Fate and Effect of Oil Spills from the Trans Mountain Expansion Project in Burrard Inlet and the Fraser River Estuary

Prepared
for

Tsleil-Waututh Nation,

City of Vancouver,

and

Living Oceans Society

Prepared
by

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1. Trans Mountain Pipeline ULC (hereafter, Trans Mountain) has applied for a Certificate of Public Convenience and Necessity to construct and operate (i) 987 km of new pipeline from Edmonton to Burnaby; (ii) an expanded petroleum storage facility in Burnaby; (iii) a new and expanded dock complex at the Westridge Marine Terminal; (iv) two new pipelines from the storage facility to the Terminal; and (v) a roughly seven-fold increase in marine shipping activities (hereafter, Project).

2. The Project would increase pipeline transport capacity from about 47,700 m^3/d to 141,500 m^3/d (i.e., 300,000 bbl/d to 890,000 bbl/d), with a concomitant increase of Aframax-class tanker traffic from five to as many as 34 vessels per month. Three new berths for the Aframax tankers would be constructed at the Westridge Marine Terminal in Burnaby, BC as well. Beginning at the Burnaby terminal, the tanker route would pass through Central, Inner and Outer Harbours of Burrard Inlet, across the mouths of the Fraser River delta in Georgia Strait, through the Gulf Island passages and Haro Strait on the southeastern end of Vancouver Island, and then through the Juan de Fuca Strait, remaining in Canadian territorial waters to the North Pacific Ocean (Figure 1). Tanker traffic would remain within about 10 km of shorelines along nearly this entire route to the open ocean. Along this route, tanker traffic passes through some of the most biologically productive, sensitive and ecologically important marine waters in Canada, especially within Georgia Strait.

3. The petroleum products shipped will consist almost entirely of oil-sands bitumen diluted with either gas condensate (i.e., "dilbit") or synthetic crude oil ("synbit"). Dilution lowers the viscosity of the resulting fluid so that it can be shipped through pipelines.

4. The Salish Sea, and especially Burrard Inlet and the Fraser River estuary, is one of the most ecologically important coastal marine habitats along the entire Pacific coast of North America. It is seasonally inhabited by over a million sea- and shorebirds, including more than 30% of the global population of snow geese. It is one of just 6 sites along the west coast of North America of international and hemispheric importance. It is the only site of comparable ecological importance from the Canadian border with the State of Washington to the Copper River delta in Alaska.

5. The Fraser River is the largest single salmon-producing river on the Pacific Coast of North America (including Alaska), supporting runs of sockeye

salmon (*Oncorhynchus nerka*) that can number in the tens of millions, along with major runs chinook (*O. tshawytscha*), chum (*O. keta*), pink (*O. gorbuscha*) and coho (*O. kisutch*) salmon, as well as steelhead trout (*O. mykiss*). These returning adult salmon support several species of marine mammals, including the endangered southern resident killer whale (*Orcinus orca*) stock, commercial fisheries worth millions of dollars, and subsistence harvests for First Nations that depend on them for maintaining their cultural heritage as well as for nutrition. Juvenile salmon out-migrating from the Fraser River depend on the estuary's high biological productivity and in turn provide forage for the seabirds.

6. The combined aggregations of extraordinarily high densities and numbers of sea- and shorebirds, marine mammals and fish make them especially vulnerable to potentially devastating mortalities should a major oil spill occur in Burrard Inlet or the Fraser River estuary as a result of the Project.

7. My report is divided into two major sections. The first section contains my peer-review of the Trans Mountain ecological risk assessment (ERA), where I evaluate the methods used for the ERA in the context of requirements stipulated by the National Energy Board. The second section contains my independent assessment of the fate and effects of oil spills from the Project in Burrard Inlet and the Fraser River estuary, focusing on how diluted bitumen accidentally discharged could disperse within the receiving waters, how long it could persist on shorelines and how it could affect marine-dependent organisms. My emphasis in the second section is on oil dispersion pathways, shoreline retention factors and mechanisms of toxic and ecological injury that are either not considered or receive inadequate emphasis in the Trans Mountain application and supporting documents.

1.2 Peer-Review of the Trans Mountain Ecological Risk Assessment

8. Oil spills are classic "low-probability/high-consequence" events, requiring careful assessment of potential impacts to the most sensitive species and habitats in addition to habitats and species most likely to be exposed. By confounding assessments of exposure probability and sensitivity of species and habitats, the Trans Mountain ERA largely excludes the most serious consequences that could occur from consideration.

9. The National Energy Board has specified that the Trans Mountain application

> …must include an assessment of potential accidents and malfunctions at the Terminal and at representative locations

along the marine shipping routes. Selection of locations should be risk informed considering both probability and consequence.

10. However, Trans Mountain ERA fails to select locations informed by the potential consequences of oil spills. Trans Mountain therefore ignores and fails to comply with the National Energy Board's requirements by selecting locations only based on their assessment of the probability of an oil spill, locations that are neither representative nor typical of the surrounding area.

11. The Trans Mountain ERA is based on a well-established five-step procedure for integrating oil exposure risk and the vulnerability of exposed species to estimate the overall likelihood of adverse impacts, including low-probability impacts that could have catastrophic consequences, should a spill occur. The five steps include: (1) problem formulation, (2) exposure assessment, (3) hazard assessment, (4) risk characterization, and (5) an evaluation of certainty and confidence in predictions. Problem formulation involves identifying the nature of the threat, and its spatial and temporal boundaries. Exposure assessment involves evaluation of the likelihood that species or habitats will be exposed to contamination, and hazard assessment involves assessment of the species' or habitat's sensitivity to exposure. Risk characterization is the process of integrating the likelihood of exposure and the likelihood of adverse consequences should exposure occur, and the uncertainty analysis assesses the overall confidence in the quantitative risk estimates of injury.

12. There are at least four fundamental deficiencies in Trans Mountain's ERA:

    (a) it fails to integrate oil exposure risk based on multiple locations within ecologically distinct sub-regions along the marine shipping routes, including at or near ecologically-sensitive areas;

    (b) it fails to assess hazard independently of exposure. Trans Mountain concludes that hazard is minimal based on its conclusion that there is a low probability of oiling. However, Trans Mountain should have assessed hazard based on species sensitivity to oiling independently of oiling probability;

    (c) it fails to assess the possibility of organisms being exposed to submerged oil; and

    (d) it fails to consider all the ways that oil can harm organisms.

1.2.1 Trans Mountain fails to integrate exposure based on multiple locations

13. The Trans Mountain ERA assessed oil exposure risk on the basis of four assumed spill origin locations, one for each ecologically distinct sub-region along the tanker route. For example, for the initial segment of the oil tanker route from the Westridge Marine Terminal to the islands in the southwestern Strait of Georgia, a single point of oil spill origin was chosen as "typical." The spill origin selected was chosen because it was considered to be the most likely site for an accident caused by a collision between ferry vessels moving between the City of Vancouver and Vancouver Island and oil tanker vessels. However, that location is well to the south of Sturgeon Bank and the South Arm Marshes, which are among the most sensitive habitats within the Salish Sea.

14. By assuming that a single point of spill origin is typical for the Strait of Georgia, the Trans Mountain ERA implicitly assumes that the only accidents that could ever occur would involve collisions between ferry and oil tanker vessels. In reality, oil spill accidents usually involve combinations of events that appear highly unlikely in retrospect. This is why these accidents are both rare and difficult to anticipate. Arbitrarily dismissing all other possibilities for accidents, including any that may occur within Burrard Inlet (apart from the Westridge Marine Terminal) or elsewhere along the tanker route amounts to unreasonably eliminating much or even most of the risk of a spill occurring. More importantly, spills that originate at different locations along the tanker route can have very different trajectories, and hence impact habitats differently. The potential effects of these differences are lost by only considering a single location for spill origin.

15. Rather than relying on a single point of origin, the oil exposure assessment should have been based on trajectory modeling results from several points along the tanker route. Integrating exposure risks across several possible spill origin sites provides a more accurate assessment of exposure risk for habitats, especially habitats of high concern such as the intertidal flats at Sturgeon Bank and the South Arm Marshes. The single spill origin selected by Trans Mountain resulted in a low probability of oiling for these sensitive habitats, but had the point been moved a few km toward Burrard Inlet, the oiling risk would likely have been considerably greater.

1.2.2 Trans Mountain fails to assess hazard independently of exposure

16. Oil slick trajectory scenarios based on models driven by historical wind and current data led to identification of habitats and shoreline types most likely to be oiled. Because results from a single location were incorrectly taken as typical of Georgia Strait, habitats and the species that had low estimated

likelihood of oiling were then presumed to have low sensitivity to oiling. This approach effectively confounds exposure risk and hazard assessment, whereas the conceptual foundation of the ERA expressly separates assessments of exposure and hazard, precisely to avoid such confounding. This confounding alone invalidates the Trans Mountain ERA.

17. The method used by Trans Mountain to evaluate the sensitivity of species to oiling is also flawed. In the Trans Mountain ERA, species sensitivity to oiling is semi-quantitatively "assessed" by assigning "biological sensitivity ranking factors" (BSF) to species or habitats categorized on the basis of taxonomic or habitat similarity. The four categories considered include seabirds, marine mammals, fish and other inhabitants of the water column and shorelines. Within each category, the same semi-quantitative measures of sensitivity (low, BSF=1; medium, BSF=2; high, BSF=3, and very high, BSF=4) are applied. This approach is invalid because it creates a misleading appearance of false equivalencies for sensitivities to oiling across species and habitats. For example, all birds are correctly viewed as highly sensitive to oil exposure, yet shorebirds are assigned the lowest BSF, equating their sensitivity to that of pelagic fish or marine invertebrates such as worms, mussels, and crabs etc., all of which are substantially less sensitive to oil exposure than shorebirds. These false equivalencies are artifacts of the inappropriate categorization scheme imposed on the organisms considered. This scheme is not based on fundamental differences in sensitivity, but on taxonomic similarities that are largely blind to the inherent sensitivities of the organisms evaluated.

1.2.3 Trans Mountain fails to assess the possibility of organisms being exposed to submerged oil

18. The Trans Mountain ERA dismisses the possibility of exposure to submerged oil on the basis of the flawed experimental studies done to evaluate the susceptibility of diluted bitumen to submerge in fresh water from evaporation alone.

19. Several experimental studies have been conducted to evaluate the environmental conditions and times required for diluted bitumen to submerge in receiving waters. In particular, five experimental studies were conducted using two bitumen/diluent blends (Access Western Blend (AWB) and Cold Lake Bitumen (CLB)) that were considered to be typical of most of the products that would be shipped through the Project. The experimental results for CLB were also used for the ERA presented in the Trans Mountain application.

20. Those studies provide limited guidance for predicting the time required for these products to submerge in water. The thick oil layers (1 mm–20 mm)

used in these experiments would rarely occur during the initial discharge phase of a real oil spill unless the spill occurred in a confined area that prevented the oil layer from spreading to its fullest natural extent. The thickness of diluted bitumen slicks that are allowed to spread in unconfined waters is around 0.4 mm, which is 3 to 50 times thinner than the oil slick layers used in the experiments. Because evaporation rates depend strongly on oil slick thickness, all of these experiments considerably over-estimated the time required for the residual diluted bitumen to submerge in water.

21. A recently-published study that directly compared measured evaporation rates from an experimental oil spill with predicted evaporation rates derived from equations based on thick oil slick experiments showed that the equations overestimated the time required for evaporative losses by a factor of around 20.

22. Appropriate corrections for actual oil slick thicknesses likely to be encountered immediately following discharge in Burrard Inlet or the Fraser River estuary indicate that under conditions of warm summer temperatures and moderate wind speeds, the density of diluted bitumen could increase above that of fresh water within as little as 24 hours, which could cause the diluted bitumen to submerge.

23. The time required for evaporative weathering to increase the density of diluted bitumen above that of fresh water is a crucial concern in Burrard Inlet and the Fraser River estuary, because the surface waters are fresh or nearly so during the spring and summer freshet of the Fraser River. The paramount concern here is not simply whether evaporation could cause diluted bitumen to sink to the seafloor in full-strength seawater, but whether it could submerge in the fresh waters of the Fraser River freshet. The threshold for submergence in fresh water is substantially lower than for sinking in seawater having salinities typical of the open ocean, because the lower density of freshwater. While not usually emphasized in their conclusions, the results of the five experimental studies that evaluated evaporation rates and concomitant density increases of diluted bitumen consistently suggest susceptibility to submergence in fresh water after as little as a day, once realistic oil slick thicknesses are accounted for.

24. As a result, potentially major oil exposure pathways are largely excluded from the Trans Mountain ERA, comprising a host of species, many of which are important for commercial and subsistence harvests. These species include clams, mussels and other suspension-feeding organisms, juvenile Pacific herring, juvenile salmonids out-migrating from the Fraser River watershed and salmon hatcheries in Burrard Inlet during spring, and adult sockeye salmon returning to the Fraser River.

25. Bitumen submerged beneath the sea surface is much more difficult to track as it disperses within receiving waters to shorelines, the seafloor, and the open ocean, all of which exposes biological communities along the way that are difficult to observe or sample, and increases uncertainty regarding the extent and severity of contamination. This increased uncertainty routinely leads to overly pessimistic public speculation regarding contamination that can have severely adverse consequences for First Nation subsistence harvesting and for commercial activities such as commercial fishing and tourism that depend on public perceptions of waters uncontaminated by oil products.

1.2.4 Trans Mountain fails to consider all the ways that oil can harm organisms

26. The Trans Mountain application fails to consider any consequences that may result from photo-enhanced toxicity. This toxicity mechanism has recently been shown to be important for species such as Pacific herring (*Clupea pallasi*) that deposit eggs on intertidal reaches of shorelines and which is an important component of the marine ecosystem in the Salish Sea.

27. Photo-enhanced toxicity occurs when some of the compounds in bitumen dissolve into water and are subsequently absorbed by translucent embryos. When exposed to sunlight, these compounds promote oxidation of tissues within the embryos, in effect burning them.

28. Photo-enhanced toxicity occurred in herring embryos on the shorelines of San Francisco Bay after the 2009 *Cosco Busan* oil spill.

1.2.5 Conclusions of Peer Review

29. The combined effects of the flawed methods incorporated into the Trans Mountain ERA are most prominently illustrated by the failure of the ERA to consider the numbers of resident and migratory birds at risk of oil exposure, and the comprehensive absence of quantitative estimates of adverse effects for any of the species considered. Whereas the Trans Mountain ERA mistakenly claims that waders and shorebirds are "...are not present in large numbers and are widely distributed", the Fraser River estuary in fact supports some of the highest densities and numbers of these birds within the western hemisphere. For example, counts of western sandpipers - a shorebird - routinely range from 0.5 – 1 million annually within the Fraser River estuary. If a spill resulted in oil driven onto Sturgeon Bank or the South Arm Marshes during the spring or fall bird migration when they may be inhabited by 100,000 or more shorebirds at a time, a massive mortality event could ensue involving possibly several hundreds of thousands of birds. Yet

such a real possibility is nowhere mentioned, let alone assessed in the Trans Mountain ERA.

30. More generally, the Trans Mountain application fails to adequately value the extraordinary biological productivity, diversity, and hence ecological importance of the estuarine ecosystem of the Fraser River. The Fraser River estuary is arguably the most important estuarine ecosystem on the entire Pacific coast of North America, but the application fails to reflect this. Instead, by considering species separately with little emphasis on the importance of the Fraser River estuary as a whole to the global populations of species or to the ecological integrity of the wider Pacific coastal ecosystem of which it is a major part, the application undervalues the potential ecological consequences of oil spills.

31. Trans Mountain's ERA is fundamentally flawed and should not therefore be used to assess the ecological risks of the Project. A proper ERA that does not confound the assessment steps, considers multiple potential spill origin sites, evaluates habitat sensitivities on the basis of species' densities and abundances and species sensitivities on the basis of their intrinsic vulnerability to bitumen exposure, recognizes the susceptibility of bitumen to submerge in receiving waters and includes the range of exposure and damage pathways must be performed to credibly evaluate the ecological risks involved.

1.3 Assessment of the Fate, Behaviour, and Effects of Oil Spilled into Burrard Inlet and the Fraser River Estuary

32. Diluted bitumen spilled into surface waters of Burrard Inlet and the Fraser River estuary will follow a characteristic sequence of changes. Immediately following initial discharge and depending on the volume spilled, rapid evaporation of the gas condensate components of diluted bitumen may create inhalation hazards for wildlife such as seabirds and marine mammals in the immediate vicinity. If winds are sufficiently strong to generate breaking waves, diluted bitumen may be entrained into the upper water column as small oil droplets, and hence available to suspension-feeding fish and invertebrates.

33. As the more volatile components are lost by evaporation, the increasing density of bitumen that remains on the sea surface may cause it to become neutrally buoyant with respect to the density of the sea surface water immediately beneath it, causing it to submerge. Submergence would be hastened if inorganic suspended particulate material (SPM) entrained in the water column adheres to the bitumen, increasing the density of the bitumen-

SPM aggregate, especially in the high-sediment plume of the Fraser River during the spring and summer freshet.

34. Bitumen remaining on the sea surface will pose a contact hazard for seabirds and marine mammals. Eventually, bitumen on the sea surface will either become tar balls that submerge in the water column, or impinge on shorelines where some of it will remain, and some of it will be re-floated back to the sea.

35. Bitumen accumulating on shorelines would pose a contact hazard for intertidal organisms generally, and additional hazards from embryotoxicity to early life stages of intertidal organisms, and from photo-enhanced toxicity to translucent organisms. If bitumen accumulates on shoreline sediments and is subsequently re-floated, it will be much more susceptible to submergence or sinking to the seafloor.

36. Surface waters of Burrard Inlet and the Fraser River estuary are often brackish or nearly fresh within the Fraser River plume. Frequent winds, warm temperatures and high Fraser River discharge during spring and summer are especially favourable for submergence of diluted bitumen. The large tidal excursion range is conducive to spilled diluted bitumen stranding on shorelines, particularly on armoured or low-gradient shorelines in Burrard Inlet, and at the highly productive, low-gradient mudflats at Sturgeon Bank and the South Arm marshes.

37. Diluted bitumen is prone to submergence in fresh and brackish waters. Experiments performed to assess how fast the density of diluted bitumen would increase during a spill have seriously overestimated the time required for it to submerge. Under near worst-case ambient conditions of warm summer temperatures and moderate winds, spilled diluted bitumen may begin to submerge in the surface layer of the Fraser River plume and Burrard Inlet about 24 hours following initial release. This possibility must be addressed in oil spill risk assessments.

38. Contamination of the water column by submerged oil opens the possibility of exposing a much wider diversity of organisms to oil, leading to multiple damage pathways that are not normally significant following typical crude oil spills and that are not adequately considered by the Trans Mountain ERA.

39. Concentrations of polycyclic aromatic hydrocarbons (PAH), which are among the most toxic components of petroleum, are similar to concentrations typical of normal crude oils. Consequently the inherent toxicity of bitumen is comparable with that of normal crude oils. Raw bitumen is also considerably more viscous than most normal crude oils. Bitumen is blended with diluents

primarily to reduce the viscosity in addition to lowering the density of the resulting mixture.

40. A credible, worst-case scenario oil spill of 16,000 m^3 near the Fraser River estuary could rank within top ten bird mortality events from an oil spill. Mortalities on this scale could have adverse consequences for ecosystems far beyond the Salish Sea, and could have major de-stabilizing effects on the estuarine food web of Burrard Inlet and the Fraser River estuary. Sea- and shorebirds are extremely sensitive to oil through physical contact, and the high productivity and habitat diversity of the Fraser River estuary places high numbers of sea- and shorebirds at risk.

41. Comparison with other spills suggests that a major spill near the Fraser River estuary could kill more than 100,000 sea- and shorebirds. Mass mortality of fish-eating birds, both resident and migratory, could result in cascading effects throughout the marine-dependent ecosystem. By substantively releasing their prey species from predation control by birds, the abundance of forage fish and other species consumed by birds can rapidly increase. These increased numbers of forage fish may in turn consume more of their mainly zoo- and phytoplankton prey, including the larval stages of numerous other coastal marine species such as shrimps, crabs, shellfish, etc., which may reduce recruitment of these species because of higher mortality at their larval stages. In addition, if the increased forage fish abundance is so great that they are no longer able to satisfy their nutritional requirements, their condition may deteriorate, turning them into "junk food" for their many predators, which include fish-eating marine mammals, seabirds and other fish.

42. Along with seabirds, marine mammals are also very vulnerable as well as sensitive to oil contamination. Marine mammals are vulnerable to oil contact because they inhabit the sea surface where they may readily encounter floating oil after a spill. Oiled pelage can reduce thermal insulation and oil ingested while preening can have toxic effects internally. Inhalation of hydrocarbon fumes may also lead to narcosis and drowning. Because of their relatively large numbers and sensitivity, a major oil spill could result in substantial mortalities of harbour seals and porpoises, and *could jeopardize the viability of the endangered southern resident killer whale population*. Loss of the killer whale population would permanently alter the marine food web of the Salish Sea. Also, large-scale mortalities of marine mammals may contribute to the cascading effects of seabird mortalities on the ecosystem, releasing populations of yet more forage and other fish from predation control, thereby increasing forage fish abundances perhaps to levels above what can be supported by forage fish prey.

43. Genwest Inc., another expert retained by Tsleil-Waututh and the City of Vancouver to model the trajectory of oil spills in Burrard Inlet, concluded that an oil spill anywhere in Burrard Inlet would almost certainly result in considerable shoreline oiling.

44. Oil retention on these shorelines depends largely on the interaction of the spilled product with the sediment pore size distribution on the shoreline. Shorelines especially susceptible to oil retention include sandy/gravel beaches covered by cobbles to boulders, beaches with extensive biological cover, and sand- or mudflats with burrows excavated by worms, crabs and other organisms that allow penetration of oil stranded on the beach surface.

45. These organisms typically occur in horizontal "biobands" along shorelines. Patterns of biobanding on shorelines are similar throughout the Salish Sea, including Burrard Inlet and the Fraser River estuary. Proceeding from the extreme upper limit of the intertidal to the extreme lower limit, the most prominent biobands on most shorelines are zones of salt-tolerant herbaceous vegetation on soils or encrusting lichens on bare rock surfaces, barnacles and rockweed, grading into green algae and blue mussels, then red algae and surfgrass, and finally kelps and eelgrass that are submerged most of the time in the lowest part of the intertidal. The biological assemblages of these biobands provide cover for many other species including marine snails, as well as larval and juvenile life stages of a host of other species including numerous species of fish and crabs.

46. Once incorporated beneath the surface of these beaches, diluted bitumen may persist for considerable periods in the absence of physical disturbance, determined mainly by oxygen availability. In low-oxygen sediments, diluted bitumen may linger for several decades or more. These lingering reservoirs of diluted bitumen pose long-term threats to intertidal organisms, predators including seabirds, marine and terrestrial mammals that consume them, and marsh-dwelling birds and mammals. They also impair the value of these habitats for subsistence harvests.

47. If diluted bitumen submerges in the fresh or brackish surface waters of Burrard Inlet or elsewhere in the Fraser River estuary, species inhabiting the water column or on adjacent shorelines may ingest oil directly. These species include fish such as juvenile herring inhabiting the estuary, out-migrating salmon from the Fraser River and from salmon hatcheries in Burrard Inlet, and adult sockeye salmon returning to the estuary and river, as well as a host of suspension-feeding invertebrates. Once ingested, these species become a route for indirect oil exposure for their predators. For example, sockeye salmon are mainly suspension feeders, and incorporation of oil through

ingestion would provide an oil exposure pathway for killer whales and other consumer species.

48. The overall consequences of water column contamination by submerged diluted bitumen are difficult to assess because of the great uncertainty in evaluating the amount of oil that submerges, tracking where it goes and hence what species and shorelines it affects, and sampling affected species to evaluate the amount of contamination accumulated by them. This uncertainty itself could lead to widespread public fears of contaminated fish and shellfish that may result in substantial economic losses for commercial and subsistence seafood harvesters.

49. An oil spill in Burrard Inlet or the Fraser River estuary could have long-lasting adverse impacts on species inhabiting the intertidal zone, the sea surface, and the water column in the ocean. Large-scale mortalities of birds and mammals could de-stabilize or permanently alter the food web of Burrard Inlet and the Fraser River estuary and cause ecosystem-level effects there and beyond.

