaspan Kestrel***
- ***Seaspan Osprey***
- ***Seaspan Resolution***

B. **Rescue Only - Summer Only:**

- ***SMIT Mississippi***
- ***SMIT Clyde***
- ***SMIT Humber***

C. **Rescue Only - All Seasons:**

- ***Seaspan Commodore***
- ***Seaspan Royal***

D. **Combined Escort and Rescue – All Seasons:**

- ***Seaspan Raven***
- ***Seaspan Eagle***
- ***SMIT Orleans***

Data sheets describing each of the above vessels are attached as Annex B.

for **ROBERT ALLAN LTD.**

Robert G. Allan, P. Eng.
Executive Chairman of the Board

RGA:da

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6. Washington State Department of Ecology Website (September 1, 2010): http://www.ecy.wa.gov/programs/spills/response_tug/tugresponsemainpage.htm

7. Draft Findings and Recommendations of the West Coast Offshore Vessel Traffic Risk Management Project (Appendix M): www.oilspilltaskforce.org/docs/**vessel_traffic**/AppendixM.pdf

8. *Termpol 3.15: General Risk Analysis and Intended Methods of Reducing Risks – Trans Mountain Pipeline Expansion Project*, DNV Report No. 167ITKV-9/PP061115 for Trans Mountain Pipeline ULC, July 2013.

* * *

Annex A

Data Sheet – Neah Bay Tug

JEFFREY FOSS

Built in 1970, by McDermott Shipyard of Morgan City, Louisiana (hull #165) as the *Jeffery Foss* for Foss Maritime of Seattle, Washington.

She was chartered by Department of Ecology for commercial tug services, including rescue standby and operational drills, at the western end of the Strait of Juan de Fuca and along Washington's outer coast. The tug had been specifically outfitted and the crew specially trained to support its mission as a dedicated rescue tug.

Powered by two EMD diesel engines, for a rated 4,300 horsepower. The tug has a fuel capacity of over 100,000 gallons.

Photo by: Unknown

Vessel Name: *JEFFREY FOSS*
USCG Doc. No.: 526844
Vessel Service: TOWING VESSEL
IMO Number: 7029536
Trade Indicator: Coastwise Unrestricted, Registry
Call Sign: WY9383
Hull Material: STEEL
Hull Number: 165
Ship Builder: MCDERMOTT SHIPYARD
Year Built: 1970
Length: 112.2
Hailing Port: SEATTLE, WA.

Hull Depth: 13.5
Hull Breadth: 31
Gross Tonnage: 177
Net Tonnage: 120
Owner:
FOSS MARITIME COMPANY
1151 FAIRVIEW AVENUE NORTH
SEATTLE, WA 98109
Previous Vessel Owners:
FOSS MARITIME COMPANY

Photo by: Clark Crawford

Back to FOSS MARINE HOLDINGS

Annex B

Datasheets for Nominated Escort and Rescue Capable Tugs in BC

Annex B-1

Escort Only Tugs – All Seasons

SEASPAN KESTREL

GENERAL

Owner	Seaspan ULC
Designer	Robert Allan Ltd.
Built	2011
Certification	
Classification	ABS +1, Towing & Escort Vessel Fi-Fi 1, +AMS, +ABCU Unrestricted service
Official No.	

DIMENSIONS

Length overall	28.20 m / 92.52’
Breadth	12.60 m / 41.34’
Draft	5.39 m / 17.68’
GRT	441 tonnes

ENGINES, PROPULSION & PERFORMANCE

Main engine	2 x Caterpillar 3516C
Total power	4,698 kw / 6,300 BHP @ 1,600 RPM
Propulsion	Z-Peller
Bollard pull	81 t / 179,000 lbs
Propellers	4 Blade CP, 240 cm / 94.5” dia.

DECK EQUIPMENT

Hawser winch	Rolls-Royce TW 2000/500 AW 24 U2 H
Deck crane	Palfinger knuckle boom crane of 1,040 kg pull at 10.3 outreach
Tow line length	152 m / 500’

TANK ARRANGEMENT

Fuel capacity	119,300 L / 26,246 Imp. gallons
Fresh water capacity	12,900 L / 2,838 Imp. gallons

SEASPAN OSPREY

GENERAL

Owner	Seaspan ULC
Designer	Robert Allan Ltd.
Built	2011
Certification	
Classification	ABS +1, Towing & Escort Vessel Fi-Fi 1, +AMS, +ABCU Unrestricted service
Official No.	836296

DIMENSIONS

Length overall	28.20 m / 92.52’
Breadth	12.60 m / 41.34’
Draft	5.39 m / 17.68’
GRT	441 tonnes

ENGINES, PROPULSION & PERFORMANCE

Main engine	2 x Caterpillar 3516C
Total power	4,698 kw / 6,300 BHP @ 1,600 RPM
Propulsion	Z-Peller
Bollard pull	81 t / 179,000 lbs
Propellers	4 Blade CP, 240 cm / 94.5” dia.

DECK EQUIPMENT

Hawser winch	Rolls-Royce TW 2000/500 AW 24 U2 H
Deck crane	Palfinger knuckle boom crane of 1,040 kg pull at 10.3 outreach
Tow line length	152 m / 500’

TANK ARRANGEMENT

Fuel capacity	119,300 L / 26,246 Imp. gallons
Fresh water capacity	12,900 L / 2,838 Imp. gallons

SEASPAN RESOLUTION

GENERAL

Owner	Seaspan ULC
Designer	Robert Allan Ltd.
Built	2008
Certification	Transport Canada NC2, Limited HT3
Classification	Lloyd's Register +100 A1 Tug
Official No.	833674

DIMENSIONS

Length overall	30 m / 98'
Breadth	12.19 m / 40'
Draft	5.38 m / 18'
GRT	469 tonnes

ENGINES, PROPULSION & PERFORMANCE

Main engine	2 x EMD L12710G7C-T2
Total power	4,476 kw / 6,000 BHP @ 900 RPM
Propulsion	Twin screw, Z-Peller
Bollard pull	82 t / 180,000 lbs
Propellers	270 cm / 106.30" dia.

DECK EQUIPMENT

Hawser winch	Burrard Iron Works electric
Tow line length	548.6 m / 1,800'

TANK ARRANGEMENT

Fuel capacity	110,000 L / 24,200 Imp. gallons
Fresh water capacity	16,000 L / 3,520 Imp. gallons

Annex B-2

Rescue Only Tugs – Summer Only

HARBOUR TOWAGE

SMIT MISSISSIPPI

Azimuth Stern Drive (ASD)
65 tonnes bollard pull harbour/coastal tug

General

IMO Number	9187241
Transport Canada Number	832964
Year Built	1999
Port of Registry	Vancouver, B.C.
Certification	C.S.I. Lloyds

Dimensions

Length overall	93.7	FT	28.56	m
Breadth over all	34.8	FT	10.61	m
Draft	16.4	FT	5.00	m
Gross Tonnage			354	mT
Displacement	688.128	LT	681.00	mT

Engines and propulsion

Main engines	2-6L26 Wartsilla
Power (hp)	4,908
Power (kW)	3,660
Reduction Gear	Twin Disc MCD 3000 Slip Clutch
Reduction Ratio	Aquamaster 4.424:1
Propeller	Aquamaster 5 Blade 2600mm
Nozzle	
Generators	2 x Cat 3304DI-T 115KVA

Performance

Bollard pull ahead	147,000	LBS	65	mT
Bollard pull astern			63	mT
Speed ahead			14	Kn
Speed astern			12.4	Kn

Tanks

Fuel Oil	22,457	Gal.	102.09	m^3

Deck equipment

Towing winch Fore	Ridderinkhof 150T	25T Line pull
Aft	Ridderinkhof 150T	30T Line pull

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2285 Commissioner Street
Vancouver, B.C.
V5L 1A8
Canada

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Fax +1 604 255 9322
company.vancouver@smit.com
www.smit.com

HARBOUR TOWAGE

SMIT CLYDE

Azimuth Stern Drive (ASD)
65 tonnes bollard pull harbour/coastal tug

General

IMO Number	9190391
Transport Canada Number	831934
Year Built	1999
Port of Registry	Vancouver, B.C.
Certification	C.S.I. Lloyds

Dimensions

Length overall	93.7	FT	28.57	m
Breadth over all	34.8	FT	10.61	m
Draft	16.4	FT	5.00	m
Gross Tonnage			354	mT
Displacement		LT	681.00	mT

Engines and propulsion

Main engines	2-6L26A Wartsilla
Power (hp) Brake	4,908
Power (kW)	3,660
Reduction Gear	Twin Disc MCD 3000 Slip Clutch
Reduction Ratio	Schottel 4.47:1
Propeller	Schottel 5 Blade 2600mm
Nozzle	SRP1515FP Schottel
Generators	2 x Cat 3304T 100KVA

Performance

Bollard pull ahead	147,000	LBS	65	mT
Bollard pull astern			63	mT
Speed ahead			14	Kn
Speed astern			12.4	Kn

Tanks

Fuel Oil	25,753	Gal.	117.08	m^3

Deck equipment

Towing winch Fore	Ridderinkhof 150T	25T Line pull
Aft	Ridderinkhof 150T	30T Line pull

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Prince Rupert, B.C.
V8J 3P4
Canada

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Fax +1 250 624 9135
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www.smit.com

SMIT

HARBOUR TOWAGE

SMIT HUMBER

General

Lloyd's Register ✣ 100 A1 Tug ✣ LMC UMS

Delivery date	April 2000
IMO Number	9190406

Dimensions

Length over all	30.60	m
Beam over all	10.60	m
Maximum draught	5.10	m 16.73
GRT	353	

Machinery/Propulsion

Main engines	2 x Wärtsilä 6L26
Total power	3,660 kw
Propulsion	2 x controllable pitch ASD propeller

Performance

Bollard pull (ahead)	65	T
Bollard pull (astern)	60	T
Speed ahead (maximum)	13	knots
Speed (economic)	9	knots

Tank Capacity

Fuel oil	136	m^3
Potable water	40	m^3
Foam	13	m^3

Accommodation

Accommodation , air-conditioned, for	8 persons

Deck equipment - fore

Fore winch	Hydraulic
	Double drum - 150 T. brake load
	Line pull 30 T. @ 12 m/min. on 1st layer

Deck equipment - aft

Towing hook	Mampaey, 65 ton SWL
Aft winch	Hydraulic
	Single drum - 150 T. brake load
	Line pull 30 T. @ 12 m/min. on 1st layer

Navigation and communication equipment

Magnetic compass	Kelvin Hughes Observator
Echo sounder	Alphatron Alphanav
VHF	Sailor RT 2048
Radar	JRC JMA 5310
GPS	Raytheon NAV 398

Other equipment

Capacity fire-fighting monitors	-
Waterspray	☐

SMIT MARINE CANADA INC.
2285 Commissioner Street
V5L 1A8 Vancouver
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Fax +1-604-2511718
info.canada@smit.com
www.smit.com

Annex B-3

Rescue Only Tugs – All Seasons

SEASPAN COMMODORE

GENERAL

Owner	Seaspan ULC
Designer	Cove Dixon & Company
Built	1974
Certification	Transport Canada NC1, Unlimited Voyages
Classification	Lloyd's Register +100 A1, Tug +LMC
Official No.	369068

DIMENSIONS

Length overall	43.3 m / 142'
Breadth	10.9 m / 35'-8"
Draft	6.19 m / 20.3'
GRT	667 tonnes

ENGINES, PROPULSION & PERFORMANCE

Main engine	2 x EMD 645
Total power	4,290 kw / 5,750 BHP @ 900 RPM
Propulsion	Twin screw, Kort nozzles
Bollard pull	82 t / 180,000 lbs
Propellers	4 Blades, 2 x 305 cm / 120"

DECK EQUIPMENT

Towing winch	Burrard double drum type HK-D
Tow pins & roller assembly	6 x 12" (30.48cm) dia pins with hold down blocks
Tow line length	4,200' pt / 3,800' stbd 1,280.16m pt / 1,158.24m stbd

TANK ARRANGEMENT

Fuel capacity	500,060 L / 110,000 Imp. gallons
Fresh water capacity	38,641 L / 8,500 Imp. gallons

SEASPAN ROYAL

Photo to come

GENERAL

Owner	Seaspan ULC
Designer	Talbot, Jackson & Assoc.
Built	1981
Certification	Transport Canada
	NC1, Unlimited Voyages
Classification	ABS
	A1, Towing Service, E, +AMS
Official No.	801519
I.M.O.	8020018

DIMENSIONS

Length overall	40.62 m / 133.26’
Breadth	11.89 m / 39’
Draft	4.54 m / 14.89’
GRT	975 tonnes

ENGINES, PROPULSION & PERFORMANCE

Main engine	2 x GM EMD 645
Total power	4,623 kw / 6200 BHP @ 900 RPM
Propulsion	Twin screw
Bollard pull	93 t / 204,000 lbs
Propellers	4 Blade , 120” fixed pitch

DECK EQUIPMENT

Towing winch	Burrard double drum type HK-D
Tow pins	5 x 12” (30.48 cm) tow pins
Tow line length	3,000’ pt / 3,800’ stbd
	914.40m pt / 1,158.24m stbd

TANK ARRANGEMENT

Fuel capacity	644,050 L / 141,674 Imp. gallons
Fresh water capacity	34,449 L / 7,579 Imp. gallons

Annex B-4

Combined Escort and Rescue Tugs – All Seasons

SEASPAN RAVEN

GENERAL

Owner	Seaspan ULC
Designer	Robert Allan Ltd.
Built	2009
Certification	Transport Canada NC2, Limited HT3
Classification	ABS +1, Towing & Escort Vessel Fi-Fi 1, +AMS, +ABCU Unrestricted service
Official No.	835230

DIMENSIONS

Length overall	28.20 m / 92.52’
Breadth	12.60 m / 41.34’
Draft	5.39 m / 17.68’
GRT	441 tonnes

ENGINES, PROPULSION & PERFORMANCE

Main engine	2 x Caterpillar 3516B
Total power	3,728 kw / 5,000 BHP @ 1,600 RPM
Propulsion	Z-Peller
Bollard pull	71 t / 157,000 lbs
Propellers	4 Blade CP, 240 cm / 94.5” dia.

DECK EQUIPMENT

Hawser winch	Rolls-Royce TW 2000/500 AW 24 U2 H
Aft towing winch	Rolls-Royce single drum
Deck crane	Palfinger knuckle boom crane of 1,040 kg pull at 10.3 outreach
Tow line length	152 m / 500’

TANK ARRANGEMENT

Fuel capacity	119,300 L / 26,246 Imp. gallons
Fresh water capacity	12,900 L / 2,838 Imp. gallons

seaspan MARINE

604.988.3111 www.seaspan.com

SEASPAN EAGLE

GENERAL

Owner	Seaspan ULC
Designer	Robert Allan Ltd.
Built	2011
Certification	
Classification	ABS +1, Towing & Escort Vessel Fi-Fi 1, +AMS, +ABCU Unrestricted service
Official No.	835966

DIMENSIONS

Length overall	28.20 m / 92.52’
Breadth	12.60 m / 41.34’
Draft	5.39 m / 17.68’
GRT	441 tonnes

ENGINES, PROPULSION & PERFORMANCE

Main engine	2 x Caterpillar 3516B
Total power	3,728 kw / 5,000 BHP @ 1,600 RPM
Propulsion	Z-Peller
Bollard pull	71 t / 157,000 lbs
Propellers	4 Blade CP, 240 cm / 94.5” dia.

DECK EQUIPMENT

Hawser winch	Rolls-Royce TW 2000/500 AW 24 U2 H
Aft towing winch	Rolls-Royce single drum
Deck crane	Palfinger knuckle boom crane of 1,040 kg pull at 10.3 outreach
Tow line length	152 m / 500’

TANK ARRANGEMENT

Fuel capacity	119,300 L / 26,246 Imp. gallons
Fresh water capacity	12,900 L / 2,838 Imp. gallons

HARBOUR TOWAGE

SMIT ORLEANS

Azimuth Stern Drive (ASD)
85 tonnes bollard pull harbour/coastal tug

General

IMO Number	9424998
Transport Canada Number	832019
Year Built	2007
Port of Registry	Prince Rupert, B.C.
Certification	C.S.I.

Dimensions

Length overall	103	FT	31.39	m
Breadth over all	40	FT	12.19	m
Draft	16.4	FT	4.97	m
Gross Tonnage			402	mT
Displacement		LT	720.00	mT

Engines and propulsion

Main engines	2 x Caterpillar 3516C
Power (hp) Brake	6,772
Power (kW)	4,476
Reduction Gear	2 x Hitachi Nico duel modulation slip
Reduction Gear no.	RGCP180KY
Propeller (Ice Strength)	Nigata 2700mmx2400mm nickle bronze
Nozzle	Nigata ZP41 Z drives
Generators	2 x Caterpillar C9 250kw
	1 x Caterpillar C2 27kw

Performance

Bollard pull ahead	200,000	LBS	85	mT
Bollard pull astern	182,000		81	mT
Speed ahead			14	Kn
Speed astern			13	Kn

Tanks

Fuel Oil	70,899	Gal.	322.31	m^3

FiFi Fishcon NV off ship fire syst.
40,000 liters per minute
5,481 litres foam capacity

Deck equipment Smith Berger tow pins

Towing winch Fore	Markey render recover DEPCF-52
Aft	JonRie ser. 525 - 2600 feet 2.25" steel

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A STUDY OF FATE AND BEHAVIOR OF DILUTED BITUMEN OILS ON MARINE WATERS

Dilbit Experiments – Gainford, Alberta

Abstract
This document is a final report for a series of physical and chemical tests that were conducted on the fate and behavior of diluted bitumen oils at a test facility in Gainford, Alberta. Additionally, as part of this study, a series of tests were conducted to determine the efficiency of various types of oil spill response equipment under similar conditions.

Witt O'Brien's, Polaris Applied Sciences, and
Western Canada Marine Response Corporation

WITT | O'BRIEN'S

POLARIS APPLIED SCIENCES, INC.

WCMRC Western Canada Marine Response Corporation

About Witt O’Brien’s

Witt O'Brien's is a global leader in preparedness, crisis management, and disaster response and recovery with the depth of experience and capability to provide services across the crisis and disaster life cycle. Witt O'Brien's is uniquely positioned to bring together policy architects and technical experts in public safety with leaders from all levels of government and private sector partners to forge solutions to emergency management challenges.

Witt O’Brien’s brings a new approach to the crisis and disaster industry by combining extensive real world experience with innovative planning, training, exercise, and technology solutions.

About Polaris Applied Sciences

Polaris Applied Sciences has been involved with oil spill response and related research for more than 30 years. They have provided assessments, made recommendations, and have assisted with the implementation of marine and onshore spill response programs worldwide for major industry response capabilities as well as national response programs. Their key industry clients have included BP, Chevron, Conoco-Philips, ExxonMobil, Pemex, Qatar Petroleum, Shell, and Total. In addition they have completed many projects for the P&I Clubs, as well as for the International Maritime Organization (IMO), the World Bank, the International Monetary Fund (IMF), and the European Bank for Reconstruction and Development (EBRD). The Polaris team provides companies worldwide with scientific support to spill response, natural resource damage assessment (NRDA) and resource reinstatement, environmental restoration services, and spill planning and training.

About Western Canada Marine Response Corporation

As a Transport Canada certified response organization, Western Canada Marine Response Corporation’s mandate is to ensure there is a state of preparedness in place and to mitigate the impact when an oil spill occurs. This includes the protection of wildlife, economic and environmental sensitivities, and the safety of both the responders and the public.

Western Canada Marine Response Corporation’s customer base (2,000+ members) includes oil handling facilities, barging companies, freighters visiting our ports, ferries, cruise ships, US-bound vessels traveling through Western Canada waters, and others including, but not limited to, forest industry facilities, fish camps, and float plane companies.

Disclaimer

This report prepared by Witt O'Brien's is provided solely for the use and benefit of the requesting party, the Trans Mountain Pipeline ULC (TMPL). Any warranties, expressed and/or implied, are specifically waived. Any statements, allegations, and recommendations in this report should not be construed as a governing policy or decision, unless so designated by other documentation. The report is based on the most accurate data available to Witt O'Brien's at the time the report was delivered and is subject to change without notice.

Acronyms and Abbreviations

Acronym	Meaning
a.k.a.	also known as
ANS	Alaska North Slope (crude)
API	American Petroleum Institute (standards, protocols)
ASTM	American Society for Testing and Materials (standards)
AWB	Access Western Blend
bbl/hr	barrels per hour (recovery rate)
BTEX	benzene, toluene, ethylbenzene, xylene
^{o}C	degrees Celsius
C1-C7	HC molecules containing between 1 to 7 carbons
C1-C29	HC molecules containing between 1 to 29 carbons
CLB	Cold Lake Blend
CLWB	Cold Lake Winter Blend
cm	centimeters
cSt	centistokes
D	day(s)
dilbit	diluted bitumen
dyn/cm	dyne per centimeter
EBRD	European Bank for Reconstruction and Development
EPA	US Environmental Protection Agency (& their test protocols)
^{o}F	degrees Fahrenheit
FAQs	Frequently Asked Questions
FERC	Federal Energy Regulatory Commission
g	grams
GC/MS	gas chromatography / mass spectrometry (combo test)
HC	hydrocarbon(s)
hr(s)	hour(s)
I.D.	identification (number)
IMF	International Monetary Fund
IMO	International Maritime Organization
in	inches
ISB	in-situ burning
kg/m^3	kilogram per meter cubed
KMC	Kinder Morgan Canada, Inc.
L	liters
LEL	lower explosive limit
m	meters
m^3/hr	meters cubed per hour (recovery rate)
mL	milliliter
mm	millimeters
MPa	megapascal
mph	miles per hour
m/s	meters per second
n/a	not applicable
NRDA	natural resource damage assessment
OSR	oil spill response
PAH	poly aromatic hydrocarbon
ppm	parts per million

Acronym	Meaning
ppt	parts per thousand
psi	pounds per square inch
SCAT	Shoreline Cleanup Assessment Technique
SOCSEX	subsurface oil in coarse sediments experiment(s)
SOP	standard operating procedure
SVOCs	semi-volatile organic compounds
synbit	synthetic (crude) bitumen
syncrude	synthetic crude oil
TMPL	Trans Mountain Pipeline ULC
TMX	Trans Mountain Pipeline Expansion Project
tPAH	total poly aromatic hydrocarbons
TPH	total petroleum hydrocarbons
μg/L	micrograms per liter
USG	US gallons (versus gallons – UK)
UV	ultraviolet (light/radiation)
WEC	World Energy Council
WCMRC	Western Canada Marine Response Corporation

Table of Contents

1 Executive Summary

In June 2012, Trans Mountain Pipeline ULC (TMPL) asked O'Brien's Response Management (now Witt O'Brien's) to organize a study on diluted bitumen (dilbit) products that are being transported out of the oil fields of Northern Alberta to support a pending application for their system expansion (Trans Mountain Pipeline Expansion Project: TMX). The purpose of the requested study was to further the knowledge of dilbit in general and, more specifically, to investigate the behavior of dilbit when spilled into a marine environment. Some of the basic questions to be answered were:

Will diluted bitumens sink or float in marine waters?

Will diluted bitumens behave any differently than other heavy crude oils as they weather?

Is the performance of the equipment currently stockpiled by North American oil spill recovery organizations adequate to mechanically remove diluted bitumens off the surface of the water?

The study's multi-disciplinary Project Team consisted of Witt O'Brien's (acting in a management role); Polaris Applied Sciences (undertaking the project science); and Western Canada Marine Response Corporation (supporting the equipment test). This team was tasked with designing and executing a controlled test to evaluate the fate and behavior of dilbit discharged into a simulated marine environment similar to that of Burrard Inlet (Vancouver, BC, Canada) where the Westridge Terminal is located.

The resulting study consisted of the following steps:

1. Literature Review;
2. Gap Analysis and Research Plan Development;
3. Execution of Test and Experiments to Support the Research;
4. Final Reporting

The literature review was conducted in the fall of 2012. World-wide, dilbit have occupied a small share of the commercial energy market with few instances of their involvement in significant spill events. As a result, limited empirical observations have been recorded about how these products reacted when spilled into the environment. The literature review was forced to rely largely on available information on other heavy crude oils.

Following the literature review, data gaps were identified and a research plan was developed. Research was conducted from May 13 through May 26 in Gainford, Alberta, and consisted of three main focus areas:

- Scientific sampling of oil and its impact on water quality as the dilbit oils weathered under varied physical conditions;
- The testing of mechanical equipment to recover these products weathering on the surface of the water over a 10-day period;
- Testing the efficacy of non-mechanical countermeasures, such as in-situ burning, chemical dispersants, and shoreline cleaning agents.

To execute the scientific portion of the study, the team employed a series of dedicated tanks where they could observe the 10 day behavior of two types of dilbit on brackish water: Cold Lake Blend (CLB) and Access Western Blend (AWB). Wind and wave generating devices were used to simulate environmental conditions for the study. Neither of the two weathered dilbits sank under the conditions tested. In the end, the behavior of both products proved to be no different than what might be expected of so-called conventional heavy crude oils when exposed to similar conditions.

For the equipment portion of the study, the operational team employed only CLB dilbit carefully discharged into a series of large rectangular tanks. The tanks were staged outdoors where they would be subject to ambient atmospheric conditions. Each recovery device was uniformly tested and analyzed for both its ability to recover spilled oil and the efficiency with which that task was accomplished. All skimming devices were able to recover the spilled dilbits at all stages of the 10-day weathering cycle.

Three non-mechanical countermeasures were investigated for their ability to mitigate spilled CLB dilbit under specific conditions. In-situ burning was found to be effective on oil that had only weathered for 24 hours or less. Chemical dispersants were marginally effective for up to a 6 hour weathering window. Corexit 9580, a shoreline cleaning agent, proved effective up to a 4 day weathering cycle.

2 Introduction

Although several detailed studies have been completed that characterize the fate and behavior of heavy crude oils made from Alberta oil sands, most are laboratory and bench-scale tests. Kinder Morgan Canada, Inc. (KMC) undertook an initiative to expand upon this knowledge through larger, meso-scale tests of diluted Alberta oil sands bitumen (dilbit) crude oil. Larger tank tests allow for simulated wave and current conditions that may be more typical of the marine setting of Burrard Inlet, the export point for dilbit from the Trans Mountain Pipeline (TMPL) (Figures 2-1 and 2-2).

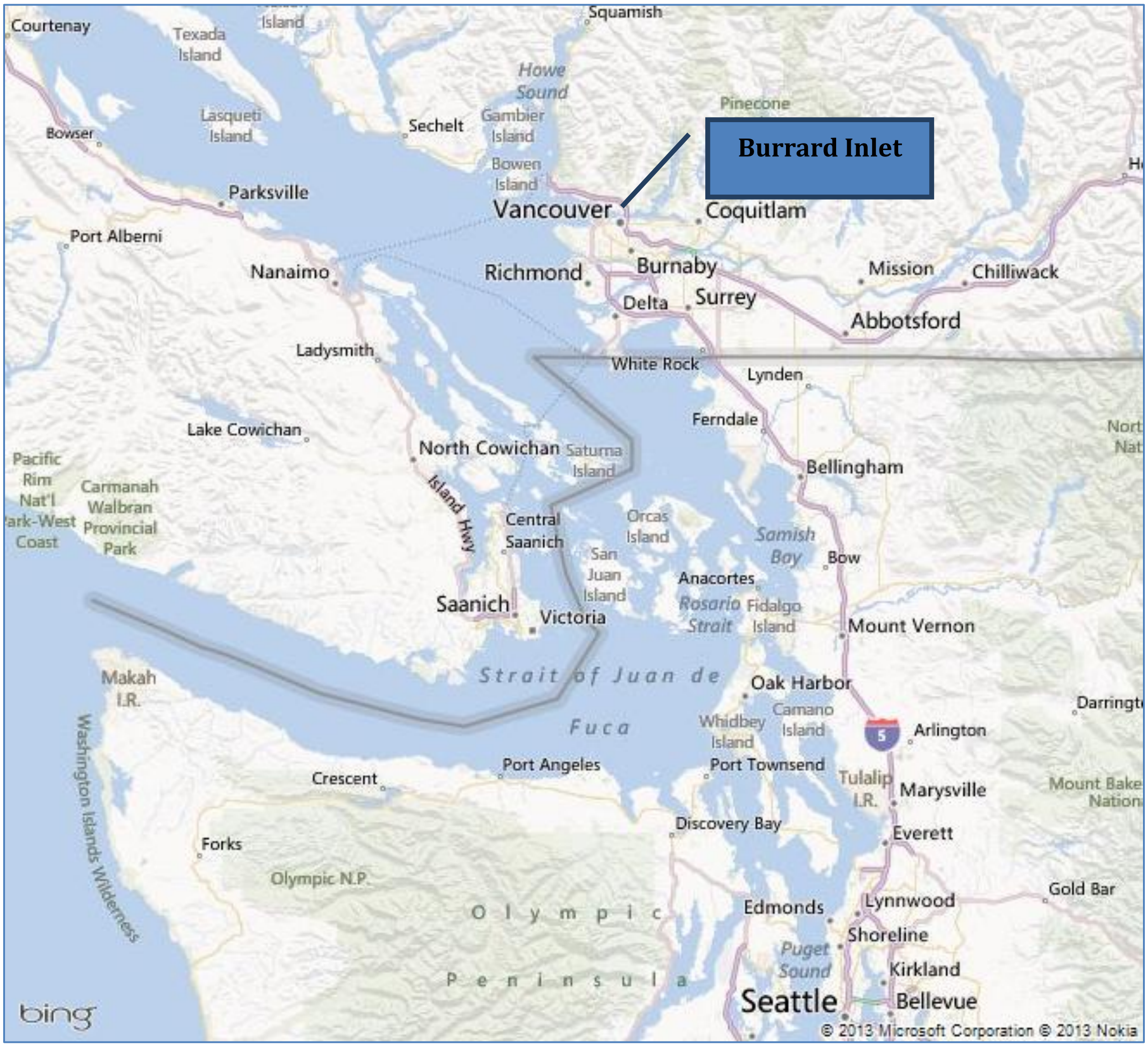

Figure 2-1: Overview of the Oil Export Area

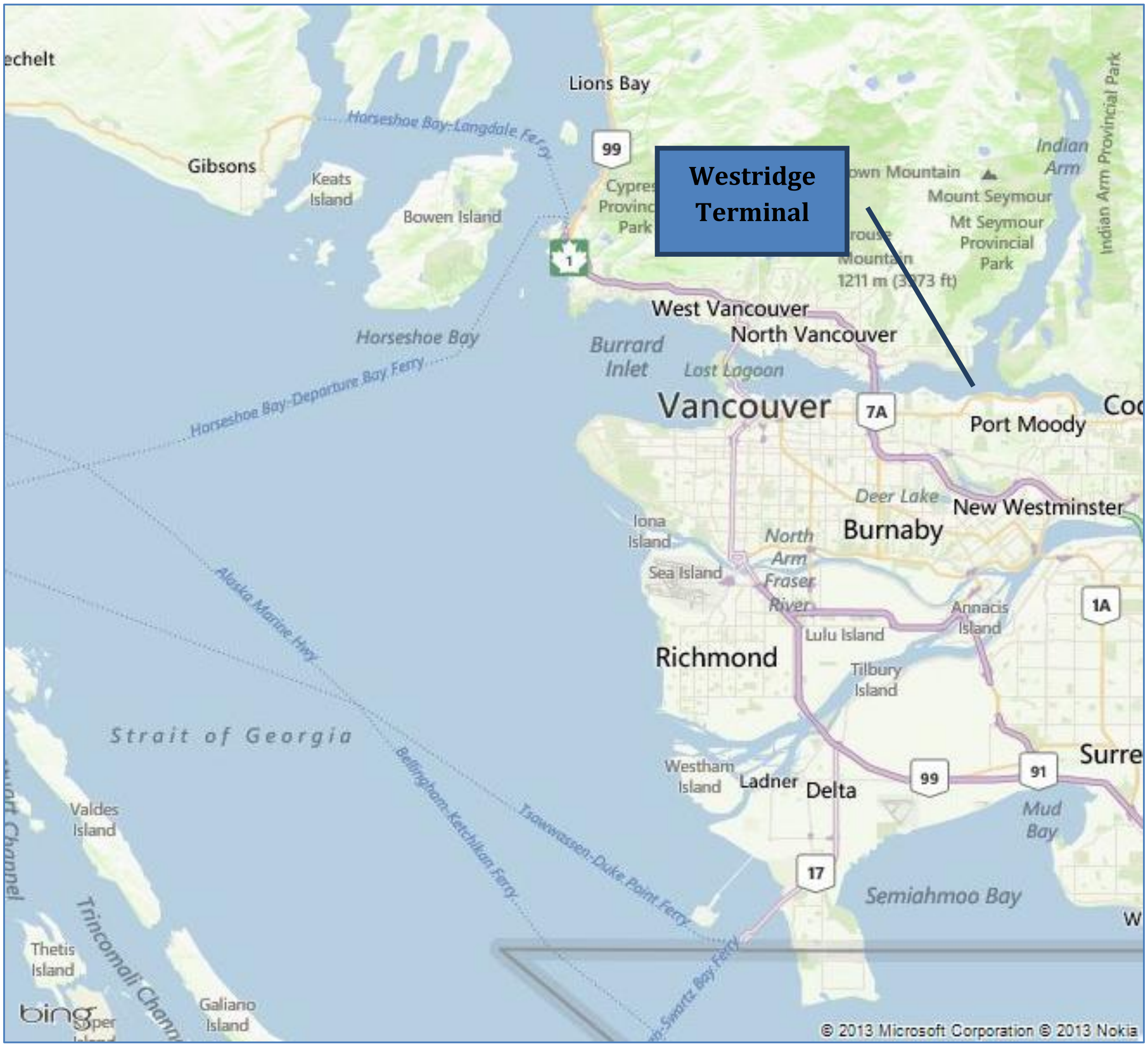

Figure 2-2: Detailed View of the Oil Export Area near Vancouver

2.1 Background

The crude bitumen contained in the Canadian oil sands can be described as a naturally occurring petroleum that exists in the semi-solid or solid phase in natural deposits. The extracted bitumen is extremely viscous, and it will not flow unless heated or diluted with lighter hydrocarbons (HC). At room temperature, it is much like cold molasses. The World Energy Council (WEC) defines natural bitumen as "oil having a viscosity greater than 10,000 centipoise under reservoir conditions and an American Petroleum Institute (API) gravity of less than 10° API." In order to transport it through pipelines, a diluent is added to the bitumen. The diluent used could be lighter crude oils, synthetic crude oils, or natural gas condensates. Diluted bitumen (diluted with naphtha to make it flow in pipelines) is known as dilbit in the Canadian petroleum industry, while bitumen upgraded to synthetic crude oil is known as syncrude, and syncrude blended with bitumen as synbit. Blending produces a homogeneous product that has considerably lower density and viscosity with good pumping and flow properties. The product has to meet quality specifications that are posted with the National Energy Board in Canada and the Federal Energy Regulatory Commission (FERC) in the US.

The oil properties and behavior of dilbit are of interest to spill modelers, transportation and handling operators, environmental scientists, and spill responders as proposed pipeline expansion programs are underway for delivery of diluted Alberta oil sands crude oils to export destinations. Although dilbits have been transported via pipeline for the past 30 years and their general properties are akin to other heavy oils, the specific characteristics and behaviors of these oils as they weather have been the subject of a limited number of published studies. As a precursor to this study, the Project Team undertook a literature search and review that focused on the behavior of, and response to, spilled dilbits. Although there are numerous reports and studies that have been conducted on heavy oils (crudes and refined), the literature review resulted in only six reported studies focused specifically on dilbits in available on-line searches. Two documented spills of dilbit into an aquatic setting are the 2010 Marshall Spill (Kalamazoo, MI) from the Enbridge Pipeline (NTSB 2012; see also Enbridge Line 6B Response) and the 2007 Burnaby Spill (Burrard Inlet) from an excavator puncture of the TMPL. The Marshall Spill involved both Cold Lake and MacKay River dilbits on land and into a freshwater setting whereas the Burrard Inlet incident was an Albian Heavy blend that reached the estuarine waters and shoreline near the TMPL Westridge Terminal (Stantec, 2012; also see TMPL Westridge 2007 Spill).

Tests conducted by Brown et al. (1992) documented the evaporative loss of CLB from four types of shoreline material, ranging from approximately 1 percent to 9 percent of 24 hour weathered oil. SLRoss (2010) evaluated the physical properties of two dilbit products to generate the necessary parameters for marine oil spill modeling. The products tested were MacKay River Heavy Bitumen diluted with synthetic crude (Suncor Synthetic Light) and CLB bitumen diluted with condensate. The 2010 report notes that test oils were placed in a wind tunnel to generate evaporated oil products under controlled conditions and measure the changes in physical properties. The tests showed that all oils, with the exception of the MacKay River blend, had densities less than one when evaporated. The MacKay River blend densities remained lighter than standard seawater throughout the evaporation tests. Subsequently, SLRoss (2011) undertook a series of meso-scale tests using a circulating loop (flume) to assess the behavior of CLB dilbit under more natural weathering conditions in freshwater where, once again, weathered dilbit continued to float on the freshwater surface in the flume during the full 13 days of testing.

Two workshops specifically focused on dilbits and the current state of knowledge, including implications for spill response, have been held in Canada (Halifax 2011 and Devon 2012). Recommendations made during both workshops included the continued need to expand knowledge of dilbit characterization, behavior when spilled into a number of distinct receiving environments, and spill countermeasures.

2.2 Study Objectives

The overall study goal was to better understand and assess oil behavior, weathering, and oil spill response (OSR) countermeasures for spilled dilbit crude in a controlled simulated condition similar to the potential receiving environment of Burrard Inlet (Figure 2-1 and Figure 2-2). The objectives of the applied research were multifaceted. One objective was to better understand and characterize the changes in physical and chemical properties of dilbit in an estuarine simulated condition over a 10-day period. Another objective of the meso-scale trials was to determine efficiency and effectiveness of dispersant, in-situ burning, and shoreline cleaning agents as potential countermeasures for various stages of weathered oil. The third part of the study was to test various types of oil spill response equipment under similar weathering conditions and to assess their efficiencies over time. Air sampling and monitoring also was included with the objective of providing measured emission rates that could be used to ground-truth numerical estimates modeled for accidental release/hazard assessment (reported separately).

2.3 Burrard Inlet Setting

A brief summary of the range of conditions found in Burrard Inlet is provided in consideration of variables for meso-scale tests, based largely on Thompson (1991).

2.3.1 Oceanography

Most of Burrard Inlet is characterized by an upper surface layer of brackish water subject to runoff and river inputs, predominantly the Fraser River for the outer harbor and the Indian, Seymour, and Capilano rivers for the inner harbor. The surface water layer temperatures are dependent on local weather conditions and precipitation, generally ranging from a mean near 7 ˚Celsius (˚C) in February to approximately 17 ˚C in July. On average, salinities decrease from approximately 20-25 ppt (parts per thousand) at First Narrows to approximately 15 ppt near the south end of Indian Arm.

2.3.2 Weather

Winds typically are east-west, controlled by local topography, with monthly mean wind speeds ranging from 2.5 meters per second (m/s) to 3 m/s for Vancouver Harbor. Average high and low temperatures (Coal Harbor) range from 7 ˚C and 1 ˚C (December) to 23 ˚C and 14 ˚C (July-August) (World Weather Online).

2.3.3 Shoreline Types

Burrard Inlet has a large range of shoreline types. Primary natural shorelines include mud flats, mixed sediment, cobble beaches, boulder beaches, and bedrock. Much of the shoreline is man-made rip-rap. Fine mud occurs in deposition areas such as Port Moody Arm, with coarse cobble and pebble at First and Second Narrows, and on river deltas such as the mouth of the Capilano River (Vancouver Harbor Shoreline Atlas).

2.3.4 Oil Types

A Cold Lake Winter Blend (CLWB) dilbit was selected to provide a “standard” dilbit, with the winter blend representing more diluent initially. The slightly higher diluent is expected to result in higher hydrocarbon flux to atmosphere and to the water column (dissolution of acutely toxic low molecular weight hydrocarbons). The summer blend has fewer lighter end hydrocarbons and hence a slightly higher initial density than CLWB. More research has been completed with CLB dilbit than other blends; thus, it was expected that results from these tests would provide a basis for comparison with a broader range of prior research.

Winter specification Access Western Blend (AWB) was the second oil tested for physical and chemical properties under similar weathering scenarios as the tests on CLWB. AWB is a dilbit from the Athabasca region south of Fort McMurray, Alberta.

Oil sands bitumens are blended with diluents to meet pipeline export specifications. These blends meet specific oil export tariffs and must fall within a defined range of density (not to exceed 940 kg/m^3 and viscosity (not to exceed 350 centistokes (cSt)) at reference temperatures (see range of oil properties for AWB and Cold Lake dilbits in Appendix A, from CrudeMonitor). The blend is a single-phase liquid with its own unique properties. Dilbit is not a bitumen in suspension, in emulsion, or a two-phase liquid.

3 Methodology

3.1 Tanks / Facility Description

The CLWB and AWB studies were conducted from May 13 through May 26, 2013 at the TMPL pump station in Gainford, Alberta (Figure 3-1). The Gainford site was divided into several distinct research areas:

- Scientific study for CLWB, located outside the shed (Figure 3-1 and Figure 3-2);
- Scientific study for AWB, located inside the facility's shed;
- Equipment testing for CLWB, located outside and adjacent to the shed (Figure 3-1 and Figure 3-2); and
- In-situ burning test site located in a close but safe distance from the rest of the research areas.

The scientific study tanks were filled with water at a prepared salinity, using SolarSalt, of 20 ppt. Water temperature, pH, and salinity were monitored twice daily in all of the science tanks.

Figure 3-1: Gainford, Alberta (site of study)

3.2 CLWB and AWB Research Tanks

The scientific study area for AWB was located inside an open shed while the CLWB dilbit study area was located outside the shed (Figure 3-2). During the first two days of weathering, all CLWB tanks were directly exposed to wind (carrying visible amounts of dust) and direct sunlight. The night of May 17 (after approximately 48 hours of weathering without cover), these tanks were covered with a tent (Figure 3-3) in preparation for forecasted windy and rainy weather.

Two types of air monitoring were carried out, for occupational safety purposes, during field testing operations:

1. At least one worker wore a four-gas detector in all potentially vaporous areas. Air monitoring for benzene, lower explosive limit (LEL), oxygen, and carbon monoxide was done throughout the test period. These gas detectors were calibrated before the field tests and were bump tested daily.

2. A field safety person carried out benzene levels monitoring whenever testing activities warranted it. For example, benzene levels were monitored during the oil pours, during skimming and pumping activities in the equipment testing area, and during sample collections in the science shed. When levels rose above 0.05 ppm, all personnel in that area donned half-face respirators. *Note: All those personnel were fit-tested before being allowed to wear respirators.*

Benzene levels were within tolerances for half-face (cartridge) respirators and were required for all personnel working with oil inside the shed or working directly with the oil in tanks. The only alarm that activated was when a worker stepped immediately downwind of the exhaust from a skimmer power pack.

Tanks S1 through S3 were used for AWB weathering. The CLWB weathering was conducted in an industrial tank, shown on the left picture in Figure 3-2, divided into three rectangular areas: S9A, S9B, and S9C. Tanks S9A and S9C were rectangular surface tanks (2.97 m^2) inside S9B (18.58 m^2). Tank S4, measuring 1 m by 1 m, was located outside, uncovered, and was used to weather CLWB for countermeasures testing. Table 3-1 summarizes the dimensions of these tanks and includes the volume of spilled oil and estimated initial oil thickness.

Tank I.D.	Tank dimensions (shape)	Water depth	Type of Dilbit	Oil spill quantity (Liters)	Initial Oil Thickness (mm)	Imposed weathering conditions
S1	2.38 m^2 x 2.13 m (Cylinder)	1.9 m	AWB	25	10.68	Static
S2	2.35 m^2 x 2.13 m (Cylinder)	1.9 m	AWB	25	10.80	Mild
S3	2.38 m^2 x 2.13 m (Cylinder)	1.9 m	AWB	25	10.68	Moderate
S4	1.49 m^2 x 1.22 m (Cube)	1 m	CLWB	20	13.46	Mild (outside)
S9A	2.97 m^2 x 1.4 m (Rectangular)	1.2 m	CLWB	30	10.09	Moderate
S9B	55.02 m^2 x 1.4 m (Rectangular)	1.2 m	CLWB	148	11.71	Static
S9C	2.97 m^2 x 1.4 m (Rectangular)	1.2 m	CLWB	30	10.09	Mild

Table 3-1: Tanks and oil characteristics

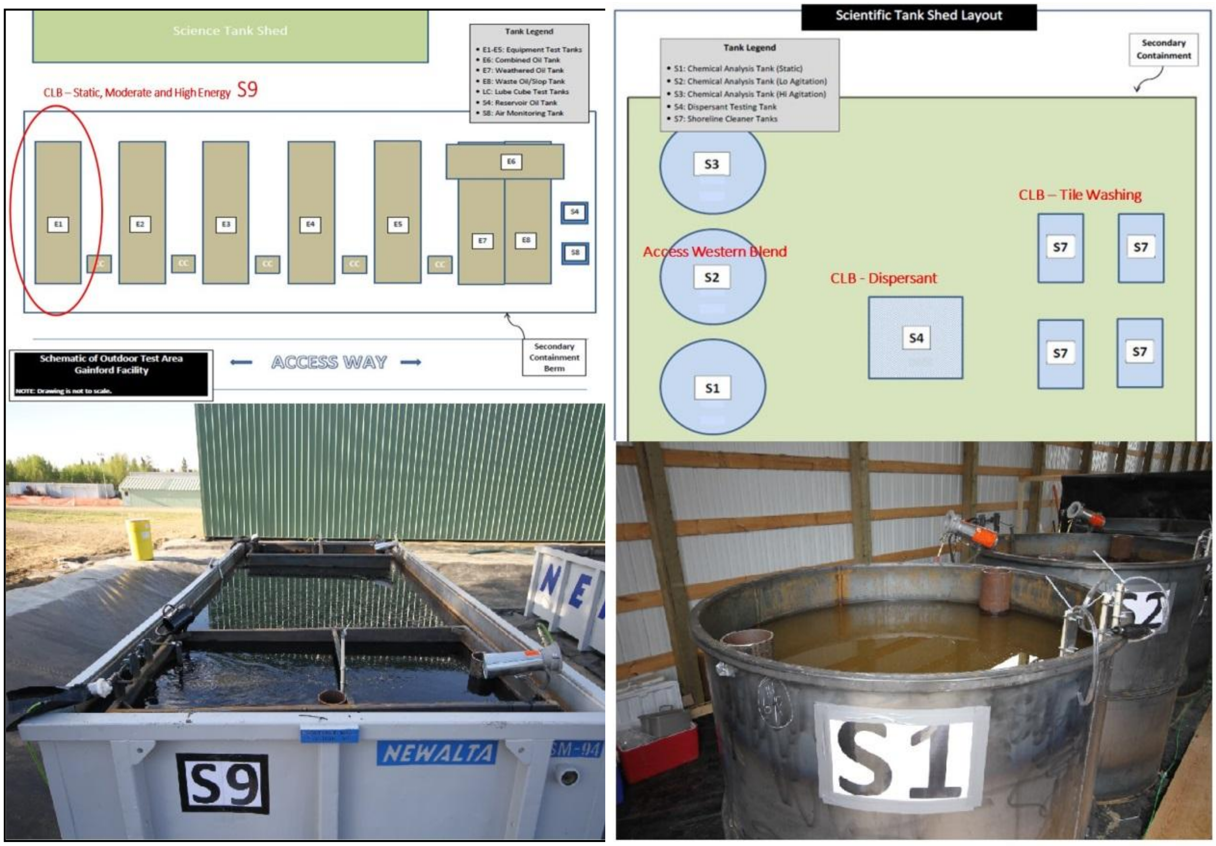

Figure 3-2: Tanks S9A, S9B, and S9C (left) and AWB tanks S1, S2, and S3 (right)

Figure 3-3: Tanks S9A, S9B, and S9C covered with tent

Each type of oil (CLWB and AWB) was exposed to three similar types of weathering conditions. Table 3-2 and Figures 3-4, 3-5, and 3-6 summarize the agitation conditions imposed on each tank:

- Static Conditions: No agitation induced. Wind exposure was minimized as far as was practical.
- Mild Agitation: Low imposed wind and wave conditions; induced by simple mechanical means through intrinsically safe fans and a paddle mechanism.
- Moderate Agitation: Greater induced wind and wave agitation.

Tank #	Dilbit Type	Agitation	Average T (Max and Min)	Average Salinity (Max and Min)	Average pH (Max and Min)
S1	AWB	Static – no agitation	15.9 (19 – 14)	20.6 (22 – 20)	7.5 (8.0 – 7.0)
S2	AWB	Mild – avg. wavelets height approx. 2 cm – 4 cm; avg. wind 5 mph (2.23 m/s)	14.3 (16 – 13)	21 (22 – 20)	7.5 (8.0 – 7.0)
S3	AWB	Moderate – avg. wavelets height approx. 5 cm – 7 cm; avg. wind 10 mph (4.5 m/s)	11.7 (16 – 10)	21.6 (23 – 20)	7.7 (9.0 – 7.0)
S4	CLWB	Mild – avg. wavelets height approx. 2 cm – 4 cm; avg. wind 5 mph (2.2 m/s)	16.1 (19 – 13)	22.5 (24 – 20)	7.6 (9.0 – 7.0)
S9A	CLWB	Moderate – avg. wavelets height approx. 5 cm – 7 cm; avg. wind 10 mph (4.5 m/s)	15.2 (23 – 9.3)	22.3 (24 – 20)	7.6 (8.5 – 7.0)
S9B	CLWB	Static – no agitation	14.9 (22 – 9)	21.2 (22 – 20)	7.5 (8.0 – 7.0)
S9C	CLWB	Mild – avg. wavelets height approx. 2 cm – 4 cm; avg. wind 5 mph (2.2 m/s)	15.1 (22 – 9.6)	21.7 (23 – 20)	7.5 (8.0 – 7.0)

Table 3-2: Summary of water conditions during weathering experiments

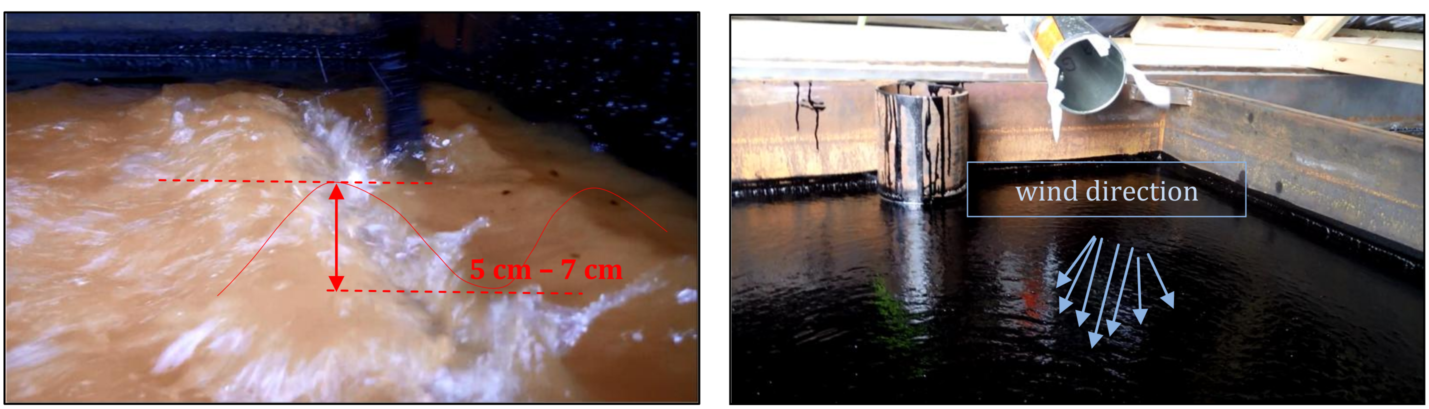

Figure 3-4: (Left) Moderate wave (5 cm – 7 cm) and (right) moderate wind (10 – 18 mph) generated in S9A

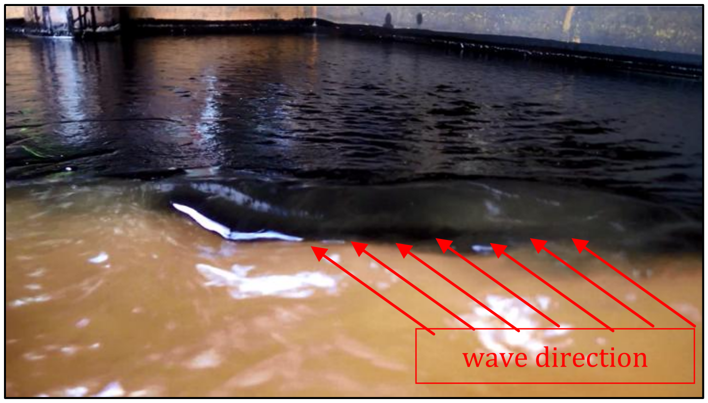

Figure 3-5: CLWB oil pushed by moderate waves and moderate wind in S9A

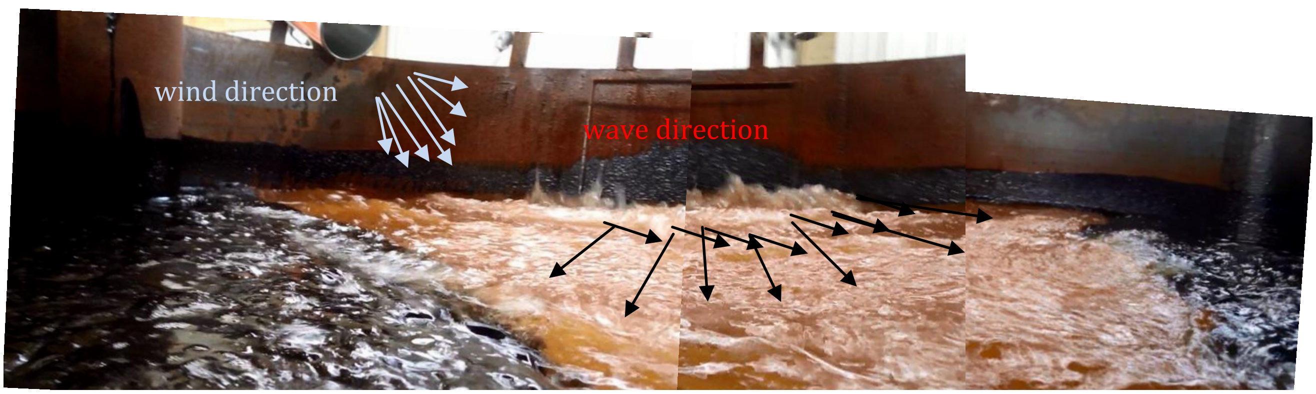

Figure 3-6: Panoramic view (180°) of AWB oil pushed by moderate waves and moderate wind in S3

3.3 Flux Chamber Sampling Program

A flux chamber sampling program was conducted outside the shed (Tank S8) to analyze the emission rate of chemical groupings (e.g., total petroleum hydrocarbon (TPH), volatile organic compounds, reduced sulphur compounds, and light hydrocarbons (C1 to C5)) from CLWB over a nine day sampling period by RWDI AIR Inc.

Tank 8 was a freshwater cube tank (1.49 m^2 by 1.22 m) exposed to ambient conditions with no agitation imposed. Using a floating flux chamber placed onto the surface of Tank S8, CLWB emission fluxes were sampled over a 2 minute period every 8 hours for the first day, every 12 hours from day 2 to day 7, and once per day on days 8 and 9.

A report of the flux chamber sampling program, including decay times in emission rates, is included in Appendix I.

3.4 Oil Fate and Weathering

Oil was applied to achieve approximately 1 cm slick thickness at the moment released (prior to evaporation or weathering processes; see Table 3-1). Containment by the tank configuration limited what would be the natural spreading of oil in an unconfined condition, creating a thick slick similar to a confined spill, thus representing a case for slower evaporation rates with possible increased exposure to light ends, and potentially greater dissolution of hydrocarbons into the water column.

Sampling was conducted throughout the 10-day weathering period for both whole oil (surface layer oil sample) and the water column of each tank at frequencies indicated in Table 3-3. Water column samples were drawn from 0.5, 1, and 1.5 m depths from each of the AWB test tanks (S1 to S3) and at 0.5 for the CLWB tanks. Physical tests for whole oil and chemical tests for water column samples were conducted by Maxxam Analytics Inc. (Maxxam) in Edmonton and Calgary, with test protocols as defined in Tables 3-4 and 3-5. During the 10-day experimental period, several probes using a weighted sorbent drop and an oil snare on the end of a hand tool were employed to ascertain if any oil had sunken to the bottom of the tanks. No evidence of sunken oil was found from these probes nor was oil observed on the bottom of the tanks at the conclusion of testing when tanks were emptied.

Note: Source oil extracted from the reservoir tank (S4) was taken to small tanks for dispersant, shoreline cleaner tests, and to an outdoor tank for in-situ burning (ISB). While sampling for physical and chemical properties of oil and water was collected in both CLWB and AWB, countermeasure tests were conducted only on CLWB oil.

Elapsed Time	Oil Properties	Water Column HC	CLWB - Field Dispersant Effectiveness	CLWB - ISB	CLWB Shore Cleaner
0 hr	√	√			
2 hrs	√	√			
4 hrs	√	√			
6 hrs	√	√	√	√	
12 hrs	√	√			
1 day	√	√	√	√	√
2 days	√	√			
3 days				√	√
4 days	√	√			
5 days					√
6 days	√	√			
8 days	√	√			
9 days	√	√			
10 days	√	√			

Table 3-3: Sampling frequency and testing protocols used for oil and water column studies

Property	Test Temperature °C	Technique/Instrumentation	Procedure (Lab SOP)
Density	15	Anton Paar Densitometer (DMA 4500)	ASTM D5002 (PTC SOP-00100)
Viscosity	Variable: 5 to 80 °C	Anton Paar Viscometer (SVM 3000 Stabinger)	ASTM D341, D7042 (PTC SOP-00267)
Interfacial Tension	15	CSC DuNouy Ring Tensiometer	ASTM D971-99a
Pour Point	N/A	ASTM Test Jars and Thermometers	ASTM D97/ASTM D5853 (PTC SOP-00068)
Flash Point	N/A	Closed Cup Flash Tester	ASTM D93 (PTC SOP-00082)
Water Content	N/A	Karl-Fischer Titration	ASTM D1123/ASTM D4377 (PTC SOP-000167)
Dispersant Effectiveness	20	Swirling Flask	ASTM F2059

Table 3-4: Test procedures used to measure physical properties of oil and/or oil-water emulsion

Analysis	Procedure (Lab SOP)	Medium	Samples
BTEX (benzene, toluene, ethylbenzene, and xylenes)	EPA 8260 -HS GC/MS (AB SOP-00039)	Water	3 each 40 mL
Alkylated PAH/SVOCs	ESTD-OR-20/EPA 8270D – GC/MS (AB SOP-000037; CAL SOP-00250)	Water	2 each 250 mL
HC Light Ends (C1-C7)	ASTM D5580	Water	2 each 250 mL
Total petroleum hydrocarbons (TPH)	EPA 3550C SM 5520CF - IR (CAL SOP-00096)	Water	1 each 500 mL
HC (C1 thru C29) + BTEX	Modified ASTM D2887	Oil	1 L

Table 3-5: Chemical analyses

Notes regarding several of the test methods and limitations due to incorporated water include:

Density- Approximately 0.7 mL of crude oil is introduced into an oscillating sample tube and the change in oscillating frequency caused by the mass in the tube is used in conjunction with internal calibration data to determine the density of the sample. Water incorporated into the oil matrix, noted in several cases, may affect the oil density, but is likely representative of the emulsion.

Viscosity- The sample is introduced into the measuring cells, which are at a closely controlled and known temperature. The measuring cells consist of a pair of rotating concentric cylinders. The dynamic viscosity is determined from the equilibrium rotational speed of the inner cylinder under the influence of the sheer stress of the sample and an eddy current brake in conjunction with adjustment data. Tests are run at increasing temperatures to achieve measurable values within the equipment range. All dynamic viscosities were measured at least at three temperatures. Viscosity values reported at temperatures other than the test temperatures were calculated by extrapolation following internal lab and the American Society for Testing and Materials (ASTM) procedures. High water content, as found in an oil-water emulsion, may affect the results.

Flash Point- A sample is heated at a slow constant rate with continuous stirring. An ignition source is directed into the test cup at regular intervals with simultaneous interruptions to stirring. The flash point is the lowest temperature at which application of the ignition source causes vapor above the sample to ignite. Presence of water in the sample may prohibit the ascension of vapor during the test which can result in a non-flammable vapor.

Pour Point- After preliminary heating, the sample is cooled at a specified rate and examined at intervals of 3 °C for flow characteristics. Water in the sample, such as from an emulsion, may interfere with test results.

3.5 Chemical Dispersant Application

Tank S4 served as the CLWB weathering reservoir tank. The weathered oil collected from S4 was used for burning, dispersant, and shore cleaning tests. Tank SD, built to the same dimensions as S4, was located inside the shed, filled with water, and prepared to a salinity of 35 ppt to simulate more oceanic conditions for the dispersant tests. Salt water was chosen to represent the most likely location for dispersant application approval as opposed to a brackish (Burrard Inlet) condition. A measured volume of weathered CLWB oil previously collected from Tank S4 was applied to the water surface and allowed to spread on the static water surface. A water sample was drawn from 1 m below the surface before and at approximately 20 minutes following oil application for hydrocarbon analysis. Dispersant (Corexit EC 9500A) was then applied directly to the oil on water at a 1:20 ratio from a handheld spray bottle. The tank was then provided with mild agitation (3 cm - 5 cm chop) to aid in dispersant mixing and penetration into the oil.

