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Dispersant Use on Canada's Pacific Coast:

Relevant factors and preliminary response gap analysis for the Enbridge Northern Gateway project area

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Disclaimer

This report is based on the research of Emma Point, Energy Campaign Researcher at Living Oceans Society. Part I of the report contains a qualitative assessment of expected dispersant efficacy based on specific characteristics of the proposed Northern Gateway Project and the associated marine operating area, drawn from existing literature. Part II of the report contains a preliminary response gap analysis, calculating the portion of time that weather conditions in the proposed marine operating area will marginalize or preclude dispersant use in the event of an oil spill. The analysis does not address the cumulative impacts of weather factors on dispersant application and efficacy and is thus considered preliminary. A more complete analysis including additional weather factors (e.g. visibility), additional buoy locations, and an assessment of cumulative weather impacts is warranted.

Acknowledgements

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Healthy Oceans. Healthy Communities.

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Executive Summary

Enbridge Northern Gateway Pipelines Inc. (Enbridge) has proposed to build and operate dual pipelines and a marine terminal to transport tar sands oil from northern Alberta to Kitimat, British Columbia. Associated tanker traffic servicing Asian and US energy markets would pose a risk of oil spills in the marine project area.

Enbridge's General Oil Spill Response Plan proposes the use of dispersants in the event of a spill. However, factors that affect the efficacy of dispersants (e.g. oil type, application timing, water temperature, water salinity, etc.) have not been evaluated for B.C. waters. Furthermore, Enbridge has provided no quantitative response gap analysis for dispersants based on weather conditions in the marine operating area. An assessment of dispersant efficacy and an estimated response gap is crucial to adequately assess the risks posed by this project.

In Part I of this report, factors that affect dispersant effectiveness are explored in the context of Enbridge's proposed project. Of all the factors that affect dispersant efficacy, oil type is the most important. No field trials have been conducted to determine if dispersants will be effective on diluted bitumen spills from Enbridge's proposed project. With respect to application timing, Enbridge's estimated response times may not fall within the relatively small window of opportunity for effective dispersant application. Winter water temperatures are well below the ideal water temperature for dispersant effectiveness and summer water salinities in the upper channels of the proposed tanker routes are too low for effective dispersant use.

Part II presents a preliminary response gap analysis for dispersants. A response gap is the portion of time that a response method is impaired or impossible based on defined operating limits. Operating limits exist for both application and efficacy of dispersants. This response gap analysis was based on wind speed and wave height operating limits for aircraft dispersant operations proposed by S.L. Ross Environmental Research Ltd. The preliminary response gap analysis determined that dispersants will often be an ineffective response strategy for oil spills in Enbridge's proposed marine project area. Across all buoy locations, dispersant response is either impaired or impossible an average of 51.37% of the time due to wind conditions alone. With respect to waves, two scenarios were considered. When waves are assumed to be less than 0.6 metres within 48 hours of dispersant application, dispersant response is either impaired or impossible 40.14% of the time due to wave height conditions alone, averaged across all buoy locations. When waves are assumed to be greater than or equal to 0.6 metres within 48 hours of dispersant application, dispersant response is either impaired or impossible 8.13% of the time due to wave height conditions alone, averaged across all buoy locations. This analysis did not assess the response gap resulting from the combined effects of wind and waves, thus offering a very conservative response gap estimate.

Based on the information reviewed and presented in this report, chemical dispersants are not likely to offer an effective oil spill strategy in the marine operating area. This is due to the preclusion or impairment of dispersant application and efficacy as a result of inherent project-related factors, oceanographic conditions, and regional weather patterns.

Introduction

Dispersants are listed as a potential hydrocarbon spill strategy in Enbridge's General Oil Spill Response Plan (GOSRP) for the proposed Northern Gateway Pipelines Project (hereafter referred to as "the project") (Northern Gateway, 2011a). However, dispersant effectiveness in the marine operating area is not assured in the event of an oil tanker spill. This report explores several factors that affect dispersant application and efficacy in the context of Enbridge's proposed project.

Dispersant efficacy is defined by the amount of oil dispersed into the water column relative to the amount of oil which remains on the surface (Fingas, 2004a). If they are effective, dispersants can prevent an oil slick from forming on the water's surface and from reaching sensitive coastal areas. However, dispersant application (by aircraft or vessel) is not always possible or successful in reaching its target (Fingas, 2008). Even if applied successfully, dispersant efficacy is dependent on numerous weather (e.g. wind and wave height) and oceanographic (e.g. water temperature and salinity) conditions, the timing of application, and the type of oil being treated.

Lessons learned from the use of dispersants during the Exxon Valdez oil spill in Prince William Sound provide evidence that this response method may not be effective in the event of a spill on B.C.'s coast. In Alaskan waters, which are affected by the same weather patterns as B.C.'s north and central coast (Irvine and Crawford, 2011), analysis of dispersant use during the Exxon Valdez spill deemed this response method ineffective due to a number of factors (Gilson, 2006).

Part I of this report discusses some of the relevant factors that influence dispersant efficacy post application, including: oil type, application timing, water temperature, and water salinity. Each factor is discussed in the context of Enbridge's proposed project, taking into consideration the chemical nature of tar sands bitumen, the logistics of reaching a spill site in a timely manner, and the surface water temperature and salinity of the proposed marine operating area.

Part 2 contains a preliminary response gap analysis for dispersants in Enbridge's proposed marine operating area. A response gap refers to the portion of time in which environmental conditions preclude or impair safe application of dispersants from aircraft or vessel *and* when environmental conditions are not conducive to dispersant efficacy. For instance, wind and wave conditions which are too low will limit the effectiveness of applied dispersants due to low mixing energy of the sea. Alternately, wind speeds and/or wave heights which are too great will impair dispersant efficacy by encouraging emulsification of the spilled oil, or will preclude application altogether if flying conditions are not deemed safe.

If Enbridge's project is approved, the threat of large oil spills in B.C. coastal waters will be real. Analysis of the efficacy Enbridge's proposed oil spill response techniques is a fundamentally important component of assessing the risks associated with this project.

Background

Dispersants

Chemical dispersants are a mixture of surfactants and solvents, and they are employed globally in oil spill response efforts. Dispersants are applied to spills with the intent to disperse oil in the water column into fine droplets, thereby preventing it from forming a slick at the surface. If dispersant application is effective, oil may be prevented from moving into sensitive coastal areas, and the impact on surface organisms can be mitigated (Lindgren *et al.*, 2001; Fingas, 2008). However, unlike mechanical recovery of oil (e.g. booms and skimmers) dispersants do not actually remove oil from the water and their use represents a conscious decision to decrease the strain on one component of the ecosystem (e.g. a coastal wetland) while increasing the strain on another (e.g. the water column and/or seafloor) (National Research Council, 2010). A number of factors can impact dispersant application procedures as well as their efficacy once applied, including weather, and oceanographic conditions, application timing, and oil type being dispersed (Nuka Research, 2008; Fingas, 2004b; Moles *et al.*, 2001; Blondina *et al.*, 1999).

Dispersant Toxicity

Even if an effective application is made, dispersants and chemically dispersed oil are known to have deleterious effects on marine life. The dispersed oil cloud that forms underwater can expose aquatic organisms that may otherwise not have been affected by the spill (Lindgren *et al.*, 2001), and chemically dispersed oil can be more toxic than naturally dispersed oil or dispersants alone (Fingas, 2008; EPA, 2010a). For example, the US Environmental Protection Agency (EPA) has found that several dispersants, when mixed with light sweet crude, were “highly toxic” to a marine invertebrate and a marine fish test species; light sweet crude alone was found to be only “moderately toxic” (EPA, 2010b). One specific toxic effect of chemically dispersed oil is increased uptake of polycyclic aromatic hydrocarbons (PAHs) in exposed fish (Ramachandran *et al.*, 2004). In general, an overall paucity of data exists concerning the actual mechanisms of toxicity from exposure to chemically dispersed oil (National Research Council, 2010). Similarly, we know little about the how dispersants will bio-accumulate in the food chain (Lindgren *et al.*, 2001).

