OIL SPILL RESPONSE ANALYSIS

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Technical Analysis of Oil Spill Response Capabilities and Limitations for Trans Mountain Expansion Project

Expert Report Prepared for:
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EXECUTIVE SUMMARY

Nuka Research and Planning Group, LLC developed this expert report for three Interveners in the National Energy Board review of the Kinder Morgan Trans Mountain Pipeline Expansion project proposal (the project application): the Tsleil-Waututh Nation; the City of Vancouver; and the Tsawout First Nation. This report was prepared by a team of authors with substantial expertise and experience in oil spill contingency planning, oil spill response operations, and the application of analytical tools to evaluate and understand oil spill risks.

Background

When an oil spill occurs, there will be impacts to the environment, wildlife, and human activities. Containing and recovering as much oil as possible can mitigate these impacts when it is done before the oil spreads too thin for recovery, reaches the shoreline, or submerges into the water column. The effectiveness of an on-water oil spill response is influenced by many inter-related factors, including environmental factors, equipment availability and suitability, availability of trained personnel, accuracy of spill tracking, and the timing and effectiveness of countermeasure deployment.

This report examines key factors that could impact the mitigation of potential oil spills along the Trans Mountain Expansion pipeline and marine vessel routes in British Columbia. While no one can predict the exact circumstances surrounding a potential future oil spill, this three-part analysis examines pragmatic factors that influence the effectiveness of an on-water response in areas that are important to the Interveners. All three analyses highlight certain conditions under which environmental conditions, response system capacity, or logistical constraints may hinder or preclude effective response to oil spills from the proposed Trans Mountain Pipeline Expansion.

Scope of Study

Analyses

The report presents three separate but related analyses that consider oil spill response capabilities and limitations in areas of Southern British Columbia that are vulnerable to potential oil spills from Trans Mountain Expansion tanker and pipeline operations.

- A **marine oil spill response gap analysis** models the impact of environmental conditions on marine oil spill response and evaluates the frequency and duration that such conditions would preclude the safe and effective deployment or operation of mechanical oil spill recovery systems at locations along the Trans Mountain Expansion tanker route. The response gap analysis in Section 2 of this report estimates the percentage of time during which environmental conditions such as wind, visibility, and waves would prevent or limit oil spill response operations.
- A **marine oil spill response capacity analysis** estimates the total capacity for mechanical recovery of major marine oil spills at scenario locations in coastal Southern BC. The response capacity analysis presented in Section 3 of this report models the best-case oil recovery for a series of simulated oil spills at locations along the Trans Mountain Expansion tanker route. Several sensitivity analyses are conducted to evaluate the potential changes to oil spill recovery by season, location, availability and location of response forces, and delays to response implementation. The potential impacts of stranding oil and submerged or sunken oil to on-water recovery are discussed.
- A **river oil spill response logistics analysis** estimates the mobilization and transport timing required to deploy equipment in time to potentially limit the downstream transport of oil spills on the Lower Fraser River between the Port Mann Bridge and the mouth. The river response logistics analysis

presented in Section 4 of this report estimates the amount of time needed to intercept oil traveling downstream in the Lower Fraser River in order to reduce the level of riverbank contamination and potentially prevent the spill from reaching open water for a range of flow conditions.

On-water Mechanical Recovery of Oil Spills

All three analyses consider the capabilities of and limits to mechanical oil spill response systems based on environmental conditions and response logistics. Mechanical oil spill response systems use mechanical equipment – primarily containment boom, skimming systems, pumps, hoses, and storage devices – to contain and recover oil that floats on the water surface.

Mechanical oil spill response systems rely upon the ability to locate and track oil slicks, which is typically done from aircraft either visually or using specialized sensing equipment. The mechanical recovery tactics presented in this report can only be successful when oil is floating on the water surface and contained to a sufficient thickness to remove using skimmers. Oil can no longer be recovered once it spreads too thin or droplets submerge or sink below the surface. Similarly, when oil strands on shorelines or riverbanks, it is no longer available for on-water mechanical recovery.

The changing nature of an oil slick presents a constant challenge to on-water mechanical recovery, because once released, the oil slick will migrate, spread, evaporate, and undergo a series of physical and chemical changes at varying rates depending upon environmental conditions. This weathering process typically leads to emulsification (mixing of oil and water into a mousse) and may increase oil viscosity (stickiness). Both of these factors tend to reduce on-water recovery efficiency.

In all three analyses, the elapsed time between when a spill occurs and when a response begins is a critical factor to evaluating whether the oil spill can be contained and recovered before it impacts shorelines.

Study Area

Figure 1 shows the study area for the three analyses. The Study Area map includes the Trans Mountain Expansion pipeline and tanker routes, the City of Vancouver, the Tsleil-Waututh Nation and Tsawout Nation Reserves, and the Tsleil-Waututh Consultation Area. The response gap and response capacity analyses span the study area, with analysis performed for several sites along the tanker route. The Lower Fraser River response logistics analysis is confined to the area shown in Inset 2.

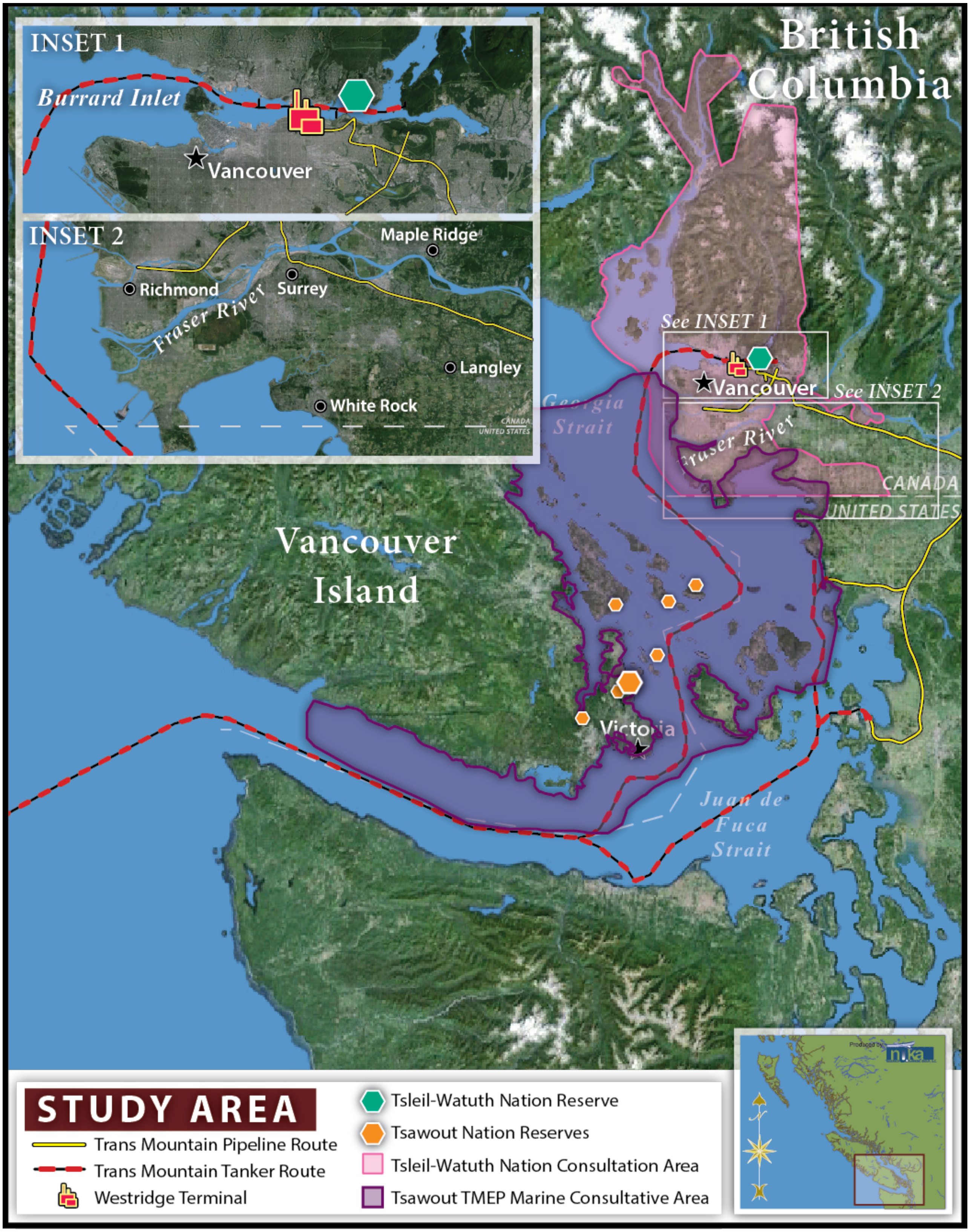

FIGURE 1. STUDY AREA

Summary of Analysis, Results, and Key Findings

Marine Oil Spill Response Gap Analysis

Research Question: How often will environmental conditions preclude or limit on-water oil spill response in the study area?

The marine oil spill response gap analysis presented in Section 2 of this report applies a set of operating limits – environmental factors that would limit or preclude oil spill response operations – to historical environmental datasets for five sites along the Trans Mountain Expansion tanker route in Southern BC. At the National Energy Board's request, Trans Mountain submitted a partial response gap analysis as part of the project application (Trans Mountain, 2014a), but it did not apply a standard methodology and did not account for several important factors, such as visibility limits, interaction among factors, and seasonal variability.

By comparison, this response gap analysis considers many of the same inputs as Trans Mountain's partial study, but applies more rigorous and detailed analysis using a standard methodology derived from multiple peer-reviewed studies. The results provide a quantitative estimate of the percentage of time during which on-water oil spill response operations would or would not be feasible in each location at different times of the year.

Table 1 shows the response gap estimates along the Trans Mountain tanker route for each of five sites: (1) Central Harbour, (2) Outer Harbour, (3) Georgia Strait, (4) Juan de Fuca Strait, and (5) Neah Bay. Figure 2 summarizes these results on a map.

TABLE 1. RESPONSE GAP ESTIMATES FOR FIVE SITES ALONG TRANS MOUNTAIN TANKER ROUTE

Location	Open Water Mechanical Recovery + Aerial Reconnaissance			Protected Water Mechanical Recovery + Aerial Reconnaissance		
	Summer	Winter	Overall	Summer	Winter	Overall
Central Harbour	n/a	n/a	**n/a**	34%	57%	**45%**
Outer Harbour	n/a	n/a	**n/a**	34%	56%	**46%**
Georgia Strait	35%	59%	**47%**	38%	63%	**51%**
Juan de Fuca	40%	60%	**49%**	46%	63%	**54%**
Neah Bay	49%	78%	**65%**	n/a	n/a	**n/a**

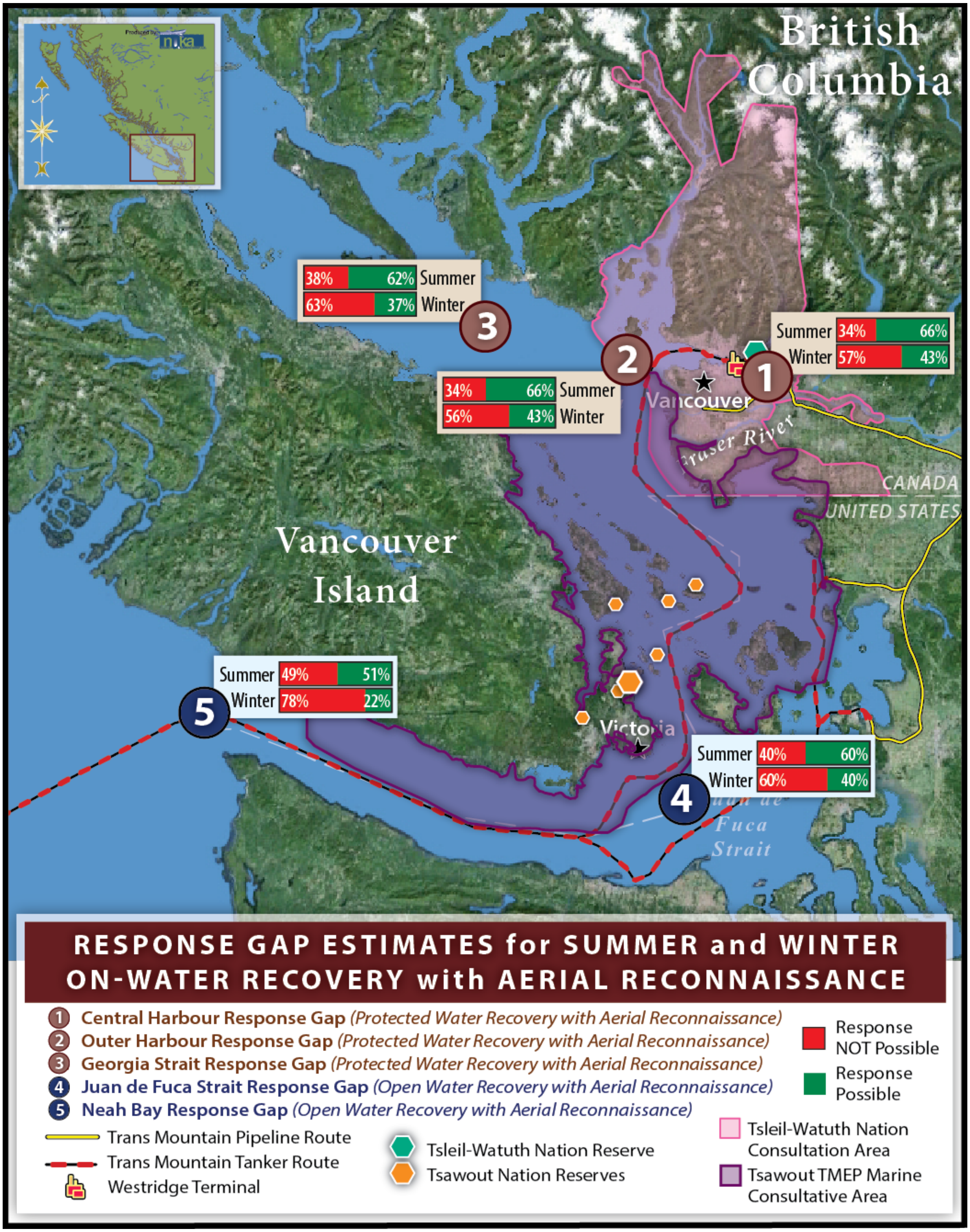

FIGURE 2. SUMMARY OF RESPONSE GAP ESTIMATES ALONG TRANS MOUNTAIN TANKER ROUTE

Figure 2 shows that the response gap – the estimated percentage of time each year that on-water oil spill recovery operations would be impeded or completely shut down because of weather or environmental conditions – ranges from 34% for a summer spill in the Central Harbour to 78% for a winter spill at Neah Bay. The response gap estimates reflect the operating limits for on-water recovery operations (using either protected water or open water response systems) simultaneous with aerial observation operations to help track the oil spill movement and direct on-water response forces to the areas of highest oil concentration. The analysis shows that the response gap is higher during the winter at all locations.

At Neah Bay, where the response gap estimate shows that on-water recovery with aerial observation is possible only 22% of the time during winter, we reviewed the data for 2013 to evaluate the total number of 24-hour days during which on-water response conditions remained favourable for the entire day. We observed that out of 134 days of complete weather observations (meaning that the weather buoy recorded conditions every hour), there were only 12 days where conditions remained favourable for a full day. During a "typical" weather week (seven days) in the winter at Neah Bay, on-water recovery would be possible for 2.25 days, and on-water recovery supported by aerial reconnaissance would be possible for only a day and a half. This illustrates the importance of spill timing to the overall success of the response. If a spill occurs at a location during a multi-day response gap, it is possible that the spill would remain unmitigated for several days until conditions improve. At that point, the window-of-opportunity for effective on-water recovery may diminish or completely close.

To examine how response gaps align across multiple sites, we evaluated the response gap estimates for Juan de Fuca Strait and Neah Bay, which are separated by approximately 120 km. The combined response gap for these two sites was estimated to consider how often conditions would be favourable at both sites simultaneously, and found that there are times during the winter months when response is possible at both locations less than 15% of the time. If a tanker spill were to occur somewhere along the transit route between these two locations, the direction in which the spill migrates may significantly impact the effectiveness of on-water recovery operations.

KEY FINDINGS FROM RESPONSE GAP ANALYSIS:

1. **There is no location along the Trans Mountain tanker route where on-water oil spill response will always be possible.**
2. **There may be times when on-water vessel operations are possible but poor visibility – including darkness – precludes aerial reconnaissance, making it very difficult to track and target oil for recovery.**
3. **During the winter, response is not possible between 56% and 78% of the time at sites along the Trans Mountain tanker route.**
4. **If a spill occurs during a time when response gap conditions exist, the unmitigated oil slick will remain in the environment until conditions improve. If the response gap conditions extend for several days, there may not be any opportunity for on-water recovery.**
5. **Lack of a response gap does not ensure that a response *will* occur, nor does it guarantee that the response will be effective.**

Marine Oil Spill Response Capacity Analysis

> **Research Question: What is the capacity for available mechanical oil spill recovery systems to contain and recover on-water oil spills in the study area and how is it increased or decreased by certain factors?**

The marine oil spill response capacity analysis presented in Section 3 of this report applies the Response Options Calculator model to a series of hypothetical oil spills at five locations along the Trans Mountain tanker route to estimate the total potential oil recovery during the first 72 hours of the spill. The analysis compares response effectiveness by location and season, and considers the difference to overall recovery based on differences in force composition, delays in response mobilization, and incorporation of night operations. The potential impact of oil submergence and stranding to overall oil recovery estimates are described but are not factored into the capacity estimates.

Figure 3 summarizes the response capacity estimates for summer and winter conditions at five sites along the Trans Mountain tanker route: (1) Central Harbour, (2) Outer Harbour, (3) Georgia Strait, (4) Race Rocks, and (5) Haro Strait. These sites are consistent with oil spill scenario locations provided in the Trans Mountain Expansion project application.

A credible worst case spill of 8,000 m^3 is modeled for the Central Harbour site; at all other sites, a 16,000 m^3 spill is modeled. The 8,000 m^3 spill at the Central Harbour site is presented as a credible worst case scenario because it represents the 90^{th} percentile spill volume for a tanker that is struck at berth, according to risk analyses provided in the Trans Mountain Expansion project application. The other spills also represent 90^{th} percentile spill volumes (expected spill size for highest 10% of potential scenarios) for tanker accidents along the route.

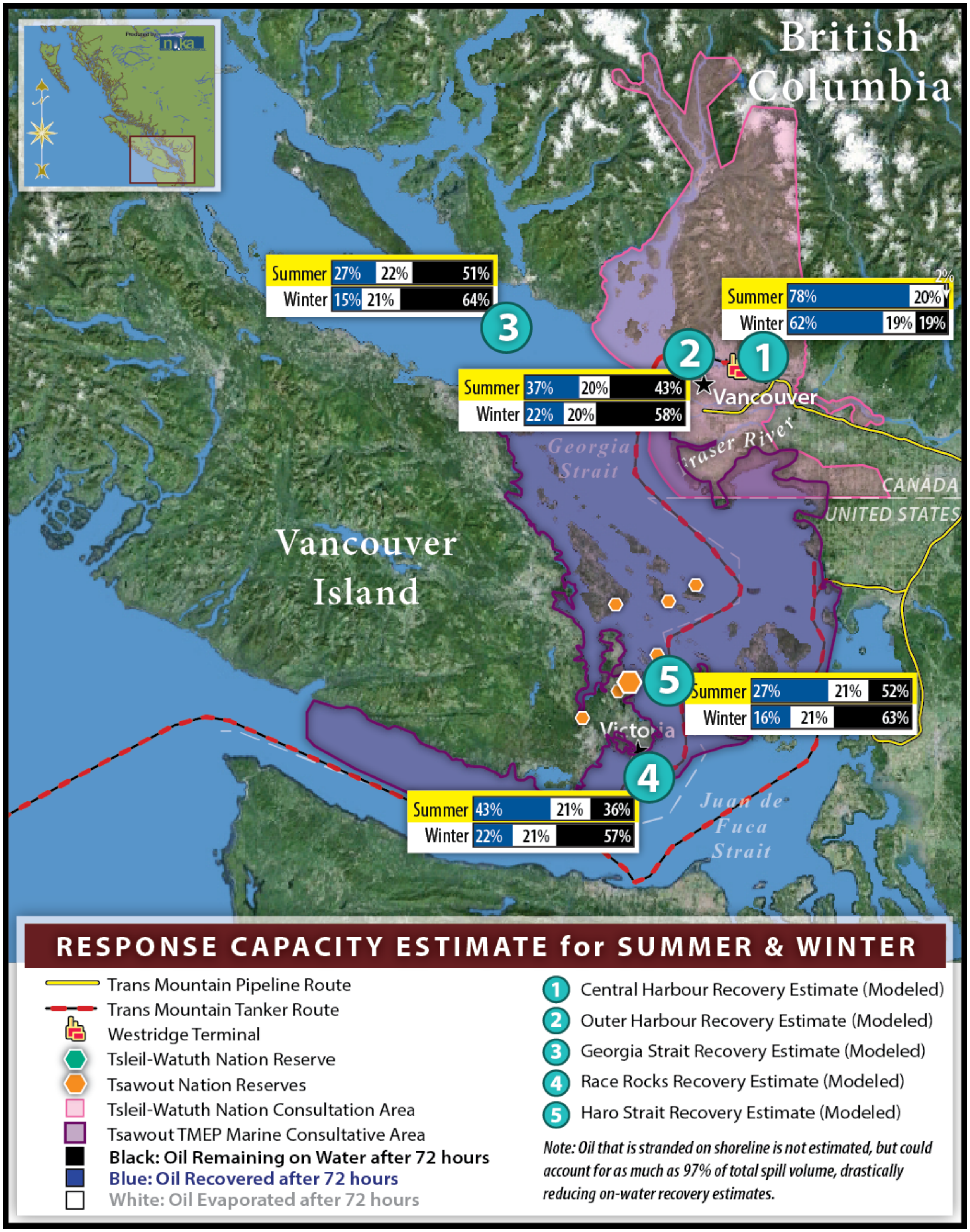

FIGURE 3. RESPONSE CAPACITY ESTIMATES FOR FIVE SITES ALONG TRANS MOUNTAIN TANKER ROUTE FOR SUMMER AND WINTER CONDITIONS

Figure 3 summarizes the estimated percentage of a worst case oil spill that could be recovered at each site during the first 72 hours of the response, showing how response capacity varies by location and time of year. These estimates likely overestimate real-world recovery because they were developed based on a series of optimistic assumptions that include prompt spill detection, perfect equipment functioning, favourable environmental conditions, and adequate availability of trained responders. The recovery estimates reflect a combination of existing spill response equipment in place in southern BC, along with additional equipment that has been proposed in project application materials but not yet purchased. The modeling approach does not incorporate other limiting factors, such as the likelihood that oil will strand on shorelines before it can be recovered, or the potential for diluted bitumen to submerge or sink so that it cannot be recovered using oil skimmers.

The highest estimates are for a summer spill at the Central Harbour site, with the model showing that 78% of the oil could be recovered using skimmers, assuming that the oil remains floating and does not strand on nearby shorelines. The lowest modeled recovery estimates are for winter spills at Georgia Strait and Haro Strait, where the model estimates that only 15-16% of a 16,000 m^3 spill would be recovered within 3 days of the spill. In each of those scenarios, close to two-thirds of the spill volume would remain in the environment after 3 days of on-water recovery operations.

A series of sensitivity analyses showed that changes to some of these assumptions – for example, delays to response implementation – reduce overall recovery estimates significantly. When the analyses were run based only on spill response equipment that is in place at the present time, recovery estimates were reduced by as much as 58%. The potential for oil to submerge, sink, strand on beaches, or become too viscous to recovery with skimming systems is not addressed in the model; however, any of these factors may reduce on-water recovery capacity, and some may stop it altogether.

KEY FINDINGS FROM RESPONSE CAPACITY ANALYSIS:

1. On-water oil spill recovery capacity is reduced during winter months by as much as 50% compared to summer.

2. If spill response were delayed for any reason – lags in detection, poor weather, equipment malfunction – the total volume of oil recovered would decrease significantly. A 48-hour delay in the modeled response to a 16,000 m^3 Outer Harbour spill would result in over 11,000 m^3 of oil left in the environment.

3. The modeled response capacity estimates do not consider the potential for shoreline stranding. This may overestimate total recovery at all sites, and most significantly in Burrard Inlet where models show up to 90% of an oil spill stranding on the beaches.

4. The spill response forces currently available in Southern B.C. have the capacity to recover only 10-20% of a worst case oil spill under favourable conditions.

5. Current response forces are clustered in the Vancouver Port area, which reduces response capacity for other sites along the Trans Mountain tanker route.

6. Night operations require double the personnel and create significant safety risks that may not be justified by the modest improvement to oil recovery from 24-hour operations.

7. Changes to diluted bitumen density and viscosity within the first few days of the release may render oil spill response systems ineffective.

Lower Fraser River Oil Spill Response Logistics Analysis

> **Research Question: How quickly must response resources be mobilized, transported, and deployed to representative control points to reduce the downstream transport of an oil spill on the Lower Fraser River?**

A river response logistics analysis was conducted for the Lower Fraser River from the Port Mann Bridge to the Delta to analyze the minimum response time required to mobilize and deploy resources to three control points. Like the marine response gap analysis, this river response study considers the *opportunity* to deploy response equipment from the perspective of whether or not resources could be mobilized or deployed to a site ahead of the leading edge of an oil spill.

The analysis compares road travel time estimates for response resources from equipment caches in Burnaby, Delta Port, and Hope to the three control points with the potential rate of downstream transport of an oil spill from the Port Mann Bridge pipeline crossing for various nominal speeds. The result estimates the window-of-opportunity to set up oil spill control countermeasures at three locations ahead of the leading edge of an oil spill. Successful deployment of control strategies could reduce the downstream transport of oil and minimize the adverse impacts to river waters, riverbanks, vegetation, and wildlife. The analysis describes the challenges of riverine oil spill response. Figure 4 shows the summary of results from the Lower Fraser River Spill Response Logistics analysis assuming slow, medium, and fast river velocities.

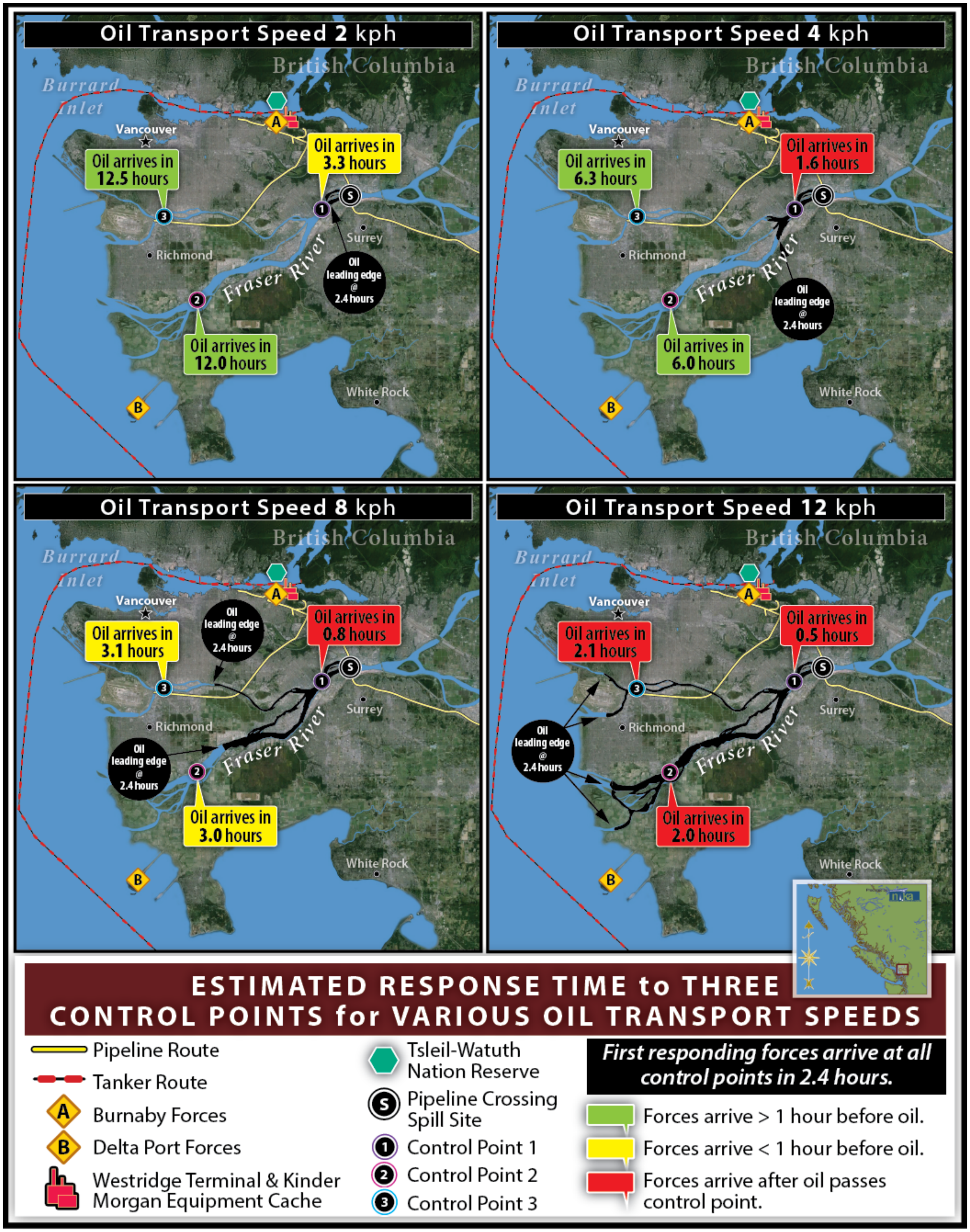

FIGURE 4. SUMMARY OF RESULTS FROM LOWER FRASER RIVER SPILL RESPONSE LOGISTICS ANALYSIS

The response logistics analysis demonstrated how the rate of downstream oil transport will be a defining factor for whether or not sufficient time is available to mobilize, transport, and deploy response equipment ahead of the leading edge of a river spill. Green indicates that there is more than an hour to spare between the estimated arrival of response resources and the leading edge of the spill. Yellow indicates that there is less than an hour to spare, and red indicates that the oil reaches the control point ahead of the equipment. The response logistics timing estimates reflect a series of optimistic assumptions in that they rely on prompt transport with no traffic delays or other hold-ups. They also assume that spill detection is instantaneous. Together, these maps show that there is a potential to beat the oil to the control points up to flow rates of 12 kph, although the margin for error narrows considerably with increased transport rates. If oil migrates downriver faster than 12 kph, it is not possible to transport and deploy equipment to the control points ahead of the spill, given the present configuration of response trailers in the region.

KEY FINDINGS FROM LOWER FRASER RIVER LOGISTICS ANALYSIS:

1. If an oil spill occurs at the Port Mann Bridge and moves downriver at 8 kph or faster, there may not be time to mobilize and deploy equipment in time to control the spill before it reaches the Lower Fraser Delta. At transport speeds of 12 kph or higher, this becomes impossible.

2. Response equipment inventories along the Lower Fraser River are limited.

3. Existing river response equipment is meant for floating oil, and would not be effective in the event that a diluted bitumen spill submerged or sank in the Lower Fraser River.

4. It is unclear whether Trans Mountain has access to the specialized oil spill response equipment, tactics, and trained personnel necessary to control oil spills in fast water conditions (greater than 0.8 kts/1.5 kph).

5. The Trans Mountain application lacks critical detail about how responders will manage practical and logistical considerations – such as site access, travel routes, boat launch access, and tactical planning – that are critical to successful river response.

Synthesis of Results

A number of common themes emerge throughout the three analyses that can inform the understanding of oil spill response capabilities and limitations for spills from the Trans Mountain Expansion project.

Timing is Critical to Oil Spill Response Capabilities and Limitations

The element of time was shown to be critical to all three analyses. Oil spill response in both marine and riverine environments is a race against the clock, because oil spills begin to change and spread from the moment they are released from a pipeline or tanker into the environment. The physical and chemical changes that all oils undergo when spilled to water can be especially important for diluted bitumen spills, because of the oil characteristics. Nearly all of these changes make on-water spill recovery more difficult and less effective, so implementation of on-water recovery tactics while the oil spill is fresh is always a top priority.

Any factors that delay the opportunity to deploy on-water containment and recovery tactics while the oil is fresh may reduce the overall effectiveness of the response. This report identifies a number of different factors that may cause response delays, including: delayed oil spill reporting or detection; occurrence of adverse environmental conditions that make response unsafe or unfeasible (response gap); or delays in mobilizing, transporting, and deploying response equipment.

The marine oil spill response gap analysis shows that the most significant gap periods occur during winter months, and the timing of these gaps may be such that adverse conditions can occur over a period of several days. If an oil spill should occur at the onset of a period of prolonged adverse conditions, the window of opportunity to respond to a spill could pass entirely.

The marine response capacity analysis shows that recovery rates diminish over the first 72 hours of a response, corresponding to the spreading and weathering of the spilled oil. Delays to response implementation diminish response capacity at a linear rate. By the time 48 hours has elapsed, the on-water recovery potential may be reduced by as much as 80%, which means that most of the spilled oil will remain in the environment until it can be cleaned off beaches.

The Lower Fraser River response logistics analysis shows that a minimum of two and a half hours is required to mobilize equipment to control points along the river, assuming no traffic or other delays. In order to set up control point tactics before the oil reaches the site, the spill must be detected, spill managers must direct the response resources to be mobilized and transported to the control point, and trained responders must arrive along with the equipment in time to deploy the tactics. Successful implementation will rely on smooth operations for the entire chain of events.

This means that there will be times when an oil spill from the Port Mann Bridge may travel the length of the Lower Fraser River and reach the delta before any countermeasures can be applied. When oil is transported downriver at rates of 4 kph or higher, the window of opportunity to deploy resources ahead of the leading edge of the spill is 6 hours or less. At a transport rate of 8 kph or higher, the window of opportunity is reduced to 3 hours.

Type, Quantity, and Location of Response Equipment is Critical

Both the marine response capacity and the Lower Fraser River response logistics analyses highlight the importance of matching response equipment to operating environment. For some sites along the tanker route, conditions may be appropriate for either protected water or open water systems, depending on prevailing weather. At other sites, one or the other system is more appropriate. For Fraser River spills, river response systems capable of containing oil under high current velocities will be critical during times when flow rates are high.

The response capacity analysis and Lower Fraser River analysis also point to limits in the current equipment inventory as potentially limiting response capabilities in Southern BC. The response capacity analysis shows that there is a striking difference between the current, existing response capacity in place for marine spills from Trans Mountain operations and the proposed future capabilities that are described in the project application. The response capacity analysis also shows how important it is to consider spill response capability from a systems perspective – boom and skimmers are important, but so are the ancillary components on on-water response forces, such as workboats to tend boom and tugs to move barges. There must also be sufficient numbers of trained responders to implement the response. The conservative estimate in the response capacity analysis shows a minimum of 181 trained personnel would be required to operate the current, proposed, and additional supplementary response forces analyzed. This does not count the people needed for ancillary operations such as support vessel crew, vessel crew to shuttle responders to and from sites, shore-based responders, heavy equipment operators, or spill management personnel.

The Lower Fraser River analysis identifies a limited cache of containment boom available to control a river spill, and only a fraction of that boom is classified as "river boom." Because there are no control point tactics identified in the project application, it is difficult to determine the strategies for allocating this boom. Response equipment inventories lack sufficient detail to determine how key response equipment (boom and skimmers) would be deployed.

Both the response capacity and Lower Fraser River analyses also show the importance of equipment cache locations and portability. The response capacity analysis shows that the distribution of response forces across the region is critical to response for sites beyond the Vancouver Port Area, where most of the current response equipment is currently located. The analysis makes assumptions about where future response forces might be located; additional planning and consideration is required to maximize response potential and to match capacity to spill risks. The Lower Fraser River analysis shows that trailered response equipment has the capability to arrive at response locations much more quickly than warehoused equipment. It also emphasizes the importance of considering routes of travel and the potential for traffic or road conditions to significantly slow response time.

Information about response equipment was difficult to distil from the project application materials, and required significant additional research through other available databases. Complete and accurate equipment inventories are critical to evaluating response capacity.

Planning Assumptions Should be Verified and Information Gaps Filled

There is a tendency for oil spill contingency plans to overstate response capacity. The disconnect between planning assumptions and reality was made clear in the aftermath of the Deepwater Horizon well blowout, where the reality of the spill response did not align with published contingency plans (USCG and USDHS, 2011). The value in any planning process is in identifying both strengths and weaknesses in a system, to inform risk mitigation and emergency preparedness, and to create realistic expectations for what can and cannot be accomplished in the event of a worst case oil spill.

The purpose of this study was to examine response capabilities and limitations for Trans Mountain Expansion oil spills, because these are not clearly presented in the oil spill contingency planning materials provided in the project application. The three components of this study apply established analytical tools to estimate the capabilities and limitations to existing and potential future oil spill response systems in Southern BC. They are presented to a group of Interveners to inform their understanding of the potential to mitigate an oil spill from Trans Mountain Expansion tanker or pipeline operations, and they build on established methods consistent with other peer-reviewed work in the field.

It is just as important for oil spill contingency plans to acknowledge oil spill response gaps and limitations as it is for them to demonstrate response capability. All three of the analyses indicate that there are times and places where effective spill response will be difficult or impossible. Anticipating these occurrences allows planners and response managers to make informed decisions about spill prevention or mitigation. For example, if a spill impacts or threatens to impact two areas and the conditions in one are marginal for spill response while at the other, they are favourable, it is important for decision-makers to be mindful of these response limits when allocating equipment. Another approach would be to take additional risk reduction measures during times when spill response may be precluded. This could include limiting tanker movement or loading during adverse conditions.

Along the Lower Fraser River, it is important to consider the timing of the spill relative to the time required to mobilize and deploy equipment. Contingency plans that do not clearly present these pragmatic limits may create a false sense of capability that undermines both planning and real-time response decision-making.

All three analyses were challenged by information gaps, which are noted throughout the report. These include contradictory or incomplete equipment lists, lack of tactical response plans, and a lack of logistics planning. Additional information about response tactics, equipment inventories, equipment specifications, mobilization and deployment plans, and other response logistics would enhance the opportunity for the Interveners and other stakeholders to more thoroughly evaluate the project. It would also provide an opportunity to improve the accuracy of the estimates in this study. Contingency planning should not be a secret process.

Finally, it is critical to verify the information and assumptions in this and other oil spill response plans and analyses through field deployments and response exercises. Assumptions regarding equipment mobilization, transportation, and deployment timetables could be refined through field exercises. The capability of response systems to operate in different environmental conditions could be tested to ground truth assumptions about operating limits.

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Oil Spill Response Analysis

TECHNICAL ANALYSIS OF OIL SPILL RESPONSE CAPABILITIES AND LIMITATIONS FOR TRANS MOUNTAIN EXPANSION PROJECT

1 INTRODUCTION

When an oil spill occurs, there will be impacts to the environment, wildlife, and human activities. Containing and recovering as much oil as possible can mitigate these impacts. The effectiveness of oil spill response operations will have a significant bearing on the overall adverse impacts from the spill. On-water oil spill response effectiveness is influenced by a number of factors, including:

- Weather and environmental conditions at the time and place where a spill occurs;
- Availability of equipment, vessels, and personnel capable of implementing spill response tactics;
- Ability to track the location and movement of the spill; and
- Window-of-opportunity to apply spill response techniques and resources to floating oil slicks before they spread too thin, strand on the shoreline,[1] or submerge or sink into the water column.

This report presents expert analysis regarding oil spill response capability and limitations by applying quantitative and qualitative analytical tools to hypothetical oil spills along the Kinder Morgan Trans Mountain Pipeline Expansion (Trans Mountain Expansion) pipeline and marine vessel routes in British Columbia (BC). Nuka Research and Planning Group, LLC (Nuka Research) developed this report for three Interveners in the National Energy Board (NEB) review of the Trans Mountain Expansion project proposal (the project application): the Tsleil-Waututh Nation, the City of Vancouver, and the Tsawout First Nation (collectively, the Interveners).

1.1 Purpose

The purpose of this report is to evaluate the expected capacity to mechanically recover oil spills that may occur along the Trans Mountain Expansion pipeline and marine vessel routes. This study analyzes the capability and limitations of mechanical oil spill response tactics and technologies to mitigate the impacts of a major oil spill from Trans Mountain Expansion pipeline or marine vessel operations at various locations in BC.

1.2 Scope

This report presents three inter-related analyses that are intended to inform the Interveners' understanding of oil spill response capabilities and limitations for tanker or pipeline spills from the Trans Mountain Expansion project in BC. Each analysis considers a discrete research question that considers how practical, logistical, and

[1] Stranded oil refers to the proportion of an oil slick that comes into contact with the shoreline and is retained within the sediment or vegetation, either temporarily or permanently. Once oil strands on a shoreline, it is no longer available for removal as part of the floating oil slick. Stranded oil may released or "remobilized" from the shoreline by tides or wave actions, but the remobilized oil may be weathered into tar balls or tar patties, or it may have sediments or debris incorporated, which can cause it to submerge or sink. (Etkin, McCay, and Michel, 2007)

environmental conditions influence oil spill response. The findings of the three analyses are synthesized to evaluate the expected capabilities and limitations to mitigate oil spills from Trans Mountain Expansion operations.

1.2.1 Marine Oil Spill Response Gap Analysis

> **Research Question: How often will environmental conditions preclude or limit on-water oil spill response in the study area?**

A **response gap analysis** models the impact of environmental conditions on marine oil spill response and evaluates the frequency and duration that such conditions would preclude the safe and effective deployment or operation of mechanical oil spill recovery systems at locations along the Trans Mountain Expansion tanker route. The response gap analysis estimates the percentage of time during which environmental conditions such as wind, visibility, and waves would prevent or limit oil spill response operations.

1.2.2 Marine Oil Spill Response Capacity Analysis

> **Research Question: What is the capacity for available mechanical oil spill recovery systems to contain and recover on-water oil spills in the study area and how is it increased or decreased by certain factors?**

A **response capacity analysis** estimates the total capacity for mechanical recovery of major marine oil spills at scenario locations in coastal BC. The response capacity analysis presented in Section 3 of this report models the best-case oil recovery for a series of simulated oil spills at locations along the Trans Mountain Expansion tanker route. Several sensitivity analyses are conducted to evaluate the potential changes to oil spill recovery by season, location, availability and location of response forces, and delays to response implementation. The potential impacts of stranding oil and submerged or sunken oil to on-water recovery are discussed.

1.2.3 River Response Logistics Analysis

> **Research Question: How quickly must response resources be mobilized, transported, and deployed to representative control points to reduce the downstream transport of an oil spill on the Lower Fraser River?**

A **river response logistics analysis** estimates the mobilization and transport timing required to deploy equipment in time to potentially limit the downstream transport of oil spills on the Lower Fraser River. The river response logistics analysis presented in Section 4 of this report estimates the amount of time needed to intercept oil traveling downstream in the Lower Fraser River in order to reduce the level of riverbank contamination and potentially prevent the spill from reaching open water for a range of flow conditions.

1.3 Authors

This report was prepared by Nuka Research and Planning Group, LLC under contract to the Tsleil-Waututh Nation, the City of Vancouver, and the Tsawout First Nation. Nuka Research was retained as an expert in oil spill contingency planning and response, and developed this report to analyze the on-water oil spill response capabilities and limitations along the Trans Mountain tanker and pipeline route. It presents primary analysis developed by the authors along with expert interpretation of results and findings. Author biographies and a summary of qualifications are provided below.

Elise DeCola, Lead Author

Elise DeCola is a founding Partner, Principal Consultant, and Operations Manager of Nuka Research, and she was the lead author for this study. She began her career in legislative affairs, where her first assignment as a marine environmental policy fellow was to develop a state-level oil spill prevention and response law in the wake of a major New England fuel barge spill. She has since worked on oil spill policy research and contingency plan development and review in the US, Canada, Europe, Australia, and Africa. Ms. DeCola has developed oil spill contingency plans and emergency response plans for vessels, pipelines, oil storage facilities, and exploration and production operations. She has advised on oil spill response operations for local, state, and aboriginal groups, including recent experience as a Technical Advisor to Unified Command during the *M/V* Marathassa spill response in English Bay.

In recent years, Ms. DeCola has led studies on oil spill prevention and response oversight for provincial and national government authorities in Canada. As the oil spill contingency planning expert for the Haisla Nation during the Joint Review Panel process for the Northern Gateway pipeline, she submitted several expert reports that were accepted into evidence, including a response gap and response capacity analysis for spill response along Northern Gateway vessel routes. She also provided testimony during oral cross-examination. Ms. DeCola was the lead author and analyst for a three-part study commissioned by the British Columbia Ministry of Environment to inform their efforts toward "world class" oil spill prevention and response. The first volume of that study included a response capacity analysis. Ms. DeCola conducted a response capacity analysis in Washington State to evaluate the capability for US resources to respond to a spill at Cape Flattery and in the Strait of Juan de Fuca. She was a contributing author to response gap analyses in Prince William Sound, the Aleutian Islands, and the US Arctic Ocean.

Ms. DeCola holds an MA in Marine Affairs from the University of Rhode Island and a BS in Environmental Science from the College of William and Mary in Virginia. Her curriculum vitae is included as an appendix to this report, and highlights some of her recent academic and technical peer-reviewed publications.

Bretwood Higman, PhD, Response Gap Analyst

Bretwood Higman is a Nuka Research Analyst, and he was responsible for all data collection and analysis used to develop the response gap estimates for this study. Dr. Higman has been lead data analyst on three previous response gap analyses, including one for the Northern Gateway pipeline route as well as the Aleutian Islands response gap analysis (performed as part of the Aleutian Islands Risk Assessment) and a response gap analysis for the US Arctic Ocean (funded by the US Bureau of Safety and Environmental Enforcement). Dr. Higman is an accomplished programmer and developed the software used to run the analysis. He has a doctorate in geology, having completed dissertation work at the University of Washington, Seattle, using quantitative methods similar to those used in the response gap analysis to evaluate seismic hazards. His capabilities includes data structures, Python programming, data analysis, and data visualization. He has worked for Nuka Research for 5 years on a variety of projects involving data analysis and oil spill risk.

Andrew Mattox, Response Capacity Analyst and Modeller

Andrew Mattox is a Nuka Research Analyst, and he performed all Response Options Calculator (Response Options Calculator) modeling and related analysis. Mr. Mattox has quantitative analytical experience related to the geological and earth sciences, environmental and weather data, and spill modeling. He has contributed to past response capacity analyses in British Columbia and Washington, US, and he recently published a peer reviewed technical paper on his methods for applying Response Options Calculator to evaluate oil spill response capacity. Mr. Mattox served for six years as a wildland firefighter for the US Forest Service, where he acquired his training in operations and the Incident Command System, which is now applied to modeling oil spill responses. Mr. Mattox recently completed an MBA in Sustainable Systems at the Bainbridge Graduate Institute, and also holds a BA in Geology from Carleton College.

Mike Popovich, Oil Spill Response Equipment Subject Matter Expert

Mike Popovich is a Senior Project Manager with Nuka Research, and he reviewed and validated response force composition for the Response Capacity Analysis. He served for 26 years with the US Coast Guard, both on active duty and as a civilian working in marine environmental response and investigation. Mr. Popovich has extensive experience overseeing responses to minor, medium, and major oil spills throughout the US As an Environmental Equipment Specialist, he managed oil spill response equipment and trained Coast Guard personnel and vessel crewmembers on the proper use of oil recovery systems. He served for several months during the Macondo well blowout in 2010, first as part of the initial US Coast Guard on-water oil skimming operations and later in the Unified Command in New Orleans acquiring and allocating boom and skimmers for multiple Incident Command Posts throughout the theater of operations. In his role at Nuka Research, he manages an oil spill training and exercise program and contributes to oil spill planning projects in Alaska and New England.

Technical Review and Editing

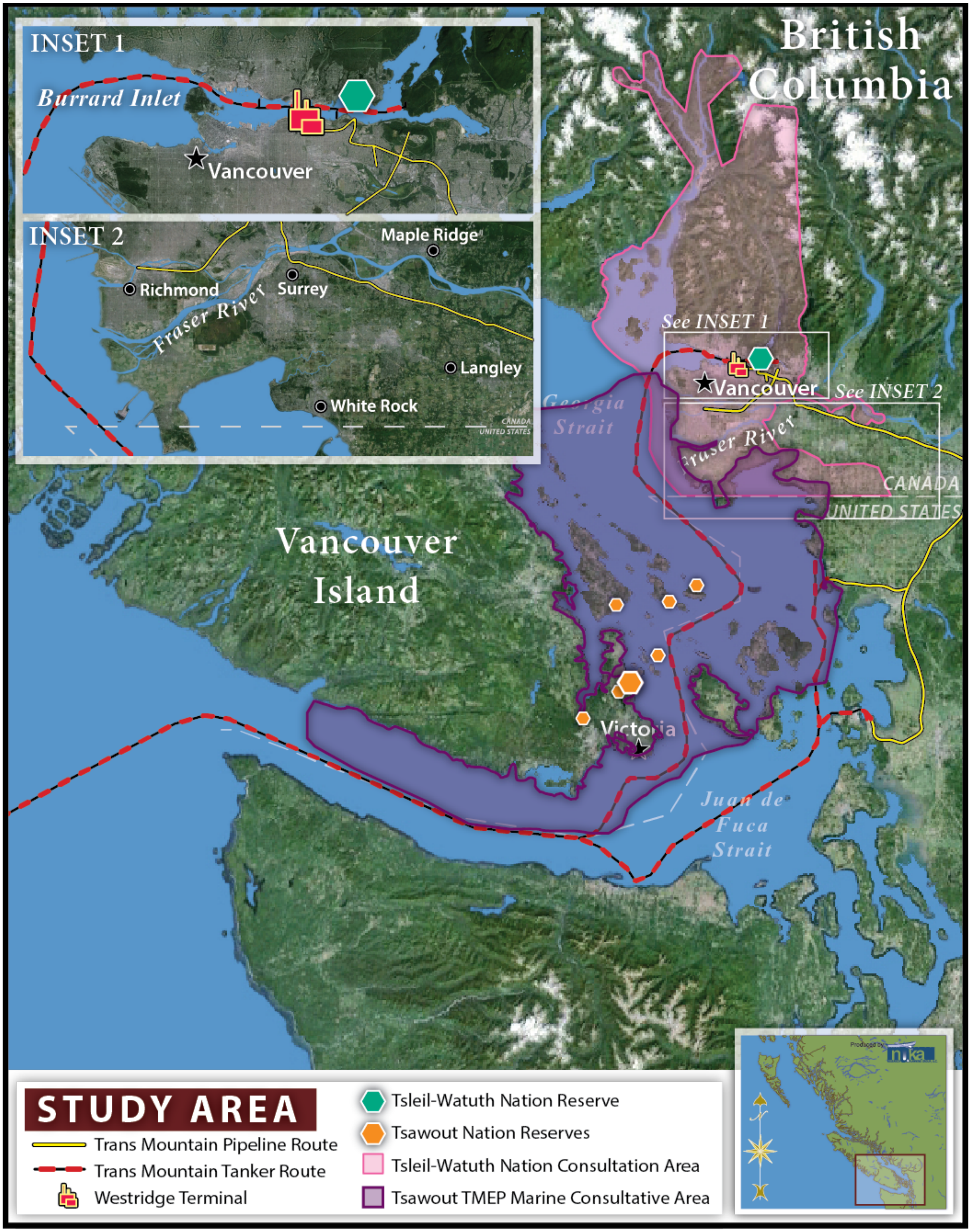
Tim Robertson, Nuka Research and Planning Group, LLC
Sierra Fletcher, Nuka Research and Planning Group, LLC
Michelle Prior, Nuka Research and Planning Group, LLC

1.4 Expert's Duty

This report has been prepared in accordance with our duty as experts to assist: (i) Tsleil-Waututh Nation, the City of Vancouver, and Tsawout First Nation in conducting their assessment of the Trans Mountain Expansion Project (Project); (ii) provincial or federal authorities with powers, duties or functions in relation to an assessment of the environmental and socio-economic effects of the Project; and (iii) any court seized with an action, judicial review, appeal, or any other matter in relation to the Project. A signed copy of our Certificate of Experts' Duty is attached as Appendix G.

