# Appendix A: Limits to effectiveness of containment booms in the Project marine area. Georgia Strait Alliance, December 5, 2018

## I. Introduction

This section examines the operating limits of oil spill response by focusing on the most basic mechanical response unit, the containment boom. Using a hindcasting approach, we have plotted containment boom failure limits, derived from oil spill response literature, response organization files, and manufacturer reports, against wind speed and wave observations taken from Environment Canada and NOAA buoys, and surface current predictions from DFO and NOAA along the Project tanker route. We find that routine coastal conditions exceed the operating limits of the equipment now in WCMRC's inventory.

From the New Dungeness buoy seaward, booms operating limits in wind speed and wave are reached frequently. Response impossibility limits, defined below, are reached 6-9% of the time at the New Dungeness buoy, 30% to 40% of the time at Neah Bay, and 43-49% at La Perouse Bank. At Neah Bay and La Perouse Bank, these operating limits are breached for days or weeks at a time, indicating mechanical containment and recovery will not be an effective option. Surface currents along the tanker route also exceed boom operating limits, making keeping booms stable in the water an operating challenge. In the Boundary Pass/Haro Strait area, currents will form an operational constraint ranging from trivial to significant, while currents at Race Passage routinely exceed stability maximums for much of WCMRC's boom inventory. With WCMRC's highest rated booms for current being overwhelmed so regularly, containment or diversion in this area will be at best a significant operational challenge, and at worst impossible.

The equipment impairment and failures detailed below are not mere theory. High-profile containment boom failure has recently occured on the BC coast, during the sinking of *Nathan E Stewart*. On October 13, 2016, the *Nathan E Stewart* ran aground in Seaforth Channel near Bella Bella in Heiltsuk Nation Territory. The resulting response operation was hampered by wind, waves and currents in the area of the sinking, as well as being hampered by slow response times, poor operational decision making, and a lack of engagement with local knowledge. Containment booms rated up to 1.5 knots of current were deployed in waters where currents were “often higher[1]”. The result was ineffective booms and “very little containment.[2]” The end result was the release of 110,000 liters of diesel, lubricants, heavy oil and other pollutants into the area[3]. This real-world experience indicates that operational mitigation for equipment limits, while theoretically possible, has failed in coastal conditions[4].

**Wind, wave, and current effects on spill response**

Wind speed affects sea state, increases wave energy and moves oil on water, potentially leading to oil containment failures (referred to as boom containment failures). Wind can also limit the operational aspects of spill response. High speed winds increase the difficulty for vessels to stay within their booming area, for crew members to deploy and operate boom[5], and may tear booms off anchor points[6].

Waves impact spill response through wave height, steepness, and energy, potentially leading to boom containment failures. Steeper, wind-driven waves create more challenges for operational response than longer wavelength swells. Operational limits take several forms. Waves make it more difficult for crews to operate safely on deck, limiting boom deployment, operation and retrieval. Vessels will have more difficulty staying in their booming area. Waves also limit visual monitoring of spilled oil[7].

Currents impact boom containment of spilled oil through the increase of relative velocity of water passing by the boom. Strong currents potentially lead to boom containment failures via this mechanism. Current can move oil at critical velocity, defined as the orthogonal velocity which will breach the ability of the boom to contain it, first in small amounts and later in large amounts. Currents can be mitigated by shifting booming angles to lessen the relative velocity orthogonal to the boom, but even in steeper-angled diversionary modes there are failure points[8]. Currents are created by a number of forces acting on water, including tides, wind, the Coriolis effect, temperature and salinity differences. The strength and direction of currents are impacted by depth contours, shoreline configurations and interactions with other currents.

We did not examine other key weather-driven limitations such as staff mobilization time, ability to conduct aerial surveillance, operating limits for skimmers, the use of in situ burning, or application of chemical dispersants. Other weather limits exist, such as wind-against-tide

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[1] Heiltsuk Tribal Council, 2017 *INVESTIGATION REPORT: The 48 hours after the grounding of the Nathan E. Stewart and its oil spill*
[2] Ibid.
[3] Ibid.
[4] Heiltsuk Tribal Council, 2017, INDIGENOUS MARINE RESPONSE CENTRE (IMRC): Creating a World-Leading Response System
[5] Nuka Research and Planning, 2015, Technical Analysis of Oil Spill Response Capabilities and Limitations for Trans Mountain Expansion Project
[6] Nuka Research and Planning, 2007, Oil Spill Response Challenges in Arctic Waters
[7] Nuka 2015
[8] Fingas, Merv, 2004, Weather Windows for Oil Spill Countermeasures

scenarios, shifts in wind directions, rip currents, tidal fronts, and visibility. Although Nuka's[9] "response impaired" and "response impossible" limits incorporate wind and wave interactions, we do not examine the combination of these two forces with surface currents. All of these would significantly change the picture of weather driven limitations. As a result this analysis is likely to underestimate the frequency of operating limits being breached. Weather impairment and failure conditions not being met does not guarantee response will be successful, only that booms could be deployed without necessarily suffering impairment or failure due to the conditions we studied.

# II. Data sources

## Weather[10] condition sources

We used NOAA[11] and Fisheries and Oceans Canada data sets[12] for weather buoys along the Project-related tanker route between the Westridge Terminal and Buoy J (located in Neah Bay). The following buoys record wind speed and wave observations that would impact all outbound tanker traffic, and directly relate to spill containment, possible response, and failure along the Project tanker route. They are New Dungeness (46088[13]), Neah Bay (46087[14]), and La Perouse Bank (46206[15]). Halibut Bank (46146) was excluded as it rarely reaches boom operating limits.

[9] Nuka 2015
[10] By "weather" we refer primarily to wind speed, wave height and current speed.
[11] NOAA National Buoy Data Center
[12] Fisheries and Oceans Canada Wave Data
[13] New Dungeness Buoy
[14] Neah Bay Buoy
[15] La Perouse Bank Historic Data

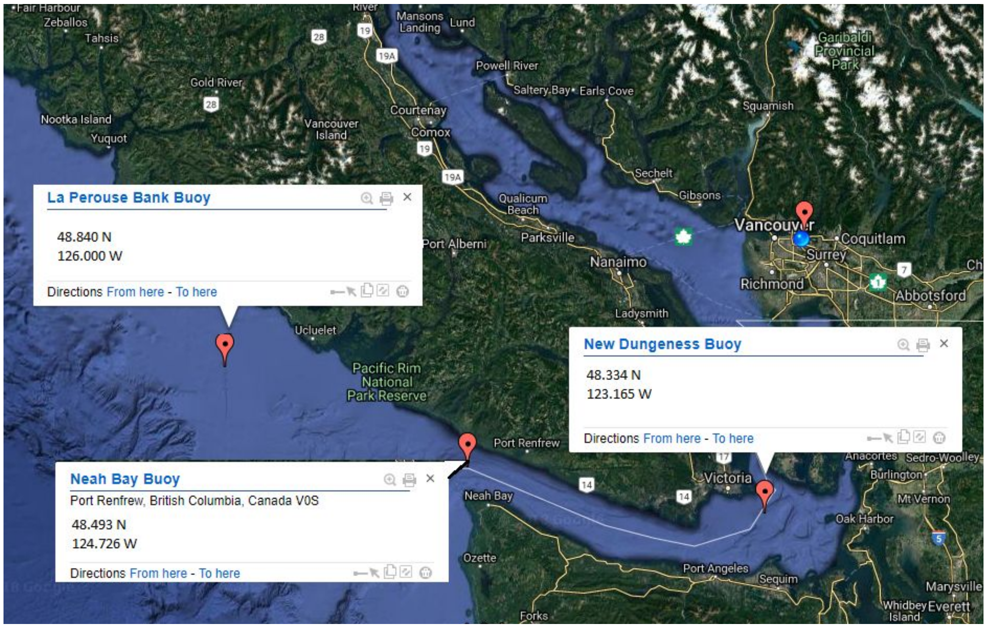


Figure 1: Map of Weather Buoy locations used

| Table 1: Wind and wave source locations | | |
|---|---|---|
| **Buoy Name** | **Latitude** | **Longitude** |
| New Dungeness | 48.334 N | 123.165 W |
| Neah Bay | 48.493 N | 124.726 W |
| La Perouse Bank | 48.840 N | 126.000 W |

Data from all buoys has been analysed for 2015, 2016 and 2017. Full charts are included in Appendix C. There are a limited number of buoys along the route, and gaps ranging from single missed observations to several months occur in the data sets. Current data was summarized from DFO current tables for 2017[16] at Race Passage, and NOAA current tables for 2015 for two locations along the Boundary Pass and Haro Strait route - two points near Skipjack Island[17], and a point west of Kellett Bluff[18].