The issue of the toxic effects of dispersants and chemically dispersed oil is serious. However, a detailed examination of this issue is not the purpose of this report. The lack of exploration of this topic in this paper is not meant to imply that dispersant toxicity should not preclude the use of chemical dispersants.

Enbridge General Oil Spill Response Plan

The General Oil Spill Response Plan (GOSRP) prepared by Enbridge contains high-level spill response concepts for their proposed project. Detailed operational plans for project components (pipeline, terminal, and marine environment) will not be available until six months before commissioning of the Project.

The GOSRP provides a list of hydrocarbon spill strategies, including "evaluate time-sensitive response technologies (i.e. dispersants, in situ burning)" (Enbridge, 2011, pg. 3-2). The GOSRP explains that the potential use of dispersants will be described for each hypothetical spill scenario and will be presented in the operational plans completed six months prior to project commissioning. Enbridge will need to gain approval of the Regional Environmental Emergency Team (REET)[1] for applying dispersants in Canada should the Project be approved.

Furthermore, Enbridge notes that "applicable learnings from the use of dispersants in response to recent oil spills will be applied to the procedures in the operational plans for using open water dispersants" (Northern Gateway, 2011a, pg 8-8). Unfortunately, scientific assessments of dispersant effectiveness at spill scenes are rarely conducted (Fingas, 2008), but lessons learned from dispersant use in Prince William Sound during the Exxon Valdez spill provide relevant data to assess the potential applicability of dispersants in the Open Water Area (OWA) and the Confined Channel Assessment Area (CCAA) of Enbridge's proposed project.

Dispersant Use in the Prince William Sound Region

Dispersants were applied multiple times in Prince William Sound over the course of cleanup operations for the Exxon Valdez spill in 1989. Analysis of dispersant use concluded this method was ineffective due to a number of factors that limited dispersant effectiveness, including: insufficient mixing energy[2], emulsification of the spilled oil, delays in application, high winds, poor visibility, dispersant spray nozzle malfunction, miscommunication, and misapplication (Gilson, 2006). Dispersant laboratory trials have supported the finding that dispersants are ineffective in Alaskan marine waters[3] (Moles *et al.*, 2001). In addition, literature reviews and independent research commissioned by the Prince William Sound Regional Citizens' Advisory Council (PWSRCAC) has documented a lack of understanding regarding the fate of chemically-dispersed oil (PWSRCAC, 2006; Fingas, 2005), and the toxic effect of dispersants on wildlife (Fingas, 2008).

More recently, a response gap analysis was conducted by Nuka Research in Prince William Sound to determine the portion of time that dispersant application and effectiveness would be impaired or impossible throughout the year due to wind, wave, and sea state conditions. The study determined that dispersant use would not be viable 75 percent and 80 percent of the year in the Central Sound and Hinchinbrook Entrance respectively (Nuka Research, 2008)[4].

Having monitored and commissioned dispersant research since the Exxon Valdez spill, PWSRCAC took the formal position that dispersants should not be considered for oil spill response in Prince William Sound until they have been demonstrated to be effective in regional

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[1] In British Columbia the REET is co-chaired by Environment Canada and the BC Ministry of Environment (Ministry of the Environment, 2011).

[2] Mixing energy (or wave energy) is related to the interconnected factors of wind and sea state (Nuka, 2008).

[3] Laboratory tests on the effectiveness of two dispersants (Corexit 950 and Corexit 9527) on Alaska North Slope (ANS) crude oil at various salinities and temperatures commonly found in the estuaries and marine waters of Southern Alaska indicated that dispersants were largely ineffective. Across all tests for Corexit 950 and Corexit 9527, effectiveness was between 2 percent and 10 percent (Moles *et al.*, 2001).

[4] In the Central Sound, darkness and sea state conditions too calm for dispersant mixing were cited as the most common environmental conditions which preclude dispersant efficacy. In Hinchbrook Entrance, darkness and sea state conditions (both too high and too low) were the relevant environmental factors (Nuka Research, 2008).

waters, and non-toxic when mixed with oil (PWSRCAC, 2006). The PWSRCAC is considered a robust model of citizens' oversight for oil tanker and terminals (Reid, 2008). Canada, with no similar model of citizens' advisory councils, has not embraced such a precautionary approach.

Part I: Factors Affecting Dispersant Efficacy in the CCAA and OWA

Dispersant effectiveness is defined by the amount of oil put into the water column relative to that which remains on the surface (Fingas, 2004a). However, efficacy is a function of both the physical application of dispersants (by vessel or aircraft) and of a dispersant's ability to disperse oil in the water column once it is applied. Assuming that weather conditions do not preclude safe application of dispersants by aircraft or vessel, a number of factors influence their efficacy in sea water, including oil type or composition, timing of application, water temperature, and water salinity (PWSRCAC, 2006; Moles *et al*., 2001; Blondina *et al*., 1999; Nuka Research, 2008). These factors are described below in relation to the project. References are made to the application of dispersants in Prince William Sound during the Exxon Valdez spill when relevant.

Oil type

Of all the factors that influence dispersant effectiveness, oil type is the most important (Fingas, 2008). As a general rule, chemical dispersion will have limited effectiveness on oils with high viscosities (Lewis, *et* al., 2005) since dispersants tend to run off the oil into the water before the solvent can penetrate the oil (ITOPF, 2010). The viscosity of bitumen is 40 to 70 times higher than the North American benchmark conventional oil (Swift *et* al., 2011).

Once oil is spilled, weathering processes can lead to emulsification (Lewis, *et al*., 2005), and emulsified oils are resistant to chemical-induced breakdown (IOTPF, 2005). Emulsification of oil is cited as a relevant factor in the failure of dispersants to combat the Exxon Valdez oil spill (Gilson, 2006). In the Technical Data Reports (TDRs) submitted for Northern Gateway, the spill-related properties of four oils[5] were examined. Fate modeling analysis indicated that MacKay River heavy bitumen diluted with synthetic light oil (MKH)[6] was likely to form an oil-in-water emulsion, and was slow to evaporate and disperse (S.L. Ross, 2010a). Laboratory modeling determined that after 48 hours, MKH could contain 75% water by weight. According to the TDR, if oil emulsifies, "it will attain very high viscosities and densities" (S.L. Ross, 2010a, pg 4-5),

Despite the known resistance of highly viscous oils to chemical dispersion, and the propensity of MKH to emulsify, Enbridge has provided no assessment of the effectiveness of dispersants on diluted bitumen.

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[5] The four oils modeled were: Cold Lake bitumen diluted with condensate (CLB); MacKay River heavy bitumen diluted with synthetic light oil (MKH); Synthetic light oil (SYN); CRW Condensate (CRW) (S.L. Ross, 2010a).

[6] MKH was modeled in place of CLB since it was assumed to "exhibit a similar long-term fate" (S.L. Ross, 2010a).

Window of Opportunity

Existing data suggest the window of opportunity for effective use of dispersants is relatively short, with estimates ranging from a few hours to a few days (Lindgren *et al.*, 2001; National Research Council, 2010). Over time, physical and chemical weathering process can lead to the formation of stable oil and water emulsions which resist chemical dispersion (Moles *et* al., 2001). The long delay (16 hours) leading up to the first dispersant application during the Exxon Valdez spill is cited as a factor that may have reduced dispersant efficacy (Gilson, 2006).