50. Finally, even spills considerably smaller than the credible worst-case scenario of 16,000 m^3 can have substantial adverse effects on sea- and shorebirds as well as marine mammals and other organisms inhabiting the sea surface, shorelines and the water column if the oil submerges. Even small to medium sized oil spills on the order of 100 to 1,000 m^3 can cause substantial mortalities to seabirds, and estimated effects for small to medium spills in Canada and in Alaska have the potential to contaminate tens of kilometers of shorelines on time scales of decades.

2.0 Introduction

2.1 Scope of Work

51. I have been retained by the law firm of Gowling Lafleur Henderson LLP on behalf of Tsleil-Waututh Nation, the City of Vancouver and the Living Oceans Society to assess the fate and effects of oil spills that might result from the Trans Mountain expansion project in Burrard Inlet and the Fraser River estuary.

52. In particular, I have been asked to: (1) review and assess the evaluation of potential fate and effects of oil spills completed by Trans Mountain in its application for a Certificate of Public Convenience and Necessity to the National Energy Board; and (2) provide my professional opinion on (a) the fate and behaviour of diluted bitumen if spilled in the marine environment, with particular attention to conditions in Burrard Inlet and the Fraser River estuary; (b) impacts to species inhabiting the intertidal zone, shellfish species, forage fish spawning beaches, eelgrass and kelp beds, with a particular focus on impacts in Burrard Inlet and the Fraser River estuary; (c) impacts to species that inhabit the ocean surface, especially marine mammals and sea-birds; and (d) impacts to species inhabiting the water column.

2.2 Statement of Qualifications

2.2.1 Education

53. I hold a Bachelor of Science degree in biochemistry and philosophy from the University of California at Riverside, a Master of Science degree in physical chemistry from the University of California at Santa Cruz, and a Doctor of Philosophy degree in fisheries from the University of Alaska at Fairbanks.

2.2.2 Experience

54. I was employed as a Research Chemist at the US National Oceanic and Atmospheric Administration, National Marine Fisheries Service for 31 years. I retired in 2008 and since that time I have primarily performed or provided support services for research projects and programs on the effects of oil pollution on marine ecosystems. Following the 1989 *Exxon Valdez* oil spill, I: (1) led numerous projects to evaluate the distribution, persistence, fate and biological effects of the spilled oil in the marine environment, reporting results in the peer-reviewed scientific literature; (2) established and managed a hydrocarbon analysis facility that analyzed biological and geological samples for oil contamination; (3) established and managed the chemistry data archive for the subsequent studies of the short- and long-

term effects of the oil spill; (4) led the chemistry data quality evaluation and interpretation for both the US Federal government and the State of Alaska; and (5) led the scientific support team for the US Department of Justice to present the scientific basis for a $100M claim against ExxonMobil Corp. for un-anticipated long-term environmental damages caused by the oil spill.

55. I have published 68 professional scientific papers on oil pollution fate and effects in the peer-reviewed scientific literature, contributed chapters to three books on the same subjects, and have presented written and oral testimony before the United States House of Representatives, the United States Senate, and the Alaska Legislature on oil spill fate, effects and responses. These studies and presentations focus primarily on the mechanisms of oil dispersal in the environment following accidental discharges, retention of oil on shorelines and the factors modulating oil persistence, and mechanisms through which oil exposure harms fish and birds.

56. In an official capacity as an employee of the US government, I have advised government agencies of foreign countries on technical matters regarding oil pollution, including Canada, Norway, the Peoples Republic of China, the Russian Federation, and the Republic of Korea. I served under an inter-governmental scientific expert exchange program between the US and Canada to provide expert witness testimony on behalf of the Canadian government during the prosecution of Canadian National Railway for the consequences of the train derailment and subsequent oil spill into Lake Wabamun, Alberta in 2005.

57. I am currently retained (since 2010) to organize and oversee scientific support for the Plaintiff's Steering Committee in the multi-district litigation of lawsuits against British Petroleum PLC and other companies for their roles in causing the 2010 Deepwater Horizon blowout in the northern Gulf of Mexico, and by the Republic of Ecuador in Bilateral Investment Treaty arbitration with Chevron Corporation stemming from oil pollution caused by Texaco (now a subsidiary of Chevron) in the Amazonian rainforest of Ecuador. I have also been retained by the Gitxa'ala First Nation to evaluate environmental risks associated with the proposed Northern Gateway Pipeline Project.

58. A copy of my curriculum vitae is attached as **Appendix 1**.

2.3 Expert's Duty

59. This report has been prepared in accordance with my duty as an expert to assist: (i) Tsleil-Waututh Nation and the City of Vancouver in conducting

their assessment of the 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 my Certificate of Expert's Duty is attached as **Appendix 2**.

2.4 Documents Reviewed

60. In preparing this report, I have reviewed:

- relevant parts of the Trans Mountain application, especially Volume 8;
- the 1979 Master of Science thesis by Davidson on the oceanography of Burrard Inlet and English Bay;
- reports by Environment Canada, Witt O'Briens and SL Ross on diluted bitumen weathering experiments;
- environmental data files from CALMET and other sources; and
- relevant scientific literature and other documents, including the literature and documents cited in my report.

2.5 Qualification of Opinions

61. My opinions in this expert report are given to a reasonable degree of scientific certainty. They are based on my education, professional experience, information and data available in the scientific literature, and information and data about this application identified herein.

62. I continue to review available information, and I reserve the right to amend or supplement this report and the opinions contained in this report on the basis of any subsequently obtained material information.

3.0 Background on Project and the Burrard Inlet and Fraser River Estuary Ecosystems

63. Trans Mountain Pipeline ULC (hereafter, Trans Mountain) has applied for a Certificate of Public Convenience and Necessity to construct and operate (i) 987 km of new pipeline from Edmonton to Burnaby; (ii) an expanded petroleum storage facility in Burnaby; (iii) a new and expanded dock complex at the Westridge Marine Terminal; (iv) two new pipelines from the storage facility to the Terminal; and (v) a roughly seven-times increase in marine shipping activities (hereafter, Project).

64. The Project would increase pipeline transport capacity from about 47,700 m^3/d to 141,500 m^3/d (i.e., 300,000 bbl/d to 890,000 bbl/d), with a concomitant increase of Aframax-class tanker traffic from five to as many as 34 vessels per month.[1] Three new berths for the Aframax tankers would be constructed at the Westridge Marine Terminal in Burnaby, BC as well. Beginning at the Burnaby terminal, the tanker route would pass through Central, Inner and Outer Harbours of Burrard Inlet, across the mouths of the Fraser River delta in Georgia Strait, through the Gulf Island passages and Haro Strait on the southeastern end of Vancouver Island, and then through the Juan de Fuca Strait, remaining in Canadian territorial waters to the North Pacific Ocean (Figure 1). Tanker traffic would remain within about 10 km of shorelines along nearly this entire route to the open ocean. Along the way, tanker traffic passes through some of the most biologically productive and ecologically important marine waters in Canada, located especially within Georgia Strait (Figure 1).

65. The petroleum products shipped on the Project will consist almost entirely of oil-sands bitumen diluted with either gas condensate (i.e., “dilbit”) or synthetic crude oil (“synbit”). Gas condensate, sometimes referred to as “natural gasoline”, consists mostly of hydrocarbons that condense from natural gas wells at atmospheric pressure and room temperatures. Most of these gas condensate hydrocarbons range from pentane (C_5H_{12}) through dodecane ($C_{12}H_{26}$). Synthetic crude oil is produced by refining oil-sands bitumen. Sometimes a mixture of gas condensate and synthetic crude oil is used as the diluent, denoted as “dilsynbit”. Dilution lowers the density and the viscosity of the resulting fluid so that it can be shipped through pipelines.[2]

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[1] Stantec Consulting Ltd. (2013) Ecological risk assessment of marine transportation spills, technical report for the Trans Mountain Pipeline ULC, Trans Mountain expansion project. Document #RE-NEB-TERA-00031, Stantec Consulting Ltd., 845 Prospect Street, Fredericton, New Brunswick, E3B 2T7.

[2] See s. 5.1.3 for additional details regarding the physical properties and chemical composition of diluted bitumen.

66. The Salish Sea, and especially Burrard Inlet and the Fraser River estuary, is one of the most ecologically important coastal marine habitats along the entire Pacific coast of North America. It is seasonally inhabited by over a million sea- and shorebirds, including more than 30% of the global population of snow geese. It is one of just 6 sites along the west coast of North America of international and hemispheric importance. It is the only site of comparable ecological importance from the Canadian border with the State of Washington to the Copper River delta in Alaska.[3]

67. The Fraser River is the largest single salmon-producing river on the Pacific coast of North America (including Alaska), supporting runs of sockeye salmon (*Oncorhynchus nerka*) that can number in the tens of millions, along with major runs chinook (*O. tshawytscha*), chum (*O. keta*), pink (*O. gorbuscha*) and coho (*O. kisutch*) salmon, as well as steelhead trout (*O. mykiss*).[4] These returning adult salmon support several species of marine mammals, including the endangered southern resident killer whale (*Orcinus orca*) stock, commercial fisheries worth millions of dollars, and subsistence harvests for First Nations that depend on them for maintaining their cultural heritage as well as for nutrition. Juvenile salmon out-migrating from the Fraser River depend on the estuary's high biological productivity and in turn provide forage for the seabirds and other fish species.

68. The combined aggregations of extraordinarily high densities and numbers of sea- and shorebirds, marine mammals and fish make them especially vulnerable to potentially devastating mortalities should a major oil spill occur in Burrard Inlet or the Fraser River estuary as a result of the Project. Seabirds and shorebirds are particularly sensitive to both internal and external oil exposure, and their foraging habits, preening behaviour and resting requirements lead to frequent contact with surface oil when present. Petroleum exposure alters feather microstructure, compressing plumage so that it loses its buoyancy, insulating function, and flight capability. Birds contaminated at sea thereby succumb from drowning, hypothermia, starvation, or dehydration.

69. My report is divided into two major sections. The first section contains my peer-review of the Trans Mountain ecological risk assessment (ERA), where I evaluate the methods used for the ERA in the context of requirements stipulated by the National Energy Board. The second section contains my

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[3] Western Hemisphere Shorebird Reserve Network (www.whsrn.org/whsrn-sites).

[4] Merkens M (2012) Information sheet on Ramsar Wetlands (RIS) – 2009 – 2012 version. Metropolitan Planning, Environment and Parks, Metro Vancouver, 4330 Kingsway, Burnaby, BC Canada V3N 2L8; Pacific Salmon Commission (2015) Report of the Fraser River Panel to the Pacific Salmon Commission on the 2009 Fraser River Sockeye and Pink salmon fishing season.

independent assessment of the fate and effects of oil spills from the Project in Burrard Inlet and the Fraser River estuary, focusing on how accidentally-discharged diluted bitumen could disperse within the receiving waters of the Salish Sea, how long it could persist on shorelines, and how it could affect marine-dependent organisms. My emphasis in the second section is on oil dispersion pathways, shoreline retention factors, and mechanisms of toxic and ecological injury that are either not considered or receive inadequate emphasis in the Trans Mountain application and supporting documents.

Figure 1. Salish Sea, including Burrard Inlet, the Westridge Marine Terminal, Sturgeon Bank, South Arm marshes, Robert's Bank, Boundary Bay, the tanker route, Haro Strait, and the oil spill origin locations selected for the oil spill trajectory models presented in the Trans Mountain ERA.

4.0 Peer-Review of the Trans Mountain Application

70. The Trans Mountain application presents an evaluation of environmental threats posed by an oil spill within the framework of a quantitative ecological risk assessment (ERA). Although this approach has often been used to evaluate environmental risks caused by one or a small number of toxic compounds associated with well-defined industrial development projects, applying it to industrial accidents, especially large ones in the case of major oil spills, is considerably more difficult. Problem formulation, assessments of exposure, and assessments of hazards are especially challenging owing to the plethora of oil spill discharge scenarios and the multiplicity of exposure pathways, compounded by multiple modes of toxic action that can result from exposure to oil.

71. Oil spills are classic "low-probability/high-consequence" events, requiring careful assessment of potential impacts to the most sensitive species and habitats in addition to habitats and species most likely to be exposed. By confounding assessments of exposure probability and sensitivity of species and habitats, the Trans Mountain ERA largely excludes the most serious consequences that could occur from consideration.

72. The National Energy Board determined that the Trans Mountain application "...must include an assessment of potential accidents and malfunctions at the Terminal and at representative locations along the marine shipping routes. Selection of locations should be risk informed considering both probability and consequence."[5]

73. However, Trans Mountain ERA fails to select locations informed by the potential consequences of oil spills. Trans Mountain therefore ignores and fails to comply with the National Energy Board's requirements by selecting locations only based on Trans Mountain's assessment of the probability of an oil spill, which are neither representative nor typical of the surrounding area.

74. The Trans Mountain ERA is based on a well-established five-step procedure for integrating oil exposure risk and the sensitivity of species exposed to estimate the overall likelihood of adverse impacts, including very low probability impacts that could have catastrophic consequences following a spill. The five steps include: (1) problem formulation, (2) exposure assessment, (3) hazard assessment, (4) risk characterization, and (5) an evaluation of certainty and confidence in predictions. Problem formulation involves identifying the nature of the threat, and its spatial and temporal

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[5] National Energy Board letter dated 10 September 2013 and attachment entitled, "Filing Requirements Related to the Potential Environmental and Socio-Economic Effects of Increased Marine Shipping Activities".

boundaries. Exposure assessment involves evaluation of the likelihood that species or habitats will be exposed to contamination, and hazard assessment involves assessment of the species' or habitat's sensitivity to exposure. Risk characterization is the process of integrating the likelihood of exposure and the likelihood of adverse consequences should exposure occur, and the uncertainty analysis assesses the overall confidence in the quantitative risk estimates of injury.

75. There are at least four fundamental deficiencies in Trans Mountain's ERA:

(a) it fails to integrate oil exposure risk based on representative locations within ecologically distinct sub-regions along the marine shipping routes, including at or near ecologically-sensitive areas;

(b) it fails to assess hazard independently of exposure. Trans Mountain concludes that hazard is minimal based on its prior conclusion that there is a low probability of oiling. However, Trans Mountain should have assessed hazard based on species sensitivity to oiling independently of oiling probability;

(c) it fails to assess the possibility of organisms being exposed to submerged oil; and

(d) it fails to consider all the ways that oil can harm organisms.

4.1 Trans Mountain fails to assess exposure based on representative locations

76. The exposure risks presented in the Trans Mountain ERA are based on oil spill trajectory models that originate from four locations judged to be "representative" along the oil transhipment corridor. These four locations include (1) the intersection of the transhipment corridor with the Vancouver-Victoria ferry route, on the premise that an oil spill caused by a collision between an oil tanker and a ferry would be most likely there; (2) a powered grounding at Arachne Reef; (3) in Juan de Fuca Strait resulting from collision with vessels crossing from Puget Sound; and (4) Buoy J near the entrance to Juan de Fuca Strait caused by vessels approaching the traffic separation scheme (Figure 1).

77. Other scenario possibilities considered but rejected include English Bay, Roberts Bank, and the pilot boarding area at Brotchie. None of the locations selected are representative.

78. Within Georgia Strait, oil slick trajectories from the single origin considered are presumed to represent the likelihood of trajectories from other locations, but clearly a spill occurring within Burrard Inlet would have very different trajectories, and hence probabilities of oiling particular habitats or shorelines. Because slick trajectories vary strongly with the location of the spill origin, a truly representative approach for estimating the probability that particular habitats, shorelines or species would be exposed to oil requires more than a single point of origin for oil spill trajectory modelling. Reliance on a single point of origin within Georgia Strait is therefore far from representative, and actually introduces a strong bias to the ERA.

79. It also introduces an additional strong bias regarding estimation of risk that an accident may occur. **By limiting the spill trajectory scenario to a single location for the spill origin, the resulting risk assessment presumes that the likelihood of a spill originating at any other point along the transhipment corridor within Georgia Strait is not just low, but *zero*.** So, a spill caused by a collision in the Outer Harbour of Burrard Inlet from some un-anticipated cause would presumably never happen. But accidents, and especially large oil spills, often happen as a result of highly improbably and unforeseen chains of causality that are very difficult to anticipate. We know that the actual risk of a tanker spill originating at other locations in Georgia Strait is not really zero, and a more credible risk assessment would take greater pains to evaluate and integrate these risks. Evaluating these other risks is important, because spills originating from different locations may have much different impacts on sensitive shoreline habitats. This is clearly evident in the results for the spill trajectory model presented for the Georgia Strait location—had the spill origin been located closer to the Outer Harbour of Burrard Inlet, the trajectory modelling would likely have led to considerably increased likelihood of oiling on Sturgeon Bank, possibly placing tens to hundreds of thousands of shorebirds at risk of oiling. Such an outcome has been demonstrated in another expert report prepared for Tsleil-Waututh Nation and the City of Vancouver by Genwest Systems, which showed that an oil spill origin in the Outer Harbour of Burrard Inlet could lead to oiling on the northern end of Sturgeon Banks.[6]

80. Risks from oil spills that originate from other locations along the transhipment route through Georgia Strait may be readily evaluated by conducting a "threat zone analysis" for habitats of high concern. A threat zone analysis is complementary to the oil spill scenario analysis presented in

[6] Genwest Systems Inc. (2015) Oil spill trajectory modeling report in Burrard Inlet for the Trans Mountain Expansion Project. Genwest Technical Report #15-03. Genwest Systems Inc., Edmonds, Washington, USA 98020

the Trans Mountain application. It consists of evaluating the likelihood of oiling at a particular location from each of several assumed spill origins distributed within the area of concern. That is, it answers the question "*Where could oil come from that could reach a particular resource area?*" In Georgia Strait, this could be readily accomplished by selecting several locations along the transhipment route, 10 say, at equal intervals from Burrard Inlet to the Gulf Islands, and evaluating the likelihood that a spill originating at each of these locations might contaminate a specified point or points of particular concern, for example the mudflats of Sturgeon Bank.

81. A shoreline threat zone analysis is readily performed and was in fact done by the Gitxa'ala Nation as part of their response to the Northern Gateway application to build a pipeline and marine oil shipment terminal at Kitimat, British Columbia.[7] The software for this analysis, Trajectory Analysis Planner (TAP II) was developed by the U.S. National Oceanographic and Atmospheric Administration (NOAA) and is readily available. The threat zone analysis performed for the Gitxa'ala First Nation involved 23 different assumed spill origin locations to evaluate the likelihood of shoreline oiling at particular sites. This approach should be included in the Trans Mountain ERA, especially given the high resource value of Fraser River delta shorelines for resident and migratory sea- and shorebirds.

82. A threat zone analysis is most usefully applied to locations and species that are especially sensitive to oil exposure. Such locations include aggregation areas of highly vulnerable species like birds, or habitats like armoured shorelines or tidal marshes were oil retention may be prolonged. A credible threat zone analysis would begin with identifying these areas ***without regard for preconceptions about the likelihood of oiling from a spill***, and then evaluate the overall risk of oiling integrated across plausible spill origin locations.

83. By focusing on habitat oiling probabilities derived from the limited number of spill origin locations considered, the Trans Mountain ERA precludes quantitative evaluation of risks for injuries to living marine-dependent resources. The current ERA only evaluates risks to habitat oiling from the spill origin locations considered on the additional assumption that wind and current regimes are always similar to those of fall 2011 through summer

[7] Beegle-Krause CJ, Emmett B, Hammond M, Short J, Spies R (Contributors) and L Beckmann (editor) (2011) Expert opinion on petroleum tanker accidents and malfunctions in Browning Entrance and Principe Channel: Potential marine effects on Gitxaala traditional lands and waters of a spill during tanker transport of bitumen from the Northern Gateway Pipeline Project (NGP). JFK Law Corporation, Counsel to Gitxaala First Nation, 340-1122 Mainland Street, Vancouver, BC V6B 5L1.

2012. The ERA does not consider the sizes of populations vulnerable to oil exposures even in the habitats identified as likely to be oiled, which precludes evaluation of the scope of population-level effects in any credible worst case scenario. This indeed is a touchstone for a credible and useful ERA – to evaluate, in quantitative numerical terms, the numbers of individuals that might be injured or killed from oil exposure. All such evaluations are conspicuously absent in the ERA because Trans Mountain's flawed implementation of the ERA methodology precludes any such estimation. So, we simply do not have any idea how many seabirds might be killed by a credible worst-case spill on the basis of Trans Mountain's ERA, yet these sorts of estimates are crucial for assessing the potential environmental effects of the Project.

4.2 Trans Mountain fails to assess hazard independently of exposure

84. The Trans Mountain ERA presumes that assessments of injury to specific populations may be dismissed if their estimate of exposure risk is sufficiently small. In the ERA, risk is usually characterized as the likelihood of exposure to an amount of toxicant capable of causing injury to a particular species, without regard for the consequence should exposure actually occur.

85. Oil slick trajectory scenarios based on models driven by historical wind and current data led to identification of habitats and shoreline types most likely to be oiled. Because results from a single location were incorrectly taken as "typical" of Georgia Strait, habitats and the species that had low estimated likelihoods of oiling were then presumed to have low sensitivity to oiling. This approach effectively confounds exposure risk and hazard assessment, whereas the conceptual foundation of ERA expressly separates assessments of exposure and hazard, precisely to avoid such confounding. This confounding alone invalidates the Trans Mountain ERA.

86. The method used by Trans Mountain to evaluate the sensitivity of species to oiling is also flawed. In the Trans Mountain ERA, species sensitivity to oiling is semi-quantitatively "assessed" by assigning "biological sensitivity ranking factors" (BSF) to species or habitats categorized on the basis of taxonomic or habitat similarity. The four categories considered include seabirds, marine mammals, fish and other inhabitants of the water column and shorelines. Within each category, the same semi-quantitative measures of sensitivity (low, BSF=1; medium, BSF=2; high, BSF=3, and very high, BSF=4) are applied. This approach is invalid because it creates a misleading appearance of false equivalencies for sensitivities to oiling across species and habitats. For example, all birds are correctly viewed as highly sensitive to oil exposure, yet

shorebirds are assigned the lowest BSF, equating their sensitivity to that of pelagic fish or marine invertebrates such as worms, mussels, and crabs etc., all of which are substantially less sensitive to oil exposure than shorebirds. These false equivalencies are artifacts of the inappropriate categorization scheme imposed on the organisms considered. This scheme is not based on fundamental differences in sensitivity, but on taxonomic similarities that are largely blind to the inherent sensitivities of the organisms evaluated.

87. In reality, all birds are extremely sensitive to oil exposure—even minor oiling of plumage results in morbidity or mortality for sea- or shorebirds inhabiting cold-water habitats (see s. 5.3.1).[8] This is because oiling interferes with flight and thermoregulation, and the time and effort required for preening to remove the oil detracts from foraging, among other adverse effects. Hence, all birds, whether seabirds, shorebirds or terrestrial birds, should be accorded very high sensitivity to oiling contact, and visible oiling of plumage is usually presumed to be lethal for birds inhabiting cool or cold climates such as that of the Georgia Strait.[9]

88. The basis for assigning BSFs to shoreline types is also over-simplified. Retention of oil by sand and mudflat shorelines is presumed to be low on the basis of their low hydraulic conductivities, which would impede penetration of oil stranded on shoreline surfaces to deeper sediment where oil might persist. But this ignores the effects of channels created by burrowing animals that inhabit these shorelines. These channels provide conduits for oil to percolate into deeper sediments, and once there the oil may persist for decades or possibly even centuries.[10] Similar conduits may be created on other shoreline types as well, when sediments dominated by sand- and mud-sized particles lie beneath coarser surface layers of cobbles to boulders.

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[8] Carter HR, Lee VA, Page GW, Parker MW, Ford RG, Swartzman G, Kress SW, Siskin BR, Singer SW, Fry DM (2003) The 1986 *Apex Houston* oil spill in central California: seabird injury assessments and litigation process. Marine Ornithology 31:9–19; Castege I, Lalanne Y, Gouriou V, Hemery G, Girin M, D'Amico F, Mouches C, D'Elbee J, Soulier L, Pensu J, Lafitte D, Pautrizel F (2007) Estimating actual seabirds mortality at sea and relationship with oil spills: lessons from the *Prestige* oil spill in Aquitaine (France). Ardeola 54:289–307; Munilla I, Arcos JM, Oro D, Álvarez D, Leyenda PM, Velando A (2011) Mass mortality of seabirds in the aftermath of the *Prestige* oil spill. Ecosphere 2:art83; Page GW, Carter HR, Ford RG (1990) Numbers of seabirds killed or debilitated by the 1986 *Apex Houston* oil spill in central California. Studies in Avian Biology 14:164-174.

[9] Page (1990).

