White Rose Extension Project

Oil Spill Fate and Behaviour Modelling

April 2012

Oil Spill Fate and Behaviour Modelling

in Support of Husky Energy White Rose Extension EA

Prepared by SL Ross Environmental Research

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Executive Summary

This document presents the results of oil spill fate and trajectory modeling and is a prepared as a support document for the White Rose Extension Project Environmental Assessment. No attempt is made to present detailed modeling results in this executive summary. Instead the basic approach to the modeling and a brief discussion of some of the key modeling inputs are provided.

Fate and trajectory modeling were completed for two distinct study areas. One was the near-shore region in Placentia Bay in the vicinity of the proposed graving dock and top-sides mating sites. The near shore modeling evaluates batch diesel spills in the months of March through July, as this is the period that marine project activities in this area will be conducted. The basic fate and trajectory of diesel spills under average seasonal conditions is presented to provide the user with typical slick characteristics and trajectories over time. Long term wind data (MSC50 data) is then used to model the trajectory of slicks released on a daily basis over a 57 year period to assess the likely trajectory of spills in this area. Water current mapping provided by the Fisheries and Oceans Canada (DFO) was used in the modeling. Slick 'time to shore' assessments and trajectory probabilities have been processed from these historical trajectories. Oil will come to shore within a few hours to a few days, depending on the wind conditions, from spills in this area and will most often impact the western and north western shores of the Avalon Peninsula within Placentia Bay. The extent of the diesel spills will be confined to Placentia Bay environs.

The second study area encompasses the broader offshore region surrounding the White Rose Field. Batch spills of diesel fuel and subsea and surface blowouts of crude oil were modelled in the offshore study area. The basic fates of oil from these spill types have been modelled under average environmental conditions to provide users with typical slick characteristics and trajectories over time for the different spill types. For the blowout scenarios, slick characteristics are provided for both the maximum oil and gas flows possible at the start of a release and the lower flows that would be likely 120 days into a release. Historical spill trajectories are modelled in the offshore region using the 57 year MSC50 data set and DFO's east coast water current data. The modeling results show that shoreline contacts from these releases are very unlikely. Slick trajectory probability contours are provided on a monthly basis to identify the zones of most likely oil movement in the offshore.

1.0 Introduction

The objective of this modelling is to assess the behaviour and trajectory of oil spills that might occur during the activities being proposed by Husky Energy in the White Rose Extension Project (WREP). The spills of concern are:

1. sub-sea and surface platform blowouts of crude oil from the offshore location,

2. small platform or vessel based batch spills of marine fuel oil at the offshore production site, and

3. marine fuel oil spills in the vicinity of the Argentia graving dock and the deep-water mating sites in Placentia Bay.

Refer to Figures 1-1 and 1-2 for locations of the White Rose field and the nearshore work sites.

The approach is to select a number of hypothetical oil spills that cover the main concerns and to describe their behaviour and trajectory. These spill scenarios, involving various spill types and sizes, serve subsequently as the basis for impact assessment and countermeasures analyses.

The spill modelling data inputs and results for the near-shore project activities are presented first, followed by the offshore site results.

Two different types of modelling are completed for each site. The first looks at the behavior of spills if seasonal (summer and winter) average air and water temperatures and wind speeds are assumed. The characteristics of the spills over time (slick width, oil thickness, oil viscosity, time to loss of surface oil, and dispersed oil concentration) are presented assuming these average environmental conditions prevail over the life of each spill. These characteristics provide a general picture of the behavior of a single patch of oil released from the spill site for each of the spill scenarios being considered. This information is useful in assessing potential spill countermeasures operations and their likely effectiveness over time and potential zones of impact from a hypothetical spill during typical weather conditions.

The second modelling effort looks at where the oil is likely to travel given long-term historical wind records. Thousands of spill trajectories are initiated from the spill sites and their fate and behavior are determined using 57 years of 6 hourly wind data. The results of the trajectories are then used to identify zones of high and low probability of surface oiling. The results of this modelling are useful in identifying the extents of possible impact zones from hypothetical spills from the operation.

Figure 1-1 Location of White Rose Field

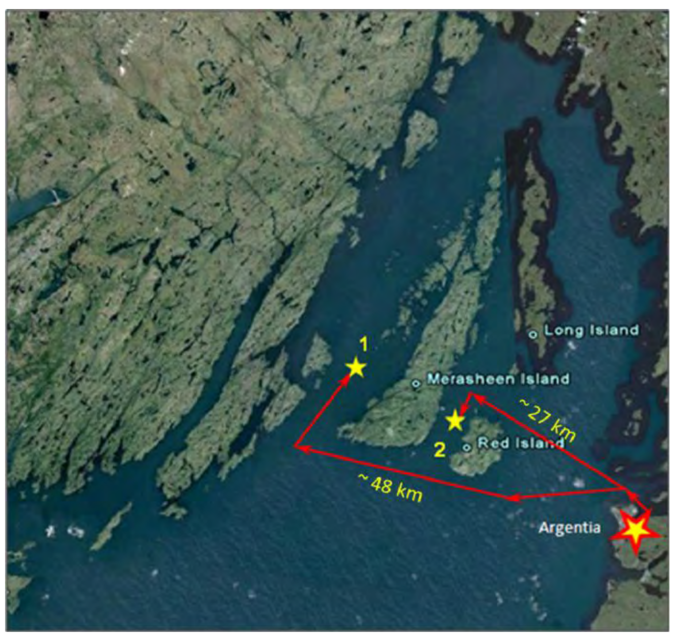


Figure 1-2 Graving Dock and Potential Deep-Water Mating Sites

2.0 Fate and Behaviour of Hydrocarbon Spills in the Near-Shore Study Area

2.1 Spill Scenarios of Interest

The only potential sources of marine spills from the WREP near-shore operations are batch spills of fuel oil as a result of ship accidents or groundings during the tow-out activities from the graving dock to the deep-water mating site and the support vessel activities during the top-sides installation (pers. com. D. Pinsent, Husky Energy). Batch spills are considered instantaneous events and are modeled by considering the surface spreading, evaporation, dispersion, emulsification and drift of a single patch or slick of oil.

2.2 Spill Modelling Inputs

The oil property data, spill volumes, air and water temperatures, winds and water currents used in the near shore spill behavior and trajectory model are described in the following sections.

2.2.1 Oil Properties

The tugs and supply vessels that will be used in the near shore operations will be fueled by marine gas oil (MGO) which is similar in makeup and spill behavior to diesel fuel. Oil property data for diesel oil from Environment Canada's online oil property database (www.etc-cte.gc.ca/databases/spills/oil_prop_e.html) have been used to develop the modelling inputs, shown in Table 2-1. These data have been used in SL Ross's oil spill model (SLROSM) to predict oil evaporation, emulsification, dispersion and property change.