1.5 Study Area

This report focuses on geographic areas of concern to the Interveners. Figure 1.1 shows the study area, which incorporates Tsleil-Waututh and Tsawout territories as well as the City of Vancouver. The pipeline route, tanker route, and Westridge Terminal are also shown on the map, as derived from the Trans Mountain Expansion project application (Kinder Morgan, 2013a). The response gap and response capacity analyses include sites along the tanker route from the Westridge Terminal in the Burrard Inlet (Inset 1) out to Neah Bay. Inset 2 shows the study area for the Lower Fraser River response logistics analysis.



146 **FIGURE 1.1. MAP OF STUDY AREA**

1.6 Background

1.6.1 Operating Environments

The concept of operating environments is central to both the response gap and response capacity analyses. For the purposes of oil spill response equipment classifications, marine operating environments are principally defined by sea state conditions at a specific location. This report uses the operating environment classifications developed by the American Society for Testing and Materials (ASTM), which are intended to "be used in formulating standards for design, performance, evaluation, contingency and response planning, contingency plan evaluation, and standard practice for spill control systems." (ASTM, 2011)

Three operating environments that are typical of the coastal marine and riverine environment in British Columbia along the Trans Mountain vessel and pipeline routes are considered, based on the ASTM definitions and supported by several other standard classifications used in oil spill response (Canadian Coast Guard, 2005; ASTM, 2011; Potter, 2013):

- **Protected water operating environment** is classified by wave heights of 1 meter or less and a Beaufort Sea State of 2, with small waves and, at most, some whitecaps.
- **Open water operating environment** is classified by wave heights up to 2 meters and a Beaufort Sea State of 3-4, with moderate waves and frequent whitecaps. The open water environment represents the upper bound for existing mechanical recovery systems to safely and effectively operate.
- **Fast water operating environment** is classified by small, short non-breaking waves with currents exceeding 0.8 knots (1.5 kph), including rivers. The Lower Fraser River is considered to have a fast water operating environment during most flow conditions.

These operating environment classifications are tied to *conditions* and not to a specific location, meaning that a single location may be classified as protected water, open water, or fast water at different times depending on sea state, currents, winds, and tides. Operating environments are also discussed in the context of on-water recovery systems, because spill response system is often categorized based on the maximum operating conditions in which it is designed to function. So, an open water recovery system is comprised of equipment and vessels that can operate in wave heights up to 2 meters and a Beaufort Sea State of 3-4.

This study refers to open water, protected water, and fast water operating environments across all three analyses.

- The response gap analysis considers the limitations on oil spill response systems based on the operating environment in which they are intended to perform. A response gap exists when a response system encounters conditions that exceed the maximum limits for the operating environment.
- The response capacity analysis classifies available and proposed new oil spill response systems based on their operating environment, and considers a series of scenarios that evaluate the potential effectiveness of these systems at different spill locations.
- The river response logistics environment includes a qualitative discussion of the implications of fast water operating environment to spill response technologies and their potential effectiveness in containing oil.

All assumptions related to operating environments and response system limits are presented in the body of each analysis.

1.6.2 Mechanical Oil Spill Response Systems

All three analyses consider the capabilities of and limits to mechanical oil spill response systems based on operating environment limits. Mechanical oil spill response systems use mechanical equipment – primarily containment boom, skimming systems, pumps, hoses, and storage devices – to contain and recover oil that floats on the water surface.

Mechanical oil spill response systems rely upon the ability to locate and track oil slicks, which is typically done from aircraft either visually or using specialized sensing equipment. The changing nature of an oil slick presents a constant challenge to on-water mechanical recovery, because once released, the oil slick will migrate, spread, evaporate, and undergo a series of physical and chemical changes at varying rates depending upon environmental conditions (Fingas, 2011; Short, 2015).

The mechanical recovery tactics presented in this report can only be successful when oil is floating on the water surface and contained to a sufficient thickness to remove using skimmers. Oil can no longer be recovered once it spreads too thin or droplets submerge or sink below the surface. Similarly, when oil strands on shorelines or riverbanks, it is no longer available for on-water mechanical recovery.[2] Other weathering may also increase the oil viscosity (stickiness) or emulsification (mixing with water), which can also impact mechanical recovery.

After being skimmed from the surface, the oil must be transferred to temporary storage tanks along with any water recovered with it. These recovered liquids must eventually be transported to a facility for long-term storage and disposal. Adequate storage is critical to on-water mechanical recovery operations. If storage runs out, recovery must cease.

The response gap analysis considers how environmental conditions impact vessel-based on-water mechanical recovery systems by classifying the systems as either protected water or open water capable, and then considering how often on-scene conditions exceed the operating limits for such systems. The response gap analysis also analyzes how often visibility limits would preclude aerial reconnaissance operations, which would make it much more difficult for vessel-based response systems to find and target oil for recovery.[3] The response capacity analysis models the performance of on-water oil spill response task forces to clean up hypothetical oil spills. For this analysis, the task forces are characterized based on the operating system in which they can operate. Taken together, the response gap analysis estimates the percentage of time that environmental conditions fall below the operating limits for protected water or open water response systems. The response capacity analysis then considers how much oil could be recovered during the first 72 hours of a spill that occurs during a time when response is feasible.

The river response logistics analysis does not directly build on the response gap and capacity analyses, but builds on many of the concepts presented in the preceding marine response analyses.

[2] Shoreline oil may re-mobilize, but such oil has typically incorporated shoreline sediments and weathered, making it more likely to submerge or sink. Shoreline oil may still be cleaned up, but adverse ecological impacts will occur as a result of the oiling, and the clean-up process can be very lengthy and labour-intense.

[3] Oil trajectory models are typically used during response to predict oil movement; however, model outputs are not always accurate. Real-time observational data about oil location, movement, and slick characteristics is critical to overall response success.

1.7 Assumptions

This study uses different modeling and analytical tools. Each relies on certain assumptions. Within each primary analysis (response gap, response capacity, and river logistics), the methodology section explains specific assumptions. Throughout the analysis, assumptions favour optimistic results. Except where noted, assumptions are consistent with project application materials.

1.7.1 Optimistic Assumptions

Across all analyses, relatively conservative estimates – erring on the side of favouring response success – were applied. For example, the response gap analysis does not consider *all* factors that could impair response, such as currents, fog, precipitation, extreme temperatures, or other factors that may impact the ability to respond to a spill. The response capacity analysis assumes smooth operations with no mistakes, equipment failures, or logistical issues that slow down deployment. The river logistics analysis assumes immediate spill detection and assumes that adequate personnel, transportation vehicles, and travel planning is in place to rapidly deploy resources to control points, and that permissions are in place to allow responders to access the river through private property.

Given the consistent application of optimistic assumptions, it is important to consider the results of these analyses as best-case scenarios.

1.7.2 Consistency with Project Application Materials

> ***"To be effective, on-water oil spill response must take a systems approach. Selected countermeasures must be appropriate for the physical properties of the oil, its fate and behaviour, and the environmental conditions where the release occurred."***
>
> *Kinder Morgan Trans Mountain Response to NEB Information Request No.1 (Section 1.65)*

Whenever possible, information from the Trans Mountain Expansion project application is incorporated into this analysis. This includes selection of scenario locations (based on routing information provided) and assumptions about spill response equipment (based on commitments made in the application to procure additional response forces). There are a few cases where our assumptions vary from the application, and these are so noted and explained in the report.[4]

1.7.3 *M/V Marathassa* Spill Response

The analysis for this study was completed in March 2015. On April 8, 2015, a bulk freight vessel spilled an undetermined volume[5] of fuel oil into English Bay. The subsequent response to the *M/V Marathassa* incident provides a reference point for some of the oil spill response logistical and practical issues considered in this report. As such, references to the *M/V Marathassa* incident have been added to this report on final edit.

[4] For example, the presumption that oil spill response operations will continue 24 hours a day (including darkness) is disputed based on the authors' experience and literature cited. The worst-case spill volume at the Westridge Terminal (Central Harbour scenario) is disputed based on casualty data provided in the project application.

[5] The volume of oil released by the *M/V Marathassa* is under investigation by Transport Canada. Initial media reports described the spill volume as 2,700 L, but this number describes the volume of oil estimated to be included in visible oil slicks approximately 18 hours after the spill was reported. The total volume released is unknown, but was greater than 2,700 L.

2 MARINE OIL SPILL RESPONSE GAP ANALYSIS

> ***"The spill response 'gap' is broadly defined as the percentage of time that a spill response option cannot be implemented due to environmental conditions such as wind, waves, temperature, visibility, and daylight."***
>
> S.L. Ross Environmental Research Limited Report to National Energy Board
> *Spill Response Gap Study for the Canadian Beaufort Sea and the Canadian Davis Strait*

Environmental conditions may make it difficult or impossible to deploy spill response tactics and technologies. A response gap analysis is a useful tool for understanding the potential for unmitigated oil spills to occur. Response gap analyses inform the oil spill planning and preparedness process by providing a quantitative estimate of the frequency and duration of environmental conditions that may preclude oil spill response operations in a geographic location. It also shows the relative influence of different factors on overall response.

This analysis provides a best-case estimate of the percentage of time during which Trans Mountain Expansion tankers are operating in coastal BC but, if an oil spill were to occur, environmental conditions would preclude a safe or effective response.

2.1 Overview

> **Research Question: How often will environmental conditions preclude or limit on-water oil spill response in the study area?**

A marine oil spill response gap analysis was performed for five locations in British Columbia: (1) Central Harbour, (2) Outer Harbour, (3) Georgia Strait, (4) Juan de Fuca Strait, and (5) Neah Bay, as shown in Figure 2.1. The locations included in the analysis were selected based on two factors: (1) proximity to areas of concern to Interveners; and (2) availability of environmental data (shown in Figure 2.1 and discussed in Section 2.2.2). Environmental conditions at the five locations are representative of protected water and open water operating environments. (See discussion in Section 1.4).

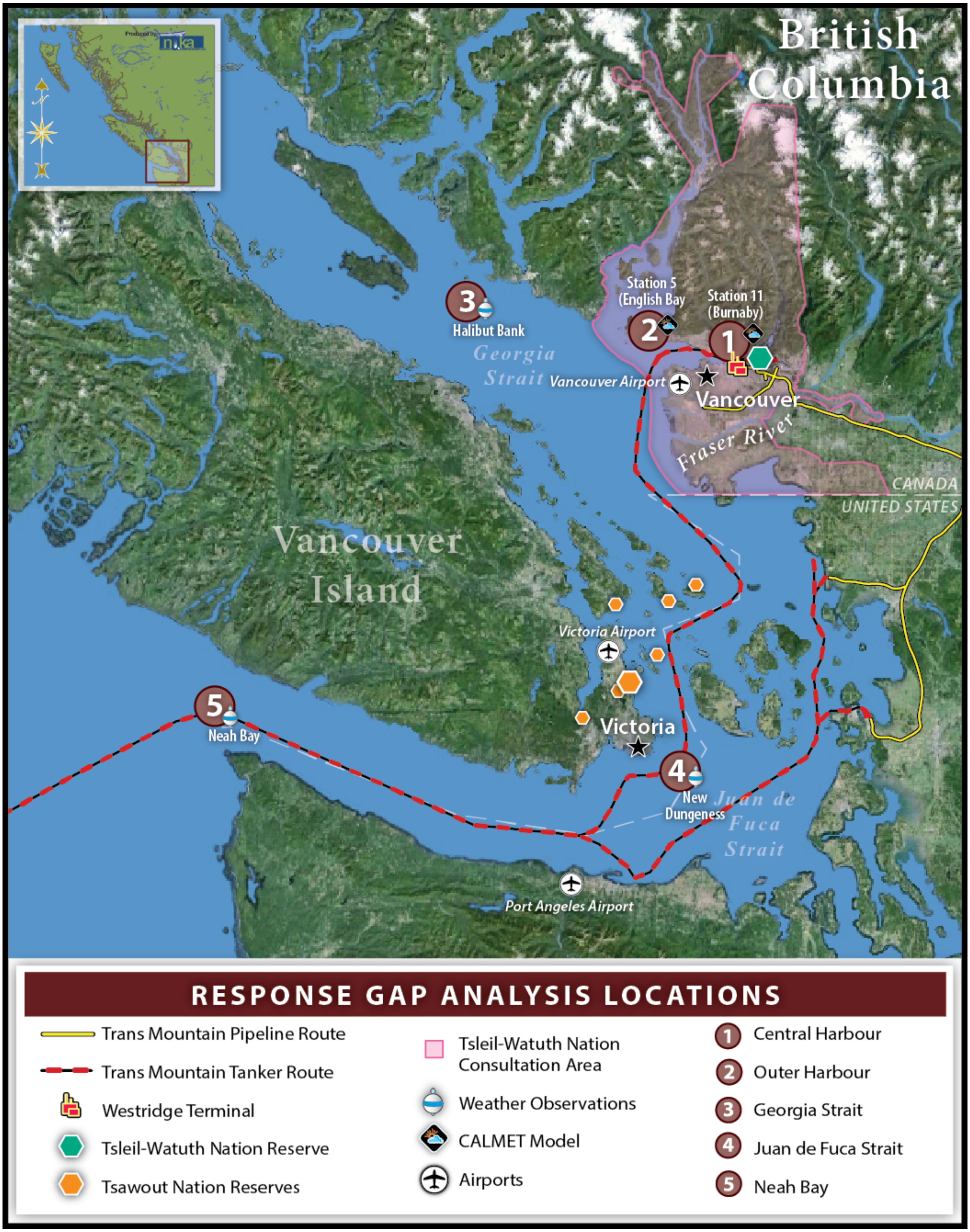


FIGURE 2.1. RESPONSE GAP ANALYSIS SITES AND ENVIRONMENTAL DATA SET LOCATIONS

There is partial overlap between the sites included in the response gap analysis and the response capacity analysis that is presented in Section 3. The three sites in Burrard Inlet and Georgia Strait are the same for both analyses; however, the sites in Juan de Fuca Strait vary. The two sites included in the response gap analysis (Juan de Fuca Strait and Neah Bay) were selected based on proximity to weather observation stations. The two sites included in the response capacity analysis were selected based on the risk of vessel spills as reported in the Trans Mountain application. The relationship between these two analyses is discussed in Section 5.

The response gap analysis applies standard methods derived from published, peer-reviewed studies (Nuka Research, 2006a; 2006b; 2007; 2008; SL Ross, 2011; Terhune, 2011; Nuka Research 2012; Nuka Research, 20014a; Nuka Research 2014b; DNV GL, 2014). The National Energy Board requested that Trans Mountain Pipeline develop an oil spill response gap analysis along the vessel route. Trans Mountain submitted a partial analysis that analyzes similar data and applies similar limits to this study, but the Trans Mountain analysis does not follow a standard methodology established in cited literature (Trans Mountain, 2014a). The response gap estimates cited by Trans Mountain do not account for the interaction among factors (e.g. the response gaps based on wind and waves are presented separately, but the combination of factors is not considered). Wave steepness is not addressed in Trans Mountain's response gap estimate, and they provide no quantitative analysis of visibility limits. Trans Mountain also does not analyze seasonal variability in response gap, which is considerable.

2.2 Methodology

The first response gap analysis reported in the published literature was conducted by Nuka Research in Prince William Sound, Alaska through a series of studies that estimated the period of time during which laden oil tankers were transiting the region but a spill response would be precluded by one or more environmental conditions (Nuka Research, 2006a; 2006b; 2007; 2008). Subsequent studies applied this concept to other regions and response options (SL Ross, 2011; Terhune, 2011; Nuka Research 2012; Nuka Research, 2014a; Nuka Research 2014b; DNV GL, 2014).

All of the foundational work in response gap analysis applies the following general approach:

- Identify response options and systems to be considered;
- Compile historical environmental data sets for relevant environmental factors in a geographic area;
- Establish operational limits for the selected environmental factors for each response option or tactic;
- Calculate response gap index by applying limits to environmental data set; and
- Analyze model outputs and express results.

2.2.1 Response Options and Systems

This response gap analysis is limited to mechanical oil spill response methods. Other response options – such as in-situ burning or chemical dispersants – were not considered because these are not identified as preferred response options in the project application (Kinder Morgan, 2013a). This analysis considers the impact of environmental conditions on the operation of open water and protected water mechanical recovery systems as well as aerial reconnaissance, as described in Section 1.4.

Figure 2.2 shows a diagram of typical on-water mechanical oil spill response systems.

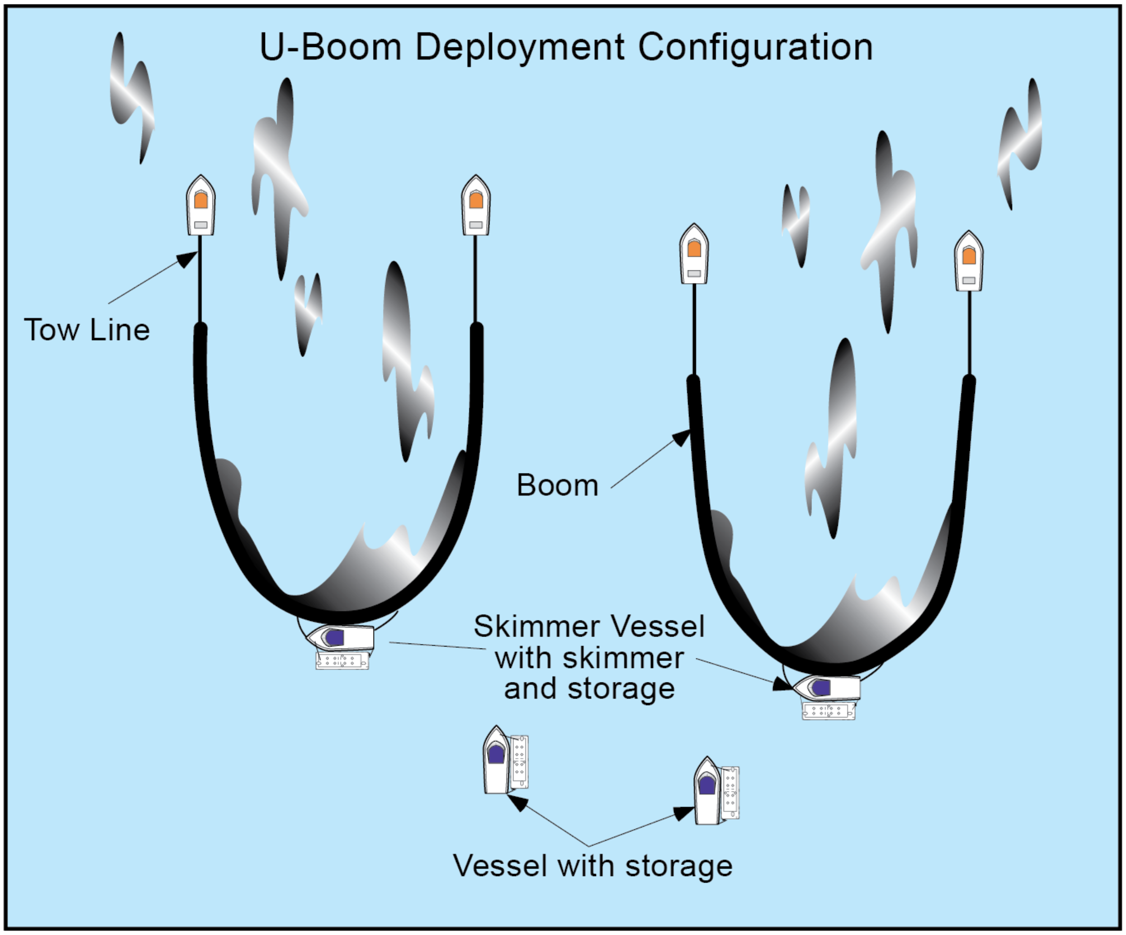


FIGURE 2.2. ON-WATER MECHANICAL RECOVERY OPERATIONS USING U-BOOM CONFIGURATION

On-water mechanical oil spill response systems use containment boom and skimming devices deployed from vessels or barges in different configurations to concentrate oil and recover it while it is floating on the water surface. In Figure 2.2, vessels are towing boom in a "U" configuration to concentrate oil at the skimmer. A mix of recovered oil and water is then pumped into a temporary storage device associated with the recovery system, and ultimately transported to a larger storage container to be processed for disposal. On-water mechanical response operations are limited by environmental factors that cause one or more of these system components to fail. The upper limit of individual system components – such as boom, skimmers or response vessels – may drive the response limit. Environmental factors that influence responder safety can also create a limit.

Aerial reconnaissance is also analyzed as a potential response gap. Figure 2.3 illustrates how aerial observation from helicopters or fixed-wing aircraft assist with spotting oil slicks and targeting recovery operations. In order to effectively conduct on-water mechanical recovery, it is important to track the location and movement of oil slicks and to communicate this information to on-water response forces. Aerial reconnaissance may be conducted using a range of technologies, from visual observation to remote sensing and imaging. For the purpose of this response gap analysis, the operating limits for representative rotary and small fixed-wing aircraft[6] are analyzed against the environmental factors.

[6] Operating limits are based on the safe operating limits for two representative aircraft: a Twin Otter fixed-wing plane and a Bell 212 helicopter. These light aircraft are typically used to support spill response operations.

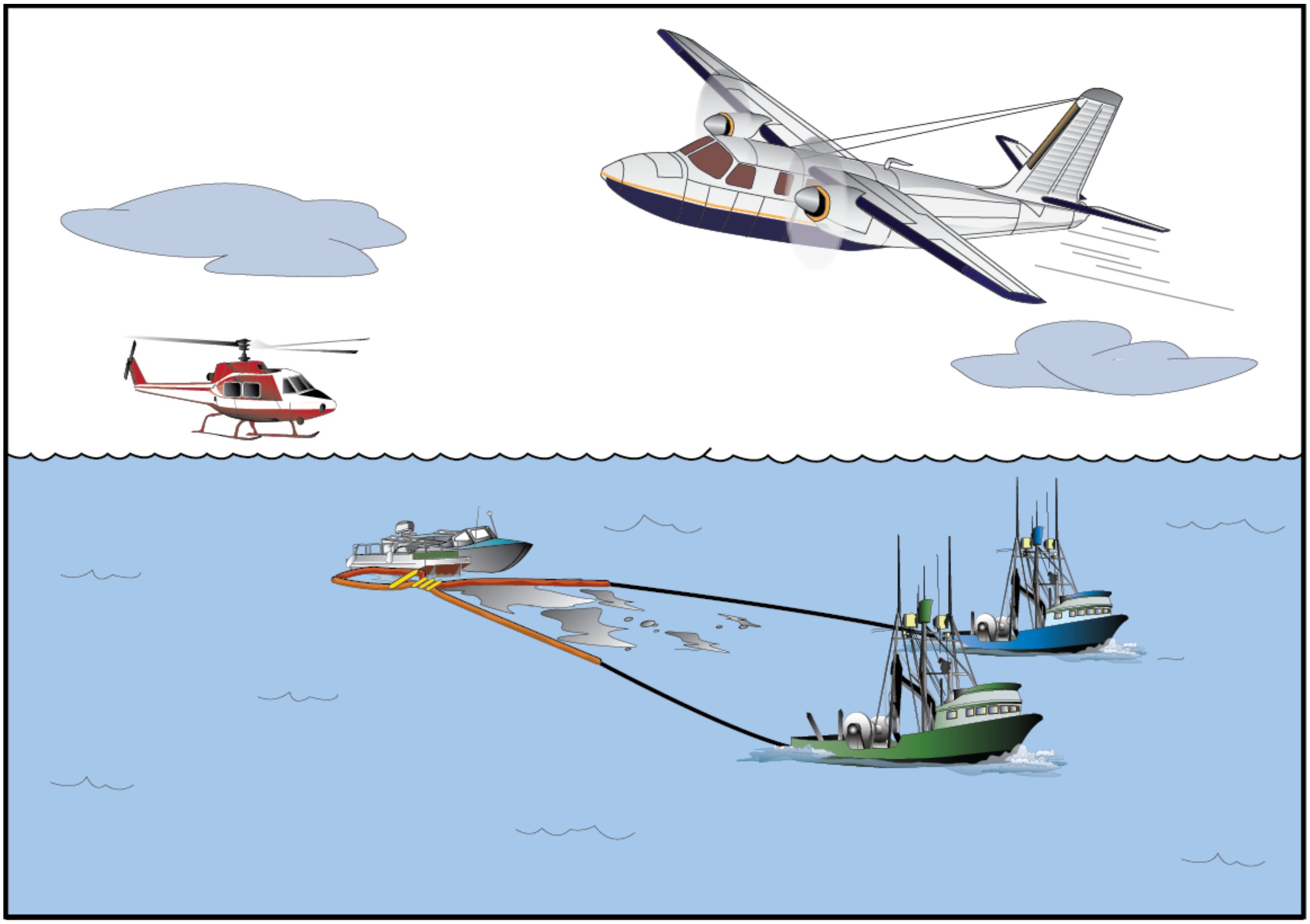


FIGURE 2.3. AERIAL OBSERVATIONS SUPPORTING ON-WATER MECHANICAL RECOVERY

2.2.2 Environmental Factors

The environmental factors included in this analysis are standard response gap parameters for on-water mechanical oil spill response systems, consistent with the cited literature:

- **Wind** can impede on-water mechanical response both through direct limits to operating vessels and equipment and by driving sea state in some areas. Vessels may not be able to keep on station, vessel crew may not be able to safely work on deck, equipment deployment and retrieval may be unsafe or impossible, and boom may fail due to wind forces.
- **Waves** can impact on-water spill response operations. For this analysis, waves were characterized in terms of both wave height and steepness. Steep, wind-driven waves typically have a more significant effect on spill response operations than longer period swells. Waves can impact mechanical spill response by causing boom failure, making it difficult for vessels to keep on station, causing skimmer failure, making it unsafe for crew to work on deck,[7] making deployment or retrieval of equipment unsafe or impossible, causing oil to submerge so that it is no longer available for recovery, and limiting the ability to track and encounter oil.

[7] During the April 2015 response to the *M/V Marathassa* incident in English Bay, the only reported safety incident involved a responder becoming seasick while cleaning oil from the hull of the *M/V Marathassa* because of sea swell generated by westerly winds, which is a typical spring/summer weather pattern for the Burrard Inlet. This swell, which was most significant in the afternoons, caused responders to halt operations on several occasions during the week of April 14.

- **Visibility** is important to mechanical response. For this analysis, visibility is considered in terms of horizontal visibility,[8] vertical visibility (cloud ceiling), and daylight vs. darkness. Horizontal visibility limits can impede or prevent on-water mechanical recovery by making it difficult to see and track oil slicks, and by making vessel or air support operations unsafe. Vertical visibility (cloud ceiling) is a limit to aerial observation from rotary or fixed-wing aircraft. Darkness will preclude some aspects of mechanical recovery due to safety or feasibility limits, and will inhibit others. Darkness limits safe deck operations, makes it more difficult for response vessels to find pockets of oil to recover, creates the need for a second shift of responders for night operations, increases tactical errors, increases risk of accidents, and makes it more difficult to deal with emergencies such as a man overboard (Genwest, 2012).

Fog can pose significant challenges to response options – localized fog banks may limit or preclude response. Because this analysis uses visibility data from coastal airports, on-water fog banks may not be represented in the visibility response gap.

2.2.3 Environmental Data Sets

Data for each environmental factor was compiled for the five response gap locations from several sources of historical and modeled data. Table 2.1 shows the source of data for each factor and summarizes data completeness.

For the two sites in the Burrard Inlet (Central Harbour and Outer Harbour), no observational data sets are publicly available, so wind and wave conditions were modeled.[9] The modeled data set is limited to one year (2005) and is 100% complete, meaning that data was recorded for 100% of the observational time periods.

For the other three sites, weather buoys maintained by the US National Buoy Data Center were used for wind and wave observation data. The National Data Buoy Center (NDBC) is a network of ocean observation stations that collects hourly observations from buoys and stations that measure: wind speed, direction and gust; barometric pressure; sea surface temperature; and wave height and period. Data completeness for the NDBC observations varied by location, with a 100% complete data set for the Georgia Strait site (Halibut Bank buoy), 91-96% completeness for the Juan de Fuca site (New Dungeness buoy), and 62-89% completeness for the Neah Bay site. Gaps in observational data are not uncommon; they occur when instrumental records of environmental conditions experience gaps in recording. The Neah Bay Buoy had a number of data gaps – particularly for wave-related data. A sensitivity analysis was conducted to weight the data to account for these data gaps but had only a minimal impact on response gap estimates (2% or less).

[8] Horizontal visibility limits are derived from airport observation data, and do not necessarily include marine fog banks, which can significantly impede on-water operations in localized areas.

[9] For wind data, detailed three-dimensional meteorological fields were produced by the diagnostic computer model CALMET, based on surface weather data, digital land use and terrain data, and prognostic meteorological model output based on the NCAR / Penn State Fifth Generation Mesoscale Model (MM5). Wave data was hindcast using the University of Miami Wave Model (UMWM) by Northwest Hydraulic Consultants (NHC). The wave modeling methods and outputs are included as Appendix A to this report.

TABLE 2.1. ENVIRONMENTAL DATA SETS

Response Gap Analysis Location	Wind Data		Wave Data		Visibility (Horizontal & Vertical)		Daylight & Darkness
	Source	Completeness	Source	Completeness	Source	Completeness	
Central Harbour	Modeled - CALMET #5 (Burnaby) - 2005	100%	Modeled- 2005	100%	Vancouver Airport 2008-2013	Horizontal: 100% Ceiling: 93%	NOAA Solar Calculator[10]
Outer Harbour	Modeled - CALMET #11 (English Bay 2) - 2005	100%	Modeled - 2005	100%	Vancouver Airport 2008-2013	Horizontal: 100% Ceiling: 93%	NOAA Solar Calculator
Georgia Strait	US NDBC Station 46146 (Halibut Bank) 2005	100%	U.S. NDBC Station 46146 (Halibut Bank) 2005	100%	Victoria Airport 2008-2013	Horizontal: 100% Ceiling: 93%	NOAA Solar Calculator
Juan de Fuca Strait	US NDBC Station 46088 (New Dungeness) 2008-2013	96%	U.S. NDBC Station 46088 (New Dungeness) 2008-2013	91%	Port Angeles Airport 2008-2013	Horizontal: 99% Ceiling: 99%	NOAA Solar Calculator
Neah Bay	US NDBC Station 46087 (Neah Bay) 2008-2013	89%	U.S. NDBC Station 46087 (Neah Bay) 2008-2013	62%	Port Angeles Airport 2008-2013	Horizontal: 99% Ceiling: 99%	NOAA Solar Calculator

A standard solar calculator developed by the US National Oceanic and Atmospheric Administration (NOAA) was used to calculate daylight and darkness.

The Vancouver Airport was used for visibility data – both horizontal and vertical – for both sites in Burrard Inlet. Visibility data from the Victoria Airport was used for the Georgia Strait site. Visibility data from the Port Angeles Airport was used for the Juan de Fuca and Neah Bay sites. Data completeness was the same for visibility data from the Vancouver and Victoria Airports; horizontal visibility data is 100% complete, and vertical visibility (ceiling) data is 93% complete. Data from the Port Angeles airport was 99% complete for both horizontal and vertical visibility.

Terrestrial airport data is not a perfect proxy for on-water visibility, but there are no on-water visibility data sets publicly available for the study area. Airport visibility data may not account for periods of localized marine fog, which can significantly hinder vessel operations. Fog advisories lasting from hours to days occur frequently in the Vancouver area, including both local and widespread events (Crawford, 2015).

Figure 2.1 (beginning of Section 2) shows the location of data sources in relation to response gap sites. There is a notable lack of Canadian observation data for the study area. Additional weather buoys – particularly in Burrard Inlet – would provide a more continuous set of observations that could inform future, similar analyses. Marine visibility data would also improve the ability to assess on-water spill response gaps.

[10] http://www.esrl.noaa.gov/gmd/grad/solcalc/

2.2.4 Operating Limits

Operating limits describe the maximum upper limit at which mechanical oil spill response tactics and systems are expected to function in the environment. The limits used in this study are consistent with past analyses (Nuka Research, 2006; 2007a; 2007b; 2008; SL Ross, 2011; Terhune, 2011; Nuka Research 2012; Nuka Research, 20014a; Nuka Research 2014b; DNV GL, 2014) and with published oil spill response tactical manuals in use in the US and Canada (Canadian Coast Guard, 2005; ADEC, 2014).[11] They reflect a thorough literature review and also incorporate the authors' past experience developing and reviewing oil spill contingency plans and regulatory standards. These limits were used in past reports performed by the authors and have been peer reviewed by oil spill response experts, academics, and regulators (Nuka Research, 2006; 2014a; 2014b). The operating limits applied to environmental data are summarized in Table 2.2.

Table 2.2 uses a three-tier characterization to describe the impact of an environmental factor on mechanical oil spill response operations:

- **Green:** environmental factor expected to have no impact on response operations (response not impaired),
- **Yellow:** environmental factor expected to impact the operations or their effectiveness (impaired), or
- **Red:** environmental factor expected to preclude response operations altogether (not possible/effective).

[11] The response limits cited in the Trans Mountain analysis are generally consistent with the limits applied in this study, with minor discrepancies. (Trans Mountain, 2014a).

TABLE 2.2. RESPONSE GAP LIMITS APPLIED IN THIS ANALYSIS

ENVIRONMENTAL FACTOR	GREEN Response Not Impaired	YELLOW Response Impaired	RED Response Not Possible/Effective
Open Water Mechanical Recovery			
Wind (W)	$W \leq 10$ m/s	10 m/s $< W < 15$ m/s	$W \geq 15$ m/s
Wave Height (H) **Wave Steepness (S)**[12]	$H \leq 0.9$ m[13]	0.9 m $< H < 1.8$ m when $S \geq 0.0025$ or 1.2 m $< H < 2.4$ m when $S < 0.0025$	$H \geq 1.8$ m when $S \geq 0.0025$ or $H \geq 2.4$ m when $S < 0.0025$
Visibility (V) **Daylight/Darkness**	$V \geq 0.9$ km & Daylight	0.9 km $> V \geq 0.2$ km & Daylight or $V \geq 0.9$ km & Darkness	$V < 0.2$ km & Daylight or $V < 0.9$ km & Darkness
Protected Water Mechanical Recovery			
Wind (W)	$W < 8$ m/s	8 m/s $\leq W < 13$ m/s	$W \geq 13$ m/s
Wave Height (H)	$H \leq 0.6$ m	0.6 m $<H<$ 0.9 m	$H \geq 0.9$ m
Visibility (V) **Daylight/Darkness**	$V \geq 0.9$ km & Daylight	0.9 km $> V \geq 0.2$ km & Daylight or $V \geq 0.9$ km & Darkness	$V < 0.2$ km & Daylight or $V < 0.9$ km & Darkness
Aerial Reconnaissance			
Visibility (V) **Ceiling (C)** **Daylight/Darkness**	$V \geq 1.9$ km & $C \geq 370$ m & Daylight	1.9 km $> V \geq 0.9$ km & 370 m $> C \geq 150$ m & Daylight	All other conditions

The response limits presented in Table 2.2 apply to three types of systems typically used in on-water mechanical response:

- **Open Water Mechanical Recovery Systems** include vessels, containment boom, skimming systems, pumps, and storage devices that can operate in the open water environment.
- **Protected Water Mechanical Recovery Systems** include vessels, containment boom, skimming systems, pumps, and storage devices that can operate in the protected water environment
- **Aerial Reconnaissance Systems** include rotary or fixed-wing aircraft implementing oil spill tracking and surveillance tactics.

The difference between the limits for open water and protected water recovery systems is derived from the classification of oil spill response equipment discussed in Section 1.4.1. For example, open water boom is "rated" for use in sea conditions up to 1.8 m, so a "red" condition is reached when sea conditions exceed 1.8 m waves. The limit for protected water boom is 0.9 m, so a "red" condition is reached when sea conditions exceed 0.9 m waves. (Canadian Coast Guard, 2005; ASTM, 2011; Potter, 2013)

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[12] Wave steepness is calculated as: Wave Height/(Gravity * Wave Period * Wave Period). The resulting value is non-dimensional (does not have units) because the units used to calculate the value cancel out.

[13] The environmental limit for wave height uses 0.9 m because the algorithm applies English measurements, and the response limit for waves is set at 3 feet, which corresponds to 0.9 m.

A preliminary exploration of the environmental data sets for the five sites included in this study shows that most sites experience both open water and protected water conditions. Therefore, the response gap analysis considers the gap for each type of system at each location, with a few exceptions. At the Central Harbour and Outer Harbour sites, wave and wind conditions exceed the operating limits for *open water* systems less than 2% of the time. Because these systems are designed for use in offshore environments, it is unlikely that open water response systems would be deployed at either of these sites. Therefore, the response gap analysis for this site looks at *protected water* response systems only. Conversely, conditions at the Neah Bay site exceed the operating limits for protected water systems more than 90% of the time year-round, and 98% of the time during the winter. Therefore the response gap analysis for this site considers only open water systems.

The transition from red to green, or a yellow condition, is based on professional judgment of the authors and validated by published studies and peer review. Yellow conditions represent the upper range of the equipment operating limits, and the use of this "response impaired" classification reflects the fact that the relationship between response equipment operability and environmental conditions follows a continuum.

2.2.5 Calculating the Response Gap

The response gap is calculated by characterizing each hourly observation in the environmental data sets based on the limits in Table 2.2. For each observation, the individual environmental condition is characterized as green, yellow, or red using a customized program.[14]

Figure 2.4 shows how the response gap accounts for the interactions among environmental factors. When all factors are green or all factors are green except one yellow, the response gap index is green, indicating that a response is possible. If one or more factors is red, the response is considered not possible because one or more operational limits of the response system has been exceeded. Even if no single environmental factor is ruled red (response not possible or not effective), the challenge of dealing with yellow (response possibly prevented) conditions for two or more factors at the same time can be expected to make effective response impossible and results in a red outcome for that time period.

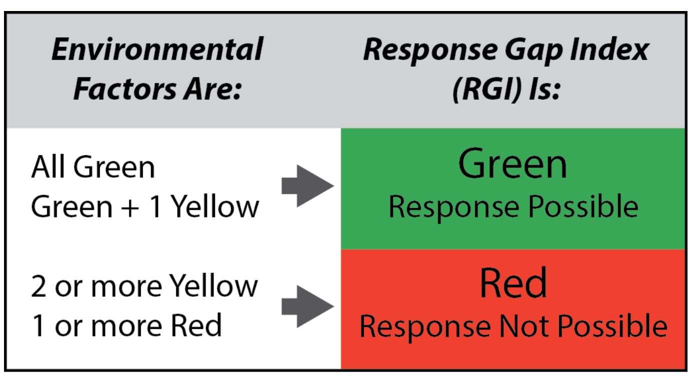


FIGURE 2.4. CLASSIFICATION OF HOURLY ENVIRONMENTAL DATA AS RED OR GREEN BASED ON COMBINATION OF ENVIRONMENTAL FACTORS

[14] A custom Python program is used to calculate the response gap. Program operation and data inputs were checked through a quality assurance process that included replicating results from the program for a subset of the data with an Excel (Visual Basic for Applications) analysis. A second quality assurance analyst verified that the program's algorithms operated as intended and that limits and other inputs were correct.

2.2.6 Assumptions and Limitations

Response gap analyses in general, and this analysis in particular, incorporate the following assumptions and limitations. Cases where these assumptions may influence the analysis are so noted. The following assumptions are consistent with other published oil spill response gap studies.

- **Field verification of response limits would improve analysis.** The response limits used in this study are consistent with past response gap analyses. Some limits are closely tied to manufacturer ratings or technical consensus standards (e.g. containment boom operating limits). Despite the large number of drills, exercises, and actual responses that have been conducted in the past 20 years, little quantitative data on response system operating limits has been collected during these events. It is unknown whether field verification of response limits would lead to overall increases or decreases in the response gap estimates. Field exercises conducted in the study region would inform actual on-water response operating limits along the Trans Mountain tanker route.
- **Hourly observation periods do not account for operations cycles.** The response gap analysis considers hourly environmental data, and the response gap estimate aggregates these hourly results as a percentage of time during a year or season during which conditions would limit a response. This approach does not account for the fact that favourable conditions must occur in succession – multiple hours during the same operational period – in order to actually support response operations. This optimistic assumption may overestimate the percentage of time during which a response is possible and underestimate the gap periods.
- **Weather data is recorded at a single location.** The observations used in this study reflect actual conditions at the location of the data buoys and airports. It is assumed that the recorded conditions are reflective of conditions in nearby waters, but conditions can and do vary from the buoy locations and localized effects may make a specific location quite different than the weather station data recorded.
- **Land-based visibility data may overestimate on-water visibility.** The visibility data is derived from airports, which compile observations on visibility data at the airport. This is not necessarily always a direct proxy for on-water visibility, which may be lowered by fog banks. The use of airport visibility data for on-water sites may overestimate the period of time during which a response is possible and underestimate the response gap.
- **Historical weather data may not be a reliable predictor of future conditions.** This study relies on hindcast[15] environmental data, but acknowledges that future conditions may vary or change over time.
- **Data availability and quality in Burrard Inlet is limited and model-derived.** There are no observational data sets publicly available for the two Burrard Inlet sites (Central and Outer Harbour), so CALMET model data was used to create a data set for a single year only (2005). An initial characterization of the 2005 modeled data against observations from nearby locations does not suggest that 2005 was a particularly anomalous year; nonetheless, a continuous multi-year observational data set would provide additional insight into the environmental conditions in Burrard Inlet.
- **Some environmental factors are not considered.** The environmental factors included in this study represent some – but not all – of the conditions that may limit response operations. Other conditions that may limit or preclude response include currents,[16] such as tidal currents, rips, or eddies, which may cause boom and skimmer failure or make it difficult for vessels to keep station. Given the potential for strong currents in parts of the study area, it is likely that this omission leads to an *overestimate* of

[15] A hindcast uses a past data set for modeling purposes. The use of hindcast meteorological data in forecasting is an established practice across many disciplines.

[16] There is insufficient data to estimate the response gap for currents to on-water oil spill response in this study area.

the percentage of time during which response would be possible and an *underestimate* of the response gap.

- **Response degradation is oversimplified.** The degradation of a spill response does not happen at a single point, nor is it necessarily a linear function. While specific numeric limits are applied in order to generate the response gap estimate, in reality there is a continuum between "possible" and "not possible." The use of the yellow, or "impaired," limits represents a simplistic means of addressing this limitation.
- **The response gap estimates the *opportunity* to conduct a response and does not guarantee a successful outcome.** The response gap describes the period of time when no response is possible. For some locations considered in this study, there is a very high percentage of time during which response *is* possible. It is important to qualify these estimates with the understanding that feasibility of response – the ability to deploy response systems – does not guarantee a particular level of success. There are many other factors that influence the effectiveness of on-water recovery operations that are beyond the scope of a response gap analysis.

The most limiting factor overall to this response gap analysis was the limited environmental observation data available. Additional meteorological observation buoys along the Trans Mountain tanker route would provide valuable data to inform future response gap analyses.

2.3 Analysis

This section summarizes the response gap analysis results. A complete set of response gap analysis outputs is included in Appendix B.

2.3.1 Response Gap Estimates by Tactic and Season

Response gaps were calculated for three types of response systems at five locations. For each location and environmental factor, response gap estimates were divided into "summer" and "winter," each representing half of the calendar year, split by the vernal and autumnal equinox.[17] This convention simplifies the seasonal cycle into fall/winter and spring/summer to illustrate in a general sense how conditions vary depending upon time of year. The response gap estimates are presented for each location by season as well as annually.

Table 2.3 summarizes the response gap results, showing the percentage of time when conditions are red, indicating that environmental conditions would prevent deployment of the specified tactics. It is important to acknowledge that the "gap" refers only to the *opportunity to deploy* response equipment. A 50% response gap means that environmental conditions limit or prevent the opportunity to deploy response equipment half of the time at a given location. During the response gap period, an oil spill may occur but no response would be possible. During the other half of the time, when environmental conditions do not preclude response, response effectiveness may vary considerably due to other factors.

[17] Summer = March 20 to September 22; Winter = September 23 to March 19

TABLE 2.3. SUMMARY OF RESPONSE GAP INDICES FOR ALL SITES BY SEASON AND TACTIC

Location	Open Water Mechanical Recovery			Protected Water Mechanical Recovery			Aerial Reconnaissance		
	Summer	Winter	Overall	Summer	Winter	Overall	Summer	Winter	Overall
Central Harbour	n/a	n/a	n/a	0%	3%	**1%**	34%	57%	**45%**
Outer Harbour	n/a	n/a	n/a	3%	6%	**4%**	34%	57%	**45%**
Georgia Strait	3%	7%	**5%**	11%	19%	**15%**	34%	58%	**46%**
Juan de Fuca	9%	18%	**13%**	19%	22%	**20%**	38%	57%	**47%**
Neah Bay	32%	68%	**52%**	n/a	n/a	n/a	37%	56%	**46%**

The response gap for **open water recovery** ranges from 3% for a summer spill in Georgia Strait to 68% for a winter spill at Neah Bay. Across all sites, open water recovery estimates are lower during winter than summer. The open water response gap estimates are higher for sites that are more exposed (Juan de Fuca Strait and Neah Bay) than for Georgia Strait. The most significant response gap occurs at Neah Bay during winter, when environmental conditions are expected to preclude open water recovery 68% of the time. This equates to roughly 4.75 days out of each week during which on-water mechanical recovery of oil would not be possible.

The response gap for **protected water recovery** ranges from 0% for a summer spill in the Central Harbour to 22% for a winter spill in Juan de Fuca Strait. Like open water recovery, the protected water recovery response gap is also higher at all sites in winter. The increase in response gap estimates moving from the relatively sheltered waters of Burrard Inlet (Central and Outer Harbour) into more exposed waterways (Georgia Strait, Juan de Fuca, and Neah Bay) illustrates how higher winds and sea states limit on-water oil spill response.

By comparison, the response gap for **aerial reconnaissance** is relatively constant across all five sites, ranging from 34% to 38% of the time during summer to 56% to 58% of the time during winter. The difference between winter and summer visibility gaps is related primarily to day length, since aerial reconnaissance is not assumed to occur at night.[18]

The response gap estimates in Table 2.3 reflect the combined effects of all of the environmental factors considered. Table 2.4 shows how each factor – visibility, waves, and wind – contributes to the response gap for each response tactic by location, showing the percentage of time when operating limits are exceeded for a specific factor. These results represent the year-round average.

[18] While there are remote sensing technologies, such as infrared sensing, available to track oil slicks during periods of low visibility, the use of such technologies to direct on-water recovery operations during darkness has not been operationally demonstrated.

TABLE 2.4. SUMMARY OF RESPONSE GAP ESTIMATES FOR ALL SITES BY TACTIC AND ENVIRONMENTAL FACTOR

Location	Open Water Mechanical Recovery				Protected Water Mechanical Recovery				Aerial Recon-naissance
	Visibility	Waves	Wind	Overall	Visibility	Waves	Wind	Overall	Visibility
Central Harbour	n/a	n/a	n/a	**n/a**	1%	0%	0%	**1%**	45%
Outer Harbour	n/a	n/a	n/a	**n/a**	1%	0%	0%	**4%**	45%
Georgia Strait	2%	0%	0%	**5%**	2%	3%	1%	**15%**	46%
Juan de Fuca	1%	1%	1%	**13%**	1%	9%	2%	**21%**	47%
Neah Bay	1%	28%	0%	**52%**	n/a	n/a	n/a	**n/a**	46%

Waves are the primary limiting factor for open water recovery at Neah Bay and for protected water recovery at Juan de Fuca. At the other sites, no single factor dominates – the response gap is derived from the interaction between marginal conditions (i.e. more than one condition is yellow, creating an overall red).

There are several cases in Tables 2.3 and 2.4 where the overall response gap for a site and tactic is higher than the sum of response gaps for any individual factors. This occurs when a combination of marginal factors results in the degradation to an overall red (response not possible). For example, the overall response gap for open water mechanical recovery on-water at Neah Bay, excluding aerial reconnaissance, is 52%. The response gap for each individual factor is 1% for visibility, 28% for waves, and 0% for wind. The 52% overall response gap is not the sum of each individual factor but is a separate modeling output that considers how the *combination* of factors influence the response. The overall response gap takes into consideration the influence of yellow conditions, so if wave conditions were yellow during an operational period where wind or on-water visibility were also yellow, then that period is considered a gap.

Figure 2.5 consolidates all response gap characterizations (red/not possible or green/possible) for every hour in the environmental dataset for Neah Bay.

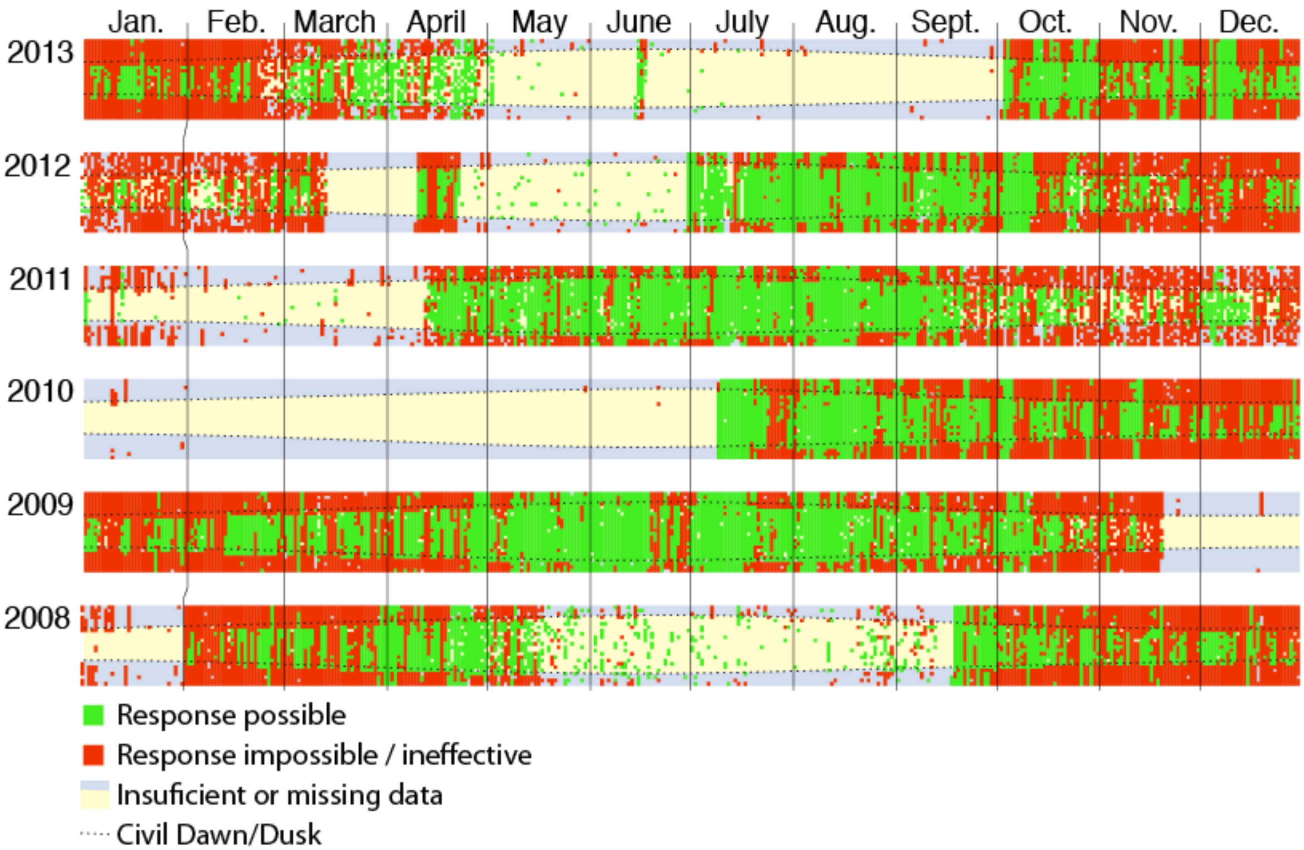


FIGURE 2.5. CALENDAR-BASED SUMMARY OF OPEN WATER RESPONSE GAP AT NEAH BAY FOR ALL HOURS IN DATA SET

Figure 2.5 represents every day in the data set for Neah Bay, by month and year. It shows how the response gap is distributed across each day, month, and year by representing every observation as red or green. Figure 2.6 shows the month of January 2013 in greater detail.