[10] Culbertson JB, Valiela I, Pickart M, Peacock EE, Reddy CM (2008) Long-term consequences of residual petroleum on salt marsh grass. Journal of Applied Ecology 45:1284-1292.

4.3 Trans Mountain fails to assess the possibility of organisms being exposed to submerged oil

89. The Trans Mountain ERA dismisses the possibility of exposure to submerged oil, mainly on the basis of flawed experimental studies done to evaluate the susceptibility of diluted bitumen to submerge in water from evaporation alone. As a result, potentially major oil exposure pathways are excluded, which could expose a host of species, many of which are important for commercial and subsistence harvests.

90. Bitumen extracted from the Alberta oil sands consists of petroleum naturally biodegraded *in situ* prior to extraction, resulting in a "heavy oil" of relatively high density (≈ 1,040 kg/m^3) as well as high viscosity.[11] At least some of the mined deposits produce bitumen with densities higher than water, making the raw bitumen susceptible to sinking in water.[12] Dilution of the bitumen with gas condensate or synthetic crude oil diluents lowers the density of the resulting mixture to less than 940 kg/m^3, which is less dense than water (density ≈ 1,000 kg/m^3) and would therefore float. However, evaporative losses of diluents can return the density of the remaining mixture to near that of the raw bitumen, making the mixture again susceptible to submerging in water.

91. Bitumen submerged beneath the sea surface is much more difficult to track as it disperses within receiving waters to shorelines, the seafloor, and the open ocean, all of which expose biological communities along the way that are difficult to observe or sample, and increase uncertainty regarding the extent and severity of contamination. This increased uncertainty typically leads to overly pessimistic public speculation regarding the extent and severity of contamination that can have seriously adverse consequences for subsistence harvests by First Nations and for commercial activities such as commercial fishing and tourism that depend on public perceptions of waters uncontaminated by oil products. In addition, oil spill response planning is much more challenging if contingencies for submerged oil must be considered and included. Determining whether diluted bitumen products can submerge in receiving waters is therefore a high priority both for oil spill contingency planning and for the ERA.

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[11] Meyer RF, Attanasi E (2004) Natural bitumen and extra-heavy oil. Ch. 4 in 2004 Survey of Energy Resources, World Energy Council, Elsevier.

[12] *Ibid*.

92. Several experimental studies have been conducted to evaluate the environmental conditions and times required for diluted bitumen to submerge in receiving waters. In particular, five experimental studies were conducted using two bitumen/diluent blends (Access Western Blend (AWB) and Cold Lake Bitumen (CLB)) that were considered to be typical of most of the products that would be shipped through the Project.[13]

93. The experimental results for CLB were used for the ERA presented in the Trans Mountain application. However, those studies provide limited guidance for predicting the time required for these products to submerge in water. Evaporation rates of diluted bitumen products from the Alberta oil sands differ markedly from those typical of normal crude oils, because diluted bitumen consists of a high-volatility diluent mixed with a very low volatility heavy petroleum, whereas the composition of normal crude oils varies more smoothly from high- to low-volatility components (see s. 5.1.3). Consequently, the density of diluted bitumen products changes even faster than that of normal crude oils immediately after discharge to receiving waters.

94. Moreover, the thick oil layers (~1.14 mm–20 mm) used in the five experimental studies would rarely occur during the initial discharge phase of a real oil spill unless the spill occurred in a confined area that prevented the oil layer from spreading to its fullest natural extent. The thickness of diluted bitumen slicks that are allowed to spread in unconfined waters is around 0.4 mm,[14] which is 3 to 50 times thinner than the oil slick layers used in the experiments. Because the time required for density increases is inversely proportional to oil slick thickness, these experiments over-estimate the time required for spilled diluted bitumen to approach the density of the surface waters and hence to submerge.

95. A recently-published study that directly compared measured evaporation rates from an experimental oil spill in the North Sea with results from equations predicting evaporation rates derived from thick oil slicks developed and used by Environment Canada showed that the equations

[13] See Appendix 3.

[14] Stronach J, Hospital A (2013) Technical memo to Trans Mountain dated 4 July 2013 re: Spreading of Diluted Bitumen.

overestimated the time required for evaporative losses by a factor of around 20.[15]

96. The time required for evaporative weathering to increase the density of diluted bitumen above that of fresh water is a crucial concern in Burrard Inlet and the Fraser River estuary. The surface waters there are often fresh or nearly so during the spring and summer freshet of the Fraser River (see s. 5.1.2).

97. The paramount concern here is not simply whether evaporation could cause diluted bitumen to sink to the seafloor in full-strength seawater, but whether it could submerge in the nearly fresh surface waters of the Fraser River freshet. The threshold for submergence in fresh water is much lower than for sinking in seawater having salinities typical of the open ocean (density ≈ 1,025 kg/m^3), because the density of freshwater is substantially lower (1,000 kg/m^3).

98. Appropriate corrections for actual oil slick thicknesses likely to be encountered immediately following discharge indicate that the density of diluted bitumen could increase above that of water within as little as 24 hours under optimal conditions of moderate winds, warm summer temperatures and low-salinity surface waters typical of the Fraser River estuary during the spring and summer freshet.[16] Other mechanisms such as contact with shoreline sediments or accumulation of small amounts of suspended inorganic material in the water column would increase the likelihood that spilled diluted bitumen could submerge in brackish receiving waters. This is of particular concern during the spring and summer freshet in the Fraser River where the discharge plume depresses the salinity of the surface water to nearly that of freshwater, and is laden with suspended inorganic material (see Figure 2).[17]

99. Submergence of diluted bitumen following an accidental release greatly increases the risk of oil exposure through contact or ingestion for species inhabiting the water column, from phytoplankton to fish. Contamination of these species in turn provides a pathway for secondary exposure for other

[15] Gros J, Nabi D, Wurz B, Wick LY, Brussard CPD, Huisman J, van der Meer JR, Reddy CM, Arey JS (2014) First day of an oil spill on the open sea: Early mass transfers of hydrocarbons to air and water. Environmental Science and Technology 48:9400-9411.

[16] See Appendix 3.

[17] Thomson RE (1991) Oceanography of the British Columbia Coast. Canadian Special Publication of Fisheries and Aquatic Sciences 56, Department of Fisheries and Oceans, Ocean Physics Division, Institute of Ocean Sciences, Sydney, British Columbia.

species that consume them, such as marine mammals. In addition, suspension-feeding organisms inhabiting shorelines are also vulnerable to oil exposure through ingestion of submerged oil droplets entrained in the water column. However, none of these exposure pathways are considered in Trans Mountain's ERA.

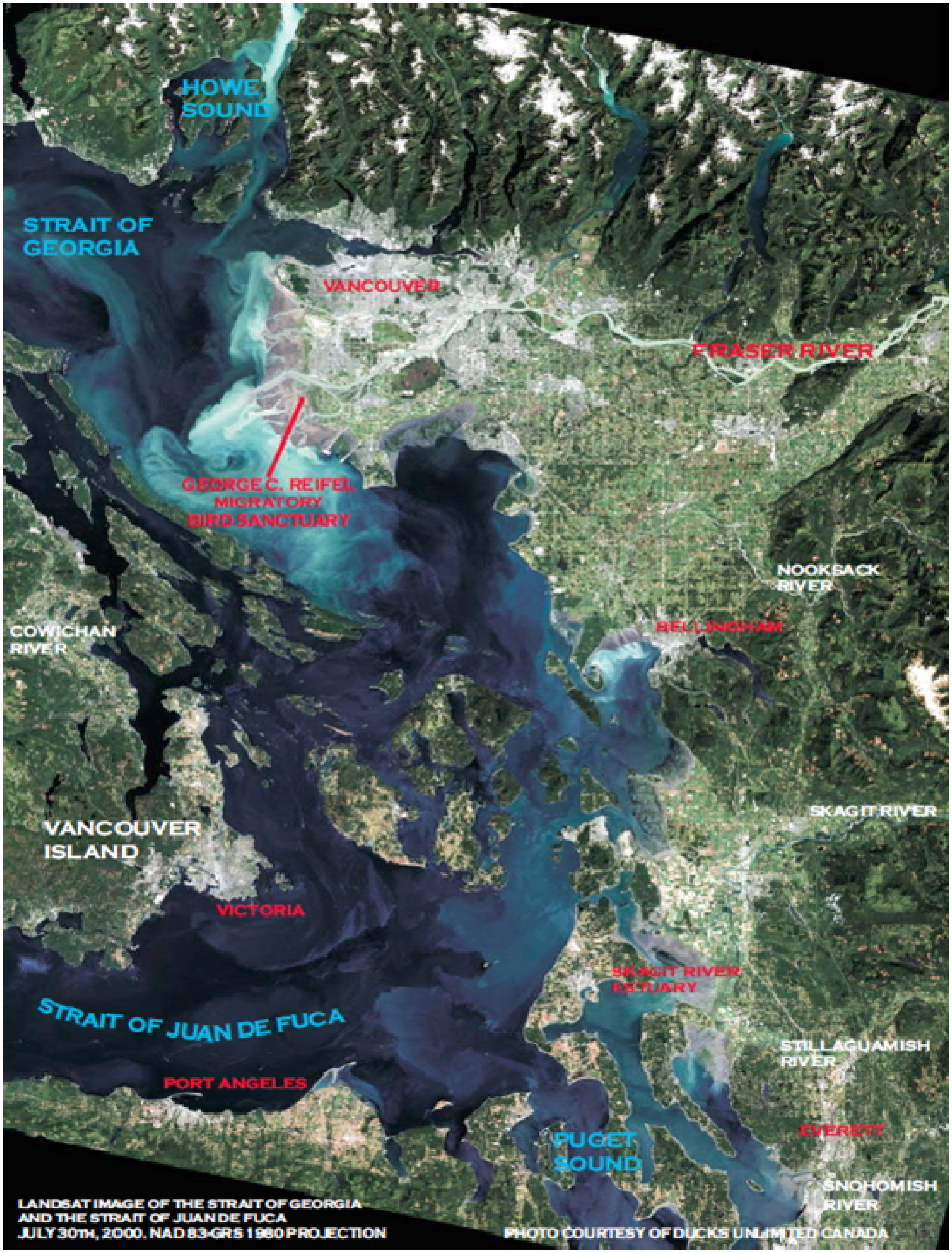

Figure 4. Spring freshet of the Fraser River into the estuary and receiving waters of the Salish Sea.

4.4 Trans Mountain fails to consider all the ways that oil can harm organisms

100. The Trans Mountain application fails to consider any consequences that may result from photo-enhanced toxicity. This toxicity mechanism has recently been shown to be important for species such as Pacific herring (*Clupea pallasi*), which are an important component of the marine ecosystem in the Salish Sea. Pacific herring deposit eggs on intertidal reaches of shorelines.[18] Certain compounds in bitumen can dissolve into water and then be absorbed by translucent Pacific herring embryos. When exposed to sunlight, these compounds promote oxidation of tissues within the embryos, in effect burning them. This effect was demonstrated to occur for herring embryos on shorelines of San Francisco Bay after the 2009 *Cosco Busan* oil spill.[19] Failure to address the different damage pathways contributes to the thematic underestimation of risks of exposure and especially consequences in the Trans Mountain ERA.

101. The cumulative effects of the flawed approach used in the Trans Mountain ERA is illustrated by comparing the conclusions reached in the ERA with the effects of an actual oil spill involving circumstances that are largely comparable with those in the Fraser River estuary and wider Salish Sea.

102. The 2007 *Hebei Spirit* off the west coast of South Korea released about 11,000 m^3 of heavy oil crude oil 8 km from the nearest shoreline. The accident resulted from a marine crane barge set adrift in heavy seas after the tow cable to the tug snapped, and the barge collided with the T/V *Hebei Spirit* while at anchor. Onshore winds caused extensive heavy shoreline oiling, including mud and sand beaches used by shorebirds and invertebrate infauna (Figure 3). All the shorebirds on the most heavily oiled sandy beaches likely died within hours (Figure 4). Shoreline oiling effects persisted for years, even on the sand beaches.[20]

103. Key points of comparison with Georgia Strait include the proximity of the spill origin to a high-value sandy-beach shoreline for both tourism and for

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[18] DFO (2005) Stock Assessment Report On Strait of Georgia Pacific Herring. Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, Science Advisory Report 2005/068.

[19] Incardona JP, Vines CA, Linbo TL, Myer MS, Sloan CA, Anulacion BF, Boyd D, Collier TK, Morgan S, Cherr GN, Scholz NL (2012) Potent phototoxicity of marine bunker oil to translucent herring embryos after prolonged weathering. PLoS ONE 7(2):e30116.

[20] Yim UH, Kim M, Sung YH, Kim S, Shim WJ (2012) Oil spill environmental forensics: the *Hebei Spirit* oil spill case. Environmental Science and Technology 46:6431-6437.

shorebirds, the un-anticipated nature of the accident, the heavy crude oil released and the cold-water sea.

Figure 3. Oiled sand beach at Tae'an, Republic of Korea days after the 2007 *Hebei Spirit* oil spill. This beach is one of the most popular seaside resorts in the Republic of Korea. Photo copyright courtesy of Jungdo-ilbo, Republic of Korea.

Figure 4. Initial oiling of Tae'an Beach, Republic of Korea, from the 2007 *Hebei Spirit* oil spill. Photo copyright courtesy of Jungdo-ilbo, Republic of Korea.

104. Considering how Trans Mountain would have evaluated the potential for the accident and effects of the *Hebei Spirit* oil spill illustrates the defects of Trans Mountain's approach. First, the accident itself would have been dismissed as too improbable for consideration because it involved an anchored tanker similar to those within the Outer Harbour of Burrard Inlet, which were excluded from consideration by the Trans Mountain ERA. Second, the likelihood of any shoreline oiling would have been dismissed as improbably low if the spill origin location chosen for modeling was not very close to the actual site of the spill. Third, effects on the shoreline habitat would have been dismissed as ephemeral and on a low-sensitivity shoreline (BSF = 1), because it is a sandy beach, despite documented effects on this now very heavily monitored beach for up to five years.[21] Finally, effects on shorebirds would have been dismissed as unlikely because of the low BSF (= 1) assigned to this group.

105. If a spill the size of the *Hebei Spirit* occurred off the Sturgeon Bank or the South Arm Marshes during onshore winds and during the spring shorebird migration, it could oil tens to hundreds of thousands of shorebirds, and any contact with oil would most likely lead to mortality.[22] This comparison illustrates the potential consequences of fundamental flaws in the approach used by Trans Mountain's ERA

106. Finally, the Trans Mountain application fails to adequately value the extraordinary biological productivity, diversity, and hence ecological importance of the estuarine ecosystem of the Fraser River. The Fraser River estuary is arguably the most important estuarine ecosystem on the entire Pacific coast of North America, but the application fails to reflect this. Instead, by considering species separately with little emphasis on the importance of the Fraser River estuary as a whole to the global populations of these species or to the ecological integrity of the wider Pacific coastal ecosystem of which it is a major part, the application undervalues the potential ecological consequences of oil spills. ***Moreover, while the ecological risk assessment attempts to be semi-quantitative with respect to risks of habitat oiling it makes no attempt to be quantitative with respect to the numbers of organisms potentially at risk of exposure.***

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[21] *Ibid*.

[22] Page (1990).

107. In summary, the ERA as implemented by Trans Mountain violates the basic principles of ecological risk assessment, rendering it thoroughly unreliable as an assessment of risks for the most serious consequences of a large oil spill in the Salish Sea. The basic principles violated include:

- Failure to account for variation in oil slick trajectories that depend strongly on the assumed point of origin for a spill in trajectory modeling, including complete absence of consideration for any spill that might occur within Burrard Inlet;
- Confounding assessments of oil exposure and the hazards presented by these exposures to habitats and marine-dependent organisms;
- Presumptive and erroneous characterization of some of the most vulnerable and sensitive habitats and species, namely shorebirds that inhabit the flats along the Fraser River delta, as among the least vulnerable to oil exposure and the least sensitive should exposure occur;
- Use of an arbitrary scheme for assigning sensitivities to habitats and species;
- Failure to consider potentially important exposure pathways associated with diluted bitumen that could submerge in the nearly fresh surface waters of the Fraser River freshet during spring and summer;
- Failure to consider all the relevant toxicity mechanisms through which exposure to toxic components of diluted bitumen can harm marine organisms; and
- Failure to provide quantitative estimates of potential injuries to species and resources most sensitive to injury from exposure to diluted bitumen.

108. These flaws lead to serious underestimation of the harm that could be inflicted by a major spill of diluted bitumen on marine organisms. As a result, the Trans Mountain ERA cannot be used or relied upon to assess the environmental effects of an oil spill from the Project.

5.0 Fate, Behaviour and Effects of Diluted Bitumen Discharged into Burrard Inlet, the Fraser River Estuary and the Salish Sea

109. In this section I present an analysis of the likely fate, behaviour and effects of diluted bitumen spilled into the Salish Sea, including Burrard Inlet and the rest of the Fraser River estuary. This analysis demonstrates the considerably broader scope for ecological damage should a spill occur than is recognized in the Trans Mountain application.

5.1 Fate and behaviour of diluted bitumen discharged into Burrard Inlet and the Fraser River estuary

110. The distribution, fate, and effects of oil spilled into receiving waters depend crucially on how the initial composition of the oil changes in response to ambient environmental conditions. This section summarizes how the physical and chemical properties of diluted bitumen will change following an accidental discharge, the most important factors affecting the rates of these changes, and how these changes affect the behaviour of spilled diluted bitumen in the receiving waters as modulated by the seasonal variation of environmental conditions. These comparisons set limits on the different ways spilled diluted bitumen can move through the marine ecosystem, and the kinds and locations of organisms at highest risk of contamination.

5.1.1 Factors affecting the fate and behaviour of oil discharged to receiving waters

KEY POINTS:

- Spilled oils follow a characteristic sequence of changes that affect the fate, behaviour, and effects on animals and plants in the environment
- The most important environmental factors that affect how fast the oil composition changes are temperature, wind speed, and slick thickness

111. Once discharged to receiving waters, the composition and physical properties of petroleum products typically follow a characteristic sequence of changes (Figure 5). If the sea surface is initially agitated, breaking waves may naturally disperse floating oil into droplets, entraining them into the water column near the sea surface. While some components of oils may dissolve into the water during submergence, other processes including

evaporation and photo-oxidation are dramatically curtailed compared with oil exposed directly to the atmosphere and direct sunlight[23].

112. In calm weather, floating oils spread rapidly on the surface of the water to a thin layer determined by the viscosity and surface tension of the oil. Spreading greatly increases the relative surface area (i.e., the surface area per unit volume of oil), which promotes evaporation of the most volatile components of the oil.

113. Evaporation of volatile components acts on time scales of hours to days. It changes the composition of the oil remaining much more rapidly than dissolution, microbial oxidation or photo-oxidation, which act on time scales of days to weeks[24]. Evaporative losses eventually increase oil viscosity and surface tension, often accompanied by increased absorption of water.[25] Together these changes cause the oil to congeal, reducing the relative surface area of the oil and hence slowing the rate of further losses by evaporation. Changes in oil composition and properties are hence most rapid during the first hours and days of a spill, modulated by the particular environmental conditions present.

114. Temperature and wind speed are the most important environmental factors that determine the rate of volatility losses from spilled petroleum products.[26] The changes in oil composition caused by these factors in turn affect other processes that alter oil composition, including dissolution of sparingly-soluble components into the underlying water column, photo-oxidation, and microbial degradation. All of these processes affect how and where oil components disseminate in the environment and move through ecosystems, how long they will persist, and what organisms they may affect.

115. The remainder of this section addresses the characteristic environmental conditions of Burrard Inlet and the Fraser River estuary, with an emphasis on conditions that might be conducive to oil submergence. It then summarizes the physical properties and chemical compositions of the diluted bitumen products most likely to be accidentally released, the effects of environmental weathering processes, and finally discusses the likely behaviour of diluted bitumen following an accidental discharge. This

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[23] Gros 2014.

[24] *Ibid*.

[25] Fingas M (2013) The Basics of Oil Spill Cleanup. CRC Press, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742.

[26] Gros 2014.

behaviour will impose constraints on the environmental distribution and biological effects of accidentally spilled diluted bitumen discussed in subsequent sections.

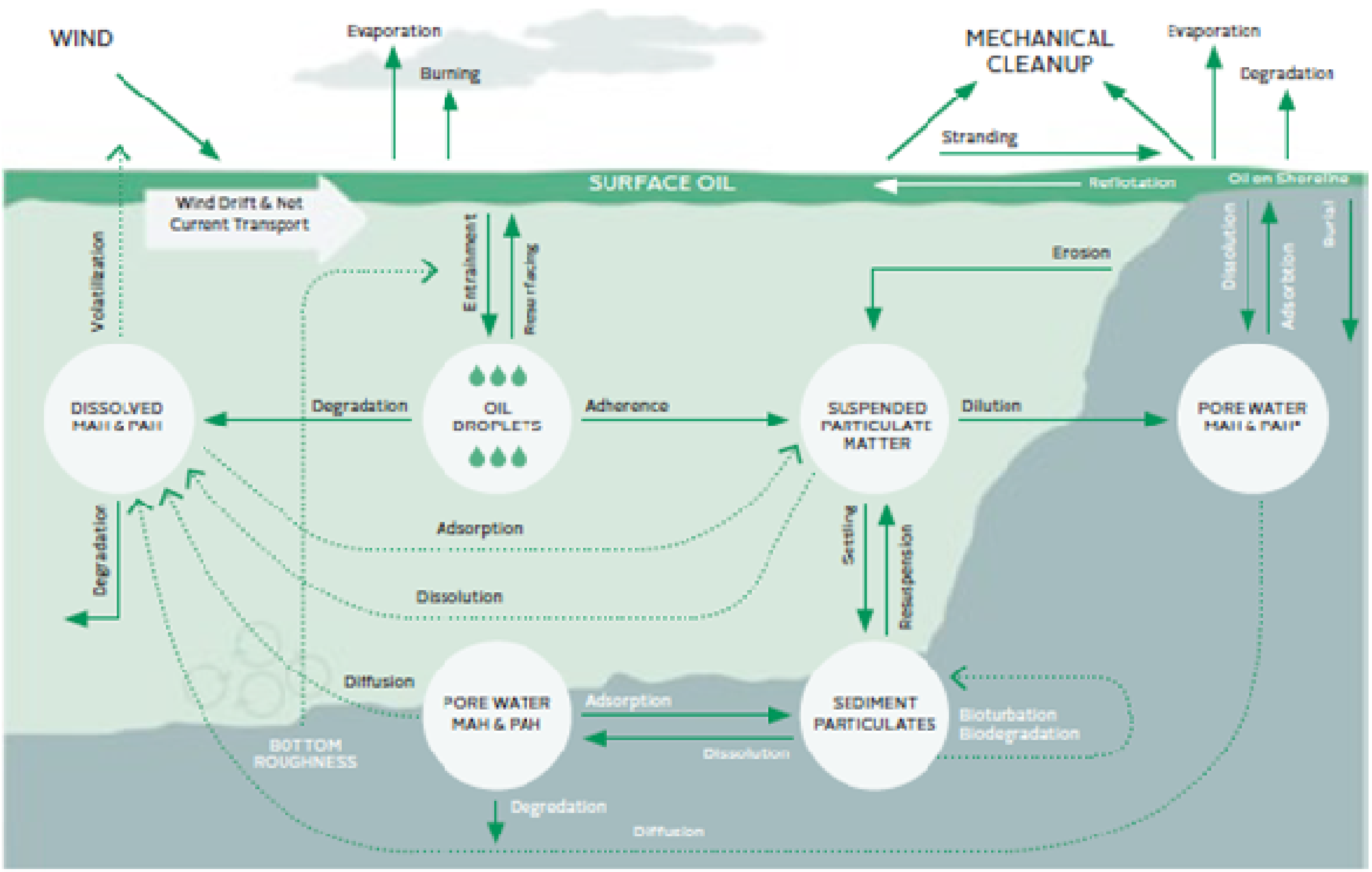

Figure 5. Conceptual diagram of processes affecting crude and refined oil products accidentally discharge to marine receiving waters. From National Energy Board, Joint Review Panel (2013) Considerations—Report of the Joint Review Panel for the Enbridge Northern Gateway Project, Volume 2, Figure 6-1. "MAH" refers to monocyclic aromatic hydrocarbons.