2.2.2 Discharge Volumes and Flow Rates

Instantaneous batch spills of 100 m^3 and 350 m^3 barrels have been modeled for diesel. The two spill sizes have been chosen as representative of a reasonably large spill and the maximum possible spill size based on the fuel tank capacity of the vessels that will be operating in the near shore.

Table 2-1 Oil Property Parameters Used in SLROSM Fuel Oil Spill Modelling

Oil Property	Diesel Fuel
Initial Density (kg/m3)	827.0
Standard Density Temperature (°C)	288.0
Density Constant 1	200.0
Density Constant 2	0.733
Initial Viscosity (cP)	5.0
Standard Viscosity Temperature (°C)	313.0
Viscosity Constant 1	8.755
Viscosity Constant 2	1607.0
Oil Water Interfacial Tension (dynes/cm)	37.0
Water Interfacial Tension Constant	0.0
Oil Air Interfacial Tension (dynes/cm)	22
Air Interfacial Tension Constant	0.0
Initial Pour Point (°C)	243.0
Pour Point Constant	0.139
ASTM Distillation Constant A (slope)	285.0
ASTM Distillation Constant B (intercept)	473.0
Emulsification Delay	99999999999
Fv Theta A	6.3
Fv Theta B	10.3

2.2.3 Water Currents

Surface water current fields developed by the Ocean Sciences Division, Maritimes Region (Atlas of Ocean Currents in Eastern Canadian Waters, Wu and Tang et.al. 2011) and by the Biological and Physical Oceanography Section, Northwest Atlantic Fisheries Centre (Han 2012), both of Fisheries and Oceans Canada (DFO), were used in the spill trajectory modelling. The east coast Atlas data were supplemented by the higher resolution surface water current field provided by the Northwest Atlantic Fisheries Centre for the Placentia Bay modelling. Seasonal mean surface water velocities were provided by DFO and these were converted to a map format used by the SL Ross oil spill model (SLROSM). Surface water current maps for spring (April to June), summer (July to September), and winter (January to March) seasons were used in the modelling. Coarse representations of the summer vector fields for the near shore study areas are provided in Figure 2-1. These water currents were combined with 3% of the average winds to determine the surface water currents influencing the initial formation and movement of the oil slicks.

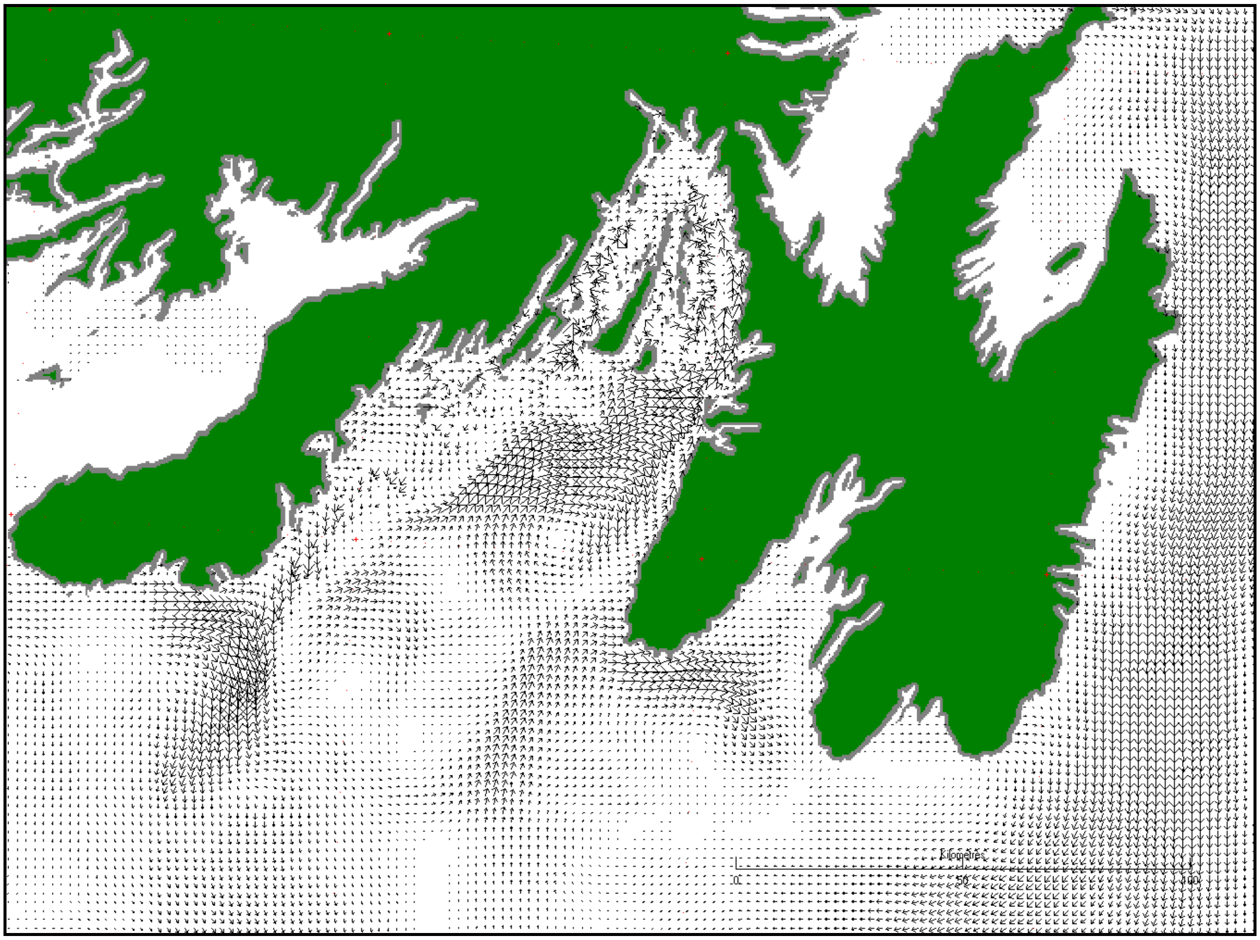


Figure 2-1 Near Shore Summer Surface Water Current Vectors

2.2.4 Air and Water Temperatures

The monthly average air and water temperatures used in the Placentia Bay historical near shore oil fate trajectory modelling are shown in Table 2-2. Summer and winter average air temperatures of 13.5°C and -0.9°C, respectively, were used in the seasonal oil fate modelling. Summer and winter average water temperatures of 14°C and 2.0°C, respectively, were used in the seasonal oil fate modelling.