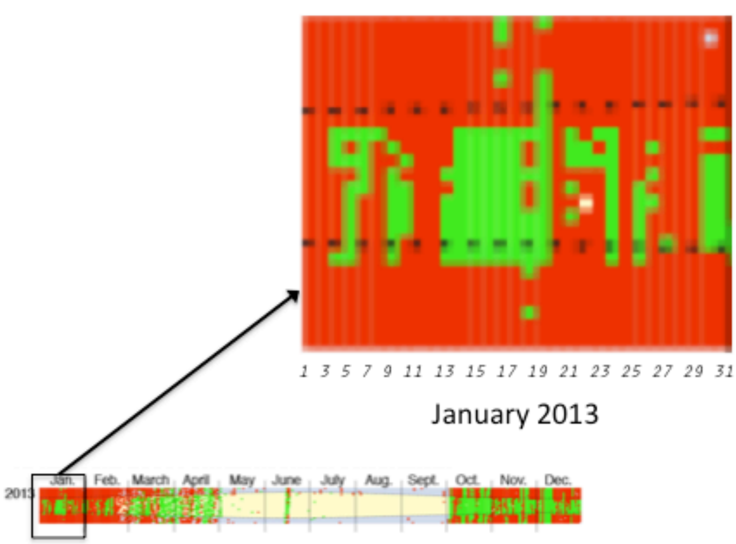


FIGURE 2.6. RESPONSE GAP FOR NEAH BAY, 2013

In Figure 2.6, the month of January is shown – each day of the month is a vertical bar within the diagram, with the red indicating observation periods where response is not possible and green indicating times when response is possible. For the first three days of January, conditions were red all day and night. From approximately January 13 through 17, there was a series of days where response was possible for most of the daylight hours (shown as the area in between the two dotted lines), but not possible at night. From May to September 2013, there are very few observations, indicating a gap in observations, which is not uncommon for buoy data.

Figure 2.6 shows that there are several instances during January and February of 2013 where red conditions are continuous or nearly continuous for a period of days or weeks. In fact, during the second half of January 2013, there are no 24-hour periods during which conditions are green for a full 8-hour period. Red conditions dominate the night time periods but there is also at least one hour of red conditions each day during the second half of that month. There are also many instances where, during daylight hours, there are a few isolated green (response possible) hours during a predominantly red (response not possible) day. In either case, days could elapse before any oil spill response was even attempted, because short time periods with conditions conducive to response do not provide sufficient time to mobilize and deploy equipment before conditions degrade.

Figures 2.5 and 2.6 present the response gap index as green or red; response is either possible or not possible. In reality, a continuum exists between when response is possible and not possible. To illustrate this continuum and show seasonal variations throughout the calendar year, Figure 2.7 presents a cycle graphic for Neah Bay, which combines the results from the full five-year Neah Bay data set and shows the response gap with greater nuance. Response degradation is represented in different shades of green or red. Dark green represents the times when all conditions are conducive to response. The color shifts as conditions degrade, first to lighter green (when only one factor is yellow), then to the shades of red, with the darkest shade representing times when all factors are either yellow or red.

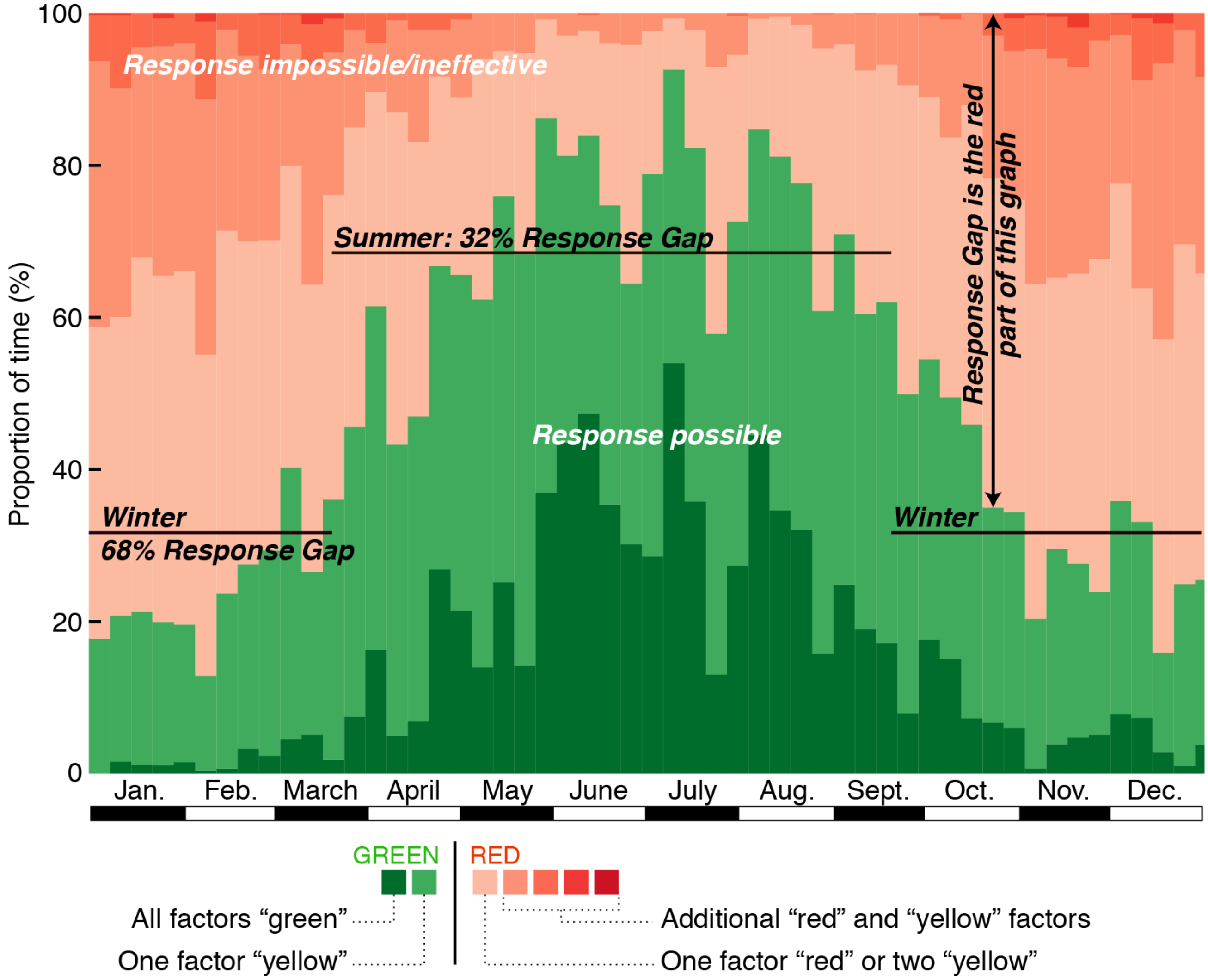


FIGURE 2.7. ANNUAL VARIABILITY IN NEAH BAY RESPONSE GAP BASED ON DATA FROM 2008-2013

Figure 2.7 shows the seasonal variations for the five years of data, with response much more likely to be feasible in the summer months than winter. The y-axis in Figure 2.7 presents the response gap estimate for each month. A 0% response gap means that response would be possible 100% of the time. A 100% response gap means that response would not be possible at all. The x-axis represents the calendar months, summarizing five years of data. Each column represents one week. So, for example, during the first week of January based on five years of environmental data, at least one factor was yellow 100% of the time. The response gap for this week is estimated at 82%, represented by the fact that the overall response gap index is green 18% of the time, and various gradations of red for the remainder.

2.3.2 Combined Response Gap for On-Water Recovery and Aerial Reconnaissance

> ***"In conditions where the visibility is restricted to less than 1 km it is difficult to direct response operations from the air and extremely difficult to find and recover oil slicks using vessels, even with state of the art remote-sensing techniques."***
>
> S.L. Ross Environmental Research Limited Report to National Energy Board
> *Spill Response Gap Study for the Canadian Beaufort Sea and the Canadian Davis Strait*

For the purpose of calculating the response gap, separate limits were applied to on-water operations and to aerial reconnaissance. However, in reality, both on-water response operations and aerial reconnaissance must both be feasible in order to maximize response efficiency.

A series of analyses applied the aerial reconnaissance visibility limits to the on-water recovery overall response gap calculation to estimate the periods of time during which simultaneous on-water recovery and aerial reconnaissance were and were not possible. The incorporation of aerial reconnaissance into the response gap analysis provides a more realistic picture of on-water response limits than looking at vessel operations alone, because on-water recovery operations typically rely on overflight observations to locate and target oil slicks. Looking at both tactics together provides a "systems" approach to oil spill response operations.

The results of this combined analysis, summarized in Table 2.5, show how the response gap significantly increases from the estimates in Table 2.4 when considering the limits to conducting on-water recovery that is simultaneously supported by aerial reconnaissance.

TABLE 2.5. SUMMARY OF RESPONSE GAP INDICES FOR ALL SITES BY SEASON AND TACTIC

Location	Open Water Mechanical Recovery + Aerial Reconnaissance			Protected Water Mechanical Recovery + Aerial Reconnaissance		
	Summer	Winter	Overall	Summer	Winter	Overall
Central Harbour	n/a	n/a	**n/a**	34%	57%	**45%**
Outer Harbour	n/a	n/a	**n/a**	34%	56%	**46%**
Georgia Strait	35%	59%	**47%**	38%	63%	**51%**
Juan de Fuca	40%	60%	**49%**	46%	63%	**54%**
Neah Bay	49%	78%	**65%**	n/a	n/a	**n/a**

Table 2.5 estimates that the combined response gap for open water mechanical recovery ranges from 35% at Georgia Strait during summer to 78% at Neah Bay during winter. For protected water recovery, response gaps range from 34% in the Burrard Inlet during summer to 63% at Georgia Strait and Juan de Fuca during winter.

The major difference in the calculation of response gap estimates in Table 2.5 when compared to Table 2.4 is the application of visibility limits. The visibility limits for vessel operations are much less significant than for aircraft, particularly because this model assumes that while vessels may operate at reduced speed during darkness, aircraft conducting aerial reconnaissance cannot operate at all.

The response gap is higher during winter and summer across all sites, and is slightly higher at more exposed sites than in more protected waters. However, in all cases, the differences between winter/summer and location are less significant when aerial reconnaissance limits are included, because these are relatively consistent across sites and are less seasonably variable than wind or wave conditions.

Figure 2.8 shows how the response gap estimate changes using vessel-based visibility limits compared to aerial operations visibility limits.

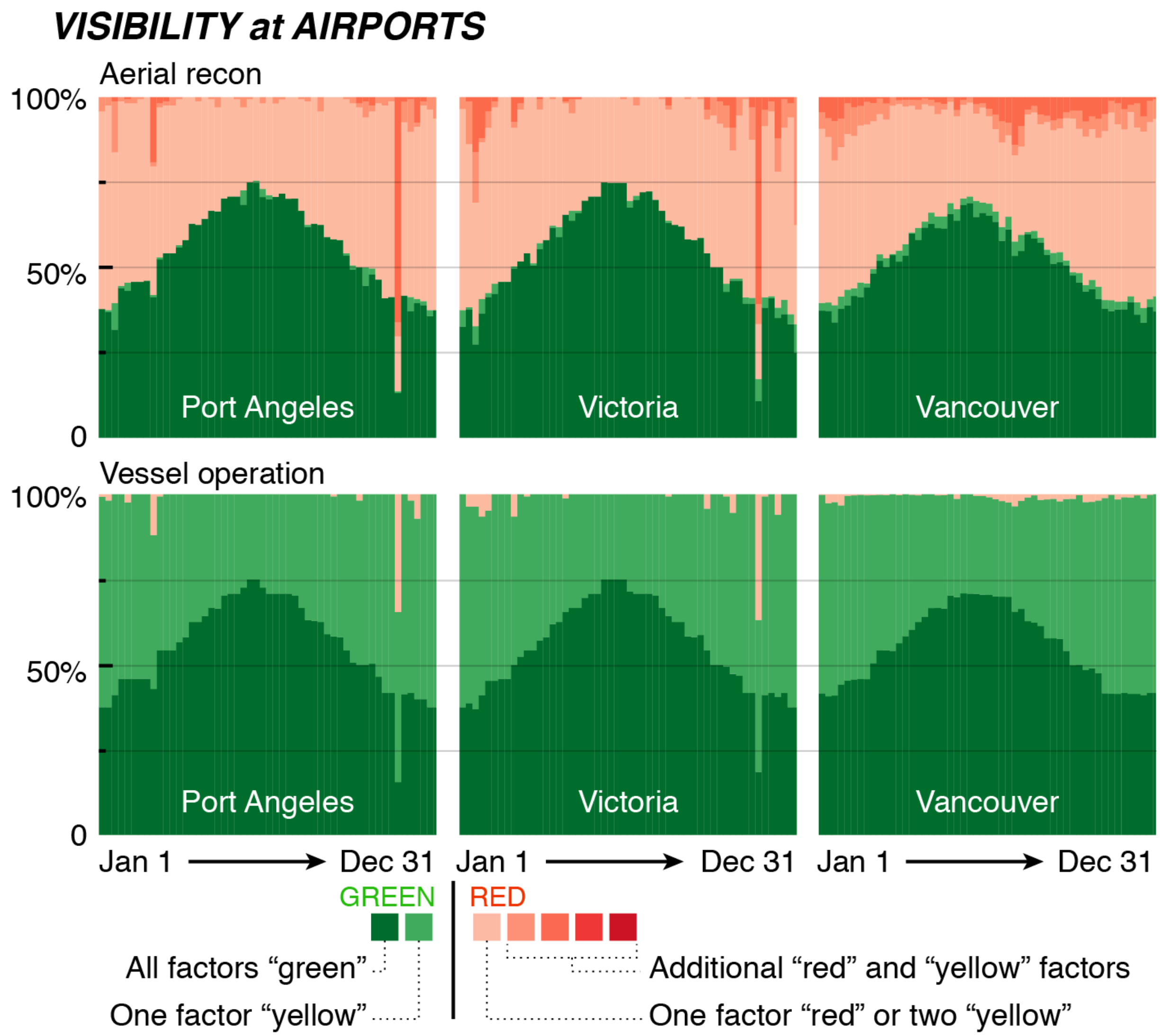


FIGURE 2.8. RESPONSE GAP ESTIMATE COMPARISON FOR AIRCRAFT AND VESSEL-BASED LIMITS

Figure 2.8 shows how the response gap estimates differ for vessel operation compared to aerial reconnaissance. The series of cycle graphics applies different response limits to the same set of airport visibility data, resulting in very different response gap estimates. The pattern is the same for vessel and aerial visibility limits, but the coloration differs. Visibility rarely creates a response gap for vessel-based response; however, it limits aerial reconnaissance nearly half of the time, on average, year-round. In winter, aerial visibility limits are red, meaning response is precluded, more than 60% of the time.

Figures 2.9 and 2.10 show the response gap estimates for open water and protected water recovery at all sites, with the aerial reconnaissance visibility limits incorporated into the overall estimate. When the response gap analysis incorporates both on-water recovery operations and aerial reconnaissance, the response gap estimate increases significantly.

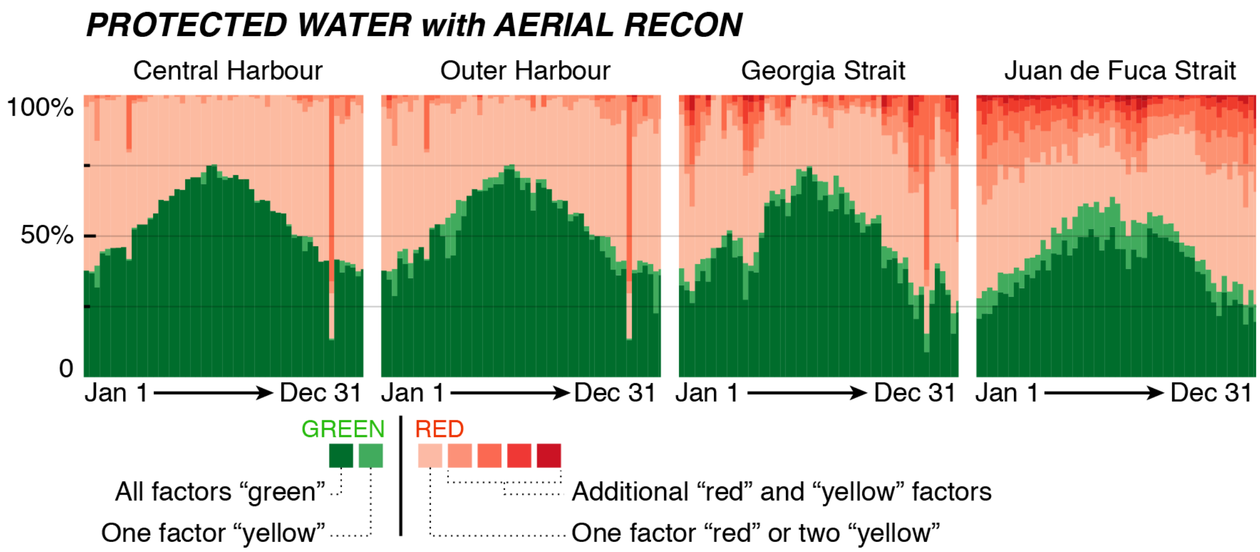


FIGURE 2.9. RESPONSE GAP ESTIMATES FOR PROTECTED WATER RECOVERY AT ALL SITES, WITH AERIAL RECONNAISSANCE INCLUDED

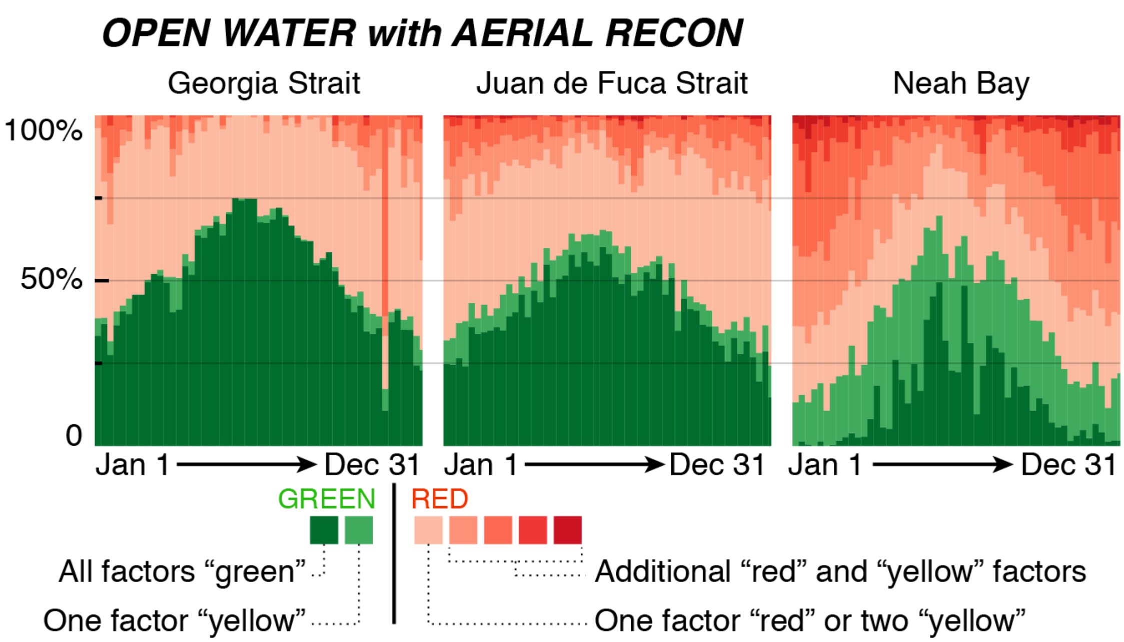


FIGURE 2.10. RESPONSE GAP ESTIMATES FOR OPEN WATER RECOVERY AT ALL SITES, WITH AERIAL RECONNAISSANCE INCLUDED

Figure 2.11 presents the response gap estimates with and without aerial reconnaissance side-by-side for two sites (Central Harbour and Juan de Fuca Strait) to illustrate how the aerial reconnaissance operating limits drive the response gap estimates.

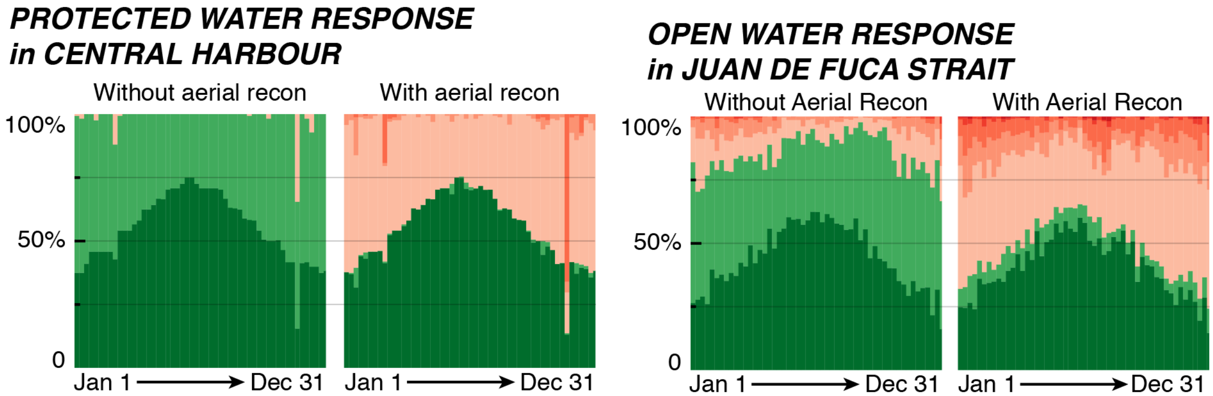


FIGURE 2.11. COMPARISON OF RESPONSE GAP ESTIMATES WITH AND WITHOUT AERIAL RECONNAISSANCE INCLUDED

Figure 2.11 shows how incorporating aerial reconnaissance into the overall response gap increases the percentage of time during which response is not possible due, in large part, to the effect of darkness. Darkness alone creates a red (response not possible) condition for aerial reconnaissance, because it is very difficult to track oil slicks during darkness (night) conditions. Visual observation is the most commonly used tool for aerial reconnaissance, and while there are some remote sensing technologies that can be used to track oil during darkness, it is not a common practice to conduct overflights at night for the purpose of tracking thick oil for potential recovery.

Night operations have been proposed to enhance spill response capabilities for the Trans Mountain Expansion project (WCMRC, 2013). However, this practice is not commonplace, creates significant safety risks, and requires sufficient trained personnel to implement. During the 2010 Deepwater Horizon oil spill in the Gulf of Mexico, night time on-water recovery operations were not attempted (although there was limited night time in-situ burning) (USCG and USDHS, 2011). The challenges associated with night operations are explored further in Section 4.

2.4 Discussion

2.4.1 Comparison of Response Gap by Location and Season

Figure 2.12 shows the summer, winter, and annual response gap estimates by response tactic at the five sites. All estimates reflect the combined response gap for on-water recovery and aerial observation. At the Central and Outer Harbour sites, the response gap was estimated based on protected water response system operating limits only, because the characteristics of those sites make it unlikely that open water response resources would be deployed there. Depending upon conditions, either protected water or open water response systems could be used in Georgia and Juan de Fuca Straits, so the response gap is estimated for both systems at these two sites. Operating conditions at Neah Bay exceed the limits for protected water systems almost all of the time, so the response gap for Neah Bay is for open water response systems only.

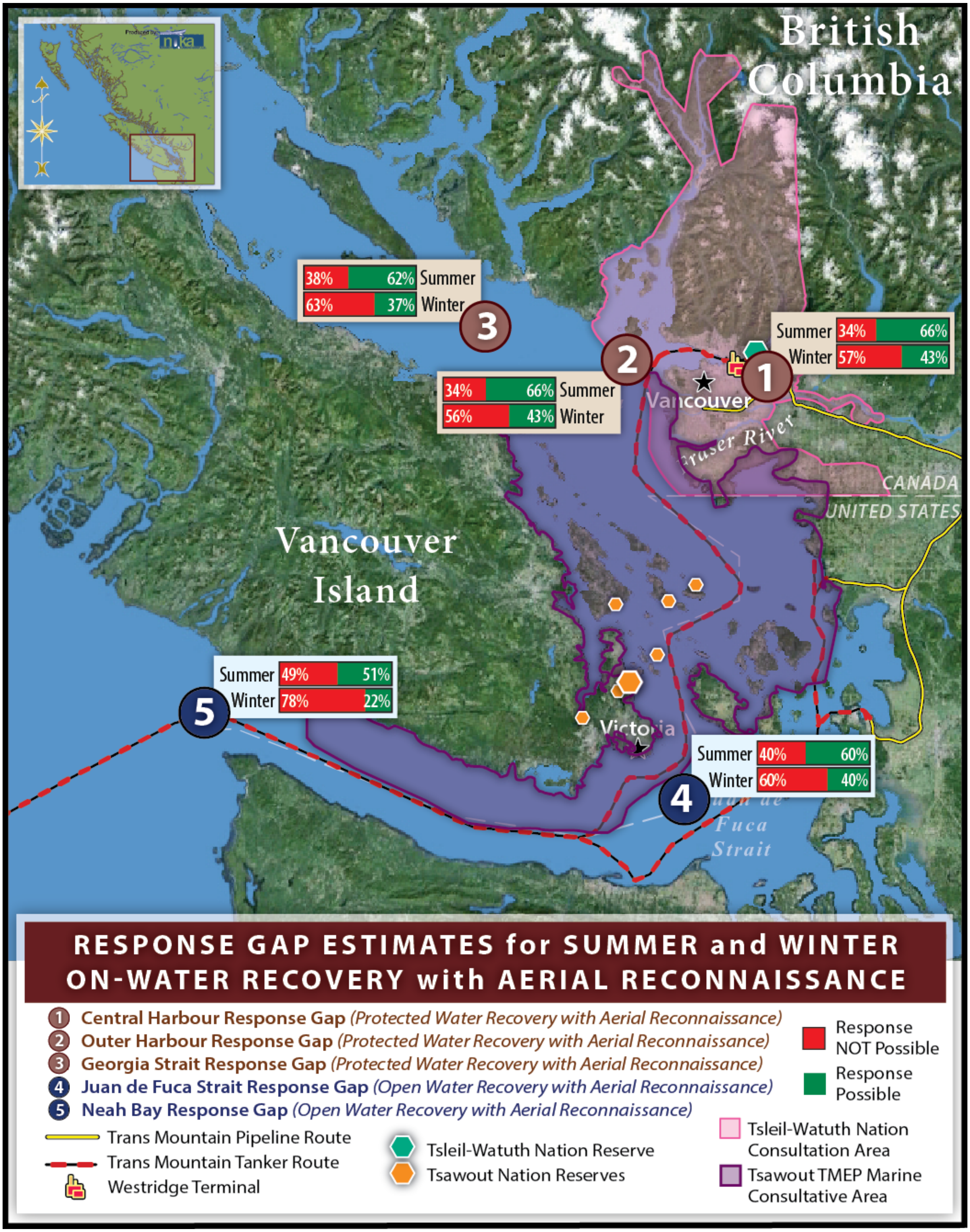


FIGURE 2.12. RESPONSE GAP ESTIMATES FOR OPEN WATER AND PROTECTED WATER RECOVERY INCLUDING AERIAL RECONNAISSANCE AT FIVE SITES ALONG TRANS MOUNTAIN VESSEL TRAFFIC ROUTE

Figure 2.12 shows that oil spill response gaps exist across the entire Trans Mountain tanker route and vary by location and season. Overall, environmental factors will have a more significant impact on mechanical oil spill response operations in Neah Bay, the Juan de Fuca Strait, and Georgia Strait than in the Outer or Central Harbour. However, even in the Burrard Inlet sites, where wind and wave conditions are relatively calm, there will be times when on-water oil spill response operations are limited, often by visibility.

2.4.2 Burrard Inlet Response Gaps

The protected water response gap estimates were similar for the two Burrard Inlet locations, Outer Harbour and Central Harbour, with a slightly higher response gap estimated for the Outer Harbour. The year-round response gap for protected water mechanical recovery supported by aerial observation is 45% at the Central Harbour and 46% at the Outer Harbour site. These gaps are driven primarily by aerial observation limits; the gap for on-water operations only ranges from 0% at Central Harbour during summer to 6% at Outer Harbour during winter (See Table 2.3). At both sites, the combined on-water/aerial observation response gap is significantly higher during winter (56-57%) compared to summer (34%). Visibility poses the most significant limit to on-water (vessel) operations in the Outer and Central Harbour sites. Wind and wave conditions never exceeded the operating limits for protected water response at either site.

2.4.3 Georgia Strait and Juan de Fuca Strait Response Gaps

The response gap locations at Georgia Strait and Juan de Fuca Strait are separated by approximately 120 km, but have similar environmental conditions. The combined aerial reconnaissance and on-water recovery response gap estimates for protected water and open water recovery systems at the Georgia and Juan de Fuca Strait sites are slightly higher for protected water systems (51% and 54%, respectively) than for open water systems (47% and 49%, respectively). At both sites, the combined on-water/aerial observation response gap is higher during winter (63% for protected water systems; 47-49% for open water systems) compared to summer (38% for protected water at Georgia Strait; 46% for protected water at Juan de Fuca; 35% for open water at Georgia Strait; 40% for open water at Juan de Fuca).

At Georgia Strait, there is no single factor that dominates the response gap for on-water operations; it is the combination of marginal wind, wave, and on-water visibility conditions that create the response gap. The inclusion of aerial observation limits into the analysis increases the response gap at Georgia Strait to 51% for protected water and 47% for open water systems (see Table 2.5), but on-water recovery operations alone experience a response gap ranging from 3% in summer (open water) to 19% in winter (protected water), even when aerial observation limits are not considered (see Table 2.3).

Like Georgia Strait, in Juan de Fuca Strait there is no single factor that dominates the response gap for on-water operations at Juan de Fuca; the response gap is created by the combination of marginal conditions for wind, wave, and on-water visibility. The inclusion of aerial observation limits into the analysis increases the response gap at Juan de Fuca Strait to 54% for protected water and 49% for open water systems (see Table 2.5), but on-water recovery operations alone experience a response gap ranging from 9% in summer (open water) to 22% in winter (protected water), even when aerial observation limits are not considered (See Table 2.3).

The response gap at Juan de Fuca Strait is higher across the board than Georgia Strait, showing that spill response may be possible at one site along the tanker route but not possible at another. The protected water response gap is significantly higher at Juan de Fuca than Georgia Strait, suggesting that open water response forces may be more appropriate for spill response planning at this site.

2.4.4 Neah Bay Response Gap

The oil spill response gap at Neah Bay is highest of all the sites included in this study. The combined aerial reconnaissance and open water response gap is 65% overall (year-round), with a 49% response gap in the summer and 78% in the winter. The winter response gap suggests that conditions would favour on-water recovery supported by aerial reconnaissance at Neah Bay only 22% of the time. Considering on-water response operations alone, without including aerial reconnaissance, the winter response gap at Neah Bay is still 68%; sea state (wave) conditions are the primary driver of the large winter response gap at Neah Bay. Year-round, wave and visibility limits contribute most significantly to the response gap for open water systems at Neah Bay.

The year-round open water recovery response gap for Neah Bay for on-water operations (excluding aerial observation) is 52%. This is a higher than a comparable analysis for a site in Alaska's Aleutian Island chain, where the year-round open water recovery response gap was estimated to be 34% in the Southeast Bering Sea (Nuka Research, 2014a).

Neah Bay weather data from 2013 shows that out of 134 days of complete weather observations (during which the weather buoy recorded conditions every hour during a 24-hour period), there were only 12 days where conditions remained favourable for a full day.

2.4.5 Combined Response Gap Across Entire Tanker Route

The methods applied in this study calculate response gap estimates for specific geographic locations. Spreading the response gap across the length of the tanker route was beyond the scope of this study. However, this section evaluates individual response gaps to consider how the differences between response gap conditions along the entire Trans Mountain Expansion tanker route may impact overall oil spill risks and mitigation potential.

The least significant response gap occurs at the Central Harbour site during summer months (broadly defined as March through September), when environmental conditions would preclude on-water response operations only 3% of the time. However, the response gap for conducting on-water response in conjunction with aerial reconnaissance is 45%. During the winter in Neah Bay, the situation is much more challenging, with a 68% response gap for on-water recovery and a 78% response gap for on-water recovery supported by aerial reconnaissance. During a "typical" weather week (seven days) in the winter at Neah Bay, on-water recovery would be possible for 2.25 days, and on-water recovery supported by aerial reconnaissance would be possible for only a day and a half. If a spill were to occur during the other four to five days of that "typical" winter week, no oil spill response would be possible.

Figure 2.13 shows how the response gap estimates for two sites – Neah Bay and Juan de Fuca Strait – overlap.

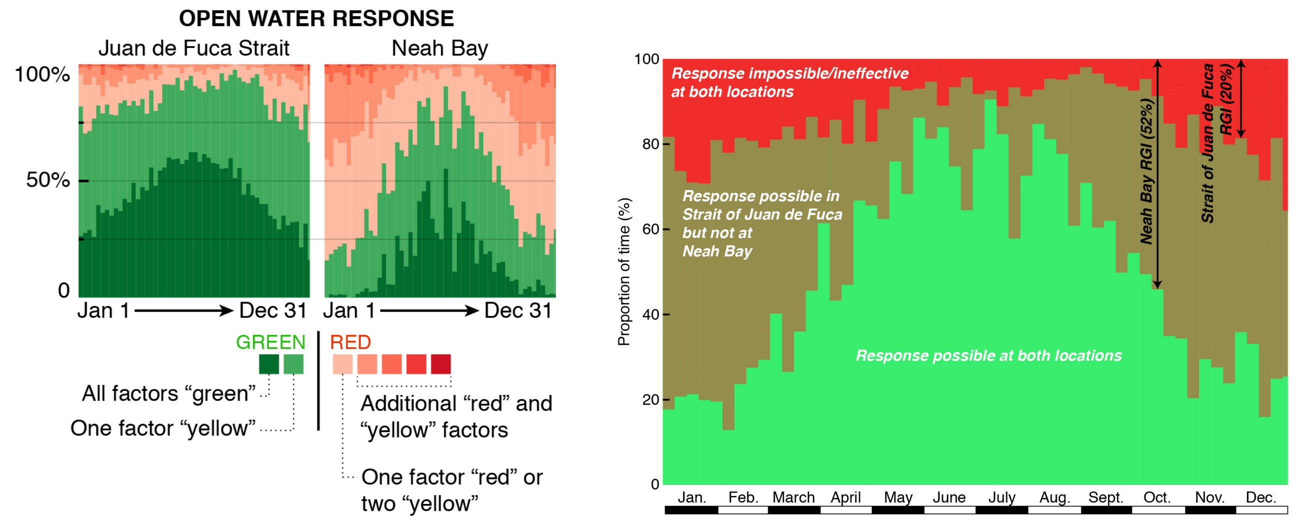


FIGURE 2.13. COMPARISON OF RESPONSE GAP ESTIMATE FOR OPEN WATER RECOVERY SYSTEMS AT JUAN DE FUCA STRAIT AND NEAH BAY

On the left side of Figure 2.13, the response gap estimates for Juan de Fuca Strait and Neah Bay, which are separated by approximately 120 km. On the right side of the figure, the combined response gap is overlaid for these two sites, showing that there are times during the winter months when response is possible at both locations less than 15% of the time. If a tanker spill were to occur somewhere along the transit route between these two locations, the direction in which the spill migrates may significantly impact the effectiveness of on-water recovery operations.

2.5 Key Findings

This response gap analysis is the first in a multi-level analysis of oil spill response capabilities and limits for oil spills from the Trans Mountain Expansion project. The response gap analysis highlights a number of practical considerations that should be factored into oil spill response planning and preparedness activities.

2.5.1 Response Gaps Exist Along the Entire Tanker Route

> **KEY FINDING: There is no location along the Trans Mountain tanker route where on-water oil spill response will always be possible.**

The response gap analysis was performed separately for five locations using consistent historical data sets, and the results differ. However, the results show that oil spill response gaps – periods of time during which a Trans Mountain tanker may spill oil but the vessels and equipment required to contain and recover the oil spill could not safely or effectively operate – occur at all five locations along the tanker route. Even in the most favourable environment of the Central and Outer Harbour protected water areas during summer, on-water recovery with aerial reconnaissance may be precluded one-third of the time. In the more exposed waters of Neah Bay, on the other hand, a summer response would be precluded almost half (49%) of the time and nearly 78% of the time in the winter.

There may be times when conditions are favourable for response at one location and not others, requiring response managers to assess environmental conditions at the time of the spill and focus response efforts on locations where conditions are conducive to response deployment.

2.5.2 Response Gap Increases when Aerial Reconnaissance is Incorporated

> **KEY FINDING: There may be times when on-water vessel operations are possible but poor visibility – including darkness – precludes aerial reconnaissance, making it very difficult to track and target oil for recovery.**

At all locations, response gap estimates were calculated first for on-water recovery operations and aerial reconnaissance separately, and then the on-water and aerial reconnaissance components were combined. In order to collect the oil, vessels operating recovery equipment need to be able to find it and to focus on the thickest part of the slick. This information is best obtained from overflights, making the limits on aerial reconnaissance critical to understanding the impact of conditions on a response effort. The additional consideration of aerial reconnaissance limits significantly increased the response gap for the Central and Outer Harbour sites, increasing from 1-4% year-round to 45% year-round. For the Georgia and Juan de Fuca Strait sites, the year-round open water recovery gap increased from 5% (Georgia) and 13% (Juan de Fuca) to 47% and 49%, respectively. At Neah Bay, where the on-water response gap was highest, the additional consideration of aerial reconnaissance increased the year-round estimate from 52% to 65%. This is almost entirely attributable to the fact that aerial reconnaissance operations are daytime-only, while the on-water response gap limits allow for operations during darkness when all other conditions are favourable. However, even during times when darkness operations may be possible, they may not be safe or advisable; on-water recovery of oil during darkness is not a common practice. The limits to on-water recovery operations during darkness are explored further in Section 4.

While darkness has the most dramatic impact on response operations, it is notable that the response gap for the two Burrard Inlet sites, which is very low, is influenced most significantly by visibility limits for vessel operations. These estimates do not take into consideration the potential for localized on-water fog banks to create localized visibility limits, since the visibility data is derived from the Vancouver Airport for these sites. Presumably, local on-water fog banks could increase the duration or frequency of gap periods. Additional observational data for on-water sites along the entire tanker routes would help to refine visibility estimates.

2.5.3 Environmental Conditions Preclude Response More Often During Winter

> **KEY FINDING: During the winter, response is not possible between 56% and 78% of the time at sites along the Trans Mountain tanker route.**

There were consistent differences across all locations between response gap estimates for summer months (defined broadly as March to September) and winter months (defined broadly as September to March). Across the board, spill response is much less favourable during winter months, because of a combination of on-water conditions (wind and waves) at more exposed locations, and shorter day lengths reducing visibility. The impact of winter conditions on spill response feasibility is most extreme at Neah Bay, where the response gap for on-water components of open water mechanical recovery occurs more than twice as often in winter (68%) than summer (32%).

At Juan de Fuca Strait, the on-water response gap for open water systems was twice as high during winter (18%) as summer (9%), while the on-water response gap for protected water systems was only slightly higher (22%) during winter as summer (19%). This suggests that open water response systems are more likely to be able to respond to a winter spill at Juan de Fuca Strait than protected water response systems. By comparison, in Georgia Strait the response gap for protected water systems is nearly double during winter

(19%) compared to summer (11%), but not appreciably different for open water systems in summer (3%) and winter (7%).

Additional exploration about the differences in response gaps during winter and summer months could inform the stockpiling of equipment. It may also inform additional prevention measures for seasons where conditions may preclude oil spill response more than half of the time.

2.5.4 Timing of Response Gap is Critical to Opportunity to Mount a Response

KEY FINDING: If a spill occurs during a time when response gap conditions exist, the unmitigated oil slick will remain in the environment until conditions approve. If the response gap conditions extend for several days, there may not be any opportunity for on-water recovery.

The response gap is estimated based on an aggregation of hourly observations across the entire study period, and does not consider whether those hours combine to allow viable operational periods, or whether they will allow responders to maximize recovery during the critical first three days of a response. Both considerations are important and will influence actual response.

- **Effective response operations must be able to be safely sustained over realistic operational periods:** On-water recovery operations are logistically complex evolutions, and are typically carried out on an operational cycle ranging between 6-12 hours depending upon day length, transit to and from recovery site, and other logistical and practical factors. When calculating the response gap, the sequence of red and green observations is not considered in the algorithm. This means that during the 20% or 30% or 80% of time during which the model shows that response is possible, there may be hours when a response is *not* possible, requiring responders to stop operations or, depending on the forecasted conditions, preventing the response from being deployed at all.
- **Impact mitigation requires that oil be recovered during the critical "window-of-opportunity":** When oil is spilled to water, it immediately begins to spread and undergoes physical and chemical changes. As the slick spreads, it becomes more difficult to recover using skimmers. As it weathers, it may evaporate, incorporate water or particulate matter, change in viscosity or density, and submerge or sink. The fate and behavior of oil varies depending upon the oil characteristics and the environmental conditions, which means that the window-of-opportunity for on-water recovery will vary. A general rule-of-thumb is that on-water oil spills that have weathered for more than 72 hours (3 days) may be very difficult to recover mechanically (Nordvik, 1995; Short, 2015). Thus, the ability to mount a response within the first three days is critical to mitigating spill impacts.

Because response gaps are not evenly distributed and the window-of-opportunity for on-water oil spill recovery is limited, timing is a critical variable to potential spill response. Visibility data from 2005 shows one notable period with four consecutive days where visibility at both the Victoria and Vancouver airports was well below the aerial reconnaissance operating limits and marginal for vessel operations. If a spill were to occur at the beginning of this gap period, several days might elapse during which no on-water recovery occurs. If a spill occurs at the end of a day, it is unlikely that on-water recovery would begin until first light the following morning.

2.5.5 Response Gap Analysis Does Not Consider Response Effectiveness

KEY FINDING: Lack of a response gap does not ensure that a response *will* occur, nor does it guarantee that the response will be effective

Lack of a response gap does not ensure that a response *will* occur, nor does it guarantee that the response will be effective. Careful planning, adequate resources, swift deployment, and the right number of personnel with the appropriate qualifications must be in place in order to capitalize on those times when environmental conditions favour on-water recovery. This distinction is important, even for sites and conditions along the tanker route where the response gap is minimal, because the opportunity to respond effectively is only the first step in a series of events that must fall into place in order to effectively remove spilled oil from the marine environment.

Section 3 of this study presents a response capacity analysis that evaluates the potential effectiveness of existing and proposed response forces for spill scenarios along the tanker route. Section 5 discusses how the response gap and capacity analyses overlap.

3 MARINE OIL SPILL RESPONSE CAPACITY ANALYSIS

Different approaches may be used to estimate the overall capacity or capability of oil spill response systems. Such analyses are typically done in a planning and preparedness context, and the results can help to inform decisions about the type and amount of equipment required to manage spills of various sizes, the location of equipment stockpiles, and the logistical constraints to response system deployment.

This marine oil spill response capacity analysis applies an established modeling approach to evaluate the capacity to mechanically recover on-water oil spills in several locations that could potentially be impacted by oil spills from the Kinder Morgan Trans Mountain Expansion project.

3.1 Overview

Research Question: What is the capacity for available mechanical oil spill recovery systems to contain and recover on-water oil spills in the study area and how is it increased or decreased by certain factors?

3.1.1 Approach

This analysis combines an operational analysis with a computer simulation to model on-water oil spill response scenarios for representative oil spills at five locations in BC that represent areas of high concern to Interveners, shown in Figure 3.1: (1) Central Harbour; (2) Outer Harbour; (3) Georgia Strait; (4) Haro Strait; and (5) Race Rocks.

As shown in Figure 3.1, the first three locations included in the response capacity analysis overlap with the sites included in the response gap analysis (Section 2). However, sites 4 and 5 differ for each study. The Juan de Fuca Strait and Neah Bay sites, which were included in the response gap analysis, were selected based on proximity to weather observation stations (in this case, weather buoys and airports) and also to represent open water operating environment conditions. Site 4 in the response capacity analysis – Race Rocks – is very close to the Juan de Fuca Strait response gap location. Race Rocks was included in this study because it is identified as a potential oil spill scenario site in application materials. (Kinder Morgan, 2013a) Site 5 in the response capacity analysis – Haro Strait – does not overlap with any of the response gap sites. It was included in the response capacity analysis because it is also an oil spill scenario location in the application materials (Kinder Morgan, 2013a) and because it is an area of high concern to the Tsawout First Nation.

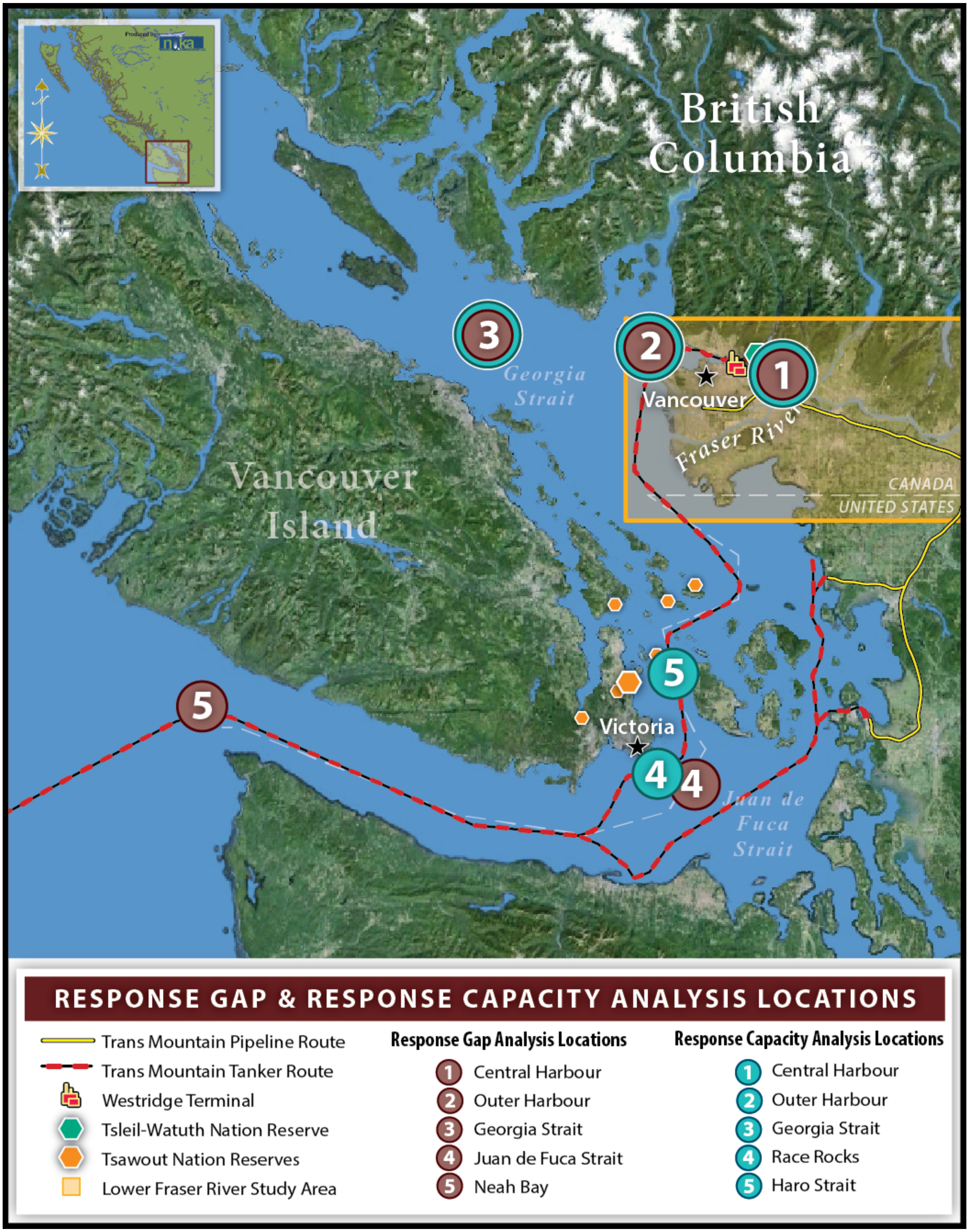


FIGURE 3.1. RESPONSE CAPACITY AND RESPONSE GAP ANALYSIS SITES

This response capacity analysis applies the Response Options Calculator as an analytical tool to model how on-water oil spill response forces in Southern BC could be applied to various spill scenarios and estimate their potential oil recovery during a 72-hour period. This method uses the Response Options Calculator to estimate the on-water recovery capacity for specific oil spill response forces under specified conditions and considers spill timing, seasonality, simplified environmental conditions, oil properties, and deployment logistics to provide estimates of on-water oil recovery during the first 72 hours (three days) after a spill occurs (Mattox et al., 2014; Dale et al., 2011). The 72-hour timeframe is built into the model and reflects the general consensus among spill response professionals about the ideal window-of-opportunity for mechanical recovery of oil spills (Dale et al., 2011; Nordvik, 1995).

Response scenarios were analyzed for hypothetical worst case volume spills at each location during winter and summer using different response forces. The results provide insight into the expected on-water oil recovery capacity under a range of conditions, and highlight the impact of response force composition and timing on spill response in open water and protected water environments.

3.1.2 Worst Case Discharges from Trans Mountain Tankers

> ***"A worst case discharge refers to the complete discharge of a tanker's oil cargo along with its bunker fuel, or, for a non-tanker vessel, the complete release of its bunker fuel."***
>
> Transport Canada Tanker Safety Expert Panel
>
> *A Review of Canada's Ship Source Oil Spill Preparedness and Response Regime*

This study models on-water spill response to worst case scenarios that are derived from the Trans Mountain Expansion project application. For all spill locations except the Central Harbour, a 16,000 m^3 spill was modeled. This spill volume is consistent with the 16,500 m^3 volume "credible worst case" oil spill volume derived from the marine transportation risk assessment for the project application (DNV, 2013). However, these spill volumes are significantly lower than a true worst case discharge, which is typically considered to be the ship's entire cargo.[19]

For the Central Harbour site, the scenario modeled is an 8,000 m^3 oil spill. This is significantly higher than the 160 m^3 spill presented in the project application; however, it is supported by the project risk assessment and is consistent with the methods used by the proponent to select worst case volumes for other locations. The project application presents a 160 m^3 loading arm spill into pre-deployed containment boom as a "credible" worst case discharge for a tanker at the Westridge Marine Terminal. This is not a credible worst case scenario, and does not align with best practices for oil spill contingency planning.

The selection of 8,000 m^3 as a worst case oil spill for the Westridge Marine Terminal is consistent with information that is presented in the project application. In evaluating the potential worst case volume of tanker oil spills from grounding or collision, the project application considers the conditional probability for various spill sizes based on modeled analysis. Conditional probabilities describe the likelihood of a particular outcome if an initiating event – in this case a tanker grounding or collision – should occur. The project application uses the 10% highest outflow (P90) for tanker groundings or collision. This represents the probabilistic estimate of spill size for the most severe 10% of cases, which is a reasonable approach to

[19] The 16,500 m^3 volume cited in the application materials is equivalent to the entire loss of two cargo compartments of a partially laden Aframax tanker. A fully laden Aframax tanker may carry up to 120,000 m^3 of oil. While Trans Mountain tankers do not operate fully laden because of draft restrictions in the Port of Vancouver, a true worst case discharge volume should reflect the maximum cargo volume that could be carried by a Trans Mountain tanker.

establish a worst case spill volume, and is the approach used to come up with a worst case discharge volume for all sites except the Westeridge Marine Terminal. (DNV, 2013)[20]

Figure 3.2 is extracted from the project risk assessment, which considers the conditional probability of oil spill volume for two types of spills that could occur at the Westridge terminal: a tanker being struck at berth or a tanker being struck at an anchorage. It is reproduced here to illustrate the justification for a higher worst case spill volume.