5.1.2 Summary of seasonal variation of atmospheric and oceanographic conditions in Burrard Inlet and the Fraser River estuary

KEY POINTS:

- Surface waters of Burrard Inlet and the Fraser River estuary are often brackish and approach freshwater within the Fraser River discharge plume. Diluted bitumen is more likely to submerge as water salinity decreases

- Frequent winds, warm temperatures, and high Fraser River discharge during the spring and summer freshet are especially favourable conditions for diluted bitumen submergence

- The high tidal excursion range is especially conducive to spilled diluted bitumen stranding on shorelines, particularly on armoured or low-gradient shorelines in Burrard Inlet, and at the highly productive, low-gradient mudflats at Sturgeon Bank and the South Arm Marshes

116. Vancouver has a temperate marine climate with cool summers and moderate winters. Mean air temperatures typically range from lows near freezing in winter to highs near 18 °C in summer[27] (see Table 1). Air temperatures monitored hourly during 2005 at stations in Burrard Inlet[28] ranged from extremes of -7.0 °C in winter to 28.8 °C in summer (Table 1). Wind speed monitoring during this same period reflect sheltering of the embayment by the surrounding terrain, with mean wind speeds ranging from ~1–4 m/s (or 3.6–14.4 km/h). Wind speed vary little seasonally[29] (Table 1). Maximum winds sustained for 1 hour typically range from 10.2–14.7 m/s (37.7–51.8 km/h) in English Bay, but only 4.5–9.2 m/s (16.2–33.1 km/h) in the more sheltered Burrard Inlet[30] (Table 1).

117. Mean annual precipitation at the Environment Canada monitoring station at Second Narrows in North Vancouver was 1,831mm for the period 1981–

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[27] Davidson LW (1979) On the physical oceanography of Burrard Inlet and Indian Arm, British Columbia. MSc Thesis, University of British Columbia.

[28] CALMET data.

[29] *Ibid*.

[30] *Ibid*.

2010, with monthly precipitation varying by a factor of about 5 from a minimum in July to a maximum in January.[31]

Table 1: Seasonal mean and 1-hr sustained maximum wind speeds, mean, maximum and minimum air temperatures, and minimum sea surface water density at four locations in English Bay, Burrard Inlet and Indian Arm, Vancouver, British Columbia.

Season:		**Jan–Mar**	**Apr–Jun**	**Jul–Sep**	**Oct–Dec**
		English Bay			
Wind Speed (m/s)[32]	**Mean**	3.6	3.9	3.5	4.0
	Max	11.2	11.3	10.8	14.7
Air Temperature (°C)[31]	**Mean**	6.2	13.4	17.2	7.3
	Max	16.1	27.3	27.5	18.5
	Min	-7.0	2.8	7.7	-1.9
Minimum Sea Surface Density (kg/m^3)[33]		1021	1010	1006	1016
		Burrard Inlet			
Wind Speed (m/s)	**Mean**	2.0	2.5	2.1	2.3
	Max	8.5	7.4	7.8	8.8
Air Temperature (°C)	**Mean**	6.3	13.4	17.1	7.2
	Max	16.7	28.3	27.7	18.4
	Min	-6.5	2.9	7.8	-1.1
Minimum Sea Surface Density (kg/m^3)		1020	1015	1011	1016

[31] http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=830&lang=e&StationName=Vancouver&SearchType=Contains&stnNameSubmit=go&dCode=0, accessed 25 Nov 2014.

[32] Seasonal wind speeds and air temperatures were computed from data produced by the CALMET monitoring program for the year 2005.

[33] Minimum sea surface densities were computed from time-depth graphs of temperature and salinity for 1974–1975 presented in Figs. 5.11 and 5.12 of Davidson (1979).

Table 1 (cont'd): Seasonal mean and 1-hr sustained maximum wind speeds, mean, maximum and minimum air temperatures, and minimum sea surface water density at four locations in English Bay, Burrard Inlet and Indian Arm, Vancouver, British Columbia.

Season:		**Jan–Mar**	**Apr–Jun**	**Jul–Sep**	**Oct–Dec**
		Burnaby			
Wind Speed (m/s)	**Mean**	1.6	1.7	1.4	1.6
	Max	6.0	5.4	4.5	5.7
Air Temperature (°C)	**Mean**	6.0	12.8	16.7	6.6
	Max	17.3	28.8	27.9	17.8
	Min	-6.6	1.9	7.8	-1.4
Minimum Sea Surface Density (kg/m^3)		1014	1010	1009	1014
		Indian Arm			
Wind Speed (m/s)	**Mean**	2.4	2.5	1.9	2.6
	Max	8.5	9.2	5.6	8.8
Air Temperature (°C)	**Mean**	6.0	12.8	16.7	6.7
	Max	17.0	28.6	27.7	17.9
	Min	-6.4	2.1	7.8	-1.3
Minimum Sea Surface Density (kg/m^3)		1014	1008	1005	1009

118. Sea surface waters in Burrard Inlet are brackish, with salinities rarely exceeding 28 ‰ and ranging as low as 11 ‰ in English Bay and less than 10 ‰ in elsewhere in Burrard Inlet.[34] In comparison, salinity offshore of Vancouver Island is typically ~32–33 ‰.[35] The lower salinity of English Bay is primarily caused by outflow of freshwater from the Fraser River, which flows northward along the coast in response to Coriolis forcing. Fraser River outflow is greatest during the late spring and early summer freshet from melting snowpack within the Fraser watershed. During this period "…a layer of brackish water with salinities of less than 15 ‰ forms the top few metres over most of the central and southern sectors of the Strait of Georgia. The surface water during this period often has a sweet taste and is drinkable"[36] (Figure 2). The lower salinities of Burrard Inlet result from wind- and tidally-driven inflow of Fraser River water, augmented by precipitation and associated runoff from the surrounding catchment basin.

119. Substantial freshwater discharges reduce the density of sea surface waters in Burrard Inlet and the Fraser River estuary. The seasonal minimum density of surface waters in English Bay varies from 1,021 kg/m^3 in winter to 1,006 kg/m^3 in summer (Table 1).[37] Similarly among three stations in Burrard Inlet, minimum sea surface densities ranged from 1,020 kg/m^3 in winter to 1,005 kg/m^3 in summer (Table 1). Elsewhere near the Fraser River delta, the occasional potability of the surface water implies densities little greater than 1,000 kg/m^3. These minimum densities of sea surface waters are important because they define thresholds for oil submergence resulting from density increases caused by evaporative weathering.

120. The Salish Sea experiences mixed semi-diurnal tides, with two high tides of unequal height alternating with two low tides of unequal height. The average tidal range is about 3 m, with an extreme tidal range of 4.8 m.[38] This high tidal excursion range is conducive for oil stranding on shorelines, especially if oil accumulates on the upper-part of low-gradient shorelines at high tide, and becomes stranded as the tidal level falls during the outgoing tide. As the tide recedes, the water table within beach sediments falls, which allows diluted

[34] Davidson 1979.

[35] Pickard GL, Emery WJ (1993) Descriptive physical oceanography – An Introduction, 5th (SI) enlarged edition. Pergamon Press, Tarrytown, NY.

[36] Thomson 1991.

[37] Davidson 1979.

[38] *Ibid*.

bitumen stranded on the beach surface to seep into the beach sediments, especially through channels created by organisms that burrow beneath the surface of the beach (see s. 5.2). Once oil penetrates into beaches it becomes trapped by capillary forces, so the next rising tide cannot dislodge all or even most of it. This sets the stage for long-term oil persistence in beaches, particularly if the oil penetrates into hypoxic (i.e., low-oxygen) sediments where the rate of microbial degradation is greatly slowed.[39]

5.1.3 Chemical composition and physical properties of diluted bitumen

KEY POINTS:

- The bitumen component of diluted bitumen consists essentially of highly biodegraded petroleum that is naturally prone to submerging in fresh and brackish water

- Diluted bitumen is a mixture of high-volatility, low-density hydrocarbon diluent with low-volatility, high-density bitumen and once spilled, rapidly looses the high-volatility components, in marked contrast with normal crude or heavy refined oils

- Concentrations of polycyclic aromatic hydrocarbons (PAH), the most toxic components of petroleum, in diluted bitumen are comparable with typical concentrations in crude oils

121. The composition of diluted bitumen are highly unusual, and differ markedly from that of typical crude oils. These composition differences affect how diluted bitumen behaves in the environment following release. The following summary of how the bitumen in diluted bitumen was formed geologically explains why these products are so prone to submerging in fresh and brackish waters, and why bioremediation would not likely be a very effective spill response option.

122. Diluted bitumen derived from Alberta oil sands are unusual petroleum products, both in the geological formation of the bitumen itself, and in the necessity for blending with other petroleum products for shipment through pipelines. Consequently results and conclusions regarding the composition, properties, and environmental behaviour that are based on measurements performed on normal crude oils must be interpreted with caution when applied to diluted bitumen. The chemical composition of bitumen differs

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[39] Li H, Boufadel MC (2009) Long-term persistence of oil from the *Exxon Valdez* spill in two-layer beaches. Nature Geoscience 3:96-99.

markedly from that of most normal crude oils, and these differences are exacerbated when bitumen is mixed with other refined petroleum products.

123. Normally petroleum is formed from accumulations of marine algae on sediments that are subsequently buried and then exposed to elevated temperatures and pressures over geological time periods. These conditions are strongly reducing, resulting in compounds spanning a continuous spectrum of molecular weights, from methane (molecular weight of 14 Da) through poorly characterized asphaltenes (molecular weights of 100,000 Da or more). Commercial deposits arise when petroleum migrates through porous sandstone or shale rocks until it encounters non-porous rock that acts as a trapping structure, allowing the petroleum to accumulate. A normal commercial petroleum deposit thus consists of a trapping structure under which are successive layers of gases, then petroleum liquids, and finally water.[40]

124. Although Alberta oil sands bitumen was initially formed the same way as normal petroleum, it did not encounter trapping structures during the ensuing migration through porous rocks. Instead, the petroleum continued migrating subsurface across the plains to the east from the source rocks where it was initially formed near the eastern margin of the Canadian Rocky Mountains. Along the way, the petroleum was exposed to oxygenated water, which allowed hydrocarbon-degrading microbes to consume most of the bioavailable oil components. Also, the hydrocarbon and other gases associated with petroleum formation and subsequent microbial degradation eventually escaped to the atmosphere through fissures and porous rocks that established conduits to the surface. As a result, Alberta oil sands bitumen characteristically is denser and considerably more viscous than ordinary crude oils. It is also “pre-biodegraded” in that nearly all of the biodegradable components have already been biodegraded.[41] As a result, remediation methods that rely on biodegradation are not likely to be very effective when shorelines are contaminated by diluted bitumen from the Alberta oil sands.

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[40] Walsh MP, Lake LW (2003) A generalized approach to primary hydrocarbon recovery. Handbook of Petroleum Exploration and Production, 4, J. Cubitt, editor. Elsevier, Oxford, UK.

[41] National Energy Board (2000) Canada’s oil sands: A supply and market outlook to 2015. National Energy Board, Calgary, AB.

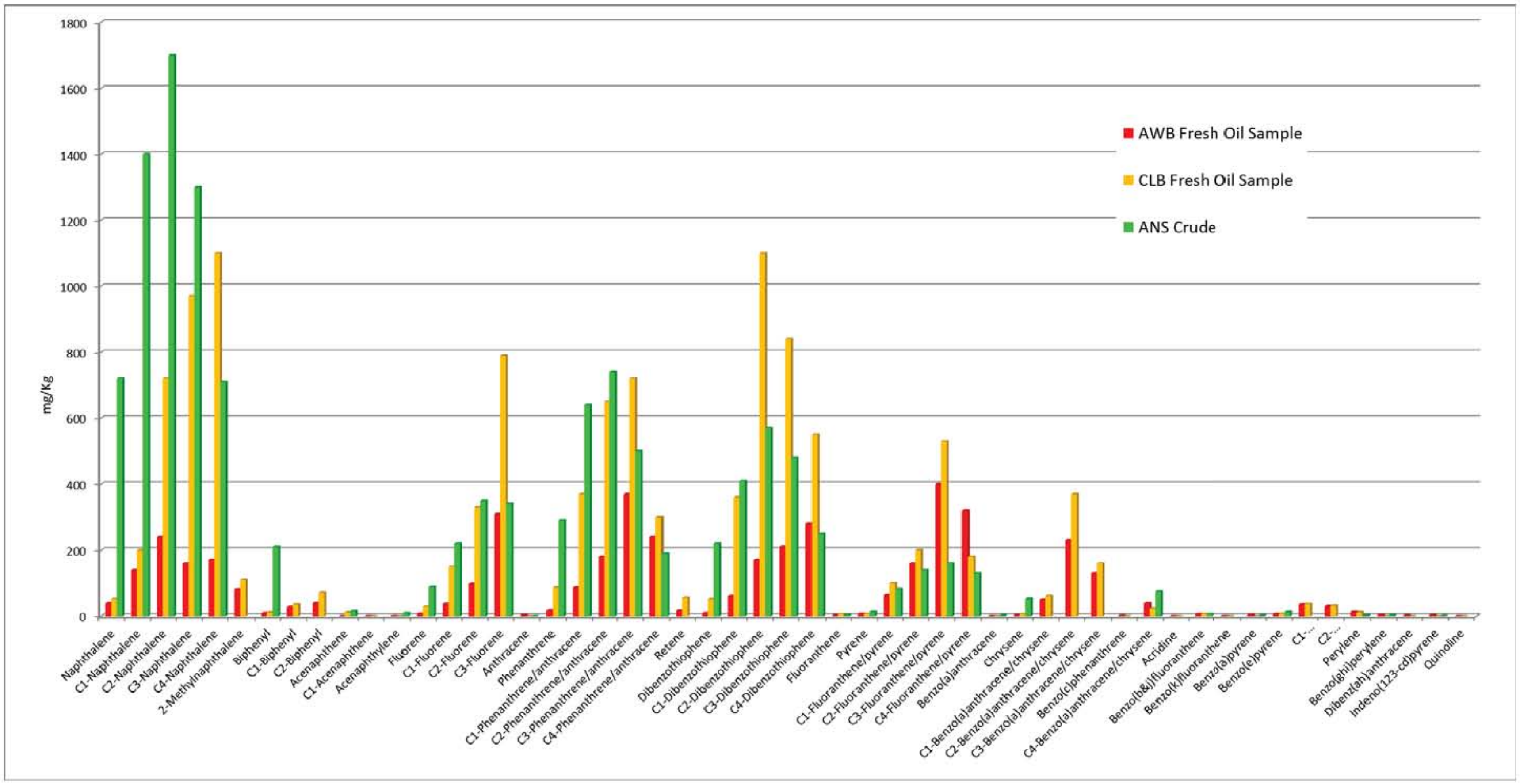

Figure 6. Distribution of un-substituted and alkyl-substitute polycyclic aromatic hydrocarbons and dibenzothiophenes in un-weathered Access Western Blend (AWB) and Cold Lake Bitumen (CLB) in comparison with Alaska North Slope (ANS) crude oil.

125. Natural biodegradation during formation of the Alberta oil sands led to substantial depletion of alkanes and of some PAH, two classes of hydrocarbons that are ordinarily prominent in crude oils. Normal alkanes, which are linear carbon chains that are saturated with hydrogen, are almost completely absent from oil sands bitumen[42] but typically account for 50–100 mg/g (i.e., 5–10% by weight) of normal crude oils.[43] Ordinarily the two-ring naphthalenes are the most abundant PAH in normal crude oils, but these are only a small proportion of the PAH in oil sands bitumen. However, while the total PAH concentration of oil sands bitumen is less than in most normal crude oils, concentrations of the more toxic 3- and 4-ring PAH are about the same (Figure 6).[44]

126. Oil sands bitumen may be considered as a normal crude oil that has undergone extensive weathering following release to the environment. The extensive composition changes caused by losses of volatile components and natural biodegradation of oil sands bitumen in natural formations are consistent with a weathering index of 5 on the Kaplan and Galperin[45] petroleum weathering scale of 1 to 10, which is often used to categorize the extent of weathering of residual oil following spills. Petroleum that has weathered to this extent has little scope for bioremediation.

127. As with weathered normal crude oils, the physical properties of oil sands bitumen are substantially different in comparison with fresh crude oils. Weathered crude oils are denser and much more viscous compared with respective un-weathered oils. The densities of oil sands bitumen are close to 1,040 kg/m^3,[46] meaning they would sink in fresh- or saltwater, whereas normal crude oils more often have densities near 900 kg/m^3.[47] Viscosities of oil sand bitumen, as with normal crude oils that have weathered as extensively, are ~100,000 mPa-s (at 15°C), compared with viscosities near

[42] Yang C, Wang Z, Yang Z, Hollebone B, Brown CE, Landriault M, Fieldhouse B (2011) Chemical fingerprints of Alberta oil sands and related petroleum products. Environmental Forensics 12:173-188.

[43] Environment Canada, 2006. Oil Properties Database. www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html.

[44] Yang 2011; Environment Canada, 2006. Oil Properties Database. www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html.

[45] Kaplan IR, Galperin Y, Lu S-T, Lee R-P (1996) Patterns of chemical changes during environmental alteration of hydrocarbon fuels. Groundwater Monitoring and Remediation: 113-124.

[46] Meyer 2004.

[47] Environment Canada (2006) Oil Properties Database. www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html.

10 mPa-s for fresh crude oils.[48] Because of these higher densities and viscosities, oil sands bitumen must be diluted with low-viscosity petroleum products to ship them through pipelines. Trans Mountain requires that products shipped through their pipelines have densities of 940 kg/m^3 (or 0.94 g/cm^3) or less, and kinematic viscosities of 350 centistokes or less.[49]

128. Oil sands bitumen is usually diluted with gas condensate to achieve the density and viscosity specifications required for pipeline shipment. Gas condensate consists of gasoline-range hydrocarbons that have boiling points ranging from that of pentane (C_5H_{12}) through dodecane ($C_{12}H_{26}$), or 36 °C to ~216 °C (Figure 7). This mixture of gas condensate (usually ~30%) and bitumen (~70%) is diluted bitumen, the product to be shipped through the proposed Trans Mountain pipeline expansion project.

129. Because diluted bitumen is essentially a mixture of raw gas condensate and extensively weathered crude oil, it does not behave in quite the same way as normal un-weathered petroleum following accidental spills. Diluted bitumen contains higher proportions of the most volatile petroleum hydrocarbons in comparison with normal crude oils (Figure 7), which are lost more rapidly once diluted bitumen is released to the environment. This causes the density of diluted bitumen to increase more rapidly than normal crude oils once spilled. Similarly, diluted bitumen also contains higher proportions of the heaviest fractions of petroleum in comparison with normal crude oils (e.g. Figure 6).

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[48] *Ibid*.

[49] http://www.transmountain.com/product-shipped-in-pipeline. Viscosity is resistance of a fluid to flow, and is measured in two ways, as dynamic viscosity (which has units of Pascal-seconds), and as kinematic viscosity (which is the ratio of dynamic viscosity and fluid density, with units of Stokes). The most commonly used viscosity units for liquids are the milliPascal-second (mPa-s) and the centiStoke (cSt), where cSt = mPa-s/ρ, where ρ indicates the density of the fluid in kg/m^3. Depending on temperature, the viscosity of water is near 1 mPa-s; of honey, 2,000–10,000 mPa-s; and of peanut butter, ~250,000 mPa-s.

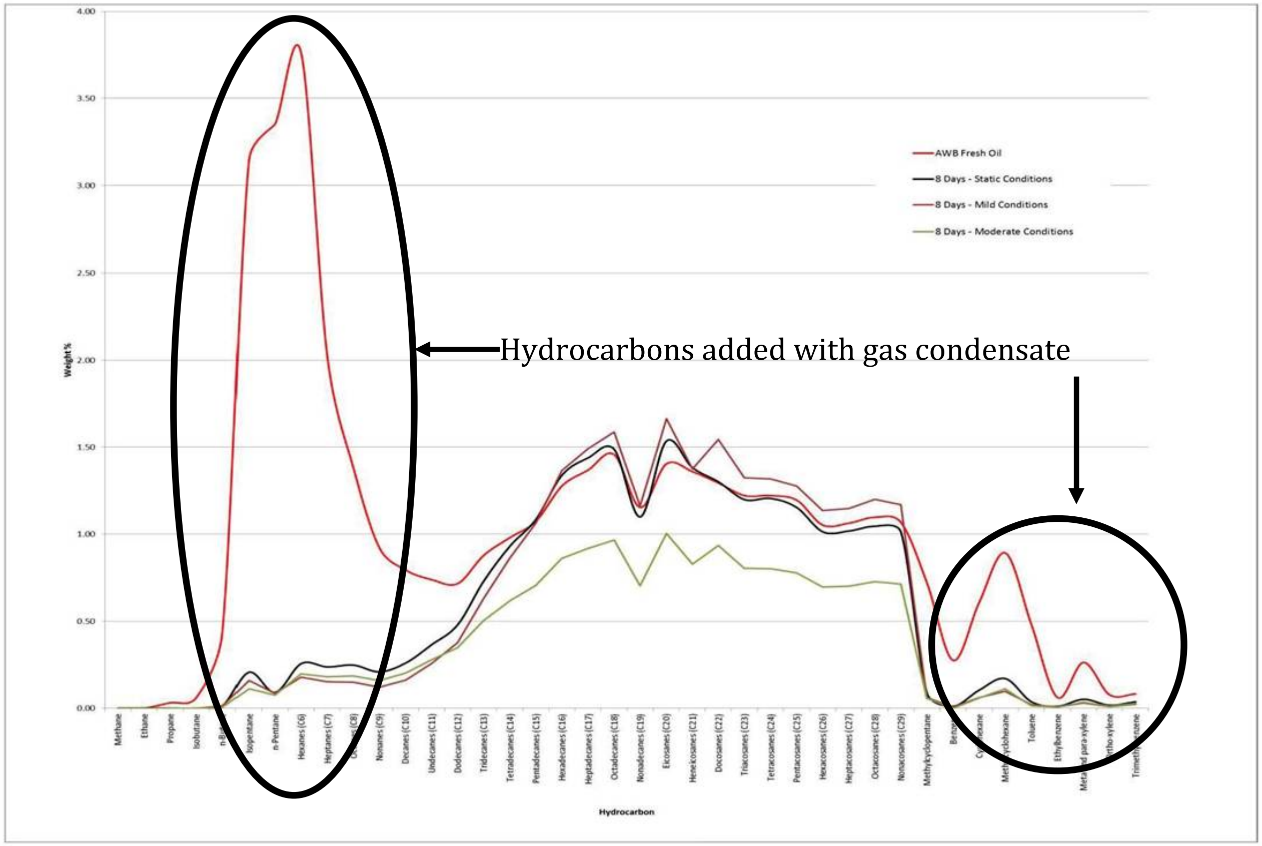

Figure 7. Concentrations of normal alkanes and of benzene, toluene, ethylbenzene and xylene (i.e., "BTEX" compounds) in fresh and weathered Access Western Blend (AWB) bitumen. Note the rapid loss of hydrocarbons associated with the gas condensate component of AWB. Figure reprinted from Figure. 4-9 in the Gainford Study[50] included in the Trans Mountain application.

[50] Witt O'Brien's, Polaris Applied Sciences, Western Canada Marine Response Corporation (2013) A study of fate and behavior of diluted bitumen oils on marine waters, dilbit experiments—Gainford, Alberta.

5.1.4 Effects of weathering on the physical properties of diluted bitumen

KEY POINTS:

- Diluted bitumen is naturally prone to submergence in fresh and brackish waters
- Experiments performed to assess how fast the density of diluted bitumen would increase during an oil spill have seriously overestimated the time required for it to submerge
- Under worst-case ambient conditions of warm summer temperatures and moderate winds, spilled diluted bitumen may begin to submerge in the surface layer of the Fraser River plume and Burrard Inlet after about 24 hours following the initial release. This possibility must be included in oil spill risk assessments

130. Unlike most normal crude oils, raw bitumen as it resides in natural deposits, including bitumen from the Alberta oil sands, is inherently susceptible to submerging in water, as noted in s. 5.1.3 above. The densities of diluted bitumen are made considerably less than freshwater by addition of low-density diluents, typically gas condensate as explained in s. 5.1.3 above, to meet pipeline shipment requirements. Evaporative loss of added diluents may therefore return the diluted bitumen to near the density of the bitumen component, which may be high enough to submerge in fresh, brackish or even full-strength seawater if all the diluent components are lost.