Dispersant application requires approval of the Regional Environmental Emergency Team (REET)[7], but Canada has no dispersant decision making policy to streamline this process (Reid, 2011). Furthermore, Northern Gateway's estimated response time is 6-12 hours in the CCAA (Northern Gateway, 2010), with additional travel time for emergency response in the OWA (Northern Gateway, 2011b). Although Northern Gateway's proposed response time is within Transport Canada's Response Organization Standards (Northern Gateway, 2011b), this may be inadequate when combined with potential delays associated with REET approval for dispersants. Furthermore, the majority of oil spill response equipment and capacity will come from the contracted Response Organization (RO) – not Enbridge vessels. Since the nearest RO station is located in Prince Rupert (WCMRC, 2011) response time to arrive on-scene may be further delayed.

In addition to regulatory delays and travel time to a spill site, environmental factors can contribute to delayed application of dispersants. Darkness and/or dangerous sea state conditions can impair or preclude safe application of dispersants by vessel or aircraft. Part 2 of this report contains a dispersant response gap analysis which quantifies the portion of time that environmental conditions could impair or preclude dispersant application and effectiveness.

Surface Water Salinity and Temperature

The efficacy of dispersants to disperse oil in the water column is strongly affected by sea water salinity. In general, efficacy increases with increasing salinity and is very low at low salinities (Chandrasekar, *et* al., 2006; Fingas, 2004a; Moles *et al.*, 2001). As salinity increases, the ionic strength of water subsequently rises, thus resulting in increased stability of dispersions (Fingas, 2004a). Depending on the specific dispersant, salinities between 25‰ and 35‰[8] are generally associated with peak efficacy, after which point there is a smooth gradient of decline in dispersant effectiveness (Fingas, 2004a).

Figure 1 and 2 illustrate the great annual and spatial variability in salinity in the CCAA and OWA as a result of fresh water runoff from land, sea surface evaporation, downwelling, upwelling, and lateral mixing (Report of the Scientific Review Panel, 2001). During the summer months, salinities in the CCAA are less than 20‰ and are below 15‰ in the upper channel areas. The low salinities in the upper channels could result in low dispersant effectiveness. Furthermore,

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[7] In British Columbia, the REET is co-chaired by Environment Canada and the BC Ministry of Environment (BC Gov, 2011).

[8] Salinity is traditionally expressed as parts per thousand (‰).

these waters have generally become less saline over the past two decades (Irvine and Crawford, 2011).

Figure 1: Summer salinities in the OWA and CCAA[9]

Figure 2: Winter salinities in the OWA and CCAA[9]

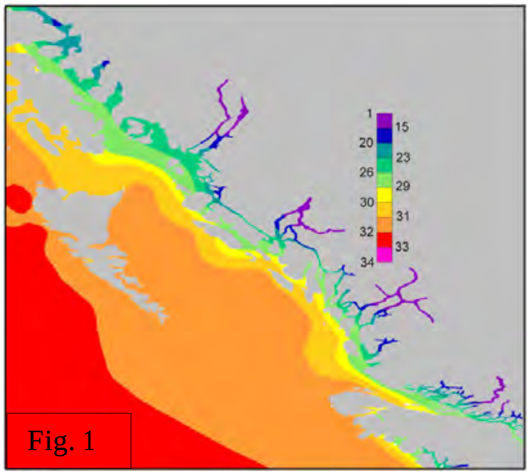

Fig. 1

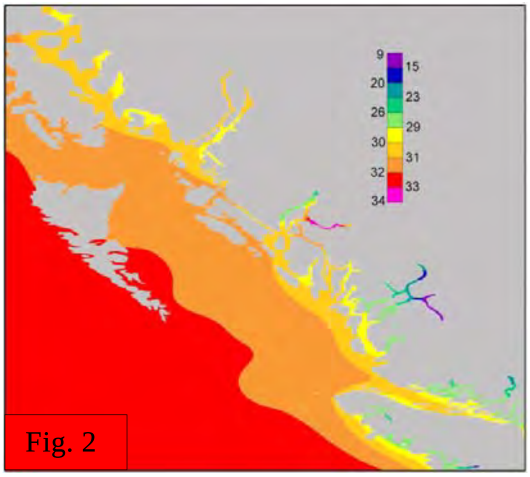

Fig. 2

Low water temperatures are also believed to decrease the efficacy of dispersants (Fingas, 2004b; Chandrasekar, *et* al., 2006; Moles, *et* al., 2001), although this relationship is influenced by salinity (Moles *et al*., 2001). According to Fingas (2008), effectiveness appears to peak at about 15°C and about 25‰ salinity.

Laboratory tests have indicated that in temperatures and salinities most common in the marine waters and estuaries of Alaska (summer= 10°C and 22‰ salinity, winter = 3°C and 32‰ salinity), dispersants are less than 10 percent effective (Moles *et al*., 2001).

Figures 3 and 4 display surface water temperatures for summer and winter in the CCAA and OWA. In the summer, surface temperatures tend to be higher than in Alaska, but lower than the ideal temperature of 15°C for peak efficacy. In the winter months, surface water temperatures for the entire region are well below temperatures ideal for dispersants. Over the past two decades, surface water temperatures along the north and central coast of B.C. have generally increased (Irvine and Crawford, 2011).

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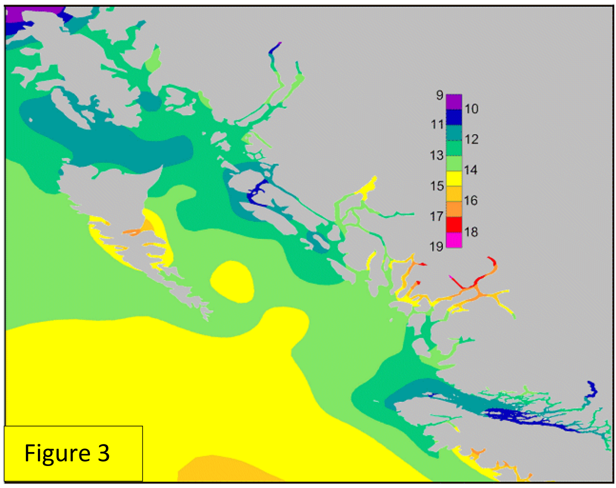
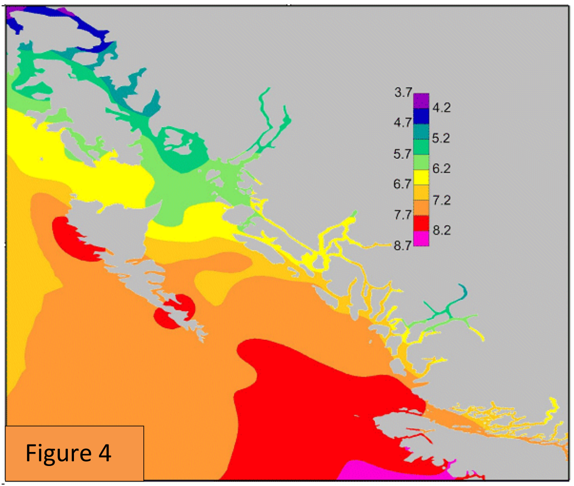
[9] Source: J.R. Irvine and W.R. Crawford. State of the Ocean Report for the Pacific North Coast Integrated Management Area (PNCIMA), 2011.

Figure 3: Summer surface water temperatures in the OWA and CCAA[9]

Figure 4: Winter surface water temperatures in the OWA and CCAA[9]





Part I Summary

Several factors can influence the efficacy of dispersants once they are applied. Most important of these factors is oil type, since highly viscous oils resist chemical dispersion and can emulsify once weathered. Enbridge has provided no assessment of whether dispersants will work on diluted bitumen.

Also important is the timing of application, since weathering of oils will increase over time. The vast distances that emergency response vessels will need to travel in the event of an oil spill in the CCAA or OWA raise concerns about timely application of dispersants.

Finally, temperature and salinity of surface water play an interconnected role in the efficacy of dispersants: low water temperatures and low salinities are generally associated with low dispersant effectiveness. In the summer months, salinities may be too low for effective dispersant use due to an influx of fresh water. In the winter, sea surface temperatures are well below desired thresholds for dispersant efficacy.