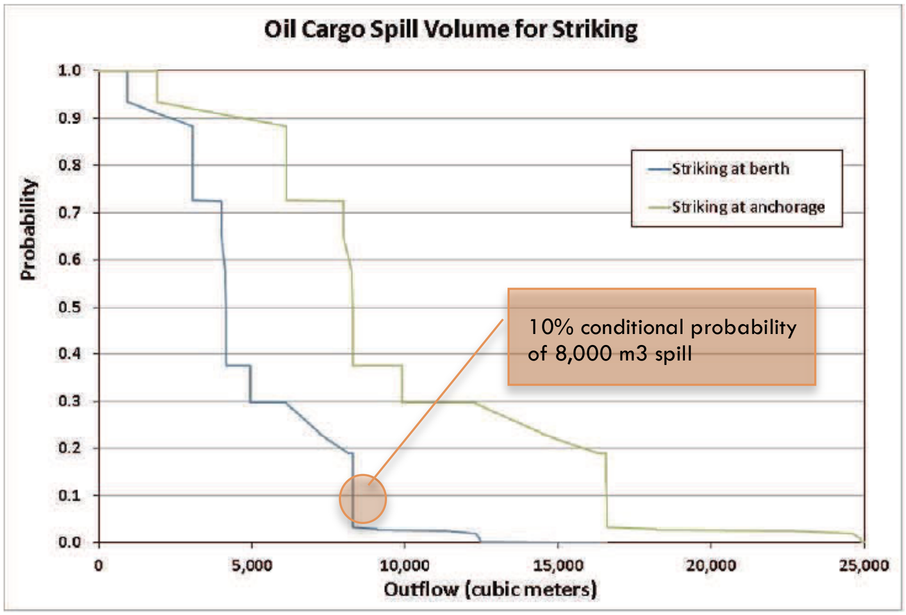


FIGURE 3.2. CONDITIONAL PROBABILITY FOR OIL SPILL VOLUMES IF A TRANS MOUNTAIN TANKER AT BERTH OR ANCHORAGE IS STRUCK BY ANOTHER VESSEL AND LEADS TO AN OIL SPILL (FROM DNV, 2013)[21]

Figure 3.2, extracted from the project risk assessment, identifies the potential spill volumes for a vessel strike at anchorage that range from approximately 3,000 to 25,000 m^3 (shown with the blue line in Figure 3.2) and potential spill volumes for a vessel strike at berth that range from approximately 2,000 to 12,000 m^3 (shown with the green line in Figure 3.2). Applying the P90 method (10%) used in the project application to estimate spill volumes for grounding and collisions yields a worst case discharge volume of 8,000 m^3 for an oil spill resulting from a tanker that is struck while at berth at the Westridge Terminal. (DNV, 2013) The authors believe that it is reasonable and consistent to use the same method to estimate a worst case volume for the Westridge Terminal as for other sites, and therefore an 8,000 m^3 spill is the worst case scenario modeled in this study.

3.2 Methodology

The methods used in this analysis build on previous published studies that apply the Response Options Calculator and/or derivative models to estimate oil spill response capacity (Nuka Research, 2013, 2012a, 2012b; Genwest Systems Inc., 2012a). The Response Options Calculator is an oil spill response modeling tool that simulates an idealized on-water oil spill under simplified environmental conditions. The Response

[20] Section 9.1.2 and 9.1.3 on pages 68-69 of TERMPOL 3.15 (TR 8C-12) "General Risk Analysis and Intended Method of Reducing Risks."

[21] This figure is presented in its original form as extracted from TERMPOL 3.15 (TR 8C-12) "General Risk Analysis and Intended Method of Reducing Risks," prepared by DNV. It appears as Figure 38 on page 74 of that report.

Options Calculator model simulates oil weathering and spreading and estimates recovery potential for mechanical recovery (containment and skimming) systems (NOAA, 2012; Genwest Systems Inc., 2012a).

The Response Options Calculator can be used to estimate the capacity of actual spill response systems by modeling the recovery performance of specific task forces when applied to hypothetical spill scenarios. In this study, the Response Options Calculator is applied to estimate the hourly recovery volume for a given scenario over a 72-hour time period. In addition to these estimates, the Response Options Calculator also generates a series of graphs that describe the changes to the oil slick as it spreads and weathers, including the oil thickness, viscosity, emulsification, and evaporation (Mattox et al., 2014).

The general process for running Response Options Calculator scenarios to estimate on-water recovery is:

1. Develop hypothetical spill response scenario parameters
2. Define response systems
3. Define model inputs and assumptions
4. Conduct model runs for all scenarios
5. Present and interpret results

3.2.1 Scenario Parameters

Oil spill response capacity analyses were performed for five hypothetical oil spill locations in British Columbia, with the following parameters:

- **Scenario Locations.** The five locations selected (Figure 3.1) represent areas of high concern to the Interveners as well as areas identified as having a relatively high risk of vessel accidents in the project application (DNV, 2013; Moffat and Nichol, 2013).
- **Season.** Winter and summer scenarios were run for all five locations. Summer and winter solstices were selected as scenario dates, and the number of daylight and darkness hours for each date and location were used as model inputs.
- **Volume.** An 8,000 m^3 spill was modeled for Central Harbour, and 16,000 m^3 spills were modeled for all other locations.
- **Oil type.** A single oil type – Cold Lake Blend diluted bitumen (CLB) – was used as the spill oil, and is consistent with the project oils proposed in the application. Oil properties are derived from the oil properties in the Response Options Calculator database.[22]
- **Response Forces.** Three different categories were used to describe the status of response forces – existing forces, proposed forces, and additional supplementary forces. Response forces were characterized based on their maximum operating environment. Response force composition is discussed in Section 3.2.2.
- **Arrival Times.** The amount of time that elapses between when a spill occurs and when response forces arrive has a significant impact on response effectiveness. Arrival time is the effective starting point of on-water recovery operations and was calculated based on travel speeds and distances that are presented in Appendix C. Base scenarios are run with arrival time at first light to maximize oil recovery time. Sensitivity scenarios are run for delayed arrival times.
- **Night Operations.** In one scenario, response forces operate during night (darkness), while in all others recovery is limited to daylight. For scenarios where night operations are modeled, efficiency discounts are applied, as explained in Section 3.3.4.

[22] API Gravity 22.6, Pour Point -45°C, Viscosity 206cSt at 16°C

Twenty-one spills were simulated using a combination of fixed and variable parameters. Table 3.1 lists the ten baseline spills that were run for summer and winter worst case discharge volume spills with a set of fixed parameters (Cold Lake Blend, all response forces, arrival at first light, and night operations).

TABLE 3.1 HYPOTHETICAL OIL SPILL SCENARIOS: 10 BASELINE SPILLS

	Variable Parameters			Fixed Parameters			
Scenario	Location	Season	Volume (m^3)	Oil Type	Response Forces Deployed	Arrival Times	Night Operations
CH-S	Central Harbour	Summer	8,000	CLB	All	First light	None
CH-W	Central Harbour	Winter	8,000	CLB	All	First light	None
OH-S	Outer Harbour	Summer	16,000	CLB	All	First light	None
OH-W	Outer Harbour	Winter	16,000	CLB	All	First light	None
GS-S	Georgia Strait	Summer	16,000	CLB	All	First light	None
GS-W	Georgia Strait	Winter	16,000	CLB	All	First light	None
HS-S	Haro Strait	Summer	16,000	CLB	All	First light	None
HS-W	Haro Strait	Winter	16,000	CLB	All	First light	None
RR-S	Race Rocks	Summer	16,000	CLB	All	First light	None
RR-W	Race Rocks	Winter	16,000	CLB	All	First light	None

Table 3.2 lists an additional series of 11 sensitivity analysis scenarios that were run to evaluate the influence of specific parameters on overall recovery. All of the sensitivity analysis scenarios are for 16,000 m^3 Cold Lake Blend spills. The "sensitivity" column lists the factor that was changed in the analysis to evaluate how changes to specific response parameters can be expected to influence overall recovery. Sensitivity factors included in this analysis were: delays to mobilization times (6, 12, 18, 24, and 48 hours); categories of response forces deployed (removing proposed and additional supplementary forces from model); and night operations.

In addition to these sensitivity analyses, qualitative analysis is presented to consider: (1) the potential for oil stranding on shorelines to reduce on-water recovery; and (2) the implications of submerged or sunken oil to response capacity estimates.

TABLE 3.2 HYPOTHETICAL OIL SPILL SCENARIOS: SENSITIVITY ANALYSES

Scenario	Sensitivity	Location	Response Forces		Arrival Times	Night Operations
			Forces Deployed	Operating Environment		
OH-S-D6	Mobilization delay	Outer Harbour	All	All	6-hr delay	None
OH-S-D12	Mobilization delay	Outer Harbour	All	All	12-hr delay	None
OH-S-D18	Mobilization delay	Outer Harbour	All	All	18-hr delay	None
OH-S-D24	Mobilization delay	Outer Harbour	All	All	24-hr delay	None
OH-S-D48	Mobilization delay	Outer Harbour	All	All	48-hr delay	None
OH-S-C	Response Forces Deployed	Outer Harbour Summer	Current only	All	First light	None
RR-S-C	Response Forces Deployed	Race Rocks Summer	Current only	All	First light	None
RR-W-C	Response Forces Deployed	Race Rocks Winter	Current only	All	First light	None
HS-S-C	Response Forces Deployed	Haro Strait Summer	Current only	All	First light	None
HS-W-C	Response Forces Deployed	Haro Strait Winter	Current only	All	First light	None
OH-S-N	Night operations	Outer Harbour	All	All	First light	Yes

3.2.2 Response Forces

The Response Options Calculator requires detailed information about the spill response force being used in each simulation. For this analysis, task forces were assembled from existing resources owned by Western Canada Marine Response Corporation (WCMRC) as listed in published inventories. The response forces were then assembled into strike teams consistent with industry practices for on-water spill response (Canadian Coast Guard, 2005; WCMRC, 2013; Kinder Morgan 2013b). All task force components are categorized based on their operating environment, capable of either protected water or open water recovery based on standard equipment ratings and operating limits (ASTM, 2011; Potter, 2013).

Response forces were also characterized based on their current status. There is an existing set of resources owned by WCMRC and available for on-water spill response in the study area: these **existing forces** represent the current on-water response capacity. WCMRC has also indicated, and the project application has cited, the intent to add to the existing response resource inventory (WCMRC, 2013; Kinder Morgan, 2013a): these **proposed forces** include response resources specifically identified in written materials. They are included in the response capacity analysis, because it is assumed that they will be put in place if the project application is approved. A third category of resources – **additional supplementary resources** – was added to the response forces by the authors based on best professional judgment. These include ancillary resources needed to fill certain minor gaps in task force composition of the proposed forces, such as work boats to support on-water recovery operations. These resources would presumably be available through WCMRC or Trans Mountain, but are not explicitly described in the current proposals.[23] The authors assume that these

[23] These additional supplementary forces consist of six protected water recovery strike teams. They reflect best practices in protected water oil recovery, and generally mirror configurations in place on the US side of the border for response in the Strait of Juan de Fuca (Nuka Research, 2012b).

response forces, or the equivalent, would also be put in place in the event that the project application is approved. Figure 3.3 shows response force locations.

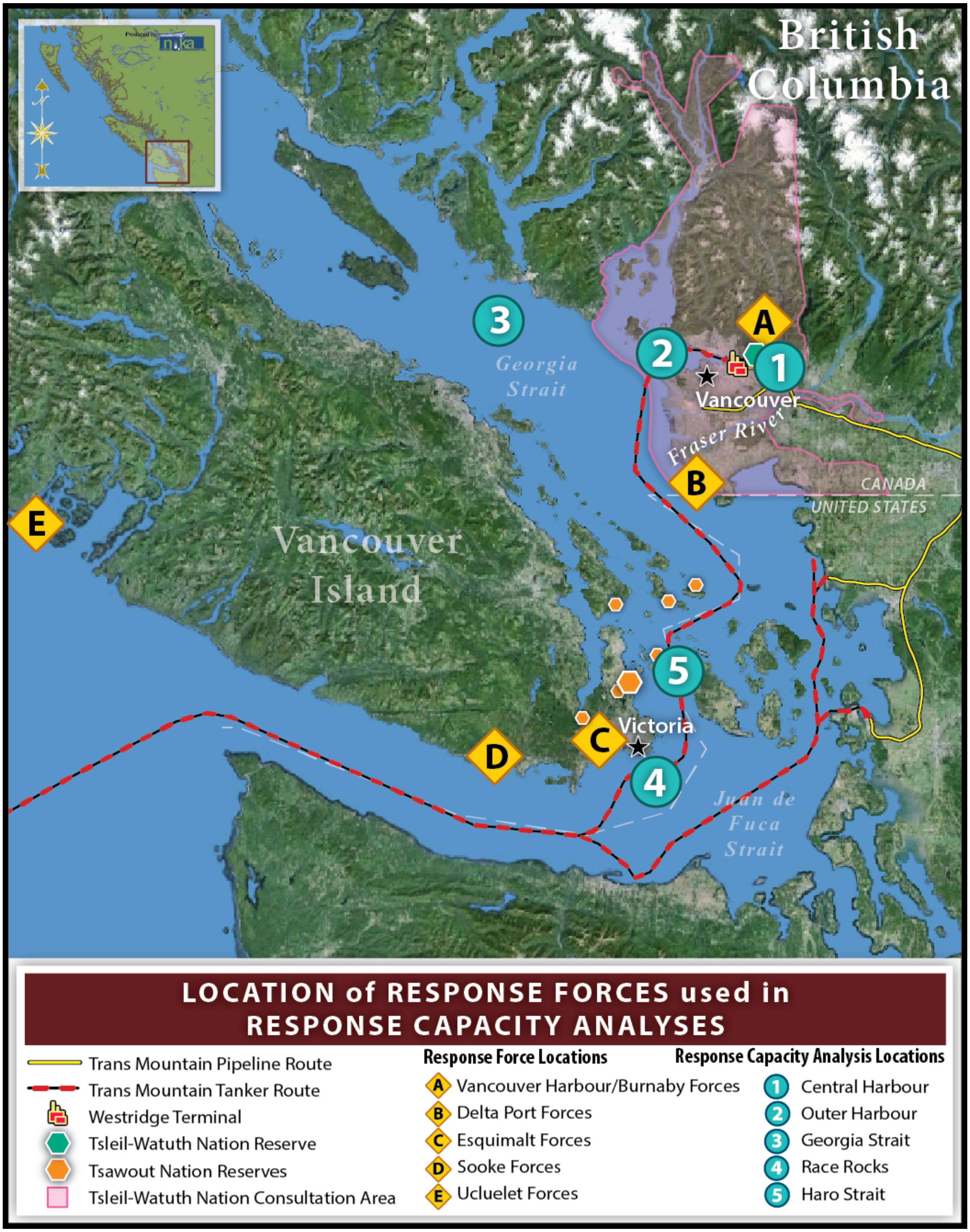


FIGURE 3.3. LOCATION OF RESPONSE FORCES

Figure 3.3 shows the geographic distribution of response forces relative to the response capacity analysis spill scenarios. The location of proposed and additional supplementary forces was selected based on best available information and the authors attempted to distribute proposed and additional supplementary forces to maximize rapid mobilization and deployment to potential spill sites.

Table 3.3 lists the Task Forces included in this analysis and identifies their component strike teams, home base locations, operating environment ratings, and category (existing, proposed, additional supplementary). Appendix C contains detailed information about response equipment in each task force.

TABLE 3.3. SUMMARY OF RESPONSE FORCES APPLIED TO RESPONSE CAPACITY ANALYSIS

Task Force	Strike Team	Home Base	Operating Environment	Response Force Category
Task Force 1	Van 1	Burnaby	Protected Water	Existing
	Van 2	Vancouver Harbour	Protected Water	Existing
	Van 3	Vancouver Harbour	Protected Water	Existing
	Van 4	Vancouver Harbour	Open Water	Existing
	Van 5	Vancouver Harbour	Protected Water	Existing
	Van 6	Burnaby	Protected Water	Existing
	Van 7	Vancouver Harbour	Open Water	Existing
Task Force 2	Esq 1	Esquimalt	Open Water	Existing
	Esq 2	Esquimalt	Open Water	Existing
Task Force 3	PR 1	Prince Rupert	Open Water	Existing
Task Force 4	JDF 1	Ucluelet	Open Water	Proposed
	JDF 2	Sooke	Open Water	Proposed
	JDF 3	Esquimalt	Open Water	Proposed
Task Force 5	Delta 1	Deltaport	Open Water	Proposed
Task Force 6	Barge 1	Ucluelet	Open Water	Proposed
	CB 1	*Barge 1*	Protected Water	Additional supplementary
	CB 2	*Barge 1*	Protected Water	Additional supplementary
Task Force 7	Barge 2	Esquimalt	Open Water	Proposed
	CB 3	*Barge 2*	Protected Water	Additional supplementary
	CB 4	*Barge 2*	Protected Water	Additional supplementary
Task Force 8	Barge 3	Esquimalt	Open Water	Proposed
	CB 5	*Barge 3*	Protected Water	Additional supplementary
	CB 6	*Barge 3*	Protected Water	Additional supplementary

3.2.3 Model Inputs

In addition to the scenario parameters, there are a number of variables that are inputted into the Response Options Calculator model in order to derive recovery estimates. Some inputs are user-defined and others are defined in the Response Options Calculator model. [24] Table 3.4 summarizes the user-defined inputs, which were developed by the authors based on best professional judgment and published literature as cited.

TABLE 3.4. RESPONSE OPTIONS CALCULATOR MODEL INPUTS USED IN THIS ANALYSIS

Factor	Explanation	Value Used
Recovery Speed	Advancing speed for on-water response systems (vessels, boom, and skimmers). Speeds vary depending upon the task force composition based on operating limits of skimming systems. Advancing speeds are important to effective containment of oil; at high speeds, oil will entrain (move under containment boom) and escape recovery.	0.65 knots/1.2 kph (traditional towed boom systems) 4 knots/7.4 kph (Current Buster® systems) (S.L. Ross, 1999; ASTM, 2011)
Decant Efficiency	On-water skimming does not recover 100% oil. The fluids recovered will be a mix of oil and water. Some of the water will emulsify (incorporate into the oil, forming an oil/water emulsification) and some will remain as free water. Free water may be recovered from storage tanks and returned to the sea in process known as decanting. Decanting reduces the total volume of recovered fluids that must be handled as waste. The decant efficiency is the percentage of recovered water that is separated out from the total recovery volume.	0% temporary storage 80% barges (Fingas, 2011)
Decant Pump Rate	Decant pump rate controls the speed of decanting, and for modeling purposes is set to 80% of the skimming nameplate recovery capacity, allowing the decant pump to keep pace with the skimmer to maximize response efficiency.	100 m^3/hr (Fingas, 2011)
Swath Width	Swath width is the width of the area within the containment boom along which floating oil is swept. Swath widths vary depending upon the task force configuration and the environmental conditions.[25] Maintaining larger swaths becomes more difficult as wind, waves, and currents increase. For every meter of swath width, it is industry standard that three meters of boom are required.	18 m for vessels using integral V-sweeps 50 m for vessels using J-concentration booms 100 m for vessels using U- or V-concentration booms (ASTM, 2011)
Throughput Efficiency	Throughput efficiency is the proportion of oil recovered to oil encountered. Skimmers do not typically recover 100% of oil that could in theory be contained in a booming system due to a variety of limitations, the most significant being variations in oil thickness and loss of containment. When tracking and observation fail (such as at night), this is exacerbated by failure to effectively target oil, which results in increasingly sweeping thin, patchy oil or missing the slicks entirely.	75% daylight 37.5% darkness[26] (Response Options Calculator default)

[24] Response Options Calculator-defined inputs apply a consistent set of mathematical algorithms to produce results, and are explained in the user manual (NOAA, 2012).

[25] Based on standard oil spill response tactics guides.

[26] Throughput for night operations (darkness) was reduced by 50% to reflect lower oil encounter rates at night due to challenges with tracking and surveillance during darkness.

Factor	Explanation	Value Used
Offload Time	Offload time is the amount of time that task forces must spend offloading recovered fluids from primary to secondary storage. During offloading, the task force cannot actively recover oil. Response Options Calculator also allows for the input of an offload pump speed; this field was set to achieve the 2-hour offload time.	2 hours (Professional judgment)
Transit to-and-from Offloading	Transit time is the time required for a vessel to transit from the recovery site to an offload location.	15 minutes each way (Professional judgment; highly optimistic assumption)
Recovery Efficiency	Recovery efficiency is the percentage of oil recovered relative to the total volume of fluids. It varies by skimmer type.	80% for oleophilic skimmers 20% for all other skimmers (Response Options Calculator default)
Mobilization Time	Mobilization time is the amount of time required for a task force to begin transiting to a recovery site, and accounts for the time required for notification or spill detection, dispatch, starting up vessels, and loading equipment.	1 hour[27] (USCG, 2008)
Travel Speed	Travel speed is the rate at which a strike team or task force can travel from home base to spill location.	Varies depending on vessels and systems. (See Appendix C.)
On-scene Setup	Once response forces arrive at the spill site, time is required to configure equipment and start machinery before recovery can begin.	1 hour (recovery) None (secondary storage) [28] (USCG, 2008)
Water Temperatures	Water temperatures are assumed to be the same for all locations and represent the June and December averages from the Halibut Bank observation buoy data (see Table 2.1).	15.8° C summer (all locations) 7.3° C winter (all locations) (National Data Buoy Center data)
Wind Speeds - Summer	Wind speeds are the seasonal mean, calculated from the data sets used in the response gap analysis (see Table 2.1).	Central Harbour: 1.6 m/s Outer Harbour: 3.5 m/s Georgia Strait: 4.7 m/s Haro Strait: 3 m/s[29] Race Rocks: 5.1 m/s
Wind Speeds - Winter	Wind speeds are the seasonal mean, calculated from the data sets used in the response gap analysis (see Table 2.1).	Central Harbour: 1.6 m/s Outer Harbour: 3.9 m/s Georgia Strait: 5.8 m/s Haro Strait: 3.5 m/s Race Rocks: 5.2 m/s

[27] One hour assumes immediate detection, prompt notification, efficient dispatch, and the presence of dedicated response forces on stand-by. Delay or failure in any of these links can extend mobilization time.

[28] Barge crews are considered to be set-up for oil transfer while underway, and can commence loading immediately upon arrival on-scene.

[29] Haro Strait was not included in the response gap analysis, and there are no observational data sets available for this area. Representative summer and winter wind speeds of 3 m/s and 3.5 m/s were selected based on nearby weather stations (Victoria airport; New Dungeoness buoy). Use of New Dungeness environmental data for the Haro Strait Response Options Calculator analysis would have resulted in lower recovery estimates, due to higher wind speeds (5.1 m/s summer, 5.2 m/s winter).

3.2.4 Assumptions and Limitations

Modeling relies on a series of assumptions. The Response Options Calculator modeling program is limited by a number of assumptions, which cause the model outputs to consistently overestimate total recovery capacity. Because the Response Options Calculator model in general, and its application in this analysis specifically, tends to overestimate total oil recovery, its outputs are not meant to be performance indicators (Genwest Systems Inc., 2012a and 2012b); it would be more appropriate to consider them as best-case estimates of maximum potential recovery under favourable conditions. Still, the comparison of multiple model outputs provides a valid indicator of relative performance of response systems, and in this way allows for meaningful comparison of how certain variables influence overall on-water response capacity.

Assumptions and limitations of the Response Options Calculator model relevant to this analysis are listed below. Cases where these assumptions may influence the analysis are noted.

- **Response Options Calculator models oil spill recovery under favourable conditions but does not predict system performance.** The oil recovery estimates are model-derived based on a series of favourable assumptions that are useful for planning purposes but should not be interpreted as a prediction of actual response outcomes. The response capacity estimates are applied in this study to estimate best-case oil recovery capacity for representative spills and evaluate the relative effect of changes on force composition, response time, and night operations on overall recovery capacity at different locations.
- **Modeled response forces include equipment that is not currently in inventory.** Three different categories of response forces were included in the base scenarios: existing, proposed, and additional supplementary. Of these three tiers, only the existing forces are in place at the present time. However, the base scenarios modeled in this analysis incorporate all three categories of response forces, meaning that the response capacity estimates reflect the capability of equipment and vessels that are not present in inventory.
- **Response Options Calculator is not geographically specific**. It does not take into account shoreline features, bathymetry, or any other location-specific factors that could influence oil fate and behaviour. Because of this limitation, Response Options Calculator recovery estimates do not account for potential interactions between oil slicks and shorelines (i.e. stranding or sediment incorporation). The likelihood that oil will strand on shorelines very soon after a spill occurs – particularly in the Burrard Inlet – means that the total volume available for recovery could be significantly less than the model estimates (Galt, 2015). The implications of this limitation may lead to a significant overestimation of total oil recovery for spills that occur in near coastal areas.
- **Response Options Calculator does not account for all environmental conditions that impact on-water spill response.** The model does not take into account influences from tides, current, debris, or complex weather conditions. Each of these may influence both oil fate and behaviour and response system efficiency. This means that total recovery estimates are likely inflated because potential efficiency losses are not considered.
- **Response Options Calculator applies a simplified oil weathering algorithm**. The manner in which oil weathers (undergoes physical and chemical changes) in the on-water environment is influenced by many complex variables and interaction. The Response Options Calculator takes into account some, but not all, of these variables. Water salinity, sediment interactions, and unusual compositional complexities of subject oils are not considered. Potential submergence of oil is also not accounted for in the Response Options Calculator weathering model. The implications of this simplified weathering model are complex, and could influence the results in either direction. For this study, the inability to model potential oil submergence or sinking may result in an overestimate of total recovery.
- **Response Options Calculator assumes optimal functionality of all equipment.** The Response Options Calculator assumes that all equipment will function properly without malfunction or failure,

and that there will be no accidents, mishaps or mistakes to hinder the response. This highly optimistic assumption may result in overestimating actual response capacity, since equipment malfunctions or operating errors can and do occur.

- **Response Options Calculator assumes that the mass balance of oil remaining on water is always available for recovery.** Response Options Calculator calculates hourly mass balance estimates for the volume of oil that is recovered, evaporated, and remains on the water. It assumes that all on-water oil is available in a floating slick that can be recovered. This does not account for the fact that some amount of the slick will reach the shoreline and strand, making it unavailable for recovery, This is particularly likely for spills that occur in proximity to coastal areas. A discussion of oil stranding is presented to illustrate how stranding may impact overall on-water recovery.
- **Response Options Calculator cannot account for variations in slick thickness.** The thickness of an oil slick has a direct impact on the ability of a skimming system to encounter and recover it. A thick oil slick is much more readily recoverable than a thin slick. The Response Options Calculator estimates thick slickness based on a spreading algorithm, but its model for recovery uses a single, average thickness that does not incorporate the fact that as a slick spreads, its thickness will not stay uniform but will become patchy and variable, creating variability in recovery rates. Real-world "patchiness" would likely reduce overall recovery estimates, again resulting in an inflated recovery estimate based on the Response Options Calculator model outputs.

The implications of specific assumptions to model outputs are discussed in Section 3.4.

3.3 Analysis

3.3.1 Model Outputs for Base Scenarios

The Response Options Calculator model outputs estimate the volume of oil recovered by each response force for each scenario on an hourly basis for the first 72 hours. Table 3.5 summarizes the recovery estimates for the 10 base scenarios (winter and summer scenarios with all response forces for worst case discharge of Cold Lake Blend at each location, with response forces arriving at first light with no night operations). The table shows the total volume of oil estimated to be recovered or remaining in the water after 72-hours of on-water recovery operations. The remaining balance of oil is estimated to have evaporated, which is why the percentages in the table do not add up to 100.[30]

[30] Evaporation estimates are not included in the table but can easily be calculated using the following formula: Amount evaporated = Spill volume – (Oil Recovered + Oil Remaining on Water). Evaporation estimates are derived from the Response Options Calculator weathering model.

TABLE 3.5 SUMMARY OF 72-HOUR ON-WATER RECOVERY ESTIMATES FOR 10 BASE SCENARIOS

Scenario	Summary	Oil Recovered (72 hours)	Spill Volume Recovered (%)	Oil Remaining on Water (72 hours)	Spill Volume Remaining (%)
CH-S[31]	Central Harbour Summer	6,235 m^3	78%[32]	162 m^3	2%
CH-W	Central Harbour Winter	4,951 m^3	62%	1,480 m^3	19%
OH-S	Outer Harbour Summer	5,843 m^3	37%	6,804 m^3	43%
OH-W	Outer Harbour Winter	3,402 m^3	21%	9,319 m^3	58%
GS-S	Georgia Strait Summer	4,387 m^3	27%	8,151 m^3	51%
GS-W	Georgia Strait Winter	2,417 m^3	15%	10,183 m^3	64%
HS-S	Haro Strait Summer	6,883 m^3	43%	5,806 m^3	36%
HS-W	Haro Strait Winter	3,588 m^3	22%	9,153 m^3	57%
RR-S	Race Rocks Summer	4,266 m^3	27%	8,248 m^3	52%
RR-W	Race Rocks Winter	2,585 m^3	16%	10,040 m^3	63%

Recovery estimates for the base scenarios shown in Table 3.5 range from 78% of the total spill volume recovered (Central Harbour 8,000 m^3 spill during summer) to 15% of the total spill volume recovered (Georgia Strait 16,000 m^3 spill during winter) during the initial 72 hours of the response. The balance of oil remaining on water after 72 hours ranges from a best-case of 2% of the total spill volume (Central Harbour summer spill) to 64% of the total spill volume (Georgia Strait winter spill). At all sites, the estimated total volume of oil recovered is significantly higher for summer scenarios than winter. For example, in the winter scenario at Haro Strait, only 22% of the oil is estimated to be recovered, with 57% of the spill volume remaining on water after 72 hours, compared to 43% recovery and 36% remaining on water for a summer scenario.

All base scenario estimates represent favourably timed oil spills (the first response forces arrive at first light on day one) using all response forces (existing, proposed, additional supplementary). The recovery estimates do not take into consideration the local geography at each spill site; this is particularly problematic for the Central Harbour site, where it is likely that the oil will reach the Burrard Inlet shoreline within the first few hours of the release and thereby significantly reduce the amount available for recovery. Unfortunately, the Response Options Calculator model cannot account for this.

Figure 3.4 shows the mass balance outputs for the Outer Harbour winter and summer scenarios, which have relatively high recovery estimates compared to other sites.

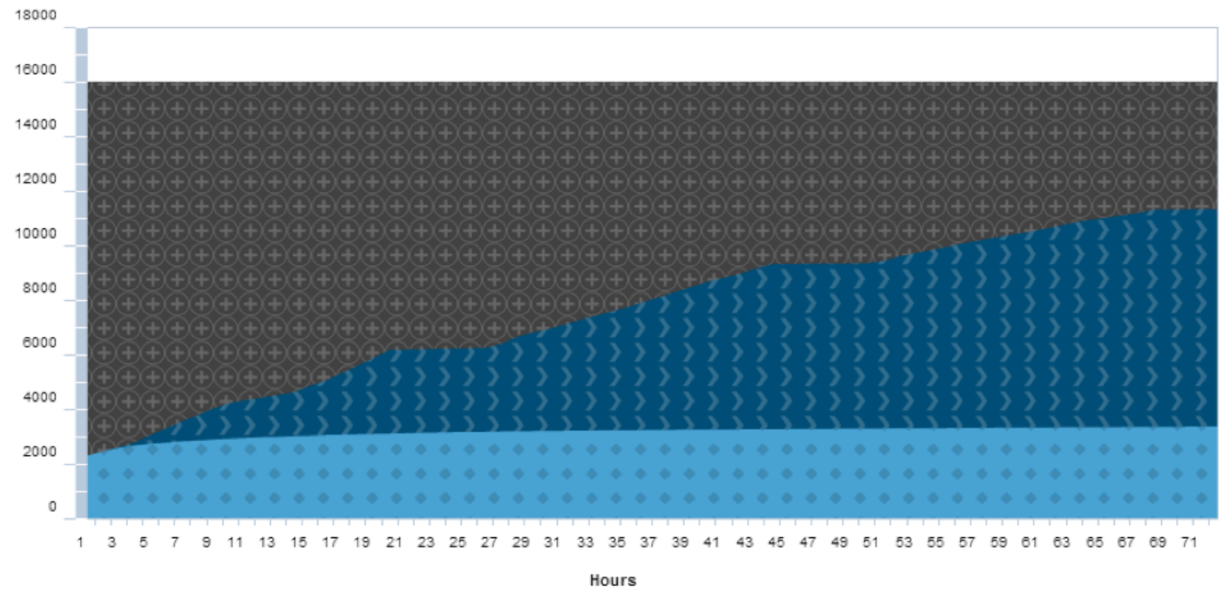
[31] Central Harbour scenarios are 8,000 m^3 oil spills while all other scenarios are 16,000 m^3

[32] Because of the location of the Central Harbour spill and the inability for Response Options Calculator to address shoreline interactions (stranding/remobilization of oil), the recovery estimates for this site be less representative of real world than others. This is discussed in Section 3.4.

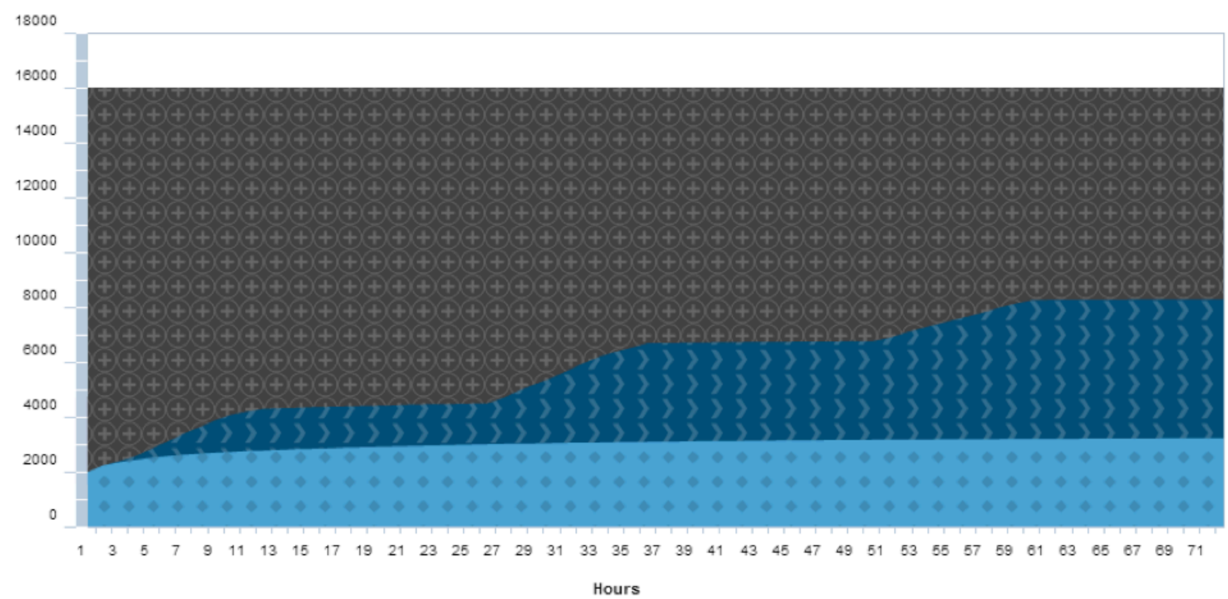
Evaporation Mechanical Oil Remaining

MASS BALANCE ESTIMATES

FOR OIL SPILL RECOVERY SCENARIOS



Outer Harbour Summer All Forces (16,000 m3 spill)



Outer Harbour Winter All Forces (16,000 m3 spill)

FIGURE 3.4. OIL BALANCE BY HOUR FOR SUMMER AND WINTER BASE SCENARIOS AT OUTER HARBOUR

Figure 3.4 is an output that is generated by the Response Options Calculator model to represent the mass balance of oil at each hour for the first 72 hours after a spill occurs. The y-axis represents the total spill volume (16,000 m^3) and the x-axis represents each hour from 1 to 72. The light blue band shows evaporation. Approximately 20% of the total spill volume is lost to evaporation in both the winter and summer scenarios, with most of the evaporation occurring almost immediately. On-water recovery begins around hour 4 in both scenarios, and the volume of the oil that is recovered is shown in dark blue. Total estimated oil recovery is 37% of the spill for the summer spill and 21% in winter. In both scenarios, there are plateaus in oil recovery that represent night time. These periods are longer during winter, which is one of the reasons that total recovery estimates are lower for winter spills.

The amount of oil remaining on water for the first 72 hours is shown in black. For the Outer Harbour summer scenario, approximately 43% of the original spill volume (6,804 m^3) is still remaining in the environment after 72 hours of on-water recovery operations. For the winter scenario, an estimated 58% of the oil (9,319 m^3) is still remaining in the environment after 3 days of on-water recovery.

The recent *M/V Marathassa* fuel oil spill in English Bay provides an opportunity to ground truth the response modeling, and helps to illustrate how the Response Options Calculator approach used in this study represents highly optimistic assumptions. During the April 2015 English Bay spill, which occurred on a clear, calm late spring day, four and a half hours elapsed between the initial report (by the public) of the oil spill and the arrival on-scene of initial response forces (Hunter, 2015). Nearly 13 hours elapsed before response crews had boomed off the leaking vessel. Incident records are unclear about when skimming operations commenced (Wright, 2015b).

Because the volume of oil spilled by the *M/V Marathassa* has not been publicly disclosed,[33] it is impossible to compare recovery estimates from the recent English Bay fuel oil spill to the modeled tanker spill. Recovered oil estimates provided by WCMRC, the clean-up contractor for the *M/V Marathassa* spill, estimate that 1,000 L of oil was recovered from on-water skimming operations during the initial two days of recovery operations (Wright, 2015a).[34] If a total spill volume for the English Bay incident is provided, this 1,000 L recovery estimate would provide an interesting point of comparison for the 37% Outer Harbour summer spill recovery estimate generated by the Response Options Calculator model (although the modeled spill at 16,000 m^3 is likely an order of magnitude larger than the English Bay fuel oil spill.

Figure 3.5 shows the mass balance outputs for the Race Rocks winter and summer scenarios, where recovery estimates are relatively low.

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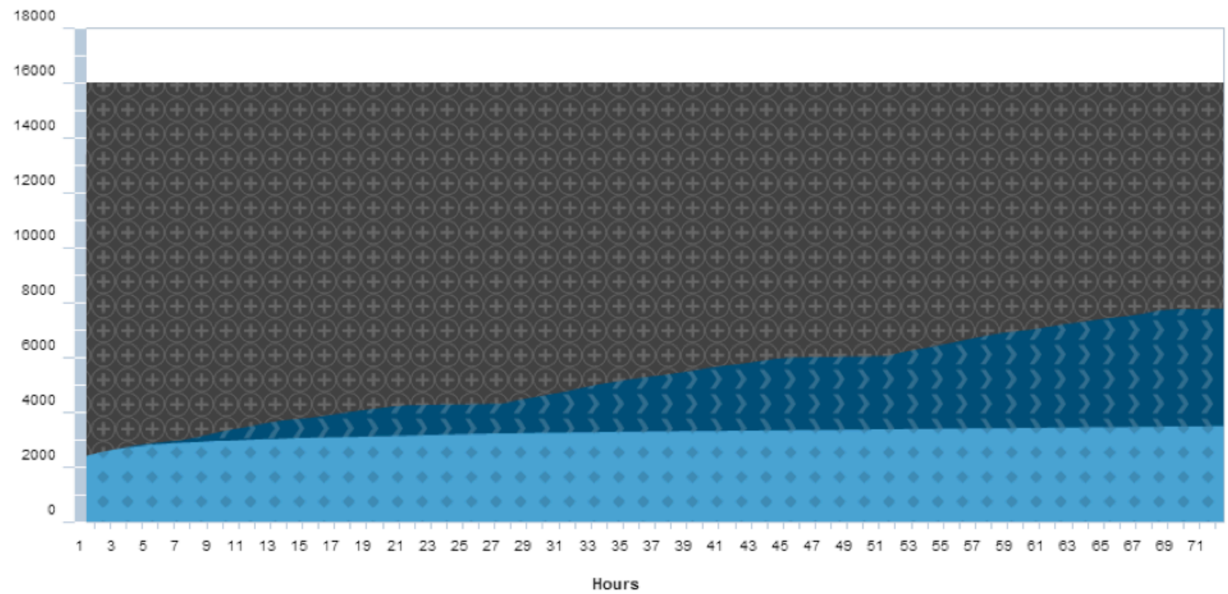
[33] Initial media reports that the spill was 2,700 L misrepresent that volume, which is actually the estimated volume of oil observed on water during an English Bay overflight on April 9, 2015. This is not a measured volume, it is an estimate derived from an overflight map of observed sheen and assumptions about the sheen thickness. It represents a snapshot in time that was taken about 18 hours after the spill was first reported and an unknown amount of time after the ship began leaking oil. At the time of the overflight, some oil had been recovered (precise volume is unclear in available documentation), some oil was still trapped in the boom around the vessel and in pockets of oil beneath the vessel, some oil had evaporated or spread beyond the visible slick, some oil had already impacted the shoreline, and some oil was still leaking from the vessel. Most likely, the actual volume spilled was greater than 2,700 L.

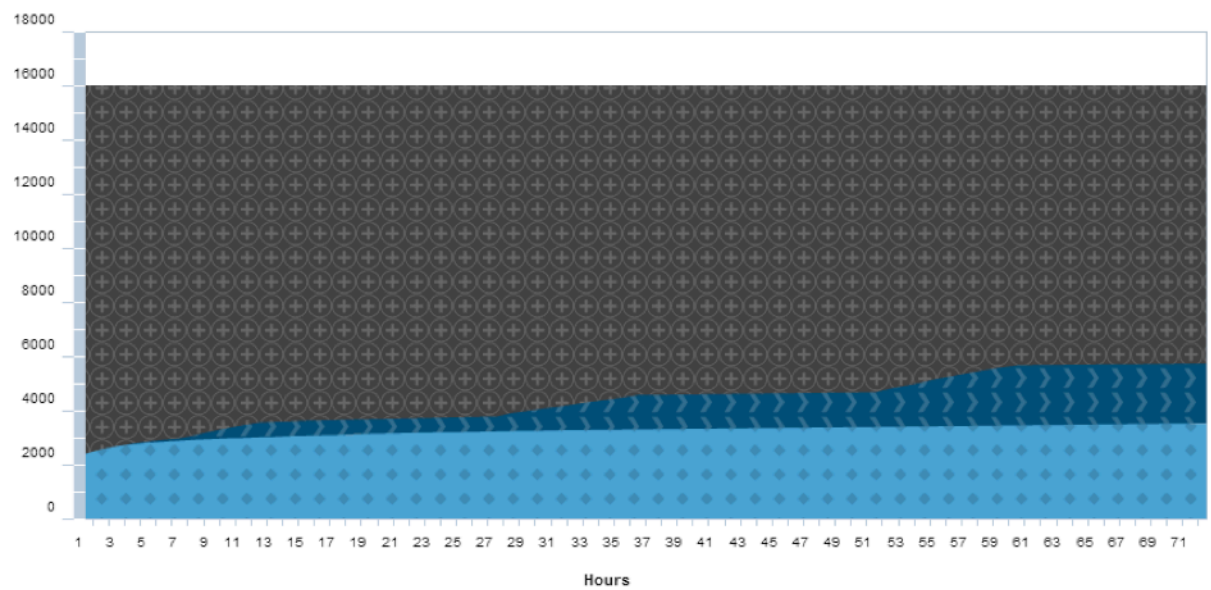
[34] Recovered oil estimates provided by WCMRC indicate that as of April 16, 2015, 8200 L of total liquids had been recovered through skimming operations, of which 800 L were calculated to be oil. An additional 300 L of oil and water was still remaining onboard the Burrard No. 3, of which 200 L was estimated to be oil. This amounts to 1,000 L of oil recovered through skimming operations. Another 402 L of oil was estimated to be recovered in the form of solid waste generated by boat crews in sorbents, protective equipment, etc. (302 L) and 100 L of oil adhered to booms, for a total recovery estimate of 1,400 L of oil.

MASS BALANCE ESTIMATES FOR OIL SPILL RECOVERY SCENARIOS

Evaporation | Mechanical | Oil Remaining



Race Rocks Summer All Forces (16,000 m3 spill)



Race Rocks Winter All Forces (16,000 m3 spill)

FIGURE 3.5. OIL BALANCE BY HOUR FOR SUMMER AND WINTER BASE SCENARIOS AT RACE ROCKS

Oil recovery estimates shown in Figure 3.5 are much lower for Race Rocks than Outer Harbour, in part because the operating environment will make it more challenging for on-water recovery forces to efficiently recover oil, and in part because transit distances are longer, delaying the arrival of response forces and the onset of recovery. The summer on-water recovery estimate for the Race Rocks scenario is 27% of the spill, with 52% remaining in the environment after 72 hours of recovery operations. In winter, this decreases to

16% estimated total recovery, with 63% of the spill (over 10,000 m^3) remaining in the environment after three days of recovery.

Figure 3.6 shows the response capacity estimates for base scenarios by location and season. Two graphs are shown at each location to summarize the modeled estimates for oil recovered on-water (dark blue), oil evaporated (light blue), and oil remaining on water (black) at 72 hours after the spill occurs.

The recovery estimates shown in Figure 3.6 reflect a number of optimistic assumptions that influence the results toward a high estimate of on-water recovery. As noted, the 78% recovery estimate for the Central Harbour summer spill and 62% for winter do not account for the high likelihood that oil spills at this location would quickly reach shorelines and therefore become unavailable to on-water skimming. The recovery estimates at all locations are presented as *baseline* estimates to show modeled recovery potential under the set of base conditions summarized in Table 3.1. These estimates are used throughout the remainder of this analysis as reference points to examine how changes to scenario parameters may influence on-water oil recovery through a series of sensitivity analyses.

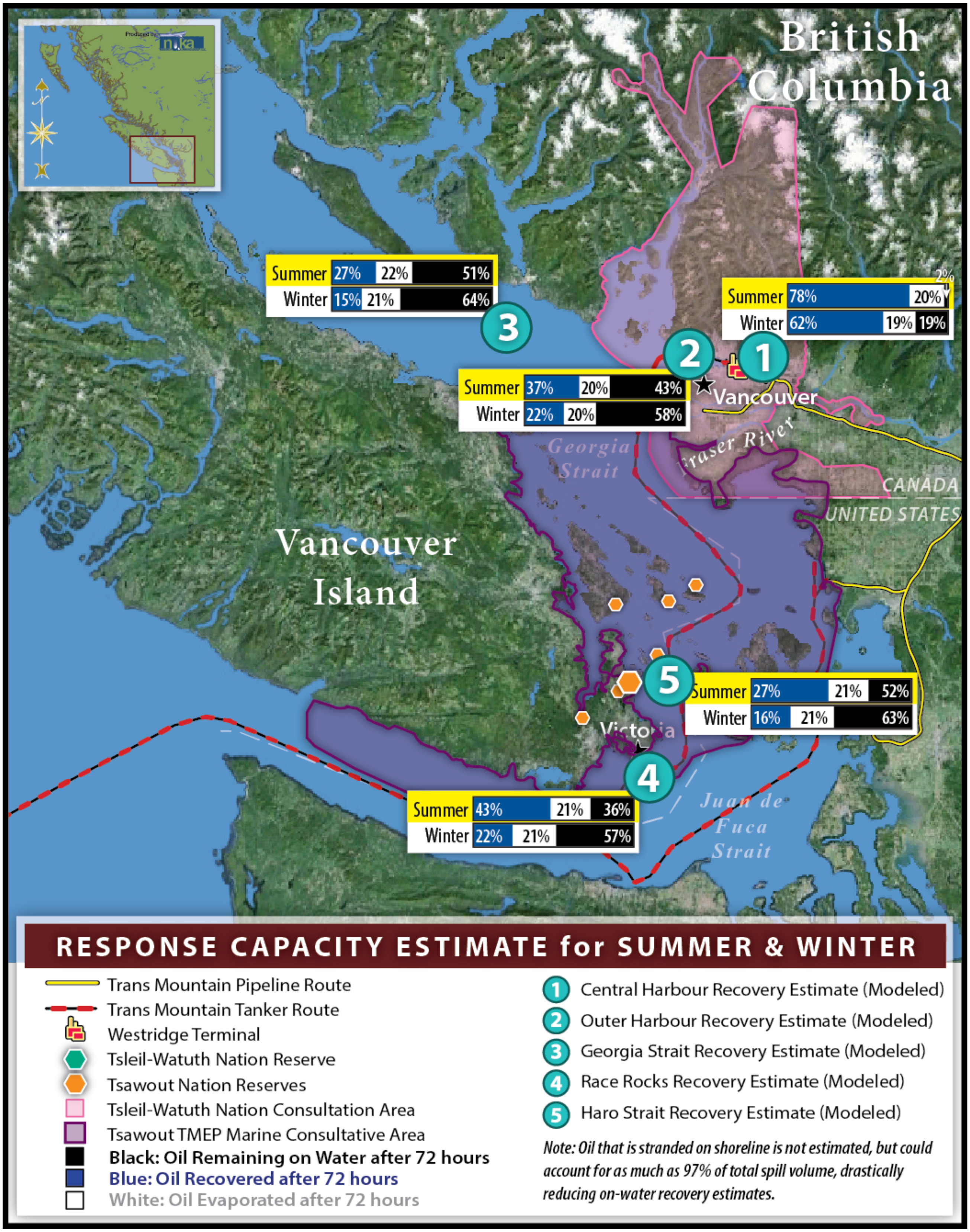


FIGURE 3.6. MAP OF RESPONSE CAPACITY ESTIMATES FOR BASE SCENARIOS

3.3.2 Seasonal Differences in Response Capacity for Baseline Spills

Figure 3.7 shows the difference between summer and winter recovery estimates for each of the five scenario locations modeled. The recovery estimates assume that current response forces are supplemented by additional forces as proposed in application materials, along with supplementary resources (ancillary equipment and work boats) that would be required to create fully functional task forces.

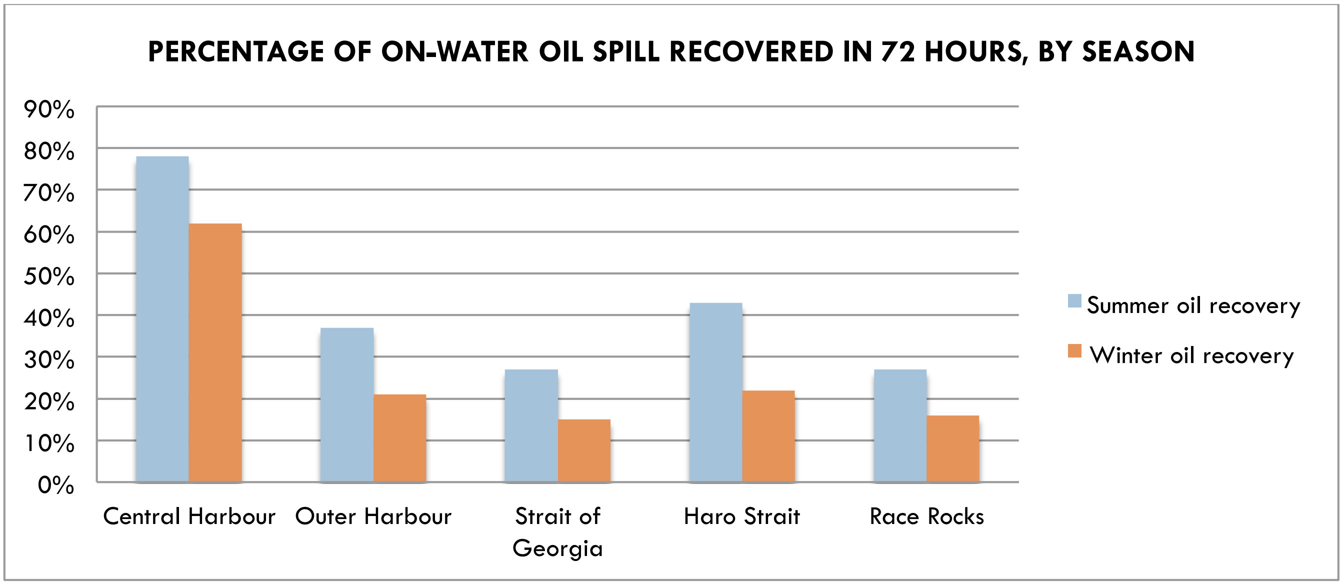


FIGURE 3.7. IMPACT OF SEASON ON ESTIMATED OIL RECOVERY (EXISTING, PROPOSED, AND ADDITIONAL SUPPLEMENTARY RESPONSE FORCES

Figure 3.7 shows that reduced response efficiency during winter conditions resulted in over 50% of the total spill volume left unrecovered in the first 72 hours at all sites but the Central Harbour. At all sites, winter recovery estimates are lower than summer estimates. Three input variables change between summer and winter: (1) wind speeds are altered to reflect mean summer and winter conditions; (2) water temperature is altered to the representative surface temperatures; and (3) length of operational periods for on-water recovery are adjusted based on day length (daylight). Recovery rates are lower in winter because of the impacts of higher wind speeds and shorter days.[35]

Although the Response Options Calculator model takes sea state into account in the weathering and spread of oil, it does not take into consideration the impacts of sea state on vessel operations, on the actual performance of recovery equipment, or on the transit to or from the recovery location. If it did, recovery estimates would probably be reduced. Likewise, if the model accounted for oil stranding as influenced by wind direction, currents, and tide state (See Section 3.4.2), the seasonal recovery estimates might be further reduced.