131. The five studies summarized in **Appendix 3** confirm that, in principle, volatility losses alone may increase the density of diluted bitumen enough to submerge in fresh or brackish water. These five studies involved monitoring changes in physical properties and chemical composition of diluted bitumen in experimental tanks of water under various conditions. Estimating the time required for evaporative losses to result in neutral buoyancy of the diluted bitumen remaining involves considerable uncertainty, owing mainly to the unrealistically thick oil films used in four of the five experiments. Even the most realistic study involved an oil film nearly three times thicker (i.e., 1.15 mm[51] vs. 0.4 mm[52]) than would occur during a real spill of diluted bitumen that was not enclosed by barriers such as oil booms or naturally enclosed water bodies, a point acknowledged by the authors of the Gainford

[51] SL Ross (2012) Meso-scale weathering of Cold Lake bitumen/condensate blend. SL Ross Environmental Research Ltd, #200 - 1140 Morrison Drive, Ottawa, ON K2H 8S9.

[52] Stronach 2013.

Study experiments.[53] Nonetheless, direct observations of the water column indicated that diluted bitumen appeared to attain neutral buoyancy within 48 hours at 15 °C. Had an unconstrained oil film having a film thickness of ~0.4 mm been used in the Gainford Study experiments instead of the 1.15 mm-thick oil film, the time required to reach neutral buoyancy may have been as brief as 24 hours. This is because evaporation rates from a natural 0.4 mm-thick slick are about three times faster than from a 1.15 mm-thick slick under identical ambient conditions, so the approach to neutral buoyancy within 48 hours at 15°C as observed in the Gainford Study experiments would have occurred after about 16 h for a natural 0.4 mm slick.

132. The Trans Mountain application assumes that the time required for diluted bitumen to approach neutral buoyancy is accurately estimated by the Gainford Study experiments, thereby failing to account for effects of slick thickness on weathering rate. Consequently the application greatly underestimates the risk of oil submergence. Accounting for realistic slick thicknesses suggests that diluted bitumen could reach neutral buoyancy and hence submerge in fresh water in as little as 24 hours.

5.1.5 Effects of weathering on the chemical composition of diluted bitumen

KEY POINTS:

- Spilled diluted bitumen loses its volatile components more quickly than normal crude oils, creating greater inhalation and safety hazards
- Spilled diluted bitumen retains the toxic PAH longer than normal crude oils, and are degraded mainly through slow biodegradation and photo-oxidation

133. Because diluted bitumen is essentially a mixture of high-volatility diluent with low-volatility bitumen, the most dramatic changes of the chemical composition of diluted bitumen initially result from evaporative losses of the diluent components. The components lost include the alkane and monocyclic aromatic hydrocarbons (including benzene, toluene, ethyl-benzene and xylenes, or BTEX) that have boiling points less than 200 °C, indicated by circles in Figure 7. These compounds are lost within the first hours to days of a spill as indicated by the experiments discussed under s. 5.1.4 above. In contrast, changes in the PAH composition within this timeframe are negligible, as indicated by the PAH composition of diluted bitumen samples

[53] Witt O'Brien's 2013.

during the Gainford study[54] (Figure 8). During the Gainford study, the pattern of relative PAH abundances did not change appreciably from fresh diluted bitumen to diluted bitumen after 8 days of exposure to mild and moderate conditions, although the absolute concentrations did. However, these absolute differences in concentration reflect imprecision in the sample mass measurements because the differences are proportionally systematic across the compounds measured. In contrast, biodegradation typically leads to differences in the relative PAH abundances, that is, the abundance of PAH relative to one another.[55] These changes are not evident in the Gainford study samples that were analyzed for PAH.

[54] *Ibid*.

[55] Prince RC, Garrett RM, Bare RE, Grossman MJ, Townsend T, Suflita JM, Lee K, Owens EH, Sergy GA, Braddock JF, Lindstrom JE, Lessard RR (2003) The roles of photooxidation and biodegradation in long-term weathering of crude and heavy fuel oils. Spill Science and Technology Bulletin 8:145-156.

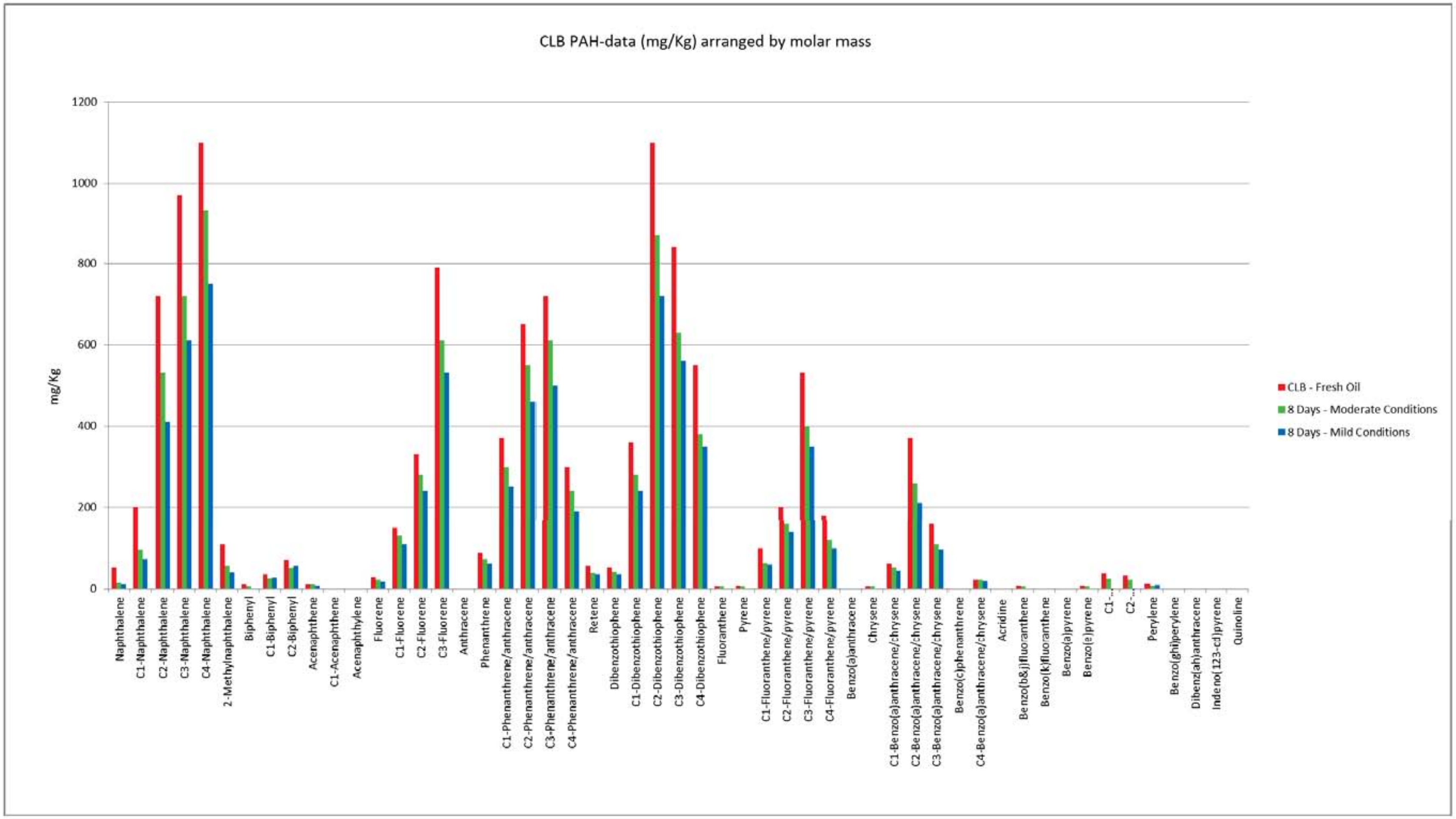

Figure 8. Concentrations of PAH in Cold Lake Bitumen initially and after 8 days of weathering under mild and moderate wind speed conditions (from Gainford Study Figure 4-8).

134. Once compounds associated with the gas condensate diluent are lost, further composition changes occur much more slowly, mainly through biodegradation and photo-oxidation. Although natural biodegradation had already removed most of the compounds in the Alberta oil sands bitumen prior to extraction (see s. 5.1.3 above), the PAH remaining are susceptible to further biodegradation.[56] The rate that these remaining PAH are biodegraded depends on numerous factors, including the availability of microbes capable of degrading PAH, oxygen, and inorganic nutrients to support microbial metabolism and growth, as well as the temperature, viscosity, and relative surface area of the oil.

135. Photo-oxidation requires exposure to oxygen and to strong sunlight. Photo-oxidation affects a relatively small proportion of the heavy compounds associated with bitumen,[57] increasing the water solubility of the oxidized compounds.

136. As biodegradation and photo-oxidation proceed, the residual bitumen eventually hardens into an asphalt-like material that has low bioavailability of any remaining toxic compounds. Conditions that promote extreme weathering losses and consequent hardening of the residual bitumen include deposition on the upper reaches of shorelines where prolonged exposure to air and strong sunlight accelerates evaporation of volatile and semi-volatile components, and photo-oxidation of the residual bitumen. In contrast, percolation of diluted bitumen into hypoxic subsurface sediments can lead to preservation with only modest changes in composition for decades or even a century.[58]

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[56] *Ibid*.

[57] Islam A, Cho Y, Yim UH, Shim WJ, Kim YH, Kim S (2013) The comparison of naturally weathered oil and artificially photo-degraded oil at the molecular level by a combination of SARA fractionation and FT-ICR MS. Journal of Hazardous Materials 263:404-411.

[58] Li 2009; Culbertson 2008; Short JW, Springman KR, Lindeberg MR, Holland LG, Larsen ML, Sloan CA, Khan C, Hodson PV, Rice SD (2008) Semipermeable membrane devices link site-specific contaminants to effects: PART II – A comparison of lingering Exxon Valdez oil with other potential sources of CYP1A inducers in Prince William Sound, Alaska. Marine Environmental Research 66:487-498; Peacock EE, Hampson GR, Nelson RK, Xu L, Frysinger GS, Gaines RB, Farrington JW, Tripp BW, Reddy CM (2006) The 1974 spill of the Bouchard 65 oil barge: Petroleum hydrocarbons persist in Winsor Cove salt marsh sediments. Marine Pollution Bulletin 54:214-225; Peacock EE, Nelson RK, Solow AR, Warren JD, Baker JL, Reddy CM (2005) The West Falmouth oil spill: ~100 Kg of oil found to persist decades later. Environmental Forensics 6:273-281; Burns KA, Garrity SD, Jorissen D, MacPherson J, Stoelting M, Tierney J, Yelle-Simmons L (1994) The Galeta oil spill. II. Unexpected persistence of oil trapped in mangrove sediments. Estuarine, Coastal and Shelf Science 38:349-364.

5.1.6 Behaviour of diluted bitumen in receiving waters

KEY POINTS:

- Spilled diluted bitumen will follow a similar sequence of changes characteristic of typical oil spills, except that diluted bitumen is more prone to submergence, thereby exposing inhabitants of the water column to submerged oil

- A diluted bitumen spill would seriously threaten seabirds, shorebirds, marine mammals, and intertidal biota generally

- Diluted bitumen stranded on shorelines would be most persistent on armoured beaches, marshes, and mudflats, all of which are common within Burrard Inlet and the Fraser River estuary

137. Diluted bitumen spilled into surface waters of Burrard Inlet and the Fraser River estuary will follow the same general sequence of changes typical of most oil spill, summarized in s. 5.1.1 (Figure 5).

138. Immediately following initial discharge and depending on the volume spilled, rapid evaporation of the gas condensate components of diluted bitumen may create contact and inhalation hazards for wildlife such as seabirds and marine mammals in the immediate vicinity of the spill. If winds are sufficiently strong to generate breaking waves, diluted bitumen may be entrained into the upper water column as small oil droplets, making them available to suspension-feeding fish and invertebrates.

139. As the more volatile components are lost by evaporation, the increasing density of oil that remains on the sea surface may cause the oil to become neutrally buoyant with respect to the density of the sea surface immediately beneath it, causing the oil to submerge.[59] Oil submergence would be hastened if inorganic suspended particulate material (SPM) entrained in the water column adheres to the oil, increasing the density of the oil-SPM aggregate, especially in the high-sediment plume of the Fraser River discharge during spring and summer (Figure 4).[60]

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[59] Note that the density of the sea surface layer depends on its salinity, with fresher water being less dense.

[60] Khelifa AM, Fingas M, Brown C (2008) Effects of Dispersants on Oil-SPM Aggregation and Fate in US Coastal Waters. Final Report to the Coastal Research Response Center, University of New Hampshire, July 2008, 38 pp.

140. Oil remaining on the sea surface will pose a contact hazard for seabirds and marine mammals. Eventually, oil on the sea surface will either become tar balls that submerge in the water column, or impinge on shorelines where some of it will remain, and some of it will be re-floated back to the sea.

141. If oil accumulates on shoreline sediments and is subsequently re-floated, it will be much more susceptible to submergence or sinking to the seafloor.

142. The effects, persistence, and fate of oil impinging on shorelines depend strongly on the shoreline morphology and the environmental conditions at the time of oil stranding.

143. Oil is least persistent on bedrock outcrops and rocky headlands because these provide relatively little surface area for adhesion and often are exposed to more energetic wave conditions that promote oil removal.

144. Oil stranded on rocky armoured beaches may be quite persistent if it penetrates beneath the armour layer and becomes trapped by capillary forces in finer-grained underlying sediments, especially if the oil penetrates into hypoxic sediments where biodegradation is impeded.

145. Penetration of oil stranded on the surface of sandy beaches is limited by low hydraulic permeability, although oil may subsequently become mixed into the subsurface by sufficiently energetic wave action. When this occurs it may create a long-term reservoir of stranded oil that sporadically re-surfaces, which may then be transported to the immediately adjacent subtidal seafloor. Once re-located to the subtidal seafloor, disturbance from wave action is considerably reduced, and the oil may persist for years to decades if it has congealed into a compact mass.

146. Penetration of oil stranded on mudflats may appear to be more limited than on sandy beaches because the hydraulic permeability of mud is even lower than sand. However, mudflats often contain holes created by burrowing organisms such as clams, worms and crabs, and oil may readily percolate into these holes and then become trapped by adhesive forces. Oil in these burrows can persist for years to decades and possibly a century.[61]

147. Finally, oil stranded on or along marine marshes or intertidal eelgrass beds may also persist for years to decades if the oil associates with decaying vegetative material that creates persistent hypoxic conditions impeding biodegradation of the oil.

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[61] Li 2009; Culbertson 2008; Short 2008; Peacock 2006; Peacock 2005; Burns 1994.

148. In summary, a spill of diluted bitumen in Burrard Inlet and the Fraser River estuary is far more likely to submerge or sink, and could be retained on shorelines for much longer than is anticipated by the Trans Mountain ERA. Contamination of the water column by submerged oil opens the possibility of exposing a much wider diversity of organisms to oil, leading to multiple damage pathways that are not normally significant following typical crude oil spills.

5.2 Effects of diluted bitumen discharged into Burrard Inlet or the Fraser River estuary

149. Diluted bitumen accidentally discharged into Burrard Inlet or the Fraser River estuary would contaminate one of the most biologically productive and ecologically important estuaries in the world. This section summarizes the biological importance of the Fraser River estuary, the associations of communities of intertidal organisms on different kinds of beaches in the Salish Sea, the various ways diluted bitumen can become stranded on these beaches, the factors that determine oil persistence once stranded, and the various ways that diluted bitumen can adversely affect the organisms inhabiting these shorelines. The interaction of all these factors serves to illustrate the complexity of the marine ecosystem in contrast with the oversimplification of the Trans Mountain ERA.

5.2.1 Biological productivity of the Fraser River estuary

KEY POINTS:

- The Fraser River estuary is the most productive, diverse and important estuary on the Pacific coast of North America
- Ecological connections of the Fraser River estuary extend over tens of thousands of kilometers through movements of migratory birds, mammals and fish, especially salmon.
- The Fraser River estuary is recognized internationally and hemispherically as an area of great ecological importance[62]

150. The Fraser River is the defining element of the adjoining estuarine and marine ecosystem, without which the Salish Sea would be just another inland passage waterway. The high freshwater discharge from the river during

[62] Western Hemisphere Shorebird Reserve Network (www.whsrn.org/whsrn-sites).

spring floods the surface of the estuary over a wide area.[63] This freshened surface layer stabilizes the water column, a necessary precondition triggering the onset of the growing season for the marine phytoplankton that form the foundation for the marine food web. The river discharge thereby prolongs the overall growing season substantially. In its absence, the necessary water column stabilization would have to await the slower process of thermally-driven stratification from the increased insolation during spring.

151. The spring freshet also brings hundreds of millions of out-migrating juvenile salmon and other anadromous fishes, which are prey for resident and migratory seabirds.

152. During fall, the spawning migration brings tens of millions of salmon, mainly sockeye (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*), and including chinook salmon (*O. tshawytscha*), through the Salish Sea and estuary as they return to the Fraser River watershed tributaries to spawn[64]. These species of salmon provide crucial forage food for numerous marine mammals. The decomposing carcasses of post-spawn salmon, augmented by the urine and fecal excretions of predators that prey on the returning adults provide a substantial subsidy of marine-derived nitrogen and phosphorus nutrients to the entire watershed.[65] These nutrients ultimately contribute to the high productivity of the Fraser River estuary itself as they are eventually washed out of the watershed.

153. The exceptionally high abundances and diversity of waterfowl in Burrard Inlet and the Fraser River estuary have led to national, international and hemispheric recognition of their ecological importance. The Fraser River estuary is recognized as one of six sites of hemispheric importance for migratory sea- and shorebirds along the Pacific coast of North America, based on use of this habitat by more than 500,000 birds and by more than 30% of the global population of at least one bird species (snow goose).[66] Burrard Inlet and the Fraser River estuary are recognized as an Important Bird Areas by Bird Life International, Bird Studies Canada, and Nature Canada.[67] The Fraser River estuary is also designated as a wetland of

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[63] Thomson 1981.

[64] Pacific Salmon Commission 2009.

[65] Larkin GA, Slaney PA (2011) Implications of trends in marine-derived nutrient influx to south coastal British Columbia salmonid production. Fisheries 22:16-24.

[66] See Western Hemisphere Shorebird Reserve Network (www.whsrn.org/whsrn-sites).

[67] See http://www.ibacanada.ca.

international importance to birds and other species as site 243 under the Ramsar Convention.[68] Ramsar site 243 includes 18,216 ha of wetlands from the lowest low tide of the year to 5–7 m above sea level at Sturgeon Bank Wildlife Management Area, South Arm Marshes Wildlife Management Area, Alaksen National Wildlife Area (which includes the George C. Reifel Migratory Bird Sanctuary), and Serpentine Wildlife Management Area (Figure 1).

5.2.2 Physical habitat associations of intertidal species

KEY POINTS:

- Biological assemblages on shorelines typically occupy horizontal bands that may extend across shoreline types
- The biomass and productivity of intertidal communities typically increases with lower tidal elevations
- Estuarine, marsh, and lagoon habitats – often associated with extensive mudflats at lower tidal elevations – account for ~19% of Burrard Inlet/Fraser River estuary shorelines and are the most productive and ecologically important shoreline types

154. Because spilled oil products can linger on shorelines for decades, some of the most long-lasting effects of oil spills may occur in these habitats. The biological assemblages found between the highest and lowest tides vary considerably depending on whether the shoreline is composed of bedrock or a conglomerate, the particle size distribution if a conglomerate, the steepness (or gradient) of the shoreline, and the exposure to wave scouring. In general, biological diversity and biomass decrease with higher tidal elevations because plants and animals have less time to acquire marine-derived nutrients and food as their submergence period declines. At lower tidal elevations, the occurrence of surface-dwelling species often declines abruptly because of greater exposure to marine predators. These two factors create characteristic bands of animal and plant assemblages on shorelines, sometimes called “biobands” or “biozones.” These zones often extend across different shoreline types and gradients, and the dominant species within these zones provide habitat for other species that are associated with them.

[68] The Ramsar Convention is an international treaty formally known as the Convention on Wetlands of International Importance, especially as Waterfowl Habitat. Canada acceded to this treaty in 1981.

155. Patterns of biobanding on shorelines are similar throughout the Salish Sea, including Burrard Inlet and the Fraser River estuary. Proceeding from the extreme upper limit of the intertidal to the extreme lower limit, the most prominent biobands on most shorelines are zones of salt-tolerant herbaceous vegetation on soils or encrusting lichens on bare rock surfaces, barnacles and rockweed, grading into green algae and blue mussels, then red algae and surfgrass, and finally kelps and eelgrass that remain submerged most of the time in the lowest part of the intertidal.[69] The biological assemblages provide cover for many other species including marine snails, and the larval and juvenile life stages of a host of other species of fish and crabs.

156. Within stable conglomerate shorelines such as armoured beaches and mudflats, rich communities of invertebrates including worms, clams and crabs live beneath the surface of the beach at densities that generally increase with lower tidal elevation. Similar species often inhabit less stable sandy beaches, but at generally lower diversity and biomass.

157. Man-made shorelines are the most common along the Burrard Inlet-Fraser River estuary, accounting for 34% of the total shoreline length (Figure 9). These are predominantly hardened structures such as docks, piers, jetties etc. that are very similar to natural rocky habitats from the perspective of intertidal biota, and biozones may be especially striking on these structures. The next most common shoreline types are sand or mixed sand and gravel (22%), estuary, marsh or lagoon, usually associated with an extensive mudflat in the lower intertidal (19%), mixed rock/gravel/sand, mostly armoured[70] (11%), and rock cliffs (9%). Most of the estuary, marsh or lagoon habitat is located within Boundary Bay, Sturgeon Banks, Westham Island and just south of Westham Island. Most of the rock cliff habitat is within Indian Arm in Burrard Inlet. The sandy and man-made shorelines are scattered throughout the area.

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[69] Coastal & Ocean Resources Inc., Archipelago Marine Research Ltd. (2005) ShoreZone Mapping Data Summary, Gulf Islands National Park Reserve. Prepared for Parks Canada, CORI project 04-35. Coastal & Oceans Resources Inc., 214-9865 West Saanich Road, Sidney, British Columbia V8M 5Y8.

[70] An "armoured" beach is one that is covered by a surface layer of relatively large cobbles to boulders, beneath which are poorly-sorted, finer-grained sediments that are protected from erosion by the armour layer.

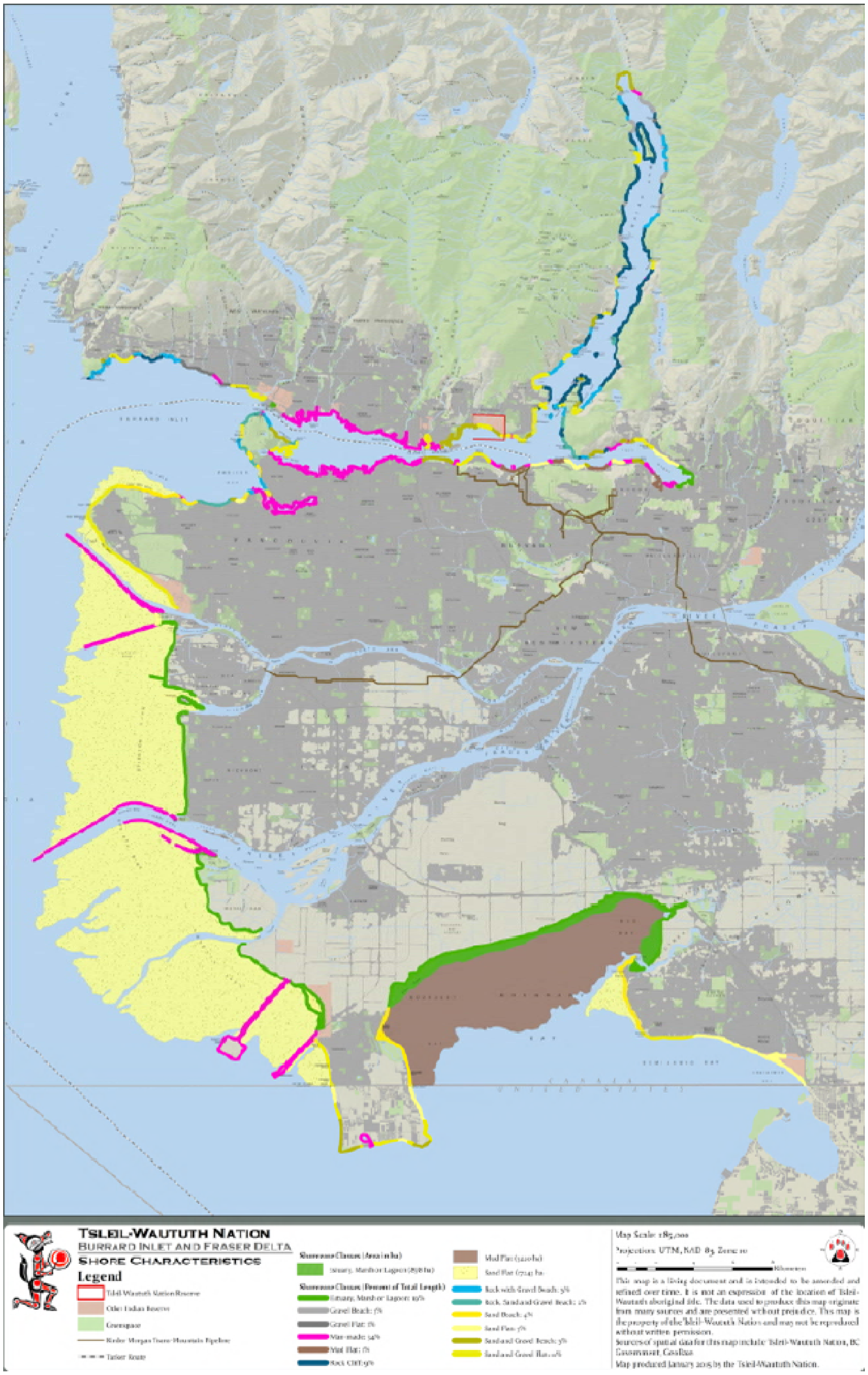

Figure 9. Shoreline types in Burrard Inlet and the Fraser River estuary within Indian Arm in Burrard Inlet. The sandy and man-made shorelines are scattered throughout the area.