[16] Race Passage (#1200) 2017 Current Table
[17] Skipjack Island, 2 miles NNE of, Skipjack Island, 1.5 miles northwest of
[18] Kellett Bluff, west of

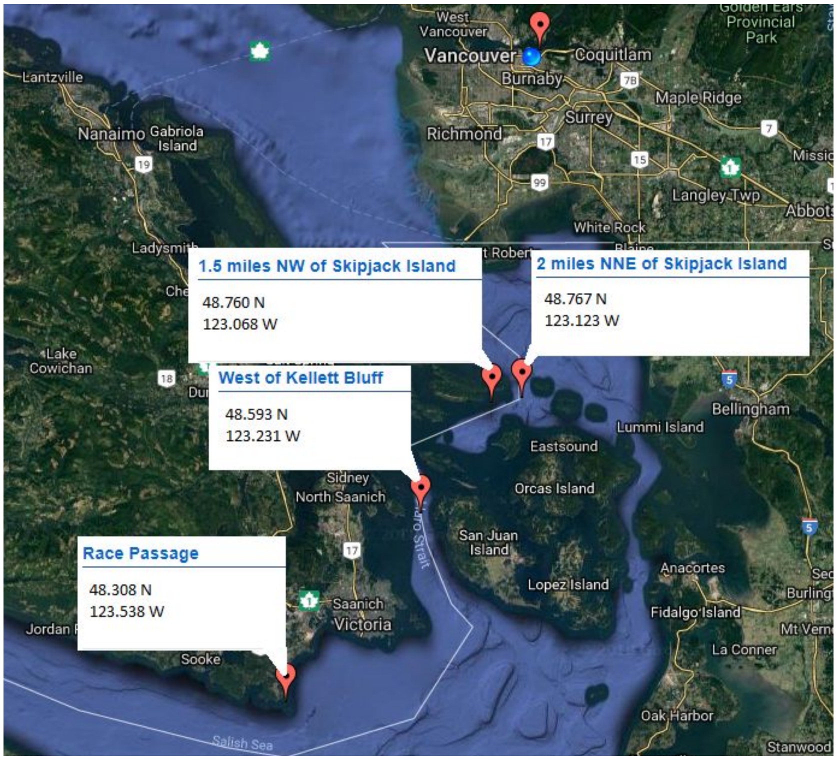


Figure 2: Map of Current Station Locations Used

| Table 2: Current prediction source locations | | |
|---|---|---|
| **Location Name** | **Latitude** | **Longitude** |
| Race Passage | 48.308 N | 123.538 W |
| Kellett Bluff, west of | 48.593 N | 123.231 W |
| Skipjack Island, 2 miles NNE of | 48.767 N | 123.0 W |
| Skipjack Island, 1.5 miles northwest of | 48.760 N | 123.068 W |

## Boom impairment and failure

Oil spill recovery is primarily achieved through mechanical means. Containing or collecting spilled oil requires specialized equipment, and the most fundamental mechanical unit for this effort is the containment boom. The purposes of containment boom include: to enclose oil to prevent spread, to protect areas of specific concern, to divert oil to areas it can be treated or recovered, and to concentrate oil at a relatively even thickness for skimmers or other response techniques[19]. The limits for recovery depend on containment booms, and the limits of containment booms are therefore the most fundamental limits to mechanical recovery. This section examines the limits of boom effectiveness in the context of waves, wind and current.

Boom impairment and failure from weather conditions takes a number of forms. Schulze (2001) describes two stages of boom failure, first loss and gross loss, and several ways that a boom might achieve either failure state.

## Terminology

*First Loss* is when droplets of oil shed continuously from the boom. Minor, non-continuous losses are not considered to be first losses.

*Gross Loss* is the current speed at which massive continual oil loss is observed escaping past the boom.

*Entrainment* occurs when oil escapes under the boom by entraining in the water as it flows under the boom.

*Drainage* occurs when oil is trapped against the boom skirt, and as water accelerates down and around the skirt or as the oil fills beyond the depth of the skirt, it escapes the boom.

*Splashover* occurs when drops or waves of oil splashes over the boom, or where in choppy seas bridging occurs and the boom is lifted between two waves crests so the trough is not boomed.

*Submergence* is when the boom is submerged due to inappropriate buoyancy and the boom sinks so oil passes over it.

*Planing* occurs when the boom rotates and flattens against the surface of the water, allowing oil to flow over and under the boom.

*Structural* failure is when the boom breaks or the components disassemble. Factors leading to breakage include, but are not limited to, relative velocity against boom and the area of boom exposed. Losses due to vortices bringing oil droplets down into the water and mixing significantly upstream from the boom are not tested for or documented due to the limitations of testing[20].

**Impairment and failure in specific weather conditions**

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[19] Fingas, Merv, 2013, *The Basics of Oil Spill Clean Up*
[20] Schulze, Robert, 2001,OIL SPILL RESPONSE PERFORMANCE REVIEW OF BOOMS

To select wind speed and wave height data, we focused on conditions classified by ASTM as open water to focus on the spill response capabilities along the tanker route, not in a protected harbour. Table 3 shows the ASTM the standards for water body classification. Table 4 shows boom properties for the ASTM water body classifications.

| Table 3: ASTM Water Body Classifications[21] | | |
|---|---|---|
| **Type** | **Wave Height in meters** | **Examples of General Conditions** |
| Calm Water | 0-0.3 | small, short, non-breaking waves |
| Protected Water | 0-1 | small waves, some whitecaps |
| Open Water | 0-2 | moderate waves, frequent whitecaps |
| Open Water (Rough) | >2 | large waves, foam crests, and some spray |

*The ASTM notes that ratio of wave height to wavelength should be considered, as should orientation of waves to current direction.*

| Table 4: ASTM Recommendations for Selection of Spill Containment Booms (adapted)[22] | | | | |
|---|---|---|---|---|
| **Boom Property** | **Calm Water** | **Calm Water - Current** | **Protected Water** | **Open Water** |
| Height Range, m | .15 to .6 m | .2 to .6 m | .45 to 1.1 m | .9 to 2.3 m+ |
| Minimum Gross Buoyancy to Weight Ratio | 3:1 | 4:1 | 4:1 | 8:1 |
| Minimum Total Tensile Strength, N | 6800 | 23000 | 23000 | 45000 |
| Minimum Fabric Tensile Strength, N/50 mm, 1 tension member | 2600 | 2600 | 2600 | 3500 |
| Minimum Fabric Tensile Strength, N/50 mm, 2 tension members | 2600 | 2600 | 3500 | 3500 |

[21] ASTM, 2006, Standard Practice for Classifying Water Bodies for Spill Control Systems
[22] ASTM, 2017, Standard Guide for Selection of Booms for Oil-Spill Response

| | | | | |
|---|---|---|---|---|
| Minimum Fabric Tear Strength | 450 | 450 | 450 | 450 |

We looked at several aspects of weather conditions contributing to boom performance impairment and failure. Primarily we focused on the measurable wind, current and wave conditions that have been observed, tested, or calculated to create boom failure. While many of the failure numbers are derived from observations, finding reported limits from specific manufacturers is difficult, testing is primarily done in tanks, and there are few sources for observed real-world limits in actual response conditions. More rigorous testing and reporting is needed.

A “75% performance impairment” is a set of wind speed and wave height conditions sourced from Fingas, 2004, *Weather windows for oil spill countermeasures*[23]. Fingas bases his “typical boom” performance deterioration on a variety of tests of boom, noting that performance varies widely over specific units. The wind limit in Tedeschi[24] is a theoretical limit derived from wind moving oil faster than a boom’s ability to contain it. We used the upper end of his 15-18 knot (7.7-9.26 m/s) range as the cut off point. Wind and wave response impairment and response impossibility limits, and their interactions, are sourced from Nuka Research and Planning’s *Technical Analysis of Oil Spill Response Capabilities and Limitations for Trans Mountain Expansion Project*[25]. These limits are based on oil spill response tactical manuals, regulatory standards, oil spill contingency plans, and past analyses of oil spill response. We have used their response impaired and response impossible conditions for open water. Failure rates in the charts are compared against total observations.

Table 5 provides a summary of impairment and failure conditions used in the GSA analysis.

| Table 5: Summary of Impairment and Failure conditions for booms used in GSA Analysis | | | |
|---|---|---|---|
| **Type of Boom Failure (single conditions)** | **Wave Height** | **Steepness Condition** | **Wind Speed** |
| Nuka Conditions for Reponse Impaired | 0.9 m | when steepness >=0.0025 | 10 m/s |
| | 1.2 m | when steepness <0.0025 | |
| Nuka Conditions for Response Impossible* | 1.8 m | when steepness >=0.0025 | 15 m/s |
| | 2.4 m | when steepness <0.0025 | |

[23] Fingas, Merv, 2004, Weather windows for oil spill countermeasures
[24] Tedeschi, Edward, 1999, Booms
[25] Nuka 2015 *Technical Analysis of Oil Spill Response Capabilities and Limitations for Trans Mountain Expansion Project*

| | | | |
|---|---|---|---|
| Fingas' Conditions for 75% Decrease in Performance[26] | 2 m | N/A | 4 m/s |
| Tedeschi Boom Failure from Wind | N/A | N/A | 9.26 m/s |

**Nuka response impossible conditions can also be met by both wind and wave response impaired conditions occurring during an observation*

Failure for currents include the highest "first loss" observations for both catenary and diversionary boom formations in Schulze (2001), gross loss in Swift (as cited in Fingas 2004), and manufacturer or response organization reported limits for Kepner boom[27], Ro-Boom 2000[28], and Current Buster 4[29] boom. The Schulze and Swift first and gross failure values are high points of a series of tests involving different boom types and manufacturers. Many boom failures begin at much lower currents, and as such these failure points are quite conservative. These are also generic limits for current, which does not deal with issues of specific oil viscosities. In the context of the Trans Mountain expansion, we note that diluted bitumen, as with any heavier oil, increased current speed and oil density generally result in less effective containment[30].