Visual and photographic documentation were obtained of the dispersant application. A third water sample was collected from 1 m below the surface at approximately 20 minutes following dispersant application for hydrocarbon analysis. Sorbent pads were used to collect all oil remaining on the water surface and clinging to tank walls following the dispersant application. Sorbents were weighed to gauge how much oil remained after dispersant application (see Appendix C). Tank S9 was then drained and cleaned immediately after each test in preparation for the next test.

Swirling flask tests (ASTM 2059) were also conducted on bulk weathered CLWB samples collected from tanks S9 and S4 (Table 3-4). Tests were run at 20 °C and with water at 33 ppt salinity.

3.6 Controlled Burning

Two liters of oil were collected from Tank S4 at each of the following weathering intervals: 6 hours, 1 day, 3 days, and 5 days. Burns were conducted under a specific Safety Plan, with a waiver for the burn ban in place at the time, and with local fire department personnel and a fire engine on site. The outdoor burn basin consisted of an open top tank, 3 m in diameter, filled with freshwater and in which a 50 cm diameter steel ring was positioned on blocks such that the ring provided approximately 5 cm of freeboard above the water line. The 2 L weathered oil sample jars were weighed, then oil was slowly poured into the ring, and the empty containers with "clingage" were re-weighed.

Burn ignition was aided with diesel and a hand-held propane torch. More weathered oils (Day 1 and Day 3) required re-starts, for which additional diesel starter was added. Data recorded during the burns included air temperature, water temperature, average wind speed and peak gusts, and time of burn. Following the burn test, oil was collected using sorbents and weighed to provide an indication of the amount of oil remaining (see Appendix D). A small quantity of small (generally less than 3 mm) oil particulates and droplets were not recovered with sorbent pads.

3.7 Substrate Washing

A series of surface washing tests using shoreline cleaning agents were conducted on granite tiles using CLWB dilbit from three stages of on-water weathering in Tank S4 and with variable drying times on tiles (Table 3-6). Shoreline cleaners, also known as surface washing agents or beach cleaners, are chemical agents applied to oil that are stranded on shoreline substrates, with the intent to lift oil off the substrate for subsequent containment and recovery. Untreated granite tiles were oiled by hand with CLWB collected after 1 day, 3 days, and 5 days of weathering in Tank S4 (Figure 3-7, Tank S4). Weathered CLWB dilbit from Tank S4 was poured onto each of six 12 in by 6 in (30.5 by 15.2 cm), light colored, porous (not polished) granite tiles by hand such that the oil covered an entire side of the tile evenly with an oil coat (0.01 to 0.1 cm) as defined by Shoreline Cleanup Assessment Technique (SCAT) standard terminology. Once oiled, tiles were allowed to stand in shade and/or sun, tilted at approximately 45 degrees, from 24 to 144 hours before treatment (Table 3-6; Figure 3-7). Oil thickness was estimated by running a thin piece of rigid waterproof paper through the oil and examining the oiled band on the paper against a graduated scale (Figure 3-7). This process was repeated with oil weathered on water for 72 hours (3 days) and 96 hours (5 days; Table 3-6). Air temperatures throughout the experiment ranged from 10°C at night to a maximum of 23°C during the day.

Tiles were treated with two agents: an off-the-shelf degreaser containing D-limonene, and Corexit 9580, a shoreline cleaning agent. Commercial D-Limonene was unavailable and the results should not be compared to other surface washing tests using commercial D-Limonene. The application rates used are those recommended by the US Environmental Protection Agency (EPA) for shoreline treatment for Corexit 9580. The application ratio tested was the recommended dosage of approximately 1 US gallon per 100 square feet (0.41 L/m^2) or 1.3 ounces (approximately 37 mL) per tile. The application volume was tested with the spray bottle to estimate the number of hand sprays that equals 1.3 ounces (≅37 mL).

A photograph of each tile was taken before and after treatment and compared to untreated wet tiles. For each test condition there was a reference tile with no shoreline cleaning agent and a tile each with cleaning agents.

The treatment consisted of ambient temperature freshwater run through a power washer adjusted to the lowest pressure available, and fitted with a fan tip to distribute the water to approximately 25 cm wide, or the width of the tile being cleaned. The tip was maintained by a governor at 22.5 cm from the tile surface (Figure 3-7). The pressure from the tip was consistent with a garden hose (0.21 – 0.31 megapascal (MPa); 30-45 pounds per square inch (psi)) and was safe for contact with human skin at 22.5 cm with no adverse effects. The treatment proceeded for 30 seconds (approximately 11 passes with the wand) and used approximately 3 L of water.

Observations included standard SCAT terminology for oil remaining on tile, oil removed in water, nature of oil removed in water (sinking, floating, color, character, adherence to sorbent materials), whether the cleaned tile produces sheen, and ease with which additional oil wipes off with casual contact and sorbent.

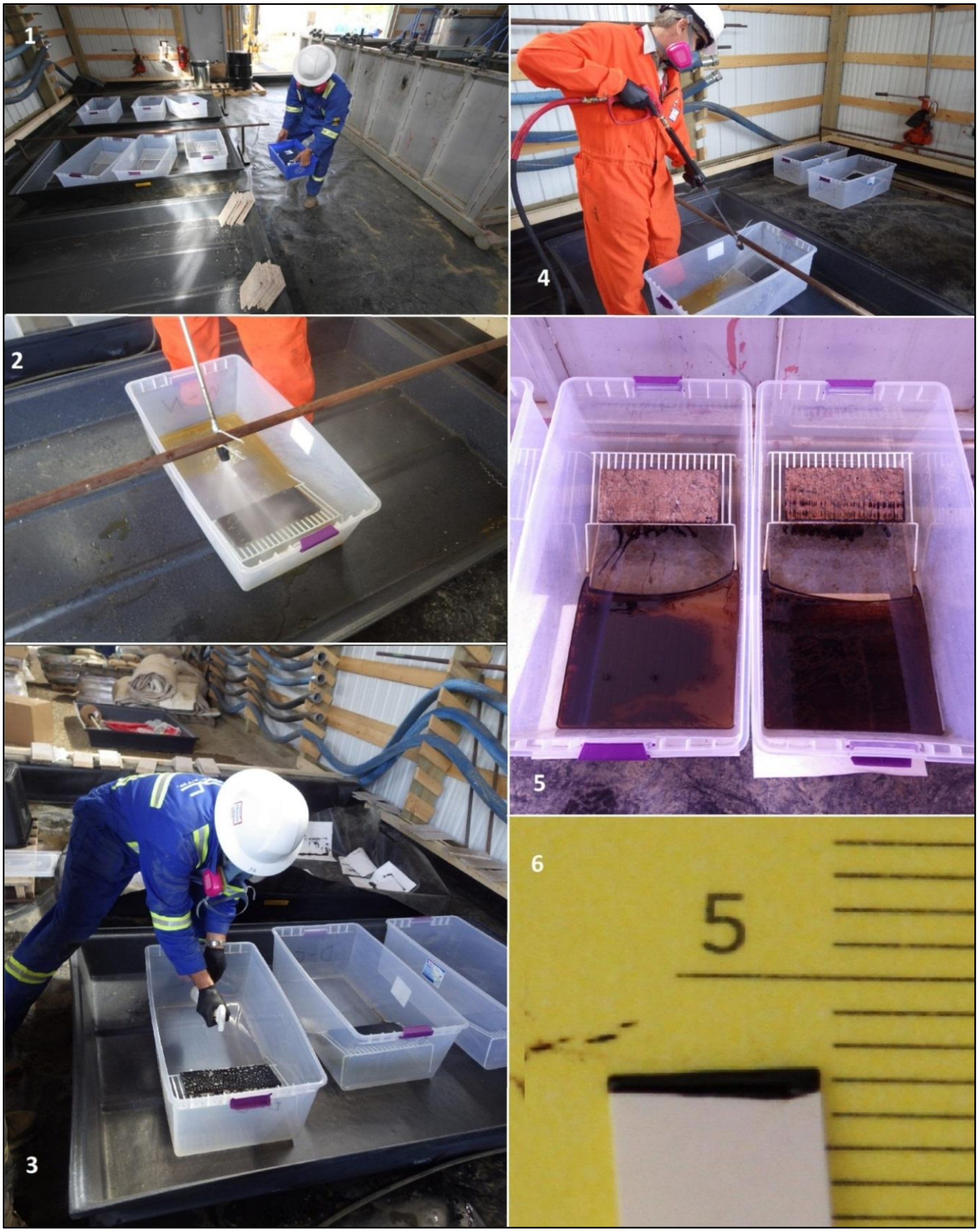

Figure 3-7: 1) Surface washing test area; 2) Apparatus for consistent wash distance and pressure; 3) Applying Corexit 9580; 4) Washing; 5) Post-wash results on side by side pre-wet and pre-dry tiles; 6) Example measure of oil thickness on tile (lines are 1 mm apart)

Tile ID	Tile Condition When Oiled	Oil on water (Days)	Agent Applied	Time Oil on Tiles Prior to Treatment (hrs.)	Total Time before Treatment (hrs.)
1D-W-C-24	Wet	1D	Corexit 9580	24	48
1D-W-L-24	Wet	1D	D-Limonene	24	48
1D-W-N-24	Wet	1D	None	24	48
1D-W-C-48	Wet	1D	Corexit 9580	48	72
1D-W-L-48	Wet	1D	D-Limonene	48	72
1D-W-N-48	Wet	1D	None	48	72
1D-D-C-24	Dry	1D	Corexit 9580	24	48
1D-D-L-24	Dry	1D	D-Limonene	24	48
1D-D-N-24	Dry	1D	None	24	48
1D-D-C-48	Dry	1D	Corexit 9580	48	72
1D-D-L-48	Dry	1D	D-Limonene	48	72
1D-D-N-48	Dry	1D	None	48	72
3D-W-C-24	Wet	3D	Corexit 9580	24	94.5
3D-W-L -24	Wet	3D	None	24	95
3D-W-C-48	Wet	3D	Corexit 9580	48	119
3D-W-N-48	Wet	3D	None	48	119
3D-W-C-72	Wet	3D	Corexit 9580	72	143
3D-W-C-96	Wet	3D	Corexit 9580	96	167
3D-D-C-24	Dry	3D	Corexit 9580	24	95
3D-D-N-24	Dry	3D	None	24	95
3D-D-C-48	Dry	3D	Corexit 9580	48	119
3D-D-N-48	Dry	3D	None	48	119
3D-D-C-72	Dry	3D	Corexit 9580	72	143
3D-D-C-96	Dry	3D	Corexit 9580	96	167
3D-W-C-120	Wet	3D	Corexit 9580	120	191
3D-D-C-120	Dry	3D	Corexit 9580	120	191
5D-W-C-24	Wet	5D	Corexit 9580	24	144
5D-W-N-24	Wet	5D	None	24	144
5D-W-C-48	Wet	5D	Corexit 9580	48	168
5D-W-N-48	Wet	5D	None	48	168
5D-W-c-72	Wet	5D	Corexit 9580	72	192
5D-W-C-96	Wet	5D	Corexit 9580	96	216
5D-D-C-24	Dry	5D	Corexit 9580	24	144
5D-D-N-24	Dry	5D	None	24	144
5D-D-C-48	Dry	5D	Corexit 9580	48	168
5D-D-N-48	Dry	5D	None	48	168
5D-D-C-72	Dry	5D	Corexit 9580	72	192
5D-D-C-96	Dry	5D	Corexit 9580	96	216
5D-W-C-120	Wet	5D	Corexit 9580	120	240
5D-D-C-120	Dry	5D	Corexit 9580	120	240

Table 3-6: Surface washing tests

Note: Some high pressure and hot water was tested following ineffective results with flushing alone.

An additional treatment included several tests of high pressure and hot water flushing following ineffective treatment using low pressure on several tiles. A pressure wand set to the lowest setting (low pressure) was used to flush a number of tiles for approximately three passes of 3-5 seconds each with the wand roughly 25 cm from the tiles. When completed, the tiles were allowed to sit for several minutes and then a photograph of each tile was taken with a label in each photograph listing date, time, post-spill day, cleaning agent applied, and indicating that high pressure flushing had occurred.

4 Results

4.1 Physical Properties of Weathered AWB Dilbit

Summaries of the measured oil physical properties for AWB during weathering are provided below in Table 4-1 through Table 4-3 (see Appendix B – Oil Physical Data for detailed results). Density increases during weathering were more pronounced with moderate agitation, whereas oil under static conditions and mild agitation had comparable change (Figure 4-1). In all cases absolute densities (at 15 °C) reached or slightly exceeded 1000 kg/m³ (freshwater equivalent). The increase in AWB pour point and in viscosity as it weathered was pronounced in the first 48 hours, with the latter ranging 108 to over 60,000 cSt within that timeframe Figure 4-3).

Sample ID	Hours post-spill	Absolute Density @ 15 °C (kg/m³)	Viscosity @ 15 °C (cSt)	Water Content (mass %)	Pour Point (°C)	Closed Cup Flash Point (°C)	Interfacial Tension (dyn/cm)
S1-PS-01	0	920.1	270.5*	3.4	-21	<-35	27
S1-2H-01	2	943.4	1,026*	6.7	-18	<-35	30
S1-4H-01	4	946.2	1,210	5.0	-12	<-35	22
S1-6H-01	6	959.0	2,844	5.1	-12	-12	22
S1-12H-01	12	967.4	6,296*	0.8	-6	<-35	51
S1-1D-01	24	980.7	--	8.3	--	<-35	22
S1-2D-01	48	979.1	20,269*	1.0	6	-10	27
S1-4D-01	96	987.3	59,126*	1.2	6	20	48
S1-6D-01	144	994.0	116,477*	1.6	12	22	55
S1-8D-01	192	997.9	228,350*	1.7	12	52	130
S1-10D-01	240	1000.0	265,263*	4.5	9	58	150

*Table 4-1: AWB in tank S1 weathered under static conditions. Note: * denotes calculated values*

Sample ID	Hours post-spill	Absolute Density @ 15 °C (kg/m³)	Viscosity @ 15 °C (cSt)	Water Content (mass %)	Pour Point (°C)	Closed Cup Flash Point (°C)	Interfacial Tension (dyn/cm)
S2-PS-01	0	920.1	270.5*	3.4	-21	<-35	27
S2-2H-01	2	936.5	749.0*	0.2	-24	<-35	31
S2-4H-01	4	942.9	1,097	0.9	-27	<-35	34
S2-6H-01	6	949.7	1,658	0.2	-18	<-35	35
S2-12H-01	12	958.4	3,128*	4.2	-15	<-35	41
S2-1D-01	24	971.2	9,027*	0.5	3	<-35	43
S2-2D-01	48	983.0	31,539*	0.9	12	-13	49
S2-4D-01	96	995.7	151,596*	3.7	9	5	76
S2-6D-01	144	978.0	241,152*	5.8	9	24	250
S2-8D-01	192	1002.0	435,942*	6.3	15	24	130
S2-10D-01	240	1010.0	763,943*	18.2	12	75	190

*Table 4-2: AWB in tank S2 weathered under mild agitation conditions. Note: * denotes calculated values*

Sample ID	Hours post-spill	Absolute Density @ 15 °C (kg/m³)	Viscosity @ 15 °C (cSt)	Water Content (mass %)	Pour Point (°C)	Closed Cup Flash Point (°C)	Interfacial Tension (dyn/cm)
S3-PS-01	0	920.1	270.5*	3.4	-21	<-35	27
S3-2H-01	2	956.3	2,665	8.6	-6	<-35	36
S3-4H-01	4	969.1	6,994*	25.3**	-6	<-35	44
S3-6H-01	6	979.2	13,766	24.1**	0	-3	50
S3-12H-01	12	982.4	26,746*	--	3	-3	52
S3-1D-01	24	984.2	35,607*	42.4**	3	4	83
S3-2D-01	48	995.8	117,267*	42.5**	15	3	96
S3-4D-01	96	997.2	371,916*	45.3**	6	25	71
S3-6D-01	144	993.7	117,493*	3.4	15	25	200
S3-8D-01	192	991.2	47,117*	52.0**	12	26	55
S3-10D-01	240	1007.0	135,014*	43.4**	12	20	190

Table 4-3: AWB in tank S3 weathered under moderate agitation conditions

*(Note: * denotes calculated values based on three measures at other temperatures; Note: ** denotes anomalies due to high level of free water content that could have affected physical properties results analyzed during lab-tests)*

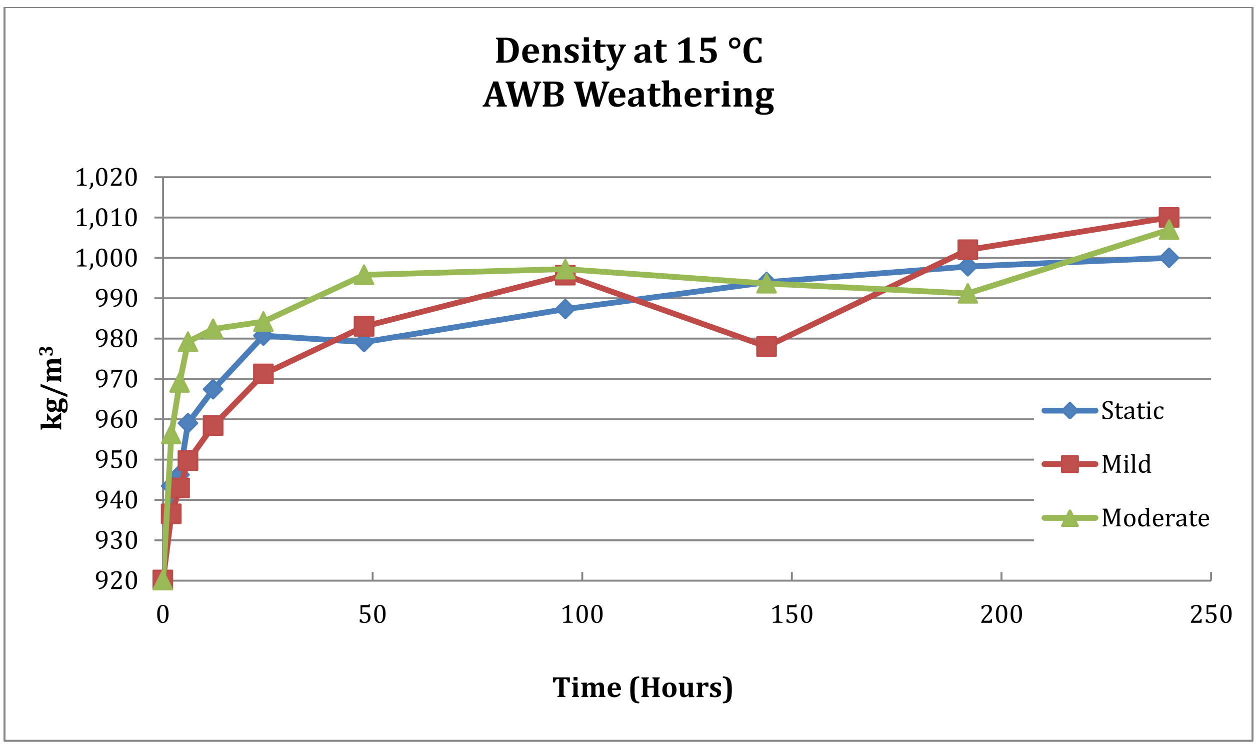

Figure 4-1: AWB - Absolute Density

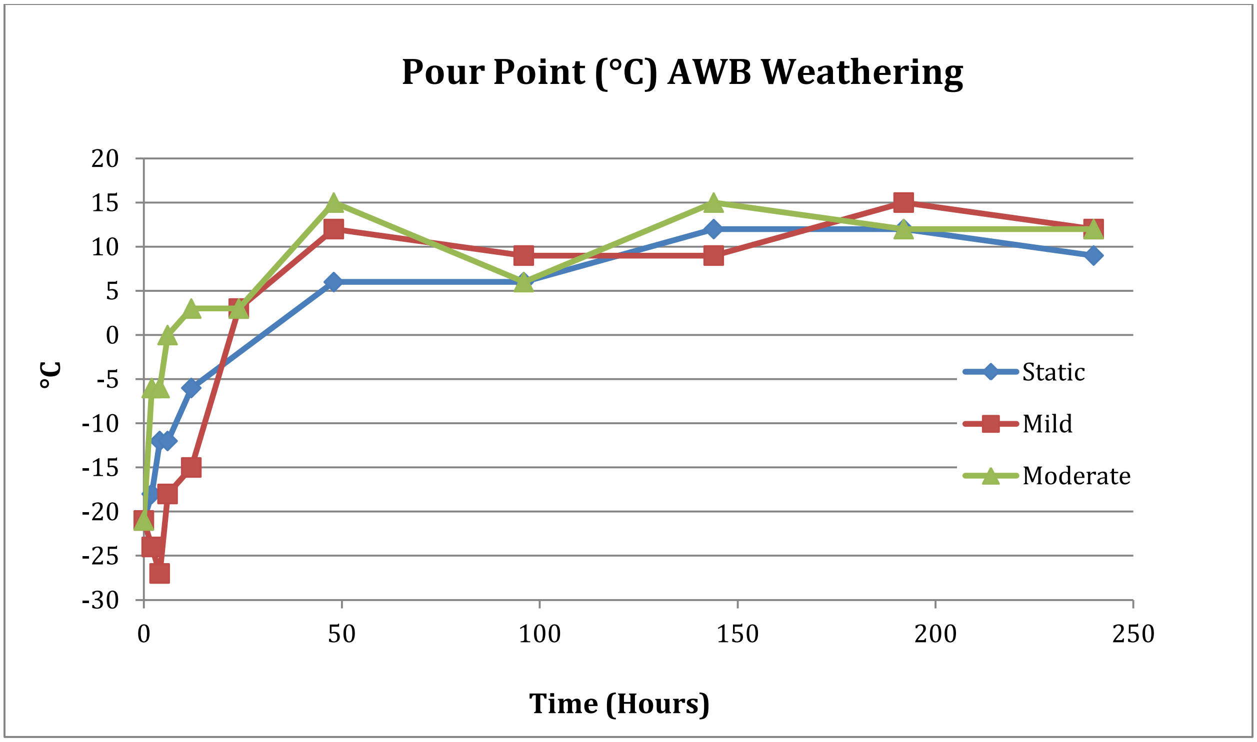

Figure 4-2: AWB - Pour Point

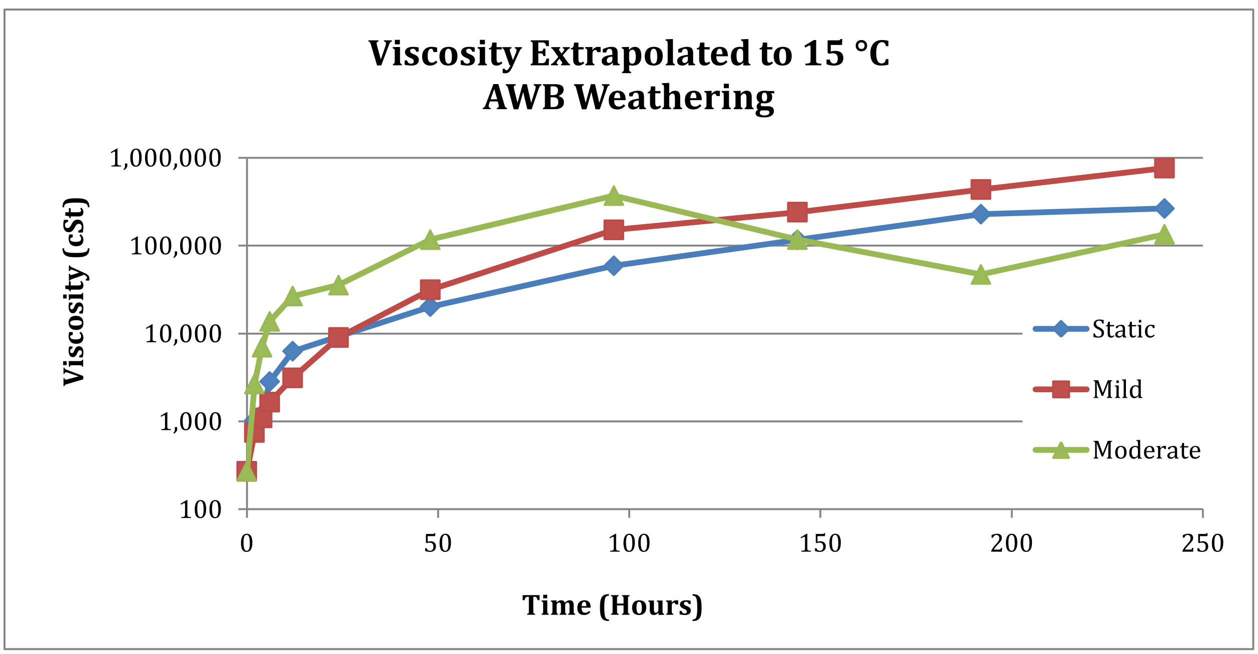

Figure 4-3: AWB Viscosities

4.2 Physical Properties of Weathered CLWB Dilbit

Summaries of the measured oil physical properties for CLWB dilbit during weathering are provided below in Tables 4-4 through 4-6 (see Appendix B – Oil Physical Data for detailed results). Density increases were more pronounced in the first 24 hours of weathering for the moderate agitation (Figure 4-4) but oils in both agitation tanks achieved similar densities after that time. In all cases, absolute densities (at 15 °C) never exceeded 1000 kg/m^3 (freshwater equivalent) with the exception of a single measurement at 8 days for the CLWB oil under moderate agitation. The increase in pour point was continual in all tanks with pour points in excess of 10 °C noted within 4-5 days (Figure 4-5). Viscosities increased to over 10,000 cSt within the first 48 hours, although increases in viscosity were much less pronounced in the static tank (Figure 4-6).

Sample ID	Hours post-spill	Absolute Density @ 15 °C (g/L)	Viscosity @ 15 °C (cSt)	Water Content (mass %)	Pour Point (°C)	Closed Cup Flash Point (°C)	Interfacial Tension (dyn/cm)
S9-OH-OIL	0	924.8	--	0.9	-21	<-35	31
S9A-2H-01	2	954.9	1661*	1.6	-15	<-35	36
S9A-4H-01	4	959.7	2706*	1.4	-9	<-35	39
S9A-6H-01	6	965.8	4521*	2.5	-21	<-22	39
S9A-12H-01	12	973.3	8933*	5.1	-6	-3	37
S9A-1D-01	24	980.4	14,133*	8.5	-3	15	40
S9A-2D-01	48	989.7	35,626*	11.4	-6	32	52
S9A-4D-01	96	995.9	154,077*	39.6**	0	70	150
S9A-6D-01	144	999.7	411,114*	40.2**	12	26	140
S9A-8D-01	192	1002.0	159,600*	36.1**	9	73	160
S9A-9D-01	216	996.5	417,801*	24.6**	24	71	190
S9A 10D 01	240	996.5	14,634*	35.9**	21	>100	170

Table 4-4: S9-A: CLWB in tank S9A weathered under moderate agitation conditions

*(Note: * denotes calculated values based on three measures at other temperatures; Note: ** denotes anomalies due to high level of free water content that could have affected physical properties results analyzed during lab-tests)*

Sample ID	Hours post-spill	Absolute Density @ 15 °C (kg/m^3)	Viscosity @ 15 °C (cSt)	Water Content (mass %)	Pour Point (°C)	Closed Cup Flash Point (°C)	Interfacial Tension (dyn/cm)
S9-OH-OIL	0	924.8	--	0.9	-21	<-35	31
S9B-2H-01	2	939.4	568*	1.4	-30	<-35	30
S9B -4H-01	4	946.1	915*	1.2	-21	<-35	34
S9B -6H-01	6	954.8	1586*	2.0	-15	<-20	38
S9B -12H-01	12	958.7	2255*	0.8	-9	<-15	36
S9B -1D-01	24	961.8	3985*	0.6	-6	-27	29
S9B-2D-01	48	969.7	5862*	1.6	-9	24	34
S9B-4D-01	96	975.6	12,179*	1.4	-6	25	34
S9B-6D-01	144	979.2	17,687*	1.1	6	5	46
S9B-8D-01	192	980.3	19,454*	0.8	9	34	40
S9B-9D-01	216	982.0	29,440*	2.2	15	34	45
S9B 10D 01	240	975.2	27,968*	1.9	12	35	51

Table 4-5: S9-B: CLWB in tank S9B weathered under static conditions

Sample ID	Hours post-spill	Absolute Density @ 15 °C (kg/m³)	Viscosity @ 15 °C (cSt)	Water Content (mass %)	Pour Point (°C)	Closed Cup Flash Point (°C)	Interfacial Tension (dyn/cm)
S9-OH-OIL	0	924.8	--	0.9	-21	<-35	31
S9C-2H-01	2	941.5	632.7	1.2	-21	<-35	39
S9C-4H-01	4	946.2	935.8	1.0	-18	<-35	36
S9C-6H-O1	6	952.4	1443	1.8	-18	<-35	33
S9C-12H-01	12	963.2	4744	1.5	--	-10	34
S9C-1D-01	24	984.4	5653	1.7	-3	-10	33
S9C-2D-01	48	983.4	26,479	2.3	3	31	45
S9C-4D-01	96	992.5	75,896	7.3	0	23	77
S9C-6D-01	144	996.3	117,498	9.7	9	73	88
S9C-8D-01	192	998.9	743,871	19.4	12	75	150
S9C-9D-01	216	997.7	195,792	--**	21	70	--
S9C 10D 01	240	996.8	302,527	22.3**	21	>100	170

Table 4-6: S9-C: CLWB in tank S9C weathered under mild agitation conditions

*(Note: * denotes calculated values based on three measures at other temperatures; Note: ** denotes anomalies due to high level of free water content that could have affected physical properties results analyzed during lab-tests)*

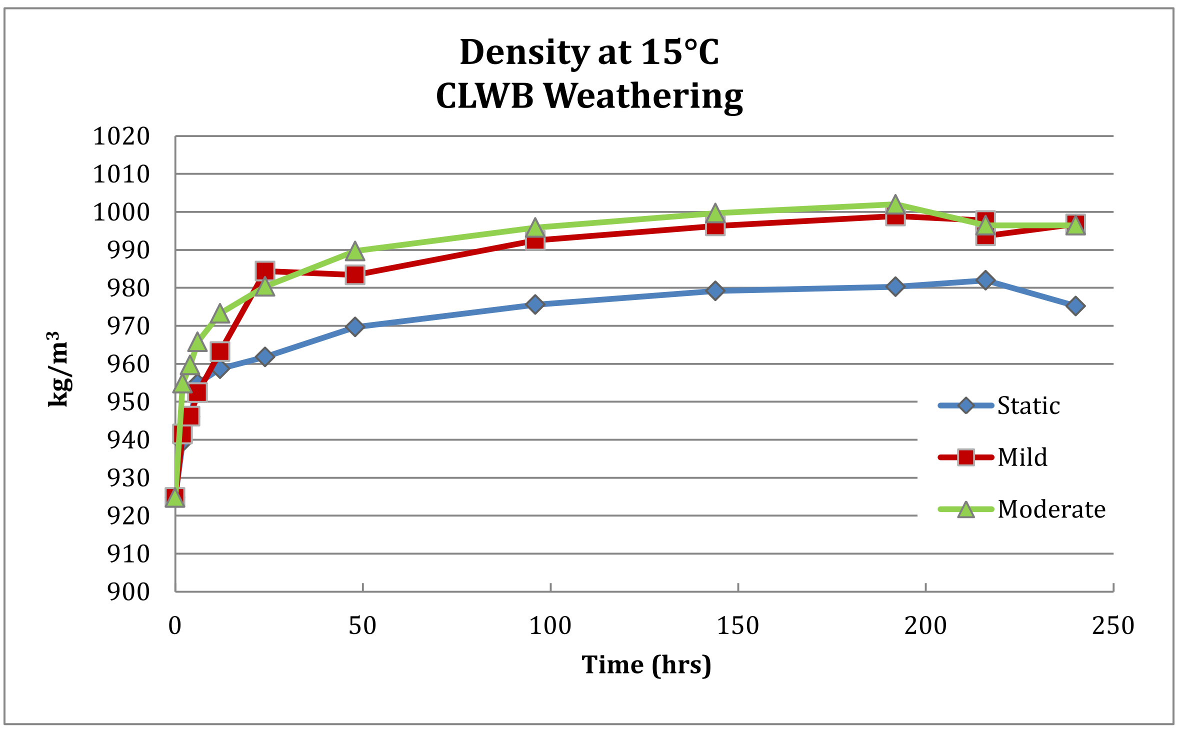

Figure 4-4: CLWB - Absolute Density

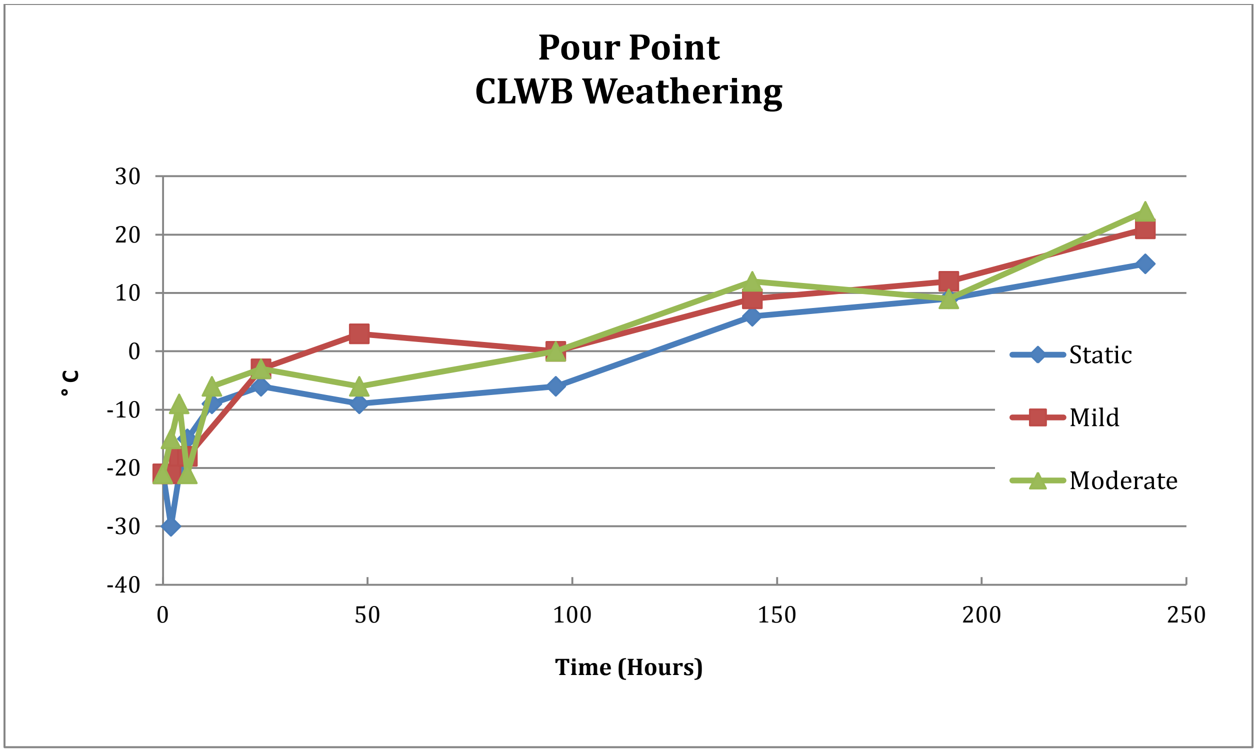

Figure 4-5: CLWB Pour Point

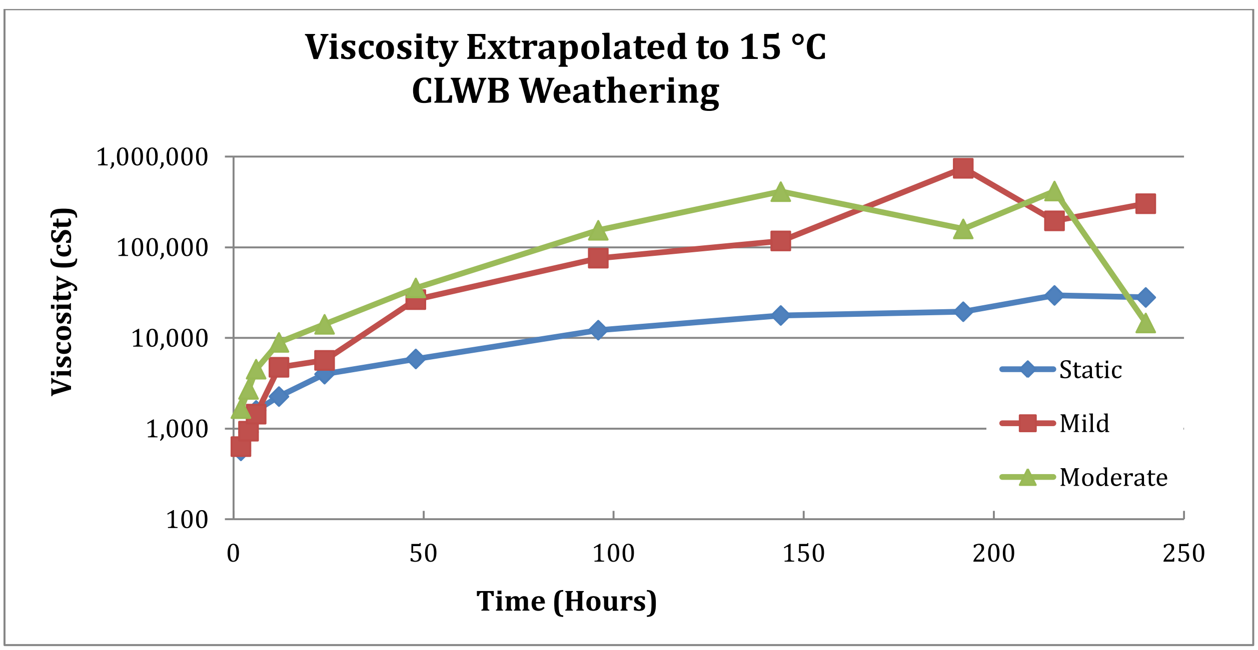

Figure 4-6: CLWB Viscosities

Tank S4 was used as a source of weathered oil for dispersant application, burning, and shore cleaning agent tests. With agitation conditions similar to Tank S2, the major difference between S2 and S4 was the location of S4 (exposed to sunlight and ambient atmospheric conditions). Absolute densities (at 15 °C) exceeded 1000 kg/m^3 (freshwater) after weathering nine days, similar to Day 8 for the moderate agitation Tank S9A (Table 4-7).

Sample ID	Hours post-spill	Absolute Density @ 15 °C (kg/m^3)	Viscosity @ 15 °C (cSt)	Water Content (mass %)	Pour Point (°C)	Closed Cup Flash Point (°C)	Interfacial Tension (dyn/cm)
S9-OH-OIL	0	924.8	--	0.9	-21	<-35	31
S4-6H-01	6	969.9	5703*	4.1	3	-12	38
S4-1D-01	24	984.2	24762*	3.5	15	4	48
S4-3D-04	72	997.7	201284*	33.4**	9	56	170
S4-5D-04	120	997.3	179587*	42.9**	9	>100	130
S4-9D-01	216	1008.0	254489*	36.8**	12	72	220

Table 4-7: CLWB in tank S4 (oil reservoir tank) – weathered under mild agitation conditions, sun light, and local weather conditions (wind and rain)

*(Note: * denotes calculated values based on three measures at other temperatures; Note: ** denotes anomalies due to high level of free water content that could have affected physical properties results analyzed during lab-tests)*

4.3 Chemistry of Weathered Oil

Oil chemistry, including C1-C30 and poly aromatic hydrocarbon (PAH) analyses, were to characterize the originating (fresh oil) dilbit and to assess hydrocarbon content and degradation patterns. Figures 4-7 and 4-8 show PAH data for weathered and fresh AWB oil samples. Figures 4-9 and 4-10 show relative weight concentrations of C1 through C30 compounds in fresh and weathered AWB and CLWB dilbits, respectively, and compare changes in these compounds with different levels of induced agitation. Also see Appendix F (Oil Chemistry Data) tables for additional details data on specific compounds.

PAH includes compounds that have some of the more serious environmental effects of the compounds in crude oil. PAHs in the environment are derived largely from combustion of oil and coal, but are also produced by the burning of wood, forest fires, and a variety of other combustion sources. In general, PAH content is low in both oils compared to many other crude oils. A typical crude oil may contain 0.2 percent to more than 7 percent total PAH. The National Research Council (2003) reports an average PAH content of 1.39 for 25 crude oils (heavy and light) using data from numerous sources. Heavy distillates and light distillates averaged 2.42 and 3.44 percent, respectively. Fresh oil samples of CLWB and AWB dilbits contained 1.1 and 0.45 percent PAH by weight, respectively.

PAH chromatograms over time show similar relative abundance of analytes in the oil with little noticeable depletion of PAH under static conditions and slightly more PAH loss in the mild and moderate weathering tanks after 10 days. Concentrations of total poly aromatic hydrocarbons (tPAH) increased in the oil over time in some instances as other lighter constituents in the oil are lost to volatilization. This is evident in the static tanks and not the weathering tanks, which had lower tPAH at the end of the experiment than in other conditions. C1-C30 analysis shows rapid depletion of lower molecular weight compounds in all instances and maximum depletion in the tanks with moderate weathering conditions (Figures 4-9 and 4-10). The percent of compounds present by weight decreases rapidly in the lighter compounds and can consequently increase in heavier molecular weight compounds in light or low weathering conditions. Moderate agitation resulted in reduction in percent by weight among all compounds.

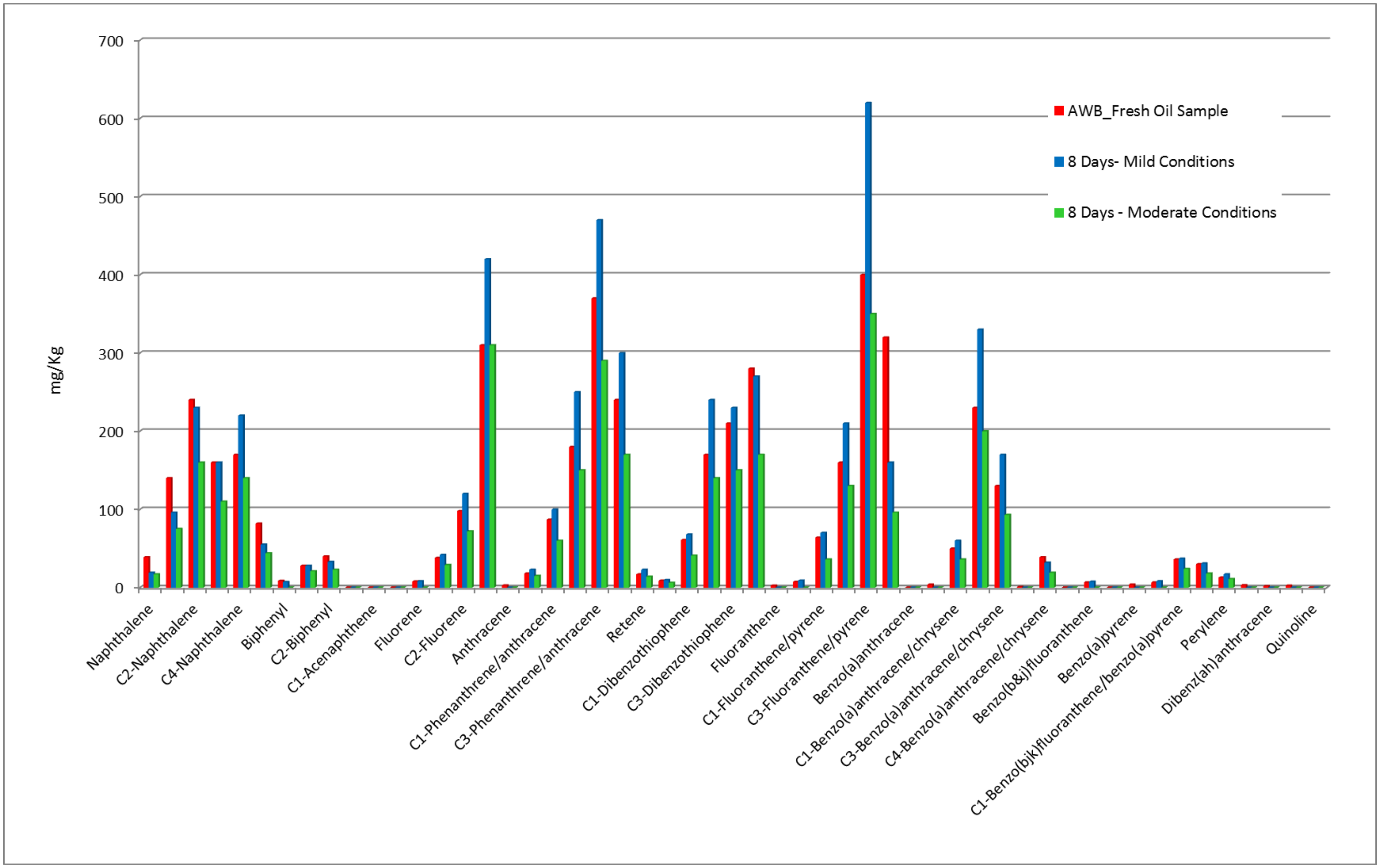

Figure 4-7: Oil chemistry data - AWB

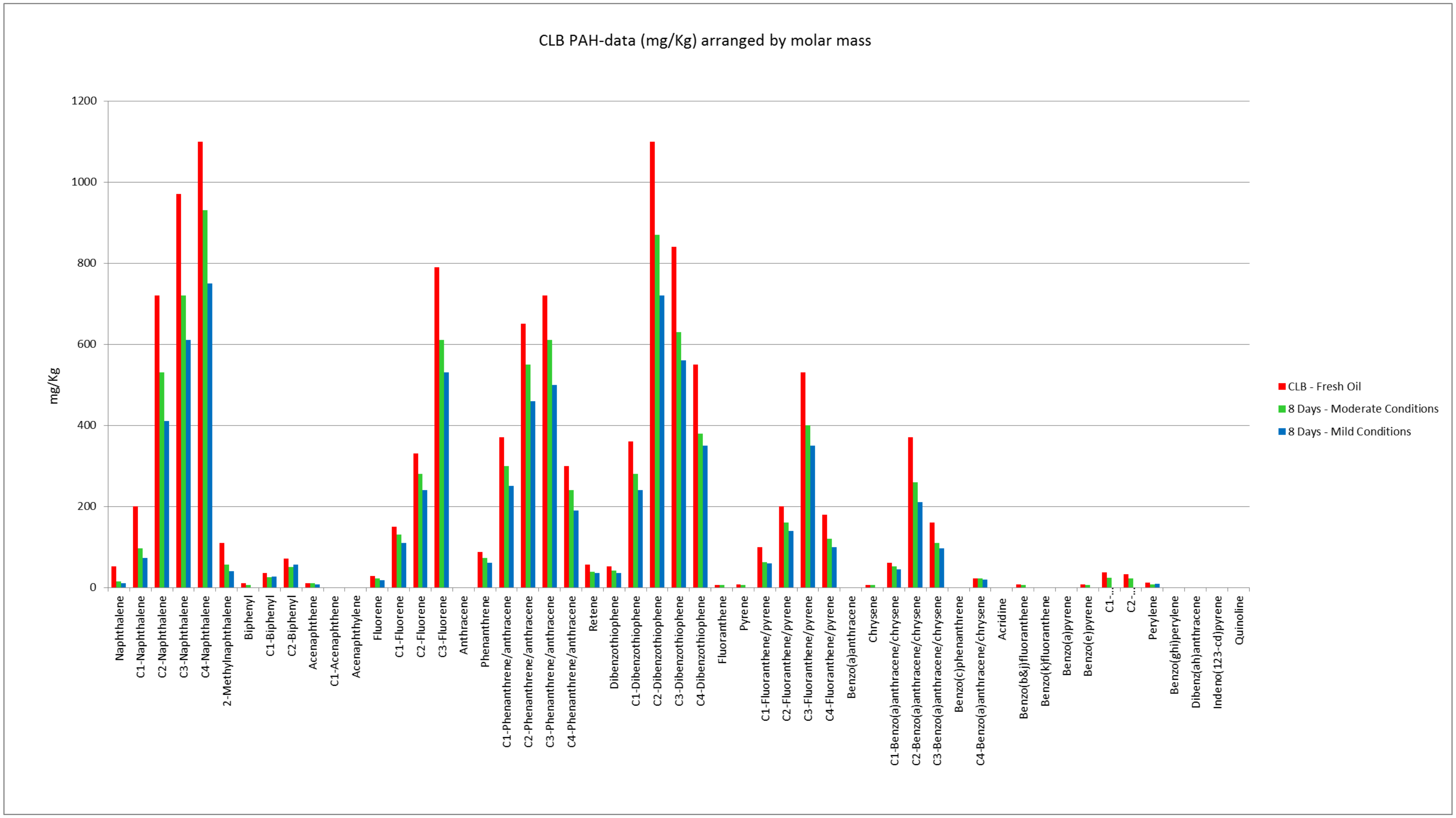

Figure 4-8: Oil chemistry data – CLWB dilbit

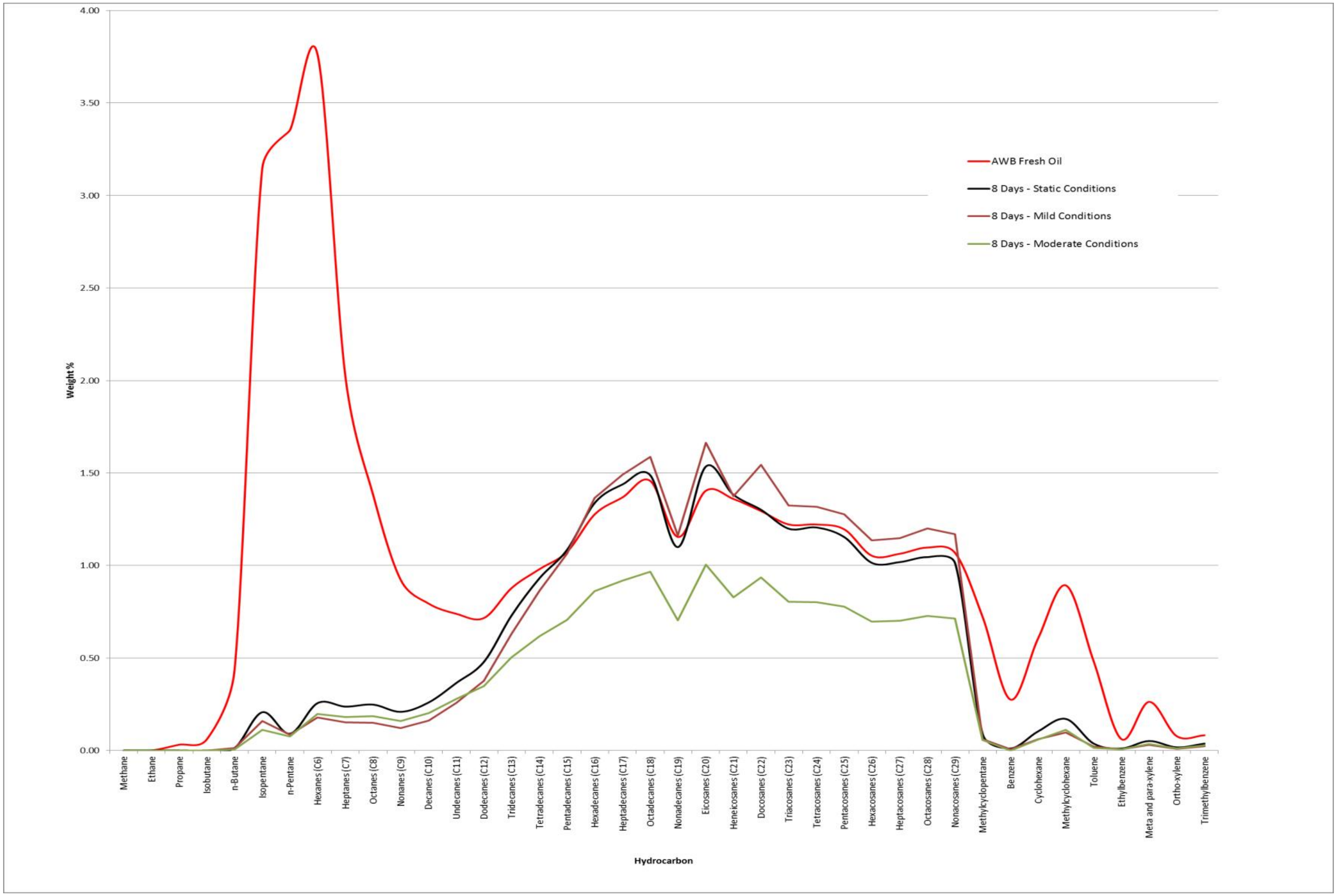

Figure 4-9: Light ends (C1 – C30) AWB

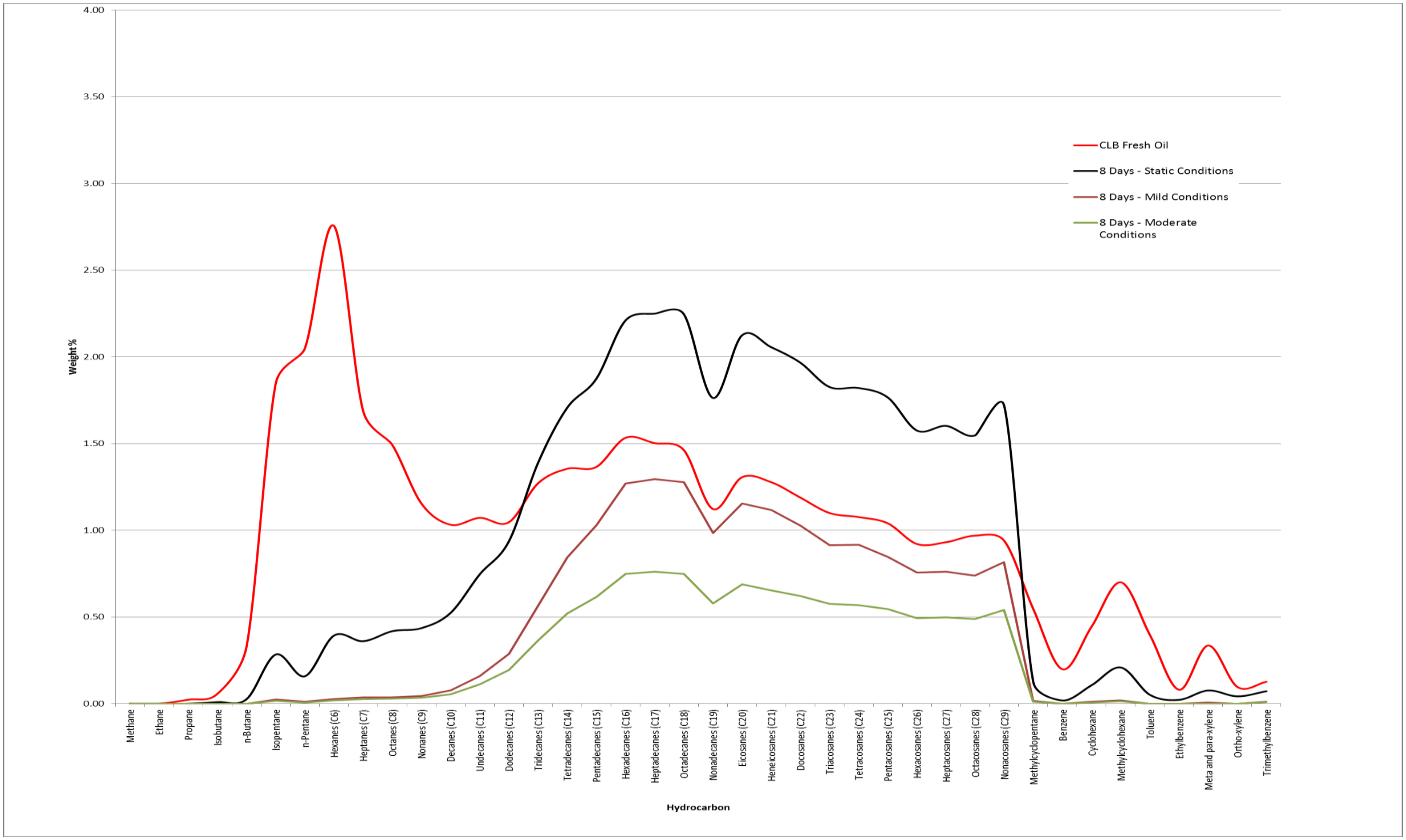

Figure 4-10: Light ends (C1-C30) CLWB dilbit

4.4 Oil Distribution in the Water Column

Oil distribution and partitioning into the water column are provided through TPH and BTEX analyses of water samples at specific depths below the water surface (also see Appendix G (Water Chemistry Data) tables and graphs for additional details). Note that the limited volume of water within each tank and the lack of any possible dilution provides for very conservative measures of oil constituents in the water column relative to what may happen in open water conditions such as in Burrard Inlet.

4.4.1 TPH in the Water Column

Total petroleum hydrocarbon (TPH) measured in the water columns of the AWB and CLWB dilbit tanks were in nearly all cases below detection thresholds (<2 mg/L) with the exception of tanks with moderate agitation (S3- AWB and S9A- CLWB). The highest TPH values measured were 120 mg/L at 1 m below the water surface from the CLWB dilbit and 60 mg/L at 50 cm below the water surface for AWB (Figure 4-11). By approximately 12 hours, all TPH values, regardless of depth in the water column or oil type, were near 10 mg/L in the tanks with moderate agitation. This pattern demonstrates that the lower molecular weight fractions of TPH tend to be more soluble in water and weather (e.g., volatilize) faster.

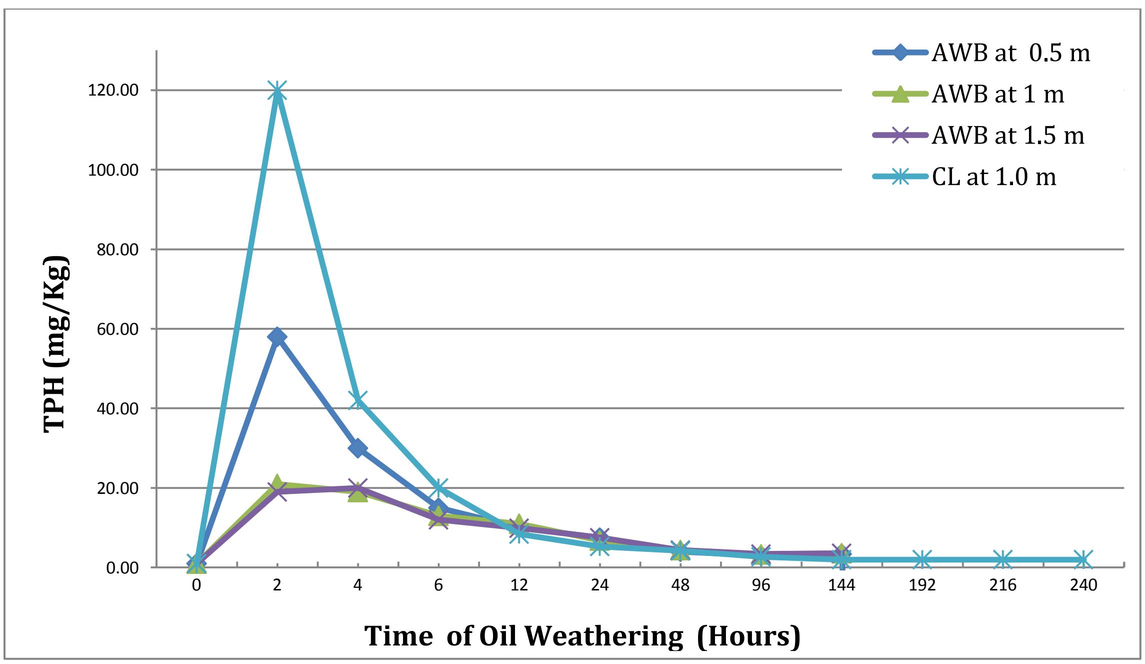

Figure 4-11: TPH in water column samples - AWB and CLWB weathering under moderate conditions

4.4.2 BTEX in the Water Column

BTEX is the collective name for benzene, toluene, ethylbenzene, and xylenes, the volatile single-ringed aromatic compounds found in crude oils. The behavior of the four compounds is somewhat similar when released to the environment and thus they are usually considered as a group. Most crude oils contain BTEX usually from about 0.5 up to 5 percent or more. The CLWB and AWB contain approximately 1 percent BTEX in the fresh oil samples, consistent with other crude oils. Gasoline can contain up to 40 percent BTEX. BTEX compounds are volatile and, if discharged into the sea, rapidly volatilize producing a net loss of BTEX compounds.