5.2.3 Effects of weathered diluted bitumen on intertidal species

KEY POINTS:

- Heavy oiling on armoured beaches, mudflats and marshes in the upper intertidal can create long-term oil exposure hazards for plants and animals, including shorebirds
- Mammals and shorebirds are especially sensitive to physical contact with oil, while early life stages of fish and translucent life stages of any species are especially sensitive to PAH
- Biological communities on sand and gravel beaches would usually recover more quickly from oiling than on other beach types

158. Spilled diluted bitumen can affect intertidal biota through three different modes of exposure: physical smothering, ingestion of dispersed oil droplets, and absorption of toxic compounds dissolved from oil into the water column.

159. Physical smothering can lead to suffocation or starvation.

160. Ingestion of oil droplets by intertidal suspension-feeding organisms including clams, mussels, barnacles as well as by fish and other species can reduce growth or in severe cases cause death.

161. Absorption of toxic compounds dissolved from oil into the water column can cause death from narcosis, embryotoxicity to early life stages of fish, and photo-enhanced toxicity to translucent organisms (which may include early life stages of fish and other organisms).

162. Accumulation of oil-derived compounds by organisms, whether through physical contact, ingestion of oil or absorption of compounds that dissolve into the water column can taint tissues at very low concentrations (parts per trillion or less), rendering plants and animals collected during subsistence harvests unpalatable.

163. Effects from these modes of exposure and toxic action depend on when, where and how diluted bitumen impinges on shorelines, the type of shoreline oiled, and the biota inhabiting the shoreline. The following subsections discuss these interactions in more detail.

5.2.3.1 Bedrock and hardened shorelines

164. Bedrock and other hardened shorelines such as piers, jetties, wharves etc. provide space for diverse biological communities. These shorelines account

about 35% of shoreline in the Fraser River Delta and Burrard Inlet (Figure 9).

165. Since both diluted bitumen and biota are limited to the surface of hardened substrates, diluted bitumen penetration and effects on animals and plants are limited to the substrate surface.

166. By the time diluted bitumen impinges on shorelines, its viscosity and adhesion are likely much greater than after initial discharge to receiving waters, making the diluted bitumen very likely to adhere to rock and concrete, and to the plant and animal communities there. Some plants such as rockweeds (*Fucus sp.*) and shellfish such as bay mussels (*Mytilus trossulus*) can form dense, interconnected assemblages that provide cover and surface area for numerous other species such as marine snails and worms. These 3-dimensional structural networks also act as a kind of "sponge" for diluted bitumen, such that viscous diluted bitumen that penetrates into these networks may be very difficult to dislodge just by tidal pumping or moderate wave action. It can persist there for weeks or months.[71]

167. If sensitive species or life stages become associated with these diluted bitumen-contaminated structural networks, the trapped diluted bitumen may provide a persistent source of contamination by slowly releasing PAH to the interstitial water of the networks, exposing eggs, larvae and other translucent species to PAH for protracted periods. This trapped oil can also pose a contact hazard for shorebirds that prey on intertidal snails, worms, and other animals that inhabit the interstices of *Fucus* and mussel beds. Moreover, shoreline remediation efforts to remove diluted bitumen trapped by these biological communities may inflict additional damage to resident plants and animals, which should be included as a toxic effect of a spill.

168. Intertidal plants and animals inhabiting bedrock or artificially hardened shorelines are vulnerable to physical smothering by oil. In extreme cases smothering may prevent respiration of plants and animals causing death. Less severe smothering may still impede or prevent feeding and movement of mobile grazers and predators such as marine snails and intertidal fish that are stranded in oiled rocky habitats such as tide pools during low tides.

169. Suspension-feeding intertidal organisms including mussels, barnacles, and many clams often inhabit rocky shorelines and can ingest small diluted bitumen droplets entrained in the water column during tidal submergence.

[71] Carls MG, Babcock MM, Harris PM, Irvine GV, Cusick JA, Rice SD (2001) Persistence of oiling in mussel beds after the Exxon Valdez oil spill. Marine Environmental Research 51:167–190.

These organisms can also absorb oil-derived compounds that dissolve into the water column. Oil compounds accumulated by these organisms can impair their growth[72] and increase their susceptibility to disease.[73] Also, the accumulated body burden of oil by these organisms can be transferred to their predators, including marine shorebirds. Accumulation of even traces of oil can taint shellfish and other biota harvested for subsistence consumption by humans, rendering them unpalatable.

170. Early life stages of fish, especially of fish that spawn and pass through their initial developmental stages in the intertidal, are also vulnerable to embryotoxicity. Embryotoxicity involves disruption of the normal sequence of embryological development after egg fertilization, and is caused by 3- and 4-ringed PAH,[74] especially alkyl-substituted PAH.[75] Fish embryos are most vulnerable immediately after hatching,[76] and the threshold for onset of these effects is in the mid-parts per trillion (i.e., ng/L).[77]

171. Translucent organisms are vulnerable to photo-enhanced toxicity. Photo-enhanced toxicity occurs when organisms accumulate certain PAH in their tissues, either by direct absorption from contaminated water in which the PAH are dissolved or by ingestion of oil, and are then exposed to direct sunlight. Certain PAH, when incorporated within translucent cells, can channel the energy in the ultraviolet (UV) component of sunlight into molecular oxygen. This makes the oxygen much more reactive. These “hot”

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[72] Widdows J, Donkin P, Brinsley MD, Evans SV, Salkeld PN, Franklin A, Law RJ, Waldock MJ (1995) Scope for growth and contaminant levels in North Sea mussels *Mytilus edulis*. Marine Ecology Progress Series 127:131-148; Luquet P, Cravedi JP, Tulliez J, Bories G (1984) Growth reduction in trout induced by naphthenic and isoprenoid hydrocarbons (dodecycyclohexane and pristane). Ecotoxicology and Environmental Safety 8:219-226.

[73] Kennedy CJ, Farrell AP (2008) Immunological alterations in juvenile Pacific herring, Clupea pallasi, exposed to aqueous hydrocarbons derived from crude oil. Environmental Pollution 153:638–648.

[74] Incardona JP, Collier TK, Scholz NL (2004) Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. Toxicology and applied pharmacology 196:191-2005.

[75] Lin H, Morandi GD, Brown RS, Snieckus V, Tantanen T, Jorgensen KB, Hodson PV (2015) Quantitative structure-activity relationships for chronic toxicity of alkyl-chrysenes and alkyl-benz[a]anthracenes to Japanese medaka embryos (*Oryzias latipes*). Aquatic Toxicology 150:109-118.

[76] Brinkworth L, Hodson P, Tabash S, Lee P (2003) CYP1A induction and blue SAC disease in early developmental stages of rainbow trout (*Oncorhynchus mykiss*) exposed to retene. Journal of Toxicology and Environmental Health, Part A 66:627-646.

[77] Ibid.; Carls MG, Marty GD, Hose JE (2002) Synthesis of the toxicological impacts of the *Exxon Valdez* oil spill on Pacific herring (*Clupea pallasi*) in Prince William Sound, Alaska, USA. Canadian Journal of Fisheries and Aquatic Sciences 59:153-172.

oxygen molecules can then oxidize proteins, DNA, and other subcellular components, thereby causing extensive damage within cells. Meanwhile the PAH that channels the UV energy usually remains unaltered, capable of channelling more energy to more oxygen molecules. This causes cells to burn from the inside out. This effect also occurs at very low PAH thresholds, on the order of one part per billion (ug/L) or less,[78] and played a major part in damaging Pacific herring eggs and larvae developing on or near oiled beaches following the *Cosco Busan* oil spill in San Francisco Bay, California.[79]

5.2.3.2 Armoured beaches

172. The sediment structure of armoured beaches is especially conducive to trapping and retaining diluted bitumen and other spilled petroleum products. Armoured beaches consist of a surface layer of cobbles to boulders that protect finer-grained sediments beneath them from eroding away, and account for about 10% of Fraser River delta and Burrard Inlet shorelines (Figure 9). Underlying sediments usually consist of an assortment of smaller grain size particles, ranging from mud-sized particles through pebbles, embedded cobbles, and boulders. Underlying sediments have relatively high hydraulic conductivity, meaning water can flow through them relatively easily. During falling tides the interstices of these sediments lose water relatively quickly, especially as the steepness of the beach increases. These conditions set the stage for trapping diluted bitumen that initially strands on the beach surface during an out-going tide.

173. Diluted bitumen coating the surface of armoured beaches would have the same effects on surface biota as it does on biota inhabiting bedrock and hardened shorelines, summarized in s. 5.2.3.1. In addition, the finer-grained sediments beneath the armour layer usually provide habitat for often rich and diverse communities of infauna, which include burrowing clams, marine worms, and small crabs. They also shelter the larval and juvenile life stages of a host of developing animals including many fish species. Diluted bitumen

[78] Duesterloh S, Short J, Barron MG (2002) Photoenhanced toxicity of weathered Alaska North Slope crude oil to two species of marine calanoid zooplankton. Environmental Science and Technology 36:3953-3959; Newsted JL, Geisy JP (1987) Predictive models for photoinduced acute toxicity of polycyclic aromatic hydrocarbons to *Daphnia magna*, strauss (cladocera, crustacea). Environmental Toxicology and Chemistry 6:445-461.

[79] Incardona JP, Ylitalo G, Myers M, Scholz N, Collier T, Vines C, Griffin F, Smith E, Cherr G (2011) The 2007 *Cosco Busan* oil spill: Field and laboratory assessment of toxic injury to Pacific herring embryos and larvae in the San Francisco estuary. *Cosco Busan* oil spill Final Report, September 2011. Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, Washington 98112.

sequestered in the rocky interstices in sediment layers beneath the armouring layer therefore provide a long-term source of exposure to toxic compounds such as PAH that slowly dissolve from the trapped diluted bitumen. Accumulation of these dissolved compounds may cause embryotoxic effects, while ingestion of diluted bitumen may impair growth[80] and possibly cause death, and physical contact with the diluted bitumen may impair mobility.

5.2.3.3 Sand and gravel beaches

174. These shorelines account for about 16% of Fraser River delta and Burrard Inlet shorelines (Figure 9). The persistence of spilled oil products on sand or gravel beaches is typically low because the sediment particle sizes are small enough that wave action can churn the upper sediment layer. This churning action serves to re-expose oil that seeps beneath the surface initially to the surface where abrasion can scour oil films from the sediments. As with armoured beaches (see s. 5.2.3.2), initial penetration of diluted bitumen into sand or gravel beaches depends mainly on the interaction of diluted bitumen viscosity and the hydraulic conductivity of the substrate. Depending on the degree of exposure to wave action, oil may be largely removed from sand or gravel beaches within 2–3 years.[81]

175. The lower stability of sand and gravel beaches makes them less hospitable for most intertidal dwelling organisms. These substrates may contain diverse communities of meiofauna, which are barely visible invertebrates that live within the sand and gravel and feed on micro-organisms there. Larger and more mobile burrowing predators that prey on the meiofauna and also on plankton during higher tide levels, such as clams, crabs, and worms may inhabit these substrates and can accumulate oil by ingestion or physical contact. Macroscopic plants are usually rare or absent, although surface films of algae may contribute to supporting meiofauna and other grazing animals such as worms. However, the resident biota is adapted to the dynamic nature of these habitats, and hence usually recovers quickly to disturbances including ephemeral oil contamination.

5.2.3.4 Mudflats

176. Mudflats account for about 6% of Fraser River delta and Burrard Inlet shorelines lengths but occupy considerable intertidal surface area (Figure 9).

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[80] Luquet (1984).

[81] Yim 2012.

Mudflats are composed of very small sediment grain sizes, most of which typically range from less than 1 μm to 200 μm. Compared with sand or gravel beaches, these small grain sizes make for greater beach stability, with less interstitial space among the sediment grains.

177. The effects of diluted bitumen stranded on the surface of mudflats are similar to those on the other beach types discussed above in ss. 5.2.3.1–5.2.3.3. Although the surfaces of mudflats may be inhabited by relatively low densities of mussels, clams, snails, and algal films, most of the animal biomass lives beneath the surface in burrows. These burrows provide conduits for oil penetration deeper beneath the surface of these beaches.[82] Nonetheless this habitat can be deceptively productive, and may be especially important as foraging habitat for resident and migratory shorebirds that feed on surface algal films or prey on inhabitants of the subsurface animal community.

5.2.3.5 Salt marshes

178. The dense vegetation characteristic of saltwater marshes in the upper intertidal account for about 16% of Fraser River delta and Burrard Inlet shorelines (Figure 9), and provide another matrix that can trap diluted bitumen for prolonged periods.[83] Spilled diluted bitumen driven ashore by wind into these marshes could associate with the vegetative matrix, both alive and dead. So could oil from a pipeline rupture that discharges diluted bitumen into the Fraser River upstream of the Fraser River estuary. Decaying vegetative mats often have high biological oxygen demands that lead to hypoxic conditions near the interface of the vegetation and the underlying soils. Diluted bitumen that percolates downward into hypoxic zones can persist for years to decades as a result of the slow rate of microbial degradation which occurs there.

179. Oil-contaminated salt marshes create potentially long-term sources of oil contact hazard to birds, mammals, and invertebrates that inhabit, traverse or otherwise depend on this habitat. Any contact with oil by birds or mammals can have serious and often lethal results. Marsh oiling may also deplete the insect and spider communities, reducing prey available for insectivorous

[82] Peacock 2006, Burns 1994.

[83] Yim 2012, Peacock 2006, Burns 1994.

birds.[84] Heavy marsh oiling may kill the marsh vegetation, exposing the underlying sediments to accelerating erosion leading to loss of marsh land.

180. Shoreline oiling following a major oil spill would inflict serious injuries to biological communities inhabiting them in the short term, and lingering effects could persist for decades to a century on porous beaches (gravel, sand and mud) and in intertidal marshes if oil becomes associated with hypoxic sediments or accumulations of organic matter. These lingering reservoirs of oil pose long-term threats to intertidal organisms, predators that consume them, and to marsh-dwelling birds and mammals.

5.3 Effects of diluted bitumen on species inhabiting the marine water surface

181. This section summarizes the extreme vulnerability of seabirds, shorebirds, and marine mammals to adverse effects of oil exposure, which are not adequately addressed in the Trans Mountain application.

5.3.1 Sea- and shorebirds

KEY POINTS:

- Sea- and shorebirds are extremely sensitive to oil exposures, and the high productivity and habitat diversity of the Fraser River estuary places high numbers of sea- and shorebirds at risk
- Comparison with other spills suggests a major (16,000 m^3) spill near the Fraser River estuary could kill more than 100,000 sea- and shorebirds
- Large-scale mortality of sea- and shorebirds could have cascading effects that could penetrate deeply into the food web of the Fraser River estuary, including Burrard Inlet

182. Seabirds and shorebirds are particularly sensitive to both internal and external oil exposure,[85] and their foraging habits, preening behaviour and resting requirements lead to frequent contact with surface oil. Petroleum

[84] Pennings SC, McCall BD, Hooper-Bui L (2014) Effects of oil spills on terrestrial arthropods in coastal wetlands. Bioscience 64:789-795.

[85] Leighton FA (1993) The toxicity of petroleum oils to birds. Environmental Reviews 1:92-103.

exposure alters feather microstructure,[86] compressing plumage so that it loses its buoyancy, insulating function, and flight capability.[87] Physiological health of birds is further impaired by oil-induced diseases,[88] including hemolytic anemia, ulcerations, cachexia, and aspergillosis.[89] Birds contaminated at sea thereby succumb from drowning, hypothermia, starvation, or dehydration. In cold-waters such as the Salish Sea it is usually assumed that any contact with surface oil will be mortal or will at least increase morbidity.[90] Narcosis from inhalation of hydrocarbon fumes above oil slicks may also cause injury, although loss of consciousness above an oil slick would often result in direct oiling following loss of flight capability, and the subsequent oiling would confound inhalation as the attributed cause of death. Whereas proximate exposure, cause-of-death, and pathologies for individual birds can be directly examined,[91] population-level effects must be approximated indirectly.[92]

183. Marine oil spills establish effective killing zones for seabirds and shorebirds when oil becomes stranded on intertidal reaches of beaches. The numbers of birds killed by contact with floating or stranded oil depends on the areal density of birds (i.e., the number of birds per unit area in the region), the rate

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86 Jenssen BM (1994) Review article: effects of oil pollution, chemically treated oil, and cleaning on thermal balance of birds. Environmental Pollution 86:207-215; O'Hara PD, Morandin LA (2010) Effects of sheens associated with offshore oil and gas development on the feather microstructure of pelagic seabirds. Marine Pollution Bulletin 60:672-678.

87 Leighton 1993.

88 Briggs KT, Yoshida SH, Gershwin ME (1996) The influence of petrochemicals and stress on the immune system of seabirds. Regulatory Toxicology and Pharmacology 23:145-155.

89 Jauniaux T, Brosens L, Coignoul F (1997) Lesions observed on stranded seabirds along the Belgian coast from 1992-1995. ICES Journal of Marine Science: Journal du Conseil 54:714-717; Balseiro A, Espi A, Marquez I, Perez V, Ferraras MC, Garcia Marin JF, Prieto JM (2005) Pathological features in marine birds affected by the *Prestige*'s oil spill in the north of Spain. Journal of Wildlife Diseases 41:371-378.

90 Page 1990: Carter 2003; Castege 2007; Munilla 2011.

91 Yamato O, Goto I, Maede Y(1996) Hemolytic anemia in wild seaducks caused by marine oil pollution. Journal of Wildlife Diseases 32:381-384; Balseiro (2005).

92 Wilhelm SI, Robertson GJ, Ryan PC, Schneider DC (2007) Comparing an estimate of seabirds at risk to a mortality estimate from the November 2004 Terra Nova FPSO oil spill. Marine Pollution Bulletin 54:537-544; Fifield DA, Baker KD, Byrne R, Robertson GJ et al (2009) Modelling seabird oil spill mortality using flight and swim behaviour. Environmental Studies Research Funds Report 186, Canadian Wildlife Service, Dartmouh, Nova Scotia; Haney JC, Geiger HA, Short JW (2014a) Acute bird mortality from the *Deepwater Horizon* MC 252 oil spill. I. Exposure probability estimates for offshore Gulf of Mexico. Marine Ecology Progress Series 513:225-237; Haney JC, Geiger HJ, Short JW (2014b) Bird mortality from the Deepwater Horizon oil spill. II. Carcass sampling and exposure probability in the coastal Gulf of Mexico. Marine Ecology Progress Series 513:239-252.

at which killed birds are replaced through influx from the surrounding area or through migratory movements, the rate at which new birds are exposed because of oil slick movement, and the proportion of exposed birds that die as a result of contact with oil.[93]

184. The combination of highly productive and diverse estuarine habitats within Burrard Inlet and the Fraser River estuary place extraordinarily high numbers of waterfowl at risk from oil spills. The Salish Sea hosts 72 bird species that are highly dependent on intertidal or marine habitat and marine-derived prey.[94] Many of these bird species overwinter in Burrard Inlet and the Fraser River Estuary because of the relatively mild climate and abundant food supply. Burrard Inlet and the Fraser River estuary are crucial staging areas on the Pacific flyway, providing feeding and roosting sites for nearly 1 million shorebirds and about 250,000 migrating and wintering waterfowl, along with hundreds of thousands of other year-round resident sea- and shorebirds.[95] Daily waterfowl counts of 100,000 are often found during fall and early winter within Boundary Bay, with similar numbers associated with Sturgeon Bank.[96] Seventeen of the overwintering or migratory waterfowl species residing in Burrard Inlet and the Fraser River estuary comprise at least 1% of their global populations, ranging as high as 30% in the case of snow geese.[97]

185. Tsleil-Waututh and the City of Vancouver retained Nuka Research to provide an expert report on, among other things, the size of a reasonable worst-case oil spill resulting from marine shipping activities associated with the Project. Nuka Research concluded that a release of 16,000 m^3 of diluted bitumen is a reasonable worst-case oil spill resulting from project-related marine shipping activities.

186. A large diluted bitumen spill near the Fraser River estuary could plausibly result in a major (i.e., >100,000) bird mortality event. For example, release of 16,000 m^3 of diluted bitumen could create a 0.4 mm thick oil slick covering about 40 km^2 (or 4,000 ha) large enough to completely cover the mudflats of Sturgeon Bank and Westham Island combined, which might be inhabited daily by more than 100,000 sea- and shorebirds during fall through spring.

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93 Haney 2014 a&b.

94 Gaydos JK, Pearson SF (2011) Birds and mammals that depend on the Salish Sea: A compilation. Northwestern Naturalist 92:79–94.

95 Merkens 2012.

96 *Ibid*.

97 *Ibid*.

Given that any contact with oil is usually lethal for waterfowl in cold-water seas, waterfowl mortalities could easily exceed 100,000, especially if an oil slick persists at sea or on mudflats for more than a few days during the fall or spring bird migrations. These migrations renew the supply of birds that could be exposed to lingering oil, thereby substantially increasing the number of birds susceptible to exposure.

187. Bird mortalities of 100,000 or more would rank within the top ten caused by oil spills world-wide.[98]

188. Data from the 2010 *Deepwater Horizon* blowout in the Gulf of Mexico suggest that large-scale mortalities of seabirds caused by an oil spill might lead to serious perturbation of the marine food web through trophic cascade effects. Recruitment of Gulf menhaden (*Brevootia patronus*), the major forage fish in the region, was about 1.6-times greater than recruitment during any prior year of the 35-year record.[99] This high recruitment occurred despite below-average spawning stock biomass,[100] and unfavourable offshore winds augmented unusually high discharges of the Mississippi and Atchafalaya Rivers during winter and spring[101] that together impeded onshore transport of larval menhaden from their offshore spawning grounds to inshore bays and estuaries necessary for rearing.[102] However, larval menhaden that managed to reach the inshore bays and estuaries faced substantially reduced predation by seabirds. The *Deepwater Horizon* blowout killed hundreds of thousands and possibly a million coastal seabirds,[103] most of which prey on juvenile menhaden. The higher survival of juveniles readily explains the abrupt increase in the menhaden population. While unusually numerous, the fat content of these juveniles declined substantially below normal as they

[98] See Haney 2014 a.

[99] Schueller A, Smith J, VanderKooy S, eds (2013) Southeast data, assessment, and review 32A Gulf of Mexico menhaden assessment report. Gulf States Marine Fisheries Commission, 2404 Government St., Ocean Springs MS 39564. 399 p.

[100] *Ibid.*

[101] Huang W-J, Cai W-J, Castelao RM, Wany Y, Lohrenz SE (2013) Effects of a wind-driven cross-shelf large river plume on biological production and CO_2 uptake on the Gulf of Mexico during spring. Limnology and Oceanography 58:1721-1735.

[102] Deegan LA (1990) Effects of estuarine environmental conditions on population dynamics of young-of-the-year gulf menhaden. Marine Ecology Progress Series 68:195-205.