**Table 6. Current Failure Conditions**

| **Type of failure** | **Current in knots** |
|---|---|
| Highest catenary "first failure" in Schulze | 1.36 knots |
| Highest diversionary "first failure" in Schulze | 1.7 knots |
| Gross Failure in Swift | 2 knots |
| Kepner boom maximum operating current | 1.5 knots |
| RoBoom 2000 current stability maximum | 3 knots |
| Current Buster maximum current | 4 knots |

# III. Results of GSA Analysis

## Boom Impairment and Failure Rates for Wind and Wave

The results presented have been achieved by comparing weather buoy data to the impairment condition estimates from Fingas 2004[31], Tedeschi 1999[32] and Nuka Research 2015[33]. A simple python script was used to make this comparison (see appendix B for full script).

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[26] Defined in the original as where "performance is decreased to 25%"
[27] ECRC-SIMEC, 2013, Kepner Boom
[28] Desmi, accessed Nov 2018, webpage for Ro-Boom
[29] NOFI, accessed Nov 2018, webpage for Current Buster 4
[30] POLARIS, 2013, A Comparison of the Properties of Diluted Bitumen Crudes with other Oils
[31] Fingas, 2004
[32] Tedeschi, Edward, 1999, Booms
[33] Nuka 2015

Each weather point was compared to a failure condition, and the results of that comparison have been compiled in a colour bar in the figures shown below.

The figures presented consist of multiple parts. The first bar represents weather data availability. Weather data sets were not perfectly complete. A vertical blue line represents an available data point over a temporal interval. Interval periods are derived from time stamps in the source data. Intervals are either 30 or 60 minute periods, as indicated on each chart. The horizontal axis is normalized for time, not data availability.

The second horizontal bar represents conditions when wave height would cause boom impairment, taken from Fingas 2004. The presence of an orange vertical line indicates that data is available, and that a deployed boom would suffer 75% performance impairment due to wave height.

The third horizontal bar represents wind speed impairment, taken from Fingas 2004. The presence of a green vertical line indicates that data is available, and that a deployed boom would suffer 75% performance impairment due to wind.

The fourth horizontal bar represents wind speed failure, taken from Tedeschi 1999. The presence of a red vertical line indicates that data is available, and that oil would move faster than a deployed boom's ability to contain it.

The fifth horizontal bar represents response conditions taken from Nuka 2015. The presence of an orange vertical line indicates that data is available and that oil spill response would be impaired. The presence of a red vertical line indicates that data is available, and that a oil spill response would be impossible.

The percentage numbers above each bar represent the percentage of weather data that was collected that would result in a boom impairment or failure were it deployed at that time.

## New Dungeness Buoy

The New Dungeness buoy is located at the eastern end of the Strait of Juan de Fuca. As this buoy is located in an area shielded from open ocean weather by land masses, conditions contributing to response impairment and failure here are more limited than buoys located more seaward.

**New Dungeness Buoy -- 2017**

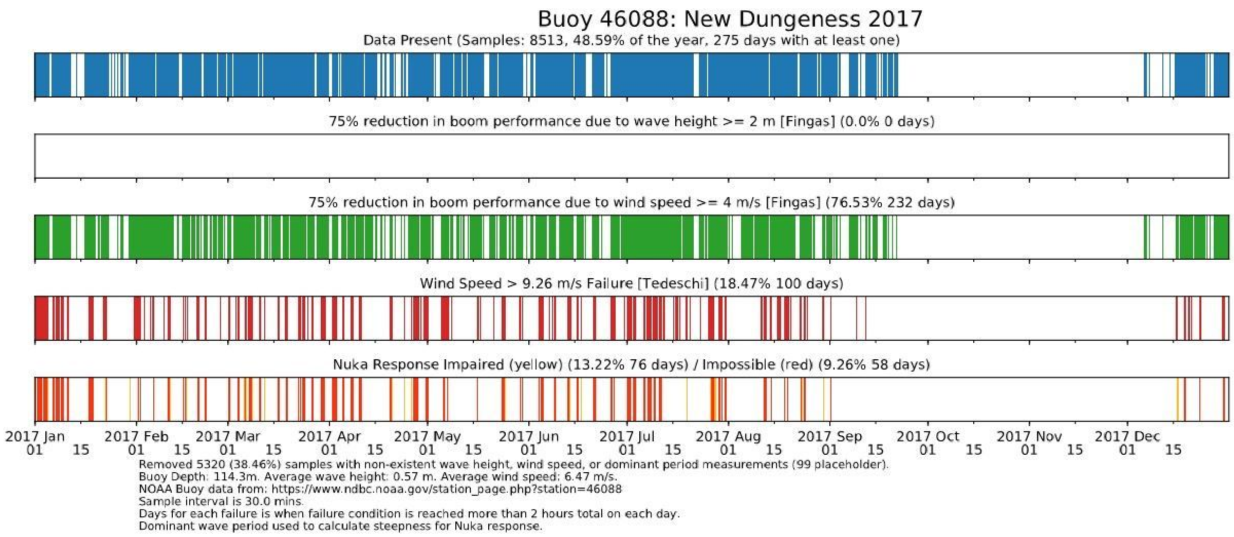


Figure 3: New Dungeness 2017 weather analysis

In figure 3, the first row shows the time periods for which data is present for New Dungeness 2017. The second row shows that for New Dungeness 2017 there were no periods of time in which the buoy data for wave height exceeds boom impairment condition. The third row shows green bands for the time periods when reported wind speed exceeded the Fingas boom impairment condition of >= 4 m/s for 75% reduction in boom performance, covering 76.53% of the data set. The fourth row shows red bands for the time periods when the reported wind speed exceeds the Tedeschi boom impairment condition of >9.26m/s, covering 18.47% of the data set. The fifth row shows orange bands for time periods when reported conditions would impair the an oil spill response, and red bands for when conditions would render a response impossible, 13.22% and 9.26% of the data set respectively.

**New Dungeness Buoy -- 2016**

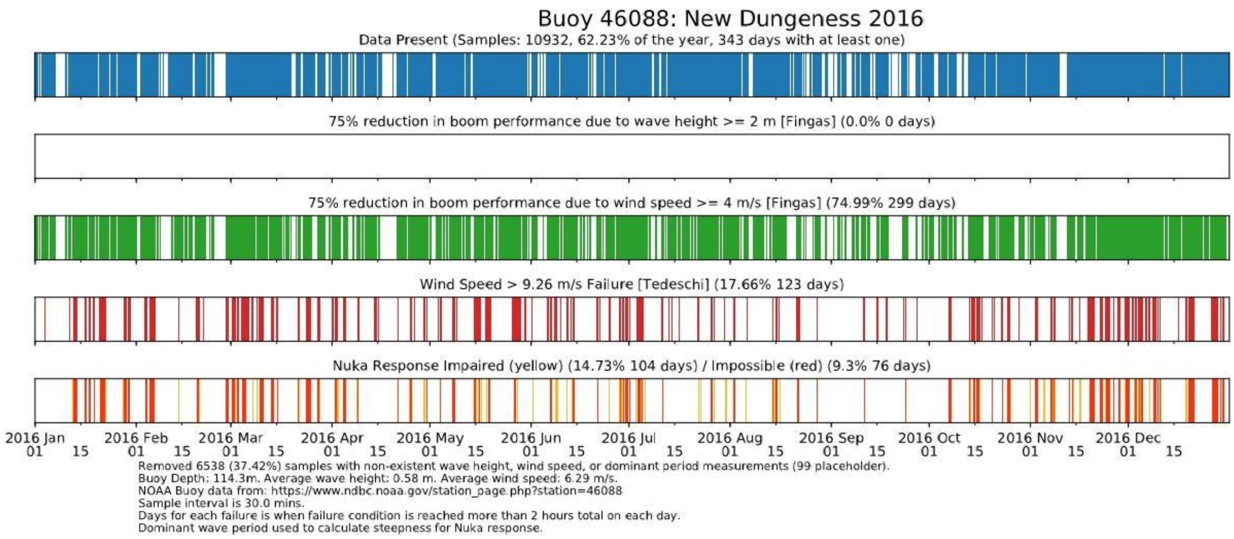


Figure 4: New Dungeness 2016 weather analysis

In figure 4, the first row shows the time periods for which data is present for New Dungeness 2016. The second row shows that for New Dungeness 2016 there were no periods of time in which the buoy data for wave height exceeds boom impairment condition. The third row shows green bands for the time periods when reported wind speed exceeded the Fingas boom impairment condition of >= 4 m/s for 75% reduction in boom performance, covering 74.99% of the data set. The fourth row shows red bands for the time periods when the reported wind speed exceeds the Tedeschi boom impairment condition of >9.26m/s, covering 17.66% of the data set. The fifth row shows orange bands for time periods when reported conditions would impair the an oil spill response, and red bands for when conditions would render a response impossible, 14.73% and 9.3% of the data set respectively.