[35] Cooler winter surface water temperatures slightly reduce spill spread, and thus improve recovery estimates, but these do not overcome the reduced efficiency resulting from higher winds and shorter days.

3.3.3 Sensitivity of Response Capacity to Mobilization Timing

> ***"A factor that contributed to the amount of crude oil released into the Tank 121 secondary containment area is that the leak was not detected as quickly as it should have been."***
>
> National Energy Board Investigation in the matter of
> 2012-01-24 Trans Mountain Pipeline ULC Sumas Tank 121 Leak

A series of variations on the Outer Harbour summer base scenario were run to evaluate the impact of mobilization timing on 72-hour recovery estimates. While the base scenarios assume that the spill is timed such that the first responding forces arrive and begin operations at first light of the first day of response, delays are common and expected in the real world. As discussed in Section 2, environmental conditions may preclude the onset of on-water recovery for a period of hours or days.

Delayed response is a common occurrence and may result from any number of factors, including:

- Delayed spill detection;
- Delays during notification process;
- Delays during equipment mobilization or transportation to spill site;
- Inability to track oil and communicate its location to on-water forces;
- Inability to mount response due to human health or responder safety risk (i.e. air quality issues, ignition risks);
- Inability to deploy forces due to environmental conditions (response gap); or
- Spill timing (e.g., if a spill occurs a few hours before twilight, response forces may not arrive in time to begin operations until the next morning).

The longer an oil slick remains on the water, the more it spreads and weathers and the less effective on-water recovery will be. Because the window of opportunity for effective on-water oil recovery is limited, any delays to spill response will result in lower overall recovery and create the potential for more extensive environmental impacts.

For this analysis, delays of 6, 12, 18, 24, and 48 hours in the arrival of all forces are used to model how recovery would change if response forces did not begin operations at the earliest possible time. Table 3.6 summarizes the modeled recovery estimates.

TABLE 3.6. INFLUENCE OF MOBILIZATION DELAYS ON 72-HOUR ON-WATER RECOVERY ESTIMATES FOR OUTER HARBOUR SUMMER SCENARIO

Scenario	Summary	Oil Recovered (72 hours)	Spill Volume Recovered (%)	Oil Remaining on Water (72 hours)	Spill Volume Remaining (%)	Percent Change in Recovery
OH-S **Baseline**	Outer Harbour Summer No Delay	5,843 m^3	37%	6,804 m^3	43%	n/a
OH-S-D6	**6-hour Delay**	4,991 m^3	31%	7,614 m^3	48%	-15%
OH-S-D12	**12-hour Delay**	4,054 m^3	25%	8,530 m^3	53%	-31%
OH-S-D18	**18-hour Delay**	3,290 m^3	21%	9,280 m^3	58%	-44%
OH-S-D24	**24-hour Delay**	2,747 m^3	17%	9,815 m^3	61%	-53%
OH-S-D48	**48-hour Delay**	1,022 m^3	6%	11,526 m^3	72%	-83%

Figure 3.7 shows how critical timing is to effective oil recovery. Unfortunately, time elapses very quickly during the initial stages of an oil spill, and any number of scenarios could delay the onset of on-water recovery operations.

For a 6-hour delay, total recovery is reduced by 15%. A 6-hour delay means that on-water recovery does not begin until six hours after the spill occurs. In reality, six hours can easily elapse between the time when a tanker has an accident or a pipeline rupture occurs and the time that on-water response forces begin skimming oil. Something as simple as the time required to mobilize and transport trained responders to a spill site could result in a 6-hour delay.

As delay time increases, recovery potential decreases. The model estimates that a 12-hour delay would reduce total oil recovery by approximately one-third. A 12-hour delay means that 12 hours elapse between the occurrence of the spill and the initiation of on-water recovery. For a tanker spill that occurs at twilight during the winter, it is quite possible that at least 12 hours could elapse before on-water recovery commences at daybreak, and even this would rely on mobilization to begin overnight. During the April 2015 English Bay fuel oil spill, 13 hours elapsed between the time the spill was first detected and reported (by a member of the public) and the time that the response contractors had completed booming around the vessel to contain the leaking oil at its source.

An 18-hour delay reduces modeled oil recovery by 44%. In reality, delays of this length can result from a range of factors, including delayed spill detection. For example, there was a 17-hour delay in detecting the 2010 Enbridge Line 6B diluted bitumen spill into the Kalamazoo River. Once detected, additional time elapsed before any on-water recovery was attempted, during which time the oil was transported downriver, stranded on riverbanks, and sunk into river sediments (NTSB, 2012).

A 24-hour delay cuts overall recovery estimates in half. A 24-hour delay may result from a response gap period (environmental factors exceed operating limits for spill response systems). As discussed in Section 2, there are often periods of 24 hours or longer, particularly during winter, when environmental conditions along the tanker route would preclude on-water recovery operations. If the delay were to last for 48 hours, the model estimates that total recovery would be reduced by 83%. It is not uncommon for oil spills to occur during extreme weather, and in such cases, response gap delays may last for 24-48 hours, or even longer. For example, during the 2004 *Selendang Ayu* incident in Alaska's Aleutian Islands, the same severe storm that caused the freighter to break up and spill approximately 1,325 m^3 of fuel oil also prevented any on-water recovery operations. All of the oil recovered from that spill was cleaned up off of beaches after they had already been impacted by the spill (Brewer, 2005).

Figure 3.8 summarizes the model outputs for the Outer Harbour summer scenario with no delays and the sensitivity analyses for response delays.

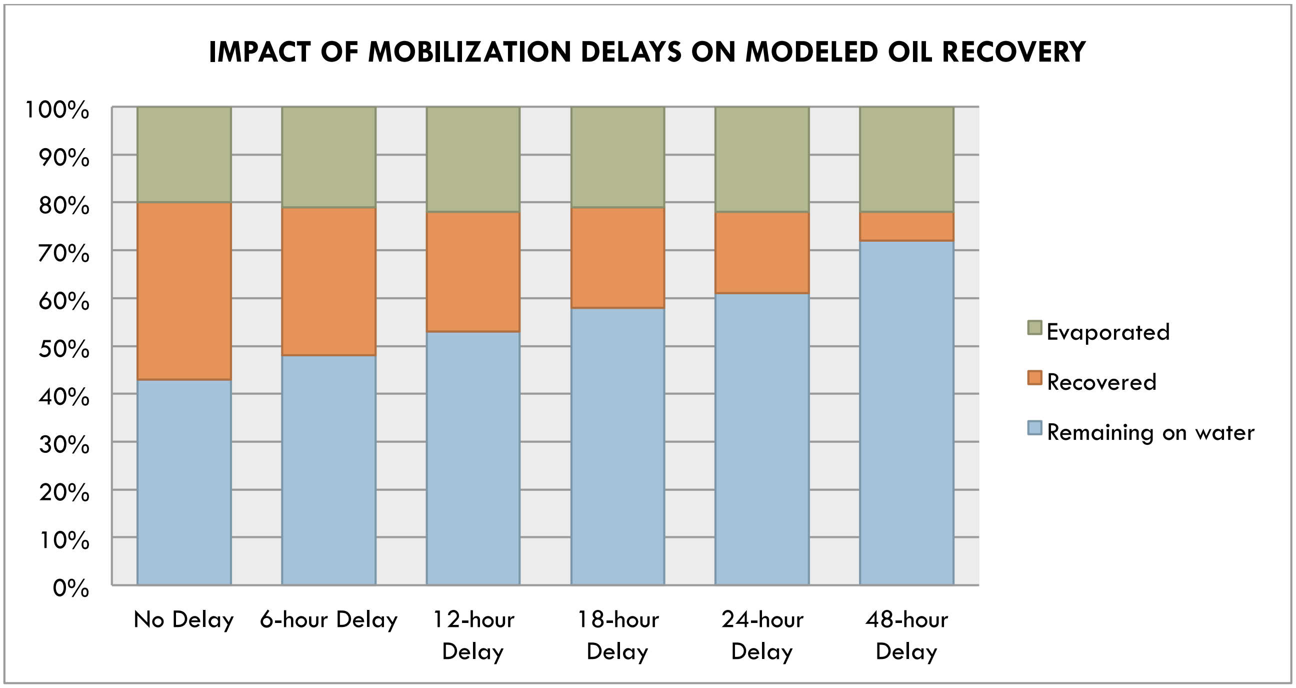


FIGURE 3.8. EFFECT OF RESPONSE DELAYS ON MODELED OIL RECOVERY FOR OUTER HARBOUR SUMMER 16,000 M³ SPILL SCENARIO

Figure 3.8 shows how the mass balance of oil recovered, evaporated, and remaining on water changes with each delay scenario for an Outer Harbour summer spill. Recovery amounts are significantly lower when recovery starts later in the spill, because the slick becomes thinner and more difficult to recover. These modeled estimates illustrate the importance of initiating recovery as soon as possible.

Figure 3.9 graphs the modeled reduction to oil recovery based on length of response delay.

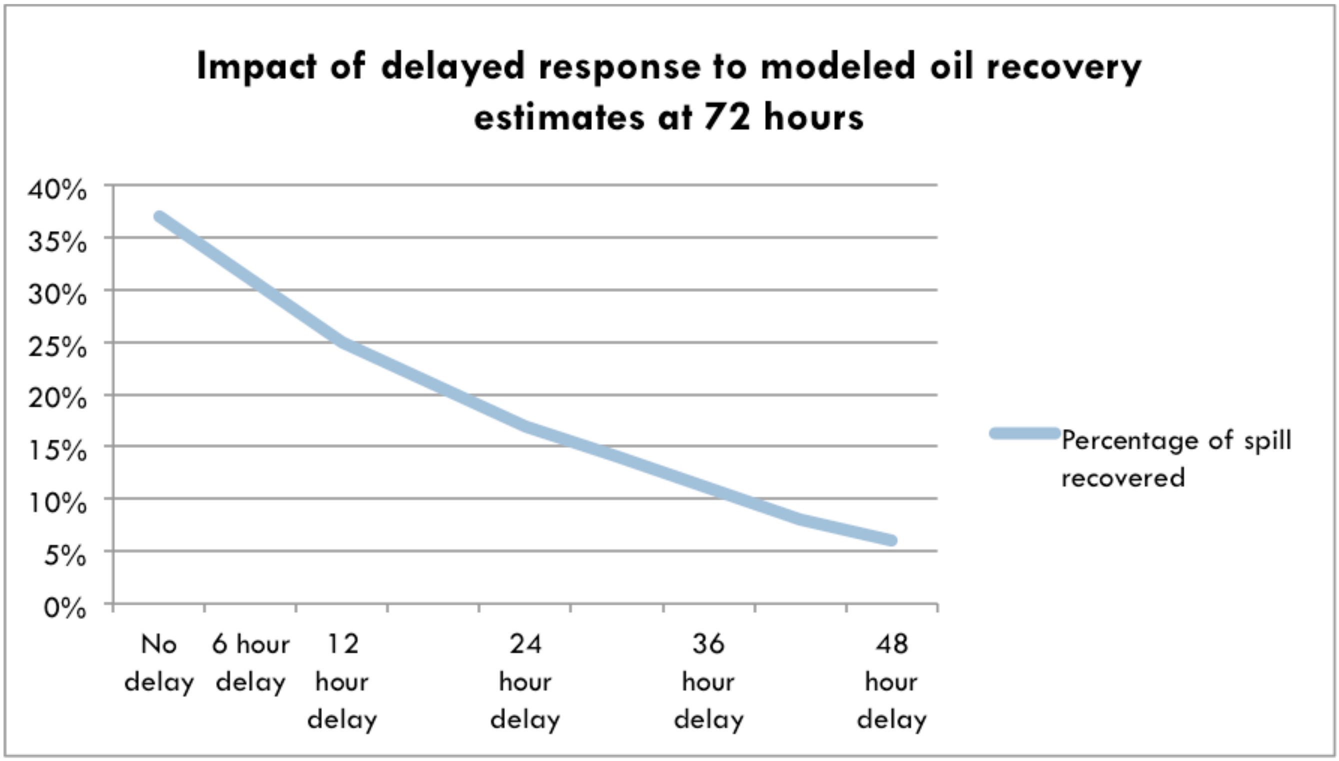


FIGURE 3.9. IMPACT OF RESPONSE DELAYS ON OIL RECOVERY ESTIMATES (OUTER HARBOUR SUMMER SCENARIO)

Figure 3.9 shows how the total oil recovery percentage decreases as the mobilization delay increases. In the baseline spill, 37% of the total spill volume (5,843 of 16,000 m^3) is recovered. A 24-hour delay reduces recovery to 17% (2,747 of 16,000 m^3), and a 48-hour delay reduces total recovery to just 6% of the original spill volume (1,022 of 16,000 m^3). This reduction reflects the fact that on-water oil spills quickly spread, weather, and strand over the first 48 hours.

3.3.4 Sensitivity of Response Capacity to Response Force Composition

Three different categories of response forces were included in the base scenarios: existing, proposed, and additional supplementary. Of these three tiers, only the existing forces are in place at the present time. All of the response capacity estimates presented thus far reflect the combined capability of existing resources supplemented by equipment and vessels that are described in the project application but which have not been purchased or stockpiled.

To evaluate the impact to recovery estimates from adding or removing response forces, sensitivity analyses were run for the Outer Harbour summer spill and for summer and winter spills at Haro Strait and Race Rocks to compare estimated 72-hour recovery for all forces to estimated recovery by current forces only. Table 3.7 presents the results of the sensitivity analysis.

TABLE 3.7. INFLUENCE OF RESPONSE FORCES ON 72-HOUR ON-WATER RECOVERY ESTIMATES FOR SELECT SCENARIOS

Scenario	Summary	Oil Recovered (72 hours)	Spill Volume Recovered (%)	Oil Remaining on Water (72 hours)	Spill Volume Remaining (%)	Percent change in total recovery	
						Reduction from All to Current	Increase from Current to All
OH-S **Baseline**	Outer Harbour Summer – All	5,843 m^3	37%	6,804 m^3	43%	n/a	n/a
OH-S-C	Outer Harbour Summer – Current	3,210 m^3	20%	9,404 m^3	59%	**-45%**	**182%**
HS-S **Baseline**	Haro Strait Summer – All	6,883 m^3	43%	5,806 m^3	36%	n/a	n/a
HS-S-C	Haro Strait Summer – Current	3,100 m^3	19%	9,524 m^3	60%	**-55%**	**222%**
HS-W **Baseline**	Haro Strait Winter – All	3,588 m^3	22%	9,153 m^3	57%	n/a	n/a
HS-W-C	Haro Strait Winter – Current	1,494 m^3	9%	11,196 m^3	70%	**-58%**	**240%**
RR-S **Baseline**	Race Rocks Summer – All	4,266 m^3	27%	8,248 m^3	52%	n/a	n/a
RR-S-C	Race Rocks Summer – Current	2,006 m^3	13%	10,471 m^3	65%	**-53%**	**213%**
RR-W **Baseline**	Race Rocks Winter – All	2,585 m^3	16%	10,040 m^3	63%	n/a	n/a
RR-W-C	Race Rocks Winter – Current	1,315 m^3	8%	11,289 m^3	71%	**-49%**	**197%**

Table 3.7 shows the recovery estimates for baseline spills, which were estimated based on the assumption that all spill response forces proposed or additional supplementary in the Trans Mountain Expansion project application are in place and strategically positioned throughout the region. The model outputs for the baseline spills are compared against modeled spills that apply only current, existing forces to the spill scenarios. The changes to total modeled oil recovery estimates are presented both in terms of the *reduction* to estimated oil recovery when the modeled forces change from all forces (current, proposed, additional supplementary) to current forces only, as well as the *increase* to estimated oil recovery that results from adding the proposed and additional supplementary forces into the model.

Figure 3.10 shows that for all sites, response capacity in place today, with existing WCMRC on-water recovery resources, is significantly lower than the future capability modeled in the baseline scenarios.

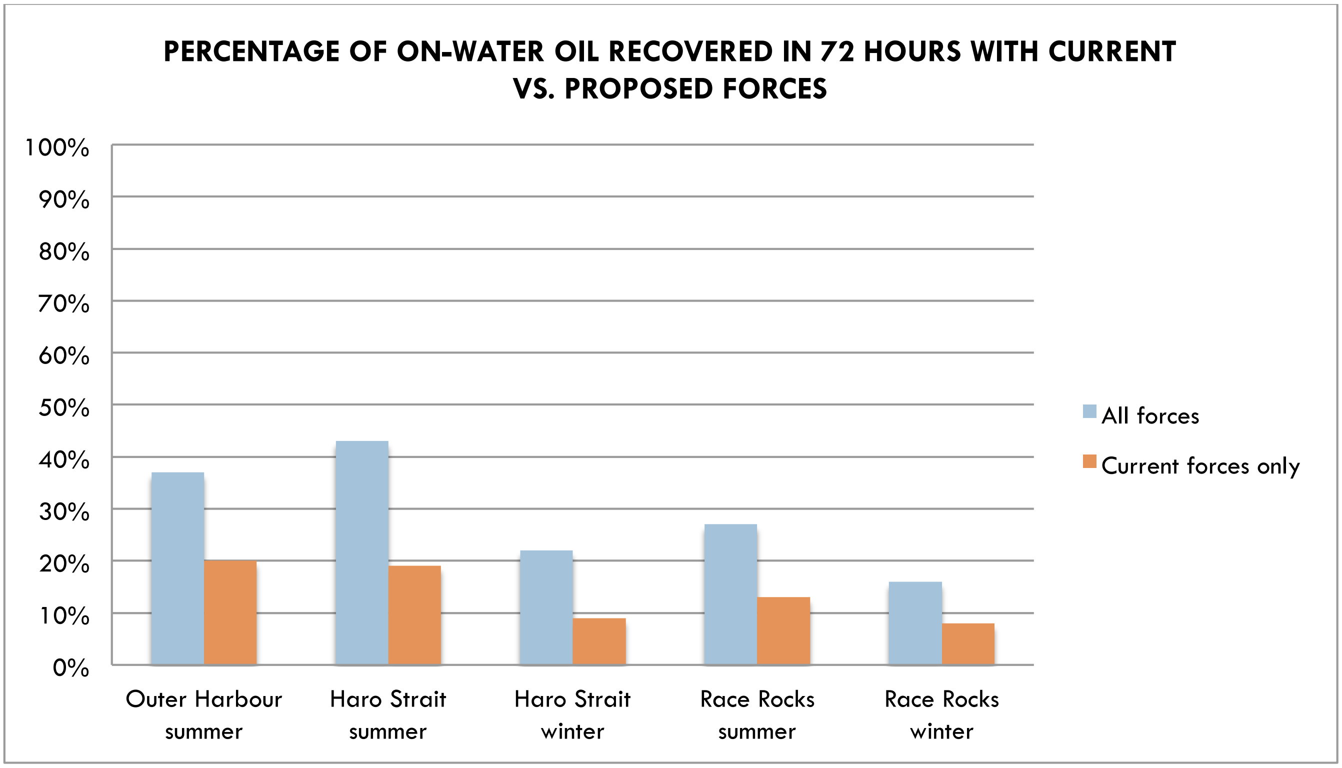


FIGURE 3.10. IMPACT OF FORCE COMPOSITION ON ESTIMATED OIL RECOVERY

The Response Options Calculator model estimates that current forces have the capacity to recover (during the first 72 hours) 20% of a 16,000 m^3 spill in the Outer Harbour under average summer conditions, compared to 37% recovery estimate for all forces. Removing the proposed and additional supplementary forces from the model reduces overall recovery by 45%.

The most striking difference occurs for a Haro Strait winter scenario, where the model shows that the on-water recovery estimates for the first 72 hours is reduced by 58% (from 22% to just 9%) when proposed and additional supplementary forces are removed and only existing forces included in the model. The summer scenario at Haro Strait is also significantly impacted when the model is run using only current, existing forces. In that case, recovery drops from 6,883 m^3 to 3,100 m^3, for a 55% reduction in recovery.

At the Race Rocks scenarios, removing the proposed and additional supplementary forces reduces recovery capacity by 53% in summer and 49% in winter; the addition of proposed and additional supplementary forces to the model increases the predicted recovery by 113% in summer and 97% in winter. Current response forces have an estimated capacity to recover (in 72 hours) only 13% of a 16,000 m^3 Race Rocks oil spill in summer and 8% in winter.

This sensitivity analysis shows that the inclusion of proposed and additional supplementary forces in the baseline scenarios significantly increases the modeled oil recovery estimates at all locations. If this response capacity analysis were performed with current forces as the baseline, recovery estimates would be reduced by between 45% and 58%.

3.3.5 Sensitivity of Response Capacity to Night Operations

> ***"Regardless of the technology for finding and identifying thick oil at sea at night, there are strong feelings among industry and regulatory groups that night operations should not be encouraged… In addition to the difficulties of working at night is a series of other issues that must be overcome to proceed safely: limited lighting on deck; problems associated with finding and staying in oil; requirements for a second shift of responders and their food and berthing needs; and the reduced ability to respond to man overboard situations."***
>
> *EDRC Project Final Report*, prepared for the US Bureau of Safety and nvironmental Enforcement by Genwest Systems, Inc.

Night operations are not a regular practice for on-water oil spill response because of reduced efficiency and increased risk to responders (Genwest Inc., 2012b). Oil spill response operations during darkness require an additional level of safety and logistics planning. The project application cites night operations as a practice that would be employed to enhance oil spill response capabilities (Kinder Morgan, 2013a). To evaluate the potential for increases to overall recovery from 24-hour operations, a sensitivity analysis was run for night (darkness) operations at the Outer Harbour summer scenario.

Table 3.8 compares modeled oil recovery for an Outer Harbour summer scenario with and without night operations.

TABLE 3.8. INFLUENCE OF NIGHT OPERATIONS ON 72-HOUR ON-WATER RECOVERY ESTIMATES FOR OUTER HARBOUR SUMMER SCENARIO

Scenario	Summary	Oil Recovered (72 hours)	Spill Volume Recovered (%)	Oil Remaining on Water (72 hours)	Spill Volume Remaining (%)	Percent increase in total recovery volume (night operations)
OH-S Baseline	**Outer Harbour Summer Daylight Only**	5,843 m^3	37%	6,804 m^3	43%	n/a
OH-S-N	**Outer Harbour Summer Night (Darkness) Operations**	7,385 m^3	46%	5,277 m^3	33%	**26%**

The sensitivity analysis for night operations shows that the total volume of oil recovered for the Outer Harbour summer spill increases by approximately 26% when forces are modeled to operate – at reduced efficiency – 24 hours a day.[36] While night operations have the potential to improve total oil recovery, it is important that adequate training, equipment, and personnel resources are in place for its safe and effective execution. While response organizations in some high latitudes do practice spill response during darkness, particularly for on-land spills, there is some disagreement among experts as to the safety and advisability of night operations on water. (Genwest Inc., 2012b). During the April 2015 English Bay spill response, there were reportedly some night operations conducted, although these are believed to have been limited to recovering

[36] Reduced efficiency results from the fact that operations take more time at night due to slower travel speeds and additional safety measures. In order to realize 24-hour operations, time must be built in for equipment down-time and maintenance. The model assumes two hours of down-time per 24 hours, which is the absolute minimum time required for daily maintenance and repair of recovery systems. During other scenarios, this activity is assumed to occur at night. During 24-hour operations, one hour each of shutdown is assigned to the beginning and end of the night shifts. This is done to optimize totally recovery, by preferentially lowering the amount of time available for the less efficient night recovery, rather than cutting into daylight recovery periods.

oil from within the containment boom around the vessel (Wright, 2015b). There is no documentation to indicate that on-water skimming of oil outside the vessel containment boom was attempted or achieved during darkness.

Figure 3.11 compares modeled oil recovery for daylight only and 24-hour operations.

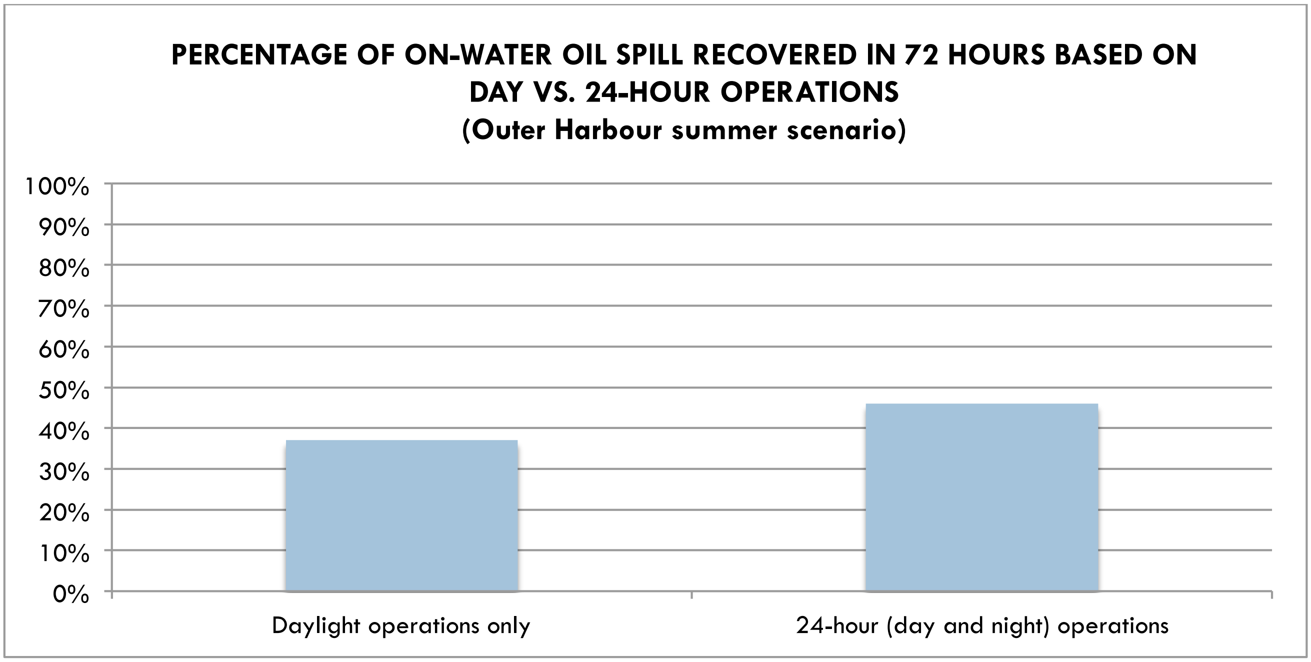


FIGURE 3.11. IMPACT OF DAYLIGHT ONLY COMPARED TO 24-HOUR (DAY AND NIGHT) OPERATIONS ON ESTIMATED OIL RECOVERY

3.3.6 Impact of Shoreline Stranding to Oil Recovery Estimates

A significant constraint of the Response Options Calculator model is the inability to account for oil that strands on shorelines. When an oil spill occurs in coastal areas, there is the potential for the slick to move toward shorelines, where the consequences of coating or toxicity may be high for intertidal or other coastal species and where at least some of the oil will become stranded, or trapped in the shoreline rocks, plants, and sediments (Short, 2015). Once oil is stranded on the shore, it is difficult and resource intensive to remove, and the removal operation may have associated impacts on species and habitat as well. The amount of oil that strands is influenced by the oil viscosity, shoreline type, and amount of energy that drives the oil toward the shoreline in the first place (wind speed and direction and tidal cycle). Different types of shoreline have differing holding capacities for stranded oil – in some cases, it may be permanently trapped onshore and therefore unavailable for on-water recovery. In other cases, some of the oil may remobilize back into the water, although the addition of sediments and debris may cause the oil to submerge or sink, so it may not be available to on-water skimming. (NAS, 2003)

The potential for shoreline stranding in the scenarios modeled for this analysis varies. Stochastic scenario modeling conducted for the Burrard Inlet showed that a substantial amount of oil was stranded on shorelines (between 50% and 90% for all cases) (Genwest Inc., 2015). Oil spilled at any of the five response capacity scenario sites modeled in this study could potentially strand along shorelines, to various degrees. Oil spills at either of the two Burrard Inlet sites – Central and Outer Harbour – are highly likely to strand.

The impact of shoreline stranding on the Response Options Calculator model outputs would be twofold:

1. **Stranding significantly reduces total oil recovery estimates.** Shoreline stranding reduces the total volume of oil available for on-water recovery. This would reduce total recovery estimates and result in a higher percentage of oil impacting the coastline.
2. **Stranding reduces the duration of on-water recovery.** In the most significant cases modeled, up to 50% of the oil had stranded by 24 hours, and up to 90% by 48 hours (Genwest Inc., 2015). This means that by 48 hours into the response, on-water recovery would be ineffective, thus shortening the response duration from the 72 hours used in this study.

While the Response Options Calculator model does not have the capacity to incorporate the effects of stranded oil on overall recovery estimate, Figure 3.12 provides a conceptual illustration of how oil stranding might impact the oil recovery estimates.

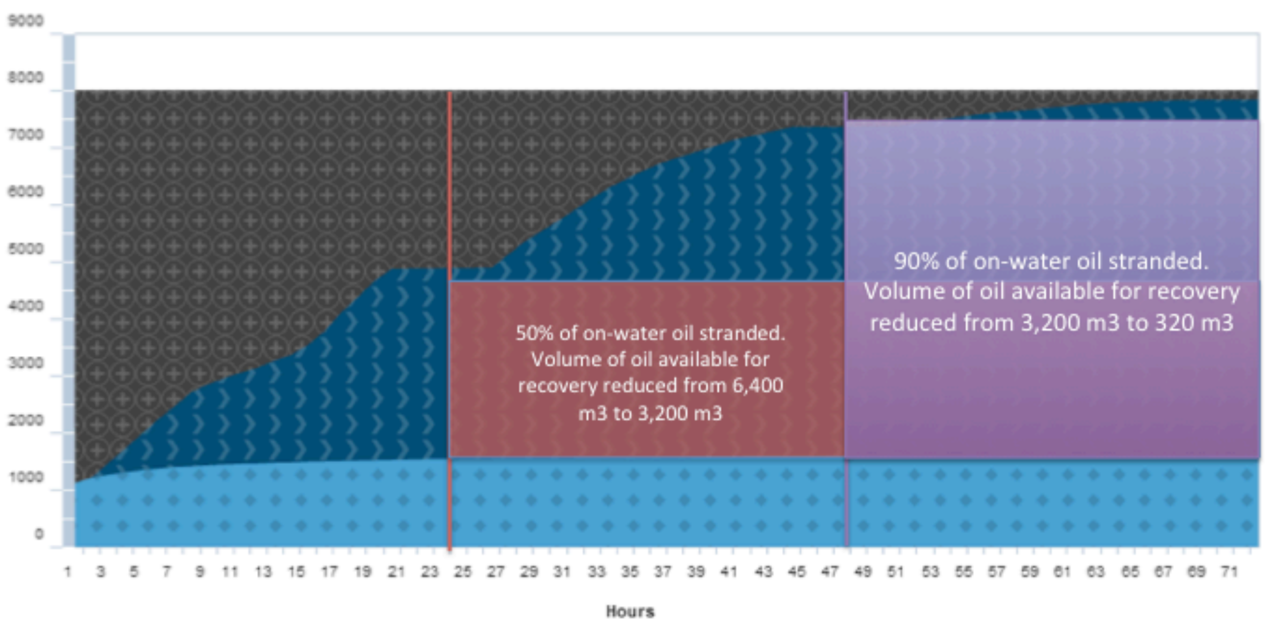


FIGURE 3.12. ILLUSTRATION OF POTENTIAL FOR OIL STRANDING TO REDUCE ON-WATER OIL RECOVERY

Figure 3.12 shows the output graph for the summer scenario at Central Harbour, in which the model estimated 78% of the 8,000 m^3 oil spill – 6,235 m^3 – would be recovered in 72 hours (another 20% would evaporate, and 2% would remain on-water at the end of 72 hours). However, if the wind and tide conditions favoured high stranding, then recovery potential would decrease and the recovery estimates generated by the model would not be possible.

Stranding oil significantly reduces the amount of oil available for on-water recovery. The red box that is overlaid on the model output graph shows 50% of the oil stranding at hour 24, which would reduce the total volume available for recovery from 6,400 m^3 to 3,200 m^3.[37] At hour 48, if 90% of the on-water oil stranded, the volume available for recovery would be further reduced from 3,200 m^3 to 320 m^3.

[37] The starting balance of oil on-water is 6,400 m^3 because 20% of the 8,000 m^3 spill (1,600 m^3) evaporates.

3.3.7 Challenges to Mechanical Recovery of Diluted Bitumen

> ***"We can predict that dilbit will weather (undergo physical and chemical changes) rapidly, becoming very dense and possibly sinking in a matter of days."***
>
> *As Oil Sands Production Rises, What Should We Expect at Diluted Bitumen (Dilbit) Spills?*
> US National Oceanic and Atmospheric Administration Office of Response and Restoration
>
> ***"This study has shown that differences in the chemical composition of various diluted bitumen products can influence their fate and behavior, including their propensity to sink following their release into marine and estuarine environments."***
>
> *Flume tank studies to elucidate the fate and behavior of diluted bitumen spilled at sea.*
> Marine Pollution Bulletin (2014), in press

Diluted bitumen, the project oil for the Trans Mountain Expansion project, is created when bitumen, an extremely heavy oil which has properties similar to an extensively weathered crude oil, is combined with gas condensate so that the product can be transported through pipelines (Short, 2015). Like any petroleum product, diluted bitumen undergoes a series of physical and chemical changes when it is released to a marine or fresh water environment. These changes include increased density and viscosity. Increased density may cause the oil to submerge or sink, and increased viscosity may cause the oil to be extremely difficult to process through skimmers, pumps, and hoses. Either factor may reduce on-water recovery efficiency significantly or preclude it altogether.

3.3.7.1 SINKING OR SUBMERGENCE

The on-water mechanical recovery systems presented in this analysis represent industry standard technologies for oil spill response. All rely on skimming technology that encounters oil slicks floating on the water surface. In order for these systems to work, the oil must remain as a floating oil slick for the duration of the 72-hour recovery period. Diluted bitumen has been the subject of significant recent study to determine the parameters under which this product may submerge or sink in waters of varying salinities (Short, 2015; King et al., 2014; Environment Canada et al., 2013; S.L. Ross, 2012).

Even if the oil submerges a few millimeters below the water surface, it becomes difficult to impossible to recover using oil skimmers, which require a layer of floating oil. Therefore, it is not necessary for the oil to sink to the bottom to halt on-water mechanical recovery; it must only submerge far enough below the surface to render oil skimmers ineffective.

A number of factors influence the potential for oil to submerge or sink, including density relative to seawater, physical agitation of oil molecules in the surface layer of the water (wave or turbulent energy driving oil droplets below the water surface), and incorporation of sediments or particulate matter that would make the oil heavier than the water. Therefore, diluted bitumen buoyancy will tend to be lower and submergence or sinking more likely during conditions of low salinity (river or estuarine environments or fresh water plumes/lenses), high turbidity or wave energy, or when the oil comes into contact with particulate matter suspended in the water column or in shoreline or riverbank sediments (Short, 2015).

While the Response Options Calculator model used in this analysis includes a basic oil weathering model, the model does not have the ability to factor in potential oil submergence or sinking because it doesn't estimate the density relative to the water in which the oil is spilled. If the model had the ability to incorporate oil submergence, it would result in a hard stop to recovery operations. Oil spills from the Trans Mountain pipeline or tankers that occur under certain conditions may sink in as little as 24 hours after the release (Short, 2015); if this were the case, then the total volume of oil recovered would be reduced.

3.3.7.2 VISCOSITY LIMITS

The Response Options Calculator model outputs include several different measurements of how the oil changes chemically and physically throughout the 72-hour simulated oil spill. While these outputs do not include density, which would be the most obvious indicator of potential submergence or sinking, they do include viscosity changes. Like density, diluted bitumen viscosity (the "stickiness" of the oil) also increases as the oil weathers. Figure 3.13 shows an example of the viscosity curve for Cold Lake Blend diluted bitumen (based on oil properties from S.L. Ross, 2012).

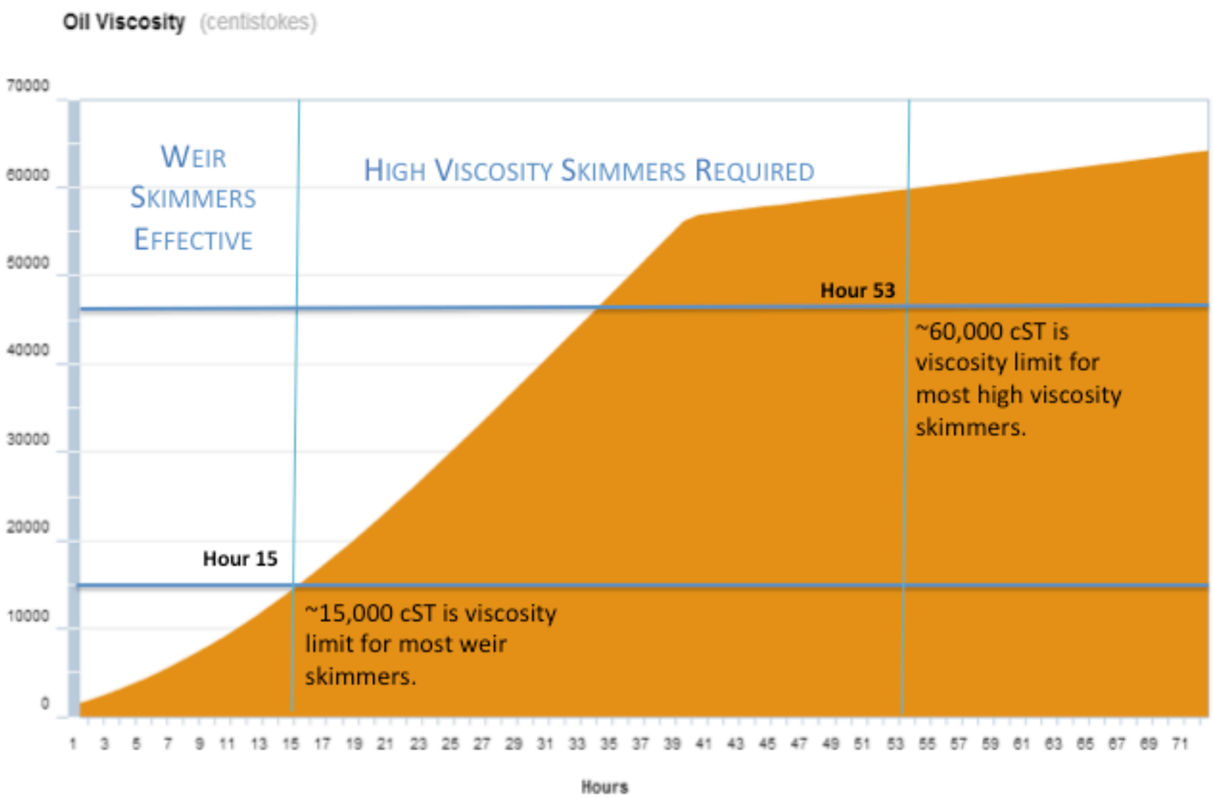


FIGURE 3.13. VISCOSITY GRAPH (GENERATED FROM ROC MODEL) FOR COLD LAKE BLEND DILUTED BITUMEN WEATHERING OVER 72 HOURS

Figure 3.13 shows, in orange, how the Cold Lake Blend diluted bitumen viscosity quickly increases upon release (Outer Harbour summer baseline spill). The oil as transported in the pipeline and tankers has a viscosity of 350 centistokes (cST). Upon release, this quickly increases, and within 15 hours of the spill, the viscosity has increased to 15,000 cST, which is the upper limit for most conventional weir skimming systems. Above this viscosity, certain types of skimmers that are not designed specifically for high viscosity oil may no longer function effectively to recover the diluted bitumen. The viscosity increase continues, and by hour 53 it has reached 60,000 cST, which is the upper limit for most skimmers that are designed to process viscous oils. As the oil viscosity continues to climb beyond hour 53, it may become too sticky to be recovered with skimmers and pumps.

The equipment inventories included in this analysis do include some skimmers that would be effective in oils up to 60,000 cST viscosity, but beyond that limit, it is uncertain whether they would continue to function and, if so, at what efficiency. The rapid changes that this oil undergoes when spilled means that equipment that may be effective at recovering the oil during the first 15 hours may be less efficient or totally inefficient by 48 or 60 hours. This is an important consideration in evaluating overall response capacity. The limits to equipment function due to oil viscosity are not explicitly modeled in the Response Options Calculator; therefore, recovery estimates do not account for efficiency losses if oil viscosity exceeds skimmer and pump operating parameters.

3.4 Discussion

3.4.1 Use of Response Options Capacity Model to Estimate Recovery Capacity

This response capacity analysis models various oil spill scenarios in order to evaluate and compare oil recovery estimates under a range of conditions. The Response Options Calculator model is well accepted as an oil spill planning and preparedness tool,[38] and its application in this analysis provides a semi-quantitative method to analyze oil spill response capacity and explore how changes to spill response infrastructure and planning may impact response capacity. Figure 3.14 shows conceptually how the recovery estimates generated by the Response Options Calculator (ROC) model represent a best-case outcome.

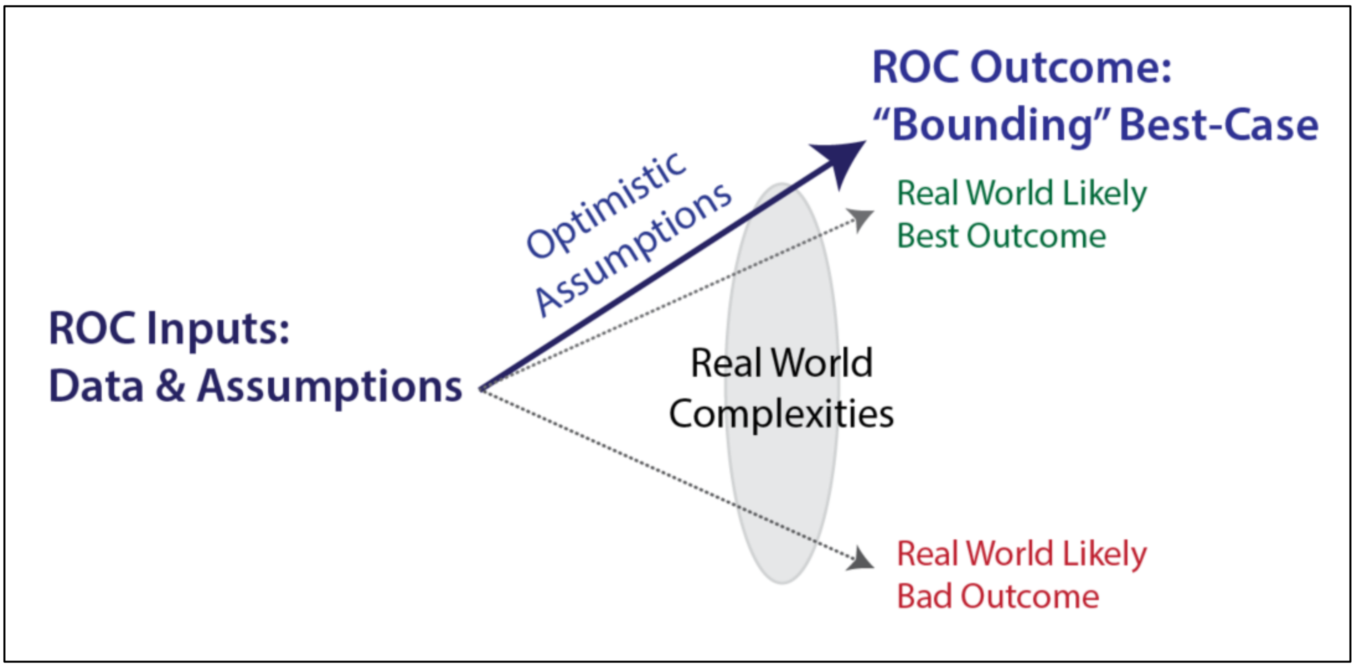


FIGURE 3.14. CONCEPTUAL DIAGRAM SHOWING INFLUENCE OF OPTIMISTIC ASSUMPTIONS IN RESPONSE OPTIONS CALCULATOR MODEL (FROM MATTOX ET AL., 2014)

Figure 3.14 illustrates how the recovered oil volumes estimated by the model represent a best-case estimate of oil recovery capacity under favourable conditions. Like all models, the Response Options Calculator uses a series of algorithms to mimic complex processes and interactions. A series of consistently optimistic assumptions are applied throughout the model. None of the real-world complexities that can slow or complicate oil spill response logistics – such as equipment malfunctions or human error – are represented in the

[38] In fact, there is a proposed rulemaking underway in the US that would apply a similar modeling tool for the purpose of oil spill contingency planning (BSEE, 2014).

scenarios. The model does not incorporate the potential for oil to submerge, sink, strand on beaches, or become too viscous to recover. The oil spill response equipment and resources modeled for all of the baseline spills in this study include assets that have been proposed in the Trans Mountain Expansion project application, but which do not presently exist in inventory. Thus, the oil recovery volume estimates presented in this study are high and should not be considered as a performance standard or prediction of actual recovery during a spill.

While the modeled recovery estimates in this study are consistently high and therefore of limited value as *absolute* estimates, the modeled recovery estimates provide insight into the *relative* impact of various response parameters to overall recovery. By holding other values constant and changing a single parameter – as in the sensitivity analyses presented in Section 3.3 – it is possible to quantitatively evaluate the significance of specific changes to the overall recovery efficiency. These observations directly inform the understanding of response capacity and may be used to guide decisions regarding equipment stockpiles, distribution of forces, and mobilization planning.

3.4.2 Personnel Required to Support On-Water Recovery Operations

The task forces included in this analysis require a minimum number of appropriately trained personnel for each operating period, with adequate backup to allow for contingencies in availability, days off, rest periods, etc. Table 3.9 provides a rough tally of the minimum number of personnel that would be required to support the existing, proposed, and additional supplementary response forces as configured. These personnel only include those directly involved in on-water oil recovery and storage and do not include ancillary operations such as support vessel crew,[39] vessel crew to shuttle responders to and from sites, shore-based responders, heavy equipment operators, or spill management personnel.

This conservative estimate indicates that approximately 67 field personnel, including vessel operators, skilled responders, and general technicians, would be required to support an on-water response with *current* forces.[40] The total number increases to 181 when proposed and additional supplementary forces are included. All response personnel must have minimum training and certifications commensurate with their responsibilities.

[39] Additional vessels such as tugboats or supplementary workboats not explicitly listed in response force tally.

[40] These general personnel classifications are used for the purpose of analysis. Specific training requirements are established by WCMRC and Kinder Morgan.

TABLE 3.9. ESTIMATED MINIMUM RESPONSE PERSONNEL REQUIREMENTS TO SUPPORT FORCES MODELED IN THIS ANALYSIS

Response Forces	Minimum Personnel Requirements			
	Vessel Operators	Skilled Responders	General Technicians	Totals
Current	18	20	29	67
Proposed	15	18	27	60
Additional supplementary	24	6	24	54
Totals	**57**	**44**	**80**	**181**

3.5 Key Findings

The response capacity analysis for marine spill response highlights several important considerations when evaluating the on-water oil spill response capabilities and limitations for spills from the Trans Mountain Expansion.

3.5.1 Spill Response Capacity is Reduced in Winter

KEY FINDING: On-water oil spill recovery capacity is reduced during winter months by as much as 50% compared to summer.

The response gap analysis in Section 2 described how environmental conditions and, more broadly, seasonality, impact the opportunity to mount an oil spill response. These conditions also impact the effectiveness of a response, during times when operations are feasible.

On-water recovery estimates are lower for oil spills that occur during winter, because of shorter day length and seasonal wind patterns. Other factors not incorporated into this model – such as sea state – have the potential to further reduce on-water recovery during winter months.

Oil recovery estimates were lower for winter scenarios than for summer scenarios at all of the sites analyzed. The most significant difference was observed at Haro Strait, where the modeled oil recovery volume in winter was only half of the recovery estimate for summer. This suggests that a spill occurring during winter will be more challenging to control and recover, and a higher percentage of the spill volume is likely to remain in the environment.

3.5.2 Delays to Response Implementation Significantly Decrease Oil Recovery

KEY FINDING: If spill response were delayed for any reason – lags in detection, poor weather, equipment malfunction – the total volume of oil recovered would decrease significantly. The model shows that a 48-hour delay in responding to a 16,000 m^3 Outer Harbour spill would result in over 11,000 m^3 of oil left in the environment.

The baseline scenarios all assume favourable timing, which allows the first-arriving response forces to begin on-water recovery operations at first light following the spill. In reality, delays to spill detection and reporting are common and expected, and could result in a situation where responders are not mobilized and deployed immediately and consequently, the initial response operating period is shortened or missed altogether. To illustrate the impact of delayed mobilization and, therefore, delayed recovery operations, a series of sensitivity analyses were performed (Section 3.3.2).

A range of factors can cause response delays, including:

- delayed spill detection or notification;
- environmental conditions (as described in the response gap analysis);
- equipment malfunctions;
- transportation delays;
- personnel shortages; or
- responder safety issues (such as unsafe air quality in the spill location).

The window-of-opportunity to mechanically recover oil slicks on-water is brief; therefore, response timing is critical to overall recovery efficiency.

3.5.3 Shoreline Stranding Reduces the Volume of Oil Available for Recovery

Key Finding: The modeled response capacity estimates do not consider the potential for shoreline stranding. This may overestimate total recovery at all sites, and most significantly in Burrard Inlet where models show up to 90% of an oil spill stranding on the beaches.

A significant limitation of the Response Options Calculator model is the inability to consider the impact of location to overall recovery estimates. For the Burrard Inlet sites in particular, this means that the on-water recovery estimates do not consider the fact that the oil slick could reach the shoreline before on-water response forces encounter it. Once oil reaches the shoreline, it may become permanently stranded or it may be re-mobilized during a future tide cycle. Remobilized oil is typically weathered and may be in the form of a tarball or tar patty that cannot be recovered with a skimmer. It may also incorporate enough sediment to submerge or sink. In either scenario, the recovery potential is significantly reduced because the recovery period may be shortened and the oil may be unavailable to on-water forces.

3.5.4 Additional Response Forces Necessary to Achieve Recovery Estimates

KEY FINDING: The spill response forces currently available in Southern BC have the capacity to recover only 10-20% of a worst case oil spill under favourable conditions.

The baseline scenarios model the recovery efficiency for forces that include current equipment and resources in inventory, along with additional resources – proposed and additional supplementary forces – that represent a reasonable estimate of additional capability that would be added in Southern BC if the Trans Mountain pipeline expansion is approved. To illustrate the difference between this estimated future capability and current response capacity, a series of sensitivity analyses were performed. When the response capacity estimates in the baseline scenarios (current, proposed, and additional supplementary response forces) were compared against the capacity of existing forces only (See Table 3.10), the results showed that the modeled response capacity of existing forces did not exceed 20% of the total spill volume for any of the spills modeled, and was less than 10% at Haro Strait and Race Rocks.

Altering force composition has a more significant impact to recovery estimates for Race Rocks and Haro Strait scenarios. Both sites are geographically distant from the Metro Vancouver area, where most response forces are currently located. Because the proposed and additional supplementary forces were distributed, for the purpose of this model, more broadly across the area, they enhance overall recovery capacity significantly for these more remote sites.

It is clear from this analysis that the response forces proposed in the Trans Mountain Expansion project application (WCMRC, 2013) will enhance the total recovery capacity in Southern BC. Conversely, existing response capacity is estimated to recover a relatively low percentage of a worst case spill. This finding is supported by previous work conducted for the BC Ministry of Environment, which estimated the 72-hour recovery capacity of Canadian response forces to be just 5% for a hypothetical 10,000 tonne (28,316 m^3) crude oil spill at Juan de Fuca Strait (Nuka Research, 2013).

It is important to recognize that the authors made a number of assumptions and inferences about supporting equipment and capabilities in order to run the spill scenarios, including giving the benefit of the doubt in places where equipment inventories were vague or incomplete. More detailed planning for response force composition is critical, and field exercises that demonstrate on-water capabilities would help to ground truth these model results.

3.5.5 Force Distribution is Critical to Recovery

KEY FINDING: Current response forces are clustered in the Vancouver Port area, which reduces response capacity for other sites along the Trans Mountain tanker route.

The difference between on-water recovery capacity for existing response forces and future proposed response forces is attributable to both the quantity and the distribution of those forces. The location of home bases for response equipment caches impacts transit times to spill sites. As described in Section 3.4.2, delays in response force arrival can significantly reduce overall recovery estimates; therefore, the positioning of resources is critical to recovery potential.