[103] Haney 2014 a&b.

matured in 2011 and 2012,[104] suggesting these fish became undernourished because there was insufficient phyto- and zooplankton food available as they grew. The abnormally low fat content of the menhaden reduced their nutritive value to the marine mammals, piscivorous fish, and remaining seabirds that feed on them. In effect, it turned the starving menhaden into "junk food" for their predators. Also, the abnormally high population of starving menhaden probably increased their removal of plankton from coastal marine waters, including zooplankton comprising the larval stages of other species such as shrimps, crabs, oysters, and other fish that are important both for the ecosystem and for commercial harvests. Those effects are an example of a trophic cascade. In the Gulf of Mexico this trophic cascade may have caused population-level ecosystem effects that operated over a broad spatial scale of about 300 km along the coast for at least three years following the blowout incident.

189. The indications of a trophic cascade triggered by seabird mortalities from oiling after the *Deepwater Horizon* blowout raises concern for these effects elsewhere, including the Fraser River estuary should a large oil spill inflict massive mortalities of seabirds there.

190. The predator-prey relationships involving sea- and shorebirds in the Fraser River estuary (including Burrard Inlet) therefore need to be carefully evaluated to identify possibilities for trophic cascade effects following large-scale mortalities of birds from an oil spill. These cascading effects may extend far beyond the Georgia Strait if migratory birds suffer population-level mortalities, because these population-level effects will have repercussions in the distant habitats occupied by these birds throughout their migrations.

191. Even spills considerably smaller than the credible worst-case scenario of 16,000 m^3 can have substantial adverse effects on sea- and shorebirds as well as marine mammals and other organisms inhabiting the sea surface, shorelines, and the water column if the oil submerges. Small to medium sized oil spills on the order of 100 to 1,000 m^3 can cause substantial mortalities to seabirds.[105] For example, the 875 m^3 of heavy Bunker oil released off Gray's Harbor from the 1988 *Nestucca* spill was estimated to have killed tens of

[104] Ramey TS, Miller M (2011) D.A. Davidson stock analyst report for Omega Protein Corp., issued August 16, 2011; Ramey TS, Miller M (2012) D.A. Davidson stock analyst report for Omega Protein Corp., issued June 14, 2012

[105] Harding LE, Englar JR (1989) The Nestucca oil spill: Fate and Effects to May 31, 1989. Environmental Protection, Conservation and Protection, Environment Canada.

thousands of seabirds in the Strait of Juan de Fuca and along the outside coast of Vancouver Island.[106]

192. In addition, a small, medium or credible worst-case scenario sized spill has the potential to contaminate tens of kilometers of shorelines on time scales of decades.[107]

193. In summary, the seasonally high abundances of sea- and shorebirds in the Fraser River estuary, including Burrard Inlet, may suffer extensive mortalities should a major accidental spill of diluted bitumen occur there. These mortalities could lead to population-level ecosystem perturbations both regionally and farther afield if substantial proportions of species' populations are killed. Ensuing ecosystem perturbations in the Fraser River estuary might lead to disruptions in the recruitment of many other aquatic species, either because of higher consumption of plankton by forage fish released from predation by seabirds, or by poor nutritive value of forage fish for their seabird, marine mammal, and other fish that consume them. These effects should be evaluated by a comprehensive food-web analysis of the marine ecosystem.

5.3.2 Marine Mammals

KEY POINTS:

- Because of their relatively large numbers and sensitivity to oil, a major oil spill would likely result in substantial mortalities of harbour seals and porpoises

- Mortalities from a major oil spill could jeopardize the viability of the endangered southern resident killer whale population, elevating their risk of extinction

194. Like seabirds, marine mammals spend part of their lives in contact with the sea surface, making them vulnerable to direct contact with oil. Marine mammals are especially vulnerable to narcosis following inhalation of

[106] Minerals Management Service, Alaska Outer Continental Shelf Region (2003) Cook Inlet planning area, oil and gas lease sales 191 and 199, final environmental impact statement. United States Department of Interior, Minerals Management Service, Alaska OCS Region, 949 East 36th Ave., Rm. 308, Anchorage, Alaska 99508-4302.

[107] WSP Canada (2014) Risk Assessment for Marine Spills in Canadian Water: Phase 1, Oil Spills South of the 60th Parallel. Report from WSP Canada Inc. to Transport Canada. 172 p. and appendices.

hydrocarbon vapours because narcosis may lead to drowning.[108] Marine mammals are vulnerable to adverse effects from ingestion of oil, through ingestion of oiled prey or through preening of oiled fur. Exposure to oil may also irritate the eyes and skin of marine mammals. Unlike other marine mammals, sea otters rely on their fur instead of a layer of blubber for their insulation, so contact with oil reduces their ability to conserve heat.

195. Oil spills are capable of causing extensive mortalities of marine mammals when present in large numbers. For example, the 1989 *Exxon Valdez* oil spill killed an estimated 300 harbour seals (or ~13% of the resident population)[109] and 2,800 sea otters (~28%).[110] Two pods of killer whales that were observed to come into contact with floating oil from the *Exxon Valdez* spill had unprecedented mortalities within the next year, and one of the pods has yet to recover.[111]

196. In the Salish Sea, there are 29 species of marine mammals that are both highly dependent on intertidal or marine habitat as well as on marine derived food. The most abundant of these species include harbour seals, river otters, harbour porpoise, and Dall's porpoise.[112] Less abundant, occasional or rare species include Northern fur seal; Steller's and California sea lions; Northern elephant seal; Minke, Bryde's, Grey, Fin, Short-finned pilot, Northern Right, Pygmy sperm, Killer, False-killer and four species of beaked whales; and Long-beaked, Short-beaked, Risso's and Pacific white-sided dolphins and sea otters.

197. Based on stock assessments conducted for the waters within the United States, harbour seals are perhaps the most abundant marine mammal in the Salish Sea. The stock assessments suggest that comparable numbers (~10,000) of harbour seals may inhabit Canadian waters in the Georgia

[108] Engelhardt FR (1987) Assessment of the vulnerability of marine mammals to oil pollution. Pp 101-115 *in* J Kiuper and WJ Van Den Brink (eds.), Fate and Effects of Oil in Marine Ecosystems. Martinus Nijhoff Publishing, Boston, Massachusetts.

[109] Frost KJ, Lowry LF, Sinclair EH, Ver Hoef J, McAllister DC (1994) Impacts on distribution, abundance and productivity of harbor seals. Pages 331-358 *in* TR Loughlin (ed.), Marine Mammals and the *Exxon Valdez*. Academic Press, New York.

[110] Garrott RA, Eberhardt LL, Burn DM (1993) Mortality of sea otters in Prince William Sound following the *Exxon Valdez* oil spill. Marine Mammal Science 9:343-359.

[111] Matkin CO, Saulitis EL, Ellis GM, Olesiuk P, Rice SD (2008) Ongoing population-level impacts on killer whales Orcinus orca following the '*Exxon Valdez*' oil spill in Prince William Sound, Alaska. Marine Ecology Progress Series 356:269-281.

[112] Gaydos 2011.

Strait.[113] The Harbour porpoise population of the inside waters of southern British Columbia and the State of Washington is around 10,000, with perhaps half that number in southern British Columbia.[114] Except for killer whales, population estimates for the other species are either unavailable or are not specific to the Salish Sea.[115]

198. The population of the southern resident stock of killer whales that mainly inhabit the Salish Sea and Puget Sound was estimated at 87 individuals in 2007, and the stock is listed as endangered under the U.S. Endangered Species Act and by the Canadian Species at Risk Act.[116] This population of killer whales is currently suffering from high body burdens of persistent organic pollutants such as flame retardants,[117] making them especially vulnerable to adverse effects from other contaminants such as oil pollution.

199. A large (e.g. 8,000–16,000 m^3) diluted bitumen spill in Burrard Inlet or near the rest of the Fraser River estuary would almost certainly kill substantial numbers of marine mammals, especially harbour seals and harbour porpoises because of their relative abundance in the Salish Sea. Other marine mammals may also be adversely affected by diluted bitumen from a spill, although detecting adverse impacts to these species remains problematic. These marine mammals are vulnerable to direct contact with diluted bitumen floating on the sea surface, and also indirectly through ingestion of oil-contaminated fish or other prey. Exposure of individual killer whales, however, could have adverse population-level consequences for this already endangered stock, where premature loss of just one individual could significantly contribute to the jeopardy of this stock.

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[113] Carretta JV, Forney KA, Lowry MS, Barlow J, Baker J, Johnston D, Hanson B, Muto MM, Lynch D, Carswell L (2009) U.S. Pacific marine mammal stock assessments: 2008. NOAA Technical Memorandum NMFS # NOAA-TM-NMFS-SWFSC-434. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center.

[114] *Ibid*.

[115] Ibid.

[116] Ibid.; Gaydos JK, Brown NA (2009) Species of concern within the Salish Sea marine ecosystem: changes from 2002 to 2008. Proceedings of the 2009 Puget Sound Georgia Basin Ecosystem Conference, Seattle, Washington.

[117] Krahn MM, Hanson MB, Baird RW, Boyer RH, Burrows DG, Emmons CK, J. Ford KB, Jones LL, Noren DP, Ross PS, Schorr GS, Collier TK (2007) Persistent organic pollutants and stable isotopes in biopsy samples (2004/2006) from Southern Resident killer whales. Marine Pollution Bulletin 54:1903–1911.

200. In summary, a major spill of diluted bitumen in Burrard Inlet or near the Fraser River estuary could inflict population-level mortalities on resident and migratory marine mammals. For the endangered southern resident stock of killer whales, any losses from an oil spill could materially contribute to the risk of extinction for this stock, which would permanently alter the marine food web of the region.

5.4 Effects of diluted bitumen on species beneath the sea surface

201. This section describes how submerged diluted bitumen would contaminate aquatic organisms in the upper water column, including fish, jellyfish and other free-swimming suspension feeders. Contamination of these fish and suspension feeding organisms not only has direct and adverse effects on the organisms themselves, but also provides an indirect oil exposure route to predators that consume these organisms. These various exposure routes provide additional examples of inadequate consideration of oil exposure effects in the Trans Mountain application.

KEY POINTS:

- The depth of diluted bitumen submergence in the upper water column is limited mainly by the salinity of the surface waters, the strength of wave action, and the extent of evaporative weathering of the diluted bitumen

- Diluted bitumen entrained into the water column can be ingested directly by fish, including juvenile salmon out-migrating from the Fraser River, and by numerous other species of jellyfish and other free-swimming suspension feeders

- Free-swimming suspension feeders that accumulate submerged diluted bitumen provide an indirect route for contaminating their predators, which include juvenile, sub-adult and adult salmon species associated with the Fraser River watershed and also salmon hatcheries in Burrard Inlet

- The overall consequences of water column contamination by submerged diluted bitumen are difficult to assess, because of the great uncertainty in evaluating the amount of oil that submerges, tracking where it goes and hence what species and shorelines it affects once submerged, and sampling affected species to evaluate the amount of contamination accumulated by them. This uncertainty itself can have major socio-economic repercussions arising from concerns of widespread contamination

5.4.1 Oil exposure mechanisms in the upper water column after an oil spill

202. As the density of spilled diluted bitumen increases because of initially rapid evaporation of the lighter gas condensate components, the remaining diluted bitumen residue becomes increasingly susceptible to entrainment into surface waters by wave action. This process is similar to a sand storm, where wind-driven turbulence can entrain sand into the air despite the much greater density of sand particles in comparison with the atmosphere. But as with a sand storm, lower-density diluted bitumen droplets entrained into surface waters will soon rise back to the surface once the mixing energy supplied by wave action is no longer supplied. This wave-driven mixing process supplies a mechanism for exposing aquatic organisms in the upper water column directly to entrained water droplets, or to oil constituents that dissolve from these droplets and from the surface oil slick.

203. As evaporative weathering proceeds, the density of the remaining diluted bitumen residue can exceed that of freshwater. It will then begin to submerge in the water column if the salinity is low at the surface. The Fraser River itself is fresh water, so a pipeline rupture upstream of the Fraser River estuary could contain submerged diluted bitumen by the time the diluted bitumen residue reaches the estuary. Submerged diluted bitumen entrained in the Fraser River could then settle on the intertidal marshes at South Arm when inundated at high tides, potentially resulting in widespread oiling throughout the marsh under worst-case conditions.[118] Evaporatively-weathered diluted bitumen could also submerge in marine waters when the surface salinity is low, as during the spring and summer Fraser River freshet or in Burrard Inlet following high watershed runoff during the spring snowmelt and augmented by heavy precipitation events. Diluted bitumen that submerges under these conditions can disperse throughout the upper water column to depths that are determined by the increase of salinity of the water with depth. This provides another mechanism for exposing aquatic organisms in the upper water column directly to entrained water droplets, or to oil constituents that dissolve from these droplets and from the surface oil slick.

[118] For example, a high volume diluted bitumen release to the Fraser River at a point far enough upstream to permit enough evaporative weathering that the diluted bitumen submerges prior to reaching the Fraser River estuary, and then reaches the estuary at high tide when the slower current speed leads to diluted bitumen deposition directly over intertidal marshes.

5.4.2 Effects of diluted bitumen naturally dispersed in the upper water column on aquatic organisms

204. Fish, gelatinous zooplankton and other suspension feeding organisms are especially likely to accumulate submerged diluted bitumen droplets, leading to adverse effects on these organisms directly, or to their predators if they ingest these oil-contaminated organisms as prey.[119] Larval and juvenile life stages of fish often target prey organisms within size ranges that are similar to those of dispersed oil droplets, and hence may ingest these droplets directly.[120] Ingestion of oil impairs growth, prolonging the window of vulnerability of these larval and juvenile stages to their predators.[121] Gelatinous zooplankton such as jellyfish, larvaceans,[122] and other organisms that filter zooplankton and other particulate matter from the water column may include naturally dispersed crude oil products such as diluted bitumen when present. Although the direct effects of ingested oil on these organisms is poorly understood, they serve as important prey for some fish species including pink salmon.[123]

205. Submerged diluted bitumen that is naturally dispersed in the upper water column presents a contamination hazard to commercially important fish, especially salmon. In addition to ingestion of submerged diluted bitumen droplets by out-migrating juvenile salmon from the Fraser River or released from salmon hatcheries in Burrard Inlet during spring, diluted bitumen may

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[119] Peterson CH, Anderson SS, Cherr GN, Ambrose RF, Anghera S, Bay S, Blum M, Condon R, Dean TA, Graham M, Guzy M, Hampton S, Joye S, Lambrinos J, Mate B, Meffert D, Powers SP, Somasundaran P, Spies RB, Taylor CM, Tjeerdema R, Adams EE (2012) A tale of two spills: Novel science and policy implications of an emerging new oil spill model. Bioscience 62:461–469.

[120] Wertheimer AC, Celewycz AG (1996) Abundance and growth of juvenile pink salmon in oiled and non-oiled locations of western Prince William Sound after the Exxon Valdez oil spill. Pp 518–532 *in* SD Rice, RB Spies, DA Wolfe, BA Wright (eds.) Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society 18.

[121] Luquet 1984; Carls MG, Holland L, Larsen M, Lum JL, Mortensen DG, Wang SY, Wertheimer AC (1996) Growth, feeding and survival of pink salmon fry exposed to food contaminated with crude oil. Pp 608-618 *in* SD Rice, RB Spies, DA Wolfe, BA Wright (eds.) Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society 18.

[122] Larvaceans are small (~1 cm) free-swimming tunicates, and pteropods are small (< 1 cm) free-swimming marine snails. Both secrete mucus films that traps particulate matter including microscopic phyto- and zooplanton from the water column, and can also trap small droplets of crude oil.

[123] Cooney RT, Allen JR, Bishop MA, Eslinger DL, Kline T, Norcross BL, McRoy CP, Milton J, Olsen J, Patrick V, Paul AJ, Salmon D, Scheel D, Thomas GL, Vaughan SL, Willette TM (2001) Ecosystem controls of juvenile pink salmon (*Oncorhynchus gorbuscha* and Pacific herring (*Clupea pallasi*) populations in Prince William Sound, Alaska. Fisheries Oceanography 10(s1):1–13.

be ingested by adult and sub-adult life stages of salmon. Adult and sub-adult sockeye salmon are suspension feeders that filter small particulate matter such as phytoplankton and zooplankton from the water column, and would ingest small droplets of diluted bitumen that fall within their filtration size range. Pink and chum salmon ingest gelatinous zooplankton, which provide a means for tainting if their prey is contaminated by oil. The mere credible threat of contamination should a large-scale spill occur could have serious adverse consequences for these fisheries stemming from impaired marketability of products suspected of tainting, even when tainting is undetectable.

6.0 Summary of Opinions

206. As set out in my report, there are at least four fundamental deficiencies with Trans Mountain's ecological risk assessment of the Project. It should not therefore be used to assess the ecological risk of the Project.

207. A recently published study[124] that intensively monitored the physical and chemical changes of an experimental oil spill in the North Sea in 2009 during the initial 24 hours found that losses of volatile oil components occurred much more rapidly than predictions based on equations developed by Environment Canada. These experimental results imply that spilled dilbit will become susceptible to submergence in fresh and brackish waters more quickly than previously considered. In their stated Views of the Panel regarding the proposed Northern Gateway pipeline from the Alberta oil sands to Kitimat, British Columbia, the National Energy Board's Joint review Panel acknowledged that spilled diluted bitumen is susceptible to submergence in fresh water as a result of evaporation of volatile hydrocarbons.[125] Results from the experimental oil spill indicate that such submergence could happen much more quickly than previously recognized.

208. Under realistic ambient conditions and slick thicknesses, the results from the experimental oil spill conducted in the North Sea strongly imply that diluted bitumen spilled in Burrard Inlet or the Fraser River estuary during the spring freshet could begin to submerge after 24 hours.

209. An oil spill from the Project or its associated marine shipping activities in Burrard Inlet or the Fraser River estuary could lead to a major ecological catastrophe.

210. The high biological productivity of the Fraser River estuary supports extraordinarily high populations and densities of marine mammals and of sea- and shorebirds, especially during their spring and fall migrations. These mammals and birds are attracted by high seasonal abundances of salmonids migrating into or out of the Fraser River and of Pacific herring and other forage fish, along with the high productivity of algae and invertebrates on the extensive sand and mudflats at Sturgeon Banks and the South Arm marshes.

211. An oil spill in the Fraser River estuary may therefore expose large populations of sea- and shorebirds to direct contact with diluted bitumen, which would kill most of the birds contaminated. A reasonable worst-case oil spill could result in mortalities of 100,000–500,000 birds, enough to disrupt

[124] Gros 2014.

[125] National Energy Board 2013.

ecosystem functioning for years or even permanently, and to affect other distant habitats occupied seasonally by migratory species. High mortalities of marine mammals could also result for species such as killer whales, porpoises, dolphins and seals that, like seabirds, routinely inhabit the sea surface, making them especially vulnerable to contact with floating diluted bitumen. In the case of the southern resident population of killer whales, any additional mortalities resulting from oil exposure could materially contribute to the extinction risk for this stock, which would permanently alter ecosystem functioning in the Salish Sea. Also, once oiled, many of the shorelines of Burrard Inlet and the rest of the Fraser River delta would retain oil residues for months to several decades, presenting long-term reservoirs of contamination for organisms associated with these shorelines, and hence substantial adverse consequences for subsistence uses, tourism and commercial fishing.

212. A major mortality event for seabirds and shorebirds might trigger a trophic cascade, and if it did it would be the most serious long-term consequence of a major oil spill in the Fraser River estuary. A large reduction of seabirds caused by exposure to spilled oil could cause a disproportionately large increase of their forage fish prey. In turn, this could depress the abundance of the planktonic organisms consumed by forage fish, including the larval stages of a host of other marine organisms such as shellfish and finfish that are important economically or for subsistence harvests.

213. Diluted bitumen consists of low-volatility, high-density bitumen mixed with high-volatility, low-density hydrocarbon diluents. It is susceptible to submergence or sinking in fresh or brackish estuarine waters. Natural bitumen from the Alberta oil sands is often inherently susceptible to submerging in brackish water, and will do so once the more volatile diluent evaporates following a spill.

214. Careful review of experiments conducted to evaluate the time required for submergence to occur suggests that diluted dilbit spilled in Burrard Inlet or the Fraser River estuary could submerge following 24 hours after an oil spill. Contact with inorganic material entrained in the estuarine water column, or by contact with sand or mud shorelines would decrease the time required for submergence.

215. Oil submergence makes tracking the movement of the oil and clean-up operations much more challenging, and opens a host of new pathways for oil exposure to organisms that inhabit the water column, seafloor and intertidal reaches of shorelines. Suspension-feeding organisms such as clams, mussels, barnacles, gelatinous zooplankton, and fish occupying these habitats may ingest oil submerged in the water column. These organisms would then

provide an indirect oil exposure pathway for species such as seabirds and marine mammals that consume them. Along with the invisible dispersion of submerged oil itself, this indirect pathway increases uncertainty regarding the extent, duration, and toxicity of oiled species and habitats. This increased uncertainty can by itself be a major adverse effect of an oil spill by dissuading peoples from continuing traditional subsistence harvests for fear of encountering cryptically-contaminated subsistence foods, by causing larger and more prolonged commercial fishery closures because of uncertainty regarding contamination of harvest species, and by reducing tourism because of concerns regarding the safety or ecological integrity of habitats frequented by tourists.

216. Widespread contamination of shorelines following a large oil spill all but guarantees that people will encounter lingering pockets of oil on high-retention shorelines for many years to decades following a spill. Once stranded on shorelines, diluted bitumen released from an accidental spill may persist for days to several decades or even a century under worst-case conditions. The factors most conducive to long-term oil retention on shorelines include: (1) porous sediments such as gravel or mixed sand and gravel, especially when protected by a surface layer of larger cobbles and boulders; (2) oil penetration along channels created by organisms inhabiting the sediments of mud or sandy beaches; (3) oil penetration beneath these beaches where low availability of oxygen and inorganic nutrients impedes microbial degradation of the oil; and (4) oil penetration into dense vegetation such as intertidal marsh grasses or eelgrass beds, where the interstices of decaying vegetation readily trap oil and the high biological oxygen demand reduces microbial degradation of the trapped oil. Shorelines susceptible to long-term retention of diluted bitumen are distributed throughout both Burrard Inlet and the Fraser River estuary.

217. In the nearer term, oil impinging on shorelines may kill organisms that respire aerobically by smothering them, or by physical disturbances caused by shoreline cleanup methods. Embryos of fish and other species that develop on the intertidal or shallow subtidal reaches of shorelines may die from toxic effects caused by exposure to PAH that leaches from oil stranded on shorelines, and translucent organisms may also die from photo-enhanced toxicity effects, also caused by certain PAH from oil. If mortalities of intertidal organisms are widespread and nearly complete, as is often the case when shorelines are smothered by oil or when cleanup operations are extensive and highly damaging, these communities may require years to recover.

218. Finally, even spills considerably smaller than the credible worst-case scenario of 16,000 m^3 can have substantial adverse effects on sea- and shorebirds as well as marine mammals and other organisms inhabiting the

sea surface, shorelines and the water column if the oil submerges. Even small to medium sized oil spills on the order of 100 to 1,000 m^3 can cause substantial mortalities to seabirds, and estimated effects for small to medium spills in Canada and in Alaska have the potential to contaminate tens of kilometers of shorelines on time scales of decades.

Dated:
May 11, 2015

Jeffrey W. Short

Jeffrey W. Short, Ph.D.

7.0 Appendices

Appendix 1

CURRICULUM VITAE

JEFFREY W. SHORT, PH.D., PRINCIPAL, JWS CONSULTING LLC

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Professional Experience:

Chevron/TexPet Ecuador Oil Contamination (since January 2013). Retained by Louis Berger, Inc. on behalf of Winston-Strawn LLP, attorneys representing the Republic of Ecuador in Bilateral Investment Treaty Arbitration in the matter of lingering petroleum contamination in the northern Amazon forest of Ecuador produced during exploration and production operations conducted by Texaco (now Chevron) prior to 1993. Responsibilities include evaluation of analytical chemistry evidence of source, toxicity, and persistence of lingering oil associated with oil production facilities.

Water Quality Monitoring Review, Lake George, New York (since December 2012).

Provide expert review of 30-year limnological monitoring program sponsored by The FUND for Lake George, and provide senior scientific guidance for The Jefferson Project, a collaboration of The FUND, Rensselaer Polytechnic University and IBM Corp. to combine advanced environmental sensors and computing power to create the most advanced ecosystem model of a lake anywhere in the world.