**New Dungeness Buoy -- 2015**

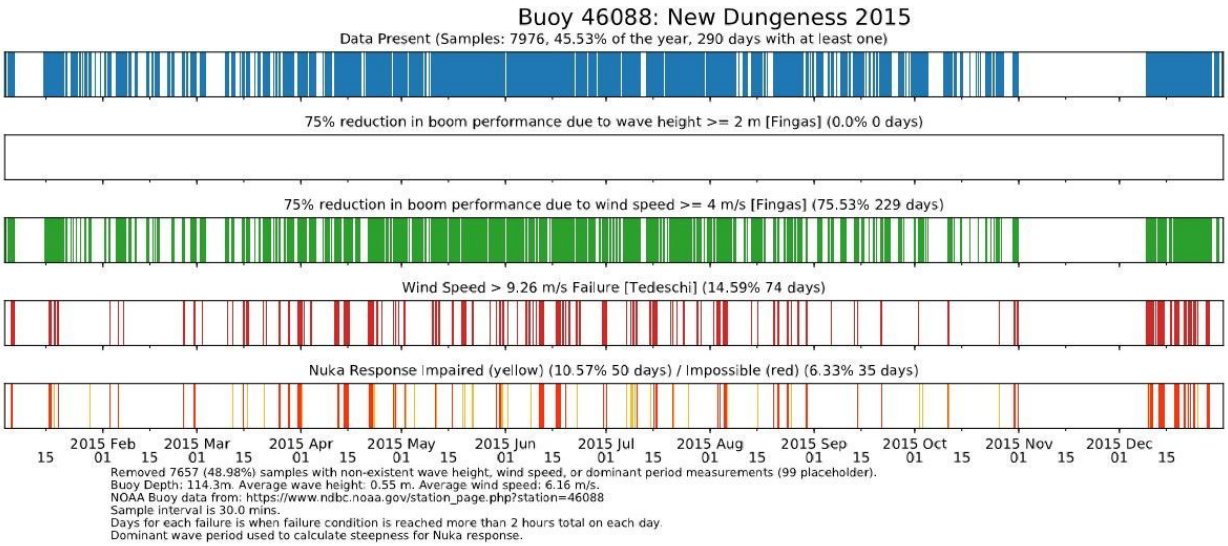


Figure 5: New Dungeness 2015 weather analysis

In figure 5, the first row shows the time periods for which data is present for New Dungeness 2015. The second row shows that for New Dungeness 2015 there were no periods of time in which the buoy data for wave height exceeds boom impairment condition. The third row shows green bands for the time periods when reported wind speed exceeded the Fingas boom impairment condition of >= 4 m/s for 75% reduction in boom performance, covering 75.53% of the data set. The fourth row shows red bands for the time periods when the reported wind speed exceeds the Tedeschi boom impairment condition of >9.26m/s, covering 14.59% of the data set. The fifth row shows orange bands for time periods when reported conditions would impair the an oil spill response, and red bands for when conditions would render a response impossible, 10.57% and 6.33% of the data set respectively.

**New Dungeness Buoy -- Observations**

For the New Dungeness Buoy, response impairments and failures are primarily driven by wind conditions. Fingas wind impairment of boom performance is ~75% in all years, while wave impairment is at 0%. Tedeschi's wind failure is reached in ~15-18% in this sample. Nuka's response impairment conditions range from 10.57-14.73%, and impossibility conditions are reached in a range of ~6-9%. There are few sustained periods of response impossibility, though wind could hamper response efforts.

## Neah Bay Buoy

Failure conditions are regularly met in Neah Bay, located at the mouth of the Strait of Juan de Fuca.

**Neah Bay Buoy -- 2017**

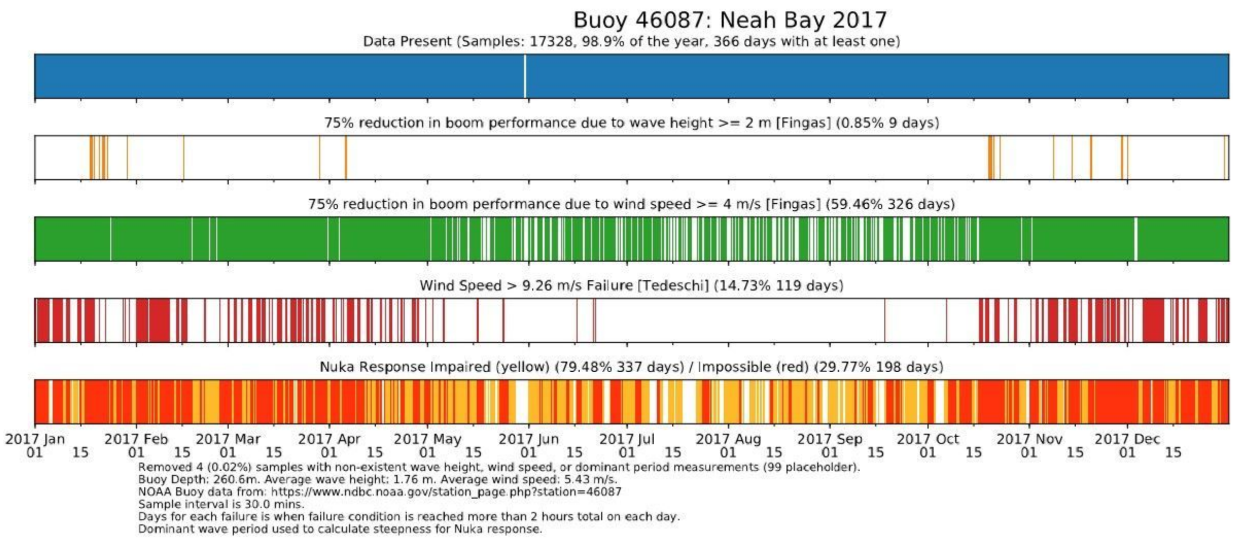


Figure 6: Neah Bay 2017 weather analysis

In figure 6, first row shows the time periods for which data is present for Neah Bay 2017. The second row shows that for Neah Bay 2017 the period of time in which the buoy data for wave height exceeds boom impairment condition of wave height >= 2m is 0.85%. The third row shows green bands for the time periods when reported wind speed exceeded the Fingas boom impairment condition of >= 4 m/s for 75% reduction in boom performance, covering 59.46% of the data set. The fourth row shows red bands for the time periods when the reported wind speed exceeds the Tedeschi boom impairment condition of >9.26m/s, covering 14.73% of the data set. The fifth row shows orange bands for time periods when reported conditions would impair the an oil spill response, and red bands for when conditions would render a response impossible, 79.48% and 29.77% of the data set respectively.

**Neah Bay Buoy -- 2016**

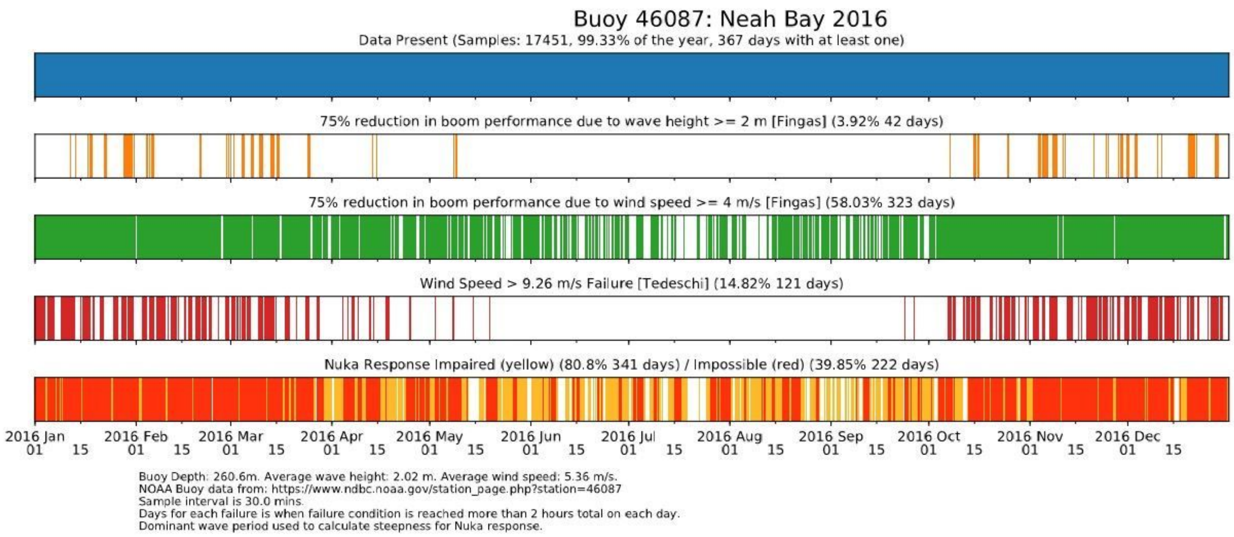


Figure 7: Neah Bay 2016 weather analysis

In figure 7, the first row shows the time periods for which data is present for Neah Bay 2016. The second row shows that for Neah Bay 2016 the period of time in which the buoy data for wave height exceeds boom impairment condition of wave height >= 2m is 3.92%. The third row shows green bands for the time periods when reported wind speed exceeded the Fingas boom impairment condition of >= 4 m/s for 75% reduction in boom performance, covering 58.03% of the data set.  The fourth row shows red bands for the time periods when the reported wind speed exceeds the Tedeschi boom impairment condition of >9.26m/s, covering 14.82% of the data set.  The fifth row shows orange bands for time periods when reported conditions would impair the an oil spill response, and red bands for when conditions would render a response impossible, 80.8% and 39.85% of the data set respectively.