Single-ringed aromatics are also soluble in water at low parts per million (ppm) levels and readily partition out of the heavy crude. In the study of both CLWB and AWB, the BTEX compounds partitioned into the water column evenly at all depths examined (Figure 4-12) but behaved somewhat differently overall under different wind and wave conditions. BTEX in both oils behaved very similarly. In the static tests, dissolution of BTEX in the water column increased at 12 to 24 hours with maximum concentrations reaching approximately 900 micrograms per liter (μg/L) (∑ BTEX) at approximately 6 days (Figure 4-12). There was little evidence of a net loss of BTEX in the static water leading up to 10 days.

In mild wind and wave conditions, BTEX began to partition into the water column immediately reaching maximum ∑ BTEX concentrations of 1,200 μg/L (CLWB) to 1,500 μg/L (AWB) in 48 hours (Figure 4-12; also see Appendix G). Net loss of BTEX to volatilization was apparent at 48 hours with water concentrations dropping to less than 200 μg/L by 8 days.

In moderate wind and wave conditions, CLWB ∑BTEX reached 3,000 μg/L almost immediately followed by a net loss to <100 μg/L in 4 days (Figure 4-12). The AWB ∑BTEX reached maximum concentrations of approximately 1,700 μg/L after four hours followed by a slightly slower net loss to <200 μg/L after 4 days. It is possible that the CLWB tanks located outdoors resulted in more rapid net loss of BTEX compounds.

In general, the results are expected, following the trend of more rapid and complete dissolution with mixing, as well as more rapid net loss of these constituents.

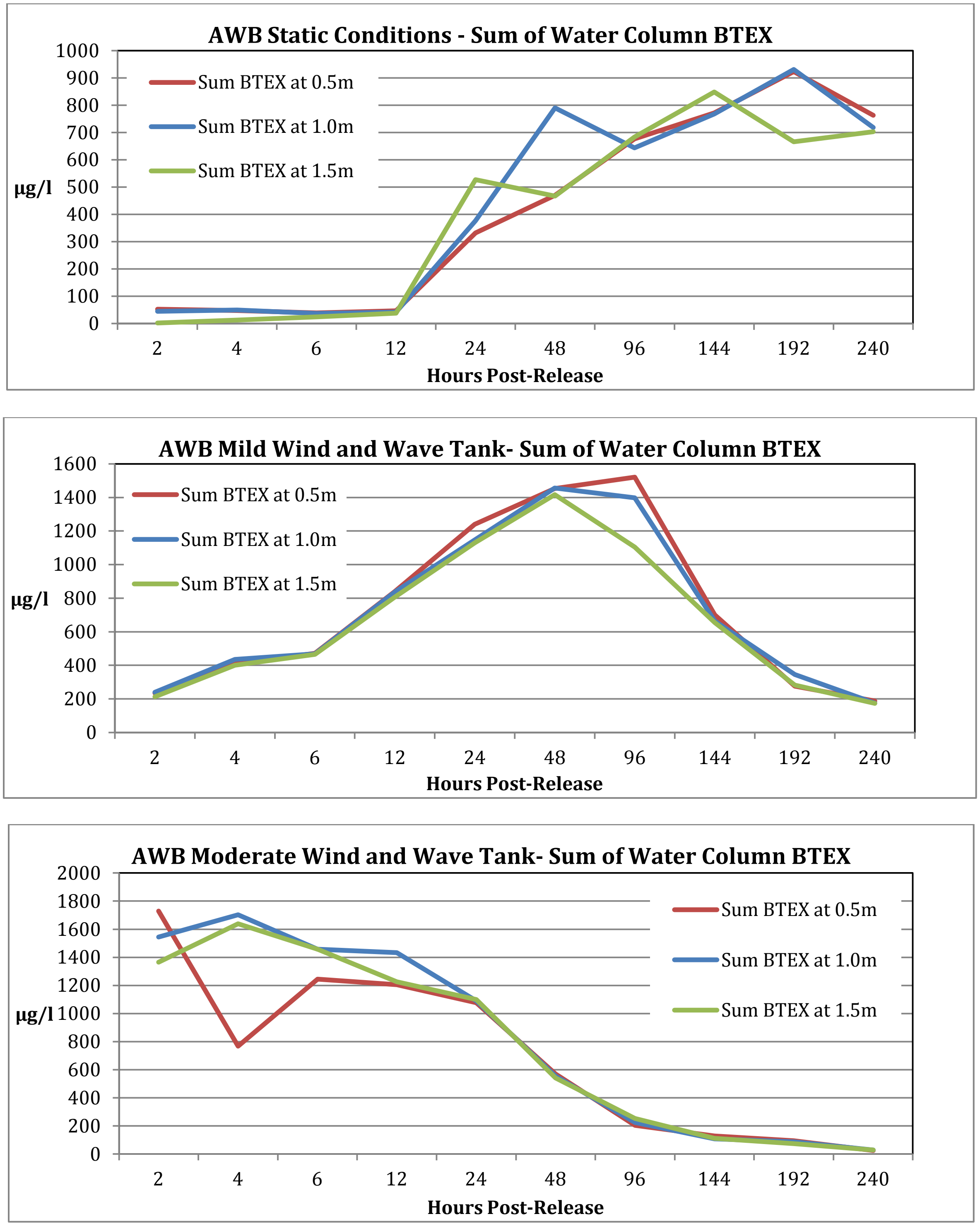

Figure 4-12: BTEX in water column samples – AWB Tanks

4.5 Dispersant Application

Visual observations suggested that the dispersant was marginally effective on the relatively fresh oil (six hours weathered CLWB) but not effective on the one day weathered CLWB. The one day weathered CLWB was affected by the dispersant as application produced oil globules/droplets in the cm-scale size range; however, substantially more oil remained on or returned to the surface following the test than the six hour weathered oil sample. Comparisons of the weights of applied oil and oil recovered on sorbent pads corroborate the visual assessment of dispersant action (Table 4-8; Figure 4-13; also see Appendix C for dispersant datasheets). Measures of the TPH content in the water column prior to oil placement, following oil placement and prior to dispersing, and post-dispersant application (Table 4-9) corroborate the visual observations.

Oil Sample (Weathering Time)	Weight Applied (g)	Weight Recovered (g)	% Dispersed (Not Recovered on Sorbent)
SD-6HR	871	422	52
SD-1 Day	895	929	-4

Table 4-8: Calculated weights of CLWB tested and recovered during dispersant trials

Oil Sample ID	Description (Weathering Time)	TPH / Alkanes (mg/L)
SD-0H-W500	Water sample taken prior to spill (6 hours weathered CLWB)	<2.0
SD-6H-W500-1	Water sample taken 20 min after spill (6 hours weathered CLWB)	<2.0
SD-6H-W500-2	Water sample taken 20 min after using Corexit 9500 on oil (6 hours weathered CLWB)	360 (1)
SD-1D-W500	Water sample taken prior to spill (1 day weathered CLWB)	<2.0
SD-1D-W500-1	Water sample taken 20 min after spill (1 day weathered CLWB)	<2.0
SD-1D-W500-2	Water sample taken 20 min after using Corexit 9500 on oil (1 day weathered CLWB)	80 (1)

Table 4-9: TPH / Alkanes (mg/L) measured in water samples during dispersant trials

Sample	Agitation	Density	% Effectiveness
S9B-6H-01	Static	0.9557	7.8
S9B-1D-01	Static	0.9627	4.6
S9B-4D-01	Static	0.9765	0
S9C-6H-01	Mild	0.9471	5.5
S9C-1D-01	Mild	0.9853	5.4
S9C-4D-01	Mild	0.9934	0
S4-6H-01	Mild	0.9708	5
S4-1D-01	Mild	0.9851	3.3
S9A-6H-01	Moderate	0.9667	6
S9A-1D-01	Moderate	0.9813	5
S9A-4D-01	Moderate	0.9968	0

Table 4-10: Laboratory measured dispersibility of weathered CLWB determined by Swirling Flask testing

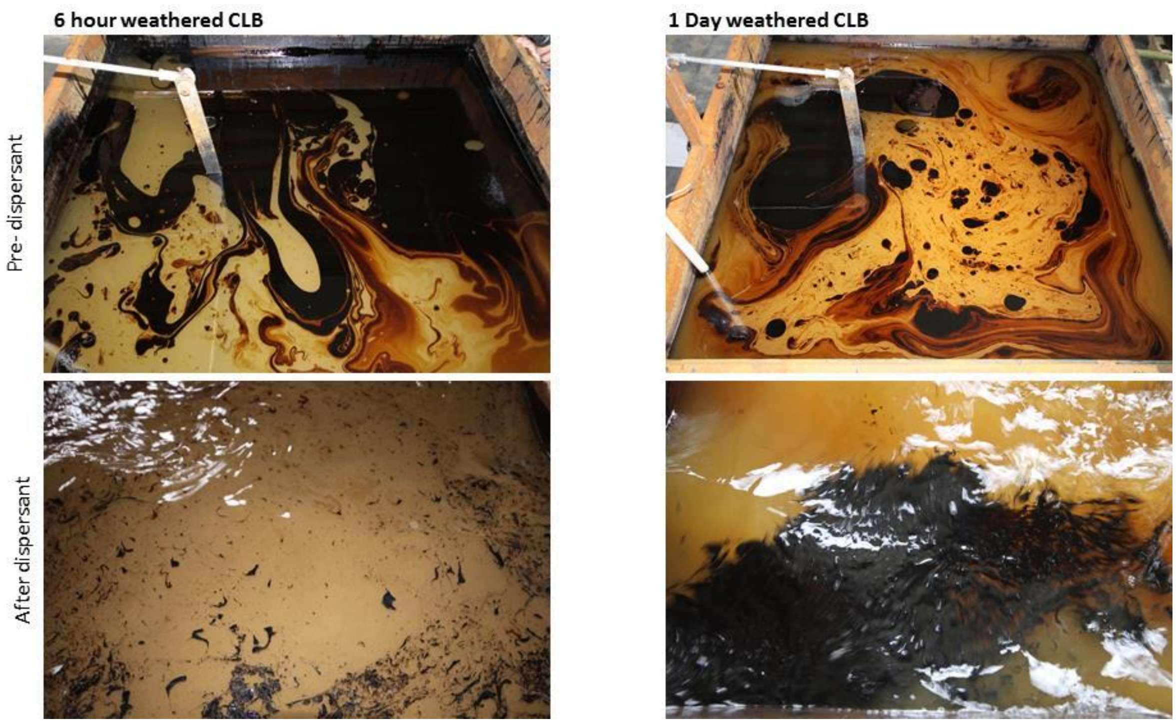

Figure 4-13: Photos of dispersant application on weathered CLWB dilbit

Although visual observations and the measured floating oil weight recovered during the meso-scale field tests indicated that Corexit 9500 is not effective on the one day weathered CLWB, additional research is required to further characterize this and other types of dispersants' effectiveness on CLWB.

Laboratory tests conducted of Corexit 9500 dispersant on weathered CLWB samples showed minimum dispersant effectiveness with values ranging between 0 to 7.8 percent (Table 4-10). All samples weathered for four days showed no dispersibility. The maximum dispersibility corresponded to six hour weathered CLWB oil that had remained in the static tank.

4.6 Controlled Burning

Tests revealed that CLWB can be successfully ignited and burned provided weathering is limited to less than three days (i.e., the 1-day weathered oil had an equivalent density of less than 984.2 kg/m^3 and viscosity of approximately 25,000 cSt at 15 °C). The first burn test (six hour weathered CLWB) ignited relatively easily and burned well for a period of approximately two minutes and extinguished on its own. The second test (24 hour weathered CLWB) was difficult to ignite and took two attempts. The second attempt, using more accelerant than 6 hour weathered CLWB (200 mL more diesel) and higher torch-temperature, burned for approximately 2 minutes once started. A sustained burn was not achieved for the 72 hour weathered oil sample, despite added diesel as an accelerant and repeated direct attempts with the propane torch. Comparisons of the weights of applied oil and oil recovered on sorbent pads provide approximate oil removal efficiency from the test burns (Table 4-11; Figure 4-14; also Appendix D for ISB datasheets). Burn residue from the successful tests was sticky and formed cohesive residue that remained floating on the fresh water surface, though easily submerged. Burn residue on the steel ring was only partially removed between burns two and three and likely contributed to the higher amount of oil recovered on sorbents following the S4-3 day post-burn attempt.

Oil Sample (Weathering Time)	Weight Applied (g)	Weight Recovered^ (g)	% Burned (Not Recovered on Sorbent)
S4-6HR	1735	447	74
S4-1 Day	1803	856	53
S4-3 Day	1657	1912	0

Table 4-11: Calculated weights of CLWB dilbit tested and recovered during burn trials

Figure 4-14: Photos of CLWB dilbit burns

4.7 Substrate Surface Washing

Flushing alone was ineffective at removing the majority of bulk oil and black stain in all instances. Increasing pressure removed bulk oil throughout the experiment but black stain persisted. Only increasing the pressure and temperature to >60 psi (0.41 MPa) and >60 °C, a point known to be more harmful to biota than the benefit of the treatment (Mauseth et al. 1997), removed all but a black stain during the test period without the use of a shoreline cleaning agent (see additional photos in Appendix E).

The duration of effectiveness of Corexit 9580 in combination with ambient temperature, low pressure flushing was determined mainly by the time oil spent weathering on land. Effectiveness diminished at approximately 4 days (96 hours) on dry land in sunlight with no immersion in water (tide exchange) (Figure 4-15). This is assumed to represent a worst case scenario of oil stranded at extreme high tide and with no further submersion. As expected, oil exposure to sunlight made a difference in cleaner effectiveness. Oiled tiles that remained in shade were effectively cleaned with Corexit 9580 after up to 5 days (120 hours) of exposure to air. The time oil spent weathering on water had little noticeable effect given that Corexit 9580 effectively removed oil from the tiles for all three on-water weathering scenarios – 1 day (24 hours), 3 days (72 hours), and 5 days (120 hours) –when oil was allowed to sit on the tiles for 96 hours (sunlight) to 120 hours (shade). The thickness of the oil on tiles after 24 hours, however, varied from 0.5 mm (24 hours in water) to up to 2 mm (5 days in water)(Figure 4-15). Despite slightly thicker oil on tiles after the oil weathered for three and five days in the water, the Corexit 9580 appeared to be similarly effective on these tiles after equivalent drying times. Oil thickness may also be affected by slope and temperature, although there was no observed difference in oil thickness on several tiles that were laid flat. Colder temperatures or prolonged weathering may result in greater oil thickness, which could lead to variations in shoreline cleaning agent effectiveness.

A portion of the removed oil in the Corexit tests floated and was recoverable in both snare and sorbent pads while a portion appeared to have been dispersed rendering the water "muddy" in appearance. Once the agent was ineffective, the oil had weathered to a point where it could only be scraped off, or removed with high pressure and temperature. Little sheen was observed in the water after flushing, even with freshly coated tiles after 24 hours.

Flushing in combination with an off-the-shelf degreaser containing D-Limonene was ineffective at removing the majority of bulk oil and black stain in all instances. Commercial D-Limonene was not available and would likely have been more effective than off-the-shelf degreaser containing D-Limonene. Given the results of Corexit 9580, there is no reason to believe commercial D-Limonene would not be similarly effective on this oil. These results are not comparable to other studies using commercial grade D-Limonene.

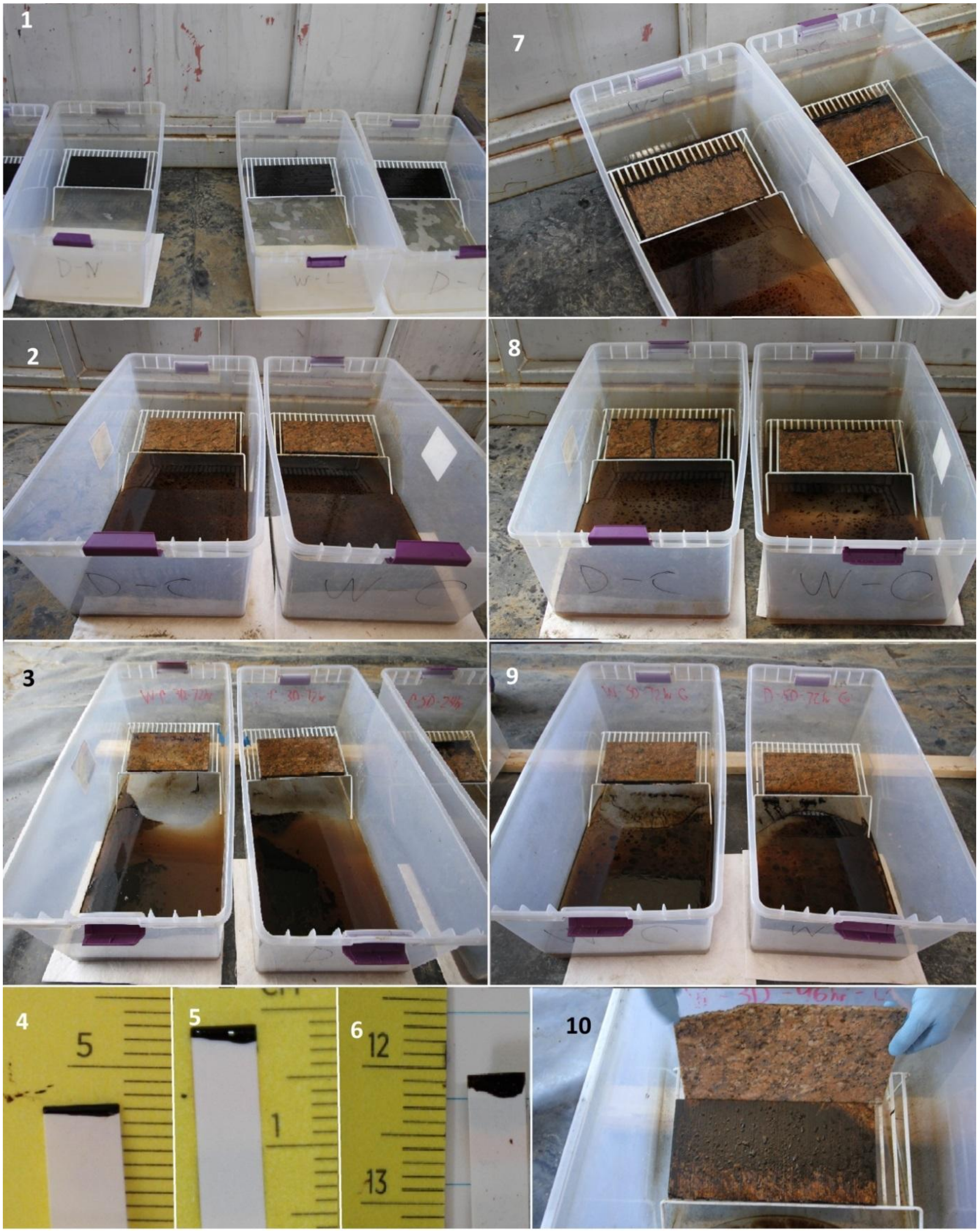

Figure 4-15: 1) Oil on water 24 hours, in air 24 hours, flushing, and D-limonene alone (ineffective); 2) Oil on water 24 hours, in air 24 hours, Corexit 9580; 3) Oil on water 3 days, 72 hours in air, Corexit 9580; 4) Oil thickness of oil on water 24 hours, in air 24 hours; 5) Oil thickness of oil on water 3 days, in air 24 hours; 6) Oil thickness of oil on water 5 days, in air 24 hours; 7) Oil on water 24 hours, in air 48 hours, Corexit 9580; 8) Oil on water 3 days, in air 48 hours, Corexit 9580; 9) Oil on water 5 days, in air 72 hours, Corexit 9580; 10) Oil on water 3 days, in air 96 hours, Corexit 9580

5 Discussion

5.1 Oil Fate and Behavior

Changes in the physical properties of AWB and CLWB dilbits were similar throughout the 10-day trials. Increased agitation (wave paddle and wind) yielded slightly faster weathering rates as revealed in oil densities (Figure 5-1). Initial oil densities of 921 kg/m^3 and 925 kg/m^3 of the AWB and CLWB dilbits, respectively, increased to greater than 980 kg/m^3 within approximately 24-48 hours of weathering in all cases in which agitation was applied. Relative densities continued to increase with further weathering albeit at a slower rate. Like many other heavy crude oils with only slightly positive buoyancy after weathering, these oils could become submerged with the addition of sediment and negatively buoyant particulates, or after contact with the shoreline where they may attach to particulate matter.

Oil and emulsion viscosities increased for both AWB and CLWB dilbits within the first 24 to 48 hours, factors that influence oil behavior on water and potentially affect oil skimming and pumping systems. AWB dilbit under moderate agitation showed the most pronounced initial increase in viscosity (Figure 5-2), increasing from an initial value of less than 1000 cSt to over 10,000 cSt within a 4 to 6 hour window. CLWB dilbit under moderate agitation reached 10,000 cSt at approximately 12 hours, whereas both dilbits, under mild agitation, required approximately 24 hours of weathering to achieve the same viscosity. Depending on the type of dilbit and agitation conditions, the viscosities of the emulsions continue to increase over time to the next order of magnitude, 100,000 cSt, after 4 to 8 days of weathering.

Exposure to ultraviolet (UV) and ambient air conditions (S4 and initial 48 hrs for S9) may account for a slight increase in weathering rates.

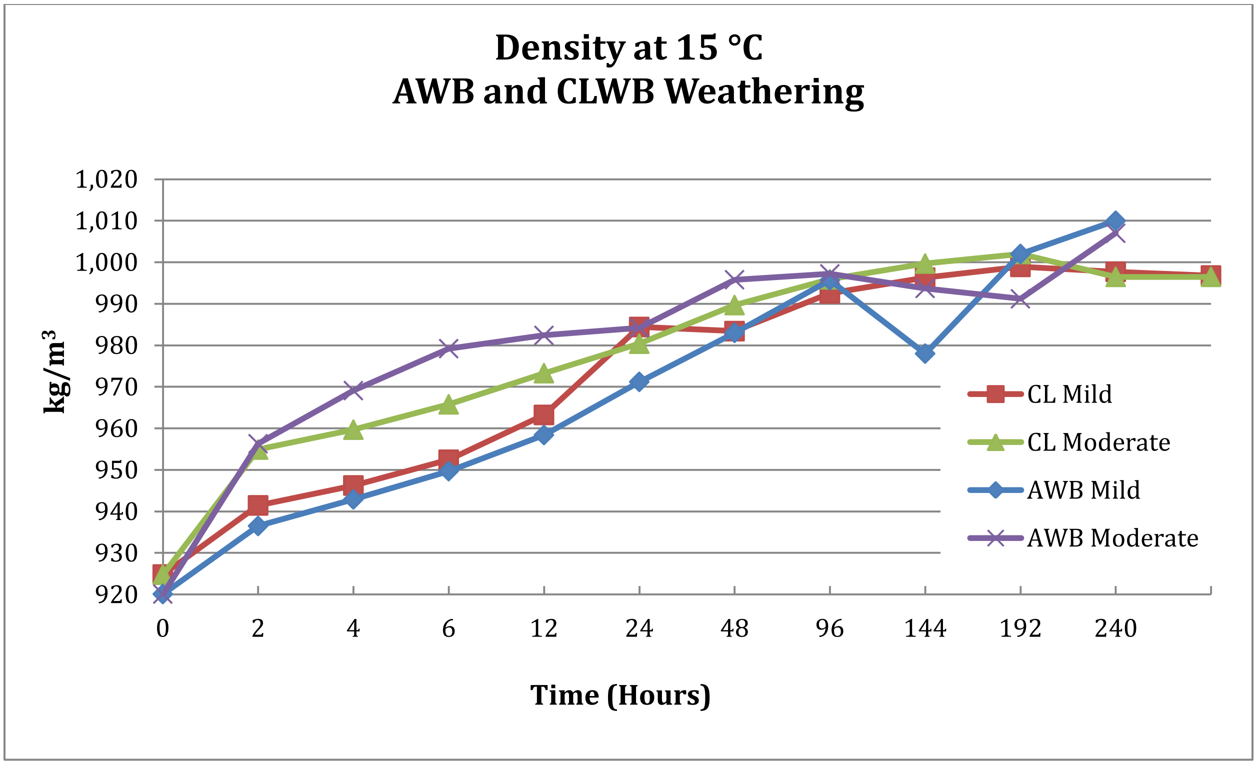

Figure 5-1: AWB and CLWB dilbit densities relative to degree of weathering

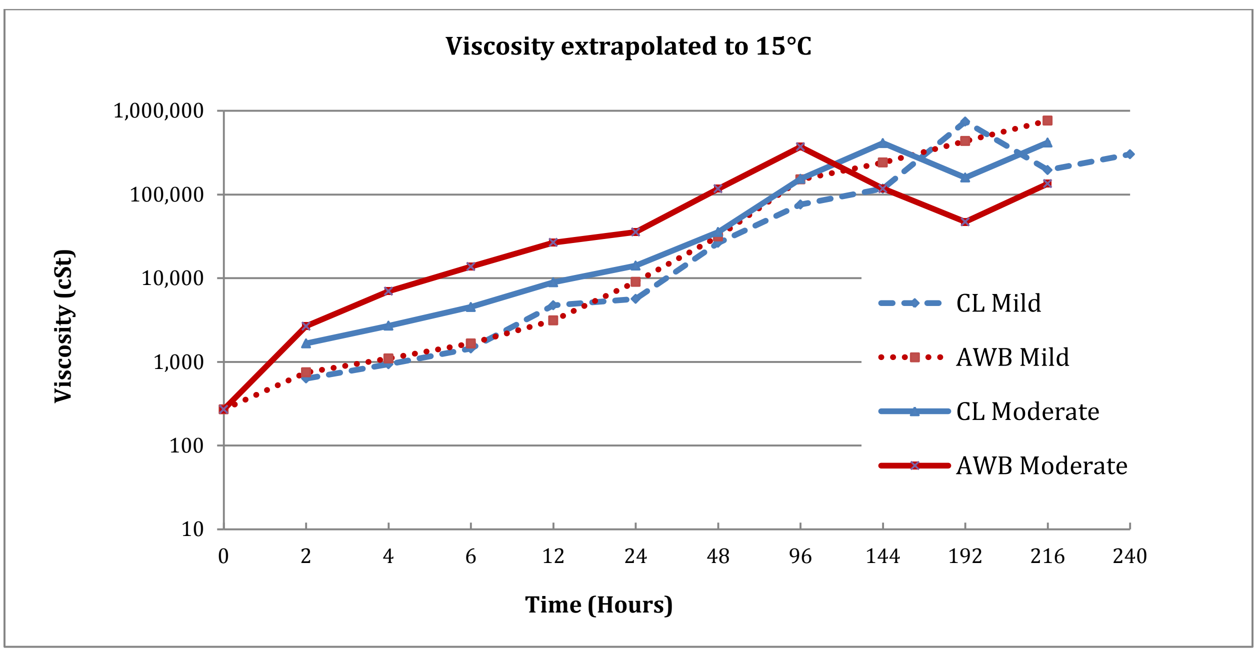

Figure 5-2: Viscosity of weathered AWB and CLWB dilbits under mild to moderate agitation

Both AWB and CLWB dilbits exhibit water uptake within the weathered oil matrix, although not as a stable, uniform emulsion but rather as a mechanically mixed and unstable oil-water combination. Water content analyses, conducted following procedures for whole oil, showed no systematic uptake or pattern for either oil during the weathering process. Given the unstable character of water in oil, sampling and sample processing may result in very different oil-water mixtures at the time of analyses; hence, no conclusions are drawn for those tests other than to note that the maximum water contents measured, above 40 percent, were noted on samples from three tanks (S3, S9A, and S4) with moderate and mild agitation, respectively, and after 1 to 3 days of weathering.

5.2 Spill Countermeasures

The meso-scale tests provided an opportunity to test various spill countermeasures and to ascertain to what extent these may be viable options for response in marine waters.

5.2.1 Dispersants' Effectiveness

Dispersants can be effective as a spill countermeasure provided appropriate environmental and operating conditions are met and that the dispersant is effective on the oil as it weathers. The meso-scale tests with weathered CLWB dilbit showed that some dispersion can be achieved using the recommended dose of 1:20 with Corexit 9500 on CLWB dilbit within the first day of response, depending on extent and degree of weathering. With viscosities approaching 10,000 cSt within the first 12 hours, the potential window for dispersant use is limited. Dispersants are very unlikely to be applicable within Burrard Inlet but may be an appropriate response option in open marine settings to complement mechanical systems. Although dispersant use has not been approved for use on actual spills in Canada, they have been conceptually approved on spill exercises and are part of the response options in the State of Washington waters of the Strait of Juan de Fuca.

5.2.2 Controlled In-Situ Burning

Like dispersants, controlled in-situ burning (ISB) can be effective as a spill countermeasure provided appropriate environmental and operating conditions are met and that ignition can be started and sustained on the oil as it weathers. The meso-scale tests conducted with weathered CLWB dilbit showed that ISB is viable on oil weathered up to one day. Agitation led to water uptake within the oil matrix and could impede initiation of a burn. Burns would not be expected to be a countermeasure used within Burrard Inlet but could be an effective countermeasure to complement mechanical response options particularly in remote areas.

5.2.3 Shoreline Cleaner

Options for shoreline cleaning depend on the degree of oiling, type of substrate oiled, and character of oil. The Gainford test provided an opportunity to consider a shore cleaning agent, Corexit 9580, for its effectiveness as a possible aid in shore cleanup operations for weathered, stranded CLWB dilbit. Prior experience during response to the Burnaby spill had shown that Corexit 9580 worked effectively to enhance shoreline cleanup. Quick assessment field tests conducted during that spill response were used to gain approval for use of the agent during cleanup of the dilbit on cobble shorelines in Burrard Inlet.

The meso-scale tests showed that removal of oil that had weathered for five days on water and then remained on tiles and exposed to air for four days was still effective when using washing substrate treated with Corexit 9580. Low pressure washing (up to approximately 50 psi) of oiled substrate alone is unlikely to be effective for a shoreline oiled with dilbit. Over-the-counter degreaser with D-Limonene proved to be ineffective, although these tests are not comparable to others using commercial formulations intended for spill response. Approval for use of Corexit 9580 should be sought immediately following a spill and prior to shoreline contact to ensure there is sufficient time to use it effectively if needed.

5.3 Oil and Water Chemistry

A comparison of the polycyclic aromatic chemical components in fresh oils (AWB, CLWB, and Alaska North Slope (ANS)) is shown in Figure 5-3. Generally, the naphthalene content is higher in the ANS crude relative to CLWB or AWB, whereas the latter crudes have slightly higher heavier PAH contents.

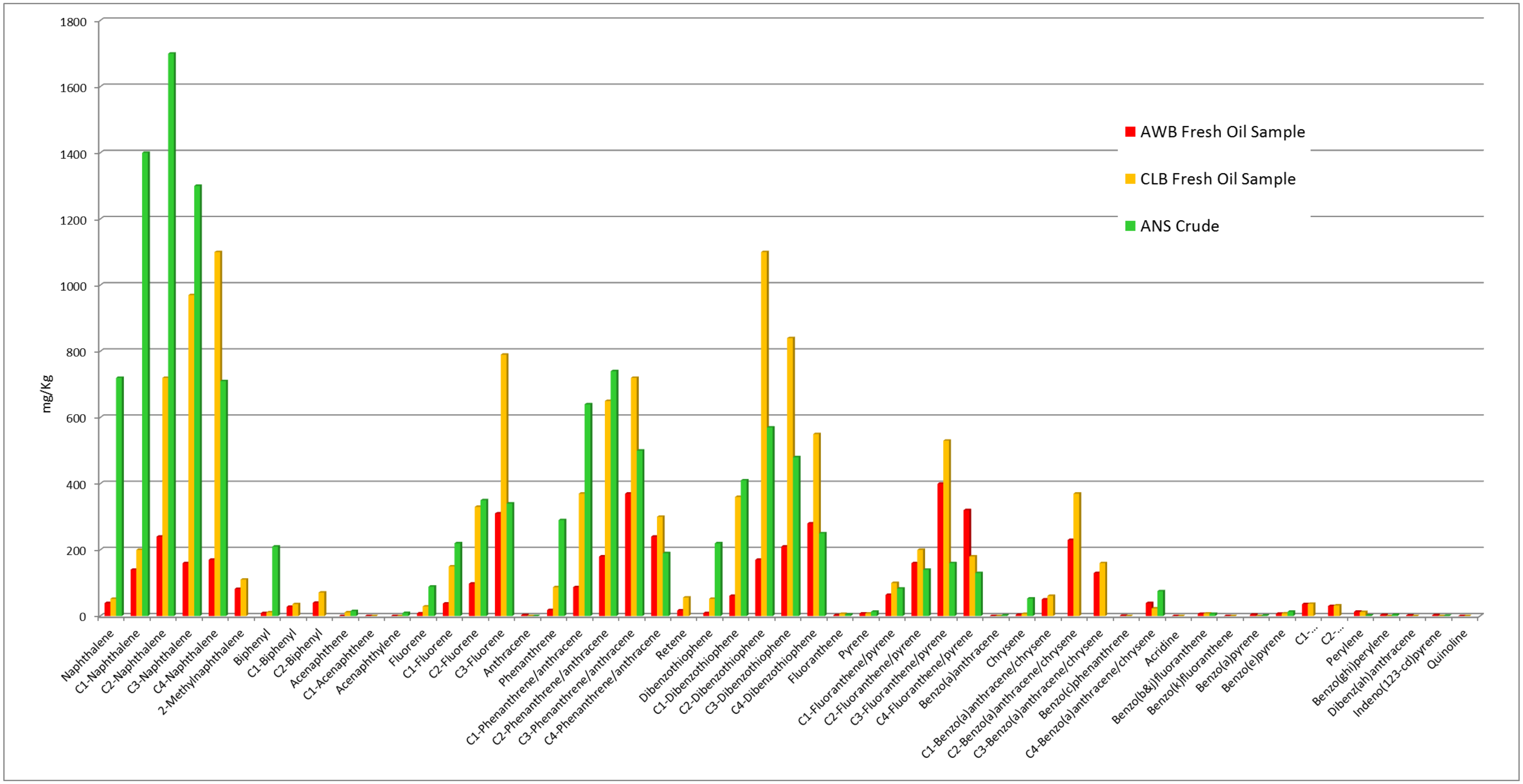

Figure 5-3: Comparison of PAH concentrations between CLWB and AWB dilbits and ANS crude

BTEX in the water column dissolves faster and is depleted in the water column with increased agitation (Figure 5-4 and Figure 5-5). These BTEX concentrations and the depletion rates shown are from the confined water in the tank below an artificially thick slick. Unconfined oil, mixing, and dilution would result in much faster depletion rates and lower concentrations.

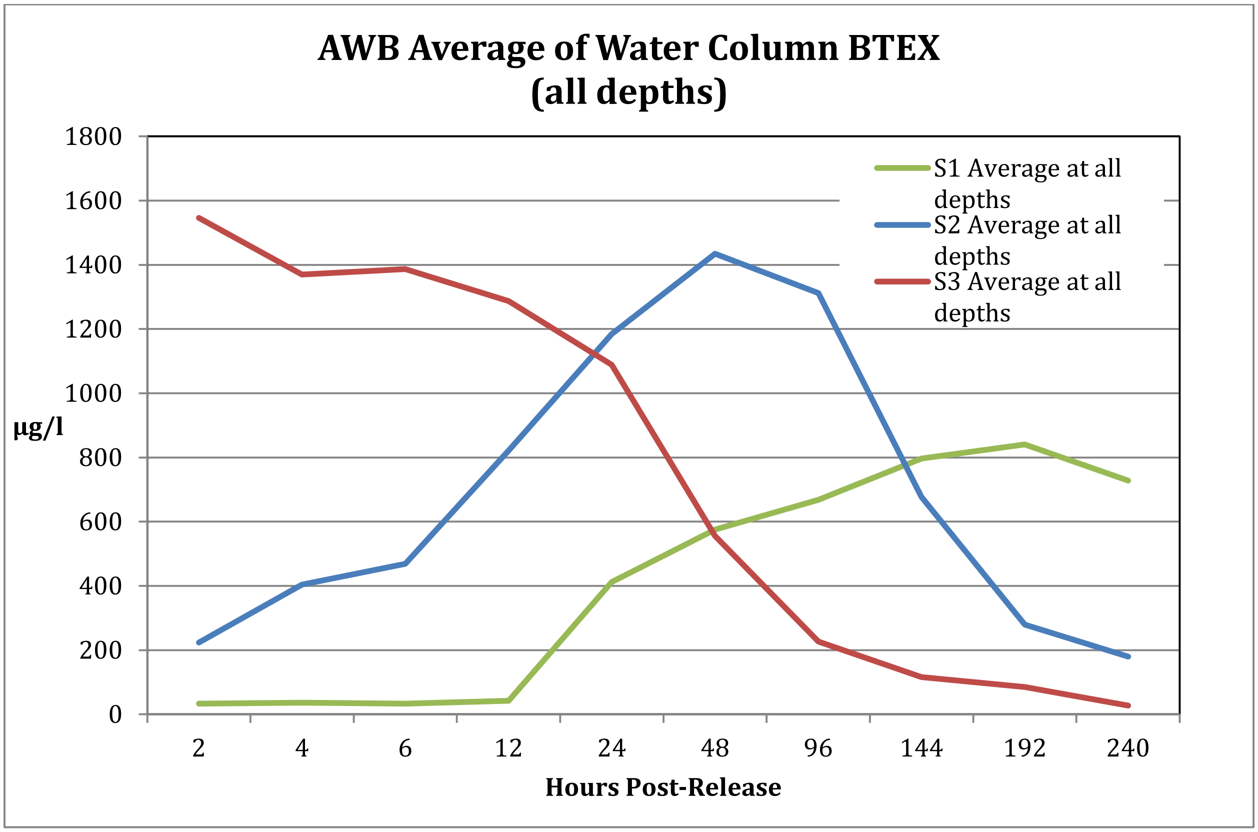

Figure 5-4: Average BTEX concentrations in water from 0.5, 1, and 1.5 m below AWB dilbit

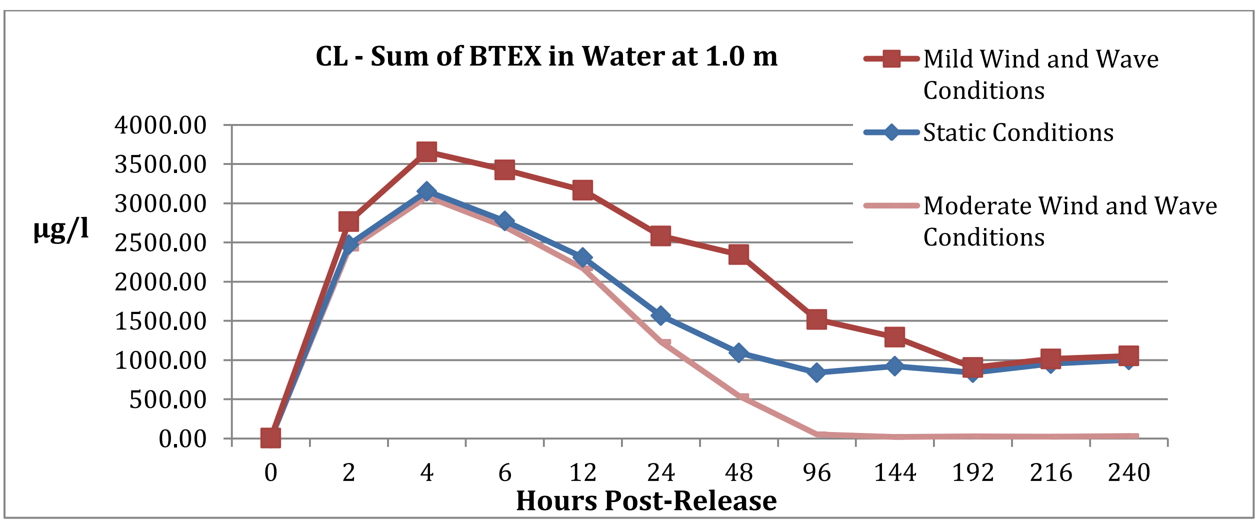

Figure 5-5: BTEX concentrations in water at 1 m depth below CLWB dilbit

6 Equipment Testing

The oil spill recovery equipment testing was conducted concurrently with the scientific study as a way to investigate the efficacy of mechanical skimmers on oil sands products, specifically dilbit. The parallel testing of skimming equipment with the scientific study offered attractive efficiencies for the project including: 1) maximum use of personnel and supporting material; 2) complete site utilization; 3) execution under similar conditions; and 4) availability of common source oil. Additionally, conducting the studies at the same time and location enabled test site visitors to simultaneously observe both studies.

Skimming equipment for the Gainford field test was provided by interested vendors who volunteered to exercise their equipment in an effort to better evaluate unit performance on oils produced from bitumen extracted from oil sands in Alberta, Canada. Western Canada Marine Response Corporation (WCMRC) personnel worked closely with the equipment vendors to enhance the overall test experience.

Figure 6-1: Vendor providing a briefing prior to equipment testing

6.1 Methodology

6.1.1 Facility Design and Tank Layout

The equipment test was conducted adjacent to the scientific study area at the same pump station located in Gainford, Alberta (Figure 6-1). Heavy equipment was used to construct a below grade containment pad which was then lined with an impermeable membrane.

Inserted into the test pit were a series of open-top welded steel bins, also known as “roll-off boxes.” These 26.5 m^3 (7,000 gallon) capacity rectangular tanks measured 6.4 m by 3.0 m by 1.4 m. Each skimmer was assigned a dedicated test tank. The equipment test tanks were given the following designations:

Tank Designation	Purpose	Note
E1-E5	Skimmer Testing	The test site was initially designed for five skimmer tests; three vendors participated in the Gainford test. Those vendors were assigned tanks E-3, E-4 & E-5. E-1 was later consigned to additional science testing and re-designated S-9. E-2 was a surplus tank.
E6	Common Discharge Tank	Described in the methodology section below.
E7	Weathered Oil Tank	Contained oil that was left to weather for ten days, then used for the last day of skimmer testing (May 22).
E8	Waste Oil Tank	a.k.a. the "Slop Tank."
CC	Calibration Cube	Used for measuring oil recovered during the timed portion of the skimmer tests.

Table 6-1: Tank designations

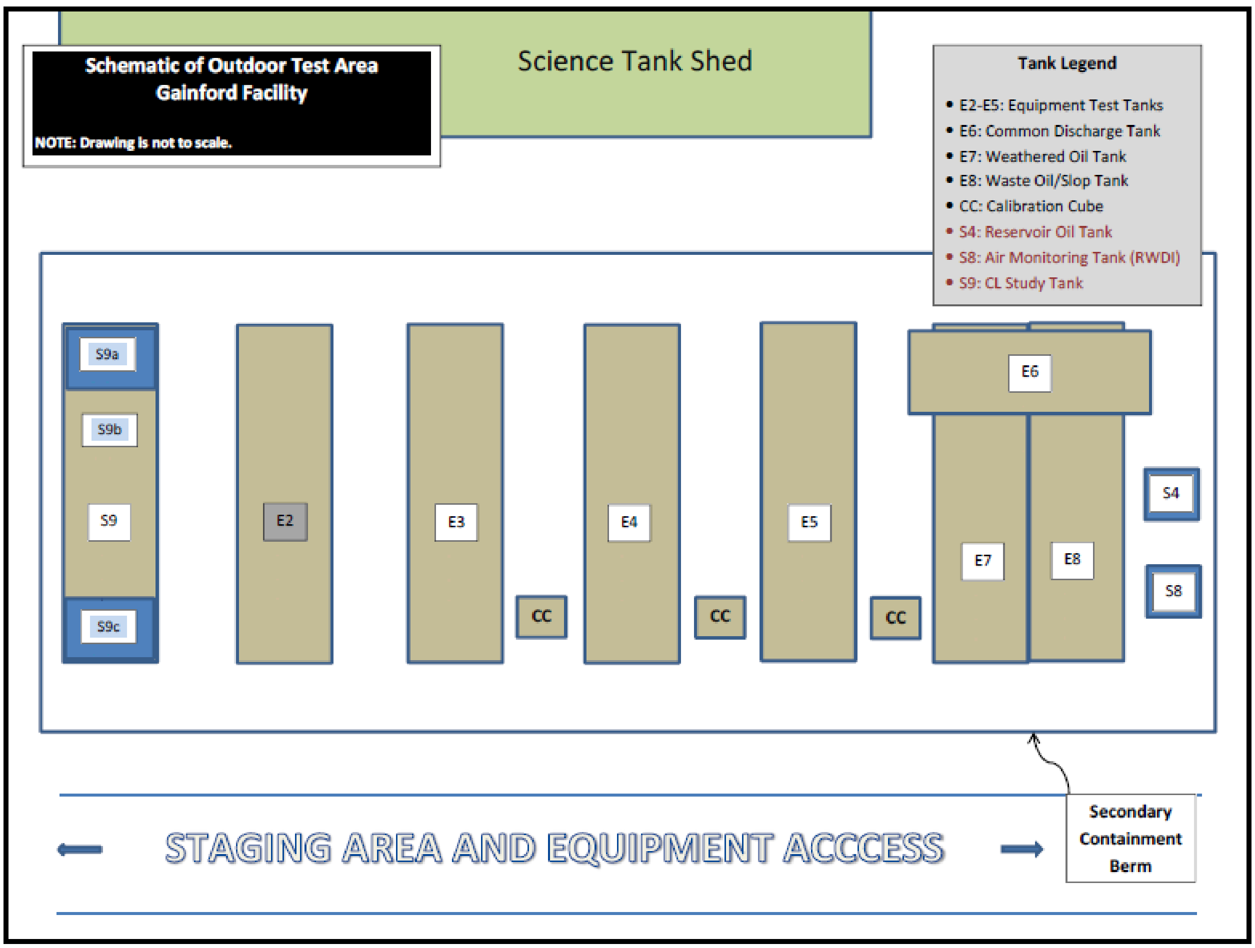

Figure 6-2: Equipment test tank schematic

6.1.2 Testing Protocols/ASTM Standards

The objective of the Gainford equipment test was to evaluate whether the current inventory of oil skimmers is suitable for recovering a common dilbit product. Each skimmer manufacturer was offered the opportunity to perform under consistent operating conditions and measurement procedures that were guided by the following ASTM standards:

F-631: Standard Guide for Collecting Skimmer Performance Data in Controlled Environments
F-2008: Standard Guide for Qualitative Observations of Skimmer Performance
F2709-08: Standard Test Method for Determining Nameplate Recovery Rate of Stationary Oil Skimmer Systems

It should be noted that each of the respective manufacturers of the devices exercised at Gainford had previously tested their units under strict adherence to ASTM standards as part of the nameplate recovery certification process. As such, it was not the intent of the Gainford study to replicate any of those prior tests. Rather, the ASTM standards referenced at Gainford were used only as guidance for the following parameters:

- Quantitative measurement of ambient conditions
- Appropriate laboratory analysis of virgin and recovered product
- Test facility design
- Test methodology
- Skimmer performance calculations

To allow vendors to correctly configure power units, check hose connections, and ensure operability prior to test commencement, vendors were given the opportunity to calibrate their equipment with the water of their respective tanks prior to the discharge of any oil.

Oil was discharged into the test tanks on May 13, and the subsequent tests followed the protocol as detailed below:

1. Allow the oil to stand for four hours prior to skimmer testing to reduce the combustible gas and benzene levels.
2. Skimmer discharge lines were plumbed so that the recovered liquids could be diverted to either a calibration cube or to the common waste tank (E6). After achieving steady state operation in the discharged oil, the subject skimmer effluent was diverted from the common waste tank (E6) to the calibration cube for a specified time (initially 30 seconds but modified in later test periods to a full 4 minutes; see modification 1 below).
3. The product in the calibration cube was allowed to settle for approximately one day after which the total liquid volume was measured. The cube was then decanted of free water. Once the water was removed the volume of the cube was again measured. An oil sample was then taken from the calibration cube sample tap and analyzed offsite for

water content according to Karl-Fischer Titration procedures (ASTM D1123). The volumetric measurements were then used to determine the skimmer's recovery capacity and efficiency.

4. The fluids accumulated in the common waste tank (E6) were allowed to settle for approximately one day. Thereafter, the water was decanted, and the remaining emulsion was gravity fed in equal amounts back to the test tanks. This procedure provided each of the skimmers with a common starting point for the next test in the sequence (see modification 2 below).

In accordance with the plan, these procedures were repeated on Day 3 (~48 hours after the initial oil release); Day 5 (~96 hours); Day 7 (~144 hours); and Day 9 (~192 hours).

On the last test day, Day 10 (~240 hours), a final test was conducted with skimmers exercised in tank E7, the weathered oil tank. The weathered oil tank (E7) was charged with 625 L (165 US gallons) of CLWB that had been poured in it on Day 1 (May 13) and left undisturbed for ten days. Originally, this last day test with 10 day weathered oil was to be a "Best in Show" exercise; however, this test was also modified (see modification 3 below) to better reflect evolving conditions.

Figure 6-3: Day 10 testing

6.1.3 Discussion of Test Modifications Made During the Test Period:

Modification 1 - Discharge Time to the Calibration Cube: The initial plan called for the tests to be conducted for a uniform 30 seconds. This duration was based on ASTM guidance and the concern that the 1 m^3 calibration cube capacity would be exceeded. After the first day of testing concluded, it was determined that the calibration cubes had sufficient capacity and that the tests could be run for longer durations. As of the second round of equipment tests (Day 3; ~48 hours), it was mutually agreed that the skimmers would run for four minutes after achieving steady state operation. This modification to the testing procedure remained consistent for the subsequent five tests.

Modification 2 - Common Waste Tank: After the first day of testing it was determined that diverting oil to the common waste tank, settling the liquids, and then redistributing that oil back to the test tanks was laborious and offered no benefit to the test. Therefore, a second protocol modification was made such that skimmer discharge – prior to diversion to the calibration cube – would no longer be directed to E6, but would now simply be recirculated back to the source tank.

Modification 3 - Last Test Day: The last test day was modified such that any vendor who wished to test their skimmer in tank E7 (10 day weathered CLWB) would be given that opportunity. Two of the vendors agreed to do so.

6.2 Oil Type and Properties

The same CLWB (winter blend) as was issued for the fate and behavior science study was chosen to be used for the equipment test. The CLWB was drawn from the pipeline in March and stored until the time of the test in closed-top drums in Edmonton, Alberta. The CLWB possessed the following properties at the beginning of the test period at Gainford:

Absolute Density (kg/m³)	925.2
Viscosity cSt @ 15 °C	220.3
Water Content (mass %)	0.43

Table 6-2: Properties of CLWB at the start of the equipment tests

Each test tank was given a measured, initial charge of three full 55 gallon drums (625 L or 165 US gallons) at the start of the test. To avoid emulsifying the oil from a plunging discharge stream, hand pumps were used to deliver the product onto a horizontal spillway resting on the surface of water. Releasing the oil into the E-series tanks took place between 1000 and 1100 on May 13.

The average thickness of the oil at the start of the test was measured to be ± 30 mm. This dimension was derived from calculations using vertical height measurements. In the interest of safety, skimmers had been pre-positioned in each tank after water depth measurements were taken but prior to discharge of the oil. This caused a perceived variation in slick thickness as a result of the different displacements of the skimming systems.

In accordance with the work plan, testing began on the first day of the release, approximately four hours after the nominal start of the spill, roughly between 1530 and 1600 on May 13.

6.3 Water Properties

Comparable to the science test tanks, the water properties of the equipment test tanks were representative of Burrard Inlet in British Columbia. The following target water conditions were determined to replicate Burrard Inlet water conditions for the purposes of this exercise:

Water Temperature	10 °C (50 °F)
Salinity	20 ppt (estuarine/brackish)
pH	7 (neutral)

Table 6-3: Water properties (target)

Site personnel were able to meet the target values for salinity and pH; however, higher than expected ambient air temperatures caused the tank water temperature to rise above the target value (see Table 6-4). Elevated water temperature was not deemed to be a significant factor in skimmer performance and realistically constituted conditions that could be experienced on Burrard Inlet surface waters during a summer day.

6.4 Equipment Tested

Under uniform conditions, the following skimming systems were tested in succession on the same days:

6.4.1 Aquaguard RBS Triton 60 DI3 Oil Skimming System

The Aquaguard system tested at Gainford was a brush skimmer driven by a diesel/hydraulic power pack. The skimmer's recovery technology uses oleophilic adhesion of the oil to the bristles of a brush rotating through the oil/water interface. A scraper removes the recovered product which is then collected in a common sump and pumped to a remote storage container.

Figure 6-4: Aquaguard RBS Triton Skimmer

Below are RBS Triton features summarized from the Aquaguard brochure:

- Stated recovery rates based on tests "witnessed by ABS Marine Services and Det Norske Veritas –tested to the ASTM-F631-93/99 standard;"
- Up to 98 percent efficiency;
- Versatile; brushes can be interchanged with either drums or discs for various oil types;
- When outfitted with the brush attachment, the recovery rate is 63 m^3/hr (396 bbl/hr).

6.4.2 Desmi DBD-5 Skimmer

The Desmi DBD-5 system was a diesel/hydraulic powered skimmer fitted with an oleophilic brush-drum assembly. The drum rotates through the oily water where oil is attracted and adheres to the brush surfaces. A scraper transfers the recovered oil into a central collection sump.

Below are DBD-5 features summarized from the Desmi brochure:

- Stated recovery rate with brushes is 7 m^3/hr (44 bbl/hr);
- This small unit has a 0.12 m or 5 inch draft suitable for use in shallow water environments

Figure 6-5: Desmi DBD-5 Skimmer

6.4.3 Lamor MultiMax LAM 50/3C Brush Skimmer

The Lamor system tested at Gainford was a stiff-brush conveyor belt type oil skimmer. The conveyor belt consists of three stiff-brush-chains. The oleophilic brush conveyor belt uses a patented brush cleaner to separate the oil from the water and lift the recovered product to the oil transfer pump.

Below are LAM 50/3C features summarized from the Lamor brochure:

- Bureau Veritas-certified recovery rate of 53.1 m^3/hr (334 bbl/hr);
- Designed to recover all types of oil with particular effectiveness in weathered oils, crude, high viscosity bunker oil, and emulsions.

Figure 6-6: Lamor MultiMax Skimmer

6.5 Results

6.5.1 Qualitative Observations and Comments

The Gainford equipment test sought to investigate the following questions:

- Does Cold Lake bitumen behave differently from other heavy crude oils commonly handled by this industry?
- Is the current inventory of skimmers, available to Trans Mountain Pipeline ULC and its contractors, capable of mechanically recovering dilbit under conditions that can be reasonably expected in the subject marine environment?
- From a recovery equipment operator's perspective, does dilbit behave differently from other crude oils you have recovered?
- Also from the operator's perspective, does the equipment get compromised in any way as a result of recovering dilbit?
- How does weathered dilbit affect equipment operation, performance, and ultimately the recovery rate?
- Can adjustments be identified to improve skimming operations of dilbit spilled on marine waters?

Observations associated with the primary equipment test objective:

- Throughout the allotted time period, all of the skimmers proved effective in recovering the product, whether it was fresh, emulsified, or naturally weathered after a 10 day exposure to ambient element conditions.
- There were no conditions during the testing period under which any of the three skimmers failed to operate.

Peripheral observations:

- At discharge the oil was less viscous than anticipated, prompting the vendors to state they would have preferred to have used oleophilic discs at the outset of the test and then switched to brushes later as the oil became more viscous.
- The oil floated throughout the 10 day period. No instances were observed of the oil's buoyancy being compromised either neutrally downward in the water column or sunken to the bottom of the tank. Visual observations of the tanks during final decontamination further affirmed the absence of sunken oil.
- Vendors and contractors both agreed that under the test conditions this dilbit behaved no differently than other crude oils and proved to be mechanically recoverable by the skimming units tested. As mentioned previously, owing to the light viscosity, recovery of the early discharged product would have been improved by the use of drum and disc skimming attachments. It was not until after a few days of weathering that the vendors would have opted to use the brush/belt attachments.

Figure 6-7: Equipment testing (Calibration Cube is to the right of Tank E5)

6.6 Weathered Oil Properties

- The data presented in Table 6-4: Summary data from equipment testing (also see Appendix H) documents the average density of the oil in the equipment test tanks starting at a value of 925.2 (absolute density at 15 °C/API 21.3) on May 13 and steadily increasing to 988.8/11.5 by May 21. These density numbers represent an average value for the oil contained in each of the three equipment test tanks over that time period. It should also be noted that this oil was not only weathering but was also being agitated and emulsified by the skimmers.
- The following density numbers for the same time period were for the undisturbed oil in tank E7 (the static tank): 925.2 kg/m^3 (API 21.3) to 975.1 kg/m^3 (API 13.5).
- Viscosities calculated (per ASTM 341) to 15 °C based on laboratory tests of oil samples collected from the tanks before skimming ranged from a starting value of 220 to over 30,000 cSt (Table 6-4).

Figure 6-8: Timed equipment test

6.7 Quantitative Data Results

Table 6-4 summarizes the conditions under which the equipment test was performed and displays a range of performance results measured during the test.

Table 6-4: Summary data from equipment testing (shown on the next two pages)

			Prior to Skimmer Testing						
Date of Test	**Duration of Peak Test**	**Number of Skimmers Tested**	**Air Temp (Avg./°C)**	**Water Temp (Avg./°C)**	**Salinity (Avg./ppt)**	**pH (Avg.)**	**Water Content in Oil Sample (lab result; mass %)**	**Density of Oil Sample (lab result; Absolute; kg/m³ @ 15 °C)**	**Viscosity of Oil Sample (lab result: cSt extrapolated to 15 °C)***
13-May	2 min	3	23.0	13.6	21.0	7.0	0.4	925.2	220
15-May	4 min	3	17.0	15.5	22.6	7.0	4.1	952.4	1252
17-May	4 min	3	14.5	17.1	20.3	7.7	8.8 - 35.5	970.1 - 985.1	6603 - 15523
19-May	4 min	3	11.8	18.9	20.0	7.6	27.7 - 41.2	982.5 - 989.9	7982 – 17234*
21-May	4 min	3	14.8	19.5	21.3	8.0	22.5 - 45.1	986.2 - 993.0	15903 – 30304
22-May	4 min	2	15.1	18.4	18.0	7.5	1.2	975.1	9642

These values were for the oil at the beginning of the test and the oil from the common discharge tank. After the modification of the test, such that skimmers were discharging into their own tanks, there was a high and low value from those three tanks.

Values are from one tank (E7) which had been left for 10 days undisturbed.

***Tank E5 extrapolated values for May 18 not included in range as curve was outlier.**

Date of Test	Approx. Elapsed Time from Oil Release that Test was Conducted (Hrs.)	Cal. Cube Avg. Settling Time (hh:mm)	Water Content in Oil Sample from Cal. Cube (lab result; %)		Total Fluid Recovered in Calibration Cube (measuring 113 cm x 92 cm; values below in cm)		Total Rate of Oil Recovery (liters/sec.)		% of Oil Content in Cal. Cube		% of Water Content in Cal. Cube	
			High	Low	High	Low	High	Low	High	Low	High	Low
13-May	4	24:00	22.0	5.7	34.0	7.5	0.86	0.21	33	19	81	66
15-May	46	19:56	91.1	8.2	16.5	14.5	0.59	0.58	95	81	18	5
17-May	96	21:03	50.4	24.1	17.7	8.1	0.70	0.31	98	79	21	2
19-May	144	21:38	47.5	20.0	39.8	10.6	0.71	0.40	94	28	72	6
21-May	192	23:40	49.0	26.2	20.0	6.1	0.82	0.25	95	79	21	5
22-May	216	22:34	17.0	13.2	8.2	2.9	0.26	0.12	97	73	27	3

This particular sample jar was almost all water and this number is an anomaly. The comparative numbers should be 11.8 (high) and 8.2 (low).

7 Recommended Future Research

7.1 Science

The experiments conducted at Gainford, combined with previous and other recent tests, have advanced the general knowledge of dilbit weathering, fate, and behavior. Recent meso-scale tank tests have encompassed different imposed energy conditions as well as freshwater to brackish water conditions. Areas for potential future investigation include:

- Sediment interaction and sinking – a series of tests to help understand the sediment/oil interaction (degree of binding or adhesion, and resulting densities). Experience from the Enbridge spill at Marshall (2010, Kalamazoo, Michigan) noted oil bound to sediment had sunk but, in many cases, was easily released back into the water column with agitation. This indirectly suggests that the weathered dilbit was not tightly bound to sediment particles.
- Effects of different diluents and bitumens – more oil weathering testing has been completed with CLB dilbit, as this is one of the predominant commodities transported; however, different diluents and source bitumens in dilbit and synthetic crude (syncrude) blends may behave differently when spilled, as well as have very different chemical characteristics and potential effects. Laboratory and meso-scale testing with additional blends would augment and broaden the knowledge base for these oils.
- Sediment penetration and flushing – a series of previous experiments were conducted by Environment Canada to determine penetration and retention of different crude oils in different sediments and under different hydraulic and environmental conditions (Harper et al., 1995; Humphrey et al., 1993). Using similar protocols, subsequent testing was conducted by Environment Canada using bitumen (Harper et al., 2002b). Additional testing, following test protocols used for the subsurface oil in coarse sediments experiment(s) (SOCSEX; Humphrey et al., 1993; Harper et al., 1995), can provide improved details on oil penetration and retention for a broader range of sediment/soil types and under different hydraulic conditions (i.e., simulated riverbed on water level drops and rises, tidal flushing). Other variables to investigate would include sediment grain size, hydraulic conditions such as water level change/ tidal flushing, and temperature and weathering state. These results could be used in conjunction with data from previous similar experiments and spill observations to describe a more accurate projection of dilbit penetration, retention, persistence, effects, and removal.
- Shoreline cleaning agents – additional testing for cleaner effectiveness using a variety of available cleaning agents is recommended. Only two cleaning agents were tested during these trials, and one proved to be effective. A more robust complement of potential cleaning agents would assist with pre-approvals should they be needed.
- Dispersant effectiveness – additional testing of dispersants using fluorometers and for different dilbit blends under variable conditions of Day 0 to Day 1 weathering will provide valuable feedback as an early countermeasure option. Additional testing using a range of dispersant to oil ratios is also suggested.