Table 2-2 White Rose Placentia Bay: Average Monthly Air and Water Temperatures

Medium	Average Temperatures (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air	-0.6	-1.6	-0.4	1.7	4.3	8.0	12.5	14.8	13.2	9.2	5.4	2.2
Water	2	2	2	2	2	14	14	14	14	14	8	8

(source: AMEC 2012. ICOADS air temperatures, BIO Hydrographic Database water temperatures)

2.2.5 Winds

The MSC50 Wind data (Swail et. al.2006) were used in the detailed spill trajectory modelling reported in section 2.4. The data set has wind and wave data for the years 1954 to 2010. Six-hourly wind speed and direction data were extracted from the full MSC 50 data set at grid points with 0.5 degree spacing over the entire study area and at 0.1 degree spacing within Placentia Bay. The Placentia Bay seasonal spill behaviour modelling uses summer and winter average wind speeds of 6.2 m/s and 10.0 m/s, respectively. These were derived from the monthly wind data presented in Table 2-3.

Table 2-3 White Rose Placentia Bay: Average Monthly Wind Speeds and Predominate Directions

Parameter	Average Wind Speeds and Predominate Direction											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Speed (m/s)	10.6	10.0	9.3	8.0	6.3	5.7	5.4	6.0	7.2	8.6	9.4	10.4
Direction	W	W	W	W	SW	SW	SW	SW	WSW	W	W	W

(source: AMEC 2012. Average of Data from 3 MSC50 Grid Points)

2.3 Oil Spill Fate Modelling Results

2.3.1 Spill Behaviour: Average Environmental Conditions

Two diesel fuel spill scenarios have been considered in Placentia Bay with spill volumes of 100 cubic metres (reasonable large spill) and 350 cubic metres (maximum volume of fuel on board). Table 2-4 shows the fate of the “batch” spills for the winter and summer seasons. The winter and summer scenarios were modeled using the average seasonal air and water temperatures provided in section 2.2.4 and the average winter and summer wind speeds shown in section 2.2.5. The following discussions assume that the spilled oil persists on the ocean surface and does not contact shore prior to loss of the surface slick. Spills within Placentia Bay could reach shore prior to complete evaporation and dispersion under certain wind and water current conditions. Section 2.4 looks at the issue of time to shore and shoreline contact locations in detail.

There are not any large differences in the behavior of the spills in the two seasons from the perspective of spill countermeasures and impacts. Since the near shore on-water WREP operations are scheduled to be completed in the late spring or summer months the most relevant fate information to consider are the summer values. The winter data are provided in Table 2-4 to show the range of possible spill behavior based on seasonal differences. The summer discharges lose about 37% of the diesel to evaporation while the winter scenario lose only about 25% by evaporation; the higher summer evaporation is due to a combination of the warmer summer temperatures and the longer slick survival times due to the less energetic summer conditions. The following data are discussed only for the summer season for the two spill sizes and assumes that the oil does not reach shore. The diesel fuel from the 100 and 350 m^3 batch spill scenarios will disperse or evaporate from the surface within about 52 and 67 hours, respectively and the surface slicks will travel distances of about 43 to 53 km (again, if they do not reach shore). The peak diesel concentration in the upper 30 m is estimated to be 0.7 and 1.1 ppm for the 100 and 350 m^3 releases, respectively. Within 52 hours the naturally dispersed oil clouds in the water column from the 100 m^3 spills will grow to a width of about 5 km and diffuse to 0.1 ppm oil concentration (assuming a conservative 30 m mixing depth). The concentration of 0.1 ppm of total petroleum hydrocarbon is the exposure concentration below which no significant biological effects are expected. The 0.1 ppm threshold is based results of many lab toxicity studies reviewed over many years (French-McCay, 2004). The dispersed oil clouds from the 350 m^3 spills will diffuse to 0.1 ppm within 90 hours and reach a diameter of 9.5 km. The dispersed oil clouds from the 100 m^3 spills will travel 43 km prior to reaching 0.1 ppm; the oil clouds from the 350 m^3 spills will travel 63 km, assuming average water currents and wind.

Table 2-4 Placentia Bay Batch Diesel Spill Characteristics: Average Environmental Conditions

Spill Volume m^3 (bbl)	Season	Initial Slick Width (m)	Slick Survival Time (hr)	Max. Slick Width (m)	Total Evap. %	Max Oil Viscosity (cP)	Dist. to Loss of Slick (km)	Peak Disp. Oil Conc. (ppm)	Time to Peak Conc. (hr)	Time to 0.1 ppm (hr)	Cloud Width at 0.1 ppm (m)	Distance to 0.1 ppm (km)
100 (630)	Winter	80	29	250	25	1311	36	1.9	6	54	5,200	43
100	Summer	80	52	269	37	2975	43	0.7	6	52	5,050	43
350 (2200)	Winter	150	39	410	25	1360	47	2.9	6	96	10,200	58
350	Summer	150	67	440	37	3080	53	1.1	6	90	9,500	63

2.3.2 Spill Trajectories Placentia Bay: Average Conditions

Spill trajectories have been run from three locations in Placentia Bay using average summer wind speeds and prevailing water currents. The three locations selected were the mid-point between the graving dock and Red Island and the two proposed deep-water mating sites. The modelling results are shown in Figure 2-2. These basic trajectories illustrate the general movement of spills from hypothetical spill sites in the near shore operation. These slicks move to the NE due to the prevailing SW summer winds and local water currents and took 19.5, 22.7 and 67 hours to reach shore.

Section 2.4 provides more details on possible spill movements and shore contact timing and locations based on a detailed assessment using 57 year of historical winds.