**Neah Bay Buoy -- 2015**

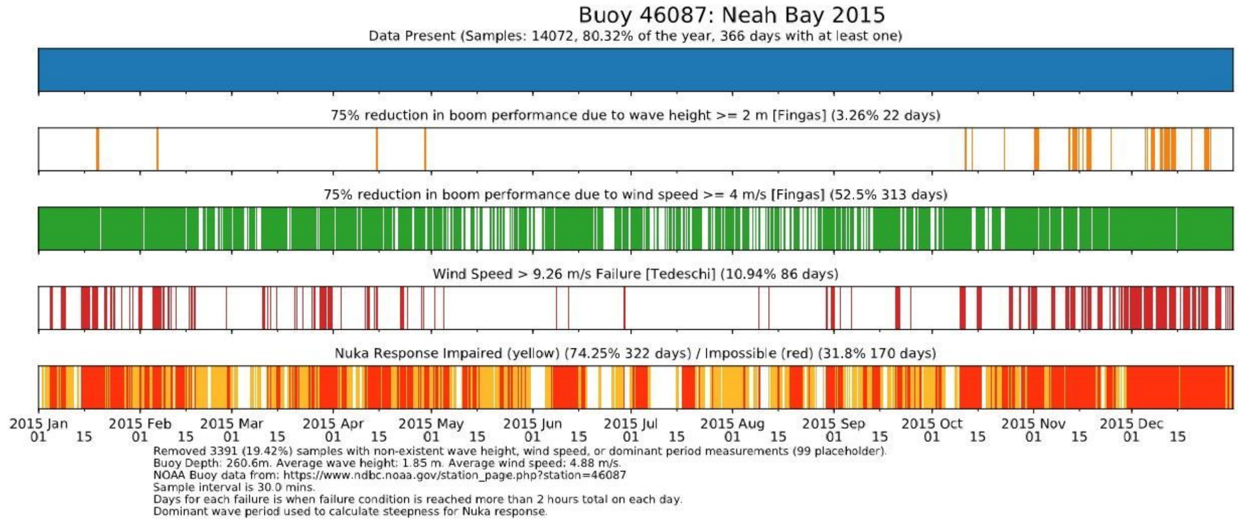


Figure 8: Neah Bay 2015 weather analysis

In figure 8, the first row shows the time periods for which data is present for Neah Bay 2015. The second row shows that for Neah Bay 2015 the period of time in which the buoy data for wave height exceeds boom impairment condition of wave height >= 2m is 3.26%. The third row shows green bands for the time periods when reported wind speed exceeded the Fingas boom impairment condition of >= 4 m/s for 75% reduction in boom performance, covering 52.5% of the data set.  The fourth row shows red bands for the time periods when the reported wind speed exceeds the Tedeschi boom impairment condition of >9.26m/s, covering 10.94% of the data set.  The fifth row shows orange bands for time periods when reported conditions would impair the an oil spill response, and red bands for when conditions would render a response impossible, 74.25% and 31.8% of the data set respectively.

**Neah Bay Buoy -- Observations**

For the Neah Bay Buoy, Fingas wave impairment conditions are minimal, ranging from .85% to 3.92%. Fingas wind impairment conditions are found over 50% of observations in all three years. Wind conditions pass the limits in Tedeschi in 14.73% of 2017 observations, 14.83% of 2016 observations, and 10.94% of 2015 observations. Nuka's interacting wind and wave analysis saw impairment over 75% every year from 2015-17, with impossible conditions ranging from 29.77% to 39.85%. Many of the failure conditions are sustained for days and weeks, indicating that mechanical recovery will not be an effective option in the event of a spill during these conditions.

## La Perouse Bank Buoy

La Perouse Bank is located off the west coast of Vancouver Island, south region. Here impairment and failures condition are met regularly.

**La Perouse Bank Buoy -- 2017**

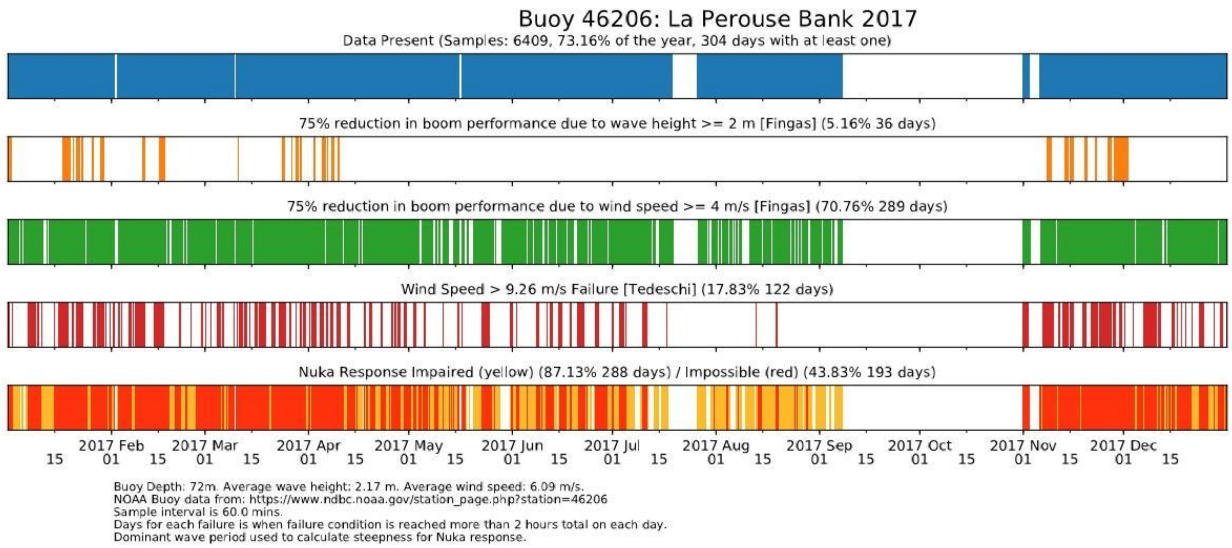


Figure 9: La Perouse Bank 2017 weather analysis

In figure 9, the first row shows the time periods for which data is present for La Perouse Bank 2017, showing significant gaps in the observations. The second row shows that for La Perouse Bank 2017 the period of time in which the buoy data for wave height exceeds boom impairment condition of wave height >= 2m is 5.16%. The third row shows green bands for the time periods when reported wind speed exceeded the Fingas boom impairment condition of >= 4 m/s for 75% reduction in boom performance, covering 70.76% of the data set. The fourth row shows red bands for the time periods when the reported wind speed exceeds the Tedeschi boom impairment condition of >9.26m/s, covering 17.83% of the data set. The fifth row shows orange bands for time periods when reported conditions would impair the an oil spill response, and red bands for when conditions would render a response impossible, 87.13% and 43.83% of the data set respectively.