PART II: Response Gap Analysis

A response gap analysis determines the portion of time a response method is impaired or impossible based on defined operating limits. With respect to dispersants, operating limits exist for both application and efficacy of the product. Beyond certain environmental conditions, dispersant application and/or effectiveness is impaired or impossible. Response limits for the environmental factors of wind, sea state[10] and visibility are documented in the literature for dispersant use (S.L. Ross, 2011; Nuka, 2008; Fingas, 2004). A response gap analysis for

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[10] Sea state refers to both wave height and wave period (Nuka, 2008).

dispersants was not included in Enbridge's project application, yet it is a crucial component to adequately assess the risks of a potential oil spill from their proposed project.

Environmental Factors

Wind: Both strong and weak winds can impair or preclude accurate and effective dispersant application. For example, above certain thresholds, wind can impair or preclude accurate application of the dispersant on target, and can create unsafe flying or watercraft conditions. Alternately, wind speeds too low do not provide enough mixing energy[11] for chemical dispersion to work (Nuka, 2008; Fingas, 2004b).

Sea State: Mixing energy for effective dispersion is also related to sea state, which is a function of both wave height and wave period. A minimum amount of wave energy (e.g. breaking waves[12]) is required for effective chemical dispersion (ITOPF, 2005; S.L. Ross, 2011), however, conditions can arise whereby chemical dispersion provides no added benefit above natural dispersion induced by high mixing energy (Nuka, 2008). Following the application of chemical dispersants, a calming sea state can also result in resurfacing of the oil (Fingas, 2005: ITOPF, 2005). Alternately, dispersants applied to calm seas can be effective if treated slicks are exposed to breaking waves within 48 hours (Lewis, *et al.*, 2010), providing that other factors (e.g. oil type, extent of weathering, salinity, temperature) do not pose additional challenges.

Existing Dispersant Response Limits

Response gap analyses conducted for Prince William Sound by Nuka Research and Planning Group (2008) and Canadian Arctic regions by S.L. Ross Environmental Research (2011) provide a basis from which to assess the response gap for dispersants in Enbridge's proposed marine operating area. Although the operational limits in these studies were generated for decision-making in Alaska and the Canadian Arctic respectively, the parameters are relevant to any marine environment in which dispersants may be applied.

In Nuka's response gap analysis, operational limits are provided for wind speed, sea state (a function of wave height and wave period), and visibility that would impair or preclude dispersant application (by large aircraft) and effectiveness once applied. Table 1 is a summary of Nuka's response limits that are relevant to this analysis from their 2008 report. Response limit parameters have been converted into metric measurements.

With respect to both wind and sea state conditions, Nuka's response limits reflect the fact that both high and low wind speeds and sea states can impair or preclude dispersant use. As stated in their report:

> *Effective dispersion requires an accurate application of the chemical and sufficient mixing (wave) energy. On the other hand, it wave energy is high enough, then the*

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[11] Mixing energy (or wave energy) is related to the interconnected factors of wind and sea state. Effective dispersion requires both accurate application of the dispersant and sufficient mixing energy (Nuka, 2008).

[12] Breaking waves (offshore) develop when wind speeds exceed 7-10 knots (3.5-5.4 metres/second) and waves are 0.5 to 1.0 metres in height (S.L. Ross, 2011).

> *chemical application will provide no added benefit over natural dispersion. There are thus both maximum and minimum wind and sea state limits for dispersant use* (Nuka, 2008, pg. 13).

Table 1 – Dispersant Response Operating Limits (Nuka, 2008)

Environmental Factor	Green: Response Not Impaired	Yellow: Response Impaired	Red: Response Not Possible
Wind Speed (m/s)	≥ 5.14 to < 11.32	≥ 3.09 to < 5.14 or ≥ 11.32 to < 14.40	≥ 0 to <3.09 or ≥ 14.40
Sea State (m)	≥ 0.61 to < 3.05	≥ 0.30 to < 0.61	≥ 0 to < 0.30 or ≥ 3.05

In S.L. Ross' response gap analysis, operational limits are provided for wind speed, wave height, daylight, visibility, ceiling, and ice cover conditions that could impair or preclude dispersant application (by large aircraft) and effectiveness once applied. Table 2 contains S.L. Ross' response limits from their 2011 report that are relevant to this analysis.

Table 2 – Dispersant Response Operating Limits (S.L. Ross, 2011)

Environmental Factor	Response Favourable	Response Marginal	Response Not Possible
Wind Speed (m/s)	< 13	≥ 13 to ≤ 15	> 15
Wave Height A[13] (m)	≥ 0.6 to < 3.0	≥ 3.0 to ≤ 4.6	< 0.6 AND > 4.6
Wave Height B[14] (m)	≥ 0 to < 3.0	≥ 3.0 to ≤ 4.6	> 4.6

Similarly to Nuka's response limits, S.L. Ross qualitatively notes that both high and low wind speeds and wave heights can impair or preclude dispersant use. As stated in their report:

> *Dispersants are most effective when slicks of fresh or lightly weathered oils can be sprayed with an adequate dose of effective dispersant product in the presence of breaking waves (NRC, 2005). In offshore environments breaking waves develop when wind speeds exceed 7 to 10 knots (3.5 to 5.4 m/s) and waves are 0.5 to 1 m in height.* (S.L. Ross, 2011, pg. 10-11)

However, the response limits included in the S.L. Ross report for wind speeds do not reflect this understanding (Table 2). Instead, S.L. Ross response limits for wind assume that any wind speeds below 13 m/s will create conditions amenable to chemical dispersion.

With respect to the necessity for breaking waves, the report goes on further to note:

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[13] Wave Height A = operational limits if wave heights within 48 hours of dispersant application are <0.6m.
[14] Wave Height B = operational limits if wave heights within 48 hours of dispersant application are ≥ 0.6m.

> *Dispersants can be applied in non-breaking wave conditions, where dispersion might not occur immediately, if breaking waves are likely to occur within a reasonable time after dispersant application. Research has shown that dispersants applied to slicks on calm seas will cause effective dispersion if the treated slicks are exposed to breaking waves within 48 hours.* (S.L. Ross, 2011, pg. 11)

Operational limits for wave height reflect this understanding (Table 2) and were provided for two wave height scenarios (A and B). Operational limits for wave height are provided for instances in which wave heights are either < 0.6 m within 48 hours (Wave Height A), or ≥ 0.6m within 48 hours (Wave Height B).

Response Gap Methodology

a) Assemble Datasets of Environmental Factors in the Proposed Project Area

Environmental datasets for the proposed project area were assembled from weather buoy data from Canada's Pacific coast. Environment Canada and Fisheries and Oceans Canada (DFO) maintain offshore weather buoys in the region. The buoys measure general weather data including air pressure, air temperature, sea surface temperature, wind observations and wave height. Data from buoys located near the proposed tanker routes were obtained[15]. The weather buoys used to assemble the datasets are summarized in Table 3. The locations of the weather buoys used are illustrated in Figure 5.

Table 3 - Weather buoys used in this analysis along the proposed tanker routes

Buoy No.	Buoy Name	Latitude	Longitude	Data Collection Start Date	Data Collection End Date
C46145	Central Dixon Entrance	54.38	-132.43	4/16/1991	8/2/2011
C46181	Nanakwa Shoal	53.82	-128.84	11/22/1988	8/2/2011
C46183	North Hecate Strait	53.57	-131.14	5/15/1991	8/2/2011
C46185	South Hecate Strait	52.42	-129.8	9/12/1991	8/2/2011

Environmental datasets for each buoy were assembled in spreadsheets and sorted according to month. To ensure only quality data were used, only readings with a rating of Good or Acceptable[16] was included in the analysis. Blank, erroneous, doubtful, or changed records were not included.

