WESTWAY EXPANSION PROJECT
OIL SPILL MODELING

PREPARED FOR:

City of Hoquiam, Washington
609 8th Street
Hoquiam, WA 98550
Contact: Brian Shay
(360) 538-3983

Washington State Department of Ecology
300 Desmond Drive SE
Lacey, WA 98503
Contact: Sally Toteff
(360) 407-0271

PREPARED BY:

ICF International
317 SW Alder Street, Suite 200
Portland, OR 97205

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Introduction

The purpose of this analysis is to provide perspective on the surface movement and behavior of crude oil spilled into the project environment, specifically into Grays Harbor and the Chehalis River. Such perspective will allow planners and decision makers to understand the range of consequences that could occur after a spill and the potential variation in those consequences based on how much oil is spilled, the type of oil spilled, the direction of currents at the time of the spill, and the direction and speed of the wind. The resulting modeled trajectories represent possible outcomes, not specific predictions. The information herein illustrates how spilled oil may travel and behave in the marine environment based on the assumptions described below.

Spills into Grays Harbor and the Chehalis River were analyzed separately using different modeling tools appropriate for each unique environment.

Movement of Oil in Grays Harbor

Methods

Trajectory analyses and oil concentration contours for three different release scenarios occurring within Grays Harbor were developed using the General NOAA Operational Modeling Environment (GNOME™) software, Location Files for Grays Harbor, and GNOME Analyst. The *GNOME™ User's Manual* describes these tools as follows (National Oceanic and Atmospheric Administration 2002: 1, 45). Additional considerations relevant to the use of GNOME versus NOAA's Trajectory Analysis Planner (TAP) are presented in Attachment A.

> GNOME is a publicly available oil spill trajectory model that simulates oil movement due to winds, currents, tides, and spreading. GNOME was developed by the Hazardous Materials Response Division (HAZMAT) of the National Oceanic and Atmospheric Administration Office (NOAA) of Response and Restoration.
>
> Location Files load predeveloped location data, such as an area map with shoreline contours and dominant current patterns.
>
> GNOME Analyst converts the 'best guess' splots[1] displayed in GNOME to oil concentration contours, and the 'minimum regret' splots to a bounding contour.[2]

The GNOME trajectory analysis was completed to provide a model of how spilled oil for each release scenario—varying by release quantity, location, and set of weather and sea state conditions—would move across the water surface and which surface areas could be affected by spilled oil in the selected timeframes (24 and 48 hours after release).

[1] Splots are point information showing movement of the individual elements used in GNOME.
[2] Further information about GNOME is available at http://response.restoration.noaa.gov/gnome.

The resulting trajectories are not specific predictions, but models that demonstrate how various climatological conditions influence spill outcomes. They depict the movement of oil on the water's surface (*spreading*) and shoreline oiling without considering how oil in the environment changes in its physical characteristics and chemical composition over time. Those changes are considered *weathering*, which includes oil evaporation, oil droplet/fragment dispersion in the water column, oil emulsification, and, eventually, biodegradation. All of these changes can affect how much oil remains in the environment and how the remaining oil spreads and moves on the water's surface. Numerous environmental factors that affect oil weathering (e.g., water salinity, the presence of microbes, the extent of sun exposure, and sediment concentrations) cannot be fully considered in the GNOME analysis. In the event of an actual spill, wind speed and direction, sea state, and currents could result in the same quantity of spilled oil moving in a different direction or farther away from the source of the release.

GNOME Analyst was used to convert the modeled trajectories into an estimate of relative oil density contours (light, medium, and heavy) for the oil remaining at the surface.[3] This output was depicted graphically for the selected scenarios using a *geographical information system (GIS*) to show the surface location for the modeled oil over the selected timeframes.

The properties of the spilled oil were further evaluated using the trajectory mass balance estimates from GNOME and the Automated Data Inquiry for Oil Spills (ADIOS)[4] for a comparison of the behavior of different types of crude oils in the environment. The mass balance estimates and ADIOS output predict how long different types of oil are likely to persist (i.e., weather) in the environment and how their properties change over time.

Trajectory Model Limitations

GNOME was selected to complete the trajectory analyses because it is a National Oceanic and Atmospheric Administration (NOAA) tool familiar to oil spill contingency planners and responders nationwide.[5] A Grays Harbor Location File was already developed by NOAA for use with GNOME during development of the Geographic Response Plan (GRP) for Grays Harbor, which facilitated implementation of the trajectory modeling.

Although GNOME was determined to be best suited for the purposes of this study, there are limitations (beyond those inherent in selecting specific modeled scenario conditions), as with all models.

The GNOME model requires selecting the specific type of oil for the modeled trajectories from a predetermined list of pollutants. Bakken crude oil and diluted bitumen, which are the two most likely types of oil under the proposed action, are not included in this list. Therefore, the GNOME model cannot fully reflect how these types of oils would behave or persist in the environment when

[3] These terms refer to the relative density of the oil on the surface of the water and should not be confused with the terms used to refer to different grades of crude oil (also referred to as light, medium, and heavy).
[4] ADIOS is an oil spill response tool, also developed by NOAA, which models how different types of oil undergo physical and chemical changes in the marine environment.
[5] During real spills, NOAA's response team uses GNOME in its advanced Diagnostic Mode, and all of the data entered into the model is carefully examined to determine if it applies to the scenario at hand (National Oceanic and Atmospheric Administration 2002:4).

spilled.[6] The GNOME mass balance output and ADIOS were used to perform additional analysis to account for this, allowing a comparison of the behavior of different types of oil in the environment.

The trajectory analysis assumes *medium crude oil* (a pollutant choice available in GNOME) as the best proxy for Bakken and diluted bitumen. Bakken crude oil has “lighter” components that act like diesel oil in the environment (by evaporating at a faster rate than heavier oils); however, there are aspects to Bakken that make it a “heavier” oil. Diesel oil is also a pollutant choice in GNOME; however, a diesel oil spill would primarily evaporate over time, and using diesel would not accurately portray how the more persistent characteristics of Bakken would behave in the environment. Bitumen, although a much heavier oil when extracted from the ground, also has a lighter component because of the way it is prepared for transport (hence the term *diluted* Bitumen). The use of a medium crude oil within the GNOME pollutant list, rather than a heavier oil, provides a set of characteristics that blends the lighter components in Bakken and diluted bitumen with the more persistent characteristics of a crude oil. Moreover, medium crude is the only crude oil selection available in the pollutant list.

The Grays Harbor Location Files used in the GNOME trajectory analysis were developed to address hydrodynamic conditions within the harbor and are not meant to model accurately the movement of oil outside of Grays Harbor.[7] Consequently, because model variables such as winds and currents are spatially constant within GNOME, they are reliable for harbor conditions but are less reliable as the distance from the harbor increases and the influence of other currents, winds, rivers (e.g., the Columbia River has a very large effect on offshore currents south of Grays Harbor) and associated climatic variables come into play. This means that graphical depictions of the modeled trajectories are limited to the geographic extent of the Location Files when, during an actual spill, oil could continue to spread over time and travel beyond the immediate vicinity of the harbor depending on the existing current and wind conditions at the time of the spill. For a discussion of factors influencing movement along the coast, see Attachment A.

It is also important to note that lacking reliable discharge data for the Chehalis River, NOAA model developers made an informed estimate of river flow conditions for the Location Files based on estimated flow data for rivers of similar size.[8] The river flow has an impact on currents within Grays Harbor, and these estimates provide a reasonable approximation of the degree of impact.

Finally, Location Files for Grays Harbor do not include the Rennie Island shoreline; however, most of the environmental conditions associated with the island are included in the model. For example, the currents in the shipping channel that adjoins Rennie Island are believed to be the strongest influence on the movement of oil in the harbor and therefore oil would most likely go around either side of the island unless directly pushed onto the shoreline by strong winds (Watabayshi pers. comm.).