- Controlled burning – additional tests of controlled burning on various dilbit blends and a range of initial oil thicknesses will provide important information to operational feasibility and constraints as an early countermeasure.
- Biodegradation – tests to determine the effectiveness of natural and enhanced biodegradation on dilbits will provide important information on guidelines for cleanup and remediation. An understanding of biodegradation rates under different environmental conditions and using varying combinations of nutrient enrichments will assist in guiding net benefits analyses for spill cleanup.

7.2 Equipment

When the opportunity for future testing presents itself, the following situations would benefit from further investigation:

- Interchanging oleophilic discs/drums with brushes at the outset or low viscosity portion of the test period.
- Providing equipment manufacturers with oil samples for use in their respective test facilities.
- While the dilbit used at Gainford did *not* sink, certain circumstances (notably those involving fresh water and robust sediment loads) may cause heavy oils to become submerged. This phenomenon would benefit from further experimentation and study.

8 Conclusions

The overall study objective was to obtain an expanded understanding and assessment of dilbit behavior, weathering, and OSR countermeasures performance under controlled simulated conditions similar to the potential receiving environment of Burrard Inlet. This objective was achieved through the Gainford meso-scale tests. Answers to some of the fundamental questions posed regarding potential dilbit spills into a setting such as Burrard Inlet were obtained, as summarized in Table 8-1.

8.1 Scientific Testing

Specific goals were to better understand and characterize the changes in physical and chemical properties and oil distribution of dilbit in an estuarine simulated condition over a 10 day period and to determine efficiency and effectiveness of dispersant, in-situ burning, and shoreline cleaning agents as potential countermeasures for various stages of weathered oil. The Gainford tests successfully met these goals.

Both AWB and CLB dilbits exhibited properties typical of a heavy, "conventional" crude oil. In no instance was any oil observed to have sunk. Visual observations of the surface of the oil in the various tanks showed that a crust, or armoring, formed as the oil weathered. In some instances, especially noted under static conditions, the lighter components of the oil came out the oil as bubbles within the slick. These bubbles rose to the surface and, in places, became trapped under the crusted layer. Weathered oil densities approached, and in several instances, exceeded that of freshwater but not that used to represent Burrard Inlet brackish water. Visual observations were made of weathered oil overwashing within tanks with agitation; however, the weathered oil did not submerge or sink in the tanks.

Chemical analyses of the weathered oils and of the water column showed that concentrations of BTEX diminished rapidly within 48 hours and that TPH in the water column only exceeded the detection limit (2 mg/L) during the first 48 hours in tanks with moderate surface agitation, despite the artificial confinement imposed by tanks relative to what may be expected in an open, natural setting.

Countermeasures tested included dispersant application, burning, and shoreline cleaners. The visual observations of the dispersant test revealed that Corexit 9500 was marginally effective on 6 hour weathered oil and not particularly effective for more weathered CLWB dilbit. The early test burn (6 hour weathered CLWB dilbit) was effective with a sustained burn of 2 L of oil lasting for more than 2 minutes with approximately 70 percent of oil removed through burning. Additional burn testing showed approximately 50 percent of 24 hour weathered oil was removed, but only after sustained effort to ignite. The 72 hour weathered oil was not successfully ignited. Tests with Corexit 9580 found the cleaning agent to be effective on oils weathered up to five days. Test observations noted that the time oil weathers on water before being placed on the tile was less important than the time the weathered oil was exposed to air.

Comments regarding frequently asked questions (FAQs; see Table 8-1) and key points are:

- There was no two-phase separation into bitumen and diluent;

- Off-gassing of light-ends has safety implications for responders and the public during the initial hours of exposure to a release, as is the case for most oil spills;
- Both AWB and CLWB dilbits remained floating on brackish water during the 10 days of weathering;
- Both AWB and CLWB weathered dilbits surpassed viscosities of 10,000 cSt within 48 hours and exhibited strong tendencies to form a more continuous thick mat rather than a thin sheen on water which, with continued weathering and agitation, can be expected to produce tar balls.

8.2 Equipment Testing

It should be recognized that any time operators, contractors, and scientists have the opportunity to work with crude oils in an environmentally-sound field exercise, all stakeholders will benefit. As such, the Gainford equipment test delivered positive results, as summarized below:

- No performance shortcomings were observed in the current inventory of recovery equipment available to TMPL and its contractors;
- The more viscous oil encountered on test days 7, 9, and 10 caused no skimmer malfunctions including stalls, seizures, or poor recovery;
- Operational adjustments to compensate for increased dilbit viscosity were no different than field adjustments made to equipment during actual spill events for most oils;
- This particular dilbit behaved similarly to any other crude oil that the Gainford spill response professionals had experienced in the past.

Does dilbit sink in water when spilled? Both Cold Lake Blend (CLB) and Access Western Blend (AWB) dilbits are lighter than freshwater. Dilbit spilled into fresh, brackish, or saltwater will stay on the water surface unless another mechanism mixes it into the water column, as would be the case for any oil. Only after extensive weathering may some portion become submerged or sink in freshwater, without invoking additional parameters that can modify the density of the spilled product.
Can dilbit be recovered from water using conventional spill response skimmers? Fresh dilbit oil is much like most medium to heavy crude oils and can be recovered using a variety of skimmer systems, ranging from weirs to oleophilic units. As dilbit weathers, the oil viscosity increases significantly but skimmers designed for more viscous oils, including brush, belt, and mechanical systems, can continue to effectively recover weathered oil (demonstrated in up to 10 days of weathering in tank tests).
Can chemical dispersants be effectively used on dilbit spills? Given appropriate safety, environmental, and operating conditions, dispersants may be effective within the first day of a spill before weathering results in oil that is too viscous to effectively disperse.
Is controlled burning a possible countermeasure for use on dilbit spills? Given appropriate safety, environmental, and operating conditions, burning may be effective but likely for a short time period (approximately 12-24 hours) before weathering results in oil that is too viscous to effectively ignite an sustain combustion.
How toxic is dilbit relative to other crude oils? The BTEX (benzene, toluene, ethylbenzene, and xylene) components in crude oils are some of the key chemicals of concern for toxicity. The BTEX content in CLB and AWB dilbits is approximately 1 to 1.2 percent by volume, respectively, which is slightly less than that found in Alaska North Slope or Alberta Sweet crude oils.
How variable are the weathering patterns and oil properties between different dilbits and synbits? The Gainford tests showed that the weathering patterns between CLB and AWB are similar and that oil physical and chemical properties are consistent with other heavy crude oil. The full range of properties of dilbit blends are well known and published (see CrudeMonitor), although weathering characterization of the range of oils is the subject of ongoing research.
Can spilled dilbit be contained on water? Lab and meso-scale tests have consistently shown both AWB and CLB dilbits to float on freshwater and saltwater. Spill containment strategies and tactics for floating oils are quite applicable to dilbit. Changes in spilled oil behavior and movement on water can be influenced by numerous factors. Effective containment requires adjusting strategies and tactics to changing conditions for a spill of any oil type.
Can spilled dilbit be effectively cleaned off shorelines? The Gainford meso-scale tests showed that fresh to very weathered CLB can be effectively removed from a hard substrate through a combination of shoreline cleaner (Corexit 9580) and low to moderate water pressure flushing. These techniques may not be suited for all types of shorelines; however, they generally are appropriate for coarse-grained materials (gravel, cobbles, and boulders and including coarse sediment mixes).

Table 8-1: Frequently Asked Questions.

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- Pam Chelgren-Koterba, Witt O'Brien's
- Michael Davies, KMC TMX
- Kevin Gardner, WCMRC
- Andy Graham, Polaris Applied Sciences
- Bikramjit Kanjilal, KMC TMX
- Mac McCarthy, Witt O'Brien's
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- Jim Morris, Witt O'Brien's
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- Gary Sergy, S3 Environmental
- Gary Shigenaka, NOAA

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- Steven Bott, CEPA
- Martin Bundred, ESRD
- André Desjardins, ECRC-SIMEC
- Heather Dettman, NRCan
- Merv Fingas, KMC contractor
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Appendix A: Crude Quality Inc. Data for Cold Lake and Access Western Blend

Witt O'Brien's, Polaris Applied Sciences, and
Western Canada Marine Response Corporation

What is Access Western Blend crude?

Access Western Blend (AWB) is a heavy, high TAN dilbit produced by Devon Energy Canada and MEG Energy Corp. Production is from the Athabasca region south of Fort McMurray, Alberta. Production is generated by SAGD thermal methods. Diluent is supplied to the production sites from Edmonton and dilbit is pumped back to Edmonton on the Access Pipeline. AWB is available for upgrading in the Edmonton area, and for export on the Enbridge and Kinder Morgan systems.

Light Ends Summary

Property*(vol%)*	Most Recent Sample	6 Month Average	1 Year Average	5 Year Average
C3-	0.02	0.02	0.03	0.03
Butanes	0.37	0.45	0.55	0.68
Pentanes	7.17	8.47	8.48	8.38
Hexanes	6.31	6.68	6.81	6.78
Heptanes	4.28	4.01	4.15	4.33
Octanes	2.31	2.18	2.27	2.55
Nonanes	0.90	1.02	1.09	1.23
Decanes	0.41	0.48	0.52	0.53

BTEX

Property*(vol%)*	Most Recent Sample	6 Month Average	1 Year Average	5 Year Average
Benzene	0.25	0.28	0.30	0.29
Toluene	0.44	0.46	0.49	0.50
Ethyl Benzene	0.04	0.05	0.05	0.06
Xylenes	0.29	0.33	0.35	0.39

Most Recent Sample Comments: AWB-803, Sep 20, 2013

Last 6 Samples

On a seasonally adjusted basis, Access Western Blend was consistent with historical averages for the month of September.

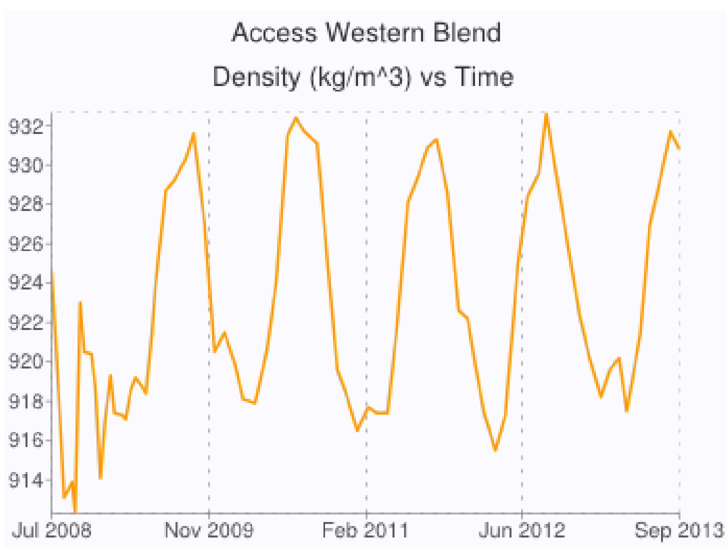
Monthly Reports

Basic Analysis

Property	Most Recent Sample	6 Month Average	1 Year Average	5 Year Average
Density *(kg/m³)*	930.8	925.3	923.6	922.7
Gravity *(°API)*	20.4	21.3	21.6	21.7
Sulphur *(wt%)*	4.12	4.01	3.95	3.94
MCR *(wt%)*	11.00	10.79	10.65	10.65
Sediment *(ppmw)*	-	94	89	193
TAN *(mgKOH/g)*	1.77	1.73	1.72	1.70
Salt *(ptb)*	-	4.7	6.4	6.4
Nickel *(mg/L)*	77.0	76.6	73.8	72.4
Vanadium *(mg/L)*	206.0	202.0	196.7	194.1
Olefins *(wt%)*	-	-	ND	ND

*ND indicates a tested value below the instrument threshold.

Trend Charts



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Access Western Blend (AWB)

Basic Analysis

	Feb 23, 2013 Sample	5 Year Average (prior to Feb 23, 2013 sample)
Density *(kg/m³)*	919.6	922.2 ± 5.5
Gravity *(°API)*	22.2	21.8 ± 0.9
Sulphur *(wt%)*	3.82	3.94 ± 0.10
MCR *(wt%)*	10.50	10.66 ± 0.50
TAN *(mgKOH/g)*	1.77	1.70 ± 0.12
Nickel *(mg/L)*	66.0	71.8 ± 4.9
Vanadium *(mg/L)*	197.0	193.2 ± 11.9

Light Ends

	Feb 23, 2013 Sample	5 Year Average
C3- *(vol%)*	0.05	0.03 ± 0.01
Butanes *(vol%)*	0.69	0.70 ± 0.14
Pentanes *(vol%)*	8.42	8.41 ± 1.20
Hexanes *(vol%)*	6.74	6.80 ± 0.68
Heptanes *(vol%)*	4.23	4.36 ± 0.48
Octanes *(vol%)*	2.56	2.58 ± 0.42
Nonanes *(vol%)*	1.29	1.25 ± 0.24
Decanes *(vol%)*	0.54	0.54 ± 0.12

BTEX

	Feb 23, 2013 Sample	5 Year Average
Benzene *(vol%)*	0.28	0.29 ± 0.03
Toluene *(vol%)*	0.50	0.50 ± 0.07
Ethyl Benzene *(vol%)*	0.06	0.06 ± 0.01
Xylenes *(vol%)*	0.39	0.39 ± 0.08

Source: http://www.crudemonitor.ca/crude.php?acr=AWB

What is Cold Lake crude?

The main players in the Cold Lake oil sands deposit are Imperial Oil Resources, Cenovus Energy, Canadian Natural Resources Limited and Shell Energy. Cold Lake production is bitumen based and requires the use of steam to release the bitumen from the underground reservoirs, and the use of diluents to meet pipeline viscosity and density specifications.

Light Ends Summary

Property*(vol%)*	Most Recent Sample	6 Month Average	1 Year Average	5 Year Average
C3-	0.02	0.03	0.04	0.04
Butanes	0.69	0.82	0.85	1.01
Pentanes	8.06	6.53	6.29	6.25
Hexanes	5.50	5.30	5.52	5.33
Heptanes	2.85	3.31	3.42	3.36
Octanes	1.36	2.04	2.18	2.21
Nonanes	0.79	1.32	1.38	1.33
Decanes	0.42	0.71	0.71	0.63

BTEX

Property*(vol%)*	Most Recent Sample	6 Month Average	1 Year Average	5 Year Average
Benzene	0.20	0.23	0.24	0.23
Toluene	0.28	0.40	0.41	0.39
Ethyl Benzene	0.02	0.05	0.06	0.06
Xylenes	0.15	0.32	0.34	0.33

Most Recent Sample Comments: CL(E)-732, Sep 21, 2013

Last 6 Samples

As expected, based on the seasonality of Cold Lake, density is slightly elevated, while light ends and BTEX are reduced for this September sample at Edmonton.

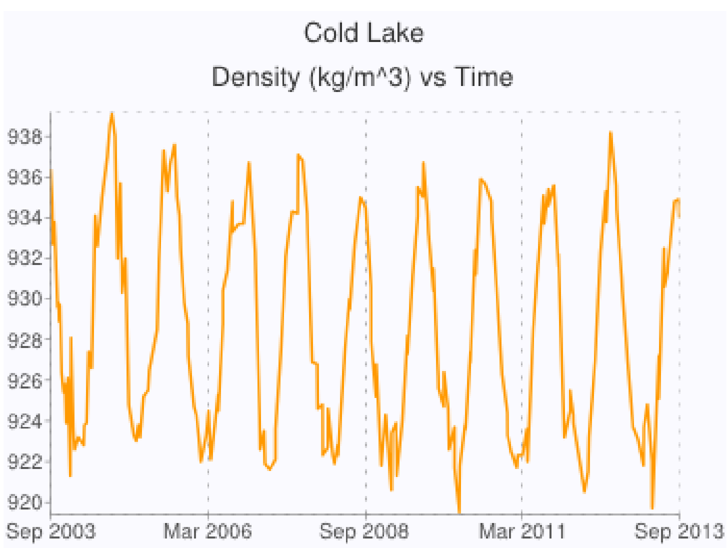
Monthly Reports

Basic Analysis

Property	Most Recent Sample	6 Month Average	1 Year Average	5 Year Average
Density *(kg/m³)*	934.0	930.0	927.9	928.1
Gravity *(°API)*	19.9	20.5	20.9	20.8
Sulphur *(wt%)*	3.91	3.83	3.79	3.80
MCR *(wt%)*	10.90	10.57	10.43	10.48
Sediment *(ppmw)*	175	119	104	162
TAN *(mgKOH/g)*	0.96	0.98	0.98	0.98
Salt *(ptb)*	7.8	8.5	9.6	11.6
Nickel *(mg/L)*	68.0	69.1	66.0	65.6
Vanadium *(mg/L)*	172.0	180.2	174.5	171.1
Olefins *(wt%)*	-	ND	ND	ND

*ND indicates a tested value below the instrument threshold.

Trend Charts



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Cold Lake (CL)

Basic Analysis

	Feb 28, 2013 Sample	5 Year Average (prior to Feb 28, 2013 sample)
Density *(kg/m³)*	923.7	928.0 ± 5.1
Gravity *(°API)*	21.6	20.9 ± 0.8
Sulphur *(wt%)*	3.68	3.80 ± 0.08
MCR *(wt%)*	10.10	10.46 ± 0.33
TAN *(mgKOH/g)*	1.00	0.98 ± 0.08
Nickel *(mg/L)*	60.0	65.3 ± 3.0
Vanadium *(mg/L)*	170.0	169.8 ± 12.5

Light Ends

	Feb 28, 2013 Sample	5 Year Average
C3- *(vol%)*	0.04	0.04 ± 0.01
Butanes *(vol%)*	0.60	1.05 ± 0.24
Pentanes *(vol%)*	5.84	6.18 ± 0.95
Hexanes *(vol%)*	5.58	5.30 ± 0.64
Heptanes *(vol%)*	3.60	3.34 ± 0.45
Octanes *(vol%)*	2.54	2.22 ± 0.40
Nonanes *(vol%)*	1.68	1.34 ± 0.27
Decanes *(vol%)*	0.78	0.62 ± 0.14

BTEX

	Feb 28, 2013 Sample	5 Year Average
Benzene *(vol%)*	0.25	0.23 ± 0.03
Toluene *(vol%)*	0.46	0.39 ± 0.06
Ethyl Benzene *(vol%)*	0.07	0.05 ± 0.01
Xylenes *(vol%)*	0.42	0.33 ± 0.06

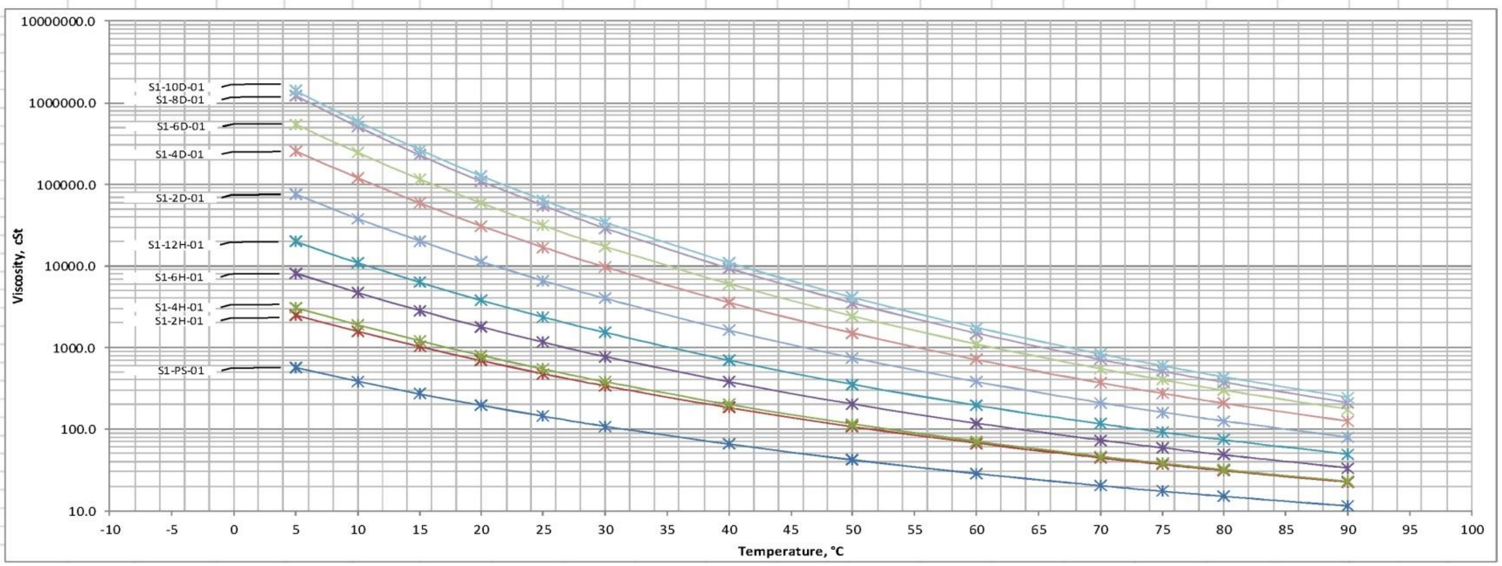
Source: http://www.crudemonitor.ca/crude.php?acr=CL

Appendix B: Oil Physical Data

Witt O'Brien's, Polaris Applied Sciences, and
Western Canada Marine Response Corporation

Maxxam

Job #	Sample #	Sample Point	API	Absolute Density @ 15°C kg/m3	Relative Density	Viscosity, cSt (shaded areas denote calculated values) 5	10	15	20	25	30	40	50	60	70	75	80	90	Pour Point °C	Flash Point °C	Water wt%
B338178	GJ6334	S1-PS-01	22.2	920.1	0.9209	565.8	385.6	270.5	194.9	143.8	108.3	65.36	41.92	28.49	20.26	17.34	14.97	11.43	-21	<-35	3.4
B338178	GJ6336	S1-2H-01	18.4	943.4	0.9443	2504	1575	1026	689.5	477.0	338.5	183.4	107.2	67.17	44.51	36.90	30.93	22.38	-18	<-35	6.7
B337952	GJ4821	S1-4H-01	17.9	946.2	0.9471	3081	1896	1210	799.0	543.8	380.6	200.7	115.2	70.95	46.37	38.22	31.86	22.85	-12	<-35	5
B338173	GJ6324	S1-6H-01	15.9	959	0.9599	8128	4707	2844	1781	1158	775.39	378.2	203.0	118.0	73.42	59.18	48.33	33.38	-12	<-35	5.1
B338179	GJ6340	S1-12H-01	14.6	967.4	0.9683	19782	10910	6296	3786	2363	1527	696.1	353.3	195.3	116.2	91.84	73.62	49.16	-6	<-35	0.78
B338894	GK3237	S1-1D-01	12.7	980.7	0.9816															<-35	8.3
B338894	GK3242	S1-2D-01	12.9	979.1	0.98	75560	38119	20269	11304	6584	3990	1626	748.3	380.8	211.0	161.5	125.7	79.57	6	-10	1
B340447	GL0002	S1-4D-01	11.7	987.3	0.9882	256290.7	119528.3	59125.5	30851.5	16899.0	9674.8	3565.9	1504.0	710.3	369.3	274.4	207.5	125.4	6	20	1.2
B340457	GL0063	S1-6D-01	10.7	994	0.9949	544443	244203	116477	58744	31169	17320	6047	2432	1101	552.5	402.8	298.8	176.2	12	22	1.6
B340457	GL0051	S1-8D-01	10.2	997.9	0.9988	1219579	510057	228350	108741	54768	29027	9334	3505	1499	716.2	510.7	374.8	211.4	12	52	1.7
B341627	GL8592	S1-10D-01	9.8	1000	1.001	1399367	589297	265263	126848	64087	34040	10969	4119	1758	834.8	599.5	435.3	245.7	9	58	4.5



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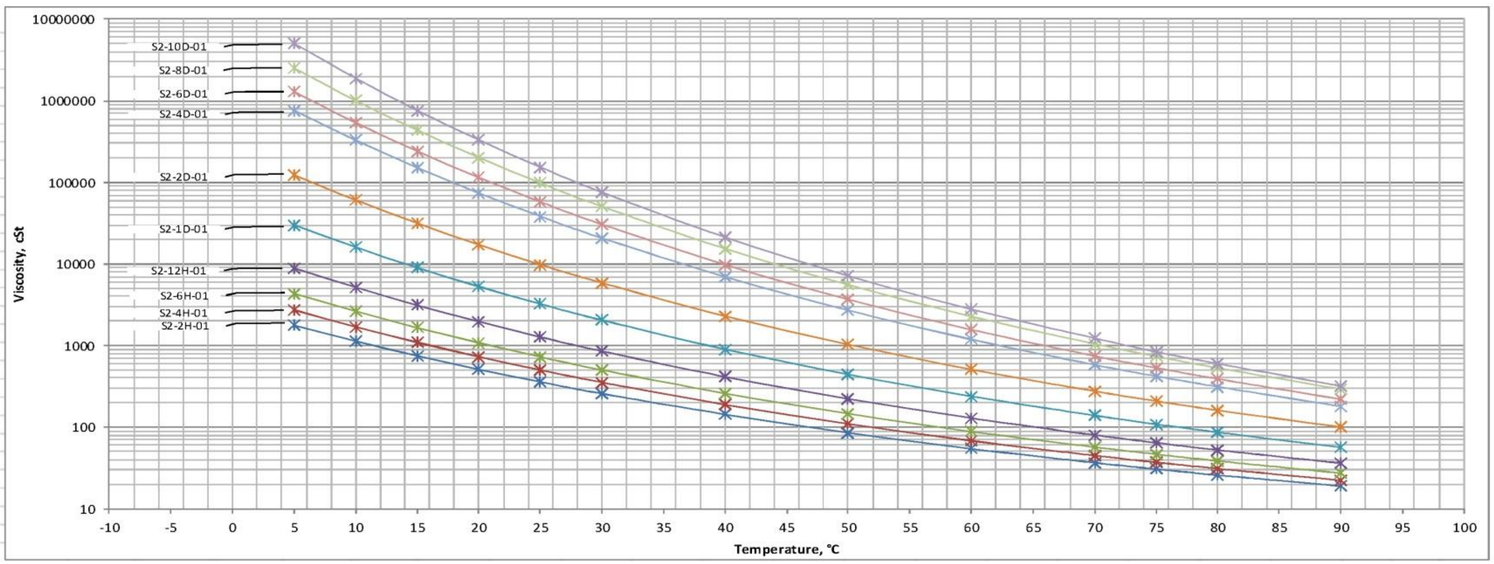
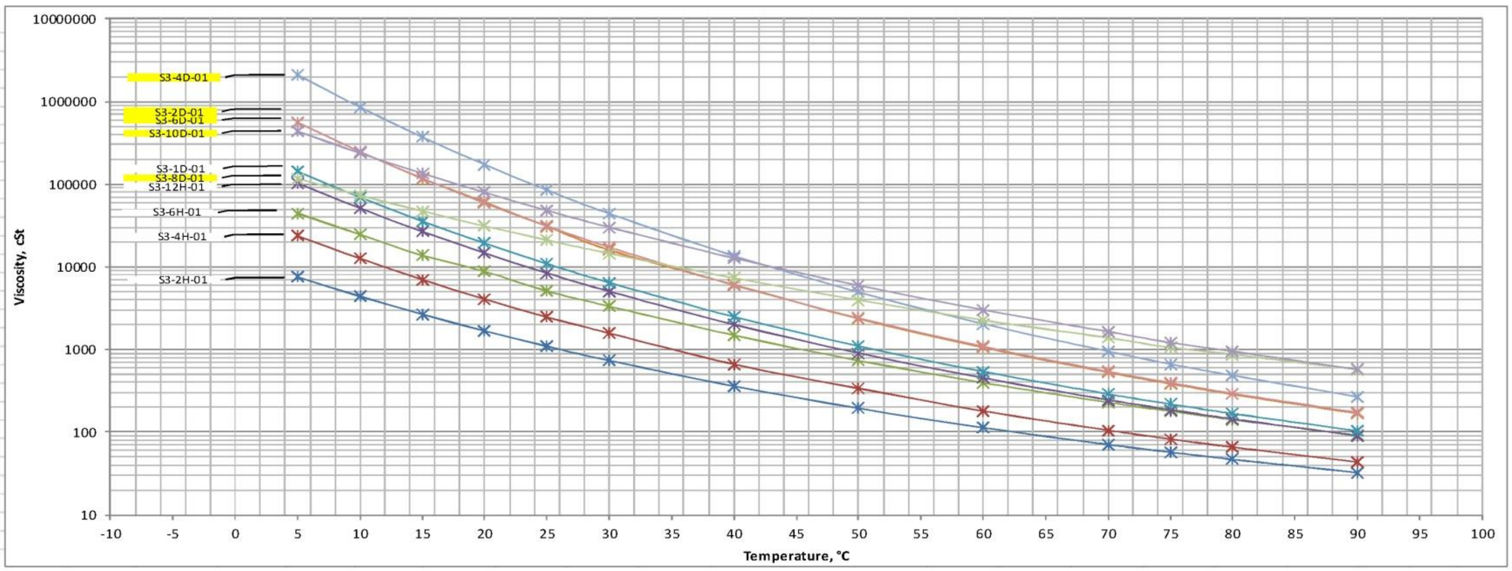
Job #	Sample #	Sample Point	API	Absolute Density @ 15°C	Relative Density	Viscosity, cSt (shaded areas denote calculated values)													Pour Point	Flash Point	Water
				kg/m3		5	10	15	20	25	30	40	50	60	70	75	80	90	°C	°C	wt%
B338178	GJ6337	S2-2H-01	19.5	936.5	0.9373	1769	1132	749.0	511.1	358.6	257.3	143.6	85.24	54.50	36.70	30.65	25.87	18.95	-24	<-35	0.22
B337952	GJ4822	S2-4H-01	18.4	942.9	0.9438	2733	1703	1097	731.4	502.0	354.1	189.2	109.7	68.20	44.90	37.13	31.05	22.37	-27	<-35	0.93
B338173	GJ6325	S2-6H-01	17.4	949.7	0.9506	4345	2634	1658	1082	726.5	502.8	259.5	146.1	88.44	56.92	46.59	38.58	27.33	-18	<-35	0.18
B338179	GJ6342	S2-12H-01	16	958.4	0.9593	8927	5176	3128	1962	1274	853.1	415.6	222.6	129.1	80.10	64.48	52.58	36.22	-15	<-35	4.2
B338894	GK3238	S2-1D-01	14.1	971.2	0.9721	29945	16054	9027	5300	3237	2050	901.8	444	239.1	139.2	108.9	86.49	56.81	3	<-35	0.5
B338894	GK3243	S2-2D-01	12.3	983	0.9839	123088	60645	31539	17227	9839	5858	2304	1031	510.6	276.4	209.3	161.2	100.2	12	-13	0.9
B340447	GL0003	S2-4D-01	10.5	995.7	0.9966	761236	328775	151596	74170	38297	20767	6955	2704	1191	581.9	422.1	313	179.7	9	5	3.7
B340457	GL0064	S2-6D-01	13.1	978	0.9789	1290365	539180	241152	114716	57714	30553	9802	3672	1567	744.8	533.3	390.6	219.8	9	24	5.8
B340457	GL0052	S2-8D-01	9.6	1002	1.003	2501399	1008067	435942	200980	98201	50652	15414	5549	2277	1048.3	738.2	531.5	292.5	15	24	6.3
B341627	GL8594	S2-10D-01	8.4	1010	1.011	5031495	1885557	763943	332161	153972	75647	21299	7153	2784	1232	839.2	602.1	320.2	12	75	18.2



Job #	Sample #	Sample Point	API	Absolute Density @ 15°C kg/m3	Relative Density	Viscosity, cSt (shaded areas denote calculated values) 5	10	15	20	25	30	40	50	60	70	75	80	90	Pour Point °C	Flash Point °C	Water wt%
B338178	GJ6338	S3-2H-01	16.3	956.3	0.9572	7554	4394	2665	1676	1093	734.3	360.3	194.3	113.5	70.85	57.20	46.79	32.41	-6	<-35	8.6
B337952	GJ4823	S3-4H-01	14.4	969.1	0.97	23801	12581	6994	4070	2468	1577	663.3	338.2	180.4	105.4	82.68	65.86	43.53	-6	<-35	25.3
B338173	GJ6326	S3-6H-01	12.9	979.2	0.9801	44568	24517	13766	8778	5099	3329	1487	734.9	395.9	229.5	178.9	141.6	92.14	0	-3	24.1
B338179	GJ6344	S3-12H-01	12.4	982.4	0.9833	103273	51157	26746	14685	8430	5044	2002	904	451.4	246.2	187.1	144.6	90.42	3	-3	
B338894	GK3239	S3-1D-01	12.1	984.2	0.9851	142304	69245	35607	19251	10893	6433	2491	1102	540.1	289.8	218.6	167.8	103.7	3	4	42.4
B338894	GK3244	S3-2D-01	10.5	995.8	0.9967	559158	248150	117267	60820	30909	16000	6078	2356	1061	528.8	386.0	287.3	168.0	15	3	42.5
B340447	GL0004	S3-4D-01	10.3	997.2	0.9981	2102287	853772	371916	172648	84910	44013	13595	4928	2043	950.6	667.6	485.5	268.5	6	25	45.3
B340457	GL0065	S3-6D-01	10.8	993.7	0.9946	554916	247529	117493	59006	31192	17277	6000	2403	1085	541.4	396.1	294.5	172.4	15	25	3.4
B340457	GL0053	S3-8D-01	11.1	991.2	0.9921	116304	73063	47117	31132	21040	14521	7324	3955	2266	1385	1057	875	569.5	12	26	52
B341627	GL8596	S3-10D-01	8.9	1007	1.008	436198	238100	135014	79295	48103	30067	12738	5936	3003	1645	1211	950.2	575.1	12	20	43.4



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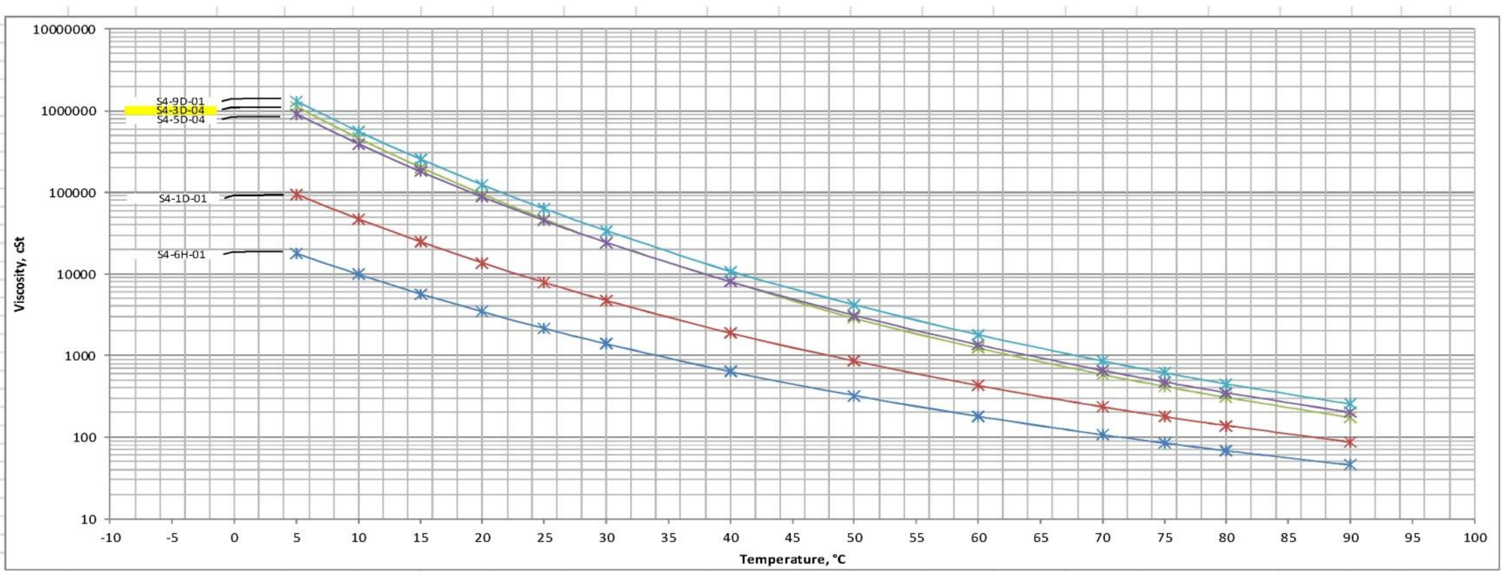
Job #	Sample #	Sample Point	API	Absolute Density @ 15°C kg/m3	Relative Density	Viscosity, cSt (shaded areas denote calculated values)													Pour Point	Flash Point	Water
						5	10	15	20	25	30	40	50	60	70	75	80	90	°C	°C	wt%
B338894	GK3240	S4-6H-01	14.3	969.9	0.9708	17897	9876	5703	3433	2145	1390	633.4	323.6	179.3	107.1	84.76	68.06	45.60	3	-12	4.1
B338894	GK3241	S4-1D-01	12.1	984.2	0.9851	94829	47175	24762	13647	7861	4724	1881	856.1	429.1	235.0	178.9	138.5	86.92	15	4	3.5
B339476	GK3579	S4-3D-04	10.2	997.7	0.9986	1119504	458023	201284	94369	46915	24200	8018	2856	1231	585.9	419.3	306.6	173.9	9	56	33.4
B340457	GL0047	S4-5D-04	10.3	997.3	0.9982	910030	391264	179587	87465	44957	24269	8056	3105	1357	658.7	475.6	350.7	200.6	9	>100	42.9
B341322	GL6305	S4-9D-01	8.7	1008	1.009	1308356	558571	254489	122999	62728	33930	10780	4199	1792	857.9	614.5	449.4	254.2	12	72	36.8



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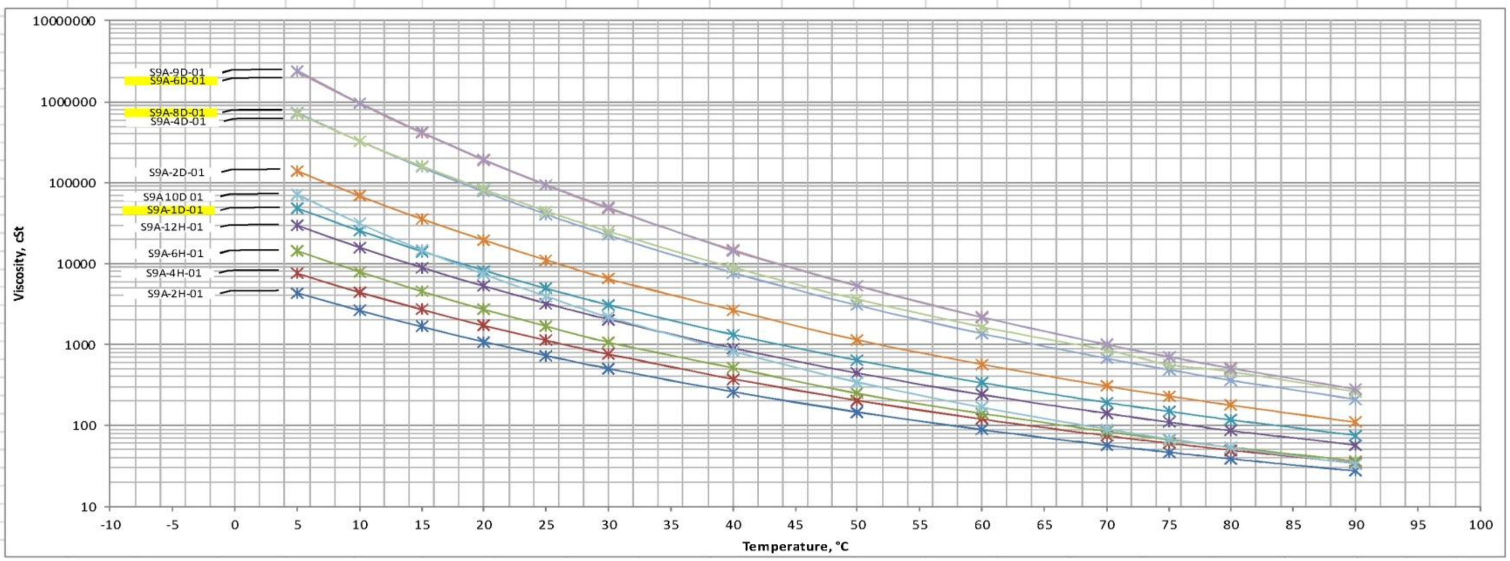
Job #	Sample #	Sample Point	API	Absolute Density @ 15°C kg/m3	Relative Density	Viscosity, cSt (shaded areas denote calculated values) 5	10	15	20	25	30	40	50	60	70	75	80	90	Pour Point °C	Flash Point °C	Water wt%
B339476	GK3570	S9A-2H-01	16.5	954.9	0.9558	4352	2638.4	1661.2	1082.5	727.8	503.3	259.9	146.2	88.52	56.97	46.63	38.62	27.35	-15	<-35	1.6
B339476	GK3573	S9A-4H-01	15.8	959.7	0.9606	7545	4429	2706	1715	1124	759.3	375.2	203.7	119.4	74.76	60.43	49.47	34.30	-9	<-35	1.4
B339476	GK3576	S9A-6H-01	14.9	965.8	0.9667	14445	7891	4521	2705	1683	1064.0	513.6	248.1	140.3	84.17	66.80	53.79	36.25	-21	<-22	2.5
B340447	GK9996	S9A-12H-01	13.8	973.3	0.9742	29470	15846	8933	5257	3217	2040	901.5	444.2	239.7	140.7	109.4	85.86	57.48	-6	-3	5.1
B340447	GL0005	S9A-1D-01	12.7	980.4	0.9813	48169	25475	14133	8189	4936	3085	1326.8	637.4	336.20	191.6	149	116.9	75.57	-3	15	8.5
B340457	GL0044	S9A-2D-01	11.3	989.7	0.9906	139303	68581	35626	19433	11081	6471	2664	1133.0	566.9	305.5	230.78	177.37	109.76	-6	32	11.4
B340457	GL0057	S9A-4D-01	10.5	995.9	0.9968	732684	325804	154077	77057	40551	22353	7685	3046	1360	673.3	488.3	360.7	209.9	0	70	39.6
B341322	GL6302	S9A-6D-01	9.9	999.7	1.0010	2352536	949342	411114	189800	92871	47911	14673	5280	2175	1003.0	708.5	509.8	281.4	12	26	40.2
B342051	GM1610	S9A-8D-01	9.6	1002.0	1.0030	706335	326380	159600	82177	44353	24991	8900	3620	1648	853.8	563.9	462.5	260.9	9	73	36.1
B343405	GM9752	S9A-9D-01	10.4	996.5	0.9974	2407676	967975	417801	192325	93863	48920	14410	5342	2173	1001	705.2	508.0	279.9	24	71	24.6
B343410	GM9767	S9A 10D 01	10.4	996.5	0.9974	71113	31084	14634	7362	3931	2188	826	341.7	167.4	90.22	68.49	53.02	33.46	21	>100	35.9



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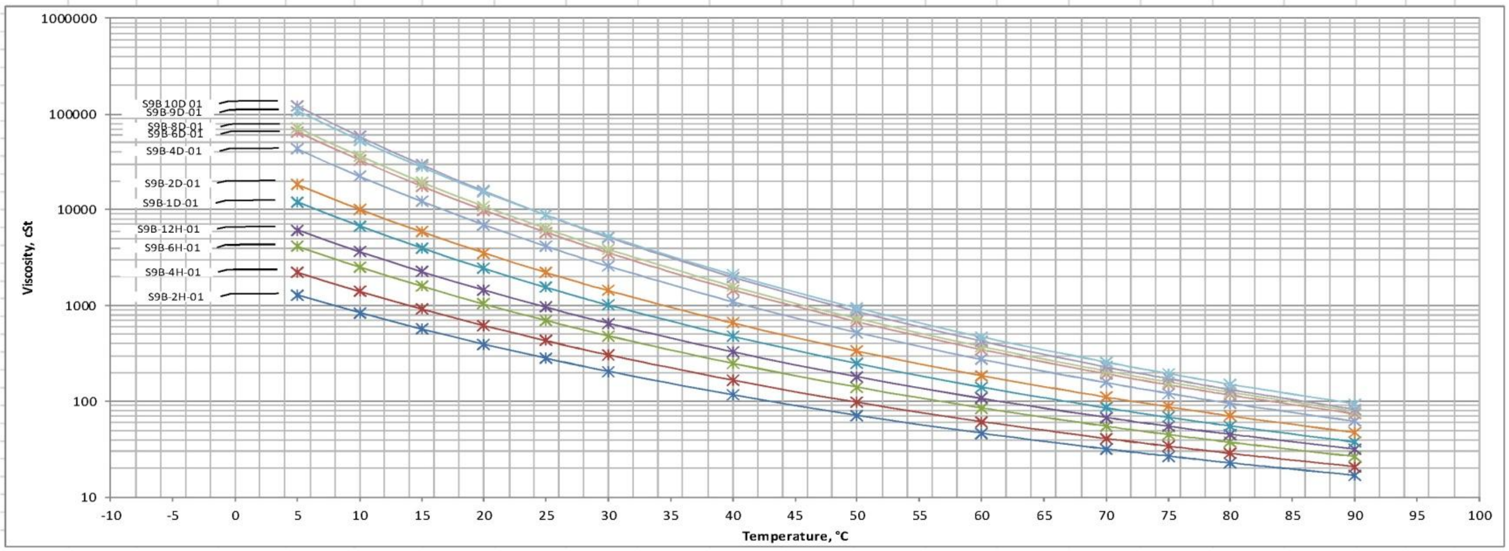
Job #	Sample #	Sample Point	API	Absolute Density @ 15°C kg/m3	Relative Density	Viscosity, cSt (shaded areas denote calculated values) 5	10	15	20	25	30	40	50	60	70	75	80	90	Pour Point °C	Flash Point °C	Water wt%
B339476	GK3571	S9B-2H-01	19.0	939.4	0.9402	1290	842.6	568.2	394.5	281.2	205.5	116.5	71.4	46.37	31.74	26.70	22.68	16.82	-30	<-35	1.4
B339476	GK3574	S9B-4H-01	17.9	946.1	0.9470	2220	1400	914.6	616.5	427.7	304.7	165.5	97.5	61.35	40.83	33.93	28.50	20.70	-21	<-35	1.2
B339476	GK3577	S9B-6H-01	16.6	954.8	0.9557	4151	2518	1586	1034.0	695.6	481.5	248.9	140.3	85.07	54.84	44.92	37.23	26.40	-15	<-20	2
B340447	GK9997	S9B-12H-01	16.0	958.7	0.9596	6140	3649	2255	1445	956.0	651.6	327.5	180.2	106.9	67.73	54.82	45.22	31.58	-9	<-15	0.8
B340447	GL0006	S9B-1D-01	15.5	961.8	0.9627	12090	6788	3985	2436	1545	1013	475.9	247.5	140.16	85.27	68.01	55.08	37.43	-6	-27	0.6
B340457	GL0045	S9B-2D-01	14.3	969.7	0.9706	18340	10137	5862	3532	2210	1430	655.4	333.4	185.0	110.4	87.41	70.16	46.98	-9	24	1.6
B340457	GL0058	S9B-4D-01	13.4	975.6	0.9765	42904	22287	12179	6968	4156	2575	1094	521.3	273.8	156.3	120.9	94.9	61.7	-6	25	1.4
B341322	GL6303	S9B-6D-01	12.9	979.2	0.9801	65127	33065	17687	9921	5809	3538	1456	675.6	346.5	193.4	148.4	115.9	73.78	6	5	1.1
B342051	GM1611	S9B-8D-01	12.7	980.3	0.9812	71985	36457	19454	10885	6358	3863	1582	730.7	373.1	207.2	159.1	123.7	78.52	9	34	0.8
B343405	GM9753	S9B-9D-01	12.5	982.0	0.9829	121634	58121	29440	15720	8806	5153	1980	867.8	424.8	227.7	172.8	132.2	82.10	15	34	2.2
B343410	GM9769	S9B 10D 01	13.5	975.2	0.9761	107913	53482	27968	15357	8815	5268	2095	942.6	470.4	256.1	194.7	150.2	93.84	12	35	1.9



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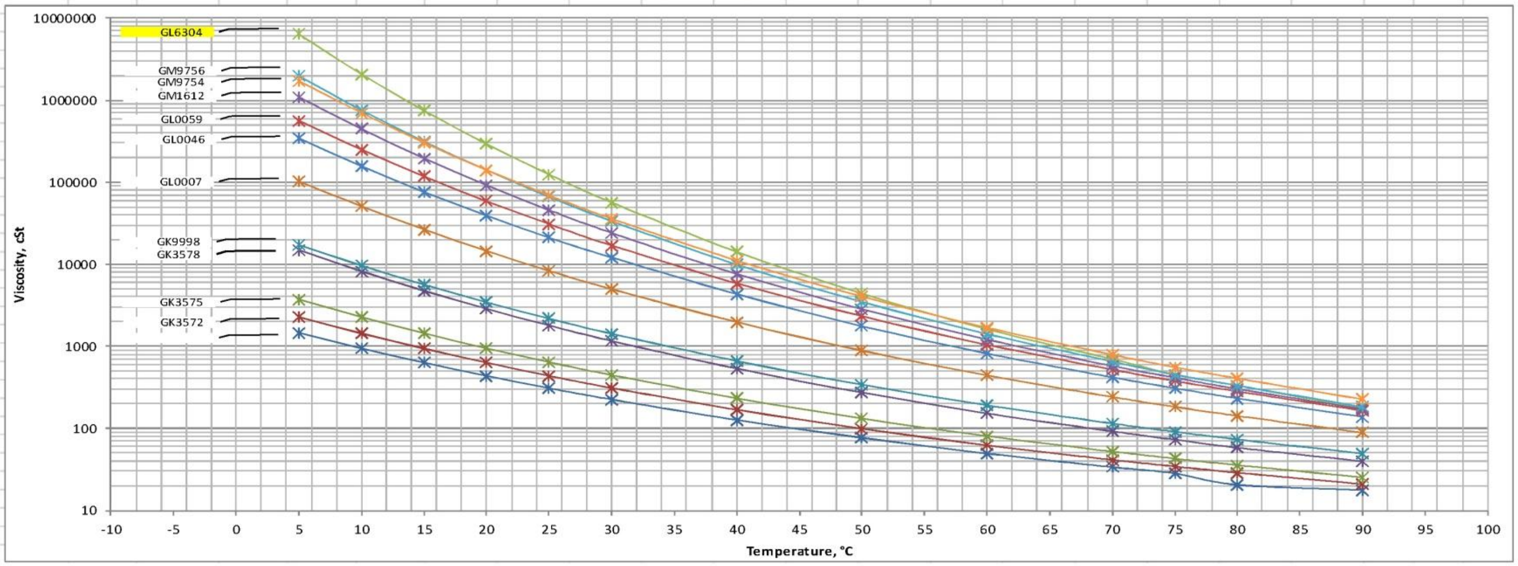
Job #	Sample #	Sample Point	API	Absolute Density @ 15°C kg/m3	Relative Density	Viscosity, cSt (shaded areas denote calculated values) 5	10	15	20	25	30	40	50	60	70	75	80	90	Pour Point °C	Flash Point °C	Water wt%
B339476	GK3572	S9C-2H-01	18.7	941.5	0.9423	1457	944.7	632.7	436.5	309.3	224.7	126.4	76.8	49.34	33.71	28.24	20.48	17.67	-21	<-35	1.2
B339476	GK3575	S9C-4H-01	17.9	946.2	0.9471	2279	1435	935.8	629.9	436.4	310.4	168.4	98.9	62.15	41.31	34.30	28.80	20.90	-18	<-35	1
B339476	GK3578	S9C-5H-01	16.9	952.4	0.9533	3731	2278	1443	946.4	640.0	445.0	232.1	131.8	80.41	52.12	42.79	35.54	25.31	-18	<-35	1.8
B340447	GK9998	S9C-12H-01	15.3	963.2	0.9641	14881	8210	4744	2859	1790	1160	533.8	272.9	152.4	92.02	72.71	58.03	39.63		-10	1.5
B340447	GL0007	S9C-1D-01	12.1	984.4	0.9853	17189	9645	5653	3446	2178	1422	662	340.6	190.8	114.76	90.71	73.27	49.19	-3	-10	1.7
B340457	GL0046	S9C-2D-01	12.3	983.4	0.9843	102728	50758	26479	14511	8317	4965	1972	886.9	442.8	241.4	183.4	141.7	88.62	3	31	2.3
B340457	GL0059	S9C-4D-01	10.9	992.5	0.9934	341675	156234	75896	38950	21012	12078	4318	1760.0	816.8	418.3	308.6	231.9	138.6	0	23	7.3
B341322	GL6304	S9C-6D-01	10.4	996.3	0.9972	564933	249604	117498	58584	30776	16954	5837	2322.9	1044	520.1	378.2	282.3	164.7	9	73	9.7
B342051	GM1612	S9C-8D-01	10.0	998.9	0.9998	6344773	2068867	743871	291988	124022	56559	14171	4382.8	1612	697.1	450.8	332.8	172.9	12	75	19.4
B343405	GM9754	S9C-9D-01	10.2	997.7	0.9986	1085349	444814	195792	91931	45767	24027	7622	2839.5	1210	575.2	415.1	301.5	171.6	21	70	
B343405	GM9756	S9C-9D-02	10.8	993.7	0.9946	1961612	753302	312862	139462	66274	33374	9862	3469.6	1411	652.2	451.2	331.4	182.5	15	>100	42.7
B343410	GM9771	S9C-10D-01	10.3	996.8	0.9977	1718368	695755	302527	140321	69013	35798	11092	4040.4	1685	789.6	555.4	406.1	226.0	21	>100	22.3



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Appendix C: Analysis Data for Tank Dispersant Tests

Witt O'Brien's, Polaris Applied Sciences, and
Western Canada Marine Response Corporation

Oil Used for Dispersant Test		DISP_1	DATE:	22-May-13	
	SD-6HR		Air Temp:		
Full	980.12		Winds:	5 mph	(Low flow)
Empty	109.02	Total Oil Used	Water Temp.	18 C	
Oil	871.1	871.1	Salinity	35 ppt	
			Waves (cm)	5-10cm	chop

	Approx Intervals (min)		
Oil on Water	0	*Comments:*	Even oil distribution
Water Sample 1	20		1m below surface
Disp Applied	23		1:20; Wave & wind applied after dispersant
Water Sample 2	43		1m below surface
Surface oil collected	50		

Oil Recovered after Dispersant Application (grams)

4Pads +1Dry	643	*Observations:*	Small, mm-size droplets visible; entrained

<u>Tare weights</u>

4 wet sorbent pads*	180	
1 dry pad	41	Total Oil Recovered
		422
		Not on Sorbents 52%

*Single sorbent pad (wet) average wt = 45g
*Single sorbent pad (dry) average wt = 41g
*Single Ziplock average weight = 12.1 g

Oil Used for Dispersant Test		DISP_2	DATE:		22-May-13	
	SD-1D		Air Temp:			
Full	1029.12		Winds:	5 mph		(Low flow)
Empty	134.35	Total Oil Used	Water Temp.	18 C		
Oil	894.77	894.77	Salinity	35 ppt		
			Waves (cm)	5-10cm		chop

	Approx Intervals (min)		
Oil on Water	0	*Comments:*	Even oil distribution
Water Sample 1	20		1m below surface
Disp Applied	23		1:20; Wave & wind applied after dispersant
Water Sample 2	43		1m below surface
Surface oil collected	50		

Oil Recovered after Dispersant Application (grams)

6Pads +1Wet	1243.68	*Observations:*	cm-size oil drops formed, re-surfacing
			not efficient
			disperant tank testing of more weathered oil cancelled

Tare weights

7 wet sorbent pads*	315	
		Total Oil Recovered
		928.68
		Not on Sorbents -4%

*Single sorbent pad (wet) average wt = 45g
*Single sorbent pad (dry) average wt = 41g
*Single Ziplock average weight = 12.1 g

Appendix D: Analysis Data for Tank ISB Test

Witt O'Brien's, Polaris Applied Sciences, and
Western Canada Marine Response Corporation

Oil Used for Burn			ISB 1	DATE:	23-May-13	
	S4-6H-02	S4-6H-03		Air Temp:	17 C	
Full	980.48	993.6		Winds:	1-3 mph	(Occasional gusts to 7 mph)
Empty	124.91	114.25	Total Oil Used	Water Temp.	16 C	
Oil	855.57	879.35	1734.92	Freshwater Tank		

	TIME		
Oil on Water	0750	*Comments:*	Even oil distribution
Diesel Starter Added	0753		100ml diesel
Begin Diesel Burn	0755		
Begin Dilbit Burn	0757		Black smoke
End Burn	0759		Sudden extinguished; gust?

