



Available online at www.sciencedirect.com

ScienceDirect

Aquatic Procedia 3 (2015) 2 – 14

Aquatic

Procedia

www.elsevier.com/locate/procedia

International Oil Spill Response Technical Seminar

Spill Response Evaluation Using an Oil Spill Model

Aurelien Hospital^{a,*}, James A. Stronach^a, M.W. McCarthy^b, Mark Johncox^c

^aTetra Tech EBA, Vancouver, BC, Canada

^bMac McCarthy Inc, Edmonds, WA, USA

^cWestern Canada Marine Response Corporation, Burnaby, BC, Canada

Abstract

Numerical simulation was used to evaluate the effectiveness of an oil spill response plan developed by Western Canada Marine Response Corporation (WCMRC) for the southwest coast of Canada. The plan was part of the permitting process for a proposed terminal expansion that would result in an increase in tanker traffic. The purpose of this response evaluation was to point the way to the development of a risk-informed enhanced oil spill response capacity that would be capable of managing large spills in coastal British Columbia. The oil spill weathering and tracking model, SPILLCALC, was used for the evaluation, and was modified to meet the needs of this study. Three-dimensional currents and water properties were provided by the hydrodynamic model, H3D; waves were simulated using the wave model, SWAN, and winds were obtained from the local network of coastal light stations and wind buoys. Booms and skimmers were the two primarily mitigation methods considered here. Mitigation inputs such as deployment time, storage capacity and speed were based on existing and proposed equipment stored in the main WCMRC facility and at outlying caches. Results confirmed the need to reduce the time to first response due to the effects of currents on the floating oil and the close proximity of shorelines along the proposed shipping route. In addition, results validated the need to upgrade availability of early on-water storage capacity, which could be met by a large fast storage vessel, enabling the spill response to be more efficient and to obtain a much higher recovery rate.

© 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of China Offshore Environmental Services Ltd

Keywords: Numerical model; oil spill; trajectory; weathering; spill response; mitigation; SPILLCALC

* Corresponding author. Tel.: +1-604-685-0275 ; fax: +1-604-684-6241.
E-mail address: aurelien.hospital@tetratech.com

1. Introduction

This work was undertaken as part of the Trans Mountain Expansion Project which proposes to increase the capacity of the current pipeline system from 300,000 bbls/day to an estimated 890,000 bbls/day. This pipeline runs from Edmonton, AB to Vancouver, BC, Canada. The majority of the increased oil in the pipeline system is proposed to be loaded onto tankers at Trans Mountain's West ridge Terminal, which is situated within Port Metro Vancouver, for shipment to offshore customers. As part of evaluating the oil spill response system along the shipping corridor between Vancouver, Canada and international waters in the Pacific Ocean, a pilot study was conducted: one representative scenario was examined in detail with respect to the nature and effectiveness of proposed mitigation measures. The hypothetical incident considered was a Credible Worst Case (CWC) oil spill ($16,500 \text{ m}^3$) based upon an oil spill accident from an Aframax tanker near Turn Point in Haro Strait which resulted in a grounding accident with Arachne Reef. Although a powered grounding has an extremely low probability, there is a number of existing risk reducing measures already in place to prevent such an event from occurring including the use of double pilots and tethered escort tug. However, it was decided to test the scenario as part of a comprehensive marine risk assessment undertaken by Trans Mountain. From the assessment, WCMRC can then enhance and adjust future emergency plans and procedures for the CWC situation. Spill response is also under review by Canadian Government agencies.

2. Scenario Description

2.1. Study area

The study area is located along the western coast of Canada in Haro Strait which connects the Strait of Georgia and Juan de Fuca Strait. Haro Strait is located on the southwestern side of Vancouver Island and is surrounded by British Columbia, Canada, and Washington State, USA. Figure 1 shows the entire study area. The pink dot shows the location of the simulated incident and the dotted rectangle shows Haro Strait, a close-up of the study area.

2.2. Oceanography of the study area incident simulated

The waters between Moresby Island and Stuart Island, Figure 2, mark the northern entrance to Haro Strait, which runs south southeasterly between the Gulf Islands on the Canadian side and the San Juan Islands on the US side. Arachne Reef is situated at the northern end of Haro Strait, off to the west side of the Strait. It consists of three drying heads (Sailing Directions, 1979), and has a navigation light.