[6] For example, the effects of emulsification are not modeled by GNOME. See *Definitions* at the end of this section.
[7] The Location File for Grays Harbor only extends approximately 10 miles north or south of Grays Harbor entrance.
[8] When running the model high and low river speeds were selected to bracket the distance that oil could travel between the two river flow extremities set within the Grays Harbor Location File.

Modeled Scenarios

Trajectory analyses and oil concentration contours for surface oiling were developed for the following hypothetical spill scenarios at 24 hours and 48 hours post-spill.[9] All scenarios assume instantaneous release of crude oil and no response actions taken.

- A release of 10,000 gallons (238 barrels) during vessel loading at the Terminal 1 berth.
- A release of 8.4 million gallons (200,000 barrels) from a storage tank at the project site.
- A release of 15.1 million gallons (360,000 barrels) of crude oil and vessel fuel from a vessel at the entrance to Grays Harbor.

The storage tank and vessel releases were modeled assuming an instantaneous release of all tank/vessel contents into the water to provide an extreme representation of these release scenarios. As discussed in Appendix M, *Risk Assessment Technical Report*, these are very unlikely scenarios. Moreover, the information displayed on Figures 1 through 6 represents oil spills that are unmitigated by response efforts such as boom placement or removal of oil by vacuum trucks and skimmers. This is also unlikely in light of federal and state preparedness and response requirements.

As discussed earlier, the GNOME Location Files provide the ability to model oil spill trajectories under oceanographic (currents and river flow) and atmospheric conditions (winds) within Grays Harbor. For this analysis the hypothetical spill scenarios were modeled as if they occurred under average seasonal conditions for the harbor; that is, oceanographic and atmospheric conditions were selected to approximate average winter and summer conditions.

Results

GNOME Trajectory Results

GNOME modeling results for each hypothetical oil spill scenario are presented for both summer and winter conditions within Grays Harbor. Although there is no single "typical" weather pattern in the Grays Harbor area, historically there are seasonal shifts in wind direction and ocean currents. In the summer, ocean currents are typically to the south and winds from the west–southwest; in the winter, ocean currents are typically to the north and winds from the east–northeast.[10] The Chehalis River is also subject to variations in river flow.

Trajectory models were developed using four sets of hydrodynamic conditions to represent these seasonal and river influences on water movement within Grays Harbor, as described in Table 1. These models depict potential surface oil movement for hypothetical spill scenarios occurring under average or typical seasonal weather patterns combined with estimates of low or high river flows.

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[9] Scenarios (quantity of oil spilled and location) were selected based on state contingency planning criteria and took into account GRP potential spill origin points and proposed project activity.

[10] Different GNOME modeling dates were chosen to obtain accurate historical weather data for depicting summer and winter seasonal conditions.

Prevailing winds and the associated sea state have a significant effect on the movement of oil spilled on the water's surface.

Table 1. Four Sets of Hydrodynamic Conditions

Season Depicted	Seasonal Winds[a,b] Direction (from)	Seasonal Winds[a,b] Average Speed (mph)	Ocean[c] Currents (to)	River Flow[c]
Summer	WSW	8	South	High
Summer	WSW	8	South	Low
Winter	ENE	10	North	High
Winter	ENE	10	North	Low

[a] Historical wind data was generated from the Iowa State University of Science and technology website using the Washington State Automated Surface Observing Systems network data collected at Hoquiam/Bowerman Airport.

[b] A review of 18 years of historical wind data was conducted to identify average or typical wind speeds and directions during the summer (July) and winter (January). Based on this review, a representative set of wind speeds and direction were selected for a 24-hour period for each season (summer and winter). The same wind conditions are repeated for the second 24 hours to achieve a full 48-hour trajectory.

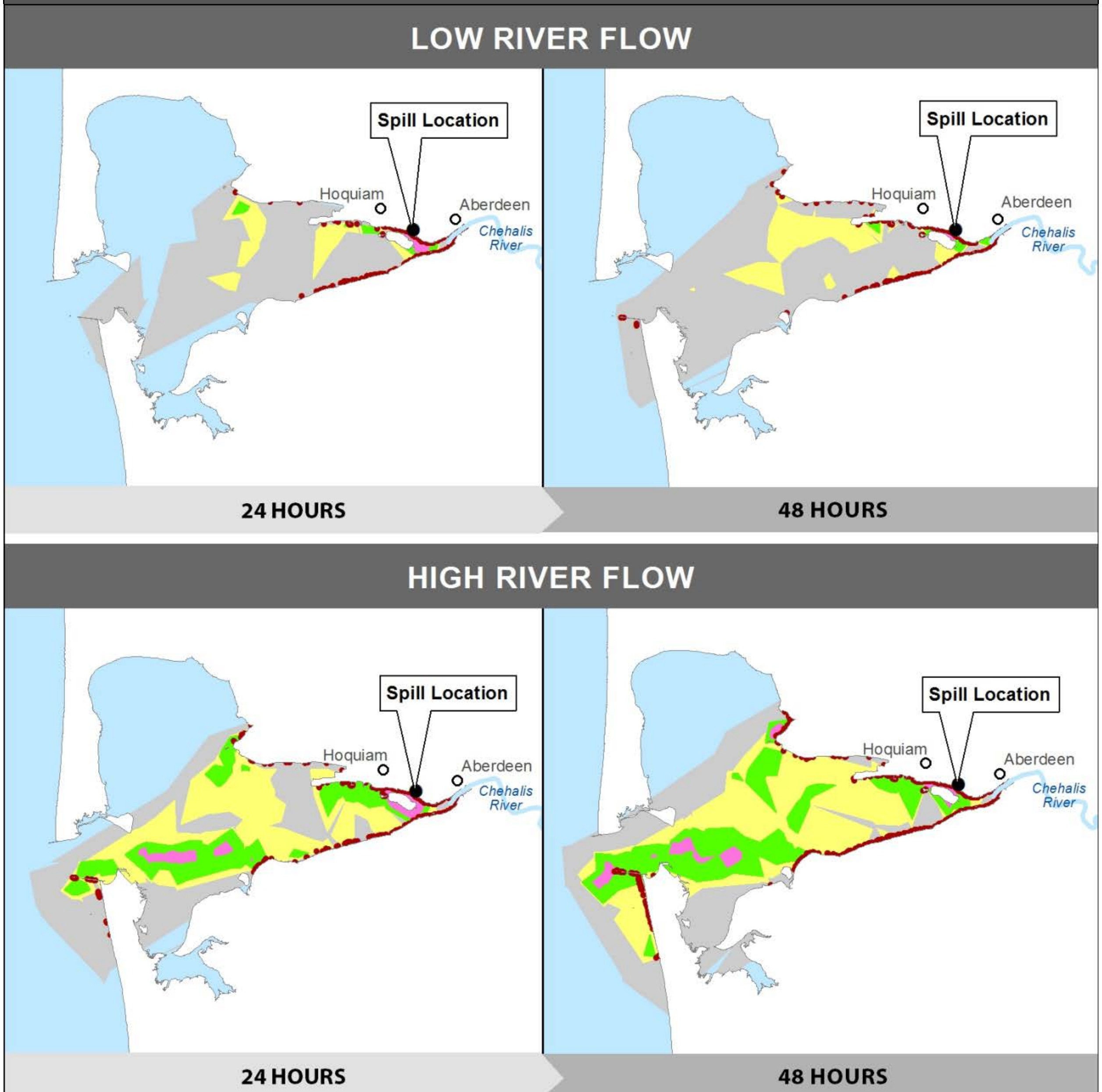
[c] Ocean currents and river flow conditions are applied from Location Files for Grays Harbor prepared by NOAA. They are developed from climatological information and are not designed to model real spills accurately.