**La Perouse Bank Buoy -- 2016**

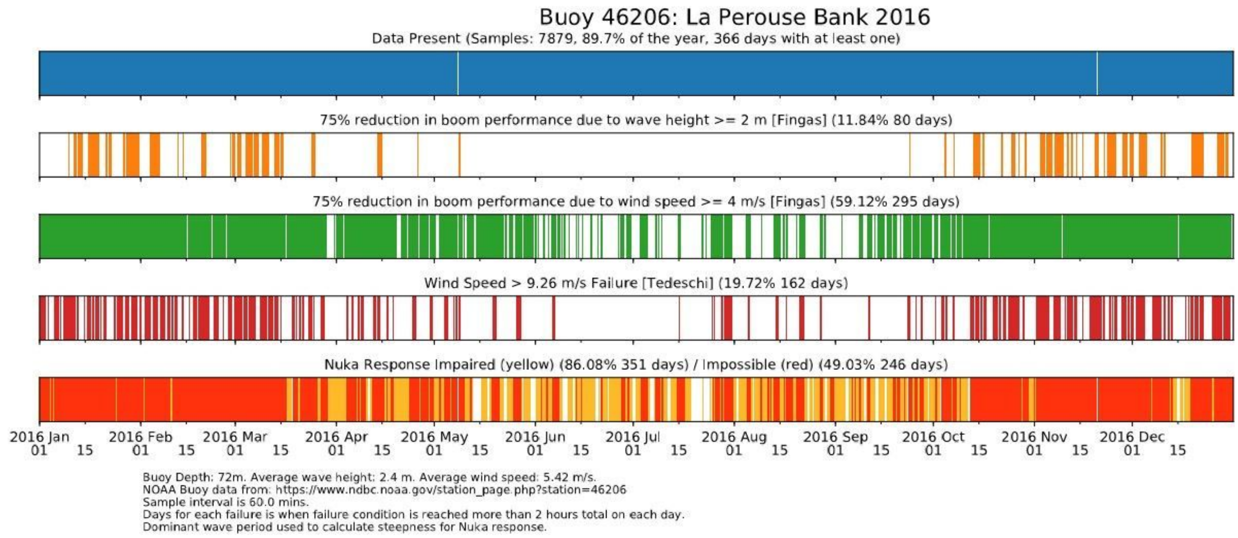


Figure 10: La Perouse Bank 2016 weather analysis

In figure 10, the first row shows the time periods for which data is present for La Perouse Bank 2016. The second row shows that for La Perouse Bank 2016 the period of time in which the buoy data for wave height exceeds boom impairment condition of wave height >= 2m is 11.84%. The third row shows green bands for the time periods when reported wind speed exceeded the Fingas boom impairment condition of >= 4 m/s for 75% reduction in boom performance, covering 59.12% of the data set. The fourth row shows red bands for the time periods when the reported wind speed exceeds the Tedeschi boom impairment condition of >9.26m/s, covering 19.72% of the data set. The fifth row shows orange bands for time periods when reported conditions would impair the an oil spill response, and red bands for when conditions would render a response impossible, 86.08% and 49.03% of the data set respectively.

**La Perouse Bank Buoy -- 2015**

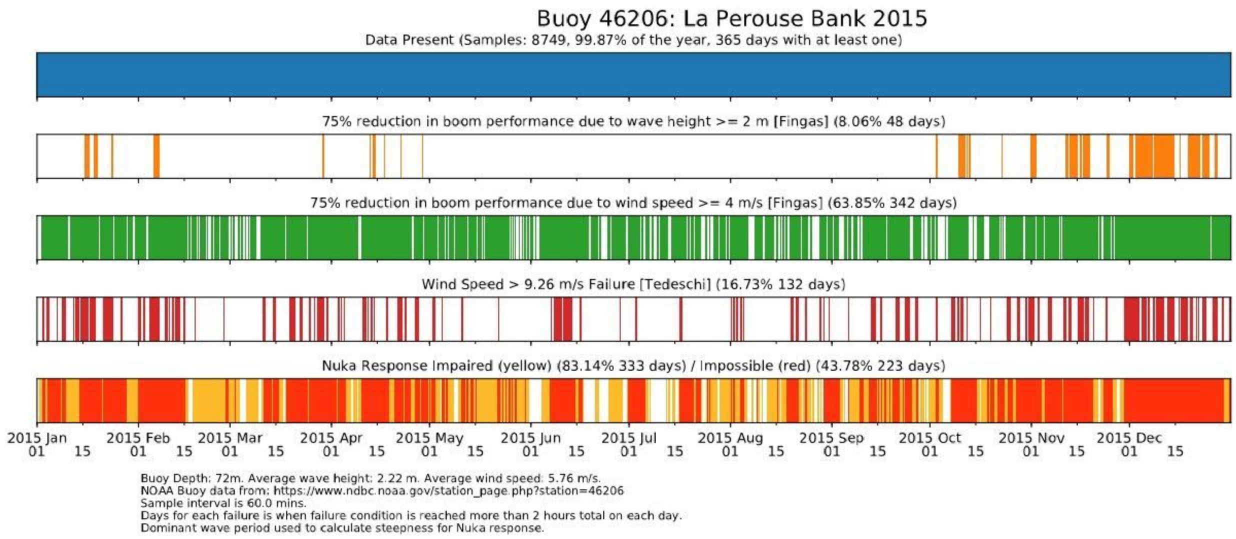


Figure 11: La Perouse Bank 2015 weather analysis

In figure 11, the first row shows the time periods for which data is present for La Perouse Bank 2015. The second row shows that for La Perouse Bank 2015 the period of time in which the buoy data for wave height exceeds boom impairment condition of wave height >= 2m is 8.06%. The third row shows green bands for the time periods when reported wind speed exceeded the Fingas boom impairment condition of >= 4 m/s for 75% reduction in boom performance, covering 63.85% of the data set. The fourth row shows red bands for the time periods when the reported wind speed exceeds the Tedeschi boom impairment condition of >9.26m/s, covering 16.73% of the data set. The fifth row shows orange bands for time periods when reported conditions would impair the an oil spill response, and red bands for when conditions would render a response impossible, 83.14% and 43.78% of the data set respectively.

**La Perouse Bank Buoy -- Observations**

For La Perouse Bank Buoy, wave impairment per Fingas range from 5-11%, and wind impairments conditions from 59-70% of observations over the three year sample. Tedeschi’s wind failure ranges from ~16-20%. Nuka’s impairment conditions are all over 83%, and impossibility conditions range from 43-49%. Many of the impairment and failure conditions are met for weeks at a time, indicating that mechanical recovery will not be an effective option in the event of a spill during these conditions.

## Current failures

The following charts are based on current predictions for selected points along the Project tanker route. Race Passage taken from DFO current predictions from 2017, and Boundary Pass and Haro Strait locations taken from NOAA current predictions for 2015. Current predictions were compared to failure conditions derived from Schulze, Swift, and manufacturer or response organization reported limits for Kepner boom, Ro-Boom 2000, and Current Buster 4. A simple python script was used to make this comparison (see Appendix B for full script).

Each figure is composed of several horizontal bars. The first bar represents data presence. A vertical blue line represents an available data point over a temporal interval. As these are predictions, data presence is complete. Intervals, indicated on each chart, are 30 minutes. The horizontal axis is normalized for time, as in the previous figures.

The second bar represents periods where current speed would meet or exceed the highest “first failure” for catenary boom deployment, as detailed in Schulze 2001. The presence of an orange vertical line indicates that in catenary deployment the boom would begin to lose oil.

The third bar represents periods where the current speed would meet or exceed the maximum operating current for Kepner boom, as found in ECRC-SIMEC files. The presence of a green vertical line indicates that Kepner boom would no longer be an effective mechanical barrier to oil.

The fourth bar represents periods where current speed would meet or exceed the highest “first failure” for diversionary boom deployment, as detailed in Schulze 2001. The presence of a red vertical line indicates that in diversionary deployment the boom would begin to lose oil.

The fifth bar represents periods where current speed would meet or exceed “gross failure”, as derived from Swift and detailed in Fingas 2004. The presence of a purple vertical line indicates that massive, continual loss of oil would escape past a deployed boom.

The sixth bar represents periods where current speed would meet or exceed Ro-Boom 2000’s maximum operating current, taken from the manufacturer. The presence of a brown vertical line indicates that the boom’s stability in the water would be compromised.

The seventh bar represents periods where current speed would meet or exceed the ability of Current Buster 4 to retain oil, taken from the manufacturer. The presence of a pink vertical indicates that Current Buster 4 would begin losing significant amounts of oil.

The percentage numbers above each bar represent the percentage of current predictions that would result in a boom impairment or failure were it deployed at that time.

## North-northeast of Skipjack Island

North-northeast of Skipjack Island, currents present a significant operational constraints for both mobile and stationary booming strategies.