In this analysis, the authors make assumptions about where proposed future response forces would be based, with the goal of distributing those forces to maximize recovery potential. This is illustrated by the more significant changes to recovery estimates for the Haro Strait and Race Rocks sites, when compared to the Outer Harbour site, when proposed future forces are removed from the capacity analysis. Current forces are concentrated in the Vancouver port region, and therefore most accessible to spills in the Central and Outer Harbour. The distribution of proposed forces shown in Figure 3.3 reflects the authors' assumption that future forces will be distributed to minimize transit distances to potential spill locations and therefore optimize recovery capacity.

3.5.6 Night Operations Questionable

KEY FINDING: Night operations require double the personnel and create significant safety risks that may not be justified by the modest improvement to oil recovery from 24-hour operations.

The baseline spill scenarios include daylight-only operations. This is one assumption that varies from the project application, because in the professional experience of the authors, on-water oil spill recovery operations are not typically undertaken in darkness.[41] A sensitivity analysis was conducted to evaluate how the addition of night time recovery during the Outer Harbour summer scenario would impact overall recovery estimates. A discounted efficiency was applied to night operations, to reflect the need for shift changes and down time associated with slower transit speeds and additional safety precautions. The model estimates showed that oil recovery increased from 37% of the spill volume to 46% with the addition of night operations (approximately 26% increase).

On-water night operations are not a common practice, and require a doubling of response personnel. The estimated personnel needs for the response forces modeled in this analysis are approximately 181 per shift to staff direct recovery forces. Night operations would double this to more than 360 responders with various levels of training required to man 24-hour hour operations during the first 72 hours of a response. If night operations continue to be part of the Trans Mountain oil spill contingency plan, it will be necessary to ensure that adequate trained personnel are available to support the increased personnel requirements.

"Although it may be possible to recover oil already collected and contained in a boom, it is not possible with the state of the art to continue offshore oil clean-up operations at night."

S.L. Ross Environmental Research Limited Report to National Energy Board
Spill Response Gap Study for the Canadian Beaufort Sea and the Canadian Davis Strait

3.5.7 Changes to Oil Properties May Reduce On-Water Recovery

Key Finding: Changes to diluted bitumen density and viscosity within the first few days of the release may render oil spill response systems ineffective.

The recovery estimates presented in this response capacity analysis all model oil recovery operations through the first three days (72 hours) after a spill occurs. The Response Options Calculator model assumes that oil remains floating and available to recovery throughout that period.

However, it is possible that the rapid physical and chemical changes to the oil properties may make it impossible for on-water mechanical recovery systems to recover oil well before the end of 72 hours. Density changes caused by rapid evaporation of the lighter components of the diluted bitumen combined with wave action or sediment interactions could make the oil heavier than the water, causing it to submerge or sink. Even

[41] The authors could not locate any examples of on-water oil recovery operations conducted during darkness in Southern BC.

a neutrally buoyant oil – one that is the same buoyancy as the surrounding waters – may be driven just below the water surface and therefore difficult to track and/or unavailable to skimming systems for recovery.

Diluted bitumen, when spilled, undergoes a rapid increase in viscosity (stickiness) that can make it very difficult to recover with some skimmer and pump systems. The characteristics of the oil may change so rapidly that by 15 hours after the spill occurs, it cannot be recovered with conventional weir skimmers. After just over two days, the oil may be so viscous that it cannot be recovered even by specially designed viscous oil skimming and pumping systems.

If either viscosity or density limits are reached, then on-water recovery operations will essentially cease. Oil that is not removed from the environment with mechanical skimming systems may impact wildlife and habitat, and oil that reaches shorelines will require clean-up.

4 RIVER RESPONSE LOGISTICS ANALYSIS

> **"Understanding the effects of cascading response equipment is an important component of oil spill planning and response. It is critical to understand both how long it takes for equipment to reach a particular location and to understand the gaps created when equipment is cascaded out of an area."**
>
> Conor Keeney, Washington State Department of Ecology
> *Cascading Response Equipment in Washington*

4.1 Overview

Sections 2 and 3 of this report apply modeling and analytical tools to examine oil spill response capabilities and limitations for marine spills from the Trans Mountain Expansion project. A third component of this study considers how response logistics influence the potential to control oil spills to the Lower Fraser River. Because the methods applied for response gap and response capacity analyses focused on the marine environment within the study area and are not readily transferrable to riverine environments, a different approach was applied. This riverine response logistics analysis applies a method derived from the oil spill response planning standards used by the Washington State Department of Ecology to assess river response capabilities (Keeney, 2014).

4.1.1 Approach

This riverine response logistics analysis is predicated on the concept that controlling the downriver transport of oil spilled into the Lower Fraser River will minimize the adverse impacts by reducing the linear distance of oiled riverbank and preventing the transport of oil into the Fraser Delta and marine waters. Avoiding or minimizing adverse impacts from oil spills to the Lower Fraser River and Delta is critical because of the high importance of this unique waterway. The Lower Fraser River has significant economic and ecological value to the City of Vancouver and the Tsawout and Tsleil-Waututh First Nations. The Fraser River delta is important local agriculture, provides critical habitat for fish and birds, and the entire Lower Fraser experiences high recreational and commercial use. (Richmond Chamber of Commerce, 2014)

A hypothetical spill scenario involving a pipeline rupture at the Fraser River crossing near the Point Mann Bridge is presented to illustrate potential travel rates and distances based on a range of flow rates. Oil response equipment transportation and mobilization timing is compared against downriver transport rates to identify minimum response times to mobilize, transport, and deploy equipment ahead of the leading edge of a river spill. This analysis uses a generic (unspecified) spill size and does not derive any volumetric response estimates. It does not make any assessments about likely success or failure of tactics deployed at each site; it only estimates the window-of-opportunity to deploy to various control points ahead of a migrating oil slick.

Figure 4.1 shows the study area for this analysis.

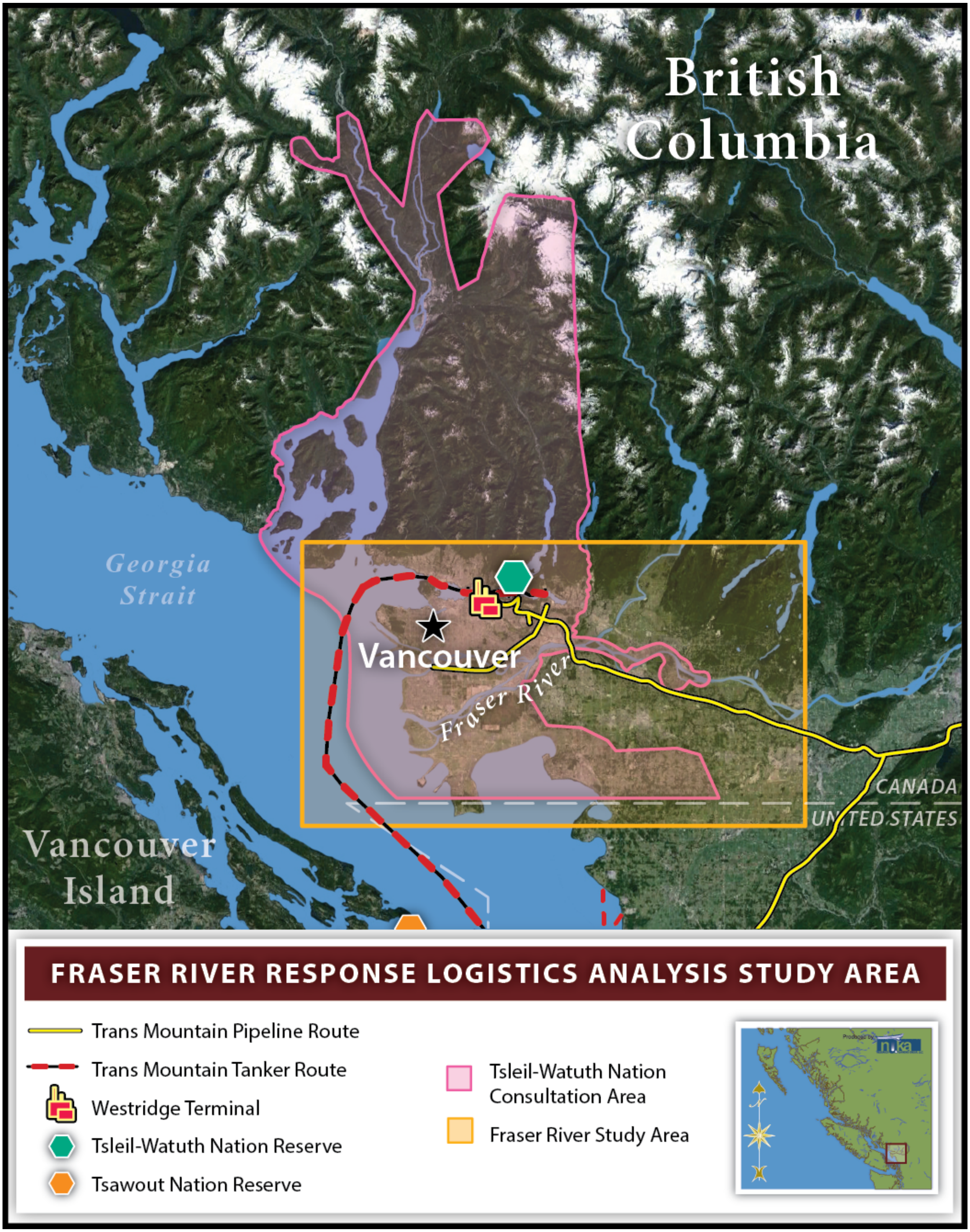


FIGURE 4.1 LOWER FRASER RIVER RESPONSE LOGISTICS ANALYSIS STUDY AREA

4.1.2 River Control Points

In the context of oil spill response, river control points describe strategic locations along a river system where resources such as containment boom, skimmers, and oil absorbent materials may be deployed to slow or stop the downriver migration of an oil spill. Tactical plans may be developed for pre-identified control points to show how much equipment would be needed and how it should be configured to contain or control oil. Control point planning usually takes into consideration shoreline access points, and control points are often selected based on access considerations for people, equipment, and vessels (UMRBA, 2010).

Booming strategies meant to slow or stop the flow of oil will be most effective if they can be deployed ahead of the leading edge of the oil spill. This means that response equipment must be loaded, transported to the control point, unloaded, and deployed. If spill control tactics cannot be deployed ahead of the spill, it may still be possible to mount recovery or clean-up operations from the control point for the duration of time during which oil continues to flow past that point. However, if these tactics are not effectively deployed ahead of the leading edge of the spill, then the spill will continue to migrate downstream and increase the area of contamination.

Figure 4.2 shows an example of a generic oil spill containment tactic that would likely be applied at a river control point (the solid black line is the boom). Even if response resources are transported and deployed at control points ahead of the oil slick, this does not guarantee that they will be effective in intercepting and controlling the migrating oil.

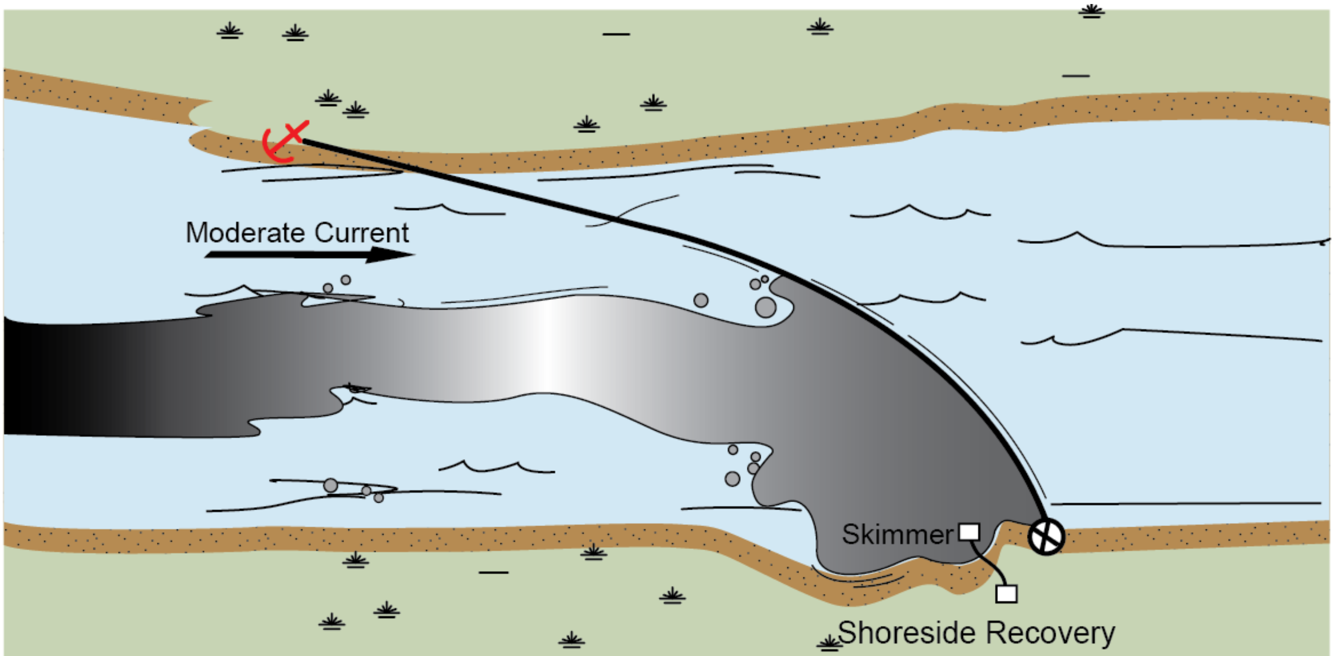


FIGURE 4.2 EXAMPLE OF OIL CONTAINMENT TACTIC FOR RIVER RESPONSE

Control point plans were not included in the Trans Mountain Expansion project application, so the authors relied on industry standard practice and best professional judgment to select river control points for this study. If control point plans were provided in the future, this analysis could be re-run to assess transit times and resource availability to support spill containment tactics.

4.2 Methodology

The methods applied in this analysis mimic the approach taken by regulators in Washington State to evaluate the readiness to respond to oil spills by calculating the travel time required for equipment to reach pre-identified locations (Keeney, 2014). This analysis considers whether it would be possible to deploy equipment at three control points before an oil slick from a spill from the Trans Mountain Expansion pipeline crossing at the Port Mann Bridge reaches each location.

The general process applied is:

1. Identify scenario locations, control points, and location and contents of oil spill response equipment caches.
2. Estimate downriver oil transport times from scenario location to control points.
3. Estimate equipment transport times from cache locations to control points.
4. Compare oil transport timing to equipment transport timing and interpret results.

4.2.1 Scenario Location and Control Points

This analysis presents a hypothetical spill from the Trans Mountain pipeline crossing at the Port Mann Bridge. Three control points in the Metro Vancouver region were identified at points downriver from the spill scenario release site, and represent targeted intercept areas where containment boom and skimmers could be deployed to stop or slow the spread of oil.[42]

- **Control Point 1** is located in Surrey/New Westminster just above the Lower Fraser bifurcation, at the location of Brownsville R.V. Park and the Patullo Bridge. It is roughly 6.5 km downstream from the Port Mann Bridge. The destination point for transit measurement is the parking area and boat ramp adjacent to the park.
- **Control Point 2** is located in Delta/Richmond just downstream of the George Massey tunnel, at a large-ship cove on the north shore of the main channel, South Arm, roughly 24 km below the Port Mann Bridge and 16 km above the river mouth. The north side of the river has riverbank access and various dock facilities. The destination point for transit measurement is a parking area adjacent to the shoreline. There is a boat launch at Captain's Cove Marina, on the south side of the river, and forces from Delta Port are dispatched to this location.
- **Control Point 3** is located in Richmond/City of Vancouver on the North Arm of the Lower Fraser River upstream of the Oak Street Bridge and downstream of the bikeway bridge. Boat launch access is via Galleon Marine. This location takes advantage of undeveloped industrial areas on the north side of the river and west tip of the island, and potentially the area of the south shoreline used in imagery to store log rafts.

Figure 4.3 shows the location of the hypothetical spill site and control points.

[42] The selection of control points is based on the authors' best professional judgment as practitioners of oil spill response geographic response planning with input from emergency response personnel from the City of Vancouver. While the project application indicates that Kinder Morgan has identified control points along the Fraser River, these were not identified in project application materials. However, Control Point 1 is identified Morgan as a strategic control point in materials not related to the project application. (Kinder Morgan, 2010)

FIGURE 4.3 LOCATION OF PORT MANN BRIDGE PIPELINE SPILL SCENARIO, CONTROL POINTS, AND EQUIPMENT CACHES USED IN ANALYSIS

4.2.2 Response Resource Caches

Figure 4.3 shows the location of the oil spill response equipment caches that were included in this analysis. Four response resource caches in three locations are identified in project application materials. Burnaby Forces (A in Figure 4.3) include Western Canada Marine Response Corporation (WCMRC) equipment at the Burnaby Warehouse and Kinder Morgan Oil Spill Containment and Recovery (OSCAR) trailers at the Westridge Terminal in Burnaby. Delta Port Forces (B in Figure 4.3) are WCMRC trailered equipment at Delta Port. Hope Forces, which are located approximately 150 km northeast of the study area and not shown on the map in Figure 4.3, consist of WCMRC trailered equipment in Hope. Table 4.1 lists the inventories of these assets, based on information provided in the project application.

TABLE 4.1 RESPONSE RESOURCES APPLIED IN RIVER ANALYSIS.

Location	Description	Boom (total feet)	Skimmers (total)	Skimmer Recovery Capacity[43]	Land Storage (bbl)	Floating Storage (bbl)	Work Boats
Burnaby	WCMRC Trailers	12000	9	3943	109	211	5
Burnaby	WCMRC Warehouse	13028	18	4066	169	491	2
Burnaby	OSCAR Trailers (Westridge)[44]	2050	unspecified	unspecified	unspecified	unspecified	
Delta Port	WCMRC Trailers	3400	none	none	none	none	none
Hope	OSCAR Trailers	750	unspecified	unspecified	unspecified	unspecified	1[45]

4.2.3 Travel Distances and Routes

Travel distances were estimated for road transit[46] using geospatial information systems. Driving routes were developed from each equipment cache to each control point using established truck routes.[47] Table 4.2 shows the travel distances for travel over land (roads) from each equipment cache. Appendix D shows the driving routes that were used to derive road travel distances from Hope, Burnaby, and Delta Port to the three control point locations.

[43] Skimmer effective daily recovery capacity (EDRC) is listed when known based on Western Response Resource List equipment listings at http://www.wrrl.us/. In some inventories, skimmer models are not identified and therefore EDRC could not be accurately derived.

[44] OSCAR trailers are described in 4.5.1 of Volume 7 of the project application; trailers are indicated to contain "skimmers" and "temporary storage" but detail is not specified (Kinder Morgan, 2013a).

[45] Hope has one response boat. It is not specified whether it is trailered or in the water.

[46] Over-water travel routes are not included.

[47] Emergency response personnel from the City of Vancouver helped to develop preferred travel routes based on local knowledge.

TABLE 4.2. TRANSIT DISTANCES APPLIED TO RIVER ANALYSIS

	Burnaby WCMRC	Burnaby Westridge	Delta Port	Hope
	Road Travel Distances			
Control Point 1[48]	16.1 km	17.7 km	34.1 km	133 km
Control Point 2	29.6 km	33.4 km	17.8 km	158 km
Control Point 3	23.4 km	2.3 km	26.3 km	161 km

4.2.4 Travel Times for Response Equipment

The amount of time required to move response equipment from a storage location to a containment point involves mobilization time to load equipment into trailers or trucks, travel time from the storage location to the control point, and setup time to unload equipment and deploy it on the river in the desired configuration.

Travel time estimates were derived from Google Maps and assume no traffic delays. As such, they represent a best-case estimate for travel timing during off-peak travel hours when road congestion is low. Traffic congestion in the Vancouver area can be significant, and the potential for traffic delays to impact response times is discussed later in this analysis (Tom Tom International BV, 2014). Table 4.3 shows road transit time estimates from each equipment location to each control point.

TABLE 4.3. ROAD TRANSIT TIME ESTIMATES (NO TRAFFIC DELAYS)

	Burnaby WCMRC	Burnaby Westridge	Delta Port	Hope
	Road Travel			
Control Point 1	0.43 hours	0.40 hours	0.45 hours	1.35 hours
Control Point 2	0.67 hours	0.62 hours	0.37 hours	1.75 hours
Control Point 3	0.57 hours	0.58 hours	0.38 hours	1.37 hours

Mobilization and deployment timing was calculated using standard mobilization timeframes, which are shown in Table 4.4, combined with the travel time estimates shown in Table 4.3. Mobilization times of one hour for trailered resources and two and four hours for warehoused resources are used for all estimates; two hours represents fairly rapid loading of warehoused equipment; four hours is a more conservative estimate.

One hour is allocated for on-scene setup of equipment. In order to achieve a one-hour set up, tactical plans would need to be in place already.

[48] To Brownsville State Park boat launch, roughly 1.5 km above Control Point 1.

TABLE 4.4. DEPLOYMENT TIMES BASED ON LOCATION, STORAGE, ROAD TRANSIT WITHOUT TRAFFIC, AND SET UP

Cache Location	Equipment Storage	Mobilization Time (hours)	Setup Time (hours)	Deployment Time Estimate (hours)		
				Control Point 1	Control Point 2	Control Point 3
Burnaby – WCMRC Warehouse	Trailer	1	1	2.4	2.7	2.6
	Warehouse	2	1	3.4	3.7	3.6
	Warehouse	4	1	5.4	5.7	5.6
Delta Port	Trailer	1	1	2.5	2.4	2.4
Burnaby - Westridge Terminal	Trailer	1	1	2.4	2.6	2.6
Hope	Trailer	1	1	3.4	3.8	3.4

Table 4.4 shows total road force transit time estimates in hours, which is the cumulative time required to mobilize, transport, unload and set up equipment. All of these estimates rely on very prompt and efficient operations with no delays.

4.2.5 Downriver Oil Transport Rates

This analysis uses Lower Fraser River flow rates as a proxy for downriver oil transport estimates. This approach represents a very simplified one-dimensional trajectory estimate and is not presented as a predictive model. Downriver transport of oil is, in fact, a complex and nuanced process that can vary significantly depending upon a number of factors including water levels, precipitation events, riverbank geomorphology, presence of debris or floating barriers, turbulence, current shear, wind, and many other variables (Overstreet and Galt, 1995).

In the Lower Fraser River, flow rates vary considerably based on location, season, precipitation, tidal influence, and other factors. An August 2014 drift card study released cards just downstream of the Port Mann Bridge and documented a 3.5 kph current in the main channel of the Fraser at the time of drop (Raincoast Conservation Foundation et al., 2014). Other published studies have cited the main channel currents in the Lower Fraser River as typically fluctuating between 0 and 9 kph, with extreme spring peak fast flows of 18 kph in isolated sections of the river (DNV, 2012).[49] Tidal influence is strong on the Lower Fraser, and it has been observed to extend through the spill scenario point, generating upriver flow at times (Kinder Morgan, 2010).[50]

For the purpose of this analysis, four oil transport rates were used to reflect a range of conditions: 2 kph; 4 kph; 8 kph; and 12 kph. Table 4.5 summarizes the downriver oil transport speeds used for each flow state at each control point, and at the Fraser Mouth. These values were selected for the purpose of this analysis to represent a range of flow conditions, and are not meant to represent a specific river condition or season.

[49] Current speeds are typically slower on the North Arm and in side channels, due to the smaller flow volume.

[50] Upstream tidal current can be strong at the spill site and control points. One card from the 2014 drift card study was found 12 km upstream of the drop point, in the Pitt River. Although an upstream control point is not analyzed, upstream control will need to be considered, particularly if a spill occurs during or at the start of a strong flood tide.

TABLE 4.5 TRANSPORT TIMES DOWNRIVER FROM PORT MANN SPILL SCENARIO TO CONTROL POINTS

River State (Downriver Oil Transport Speed)	Transport Rate	Control Point 1 (6.5 km)	Control Point 2 (24 km)	Control Point 3 (25 km)	Fraser Mouth (40 km)
Slow Flow (Slow Oil Transport)	Slackwater	No transport; not analyzed.			
	2 kph (1.1 kts)	3.3 hours	12.0 hours	12.5 hours	20.0 hours
Medium Flow (Medium Oil Transport)	4 kph (2.1 kts)	1.6 hours	6.0 hours	6.3 hours	10.0 hours
	8 kph (4.3 kts)	0.8 hours	3.0 hours	3.1 hours	5.0 hours
Fast Flow (Fast Oil Transport)	12 kph (6.5 kts)	0.5 hours	2.0 hours	2.1 hours	3.3 hours
	16 kph (8.6 kts)	0.4 hours	1.5 hours	1.6 hours	2.5 hours

Figure 4.4 shows the estimated downriver transport distances for pipeline spills that move at the river velocities shown in Table 4.5. The figure shows oil transport from between two and three hours from the time a pipeline spill occurs, with a focus on the location of the leading edge at 2.4 hours, since this is the shortest minimum mobilization and deployment time (Table 4.4).

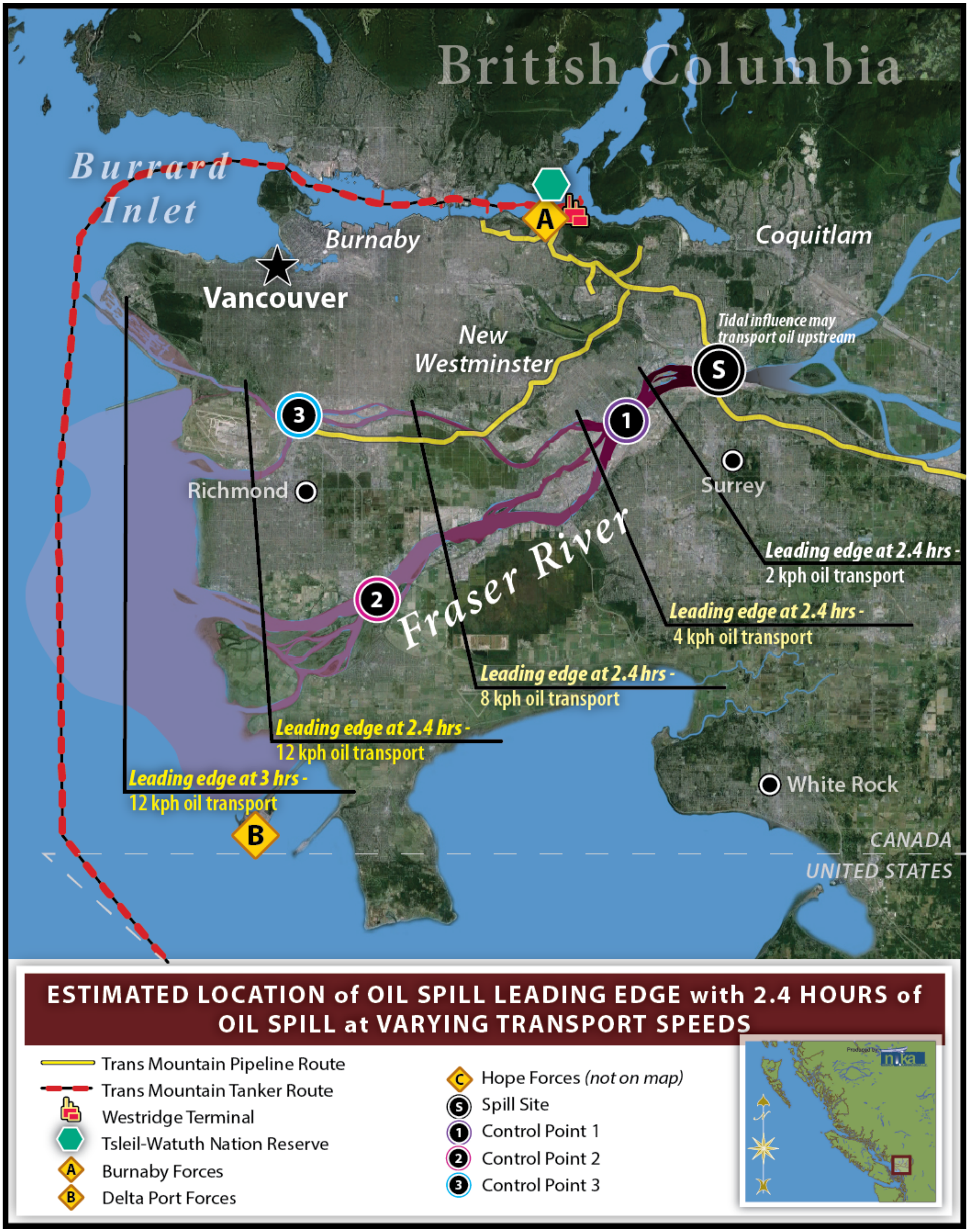


FIGURE 4.4. 3-HOUR OIL TRANSPORT DISTANCE ESTIMATES BASED ON AVERAGE FLOW RATES (SLOW, MEDIUM, AND FAST FLOW)

Figure 4.4 maps the downstream movement of the leading edge of an oil slick from a spill at the Port Mann Bridge. It illustrates how quickly the oil could reach each of the three Control Points under a range of transport speeds. At the slowest transport speed (2 kph), the leading edge does not reach any of the control points within 2.4 hours. At the moderate transport speeds (4 and 8 kph), the oil travels beyond Control Point 1 but does not reach Control Points 2 or 3. At the highest transport speed (12 kph), the leading edge of the oil travels past all three control points in 2.4 hours, and within 3 hours oil traveling at this speed would reach the Fraser Delta. Oil traveling downstream at any speeds higher than 12 kph will reach the delta in under 3 hours.

4.2.6 Assumptions and Limitations

This analysis is based on a series of assumptions that influence the outcome. They are an important consideration in interpreting results.

- **Travel time estimates reflect no-traffic situations.** The travel times used in this analysis assume that roadways are not congested and traffic is moving at posted speed limits. The potential for traffic delays to impact spill response mobilization and logistics is considerable, particularly for large trucks towing trailers full of response equipment. There is often heavy traffic in the Metro Vancouver region, and the result of heavy traffic would be an increased transportation time and a decreased opportunity to deploy spill countermeasures ahead of the leading edge of the spill.
- **Immediate spill detection is assumed.** The response logistics timing is measured from the time of spill occurrence, presuming that detection of the spill is instantaneous. Any delays to spill detection would push back the timeline and change the outlook considerably. Several recent pipeline spills in the US have involved detection delays – most notably, the 17-hour delay that elapsed between the time the Kalamazoo River diluted bitumen spilled occurred and when it was detected. Based on the analysis here, oil spilled at the Port Mann Bridge could reach the Fraser Delta within 3 hours.
- **All equipment in caches is assumed to be available.** The four major equipment caches considered in this analysis are located in three different regions along the pipeline route. This analysis assumes there are no restrictions to the movement of equipment from each cache to a spill anywhere along the route. In reality, some of the equipment in the Burnaby warehouse is reserved for the Westridge Terminal and may not be released in the event of a spill on the Lower Fraser River. Moving all of the equipment in the region to control points on the Lower Fraser River obviously leaves other areas vulnerable.
- **River flow is used as a direct proxy for spill movement.** For the purpose of this simplified analysis, river flow rates are used to approximate the rate of travel for an oil slick. In fact, the movement of an oil slick on the Fraser River may be influenced by a number of factors that may increase or decrease the rate of downstream transport.
- **The analysis does not consider the potential for oil to submerge.** This analysis considers the opportunity to deploy spill countermeasures ahead of the leading edge of an oil slick on the Lower Fraser River. The type of equipment in the caches listed in Table 4.4 is appropriate for containing and controlling floating oil only. An oil spill to the Lower Fraser River during high turbidity or high sediment load could result in some or all of the oil submerging below the water surface (Short, 2015). If oil spill response equipment reaches the containment point ahead of the leading edge of the slick, but the oil has begun to submerge or sink, then the containment countermeasures will not be able to intercept the oil, even if they arrive in sufficient time.
- **The ability to mobilize, transport, and deploy equipment ahead of an oil slick does not guarantee that the response tactic will be successful in containing or controlling the oil.** Like the response gap analysis presented in Section 2, this report focuses on the *opportunity* to conduct oil spill response operations. It considers whether sufficient time exists to transport and deploy equipment at specific control points ahead of an oil slick moving at different speeds. Even if equipment can be deployed in

time, there is no guarantee that the countermeasures will fully or even partially succeed in containing the oil slick.

4.3 Analysis

4.3.1 Response Mobilization Time Estimates

To estimate the amount of time required to mobilize response resources from the four regional equipment caches to control points along the Lower Fraser River ahead of the leading edge of a spill from the pipeline at the river crossing, the downriver oil transport velocities were compared against response equipment deployment time estimates. Three categories were used to describe the deployment timing:

- **Green** indicates that the estimated arrival time of response forces is more than one hour ahead of the oil, based on the fastest route of transport from one or more equipment caches. This represents the most favorable opportunity to deploy containment or control resources ahead of the spill.
- **Yellow** indicates that the estimated arrival time of response forces is ahead of the oil, but by less than one hour, based on the fastest route of transport. This means that it is possible to deploy containment or control resources ahead of the spill, with virtually no margin for error.
- **Red** indicates that the estimated arrival time of response equipment is concurrent with or after the oil reaches the control point. This would not allow for sufficient time to deploy containment or control equipment before the oil migrates past the control point.

Table 4.6 summarizes the results of the response logistics analysis for the three control points.

TABLE 4.6. RESPONSE LOGISTICS TIMING FOR THREE CONTROL POINTS ON LOWER FRASER RIVER

Response Logistics Timing (Oil Transport vs. Equipment Mobilization)					
River State (Oil Transport)	**Current Velocity**	**Control Point 1 (6.5 km)**	**Control Point 2 (24 km)**	**Control Point 3 (25 km)**	**Fraser Mouth[51] (40 km)**
Slow Flow (Slow Transport)	Slack water	No transport; ordinary spreading			
	2 kph (1.1 kts)	3.3 hours	12.0 hours	12.8 hours	20.0 hours
Medium Flow (Medium Transport	4 kph (2.2 kts)	1.6 hours	6.0 hours	6.3 hours	10.0 hours
	8 kph (4.3 kts)	0.8 hours	3.0 hours	3.2 hours	5.0 hours
Fast Flow (Fast Transport)	12 kph (6.5 kts)	0.5 hours	2.0 hours	2.1 hours	3.3 hours
	16 kph (8.6 kts)	0.4 hours	1.5 hours	1.6 hours	2.5 hours
First Responding Road Forces can arrive at all Control Points in roughly 2.4 hours without traffic.					
(Green)	Green: Forces arrive > 1 hour ahead of oil.				
(Yellow)	Yellow: Forces arrive ahead of oil, but with less than 1 hour.				
(Red)	Red: Forces arrive concurrent with or after oil.				

[51] Oil transportation times are estimated to show potential for oil to reach marine waters, but response times to the Fraser River mouth are not calculated.

Figure 4.5 compares the oil transport time at different flow rates for the three control points and the Fraser River Mouth. Because of the proximity to the spill location, spill response resources must be deployed at Control Point 1 in 3.3 hours or less to get ahead of the leading edge of the spill. At Control Points 2 and 3, equipment must be deployed between 1.5 and 12.8 hours of the spill to encounter the leading edge.

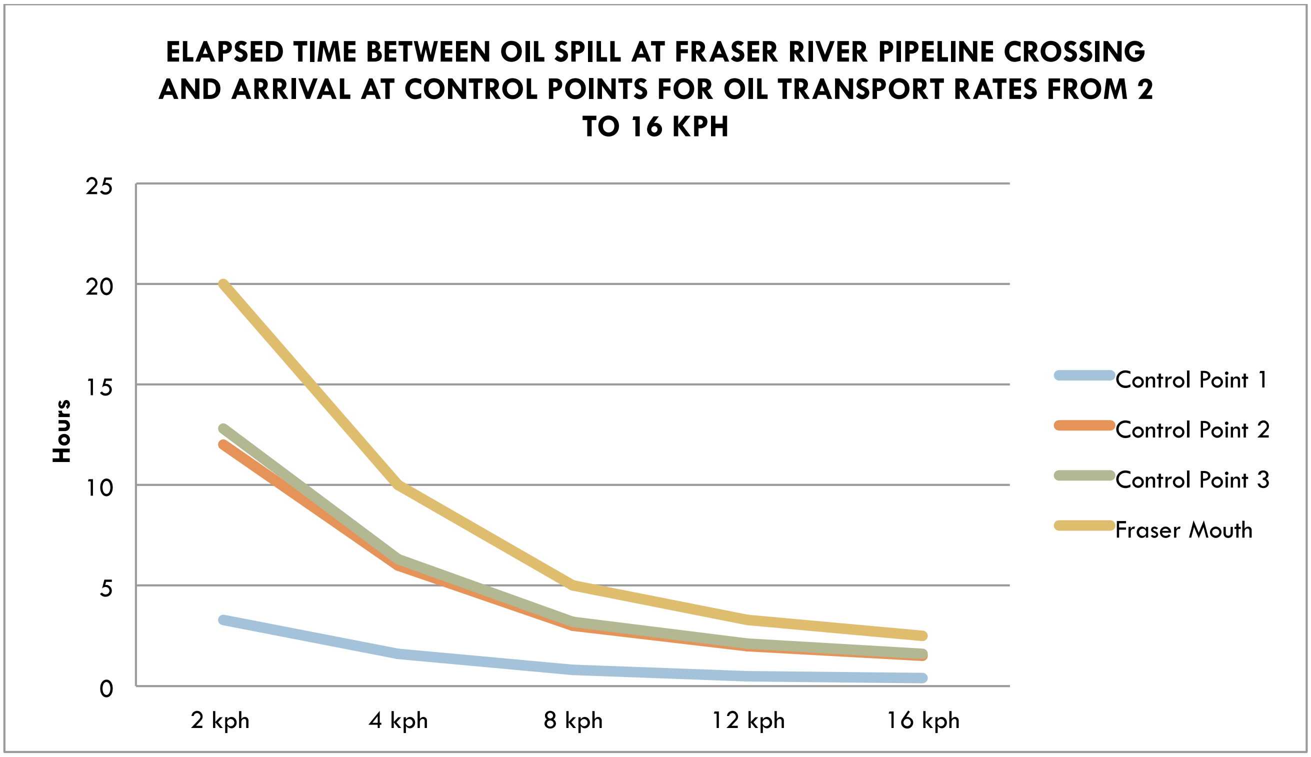


FIGURE 4.5. ELAPSED TRAVEL TIME FOR LOWER FRASER RIVER PIPELINE CROSSING SPILLS TO CONTROL POINTS BASED ON FLOW RATES

Figure 4.6 shows the arrival timing for response resources compared to the leading edge of an oil spill from the Trans Mountain Expansion Lower Fraser River pipeline crossing during low flow/slow oil transport (2 kph) conditions. Oil arrives at Control Point 1 by 3.3 hours after the release, and reaches Control Points 2 and 3 between 12 and 13 hours after the spill occurs. Based on this estimate, which does not account for traffic or other delays, response forces arrive at Control Point 1 just under an hour before the leading edge of the spill. Under these conditions, it would be possible to deploy oil containment tactics ahead of the oil. There is significantly more time to set up river control tactics at Control Points 2 and 3 under low flow conditions.

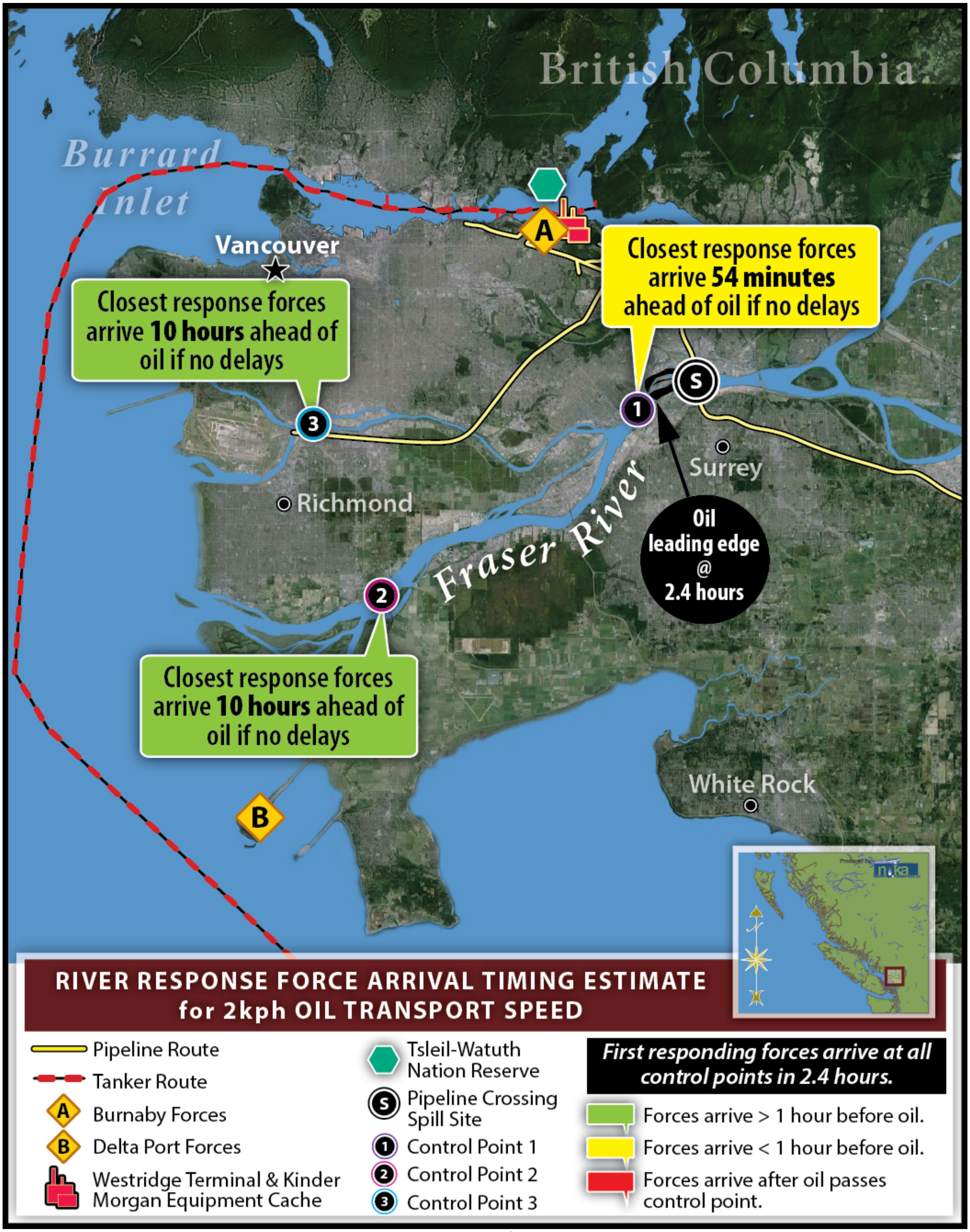


FIGURE 4.6. RIVER RESPONSE ARRIVAL TIMING – LOW FLOW/SLOW OIL TRANSPORT (2 KPH) CONDITIONS

Figures 4.7 and 4.8 show the arrival timing for response resources compared to the leading edge of an oil spill from the Lower Fraser River pipeline crossing during the two moderate flow/moderate oil transport speed (4 and 8 kph) conditions. In Figure 4.7, at a moderate travel speed of 4 kph, oil arrives at Control Point 1 at 1.6 hours after the release. In Figure 4.8, at a moderate travel speed of 8 kph, oil arrives at Control Point 1 at 0.8 hours. Under either moderate oil transport condition, there is not enough time to mobilize and transport equipment to the first control point ahead of the oil.

As shown in Figure 4.7, when moderate oil transport is at the lower end of the speed range (4 kph), oil reaches Control Points 2 and 3 around six hours after the spill occurs. At the higher moderate transport speed shown in Figure 4.8, oil reaches Control Points 2 and 3 at about three hours after the spill occurs. Based on these best-case estimates, it would be possible to deploy oil containment tactics ahead of the oil during the 4 kph moderate transport speed, but timing becomes very tight at an 8 kph transport speed rate, leaving only about a half hour of spare time. Any minor delay (traffic, personnel activation, equipment loading delays, site access problems) could easily result in a scenario where the oil passes the containment point before equipment can be unloaded and set up at the control point.

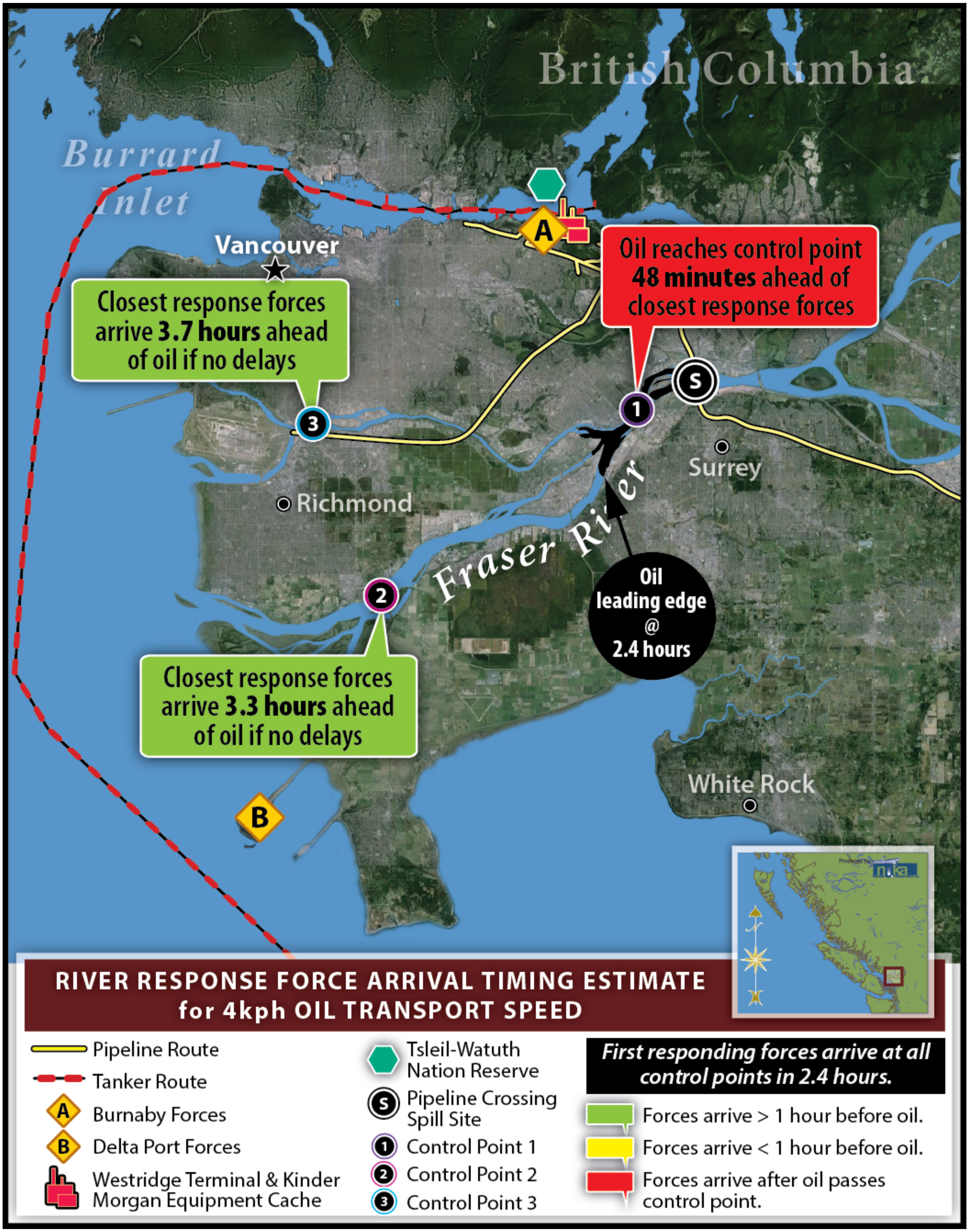


FIGURE 4.7. RIVER RESPONSE ARRIVAL TIMING – MODERATE FLOW/ OIL TRANSPORT (4 KPH) CONDITIONS

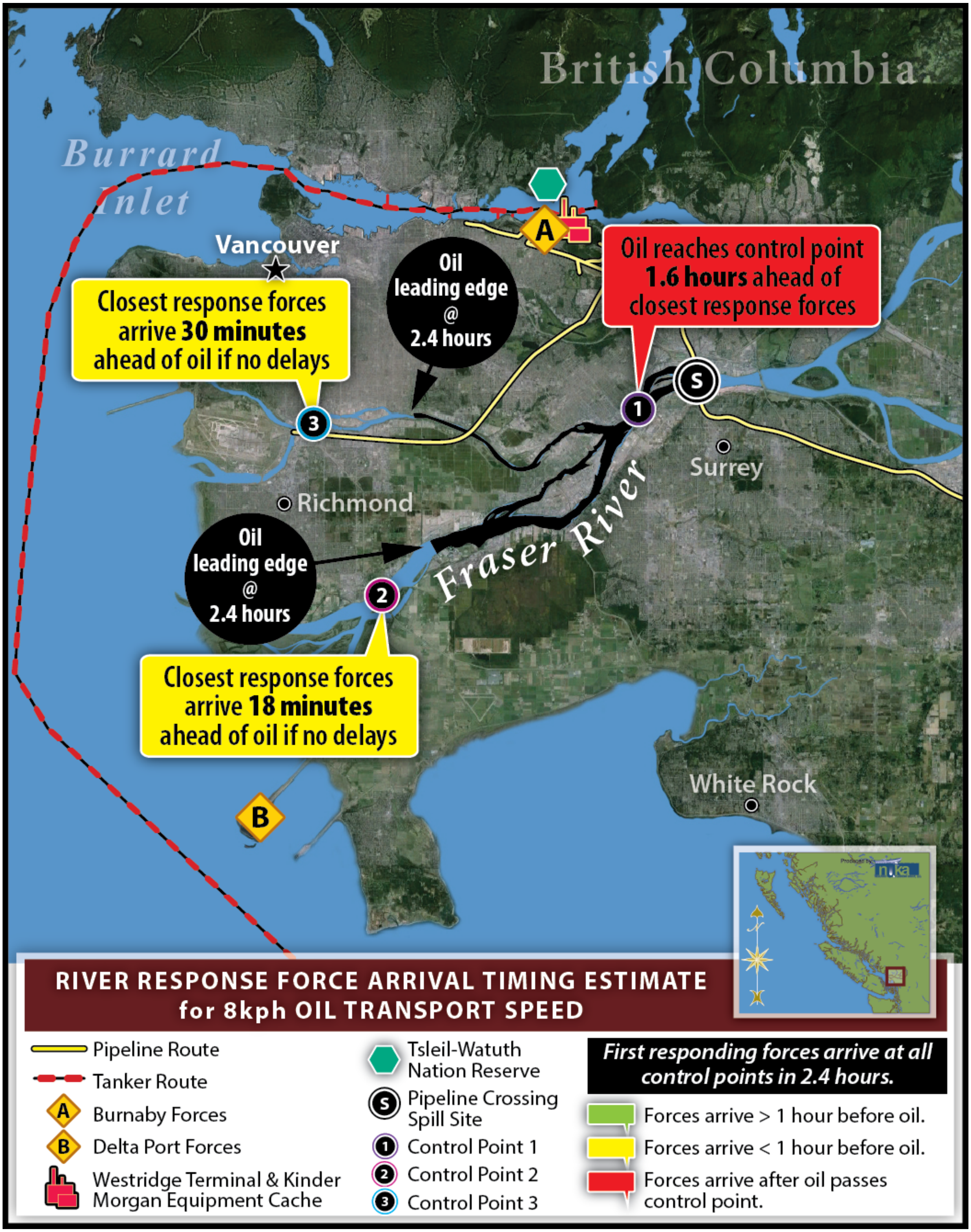
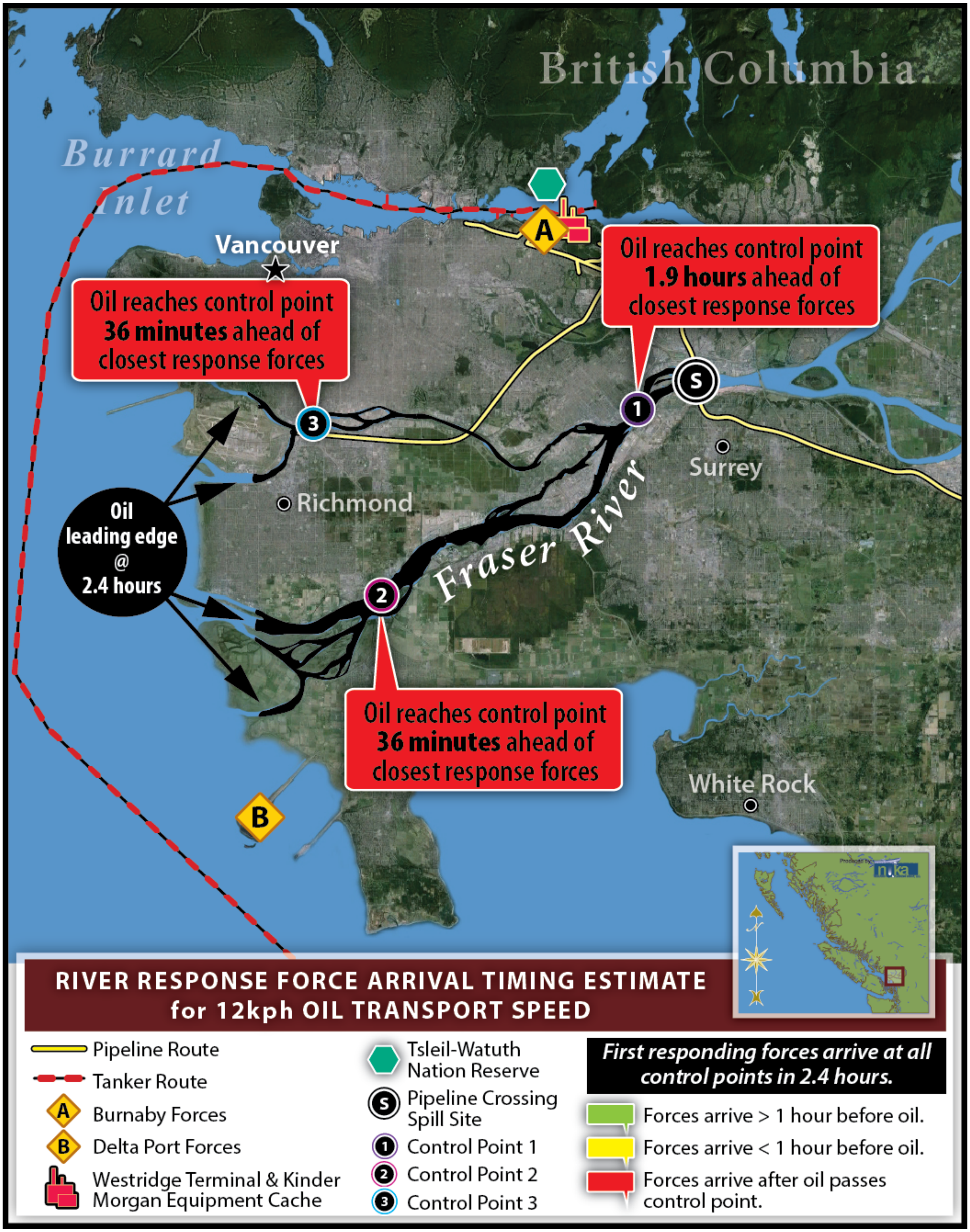


FIGURE 4.8. RIVER RESPONSE ARRIVAL TIMING – MODERATE FLOW/OIL TRANSPRT (8 KPH) CONDITIONS

Figure 4.9 shows the arrival timing for response resources compared to the leading edge of an oil spill from the Lower Fraser River pipeline crossing during high flow conditions/high oil transport speeds (12 kph). The oil will travel past all control points before equipment can be mobilized and deployed to control points. Within 2.5 hours of a release that migrates downriver at 12 kph, oil will have just about reached the mouth of the Fraser River. This suggests that, under high flow/high oil transport rate conditions, it is very unlikely that control point tactics could be deployed in time to slow or contain the downriver transport of a spill from the Trans Mountain Expansion pipeline crossing. Instead, response would involve a combination of riverbank cleanup and oil recovery and marine on-water recovery.