WSW = west–southwest; ENE = east–northeast; mph = miles per hour

The modeled trajectory results are presented for each release scenario in Figures 1 through 6. Trajectories for each release scenario show surface and shoreline oiling for two separate seasonal currents (e.g., summer winds/currents to the south and winter winds/currents to the north). For each seasonal current depiction, the trajectories are shown at 24 hours and at 48 hours after the release. Trajectories for high and low flows in the Chehalis River are also shown. For each modeled condition (Figures 1 through 6), the *bounding contour*, or confidence limit (represented as light gray on the figures), represents the "minimum regret" solution that accounts for uncertainty in the trajectory model.[11]

[11] According to the *GNOME User's Manual*, "As a very rough rule of thumb—assuming a 'typical' degree of uncertainty in the wind and current information you use in modeling a spill scenario—the chance that the spilled oil will remain within the area covered by the red splots is on the order of 90%" (National Oceanic and Atmospheric Administration 20002:28) In the trajectory maps used for this analysis the red splots are represented by the bounding contour/confidence limit – the gray shading.

Figure 1. Trajectory of an Instantaneous Release during Vessel Loading at Terminal 1—Summer Winds/Currents to the South



Legend

- Beached Oil

Relative Distribution

- Light
- Medium
- Heavy
- Confidence Limit

Model reflects trajectory (direction and extent) of oil spill during low (top) and high (bottom) river flows at 24 hours (left) and 48 hours (right) if no response actions were taken.

Release Location: Grays Harbor at Terminal 1 Dock

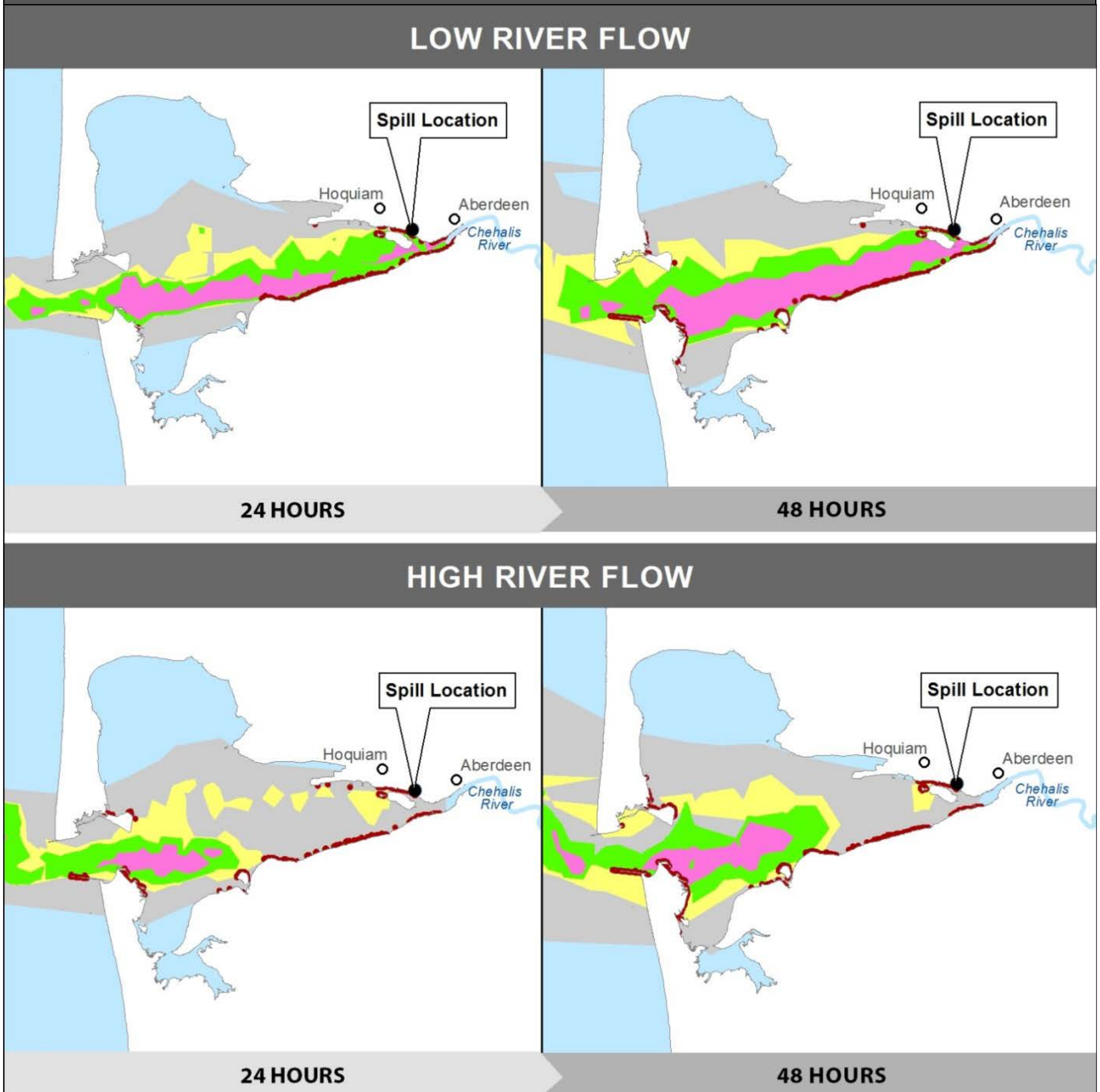
Release Volume: 238 Barrels of Crude Oil

Winds: Variable, Predominantly from the West South West (8 mph average)

Currents: to the South

Distribution contours are modeled results obtained from the NOAA GNOME Analyst software

Figure 2. Trajectory of an Instantaneous Release during Vessel Loading at Terminal 1—Winter Winds/Currents to the North



Legend

- Beached Oil

Relative Distribution

- Light
- Medium
- Heavy
- Confidence Limit

Model reflects trajectory (direction and extent) of oil spill during low (top) and high (bottom) river flows at 24 hours (left) and 48 hours (right) if no response actions were taken.

Release Location: Grays Harbor at Terminal 1 Dock

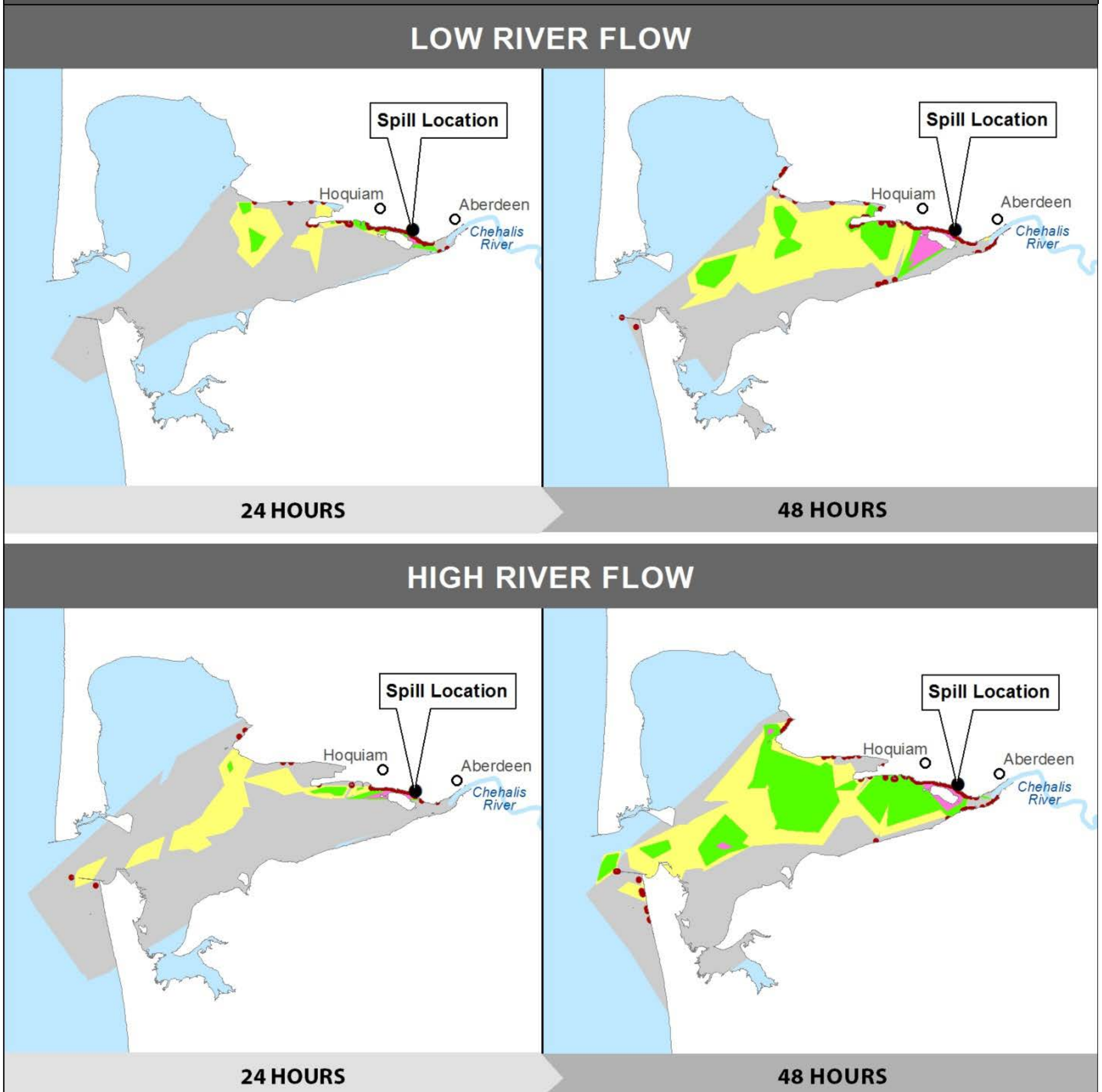
Release Volume: 238 Barrels of Crude Oil