The typical tidal range varies from 2.4 m for mean tides to 3.8 m for large tides. Tidal currents in Haro Strait largely follow the channel alignment and can reach 2.0 to 3.0 m/s on an ebb tide (Canadian Hydrographic Service, 2005; Thomson, 1981). As in many tidal systems, currents during slack tide are weak and relatively spatially incoherent. Since Arachne Reef is off the main channel of Haro Strait, currents are weaker, being about 50% of the full streams in Haro Strait, based on circulation modelling conducted in the Strait of Georgia, Juan de Fuca Strait and Haro Strait.

Wind fetch in most parts of the Strait is rather limited and narrow, except near the southern end where waves approach from Juan de Fuca Strait in the southwest and from Puget Sound in the southeast.

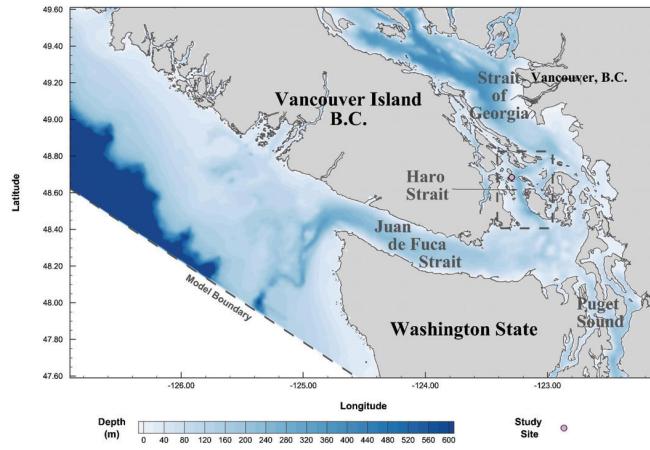


Fig.1. Study area

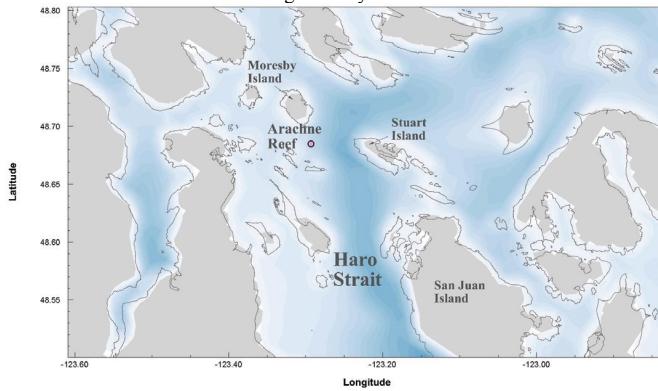


Fig.2. Arachne Reef incident area

2.3. Incident simulated

A partly loaded Aframax tanker departs the Westridge Terminal during high tide with a cargo of Cold Lake Diluted Bitumen and arrives in the vicinity of Arachne Reef in the evening. A plausible (but very low probability) event would be a powered grounding of the tanker on Arachne Reef, as a result of a navigation failure. All commercial vessels traveling between Vancouver and the Pacific Ocean typically transit this route and the section near Arachne Reef is considered to be one of the more complexes during the transit. This hypothetical incident is given to have occurred at 22:00 on August 17th 2012. Observed winds and hindcast currents are the drivers for the evolving spill. A total volume of 16,500 m³ of oil, the amount calculated as a credible worst-case oil spill for a partly loaded Aframax tanker, is released over 13 hours.

The scenario was selected from an array of stochastic simulations based on the representativeness of the resulting spill in terms of environmental and human-health damages. The probability of this event's occurrence is extremely low but was required to be considered for mitigation planning.

3. Mitigation Modelling System

3.1. Hydrodynamic model, H3D

The oil spill simulations, which form the basis of the mitigation analysis, use surface currents that were hindcast using a proprietary three-dimensional hydrodynamic model, H3D. This model is derived from GF8 (Stronach et al. 1993) developed for Fisheries and Oceans Canada. H3D has been used on several studies along the British Columbia coast. An extensive application of an operational version of this model to the St. Lawrence Estuary is described in Saucier and Chassée (2000).

H3D is a three-dimensional time stepping numerical model that computes the three components of velocity (u , v and w) on a regular grid in three dimensions (x , y and z), as well as scalar fields such as temperature, salinity and various introduced contaminants. A time stepping numerical model is one in which the period of interest (e.g., a year-long simulation of currents in Haro Strait) is broken up into a number of small time intervals (e.g., 100 seconds each). The model then takes advantage of the fact that over a short time interval, known as a time step, changes in currents, salinities, and other properties are small and can be computed according to physical laws, suitable for coding in a numerical model.