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1947 **FIGURE 4.9. RIVER RESPONSE ARRIVAL TIMING – FAST FLOW/OIL TRANSPORT (12 KPH) CONDITIONS**

4.3.2 Quantity and Type of River Response Resources

The river response logistics analysis provides estimates about the possibility to transport response resources to river control points ahead of a spill, based on variable flow conditions. Response timing is an important consideration for controlling a river spill; however, the type and quantity of equipment available will also influence the potential effectiveness of river control tactics.

Table 4.7 compiles an inventory of the actual resources available for deployment at the 1, 2, 4 and 6-hour marks.[52] These estimates apply to all three Control Points, because there were only nominal differences in the deployment times to each site (for example; travel time from Burnaby to the Control Points ranged from 24 to 40 minutes; from Delta Port travel times ranged from 22 to 27 minutes; from Hope travel times ranged from 81 to 105 minutes).[53] The arrival times indicate the time at which the resources arrive at the Control Point and do not factor in time required to set-up or implement spill response tactics on-scene.

TABLE 4.7. INVENTORY OF RESPONSE RESOURCES BY ARRIVAL TIME AT LOWER FRASER RIVER CONTROL POINTS

LAND RESOURCES	1 hour	2 hours	Warehouse Resources[54]	
			4 hours	**6 hours**
Workboats	None	6	7	2
Boom (all types)	None	17,450 feet	7,278 feet	6,500 feet
Skimmers	None	6[55]	7[56]	6[57]

The resources listed in Table 4.7 represent the current available equipment for a Trans Mountain river spill response in the Metro Vancouver area, based on the best available information.[58] Trailered resources can be mobilized from Burnaby, Delta Port, or Hope to any of the three control points within two hours, assuming that there are no traffic delays or logistical challenges. The two-hour column in Table 4.7 sums up the amount of equipment available in trailers at all four equipment storage sites. The trailered equipment that could arrive

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[52] The 2- and 6-hour response timing thresholds can be compared to US planning standards (See Kinder Morgan, 2013b).

[53] See Table 4.5. Travel time estimates were nearly equal for Control Points 1 and 3; travel times for Control Point 2 were the longest.

[54] The timing of warehouse equipment arrival is most difficult to predict because it is predicated on how the equipment is stored and how quickly it can be loaded for transport. In this analysis, we assume that half of the equipment is able to arrive at control points within 4 hours and half within 6 hours.

[55] The various trailer inventories list four skimmers with known recovery efficiencies (3,943 bbl total EDRC) and two with no specifications.

[56] Warehouse inventories list 7 skimmers with known recovery efficiencies (4,066 bbl total EDRC) and 6 with no specifications.

[57] Warehouse inventories list 7 skimmers with known recovery efficiencies (4,066 bbl total EDRC) and 6 with no specifications.

[58] Information sources included the Western Response Resource List (wrrl.us), Western Canada Marine Response Corporation (WCMRC) online inventory (WCMRC, 2013b) and project application materials (Kinder Morgan, 2013a; WCMRC, 2013a). The authors addressed information gaps and inconsistencies among these sources by applying best professional judgment and firsthand knowledge of spill response equipment. Additional specificity and improved consistency in response equipment inventories would facilitate future analyses and oil spill contingency planning efforts.

at the three control points within two hours includes 17,450 feet[59] of boom ranging in size from 18-inch to 60-inch boom, with most of the boom 24-inch "general purpose" boom (WCMRC, 2013b).

As shown in Figures 4.5 through 4.8, the only opportunity to deploy response equipment at Control Point 1 ahead of a river spill at the Lower Fraser River crossing would be if oil moved downriver at 2 kph or less. In the event of moderate oil transport speed (4 kph to 8 kph), resources could be deployed to Control Points 2 and/or 3 ahead of the leading edge of a spill from the river crossing. In the event of high oil transport speeds (12 kph or higher), it would not be possible to reach any of the control points with trailered resources ahead of the leading edge of the spill.

The total amount of trailered equipment listed in Table 4.7 is split among four trailers – two in Burnaby, one in Delta Port, and one in Hope. Response managers would be responsible for determining which trailers to deploy to which control point, in the event of an actual spill, based on specific tactical plans and strategic objectives.[60] If the oil slick moved downriver at a rate of 2 kph or slower, response equipment could be allocated to any of the three control points ahead of the slick. For oil slicks moving at a moderate speed, there would not be sufficient time to mobilized equipment to Control Point 1, so it would need to be allocated between Control Points 2 and 3, depending upon spill trajectory and response priorities. For a slick that moves downriver faster than 12 kph, there is not sufficient time to mobilize and deploy equipment to control points before the spill reaches marine waters.

It is also important to note that of the 17,450 feet of boom identified in the Trans Mountain project application materials, only 1,600 feet is identified as *river boom*, which means that it is specifically designed for deployment in river systems. River boom is typically smaller than boom designed for protected or open water operating environments; the smaller size and draft make the boom work more effectively against a strong current. There are also specific fast-water booming systems that are available on the market, but none are identified in the project application inventory. Table 4.7 also shows an additional 13,000 feet of boom that could be transported to the control points from warehouses, with response times ranging from four to six hours from the time of release. In a low moderate flow scenario (4 kph), there may be sufficient time to transport and deploy this additional equipment at Control Points 2 and 3.

To assess the potential capability to control a river spill with the 17,450 feet of trailered boom that could potentially be deployed within two hours of a spill, the total length of boom that would be required to boom across the river was estimated using simple geometric calculations. Table 4.8 estimates the length of boom that would be required to configure boom across the river at each control point, based on the approximate width of the river from bank to bank and the boom angle.

[59]Equipment inventories are provided in US measurements in the WRRL and WCMRC inventories, so these measurements are also presented here.

[60] The control points included in this analysis were selected by the authors because the Trans Mountain Expansion project application does not specify control points. Different or additional control points may result in slightly different response timing.

TABLE 4.8. BOOM LENGTH ESTIMATES BY CONTROL POINT BASED ON BOOM ANGLE AND CONFIGURATION

Control Point	Width of River (approximate)	Boom Angle	Maximum current	Length of Boom[61] – Single Leg	Length of Boom – Double Leg
Control Point 1	1,900 ft	60	2 kph (1.1 kts)	2,200 ft	4,400 ft
Control Point 2	1,600 ft	40	2.8 kph (1.5 kts)	2,000 ft	4,000 ft
		30	3.7 kph (2 kts)	2,800 ft	5,600 ft
		20	4.6 kph (2.5 kts)	4,400 ft	8,800 ft
		15	5.5 kph (3 kts)	6,000 ft	12,000 ft
Control Point 3	800 ft	40	2.8 kph (1.5 kts)	1,000 ft	2,000 ft
		30	3.7 kph (2 kts)	1,400 ft	2,800 ft
		20	4.6 kph (2.5 kts)	2,200 ft	4,400 ft
		15	5.5 kph (3 kts)	3,000 ft	6,000 ft

The approximate distance across the river at each control point was derived from geospatial information systems maps. At Control Point 1, a 60-degree boom angle is used to estimate boom length, since the maximum current speed that would allow for pre-deployment of boom ahead of the leading edge of the slick is 2 kph (1.1 kts). At the other two control points, a range of current speeds and boom angles are presented to compare boom lengths that may be needed to attempt to contain oil moving downriver.

The boom angles and corresponding maximum current speeds shown in the third and fourth columns of Table 4.8 represent standard planning factors for angling boom against currents, based on the formulas shown in Figure 4.10.

Figure 4.10 reflects the fact that most boom is not designed to hold against a water current of higher than 2.8 kph (1.5 kts). Above that current velocity, oil will tend to escape from underneath or around the containment boom. Decreasing the boom angle can overcome this limit to a certain extent. Table 4.8 shows how increased current speed requires a decreased boom angle in order to effectively contain oil, and clearly shows how increased lengths of boom are required at higher currents to achieve angles that will hold against the current.

[61] Calculated using basic triangle geometry and validated with an online calculator. http://www.calculator.net/triangle-calculator.html

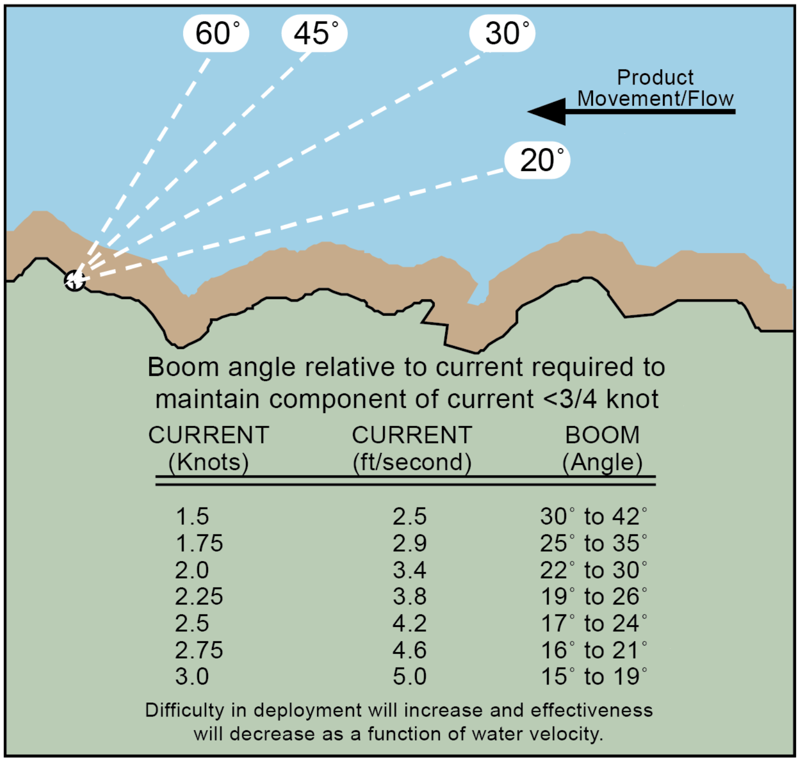

FIGURE 4.10. BOOM ANGLE RELATIVE TO CURRENT PLANNING TABLE (SOURCE: ADEC, 2014)

Table 4.8 and Figure 4.10 meant to put the 17,450 feet of trailered boom – the amount of boom available for deployment within two hours to the selected control points – in perspective. For example, if the river currents were 3.7 kph (2 kts) at Control Points 2 and 3, then a boom angle of 30 degrees would be required to effectively contain the oil. This would require at least 2,800 feet of boom at Control Point 2 and 1,400 feet at Control Point 3 (4,200 feet total) just to run a single length of boom across the river. If the current were 5.5 kph (3 knots), the minimum boom requirement for a single length of boom across the river would be 6,000 feet at Control Point 2 and 3,000 feet at Control Point 3 (9,000 feet total). If double legs were used (this is common practice in high current environments – the second leg serves as a back-up to catch any oil that escapes the first leg), then 18,000 feet of boom would be needed, more than the total amount available in trailers that could arrive within two hours of the release (Hansen and Coe, 2001).

More importantly, once the river current is above 3 knots (5.5 kph), it is highly unlikely that boom would be able to effectively contain oil because the forces on the boom would cause it to fail and allow oil to flow by (Hansen and Coe, 2001).

4.4 Discussion

4.4.1 Challenges to Oil Spill Containment and Recovery in Rivers

> ***"At a minimum, we're writing a chapter in the oil spill cleanup book on how to identify submerged oil."***
>
> Raplh Dollhopf, US Environmental Protection Agency
>
> *Kalamazoo River oil spill responders 'writing the book' on submerged oil clean up, Michigan Live*

This analysis does not specify spill volume nor does it estimate recovery capacity; it focuses solely on the logistics of mobilizing and transporting equipment to control points ahead of an oil spill based on variable river flow rates. Assuming that containment and recovery resources can be deployed ahead of the spill, it is unlikely that they will successfully contain and recover the full volume of on-water oil. Like marine spill response operations, on-water recovery in a riverine environment is also challenged by the limitations of mechanical oil recovery systems. Additional challenges of river spill response include:

- Potential for oil submergence or sinking;
- High currents; and
- River bank access.

River waters typically have lower salinity than marine waters, which means that some oils may sink more readily in river spills. High turbidity or suspended sediments may also contribute to potential submergence or sinking (NOAA, 2015; Short, 2015). The skimmers and boom included in this river response logistics analysis are designed to function on floating oils, and would not be effective in containing or recovering submerged or sunken oils in the Fraser River.

The 2010 diluted bitumen spill into the Kalamazoo River illustrated the potential for diluted bitumen to submerge and sink under certain river conditions, and presented a significant challenge to responders both in terms of locating the submerged oil and remediating it. The Kalamazoo River spill migrated 40 miles (65 km) downriver from the pipeline release point before it was contained. By comparison, the Lower Fraser River runs approximately 40 km from the Port Mann bridge pipeline crossing to the mouth.

Figure 4.11 shows a conceptual model of how the Kalamazoo River spill impacted the river flow, bottom sediments, riverbank, vegetation, and overbank areas (Enbridge, 2013).

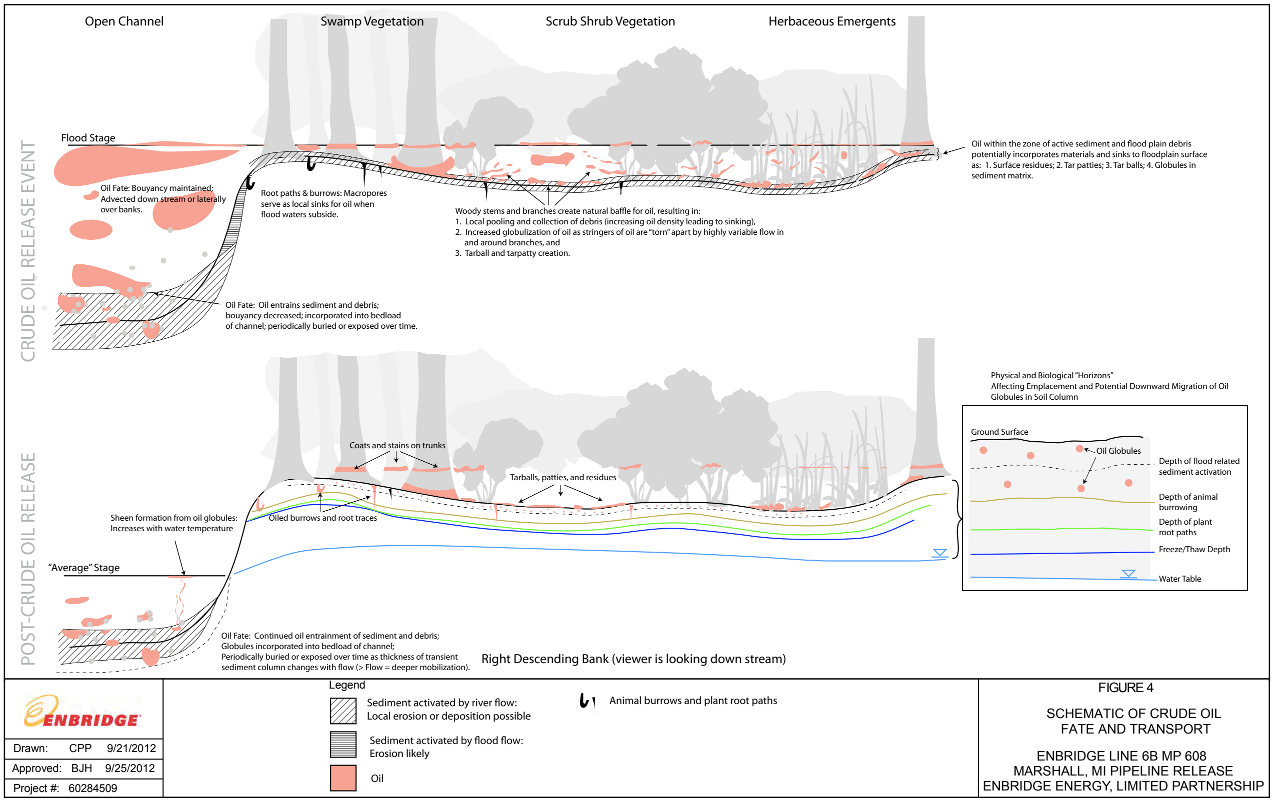

FIGURE 4.11. CONCEPTUAL MODEL OF FATE AND TRANSPORT OF KALAMAZOO RIVER DILUTED BITUMEN SPILL

High velocity river currents may cause booms and skimmers to fail or function at a low efficiency. While it is possible to mobilize response resources to control points ahead of oil spills in low and moderate flow conditions, increasingly shallow angles and special anchoring techniques are required to effectively deploy boom against a current that exceeds 2 kph. There are fast-water booming systems that may be deployable in currents up to 8 kph, but these do not appear to be in the inventory of Kinder Morgan or WCMRC, and require specially trained personnel to deploy them. There are no oil containment systems that have been proven effective in 12 kph currents. (Hansen and Coe, 2001)

Riverbanks may be difficult to access due to property ownership or limited roadways or footpaths. This is a clear challenge along the Lower Fraser River, which is largely privately owned and heavily developed. Shallow waters or shoal areas may require shallow-draft response vessels. Section 4.4.2 discusses the need to pre-arrange river access points.

4.4.2 Need for Detailed Control Point Planning

> ***"Containment Sites are areas of opportunity that can enhance containment efforts. Preplanned containment sites are an essential component of our contingency plans."***
>
> *Oil Spill Response in Fast Water and Currents*, Alaska Clean Seas

The river response logistics analysis for the three Lower Fraser River Control Points focuses on equipment transportation and deployment only. Specific response tactics are not considered because the Trans Mountain project application does not include Control Point plans, although such plans are often made public in other jurisdictions.[62] While the use of the three example control points is sufficient for the purpose of this analysis – to illustrate the importance of response timing, equipment mobilization, and logistics pre-planning to overall response preparedness – more detailed control point planning is needed in order to understand the *specific* capabilities and limitations to control a spill from the Trans Mountain Expansion pipeline to the Lower Fraser River.

The estimates of response resources and river logistics timing provided here could be refined if actual information was provided about control point locations and response tactics and mobilization plans along the Lower Fraser River. Pre-defined control point tactics could be used to evaluate how equipment is distributed across the response trailers and how it would be allocated to one control point or another. For example, it would be useful to consider *which* response trailers would be deployed to which control point, and to ensure that a complete resource set was included in the trailer inventory.

The Lower Fraser River runs approximately 40 km from the pipeline scenario release point to the mouth. The selection of control points for this analysis was challenged by the limited availability of access points and boat launches across this length of the river. Significant human populations and industrial/commercial development along the riverfront make access challenging. Private land access may need to be pre-arranged to avoid response delays.

Getting the equipment to the control point is only the first step in mounting an effective response. Personnel must also be called to the spill site within the relatively short timeframes, and the equipment must be deployed in appropriate and effective configurations. While having enough boom is important to containing floating oil, it is equally important to have all of the ancillary equipment required to deploy boom – such as anchors, line, connector points, floats, and other resources.

[62] For example, the Washington Department of Ecology has published geographic response plans for sites including inland rivers throughout Washington State (Ecology, 2015).

4.5 Key Findings

4.5.1 Timing is Critical for River Response

KEY FINDING: If an oil spill occurs at the Port Mann Bridge and moves downriver at 8 kph or faster, there may not be time to mobilized and deploy equipment in time to control the spill before it reaches the Fraser Delta. At transport speeds of 12 kph or higher, this becomes impossible.

All three analyses presented in this study emphasize the importance of timing in on-water oil spill response. However, timing is perhaps most critical in a riverine environment because transport of floating oil is typically downriver and often at relatively high velocities.

This analysis presents a range of spill transport speeds and considers optimistic timelines for mobilization and deployment of response equipment from Burnaby, Delta Port, and Hope to three hypothetical control points. For the Trans Mountain pipeline Lower Fraser River crossing spills modeled in this analysis, spills may migrate the length of the river all the way to the mouth in less than 2.5 hours under conditions where the oil moves at 12 kph (6.5 knots) or faster. This does not allow sufficient time to load equipment, transport it to control points, and deploy it ahead of the leading edge of the spill, based on the location of existing equipment caches. Even under moderate transport conditions (4kph to 8 kph), mobilization and deployment timing is tight. Any complications caused by spill detection delays, equipment malfunction, personnel activation, traffic, or other unforeseen factors could allow the spill to migrate the entire 40 km of the Lower Fraser River from the pipeline crossing to the mouth, contaminating river banks and river resources along the entire reach.

In order for any of the response estimates presented here to be realized, oil spill detection must be nearly instantaneous. Given that spill detection and reporting delays have been well documented for past pipeline spills (e.g., NEB, 2012), this is a significant consideration. Prompt detection of pipeline spills may be the deciding factor for the effectiveness of spill containment and recovery on the Lower Fraser River.

4.5.2 Available River Response Resources are Limited

KEY FINDING: Response equipment inventories along the Lower Fraser River are limited.

An inventory of equipment identified in project application materials and online databases show that there is approximately 30,000 feet of boom available in trailers and warehouses in Southern BC, along with approximately 19 skimmers. Approximately 17,000 feet of this is stored in trailers that can be deployed to Lower Fraser River control points within 2 hours, assuming that all of this boom can be released from its storage location. Depending upon the angle and configuration of booming arrays and the manner in which equipment is stored and transported, equipment availability could be a limiting factor for controlling river spills.

In addition to equipment inventories, it is also important to consider how the allocation of available resources to one or more control points may affect the overall spill response objectives. Given a finite set of available resources and the time sensitivity of deploying equipment ahead of the leading edge of a spill, equipment allocation decisions during the initial hours of a response are critical to the potential to control an oil spill before it migrates the length of the Lower Fraser River. If equipment is sent to one control point, only to arrive after the leading edge of the spill has passed, time and opportunity to intercept the spill further down river may be lost.

One challenge in conducting this analysis was reconciling the various equipment lists and databases currently available. In some cases, information about equipment specifications – such as skimmer capacity – is limited or incomplete. There are no publicly available tactics guides or control point plans that show how equipment would be configured for deployment on the Lower Fraser River, and there is little information available about ancillary response equipment such as anchors, line, tackle, floats, and other equipment that is critical to deploying response tactics. More detailed plans would make it easier to understand the level of tactical planning in place and evaluate the sufficiency of response resources to control river spills.

> ***"The challenge will always be there in the ability to quickly deploy with the correct amount of resources in a[n] ever changing river environment."***
>
> Mark Cook, Alyeska Pipeline Service Company, *Advance Fast Water Spill Response Tactics*

4.5.3 Available Response Equipment Appropriate for Floating Oils Only

> **KEY FINDING: Existing river response equipment is meant for floating oil, and would not be effective in the event that a diluted bitumen spill submerged or sank in the Lower Fraser River.**

Several recent studies have examined the potential fate and behaviour of diluted bitumen spills in various types of water body (Short, 2015; King et al., 2014; Environment Canada et al., 2013; Crosby et al., 2013; S.L. Ross, 2012). While there is some variability in methods and results, these studies present a general consensus that diluted bitumen has the potential to submerge or sink under certain conditions. The 2010 diluted bitumen spill in the Kalamazoo River demonstrated this potential.

The 2010 oil spill from Enbridge's Line 6B in Michigan is reported by the company to have released 843,000 gallons[63] of diluted bitumen into the Kalamazoo River during July when the river was at a flood state. An unknown volume of that oil submerged and ultimately sank, becoming entrapped in river bottom sediments and creating a significant clean-up challenge. As of July 2013, three years after the spill occurred, the US government estimated that approximately 180,000 gallons of the diluted bitumen spill remained trapped in river sediments. The government ordered Enbridge to dredge another 12,000 to 18,000 gallons of that oil, but determined that beyond those measures, the oil should be left in the riverbed because additional clean-up would cause "significant adverse impacts to the river." (USEPA, 2013)

While it is impossible to predict the outcome of a Trans Mountain pipeline spill on the Lower Fraser River, there is a very real possibility that at least some of the spilled oil could submerge and sink. The clean-up challenges experienced in Michigan still exist – removal of submerged and sunken oil is a labour-intense process that can be highly disruptive to the river sediments, bank, and vegetation (NOAA, 2015). In some cases, such as the remaining 162,000-168,000 gallons of oil estimated to remain in the Kalamazoo River, the least harmful option may be no clean-up.

[63] The US Environmental Protection Agency reports that, as of July 2013, 1.15 million gallons of oil had been recovered, with more remaining in the river system, creating some confusion about the accuracy of the reported spill volume.

> ***"All of our response capabilities assume oil floats."***
>
> Jacqueline Michel, Research Planning Inc., quoted in *Inside Climate News*
>
> ***"There are no proven containment methods for oil either suspended in the water column or deposited on the seafloor."***
>
> *Development of Bottom Recovery Systems*, Final Project Report to US Coast Guard Research and Development Center, 2013

4.5.4 Oil spill response in high velocity currents requires special capabilities.

> **KEY FINDING: It is unclear whether Trans Mountain has access to the specialized oil spill response equipment, tactics, and trained personnel necessary to control oil spills in fast water conditions (greater than 0.8 kts/1.5 kph).**

Like marine waters, riverine environments are subject to a range of conditions based on weather and other environmental factors. In the Lower Fraser River, there is the potential for high velocity currents along certain sections at different times of the year. When river currents exceed 1.5 to 2 kph, the operating environment is classified as fast water, and specialized equipment and tactics may be required to successfully control an oil spill (ASTM, 2011; Hansen and Coe, 2001).

High velocity currents create drag on boom, which is exacerbated by the draft of the boom (height of boom underwater). For this reason, smaller boom or boom with special adaptations for high current environments may be more successful in holding a configuration in a high current river (Cook 2014; Hansen and Coe, 2011). The Trans Mountain project application and supporting documentation (WCMRC 2013a and 2013b) identify 1,600 feet of river boom as an available resource, but do not provide any additional information about fast water response tactics or capabilities.

Deployment of fast water booming techniques requires special training and frequent practice through drills and exercises (Hansen, 2001).

4.5.5 Pre-Planned Logistics are Critical to Successful River Oil Spill Response

KEY FINDING: The Trans Mountain application lacks critical detail about how responders will manage practical and logistical considerations – such as site access, travel routes, boat launch access, and tactical planning – that are critical to successful river response.

The Trans Mountain Expansion project application indicates that control point planning has been, or will be, done for points along the Fraser River. However, this information is not available for review. In the absence of actual tactical plans, the authors applied our expertise to identify three control points that could be used to try to intercept a spill on the Lower Fraser River. Absent specific pre-planned tactics and logistics, it will be nearly impossible to control a spill on the Lower Fraser River before it reaches the Delta, especially during high flow conditions.

Detailed logistical planning is critical to improve the opportunity to rapidly deploy oil control equipment ahead of the leading edge of an oil spill. The level of pre-planning typically conducted for river response plans includes identifying response tactics, equipment requirements (including personnel, vessels, and transportation methods), response timing, site access plans (permissions, where needed), routes of travel (including alternates for road closures or traffic), and other information that may expedite the response process. Access to real-time information about river flow rates, flood state, sediment load, temperature, and other factors that will influence oil behaviour and response tactic implementation are also critical. Until this level of detail is provided for Fraser River spill response, it is difficult to assess the river response capacity for a Trans Mountain Expansion pipeline release.

5 CONCLUSIONS

5.1 Synthesis of Results

This report presents three separate but related analyses that consider oil spill response capabilities and limitations in areas of Southern BC that are vulnerable to potential oil spills from Trans Mountain Expansion tanker and pipeline operations. The analysis was prepared for three Interveners to inform their understanding of the potential for unmitigated oil spills from the Trans Mountain Expansion project. This report was prepared by a team of authors with substantial expertise and experience in oil spill contingency planning, oil spill response operations, and the application of analytical tools to evaluate and understand oil spill risks. Table 5.1 summarizes the three analyses.

TABLE 5.1. RESEARCH QUESTIONS, ANALYTICAL METHODS, AND FINDINGS FOR THREE OIL SPILL RESPONSE STUDIES

Research Question	Analysis	Key Findings
How often will environmental conditions preclude or limit on-water oil spill response in the study area?	The **marine oil spill response gap analysis** estimates the percentage of time that an on-water spill response and aerial surveillance could be deployed based on historical or modeled weather conditions in coastal and marine areas in Southern BC.	1. Response gaps exist along the entire tanker route. 2. The response gap is more significant when on-water operations and aerial reconnaissance are considered together. 3. Response gaps are higher during winter. 4. The timing of response gaps is critical to overall response opportunities. 5. Lack of a response gap does not guarantee that effective response will occur, only that it is possible.
What is the capacity for available mechanical oil spill recovery systems to contain and recover on-water oil spills in the study area and how is it increased or decreased by certain factors?	The **marine oil spill response capacity analysis** estimates the amount of oil that would be recovered from a worst case spill to coastal and marine waters in the first three days, representing the critical window-of-opportunity to mitigate impacts.	1. Spill response capacity is lower across all locations during winter. 2. Delays to response implementation significantly decrease oil recovery. 3. Shoreline stranding reduces the volume of oil available for on-water recovery. 4. Additional response forces are necessary to achieve the modeled oil spill recovery estimates. 5. Force distribution is critical to on-water oil recovery. 6. Night operations modestly increase oil recovery. 7. Changes to oil properties may reduce on-water spill recovery.
How quickly must response resources be mobilized, transported, and deployed to representative control points to reduce the downstream transport of an oil spill on the Lower Fraser River?	The **Lower Fraser River response logistics analysis** estimates the mobilization and transport timing required to deploy equipment in time to potentially limit the downstream transport of oil spills on the Lower Fraser River.	1. Timing is critical for river response. 2. Available river response resources are limited. 3. Available oil spill response equipment is appropriate for floating oils only, but a spill to the Lower Fraser River may sink. 4. Oil spill response in high velocity currents requires special capabilities that are not currently in place in the region. 5. Pre-planned logistics are critical to successful river spill containment but have not been provided in the project application.

5.2 Putting it All Together: Oil Spill Response Capabilities and Limitations

> ***"Cleaning up of an oil spill in a marine environment is in general a challenging and resource-intensive task. Even under relatively favourable response conditions recovery operations will usually remove a limited fraction of the total spilled volume."***
>
> DNV GL Oil and Gas Technical Report:
> *Anchoring the Future: Challenges and Best Practice of Oil Spill Response in the Arctic*

A number of common themes emerge throughout the three analyses that can inform the understanding of oil spill response capabilities and limitations for spills from the Trans Mountain Expansion project.

5.2.1 Timing is Critical to Oil Spill Response Capabilities and Limitations

The element of time was shown to be critical to all three analyses. Oil spill response in both marine and riverine environments is a race against the clock. The moment that oil escapes from a pipeline or tank into a water body, it undergoes a progression of physical and chemical changes. The oil will spread into an increasingly thin layer, unless it is contained by barriers. Components of the oil evaporate, making the on-water component denser, thicker, and stickier. The oil may incorporate water and may also take on sediments. It may reach the shoreline and permanently strand, or it may wash back into the water body. These physical and chemical changes can be dramatic for diluted bitumen spills, because of the oil characteristics. Nearly all of these changes make on-water spill recovery more difficult and less effective, so implementation of on-water recovery tactics while the oil spill is fresh is always a top priority.

Any factors that delay the opportunity to deploy on-water containment and recovery tactics while the oil is fresh may reduce the overall effectiveness of the response. This report identifies a number of different factors that may cause response delays, including: delayed oil spill reporting or detection; occurrence of adverse environmental conditions that make response unsafe or unfeasible (response gap); or delays in mobilizing, transporting, and deploying response equipment.

The oil spill response gap – the period of time during which conditions preclude oil spill response operations – varies significantly by season along the Trans Mountain tanker route. The most significant gap periods occur during winter months, and the timing of these gaps may be such that adverse conditions can occur over a period of several consecutive days. If an oil spill should occur at the onset of a period of prolonged adverse conditions, it is possible that the window of opportunity to respond to a spill could pass entirely, and the entire spill volume would remain unmitigated.

The marine response capacity analysis modeled on-water recovery for a series of hypothetical spills and expressed the results as a mass balance of oil recovered, evaporated, and left on the water at the end of each hour during the first three days of a spill. The model outputs showed how recovery rates diminish over the first 72 hours of a response, corresponding to the spreading and weathering of the spilled oil. The response capacity analysis also presented a series of comparisons where delayed response timing was modeled to evaluate the impact on oil recovery. The reduction in oil recovery efficiency showed a linear rate of reduction when plotted against response delays. A delay of just 48 hours reduced modeled recovery by up to 80% in some scenarios.

The Lower Fraser River response logistics analysis evaluated the opportunity to move equipment from trailers and warehouses in Southern BC to control points along the Lower Fraser River in time to beat the leading edge of an oil spill, and found that for oil transport rates of 4 kph or higher, the window of opportunity to deploy resources ahead of the leading edge of the spill was 6 hours or less. This means that in order to set up control point tactics before the oil reaches the site, the spill must be detected, spill managers must direct the response resources to be mobilized and transported to the control point, and trained responders must arrive along with the equipment in time to deploy the tactics. Successful implementation will rely on smooth operations for the entire chain of events. In the event that diluted bitumen submerges in the Lower Fraser River due to turbidity, sediment, or salinity factors, control point booming would be futile.

Regardless of where a spill may occur, careful planning, adequate resources, swift deployment, and the right number of personnel with the appropriate qualifications must be in place in order to capitalize on those times when environmental conditions favour on-water recovery. This distinction is important, even for sites and conditions along the tanker route or pipeline corridor where the response gap is minimal, because the opportunity to respond effectively is only the first step in a series of events that must fall into place in order to effectively remove spilled oil from the marine environment.

5.2.2 The Type, Quantity, and Location of Response Equipment is Critical

The marine response capacity analysis and the Lower Fraser River response logistics analysis evaluate the availability, suitability, and capacity of on-water response equipment to contain and recover spills from Trans Mountain tankers or pipelines. Both analyses highlight the importance of matching response equipment to operating environment. For some sites along the tanker route, conditions may be appropriate for either protected water or open water systems, depending on prevailing weather. At other sites, one or the other system is more appropriate. For Fraser River spills, river response systems capable of containing oil under high current velocities will be critical during times when flow rates are high.

The response capacity analysis and Lower River analysis also point to limits in the current equipment inventory as potentially limiting response capabilities in Southern BC. The response capacity analysis shows that there is a striking difference between the current, existing response capacity in place for marine spills from Trans Mountain operations and the proposed future capabilities that are described in the project application. The response capacity analysis also shows how important it is to consider spill response capability from a systems perspective – boom and skimmers are important, but so are the ancillary components on on-water response forces, such as workboats to tend boom and tugs to move barges. There must also be sufficient numbers of trained responders to implement the response. The conservative estimate in the response capacity analysis shows that a minimum of 181 trained personnel would be required to operate the current, proposed, and additional supplementary response forces analyzed. This does not count the people needed for ancillary operations such as support vessel crew, vessel crew to shuttle responders to and from sites, shore-based responders, heavy equipment operators, or spill management personnel.

The Lower Fraser River analysis identifies approximately 17,500 feet of boom available within 2 hours of the Lower Fraser River control points; less than 10% of this boom is specifically designed for us in rivers. No additional specialized river response equipment is identified. Because there are no control point tactics identified in the project application, it is difficult to determine the strategies for allocating this boom. Response equipment inventories lack sufficient detail to determine how key response equipment (boom and skimmers) would be deployed.

Both the response capacity and Lower Fraser River analyses also show the importance of equipment cache locations and portability. The response capacity analysis shows that the distribution of response forces across the region is critical to response for sites beyond the Vancouver Port Area, where most of the current response equipment is currently located. The analysis makes assumptions about where future response forces might be located; additional planning and consideration is required to maximize response potential and to match capacity to spill risks. The Lower Fraser River analysis shows that trailered response equipment has the capability to arrive at response locations much more quickly than warehoused equipment. It also emphasizes the importance of considering routes of travel and the potential for traffic or road conditions to significantly slow response time.

5.2.3 Planning Assumptions Should be Verified and Information Gaps Filled

There is a tendency for oil spill contingency plans to overstate response capacity. The disconnect between planning assumptions and reality was made clear in the aftermath of the Deepwater Horizon well blowout, where the reality of the spill response did not align with published contingency plans (USCG and USDHS, 2011). The value in any planning process is in identifying both strengths and weaknesses in a system, to inform risk mitigation and emergency preparedness, and to create realistic expectations for what can and cannot be accomplished in the event of a worst case oil spill.

The purpose of this study was to examine response capabilities and limitations for Trans Mountain Expansion oil spills, because these are not clearly presented in the oil spill contingency planning materials provided in the project application. The three components of this study apply established analytical tools to estimate the capabilities and limitations to existing and potential future oil spill response systems in Southern BC. They are presented to a group of Interveners to inform their understanding of the potential to mitigate an oil spill from Trans Mountain Expansion tanker or pipeline operations, and they build on established methods consistent with other peer-reviewed work in the field.

It is just as important for oil spill contingency plans to acknowledge oil spill response gaps and limitations as it is for them to demonstrate response capability. All three of the analyses indicate that there are times and places where effective spill response will be difficult or impossible. Anticipating these occurrences allows planners and response managers to make informed decisions about spill mitigation. Additional exploration about the differences in response gaps and response capacity during winter and summer months could inform the stockpiling of equipment. It may also inform additional prevention measures for seasons (winter), when conditions may preclude oil spill response more than half of the time and even during those times when response may be possible, recovery efficiency would be significantly reduced. Contingency plans that do not clearly present these pragmatic limits may create a false sense of capability that undermines both planning and real-time response decision-making.

The authors represent these analyses as accurate within the bounds of available information. As noted throughout the study, there are a number of areas where the requisite inputs were not available in the Trans Mountain Expansion project application and supporting documentation. These information gaps are noted throughout the report, and the authors recommend that the provision of additional information about response tactics, [64] equipment inventories, equipment specifications, mobilization and deployment plans, and other response logistics would enhance the opportunity for the Interveners and other stakeholders to more thoroughly evaluate the project. It would also provide an opportunity to improve the accuracy of the estimates in this study.

[64] See the Alaska Clean Seas Technical Manual as an example of an industry standard tactics guide. It is available in full online at: http://www.alaskacleanseas.org/tech-manual/

It is perhaps more critical to verify the information and assumptions in this analysis through field deployments and response exercises. Assumptions regarding equipment mobilization, transportation, and deployment timetables could be refined through field exercises. The capability of response systems to operate in different environmental conditions could be tested to ground truth assumptions about operating limits. Exercises could be used to explore the capabilities and limitations to mount on-water recovery operations at night.

Until these critical planning assumptions are validated with real-world experience, they should not be interpreted as a guarantee of performance. Actual oil spills – such as the recent fuel oil release in English Bay – reinforce the reality that collecting and removing oil from the sea surface is a challenging, time-sensitive, and often ineffective process, even under the most favourable conditions.

Date: May 22, 2015 Signature: ____________________

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2577 APPENDIX A. BURRARD INLET WAVE MODEL DATA

30 Gostick Place | North Vancouver, B.C. V7M 3G3 | 604.980.6011 | www.nhcweb.com

nhc
northwest hydraulic consultants

Project: 300323
Date: 2014 October 09

Tsleil-Waututh Nation
Burrard Indian Band
3075 Takaya Drive
North Vancouver, British Columbia, V7H 3A8

Attention: **John Konovsky, MSc**
Natural Resources Planner

Dear Mr. Konovsky:

Subject: **Burrard Inlet Wave Model Data**
2005 Sea State Information

1 INTRODUCTION

Northwest Hydraulic Consultants Ltd. (NHC) has been working for the Tsleil-Waututh Nation (TWN) to provide an assessment of the shoreline along the north shore of Burrard Inlet. TWN has requested NHC to provide hourly sea state information (wave height, wave period, and wave steepness) for year 2005 at two locations within Burrard Inlet to support additional studies being conducted by a third party. The two locations of interest are *P11 - English Bay #2* and *P5 - Burnaby* as shown in **Figure 1**.

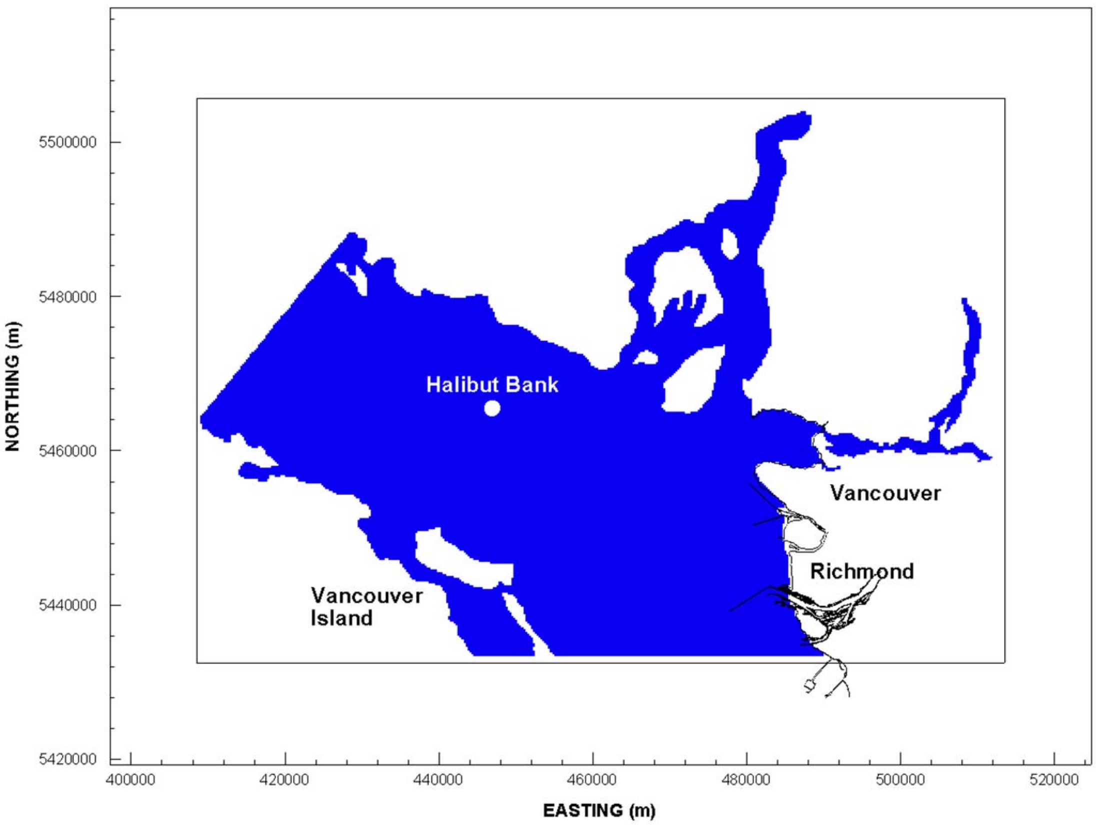
Figure 1: Location of data request.

2578 water resource specialists

2 METHODOLOGY

Since there is no comprehensive measurement of waves in Burrard Inlet, the incident wave climate was hindcast using the University of Miami Wave Model (UMWM). UMWM is a spectral ocean wave model applicable on a wide range of spatial and temporal scales; small lakes to global applications. The Strait of Georgia/Burrard wave model was implemented on a model grid resolved on a 250 m by 250 m orthogonal grid spacing. The model grid was generated using data from the local hydrographic chart. The grid extends 105,250 m in the east-west direction and 73,500 m in the north-south direction (**Figure 2**).

Figure 2: Strait of Georgia/Burrard Inlet wave model extent.



The effects of fetch (distance along water in a particular direction) and duration (length of time the wind has been blowing that direction and speed) on the wind-generated wave field are incorporated in the model. The model provides values of wave height, period, and direction at all grid cells within the model, at hourly intervals, for the duration of the simulation. Wave steepness, defined as wave height divided by wave length, is calculated based on modelled wave height and period. Note that the model computes deepwater waves only; that is, the effects of shoaling and refraction are not incorporated.

A two-dimensional, time-dependent wind field required as input by UMWM was generated from the hourly wind data provided by TWN[1] at 12 locations (**Table 1**) from CALMET model as well as wind data from Environment Canada (EC) Halibut Bank wave buoy (C46146).

Table 1. Input wind station locations.

Point	Name	Easting (m)	Northing (m)
1	North End of Indian Arm	509,125	5,472,625
2	Central Indian Arm	507,375	5,466,375
3	Port Moody	510,125	5,459,875
4	Belcarra	504,375	5,461,625
5	Burnaby	502,625	5,460,125
6	Second Narrows	498,125	5,460,125
7	Burrard Inlet #2	494,625	5,460,625
8	Burrard Inlet #1	492,375	5,460,875
9	Lions Gate (First Narrows)	489,875	5,462,625
10	English Bay #1	486,375	5,461,375
11	English Bay #2	482,375	5,461,625
12	Vancouver Airport	487,375	5,449,625
13	Halibut Bank	446,970	5,465,509

[1] email correspondence (September 4, 2014). File: R614-1406-00_MV+CALMET_Data_Extraction.xlsx

3 MODEL RESULTS

The Strait of Georgia/Burrard Inlet wave model was simulated for year 2005. Hourly hindcast wave data at Halibut Bank, English Bay #2, and Burnaby was archived. As an example of model output, **Figure 3** shows the modelled significant wave height result for a storm event occurred on November 3rd, 2005. The shading of the map represents wave height as shown by the colour bar. Vectors represent the direction of wave propagation.

Figure 3: Burrard Inlet wave model example results.

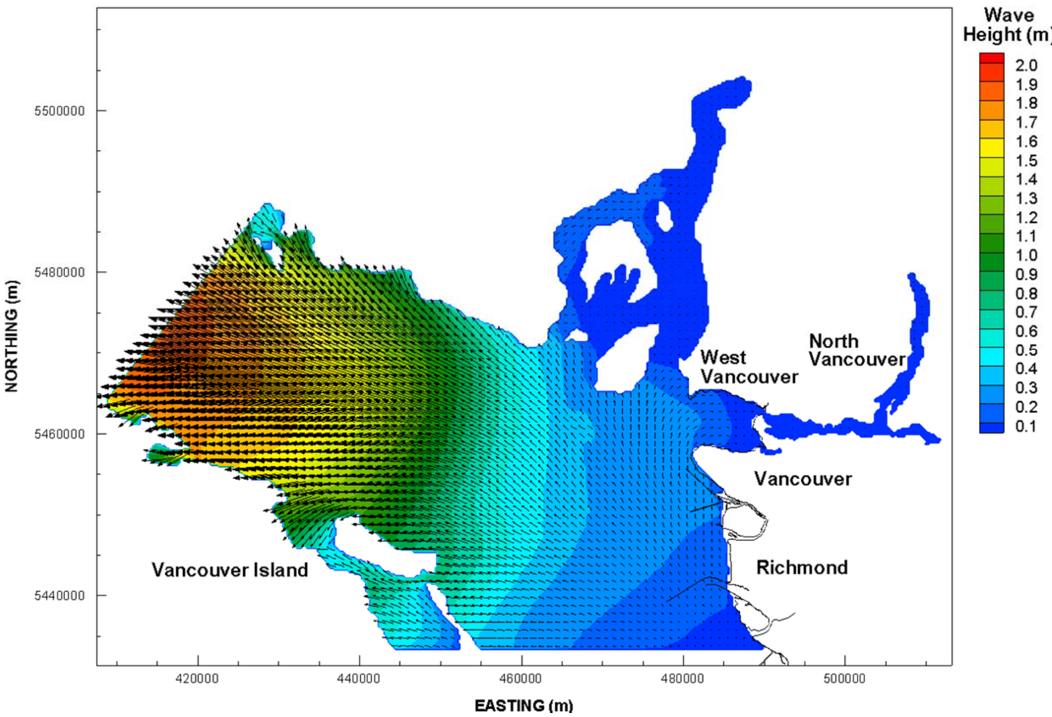
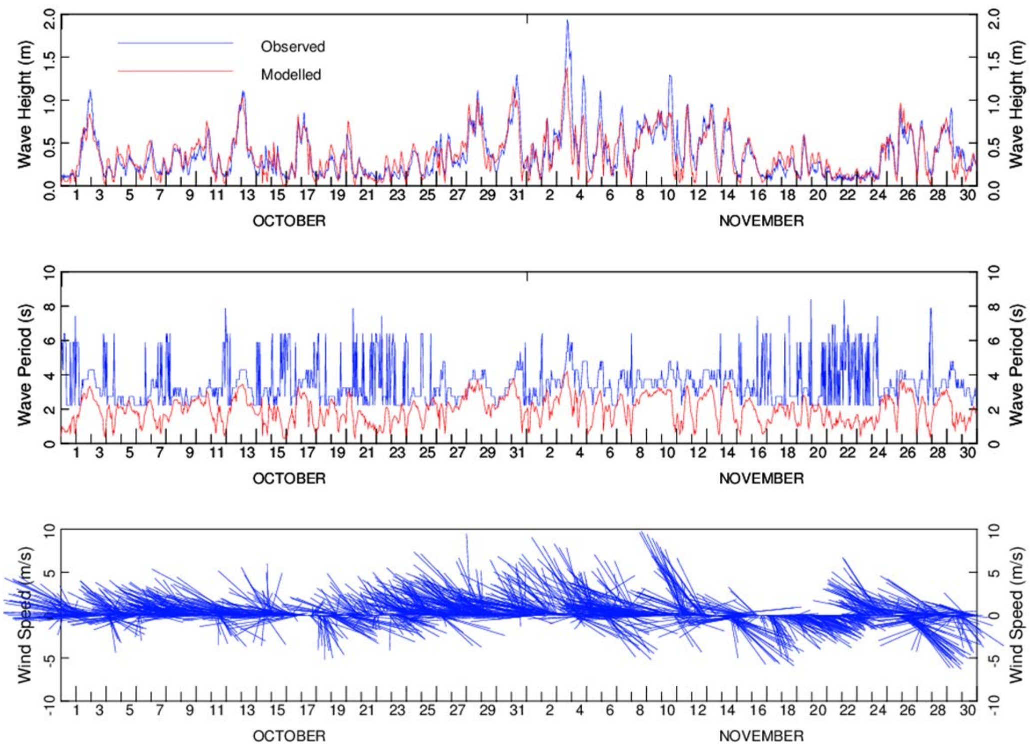


Figure 4 shows a comparison between the modelled and observed wave conditions at Halibut Bank for October and November 2005. The top panel provides a comparison of wave height. The middle panel provides a comparison of wave period. The bottom panel shows the wind velocity. In these panels, the blue line represents observed values and the red line represents modelled results.