Science Coordinator, BP MDL 2179 PSC (since December 2010). Retained by the Plaintiff's Steering Committee for the British Petroleum Multi-District Litigation to oversee scientific support for the transport, fate and environmental effects of oil released from the April 2010 *Deepwater Horizon* blowout in the Gulf of Mexico. Responsibilities included formulating the overall science strategy, identifying and recruiting internationally recognized experts to support it, and providing scientific guidance, insight and advice to the PSC attorneys. This case recently settled for ~$7.8B on terms favorable to the PSC, based in part on the strength of the scientific positions established by the expert team I recruited.

Jet A Fuel Oil Review for the Vancouver Airport Fuel Delivery Project (January–February 2012). Retained by Coastal & Ocean Resources Inc. to review ecotoxicological risks posed by jet A/A-1 fuels and additives following accidental spills.

Expert Witness, Northern Gateway Pipeline Proposal (since May 2011). Retained by Janes Freedman Kyle Law Corporation on behalf of the Gitxa'ala First Nation for a scientific expert panel to review environmental risks presented by the Northern Gateway pipeline project from Edmonton, Alberta to Kitimat, British Columbia proposed by Enbridge Corporation.

Pacific Science Director, Oceana (November 2008 to December 2010). My main focus was to foster and coordinate the collaborative development and articulation of the scientific rationale for ocean policy recommendations of the Pacific Team of Oceana. My responsibilities included ensuring that policy recommendations have a firm scientific basis and providing scientific advice regarding advocacy and litigation priorities. As supervisor of the Pacific Team's scientific staff, I was also responsible for the scientific defense of Oceana's advocacy positions at scientific, litigation and policy venues relevant to Pacific and Arctic Ocean issues, including their articulation in media ranging from op/ed articles and news releases to peer-reviewed scientific manuscripts, and for supporting these activities through grant writing. Finally, I promoted our contacts with the scientific community engaged in ocean and climate research, with relevant government agencies and with other environmental organizations, which included organizing the scientific program for the 2009 International Arctic Fisheries Symposium held in Anchorage, Alaska.

Expert Witness, Cosco Busan Oil Spill (April 2009 to April 2011). Retained by Cotchett, Pitre & McCarthy LLP to provide advice and testimony on behalf of fishing industry plaintiffs injured by the 2008 Cosco Busan oil spill in San Francisco Bay, California.

Expert Witness, Lake Wabamun Oil Spill (October 2007 to November 2008). On loan from the US Government to the Government of Canada, I designed and supervised a study to estimate the amount of oil remaining in Lake Wabamun, Alberta following a Canadian National derailment a year earlier, and wrote an expert opinion on the implications of the results. Case settled out of court in favor of the government.

Supervisory Research Chemist, Alaska Fisheries Science Center, National Marine Fisheries Service (1982 through November 2008). My four basic responsibilities include acting as principal investigator (PI) on research projects, managing the Center's marine chemistry laboratory, advising the government's legal team on the long-term fate and effects of the 1989 *Exxon Valdez* oil spill, and reviewing research products that touch on the environmental chemistry of oil for the Center and for numerous peer-reviewed environmental journals.

- **Research Project Principal Investigator.** This includes conceiving, designing, securing funding, executing, analyzing and publishing results for environmental research projects, usually in collaboration with numerous colleagues and support staff. Most of my work has been on the *Exxon Valdez* oil spill. Major projects included: (1) assessment of the initial distribution and persistence of the spilled oil in seawater; (2) discovery and elucidation of a cryptic toxicity mechanism through which oil pollution is nearly 1,000-fold more toxic to fish eggs than previously thought; (3) definitive refutation of alternative hydrocarbon pollution sources advanced by scientists employed by Exxon Corp. as plausible causes of biological effects in the *Exxon Valdez* impact area; (4) discovery of a natural hydrocarbon trophic tracer in the marine food web of the northern Gulf of Alaska; and (5) quantitative measurement of the amount and loss rate of *Exxon Valdez* oil lingering in beaches 12 years or longer after the incident. Each of these was funded at \$500K to \$5M, and I played the leading role on all but the second. A summary of these projects appeared in *Science* as a review article I co-authored in 2003 (See Peterson, C.H et al.).

- **Manager, AFSC Marine Chemistry Laboratory.** I presided over a major expansion of the AFSC marine chemistry laboratory in the aftermath of the *Exxon Valdez* spill, when the government urgently needed additional capacity capable of meeting the stringent standards imposed by impending litigation. Staff increased nearly tenfold from two, and successfully qualified as one of only three such facilities nationally to participate, generating revenues of \$500K - \$1M annually. Today the facility is internationally recognized, specializing in the environmental analysis of hydrocarbons, biogenic lipids in support of nutritional ecology studies, and high-precision characterization of the marine carbonate buffer system in support of incipient studies on ocean acidification.

- **Scientific Advisor to the *Exxon Valdez* Legal Team for the Governments of Alaska and the United States.** The civil settlement between Exxon Corp. and the governments of Alaska and the US created a $900M fund administered by the *Exxon Valdez* Trustee Council that supported scientific studies, habitat acquisition, and other impact offsets. I was one of four scientists selected to design the Council's scientific review policy and administrative structure, and I have since provided policy guidance on request on numerous occasions, leading to publication of the 1993 symposium presenting the initial findings of the Exxon Valdez oil spill impacts as a book, establishment of and support for the annual Alaska Marine Science Conference begun in 1993, and leading the team that drafted the scientific support for invoking the $100M "re-opener" clause of the Exxon Valdez settlement on behalf of the US Department of Justice.

- **Reviewer and Advisor for the AFSC on Chemistry Issues.** In addition to providing peer-review of dozens of manuscripts submitted to scientific journals and proposals submitted to various funding agencies, I provided scientific advice to or on behalf of NMFS management. This includes providing occasional invited testimony to the Alaska Legislature and Governor, NOAA management and the Scientific and Statistical Committee of the North Pacific Fisheries Management Council, and advice to government agencies in Canada, China, Norway and Russia.

Education:

- **Bachelor of Science, Biochemistry and Philosophy, University of California at Riverside, 1973**
- **Master of Science, Physical Chemistry, University of California at Santa Cruz, 1982**
- **Doctor of Philosophy, Fisheries Biology, University of Alaska at Fairbanks, 2005**
- **Languages: Mandarin Chinese (speak, read and write); Russian (read)**

Selected Activities and Honors:

- **Bronze Medal, U. S. Department of Commerce, "For scientific research and publications describing the long-term, insidious effects of oil pollution on fish embryos at parts per billion levels"**
- **Program reviewer for studies conducted by the Korean Ocean Research & Development Institute on the effects of the 2007 Hebei Spirit oil spill in Korea**

- **Appointment as Visiting Professor for the Key Laboratory of Oil Spill Identification and Damage Assessment Technology, State Oceanic Administration, Qingdao, People's Republic of China**
- **Coordinating scientist for an on-going, privately-funded studies of the impacts of polycyclic aromatic hydrocarbons and toxic metals on the Athabasca River system from oil sands mining, in conjunction with the University of Alberta, the University of Saskatchewan and Queen's University in Canada**
- **Advisor to the Sakhalin Research Institute for Fisheries & Oceanography for hydrocarbon monitoring and analysis, Yuzhno-Sakhalinsk, Russian Federation**

Selected Publications:

Haney, J.C., Geiger, H.J. and **Short, J.W.** 2014. Bird mortality from the Deepwater Horizon oil spill. I. Exposure probability in the offshore Gulf of Mexico. Mar. Ecol. Prog. Ser. 5113:225-237

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Alaska State Legislature Testimony

Short, J. W. September 21, 2010 Written Testimony Submitted to the State of Alaska, Senate Natural Resources Committee “Alaska’s Oil Spill Preparedness and Response Capability”

Appendix 2

Certificate of Expert's Duty

I, Dr. Jeffrey W. Short of Juneau, Alaska, U.S.A. have been engaged on behalf of the Tsleil-Waututh Nation, the City of Vancouver and the Living Oceans Society 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, I acknowledge that it is my 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 my area of expertise; and

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

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

Date: May 11, 2015 Signature: Jeffrey W Short

Appendix 3

Peer Review of Experimental Studies of the Effects of Volatility Losses on the Density of Diluted Bitumen Relied on by Trans Mountain

1. Recognition that evaporative loss alone may return the bitumen in diluted bitumen to near its original density, which may be high enough to submerge in fresh, brackish or in extreme cases even full-strength seawater, led to five studies aimed at characterizing the effects of temperature and wind speed on the rate of mass lost by evaporation of volatile components from diluted bitumen. Unfortunately, all five of these studies involved unrealistic exposure conditions that led to substantial overestimation of the time required for evaporation to increase the density of diluted bitumen enough to submerge in water. These unrealistic exposure conditions were most likely adopted on the basis of a flawed Environment Canada study that was aimed at determining the most important factors affecting the rate of evaporative losses of mass from crude oils.[126]

2. Based on an extensive series of experiments, Environment Canada concluded that the effect of temperature far exceeded other factors including wind speed, oil slick thickness, and the relative surface area (i.e., surface area per unit volume) of the oil. Consequently, Environment Canada proposed that the time required for evaporative losses of mass from unrealistically thick[127] (~10 mm) oil films could be related to temperature through relationships of the form:

$$\%Ev = (A+B\,T)\ln t \qquad \text{Eq 1}$$

   where %Ev is the percent of total mass lost by evaporation, T is the ambient temperature in degrees Celsius, ln t is the natural logarithm of time for evaporation in minutes, and A and B are constants that depend on the particular oil involved.[128] However, a recent field study has conclusively demonstrated that these equations seriously overestimate the time required for evaporative losses during actual oil spills, because wind speed, oil film thickness, and relative

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[126] Fingas MV (2004) Modeling evaporation using models that are not boundary-layer regulated. Journal of Hazardous Materials 107:27-36.

[127] Oil slick thicknesses immediately following accidental discharges typically range from 0.010 – 0.5 mm (Gros 2014). The initial thickness of an un-weathered diluted bitumen sample was 0.4 mm once it stopped spreading after addition to the surface of water (Stronach 2013).

[128] Fingas 2004

surface area *are* important factors affecting the evaporation rate of volatile oil components.[129]

3. Extensive monitoring of an experimental oil spill in the North Sea during 2009 showed that mass losses predicted to require more than one day by Eq 1 actually occurred within one hour.[130] Hence estimates of the time required for evaporative losses of mass that are based on experiments involving unrealistically thick oil films and that consider only temperature using Eq 1 must be interpreted with considerable caution, recognizing that evaporative loss rates are almost certain to be much faster during actual oil spills. Recognition of these possibilities led to five studies aimed at characterizing the effects of temperature and wind speed on the rate of mass lost by evaporation of volatile components from diluted bitumen. Unfortunately, all five of these studies involved serious flaws that led to substantial overestimation of the time required for evaporation to increase the density of diluted bitumen enough to sink in water. These studies and their defects are summarized below.

4. A recent study by Environment Canada[131] reported results of weathering experiments on two diluted bitumen products, Access Western Blend (AWB) and Cold Lake Bitumen (CLB), chosen because they are likely to account for the greatest proportion of products shipped through the proposed Trans Mountain pipeline. Evaporative removal of the diluent, about 25% of the diluted bitumen mass, increased the density of AWB from 925.3 kg/m^3 to 1,021.1 kg/m^3 (at 15 °C), and of CLB from 924.9 kg/m^3 to 1,008.5 kg/m^3, confirming that prior to dilution with gas condensate, the bitumen in these products is itself more dense than freshwater or brackish seawater. Also, the viscosity of the diluted bitumen increased by factors near 100,000, confirming that evaporative losses of the volatile diluent components dramatically increase viscosity.

5. Separate experiments reported in the same study[132] that were aimed at documenting the time required to evaporate volatile components from thick

[129] Gros 2014; Polaris Applied Sciences, Inc., (2013) A comparison of the properties of diluted bitumen crudes with other oils. Trans Mountain application at V8C_TR_8C_12_TR_S8_COMPAR_BITUMEN_OTHER_OILS_-_A3S5G7.

[130] *Ibid*.

[131] Environment Canada et al. (2013).

[132] *Ibid*.

films of diluted bitumen under in the absence of wind[133] found that the equation[134] relating the percent of mass lost by evaporation to ambient temperature and time for AWB was given as:

$$\%\mathrm{Ev} = (1.72 + 0.045\ T)\ \ln t \qquad \text{Eq 2}$$

and for CLB as:

$$\%\mathrm{Ev} = (1.51 + 0.045\ T)\ \ln t \qquad \text{Eq 3}$$

6. However, the authors noted that these equations underestimated the actual mass lost over the first 50 hours of these experiments, and overestimated the mass lost afterward. These discrepancies reflect the fact that equations of the form of Eq 1 were developed based on experiments with normal crude oils and hence were intended for application to them, but in contrast, diluted bitumen is actually a mixture of a very volatile component (i.e., gas condensate) and what is in effect a very weathered crude oil (i.e., bitumen). Recognizing these differences, the authors of this study concluded that these "Simple fit models may not be very useful for diluted bitumen, particularly in the early stages of a spill."[135] Hence, although the estimated time required for evaporation to remove 25% of the mass from AWB based on Eq 2 nearly 24 days, comparison of results based on Eq 1 and rates of evaporation during the 2009 experimental oil spill in the North Sea[136] suggest that such losses might actually occur within one day. Comparison of the density of 25% weathered AWB (~1,021 kg/m^3) with the minimum surface water densities in English Bay and Burrard Inlet (see Table 1 in the main text of this report) indicates that AWB diluted bitumen discharged into these waters might submerge beneath the surface at any time of the year, but especially during spring and summer when surface waters are less brackish because of increased flow of the Fraser River.

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[133] These conditions reflect the incorrect assumptions that oil film thickness and wind speed are negligible factors.

[134] Note that these equations are presented incorrectly in the Environment Canada et al. (2013) study as %EV = (1.72–0.045 *T*) ln *t* and %Ev = (1.51–0.045 *T*) ln *t*. Subtraction of the "0.045 T" term gives implausible results, and addition of this term is indicted in the original reference for these equations (i.e. Fingas 2004).

[135] *Ibid*.

[136] Gros 2014.

7. A separate study[137] recently reported direct observation of diluted bitumen submerged in brackish water that resulted from evaporative weathering. Portions of AWB diluted bitumen submerged in brackish (<17‰) seawater at about 20 °C following exposure of an 8 mm thick layer of the diluted bitumen to an average wind speed of 2.5 m/s for 6 days. These exposure conditions imply the submerged AWB diluted bitumen reached a density of about 1,010 kg/m^3, the density of 16‰ seawater at 20 °C[138] through evaporative weathering. The 8 mm layer was maintained by confining the diluted bitumen within a floating polyvinyl chloride containment barrier. This barrier prevented the diluted bitumen from spreading to its unconfined equilibrium thickness, likely on the order of 0.4 mm.[139] Allowing the diluted bitumen to spread unconfined would have dramatically increased the evaporation rate of the volatile diluent components.[140] Assuming the evaporation rate of a fixed initial volume of diluted bitumen is inversely proportional with the slick thickness, the time needed for the diluted bitumen to submerge in brackish water would decrease from 6 days for an 8 mm thick slick to less than 8 hours for a 0.4 mm thick slick.

8. A study conducted by Witt O'Briens for Trans Mountain at Gainford, AB during June 2012 evaluated the changes of chemical composition and of physical properties of AWB and CLB diluted bitumen exposed to static, mild, and moderate weathering conditions.[141] The composition and physical properties of 10.09–13.46 mm oil films were monitored over 10 days at temperatures ranging from 10–23 °C and salinities ranging from 20–24 ‰. The mild weathering condition included average winds of 2.23 m/s and 2–4 cm waves, while the moderate condition included 4.5 m/s winds and 5–7 cm waves. The experiments with AWB and one of the CLB experiments were conducted inside a covered shed, but the other CLB experiments were conducted outside.

9. The density of AWB diluted bitumen increased from 920.1 kg/m^3 initially to maximum values of 1000.0 kg/m^3, 1010.0 kg/m^3, and 1007.0 kg/m^3 respectively in the static, mild and moderate weathering experiments. Viscosities increased from 270.5 centistokes (or 249 mPa-s at ~15 °C) to

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[137] King TL, Robinson B, Boufadel M, Lee K (2014) Flume tank studies to elucidate the fate and behavior of diluted bitumen spilled at sea. Marine Pollution Bulletin 83:32-37.

[138] Pilson (1998) An Introduction to the Chemistry of the Sea. Pearson Education.

[139] Stronach 2013.

[140] Gros 2014.

[141] Witt O'Brien's 2013.

several hundred thousands of centistokes (or mPa-s). Similarly, the density of CLB diluted bitumen increased from 924.8 kg/m^3 initially to maximum values of 982.0 kg/m^3, 998.9 kg/m^3 and 1002.0 kg/m^3 respectively in the static, mild and moderate weathering experiments.

10. In a separate experiment, CLB diluted bitumen exposed to the mild weathering condition led to a maximum density of 1,008.0 kg/m^3. The difference in maximum densities attained by CLB diluted bitumen exposed to mild weathering conditions, 998.9 kg/m^3 in one case and 1,008.0 kg/m^3 in another, reflects the imprecision in the weathering conditions and measurements. Unfortunately, the precision of the measurements in this study was either not determined or not reported, making it problematic to distinguish contributions of measurement errors and variation in experimental conditions to overall imprecision (i.e., poor reproducibility of results).

11. Most of the density increases observed during the Gainford experiments occurred within the first 24 hours. Maximum densities occurred after 8–10 days. In some experiments the diluted bitumen density appeared to decline after reaching a maximum before termination of the experiment at 10 days. These apparent declines most likely reflect measurement errors, because the more volatile and soluble components are strongly correlated inversely with molecular weight, so typically oil and diluted bitumen densities increase monotonically as evaporation and dissolution proceeds. In contrast, increases of viscosity generally persisted throughout the 10 day exposure period, although the greatest proportional increases also occurred within the first 24 hours of the experiments.

12. A study conducted by SL Ross[142] evaluated density changes of diluted Cold Lake bitumen (CLB) and diluted MacKay River Heavy (MKH) bitumen at three weathering states, one of which was un-weathered. The CLB was diluted with gas condensate (i.e., diluted bitumen) whereas the MKH was diluted with synthetic light oil (i.e., synbit). A 20 mm-thick layer of diluted bitumen was placed in a wind tunnel operating at a wind speed of 3 m/s and temperature of 20 °C, and samples were collected initially and after 2 and 14 days. The density of each sample was measured at 1 °C and 15 °C.

13. The CLB lost 14.28% of the initial mass after 2 days, and 16.99% after two weeks, causing the density to increase from 936 kg/m^3 initially to 977 kg/m^3

[142] Belore, R. (2010), Properties and fate of hydrocarbons associated with hypothetical spills at the marine terminal and in the confined channel assessment area—Enbridge Northern Gateway Project. Technical Data Report, SL Ross, Calgary, Alberta.

after two days and 981 kg/m^3 after two weeks when measured at 15 °C. Densities were slightly greater when measured at 1°C, increasing from 948 kg/m^3 initially to 987 kg/m^3 after two days and 990 kg/m^3 after two weeks. The dynamic viscosity increased from 368 mPa-s initially to 9227 mPa-s after two days and 14486 mPa-s after two weeks when measured at 15 °C.

14. The MKH synbit experienced smaller losses of mass during these experiments owing to the lower volatility of the synthetic light oil diluent. The MKH lost 8.85% of the initial mass after 2 days, and 12.87% after two weeks, causing the density to increase from 943 kg/m^3 initially to 965 kg/m^3 after two days and 970 kg/m^3 after two weeks when measured at 15 °C. As with CLB, densities were slightly greater when measured at 1°C, increasing from 952 kg/m^3 initially to 970 kg/m^3 after two days and 977 kg/m^3 after two weeks. The dynamic viscosity increased from 241.9 mPa-s initially to 1377 mPa-s after two days and 2573 mPa-s after two weeks when measured at 15 °C.

15. The time required for evaporative losses of mass is assumed to be directly proportional to oil film thickness in this study.[143] The authors acknowledge that the time required for equivalent changes in 1 mm-thick oil films would be about 20 times faster than for the 20 mm (= 2 cm) film thickness they used in their experiments. This implies that the changes in density and viscosity they observed at 2 days and at 2 weeks would occur within 2–3 hrs and one day respectively. These changes would occur even faster for an unconfined, free-floating diluted bitumen slick having a thickness of 0.4 mm, needing only 1 h and 7 h respectively. Consequently, although the densities did not approach values (~1,000 kg/m^3) that would cause the oils to submerge in fresh or brackish waters in these experiments, they might have done so given more time for additional evaporation or if thinner oil films had been used.

16. Recognizing the limitations and attendant uncertainties imposed by the unrealistically thick oil films used in the SL Ross experiments reported by Belore (2010)[144], SL Ross conducted a follow-up study of CLB using a more realistic oil film thickness near 1 mm[145]. Two experiments were run, one for 120.5 hours (5 days) and the other for 311 hours (~13 days) using fresh water at 15 °C, with an oil film thickness of 1.15 mm, a wind speed of 1.5 m/s and a water velocity of 0.25 m/s. Both experiments included an apparatus to

[143] Ibid.

[144] Ibid.

[145] SL Ross 2012.

agitate the surface of the circulating water by means of cascading water, simulating effects of mild wave action. The 311 hour experiment included an ultraviolet (UV) lamp with an irradiance of 15 mW/cm^2, which is approximately three times the maximum UV irradiance of natural sunlight at 45° latitude.

17. Oil viscosity increased from ~3,300 mPa-s initially to more than 190,000 mPa-s after 24 hours in both experiments. Oil viscosity continued increasing thereafter, exceeding 1,000,000 mPa-s after 12 days in the second experiment.

18. Oil densities were measured at 20 °C instead of at 15 °C because the high viscosities of many of the oil samples interfered with the reliability of the density measurements at the lower temperature.[146] In the first experiment, the density of CLB increased from 945 kg/m^3 initially to 995 kg/m^3 after 96 hours. In the second experiment, the density increased to 998 kg/m^3 by 96 hours, and appeared to fluctuate between values of 995 kg/m^3 and 998 kg/m^3 thereafter. These fluctuations, especially for samples collect at 96 hours through 140 hours when the oil viscosity changed relatively little, provide an indication of the precision of the measurements. The average of the density measurements from 96 h on was 996.8 kg/m^3, slightly below the density of fresh water at 20 °C (998 kg/m^3).

19. Because the density of oil increases with decreasing temperature, and does so faster in comparison with fresh water, the CLB should have reached neutral buoyancy at 15 °C in the second experiment after about 96 hours. Neutral buoyancy means that entrained oil droplets have no tendency to sink or to float to the surface. In fact, entrained oil droplets were observed in the water column of the second experiment after 96 hours[147], confirming that evaporative processes alone might plausibly cause oil to submerge beneath the water surface during an oil spill in fresh or brackish water, depending on the temperature, wind speed, slick thickness and salinity of the receiving water. Had an unconfined CLB slick of 0.4 mm thickness been used in these experiments, neutral buoyancy might have been attained after only ~40 hours, and even sooner if higher wind speeds had been used.

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[146] Ibid. This problem very likely accounts for the relatively poor precision of the density measurements reported in the Belore (2010) study, which used the same method for density determination.

[147] SL Ross 2012.

20. Comparison of results from the two SL Ross studies[148] confirms the importance of oil film thickness for estimating the time required for density changes of diluted bitumen. In the Belore 2010 study, the density of the 20 mm-thick film increased from 936 kg/m^3 initially to 977 kg/m^3 after two days. Comparable changes took only about an hour in the SL Ross 2012 study, where density increased from 945 kg/m^3 initially to 976 - 981 kg/m^3 after 1–1.5 hours[149]. The oil density increases observed during the SL Ross 2012 study was about twice as fast as was anticipated on the basis of the Belore 2010 study, despite the lower wind speed used for the SL Ross 2012 study (1.5 m/s vs. 4.5 m/s). This comparison provides direct confirmation of the importance of oil film thickness on the evaporation rate of volatile oil components. In consequence, the simple relation developed by Environment Canada to predict the time required for evaporative losses to occur (i.e., Eq. 1 above) is not reliable because it drastically overestimates the evaporative loss rates of unconstrained and hence thin (<1 mm) oil films.

[148] Belore 2010 and SL Ross 2012.

[149] The higher initial and subsequent densities reported in the SL Ross 2012 study compared with the Belore 2010 study result from measurement of densities at 20 °C in the SL Ross study but at 15 °C in the Belore 2010 study. As with almost all liquids, the density of oil increases as temperature decreases.