Winds: Variable, Predominantly from the East North East (10 mph average)

Currents: to the North

Distribution contours are modeled results obtained from the NOAA GNOME Analyst software

Figure 3. Trajectory of an Instantaneous Release of a Storage Tank—Summer Winds/Currents to the South



Legend

- Beached Oil

Relative Distribution

- Light
- Medium
- Heavy
- Confidence Limit

Model reflects trajectory (direction and extent) of oil spill during low (top) and high (bottom) river flows at 24 hours (left) and 48 hours (right) if no response actions were taken.

Release Location: Project Site Tank Storage Area

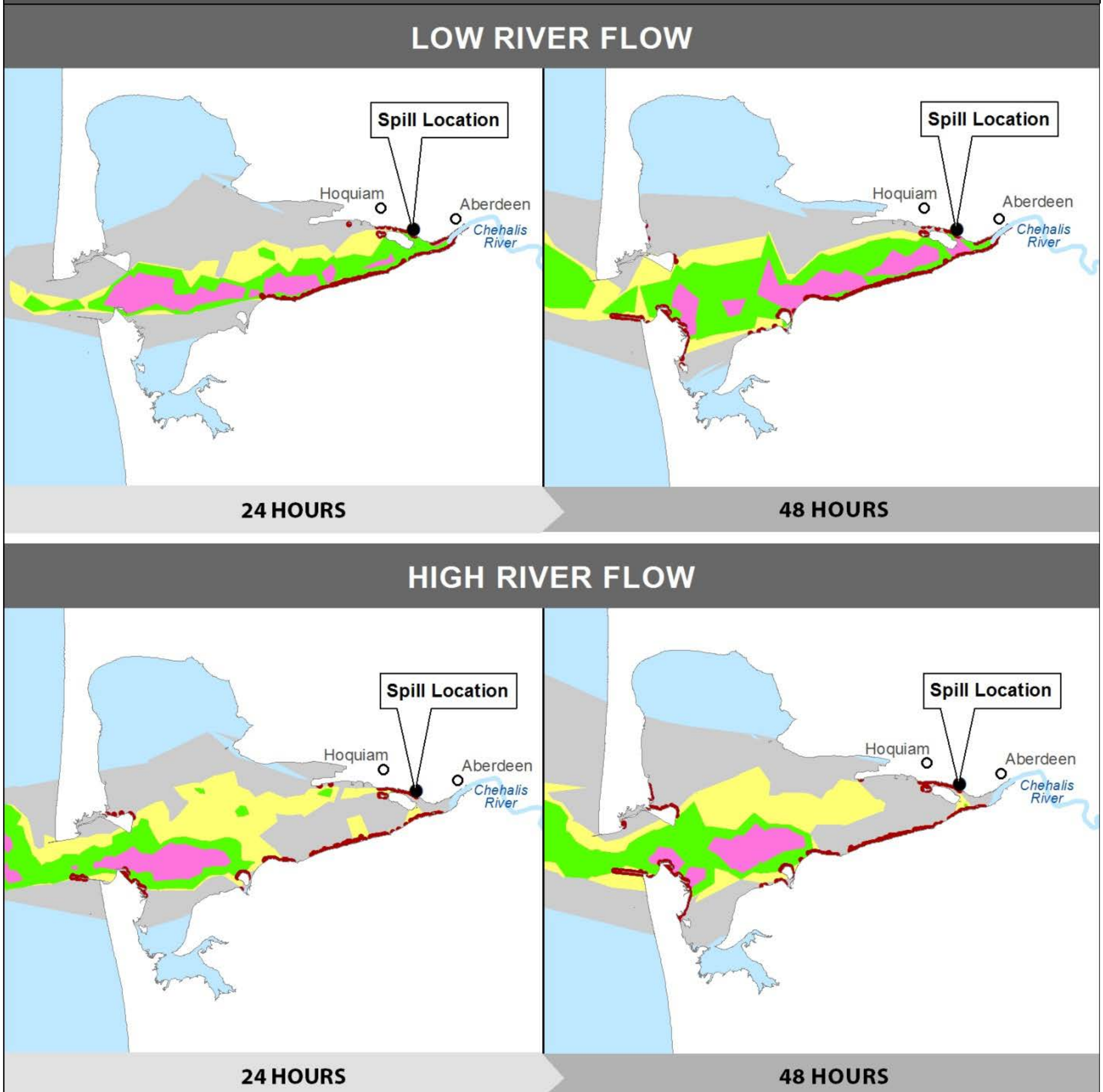
Release Volume: 200,000 Barrels of Crude Oil

Winds: Variable, Predominantly from the West South West (8 mph average)

Currents: to the South

Distribution contours are modeled results obtained from the NOAA GNOME Analyst software

Figure 4. Trajectory of an Instantaneous Release of a Storage Tank—Winter Winds/Currents to the North