Figure 4: Strait of Georgia/Burrard model validation.



The results show that the model reproduces the wave height and wave period reasonably well. The Root Mean Square Deviations (RMSD) for wave height and wave period are 0.15 m and 3.2 second respectively. Note that the model underestimates the wave period during the calm period (arbitrarily defined in this study as wave height less than 0.2 m). The long wave periods are typically associated with swell waves which consist of wind-generated waves that are not usually affected by local wind at that time. The swells have been generated elsewhere or some time ago. The swell process is not incorporated in the deepwater wave model. When all observed data points with wave height less than 0.2 m are removed from the analysis, the RMSDs for wave height and wave period reduced to 0.14 m and 1.5 second respectively.

Note that most waves in Burrard Inlet are locally generated as opposed to swell propagating from the open sea. When swells do propagate into the inlet following frontal systems, swells rapidly diminish in strength along the axis of the channel (Thomson 1977). Swell is not the dominant wave process in Burrard Inlet and was therefore not consider it in this analysis.

Figure 5 and **Figure 6** show the time-series of modelled waves at P11-English Bay #2 and at P5-Burnaby respectively.

Figure 5: Hindcast wave height at P11-English Bay #2.

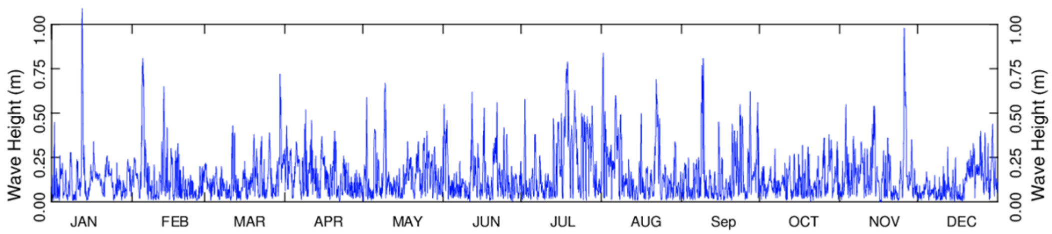
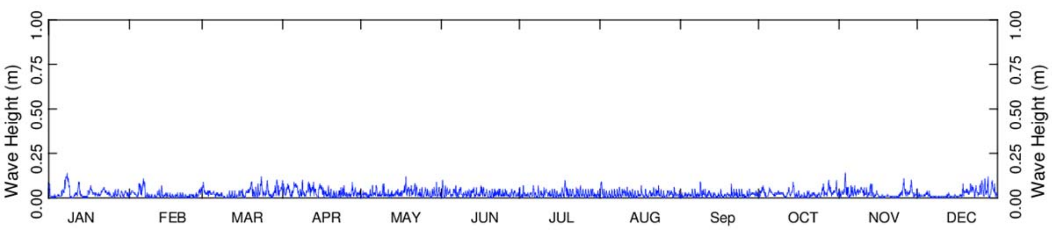


Figure 6: Hindcast wave height at P5-Burnaby.



The maximum wave height hindcast by the model at English Bay #2 and at Burnaby are about 1.09 m and 0.14 m respectively. To gain an understanding on the difference in wave climate between these two stations, wind rose plots[2] (**Figure 7** and **Figure 8**) were prepared using hourly wind data at English Bay #2 and at Burnaby.

[2] Wind rose plot is a graphic presentation of winds for specified areas, utilizing arrows at the cardinal and inter-cardinal compass points to show the direction from which the winds blow and the magnitude and frequency for a given period of time.

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Figure 7: Wind rose plot - English Bay #2.

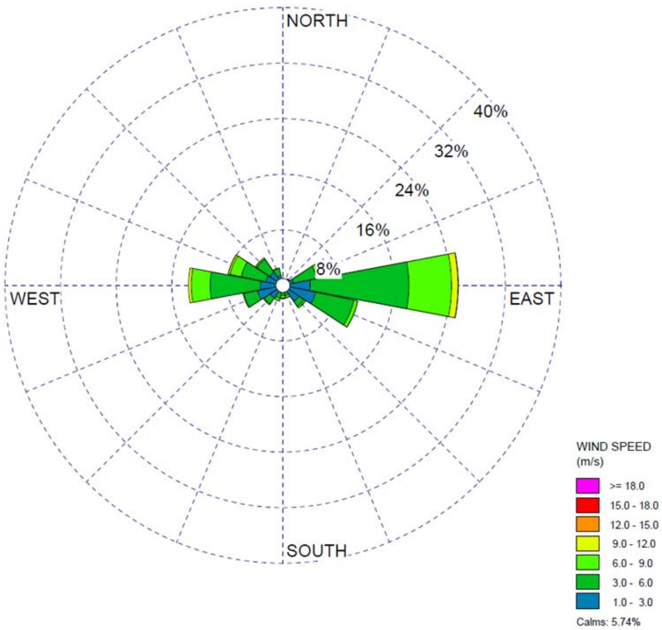
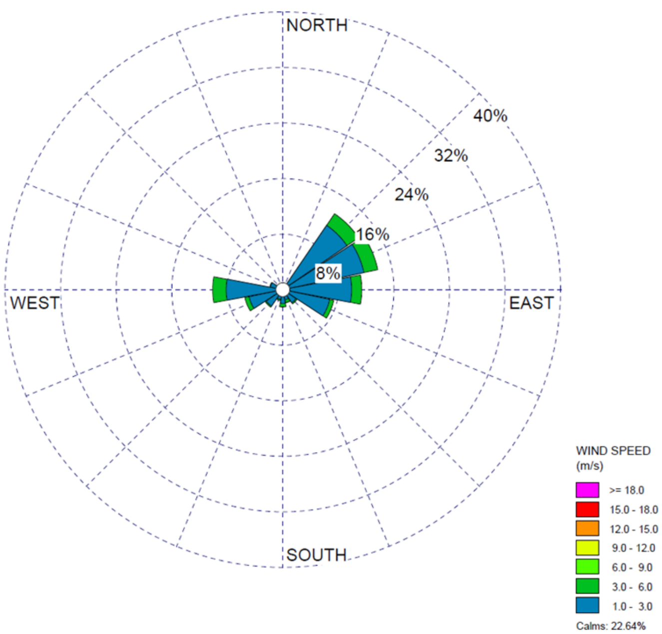


Figure 8: Wind rose plot – Burnaby.



The wind rose plots show that the wind climate at English Bay #2 is substantially windier than Burnaby. The wind speed at English Bay #2 was greater than 6 m/s (gentle to moderate breeze) about 16% of the time. The wind speed at Burnaby on the other hand exceeded 6 m/s only 0.01% of the time and was less than 3 m/s (calm to light breeze) about 91% of the time. The combination of the limited fetch and small local wind speed within Burrard Inlet makes it impossible to generate waves of any appreciable significance. Thus, it is expected that the hindcast waves would be much smaller at the Burnaby site.

The model results were based on hourly wind data generated by the CALMET Meteorological Model at 12 locations and observed wind at Halibut Bank. Field experience suggests that the hindcast waves at Burnaby appear to be small. Wind rose plots for the other three stations (Port Moody, Belcarra, and Second Narrows) situated on the east basin of the Burrard Inlet were prepared and shown below.

Figure 9: Wind rose plot – Port Moody.

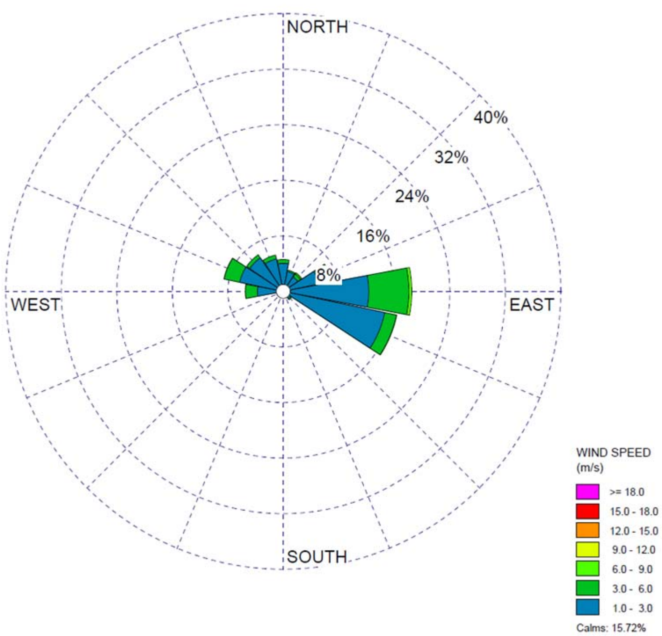


Figure 10: Wind rose plot – Belcarra.

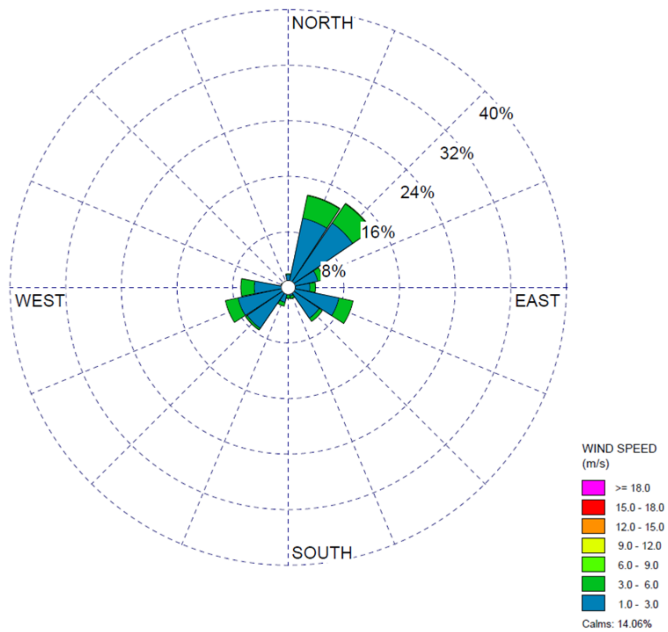
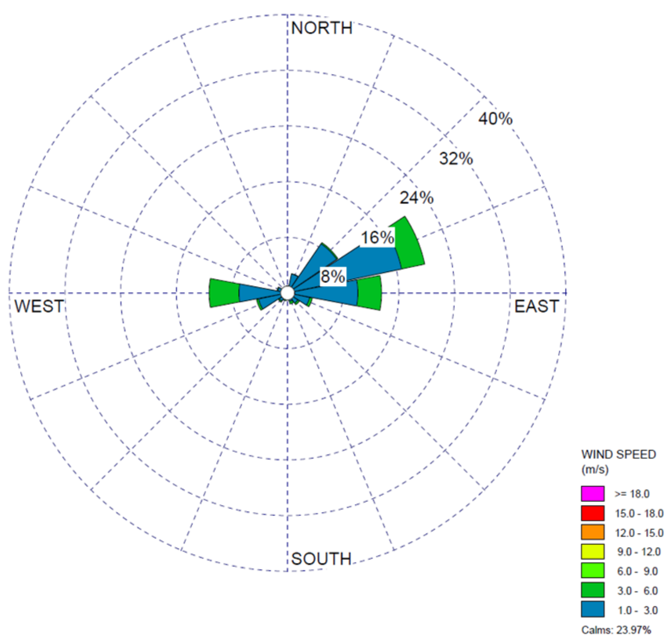


Figure 11: Wind rose plot – Second Narrows.



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The figures show that input winds in the east basin of Burrard Inlet are relatively calm. Winds exceeded 6 m/s only 0.8%, 0.3%, and 0.0% at Port Moody, Belcarra, and Second Narrows respectively. Therefore, only small waves would be predicted by the wave model.

Hourly wind data is available at the west basin of the Burrard Inlet from EC Vancouver Harbour CS Station (#1108446) between 1976 and 1988. This station is situated close to CALMET Station 08 – Burrard Inlet #1 as shown in (**Figure 12**).

Figure 12: Vancouver Harbour Station and Burrard Inlet #1 Station location.

Wind rose plots (**Figure 13** and **Figure 14**) were prepared using hourly wind data at Burrard Inlet #1 (2005) and at Vancouver Harbour CS (1976 to 1988).

Figure 13: Wind rose plot – CALMET Burrard Inlet #1 (2005).

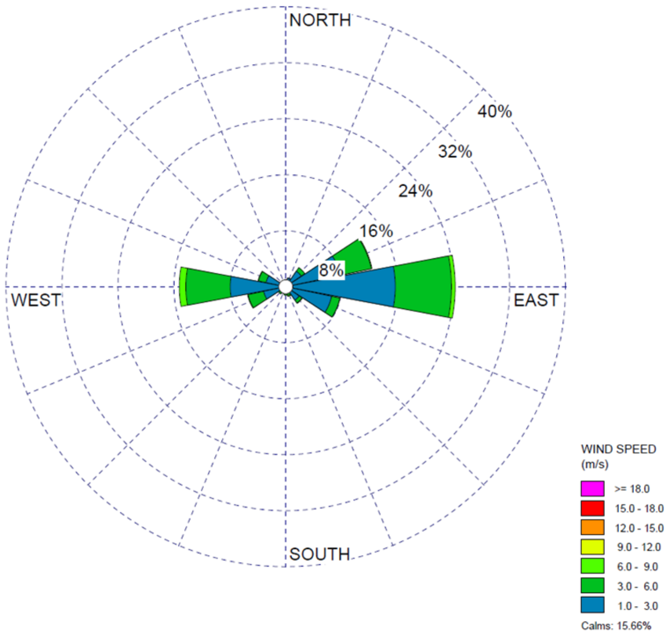
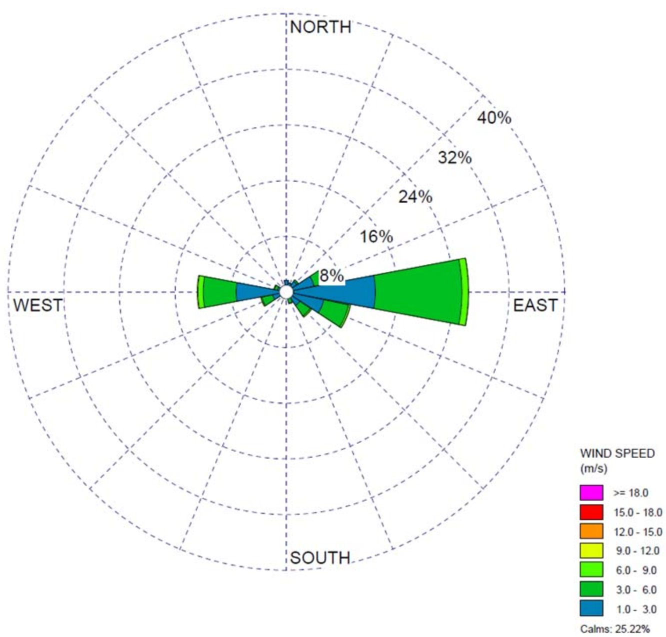


Figure 14: Wind rose plot – Vancouver Harbour Station (1976 to 1988).



The figures show that CALMET model predicts the wind direction in the west basin reasonably well but may slightly underestimate wind speed. At Burrard Inlet #1 station, wind speed exceeded 6 m/s about 1.9% of the time whereas at Vancouver Harbour station, the wind exceeded 6 m/s about 3.0% of the time. The maximum wave height hindcast by the model at Burrard Inlet #1 location is about 0.25 m.

A sensitivity test was conducted using only the observed wind data from Halibut Bank and from Vancouver International Airport (YVR). **Figure 15** and **Figure 16** show the time-series of modelled waves at English Bay #2 and at Burnaby respectively. Using this wind data the maximum wave height hindcast by the model at English Bay #2 and at Burnaby increased to about 1.30 m and 0.53 m respectively.

Figure 15: Hindcast wave height at English Bay #2 using Halibut Bank and YVR data.

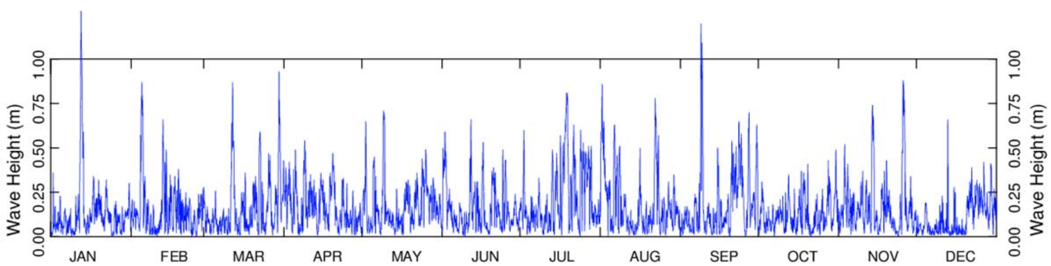
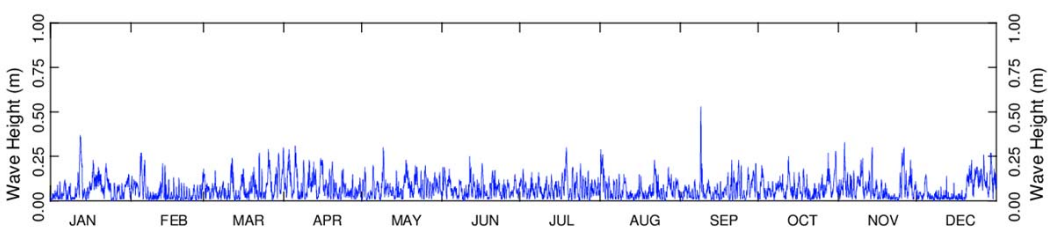


Figure 16: Hindcast wave height at Burnaby using Halibut Bank and YVR data.



4 SUMMARY AND CONCLUSIONS

A deepwater wave model was developed to hindcast the sea state condition at two locations (English Bay #2 and Burnaby) in Burrard Inlet for the year 2005. Key model inputs include hourly wind data at 12 locations provided by TWN as well as wind data from Environment Canada wave buoy at Halibut Bank. The wind climate at English Bay #2 is substantially windier than that at Burnaby. The maximum wave height hindcast by the model at English Bay #2 and at Burnaby are about 1.09 m and 0.14 m respectively. Field experience suggests that the hindcast waves at Burnaby appear to be small. A review of the data from the four wind stations in the east basin of Burrard Inlet confirms that the input wind climate is relatively calm in the east basin leading to small hindcast waves. A sensitivity test was conducted using only the observed wind data from Halibut Bank and from Vancouver International Airport. Using this wind data the maximum wave height hindcast by the model at English Bay #2 and at Burnaby increased to about 1.30 m and 0.53 m respectively.

If you have any questions, please do not hesitate to contact me at 604.980.6011.

Sincerely,

northwest hydraulic consultants ltd.

Prepared by:	Reviewed by:
E. C. WANG # 29366 — DEC 11	D.P. MUIR 27657 — 2014 DEC 11
Edwin Wang, P.Eng.	Dale Muir, P.Eng.
Hydrotechnical Engineer	Principal Engineer

REFERENCES

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DISCLAIMER

APPENDIX B. RESPONSE GAP ANALYSIS OUTPUTS

TABLE B.1 RESPONSE GAP ANALYSIS OUTPUTS FOR ALL LOCATIONS, FACTORS, TACTICS, AND SEASONS

Location	Tactic	Environmental Factor	Response Gap Index		
			Summer	Winter	Overall
Central Harbour	Aerial Recon	Visibility	34%	56%	45%
	Open Water (OW)	All	0%	2%	1%
		Wave	0%	0%	0%
		Wind	0%	0%	0%
	Protected Water (PW)	All	0%	2%	1%
		Wave	0%	0%	0%
		Wind	0%	0%	0%
	OW & PW	Visibility	0%	2%	1%
Outer Harbour	Aerial Recon	Visibility	34%	56%	45%
	Open Water (OW)	All	0%	3%	2%
		Wave	0%	0%	0%
		Wind	0%	0%	0%
	Protected Water (PW)	All	2%	6%	4%
		Wave	0%	0%	0%
		Wind	0%	0%	0%
	OW & PW	Visibility	0%	2%	1%
Georgia Strait	Aerial Recon	Visibility	34%	57%	45%
	Open Water (OW)	All	3%	8%	5%
		Wave	0%	0%	0%
		Wind	0%	0%	0%
	Protected Water (PW)	All	11%	18%	15%
		Wave	3%	3%	3%
		Wind	1%	1%	1%
	OW & PW	Visibility	0%	3%	2%
Neah Bay	Aerial Recon	Visibility	37%	56%	46%
	Open Water (OW)	All	31%	68%	52%
		Wave	14%	39%	28%
		Wind	0%	1%	0%
	Protected Water (PW)	All	85%	98%	92%
		Wave	80%	95%	88%
		Wind	0%	3%	2%
	OW & PW	Visibility	1%	1%	1%
Salish Sea	Aerial Recon	Visibility	37%	56%	47%
	Open Water (OW)	All	10%	18%	14%
		Wave	0%	2%	1%
		Wind	0%	1%	1%
	Protected Water (PW)	All	20%	22%	21%
		Wave	7%	12%	9%
		Wind	1%	3%	2%
	OW & PW	Visibility	1%	1%	1%

APPENDIX C. RESPONSE CAPACITY ANALYSIS TASK FORCES AND TRANSITS

Proposed Forces (Described in Project Application but not currently in WCMRC inventory)

	Strike Team	Type	Vessels	Specifications	Recovery (t/h)[50]	Storage (m^3)	Operating Environment	Home-port	Swath (m)	Boom (m)	Person-nel	Notes
TF 4	JDF 1	**Recovery (OSRV)**	High-Speed OSRV	27.5 m self-propelled	32	50 + (40)	Open Water	Ucluelet	50	100	10	Assigned oleophilic skimmers competent in heavy oils.
		Ancillary, Inferred	Workboat	5 m workboat	Tows J-boom for recovery with enhanced swathe width.							
			Additional Workboats		Ferry portable storage bladders (40 m^3)							
	JDF 2	**Recovery (OSRV)**	High-Speed OSRV	27.5 m self-propelled	32	50 + (40)	Open Water	Sooke	50	100	10	Assigned oleophilic skimmers competent in heavy oils.
		Ancillary, Inferred	Workboat	5 m workboat	Tows J-boom for recovery with enhanced swathe width.							
			Additional Workboats		Ferry portable storage bladders (40 m^3)							
	JDF 3	**Recovery (OSRV)**	High-Speed OSRV	20 m self-propelled	32	32 + (40)	Open Water	Esquimalt	50	100	10	Assigned oleophilic skimmers competent in heavy oils.
		Ancillary, Inferred	Workboat	5 m workboat	Tows J-boom for recovery with enhanced swathe width.							
			Additional Workboats		Ferry portable storage bladders (40 m^3)							
TF 5	SG 1	**Recovery (OSRV)**	High-Speed OSRV	20 m self-propelled	32	32 + (40)	Open Water	Delta Port	50	100	10	Assigned oleophilic skimmers competent in heavy oils.
		Ancillary, Inferred	Workboat	5 m workboat	Tows J-boom for recovery with enhanced swathe width.							
			Additional Workboats		Ferry portable storage bladders (40 m^3)							
TF 6	Barge 1[51]	**Recovery, Storage & Support**	**Large Response Barge**	10,000 m^3 tank barge	60	10,000 + (4) mini-barges	Open Water	Ucluelet	100	300	8[52]	Mini barges assigned to Current Buster strike teams.
		Ancillary, Inferred	(2) Workboats	5 m workboats	Tow concentration boom.							
TF 7	Barge 2	**Recovery, Storage & Support**	**Medium Response Barge**	5,000 m^3 tank barge	60	5,000 + (4) mini-barges	Open Water	Esquimalt[53]	100	300	6[4]	Mini barges assigned to Current Buster strike teams.
		Ancillary, Inferred	(2) Workboats	5 m workboats	Tow concentration boom.							
TF 8	Barge 3	**Recovery, Storage & Support**	**Medium Response Barge**	5,000 m^3 tank barge	60	5,000 + (4) mini-barges	Open Water	Esquimalt	100	300	6[4]	Mini barges assigned to Current Buster strike teams.
		Ancillary, Inferred	(2) Workboats	5 m workboats	Tow concentration boom.							

[50] WCMRC derated recoveries in t/hr are listed. For simulation purposes, a 1:1 conversion of t:m3 is used.

[51] Barges are described in section 13.11 of WCMRC, 2013: *"Similar to the existing Burrard Cleaner No. 18, the response barges will be fitted with offshore and sheltered water response gear including current buster sweep systems, traditional sweep sstems, ... One larger (10,000 tonnes of storage) in the Western area, and two secondary barges (5,000 tonnes of storage each) in the eastern area. The current Burrard Cleaner No. 10 should be moved to the Nanaimo Area."*

[52] Barge personnel include basic barge staffing requirements. They do not include tugboat crews, personnel on board for additional logistical duties, or extra personnel to manage offloading stations beyond those which can be operated by a light crew and strike team/shuttle boat crews. Personnel needs for WCMRC's proposed support OSV or for other logistical, command, reconnaissance, and other functions are not estimated.

[53] Barges were stationed in Esquimalt; specific final bases are not currently proposed by WCMRC. A strong argument might be made or relocate closer to the north or central Saanich Peninsula, such as Sidney or Duncan. This might slightly improve ROC results in the Strait of Georgia and possibly in Haro Strait. Burrard Cleaner No. 10 was not relocated to Nanaimo for this analysis; this move would be expected to slightly improve Strait of Georgia recoveries and degrade Outer Harbor recoveries, with minimal impact elsewhere.

Inferred Forces (Not included in WCMRC inventory or specified in project application but identified by authors as industry standard								
	Strike Team	Type	Vessels	Recovery (m^3/hr)[54]	Storage	Operating Environment	Mother Vessel	Personnel
TF 6	CB 1	Current Buster[55]	(1) small vessels to operate skimmer (1) small vessel to shuttle mini-barges (2) workboats	19.4	(2) 249 bbl mini-barges (29.7 m^3)	Protected Water	TF 6 Barge 1	9
	CB 2	Current Buster	(1) small vessels to operate skimmer (1) small vessel to shuttle mini-barges (2) workboats	19.4	((2) 249 bbl mini-barges (29.7 m^3)	Protected Water	TF 6 Barge 1	9
TF 7	CB 3	Current Buster	((1) small vessels to operate skimmer (1) small vessel to shuttle mini-barges (2) workboats (2) workboats	19.4	(2) 249 bbl mini-barges (29.7 m^3)	Protected Water	TF 7 Barge 2	9
	CB 4	Current Buster	(1) small vessels to operate skimmer (1) small vessel to shuttle mini-barges (2) workboats	19.4	(2) 249 bbl mini-barges (29.7 m^3)	Protected Water	TF 7 Barge 2	9
TF 8	CB 5	Current Buster	((1) small vessels to operate skimmer (1) small vessel to shuttle mini-barges (2) workboats	19.4	(2) 249 bbl mini-barges (29.7 m^3)	Protected Water	TF 8 Barge 3	9
	CB 6	Current Buster	(1) small vessels to operate skimmer (1) small vessel to shuttle mini-barges (2) workboats	19.4	(2) 249 bbl mini-barges (29.7 m^3)	Protected Water	TF 8 Barge 3	9

54 A crucial disc skimmer is assigned to each CB strike team. The crucial disc is selected as an advance skimmer well-tested in harsh environments (ADEC IOSC Presi). Although the crucial disc is only certified as competent in Grade I-III oils, anecdotal Deepwater Horizon reports suggest it may be competent in heavier oils. This analysis uses crucial disc skimmers as a proxy for the actual selection of an advanced oleophilic skimmer which will be competent in all oil weights expected over 72 hours of dilbit weathering in temperate marine waters. Recovery listed is the non-derated nameplate used in ROC.

55 Current Buster strike teams are equipped with a CB6, as described in WCMRC, 2013. Skimmers are not specified by WCMRC, except to list 4 extra brush skimmers of a given capacity on response barges.

Transit Distances & Times for Marine Response Forces

Task Force / Strike Team	Homeport[56]	Speed (knots)	To Outer Harbor Spill		To Central Harbor Spill[57]		To Strait of Georgia Spill		To Race Rocks Spill		To Haro Strait Spill	
			Distance (nm)	Travel Time (hrs)	Distance (nm)	Travel Time (hrs)	Distance (nm)	Travel Time (hrs)	Distance (nm)	Travel Time (hrs)	Distance (nm)	Travel Time (hrs)
TF 1 / Van 1	Burnaby	25	11.0	0.4	Nominal	0.3	31.0	1.2	88.0	3.5	60.0	2.4
TF 1 / Van 2	Vancouver Harbour	8.0	11.0	1.4	Nominal	0.3	31.0	3.9	88.0	11.0	60.0	7.5
TF 1 / Van 3	Vancouver Harbour	6.0	11.0	1.8	Nominal	0.3	31.0	5.2	88.0	14.7	60.0	10.0
TF 1 / Van 4	Vancouver Harbour	6.0	11.0	1.8	Nominal	0.3	31.0	5.2	88.0	14.7	60.0	10.0
TF 1 / Van 5	Vancouver Harbour	6.0	11.0	1.8	Nominal	0.3	31.0	5.2	88.0	14.7	60.0	10.0
TF 1 / Van 6	Burnaby	17.0	11.0	0.6	Nominal	0.3	31.0	1.8	88.0	5.2	60.0	3.5
TF 1 / Van 7	Vancouver Harbour	6.0	11.0	1.8	Nominal	0.3	31.0	5.2	88.0	14.7	60.0	10.0
TF 2 / Esq 1	Esquimalt Harbour	11.0	72.0	6.5	83.0	7.5	78.0	7.1	9.0	0.8	19.0	1.7
TF 2 / Esq 2	Esquimalt Harbour	6.0	72.0	12.0	83.0	13.8	78.0	13.0	9.0	1.5	19.0	3.2
TF 3 / PR 1	Prince Rupert	25.0	480.0	19.2	491.0	19.6	460.0	18.4	545.5	21.8	532.5	21.3
TF 4 / JDF 1	Ucluelet ** (Bamfield or Ucluelet)	20.0	167.0	8.4	178.0	8.9	173.0	8.7	91.0	4.6	114.0	5.7
TF 4 / JDF 2	Sooke**(Sooke or Becher Bay)	20.0	87.0	4.4	98.0	4.9	93.0	4.7	11.0	0.6	34.0	1.7
TF 5 / SG 1	Delta Port	26.0	22.0	0.8	33.0	1.3	29.5	1.1	56.0	2.2	34.0	1.3
TF 4 / JDF 3	Esquimalt ** (Saanich Pen.)	26.0	72.0	2.8	83.0	3.2	78.0	3.0	9.0	0.3	19.0	0.7
TF 6 / Barge 1, CB 1 & 2	Ucluelet	6.0	167.0	27.8	178.0	29.7	173.0	28.8	91.0	15.2	114.0	19.0
TF 7 / Barge 2, CB 3 & 4	Esquimalt	6.0	72.0	12.0	83.0	13.8	78.0	13.0	9.0	1.5	19.0	3.2
TF 8 / Barge 3, CB 5 & 6	Esquimalt** (Saanich Pen.)	6.0	72.0	12.0	83.0	13.8	78.0	13.0	9.0	1.5	19.0	3.2

56 Proposed forces locations are indicated with ** based on WCMRC statements and are not definitive. Parenthetical statements indicate the language of WCMRC's proposed location. As footnoted in task force composition tables, WCMRC may opt to distribute new forces differently. In particular, it is likely that a 20 m OSRV (JDF 3) and a medium response barge (TF 7 or 8) would be located on the northern Saanich Peninsula, rather than at Esquimalt. WCMRC also states the possible intention to move Burrard Cleaner No. 10 (TF 2 / Esq 2) to Nanaimo.

57 A nominal minimum transit time is used in the central harbor, of 15 minutes, for any calculations showing less than this time for transit. WRRL entries for WCMRC equipment in Burnaby & Vancouver Harbour all list a single Lat/Long coordinate. The granularity of data does not support more precise estimates; it is assumed that vessels may change in berth, state-of-readiness, and in their maneuvering needs at time of mobilization.

APPENDIX D. TRAVEL ROUTES IN LOWER FRASER RIVER ANALYSIS

TABLE D.1. TRANSIT ROUTES FOR BURNABY FORCES

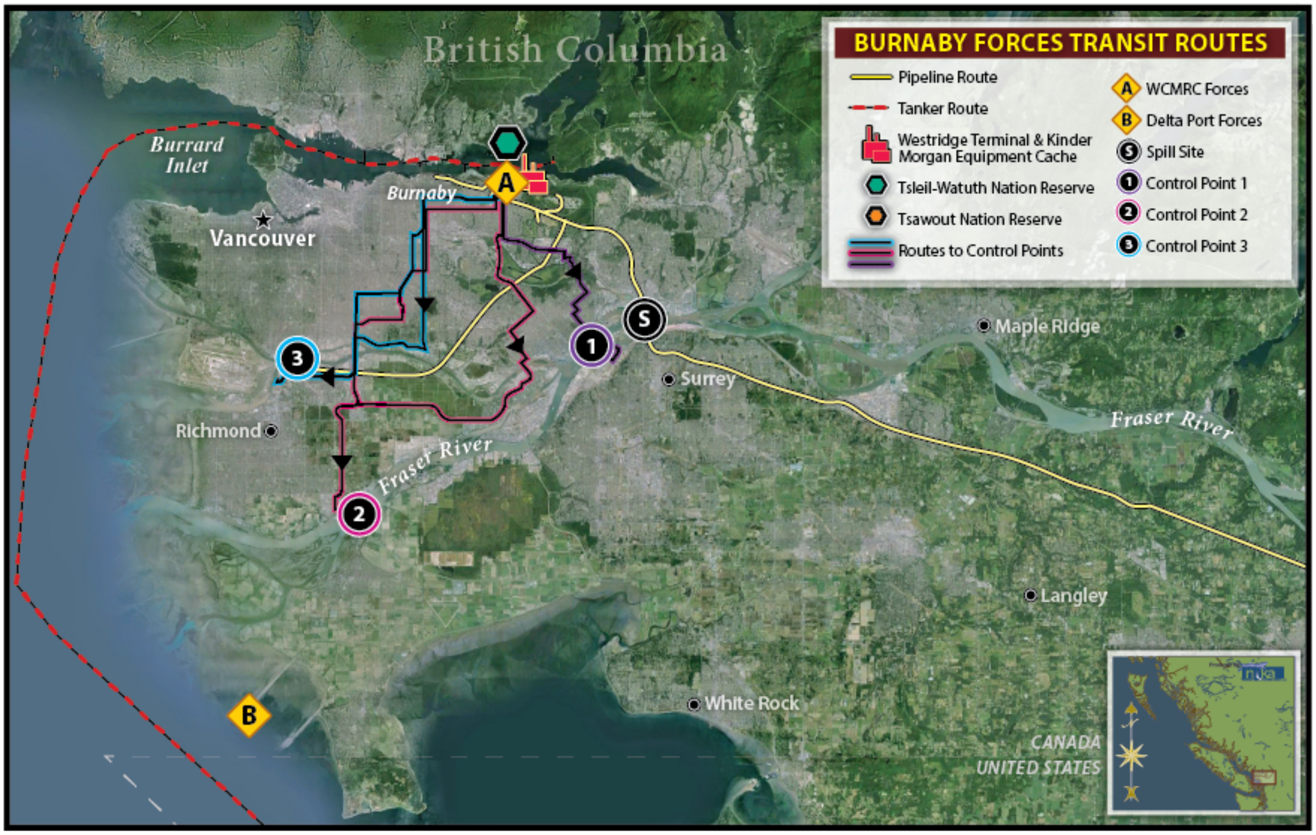


TABLE D.2. TRANSIT ROUTES FOR DELTA PORT FORCES

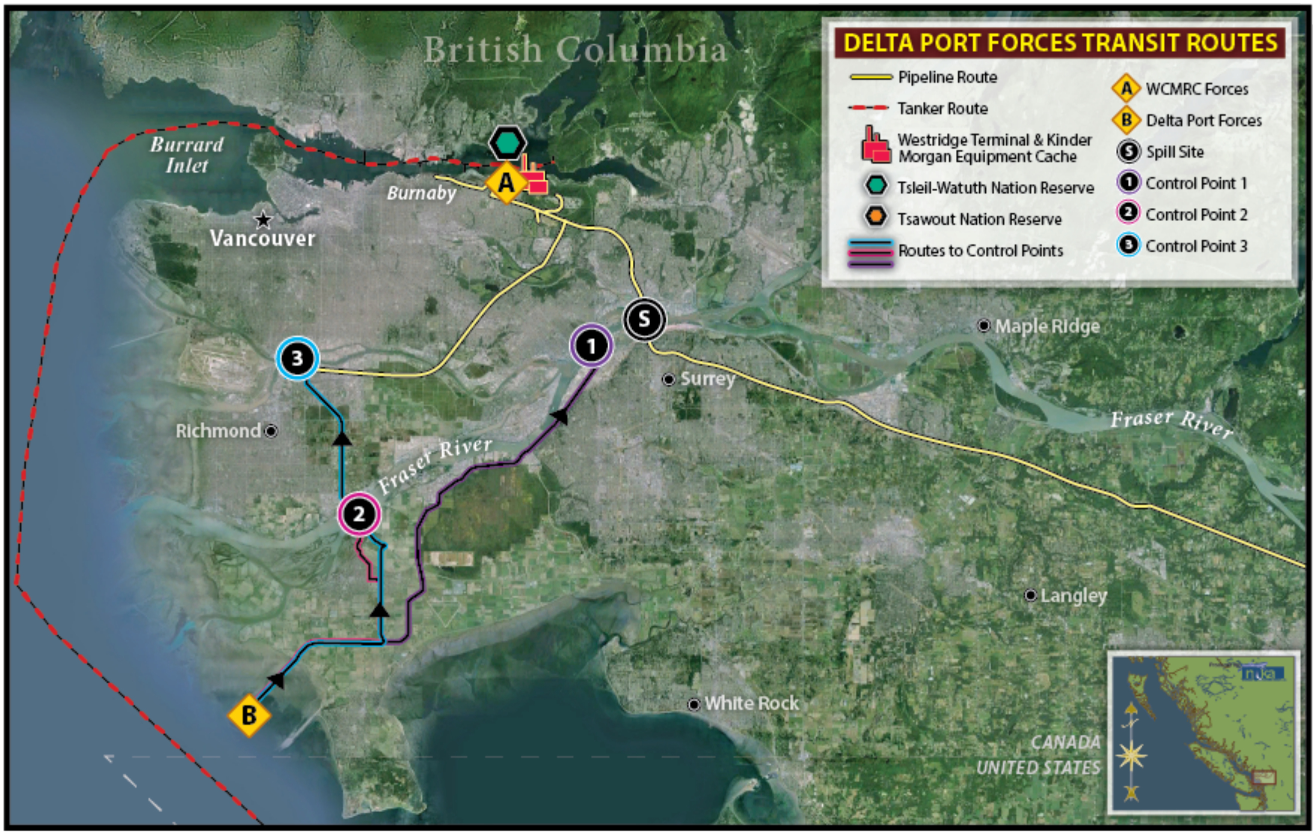
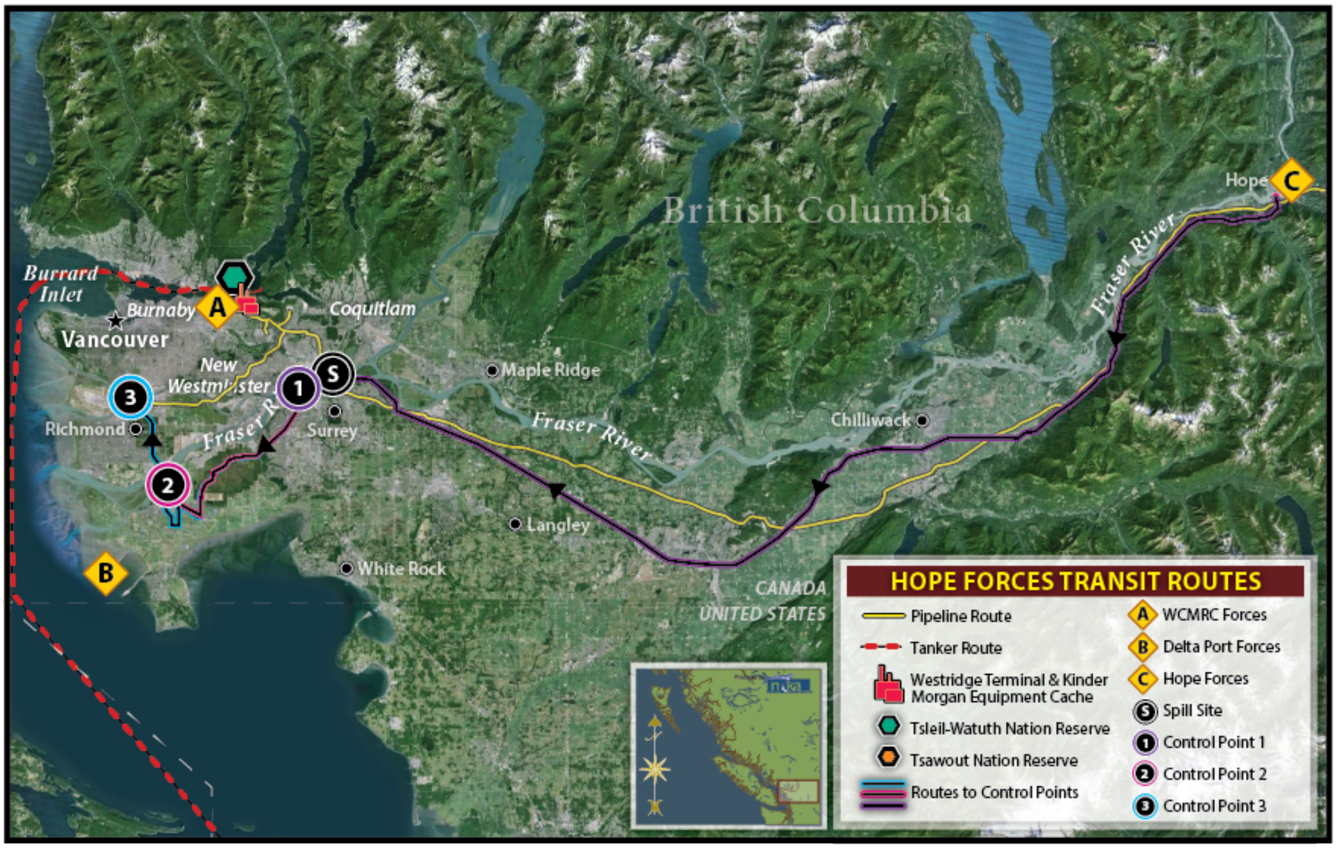


TABLE D.3. TRANSIT ROUTES FOR HOPE FORCES



2613 # APPENDIX E. CURRICULUM VITAE

Elise G. DeCola Curriculum Vitae

Elise G. DeCola

10 Samoset St., Plymouth, MA 02362
(508) 454-4009 * elise@nukaresearch.com

SUMMARY OF QUALIFICATIONS

Executive-level professional with deep expertise in marine environmental policy and resource management. Accomplished strategist and analyst with the ability to synthesize complex technical information to inform high-level policy.

EDUCATION AND CERTIFICATIONS

M.A., Marine Affairs, University of Rhode Island (1996)
Graduate Teaching and Research Assistant for Professor of Admiralty Law

B.S., Environmental Science, College of William and Mary (1992)

Incident Command System (ICS) 100-400; Hazwoper (24-hour); Coastal Oil Spill Response (NOAA); Shoreline Cleanup and Assessment Techniques (SCAT) Training; Oil Spill Response in Fast Water; Cold Water Oil Spill Response; Systematic Development of Informed Consent; FEMA Continuity of Operations (COOP) IS546 & IS547; Homeland Security Exercise and Evaluation Program (HSEEP) IS120, IS130, IS139; PADI Certified Divemaster

EXPERIENCE

Operations Manager, Nuka Research and Planning Group, LLC (2004 – Present) Co-founder and Operations Manager of environmental consulting firm specializing in oil spill prevention and response, risk and vulnerability assessment, all-hazards planning and mitigation, regulatory compliance, project management, marine transportation, and work group facilitation. Lead author for hundreds of technical studies, articles, and papers; serves as Principal Investigator for projects. A full list of project work is available upon request; selected projects include:

- *Oil Spill Contingency Plan development (pipeline, facility, vessel) (1996-present).* Developed oil spill contingency and emergency response plans for oil operations, including facilities, pipelines, exploration and production platforms, and vessels throughout US and in Australia and West Africa. Industry and government clients.
- *Expert witness, Northern Gateway Joint Review Panel (2011-2013).* Provided expert analysis and testimony to support First Nation Intervener review of Enbridge Northern Gateway pipeline Canadian National Energy Board Review.
- *British Columbia West Coast Spill Response Study (2013).* Researched and wrote three-volume study assessing state of oil spill preparedness and response planning in coastal British Columbia. Study included vessel traffic analysis for all Canadian Pacific waters and international best practices review to identify key elements of "world class" oil spill preparedness and response.
- *Geographic Response Plan Field Exercise Design and Facilitation (2009-present).* Developed and led multi-year project for Commonwealth of Massachusetts to systematically test protective coastal booming strategies across entire coastline.

1

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- *Oil Simulants Project (2013-present).* U.S. federal government-sponsored project to convene and facilitate a high-level working group to develop consensus on the use of oil simulant and surrogate materials in U.S. waters, including best practices.

Research Editor, Cutter Environment/Aspen Publishers/Oil Spill Intelligence Report (1998 – 2002) Freelance writer and editor of environmental literature; developed technical reports for oil spill professionals on topics including oil spill contingency planning, dispersant use, in-situ burning, non-tank vessel spills, environmental risk management, and statistical analyses of annual oil spill data.

Project Manager, Technical Response Planning Corporation (1996 – 2003) Managed special projects for major oil companies. Developed, trained, and exercised a Y2K Crisis Management Team for Texaco's International Safety, Health and Environment Division, and developed an on-line training program and response manual for Conoco's North America Incident Support Team.

Owner, private consulting business (1996 – 2003) Owner and manager of a private consulting business providing clients with project management and general consulting in natural resource issues. The firm specialized in environmental compliance and emergency response planning.

Marine Environmental Policy Fellow, Rhode Island Senate Fiscal and Policy Office (1996) Researched and developed legislation to strengthen the state's requirements for oil-carrying vessels, and participated in U.S. Senate hearings on the Chaffee Amendments to the Oil Pollution Act of 1990.

Marine Policy Intern, Save the Bay (Narragansett Bay) (1996) Participated in an agency-industry cooperative Regional Risk Assessment Team to develop oil pollution prevention regulations for a special Regulated Navigation Area for New England waterways.

SELECTED PUBLICATIONS

A complete list of publications is available upon request.

DeCola, E.G., T. L. Robertson, J. Robida, B. House, and W.S. Pegau. *2014. Oil spill simulants workshop process and outcomes*. International Oil Spill Conference Proceedings: May 2014, Vol. 2014, No. 1, pp. 102-113.

Mattox, A., E.G. DeCola, and T. Robertson. 2014. *Estimating mechanical oil recovery with the response options calculator*. Presented at 2014 International Oil Spill Conference. Vol. 2014, No. 1, pp. 1759-1771.

Nuka Research and Planning Group, LLC. 2013. *West Coast spill response study, Volume 1: Assessment of British Columbia marine oil spill prevention and response regime*. Report to the British Columbia Ministry of Environment.

Nuka Research and Planning Group, LLC. 2010. *Alaska Risk Assessment of Oil and Gas Infrastructure: Summary of Phase 1 Alaska Risk Assessment Challenges and Accomplishments.* Report to Alaska Department of Environmental Conservation.

DeCola, E.G., M. Popovich, and J. Ball. 2009. *From Theory to Practice: Lessons Learned during the Geographic Response Plan Exercise in Rhode Island.* Proceedings of the 32nd Arctic and Marine

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RECOGNITION AND OTHER ACTIVITIES

First Place Planning Poster, International Oil Spill Conference (2011)
Peer Reviewer, International Oil Spill Conference (2011, 2014)
Platform Session Presenter, International Oil Spill Conference (1999, 2003, 2008, 2014)
Platform Session Presenter, Arctic Marine Oilspill Pollution Technical Seminar (2000, 2006, 2008, 2009, 2011)
Presenter, Coastal Zone Conference (1997, 2001)
Presenter, Massachusetts Soils Conference (2010)
Member, Environmental Business Council of New England
Member, Society for Women Environmental Professionals
Appointed Member, Plymouth Tidal Beaches Advisory Councill (2011-2014)

APPENDIX F. ACRONYMS AND ABBREVIATIONS

API	American Petroleum Institute
ASTM	American Society for Testing and Materials
bbl	Barrel
BC	British Columbia
CALMET	California Meteorological Model
CB	Current Buster
CLB	Cold Lake Blend Diluted Bitumen
CP	Containment Point
cST	Centistokes
Dilbit	Diluted bitumen
DNV	Det Norske Veritas
EDRC	Effective Daily Recovery Capacity
ft	Feet
hr	Hour
IOSC	International Oil Spill Conference
Km	Kilometer
kph	Kilometers per hour
kts	Knots
LLC	Limited Liability Company
m	Meter
m^3	Cubic meter
MM5	Penn State Fifth Generation Mesoscale Model
n/a	Not applicable
NAS	National Academy of Sciences (US)
NCAR	National Center for Atmospheric Research (US)
NDBC	National Data Buoy Center (US)

NEB	National Energy Board (CA)
NHC	Northwest Hydraulic Consultants
NOAA	National Oceanic and Atmospheric Administration (US)
OSCAR	Oil Spill Containment and Response
OSV	Offshore Supply Vessel
OSRO	Oil Spill Response Organizations
OSRV	Oil Spill Recovery Vessel
OW	Open Water
PW	Protected Water
RCA	Response Capacity Analysis
RGA	Response Gap Analysis
RGI	Response Gap Index
ROC	Response Options Calculator
ST	Strike Team
TF	Task Force
Trans Mountain Expansion	Trans Mountain Pipeline Expansion
TR	TERMPOL Report
UMBRA	Upper Mississippi River Basin Association
UMWM	University of Miami Wave Model
US	United States
USCG	United States Coast Guard
USDHS	United States Department of Homeland Secuirty
USEPA	United States Environmental Protection Agency
WCMRC	Western Canada Marine Response Corporation
WRRL	Western Response Resource List

APPENDIX G. CERTIFICATE OF EXPERTS' DUTY

Nuka Research has been engaged on behalf of the Tsleil-Waututh Nation, the City of Vancouver, and Tsawout First Nation to provide evidence in relation to Trans Mountain Pipeline ULC's Trans Mountain Expansion Project application currently before the National Energy Board.

In providing evidence in relation to the above-noted proceeding, Nuka Research acknowledges that it is our duty to provide evidence as follows:

1. to provide evidence that is fair, objective, and non-partisan;

2. to provide evidence that is related only to matters within our area of expertise; and

3. to provide such additional assistance as the tribunal may reasonably require to determine a matter in issue.

We acknowledge that our duty is to assist the tribunal, not act as an advocate for any particular party. This duty to the tribunal prevails over any obligation we may owe any other party, including the parties on whose behalf we are engaged.

Date: May 22, 2015 Signature: ____________________