The spatial grid may be visualized as an array of interconnected computational cells collectively representing the water body. Velocities are determined on the faces of each cell and non-vector variables, such as temperature or salinity, are determined in the centre of each cell. The selection of grid size is based on consideration of the scale of the phenomena of interest, the grid domain, and available computational resources.

In the vertical, the cells are usually configured such that they are relatively thin near the surface and increase in thickness with depth. The increased vertical resolution near the surface is needed because much of the variability (e.g., stratification, wind mixing, inputs from streams and land drainage) is concentrated near the surface.

For the simulation described in this paper, one grid, or model, was used: a 1,000-metre resolution model of the Strait of Georgia-Juan de Fuca-Puget Sound system, extending out onto the shelf at the western end of Juan de Fuca (Figure 1).

Important dynamic forcing contained in H3D includes:

- Tidal water level fluctuations;
- Winds;
- Inflows from 50 rivers and creeks;
- Other meteorological parameters used to compute heat flux into the waterbody and thus its temperature structure;
- Turbulence modelling for horizontal and vertical turbulent transfers of momentum and scalars; and
- Oceanic boundary conditions for salinity and temperature, available via models maintained by the Alaska Ocean Observing System (AOOS).

3.2. Spill Trajectory and Weathering Model, SPILLCALC

SPILLCALC is a proprietary oil spill model developed by Tetra Tech EBA. SPILLCALC is a time stepping model that computes the motion and weathering of liquid hydrocarbon spills. In this application, SPILLCALC used current data from H3D, described above. SPILLCALC also has the capability to assimilate currents from other hydrodynamic models such as Delft 3D and HYCOM.

Oil released on the water surface is represented as a large number of independent floating particles. Individual particles are not intended to be physically meaningful. Instead, the cloud of particles as a whole represents the area

covered by the spill and its progress indicates the spill's dispersion and trajectory. SPILLCALC uses a time step appropriate to the grid size and drift velocities.

The key components driving the movement of particles are:

- Advection, based on surface currents obtained from hydrodynamic model;
- Wind leeway, using winds interpolated from several stations over the Strait of Georgia and Juan de Fuca Strait;
- Eddy diffusion by oceanic turbulence, simulated through the Monte Carle method as a random velocity component;
- Shoreline retention; and
- Weathering processes such as evaporation, dissolution, submergence and sinking, tar ball formation, biodegradation and oil-mineral aggregate formation. Figure 3 shows a schematic of the various weathering processes. Evaporation incorporates the effects of molecular diffusion based on the slick thickness (Hospital and Stronach, 2014). Dispersion is based on wave conditions provided by an independent SWAN model (Booij et al., 2006).

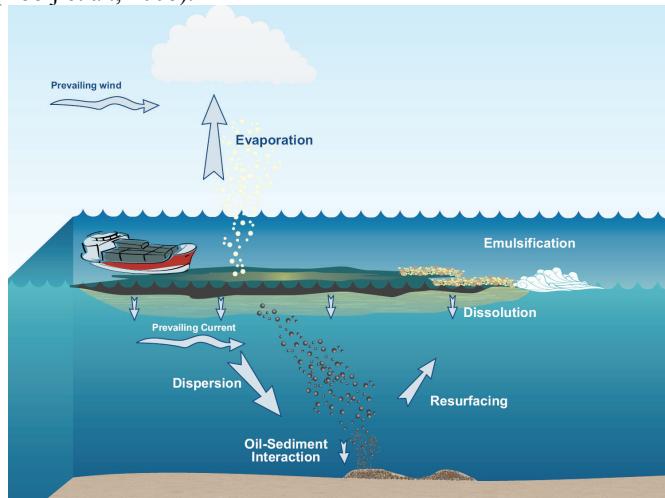


Fig.3. Weathering processes

3.3. Mitigation Modelling System

Overall concept

The idea of this approach is to combine a numerical oil spill model with spill response operational inputs to evaluate and improve the response plan.

The mitigation modelling system combines three components:

- A schedule of asset assignments, developed by WCMRC. The efficiency of these assets are time and weather dependent, both have been incorporated;
- Numerical simulations to evaluate the impact of these assets on the modelled spill in terms of reducing the amount of oil on the water; and
- Refinements to the mitigation strategy plan, iteratively tested in repeated simulations.

First, a schedule of asset assignments is constructed as an additional input to the oil spill model SPILLCALC. For each asset this schedule lists the time and location of deployment, total storage, and volumetric uptake capacity over a one-hour period.