Legend

- Beached Oil

Relative Distribution

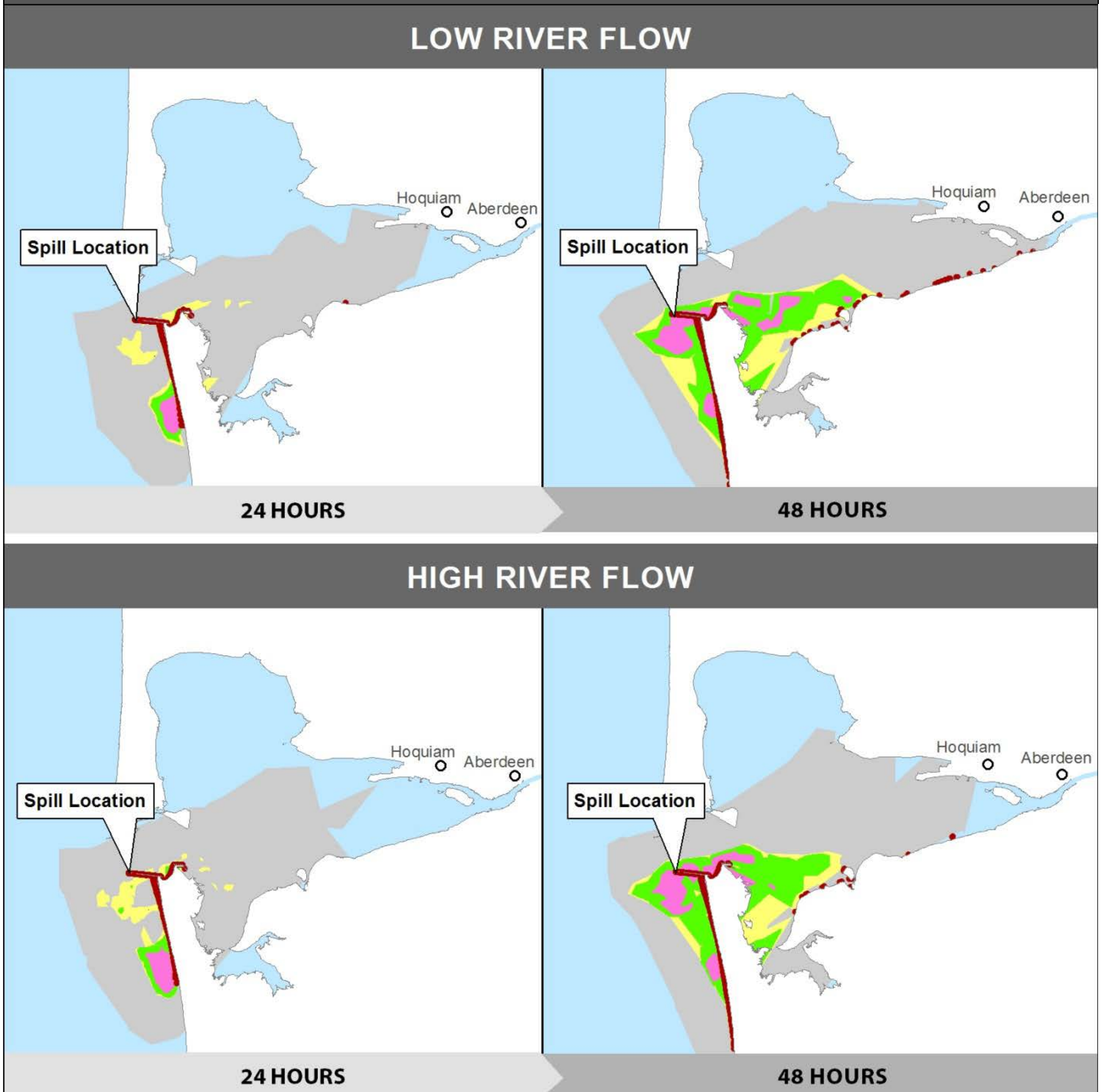
- Light
- Medium
- Heavy
- Confidence Limit

Model reflects trajectory (direction and extent) of oil spill during low (top) and high (bottom) river flows at 24 hours (left) and 48 hours (right) if no response actions were taken.

Release Location:	Project Site Tank Storage Area
Release Volume:	200,000 Barrels of Crude Oil
Winds:	Variable, Predominantly from the East North East (10 mph average)
Currents:	to the North

Distribution contours are modeled results obtained from the NOAA GNOME Analyst software

Figure 5. Trajectory of an Instantaneous Release from Tank Vessel during Transit—Summer Winds/Currents to the South



Legend

- Beached Oil

Relative Distribution

- Light
- Medium
- Heavy
- Confidence Limit

Model reflects trajectory (direction and extent) of oil spill during low (top) and high (bottom) river flows at 24 hours (left) and 48 hours (right) if no response actions were taken.

Release Location: Near Grays Harbor Entrance Jetties

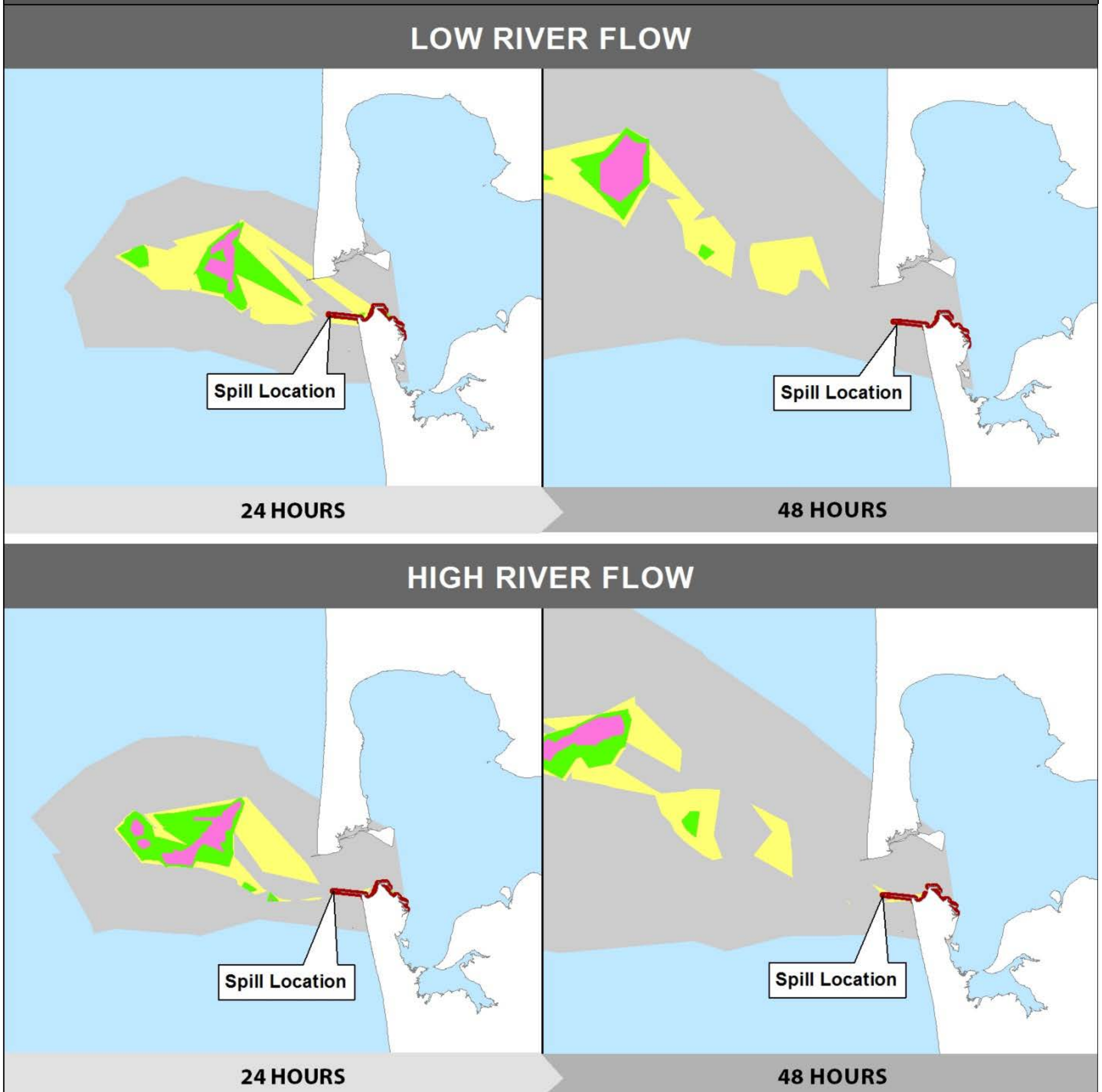
Release Volume: 360,000 Barrels of Crude Oil and Vessel Fuel

Winds: Variable, Predominantly from the West South West (8 mph average)

Currents: to the South

Distribution contours are modeled results obtained from the NOAA GNOME Analyst software

Figure 6. Trajectory of an Instantaneous Release from Tank Vessel during Transit—Winter Winds/Currents to the North



Legend

Beached Oil

Relative Distribution

Light

Medium

Heavy

Confidence Limit

Model reflects trajectory (direction and extent) of oil spill during low (top) and high (bottom) river flows at 24 hours (left) and 48 hours (right) if no response actions were taken.