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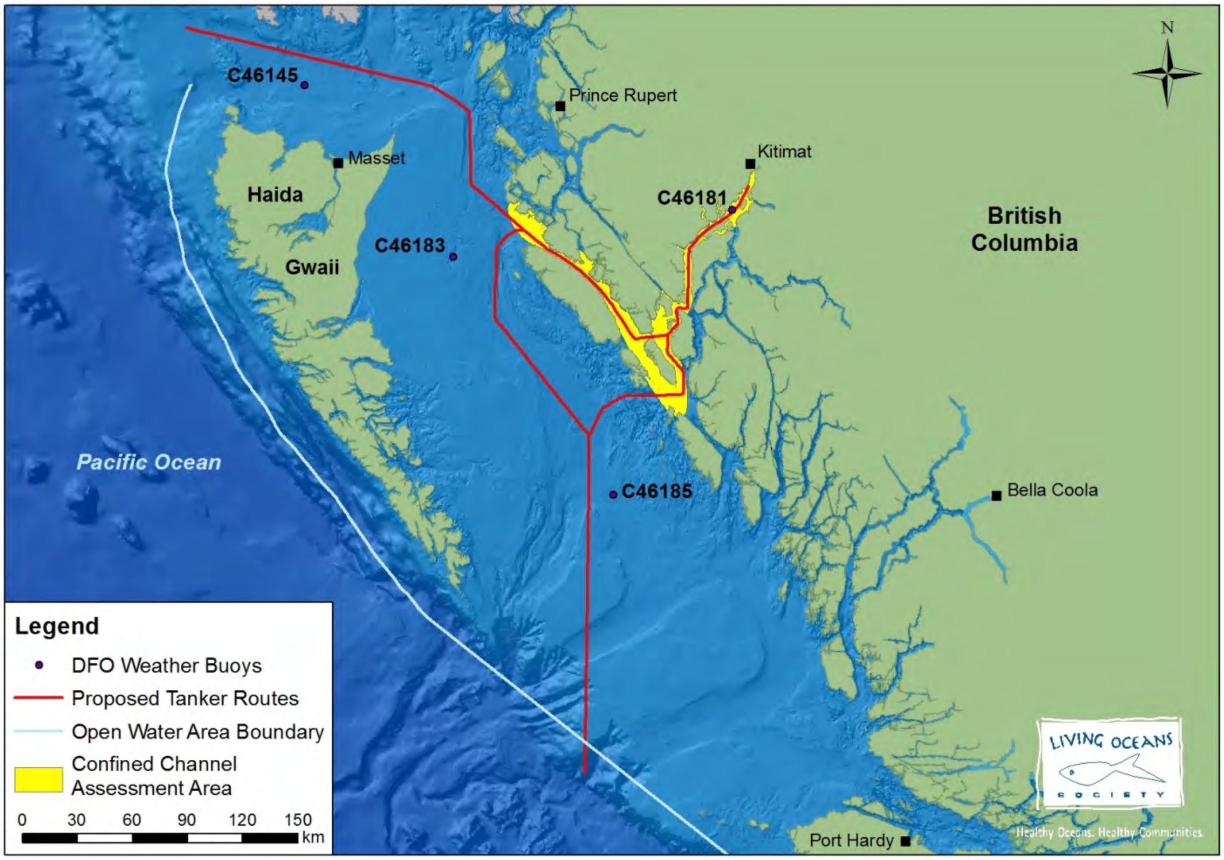
[15] Buoy data was downloaded from: Fisheries and Oceans Canada (DFO) at http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/search-recherche/list-liste/index-eng.asp?MedsID=C46&ID=&StnName=&Lat1=&Lat2=&Long1=&Long2=&sDate=&eDate=&typedisplay=HTML&Search=Get+Results

[16] Environment Canada and DFO rate each reading in these datasets for quality control. A quality control rating of "Good" means quality control was performed, record appears correct. A quality control rating of "Acceptable" means quality control was performed, but record appears inconsistent with other records.

Figure 5 - Weather buoy locations used in this analysis along the proposed tanker routes



b) Determine Response Limits for Dispersant Application and Effectiveness

As noted above, response gap analyses were conducted by Nuka Research and S.L. Ross Environmental Research that provide relevant response limits for a variety of environmental conditions in Prince William Sound and the Canadian Arctic. Response limits proposed by S.L. Ross were used in this analysis[17]. However, to incorporate the known low wind speed limitations for dispersant use (S.L. Ross, 2011), low wind speed parameters were incorporated into these response limits, based on the wind parameters necessary for breaking waves described by S.L. Ross (2011). Table 4 presents the response limits used in this preliminary response gap analysis for the proposed project area.

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[17] Nuka's operational limits for waves are based on sea state, which was not easily calculable from offshore weather buoy data.

Table 4 – Dispersant Response Limits for the Preliminary Response Gap Analysis for the Proposed Project Area

Environmental Factor	Response Favourable	Response Marginal	Response Not Possible
Wind Speed (m/s)	≥ 5.4 to <13	≥ 3.5 to <5.4 AND ≥ 13 to ≤ 15	≥ 0 to <3.5 AND >15
Wave Height A[18] (m)	≥ 0.6 to <3.0	≥ 3.0 to ≤ 4.6	<0.6 AND >4.6
Wave Height B[19] (m)	≥ 0 to <3.0	≥ 3.0 to ≤ 4.6	>4.6

S.L. Ross' dispersant operational limits are based on application by large aircraft, rather than marine vessel. It is unclear whether Enbridge's marine response plan will include aerial spraying marine vessel application or both. If Enbridge intends to apply dispersants via marine vessels, a response gap using response limits for vessel application of dispersants should also be undertaken to assess associated risks.

c) Calculate Proportion of Time that Response Limits Preclude Effective Response in the Project Area

The datasets of environmental factors were analyzed using basic queries in Excel to determine how often response is “favorable”, “marginal” or “not possible” at each of the specified buoy locations. Data were analyzed on a monthly basis.

Response Gap Results

The response gap at each location is based the on the percentage of time that dispersant response limits (for wind and waves separately) are exceeded and dispersant response is either: favorable, marginal, or not possible.

Wind

Dispersant response gap results for wind, averaged over all months of the year, are presented in Table 5. Dispersant response gap results for wind conditions are presented on a month by month basis for each buoy in Appendix A.

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[18] Wave Height A = operational limits if wave heights within 48 hours of dispersant application are < 0.6m.

[19] Wave Height B = operational limits if wave heights within 48 hours of dispersant application are ≥ 0.6m.

Table 5 – Dispersant Response Gap for Wind Conditions (All Months)

Buoy Location	Response Favourable	Response Marginal	Response Not Possible
Central Dixon Entrance	54.99%	22.30%	22.70%
Nanakwa Shoal	36.80%	21.31%	41.89%
North Hecate Strait	52.80%	19.89%	27.30%
South Hecate Strait	49.92%	21.34%	28.74%
Average – all buoy locations	**46.03%**	**21.21%**	**30.16%**

In Central Dixon Entrance, dispersant response is either marginal or not possible 45.00 percent of the time. In Nanakwa Shoal, dispersant response is either marginal or not possible 63.20 percent of the time. In North Hecate Strait, response is marginal or not possible 47.20 percent of the time. In South Hecate Strait, response is marginal or not possible 50.08 percent of the time. **On average across all buoy locations, dispersant response is either marginal or not possible 51.37 percent of the time due to wind conditions alone.**

In general, there is little difference between the response gap due to wind in winter versus summer. This may be counter-intuitive given the strong winter winds that prevail throughout Hecate Strait due to the Aleutian Low pressure system (Irvine and Crawford, 2011). However, since weak winds (i.e. <5.4 m/sec, as per Table 4) decrease the efficacy of dispersants (S.L. Ross, 2011), their application in low wind conditions is relatively ineffective. In fact, for the 30.16 percent of observations (averaged over all locations) calculated as impossible due to wind, 90.52 percent were calculated as such because of *low* wind speed (i.e. <3.5 m/sec).