Oil Recovered after Burn (grams)			
Liter Bottle & Burn Residue	149.21	*Observations:*	Sticky and cohesive residue; some almost brittle
Bag 1 + oiled sorbents	320.56		mm-size residue particulates entrained in freshwater
Bag 2 + oiled sorbents	331.14		

Tare weights		
6 sorbent pads*	270	
1 L empty	60	Total Oil Recovered
2 Ziplock bags*	24.4	446.51

Estimated % Burned 74%

*Single sorbent pad (wet) average wt = 45g
*Single sorbent pad (dry) average wt = 41g
*Single Ziplock average weight = 12.1 g

Oil Used for Burn (grams)			ISB 2	DATE:	23-May-13	
	S4-1D-02	S4-1D-03		Air Temp:	17 C	
Full	1070.78	1042.22		Winds:	0-3 mph	(Occasional gusts to 5 mph)
Empty	163.54	146.67	Total Oil Used	Water Temp.	16 C	
Oil	907.24	895.55	1802.79	Freshwater Tank		

	TIME		
Oil on Water	0851	*Comments:*	
Diesel Starter Added	0852		100ml diesel
Begin Diesel Burn 1	0854		
Begin Diesel Burn 2	0856		
Propane to Dilbit Burn	0857		Limited black smoke, not sustained
Diesel Starter Added	0904		200ml diesel
Begin Diesel Burn 3	0905		
Begin Dilbit Burn			
End Burn	0907		

Oil Recovered after Burn (grams)			
Bag 1 + oiled sorbents	546.17	*Observations:*	Difficult to start ignition
Bag 2 + oiled sorbents	462.54		Thick (approx. 3mm) residue on burn ring wall
Bag 3 + oiled sorbents	198.53		Residue very slightly positively bouyant on freshwater

Tare weights		
7 sorbent pads*	315	
3 Ziplock bags*	36.3	Total Oil Recovered
		855.94

Estimated % Burned 53%

*Single sorbent pad (wet) average wt = 45g
*Single sorbent pad (dry) average wt = 41g
*Single Ziplock average weight = 12.1 g

Oil Used for Burn (grams)			ISB 3		DATE:	23-May-13	
	S4-3D-02	S4-3D-03			Air Temp:	18 C	
Full	1016.81	1025.54			Winds:	3-4 mph	(Occasional gusts to 8 mph)
Empty	170	214.9	Total Oil Used		Water Temp.	16 C	
Oil	846.81	810.64	1657.45		Freshwater Tank		

	TIME		
Oil on Water	1036	*Comments:*	
Diesel Starter Added	1037		100ml diesel used to rinse each bottle (for total 200ml as starter)
Begin Diesel Burn 1	1038		Limited black smoke, not sustained
Propane to Dilbit Burn	1040		Limited black smoke, not sustained
Diesel Starter Added	1046		100 or 200ml added???
Begin Diesel	1046		
End Burn	1047		Diesel burned out; dilbit did not start with diesel restart or direct torch

Oil Recovered after Burn (grams)			
Bag 1 + oiled sorbents	539.54	*Observations:*	Two waterbugs survived in tank ---all burns
Bag 2 + oiled sorbents	878.67		No burn
Bag 3 + oiled sorbents	378.49		
Bag 4+1L bottle+sorbent	493.73		

<u>Tare weights</u>		
5 sorbent pads*	270	
4 Ziplock bags*	48.4	Total Oil Recovered
1 L empty	60	1912.03
		Estimated % Burned -15%

*Single sorbent pad (wet) average wt = 45g
*Single sorbent pad (dry) average wt = 41g
*Single Ziplock average weight = 12.1 g

Appendix E: Substrate Washing Tests

Witt O'Brien's, Polaris Applied Sciences, and
Western Canada Marine Response Corporation

Tile ID	W/D	Days Oil on water	Date Oiled	Hours post-spill	Oiled observations	Thickness Measured (mm)	Agent Applied	Setup Hours	Total Time	Clean observations^	Comments	Conclusion
1D-W-C-24	Wet	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	Corexit 9580	24	48	"<1%, FL/ST"	Oil floating in water	Effective
1D-W-L-24	Wet	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	D-Limonene	24	48	"100%, CT"	No oil in water	Ineffective
1D-W-N-24	Wet	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	None	24	48	"100%, CT"	No oil in water	Ineffective
1D-W-C-48	Wet	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	Corexit 9580	48	72	"<1%, FL/ST"	Oil floating on water	Effective
1D-W-L-48	Wet	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	D-Limonene	48	72	"100%, CT"	No oil in water	Ineffective
1D-W-N-48	Wet	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	None	48	72	"100%, CT"	No oil in water	Ineffective
1D-D-C-24	Dry	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	Corexit 9580	24	48	"3-5%, FL/ST"	Oil floating in water	Effective
1D-D-L-24	Dry	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	D-Limonene	24	48	"100%, CT"	No oil in water	Ineffective
1D-D-N-24	Dry	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	None	24	48	"100%, CT"	No oil in water	Ineffective
1D-D-C-48	Dry	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	Corexit 9580	48	72	"2%, FL/ST"	Oil floating in water	Effective
1D-D-L-48	Dry	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	D-Limonene	48	72	"100%, CT"	No oil in water	Ineffective
1D-D-N-48	Dry	1D	14/May/13	24	"100%, CT"	0.5 - 1.0	None	48	72	"100%, CT"	No oil in water	Ineffective
3D-W-C-24	Wet	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	Corexit 9580	24	94.5	"1%,FL/ST"	Oil on water	Effective
3D-W-L -24	Wet	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	None	24	95	"100%, CT/CV"	No oil in water	Ineffective
3D-W-C-48	Wet	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	Corexit 9580	48	119	1-3% CT FL/ST	Oil on water	Effective
3D-W-N-48	Wet	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	None	48	119	"100%, CT/CV"		Ineffective
3D-W-C-72	Wet	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	Corexit 9580	72	143	"5% CT, 95% ST/FL"	Oil in water	Mostly Effective
3D-W-C-96	Wet	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	Corexit 9580	96	167	"80% ST/CT, 20% ST/FL, "	Oil in water	Marginally effective
3D-D-C-24	Dry	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	Corexit 9580	24	95	"1-3% CT, FL/ST"	Oil on water	Effective
3D-D-N-24	Dry	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	None	24	95	"100%, CT/CV"	No oil on water	Ineffective
3D-D-C-48	Dry	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	Corexit 9580	48	119	"1-3%, FL/ST"	Oil on water	Effective
3D-D-N-48	Dry	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	None	48	119	"100%, CT/CV"	No oil on water	Ineffective
3D-D-C-72	Dry	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	Corexit 9580	72	143	"1-3% CT, 97% ST/FL"	Oil in water"	Mostly effective
3D-D-C-96	Dry	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	Corexit 9580	96	167	"65% CT/ST (black), 35% ST/FL"	Oil in water	"Marginally effective, possibly needs full 30 min soak time"
3D-W-C-120	Wet	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	Corexit 9580	120	191	"85% CT/ST (black), 15% ST (transparent)"	"Previously washed in water only (24h), oil in water, black oil thickness < 0.5 mm"	Removed oil but left black stain

Tile ID	W/D	Days Oil on water	Date Oiled	Hours post-spill	Oiled observations	Thickness Measured (mm)	Agent Applied	Setup Hours	Total Time	Clean observations^	Comments	Conclusion
3D-D-C-120	Dry	3D	16/May/13	71	"100%, CT/CV"	1.0 - 1.1	Corexit 9580	120	191	"70% CT/ST, 30% ST"	"Previously washed in water only (24h), oil in water, black oil thickness < 0.5 mm"	Removed oil but left black stain
5D-W-C-24	Wet	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	Corexit 9580	24	144	"20% CT, 80% ST/FL"	"Oil on water, lower part of tile likely had thicker oil"	Mostly effective
5D-W-N-24	Wet	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	None	24	144	100% CT/CV	"Ineffective, no oil on water"	Ineffective
5D-W-C-48	Wet	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	Corexit 9580	48	168	"90% ST/FL, 5-10% ST/CT"	Oil in water	Effective
5D-W-N-48	Wet	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	None	48	168	100% CT/CV	No oil in water	Ineffective
5D-W-c-72	Wet	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	Corexit 9580	72	192	100% ST/FL	Oil in water	effective
5D-W-C-96	Wet	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	Corexit 9580	96	216			
5D-D-C-24	Dry	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	Corexit 9580	24	144	"15% CT, 85% ST/FL"	"Oil on water, lower part of tile likely had thicker oil"	Mostly Effective
5D-D-N-24	Dry	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	None	24	144	100% CT/CV	No oil on water	Ineffective
5D-D-C-48	Dry	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	Corexit 9580	48	168	"90% ST/FL, 10% CT"	Oil in water	Effective
5D-D-N-48	Dry	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	None	48	168	100% CT/CV	"Ineffective, no oil on water"	Ineffective
5D-D-C-72	Dry	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	Corexit 9580	72	192	100% ST/FL	Oil in water	Effective
5D-D-C-96	Dry	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	Corexit 9580	96	216			
5D-W-C-120	Wet	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	Corexit 9580	120	240		Previously washed in water only (24h)	
5D-D-C-120	Dry	5D	18/May/13	120	"100%, CV"	1.0 - 2.0	Corexit 9580	120	240		Previously washed in water only (24h)	

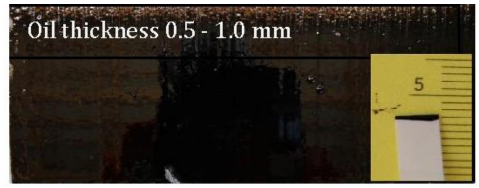
^ Notes: % denotes percent covered with oil: Oil thicknesses are CV>0.1cm but ≤1cm, CT ≤ 0.1cm and >0.01 cm (can be scratched off tile with fingernail, ST is visible oil but ≤0.01cm (not easily scratched off), and FL is film (usually as a translucent sheen)

Table E-1: Substrate Washing Test Results

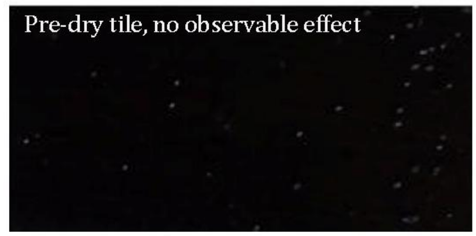
Tiles coated with CLWB in 20 ppt seawater weathering under mild conditions (2 cm – 3 cm waves and 5 mph (2.2 m/s) winds).

May 15, 2013
Granite tiles pre and post oiling.

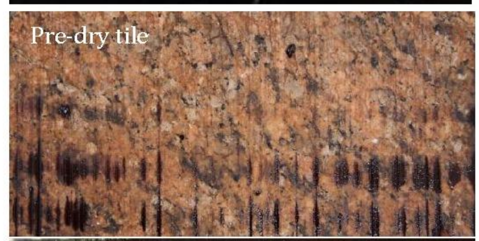
Oil on water 24 hours, oil on tile 24 hours.



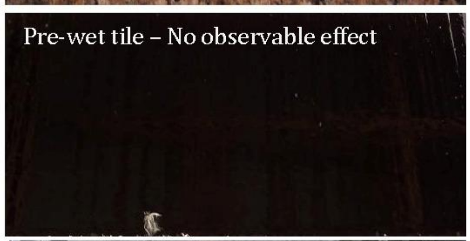
Tiles after 24 hours on land, treated for 20 mins with commercial D-Limonene and washed for 30 sec.



Tiles after 24 hours, treated with Corexit 9580 (20 min) and washed with low pressure for 30 sec.

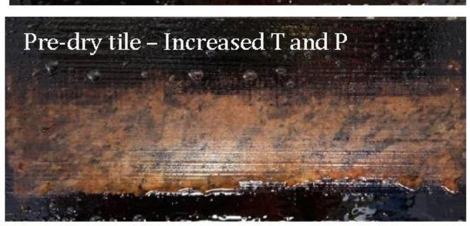


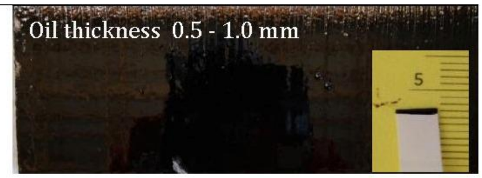
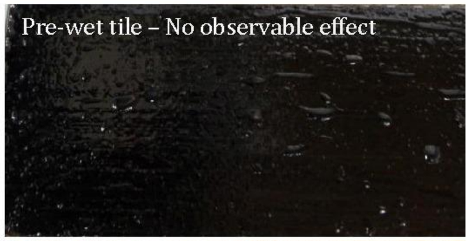
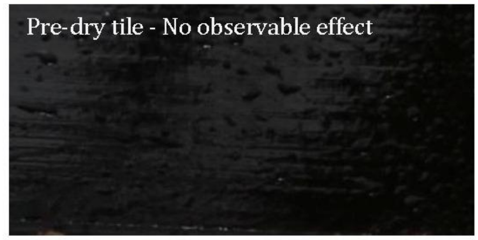
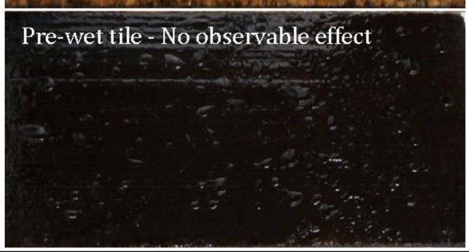
Control with no treatment and washed with low pressure for 30 sec. No observable difference.



Increased pressure by applying wand at 5 cm.

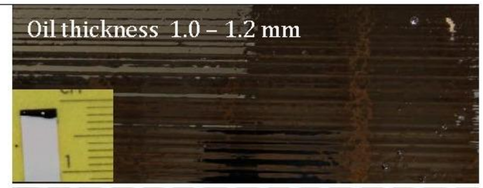
Increased temp from ambient to 190C.



Granite tiles pre and post oiling. Oil on tiles 48 hours.		
Tiles after 48 hours, treated for 20 mins with Commercial D-Limonene and washed with low pressure for 30 sec.		
Pre-wetted and dry tiles after 48 hours, treated with Corexit 9580 (20 min) and washed with low pressure for 30 sec.		
Control with no treatment and washed with low pressure for 30 sec. No observable difference.		

Granite tiles pre and post oiling.

Oil on water 72 hours.

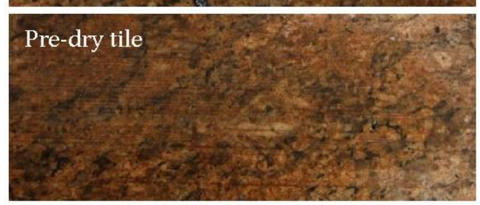


Oil 24 hours on tile. Not treated and washed for 30 sec.

Oil on tiles 24 hours, treated with Corexit 9580 (20 min) and washed for 30 sec.

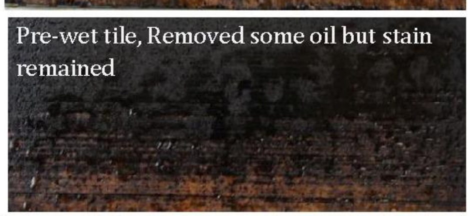
Oil on tiles 48 hours, treated with Corexit 9580 (20 min) and washed for 30 sec.

Oil on tiles 72 hours, treated with Corexit 9580 (20 min) and washed for 30 sec.

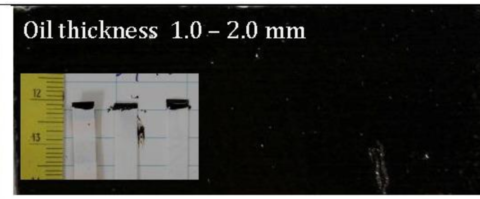
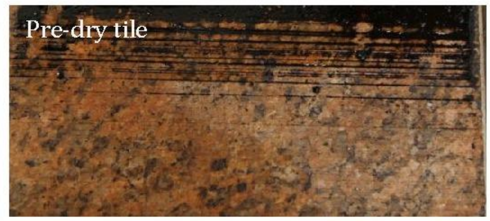


Oil on tiles 96 hours, treated with Corexit 9580 (20 min) and washed for 30 sec.

Oil on tiles 120 hours, treated with Corexit 9580 (20 min) and washed for 30 sec.



Oil on tiles 144 hours, treated with Corexit 9580 (20 min) and washed for 30 sec.

Granite tiles pre and post oiling. Oil on water 96 hours.		
Oil 24 hours on tile. Not treated and washed for 30 sec.		
Oil on tiles 24 hours, treated with Corexit 9580 (20 min) and washed for 30 sec.		
Oil on tiles 48 hours, treated with Corexit 9580 (20 min) and washed for 30 sec.		
Oil on tiles 72 hours (shade), treated with Corexit 9580 (20 min) and washed for 30 sec.		
Oil on tiles 96 hours, treated with Corexit 9580 (20 min) and washed for 30 sec.		
Oil on tiles 96 hours (partial sun), treated with Corexit 9580 (20 min) and washed for 30 sec.		

Oil on tiles 96 hours (partial sun), treated with Corexit 9580 (20 min) and washed for 30 sec.		
96 hours full sun, treated with Corexit 9580, washed after 20 mins.		

Appendix F: Oil Chemistry Data

Witt O'Brien's, Polaris Applied Sciences, and
Western Canada Marine Response Corporation

Introduction

This appendix section presents the chemistry data (light ends in weight % according to ASTM D5580) and poly aromatic hydrocarbons (PAHs) of Access Western Blend (AWB) and Cold Lake Winter Blend (CLWB) as they weather under three turbulence conditions:

- Static Conditions: One tank with no agitation induced. Wind exposure was minimized as far as was practical.
- Mild Agitation: One tank with low wind and wave conditions (e.g. 2 cm – 4 cm waves and 5 mph (2.2 m/s) winds, which were induced by simple mechanical means (intrinsically safe fans and paddles mechanism)).
- Moderate Agitation: One tank with conditions similar to Tank 2 but with a larger induced wind and wave agitation (e.g. 5-7 cm waves and 10 mph (4.5 m/s) winds).

COMPONENT	0 Hours (WT%)	12 Hours (WT%)	I Day (WT%)	2 Days (WT%)	2 Days (WT%)	8 Days (WT%)	10 Days (WT%)	10 Days (WT%)	10 Days (WT%)
Methane	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ethane	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propane	0.03	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Isobutane	0.06	0.02	0.01	0.01	0.01	<0.01	0.01	<0.01	<0.01
n-Butane	0.43	0.10	0.03	0.05	0.06	0.01	0.02	0.02	0.01
Isopentane	3.15	1.13	0.31	0.59	0.65	0.21	0.19	0.09	0.07
n-Pentane	3.35	0.90	0.23	0.41	0.45	0.09	0.08	0.05	0.05
Hexanes (C6)	3.76	1.46	0.40	0.76	0.75	0.26	0.22	0.09	0.13
Heptanes (C7)	2.02	1.03	0.31	0.59	0.51	0.24	0.21	0.09	0.14
Octanes (C8)	1.38	0.88	0.27	0.53	0.44	0.25	0.22	0.09	0.14
Nonanes (C9)	0.92	0.71	0.21	0.41	0.34	0.21	0.20	0.07	0.12
Decanes (C10)	0.79	0.72	0.22	0.45	0.38	0.26	0.24	0.09	0.16
Undecanes (C11)	0.74	0.75	0.24	0.52	0.46	0.36	0.35	0.16	0.22
Dodecanes (C12)	0.72	0.78	0.25	0.55	0.53	0.48	0.48	0.26	0.29
Tridecanes (C13)	0.88	1.00	0.32	0.71	0.72	0.73	0.77	0.49	0.43
Tetradecanes (C14)	0.98	1.13	0.36	0.81	0.86	0.93	1.02	0.74	0.53
Pentadecanes (C15)	1.07	1.25	0.38	0.90	0.96	1.08	1.23	0.98	0.61
Hexadecanes (C16)	1.28	1.49	0.45	1.06	1.18	1.34	1.54	1.30	0.75
Heptadecanes (C17)	1.37	1.60	0.45	1.11	1.21	1.44	1.68	1.48	0.81
Octadecanes (C18)	1.46	1.71	0.50	1.16	1.37	1.49	1.79	1.59	0.83
Nonadecanes (C19)	1.15	1.36	0.37	0.93	1.06	1.10	1.40	1.25	0.66
Eicosanes (C20)	1.40	1.67	0.45	1.11	1.28	1.53	1.57	1.40	0.72
Heneicosanes (C21)	1.36	1.63	0.42	1.07	1.24	1.38	1.76	1.53	0.77
Docosanes (C22)	1.29	1.56	0.41	1.02	1.17	1.30	1.46	1.33	0.66
Triacosanes (C23)	1.22	1.45	0.38	0.96	1.08	1.20	1.41	1.30	0.65
Tetracosanes (C24)	1.22	1.49	0.37	0.95	1.07	1.21	1.39	1.27	0.64
Pentacosanes (C25)	1.20	1.45	0.35	0.93	1.03	1.15	1.30	1.24	0.60
Hexacosanes (C26)	1.05	1.28	0.30	0.81	0.90	1.01	1.13	1.06	0.51
Heptacosanes (C27)	1.06	1.33	0.29	0.84	0.91	1.02	1.09	1.01	0.47
Octacosanes (C28)	1.10	1.37	0.29	0.87	0.93	1.05	1.03	0.93	0.42
Nonacosanes (C29)	1.07	1.35	0.27	0.84	0.91	1.01	1.12	1.00	0.43
Methylcyclopentane	0.72	0.35	0.11	0.20	0.18	0.09	0.09	0.05	0.05
Benzene	0.27	0.11	0.03	0.05	0.04	0.01	0.01	<0.01	<0.01
Cyclohexane	0.61	0.33	0.11	0.21	0.19	0.10	0.09	0.03	0.04
Methylcyclohexane	0.89	0.54	0.17	0.34	0.30	0.17	0.15	0.05	0.08
Toluene	0.48	0.25	0.08	0.14	0.06	0.04	0.02	0.01	0.01
Ethylbenzene	0.06	0.04	0.01	0.03	0.02	0.01	0.01	<0.01	<0.01
Meta and para-xylene	0.26	0.19	0.07	0.14	0.11	0.05	0.03	0.01	0.02
Ortho-xylene	0.08	0.06	0.02	0.04	0.03	0.02	0.01	<0.01	0.01
Trimethylbenzene	0.08	0.08	0.03	0.07	0.06	0.04	0.03	0.01	0.02

Table F-1: Light ends (C1-C30) of AWB weathering under static conditions

COMPONENT	0 Hours (WT%)	12 Hours (WT%)	I Day (WT%)	8 Days (WT%)
Methane	<0.01	<0.01	<0.01	<0.01
Ethane	<0.01	<0.01	<0.01	<0.01
Propane	0.03	0.01	<0.01	<0.01
Isobutane	0.06	0.02	0.01	<0.01
n-Butane	0.43	0.12	0.03	0.01
Isopentane	3.15	1.07	0.31	0.16
n-Pentane	3.35	0.95	0.23	0.08
Hexanes (C6)	3.76	1.29	0.72	0.18
Heptanes (C7)	2.02	0.81	0.47	0.15
Octanes (C8)	1.38	0.63	0.38	0.15
Nonanes (C9)	0.92	0.47	0.29	0.12
Decanes (C10)	0.79	0.45	0.30	0.16
Undecanes (C11)	0.74	0.46	0.34	0.26
Dodecanes (C12)	0.72	0.46	0.36	0.38
Tridecanes (C13)	0.88	0.57	0.46	0.63
Tetradecanes (C14)	0.98	0.63	0.52	0.86
Pentadecanes (C15)	1.07	0.69	0.57	1.06
Hexadecanes (C16)	1.28	0.81	0.68	1.36
Heptadecanes (C17)	1.37	0.85	0.71	1.49
Octadecanes (C18)	1.46	0.89	0.74	1.59
Nonadecanes (C19)	1.15	0.70	0.57	1.16
Eicosanes (C20)	1.40	0.85	0.69	1.66
Heneicosanes (C21)	1.36	0.82	0.66	1.37
Docosanes (C22)	1.29	0.77	0.65	1.54
Triacosanes (C23)	1.22	0.72	0.61	1.32
Tetracosanes (C24)	1.22	0.72	0.61	1.32
Pentacosanes (C25)	1.20	0.70	0.59	1.28
Hexacosanes (C26)	1.05	0.62	0.53	1.14
Heptacosanes (C27)	1.06	0.62	0.53	1.15
Octacosanes (C28)	1.10	0.64	0.54	1.20
Nonacosanes (C29)	1.07	0.62	0.53	1.17
Methylcyclopentane	0.72	0.29	0.16	0.06
Benzene	0.27	0.09	0.04	0.01
Cyclohexane	0.61	0.26	0.17	0.06
Methylcyclohexane	0.89	0.41	0.25	0.10
Toluene	0.48	0.20	0.11	0.02
Ethylbenzene	0.06	0.03	0.02	0.01
Meta and para-xylene	0.26	0.14	0.10	0.03
Ortho-xylene	0.08	0.04	0.03	0.01
Trimethylbenzene	0.08	0.05	0.04	0.02

Table F-2: Light ends (C1-C30) of AWB weathering under mild agitation conditions

COMPONENT	0 Hours (WT%)	12 Hours (WT%)	I Day (WT%)	2 Days (WT%)	8 Days (WT%)
Methane	<0.01	<0.01	<0.01	<0.01	<0.01
Ethane	<0.01	<0.01	<0.01	<0.01	<0.01
Propane	0.03	<0.01	<0.01	<0.01	<0.01
Isobutane	0.06	0.01	<0.01	0.01	<0.01
n-Butane	0.43	0.03	0.02	0.03	0.01
Isopentane	3.15	0.39	0.21	0.33	0.11
n-Pentane	3.35	0.29	0.15	0.23	0.08
Hexanes (C6)	3.76	0.50	0.25	0.41	0.20
Heptanes (C7)	2.02	0.38	0.19	0.30	0.18
Octanes (C8)	1.38	0.35	0.17	0.27	0.18
Nonanes (C9)	0.92	0.30	0.14	0.21	0.16
Decanes (C10)	0.79	0.33	0.16	0.23	0.20
Undecanes (C11)	0.74	0.38	0.19	0.28	0.28
Dodecanes (C12)	0.72	0.43	0.21	0.32	0.35
Tridecanes (C13)	0.88	0.56	0.28	0.46	0.50
Tetradecanes (C14)	0.98	0.65	0.32	0.55	0.62
Pentadecanes (C15)	1.07	0.72	0.35	0.63	0.70
Hexadecanes (C16)	1.28	0.87	0.42	0.79	0.86
Heptadecanes (C17)	1.37	0.93	0.44	0.83	0.92
Octadecanes (C18)	1.46	0.99	0.46	0.96	0.97
Nonadecanes (C19)	1.15	0.80	0.35	0.77	0.70
Eicosanes (C20)	1.40	0.96	0.42	0.93	1.00
Heneicosanes (C21)	1.36	0.96	0.41	0.92	0.83
Docosanes (C22)	1.29	0.90	0.40	0.91	0.94
Triacosanes (C23)	1.22	0.84	0.38	0.82	0.80
Tetracosanes (C24)	1.22	0.86	0.38	0.82	0.80
Pentacosanes (C25)	1.20	0.84	0.37	0.80	0.78
Hexacosanes (C26)	1.05	0.74	0.33	0.72	0.70
Heptacosanes (C27)	1.06	0.77	0.33	0.73	0.70
Octacosanes (C28)	1.10	0.80	0.35	0.76	0.73
Nonacosanes (C29)	1.07	0.79	0.34	0.75	0.71
Methylcyclopentane	0.72	0.14	0.06	0.11	0.06
Benzene	0.27	0.03	0.01	0.01	<0.01
Cyclohexane	0.61	0.13	0.07	0.11	0.06
Methylcyclohexane	0.89	0.21	0.11	0.18	0.11
Toluene	0.48	0.08	0.04	0.05	0.01
Ethylbenzene	0.06	0.02	0.01	0.01	0.01
Meta and para-xylene	0.26	0.07	0.05	0.07	0.04
Ortho-xylene	0.08	0.02	0.01	0.02	0.01
Trimethylbenzene	0.08	0.04	0.02	0.04	0.03

Table F-3: Light ends (C1-C30) of AWB weathering under moderate agitation conditions

COMPONENT	0 Hours (WT%)	12 Hours (WT%)	I Day (WT%)	2 Days (WT%)	4 Days (WT%)	8 Days (WT%)	10 Days (WT%)
Methane	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ethane	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propane	0.02	0.01	0.01	<0.01	<0.01	<0.01	<0.01
Isobutane	0.06	0.02	0.03	0.02	0.01	0.01	0.01
n-Butane	0.33	0.10	0.10	0.06	0.04	0.03	0.02
Isopentane	1.85	0.81	0.81	0.49	0.39	0.28	0.21
n-Pentane	2.05	0.70	0.67	0.37	0.25	0.16	0.11
Hexanes (C6)	2.76	1.26	1.18	0.73	0.58	0.39	0.29
Heptanes (C7)	1.69	0.97	0.88	0.59	0.50	0.36	0.29
Octanes (C8)	1.49	1.04	0.94	0.67	0.61	0.42	0.34
Nonanes (C9)	1.15	0.93	0.84	0.63	0.70	0.44	0.36
Decanes (C10)	1.03	0.94	0.86	0.69	0.69	0.52	0.44
Undecanes (C11)	1.07	1.11	1.02	0.85	0.93	0.75	0.65
Dodecanes (C12)	1.05	1.18	1.10	0.95	1.10	0.94	0.83
Tridecanes (C13)	1.27	1.53	1.43	1.25	1.54	1.39	1.26
Tetradecanes (C14)	1.35	1.71	1.60	1.41	1.80	1.71	1.57
Pentadecanes (C15)	1.37	1.77	1.67	1.46	1.91	1.87	1.74
Hexadecanes (C16)	1.53	2.02	1.90	1.65	2.19	2.21	2.04
Heptadecanes (C17)	1.50	2.02	1.90	1.63	2.18	2.25	2.07
Octadecanes (C18)	1.46	1.99	1.89	1.60	2.12	2.25	2.05
Nonadecanes (C19)	1.12	1.55	1.48	1.25	1.49	1.76	1.60
Eicosanes (C20)	1.31	1.70	1.63	1.43	2.03	2.12	1.91
Heneicosanes (C21)	1.28	1.94	1.88	1.41	1.64	2.06	1.83
Docosanes (C22)	1.19	1.71	1.65	1.27	1.88	1.97	1.75
Triacosanes (C23)	1.10	1.58	1.52	1.13	1.59	1.83	1.64
Tetracosanes (C24)	1.08	1.57	1.55	1.14	1.57	1.82	1.62
Pentacosanes (C25)	1.04	1.53	1.50	1.05	1.48	1.77	1.57
Hexacosanes (C26)	0.92	1.38	1.36	0.94	1.30	1.58	1.40
Heptacosanes (C27)	0.93	1.44	1.43	0.94	1.28	1.60	1.41
Octacosanes (C28)	0.97	1.41	1.42	0.97	1.28	1.55	1.37
Nonacosanes (C29)	0.94	1.60	1.62	0.94	1.18	1.72	1.51
Methylcyclopentane	0.54	0.31	0.29	0.19	0.17	0.12	0.10
Benzene	0.20	0.09	0.07	0.05	0.03	0.02	0.01
Cyclohexane	0.45	0.27	0.25	0.02	0.17	0.11	0.09
Methylcyclohexane	0.70	0.47	0.43	0.31	0.28	0.21	0.17
Toluene	0.40	0.22	0.29	0.13	0.06	0.05	0.04
Ethylbenzene	0.08	0.06	0.05	0.04	0.03	0.02	0.02
Meta and para-xylene	0.34	0.24	0.21	0.15	0.11	0.08	0.06
Ortho-xylene	0.10	0.07	0.07	0.05	0.04	0.04	0.04
Trimethylbenzene	0.13	0.12	0.11	0.09	0.08	0.07	0.06

Table F-4: Light ends (C1-C30) of CLWB weathering under static conditions

COMPONENT	0 Hours (WT%)	12 Hours (WT%)	I Day (WT%)	2 Days (WT%)	4 Days (WT%)	8 Days (WT%)	10 Days (WT%)
Methane	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ethane	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propane	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Isobutane	0.06	0.02	0.02	0.01	<0.01	<0.01	<0.01
n-Butane	0.33	0.09	0.06	0.02	0.01	<0.01	0.01
Isopentane	1.85	0.71	0.54	0.19	0.08	0.02	0.02
n-Pentane	2.05	0.61	0.43	0.12	0.04	0.01	0.01
Hexanes (C6)	2.76	1.06	0.80	0.26	0.10	0.03	0.02
Heptanes (C7)	1.69	0.79	0.63	0.23	0.10	0.04	0.04
Octanes (C8)	1.49	0.86	0.73	0.28	0.13	0.04	0.04
Nonanes (C9)	1.15	0.80	0.71	0.30	0.18	0.05	0.04
Decanes (C10)	1.03	0.85	0.80	0.38	0.22	0.08	0.07
Undecanes (C11)	1.07	1.03	1.02	0.57	0.41	0.16	0.16
Dodecanes (C12)	1.05	1.12	1.16	0.73	0.63	0.29	0.30
Tridecanes (C13)	1.27	1.46	1.55	1.07	1.07	0.56	0.64
Tetradecanes (C14)	1.35	1.62	1.76	1.27	1.42	0.84	1.03
Pentadecanes (C15)	1.37	1.68	1.84	1.36	1.61	1.03	1.34
Hexadecanes (C16)	1.53	1.92	2.12	1.57	1.91	1.27	1.68
Heptadecanes (C17)	1.50	1.89	2.12	1.55	1.93	1.29	1.78
Octadecanes (C18)	1.46	1.88	2.09	1.52	1.89	1.28	1.81
Nonadecanes (C19)	1.12	1.47	1.67	1.18	1.34	0.99	1.41
Eicosanes (C20)	1.31	1.61	1.82	1.37	1.82	1.15	1.69
Heneicosanes (C21)	1.28	1.81	2.07	1.36	1.47	1.12	1.63
Docosanes (C22)	1.19	1.61	1.82	1.23	1.66	1.03	1.55
Triacosanes (C23)	1.10	1.50	1.66	1.07	1.38	0.91	1.44
Tetracosanes (C24)	1.08	1.48	1.70	1.07	1.34	0.92	1.45
Pentacosanes (C25)	1.04	1.45	1.61	0.99	1.28	0.85	1.39
Hexacosanes (C26)	0.92	1.31	1.49	0.89	1.11	0.76	1.26
Heptacosanes (C27)	0.93	1.36	1.53	0.89	1.12	0.76	1.29
Octacosanes (C28)	0.97	1.33	1.52	0.92	1.13	0.74	1.25
Nonacosanes (C29)	0.94	1.51	1.74	0.88	1.07	0.82	1.41
Methylcyclopentane	0.54	0.26	0.21	0.08	0.04	0.02	0.02
Benzene	0.20	0.07	0.05	0.01	0.01	<0.01	<0.01
Cyclohexane	0.45	0.23	0.19	0.07	0.04	0.01	0.01
Methylcyclohexane	0.70	0.39	0.33	0.13	0.06	0.02	0.02
Toluene	0.40	0.18	0.23	0.04	<0.01	<0.01	<0.01
Ethylbenzene	0.08	0.05	0.04	0.02	0.01	<0.01	<0.01
Meta and para-xylene	0.34	0.21	0.17	0.07	0.02	0.01	0.01
Ortho-xylene	0.10	0.07	0.06	0.02	0.01	<0.01	<0.01
Trimethylbenzene	0.13	0.11	0.10	0.05	0.03	0.01	0.01

Table F-5: Light ends (C1-C30) of CLWB weathering under mild agitation conditions

COMPONENT	0 Hours (WT%)	12 Hours (WT%)	I Day (WT%)	2 Days (WT%)	4 Days (WT%)	8 Days (WT%)	10 Days (WT%)
Methane	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ethane	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propane	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Isobutane	0.06	0.01	0.01	<0.01	<0.01	<0.01	<0.01
n-Butane	0.33	0.05	0.04	0.01	0.01	<0.01	0.01
Isopentane	1.85	0.43	0.32	0.09	0.04	0.02	0.02
n-Pentane	2.05	0.35	0.25	0.06	0.03	0.01	0.01
Hexanes (C6)	2.76	0.65	0.47	0.13	0.06	0.02	0.02
Heptanes (C7)	1.69	0.53	0.38	0.12	0.06	0.03	0.03
Octanes (C8)	1.49	0.61	0.45	0.15	0.08	0.03	0.03
Nonanes (C9)	1.15	0.62	0.47	0.16	0.09	0.03	0.03
Decanes (C10)	1.03	0.72	0.57	0.22	0.14	0.05	0.05
Undecanes (C11)	1.07	0.96	0.81	0.35	0.25	0.11	0.09
Dodecanes (C12)	1.05	1.12	1.00	0.47	0.39	0.20	0.14
Tridecanes (C13)	1.27	1.51	1.40	0.71	0.68	0.37	0.26
Tetradecanes (C14)	1.35	1.72	1.63	0.87	0.91	0.52	0.37
Pentadecanes (C15)	1.37	1.80	1.71	0.94	1.04	0.62	0.43
Hexadecanes (C16)	1.53	2.06	1.97	1.08	1.24	0.75	0.51
Heptadecanes (C17)	1.50	2.06	1.96	1.06	1.26	0.76	0.51
Octadecanes (C18)	1.46	2.02	1.93	1.03	1.24	0.75	0.49
Nonadecanes (C19)	1.12	1.59	1.50	0.79	0.89	0.58	0.37
Eicosanes (C20)	1.31	1.72	1.65	0.91	1.22	0.69	0.43
Heneicosanes (C21)	1.28	1.97	1.83	0.87	1.00	0.65	0.40
Docosanes (C22)	1.19	1.72	1.66	0.79	1.14	0.62	0.38
Triacosanes (C23)	1.10	1.57	1.53	0.69	0.96	0.58	0.34
Tetracosanes (C24)	1.08	1.58	1.51	0.68	0.94	0.57	0.34
Pentacosanes (C25)	1.04	1.52	1.48	0.62	0.91	0.55	0.32
Hexacosanes (C26)	0.92	1.36	1.32	0.54	0.81	0.49	0.28
Heptacosanes (C27)	0.93	1.41	1.36	0.53	0.83	0.50	0.28
Octacosanes (C28)	0.97	1.38	1.33	0.54	0.87	0.49	0.27
Nonacosanes (C29)	0.94	1.56	1.50	0.50	0.82	0.54	0.30
Methylcyclopentane	0.54	0.17	0.12	0.04	0.03	0.01	0.01
Benzene	0.20	0.04	0.03	0.01	<0.01	<0.01	<0.01
Cyclohexane	0.45	0.15	0.12	0.04	0.02	0.01	0.01
Methylcyclohexane	0.70	0.27	0.20	0.07	0.03	0.01	0.01
Toluene	0.40	0.12	0.16	0.02	0.01	<0.01	<0.01
Ethylbenzene	0.08	0.04	0.03	0.01	<0.01	<0.01	<0.01
Meta and para-xylene	0.34	0.16	0.12	0.04	0.02	<0.01	<0.01
Ortho-xylene	0.10	0.05	0.04	0.01	0.01	<0.01	<0.01
Trimethylbenzene	0.13	0.09	0.08	0.03	0.02	0.01	0.01

Table F-6: Light ends (C1-C30) of CLWB weathering under moderate agitation conditions

COMPONENT	0 Hours (WT%)	6 Hours (WT%)	I Day (WT%)	5 Days (WT%)
Methane	<0.01	<0.01	<0.01	<0.01
Ethane	<0.01	<0.01	<0.01	<0.01
Propane	0.02	<0.01	<0.01	<0.01
Isobutane	0.06	0.01	<0.01	<0.01
n-Butane	0.33	0.05	0.01	<0.01
Isopentane	1.85	0.38	0.11	0.01
n-Pentane	2.05	0.33	0.08	<0.01
Hexanes (C6)	2.76	0.25	0.18	0.01
Heptanes (C7)	1.69	0.19	0.17	0.02
Octanes (C8)	1.49	0.17	0.22	0.02
Nonanes (C9)	1.15	0.14	0.25	0.02
Decanes (C10)	1.03	0.16	0.33	0.04
Undecanes (C11)	1.07	0.19	0.49	0.10
Dodecanes (C12)	1.05	0.21	0.63	0.19
Tridecanes (C13)	1.27	0.28	0.87	0.38
Tetradecanes (C14)	1.35	0.32	1.00	0.58
Pentadecanes (C15)	1.37	0.35	1.04	0.71
Hexadecanes (C16)	1.53	0.42	1.17	0.88
Heptadecanes (C17)	1.50	0.44	1.16	0.91
Octadecanes (C18)	1.46	0.46	1.12	0.90
Nonadecanes (C19)	1.12	0.35	0.86	0.70
Eicosanes (C20)	1.31	0.42	1.00	0.82
Heneicosanes (C21)	1.28	0.41	0.97	0.81
Docosanes (C22)	1.19	0.40	0.89	0.73
Triacosanes (C23)	1.10	0.38	0.80	0.65
Tetracosanes (C24)	1.08	0.38	0.79	0.65
Pentacosanes (C25)	1.04	0.37	0.75	0.60
Hexacosanes (C26)	0.92	0.33	0.66	0.55
Heptacosanes (C27)	0.93	0.33	0.67	0.55
Octacosanes (C28)	0.97	0.35	0.69	0.57
Nonacosanes (C29)	0.94	0.34	0.67	0.55
Methylcyclopentane	0.54	0.15	0.06	0.01
Benzene	0.20	0.04	0.01	<0.01
Cyclohexane	0.45	0.14	0.05	<0.01
Methylcyclohexane	0.70	0.25	0.10	0.01
Toluene	0.40	0.13	0.04	<0.01
Ethylbenzene	0.08	0.04	0.01	<0.01
Meta and para-xylene	0.34	0.16	0.06	<0.01
Ortho-xylene	0.10	0.05	0.02	<0.01
Trimethylbenzene	0.13	0.09	0.05	0.01

Table F-7: Light ends (C1-C30) of CLWB used for dispersant effectiveness tests (weathering under mild agitation conditions)

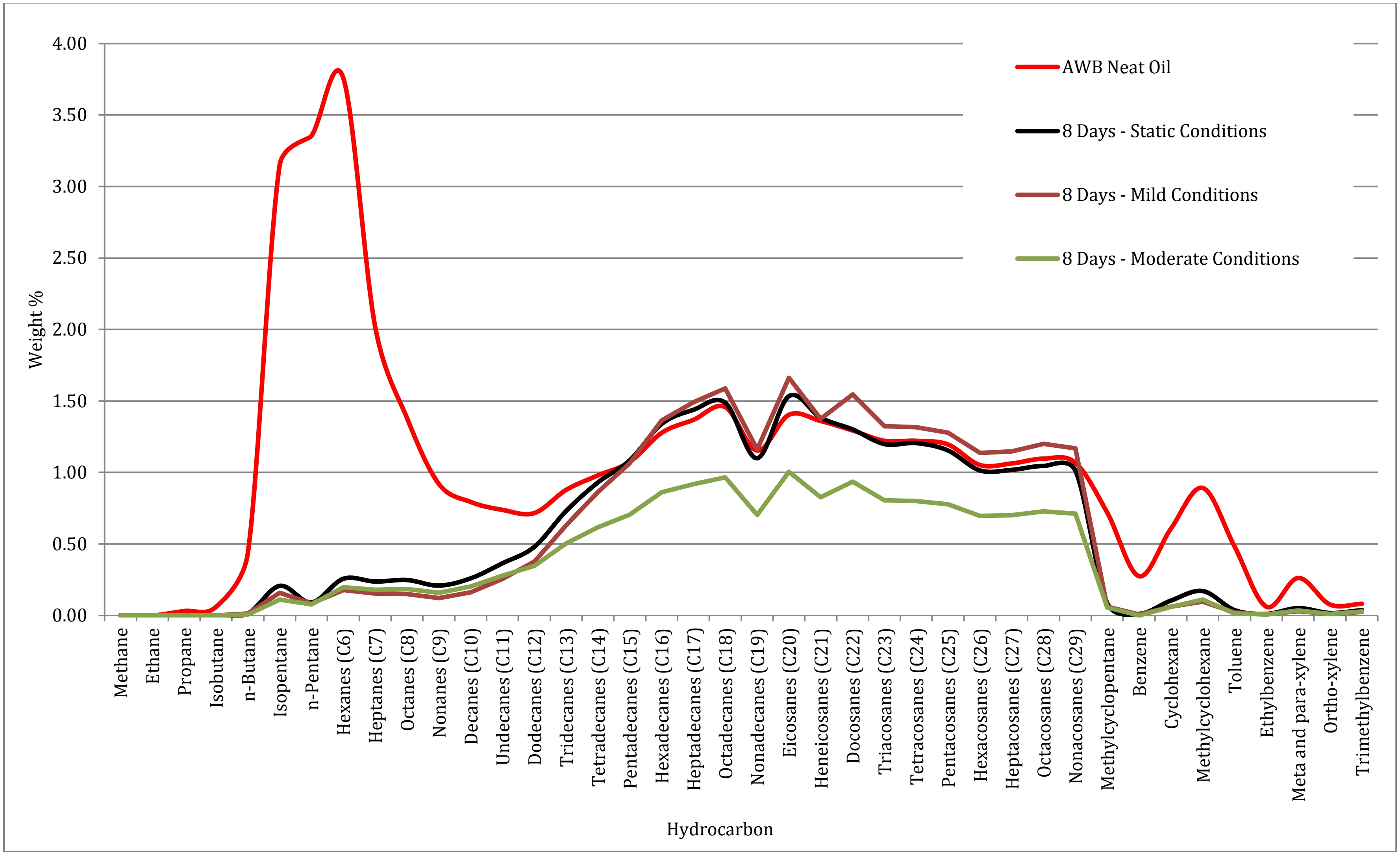


Figure F-1: AWB Light ends (C1 - C30)

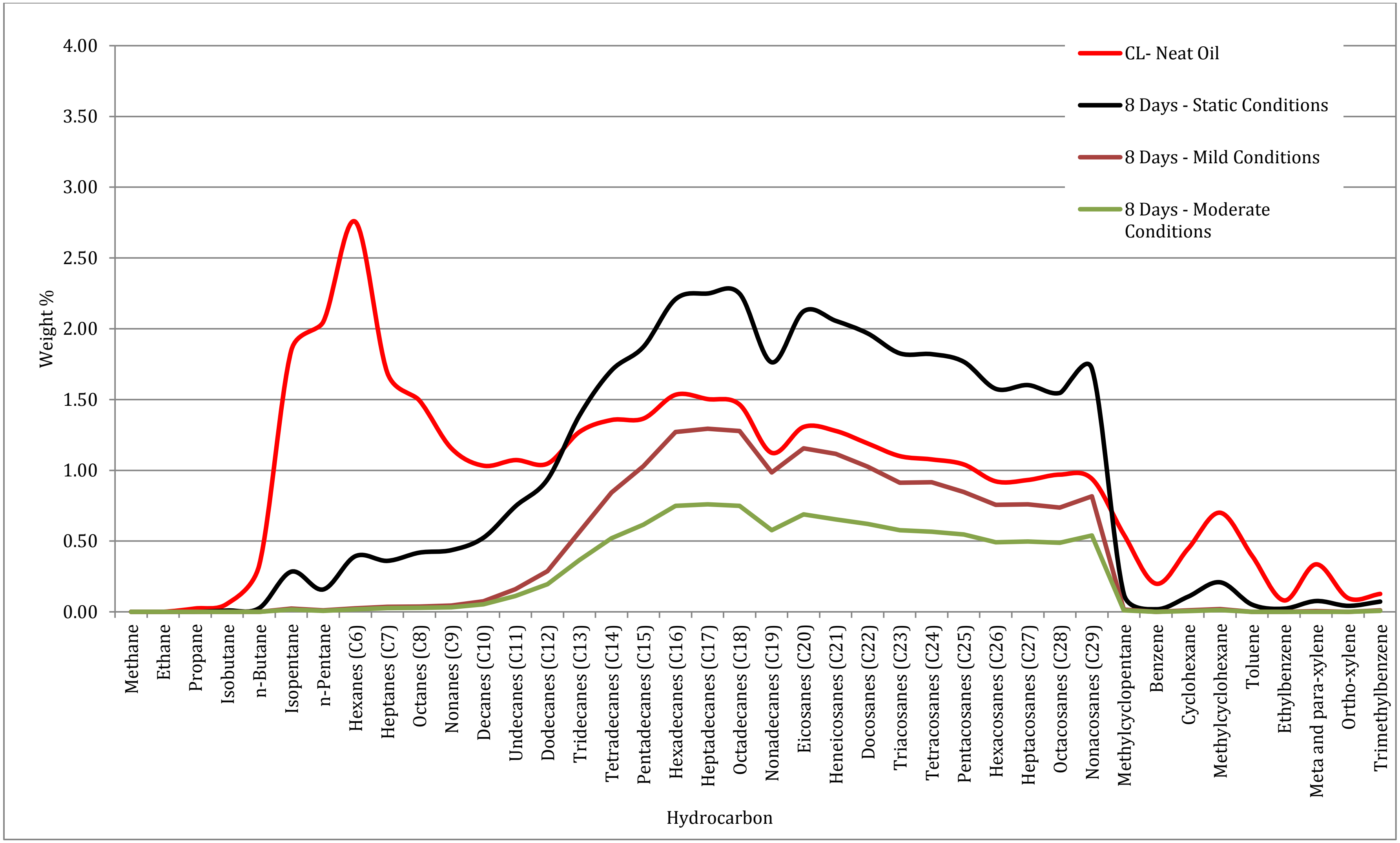


Figure F-2: CLWB Light ends (C1 - C30)

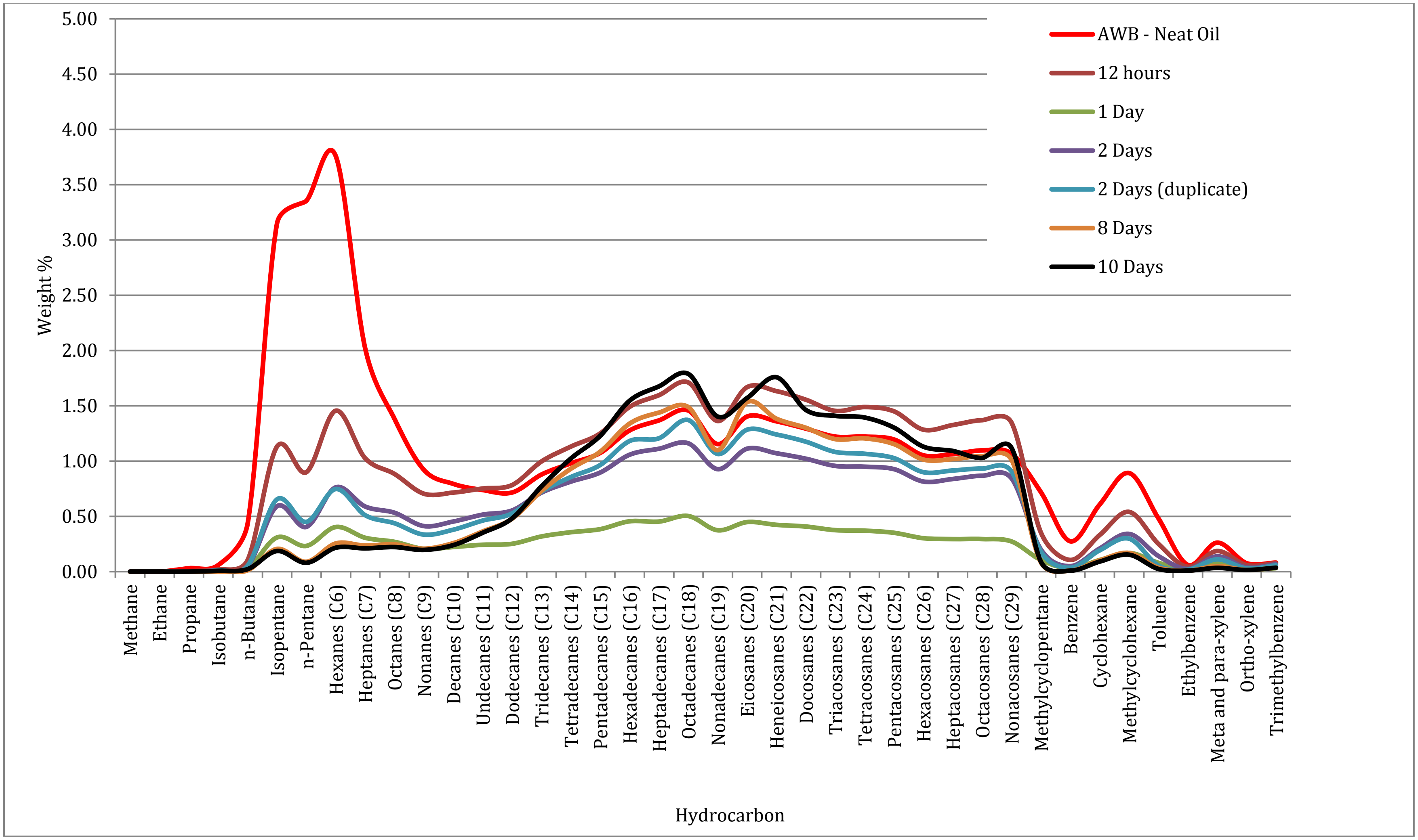


Figure F-3: AWB Light ends (C1 - C30) - Static conditions

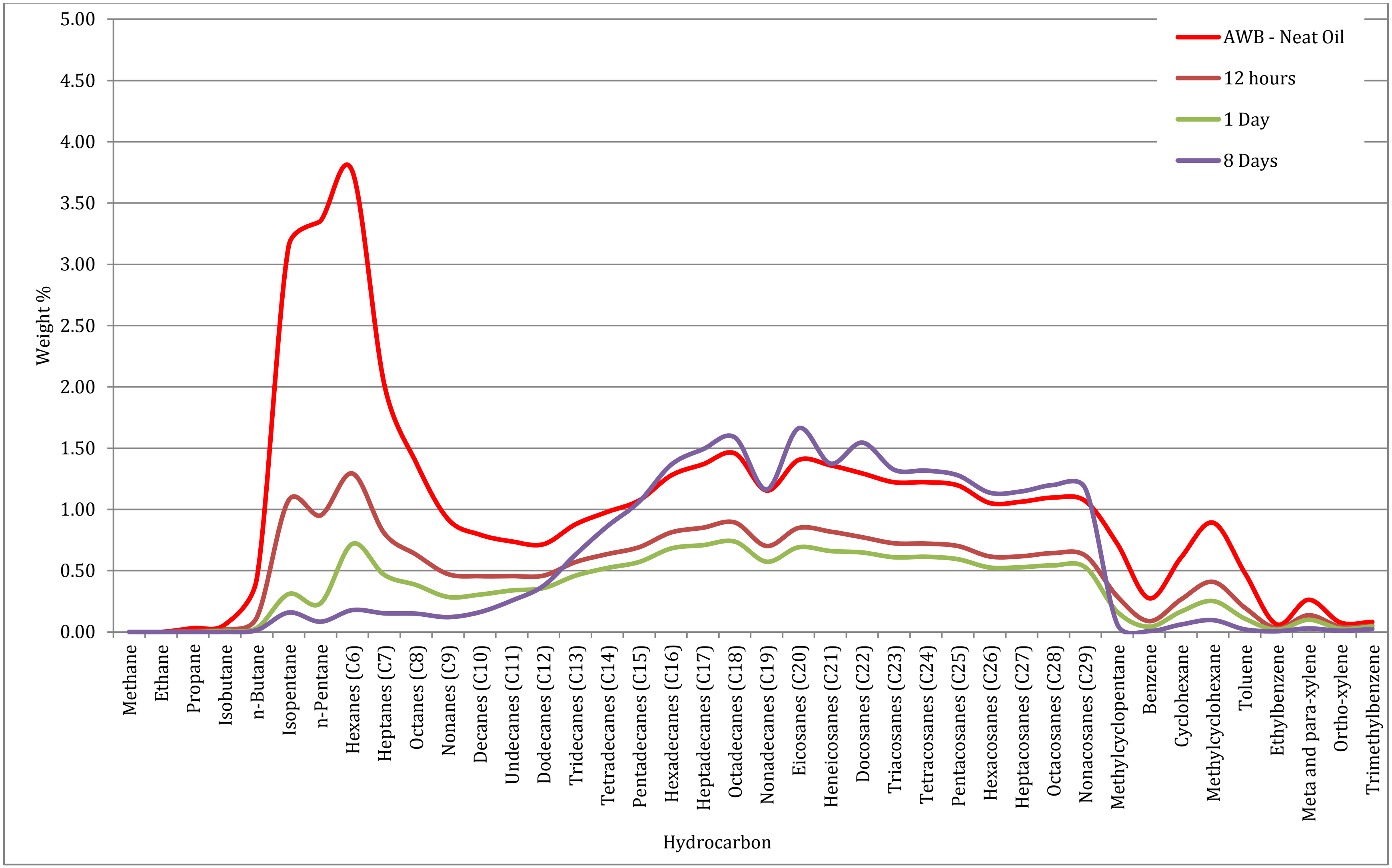


Figure F-4: AWB Light ends (C1 - C30) - Mild conditions

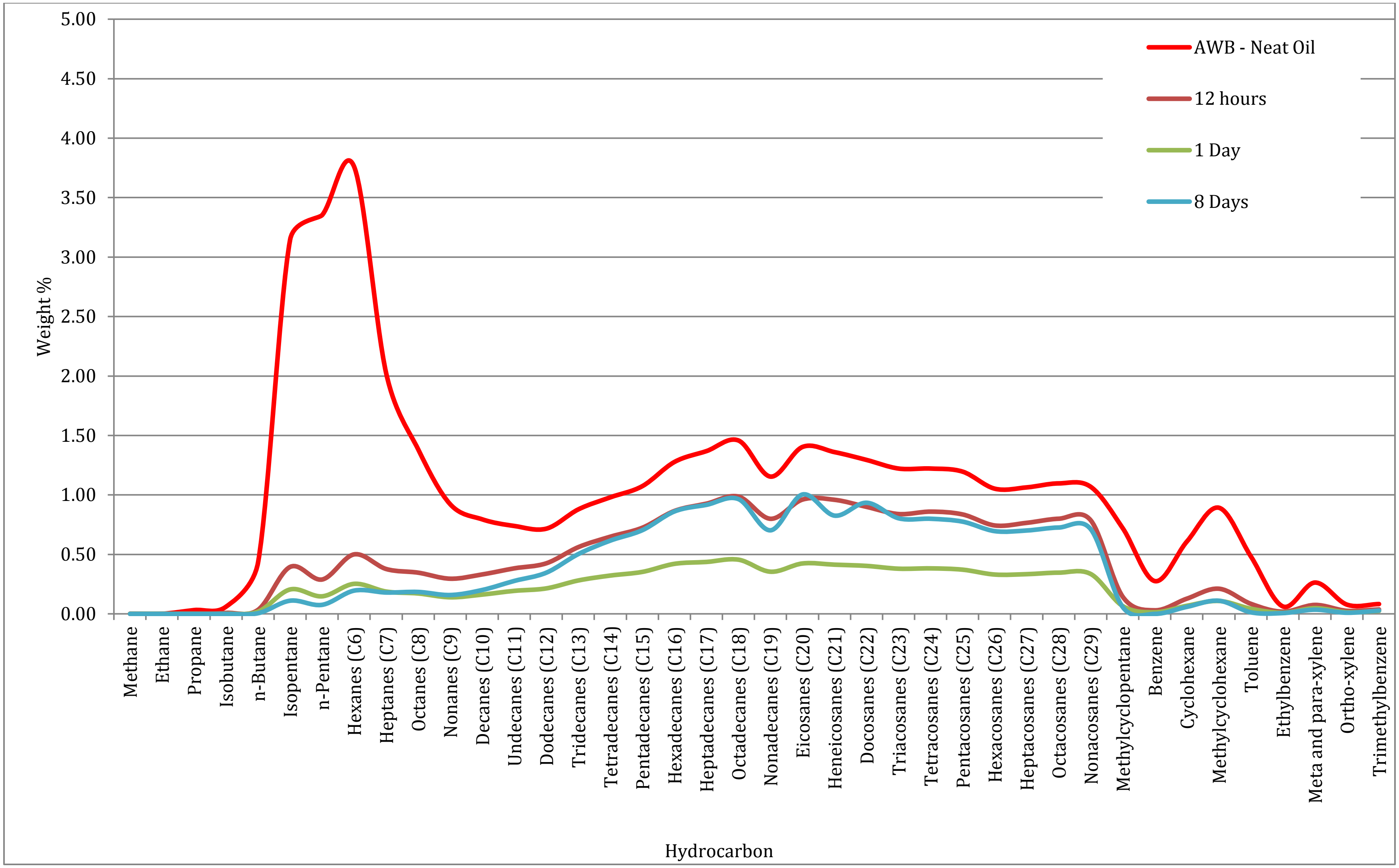


Figure F-5: AWB Light ends (C1 - C30) - Moderate condition

Appendix G: Water Chemistry Data (PAH, BTEX & C6-C10, and TPH)

Witt O'Brien's, Polaris Applied Sciences, and
Western Canada Marine Response Corporation

Introduction

This appendix section presents the chemistry data (PAH, BTEX, and TPH) of water samples collected from AWB and CLWB fate and behavior tests as the oils weathered under three agitation conditions:

- Static Conditions: One tank with no agitation induced. Wind exposure was minimized as far as was practical.
- Mild Agitation: One tank with low wind and wave conditions (e.g. 2 cm – 4 cm waves and 5 mph (2.2 m/s) winds, which were induced by simple mechanical means (intrinsically safe fans and paddles mechanism)).
- Moderate Agitation: One tank with conditions similar to Tank 2 but with a larger induced wind and wave agitation (e.g. 5-7 cm waves and 10 mph (4.5 m/s) winds).

mple Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S1-PS-L2-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.14	0.12	0.056	<0.050	<0.020	<0.20	<0.050	0.34	0.3	0.12	<0.10
S1-PS-L2-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.15	0.13	0.061	<0.050	<0.020	<0.20	<0.050	0.35	0.31	0.11	<0.10
S1-2H-L1-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.18	0.16	0.069	<0.050	<0.020	0.21	<0.050	0.41	0.36	0.14	0.11
S1-2H-L1-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	0.0093	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.17	0.15	0.067	<0.050	<0.020	<0.20	<0.050	0.38	0.36	0.13	0.11
S1-4H-L1-W250-1																											
S1-4H-L1-W250-2																											
S1-6H-L1-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.15	0.16	<0.050	<0.050	<0.020	<0.20	<0.050	0.28	0.33	<0.10	0.13
S1-6H-L1-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.21	0.23	0.06	<0.050	<0.020	<0.20	<0.050	0.41	0.47	0.15	0.16
S1-12H-L1-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.16	0.18	0.064	<0.050	<0.020	0.2	<0.050	0.3	0.35	0.13	0.1
S1-12H-L1-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.16	0.16	0.061	<0.050	<0.020	0.21	<0.050	0.29	0.31	0.13	<0.10
S1-1D-L1-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.32	0.43	0.054	<0.050	<0.020	0.25	<0.050	0.66	0.4	0.13	0.11
S1-1D-L1-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.31	0.43	0.053	<0.050	<0.020	0.22	<0.050	0.62	0.42	0.13	<0.10
S1-2D-L1-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	0.027	<0.040	<0.050	<0.0085	0.43	0.61	0.056	<0.050	<0.020	0.22	<0.050	0.88	0.55	0.16	0.13
S1-2D-L1-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.020	<0.040	<0.050	<0.0085	0.44	0.62	0.058	<0.050	<0.020	0.24	<0.050	0.9	0.55	0.15	0.14
S1-4D-L1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.77	1.1	0.069	<0.050	<0.020	<0.85	<0.050	1.4	0.82	0.23	0.16
S1-6D-L1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.055	<0.0085	0.83	1.1	0.074	<0.050	<0.020	<0.65	<0.050	1.5	1.1	0.21	0.13
S1-8D-L1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.083	<0.0085	1.2	1.7	0.097	<0.050	<0.020	0.83	<0.050	2.1	1.2	0.33	0.26
S1-10D-L1	<0.10	<0.10	<0.20	0.014	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.077	<0.0085	1.4	1.9	0.097	<0.050	<0.020	0.9	<0.050	2.6	1.6	0.46	0.28

mple Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(bjk)fluoranthene/benzo(a)py	C2-Benzo(bjk)fluoranthene/benzo(a)py	C1-Acenaphthene
S1-PS-L2-W250-1	0.028	0.15	0.071	0.089	0.13	0.2	0.035	0.037	0.082	0.046	<0.020	0.055	<0.050	0.06	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-PS-L2-W250-2	0.032	0.16	0.075	0.09	0.12	0.23	0.035	0.039	0.073	0.037	<0.020	0.059	<0.050	0.054	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-2H-L1-W250-1	0.032	0.14	0.071	0.098	0.15	0.18	0.038	0.052	0.1	0.091	<0.020	0.075	0.088	0.16	0.072	<0.020	0.05	0.068	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-2H-L1-W250-2	0.034	0.17	0.087	0.1	0.13	0.2	0.036	0.044	0.091	0.076	<0.020	0.075	0.074	0.14	0.051	<0.020	0.046	0.049	<0.020	0.015	0.046	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-4H-L1-W250-1																										
S1-4H-L1-W250-2																										
S1-6H-L1-W250-1	0.03	0.14	0.079	0.083	0.095	<0.10	0.028	0.04	0.07	0.079	<0.020	0.054	0.055	0.059	<0.050	<0.020	0.043	0.064	<0.020	0.0094	0.069	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-6H-L1-W250-2	0.039	0.18	0.11	0.1	0.15	<0.10	0.039	0.047	0.084	0.053	<0.020	0.071	0.076	0.11	0.06	0.028	0.06	0.089	0.043	0.017	0.12	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-12H-L1-W250-1	0.032	0.18	0.099	0.14	0.16	0.13	0.036	0.045	0.075	0.052	<0.020	0.074	0.068	0.067	<0.050	<0.020	0.034	<0.020	<0.020	0.011	0.043	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-12H-L1-W250-2	0.031	0.18	0.091	0.14	0.15	0.14	0.035	0.041	0.079	0.052	<0.020	0.069	0.071	0.072	<0.050	<0.020	0.033	<0.020	<0.020	<0.0085	0.049	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-1D-L1-W250-1	0.047	0.15	0.081	0.084	0.11	0.24	0.032	0.036	0.059	0.049	<0.020	0.074	<0.050	0.055	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	0.03	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-1D-L1-W250-2	0.045	0.14	0.14	0.089	0.12	0.19	0.032	0.042	0.059	0.044	<0.020	0.067	<0.050	<0.050	<0.050	<0.020	0.027	<0.020	<0.020	<0.0085	0.025	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-2D-L1-W250-1	0.052	0.16	0.079	0.092	0.13	<0.050	0.035	0.043	0.076	0.074	<0.020	0.071	0.069	0.061	<0.050	<0.020	0.03	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-2D-L1-W250-2	0.053	0.15	0.079	0.1	0.14	<0.050	0.037	0.043	0.083	0.071	<0.020	0.077	0.058	0.06	<0.050	<0.020	0.026	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-4D-L1	0.1	0.17	0.17	0.1	0.11	<1.4	0.04	<0.020	0.072	0.054	<0.020	0.11	0.058	0.054	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.060	<0.33	<0.14	<0.22	<0.10
S1-6D-L1	0.094	0.27	0.2	0.11	0.11	0.19	0.035	0.047	0.092	0.055	0.53	0.083	0.068	0.053	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-8D-L1	0.13	0.27	0.24	0.17	0.2	0.42	0.051	0.087	0.11	0.07	<0.020	0.11	0.1	0.07	<0.050	0.021	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10
S1-10D-L1	0.18	0.27	0.21	0.16	0.16	<1.4	0.055	0.084	0.1	0.07	<0.020	0.14	0.15	0.13	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.060	<0.33	<0.14	<0.22	<0.10