Release Location: Near Grays Harbor Entrance Jetties

Release Volume: 360,000 Barrels of Crude Oil and Vessel Fuel

Winds: Variable, Predominantly from the East North East (10 mph average)

Currents: to the North

Distribution contours are modeled results obtained from the NOAA GNOME Analyst software

GNOME Mass Balance Results

As mentioned previously, GNOME also calculates a mass balance of the "best guess," or forecast, solution for each spill. In the case of this analysis, the mass balance is the fate (i.e., proportion of the spilled oil that is floating, gets beached, or evaporates or is dispersed) of different portions of the oil spill due to the trajectory, the pollutant type, and the weathering that the pollutant has undergone (National Oceanic and Atmospheric Administration 2002:81). GNOME shows the mass balance in percentages over time as the proportion of the spill that is floating, beached, evaporated and dispersed, and off the map (National Oceanic and Atmospheric Administration 2002:52).[12]

Because GNOME does not currently offer the ability to model spilled Bakken crude or diluted bitumen, all mass balance estimates herein are based on modeling medium crude oil as the spilled pollutant. Medium crude oil was selected to present an over-estimation of persistence in the environment, comparable to an actual spill of Bakken crude oil or of diluted bitumen. However, both Bakken and diluted bitumen will not behave identically to medium crude under spill conditions due to their different compositions.

The numbers in Table 2, representative of a spill of medium crude, depict the model's best estimates for the most quantity of oil that would remain in the environment as time progresses (from a 24- to 48-hour period) post-spill, presented as a percentage range across the four sets of hydrodynamic conditions for each scenario.

Table 2. Range of Mass Balance Estimates for "Best Guess" GNOME Analysis of Selected Scenarios

Scenario		Percentage Range of Oil Floating	Percentage Range of Oil Beached	Percentage Range of Oil Evaporated and/or Dispersed
Release During Vessel Loading (10,000 gallons or 238 barrels)	At 24 hours	2.9–20.0%	57.2–74.3%	22.8%
	At 48 hours	3.2–15.7%	51.6–64.1%	32.7%
Facility Release (8.4 million gallons or 200,000 barrels)	At 24 hours	1.9–18.6%	58.6–75.3%	22.8%
	At 48 hours	1.9–15.0%	52.3–65.4%	32.7%
Vessel Release (15.1 million gallons or 360,000 barrels)	At 24 hours	2.7–31.4%	45.8–74.5%	22.80%
	At 48 hours	2.4–5.7%	61.4–64.9%	32.7–32.8%

ADIOS Output Comparison Results

The mass balance outputs in GNOME for spills of medium crude provide a baseline for comparison when estimating the persistence of a spill of Bakken crude oil or diluted bitumen in the environment. Some understanding of the differences in the behavior of Bakken crude oil or diluted bitumen in the environment may be obtained by comparing the weathering properties of the two

[12] The "off map" numbers for all of the trajectories were zero and are omitted for the sake of brevity.

products against the weathering properties of medium crude oil using NOAA's ADIOS (National Oceanic and Atmospheric Administration 2015). A general discussion of oil properties is presented in Attachment B.

This section provides an ADIOS modeling comparison to further illustrate the difference in oil properties and behaviors. A spill of each type of oil (medium crude, Bakken crude, and diluted bitumen) was modeled in ADIOS (at a wind speed of 10 miles per hour) to allow for a comparison of oil characteristics and weathering.

The oil properties depicted in the ADIOS model are from samples of oil that were analyzed by a laboratory or, if no sample were available of a particular blend, the best-known information available about the crude oil. During an actual spill event, the oil spilled may exhibit slightly different properties even if it is referred to by the same name (i.e., Bakken or diluted bitumen) because of where it was mined or how it was treated for transportation.

A comparison of select chemical property values (viscosity and density) and weathering effects (rate of evaporation, dispersion, and oil remaining) of medium, Bakken, and diluted bitumen crude oils after 48 hours in the environment is shown in Table 3. The spill amount modeled was the same in all cases.

Chemical property and weathering terms are provided in *Definitions*, below to help understand the ADIOS results.

Table 3. Comparison of Oil Properties after 48 Hours in the Environment with 10 mph Winds

Property	Medium Crude Oil[a]	Bakken Crude Oil[b]	Diluted Bitumen Crude Oil[c]
Viscosity (cSt)	>100,000	500–600	>100,000
Density (kg/cu m)	1,000	896	995
Evaporated	23%	49%	25%
Dispersed	<1%	15%	<1%
Oil Remaining	77%	36%	75%

[a] An Alaska North Slope (ANS) crude blend was modeled in ADIOS as the medium crude oil. ANS crude blends are considered medium grade oils and can have an *American Petroleum Institute (API*) gravity generally in the range of 27.5 to 31.4. [13]

[b] NOAA used data from a Bakken spill in February 2014 to characterize Bakken crude oil behavior. API gravity for this sample was 40.8.

[c] The diluted bitumen selected in ADIOS was the Cold Lake Blend (from Alberta, Canada). The API gravity for this particular crude oil is 22.6.

cSt = centistokes

kg/cu m = kilograms per cubic meter

[13] API gravity will vary depending on the source of the crude oil. The NOAA Office of Response and Restoration website *Alaska North Slope Crude Blends* (http://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/alaska-north-slope-crude-blends.html) introduces a BP ANS crude from Pump Station #9 with an API gravity of 29.6. The ANS crude used in GNOME has an API of 27.5. ExxonMobile mines and distributes an ANS crude with an API of 31.4 (http://www.exxonmobil.com/crudeoil/about_crudes_api.aspx#c101).

Definitions

- **Viscosity**: the amount of resistance to flow by a liquid. Low viscosity oils spread more quickly than those with a high viscosity. In addition to the chemical properties inherent to the oil, ambient temperature will influence oil viscosity. At low temperatures, an oil will tend to be more viscous (and spread less rapidly) than at higher temperatures. The medium crude modeled in ADIOS is slightly less viscous than the diluted bitumen.
- **Density**: the property of oil that reflects the mass or weight of the oil. The specific gravity of oil relates the density of oil to fresh water. If the specific gravity of an oil is greater than 1, then the oil is likely to sink in fresh water. None of the oils evaluated for this analysis have a specific gravity greater than 1.
- **Evaporation**: the physical change by which any substance is converted from a liquid to a vapor or gas. The rate of evaporation and the speed at which it occurs depend upon the volatility of the oil.
- **Dispersion**: waves and turbulence at the water's surface can cause some or all of the oil slick to break up into fragments and droplets. Some of the oil will become mixed into the upper levels of the water column and may remain suspended or even sink if they meet silt or sand. Other droplets may rise back to the surface and create a new slick or spread out in to a very thin film. The comparison in Table 3 shows that Bakken crude is the most likely of the three oils to disperse after a period in a turbulent marine environment.
- **Oil remaining**: represents the balance of spilled oil that is not evaporated or dispersed and that remains in the environment, either on the water's surface or on the shoreline.

Also relevant to a discussion about weathering is *emulsification*, which occurs when oil and water combine over time, resulting in the suspension of seawater droplets in oil creating a water-in-oil emulsion. This occurs by physical mixing promoted by turbulence at the sea surface. The emulsion formed is usually very viscous and more persistent than the original oil and is sometimes referred to as chocolate mousse because of its appearance. (International Tanker Owners Pollution Federation Limited 2015)

The ADIOS analysis demonstrated that, in most cases, medium crude oil would persist longer in the environment than Bakken. An exception is that Bakken is shown to be more likely to disperse than medium crude. This tendency may result in a mixing of the oil droplets or fragments with sediment in the water column and a resultant suspension of oil beneath the water's surface. As discussed in Attachment B, at the Marshall spill into Talmadge Creek and the Kalamazoo River, under certain conditions, diluted bitumen was observed as suspended in the water column or even sank.