The mitigation simulation proceeds as if responding to a real incident: the spill is initiated, assets are dispatched, and their initial deployment is based on the spill characteristics as simulated by SPILLCALC. The dispatch and rotation of oil spill response assets are handled by an expert in oil spill response. Going forward every hour thereafter, the operator examines the configuration of the spill and assets are moved to areas with the greatest slick thickness or the greatest proximity to a sensitive shoreline. Over the ensuing hours, the spill continues to evolve, but the assets remove oil based on their capacity. At the end of each hour, the cycle is repeated. The simulation at present requires continuous operator intervention. Automation possibilities exist; however, the operational training aspect of continuous oversight, strategic evaluation and the development of new response interventions is a desired feature. The advantage of this system is that it allows evaluation and improvement of a spill response plan by considering realistic environmental conditions and oil distribution and trajectory.

Example

Table 1 shows an example of the schedule of asset assignments, input for SPILLCALC. As an example, four hours following the incident, two vessels are on site and operational:

- Current Buster #1: a towed combination containment and recovery device; and
- Rozema #1: a self-propelled skimming vessel with a side-sweep enhancement.

Table 1: Schedule of Asset Assignments for SPILLCALC

Table 1: Schedule of Asset Assignments for SPILLCALC				
Time	Item	Current Buster #1	Rozema #1	Rozema #2
August 18 @ 2:00am	Model Cell Index	467 / 723	467 / 722	-
	Oil Thickness (µm)	4,750	3,240	-
	De-rated Capacity (m³/hr)	N/A	34	-
	Total Storage (m³)	68	76	-
	Storage Left (m³)	Full	42	-
	Model Cell Index	-	467 / 723	467 / 724
August 18 @ 3:00am	Oil Thickness (µm)	-	2,510	2,755
	De-rated Capacity (m³/hr)	-	34	34
	Total Storage (m³)	-	76	56
	Storage Left (m³)	-	8	22
	Model Cell Index	-	468 / 722	467 / 724
	Oil Thickness (µm)	-	6,550	2,490
August 18 @ 4:00am	De-rated Capacity (m³/hr)	-	34	34
	Total Storage (m³)	-	118	56
	Storage Left (m³)	-	16	Full

Based on oil distribution and environmental conditions such as wind and waves, Current Buster #1 achieves maximum capacity after one hour of recovery. It then must unload its contents to a storage barge. Rozema #1 has larger internal storage (35 m³) that can be extended with supplemental mini-barge storage (41 m³), hence can operate for a few hours. Coming from a different base, Rozema #2, with similar capacity to Rozema #1, arrives on site after 5 hours. Its internal storage is smaller than Rozema #1 and will be full within two hours of operation. This process is repeated for all the recovery vessels for each hour, taking into account the unloading time, time for the vessel to move, environmental conditions, oil distribution, etc.

Application to the simulated incident

A similar input mitigation list was constructed in response to the simulated incident. An iterative process of numerical simulations followed by revised schedule of asset assignment was the key in evaluating and improving the spill response plan. This iterative process is described below.

Every hour, SPILLCALC receives an updated list of vessels assigned to mitigation. If a vessel requires a few hours to reach its maximum internal storage capacity, the vessel will be moved according to its speed for efficient skimming and the oil distribution map. SPILLCALC steps through the spill evolution, and applies each of the assets at the time it is deployed, removing oil from the water surface according to the asset's uptake rate and oil availability. More precisely, SPILLCALC uses the encounter-rate method: during one hour, the asset would skim an amount of oil equal to the lesser of its de-rated skimming capacity and the oil available on that cell. During this hour, the spill model computes the oil movement and produces a mitigated spill map, and a corresponding entry into the mass balance tables. This process is repeated for the 96 hours (4 days) following the spill in the simulated incident scenario at Arachne Reef.

Figure 4 shows the system scheme on an hourly basis.

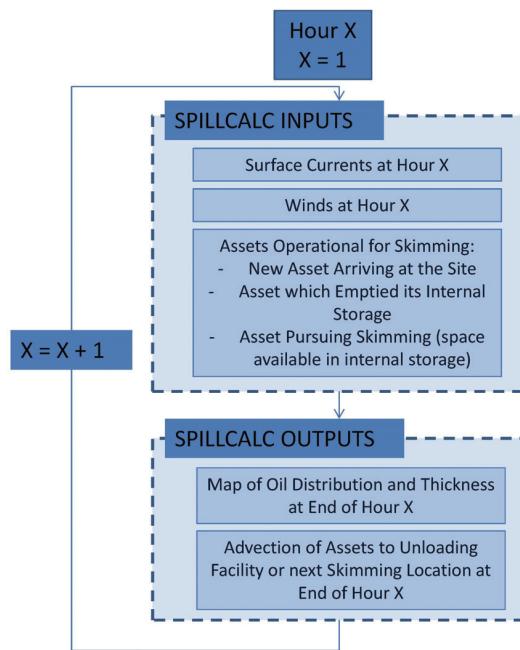


Fig.4. System scheme

Notes on the assets that were considered in the scenario:

- Assets are assumed to be operational 20-hours each day with a daily 4-hour maintenance shutdown period beginning on Day-2.
- Primary and secondary containment - essentially sufficient boom to encircle the stranded vessel twice. This tactic is highly effective in containing the spread of oil and assisting in its recovery since the oil within the boom will be thick and fresh, hence amenable to skimming and pumping. However, booming a ship in distress has its own associated difficulties. If the incident occurs in open waters, the water depth may be too great or the seabed may not be conducive to holding the anchor systems necessary to keep the boom away from the ship to achieve containment.

Since this scenario assumes the vessel to be firmly aground, the issue then becomes holding the boom in place in the relatively strong tidal currents that flow around the reef.

- Skimmers in common use within the WCMRC inventory were assigned to collect oil in the scenarios. Tests done at Gainford (Polaris & WCMRC, 2013) over a period of ten days in the spring of 2013 proved that the oil cargo floats under meso-scale test conditions. Conventional skimming technology can be used to recover oil from the water's surface for several days after the release.
- Temporary on-water storage devices (bladders, mini-barges, integral storage in a supply boat, full-size barges) are important assets that were found to increase spill response effectiveness. Although high volume tank barges are optimal as on-water storage devices, they are slow to reach the spill from their base port, given the long mobilization times and their slow speed of advance. Thus, the provision of integral storage (1,880 mt) on an offshore supply vessel (OSV) helps to significantly bridge the storage gap from the start of the incident to the on-site arrival of the first barge.

4. Spill Response Plan

The spill response plan was divided on a daily basis. A vessel cleaning and rotation period was considered at the end of each day. A summary of recovery operations is described below, followed by a summary of amount of oil recovered on a daily basis in Table 2.

4.1. Initial response

A summary of recovery operations at the end of Day-1 reveals the following information:

- 14 skimmers performed 44 individual recovery sorties by the end of the day;
- During the first 8 hours of the response, the OSV (with 1,880 mt of integral storage) provided temporary storage until the arrival of a large barge;
- In addition to the OSV, Barge #1 (5,000 mt) will be the only other dedicated storage unit during Day-1;
- Eight 40-tonne mini-barges were deployed and cycled throughout the day to extend the recovery times of certain skimmers.
- A containment boom was deployed around the tanker, allowing recovery inside this containment boom through skimming. Oil leakage through the boom due to environmental conditions was taken into account.

4.2. Response during day-2

A summary of recovery operations at the end of Day-2 reveals the following information:

- 17 skimmers performed 61 individual recovery sorties by the end of the day;
- In addition to the OSV (1,880 mt), Barge #1 (5,000 mt) and Barge #3 (10,000 mt) were used as dedicated storage units during Day-2;
- Twenty 40-tonne mini-barges were deployed and cycled throughout the day to extend the recovery times of certain skimmers.

4.3. Response during day-3& day-4

A summary of recovery operations at the end of Day-3 and Day-4 reveals the following information:

- 18 skimmers performed 58 individual recovery sorties by the end of the Day-3;
- 18 skimmers performed 48 individual recovery sorties by the end of the Day-4;
- In addition to the OSV (1,880 mt), Barge #1 (5,000 mt), Barge #3 (10,000 mt) and Barge #4 (> 2,000 mt) were used as dedicated storage units during Day-3 and Day-4;
- Twenty 40-tonne mini-barges were deployed and cycled throughout the two days to extend the recovery times of certain skimmers.

Table 2. Summary of recovery per day

	Recovered inside the Containment Boom(m ³)	Recovered at Sea (m ³)	Total Recovered (m ³)
Day 1	170	2,881	3,051
Day 2	696	1,941	2,637
Day 3	1,100	1,830	2,930
Day 4	1,100	693	1,793
Total	3,066	7,345	10,411

4.4. Results

Two types of mitigation were simulated in this study: the containment and subsequent recovery of the oil around the ship and the mechanical recovery by skimmers of free-floating oil at sea.

The recovery of the oil inside the containment area and the recovery of the oil at sea were modelled based on the response plan summarized above, for four days of operations. Figures 5 and 6 show the oil distribution map for both mitigated and unmitigated cases, as computed by SPILLCALC after 6 hrs, 12 hrs, 24 hrs, 48 hrs, 72 and 96 hours. The maps take into account the skimmer operations and the deployment of the primary and secondary booms around the casualty vessel.