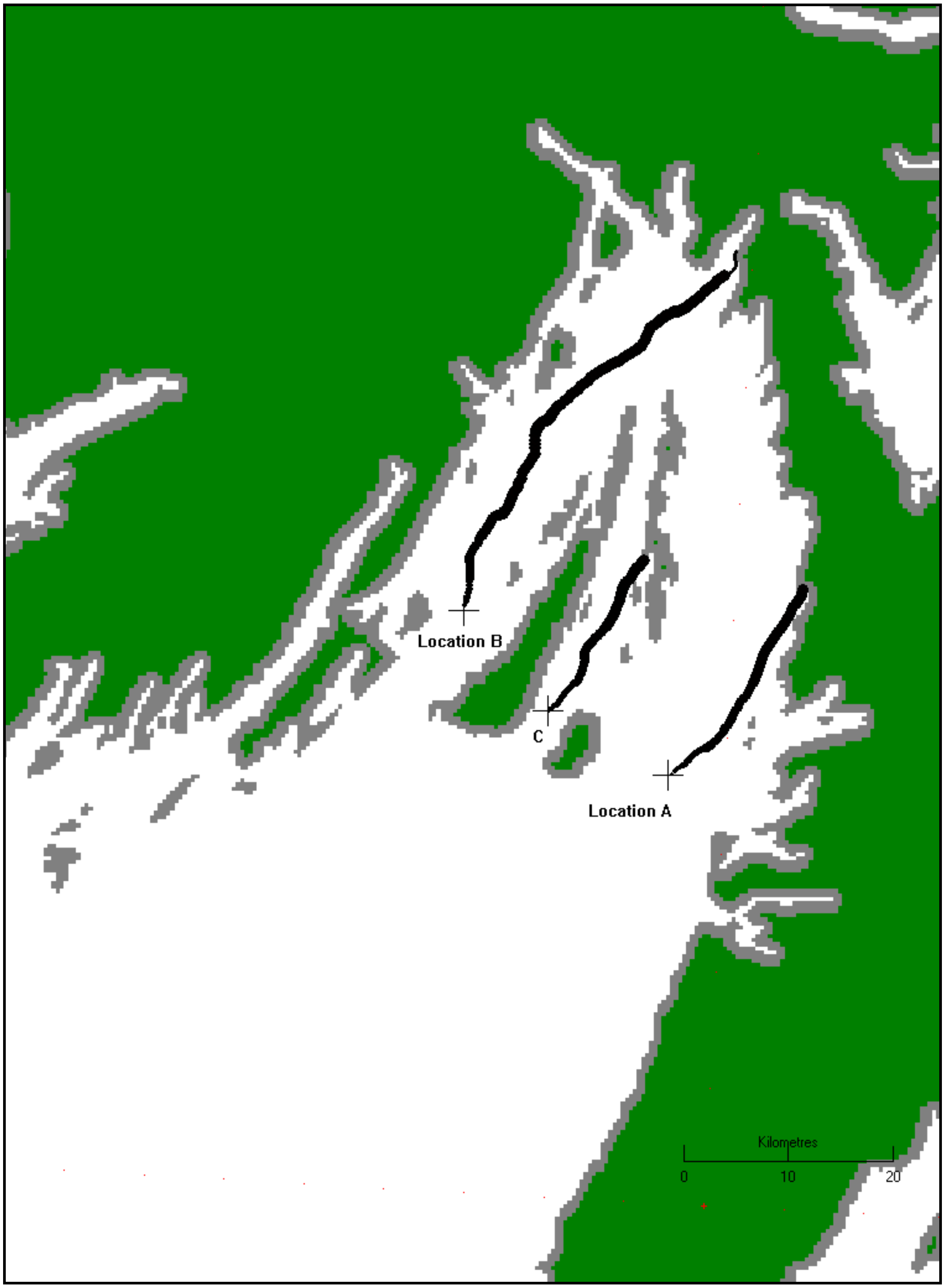


Figure 2-2 Average Conditions Trajectory Modelling: 350 m3 Batch Diesel Spills

2.4 Historical Spill Trajectory Assessment

A total of 8721 trajectories from batch diesel spills were run in this analysis from locations A and B shown in Figure 2-2. These trajectories used the 57 years of wind data available from the MSC50 dataset as described in Section 2.2.5. Trajectories were completed in the months of March, April, May, June and July as these are the months when marine-based activities likely will be occurring in the near shore. For months with 30 days a total of 1710 individual slick trajectories were followed, one released every day starting at the beginning of the first day in each the month. For months with 31 days a total of 1767 trajectories were modelled. The shoreline contact statistics on a monthly basis from these hypothetical spills are provided in Table 2-5 for Location A and Table 2-6 for Location B. A high percentage of slicks reach shore due to the close proximity of the spill sites to land and the prevailing W or SW winds. The minimum time to shore values ranged from 2 to 5 hours. The minimum and maximum survival times for slicks that did not reach shore but instead evaporated and dispersed offshore are shown in the last two columns of Tables 2-5 and 2-6. The minimum survival times were on the order of 0.5 to 1 day and the maximum survival times between 4.5 to 8 days.

Table 2-5 Slick Shoreline Contact and Slick Life at Sea for 350 m3 Batch Diesel Spills From Location A

Month	Number of Slicks Tracked	# of Slicks Tracked Reaching Shore	Minimum Time to Shore (hr)	Maximum Time to Shore (hr)	Minimum Slick Life at Sea (hr)	Maximum Slick Life at Sea (hr)
March	1767	1548	4	94	12	130
April	1710	1476	4	122	16	132
May	1767	1530	4	126	22	184
June	1710	1554	4	143	16	165
July	1767	1532	5	131	17	194

Table 2-6 Slick Shoreline Contact and Slick Life at Sea for 350 m3 Batch Diesel Spills From Location B

Month	Number of Slicks Tracked	# of Slicks Tracked Reaching Shore	Minimum Time to Shore (hr)	Maximum Time to Shore (hr)	Minimum Slick Life at Sea (hr)	Maximum Slick Life at Sea (hr)
March	1767	1636	2	111	13	106
April	1710	1611	2	137	16	104
May	1767	1657	3	159	21	165
June	1710	1551	3	159	20	152
July	1767	974	4	145	17	195

The time-to-shore data for all five months has been combined and plotted in Figures 2-3 and 2-4 for locations A and B, respectively. During the near-shore operations period between March and July over 55% of the time slicks will reach shore within less than 24 hours and over 75% of the time they will reach shore within 48 hours. This is based on the 57 years of MSC50 wind data used to drive the trajectories.