Wave Height

Recall that operational limits were provided for two wave height scenarios (A and B) reflecting the expectation that dispersants applied to calm seas may in fact be effective if the treated slicks are exposed to breaking waves within 48 hours.

Wave Height A:

Dispersant response gap results for “Wave Height A”, averaged over all months of the year, are presented in Table 6. Dispersant response gap results for “Wave Height A” conditions are presented on a month by month basis for each buoy in Appendix B.

Table 6 – Dispersant Response Gap for Wave Height if Waves are <0.6m within 48 Hours (All Months)

Buoy Location	Response Favorable	Response Marginal	Response Not Possible
Central Dixon Entrance	84.52%	7.99%	7.50%
Nanakwa Shoal	5.89%	0.05%	94.06%
North Hecate Strait	69.55%	6.35%	24.10%
South Hecate Strait	79.48%	10.78%	9.74%
Average – all buoy locations	**59.86%**	**6.29%**	**33.85%**

When waves are assumed to be <0.6m within 48 hours of dispersant application, dispersant response is either impaired or impossible 15.48 percent of the time in Central Dixon Entrance. In Nanakwa Shoal, dispersant response is either impaired or impossible 94.11 percent of the time. In North Hecate Strait, response is impaired or impossible 30.45 percent of the time. In South Hecate Strait, response is impaired or impossible 20.52 percent of the time. **On average across all buoy locations, dispersant response is either impaired or impossible 40.14 percent of the time due to wave height conditions alone, when waves are <0.6m within 48 hours.**

In Central Dixon Entrance, Nanakwa Shoal and North Hecate Strait, summer months are generally associated with a larger response gap due to wave height than winter months (i.e. response is possible less often). This is not the case in South Hecate Strait where the response gap is variable throughout the year. Of the 33.85 percent of observations (averaged over all locations) calculated as impossible due to wave height, 75.32 percent were calculated as such because of *low* wave height (<0.60m).

Wave Height B:

Dispersant response gap results for “Wave Height B”, averaged over all months of the year, are presented in Table 7. Dispersant response gap results for “Wave Height B” conditions are presented on a month by month basis for each buoy in Appendix C.

Table 7 – Dispersant Response Gap for Wave Height if Waves are ≥0.6m within 48 Hours (All Months)

Buoy Location	Response Favorable	Response Marginal	Response Not Possible
Central Dixon Entrance	91.06%	7.99%	0.96%
Nanakwa Shoal	99.91%	0.05%	0.05%
North Hecate Strait	91.78%	6.35%	1.87%
South Hecate Strait	84.75%	10.78%	4.47%
Average – all buoy locations	**91.87%**	**6.29%**	**1.84%**

When waves are assumed to be ≥ 0.6m within 48 hours of dispersant application, dispersant response is either impaired or impossible 8.94 percent of the time in Central Dixon Entrance. In Nanakwa Shoal, dispersant response is either impaired or impossible 0.09 percent of the time. In North Hecate Strait, response is impaired or impossible 8.22 percent of the time. In South Hecate Strait, response is impaired or impossible 15.25 percent of the time. **On average across all buoy locations, dispersant response is either impaired or impossible 8.13 percent of the time due to wave height conditions alone, when waves are ≥0.6m within 48 hours.**

Part II Summary

The preliminary dispersant response gap analysis, based on response limits provided by S.L. Ross for wind and waves, indicates that a response gap exists for a substantial portion of time in the marine project area. Across all buoy locations, dispersant response is predicted to be marginal or impossible 51.37 percent of the time due to wind conditions alone. There is little difference between the response gap due to wind in winter versus summer and over 90% of wind observations calculated as impossible, were calculated as such due to low wind speed (i.e. <3.5 m/sec).

To determine the effect of wave height on the dispersant response gap, two wave height scenarios were considered. When waves are assumed to be <0.6m within 48 hours of dispersant application, dispersant response is predicted to be marginal or impossible 40.14 percent of the time across all buoy locations due to wave height conditions alone. Within these parameters, over 75% of wave height observations calculated as impossible were calculated as such due to low wave heights (i.e. <0.60m). Alternately, when waves are assumed to reach heights of ≥0.6m within 48 hours of dispersant application, dispersant response is predicted to be marginal or impossible only 8.13 percent of the time across all buoy locations, due to wave height conditions alone.

Discussion

An examination of relevant factors for dispersant efficacy has highlighted a number of concerns related to Enbridge's proposed use of dispersants in the event of an oil spill on Canada's Pacific Coast.

Oil type is widely cited as the most relevant factor in dispersant efficacy (Fingas, 2008; ITOPF, 2005) and the high viscosity of tar sands bitumen (Swift *et al.*, 2011) may limit the effectiveness of chemical dispersants (Lewis *et al.*, 2005). Furthermore, both Cold Lake bitumen diluted with condensate (CLB) and MacKay River heavy bitumen diluted with Suncor synthetic light oil (MKH) are expected to form emulsions within 2 days of a spill before evaporation has occurred (S.L. Ross, 2010a). Emulsified oil is resistant to chemical-induced breakdown (ITOPF, 2005) and water-in-oil emulsion is cited as a relevant factor in the failure of dispersants to combat the Exxon Valdez oil spill (Gilson, 2006). Despite the known resistance of highly viscous, emulsifying oils to chemical dispersion, Enbridge has not submitted an analysis on the efficacy of dispersants on diluted bitumen.

The relevance of dispersant application timing is cause for similar concern. Over time, viscosity of spilled oil increases, water-in-oil emulsion develops, and dispersant effectiveness is thusly reduced (Gilson, 2006; Moles *et* al., 2001). The proposed marine project area is vast and Enbridge's own estimates for reaching a spill or distressed vessel suggest that the small window of opportunity for effective dispersant application may be missed. Response time by the contracted Response Organization may be even longer due to their relative distance to the marine project area. The long delay (16 hours) leading up to the first dispersant application during the Exxon Valdez spill is cited as a factor that may have reduced dispersant efficacy (Gilson, 2006).

Even if the oil is conducive to chemical dispersion, and emergency response vessels reach a spill without delay, sea surface water temperatures and salinity of the marine project area may cause dispersants to be ineffective at certain times of year. Sea water conditions for peak effectiveness of dispersants are 15°C and 25 ‰ salinity as cited by a leading surfactant scientist (Fingas, 2008). These conditions are not expected much of the year in the marine project area. Winter sea surface temperatures range from 4.7°C to 8.2°C (Figure 4), and even in the summer sea surface temperatures are below 15°C (Figure 3). During the summer months, salinities in the CCAA are less than 20 ‰ and are below 15 ‰ in the upper channel areas (Figure 1).

Furthermore, results of the preliminary response gap analysis indicate that dispersant response will be marginal or impossible for a substantial period over the course of a year due to either wind or wave conditions alone. Dispersant application by aircraft is dependent on safe flying conditions as well as oceanic conditions that discourage emulsification of oil yet provide enough mixing energy for dispersants to work. Given these parameters, dispersant response is either impaired or impossible 51.37% of the time due to wind conditions alone. Dispersant response is either impaired or impossible 40.14% of the time due to wave height conditions alone when waves are assumed to be <0.6m within 48 hours of dispersant application. If waves heights become ≥0.6 meters within 48 hours of dispersant application, dispersant response is marginal or impossible 8.13% of the time. A response gap analysis for dispersants was not included in Enbridge's project application, yet it is a crucial component to adequately assess the risks of a potential oil spill. The preliminary response gap analysis described in this report will offer a useful comparison with respect to methodological choices and final results of Enbridge's own response gap analysis, if submitted.