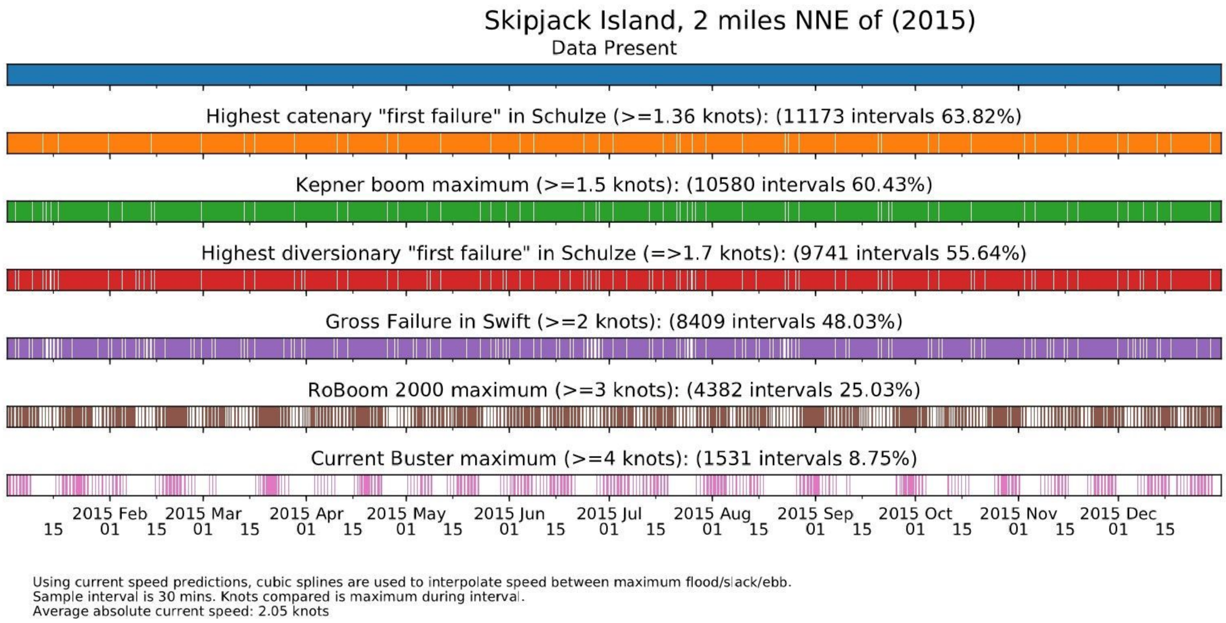


Figure 12: Skipjack Island - 2 miles NNE 2015 current analysis

In figure 12, the first row shows the time periods for which data is present for Skipjack Island, 2 miles NNE, in 2015. The second row shows that for this location the period of time in which the prediction data exceeds the highest “first failure” for catenary boom deployment, as detailed in Schulze 2001 is 63.82% of the data. The third bar shows that periods where the current speed would meet or exceed the maximum operating current for Kepner boom are 60.43% of the data. The fourth bar shows that the periods where current speed would meet or exceed the highest “first failure” for diversionary boom deployment, as detailed in Schulze 2001, is 55.64% of the data. The fifth bar shows that the periods where current speed would meet or exceed “gross failure”, as derived from Swift and detailed in Fingas 2004, are 48.03% of the data. The sixth bar shows that the periods where current speed would meet or exceed Ro-Boom 2000’s maximum operating current, taken from the manufacturer is 25.03% of the data. The seventh bar shows that the periods where current speed would meet or exceed the ability of Current Buster 4 to retain oil, taken from the manufacturer is 8.75% of the data.

## Northwest of Skipjack Island

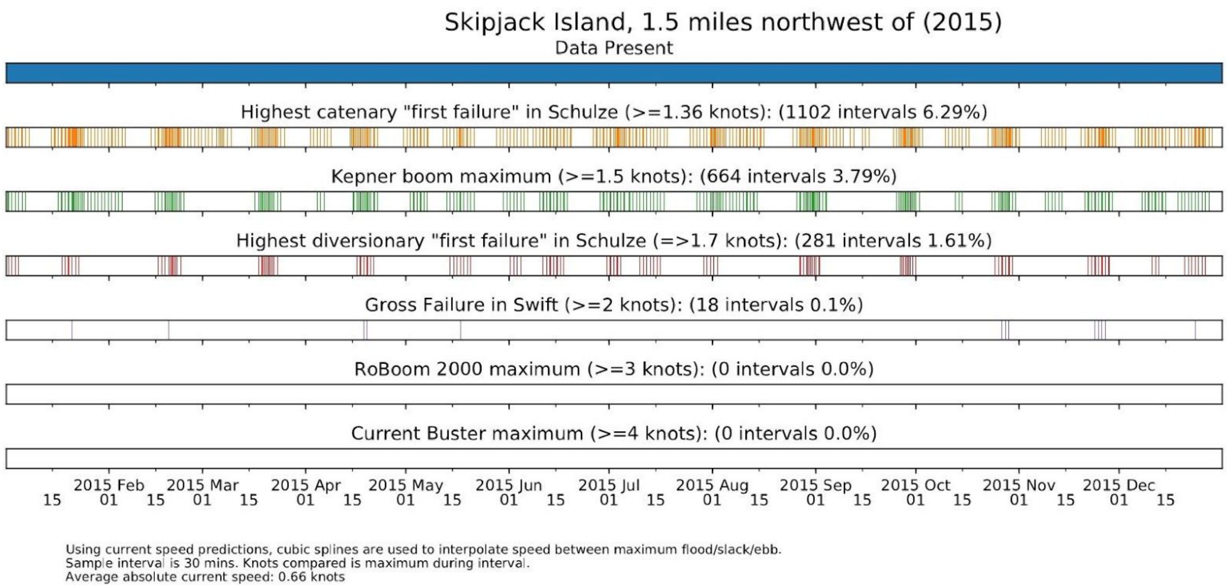


Figure 13: Skipjack Island - 1.5 miles NW 2015 current analysis

In figure 13, the first row shows the time periods for which data is present for Skipjack Island, 1.5 miles NW, in 2015. The second row shows that for this location the period of time in which the prediction data exceeds the highest “first failure” for catenary boom deployment, as detailed in Shulze 2001 is 6.29% of the data. The third bar shows that periods where the current speed would meet or exceed the maximum operating current for Kepner boom are 3.79% of the data. The fourth bar shows that the periods where current speed would meet or exceed the highest “first failure” for diversionary boom deployment, as detailed in Schulze 2001, is 1.61% of the data. The fifth bar shows that the periods where current speed would meet or exceed “gross failure”, as derived from Swift and detailed in Fingas 2004, are 0.1% of the data. The sixth bar shows that the periods where current speed would meet or exceed Ro-Boom 2000’s maximum operating current, taken from the manufacturer is 0% of the data. The seventh bar shows that the periods where current speed would meet or exceed the ability of Current Buster 4 to retain oil, taken from the manufacturer is 0% of the data.

### Skipjack Island observations

Catenary first failures are at 64% of intervals, and diversionary first failures at 56% of intervals. Kepner boom operating limits are reached in 60% of intervals, and gross failures at 48%. Many of these failures occur for significant periods of time, beyond full ebb and flood maxima.

Ro-Boom maximum is hit in 25% of intervals. Current Buster 4 would face less severe constraints. North west of Skipjack Island constraints are minimal. Maxima are rarely reached, and little operational adjustments for current will need to be made. At a distance of ~3.8 km, these two locations indicate how localized current flows, and current maxima, can be.

## Kellett Bluff

Kellett Bluff presents a medium current flow.

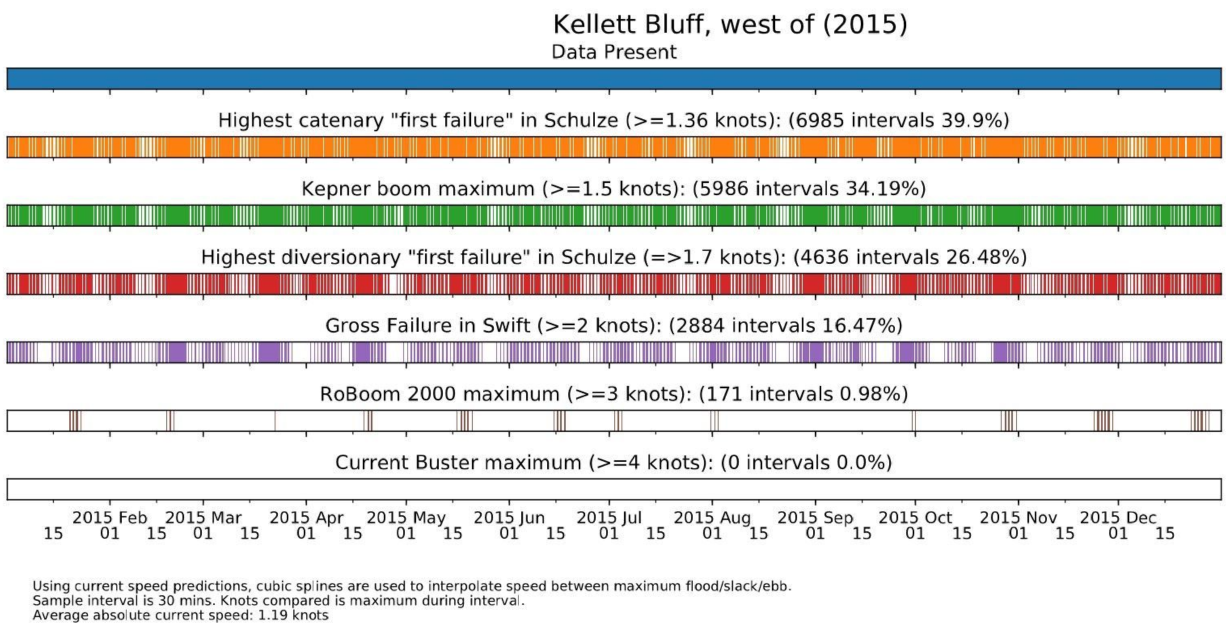


Figure 14: Kellet Bluff, west of 2015 current analysis

In figure 14, the first row shows the time periods for which data is present for Kellett Bluff, W (2015). The second row shows that for this location the period of time in which the prediction data exceeds the highest “first failure” for catenary boom deployment, as detailed in Schulze 2001 is 39.9% of the data. The third bar shows that periods where the current speed would meet or exceed the maximum operating current for Kepner boom, as found in ECRC-SIMEC files are 34.19% of the data. The fourth bar shows that the periods where current speed would meet or exceed the highest “first failure” for diversionary boom deployment, as detailed in Schulze 2001, is 26.48% of the data. The fifth bar shows that the periods where current speed would meet or exceed “gross failure”, as derived from Swift and detailed in Fingas 2004, are 16.47% of the data. The sixth bar shows that the periods where current speed would meet or exceed Ro-Boom 2000’s maximum operating current, taken from the manufacturer is 0.98% of the data. The seventh bar shows that the periods where current speed would meet or exceed the ability of Current Buster 4 to retain oil, taken from the manufacturer is 0% of the data.