Movement of Oil in Chehalis River

Methods

Three different rail scenarios were modeled to demonstrate the movement of oil in the Chehalis River. Based on the modeled oil spill locations, the existing Hydrologic Engineering Centers River Analysis System (HEC-RAS) one-dimensional hydraulic model for the Chehalis River and its tributaries was pared down to focus on the area of interest in the lower Chehalis River. The hydraulic model was used to assess the river channel characteristics for three flow events: low flow (731 cubic feet per second), 2-year flood (31,000 cubic feet per second), and 100-year flood (83,000 cubic feet per second). The low-flow rate was developed based on the period of record (1952–2013) for U.S. Geological Survey stream gage #12031000 – Chehalis River at Porter, Washington.

The modeling results of interest included channel velocity, depth, and flow area at each representative river channel cross section. The model also included existing bridges and adjacent floodplains. The volume of spilled oil for three scenarios—one car, three cars, and five cars—was compared to the predicted volume of flowing water in the river for three flow rates. In most cases the total volume of the spill was less than 5% of the water volume in the river. However, at certain bridge locations the flow area is constricted, and oil volumes could greatly increase the combined depth of oil and water at the bridge, creating a localized flood stage scenario.

To determine the travel time from the location of the oil spill to the mouth of the lower Chehalis River in the Grays Harbor estuary, the measured distance between modeled cross sections was divided by the calculated velocity between two adjacent cross sections. This was repeated for all of the modeled cross sections and added to determine the cumulative travel time from the spill location to the estuary.

T = L/V, converted from seconds to minutes

where

T = time (minutes)

L = length (in feet between cross sections)

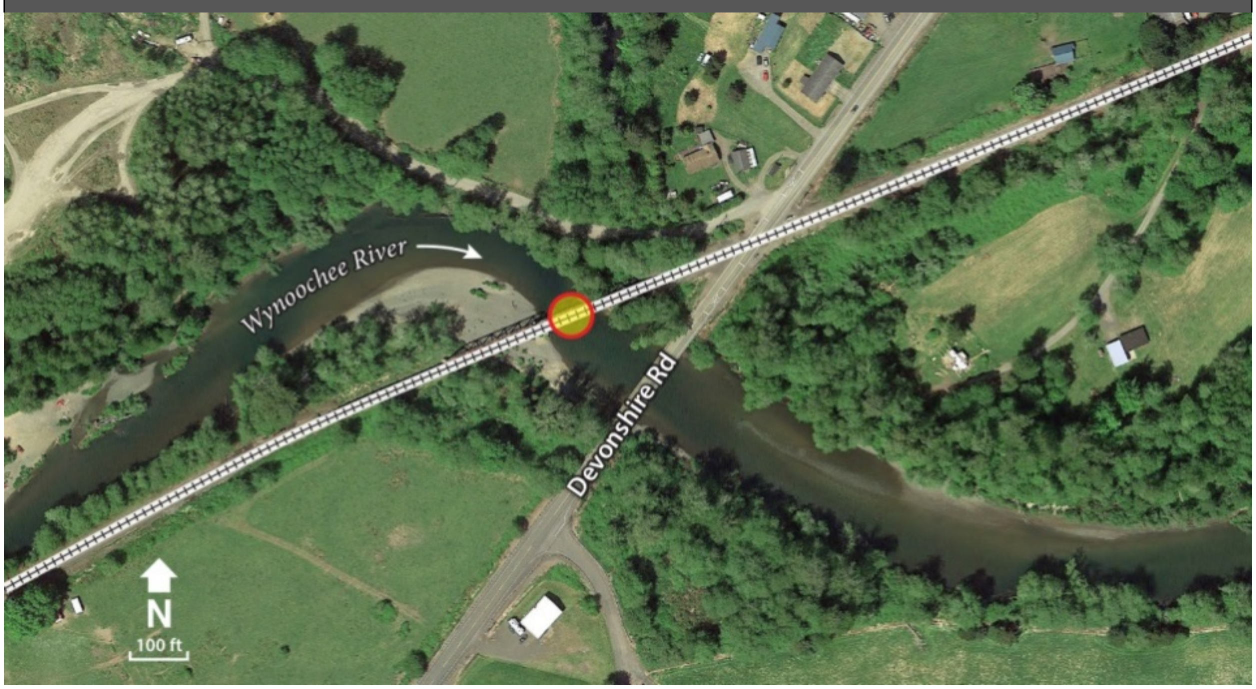
V = velocity (hydraulic velocity in feet per second)/60 second per minute

Modeled Scenarios

Two locations were evaluated for the discharge of oil into the Chehalis River from rail tank cars involved in an accident. Each location was evaluated for three different flow events: low, 2-year, and 100-year. The first location was along the Chehalis River near Porter Creek Road West, in Elma and the second location was at the Wynochee Bridge (Figures 7 and 8).

Figure 7. Chehalis River near Porter Creek Road West

Figure 8. Wynochee Bridge



The low flow event was an average minimum flow based on the U.S. Geological Survey stream gage record that dates from the 1950s to the present.

ICF developed a 1-dimensional hydraulic model (HEC-RAS) to review the potential travel time of oil if a spill were to occur along the shoreline of the Chehalis River during various flood stages. The model relied on the geometry and hydrology that was previously developed by the Washington Office of Financial Management as part of the ongoing Chehalis River Flood Reduction Analysis (Elliot and Karpack 2014).

Amounts spilled at each location and evaluated within the model are shown in Table 4.

Table 4. Spill Amounts Modeled in the Chehalis River

One Rail Car	Three Rail Cars	Five Rail Cars
714 barrels	2,143 barrels	3,571 barrels
30,000 gallons	90,000 gallons	150,000 gallons

Model Results

Travel times consider that all of the oil spilled is transported to the estuary and do not account for the fate of the oil (due to weathering or transport of the oil onto shorelines or debris, for example) while it is in the river. Table 5 summarizes the results in travel times downstream from the spill point.

Table 5. Travel Times (in hours) of the Oil in the River for Three Different River Flows

Spill Location	Low Flow	2-Year	100-Year
Elma	108.5	18.1	7.6
Wynochee	75.3	11.5	8.2

References

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Attachment A
GNOME and TAPs

The GNOME and a NOAA Location File for Grays Harbor was used to conduct modeling in Grays Harbor. The GNOME model is used in all NOAA Emergency Response Division spill responses that require modeling. Because the primary forces that move the oil (e.g., wind, currents) are not generated by GNOME, but through input by the user, the user is ultimately responsible for the results.

GNOME's Location Files are developed to simulate local climatological conditions. Though tides are predictable, other environmental conditions are not so simple. Location Files are not appropriate for spill response, just as an almanac is not appropriate to predict the weather for a particular day. The Location file for Grays Harbor was initially developed to support prioritization of Geographic Response Plans. It was not developed to be used during spills.

GNOME is a trajectory model and TAP is a Trajectory Analysis Planner—these two tools serve different purposes. GNOME runs single trajectories. If GNOME is run thousands of times (using historical winds, tides, and currents), TAP can be used to analyze all those trajectories and calculate statistics from them.

TAP provides the probability of oil movement by looking at those thousands of trajectories. These probabilities allow planners to look at "what if" situations based on the regional oceanography and climate. Decision-makers can use TAP to decide whether to buy more boom or another skimmer, or where to site a lightering area.

TAP cannot be used in the event of a real spill. The situation on a particular day may not be well represented in the statistics, because spills often happen due to unusual circumstances. In the case of a real spill, GNOME can be quickly set up to represent the environmental conditions of the spill. TAP is best used for planning, when it is not known what conditions will be when a spill occurs.