It is important to note that the determination of operational limits for dispersant use is a subjective process. Comparison of the operational limits proposed by Nuka Research and S.L. Ross exemplifies this fact. For instance, whereas S.L. Ross acknowledges the importance of a minimum wind speed necessary for effective chemical dispersion, they do not incorporate this into the response limits used in their response gap analysis. This effectively ignores the necessity of a minimum wind speed, artificially reducing the projected response gap. In contrast, Nuka's operational limits did reflect the necessity of a minimum wind speed for dispersion. In this preliminary response gap analysis for the Enbridge proposed project area, it was decided that known limitations of low wind speeds should in fact be reflected in operational limits. If and when Enbridge commissions a more comprehensive response gap analysis, operational limits should generally reflect those from existing dispersant response gap analyses, and should incorporate the known limitations associated with low wind speeds and wave heights.

Interactions between environmental conditions were not considered in S.L. Ross' analysis, nor are they considered in this preliminary response gap analysis. For example, a situation could arise in which the combination of a particular wave height and wind speed could limit or preclude a response, even if each factor considered individually would not. This analysis also did not take into consideration the response gap that exists due to darkness or visibility impairment (e.g. fog) (Nuka, 2008; S.L Ross, 2011). The result is that this response gap is likely conservative and thus should be considered preliminary. Assessing all relevant weather conditions and the cumulative effects of environmental factors is essential for a more in depth analysis. Should Enbridge conduct a more in-depth analysis, this preliminary report will serve as a useful comparison with respect to methodological choices and results.

Conclusion

Northern Gateway has proposed the use of dispersants as a potential response strategy for hydrocarbon spills in the proposed marine operating area. Although dispersants are used as an oil spill response method in other parts of the world, they are only effective under a limited range of conditions. The information reviewed and presented in this report indicates that chemical dispersants are not an effective hydrocarbon spill strategy for Enbridge's proposed project and the associated marine operating area, for the following reasons:

- Bitumen is a heavy, viscous oil with a tendency to emulsify; chemical dispersants are not effective on oils that are highly viscous or form emulsions;
- The marine project area is vast and best estimates for emergency response time may be outside the window of opportunity for effective dispersant application;
- Seasonal variation in salinity and temperature in the marine operating area may reduce the efficacy of dispersants, and
- Based on the response gap analysis presented in this paper, wind and wave conditions in the marine operating area can be expected to impair or preclude dispersant application and/or efficacy for a substantial portion of the year.

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Appendix A – Dispersant Response Gap for Wind Conditions for Individual Buoy Locations[20]

Central Dixon Entrance – Buoy No. C46145						
		Response Favorable	Response Marginal		Response Not Possible	
Month	Total wind speed observations	Percent >=5.4 m/s to <13 m/s	Percent >=13 m/s to <=15 m/s	Percent >=3.5 m/to <5.4 m/s	Percent >15 m/s	Percent >=0 m/s to <3.5 m/s
Jan	12334	59.21	6.11	14.01	3.79	16.89
Feb	11666	57.95	5.47	14.40	2.85	19.34
Mar	12651	59.77	4.97	14.09	2.62	18.54
Apr	11116	53.83	2.08	21.01	1.28	21.81
May	11984	55.61	1.47	22.23	0.57	20.13
Jun	13047	51.38	1.16	22.79	0.09	24.57
Jul	13591	49.00	0.23	24.68	0.06	26.03
Aug	13935	44.06	0.70	25.62	0.19	29.44
Sep	13530	45.91	1.09	26.23	0.58	26.19
Oct	13286	57.20	3.99	18.27	2.73	17.81
Nov	13118	62.88	5.98	13.52	3.47	14.16
Dec	12963	63.12	7.28	10.28	5.27	14.06
Average		**54.99**	**3.38**	**18.93**	**1.96**	**20.75**

Nanakwa Shoal – Buoy No. C46181						
		Response Favorable	Response Marginal		Response Not Possible	
Month	Total wind speed observations	Percent >=5.4 m/s to <13 m/s	Percent >=13 m/s to <=15 m/s	Percent >=3.5 m/s to <5.4 m/s	Percent >15 m/s	Percent >=0 m/s to <3.5 m/s
Jan	10575	48.91	5.79	12.64	1.80	30.87
Feb	9076	43.32	2.01	14.68	0.14	39.85
Mar	9713	38.81	0.84	17.00	0.07	43.27
Apr	8782	26.06	0.08	21.36	0.02	52.47
May	9444	29.44	0.06	23.92	0.02	46.56
Jun	9126	36.18	0.01	24.76	0.00	39.04
Jul	8719	40.00	0.00	25.62	0.00	34.37
Aug	8810	33.61	0.01	26.30	0.00	40.08
Sep	8785	27.77	0.00	24.11	0.00	48.12
Oct	9594	31.66	0.36	20.56	0.03	47.38
Nov	10051	40.78	1.97	15.58	0.20	41.47
Dec	10801	45.00	4.43	13.61	1.12	35.85
Average		**36.80**	**1.30**	**20.01**	**0.28**	**41.61**

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[20] Monthly percentages may not add up to 100% due to rounding.

North Hecate Strait – Buoy No. C46183						
		Response Favorable	Response Marginal		Response Not Possible	
Month	Total wind speed observations	Percent >=5.4 m/s to <13 m/s	Percent >=13 m/s to <=15 m/s	Percent >=3.5 m/s to <5.4 m/s	Percent >15 m/s	Percent >=0 m/s to <3.5 m/s
Jan	12093	52.05	6.78	12.48	7.38	21.31
Feb	11702	50.57	5.61	12.72	4.42	26.68
Mar	12646	52.01	5.88	12.10	5.22	24.79
Apr	11398	50.39	4.19	13.60	3.54	28.29
May	11470	49.68	2.21	15.94	1.14	31.03
Jun	10963	49.83	2.31	17.01	0.35	30.50
Jul	11499	51.13	0.83	19.25	0.28	28.51
Aug	11362	49.64	1.77	20.39	0.82	27.38
Sep	11089	51.95	2.68	19.49	1.79	24.10
Oct	11975	56.06	4.99	16.77	5.19	16.99
Nov	12393	60.94	8.32	12.79	7.43	10.52
Dec	12071	59.37	8.33	12.29	9.75	10.26
Average		**52.80**	**4.49**	**15.40**	**3.94**	**23.36**

South Hecate Strait – Buoy No. C46185						
		Response Favorable	Response Marginal		Response Not Possible	
Month	Total wind speed observations	Percent >=5.4 m/s to <13 m/s	Percent >=13 m/s to <=15 m/s	Percent >=3.5 m/s to <5.4 m/s	Percent >15 m/s	Percent >=0 m/s to <3.5 m/s
Jan	12440	53.57	6.79	12.44	7.12	20.07
Feb	11692	51.23	5.50	15.16	3.92	24.19
Mar	12883	49.45	4.79	13.54	4.14	28.08
Apr	10864	40.14	1.89	14.54	1.45	41.97
May	10826	44.65	2.18	20.52	0.60	32.05
Jun	11018	45.97	1.75	26.15	0.15	25.98
Jul	11282	46.14	1.24	24.33	0.14	28.15
Aug	10781	48.09	1.91	23.57	0.37	26.06
Sep	11162	52.24	2.56	21.39	1.24	22.57
Oct	11959	58.54	4.71	16.67	4.49	15.59
Nov	11447	57.19	6.32	12.68	5.25	18.56
Dec	12468	51.80	6.50	8.92	7.35	25.43
Average		**49.92**	**3.85**	**17.49**	**3.02**	**25.72**

Appendix B – Dispersant Response Gap for "Wave Height A" Conditions for Individual Buoy Locations[21]

Operational limits for "Wave Height A" assume that wave heights are <0.6 metres within 48 hours of application (S.L. Ross, 2011).