As one can observe in Figure 5, there is no obvious difference between mitigated and unmitigated case after 6 hours and 12 hours. This can be explained by the fact that few vessels have arrived on site within this timeframe. The recovery of oil by these vessels has been enhanced by the addition of the offshore supply vessel (OSV), which enables all the skimmers to recover and offload normally until the larger barge arrives at site.

After 24 hours, the geographical distribution of oil hasn't changed; however, the thickest spots of oil have been partially skimmed. Hence the thickness (intensity in red color) has decreased.

Finally, after 96 hours, i.e. 4 days, Figure 6 clearly shows that much less oil is left on water in the mitigated case (right panel), compared to the unmitigated case (left panel). The efficiency of the mitigation can be appreciated with a glance. It should be pointed out that oil on shore was not displayed on these figures for clarity purpose.

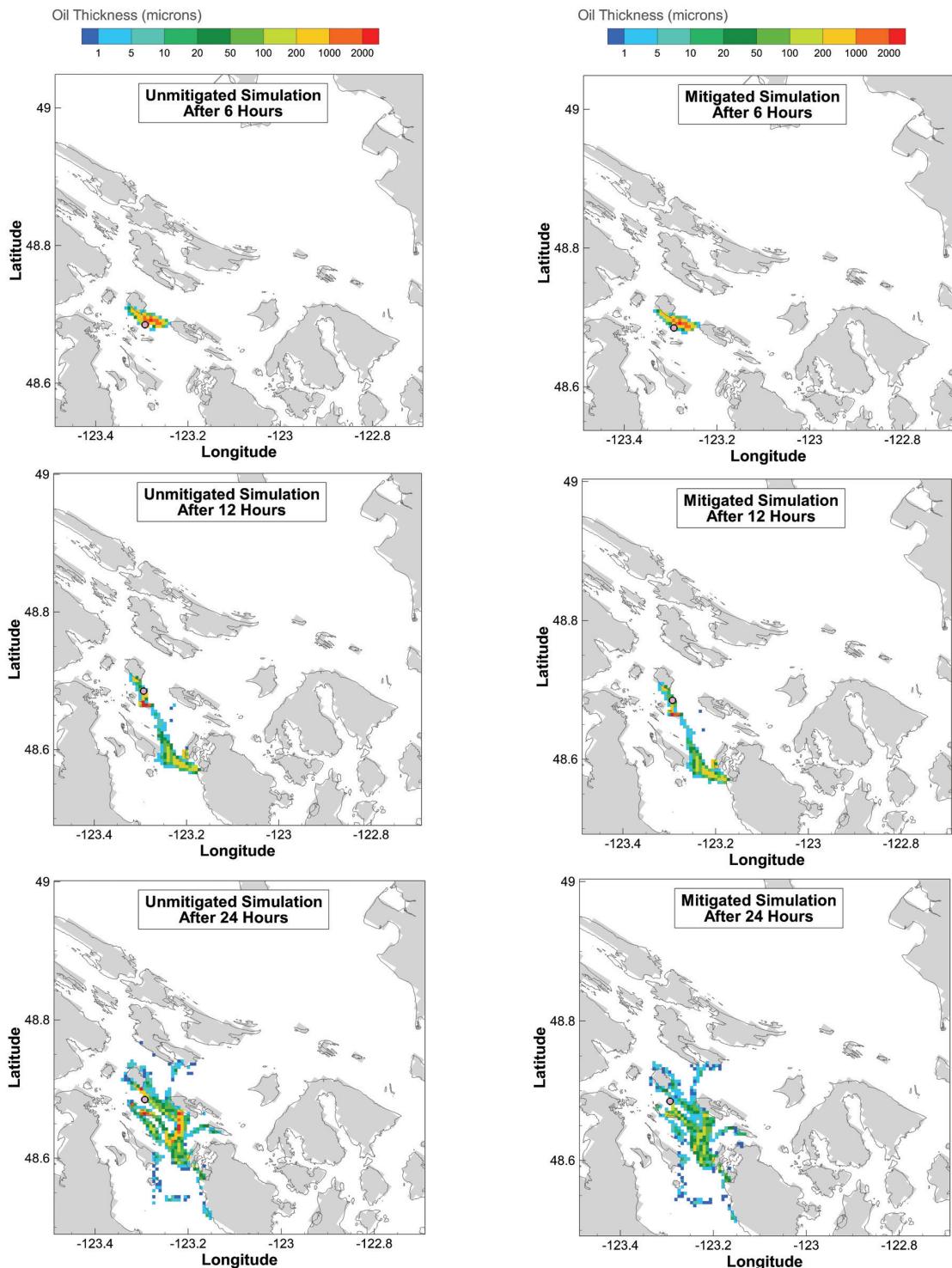


Fig. 5. Oil thickness map after 6/12/24 hours

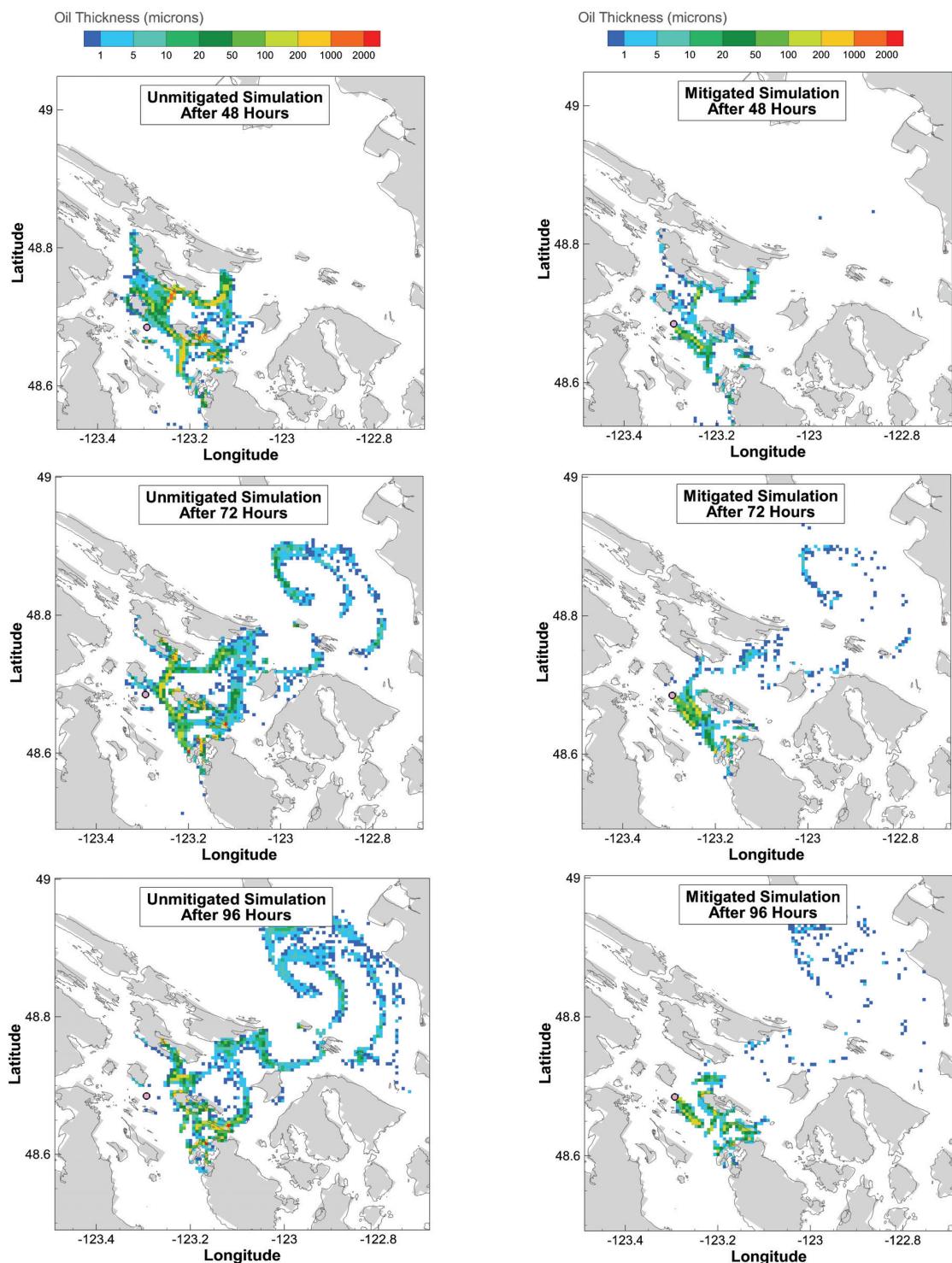


Fig. 6. Oil thickness map after 48/72/96 hours

Table 3 compares the mass balance in the unmitigated and mitigated cases. Recovery of the oil was conducted at sea and in the containment area. Of the total oil outflow from the tanker in this simulated accident, 44.5% was recovered from the sea outside the boom and 18.6% was recovered from within the containment area. The containment boom still contains about 1% of the total release after four days. This amount will be collected over the course of the fifth day. There is a net benefit in terms of shoreline contact: after 4 days, 38.5% of the oil would have reached the shore with no mitigation. This number has been brought down to 15.8% with mitigation. After 4 days, there is almost no oil inside the containment boom as a result of the recovery operations and less than 10% of the oil is left on water.