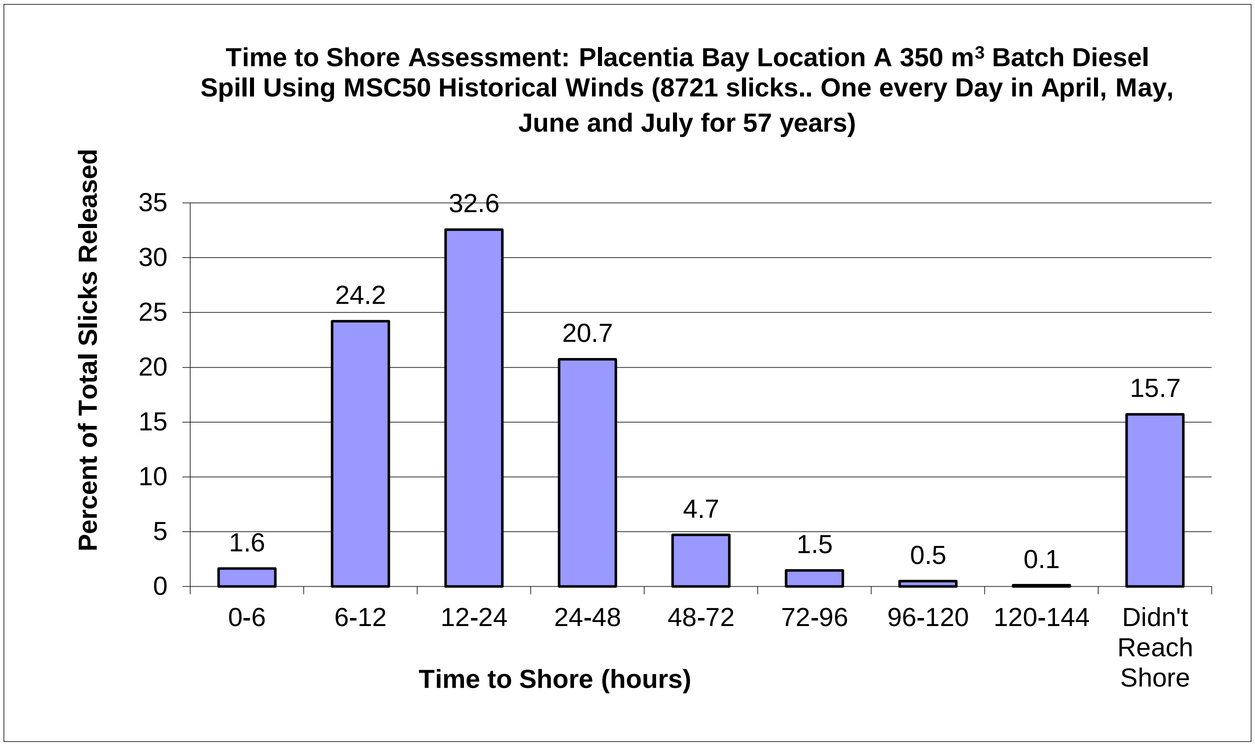


Figure 2-3 Time to Shore Statistics Placentia Bay Location A

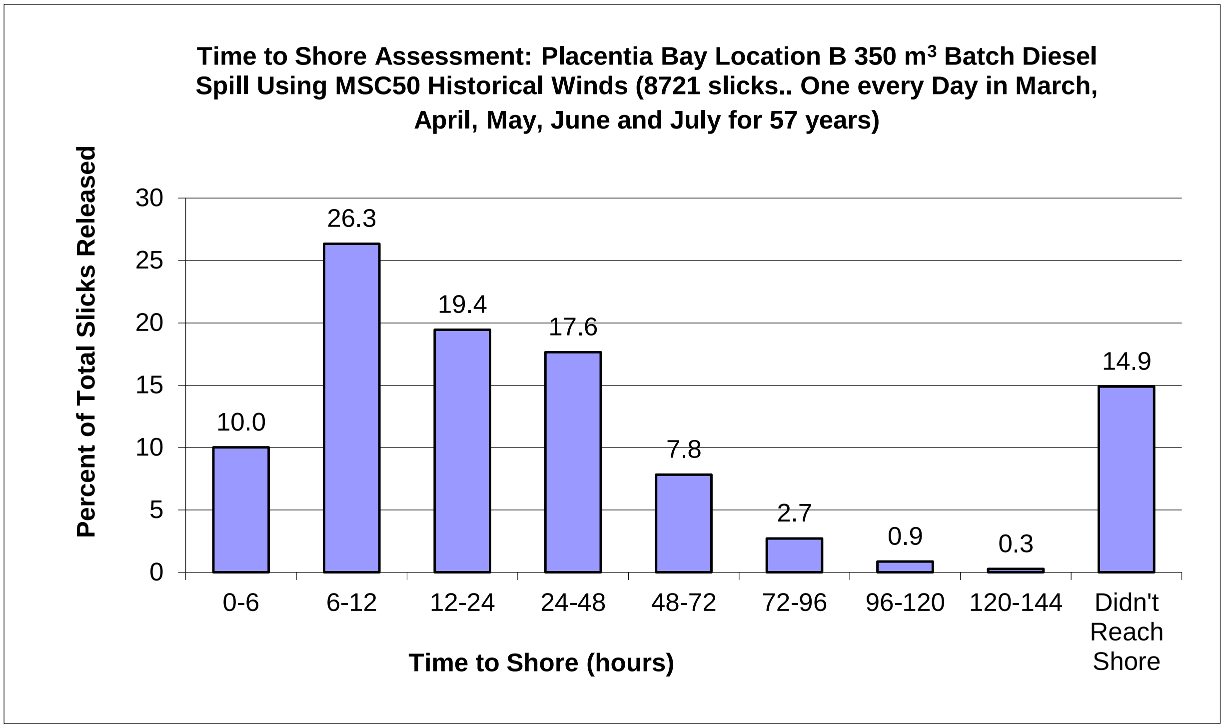


Figure 2-4 Time to Shore Statistics Placentia Bay Location B

The trajectory data has been further processed, on a monthly basis, to identify the probability of a slick reaching specific areas. The slick movements for all spills released in a given month of the year, for the 57 years of data, have been processed to identify the percent of the spills released in the month that enter each grid area in a 1 km x 1 km grid placed over the study area. Figures 2-5 through 2-9 show the spill movement probabilities on a month by month basis for releases from Location A, as identified in Figure 2-2. The total sweep area of each slick has been used in this assessment. The zones on these figures represent areas where 1 to 5% of the slicks released over the 57 years of trajectory processing will pass (light green), 5 to 10% (yellow), 10 to 25% (brown), 25 to 50% (red), and 50 to 100% (black). These figures provide insight into the most likely path of oil and which shore zones are most likely to be oiled based on the 57 years of available wind data. These figures **do not** show areas covered by oil at a point in time but rather identify the probability that oil from a release on any given day will pass through the zone. For releases from location A, the figures show that the oil will generally move to the east and is more likely to contact shore along the western shore of the Avalon Peninsula in Placentia Bay. The likelihood of oil reaching the Burin Peninsula from spills at Location A is small.