Central Dixon Entrance – Buoy No. C46145					
		Response Favorable	**Response Marginal**	**Response Not Possible**	
Month	**Total wave height observations**	**Percent >=0.6 m and <3.0 m**	**Percent >=3.0 m and <=4.6 m**	**Percent >4.6 m**	**Percent <0.6 m**
Jan	12334	86.28	12.69	0.81	0.22
Feb	11666	85.98	12.33	0.87	0.83
Mar	12651	88.14	9.64	1.19	1.04
Apr	11116	89.81	5.40	0.57	4.23
May	11984	88.04	1.03	0.07	10.86
Jun	13047	82.92	0.28	0.00	16.80
Jul	13591	80.10	0.09	0.00	19.81
Aug	13935	82.21	0.19	0.00	17.60
Sep	13530	90.40	3.70	0.41	5.49
Oct	13286	86.25	11.54	1.21	1.00
Nov	13118	79.82	16.72	2.85	0.61
Dec	12963	74.23	22.22	3.51	0.04
Average		**84.52**	**7.99**	**0.96**	**6.54**

Nanakwa Shoal – Buoy No. C46181					
		Response Favorable	**Response Marginal**	**Response Not Possible**	
Month	**Total wave height observations**	**Percent >=0.6 m and <3.0 m**	**Percent >=3.0 m and <=4.6 m**	**Percent >4.6 m**	**Percent <0.6 m**
Jan	10575	22.01	0.34	0.27	77.37
Feb	9076	10.40	0.09	0.03	89.48
Mar	9713	8.48	0.00	0.00	91.52
Apr	8782	1.56	0.00	0.00	98.44
May	9444	1.52	0.00	0.00	98.48
Jun	9126	1.68	0.00	0.00	98.32
Jul	8719	0.53	0.00	0.00	99.47
Aug	8810	0.24	0.00	0.00	99.76
Sep	8785	0.34	0.00	0.00	99.66
Oct	9594	1.70	0.00	0.00	98.30
Nov	10051	8.87	0.00	0.00	91.13
Dec	10801	13.40	0.12	0.25	86.23
Average		**5.89**	**0.05**	**0.05**	**94.01**

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[21] Monthly percentages may not add up to 100% due to rounding.

North Hecate Strait – Buoy No. C46183					
		Response Favorable	**Response Marginal**	**Response Not Possible**	
Month	**Total wave height observations**	**Percent >=0.6 m and <3.0 m**	**Percent >=3.0 m and <=4.6 m**	**Percent >4.6 m**	**Percent <0.6 m**
Jan	12093	75.25	11.93	4.50	8.32
Feb	11702	75.75	10.09	2.50	11.66
Mar	12646	77.11	8.47	2.75	11.67
Apr	11398	72.81	6.14	1.37	19.68
May	11470	66.87	2.87	0.10	30.17
Jun	10963	65.47	0.99	0.02	33.51
Jul	11499	56.74	0.45	0.09	42.72
Aug	11362	56.26	1.82	0.24	41.68
Sep	11089	61.75	2.74	0.78	34.72
Oct	11975	71.09	8.15	1.96	18.80
Nov	12393	78.67	11.04	3.01	7.28
Dec	12071	76.78	11.48	5.19	6.55
Average		**69.55**	**6.35**	**1.87**	**22.23**

South Hecate Strait – Buoy No. C46185					
		Response Favorable	**Response Marginal**	**Response Not Possible**	
Month	**Total wave height observations**	**Percent >=0.6 m and <3.0 m**	**Percent >=3.0 m and <=4.6 m**	**Percent >4.6 m**	**Percent <0.6 m**
Jan	12440	68.89	19.92	10.40	0.79
Feb	11692	72.05	16.27	7.20	4.48
Mar	12883	76.60	15.82	6.15	1.43
Apr	10864	85.51	9.67	3.06	1.76
May	10826	89.90	4.03	0.64	5.43
Jun	11018	88.96	2.73	0.15	8.16
Jul	11282	84.13	0.86	0.12	14.89
Aug	10781	82.55	2.24	0.09	15.11
Sep	11162	87.09	4.22	1.11	7.58
Oct	11959	80.39	12.03	4.82	2.76
Nov	11447	70.54	20.27	8.58	0.61
Dec	12468	67.16	21.25	11.38	0.21
Average		**79.48**	**10.78**	**4.47**	**5.27**

Appendix C – Dispersant Response Gap for "Wave Height B" Conditions for Individual Buoy Locations[22]

Operational limits for "Wave Height B" assume that wave heights are >=0.6 metres within 48 hours of application (S.L. Ross, 2011).

Central Dixon Entrance – Buoy No. C46145				
		Response Favorable	**Response Marginal**	**Response Not Possible**
Month	**Total wave height observations**	**Percent >=0.0 m and <3.0 m**	**Percent >=3.0 m and <=4.6 m**	**Percent >4.6 m**
Jan	12334	86.50	12.69	0.81
Feb	11666	86.81	12.33	0.87
Mar	12651	89.17	9.64	1.19
Apr	11116	94.04	5.40	0.57
May	11984	98.90	1.03	0.07
Jun	13047	99.72	0.28	0.00
Jul	13591	99.91	0.09	0.00
Aug	13935	99.81	0.19	0.00
Sep	13530	95.89	3.70	0.41
Oct	13286	87.25	11.54	1.21
Nov	13118	80.43	16.72	2.85
Dec	12963	74.27	22.22	3.51
Average		**91.06**	**7.99**	**0.96**

Nanakwa Shoal – Buoy No. C46181				
		Response Favorable	**Response Marginal**	**Response Not Possible**
Month	**Total wave height observations**	**Percent >=0.0 m and <3.0 m**	**Percent >=3.0 m and <=4.6 m**	**Percent >4.6 m**
Jan	10575	99.39	0.34	0.27
Feb	9076	99.88	0.09	0.03
Mar	9713	100.00	0.00	0.00
Apr	8782	100.00	0.00	0.00
May	9444	100.00	0.00	0.00
Jun	9126	100.00	0.00	0.00
Jul	8719	100.00	0.00	0.00
Aug	8810	100.00	0.00	0.00
Sep	8785	100.00	0.00	0.00
Oct	9594	100.00	0.00	0.00
Nov	10051	100.00	0.00	0.00
Dec	10801	99.63	0.12	0.25
Average		**99.91**	**0.05**	**0.05**

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[22] Monthly percentages may not add up to 100% due to rounding.

North Hecate Strait – Buoy No. C46183				
		Response Favorable	**Response Marginal**	**Response Not Possible**
Month	**Total wave height observations**	**Percent >=0.0 m and <3.0 m**	**Percent >=3.0 m and <=4.6 m**	**Percent >4.6 m**
Jan	12093	83.57	11.93	4.50
Feb	11702	87.41	10.09	2.50
Mar	12646	88.78	8.47	2.75
Apr	11398	92.49	6.14	1.37
May	11470	97.04	2.87	0.10
Jun	10963	98.99	0.99	0.02
Jul	11499	99.46	0.45	0.09
Aug	11362	97.94	1.82	0.24
Sep	11089	96.47	2.74	0.78
Oct	11975	89.89	8.15	1.96
Nov	12393	85.95	11.04	3.01
Dec	12071	83.33	11.48	5.19
Average		**91.78**	**6.35**	**1.87**

South Hecate Strait – Buoy No. C46185				
		Response Favorable	**Response Marginal**	**Response Not Possible**
Month	**Total wave height observations**	**Percent >=0.0 m and <3.0 m**	**Percent >=3.0 m and <=4.6 m**	**Percent >4.6 m**
Jan	12440	69.68	19.92	10.40
Feb	11692	76.53	16.27	7.20
Mar	12883	78.03	15.82	6.15
Apr	10864	87.27	9.67	3.06
May	10826	95.34	4.03	0.64
Jun	11018	97.12	2.73	0.15
Jul	11282	99.02	0.86	0.12
Aug	10781	97.66	2.24	0.09
Sep	11162	94.67	4.22	1.11
Oct	11959	83.15	12.03	4.82
Nov	11447	71.15	20.27	8.58
Dec	12468	67.36	21.25	11.38
Average		**84.75**	**10.78**	**4.47**