Table G-1: AWB Static - PAH water data at 0.5 m

mple Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S1 2H L2 W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.16	0.15	0.06	<0.050	<0.020	<0.20	<0.050	0.36	0.34	0.12	0.1
S1 2H L2 W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.18	0.16	0.071	<0.050	<0.020	<0.20	<0.050	0.41	0.37	0.14	0.14
S1-4H-L2-W250-1																											
S1-4H-L2-W250-2																											
S1-6H-L2-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.16	0.17	<0.050	<0.050	<0.020	<0.22	<0.050	0.29	0.36	0.13	0.11
S1-6H-L2-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.18	0.22	0.051	<0.050	<0.020	<0.20	<0.050	0.32	0.38	0.12	0.12
S1-12H-L2-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.052	<0.0085	0.16	0.17	0.061	<0.050	<0.020	0.24	<0.050	0.27	0.32	0.1	0.11
S1-12H-L2-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.15	0.16	0.056	<0.050	<0.020	0.21	<0.050	0.27	0.3	<0.10	<0.10
S1-1D-L2-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.37	0.51	0.061	<0.050	<0.020	0.23	<0.050	0.73	0.52	0.16	0.11
S1-1D-L2-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.35	0.48	0.054	<0.050	<0.020	0.21	<0.050	0.69	0.46	0.15	0.1
S1-2D-L2-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	0.028	<0.040	<0.050	<0.0085	0.46	0.66	0.062	<0.050	<0.020	0.24	<0.050	0.95	0.6	0.19	0.15
S1-2D-L2-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.020	<0.040	<0.050	<0.0085	0.42	0.6	0.058	<0.050	<0.020	0.22	<0.050	0.86	0.57	0.16	0.13
S1-4D-L2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.75	1.1	0.066	<0.050	<0.020	<0.85	<0.050	1.4	0.81	0.22	0.19
S1-6D-L2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.052	<0.0085	0.86	1.2	0.072	<0.050	<0.020	<0.52	<0.050	1.6	0.9	0.23	0.12
S1-8D-L2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.082	<0.0085	1.2	1.7	0.088	<0.050	<0.020	0.74	<0.050	2.1	1.2	0.31	0.2
S1-10D-L2	<0.10	<0.10	<0.20	0.013	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.078	<0.0085	1.4	1.8	0.095	<0.050	<0.020	0.87	<0.050	2.4	1.5	0.46	0.29

mple Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(bjk)fluoranthene/benzo(a)py	C2-Benzo(bjk)fluoranthene/benzo(a)py	C1-Acenaphthene	1-Methylnaphthalene
S1 2H L2 W250-1	0.032	0.15	0.077	0.093	0.14	0.18	0.034	0.047	0.089	0.078	<0.020	0.075	0.073	0.13	0.056	<0.020	0.042	<0.020	<0.020	0.012	0.079	0.017	<0.0085	<0.0075	<0.0075	<0.10	0.13
S1 2H L2 W250-2	0.034	0.16	0.079	0.1	0.18	0.26	0.038	0.047	0.095	0.077	<0.020	0.085	0.081	0.15	0.057	<0.020	0.039	0.04	0.021	0.012	0.068	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.15
S1-4H-L2-W250-1																											
S1-4H-L2-W250-2																											
S1-6H-L2-W250-1	0.029	0.15	0.1	0.097	0.13	<0.10	0.03	0.039	<0.020	0.084	<0.020	0.071	0.078	0.065	0.05	0.021	0.046	0.074	<0.020	0.015	0.11	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.14
S1-6H-L2-W250-2	0.03	0.17	0.077	0.082	0.15	<0.10	0.033	0.037	0.073	0.097	<0.020	0.071	0.1	0.094	0.067	<0.020	0.06	0.036	<0.020	0.014	0.12	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.14
S1-12H-L2-W250-1	0.033	0.2	0.097	0.15	0.17	0.15	0.035	0.046	0.07	0.067	<0.020	0.076	0.074	0.074	<0.050	<0.020	0.04	<0.020	<0.020	0.01	0.047	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.12
S1-12H-L2-W250-2	0.029	0.16	0.09	0.14	0.16	0.16	0.033	0.04	0.076	0.056	<0.020	0.071	0.065	0.068	<0.050	<0.020	0.031	<0.020	<0.020	<0.0085	0.034	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.12
S1-1D-L2-W250-1	0.05	0.15	0.084	0.1	0.14	0.23	0.036	0.041	0.07	0.052	<0.020	0.079	0.066	0.061	<0.050	<0.020	0.027	<0.020	<0.020	0.0095	0.037	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.28
S1-1D-L2-W250-2	0.046	0.13	0.065	0.087	0.13	0.19	0.033	0.037	0.065	0.047	<0.020	0.073	0.061	0.057	<0.050	<0.020	0.025	<0.020	<0.020	<0.0085	0.029	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.26
S1-2D-L2-W250-1	0.056	0.17	0.086	0.12	0.16	<0.050	0.04	0.053	0.084	0.077	<0.020	0.083	0.071	0.068	<0.050	<0.020	0.028	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.38
S1-2D-L2-W250-2	0.051	0.16	0.082	0.1	0.14	<0.050	0.035	0.039	0.075	0.074	<0.020	0.077	0.067	0.067	<0.050	<0.020	0.025	<0.020	<0.020	<0.0085	0.036	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.34
S1-4D-L2	0.091	0.18	0.16	0.097	0.11	<1.4	0.035	0.068	0.065	0.052	<0.020	0.14	0.15	0.12	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	0.034	<0.060	<0.33	<0.14	<0.22	<0.10	
S1-6D-L2	0.097	0.24	0.18	0.11	0.11	0.26	0.037	0.071	0.072	0.052	0.5	0.079	0.058	<0.050	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S1-8D-L2	0.14	0.25	0.23	0.17	0.17	0.38	0.051	0.061	0.1	0.065	<0.020	0.094	0.098	0.081	<0.050	<0.020	0.033	<0.020	<0.020	0.013	0.012	0.0099	0.017	<0.0075	<0.0075	<0.10	
S1-10D-L2	0.16	0.25	0.19	0.15	0.14	<1.4	0.054	0.074	0.12	0.073	<0.020	0.16	0.18	0.12	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.060	<0.33	<0.14	<0.22	<0.10	

Table G-2: AWB Static - PAH water data at 1.0 m

mple Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S1-2H-L3 W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.14	0.13	0.055	<0.050	<0.020	<0.20	<0.050	0.32	0.29	0.1	<0.10
S1 2H L3 W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.14	0.12	0.053	<0.050	<0.020	<0.20	<0.050	0.32	0.28	<0.10	<0.10
S1-4H-L3-W250-1																											
S1-4H-L3-W250-2																											
S1-6H-L3-W250-1																											
S1-6H-L3-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.16	0.21	<0.050	<0.050	<0.020	<0.20	<0.050	0.31	0.35	0.11	<0.10
S1-12H-L3-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.15	0.19	0.059	<0.050	<0.020	0.24	<0.050	0.29	0.31	0.12	0.11
S1-12H-L3-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.15	0.17	0.053	<0.050	<0.020	0.23	<0.050	0.3	0.33	0.11	0.1
S1-1D-L3-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.42	0.6	0.057	<0.050	<0.020	0.27	<0.050	0.83	0.52	0.18	0.12
S1-1D-L3-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.44	0.63	0.062	<0.050	<0.020	0.25	<0.050	0.88	0.57	0.17	0.11
S1-2D-L3-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	0.028	<0.040	<0.050	<0.0085	0.5	0.75	0.061	<0.050	<0.020	0.24	<0.050	1	0.63	0.17	0.13
S1-2D-L3-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.020	<0.040	<0.050	<0.0085	0.51	0.75	0.063	<0.050	<0.020	0.23	<0.050	1	0.66	0.15	0.15
S1-4D-L3	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.72	1	0.064	<0.050	<0.020	<0.85	<0.050	1.4	0.78	0.22	0.17
S1-6D-L3	<0.10	<0.10	<0.20	0.014	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.062	<0.0085	0.97	1.3	0.092	<0.050	<0.020	<0.54	<0.050	1.9	0.97	0.27	0.16
S1-8D-L3	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.082	<0.0085	1.1	1.6	0.097	<0.050	<0.020	0.75	<0.050	1.9	1.2	0.31	0.2
S1-10D-L3	<0.10	<0.10	<0.20	0.012	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.073	<0.0085	1.3	1.8	0.091	<0.050	<0.020	1.2	<0.050	2.3	1.4	0.43	0.27

mple Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(bjk)fluoranthene/benzo(a)py	C2-Benzo(bjk)fluoranthene/benzo(a)py	C1-Acenaphthene	1-Methylnaphthalene
S1-2H-L3 W250-1	0.028	0.14	0.067	0.087	0.13	0.17	0.033	0.03	0.055	0.044	<0.020	0.057	<0.050	0.078	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.12
S1 2H L3 W250-2	0.027	0.14	0.071	0.085	0.14	0.16	0.033	0.039	0.065	0.043	<0.020	0.057	<0.050	0.077	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.12
S1-4H-L3-W250-1																											
S1-4H-L3-W250-2																											
S1-6H-L3-W250-1																											
S1-6H-L3-W250-2	0.028	0.11	0.086	0.086	<0.050	<0.10	0.031	<0.020	0.079	0.079	<0.020	<0.050	0.082	0.11	<0.050	<0.020	0.048	0.063	0.049	0.013	0.091	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.13
S1-12H-L3-W250-1	0.032	0.18	0.097	0.15	0.17	<0.050	0.033	0.044	0.067	0.073	<0.020	0.08	0.084	0.096	<0.050	<0.020	0.041	<0.020	0.048	0.015	0.071	0.028	<0.0085	<0.0075	<0.0075	<0.10	0.12
S1-12H-L3-W250-2	0.03	0.17	0.094	0.14	0.17	0.15	0.035	0.043	0.084	0.076	<0.020	0.068	0.076	0.078	<0.050	<0.020	0.043	0.059	0.034	0.012	0.061	0.019	<0.0085	<0.0075	<0.0075	<0.10	0.12
S1-1D-L3-W250-1	0.053	0.16	0.089	0.097	0.11	0.24	0.032	0.038	0.072	0.056	<0.020	0.074	0.073	0.077	<0.050	<0.020	0.032	<0.020	<0.020	0.011	0.041	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.31
S1-1D-L3-W250-2	0.056	0.15	0.15	0.1	0.12	0.23	0.034	0.043	0.072	0.058	<0.020	0.064	0.072	0.072	<0.050	<0.020	0.044	0.051	0.025	0.013	0.06	0.022	<0.0085	<0.0075	<0.0075	<0.10	0.33
S1-2D-L3-W250-1	0.059	0.17	0.087	0.12	0.15	<0.050	0.039	0.049	0.082	0.072	<0.020	0.077	0.062	0.066	<0.050	<0.020	0.034	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.41
S1-2D-L3-W250-2	0.06	0.17	0.072	0.11	0.12	<0.050	0.041	0.05	0.081	0.075	<0.020	0.086	0.081	0.077	<0.050	<0.020	0.031	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.4
S1-4D-L3	0.098	0.18	0.17	0.089	0.092	<1.4	0.035	0.052	0.067	0.047	<0.020	0.11	0.061	0.1	<0.050	<0.020	<0.020	<0.020	<0.020	0.009	<0.0085	<0.060	<0.33	<0.14	<0.22	<0.10	
S1-6D-L3	0.11	0.27	0.12	0.13	0.15	0.26	0.045	7.9	0.11	<0.020	0.54	0.1	0.076	0.07	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S1-8D-L3	0.13	0.26	0.26	0.19	0.18	0.37	0.051	0.021	0.09	0.083	<0.020	0.11	0.11	0.079	<0.050	0.02	0.053	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S1-10D-L3	0.17	0.25	0.2	0.15	0.16	<1.4	0.053	0.081	0.14	0.094	<0.020	0.13	0.15	0.11	<0.050	<0.020	0.028	<0.020	<0.020	<0.0085	0.029	<0.060	<0.33	<0.14	<0.22	<0.10	

Table G-3: AWB Static - PAH water data at 1.5 m

mple Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S2-2H-L1-W40	<0.19	<0.19	<0.37	<0.019	<0.016	<0.016	<0.016	<0.016	<0.093	<0.014	<0.093	<0.016	<0.014	<0.074	<0.093	<0.016	<0.19	<0.19	<0.093	<0.093	<0.037	<0.37	<0.093	0.23	0.28	<0.19	<0.19
S2-4H-L1-W250-1																											
S2-4H-L1-W250-2																											
S2-6H-L1-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.31	0.43	0.07	<0.050	<0.020	0.21	<0.050	0.65	0.48	0.16	0.13
S2-6H-L1-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.052	<0.0085	0.33	0.46	0.084	<0.050	<0.020	0.22	<0.050	0.73	0.48	0.18	0.14
S2-12H-L1-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.052	<0.0085	0.42	0.67	0.057	<0.050	<0.020	0.32	<0.050	0.84	0.54	0.16	0.12
S2-12H-L1-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.052	<0.0085	0.42	0.66	0.059	<0.050	<0.020	0.28	<0.050	0.85	0.53	0.15	0.1
S2-1D-L1-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.65	1	0.059	<0.050	<0.020	0.28	<0.050	1.3	0.7	0.2	0.12
S2-1D-L1-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.72	1.1	0.064	<0.050	<0.020	0.3	<0.050	1.4	0.74	0.2	0.12
S2-2D-L1-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.020	<0.040	0.069	<0.0085	1.2	1.9	0.081	<0.050	<0.020	0.34	<0.050	2.3	1.3	0.34	0.18
S2-2D-L1-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.020	<0.040	0.067	<0.0085	1.2	1.9	0.079	<0.050	<0.020	0.33	<0.050	2.3	1.3	0.34	0.18
S2-4D-L1	<0.10	<0.10	<0.20	0.011	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	0.0088	<0.050	<0.0085	<0.0075	<0.040	0.093	<0.0085	2	2.6	0.1	<0.050	<0.020	1.4	<0.050	3.5	2	0.55	0.3
S2-6D-L1	<0.10	<0.10	<0.20	0.012	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.097	<0.0085	1.5	1.6	0.11	<0.050	<0.020	<0.75	<0.050	2.8	1.8	0.49	0.24
S2-8D-L1	<0.10	<0.10	<0.20	0.016	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.14	<0.0085	1.4	1.5	0.16	<0.050	<0.020	1.2	<0.050	2.5	1.8	0.65	0.35
S2-10D-L1	<0.10	<0.10	<0.20	0.021	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.13	<0.0085	1.5	1.3	0.14	<0.050	<0.020	1.3	<0.050	2.6	2.2	0.71	0.45

mple Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(bjk)fluoranthene/benzo(a)py	C2-Benzo(bjk)fluoranthene/benzo(a)py	C1-Acenaphthene	1-Methylnaphthalene
S2-2H-L1-W40	0.045 (1)	0.30 (1)	0.42 (1)	0.19 (1)	0.13 (1)	0.51 (1)	<0.037	<0.037	0.050	0.045	0.073	<0.093	<0.093	<0.093	<0.093	<0.037	<0.037	<0.037	<0.037	<0.016	<0.016	<0.016	<0.016	<0.014	<0.014	<0.19	<0.19
S2-4H-L1-W250-1																											
S2-4H-L1-W250-2																											
S2-6H-L1-W250-1	0.046	0.18	0.09	0.11	0.15	0.18	0.037	0.05	0.098	0.07	<0.020	0.088	0.077	0.13	<0.050	<0.020	0.049	0.048	<0.020	0.014	0.073	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.24
S2-6H-L1-W250-2	0.055	0.2	0.095	0.11	0.2	0.26	0.041	0.056	0.092	0.074	<0.020	0.087	0.086	0.16	0.057	<0.020	0.042	0.036	<0.020	0.013	0.057	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.25
S2-12H-L1-W250-1	0.051	0.18	0.089	0.15	0.17	0.14	0.037	0.042	0.086	0.062	<0.020	0.074	0.082	0.087	<0.050	<0.020	0.039	0.051	0.047	0.014	0.059	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.31
S2-12H-L1-W250-2	0.05	0.18	0.099	0.15	0.18	0.11	0.036	0.044	0.08	0.063	<0.020	0.074	0.084	0.081	<0.050	<0.020	0.038	0.051	0.043	0.012	0.063	0.018	<0.0085	<0.0075	<0.0075	<0.10	0.32
S2-1D-L1-W250-1	0.073	0.15	0.067	0.1	0.15	0.21	0.034	0.04	0.052	0.047	<0.020	0.081	0.065	0.057	<0.050	<0.020	0.034	<0.020	0.022	<0.0085	0.04	0.018	<0.0085	<0.0075	<0.0075	<0.10	0.47
S2-1D-L1-W250-2	0.079	0.16	0.066	0.1	0.13	0.2	0.036	0.042	0.065	0.048	<0.020	0.08	0.063	0.06	<0.050	<0.020	0.036	<0.020	<0.020	<0.0085	0.037	0.013	<0.0085	<0.0075	<0.0075	<0.10	0.52
S2-2D-L1-W250-1	0.13	0.23	0.1	0.14	0.21	<0.050	0.046	0.049	0.075	0.059	<0.020	0.1	0.079	0.059	<0.050	<0.020	0.037	<0.020	<0.020	0.0091	0.024	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.91
S2-2D-L1-W250-2	0.13	0.22	0.099	0.12	0.18	<0.050	0.044	0.05	0.071	0.056	<0.020	0.1	0.072	0.06	<0.050	<0.020	0.026	<0.020	<0.020	<0.0085	0.03	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.89
S2-4D-L1	0.24	0.32	0.19	0.15	0.13	<1.4	0.049	0.072	0.08	0.066	<0.020	0.15	0.085	0.061	<0.050	<0.020	<0.020	<0.020	<0.020	0.01	0.017	<0.060	<0.33	<0.14	<0.22	<0.10	
S2-6D-L1	0.17	0.34	0.16	0.16	0.16	<0.050	0.044	0.06	0.076	0.062	<0.020	0.12	0.098	0.081	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S2-8D-L1	0.21	0.39	0.29	0.24	0.21	0.42	0.064	0.096	0.11	0.095	<0.020	0.17	0.16	0.11	<0.050	0.029	0.041	<0.020	<0.020	<0.0085	0.014	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S2-10D-L1	0.23	0.34	0.25	0.21	0.18	<1.4	0.068	0.084	0.11	0.071	<0.020	0.21	0.24	0.18	<0.050	0.025	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.060	<0.33	<0.14	<0.22	<0.10	

Table G-4: AWB Mild Conditions - PAH water data at 0.5 m

mple Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S2-2H-L2-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.19	0.19	<0.050	<0.050	<0.020	<0.20	<0.050	0.36	0.33	0.13	0.11
S2-2H-L2-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.19	0.2	0.051	<0.050	<0.020	<0.20	<0.050	0.37	0.35	0.12	0.11
S2-4H-L2-W250-1																											
S2-4H-L2-W250-2																											
S2-6H-L2-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.051	<0.0085	0.31	0.43	0.082	<0.050	<0.020	0.25	<0.050	0.64	0.5	0.18	0.12
S2-6H-L2-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.29	0.4	0.072	<0.050	<0.020	0.24	<0.050	0.64	0.46	0.17	0.15
S2-12H-L2-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.052	<0.0085	0.42	0.67	0.065	<0.050	<0.020	0.28	<0.050	0.82	0.5	0.18	0.13
S2-12H-L2-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.051	<0.0085	0.42	0.66	0.065	<0.050	<0.020	0.29	<0.050	0.84	0.56	0.21	0.13
S2-1D-L2-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.67	1	0.063	<0.050	<0.020	0.29	<0.050	1.3	0.72	0.2	0.11
S2-1D-L2-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.67	1.1	0.064	<0.050	<0.020	0.32	<0.050	0.49	0.74	0.2	0.12
S2-2D-L2-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.020	<0.040	0.069	<0.0085	1.3	1.9	0.081	<0.050	<0.020	0.33	<0.050	2.4	1.3	0.36	0.2
S2-2D-L2-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.020	<0.040	0.067	<0.0085	1.3	2	0.081	<0.050	<0.020	0.3	<0.050	2.5	1.3	0.36	0.2
S2-4D-L2	<0.10	<0.10	<0.20	0.012	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.11	<0.0085	2.3	3	0.12	<0.050	<0.020	1.2	<0.050	4.1	2.4	0.56	0.3
S2-6D-L2	<0.10	<0.10	<0.20	0.012	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.1	<0.0085	1.6	1.7	0.11	<0.050	<0.020	<0.61	<0.050	2.9	1.8	0.48	0.25
S2-8D-L2	<0.10	<0.10	<0.20	0.017	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.12	<0.0085	1.3	1.3	0.14	<0.050	<0.020	1.2	<0.050	2.2	1.8	0.59	0.35
S2-10D-L2	<0.10	<0.10	<0.20	0.021	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.12	<0.0085	1.4	1.3	0.14	<0.050	<0.020	1.1	<0.050	2.5	2	0.7	0.42

mple Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(bjk)fluoranthene/benzo(a)py	C2-Benzo(bjk)fluoranthene/benzo(a)py	C1-Acenaphthene	1-Methylnaphthalene
S2-2H-L2-W250-1	0.046	0.14	0.14	0.072	0.12	0.48	0.033	0.051	0.099	0.093	<0.020	0.062	0.083	0.1	0.056	<0.020	0.059	0.089	<0.020	0.015	0.063	0.049	<0.0085	<0.0075	0.016	<0.10	
S2-2H-L2-W250-2	0.047	0.15	0.095	0.074	0.11	0.43	0.032	0.052	0.091	0.083	<0.020	0.062	0.073	0.088	0.053	<0.020	0.051	0.098	<0.020	0.013	0.044	0.033	0.057	0.021	0.032	<0.10	
S2-4H-L2-W250-1																											
S2-4H-L2-W250-2																											
S2-6H-L2-W250-1	0.05	0.2	0.099	0.12	0.14	0.21	0.039	0.05	0.099	0.079	<0.020	0.09	0.077	0.2	0.053	<0.020	0.047	0.046	<0.020	0.015	0.091	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.24
S2-6H-L2-W250-2	0.046	0.19	0.089	0.11	0.13	0.21	0.037	0.045	0.084	0.069	<0.020	0.081	0.08	0.16	<0.050	<0.020	0.043	<0.020	<0.020	0.012	0.046	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.23
S2-12H-L2-W250-1	0.051	0.16	0.091	0.14	0.18	0.16	0.036	0.041	0.087	0.07	<0.020	0.077	0.083	0.096	<0.050	<0.020	0.036	<0.020	0.056	0.012	0.067	0.014	<0.0085	<0.0075	<0.0075	<0.10	0.31
S2-12H-L2-W250-2	0.052	0.18	0.098	0.15	0.18	0.18	0.038	0.042	0.093	0.065	<0.020	0.079	0.081	0.1	<0.050	<0.020	0.049	0.089	0.049	0.014	0.061	0.017	<0.0085	<0.0075	<0.0075	<0.10	0.31
S2-1D-L2-W250-1	0.076	0.17	0.072	0.1	0.14	0.17	0.034	0.035	0.064	0.046	<0.020	0.078	0.061	0.054	<0.050	<0.020	0.027	0.035	0.022	<0.0085	0.05	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.49
S2-1D-L2-W250-2	0.076	0.17	0.066	0.1	0.14	0.24	0.033	0.041	0.06	0.049	<0.020	0.075	0.06	0.059	<0.050	<0.020	0.03	<0.020	<0.020	<0.0085	0.044	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.49
S2-2D-L2-W250-1	0.14	0.23	0.11	0.14	0.21	<0.050	0.046	0.054	0.082	0.06	<0.020	0.097	0.077	0.067	<0.050	<0.020	0.035	<0.020	<0.020	0.011	0.041	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.94
S2-2D-L2-W250-2	0.13	0.22	0.097	0.13	0.17	<0.050	0.047	0.054	0.087	0.064	<0.020	0.098	0.074	0.065	<0.050	<0.020	0.033	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.94
S2-4D-L2	0.27	0.35	0.25	0.16	0.16	<1.4	0.053	0.071	0.081	0.07	<0.020	0.16	0.18	0.14	<0.050	<0.020	0.028	<0.020	<0.020	<0.0085	0.025	<0.060	<0.33	<0.14	<0.22	<0.10	
S2-6D-L2	0.19	0.35	0.22	0.17	0.16	0.22	0.045	0.072	0.089	0.054	<0.020	0.13	0.093	0.078	<0.050	0.022	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S2-8D-L2	0.19	0.35	0.29	0.24	0.19	0.33	0.058	0.078	0.093	0.073	<0.020	0.14	0.12	0.084	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S2-10D-L2	0.21	0.34	0.27	0.19	0.14	<1.4	0.061	0.073	0.1	0.065	<0.020	0.18	0.17	0.13	<0.050	0.025	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.060	<0.33	<0.14	<0.22	<0.10	

Table G-5: AWB Mild Conditions - PAH water data at 1.0 m

mple Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S2-2H-L3-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.18	0.2	<0.050	<0.050	<0.020	<0.20	<0.050	0.33	0.32	0.11	<0.10
S2-2H-L3-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	0.0088	0.18	0.2	<0.050	<0.050	<0.020	<0.20	<0.050	0.35	0.32	0.12	0.12
S2-4H-L3-W250-1																											
S2-4H-L3-W250-2																											
S2-6H-L3-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.31	0.42	0.074	<0.050	<0.020	0.23	<0.050	0.61	0.43	0.17	0.13
S2-6H-L3-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.053	<0.0085	0.32	0.44	0.087	<0.050	<0.020	0.22	<0.050	0.66	0.46	0.19	0.13
S2-12H-L3-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.056	<0.0085	0.41	0.64	0.071	<0.050	<0.020	0.26	<0.050	0.74	0.52	0.2	0.13
S2-12H-L3-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	0.0095	<0.050	<0.0085	<0.0075	<0.040	0.054	<0.0085	0.39	0.61	0.069	<0.050	<0.020	0.25	<0.050	0.79	0.48	0.17	0.11
S2-1D-L3-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.72	1.1	0.069	<0.050	<0.020	0.33	<0.050	1.4	0.73	0.21	0.14
S2-1D-L3-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.68	1.1	0.063	<0.050	<0.020	0.26	<0.050	1.3	0.72	0.22	0.12
S2-2D-L3-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.020	<0.040	0.07	<0.0085	1.3	2	0.081	<0.050	<0.020	0.29	<0.050	2.5	1.4	0.35	0.21
S2-2D-L3-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.020	<0.040	0.069	<0.0085	1.3	1.9	0.082	<0.050	<0.020	0.33	<0.050	2.4	1.4	0.36	0.17
S2-4D-L3	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.11	<0.0085	2.2	2.9	0.11	<0.050	<0.020	1.2	<0.050	3.9	2.2	0.59	0.33
S2-6D-L3	<0.10	<0.10	<0.20	0.015	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.11	<0.0085	1.6	1.7	0.12	<0.050	<0.020	<0.48	<0.050	2.9	2	0.48	0.26
S2-8D-L3	<0.10	<0.10	<0.20	0.019	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.13	<0.0085	1.4	1.5	0.14	<0.050	<0.020	0.99	<0.050	2.6	1.9	0.65	0.4
S2-10D-L3	<0.10	<0.10	<0.20	0.017	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.12	<0.0085	1.4	1.3	0.14	<0.050	<0.020	1.5	<0.050	2.6	2	0.7	0.42

mple Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(bjk)fluoranthene/benzo(a)p	C2-Benzo(bjk)fluoranthene/benzo(a)p	C1-Acenaphthene	1-Methylnaphthalene
S2-2H-L3-W250-1	0.047	0.14	0.14	0.069	0.1	0.52	0.03	0.044	0.087	0.09	<0.020	0.061	0.069	0.096	<0.050	<0.020	0.043	<0.020	<0.020	0.012	0.067	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S2-2H-L3-W250-2	0.05	0.13	0.063	0.068	0.11	0.42	0.031	0.051	0.084	0.092	0.033	0.064	0.072	0.091	<0.050	<0.020	0.043	<0.020	<0.020	0.013	0.045	0.033	<0.0085	<0.0075	0.011	<0.10	
S2-4H-L3-W250-1																											
S2-4H-L3-W250-2																											
S2-6H-L3-W250-1	0.047	0.2	0.092	0.12	0.18	0.2	0.036	0.048	0.099	0.077	<0.020	0.08	0.07	0.12	0.059	<0.020	0.043	0.021	<0.020	0.012	0.046	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.23
S2-6H-L3-W250-2	0.054	0.22	0.095	0.13	0.16	0.23	0.041	0.048	0.11	0.084	<0.020	0.088	0.089	0.17	0.06	<0.020	0.063	0.031	<0.020	0.015	0.043	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.25
S2-12H-L3-W250-1	0.055	0.2	0.11	0.15	0.18	<0.050	0.036	0.047	0.088	0.07	<0.020	0.081	0.076	0.1	<0.050	<0.020	0.045	<0.020	<0.020	0.013	0.053	0.016	<0.0085	<0.0075	<0.0075	<0.10	0.3
S2-12H-L3-W250-2	0.053	0.19	0.095	0.14	0.15	0.14	0.035	0.04	0.083	0.065	<0.020	0.074	0.076	0.092	<0.050	<0.020	0.038	0.061	0.044	0.013	0.063	0.012	<0.0085	<0.0075	<0.0075	<0.10	0.29
S2-1D-L3-W250-1	0.083	0.18	0.18	0.11	0.15	0.26	0.037	0.051	0.068	0.063	<0.020	0.084	0.065	0.074	<0.050	<0.020	0.041	0.049	<0.020	<0.0085	0.048	0.0099	<0.0085	<0.0075	<0.0075	<0.10	0.53
S2-1D-L3-W250-2	0.077	0.16	0.066	0.098	0.12	0.17	0.034	0.041	0.062	0.044	<0.020	0.073	<0.050	0.053	<0.050	<0.020	0.023	<0.020	<0.020	<0.0085	0.03	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.49
S2-2D-L3-W250-1	0.14	0.23	0.098	0.12	0.2	<0.050	0.047	0.057	0.093	0.068	<0.020	0.098	0.087	0.07	<0.050	<0.020	0.026	<0.020	<0.020	<0.0085	0.035	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.94
S2-2D-L3-W250-2	0.13	0.23	0.1	0.13	0.16	<0.050	0.046	0.055	0.081	0.074	<0.020	0.1	0.091	0.058	<0.050	<0.020	0.039	<0.020	<0.020	<0.0085	0.054	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.93
S2-4D-L3	0.25	0.33	0.23	0.16	0.14	<1.4	0.055	0.059	0.086	0.081	<0.020	0.18	0.11	0.17	<0.050	0.02	<0.020	<0.020	<0.020	<0.0085	0.03	<0.060	<0.33	<0.14	<0.22	<0.10	
S2-6D-L3	0.19	0.37	0.24	0.17	0.16	0.22	0.048	0.069	0.094	0.07	<0.020	0.13	0.11	0.092	<0.050	0.022	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S2-8D-L3	0.21	0.34	0.28	0.23	0.21	0.3	0.067	0.081	0.12	0.072	<0.020	0.15	0.14	0.092	<0.050	0.026	0.043	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S2-10D-L3	0.21	0.33	0.21	0.2	0.15	<1.4	0.066	0.07	0.1	0.068	<0.020	0.2	0.21	0.14	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.060	<0.33	<0.14	<0.22	<0.10	

Table G-6: AWB Mild Conditions - PAH water data at 1.5 m

mple Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S3-2H-L1-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	0.033	<0.0085	0.046	<0.050	0.02	<0.050	<0.0085	<0.0075	<0.040	0.091	0.022	1.3	1.4	0.17	0.084	0.045	<0.20	0.075	2.1	2.9	1	1.1
S3-2H-L1-W250-2	<0.10	<0.10	<0.20	<0.010	0.021	0.057	<0.0085	0.055	<0.050	0.037	0.065	0.038	0.02	<0.040	0.12	0.037	1.4	1.5	0.23	0.15	0.068	0.23	0.12	1.4	2.6	1.5	1.7
S3-4H-L1-W250-1																											
S3-4H-L1-W250-2																											
S3-6H-L1-W250-1	<0.10	<0.10	<0.20	0.017	0.021	0.065	0.013	0.055	<0.050	0.049	0.065	0.036	<0.022	<0.040	0.16	<0.027	2	2.3	0.33	0.15	0.094	0.41	0.2	3.6	3.4	1.9	1.8
S3-6H-L1-W250-2	<0.10	<0.10	<0.20	0.035	0.04	0.13	0.032	0.081	<0.050	0.098	0.12	0.09	<0.046	0.062	0.23	<0.054	2.3	2.2	0.54	0.29	0.18	0.42	0.42	4.3	5.3	3.4	3.6
S3-12H-L1-W250-1	<0.10	<0.10	<0.20	0.013	0.012	0.045	<0.0085	0.03	<0.050	0.03	<0.050	0.021	<0.034	<0.040	0.15	<0.020	1.8	2.1	0.25	0.095	0.067	0.47	0.12	3.3	2.9	1.5	1.3
S3-12H-L1-W250-2	<0.10	<0.10	<0.20	0.011	<0.0085	0.031	<0.0085	0.022	<0.050	0.015	<0.050	0.016	<0.035	<0.040	0.14	<0.014	1.7	2.1	0.21	0.061	0.047	0.49	0.093	3.2	2.6	1.2	1
S3-1D-L1-W250-1	<0.10	<0.10	<0.20	0.018	0.026	0.066	0.011	0.044	<0.050	0.036	0.061	0.039	<0.021	<0.040	0.14	<0.040	1.7	2.1	0.3	0.15	0.097	0.47	0.21	3.2	3.1	1.9	1.9
S3-1D-L1-W250-2	<0.10	<0.10	<0.20	0.018	0.018	0.057	0.01	0.041	<0.050	0.047	0.057	0.025	<0.016	<0.040	0.15	<0.040	1.9	2.3	0.29	0.14	0.09	0.46	0.18	3.5	3.1	1.8	1.7
S3-2D-L1-W250-1	<0.10	<0.10	<0.20	0.016	0.016	0.049	0.0094	0.033	<0.050	0.037	<0.050	0.035	<0.020	<0.040	0.13	<0.024	1.6	2	0.25	0.11	0.077	0.42	0.14	3	2.5	1.4	1.4
S3-2D-L1-W250-2	<0.10	<0.10	<0.20	0.014	0.015	0.047	<0.0085	0.029	<0.050	0.024	<0.050	0.027	<0.020	<0.040	0.13	<0.019	1.6	2.1	0.24	0.1	0.072	0.4	0.14	3.1	2.5	1.3	1.3
S3-4D-L1	<0.10	<0.10	<0.20	0.017	<0.0085	0.034	<0.0085	0.023	<0.050	0.017	<0.050	0.015	0.0075	<0.040	0.1	0.017	1.2	1.5	0.17	0.064	0.047	1.9	0.084	2.1	1.6	0.83	1.1
S3-6D-L1	<0.10	<0.10	<0.20	0.028	<0.0085	0.027	<0.0085	0.019	<0.050	0.014	<0.050	<0.0085	<0.0075	<0.040	0.092	<0.0085	1	1.2	0.15	0.052	0.05	<0.90	0.065	1.9	1.3	0.55	0.59
S3-8D-L1	<0.10	<0.10	<0.20	0.026	<0.0085	0.019	<0.0085	0.0094	<0.050	0.0089	<0.050	<0.0085	<0.0075	<0.040	0.12	<0.0085	1.4	1.6	0.17	<0.050	0.04	1	<0.050	2.4	1.7	0.62	0.55
S3-10D-L1	<0.10	<0.10	<0.20	0.027	<0.0085	0.015	<0.0085	<0.0085	<0.050	0.0087	<0.050	<0.0085	<0.0075	<0.040	0.09	<0.0085	0.96	1	0.14	<0.050	0.044	1.9	<0.050	1.7	1.2	0.53	0.48

mple Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(bjk)fluoranthene/benzo(a)py	C2-Benzo(bjk)fluoranthene/benzo(a)py	C1-Acenaphthene	1-Methylnaphthalene
S3-2H-L1-W250-1	0.16	0.31	0.39	0.28	0.62	1.8	0.089	0.31	0.91	1.1	1.3	0.54	1.1	1.9	1.2	0.3	0.95	2	1.5	0.26	0.97	0.66	0.72	0.18	0.19	<0.10	
S3-2H-L1-W250-2	0.18	0.43	0.52	0.41	0.85	2.7	0.12	0.43	1.4	1.9	2.1	0.82	1.7	3.2	2.2	0.53	1.4	3.5	2.5	0.46	1.7	1.1	1.5	0.36	0.29	<0.10	
S3-4H-L1-W250-1																											
S3-4H-L1-W250-2																											
S3-6H-L1-W250-1	0.23	0.54	0.38	0.48	1.2	2.6	0.14	0.51	1.5	1.9	2.4	0.96	1.9	3.8	2.4	0.64	1.7	3.8	2	0.47	3.7	1.3	0.41	0.46	0.3	<0.10	1.4
S3-6H-L1-W250-2	0.29	0.78	0.7	0.87	2	4.8	0.22	0.95	3	4.2	5.3	1.6	3.7	7.4	4.8	1.3	3.1	7.5	5.3	0.92	7.7	2.4	0.63	0.84	0.62	0.16	1.6
S3-12H-L1-W250-1	0.21	0.47	0.31	0.44	0.99	0.89	0.11	0.32	1.2	1.3	1.7	0.64	1.3	2.6	1.6	0.44	1.1	2.4	1.4	0.3	2.3	1.1	0.16	0.63	0.83	<0.10	1.3
S3-12H-L1-W250-2	0.2	0.47	0.26	0.36	0.73	0.58	0.09	0.25	0.81	0.97	0.99	0.48	0.89	1.8	1.1	0.28	0.76	1.5	0.94	0.2	1.6	0.4	0.1	0.16	0.077	<0.10	1.2
S3-1D-L1-W250-1	0.21	0.49	0.3	0.47	0.99	2.8	0.13	0.5	1.5	1.9	2.3	0.98	1.9	3.7	2.4	0.62	1.8	3.9	2.8	0.49	3.9	1.3	0.35	0.43	0.37	<0.10	1.3
S3-1D-L1-W250-2	0.23	0.46	0.29	0.45	0.93	2.5	0.12	0.42	1.4	1.8	2	0.85	1.7	3.4	2.1	0.55	1.6	3.2	2.5	0.43	3.5	1.1	0.32	0.37	0.29	<0.10	1.4
S3-2D-L1-W250-1	0.2	0.41	0.27	0.39	0.88	2.3	0.11	0.36	1.2	1.6	1.9	0.7	1.4	2.9	1.9	0.48	1.3	2.8	1.7	0.36	3	1	0.21	0.43	0.27	<0.10	1.2
S3-2D-L1-W250-2	0.2	0.39	0.27	0.36	0.69	1.9	0.11	0.32	1.1	1.5	1.7	0.67	1.3	2.7	1.8	0.46	1.1	2.4	1.4	0.33	2.7	0.89	0.17	0.37	0.29	<0.10	1.2
S3-4D-L1	0.18	0.28	0.33	0.27	0.49	1.5	0.068	0.25	0.69	0.85	1.1	0.51	1	2	1.3	0.32	0.98	1.9	0.98	0.25	1.4	0.69	<0.33	0.28	0.26	<0.10	
S3-6D-L1	0.14	0.3	0.25	0.23	0.44	0.95	0.055	0.21	0.52	0.63	0.77	0.39	0.74	1.4	0.9	0.23	0.59	1.4	0.82	0.2	0.74	0.44	0.1	0.11	0.11	<0.10	
S3-8D-L1	0.18	0.32	0.32	0.28	0.36	0.94	0.079	0.17	0.39	0.44	0.5	0.3	0.5	0.86	0.48	0.16	0.36	0.72	0.4	0.11	0.54	0.25	0.051	0.095	0.055	<0.10	
S3-10D-L1	0.14	0.22	0.21	0.18	0.25	<1.4	0.061	0.13	0.33	0.46	0.58	0.32	0.54	0.94	0.54	0.16	0.39	0.85	0.43	0.12	0.61	0.3	<0.33	<0.14	<0.22	<0.10	

Table G-7: AWB Moderate Conditions - PAH water data at 0.5 m

mple Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S3-2H-L2-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	0.055	<0.0085	0.059	<0.050	0.035	0.062	0.026	0.021	<0.040	0.12	0.036	1.3	1.3	0.22	0.14	0.072	<0.20	0.12	2.3	2.6	1.5	1.8
S3-2H-L2-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	0.06	<0.0085	0.053	<0.050	0.036	0.07	<0.0085	0.021	<0.040	0.11	0.042	1.4	1.3	0.24	0.15	0.071	<0.20	0.13	2.2	2.7	1.6	1.9
S3-4H-L2-W250-1																											
S3-4H-L2-W250-2																											
S3-6H-L2-W250-1	<0.10	<0.10	<0.20	0.03	0.035	0.12	0.019	0.074	<0.050	0.087	0.11	0.054	<0.032	0.057	0.2	<0.049	2.1	2.1	0.5	0.27	0.17	0.44	0.37	3.9	5	3	3
S3-6H-L2-W250-2	<0.10	<0.10	<0.20	<0.020	0.03	0.081	0.017	0.051	<0.050	0.062	0.077	0.042	<0.029	<0.040	0.16	<0.036	1.8	1.9	0.36	0.17	0.11	0.36	0.24	3.3	3.4	2	2.1
S3-12H-L2-W250-1	<0.10	<0.10	<0.20	0.012	0.0095	0.038	<0.0085	0.025	<0.050	0.017	<0.050	0.015	<0.013	<0.040	0.15	<0.018	1.9	2.2	0.23	0.078	0.057	0.48	0.1	3.5	3	1.3	1.2
S3-12H-L2-W250-2	<0.10	<0.10	<0.20	0.012	0.0097	0.04	<0.0085	0.027	<0.050	0.018	<0.050	0.017	<0.013	<0.040	0.14	<0.024	1.9	2.2	0.23	0.082	0.059	0.4	0.11	3.5	3	1.4	1.1
S3-1D-L2-W250-1	<0.10	<0.10	<0.20	0.021	0.021	0.076	0.0088	0.051	<0.050	0.042	0.07	0.031	<0.022	<0.040	0.17	<0.040	1.9	2.3	0.35	0.17	0.11	0.47	0.26	3.5	3.5	2.1	2.1
S3-1D-L2-W250-2	<0.10	<0.10	<0.20	0.017	0.016	0.058	0.014	0.039	<0.050	0.033	0.053	0.021	<0.015	<0.040	0.14	<0.040	1.8	2.1	0.27	0.13	0.085	0.47	0.17	3.3	2.8	1.6	1.6
S3-2D-L2-W250-1	<0.10	<0.10	<0.20	0.019	0.017	0.06	0.01	0.04	<0.050	0.034	0.058	0.035	0.027	<0.040	0.14	<0.027	1.7	2.1	0.29	0.13	0.091	0.44	0.19	3.1	2.6	1.6	1.7
S3-2D-L2-W250-2	<0.10	<0.10	<0.20	0.018	0.019	0.055	0.011	0.038	<0.050	0.032	0.054	0.028	<0.020	<0.040	0.15	<0.025	1.8	2.2	0.27	0.12	0.084	0.47	0.17	3.3	2.6	1.5	1.5
S3-4D-L2	<0.10	<0.10	<0.20	0.02	<0.0085	0.036	<0.0085	0.024	<0.050	0.018	<0.050	<0.0085	0.0083	<0.040	0.11	0.019	1.3	1.7	0.19	0.081	0.057	1.9	0.12	2.3	1.7	0.9	1.1
S3-6D-L2	<0.10	<0.10	<0.20	0.037	0.014	0.035	<0.0085	0.023	<0.050	0.019	<0.050	0.016	<0.0075	<0.040	0.12	0.013	1.4	1.6	0.19	0.069	0.048	<0.75	0.084	2.5	1.8	0.72	0.73
S3-8D-L2	<0.10	<0.10	<0.20	0.015	<0.0085	0.025	<0.0085	0.012	<0.050	0.012	<0.050	<0.0085	<0.0075	<0.040	0.13	0.01	1.4	1.5	0.16	<0.050	0.047	1.2	0.051	2.4	1.7	0.63	0.69
S3-10D-L2	<0.10	<0.10	<0.20	0.031	<0.0085	0.021	<0.0085	0.016	<0.050	0.011	<0.050	<0.0085	<0.0075	<0.040	0.1	0.011	1.1	1.1	0.16	<0.050	0.038	1.4	<0.050	2	1.5	0.61	0.62

mple Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(bjk)fluoranthene/benzo(a)py	C2-Benzo(bjk)fluoranthene/benzo(a)py	C1-Acenaphthene	1-Methylnaphthalene
S3-2H-L2-W250-1	0.17	0.44	0.49	0.4	0.97	3.1	0.11	0.45	1.5	1.9	2.4	0.83	1.7	3.5	2.1	0.55	1.5	3.6	2.5	0.44	1.8	1.1	1.1	0.32	0.31	<0.10	
S3-2H-L2-W250-2	0.17	0.39	0.49	0.42	1	2.9	0.12	0.5	1.6	2	2.4	0.9	1.8	3.6	2.2	0.58	1.6	3.7	2.8	0.45	1.8	1.3	1.2	0.31	0.29	<0.10	
S3-4H-L2-W250-1																											
S3-4H-L2-W250-2																											
S3-6H-L2-W250-1	0.26	0.68	0.58	0.85	2	3.8	0.21	0.8	3.1	3.9	4.3	1.6	3.5	7	4.4	1.1	2.9	7.2	3.8	0.85	7	2.3	0.58	0.75	0.66	0.14	1.5
S3-6H-L2-W250-2	0.21	0.55	0.43	0.56	1.2	3.1	0.14	0.58	1.9	2.5	2.8	1	2.4	4.5	2.8	0.73	1.9	4.2	2.6	0.55	4.6	1.5	0.35	0.48	0.23	0.11	1.3
S3-12H-L2-W250-1	0.22	0.49	0.32	0.4	0.67	1.6	0.1	0.27	0.93	1	1.3	0.56	1	2	1.3	0.34	0.89	2.3	1.3	0.25	2	0.73	0.27	0.22	0.17	<0.10	1.3
S3-12H-L2-W250-2	0.21	0.44	0.3	0.43	0.7	1.8	0.11	0.28	0.98	1.2	1.4	0.57	1.1	2.2	1.3	0.36	0.97	2.1	1.2	0.26	2.1	0.74	0.21	0.24	0.24	<0.10	1.3
S3-1D-L2-W250-1	0.24	0.51	0.44	0.56	1.1	3.2	0.15	0.54	1.8	2.5	2.8	1.1	2.1	4.3	2.8	0.74	1.8	4.4	3.7	0.54	4.4	1.3	0.4	0.46	0.4	0.1	1.4
S3-1D-L2-W250-2	0.22	0.41	0.26	0.43	0.92	2	0.12	0.43	1.4	1.6	2	0.84	1.6	3.2	2.1	0.56	1.5	3.1	1.9	0.41	3.3	1	0.34	0.34	0.33	<0.10	1.3
S3-2D-L2-W250-1	0.21	0.41	0.36	0.46	1.1	2.6	0.12	0.41	1.4	1.8	2.3	0.82	1.6	3.3	2.2	0.6	1.5	3.3	1.9	0.43	3.6	1.2	0.22	0.49	0.37	<0.10	1.2
S3-2D-L2-W250-2	0.22	0.43	0.32	0.42	0.95	2	0.12	0.41	1.4	2	2.2	0.77	1.6	3.2	2.2	0.54	1.4	3	1.8	0.4	3.2	1.2	0.24	0.44	0.4	<0.10	1.3
S3-4D-L2	0.18	0.28	0.33	0.27	0.63	2.3	0.076	0.25	0.77	1.1	1.4	0.59	1.2	2.3	1.4	0.38	1.1	2.1	1.2	0.3	1.6	0.72	<0.33	0.34	0.36	<0.10	
S3-6D-L2	0.18	0.4	0.24	0.29	0.54	1.3	0.084	0.26	0.67	0.89	1	0.5	0.96	1.9	1.1	0.31	0.85	1.8	1	0.27	0.98	0.68	0.13	0.14	0.14	<0.10	
S3-8D-L2	0.18	0.33	0.3	0.25	0.36	0.96	0.082	0.19	0.5	0.6	1.5	0.33	0.6	1	0.67	0.19	0.53	1.3	0.62	0.14	0.69	0.37	0.072	0.1	0.081	<0.10	
S3-10D-L2	0.16	0.25	0.25	0.2	0.34	<1.4	0.074	0.16	0.41	0.56	0.73	0.39	0.72	1.2	0.71	0.2	0.49	1.2	0.66	0.15	0.76	0.41	<0.33	0.18	<0.22	<0.10	

Table G-8: AWB Moderate Conditions - PAH water data at 1.0 m

mple Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S3-2H-L3-W250-1	<0.10	<0.10	<0.20	<0.010	0.011	0.037	<0.0085	0.027	<0.050	0.019	<0.050	0.014	0.015	<0.040	0.08	0.021	1.1	1.3	0.16	0.083	0.037	<0.20	0.095	1.1	3	0.99	1.2
S3-2H-L3-W250-2	<0.10	<0.10	<0.20	<0.010	0.017	0.052	<0.0085	0.041	<0.050	0.032	0.057	0.017	0.011	<0.040	0.095	0.03	1.2	1.2	0.21	0.13	0.063	<0.20	0.16	1.2	3.3	1.4	1.6
S3-4H-L3-W250-1																											
S3-4H-L3-W250-2																											
S3-6H-L3-W250-1	<0.10	<0.10	<0.20	0.026	0.036	0.11	0.022	0.071	<0.050	0.052	0.11	0.056	<0.026	0.05	0.19	<0.045	2.1	2.1	0.45	0.24	0.15	0.46	0.33	3.8	4.4	2.9	2.9
S3-6H-L3-W250-2	<0.10	<0.10	<0.20	0.019	0.022	0.067	0.012	0.048	<0.050	0.054	0.069	0.03	<0.015	<0.040	0.16	<0.034	1.8	2.1	0.34	0.16	0.1	0.39	0.22	3.4	3.4	2	1.9
S3-12H-L3-W250-1	<0.10	<0.10	<0.20	0.015	0.013	0.045	<0.0085	0.031	<0.050	0.022	<0.050	0.02	0.011	<0.040	0.15	0.019	2	2.3	0.25	0.1	0.069	0.48	0.13	3.7	3.1	1.5	1.5
S3-12H-L3-W250-2	<0.10	<0.10	<0.20	0.018	0.017	0.058	0.01	0.038	<0.050	0.03	0.053	0.036	<0.019	<0.040	0.15	<0.027	1.9	2.2	0.28	0.12	0.081	0.47	0.18	3.6	3.3	1.8	1.7
S3-1D-L3-W250-1	<0.10	<0.10	<0.20	0.02	0.026	0.076	0.014	0.056	<0.050	0.037	0.074	0.041	0.023	<0.040	0.16	0.034	1.9	2.2	0.35	0.18	0.11	0.45	0.24	3.6	3.6	2.3	2.4
S3-1D-L3-W250-2	<0.10	<0.10	<0.20	0.018	0.018	0.064	0.011	0.043	<0.050	0.035	0.062	0.034	<0.019	<0.040	0.17	<0.040	2.2	2.6	0.32	0.14	0.097	0.6	0.18	4	3.5	1.9	1.9
S3-2D-L3-W250-1	<0.10	<0.10	<0.20	0.018	0.019	0.058	0.0098	0.036	<0.050	0.028	0.055	0.033	0.023	<0.040	0.14	<0.024	1.7	2.1	0.28	0.13	0.089	0.48	0.17	3.2	2.8	1.6	1.7
S3-2D-L3-W250-2	<0.10	<0.10	<0.20	0.016	0.017	0.051	0.01	0.034	<0.050	0.027	<0.050	0.029	<0.020	<0.040	0.13	<0.021	1.6	2.1	0.25	0.11	0.076	0.53	0.16	3.1	2.5	1.4	1.5
S3-4D-L3	<0.10	<0.10	<0.20	0.022	0.012	0.043	<0.0085	0.026	<0.050	0.02	<0.050	0.013	0.0089	<0.040	0.12	0.022	1.6	2	0.22	0.09	0.061	1.5	0.11	2.8	2.2	1.1	1.3
S3-6D-L3	<0.10	<0.10	<0.20	0.028	0.0089	0.027	<0.0085	0.021	<0.050	0.015	<0.050	0.017	<0.0075	<0.040	0.099	0.013	1.1	1.3	0.16	0.057	0.04	<0.62	0.063	2	1.4	0.6	0.71
S3-8D-L3																											
S3-10D-L3	<0.10	<0.10	<0.20	0.026	<0.0085	0.019	<0.0085	0.017	<0.050	0.0089	<0.050	<0.0085	<0.0075	<0.040	0.094	0.01	0.97	1	0.15	<0.050	0.034	1.3	0.056	1.8	1.3	0.58	0.61

mple Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(bjk)fluoranthene/benzo(a)py	C2-Benzo(bjk)fluoranthene/benzo(a)py	C1-Acenaphthene	1-Methylnaphthalene
S3-2H-L3-W250-1	0.15	0.081	0.28	0.27	0.56	2	0.08	0.31	0.89	1.1	1.1	0.48	0.98	1.8	1.1	0.29	0.86	2.1	0.8	0.25	0.92	0.64	0.21	0.15	0.14	<0.10	
S3-2H-L3-W250-2	0.16	0.085	0.42	0.35	0.87	2.9	0.1	0.48	1.3	1.6	1.7	0.69	1.5	2.8	1.7	0.46	1.4	3.1	1.1	0.38	1.4	1.1	0.26	0.22	0.19	<0.10	
S3-4H-L3-W250-1																											
S3-4H-L3-W250-2																											
S3-6H-L3-W250-1	0.25	0.69	0.58	0.72	1.8	4.2	0.19	0.71	2.6	3.5	4.1	1.4	3	6.4	4.1	1.1	2.8	6	3.8	0.8	6.3	2.2	0.51	0.72	0.5	0.15	1.5
S3-6H-L3-W250-2	0.22	0.53	0.38	0.53	1.1	2.7	0.14	0.5	1.6	2.5	2.7	1	2	4.1	2.6	0.66	1.8	4.2	2.5	0.51	4.2	1.5	0.31	0.45	0.39	0.1	1.3
S3-12H-L3-W250-1	0.22	0.48	0.34	0.43	0.81	2	0.11	0.33	1	1.5	1.7	0.68	1.3	2.5	1.6	0.46	1.1	2.4	1.4	0.32	2.5	0.85	0.24	0.29	0.3	<0.10	1.4
S3-12H-L3-W250-2	0.22	0.49	0.37	0.48	0.93	2.3	0.12	0.4	1.4	1.8	2.2	0.81	1.7	3.1	2.1	0.54	1.4	4	2	0.4	3.2	1	0.31	0.33	0.3	<0.10	1.4
S3-1D-L3-W250-1	0.24	0.53	0.63	0.59	1.3	3.3	0.15	0.54	1.8	2.5	2.8	1.1	2.2	4.3	2.9	0.81	2.2	4.6	3.2	0.56	4.5	1.4	0.33	0.48	0.41	<0.10	1.4
S3-1D-L3-W250-2	0.26	0.52	0.53	0.49	1.1	2.8	0.14	0.44	1.5	2	2.3	0.95	1.7	3.5	2.3	0.61	1.5	3.3	1.8	0.45	3.6	1.1	0.32	0.38	0.32	<0.10	1.6
S3-2D-L3-W250-1	0.21	0.45	0.34	0.43	1.1	2.6	0.12	0.42	1.4	1.9	2.3	0.81	1.7	3.3	2.1	0.55	1.4	3.4	2	0.41	3.3	1.1	0.23	0.5	0.37	<0.10	1.3
S3-2D-L3-W250-2	0.2	0.4	0.28	0.37	0.81	2	0.11	0.36	1.1	1.6	1.9	0.72	1.5	3	1.8	0.49	1.3	2.9	1.7	0.36	2.9	0.98	0.23	0.37	0.29	<0.10	1.2
S3-4D-L3	0.23	0.34	0.37	0.31	0.73	2.3	0.096	0.31	0.88	1.2	1.5	0.65	1.3	2.6	1.5	0.39	1.1	2.4	1.4	0.31	1.6	0.79	0.36	0.32	0.34	<0.10	
S3-6D-L3	0.15	0.34	0.31	0.23	0.43	1.3	0.065	0.22	0.53	0.76	0.79	0.41	0.78	1.6	0.91	0.26	0.7	1.4	0.79	0.21	0.86	0.49	0.16	0.12	0.097	<0.10	
S3-8D-L3																											
S3-10D-L3	0.15	0.26	0.3	0.2	0.28	<1.4	0.066	0.16	0.43	0.54	0.66	0.35	0.66	1.2	0.71	0.2	0.48	1	0.56	0.15	0.8	0.39	<0.33	<0.14	<0.22	<0.10	

Table G-9: AWB Moderate Conditions - PAH water data at 1.5 m

Sample Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S9B-2H-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.21	0.13	0.063	<0.050	<0.020	0.22	<0.050	0.43	0.48	0.15	0.13
S9B-2H-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.19	0.13	0.056	<0.050	<0.020	<0.20	<0.050	0.41	0.46	0.15	<0.10
S9B-4H-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.2	0.14	0.062	<0.050	<0.020	<0.20	<0.050	0.45	0.48	0.15	0.1
S9B-4H-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.21	0.15	0.068	<0.050	<0.020	0.22	<0.050	0.47	0.49	0.18	0.12
S9B-6H-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.23	0.15	0.094	<0.050	<0.020	<0.30	<0.050	0.48	0.68	0.27	0.25
S9B-6H-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.22	0.15	0.085	<0.050	<0.020	<0.35	<0.050	0.46	0.63	0.27	0.18
S9B-12H	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.073	<0.0085	0.26	0.24	0.13	<0.050	<0.020	0.93	<0.050	0.52	0.59	0.24	0.12
S9B-24H	0.11	<0.10	<0.20	0.023	0.013	0.024	<0.0085	0.02	<0.050	0.012	<0.050	0.027	<0.0075	0.042	0.27	0.017	1.8	1.9	0.54	<0.050	0.032	1.5	0.17	3.2	5.4	4.4	4.2
S9B-2D	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.11	<0.0085	0.63	0.76	0.16	<0.050	<0.020	1.2	<0.050	1.2	1.3	0.53	0.3
S9B-4D	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.15	<0.0085	1	1.3	0.23	<0.050	<0.020	1.6	<0.050	1.9	2.3	0.93	0.42
S9B-6D	0.1	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.18	<0.0085	1.3	1.5	0.25	<0.050	0.036	1.2	<0.050	2.4	2.5	1.2	0.61
S9B-8D	0.12	<0.10	<0.20	0.017	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.21	<0.0085	1.3	1.6	0.27	<0.050	0.03	1.6	<0.050	2.5	2.7	1.4	0.62
S9B 9D	0.15	<0.10	<0.20	0.02	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.24	<0.0085	1.7	2.1	0.29	<0.050	0.035	1.4	<0.050	3.2	3.6	1.7	0.81
S9B 10D	0.16	<0.10	<0.20	0.027	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.24	<0.0085	1.9	2.3	0.31	<0.050	0.041	1.7	<0.050	3.6	4	1.9	0.89