**Kellett Bluff observations**

Catenary first failures occur in 40% of intervals. Kepener boom limits are present in 34% of intervals. Diversionary first failure limits are reached in 26% of intervals. Gross failures are at 16%. Ro-Boom reaches its limit in only 1% of cases, and Current Buster 4 not at all. Operational constraints for stationary booming strategies will be real, and may minimize their use, though mobile booming strategies could compensate for currents.

## Race Passage

Race Passage presents extreme operational constraints for containment booms.

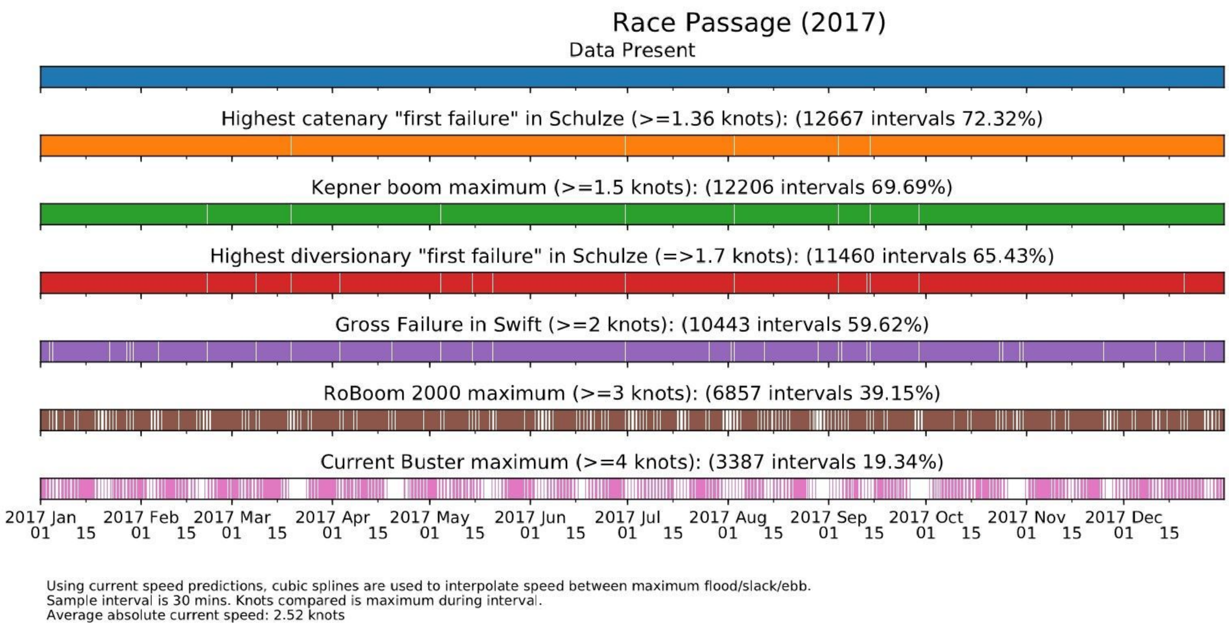


Figure 15: Race Passage 2017 current analysis

In figure 15, the first row shows the time periods for which data is present for Race Passage 2017. The second row shows that for this location the period of time in which the prediction data exceeds the highest “first failure” for catenary boom deployment, as detailed in Schulze 2001 is 72.32% of the data. The third bar shows that periods where the current speed would meet or exceed the maximum operating current for Kepner boom, as found in ECRC-SIMEC files are 69.69% of the data. The fourth bar shows that the periods where current speed would meet or exceed the highest “first failure” for diversionary boom deployment, as detailed in Schulze 2001, is 65.43% of the data. The fifth bar shows that the periods where current speed would meet or exceed “gross failure”, as derived from Swift and detailed in Fingas 2004, are 59.62% of the data. The sixth bar shows that the periods where current speed would meet or exceed Ro-Boom 2000’s maximum operating current, taken from the manufacturer is 39.15% of the data. The seventh bar shows that the periods where current speed would meet or exceed the ability of Current Buster 4 to retain oil, taken from the manufacturer is 19.34% of the data.

**Race Passage observations**

Catenary and diversionary first failures in the Race Passage area, both over 65% of intervals, will be the rule rather than the exception. Gross failures per Swift, leading to significant oil loss, are reached in ~60% of cases. Boom operating maximums for stability in current are regularly breached. Currents at full ebb and flood routinely breach the maximum operating limits of WCMRC's most robust booms - Current Buster 4 fails in 19% of cases, Ro-Boom at 39%, and Kepner boom at 70%. Sustained periods of maxima are seen. With even the highest rated booms for current overwhelmed so regularly, containment or diversion in this area will be at best a significant operational challenge, and at worst impossible. Oil control at this location will face significant operational constraints, and stationary booming strategies are unlikely to be functional for any significant period of time.

**Current maxima in proponent information**

At a less precise level of detail, Trans Mountain has discussed current along the tanker route in terms of maxima. They note currents at Boundary Pass of up to 3 knots at ebb, and 3.8 knots at flood; in Haro Strait 3-5.8 knots at ebb tide; seaward of Race Rocks at up to 5.8 knots; and in the Strait of Juan de Fuca at about 2.5 knots[34]. They also note that currents at the mouth of the Fraser during spring freshet can reach 4.9 knots. All of these maximums surpass Schulze and Swift generic failure points and the operating maximums of Kepner boom. Some breach Ro-Boom 2000 and Current Buster operating limits. At a more precise level of detail, there are short term datasets and models available, which the proponent's oil spill modelling has incorporated. Given the short timeline for producing evidence, we were unable to engage with some of the more in-depth and complex data.

# V. Conclusions

Wind and wave conditions will present significant constraints for containment booms along much of the project tanker route. From the New Dungeness buoy seaward, booms operating limits in wind and wave are reached frequently. 75% boom impairment limits for wind are reached in over 50% of tanker route data sets, Tedeschi's theoretical wind failure limit is hit in 10-20% of observations. Response impossibility limits, defined in Nuka 2015, are reached 6-9% of the time at the New Dungeness buoy, 30% to 40% of the time at Neah Bay, and 43-49% at

[34] EBA Engineering Consultants Ltd, on behalf of Trans Mountain, METEOROLOGICAL AND OCEANOGRAPHIC DATA RELEVANT TO THE PROPOSED WESTRIDGE TERMINAL SHIPPING EXPANSION. Converted from m/s.

La Perouse Bank. At Neah Bay and La Perouse, these operating limits are breached for days or weeks at a time, indicating mechanical containment and recovery will not be an effective option in these areas.

Current limitations for booms were examined in select areas in the Boundary Pass and Haro Strait area and at Race Passage. Given the above interactions between current predictions and the selected limits, currents in the Boundary Pass/Haro Strait area will form an operational constraint ranging from trivial (Skipjack Island, 1.5 northwest of 2) to significant (Skipjack Island, 2 miles NNE of); at Race Passage currents will be an extreme operational constraint. For mobile booming operations, WCMRC may be able to operationally mitigate for current limits by moving with the current, though oil proximity to shorelines may then become a limiting factor in many sections of the area. Strategies that involve stationary booms, such a protective or diversionary measures for areas of high concern, or encirclement of vessels, will be adversely affected[35] and where currents are strong enough, like at Race Passage, may be impossible. Boom failures due to current may not be catastrophic - depending on the type of boom and operational strategies, losses may be small in each instance. But numerous small oil losses can add up, increasing the risk to nearby shorelines and the potential for ecosystem impacts. As demonstrated in the Nathan E Stewart response, some losses from boom failure aren't small, leading to total release of product.

**Operating limits for containment booms along the Project tanker route**

- Wind and wave conditions will present significant constraints for effective containment booms along much of the Project tanker route.
- For portions of the route near Neah Bay and La Perouse Bank buoys, operating limits for booms are breached for days or weeks at a time, indicating mechanical containment and recovery will not be effective at these times.
- Currents along the tanker route range in strength, with many areas experiencing maxima beyond the operational limits of containment booms.
- Currents in the Boundary Pass/Haro Strait area will form an operational constraint for effective containment booms ranging from trivial to significant, while at Race Passage currents will be an extreme operational constraint.

[35] Materials Management Service, 1996, Cook Inlet Planning Area, Alaska OCS (Outer Continental Shelf) Oil And Gas Sale 149: Environmental Impact Statement