Table 3. Mass balance comparison between mitigated and unmitigated simulations

Amount after 4 Days (m ³)	Unmitigated Case	Mitigated Case (simulated)
On Shore	38.5 %	15.8 %
Adrift on Water	35.9 %	8.9 %
Evaporated	19.9 %	7.3 %
Dissolved	3.8 %	3.4 %
Biodegraded	1.9 %	0.5 %
Inside the Containment Area but Not Yet Recovered	N/A	1.0 %
Recovered Inside the Containment Boom	N/A	18.6 %
Recovered at Sea	N/A	44.5 %
Total	100 %	100 %

5. Approach Benefits

Interactive use of an oil spill model is a powerful tool that can effectively challenge and validate response strategies. Prior to participation in the modelling project, WCMRC had developed a preliminary equipment package and response base location plan to support the proposed Westridge Terminal expansion. The proposed equipment package was designed to mitigate a substantial release anywhere along the shipping route between the terminal, located in Vancouver, BC, and Buoy J, on the western entrance of Juan de Fuca Strait facing the Pacific Ocean. Proposed bases were sited based on accessibility and calculated risk, thus it was not random that a response base at Sidney would be close to a scenario involving Arachne Reef, one of the locations with elevated navigational risk.

After completing two preliminary model runs, it became evident that, to be successful, the proposed equipment package had to address the early shortfall of high-volume temporary storage and the ability to recover high-value oil leaking from the containment boom deployed around the damaged ship. Hence a proposed medium-speed offshore supply vessel with significant integral tankage and a deck capable of carrying four Current Buster recovery devices was added to the package and was considered in this current analysis.

6. Conclusion

Oil spill modelling is a great enhancement to the development of response tactics and strategies. Historically, oil spill response efforts have generally achieved mixed, and sometimes less-than-optimal, recovery results. Although these historic events weren't studied as part of this analysis, we speculate, based on lessons learned from the iterative approach taken to optimize oil recovery at the study site, that the availability of good support tools for optimizing asset assignment can greatly improve oil recovery. The mitigations simulated here affirm the premise that oil spill recovery at sea can be effective and can be continuously improved given adequate assets, a timely response, access to good environmental and spill information, and the ability to identify and correct inefficiencies

before they become replicated throughout the response system. All of the above functionalities and systems contribute to a highly effective and informed Spill Management System, also called an Incident Command System (ICS) in North America.

Acknowledgements

We would like to acknowledge Trans Mountain for allowing us to work on this study, with a special thanks to Captain Bikramjit Kanjilal (Trans Mountain Expansion Project Marine Lead) and Mr. Mike Davies, Kinder Morgan Canada.

References

- Booij, N., I.J. Haagsma, L. Holthuijsen, A. Kieftenburg, R. Ris, A. van der Westhuysen, M. Zijlema, 2006. SWAN User Manual, Cycle III Version 40.51. Delft University of Technology, Netherlands, 111.
- Hospital, A., A. Stronach, 2014. The Implementation of Molecular Diffusion to Simulate the Fate and Behaviour of a Diluted Bitumen Oil Spill and its Application to Stochastic Modelling. Proceedings of 37th AMOP Technical Seminar on Environmental Contamination and Response, Environment Canada, 353-373.
- Stronach, J.A., J.O. Backhaus, T.S. Murty , 1993. An update on the numerical simulation of oceanographic processes in the waters between Vancouver Island and the mainland: the GF8 model. Oceanography and Marine Biology Annual Review 31, 1-86.
- Tetra Tech EBA ,2013. Report: Stochastic and Deterministic Oil Spill Numerical Modelling for the Trans Mountain Expansion Project
- Thompson, R.E. , 1981. Oceanography of the British Columbia Coast, Can. Spec. Publ. Fish. Aquat. Sci. 56, 291.
- Western Canada Marine Response Corporation, 2013. Report: Review of Trans Mountain Expansion Project, Future Oil Spill Response Approach Plan, Recommendations on Bases and Equipment.