Sample Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(b|k)fluoranthene/benzo(a)py	C2-Benzo(b|k)fluoranthene/benzo(a)py	C1-Acenaphthene	1-Methylnaphthalene
S9B-2H-W250-1	0.024	<0.10	0.059	0.08	0.19	0.45	0.05	0.088	0.16	0.081	<0.020	0.13	0.092	0.063	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.17
S9B-2H-W250-2	<0.020	<0.10	0.044	0.071	0.17	0.31	0.043	0.078	0.14	0.076	<0.020	0.11	0.087	<0.050	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.15
S9B-4H-W250-1	0.024	<0.10	0.066	0.074	0.21	0.46	0.046	0.076	0.14	0.079	<0.020	0.12	0.081	<0.050	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.17
S9B-4H-W250-2	0.03	0.13	0.071	0.08	0.22	0.41	0.051	0.084	0.15	0.079	<0.020	0.13	0.083	0.072	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.17
S9B-6H-W250-1	0.044	0.23	0.11	0.13	0.12	0.84	0.051	0.16	0.26	0.16	<0.020	0.2	0.21	0.16	<0.050	0.028	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S9B-6H-W250-2	0.042	0.21	0.083	0.11	0.17	0.48	0.049	0.15	0.19	0.12	<0.020	0.15	0.13	0.091	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S9B-12H	0.049	0.27	0.22	0.19	0.25	0.77	0.058	0.14	0.17	0.097	<0.020	0.16	0.15	0.14	<0.050	<0.020	0.048	<0.020	<0.020	0.01	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S9B-24H	0.17	0.48	0.63	0.88	1.4	2.6	0.32	1.3	3.2	2.3	1.5	1.5	2.2	2.4	1	0.35	0.63	1.2	0.72	0.2	0.93	0.44	0.076	0.12	0.079	0.14	
S9B-2D	0.078	0.21	0.1	0.21	0.24	0.77	0.098	0.16	0.19	0.093	0.043	0.21	0.17	0.076	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S9B-4D	0.12	0.24	0.13	0.3	0.31	1	0.14	0.26	0.3	0.11	0.043	0.27	0.2	0.11	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S9B-6D	0.14	0.28	0.29	0.36	0.5	1	0.18	0.21	0.35	0.18	<0.020	0.31	0.22	0.12	0.055	<0.020	0.035	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S9B-8D	0.15	0.32	0.34	0.41	0.46	1.2	0.2	0.33	0.36	0.17	<0.020	0.33	0.25	0.11	0.057	<0.020	0.052	<0.020	<0.020	<0.0085	<0.0085	<0.0085	0.013	<0.0075	<0.0075	<0.10	
S9B 9D	0.18	0.33	0.3	0.42	0.49	1	0.23	0.41	0.4	0.19	0.074	0.39	0.25	0.15	0.077	0.039	0.071	<0.020	<0.020	<0.0085	<0.0085	<0.0085	0.018	0.011	0.016	<0.10	
S9B 10D	0.21	0.34	0.31	0.38	0.48	1.5	0.23	0.37	0.38	0.17	<0.020	0.44	0.29	0.19	0.061	0.034	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.060	<0.33	<0.14	<0.22	<0.10	

Table G-10: CLWB Static Conditions - PAH water data at 1.0 m

mple Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S9C-2H-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.27	0.29	0.066	<0.050	<0.020	0.23	<0.050	0.56	0.59	0.25	0.17
S9C-2H-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.28	0.29	0.068	<0.050	<0.020	0.26	<0.050	0.57	0.58	0.27	0.16
S9C-4H-W250-1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.38	0.41	0.082	<0.050	<0.020	<0.48	<0.050	0.72	0.87	0.32	0.18
S9C-4H-W250-2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	<0.050	<0.0085	0.37	0.39	0.086	<0.050	<0.020	<0.40	<0.050	0.7	0.75	0.3	0.17
S9C-6H-W250 1	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.057	<0.0085	0.48	0.54	0.097	<0.050	<0.020	<0.52	<0.050	0.93	1	0.4	0.19
S9C-6H-W250 2	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.058	<0.0085	0.48	0.55	0.099	<0.050	<0.020	<0.48	<0.050	0.89	0.89	0.39	0.18
S9C-12H	<0.10	<0.10	<0.20	<0.010	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.11	<0.0085	0.76	0.98	0.16	<0.050	<0.020	1	<0.050	1.4	1.5	0.64	0.38
S9C-24H	0.16	<0.10	<0.20	<0.040	0.018	0.031	<0.020	0.018	<0.050	0.015	<0.050	0.029	0.015	0.048	0.29	0.021	1.8	1.9	0.55	<0.050	0.035	1.9	0.17	3.3	5.5	4.6	4.5
S9C-2D	0.17	<0.10	<0.20	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.31	<0.0085	2.1	2.4	0.41	<0.050	<0.020	1.9	<0.050	3.8	5	2.5	1.5
S9C-4D	0.27	<0.10	<0.20	0.031	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.46	<0.0085	2.8	2.6	0.55	<0.050	0.02	2.5	<0.050	5.2	7.1	3.5	1.7
S9C-6D	0.28	<0.10	<0.20	0.037	<0.0085	0.015	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.48	<0.0085	2.6	2.2	0.55	<0.050	0.022	2.1	<0.050	4.8	7.1	3.7	1.6
S9C-8D	0.19	<0.10	<0.20	0.034	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.4	<0.0085	1.2	0.79	0.51	<0.050	0.022	1.9	<0.050	2.2	4.1	3.2	1.6
S9C 9D	0.26	<0.10	<0.20	0.045	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.49	<0.0085	1.6	1	0.58	<0.050	<0.020	1.6	<0.050	3.1	6.9	3.6	1.8
S9C 10D	0.25	<0.10	<0.20	0.044	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.47	<0.0085	1.7	1.1	0.52	<0.050	<0.020	2	<0.050	3.2	6.7	3.5	1.8

mple Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(bjk)fluoranthene/benzo(a)py	C2-Benzo(bjk)fluoranthene/benzo(a)py	C1-Acenaphthene	1-Methylnaphthalene
S9C-2H-W250-1	0.03	0.1	0.064	0.086	0.17	0.29	0.049	0.08	0.17	0.11	<0.020	0.12	0.1	0.077	<0.050	<0.020	0.024	<0.020	<0.020	<0.0085	0.012	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.22
S9C-2H-W250-2	0.031	0.1	0.063	0.088	0.18	0.3	0.048	0.079	0.17	0.1	<0.020	0.12	0.11	0.074	<0.050	<0.020	0.031	<0.020	<0.020	<0.0085	0.023	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	0.22
S9C-4H-W250-1	0.052	0.22	0.086	0.1	0.081	0.5	0.04	0.07	0.12	0.066	<0.020	0.11	0.096	0.066	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S9C-4H-W250-2	0.049	0.21	0.089	0.1	0.16	0.53	0.046	0.079	0.14	0.082	<0.020	0.13	0.11	0.078	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S9C-6H-W250 1	0.061	0.22	0.099	0.12	0.13	0.46	0.052	0.11	0.14	0.08	<0.020	0.13	0.11	0.085	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S9C-6H-W250 2	0.063	0.24	0.097	0.13	0.18	0.39	0.055	0.11	0.15	0.084	<0.020	0.14	0.084	0.054	<0.050	<0.020	<0.020	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	<0.10	
S9C-12H	0.084	0.26	0.25	0.25	0.27	0.63	0.079	0.15	0.21	0.11	<0.020	0.19	0.17	0.11	<0.050	0.023	0.056	<0.020	<0.020	0.012	0.041	0.013	<0.0085	<0.0075	<0.0075	<0.10	
S9C-24H	0.18	0.48	0.63	0.9	1.5	2.6	0.33	1.4	3.3	2.4	1.4	1.5	2.3	2.5	1	0.37	0.72	1.3	0.81	0.23	1.1	0.44	0.11	0.11	0.1	0.18	
S9C-2D	0.21	0.36	0.25	0.55	0.46	0.6	0.25	0.46	0.81	0.49	0.24	0.56	0.58	0.47	0.16	0.064	0.15	0.19	<0.020	0.037	0.13	0.065	<0.0085	<0.0075	<0.0075	<0.10	
S9C-4D	0.3	0.46	0.34	0.76	0.57	<0.050	0.35	0.53	0.72	0.35	0.17	0.65	0.54	0.38	0.12	0.071	0.11	<0.020	<0.020	0.024	0.099	<0.0085	<0.0085	<0.0075	<0.0075	0.16	
S9C-6D	0.3	0.48	0.53	0.8	0.55	0.73	0.39	0.56	0.61	0.27	<0.020	0.6	0.41	0.25	0.082	0.052	0.055	<0.020	<0.020	<0.0085	<0.0085	<0.0085	<0.0085	<0.0075	<0.0075	0.15	
S9C-8D	0.18	0.35	0.45	0.74	0.54	0.71	0.37	0.58	0.71	0.33	<0.020	0.6	0.47	0.32	0.12	0.054	0.072	<0.020	<0.020	0.019	0.094	<0.0085	0.032	<0.0075	0.014	0.13	
S9C 9D	0.22	0.44	0.52	0.84	0.59	0.7	0.42	0.64	0.73	0.3	0.12	0.68	0.46	0.27	0.15	0.054	0.076	<0.020	0.022	<0.0085	<0.0085	<0.0085	<0.0085	0.008	0.013	0.16	
S9C 10D	0.24	0.45	0.51	0.84	0.57	0.65	0.38	0.6	0.69	0.31	<0.020	0.63	0.46	0.27	0.11	0.052	0.078	<0.020	<0.020	0.014	0.045	0.02	0.016	<0.0075	0.01	0.15	

Table G-11: CLWB Mild Conditions - PAH water data at 1.0 m

mple Point	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(b&j)fluoranthene	Benzo(k)fluoranthene	Benzo(ghi)perylene	Benzo(c)phenanthrene	Benzo(a)pyrene	Benzo(e)pyrene	Chrysene	Dibenz(ah)anthracene	Fluoranthene	Fluorene	Indeno(123-cd)pyrene	2-Methylnaphthalene	Naphthalene	Phenanthrene	Perylene	Pyrene	Quinoline	Retene	C1-Naphthalene	C2-Naphthalene	C3-Naphthalene	C4-Naphthalene
S9A-2H-W250-1	1.7	<0.50	<1.0	0.35	0.61	0.6	0.12	0.34	<0.25	0.47	0.56	0.79	<0.15	0.58	2.8	<0.20	11	4.6	8.9	1.1	0.97	<30	5.1	20	68	92	94
S9A-2H-W250-2	0.94	<0.10	<0.20	0.18	0.22	0.31	0.06	0.19	<0.050	0.26	0.3	0.46	0.095	0.3	1.6	<0.13	6.4	3.8	4.9	0.58	0.49	<1.9	2.6	12	35	49	50
S9A-4H-W250-1	0.4	<0.10	<0.20	0.066	0.072	0.11	0.019	0.065	<0.050	0.066	0.099	0.16	<0.030	0.11	0.72	<0.043	3.7	3.3	1.9	0.19	0.17	<1.1	0.8	6.9	15	17	16
S9A-4H-W250-2	0.35	<0.10	<0.20	0.052	0.057	0.076	0.015	0.049	<0.050	0.059	0.076	0.11	<0.022	0.084	0.62	<0.032	3.6	3.6	1.5	0.14	0.13	0.94	0.66	6.8	13	14	13
S9A-6H-W250-1	0.25	<0.10	0.71	0.12	0.055	0.083	0.011	0.048	<0.050	0.049	0.083	0.11	0.027	0.09	0.61	0.031	3.4	3.1	1.4	0.14	0.1	<0.81	0.58	6.2	12	12	11
S9A-6H-W250-2	0.31	<0.10	0.51	0.084	0.032	0.056	<0.0085	0.04	<0.050	0.034	0.053	0.073	0.02	0.063	0.55	0.027	3.5	3.4	1.1	0.092	0.071	<1.3	0.4	6.4	12	9.6	8
S9A-12H	0.36	<0.10	<0.20	<0.10	0.035	0.061	<0.010	0.036	<0.050	0.038	0.06	0.066	0.025	0.08	0.66	0.024	4	4	1.3	0.094	0.071	3	0.4	7	12	11	11
S9A-24H	0.33	<0.10	<0.20	0.06	0.019	0.034	<0.0085	0.022	<0.050	0.021	<0.050	0.045	0.0094	0.061	0.57	0.016	3.4	3.3	0.99	0.062	0.046	3.2	0.26	5.9	10	7.9	6.5
S9A-2D	0.37	<0.10	<0.20	<0.080	0.027	0.044	<0.0085	0.03	<0.050	0.024	<0.050	0.055	<0.0075	0.064	0.71	0.022	3.3	2.8	1.2	0.063	0.054	2.6	0.31	5.9	11	8.6	7.8
S9A-4D	0.26	<0.10	<0.20	<0.050	0.011	0.025	<0.0085	0.017	<0.050	0.017	<0.050	0.031	<0.0075	0.048	0.54	0.014	1.5	1.2	0.94	<0.050	0.039	3.2	0.2	2.9	5.6	4.8	4.4
S9A-6D	<0.24	<0.24	<0.49	<0.024	<0.021	<0.021	<0.021	<0.021	<0.12	<0.018	<0.12	<0.021	<0.018	<0.098	0.29	<0.021	0.73	0.58	0.42	<0.12	<0.049	<0.49	<0.12	1.6	3.5	2	0.94
S9A-8D																											
S9A 9D	0.14	<0.10	<0.20	0.044	<0.0085	0.01	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.33	<0.0085	0.84	0.6	0.54	<0.050	0.034	2.1	<0.050	1.5	3.1	2.6	1.7
S9A 10D	0.17	<0.10	<0.20	0.052	<0.0085	<0.0085	<0.0085	<0.0085	<0.050	<0.0075	<0.050	<0.0085	<0.0075	<0.040	0.36	<0.0085	1	0.7	0.59	<0.050	0.036	2.5	<0.050	2	3.5	2.8	1.8

mple Point	Biphenyl	C1-Biphenyl	C2-Biphenyl	C1-Fluorene	C2-Fluorene	C3-Fluorene	Dibenzothiophene	C1-Dibenzothiophene	C2-Dibenzothiophene	C3-Dibenzothiophene	C4-Dibenzothiophene	C1-Phenanthrene/anthracene	C2-Phenanthrene/anthracene	C3-Phenanthrene/anthracene	C4-Phenanthrene/anthracene	C1-Fluoranthene/pyrene	C2-Fluoranthene/pyrene	C3-Fluoranthene/pyrene	C4-Fluoranthene/pyrene	C1-Benzo(a)anthracene/chrysene	C2-Benzo(a)anthracene/chrysene	C3-Benzo(a)anthracene/chrysene	C4-Benzo(a)anthracene/chrysene	C1-Benzo(bjk)fluoranthene/benzo(a)py	C2-Benzo(bjk)fluoranthene/benzo(a)py	C1-Acenaphthene	1-Methylnaphthalene
S9A-2H-W250-1	1.1	4.1	6.5	15	29	65	5.2	30	94	70	46	33	56	63	28	8.8	18	36	19	5.5	40	13	3.3	3.7	3.2	3	7.6
S9A-2H-W250-2	0.66	2	3.7	8	16	30	2.8	12	49	35	24	16	29	25	14	4.7	9.2	17	10	2.9	21	6.9	1.6	2.1	1.7	1.5	4.7
S9A-4H-W250-1	0.35	0.93	1.3	2.9	5.1	10	1.1	4.4	16	12	8	5.5	9.6	11	4.1	1.6	3.1	6	3.5	1	7.1	2.2	0.53	0.71	0.54	0.56	2.7
S9A-4H-W250-2	0.33	0.77	1	2.4	4	7.4	0.91	3.4	12	8.8	6.4	4.4	7.3	8	3.2	1.2	2.3	4.4	2.5	0.72	5.3	1.4	0.38	0.51	0.37	0.42	2.7
S9A-6H-W250-1	0.29	0.76	1.3	2.3	3.9	8.7	0.82	4.1	12	8.2	5.7	4.6	7.3	6	2.9	1.2	2.2	4.6	2.5	0.78	2.8	1.7	0.36	0.36	0.28	0.42	
S9A-6H-W250-2	0.3	0.69	1.1	1.9	3	6.2	0.66	2.9	7.6	5.4	4.4	3.4	5	4.3	2.2	0.81	1.6	2.6	1.9	0.53	1.9	1.1	0.3	0.28	0.25	0.37	
S9A-12H	0.39	0.82	1.2	2.1	3.1	7.4	0.77	3.4	8.4	6.2	3.5	3.5	5.3	6	2.5	0.85	1.6	3.4	1.9	0.54	2.7	1.2	0.069	0.26	0.23	0.41	
S9A-24H	0.34	0.66	1	1.6	2	3.7	0.6	2.2	5	3.5	2.1	2.4	3.4	3.7	1.5	0.51	1	1.9	1.1	0.31	1.5	0.64	0.13	0.18	0.15	0.28	
S9A-2D	0.37	0.64	0.9	1.8	2.4	4.1	0.79	2.6	6.7	4.5	2.7	2.8	4.1	4.3	1.6	0.63	1.2	2.5	0.84	0.39	2	0.83	0.12	0.19	0.18	0.38	
S9A-4D	0.21	0.44	0.67	1.2	1.5	2.5	0.6	1.8	3.7	2.5	1.5	1.8	2.4	2.6	1	0.37	0.75	1.7	0.47	0.23	1.1	0.47	0.099	0.13	0.11	0.22	
S9A-6D	0.13 (1)	0.47 (1)	0.66 (1)	0.62 (1)	0.48 (1)	1.3 (1)	0.25	0.36	0.66	0.35	0.18	0.48	0.40	0.30	0.13	0.054	0.12	0.27	0.083	0.029	0.072	<0.021	<0.021	<0.018	<0.018	<0.24	0.64
S9A-8D																											
S9A 9D	0.12	0.31	0.42	0.71	0.66	1.2	0.37	0.78	1.2	0.79	0.5	0.8	0.81	0.69	0.29	0.12	0.21	0.3	0.2	0.051	0.25	0.11	0.031	0.031	0.018	0.1	
S9A 10D	0.15	0.29	0.39	0.73	0.67	<1.4	0.35	0.62	1	0.62	0.38	0.9	0.87	0.7	0.24	0.096	0.18	0.29	0.12	0.042	0.16	<0.060	<0.33	<0.14	<0.22	0.12	

Table G-12: CLWB Moderate Conditions - PAH water data at 1.0 m

Sample Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S1-2H-L1-W40-1	37	18	0.71	3.8	1.2	5	<100	<100
S1-2H-L1-W40-2	29	14	0.53	3	1	4	<100	<100
S1-2H-L1-W40-3	30	15	0.55	3.2	1.1	4.3	<100	<100
S1-4H-L1-W40-1	28	13	0.49	2.8	0.88	3.7		<100
S1-4H-L1-W40-2	30	14	0.5	2.9	0.99	3.9		<100
S1-4H-L1-W40-3	29	14	0.5	2.9	1	3.9		<100
S1-6H-L1-W40-1	21	11	0.4	2.3	0.76	3	<100	<100
S1-6H-L1-W40-2	25	13	0.49	2.7	0.89	3.6	<100	<100
S1-6H-L1-W40-3	23	11	0.43	2.4	0.81	3.2	<100	<100
S1-12H-L1-W40-1	27	13	0.59	3.1	1	4.2	<100	<100
S1-12H-L1-W40-2	28	14	0.61	3.3	1.1	4.4	<100	<100
S1-12H-L1-W40-3	28	14	0.58	3.2	1.1	4.3	<100	<100
S1-1D-L1-W40-1	180	110	3.3	21	7.1	28	<100	410
S1-1D-L1-W40-2	200	110	3.5	22	7.6	29	<100	410
S1-1D-L1-W40-3	190	110	3.4	21	7.4	29	<100	300
S1-2D-L1-W40-1	250	160	4.9	33	11	44	<100	490
S1-2D-L1-W40-2	260	170	5.2	35	11	46	<100	450
S1-2D-L1-W40-3	250	170	5.3	35	11	46	120	600
S1-4D-L1	350	250	8.7	50	17	68	120	790
S1-6D-L1	400	290	9.4	53	20	73	<100	750
S1-8D-L1	450	360	14	73	30	100	260	1200
S1-10D-L1	390	300	9.3	42	22	64	370	1100

Table G-13: AWB Static - BTEX and C6-C10 water data at 0.5 m

Sample Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S1 2H L2 W40-1	26	13	0.46	2.7	0.93	3.7	<100	120
S1 2H L2 W40-2	23	12	0.46	2.8	0.87	3.6	<100	<100
S1 2H L2 W40-3	31	15	0.61	3.3	1.1	4.4	<100	<100
S1-4H-L2-W40-1	31	14	0.53	2.9	0.93	3.8		<100
S1-4H-L2-W40-2	30	14	0.54	3.1	0.95	4		<100
S1-4H-L2-W40-3	31	15	0.56	3.1	1.1	4.2		<100
S1-6H-L2-W40-1	30	14	0.53	2.9	0.94	3.8	<100	<100
S1-6H-L2-W40-3	16	7.8	<0.40	1.6	0.63	2.2	<100	<100
S1-12H-L2-W40-1	25	11	0.42	2.4	0.86	3.2	<100	<100
S1-12H-L2-W40-2	27	13	0.61	3.3	1	4.3	<100	<100
S1-12H-L2-W40-3	25	12	0.54	3	1	4	<100	<100
S1-1D-L2-W40-1	210	120	3.9	24	8.4	33	<100	340
S1-1D-L2-W40-2	220	130	3.9	25	8.4	33	<100	450
S1-1D-L2-W40-3	210	130	3.9	25	8.4	33	<100	440
S1-2D-L2-W40-1	230	140	4.9	30	10	40	340	750
S1-2D-L2-W40-2	260	160	5.3	33	11	44	<100	440
S1-2D-L2-W40-3	830	500	16	110	33	140	340	1800
S1-4D-L2	330	240	8.3	49	17	66	<100	750
S1-6D-L2	390	290	9.9	57	21	78	470	1200
S1-8D-L2	460	360	13	70	28	98	240	1200
S1-10D-L2	370	280	8.4	38	22	60	<100	780

Table G-14: AWB Static - BTEX and C6-C10 water data at 1.0 m

mple Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S1-2H L3 W40-1	0.6	0.72	<0.40	<0.80	<0.40	<0.80	<100	<100
S1-2H-L3-W40-2	0.62	0.8	<0.40	<0.80	<0.40	<0.80	<100	<100
S1-2H-L3-W40-3	0.61	0.76	<0.40	<0.80	<0.40	<0.80	<100	<100
S1-4H-L3-W40-1	6.7	3.3	<0.40	1.5	0.59	2.1	<100	<100
S1-4H-L3-W40-2	6.6	3.1	<0.40	1.1	0.44	1.5	<100	<100
S1-4H-L3-W40-3	8.2	4	<0.40	1.1	0.44	1.5	<100	<100
S1-6H-L3-W40-1	15	7	<0.40	1.7	0.58	2.3	<100	<100
S1-6H-L3-W40-2	15	6.9	<0.40	1.8	0.56	2.3	<100	<100
S1-6H-L3-W40-3	15	7	<0.40	1.8	0.58	2.4	<100	<100
S1-12H-L3-W40-1	23	11	0.46	2.5	0.89	3.3	<100	<100
S1-12H-L3-W40-2	23	11	0.48	2.5	0.87	3.4	<100	<100
S1-12H-L3-W40-3	23	10	<0.40	2.2	0.83	3.1	<100	<100
S1-1D-L3-W40-1	310	180	5.5	35	12	47	<100	600
S1-1D-L3-W40-2	300	170	5.2	34	11	45	<100	570
S1-1D-L3-W40-3	300	170	5.3	34	12	45	<100	550
S1-2D-L3-W40-1	270	170	5.8	35	12	46	220	700
S1-2D-L3-W40-2	240	160	5.2	32	11	43	230	680
S1-2D-L3-W40-3	250	160	5.6	34	11	45	280	740
S1-4D-L3	350	250	8.9	56	19	75	150	840
S1-6D-L3	430	320	11	64	24	88	360	1200
S1-8D-L3	320	260	10	54	22	76	390	1100
S1-10D-L3	370	270	7.8	35	20	55	<100	610

Table G-15: AWB Static - BTEX and C6-C10 water data at 1.5 m

Sample Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S2-2H-L1-W40-1	170	73	1.9	11	3.4	14		
S2-2H-L1-W40-2	140	62	1.9	11	3.2	14		
S2-2H-L1-W40-3	150	63	1.9	11	3.4	14		
S2-4H-L1-W40-2	270	130	3.3	20	6	26	<100	480
S2-4H-L1-W40-3	250	110	3	18	5.6	24	<100	380
S2-6H-L1-W40-1	310	140	3.7	23	7.5	31	120	600
S2-6H-L1-W40-2	300	140	3.7	23	7.2	30	<100	520
S2-6H-L1-W40-3	290	140	3.8	23	<0.40	23	<100	460
S2-12H-L1-W40-1	490	250	8.2	47	15	62	140	960
S2-12H-L1-W40-2	510	260	8.3	48	15	64	120	960
S2-12H-L1-W40-3	520	270	8.7	50	16	65	150	1000
S2-1D-L1-W40-1	660	360	10	61	22	83	210	1300
S2-1D-L1-W40-2	690	400	11	70	23	92	<100	1200
S2-1D-L1-W40-3	830	460	13	85	26	110	<100	880
S2-2D-L1-W40-1	790	480	16	110	34	140	360	1800
S2-2D-L1-W40-2	830	520	17	110	36	150	280	1800
S2-2D-L1-W40-3	780	480	16	100	34	140	290	1700
S2-4D-L1	800	540	20	120	40	160	480	2000
S2-6D-L1	350	260	9.7	60	21	81	480	1200
S2-8D-L1	120	110	4.7	30	11	41	180	460
S2-10D-L1	87	72	2.8	16	8.4	25	230	410

Table G-16: AWB Mild Conditions - BTEX and C6-C10 water data at 0.5 m

Sample Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S2-2H-L2-W40-1	150	73	1.9	12	3.6	15		
S2-2H-L2-W40-2	150	72	1.9	12	3.5	15		
S2-2H-L2-W40-3	150	73	1.9	12	3.6	16		
S2-4H-L2-W40-1	260	120	3	20	6	26		450
S2-4H-L2-W40-2	290	140	3.4	22	6.5	28		480
S2-6H-L2-W40-1	290	140	4.2	25	7.7	32	<100	430
S2-6H-L2-W40-2	300	140	3.7	24	7.5	32	<100	560
S2-6H-L2-W40-3	290	140	3.5	22	7.3	29	<100	470
S2-12H-L2-W40-1	510	260	8.4	49	16	65	300	1100
S2-12H-L2-W40-2	500	260	8.2	49	15	64	240	1100
S2-12H-L2-W40-3	500	260	8	48	15	63	190	1000
S2-1D-L2-W40-1	680	380	13	75	24	99	<100	1200
S2-1D-L2-W40-2	670	380	11	68	23	90	<100	1100
S2-1D-L2-W40-3	650	370	11	64	22	86	<100	1100
S2-2D-L2-W40-1	820	500	17	110	36	150	<100	1600
S2-2D-L2-W40-2	800	490	16	110	35	140	360	1800
S2-2D-L2-W40-3	790	490	16	110	35	140	420	1900
S2-4D-L2	720	510	18	110	38	150	<100	1300
S2-6D-L2	330	250	9.1	55	20	75	200	860
S2-8D-L2	160	130	5.7	37	13	50	120	470
S2-10D-L2	84	68	2.6	15	6.2	21	<100	190

Table G-17: AWB Mild Conditions - BTEX and C6-C10 water data at 1.0 m

Sample Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S2-2H-L3-W40-1	130	64	1.7	11	3.1	14		
S2-2H-L3-W40-2	140	65	1.6	11	3.2	14		
S2-2H-L3-W40-3	130	62	1.6	10	3	13		
S2-4H-L3-W40-1	250	120	2.7	18	5.6	24		360
S2-4H-L3-W40-2	250	120	2.9	18	5.8	24		490
S2-4H-L3-W40-3	260	120	3.1	19	5.8	25		470
S2-6H-L3-W40-1	290	140	4	23	7.6	31	<100	380
S2-6H-L3-W40-2	290	140	4.1	24	7.5	32	<100	410
S2-6H-L3-W40-3	290	140	4.1	23	7.6	31	<100	410
S2-12H-L3-W40-1	480	250	8	46	14	60	<100	860
S2-12H-L3-W40-2	490	250	7.9	47	15	61	<100	910
S2-12H-L3-W40-3	490	250	8.2	47	15	61	170	980
S2-1D-L3-W40-1	680	370	12	70	24	94	<100	1000
S2-1D-L3-W40-2	630	360	11	64	21	85	<100	1200
S2-1D-L3-W40-3	670	370	12	72	24	96	<100	950
S2-2D-L3-W40-1	780	480	16	110	33	140	190	1600
S2-2D-L3-W40-2	800	480	16	110	34	140	470	1900
S2-2D-L3-W40-3	770	470	16	110	33	140	390	1800
S2-4D-L3	560	410	14	89	31	120	<100	1100
S2-6D-L3	330	240	8.8	55	20	75	450	1100
S2-8D-L3	130	110	4.3	28	10	38	<100	240
S2-10D-L3	84	66	2.5	14	6	20	<100	210

Table G-18: AWB Mild Conditions - BTEX and C6-C10 water data at 1.5 m

mple Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S3-2H-L1-W40-1	990	590	20	130	38	170		
S3-2H-L1-W40-2	970	570	20	130	37	170		
S3-2H-L1-W40-3	950	560	19	130	36	160		
S3-4H-L1-W40-1	210	130	4.3	27	9.5	37	<100	410
S3-4H-L1-W40-2	880	54	1.9	12	3.7	15	1800	2800
S3-4H-L1-W40-3	900	54	1.8	12	3.7	16	1600	2500
S3-6H-L1-W40-1	710	390	14	87	32	120	150	1400
S3-6H-L1-W40-2	540	300	10	69	24	93	<100	1000
S3-6H-L1-W40-3	870	510	19	120	39	160	310	1900
S3-12H-L1-W40-1	650	400	15	95	32	130	160	1300
S3-12H-L1-W40-2	680	410	15	98	33	130	280	1500
S3-12H-L1-W40-3	660	390	14	91	32	120	210	1400
S3-1D-L1-W40-1	500	400	16	110	33	140	160	1300
S3-1D-L1-W40-2	520	410	17	110	33	140	480	1600
S3-1D-L1-W40-3	520	410	17	110	34	140	480	1600
S3-2D-L1-W40-1	210	250	13	85	28	110	240	820
S3-2D-L1-W40-2	200	240	12	81	28	110	<100	650
S3-2D-L1-W40-3	200	240	12	81	27	110	220	780
S3-4D-L1	44	100	6.1	39	14	53	<100	260
S3-6D-L1	17	64	5	32	12	43	<100	180
S3-8D-L1	5	41	4.5	32	11	43	210	310
S3-10D-L1	1.8	9.9	1.4	8.1	2.8	11	<100	<100

Table G-19: AWB Moderate Conditions - BTEX and C6-C10 water data at 0.5 m

Sample Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S3-2H-L2-W40-1	880	520	17	110	33	140		
S3-2H-L2-W40-2	880	510	17	110	32	150		
S3-2H-L2-W40-3	850	500	17	110	32	150		
S3-4H-L2-W40-1	970	580	20	130	37	170	650	2400
S3-4H-L2-W40-2	960	570	19	130	36	160	550	2300
S3-4H-L2-W40-3	930	550	19	120	35	160	710	2400
S3-6H-L2-W40-1	790	500	18	110	34	140	100	1500
S3-6H-L2-W40-2	810	520	18	110	35	150	160	1700
S3-6H-L2-W40-3	780	490	17	100	33	140	140	1600
S3-12H-L2-W40-1	790	530	22	130	41	170	820	2300
S3-12H-L2-W40-2	770	510	21	120	39	160	740	2200
S3-12H-L2-W40-3	730	440	16	100	36	140	420	1700
S3-1D-L2-W40-1	500	400	16	110	33	140	200	1300
S3-1D-L2-W40-2	520	420	17	110	35	150	290	1400
S3-1D-L2-W40-3	530	420	17	110	34	140	390	1500
S3-2D-L2-W40-1	190	240	12	80	26	110	340	880
S3-2D-L2-W40-2	190	230	12	79	27	110	240	780
S3-2D-L2-W40-3	200	250	12	82	28	110	200	770
S3-4D-L2	48	110	6.7	45	15	59	120	340
S3-6D-L2	14	53	4.1	26	9.6	36	170	280
S3-8D-L2	4.9	37	4.3	31	9.7	40	<100	150
S3-10D-L2	2.1	12	1.5	9.4	3.5	13	<100	<100

Table G-20: AWB Moderate Conditions - BTEX and C6-C10 water data at 1.0 m

Sample Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S3-2H-L3-W40-1	770	440	15	98	28	130		
S3-2H-L3-W40-2	800	460	15	100	29	130		
S3-2H-L3-W40-3	760	440	14	95	28	120		
S3-4H-L3-W40-1	920	540	18	120	35	150	790	2400
S3-4H-L3-W40-2	910	540	18	120	34	150	580	2200
S3-4H-L3-W40-3	930	560	19	120	36	160	720	2400
S3-6H-L3-W40-1	810	490	18	110	33	140	160	1600
S3-6H-L3-W40-2	780	480	17	100	34	140	130	1500
S3-6H-L3-W40-3	830	510	18	110	35	140	160	1700
S3-12H-L3-W40-1	750	500	21	130	39	170	770	2200
S3-12H-L3-W40-2	740	490	20	120	38	160	530	1900
S3-12H-L3-W40-3	500	260	<0.40	49	15	64	1200	2000
S3-1D-L3-W40-1	500	410	17	110	33	140	320	1400
S3-1D-L3-W40-2	530	430	17	110	35	150	150	1300
S3-1D-L3-W40-3	520	420	17	110	34	150	210	1300
S3-2D-L3-W40-1	190	240	12	82	26	110	150	690
S3-2D-L3-W40-2	180	230	12	79	25	100	190	720
S3-2D-L3-W40-3	190	240	12	81	27	110	340	880
S3-4D-L3	54	120	8.1	53	17	70	220	470
S3-6D-L3	15	55	4.2	27	10	37	120	230
S3-8D-L3	4.4	31	3.9	26	8.8	35	110	180
S3-10D-L3	2.6	12	1.4	9.2	3.3	12	<100	110

Table G-21: AWB Moderate Conditions - BTEX and C6-C10 water data at 1.5 m

Sample Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S9B-2H-W40-1	34	17	0.74	3.3	1.3	4.6		
S9B-2H-W40-2	27	13	0.58	2.6	1.1	3.7		
S9B-2H-W40-3	33	16	0.72	3.2	1.2	4.5		
S9B-4H-W40-1	42	21	0.87	4	1.6	5.6		
S9B-4H-W40-2	41	21	0.84	4	1.5	5.5		
S9B-4H-W40-3	41	21	0.84	3.9	1.5	5.4		
S9B-6H-W40 1	44	22	0.9	4.1	1.7	5.8		
S9B-6H-W40 2	45	22	0.92	4.3	1.7	6		
S9B-6H-W40 3	41	22	0.87	4.6	1.8	6.4		
S9B-12H	86	40	1.8	8	3.3	11	<100	150
S9B-24H	200	100	4.7	21	9	30	220	550
S9B-2D	300	190	8.7	38	17	54	<100	510
S9B-4D	430	280	13	37	27	63	220	1000
S9B-6D	500	340	13	21	28	49	140	1000
S9B-8D	430	310	17	22	34	56	430	1200
S9B 9D	490	360	19	22	41	63	<100	970
S9B 10D	520	370	20	20	41	61	<100	980

Table G-22: CLWB Static Conditions - BTEX and C6-C10 water data at 1.0 m

ample Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S9C-2H-W40-1	180	93	3.9	18	6.6	24		
S9C-2H-W40-2	180	92	3.8	17	6.6	24		
S9C-2H-W40-3	170	86	3.5	16	6.3	23		
S9C-4H-W40-1	300	150	6.1	29	11	40		
S9C-4H-W40-2	310	160	6.2	30	12	41		
S9C-4H-W40-3	300	150	6	29	11	40		
S9C-6H-W40 1	370	210	8.4	43	16	59		
S9C-6H-W40 2	370	210	8.3	43	16	58		
S9C-6H-W40 3	380	210	8.5	43	16	59		
S9C-12H	510	260	12	54	22	76	<100	870
S9C-24H	570	320	16	75	30	110	180	1200
S9C-2D	610	460	23	120	47	160	<100	1100
S9C-4D	320	250	14	66	30	95	140	810
S9C-6D	190	130	6.5	27	17	44	190	570
S9C-8D	30	24	1.8	6.3	4.4	11	<100	<100
S9C 9D	25	23	1.7	6.6	4.7	11	220	280
S9C 10D	20	20	1.4	6.2	4.3	11	<100	<100

Table G-23: CLWB Mild Conditions - BTEX and C6-C10 water data at 1.0 m

Sample Point	Benzene	Toluene	Ethylbenzene	m & p-Xylene	o-Xylene	Xylenes (Total)	F1 (C6-C10) BTEX	C6-C10
S9A-2H-W40-1	1300	790	43	200	76	270		
S9A-2H-W40-2	1300	810	45	210	78	280		
S9A-2H-W40-3	1300	800	44	210	77	280		
S9A-4H-W40-1	1600	980	56	260	98	360		
S9A-4H-W40-2	1600	1100	58	270	100	370		
S9A-4H-W40-3	1600	1100	58	270	100	370		
S9A-6H-W40-1	1300	960	50	250	93	340		
S9A-6H-W40-2	1400	950	50	250	92	340		
S9A-6H-W40-3	1400	940	48	240	91	330		
S9A-12H	1100	750	40	200	77	280	1800	4000
S9A-24H	650	410	22	110	44	150	830	2100
S9A-2D	230	210	12	62	26	88	<100	550
S9A-4D	14	22	2.1	10	5	15	<100	<100
S9A-6D	5.9	8.6	0.71	3.7	1.8	5.5	<100	<100
S9A-8D	6.2	11	0.94	5.6	2.6	8.2	<100	<100
S9A 9D	5.6	9.5	1	4.1	2	6	<100	<100
S9A 10D	8.4	13	1.3	5.5	2.5	8	<100	<100

Table G-24: CLWB Moderate Conditions - BTEX and C6-C10 water data at 1.0 m

Sample Point	Total Petroleum Hydrocarbon
S1-2H-L1-W500	<2.0
S1-6H-L1-W500	<2.0
S1-12H-L1-W500	<2.0
S1-1D-L1-W500	<2.0
S1-2D-L1-W500	2.7
S1-4D-L1	<2.0
S1-6D-L1	<2.0
S1-8D-L1	<2.0
S1-2H L2 W500	<2.0
S1-6H-L2-W500	<2.0
S1-12H-L2-W500	<2.0
S1-1D-L2-W500	<2.0
S1-2D-L2-W500	<2.0
S1-4D-L2	<2.0
S1-6D-L2	<2.0
S1-8D-L2	<2.0
S1-2H L3-W500	<2.0
S1-6H-L3-W500	<2.0
S1-12H-L3-W500	<2.0
S1-1D-L3-W500	<2.0
S1-2D-L3-W500	<2.0
S1-4D-L3	<2.0
S1-6D-L3	<2.0
S1-8D-L3	<2.0

Table G-25: AWB Static Conditions – TPH at 0.5 m (L1 series), 1.0 m (L2 series), and 1.5 m (L3 series)

Sample Point	Total Petroleum Hydrocarbon
S2-4H-L1-W500	<2.0
S2-12H-L1-W500	<2.0
S2-1D-L1-W500	<2.0
S2-2D-L1-W500	2.9
S2-4D-L1	2.2
S2-6D-L1	<2.0
S2-8D-L1	<2.0
S2-2H-L2-W500	<2.0
S2-12H-L2-W500	2.8
S2-1D-L2-W500	<2.0
S2-2D-L2-W500	3.3
S2-4D-L2	<2.0
S2-6D-L2	<2.0
S2-8D-L2	<2.0
S2-2H-L3-W500	<2.0
S2-12H-L3-W500	<2.0
S2-1D-L3-W500	<2.0
S2-2D-L3-W500	3.7
S2-4D-L3	2
S2-6D-L3	<2.0
S2-8D-L3	<2.0

Table G-26: AWB Mild Conditions – TPH at 0.5 m (L1 series), 1.0 m (L2 series), and 1.5 m (L3 series)

Sample Point	Total Petroleum Hydrocarbon
S3-2H-L1-W500	58
S3-4H-L1-W500	30
S3-12H-L1-W500	15
S3-1D-L1-W500	10
S3-2D-L1-W500	7.5
S3-4D-L1	4
S3-6D-L1	3
S3-8D-L1	3.4
S3-2H-L2-W500	21
S3-4H-L2-W500	19
S3-12H-L2-W500	13
S3-1D-L2-W500	11
S3-2D-L2-W500	6.8
S3-4D-L2	4.4
S3-6D-L2	3.3
S3-8D-L2	3.6
S3-2H-L3-W500	19
S3-4H-L3-W500	20
S3-12H-L3-W500	12
S3-1D-L3-W500	9.9
S3-2D-L3-W500	7.5
S3-4D-L3	4.4
S3-6D-L3	3.4
S3-8D-L3	3.6

Table G-27: AWB Moderate Conditions – TPH at 0.5 m (L1 series), 1.0 m (L2 series), and 1.5 m (L3 series)

Sample Point	Total Petroleum Hydrocarbon
S9A-2H-W500	120
S9A-4H-W500	42
S9A-6H-W500	20
S9A-12H	8.4
S9A-24H	5.3
S9A-2D	4.2
S9A-4D	2.7
S9A-6D	<2.0
S9A-8D	<2.0
S9A 9D	<2.0
S9A 10D	<2.0
S9B-2H-W500	<2.0
S9B-4H-W500	<2.0
S9B-6H-W500	<2.0
S9B-12H	<2.0
S9B-24H	<2.0
S9B-2D	<2.0
S9B-4D	<2.0
S9B-6D	2.1
S9B-8D	<2.0
S9B 9D	2.1
S9B 10D	<2.0
S9C-2H-W500	<2.0
S9C-4H-W500	<2.0
S9C-6H-W500	<2.0
S9C-12H	<2.0
S9C-24H	4.6
S9C-2D	<2.0
S9C-4D	<2.0
S9C-6D	<2.0
S9C-8D	<2.0
S9C 9D	<2.0
S9C 10D	<2.0

Table G-28: TPH measured in water samples at 1.0 m - CLWB Static Conditions (S9B series), Mild Conditions (S9C series), and Moderate Conditions (S9A series)

Appendix H: Equipment Testing Oil Sample Analysis

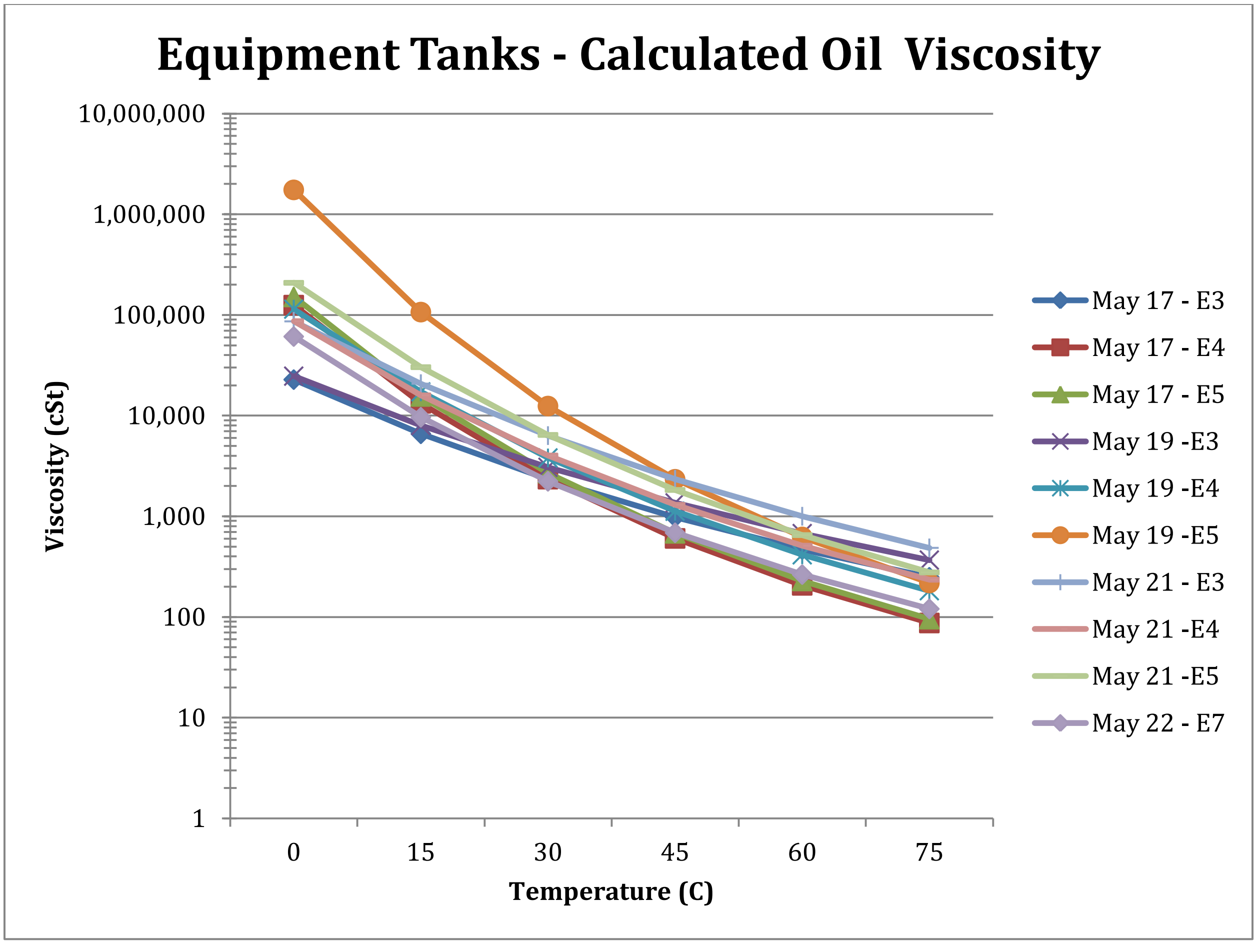
Witt O'Brien's, Polaris Applied Sciences, and
Western Canada Marine Response Corporation

Date Sample Taken	Witt|O'Brien's No.	Maxxam ID No.	Results										
			Density @ 15°C			Viscosity							Water Content
			Rel. Dens.	API	Abs. Den.	@ 5°C	@ 10°C	@ 15°C	@ 60°C	@ 70°C	@ 80°C	@ 90°C	[redacted]
May 13	E7-WC-13 May 2013	GJ4758											.43
May 13	E7-SG-13 May 2013	GJ4759	0.926	21.3	925.2								
May 13	E7-Vis-13 May 2013	GJ4760				447.4	309.6	220.3					
May 15	E6-WC-15 May 2013	GJ9950											4.1
May 15	E6-SG-15 May 2013	GJ9951	0.9533	16.9	952.4								
May 15	E6-Vis-15 May 2013	GJ9952				3224	1963	1252					
May 17	E3-SG-5-17 E3-Vis-5-17 E3-WC-5-17	GL0000	0.986	12	985.1					303.4	205	125.1	35.5
May 17	E4-SG-5-17 E4-Vis-5-17 E4-WC-5-17	GL0001	0.971	14.2	970.1					113.9	68.02		8.8
May 17	E5-SG-5-17 E5-Vis-5-17 E5-WC-5-17	GK9999	0.9756	13.5	974.7				203.2	124.8	73.95		17.7
May 19	E3-SG-5-19 E3-Vis-5-19 E3-WC-5-19	GL0066	0.9908	11.3	989.9					446.2	306.1	184.6	41.2
May 19	E4-SG-5-19 E4-Vis-5-19 E4-WC-5-19	GL0067	0.9834	12.4	982.5					235.9	143.3	95.71	27.7
May 19	E5-SG-5-19 E5-Vis-5-19 E5-WC-5-19	GL0068	0.9879	11.7	987.0					301.5	160.8		28.2
May 21	E3-SG-5-21 E3-Vis-5-21 E3-WC-5-21	GL0054	0.9939	10.9	993.0					611.3	391.2	213.7	45.1
May 21	E4-SG-5-21 E4-Vis-5-21 E4-WC-5-21	GL0055	0.9871	11.9	986.2					299.7	186.2	111.2	22.5
May 21	E5-SG-5-21 E5-Vis-5-21 E5-WC-5-22	GL0056	0.9881	11.7	987.2					362.1	215.3	110.7	33.0
May 22	E7-SG-5-22 E7-Vis-5-22 E7-WC-5-22	GL6308	0.976	13.5	975.1					153.8	95.6		1.2

Density, Viscosity and Water Content from E-Tanks Prior to Equipment Testing.

Date Sample Taken	Witt|O'Brien's No.	Maxxam ID No.	Results (% Water Content)
May 14	LC3-WC-14 May 2013	GJ9937	22
May 14	LC4-WC-14 May 2013	GJ9938	5.7
May 14	LC5-WC-14 May 2013	GJ9939	11
May 16	LC3-WC-16 May 2013	GK3580	11.8
May 16	LC4-WC-16 May 2013	GK3581	8.2
May 16	LC5-WC-16 May 2013	GK3582	91.1
May 18	WC-E3-5-18	GL0049	50.4
May 18	WC-E4-5-18	GL0050	24.1
May 18	WC-E5-5-18	GL0048	31.6
May 20	WC-E3-5-20	GL0060	47.5
May 20	WC-E4-5-20	GL0061	20.0
May 20	WC-E5-5-20	GL0062	36.3
May 22	WC-E3-5-22	GL8599	49
May 22	WC-E4-5-22	GL8600	26.2
May 22	WC-E5-5-22	GL8601	35.2
May 23	WC-E7-Lamor-23	GL8597	13.2
May 23	WC-E7-Aqua-23	GL8598	17.0

Water Content from Calibration Cubes: (samples taken directly from cube after manual, gross, decanting of water).


Equipment Tanks - Calculated Oil Viscosity
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
Viscosity (cSt)
0
15
30
45
60
75
Temperature (C)
May 17 - E3
May 17 - E4
May 17 - E5
May 19 -E3
May 19 -E4
May 19 -E5
May 21 - E3
May 21 -E4
May 21 -E5
May 22 - E7

Appendix I: Flux Chamber Sampling Program in Support of Spill Modelling for the Trans Mountain Expansion Project Final Report

Witt O'Brien's, Polaris Applied Sciences, and
Western Canada Marine Response Corporation

Introduction

RWDI AIR Inc.'s final report, "Flux Chamber Sampling Program in Support of Spill Modelling for the Trans Mountain Expansion Project," dated September 6, 2013, is located on the following pages. Due to the size of the entire report, only the base report is included, and the appendices are excluded. The complete report and further information is available from the Fate and Behavior Final Report authors.

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CONSULTING ENGINEERS & SCIENTISTS

CANADA'S BEST MANAGED COMPANIES

Flux Chamber Sampling Program in Support of Spill Modelling for the Trans Mountain Expansion Project

Gainford, Alberta

Final Report

RWDI # 1202006-7017
September 6, 2013

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EXECUTIVE SUMMARY

RWDI AIR Inc. (RWDI) completed flux chamber measurements in support of watercourse spill hazard modelling at the KMC facility in Gainford, Alberta over the period, May 13 to 22, 2013. RWDI directly measured emission flux rates off of a spill water holding tank. The objective of the study was to measure emission rates that could be used to ground-truth the numerical estimates modelled in the accidental release/hazard assessment for the watercourse and marine spill scenarios. The fresh water tank was loaded to a depth of 25 mm of Cold Lake Winter Blend Diluent Bitumen (dilbit) and left open to changing ambient conditions associated with solar load, wind, precipitation, temperature and so on.

The sampling protocols proposed for this study were based on reference testing methods as published by the Ontario Ministry of the Environment (OSTC ON-6) and the United States Environmental Protection Agency. Samples were collected into glass lined 1.4 L SUMMA canister and were analysed for Total Petroleum Hydrocarbons (aliphatic and aromatic fractionation: Aliphatics >C_5-C_6, Aliphatics >C_6-C_8, Aliphatics >C_8-C_{10}, Aliphatics >C_{10}-C_{12}, Aliphatics >C_{12}-C_{16}, Aromatics >C_7–C_8, Aromatics >C_8-C_{10}, Aromatics >C_{10}-C_{12}, Aromatics >C_{12}-C_{16}); volatile organic compounds, reduced sulphur compounds, and light hydrocarbons (C_1 to C_5). Over the nine day sampling period, emission fluxes were sampled over a two minute period every 8 hours for the first day, every 12 hours from day 2 to day 7, and once per day on days 8 and 9. Sample blanks were also submitted to the outside laboratory.

Decay curves were plotted for all of the chemical groupings noted above and several speciated hydrocarbons. The time duration for a decrease in the emission rate relative to the initial emission rate is summarized in the following table by chemical group.

Chemical Group	Time to Achieve Emission Rate Reduction by > 80%	> 90%	> 95%
Light Hydrocarbons	6 h	12 h	175 h
Volatile Organic Compounds	12 h	66 h	82 h
Volatile Organic Hydrocarbons	12 h	82 h	175 h
Total Reduced Sulphurs	< 6 h	< 6 h	< 6 h
Total Hydrocarbons (Detected)	< 6 h	6 h	30 h
Total Volatile Organic Hydrocarbons (Detected)	12 h	30 h	37 h

The decay times in the emission rates varied by chemical group. For example, the light hydrocarbon emission rate was 80% lower after 6 hours which indicates the high volatility of this group. However, the light hydrocarbon group did not reach the 95% reduction in emission rate until 175 hours. The reduced sulphurs were the most volatile achieving a 95% reduction in less than six hours.

For all chemical groups and relative to the initial spill, the emission rates declined by 80% after 12 hours and by 90% after 3.4 days.

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Appendices

1. INTRODUCTION

RWDI AIR Inc. was retained by Tera Consulltants on behalf of Kinder Morgan Canada to conduct flux chamber sampling on a test oil spill at the Kinder Morgan facility located in Gainford, Alberta. RWDI was given a freshwater tank, Tank S8, in the field program which was part of a larger fate and behaviour study of heavy crude oil (Cold Lake Winter Blend dilbit) on marine waters. Tank S8 was left exposed to ambient conditions (i.e. solar load, precipitation, wind, etc.). Flux chamber samples were taken off of Tank S8 from May 13, 2013 to May 22, 2013. The objective of the survey was to take 'real-world' emission samples that would be used to ground-truth estimated emission rates used in the hazard and dispersion analysis of a spill to water.

The ambient parameters monitored during the flux chamber emission sampling included:

- Flux chamber temperature, pressure, and nitrogen gas flow rate;
- Tank S8 fresh water temperature below the dilbit; and,
- Ambient air temperature at time of sampling.

Collected samples were analyzed by Maxxam Analytics in Mississauga, Ontario for the following parameters:

- Benzene, toluene, ethyl benzene, and xylenes (BTEX);
- Total hydrocarbons (C_1 to C_5);
- Volatile organic hydrocarbons (VOHC, aliphatic and aromatic hydrocarbons C_5 to C_{16});
- Volatile organic compounds (VOCs, including chlorinated organics); and,
- Sulphur compounds (measured until all parameters dropped below detection limits).

Appendix A contains the pre-test work plan developed by RWDI for this study.

2. SOURCE DESCRIPTION

2.1 Tank Description

Tank S8 was designated for use by RWDI to conduct flux chamber measurements on site at the Gainford, Alberta facility. Tank S8 contained fresh water with a simulated oil spill to a depth of 25.4 mm (1 in.) on the surface. The tank was left outside exposed to ambient temperature, solar loading, wind conditions, and precipitation.

3. TEST PROGRAM

3.1 Sample Location

The floating flux chamber was placed directly onto Tank S8 as shown in Figure 1. When not in use, the flux chamber was cleaned and held suspended above the surface of the tank by about 250 mm as shown in Figure 2.

Figure 1: Floating flux chamber in sampling position on oil spill in Tank S8

Figure 2: Floating flux chamber suspended above oil spill after sampling event

3.2 Description of Testing Methodology

Flux sampling was performed in accordance with the Ontario Source Testing Code, version 3 Method ON-6, Part G, Section 7.0. A modification to the method allowed for the use of a floating flux chamber placed onto the surface of Tank S8. The flux chamber and floats were all stainless steel in construction to prevent cross contamination had plastic/rubber floats been used instead.

The flux chamber was purged with nitrogen at a rate of 0.00064 $m^3/s/m^2$ and allowed four air changes to occur before sample collection was initiated. Sampling was conducted using 1.4 L SUMMA canisters with a two minute fill time for the canisters (flow controller). The two minute fill time for the canister was to prevent air entrainment through a negative pressure condition on the flux chamber. The flux chamber pressure was monitored at all times to ensure that the chamber was maintained at a slight positive pressure. All sample lines and nitrogen lines were constructed of Teflon®, an inert material.

Upon completion of the sampling, the SUMMA canisters were sealed and packaged for transport to Maxxam Analytical Services in Mississauga, Ontario for analysis. Samples were collected on less frequently as the decrease in emission rates was observed using a handheld photo-ionization detector. Samples were taken according to the schedule in Table 1.

Table 1: Sampling Summary and Sample Log

RWDI Sample ID	Sampling Date	Start Time	End Time[1]
D01-H00	13-May-13	14:53	14:55
D01-H06	13-May-13	20:52	20:54
D01-H12	14-May-13	02:52	02:54
D01-H18	14-May-13	09:00	09:02
D01-H24	14-May-13	13:20	13:22
D02-H06	14-May-13	21:35	21:37
D02-H12	15-May-13	03:52	03:54
D02-H18	15-May-13	09:56	09:58
D02-H24	15-May-13	15:29	15:31
D03-H00	16-May-13	00:32	00:34
D03-H08	16-May-13	08:51	08:53
D03-H16	16-May-13	15:53	15:55
D04-H00	17-May-13	00:34	00:36
D04-H08	17-May-13	08:44	08:46
D04-H16	17-May-13	15:52	15:54
D05-H00	18-May-13	00:37	00:39
D05-H08	18-May-13	08:50	08:52
D05-H16	18-May-13	16:24	16:26
D06-H00	19-May-13	00:35	00:37
D06-H08	19-May-13	08:47	08:49
D06-H21	19-May-13	21:36	21:38
D07-H09	20-May-13	09:05	09:07
D07-H21	20-May-13	21:32	21:34
D08-H09	21-May-13	09:12	09:14
D08-H21	21-May-13	21:52	21:54
D09-H08	22-May-13	08:36	08:38

[1] All samples are identified by their end time

3.3 Process Data

Conditions during the sampling were monitored by RWDI personnel. The temperature of the air inside the flux chamber, fresh water temperature, ambient temperature, nitrogen flow rate into the flux chamber, and the pressure inside the flux chamber were all monitored at the time of sampling. Temperatures were measured with a chromel-alumel type-k thermocouple in conjunction with a digital temperature indicator. The flow rate of nitrogen was monitored using a positive displacement gas flow calibrator. Pressure within the flux chamber was monitored using a magnehelic gauge ranging from 0 to 0.5 in. w.g.

3.4 Quality Assurance/Quality control Activities

Applicable quality assurance measures were implemented during the sampling program to ensure the integrity of the results. These measures included detailed documentation of field data, equipment calibrations for all measured parameters, completion of Chain of Custody forms when submitting laboratory samples, and submission of field blank samples to the laboratory.

Leak checks were performed on the flux chamber by plugging exits to ensure that the pressure within the chamber would increase. This check was conducted before purging of the chamber during each test. Daily temperature sensor audits were completed by noting the ambient temperature, as measured by a mercury reference thermometer, and comparing these values to those obtained from the handheld sensor.

4. RESULTS

The average emission results for this study are presented in the 'Tables' section of this report. Table 1 presents a summary of test dates and times. Below is a summary of the applicable Tables (in Appendix D) and Figures(in Appendix E) numbers corresponding to each test parameter.

Parameter	Table	Figure
Light Hydrocarbons	D1	E1 to E6
Volatile Organic Compounds	D2	E7 to E17
Volatile Organic Hydrocarbons	D3	E18 to E23-
Total Reduced Sulphurs	D4	Not Plotted
Total Hydrocarbons (Detected)	D5	E24
Total Volatile Organic Hydrocarbons (Detected)	D6	E25

All sampling field notes are provided in Appendix B. In the same appendix, the diluted gas concentrations for several gases (i.e., H_2S, O_2, CO, total VOC's and benzene) and LEL (expressed as methane) are provided. All laboratory analytical results are included in Appendix C.

4.1 Discussion of Results

All reported concentrations and emission rates were corrected to reference conditions of 25°C, and 101.3 kPa. When the laboratory reported values were less than their method detection limit for a specific component, the respective concentration and emission rates were calculated using this method detection limit. This method is a conservative approach when calculating the emission rates.