Figure 2-5 Batch Spill Trajectory Probabilities for Location A Release: March

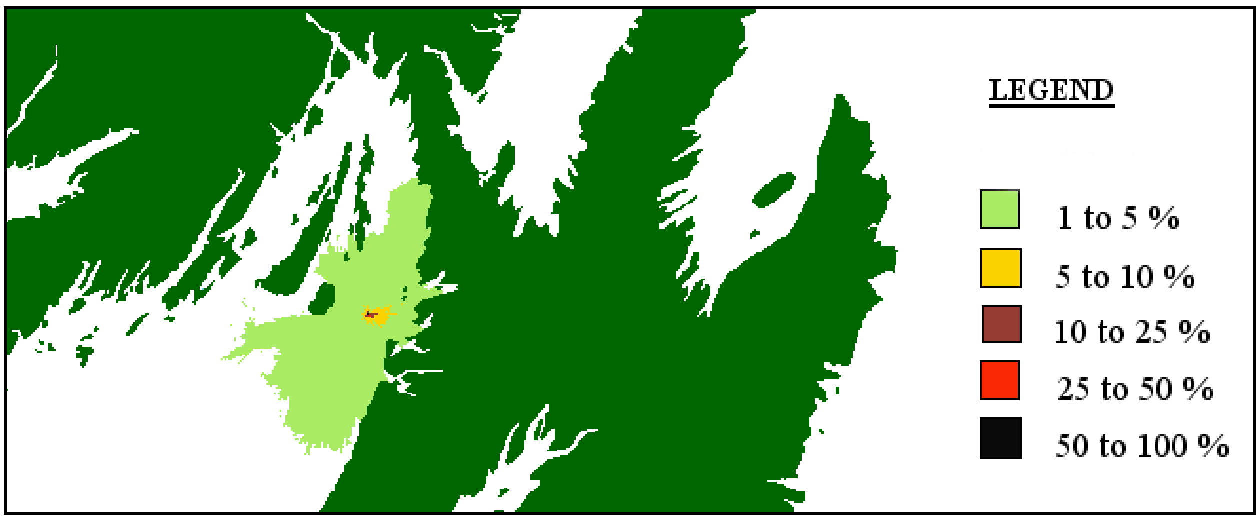


Figure 2-6 Batch Spill Trajectory Probabilities for Location A Release: April

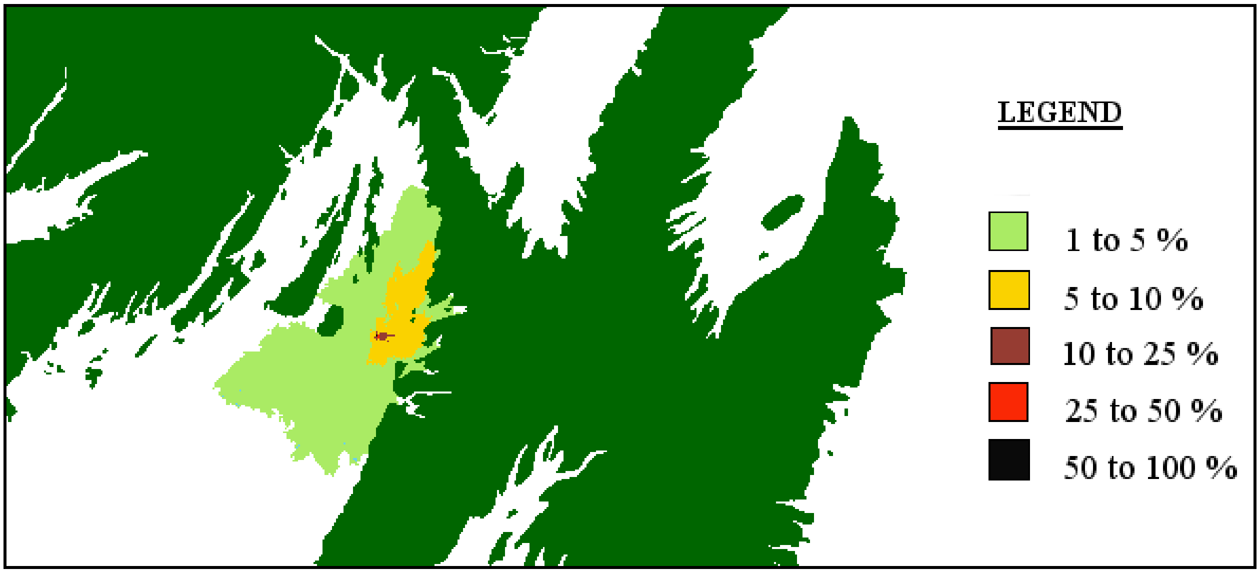


Figure 2-7 Batch Spill Trajectory Probabilities for Location A Release: May

Figure 2-8 Batch Spill Trajectory Probabilities for Location A Release: June

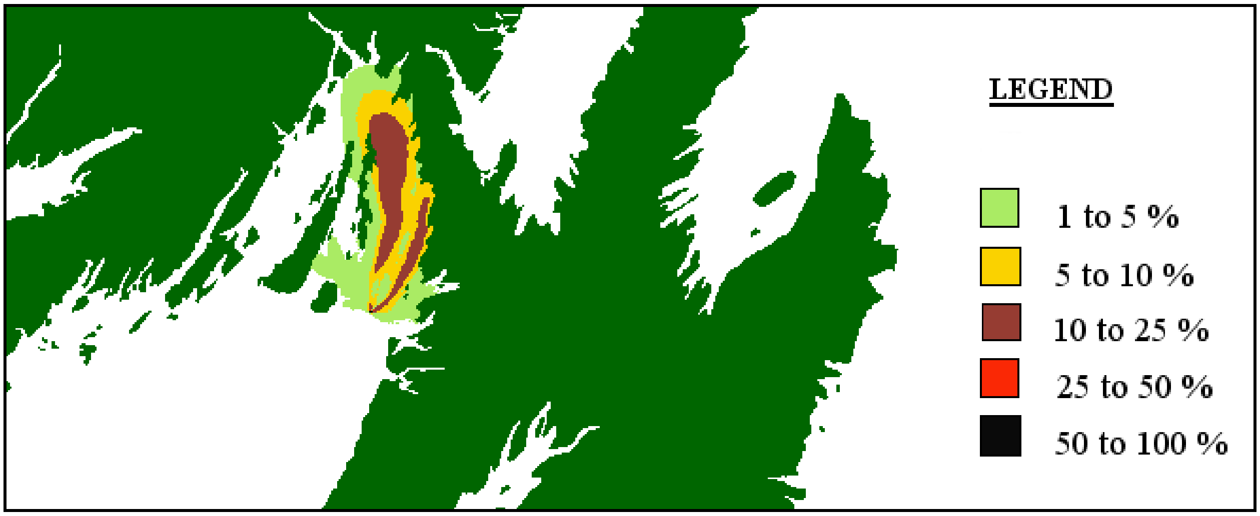


Figure 2-9 Batch Spill Trajectory Probabilities for Location A Release: July

Figures 2-10 through 2-14 show the spill movement probabilities on a month by month basis for releases from Location B, as identified in Figure 2-2. Spills from this location will tend to contact shore areas in the upper reaches of Placentia Bay and the eastern shores of the Burin Peninsula. In May, June and July there is a stronger tendency for the oil to move consistently to the north-east.