Attachment B
Factors Influencing Movement along the Washington Coast

Factors

Oil pushed outside of Grays Harbor by the local currents and the winds will migrate due to the influences of ocean winds and currents. Along the coastline and just off entrances to inland waterways (such as Grays Harbor and the Columbia River) currents are influenced by tidal and drainage effects. Farther offshore and at specific times of the year, currents depend largely upon prevailing winds[14]. Furthermore, as with the currents and winds within Grays Harbor, there are seasonal influences on ocean currents. Two oil spills that occurred off the Washington coastline illustrate the directions oil can migrate offshore depending upon seasonal conditions: The *Tenyo Maru* oil spill off Neah Bay, Washington, in July 1991 and the barge *Nestucca* oil spill that occurred in December 1988 just outside of Grays Harbor.

The *Tenyo Maru*, a fish processor vessel, and the Chinese freighter *Tuo Hai* collided on July 22, 1991, approximately 20 miles west of Cape Flattery, Washington, and 20 miles south of Vancouver Island, British Columbia, Canada. The location of the accident was approximately 110 miles north of the entrance to Grays Harbor. The collision resulted in the sinking of the *Tenyo Maru* in an estimated 350 feet of water. At the time, the *Tenyo Maru* was carrying 273,000 gallons (6,500 barrels) of intermediate fuel oil; 90,972 gallons (2,166 barrels) of diesel oil; and some quantity of lube, bilge, and fish oils. The oil leaked from the *Tenyo Maru* and migrated southeast for the most part, although a reversal of winds for a few days resulted in a northward movement (Watabayshi pers. comm.). Although oil shoreline impacts were north of Grays Harbor (oil was observed at Shi Shi beach, Cape Flattery, and the area between Tatoosh Island and Rialto Beach, with the heaviest impacts at Shi Shi; some impacts were also observed at Hobach Beach, Sooes Beach and Cape Alava), the case study illustrates how oil from a spill occurring offshore of Washington could migrate south (National Oceanic and Atmospheric Administration 1992:188).

The tug *Ocean Service* collided with its tow, the barge *Nestucca*, while trying to replace a broken towline. The collision occurred approximately 3 kilometers off the coast of Washington, near Grays Harbor on December 23, 1988, while the tug and tow were en route from Ferndale, Washington, to Portland, Oregon. The tug punctured a cargo tank on the *Nestucca*, spilling an estimated 231,000 gallons (5,500 barrels) of the heavy marine fuel oil that the barge was carrying (the barge was carrying over 2.9 million gallons (69,000 barrels) of Number 6 fuel oil; one tank was punctured). Some spilled oil entered Grays Harbor, affecting the mudflats. Oil also moved north and some came ashore on Vancouver Island on December 31, 1988 (8 days after the collision). Over the next 15 days, the oil reached to Cape Scott at the northwest tip of Vancouver Island, and, on January 27, 1989, oiled material, determined to be from the *Nestucca*, was found in the Moore Islands area on

[14] National Oceanic and Atmospheric Administration. 1992. Oil Spill Case Histories 1967–1991. September. Report No. HMRAD 92-11. Page 260.

the mainland of British Columbia. Along the coastline (north of Grays Harbor), the Canadian Coast Guard estimated that a total of about 95 miles of shoreline were oiled, with 1.5 miles heavily oiled.[15]

Neither of these oil spills originated within Grays Harbor, and it is impossible to compare the movement of oil from a spill origin point outside the harbor to one inside the harbor because of the heavier tidal influences within the harbor. Nevertheless, these case studies illustrate the many variables involved with an oil spill: the type of oil, the location spilled, and the climatological and hydrodynamic conditions in effect at the time of the spill all influence the movement, physical behavior, and ultimate disposition of the oil.

[15] *Ibid: page 128.*

Attachment C
Oil Properties

Bakken

> From an analysis of spilled Bakken Crude Oil taken from the Mississippi River
>
> *The unweathered oil is highly aliphatic and contains a moderate amount of aromatics. The oil is highly volatile and caution should be taken when dealing with oil in confined areas.*
>
> NOAA Office of Response and Restoration. Incident News for Barge E2MS 303. 22 Feb. 2014.

Bakken crude oil, like other crude oils, consists of a range of primarily hydrocarbon gases and liquids. Bakken crude oil is regarded as a light crude oil based upon its chemical properties (light crude oils are generally regarded as those crude oils with an American Petroleum Institute [API] gravity of 37 degrees or more). Light crudes tend to have higher concentrations of light ends (such as methane, ethane, propane, butanes, and pentanes) than heavier crude oils (like the medium crude modeled in GNOME). [16] The presence of these increasing amounts of dissolved gases and other light ends means that, spilled onto water, unweathered Bakken crude oil will primarily float on the surface.[17]

Other general, but related, distinctions between a spill of medium crude oil and Bakken crude oil are as follows.

- Bakken crude oil has an API gravity generally in the range of 40 to 44.[18] This means that the Bakken crude oil is less viscous than a medium grade crude oil and will spread out more thinly on the surface of the water.
- Bakken crude oil's volatility suggests additional care if the material is corralled into a confined area.

In other words, compared to a spill of medium crude oil, as was modeled for the environmental impact statement using GNOME, the Bakken crude oil would more easily spread on the water's surface, and more of the oil would evaporate into the air over the same period.[19]

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[16] American Fuel & Petrochemical Manufacturers. 2014. *Survey of Bakken Crude Oil Characteristics for the U.S. DOT*. May 14. Page 12.

[17] As spilled oil remains in the environment, its physical and chemical characteristics interact with the physical and biochemical features of the habitat where the spill occurred. The sum of these processes is called "weathering" of the oil. See NOAA Office of Response and Restoration, "What is Weathering?" at http://response.restoration.noaa.gov/oil-and-chemical-spills/significant-incidents/exxon-valdez-oil-spill/what-weathering.html.

[18] *Survey of Bakken Crude Oil Characteristics for the U.S. DOT* and Louisiana State University Department of Environmental Sciences analysis of Bakken crude from E2MS303 barge spill.

[19] On February 22, 2014, a tank barge (E2MS 303) carrying Bakken crude oil as cargo collided with a towing vessel in the Mississippi River near Vacherie, Louisiana. Samples of the spilled oil were taken from the waterway and analyzed by the Louisiana State University Department of Environmental Sciences (taking samples for analysis is standard procedure for the investigation of oil spills). The results of that analysis informed the ADIOS model.

Diluted Bitumen

Diluted bitumen crude oil represents a range of oils produced from bitumen extracted from oil sands in Western Canada. In its original form, bitumen does not flow through a pipeline efficiently, so it is mixed with diluents to be readied for transportation.[20] Although diluted bitumen is a crude oil blend with an initial "heavy" constitution, its behavior in the environment when spilled and subsequently weathered is not fully understood because of the limited spill history associated with the oil. Taylor (2013:13) reported the following based on tests and two actual spills.

> The most significant observations are that the behavior of diluted bitumens tested or spilled are consistent with Group 3 and 4 crude oils: they float on water until oil densities change through weathering and/or sediment uptake. As with most crude oils, diluted bitumens may gradually overwash, become suspended in the water column, or sink depending upon the degree of weathering and formation of oil-mineral aggregates. The Marshall spill into Talmadge Creek and the Kalamazoo River resulted in oil transport down river with most oil remaining on the water surface. A portion of oil, mixed with riverbank and/or suspended settlement, and submerged or in places sank.

The API of diluted bitumen ranges from 18 to 39 (Taylor 2013:5). The values provided include weathered diluted bitumen from tests.

[20] American Petroleum Institute (API) and Association of Oil Pipelines. 2013. *Diluted Bitumen*. April. Available: http://www.api.org/policy-and-issues/policy-items/oil%20sands/diluted-bitumen. Accessed: January 2015.