All compounds that were analyzed are listed in the 'Tables' section; however, figures are only presented for those compounds that had a representative number of samples above the method detection limit so that a decay curve could be plotted. No figures for total reduced sulphur compounds were created as these compounds volatilized quickly; a greater than 95% decrease to emission rate was observed in the first six hours (i.e., the first sampling interval).

For some canisters, the reduced sulphur compounds were analyzed after the maximum three day holding time; where sulphur compounds are considered to be stable. Samples that were analyzed within the three day holding time were re-analyzed several days later to try and calculate a decay trend for the different sulphur compounds. The objective was to apply this decay trend to those samples that were analyzed beyond the three day holding period. Due to the speed at which sulphur compounds volatilized, which was less than six hours to decrease below the detection limit, the application of an adjustment for the decay trend was not required.

To calculate the Total Hydrocarbons (Detected), or THC and the Total Volatile Organic Hydrocarbons (Detected), or TVOC; the sum, of all detectable compounds was taken and reported as methane equivalent (CH_4) for THC and ethyl benzene for TVOC. In order to determine the contribution of aliphatic compounds for THC and aromatic compounds for THC and TVOC, an average molecular mass was taken for the grouped compounds. As an example, to determine the molecular mass of aromatics in the grouping of eight to 10 carbon containing species, the molecular mass of ethyl benzene (106 g/mol) and cyclodecane (140 g/mol) were averaged to give the group of aromatics a molecular mass (123 g/mol). This averaging approach is expected to create minor errors in each group. Specifically, for the aromatics between eight and 10 carbons, the error is < 0.01% for the overall THC (expressed as methane) calculation.

Table 2 shows the time duration for specific compound groups, on average for those compounds that were measured, reached an 80%, 90%, and 95% decrease relative to the initial measured emission rate. For example, if the initial flux emission rate was 100 µg/s/m³, then an 80% decrease would be when the emission rate dropped below 20 µg/s/m³.

Table 2: Time Duration to Achieve Average Emission Rate Losses by Compound Group

Chemical Group	Time to Achieve Emission Rate Reduction by		
	> 80%	> 90%	> 95%
Light Hydrocarbons	6 h	12 h	175 h
Volatile Organic Compounds	12 h	66 h	82 h
Volatile Organic Hydrocarbons	12 h	82 h	175 h
Total Reduced Sulphurs	< 6 h	< 6 h	< 6 h
Total Hydrocarbons (Detected)	< 6 h	6 h	30 h
Total Volatile Organic Hydrocarbons (Detected)	12 h	30 h	37 h

5. CONCLUSIONS

A flux chamber sampling program was completed over the period, May 13 to 22, 2013 at the KMC Gainford, AB facility. This survey was used to directly measure flux rates from a spill of dilbit on fresh water to atmosphere for several chemicals and chemical groups. The results will be of interest for dispersion modeling of emissions related to an accidental spill as part of the hazard assessments for watercourse and marine releases. For all chemical groups and relative to the initial spill, the emission rates declined by 80% after 12 hours and by 90% after 3.4 days.

A Comparison of the Properties of Diluted Bitumen Crudes with other Oils

POLARIS Applied Sciences, Inc. (2013)

Abstract

Diluted bitumen (dilbit) crude oil represents a range of oils produced from bitumen extracted from oil sands in Western, Canada. As these reserves are increasingly in demand, more transportation options are being sought to deliver the product to refineries both in North America and abroad. Concerns over potential spills have been the point of discussion with questions raised about applicable countermeasures and limitations, the possible fate and behavior of these oils, and environmental effects. Limited related research has been conducted on these oils over the past 30 years although recent testing was completed in 2013. Laboratory and mesoscale weathering experiments show dilbits have physical properties very much aligned with a range of intermediate fuel oils and other heavy crude oils and generally, depending the initial blend and the state of weathering, and are not characterized as nonfloating oils. This paper provides a review of dilbit oil properties, applicable countermeasures, and potential fate and behavior for spills to land, freshwater, and marine settings and compares these oils to other oil commodities transported and used over the past decades.

Contents

Introduction

The oil properties and behavior of diluted bitumen are of interest to spill modelers, transportation and handling operators, environmental scientists and spill responders as proposed pipeline expansion programs are underway for delivery of diluted Alberta oil sands crude oils to export destinations. Although dilbits have been transported via pipeline for the past 30 years, and their general properties are akin to other heavy oils, the specific characteristics and behaviors of these oils as they weather have been the subject of a limited number of published studies (Brown and Nicholson, 1991; Brown et al., 1992; SLRoss 2010a,b; WPW, 2013). Oil fate, behavior and spill response issues associated with heavy oils in general have been the focus of numerous reports (Ansell et al., 2001; BMT Cordah, 2009; Brown et al., 1997; Lee et al., 1992; Michel et al., 1995; NRC, 1999). This review and compilation of dilbit properties and comparison to other crude oils and refined products provides perspective to their behavior, effects, and potential oil spill countermeasures in context of the range of hydrocarbons commonly transported today.

The bitumen contained in the Alberta oil sands is naturally occurring petroleum that exists in the semi-solid or solid phase in natural deposits. The extracted bitumen is extremely viscous and will not flow unless heated or diluted with lighter hydrocarbons used as a diluent. At room temperature, it is much like cold molasses. The World Energy Council (WEC) defines natural bitumen as "oil having a viscosity greater than 10,000 centipoise under reservoir conditions and an API gravity of less than 10° API". In order to transport it through pipelines, a diluent is added to the bitumen. The combination of bitumen with diluent produces a homogeneous blend that has considerably lower density and viscosity with good pumping and flow properties. This product is often referred to as Diluted Bitumen or Dilbit. The diluent used could be lighter crude oils, synthetic crude oils, or natural gas condensates. The dilbit product must meet quality specifications that are posted with the National Energy Board in Canada and the Federal Energy Regulatory Commission in the U.S. To ensure pipeline transportability, NEB tariffs specify that the density of crude oil shipments not exceed 940 kg/m^3 at a reference temperature of 15°C and that viscosity not exceed 350 cSt, when measured at the posted pipeline operating temperature. Given the range of temperatures throughout the year in which pipelines operate, the posting temperatures vary and blending must be adjusted to ensure viscosity is not exceeded.

Oil Classifications

Petroleum-based oils range from naturally occurring materials, such as condensate, crude oil, bitumen, and tar, to refined processed products such as aviation fuels, gasoline, and lube oils. Whether naturally occurring or processed, petroleum-based oils encompass a wide range of physical and chemical properties. The oil spill response community has developed different classifications to pool types of oil. Classifications include:

- persistent and non-persistent (see examples of used in Alaska Dep. Of Environmental Conservation regulations, OPRC Conventions, and International Tanker Owners Pollution Federation),
- Groups 1 through 5 (or I through V)

In the US, the EPA and USCG define petroleum-based oil groups as follows:

Group 1 oils include:

Petroleum-based oil that, at the time of shipment, consists of hydrocarbon fractions:

- at least 50 percent of which by volume, distill at a temperature of 340 degrees C (645 degrees F); and
- at least 95 percent of which by volume, distill at a temperature of 370 degrees C (700 degrees F); and

Group 2 - specific gravity less than 0.85;
Group 3 - specific gravity equal to or greater than 0.85 and less than 0.95;
Group 4 - specific gravity equal to or greater than 0.95 and less than 1.0; or
Group 5 - specific gravity equal to or greater than 1.0.

Group 1 oils (non-persistent) tend to dissipate completely through evaporation within a few hours and do not normally form emulsions (Table 1). Group 2 and 3 oils can lose up to 40% by volume through evaporation but, because of their tendency to form viscous emulsions, there may be an initial volume increase as well as limited natural dispersion, particularly in the case of Group 3 oils. Group 4 oils are very persistent due to the minimal content of volatile hydrocarbons and their high viscosity, which preclude both evaporation and dispersion. Group 5 is meant to collectively classify oils whose density is higher than that of freshwater.

Table 1 Oil groups and examples

Group	Density	API	Examples
Group 1	Less than 0.8	>45.2	Gasoline, Kerosene
Group 2	0.8 - 0.85	45.2-34.8	Gas Oil, Alberta light crude
Group 3	0.85 - 0.95	34.8-17.3	Alberta medium to heavy crude oils; dilbits
Group 4	Greater than 0.95 and less than 1	<17.3 to ≥10	Intermediate Fuel Oil (IFO) 180 (Bunker B), IFO ≥380 (Bunker C)
Group 5	Greater than 1	<10	Orimulsion®, Boscan crude

Floating and Non-floating Oils

Group 5 oils are by definition more dense than freshwater and, as such, would sink if spilled into water with a density of 1. There have been a number of Group 5 spills attended to by response organizations, some of which showed that even Group 5 oils can float depending on their composition and the characteristics of the receiving waters (salinity, temperature, suspended sediment content) (Michel et al., 1995; Michel, 2008). Oils in Groups 3 and 4 can become neutrally or negatively buoyant in freshwater or saltwater, as can Group 5 oils in saltwater, through several mechanisms (Michel and Galt, 1995). Burns et al. (1995) reported two factors as the major causes for the formation of non-floating oil during the discharge of over 3,000 m^3 of low API gravity oil in San Juan, Puerto Rico in 1994: (1) the oil properties (Group 5 with an API gravity of 9.5) and (2) a high likelihood of sand being rapidly mixed with oil into the high energy surf zone. These same mechanisms are recognized as the primary factors causing heavy oils to submerge or sink (NRC, 1999).

Whether a dilbit sinks after losing its light fractions due to evaporation was one of the main questions that triggered tank tests to investigate the behavior of diluted bitumen when spilled into a freshwater (SL Ross 2010) or brackish marine environment (WPW, 2013). Both Cold Lake and Access Western Blend dilbits are lighter than freshwater, as required for pipeline specifications (i.e., absolute density less than or equal to 940 at reference temperature). Mesoscale weathering experiments done in Gainford, Alberta (WPW 2013) showed that Cold Lake (CL)and Access Western Blend (AWB) dilbits exhibited properties typical of a heavy, “conventional” crude oil as they weathered but in no instance was any oil observed to have sunk after 10 days of weathering on 20 ppt brackish water under varied physical conditions. The physical properties of weathering oil measured during those tests showed that dilbit spilled into fresh, brackish, or saltwater will stay on the water surface for days unless another mechanism mixes it into the water column, as would be the case for most Group 3 and 4 oils. Only after extensive weathering, or mixing with suspended particulate material, may some portion of weathered dilbit become submerged or sink.

Comparison of Physical Properties

Typical physical properties for a broad range of oil types are summarized in Table 2.

Table 2 Ranges of physical properties for example oil types.

Property	Units	Oil Types							
		Gasoline	Diesel	Light Crude	Dilbit[1]	Heavy Crude	Intermediate Fuel Oil	Bunker C	Crude Oil Emulsion
Density	Kg/m^3 at 15^oC	720	840	780 to 880	824 to 941	880 to 1000	940 to 990	960 to 1040	950 to 1000
API Gravity		65	35	30 to 50	18 to 39	10 to 30	10 to 20	5 to 15	10 to 15
Viscosity	mPas at 15^oC	0.5	2	5 to 50	270.5* to 265,263 **	50 to 50,000	1,000 to 15,000	10,000 to 50,000	20,000 to 100,000
Flash point	15^oC	-35	45	-30 to 30	<-35$**^m$ to 58$*^m$	-30 to 60	80 to 100	>100	>80
Solubility in Water	ppm	200	40	10 to 50	-	5 to 30	10 to 30	1 to 5	-
Pour Point	^oC	NR	-35 TO -1	-40 to 30	-30$**^m$ to 15$**^m$	-40 to 30	-10 to 10	5 to 20	>50
Interfacial Tension	mN/m at 15^oC	27	27	10 to 30	27$*^m$ to 150$*^m$	15 to 30	25 to 30	25 to 35	-

Modified from Fingas (2001); [1]Values provided include weathered dilbit from tests; NA= not relevant; * Calculated for AWB; ** Calculated value for CL;$*^m$ Measured value of AWB; $**^m$ Measured value of CL

Crude oils produced in Alberta have similar physical characteristics that encompass the light to heavy crude oil properties (Table 3) and overlap with intermediate fuel oil and bunker fuel listed in Table 2. The Access Western Blend (AWB) and Cold Lake (CL) dilbits tested at Gainford (WPW, 2013), were slightly less dense (922 and 928 Kg/m^3 , respectively) than 5 other common oil products from Alberta and within 3% of the average density of the listed Alberta crude oil blends in Table 3.

Table 3 Ranges of physical properties for example Alberta crude oil blends and ANS crude

Properties	Mixed Sweet Blend (MSW)	Husky Synthetic Blend (HSB)	Premium Albian Synthetic (PAS)	Lloyd Kerrobert (LLK)	Wabasca Heavy (WH)	Western Canadian Blend (WCB)	Access Western Blend (AWB)	Cold Lake (CL)	Western Canadian Select (WCS)	Albian Heavy Synthetic (AHS)	ANS Crude[2]
Type crude	Light sweet	Light synthetic		Heavy sour conventional			Dilbit			Dilsynbit	Medium
Density[1] (kg/m^3)	827.2 ± 3.3	863.8 ± 3.8	860.4 ± 5.4	929.8 ± 4.6	932.2 ± 4.8	929.5 ± 4.7	922.2 ± 5.4	928.0 ± 5.1	929.3 ± 4.9	938.8 ± 2.4	866 - 894
Gravity[1] (°API)	39.4 ± 0.7	32.2 ± 0.7	32.8 ± 1.0	20.6 ± 0.7	20.2 ± 0.8	20.6 ± 0.8	21.8 ± 0.9	20.9 ± 0.8	20.6 ± 0.8	19.1 ± 0.4	31.8 – 26.6
10% Mass Recovered[1]	87.4 ± 9.26	175.1 ± 11.07	174.1 ± 5.90	141.8 ± 44.55	142.6 ± 20.54	162.9 ± 28.69	83.0 ± 17.27	105.3 ± 25.76	127.8 ± 34.17	106.4 ± 25.45	99 - 127
20% Mass Recovered[1]	130.9 ± 8.50	240.1 ± 9.60	212.8 ± 7.08	271.1 ± 19.59	249.6 ± 15.61	265.8 ± 13.40	234.3 ± 44.40	255.3 ± 20.62	261.4 ± 19.36	256.8 ± 47.21	159 - 197
30% Mass Recovered[1]	183.6 ± 10.86	277.4 ± 9.50	240.7 ± 8.70	343.0 ± 15.07	324.1 ± 13.11	331.6 ± 11.67	348.7 ± 21.50	340.2 ± 13.90	336.9 ± 13.29	377.0 ± 17.89	216 - 262
40% Mass Recovered[1]	240.1 ± 12.26	307.0 ± 8.78	265.0 ± 9.79	408.6 ± 13.54	394.9 ± 12.57	394.2 ± 12.01	424.1 ± 17.81	411.4 ± 13.30	403.6 ± 13.12	433.8 ± 12.07	236 - 316

Notes: 1) from CrudeMonitor (2013) - 5-yr average and range; 2) Range obtained from ETC Oil Database

Comparison of Chemical Properties

The principal compounds in petroleum are paraffins (alkanes), naphthenes (cyclohexanes), and aromatic hydrocarbons, with lesser amounts of asphaltic materials. Paraffins are alkanes consisting only of hydrogen and carbon atoms forming an open chain by single bonds (not joined in cyclic structures). The simplest possible alkane (the parent molecule) is methane, CH_4. Saturated oils and waxes are examples of larger alkanes where the number of carbon atoms in chain is greater than 10, with a hydrogen atom in every possible location (saturated). Crude oils have a wide range of alkanes from as low as 20% to over 60% by composition. Diluted bitumen blends contain between 20 to over 30% alkanes below C10 (Table 4), the most common being pentanes and hexanes as is typical in other crude oils. C11 through C30 (saturated oils and waxes) represented another approximately 20% by weight of the dilbits tested at Gainford (WPW, 2013). The overall composition of paraffins in dilbit blends of 40 to 50% found during the Gainford tests (WPW, 2013) is within the range of other crude oils.

Monocyclic and polycyclic aromatic hydrocarbons are commonly associated with the majority of acute and chronic oil toxicity and are more commonly evaluated analytically following oil spills. Crude oils contain lower percentages of aromatics than refined oils that have both higher aromatic and residual concentrations from the refining process. The AWB and CL dilbit tested at Gainford contained approximately 5% (AWB) to 11% (CL) total PAH by weight prior to weathering, with approximately 1% by weight comprised of monocyclic compounds (BTEX) (WPW, 2013). The aromatic composition is similar to other crude oils and much less than intermediate fuel oils with aromatics of 30% or more. An overall comparison of BTEX and alkane content of example dilbit blends is provided in Table 4.

Cyclohexanes are commonly called naphthenes in the oil industry and consist of saturated hydrocarbon structures linked in a ring. Naphthenes comprise the remainder of the composition of crude oils at 30 to 60%.

Table 4 Ranges of select chemical properties (volume percent) for example Alberta crude oil blends

Component	Mixed Sweet Blend (MSW)	Husky Synthetic Blend (HSB)	Premium Albian Synthetic (PAS)	Lloyd Kerrobert (LLK)	Wabasca Heavy (WH)	Western Canadian Blend (WCB)	Access Western Blend (AWB)	Cold Lake (CL)	Western Canadian Select (WCS)	Albian Heavy Synthetic (AHS)
Benzene	0.27 ± 0.05	0.04 ± 0.01	0.03 ± 0.01	0.14 ± 0.05	0.12 ± 0.02	0.10 ± 0.03	0.29 ± 0.03	0.23 ± 0.03	0.16 ± 0.03	0.15 ± 0.03
Toluene	0.81 ± 0.13	0.15 ± 0.03	0.21 ± 0.07	0.21 ± 0.08	0.29 ± 0.07	0.18 ± 0.04	0.50 ± 0.08	0.39 ± 0.07	0.30 ± 0.06	0.37 ± 0.09
Ethyl Benzene	0.24 ± 0.03	0.10 ± 0.02	0.16 ± 0.03	0.04 ± 0.01	0.13 ± 0.02	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.12 ± 0.03
Xylenes	1.06 ± 0.13	0.33 ± 0.05	0.54 ± 0.16	0.19 ± 0.06	0.47 ± 0.10	0.25 ± 0.04	0.39 ± 0.08	0.33 ± 0.07	0.29 ± 0.06	0.43 ± 0.12
Butanes	3.86 ± 0.62	2.32 ± 0.74	0.24 ± 0.45	1.75 ± 0.36	1.73 ± 0.34	0.62 ± 0.12	0.68 ± 0.15	1.02 ± 0.25	2.02 ± 0.39	1.50 ± 0.33
Pentanes	3.35 ± 0.58	1.61 ± 0.34	0.41 ± 0.27	5.57 ± 0.92	2.70 ± 0.79	3.72 ± 0.76	8.42 ± 1.21	6.18 ± 0.99	4.36 ± 0.81	4.66 ± 1.19
Hexanes	5.68 ± 0.55	2.02 ± 0.31	1.04 ± 0.29	3.19 ± 0.84	3.07 ± 0.37	3.11 ± 0.47	6.81 ± 0.67	5.31 ± 0.64	3.90 ± 0.54	5.10 ± 0.66
Heptanes	7.05 ± 0.57	2.03 ± 0.27	1.75 ± 0.34	2.07 ± 0.51	2.95 ± 0.40	2.51 ± 0.29	4.35 ± 0.49	3.36 ± 0.47	2.80 ± 0.43	3.81 ± 0.55
Octanes	7.10 ± 0.60	2.73 ± 0.34	3.31 ± 0.55	1.48 ± 0.35	3.01 ± 0.54	2.13 ± 0.22	2.57 ± 0.44	2.23 ± 0.43	2.11 ± 0.37	3.30 ± 0.64
Nonanes	5.51 ± 0.46	2.43 ± 0.31	3.96 ± 0.62	1.20 ± 0.29	2.50 ± 0.49	1.84 ± 0.31	1.25 ± 0.24	1.35 ± 0.31	1.49 ± 0.31	2.08 ± 0.51
Decanes	2.49 ± 0.26	1.29 ± 0.17	2.35 ± 0.40	0.59 ± 0.19	1.13 ± 0.28	0.88 ± 0.25	0.54 ± 0.12	0.63 ± 0.18	0.71 ± 0.16	0.93 ± 0.24

Source: CrudeMonitor (2013) - 5-yr average and range

Comparison of Spilled Oil Behavior

The main properties that affect the fate of spilled oil at sea are: specific gravity or density; distillation characteristics (its volatility); viscosity (its resistance to flow); and pour point (the temperature below which it will not flow). In addition, the wax and asphaltene content influence the likelihood that the oil will mix with water to form a water-in-oil emulsion. Oils that form stable oil-in-water emulsions persist longer at the water surface. The resin and asphaltene content determine the likelihood of tar-ball formation. These properties will change through time as spilled oil weathers. The behavior and character of the weathering oil are important considerations for spill response strategies and tactics.

Table 5 provides a summary comparison of the *changes* in key physical properties of representative oils through evaporative loss of lighter-end hydrocarbons. Table 6 summarizes example changes in oil chemistry.

Table 5 Changes in oil physical properties as a function of evaporative loss of light-ends

	Weathering (weight %)	API	Sulphur Content (weight %)	Water (vol %)	Flash Point (C)	Density (g/mL) @ 0/15		Pour Point (C)	Dynamic Viscosity (cP) @ 0/15		Chemical Dispersability (%)	Adhesion (g/m^2)	Surface Tension (mN/m) @ 0/15		Oil/Brine(33ppt) Interfacial Tension (mN/m) @ 0/15		Oil Freshwater Interfacial Tension (mN/m) @ 0/15		Emulsion Formation: Visual Stability	Emulsion Formation: Complex Modulus (Pa)	Emulsion Formation: Emulsion Water Content (%)	Reference
						*0 C/1 C**	*15 C*		*0 C/1 C**	*15 C*			*0 C*	*15 C*	*0 C*	*15 C*	*0 C*	*15 C*	15 C/14 C*			
ANS Crude Oil	0	30.89	1.1	< 0.1	< -8	0.877	0.8663	-32	23.2	11.5	47	20	27.3	26.4	22.5	20.2	26.7	23.6	Unstable			1
	10		1.2	< 0.1	19	0.9054	0.894	-20	76.7	31.8	45	35	29.8	28.4	25.3	23.1	28.1	25.5	Unstable			1
	22.5		1.38	< 0.1	75	0.9303	0.9189	-9	614	152	34	38	31.2	30.4	26.8	24.2	30.8	27.7	Unstable			1
	30.5		1.5	< 0.1	115	0.9457	0.934	-6	4230	614.7	15	40	33.1	31.8	30.1	25.6	33.2	30.2	Mesostable	155	72.9	1
Albert Sweet Mixed Blend	0	35.72	0.63	< 0.1	-4.3	0.8536	0.8404	-18	23.6	6.1	28.1	4.8	28.3	25.5	19.2	23.1	30.7	14.3	Mesostable	133	89.6	1
	12.6		0.7	< 0.1	27.8	0.8805	0.8676	-12	45.3	13.8	26.6	25	29.1	27.2	29	23.1	33.9	16	Mesostable	409	92.9	1
	24.3		0.78	< 0.1	67.8	0.8987	0.8852	-12		31.5	17.2	33.6	30.1	28	21.1	24.1	31.1	15.3	Stable	630	87.7	1
	36.8		0.89	< 0.1	>110	0.9151	0.9017	9		123.2	10.9	43.7	31.1	29.9	20.1	23.2	32.7	14.3	Stable	1025	86	1
Arabian Light	0	31.3	1.93	< 0.1	<-10	0.8776	0.8641	-21	32.6	13	19	17	27.2	26	21.3	21.6	23.5	23.8	Mesostable	92.7	91.1	1
	9.2		2.17	< 0.1	36.5	0.8994	0.866	-15	77.6	27.4	13.8	28	29.2	27.9	22.2	22.8	22.4	22	Mesostable	212	88.6	1
	17.6		2.36	< 0.1	71.7	0.9154	0.9028	-8		59.9	10	30	30.6	28.4	16.4	24.6	28.3	25.7	Stable	274	83.8	1
	26		2.6	< 0.1	>110	0.9321	0.9193	-9		173.7	7.9	35	30.9	30.2	26.8	20.4	30.1	22.4	Stable	503	83.8	1
Sockeye	0	19.32	4.51	0.8	-4	0.9465	0.9354	-25	3220	761	11.8	70	30.1	28.8	23	21.9	23.7	21.4	Mesostable	183	75.6	1
	6.9		4.95	0.1	35	0.9642	0.9537	-18	13600	2720	9.6	70	NM	31.3	NM	23.1	NM	24.9	Mesostable	251	73.3	1
	13		5.19	0.1	72	0.9798	0.9692	2	143000	15100	10.1	90	NM	32.2	NM	NM	NM	NM	Entrained Water	391	53.4	1
	19.8		5.47	< 0.1	>110	0.9951	0.9839	13	5300000	274000	8.9	350	NM	NM	NM	NM	NM	NM	Entrained Water	1298	17.7	1
South Louisiana	0	32.72	0.49	< 0.1	<-10	0.8668	0.8562	-41	18.5	10.1	26.5	24	28.3	26.1	20.9	16.8	20.8	15.5	Unstable			1
	10.9		0.71	< 0.1	42.3	0.8888	0.877	-19	54.8	23.7	23.5	34	29.3	28.1	22	19.4	25.2	15.8	Unstable			1
	19.7		0.79	< 0.1	80.7	0.9025	0.8906	-14	217.3	48.9	15.8	50	30.4	29.4	22	22.2	25.3	22.3	Unstable			1
	27.7		0.88	< 0.1	>110	0.9135	0.9018	-11	515.9	141	10.3	28	31.1	29.8	20.6	18.4	24.7	21.9	Unstable			1
West Texas Intermediate	0	34.38	0.86	< 0.1	<-10	0.8594	0.8474	-22	19.2	8.6	27.7	12.4	27.4	26	18.8	15.6	19.3	15.8	Unstable			1
	10.1		1.01	< 0.1	32.8	0.8792	0.8665	-12	42.1	16.4	23.6	16.8	28.7	27.6	19.4	14.6	19.9	18.1	Unstable			1
	21		1.11	< 0.1	66	0.8956	0.8827	1	253.6	37.5	13.3	27.6	29.7	28.7	19.2	12.6	21	17.2	Mesostable	19.1	82.7	1
	31.7		1.24	< 0.1	>110	0.9103	0.8973	7	853.6	112.3	12.8	33.2	31.4	29.2	19.9	17.3	22.7	17.1	Mesostable	81.9	83.6	1
Fuel Oil #2/Diesel	0	37.52	0.09	< 0.1	54	0.8423	0.831	-50	4.08	2.76	72	2	28.7	27.5	21.5	18.1	25	21.6	Unstable			1
	7.2		0.1	< 0.1	65	0.8468	0.835	-49	4.55	3.27	71	12	28.8	27.7	24.8	19.5	28.1	23.9	Unstable			1
	14.2		0.1	< 0.1	76	0.8493	0.8383	-43	5.16	3.42	64	13	28.6	28.1	26.6	20.7	28.5	24.3	Unstable			1
	22		0.1	< 0.1	85	0.8524	0.8416	-41	5.59	4.18	66	8	29.3	28.3	28.5	21.9	29.1	25.7	Unstable			1
Fuel Oil #5	0	11.5	1	3.1	94	1.0034	0.9883	-19	18600	1410	15	34	NM	NM	NM	NM	NM	NM	Stable	1590	78.3	1
	7.2		1.08	<0.1	136	1.016	1.0032	-3	72000	4530	7	47	NM	NM	NM	NM	NM	NM	Stable	2490	72.8	1
																						1
																						1
Heavy Fuel Oil	0	11.47	1.48	0.1	111	1.0015	0.9888	-1	241000	22800	9	100	NM	NM	NM	NM	NM	NM	Entrained	752	57.7	1
	2.5		1.5	<0.1	133	1.0101	0.9988	11	3600000	149000	6	240	NM	NM	NM	NM	NM	NM	Entrained	984	24.1	1
																						1
																						1
CL	0	21.4^{+}		0.9	-4.5	0.0948*	0.936	<-24	1363*	368						23.2			Mesostable*		53	2/3
	14.3	14.3^{+}			4	0.987*	0.977	-15	57548*	9227						24.7			Unstable*		0	2/3
	17	12.1^{+}			4	0.990*	0.981	-12	98625*	14486						>27			Unstable*		0	2/3
	23^{+}	10.2		33.4	56		0.9986	9														3

References: 1) Wang et al 2003, 2) Values are calculated based on data from WPW (2013) and fit to the evaporation vs. density chart from SL Ross (2010a)

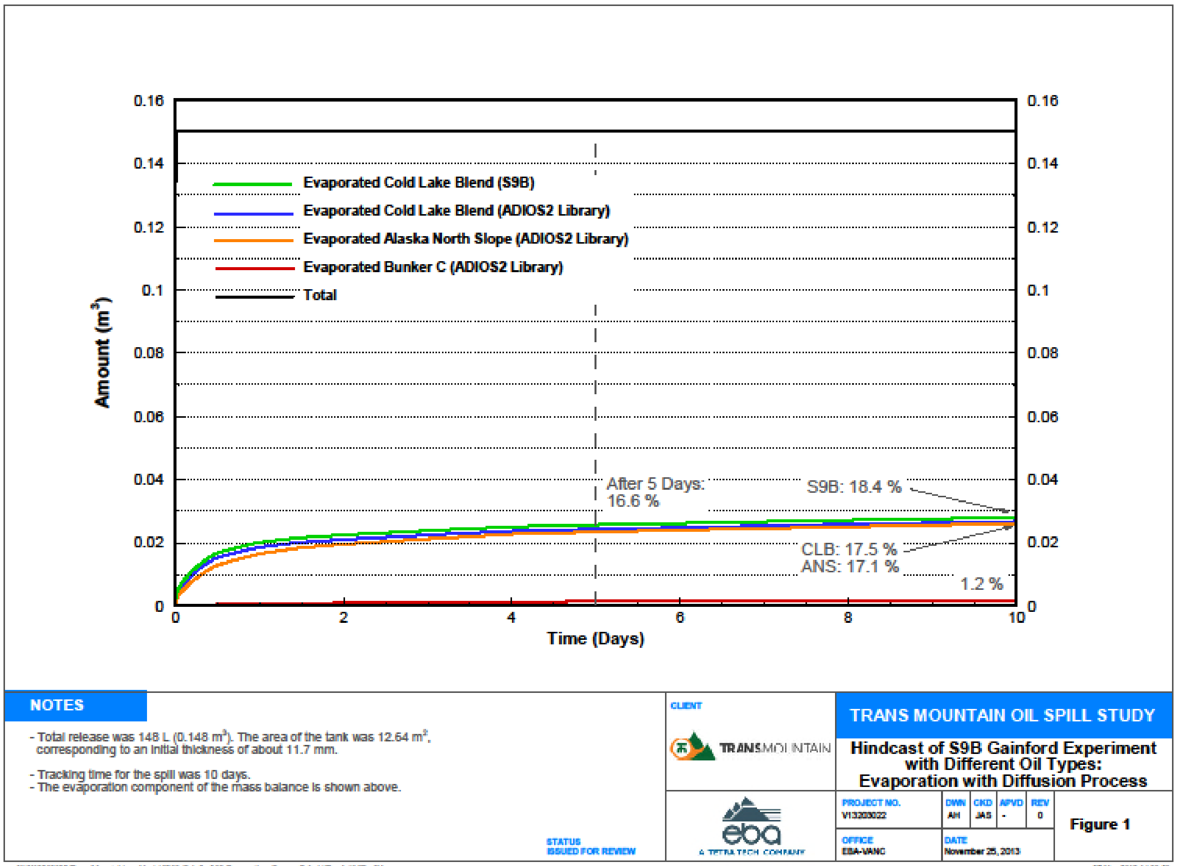
Table 6 Changes in key oil chemical properties as a function of evaporative loss of light-ends

	Weathering (weight %)	Benzene		Toluene		Ethylbenzene		Xylenes		BTEX		Reference
		% vol	*ug/g*	*% vol*	*ug/g*	*% vol*	*ug/g*	*% vol*	*ug/g*	*% vol*	*ug/g*	
ANS Crude Oil	0	0.283	2866	0.592	5928	0.132	1319	0.616	6187	1.624	16300	1
	30.5	0	0	0	0	0	0	0	0	0	0	1
Alberta Sweet Mixed Blend	0	0.217	2261	0.515	5308	0.160	1646	0.865	8954	1.756	18170	1
	36.8	0	0	0.001	10	0	0	0.865	0	1.756	10	1
Arabian Light	0	0.097	979	0.304	3050	0.199	1995	0.489	4927	1.089	10950	1
	26	0.001	11	0.007	74	0.043	434	0.150	1508	0.202	2030	1
Sockeye	0	0.143	1343	0.219	2031	0.105	974	0.417	3880	0.885	8230	1
	19.8	0.001	9	0.001	12	0	0	0.000	1	0.002	20	1
South Louisiana	0	0.156	1598	0.351	3552	0.088	891	0.607	6164	1.202	12210	1
	27.7	0	0	0.001	10	0	0	0.000	2	0.001	12	1
West Texas Intermediate	0	0.389	4026	0.723	7395	0.474	4845	0.692	7105	2.278	23370	1
	31.7	0	0	0.001	13	0.000	0	0.000	1	0.001	14	1
Fuel Oil #2/Diesel	0	0.013	136	0.098	1024	0.059	619	0.360	3774	0.531	5550	1
	22	0	0	0	0	0	0	0.001	7	0.001	7	1
Fuel Oil #5	0	0	0	0.017	149	0.014	124	0.070	612	0.101	890	1
	7.2	0	0	0	0	0.000	1	0.000	2	0.000	0	1
Heavy Fuel Oil	0	0.005	40	0.016	136	0.007	58	0.045	396	0.072	630	1
	2.5	0	0	0	0	0	0	0	0	0	0	1
Orimulsion-400	0	0.002	16	0.003	29	0.003	22	0.003	29	0.011	100	1
Lloyd Kerrobert	0	0.13	1226	0.19	1772	0.05	466	0.17	1592	0.54	5056	2
AWB	0	0.3	2849	0.51	4791	0.06	563	0.38	3583	1.25	11787	3
CL	0	0.24	2247	0.43	3983	0.06	555	0.36	3346	1.25	10132	3
Albian Heavy Synthetic	0	0.2	1879	0.37	3438	0.08	743	0.35	3264	1.25	9324	2

Reference: 1) Wang et al 2003; 2) CrudeMonitor; 3) WPW, 2013

Evaporation studies of CL (Brown and Nicholson, 1991; SLRoss 2010a) showed that the first hours of exposure to air results in rapid loss of portions of the diluent with resulting increases in density and viscosity. Evaporative loss is partly a function of air temperature, oil surface area and thickness, and wind. Figure 1 compares the predicted evaporative loss for CL, ANS and Bunker C oil under conditions assumed to be similar to those prevailing at Gainford for CL weathering under static conditions. The comparison shows a faster loss of light ends from dilbit with respect to ANS crude; however, the final evaporative loss for the two oils is similar. The heavier Bunker C has minimal light ends and negligible evaporative loss. The Gainford tests (WPW, 2013) showed that the absolute densities and viscosities (at 15°C) for CL increased from the fresh dilbit values of approximately 925 and 220 cSt, respectively, to over 960 and 4500 cSt within 6 to 24 hours of weathering, depending on the degree of physical energy applied to the oil on water, and corresponding to near 8% volume loss through evaporation (inferred from SLRoss (2010a) evaporation curves). These weathered properties are comparable to ANS crude at only at colder temperatures (near 1°C) and after 30% volume loss (Table 5). Slower evaporation rates for dilbit would be expected for colder winter conditions (Brown and Nicholson, 1991).

Figure 1 Comparison of evaporative loss versus time for example oils



Behavior for Spills to Ground or Shore

Oil spilled to soil, ground or on shorelines (including river/stream banks) will tend to spread, evaporate, move downslope, and penetrate into the substrate. Key factors in oil behavior over substrates include ambient temperature, substrate grain sizes, substrate saturation (water), and additional components on or in substrate such as organic matter, vegetation, roots, and snow. Oil penetration into substrate is a function of oil viscosity (affected by temperature and emulsion, if stranded after being on water) and effective permeability (measured relative to the viscosity of the stranded oil).

Tsaprailis, et al., 2013 reported the results of a study comparing the vertical penetration of a representative light, medium-heavy, heavy conventional crude oil, and dilbit in a sand-column. The conventional heavy crude (oil type not specified but initial viscosity of 177 cSt) penetrated the sand column more quickly than the diluted bitumen (180 cSt). The study concluded that the dilbit will spread and penetrate less into sand than the comparable crudes in the event of a spill.

Examples of measured oil retention in sediment are provided for Bunker C and IFO in Table 7. Coastal and Ocean Resources (2013) estimated dilbit penetration and retention on different substrates, assuming that weathered dilbit will: (1) have <1 cm of penetration in sands, < 5 cm in pebbles and < 10 cm in cobbles (Harper and Kory 1995); (2) retention of 300 L/m^3 for sand, 200 L/m^3 for pebble and 100 L/m^3 for cobbles (Harper and Kory 1995); and (3) a layer of weathered oil above the sediments of 1 cm for rock, sand, pebbles and cobbles. These assumptions are derived from extrapolating the Bunker C results, which may reasonably reflect weathered dilbit behavior but are not representative of fresh dilbit.

Table 7 Comparison of measured and estimated oil retention in sediments

		Oil Retention (L/m^3)		
Oil Type (% Evap, Temp)	**Viscosity (cP)**	**Medium Pebbles**	**Large Pebbles**	**V. Large Pebbles**
Bunker-6%, 2°	160,000	288	157	85
Bunker-0%,2°	80,000	197	94	77
Bunker-0%,5°	50,000	213	130	51
Bunker-0%,10°	30,000	155	47	24
Bunker-0%,15°	15,000	52	68	5
IFO-2.5%,2°	13,000	60	30	5
IFO-2.5%,15°	3,000	18	5	0.1

Data from SOCSEX II (Harper and Kory 1995)

The range of viscosities associated with dilbits, depending on original blending and state of weathering, has implicit implications on the degree of potential penetration into soils or shoreline and retention. As with all crude oils, relatively fresh dilbit may penetrate into more porous and permeable materials but is less likely to be retained. As the degree of oil weathering, and viscosity, increases there is less penetration and a higher retention for oil that does enter into substrate pore space.

Table 8 documents oil penetration and the evaporative loss of CL that had been artificially weathered for 24 hours from four types of shoreline material at 10°C. Evaporative loss for stranded dilbit was highest on mixed sediment in low energy conditions, reaching 9.5% by the end of 48 hours after application.

Table 8 Summary of CL evaporation and penetration in Burrard Inlet sediments (derived from Brown et al., 1992)

	Sediment characteristics			Percent Evaporation		Penetration
	% Shell fragments	Sorting	Sand	hr	%	
Low energy mixed sediment	10 - 60	Wide variation; all sizes up to 4 cm	Top 3" of shore at mid tide point	8 15 24 36 48	2.5 5 7.2 8.8 9.5	Low water retention, resulted in high oil permeability
High energy mixed sediment	10%	Wide variation of well-rounded rock sizes: 10 cm to 5 mm	Small amount	8 15 24 36 48	2 3 3.8 4.5 4.7	
Low energy sand sediment	-	Well sorted sandy shore	Tidal flat sandy beach	8 15 24 36 48	1 2 3.4 4 4.6	High penetration at top 1 mm; below 1 mm wet sediment has low oil permeability
Low energy estuary sand sediment	-	Well sorted sandy shore	Fine sediment, sand from estuary beach	8 15 24 36 48	0.8 1 1.8 2.1 2.2	

Behavior for Spills to Water

Major factors influencing the behavior of spilled oil to water include size of spill relative to receiving waterbody (e.g., limited vs. unlimited spreading), ambient temperature (water and air), salinity, flow (turbulent, laminar, static), wind and wave energy, and materials in the waterbody such as vegetation, suspended sediment loads, organic matter, and snow/ice. Spreading and evaporation are more significant processes in the early stages of oil fate on water.

Understanding of the behavior of dilbit spilled to water is available from lab to mesoscale testing in tanks and from observations made following actual spills, such as the Westridge 2007 (Stantec, 2012) and Marshall 2010 (Enbridge, 2013; NTSB, 2012) spills. The most significant observations are that the behavior of dilbits tested or spilled are consistent with Group 3 and 4 crude oils: they float on water until oil densities change through weathering and/or sediment uptake. As with most crude oils, dilbits may gradually overwash, become suspended in the water column, or sink depending on the degree of weathering and formation of oil-mineral aggregates. The Marshall spill into Talmadge Creek and the Kalamazoo River resulted in oil transport down river with most oil remaining on the water surface. A portion of oil, mixed with river bank and/or suspended sediment, and submerged or in places sank. The Westridge spill resulted in a portion of dilbit on the surface waters of Burrard Inlet. No submerged or sunken oil was noted during that incident (Stantec, 2012). NRC (2012) noted that from 1991 to 1996, approximately 23% of the petroleum products spilled in U.S. waters were heavy oils. In only 20% of those spills did a significant portion of the spilled products sink or become suspended in the water column. Most of the time, spills of heavy oil remained on the surface, as would be the case for most dilbit spills to non-turbulent water.

Comparison of Spill Countermeasures, Effectiveness and Limitations

Oil spill countermeasures include the more widely used mechanical systems for containment and collection as well as non-mechanical options. Response methodologies in these two general categories are applicable to most oils although the lightest and heaviest ends of the oil spectrum typically limit effective applicability of either.

Mechanical Containment and Recovery

Barriers commonly are used to mechanically impede oil spreading and movement. On land these may consist of berms, walls, and trenches. Booms, dam, and weirs are used to contain and concentrate oil on water. Containment challenges with booms include flow relative to the boom (current or towing speeds), turbulence, wave action, oil load in boom, and oil density relative to water. Heavy floating oil can be contained with conventional boom but boom efficiency may decrease as oil weathers to densities near those of the water body.

As oils are entrained into the water column, either through turbulence or combination of flow and densities near those of the receiving water body, conventional surface booming becomes less effective. Conventional booms might help to contain oils that are only slightly submerged and references that trawl nets specifically designed to recover heavy oils have proved effective in some incidents (BMT, 2009). Brown et al., (1992) performed containment tests on 24-hr weathered dilbit, bitumen, and emulsified dilbits using three barrier systems: conventional boom, fine mesh net, and bubble barrier. Only the boom and net barriers proved to be partially successful. Boom with mesh skirts provided moderately improved containment but were limited to approximately 0.48 m/s. Boom losses were greater for bitumen and emulsified dilbit relative to the 24-hr weathered dilbit. As would be expected for any heavy oil (natural or through weathering and/or emulsification), increased current speed and oil density result in less effective containment. The fine mesh tested successfully trapped floating and submerged oil, though some of that oil gradually extruded from the net.

Boom containment for dilbits and heavy oils is most effective prior to significant weathering and before any sediment uptake, hence the need to contain the relatively fresh oil. Once oil is easily overwashed or near neutral density, alternative forms of containment must be considered (Figure 2).

Figure 2 Containment options for submerged oil

Oil has:	Depth (m) is:	
Near Neutral Buoyancy (oil suspended in water column)	0–2 ±	• Physical Barrier
	0–3 ±	• Silt Curtain
	Maximum working depth not established	• Pneumatic Curtain • Contain Onshore
Negative Buoyancy (sinks to bottom)	0–2 ±	• Physical Barrier
	No depth restriction	• Allow to collect in natural or artificial depression • Contain Onshore
SOURCE: Castle *et al.* 1995		

Practical experience with containing dilbit was gained during response to the Marshall spill (Enbridge 2010). Containment on land encompassed berms and sorbent barriers. On water containment entailed multiple boom lines. These barriers helped to minimize oil movement and to concentrate oil for collection. As oil weathered and interacted with sediment, a portion became neutrally to negatively buoyant. Containment of the submerged to sunken portions of the oil included natural collection points (pools, basins) for sunken oil and geotextile barriers for submerged oil.

Skimming or collection of spilled dilbit can, and has been, achieved through conventional mechanical spill skimmer and pump systems. Pumps and skimmers that can recover~~y~~ medium oils are well suited to collecting dilbits (Figure 3). Skimming systems are used to collect oil from the water surface and work best if oil is contained and preferably concentrated (hence booms) at the skimmer. Pumps are used in conjunction with skimmers to transfer oil to tanks but pumps also can be used directly on pooled oil, either on land or from sumps or collection/concentration areas in the case of sunken oil (BMT, 2009; Burns et.al., 1995; Ploen, 1995).

Figure 3 Skimmer selection guide (from ExxonMobil, 2008)

		Skimmer Type														
		Weir Skimmers					Oleophilic Skimmers						Hydro-dynamic Skimmers			*
		Simple Weir	Self-Leveling Weir	Weir with Integral Screw Auger	Advancing Weir	Weir Boom	Drum	Disc	Rope Mop	Zero Relative Velocity Rope Mop	Sorbent Lifting Belt	Brush	Water Jet	Submersion Plane/Belt	Rotating Vane	Paddle Belt
Operating Environment	Open Water	●	●	●	◑	◑	◑	◑	○	○	○	◑	●	●	◑	●
	Protected Water	◑	●	●	○	○	○	○	○	○	○	○	◑	◑	○	○
	Calm Water	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	High Current >1 knot (> 0.5 m/s)	●	●	◑	○	◑	●	●	◑	●	◑	◑	◑	◑	◑	●
	Shallow Water <1 foot (< 0.3 m)	○	◑	●	●	●	◑	◑	○	●	●	◑	●	◑	◑	○
	Debris (Including ice)	●	●	○	◑	●	◑	●	○	○	○	○	◑	◑	◑	○
Oil Viscosity	High Viscosity	●	●	◑	●	●	◑	●	●	●	○	○	○	◑	◑	○
	Medium Viscosity	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Low Viscosity	○	○	◑	○	○	◑	◑	◑	◑	●	●	○	◑	○	◑
Skimmer Characteristics	Oil/Water Pickup % **	●	◑	◑	◑	◑	○	○	○	○	◑	◑	◑	◑	◑	○
	Recovery Rate	◑	●	●	◑	○	◑	◑	●	◑	◑	◑	●	◑	◑	◑
	Ease of Deployment	○	○	◑	◑	●	○	○	◑	○	○	○	◑	●	◑	◑
Available as VOSS (Vessel of Opportunity Skimming System)		✔	✔	✔		✔	✔	✔	✔		✔	✔			✔	✔
Available as Advancing Skimmer					✔	✔				✔	✔	✔	✔	✔		✔
Available with Storage					✔	✔	✔	✔		✔	✔	✔	✔	✔		✔

Legend ○ Good ◑ Fair ● Poor ✔ = Yes

* Other Devices
** Oil/Water Pickup % = % Oil in Recovered Product

The Gainford trials (WPW, 2013) revealed effective skimming capacity for three brush-style skimmers on CL and AWS dilbits throughout the 10-day weathering study. The skimmers tested were:

1. Aquaguard RBS Triton 60 DI3
2. Desmi DBD-5
3. Lamor MultiMax LAM 50/3C

Test results showed that all skimmers effectively recovered dilbit from the water surface for up to 8 days of weathering in open tanks. Weathered oil densities reaching 0.99 g/cm^3 and viscosities of over 30,000 cSt (both expressed at 15°C). Skimmer efficiencies (i.e., oil collected, some partially emulsified or with entrained water but not free water) generally ranged from near 70% to over 95% with weathered oil recovery rates ranging from approximately 1 to 3 m^3/hr. Skimmer manufacturers at the Gainford trials noted that the equipment, oleophilic brush systems set up for heavy oil collection, may have benefited from a different approach initially, such as using oleophilic disks and even weir skimmers with suitable pumps during the first days of the trials.

As oil weathers and attains high viscosity, enhanced skimming and pumping systems are required to maintain effective recovery. Numerous systems have been developed and tested to handle viscous oils (Hansen, 2010; Hvidbak, 2005). Three brush adapters used with weir skimmers and a screw pump were successfully tested with a GT-185 skimmer in highly viscous oil by SAIC Canada at Environment Canada's Environmental Technology Centre in February 2006 (Cooper, 2006). Three other skimmers tested by Cooper (2006) successfully picked up and processed refloated bitumen:

1. The ERE Skimmer (Dynamic Inclined Plane; Western Canada)- a small stationary skimmer that features a mesh honey-comb structure steel belt
2. The KLK 602 Skimmer- a small stationary device with two counter-rotating nonsymmetrical drums that lift, or scoop, viscous oil.
3. The larger Hobs rotating belt skimmer that lifts oil to a scraper and deposits it into a sump.

Western Canada Spill Services (WCSS) continues to work on a smaller version of the ERE Oriliminator 30 heavy oil skimmer with applicability to bitumen and dilbit oil recovery.

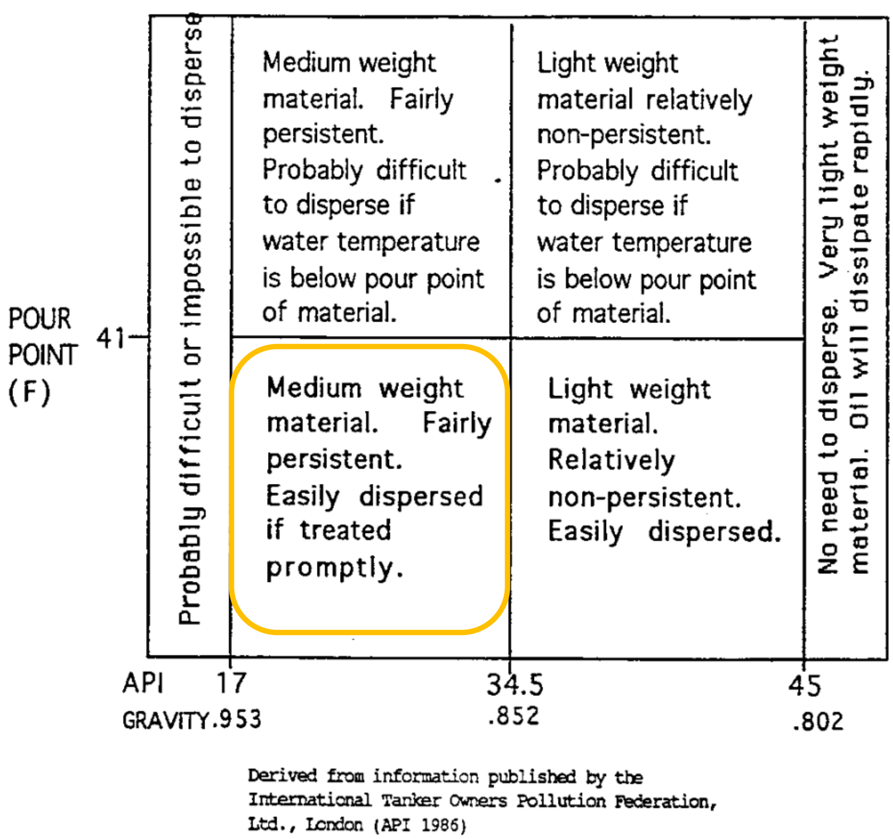
If a portion of a dilbit or even moderate to heavy oil achieves higher densities through weathering and/or material incorporated into the oil mass, then its location in the water column or on the bottom is more challenging to define relative to oil on the water surface. The underwater environment poses major complications for oil containment and recovery including poor visibility, difficulty in tracking oil spill movement, and colder temperatures (Hansen et al., 2009). Effective tracking and recovery methods and technologies suitable for these conditions are major challenges. Review of techniques applicable for tracking, containment, and recovery of submerged and sunken oils are provided in Castle et al. (1995), CRCC (2007), BMT Cordah (2009), and Hansen (2010).

Dispersant Application

Chemical dispersants cause a physical interaction between oil and water that help with oil droplet formation and stability within the water column. The increased surface area of oil droplets relative to undispersed oil aids natural weathering rates of the oil. Dispersants can be used in conjunction with mechanical recovery and other countermeasures to reduce the overall impact of a spill, although not on the same portion of a slick.

The effectiveness of dispersants is a function of the density, pour point, and viscosity of the oil (Figure 4). Some oils will not disperse, as their viscosity is too high. As oils emulsify, the viscosity increases significantly. For most crude oils, dispersants begin to lose their effectiveness after twenty-four (24) hours and most oils will no longer disperse after four to five (4-5) days. General guidelines for dispersant use note that the technique may be effective for oil viscosities up to approximately 5,000 cSt (IMO, 2005) and that limited effectiveness shown may be extended to *in-situ* viscosities of up to 10,000 cSt (Daling and Lewis, 2001; ITOPF, 2011). Gainford trials (WPW, 2013) with AWS and CL dilbits showed that chemical dispersant may be an option during the first 6 hours of weathering but given the significant increase in viscosity of dilbits as they weather, the available window of opportunity for dispersant is limited. Many spills are not instantaneous but occur over a prolonged time frame, which can extend the window of opportunity for dispersant use. In this regard, the option and limitations for use of dispersant on dilbit spills is similar to that of intermediate to heavy fuel oils, other heavy crude oils, and even lighter but emulsified crude oils.

Figure 4 General guide for dispersant applicability to spilled oil on marine waters



In-Situ Burning (ISB)

Controlled on-water burning is a viable response option under appropriate conditions for dilbit spills. Mitchell and Moir (1992) reported on successful burns of dilbit floating on water in tanks and positive results of using an additive (RMS 9757) to reduce smoke emissions. The Gainford tests (WPW, 2013) proved that CL ignited easily after 6 and 12 hours of weathering. Although not as easy to ignite as lighter oils, the Gainford trials showed that CL is similar to other medium and heavy crude oils with respect to the potential applicability of ISB (Table 9).

Table 9 Comparison of burn characteristics of different oils (from WCCS, 2012)

Fuel	Burnability	Ease of Ignition	Flame Spread	Burning Rate* (mm/min)	Sootiness of Flame	Efficiency Range (%)
Gasoline	Very high	Very easy	Very rapid – through vapors	4	Medium	95-99
Diesel Fuel	High	Easy	Moderate	3.5	Very high	90-98
Light Crude	High	Easy	Moderate	3.5	High	85-98
Medium Crude	Moderate	Easy	Moderate	3.5	Medium	80-95
Heavy Crude	Moderate	Easy	Moderate	3	Medium	75-90
Weathered Crude	Low	Difficult, add primer	Slow	2.8	Low	50-90
Crude oil with ice	Low	Difficult, add primer	Slow	2	Medium	50-90
Heavy Fuel Oil	Very low	Difficult, add primer	Slow	2.2	Low	40-70
Waste Oil	low	Difficult, add primer	slow	2	Medium	30-60
*Typical rates only – to get the rate in L/m^2/hour multiply by 60						

Shoreline Cleanup

Guidelines such as those presented in the Waste Management Calculator (PAS and TOSTC, 2008), NOAA (1992), Owens et al (1992), and Environment Canada (2010) provide an indication of treatment options for distinct shoreline types and as a function of oil type (Figure 5). As spilled oil properties change with weathering, treatment options may also need to be adjusted. For instance, low pressure flushing is an applicable treatment technique for medium oils, including relatively fresh dilbit, on coarse and mixed substrates; however, the technique may be ineffective for a heavy oil or weathered dilbit. The Gainford trials showed that low pressure washing to remove weathered dilbit from tiles was ineffective until combined with a surface washing agent (WPW, 2013). The mesoscale tests showed that oil that had weathered for five days on water and then had remained on tiles exposed to air for four days was effectively removed when washing the substrate treated with Corexit 9580. The Gainford washing tests, like those completed for Orimulsion and Bunker C (Guénette et al., 1998) and IFO 380 (Jézéquel et al., 2009), emphasize the need for an expedited approval process for use of tested surface treating agents as part of spill response planning and readiness.

	Treatment Tactic - Medium Oil						
Substrate Type	Natural Recovery	Washing Recovery	Manual Removal	Mechanical Removal	In-situ Mixing Relocation	In-situ Burning	Bio-remediation
sand-mixed	Y	Y	YS	Y	Y	N	YS
course sediment	Y	Y	YS	Y	Y	N	YS
cobble / boulder	Y	Y	YS	Y	Y	N	YS
bedrock - solid	Y	Y	YS	N	N	N	YS
vegetation	Y	Y	YS	N	N	Y	N
oiled debris	Y	N	YS	Y	N	Y	N
snow	YS	Y	YS	Y	Y	Y	N

	Treatment Tactic - Heavy Oil						
Substrate Type	Natural Recovery	Washing Recovery	Manual Removal	Mechanical Removal	In-situ Mixing Relocation	In-situ Burning	Bio-remediation
sand-mixed	N	N	YS	Y	Y	N	YS
course sediment	N	N	YS	Y	Y	N	YS
cobble / boulder	N	N	YS	Y	N	N	YS
bedrock - solid	YS	Y	YS	N	N	N	YS
vegetation	YS	N	YS	N	N	Y	N
oiled debris	Y	N	YS	Y	N	Y	N
snow	N	N	YS	Y	N	N	N

Figure 5 Guidelines for shoreline treatment options for medium and heavy oils (from PAS and TOSTC, 2008)

Experience from shoreline cleanup of the AHS dilbit following the 2007 Westridge spill showed that techniques used on the mixed sediment shorelines of Burrard Inlet (flushing, manual cleanup, shore cleaning agents, and tilling) worked effectively as applied for appropriate shore types and oiling conditions (Stantec, 2012). Techniques used on land and along stream/river banks following the Marshall (2010) spill included manual and mechanical removal and flushing.

Wildlife Treatment

Wildlife may be exposed to spilled oil through several pathways: inhalation, ingestion, and direct contact. The latter may entail smothering and/or thermal impairment due to oil coating on fur or feathers. Due to the relatively rapid loss, or lower concentration, of light-end volatile hydrocarbons, most wildlife treatment is for stabilization, cleaning, and rehabilitating oiled animals. Wildlife treatment following the 2010 Marshall spill response entailed cleaning and rehabilitation of birds and many turtles using protocols and procedures common to spills of medium to heavy oils. Focus Wildlife, contracted by Enbridge for the response, reported successful use of mineral oil as a cleaning agent for turtles and Dawn™ soap for feathers (birds).

Conclusions

Dilbits are not a new commodity on the oil market; however, the increased production of crude oil from the Alberta oil sands and its transport to refineries and markets has heightened awareness about dilbits and some of the differences between these oils and other crude oils. Dilbits have a range of properties similar to other medium to heavy oils and, like most oils, these properties depend on temperature and local environmental conditions. Furthermore, oil properties change as oil weathers and interacts with other media.

Spill response countermeasures applicable and appropriate for response to a medium crude are also applicable to the CL and AWS dilbits tested at Gainford. As the medium crude weathers and increases in density, viscosity, and pour point, spill countermeasures should be reassessed and adjusted for those changes and for differences in the environmental setting. Similarly, adjustments must be made for response to a dilbit release. The key difference between a CL dilbit, for example, and a medium crude oil, such as ANS, is a shorter weathering timeframe for a dilbit. The ANS crude may weather and/or emulsify to achieve the characteristics of a heavy oil generally over the course of many days to weeks whereas a dilbit may weather to a heavy oil state within one to a few days, depending on its original formulation and the active weathering processes.

Knowledge of the behavior of dilbit spilled to water is available from lab to mesoscale testing in tanks and from observations made following actual spills (Westridge and Marshall). Most significantly, the behavior of dilbits tested or spilled are consistent with Group 3 and 4 crude oils: they float on water until oil densities change through weathering and/or sediment uptake. As with most crude oils, dilbits gradually may overwash, become suspended in the water column, or sink depending on the degree of weathering and uptake of particulate matter.

A concluding comparison and potential challenges of dilbit spills in context of other oils is provided in (Table 10).

Table 10 Summary of oil type physical/chemical properties adverse effects on environment

Oil Type	Physical/Chemical Properties	Adverse Effects on Environment
Light to volatile oils	• Spread rapidly • Tend to form unstable emulsions • High evaporation and solubility • May penetrate substrate • Removed from surfaces by agitation and low-pressure flushing	• Toxicity is related to the type and concentration of aromatic fractions: 1) naphthalene, 2) benzene • Toxicity of aromatic fractions depends on their biological half- lives in different species • Toxic to biota when fresh • Marsh plants may be chronically affected due to penetration and persistence of aromatic compounds in sediments
Moderate to heavy oils (with notes re dilbits)	• Moderate to high viscosity • Tend to form stable emulsions under high energy marine environments (dependent on type of dilbit) • Penetration depends on substrate particle size (CL appears to have less penetration than comparable viscosity crude) • Weathered residue may sink and be absorbed by sediment (may become neutrally buoyant to sink, depending on degree of weathering, type of dilbit, and receiving water) • Immiscibility assists in separation from water • Weather to tar balls	• Adverse effects in marine organisms result from chemical toxicity and smothering • Toxicity depends on size of light fraction (dilbit formulation dependent but typically very light end diluents are rapidly lost through evaporation) • Low toxicity residue tends to smother plants or animals • Light fractions contaminate interstitial waters
Asphalt, #6 fuel-oil, Bunker C, waste oil	• Form tar balls at ambient temperatures • Resist spreading and may sink • May soften and flow when exposed to sunlight • Very difficult to recover from the water • Easy to remove manually from beach surface with conventional equipment	• Immediate and delayed adverse effects due to small aromatic fractions and smothering • Most toxic effects due to incorporation in sediment • Absorption of radiated heat places thermal stress on the environment • Lower toxicity on marine plants than mobile animals

(modified from ExxonMobil, 2008)

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