Figure 2-10 Batch Spill Trajectory Probabilities for Location B Release: March

Figure 2-11 Batch Spill Trajectory Probabilities for Location B Release: April

Figure 2-12 Batch Spill Trajectory Probabilities for Location B Release: May

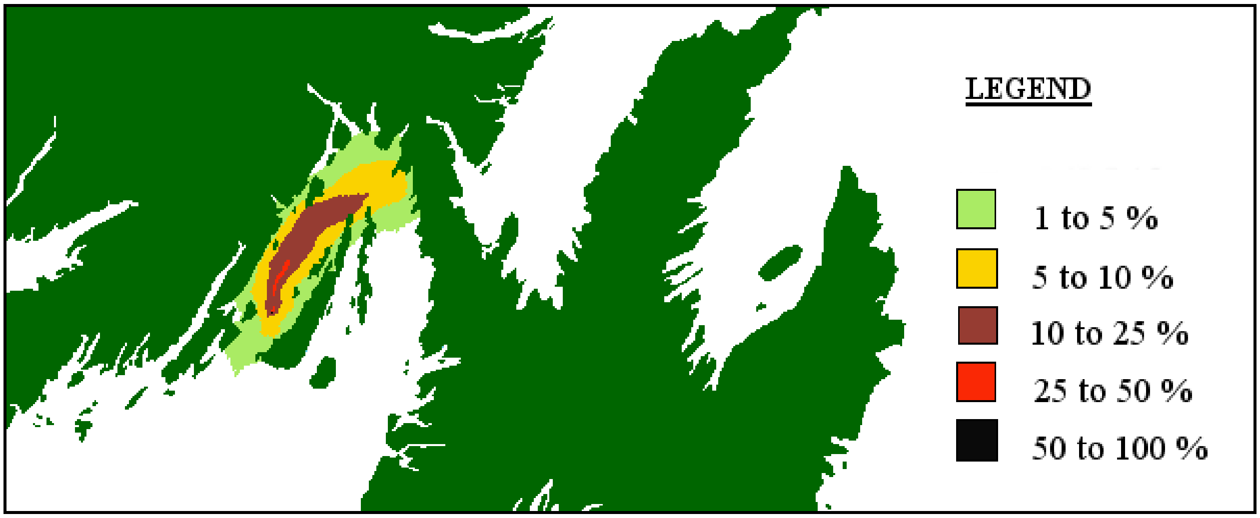


Figure 2-13 Batch Spill Trajectory Probabilities for Location B Release: June

Figure 2-14 Batch Spill Trajectory Probabilities for Location B Release: July

3.0 Fate and Behaviour of Hydrocarbon Spills in the Offshore

3.1 General Oil Spill Behaviour of Spill Scenarios of Interest

The following sections describe the general behaviour of oil associated with the key spill scenario types that may occur during the offshore activities of the WREP: small fuel oil batch spills from vessels or the platform, and subsea and above surface crude oil blowouts from the offshore drilling activities.

3.1.1 Small Batch Spills

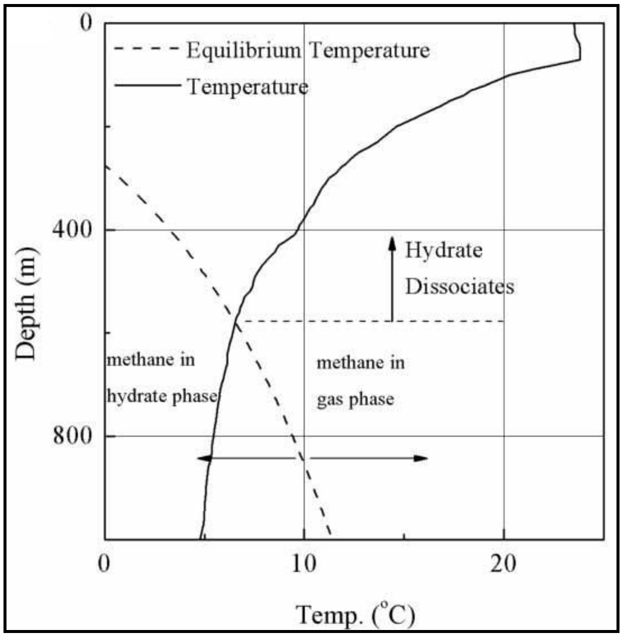
Small batch spills of diesel fuel from hose ruptures during transfer operations from a supply vessel or from platform storage facilities are a possibility during drilling operations. Ship collisions could conceivably result in larger batch spills of fuel oil up to a maximum volume of the size of the vessels fuel tanks. Batch spills are considered instantaneous events and are modeled by considering the surface spreading, evaporation, dispersion, emulsification and drift of a single patch or slick of oil.

3.1.2 Subsea Blowouts

Well blowouts generally involve crude oil (or gas condensate) and natural gas. The volume ratio of the oil and gas is a function of the characteristics of the fluids and the producing reservoir. The natural gas, being a compressible fluid under pressure at reservoir conditions, provides the driving force for an uncontrolled blowout. As the well products flow upwards, the gas expands, finally exiting at the well head at very high velocities. At this point oil often makes up only a small fraction of the total volumetric flow.

Subsea blowouts can be classified as shallow- or deep- water blowouts based on the behavior of the gas once it exits and comes in contact with water. Deep water blowouts are those where the gas exiting from the subsea release point quickly combines with water to form a solid ice-like substance known as hydrates that form under high pressure and cold temperatures. The gas volume may also be depleted through dissolution into the water. With the loss of gas through either or both of these processes, the driving buoyancy of a rising gas bubble plume may be completely lost, which will result in the oil droplets rising slowly under gravity forces alone. The movement of the oil droplets is affected by cross currents during their rise. This will result in the separation of the oil droplets based on their drop size. The large diameter oil drops will surface first and smaller drops will be carried further down current prior to reaching the surface. Oceanic diffusion processes will result in additional separation of the oil drops due to their varying residence times in the water column. The 2010 BP Macondo blowout in the Gulf of Mexico was a deep-water subsea blowout.

In 5°C waters deeper than about 600 to 700 m complete conversion of the gas to solid hydrates is likely whereas in 5°C waters less than about 500 m deep little hydrate formation is likely. The phase diagram for methane presented in Figure 3-1 provides guidance in the likely formation of hydrates as a function of water depth (pressure) and temperature. The formation of hydrates is also dependent on the actual composition of the gas and impurities in the gas and water so there is some uncertainty in the prediction of hydrate formation in water depths between 400 to 800 m. Because the water depth at the proposed drilling site is only about 120 m deep and the water temperature is 5°C or more, a subsea blowout at this site would behave as a shallow-water event in this situation and conversion of gas to hydrate will not occur.



Source: from Yapa et al 2010

Figure 3-1 Methane Phase Diagram

In a shallow water blowout most or all of the gas does not convert to hydrates and a gas bubble plume develops that powers the movement of oil and gas and entrained water quickly to the water surface. Oil and gas released from a shallow subsea blowout pass through three zones of interest as they move to the sea surface (Figure 3-2). The high velocity at the well head exit generates the jet zone dominated by the initial momentum of the gas. This highly turbulent zone is responsible for the fragmentation of the oil into droplets ranging from 0.5 to 2.0 mm in diameter (Dickins and Buist 1981). Because water is also entrained in this zone, there is a rapid loss of momentum a few metres from the discharge location. In the buoyant plume zone, momentum is no longer significant relative to buoyancy, which then becomes the driving force for the remainder of the plume. In this region, the gas continues to expand due to reduced hydrostatic pressures. As the gas rises, oil and water in its vicinity are entrained in the flow and carried to the surface.

Although the terminal velocity of a gas bubble in stationary water is only about 0.25 m/sec, velocities in the center of blowout plumes can reach 5 to 10 m/sec due to the pumping effect of the rising gas in the bulk liquid. That is, the water surrounding the upward moving gas is entrained and given an upward velocity, which is then increased as more gas moves through at a relative velocity of 0.25 m/sec. When the plume becomes fully developed, a considerable quantity of water containing oil droplets is pumped to the surface.

In the surface interaction zone, the upward flow of water turns and moves in a horizontal layer away from the center of the plume. The influence of the surface water current causes this radial flow to turn and form a parabolic surface influence as seen in Figure 3-2. This surface influence carries the oil down-current and spreads it over the surface up to the point where this flow no longer affects the surface water motion (between 1 to 1.5 slick widths down-current). At this point the oil moves with the prevailing currents and spreads as any batch spill of oil would. The gas exits from the center of the plume and causes a surface disturbance or “boil zone” identified by the arrows in the top view of Figure 2-2. At the surface, the oil is spread into an area much faster than conventional oil slick diffusion or spreading rates.

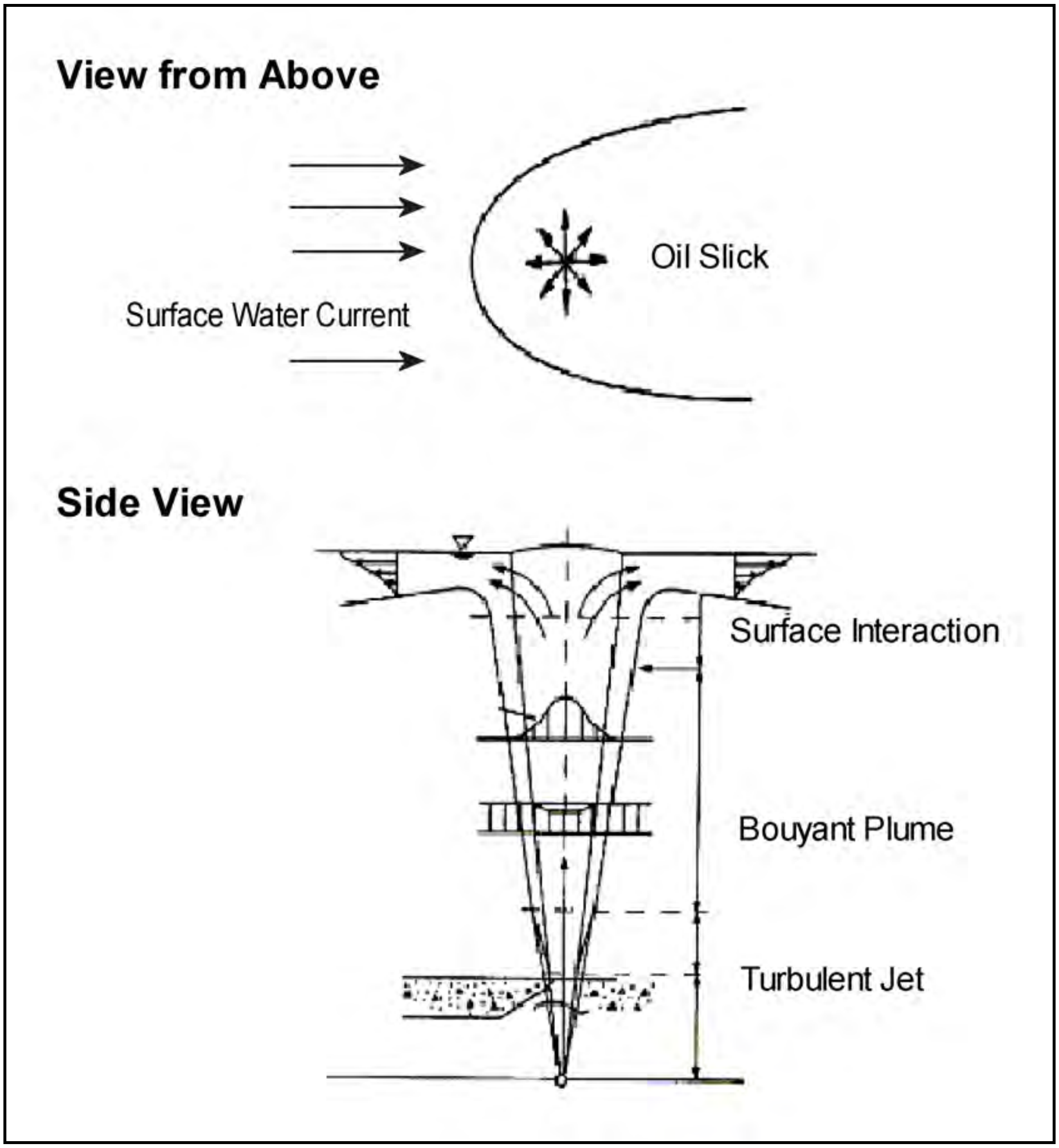


Figure 3-2 Subsea Blowout Schematic

The equations of motion and supporting parameters developed by Fannelop and Sjoen (1980) have been used to model the behaviour of subsea gas and oil releases. These equations and their numerical solution form the basis for the subsea modelling component of the SL Ross Oil Spill Model (SLROSM) used in this report to estimate the oil slick characteristics from shallow subsea blowouts.

3.1.3 Above-Surface Blowouts

Oil released during a blowout from an offshore platform above the water's surface will behave differently than that from a subsurface discharge. The gas and oil will exit at a high velocity from the well-head and will be fragmented into a cloud of fine droplets. The height that this cloud rises above the release point will vary depending on the gas velocity and the prevailing wind velocity. Atmospheric dispersion processes and the settling velocity of the oil particles determine the fate of the oil and gas at this point.

Figure 3-3 illustrates a simple Gaussian model of this behaviour that can be used to predict the concentrations of oil and gas downwind from the release point. Atmospheric dispersion is controlled in part by atmospheric turbulence that is influenced by solar radiation, wind speeds and temperatures.

On clear, sunny days, with light winds, solar radiation will create highly turbulent conditions. Overcast conditions regardless of the winds will result in a neutral atmospheric stability. Low winds will tend to make mixing more prominent whereas high winds tend to reduce the vertical and lateral mixing conditions. The shape of the concentration profile of the plume will vary depending on the atmospheric stability. In very stable conditions the spread both vertically and laterally will be less than in very turbulent conditions.

The atmospheric plume representation shown in Figure 3-3 can also be used to illustrate the behaviour of oil droplets with the following two modifications. The plume centerline is sloped down to account for the oil droplets' fall velocities. The oil will "rain" down, with the larger droplets falling closer to the release point. As oil drops fall, they will also be spread by atmospheric turbulence. A portion of the falling oil evaporates and the remainder eventually lands on the water and is carried down current. As water passes through the area of falling oil it will be "painted" by the falling oil and an accumulation of oil over the width of the fallout zone will occur. Changing wind and water current directions will affect the ultimate distribution of the oil on the water surface in the fallout zone. If the gas and oil is blowing through the derrick or some other obstruction, some of the oil droplets may agglomerate on the obstruction(s) and flow down onto the rig floor and eventually to the water surface. This portion of the oil will then behave more like a continuous surface release of oil.

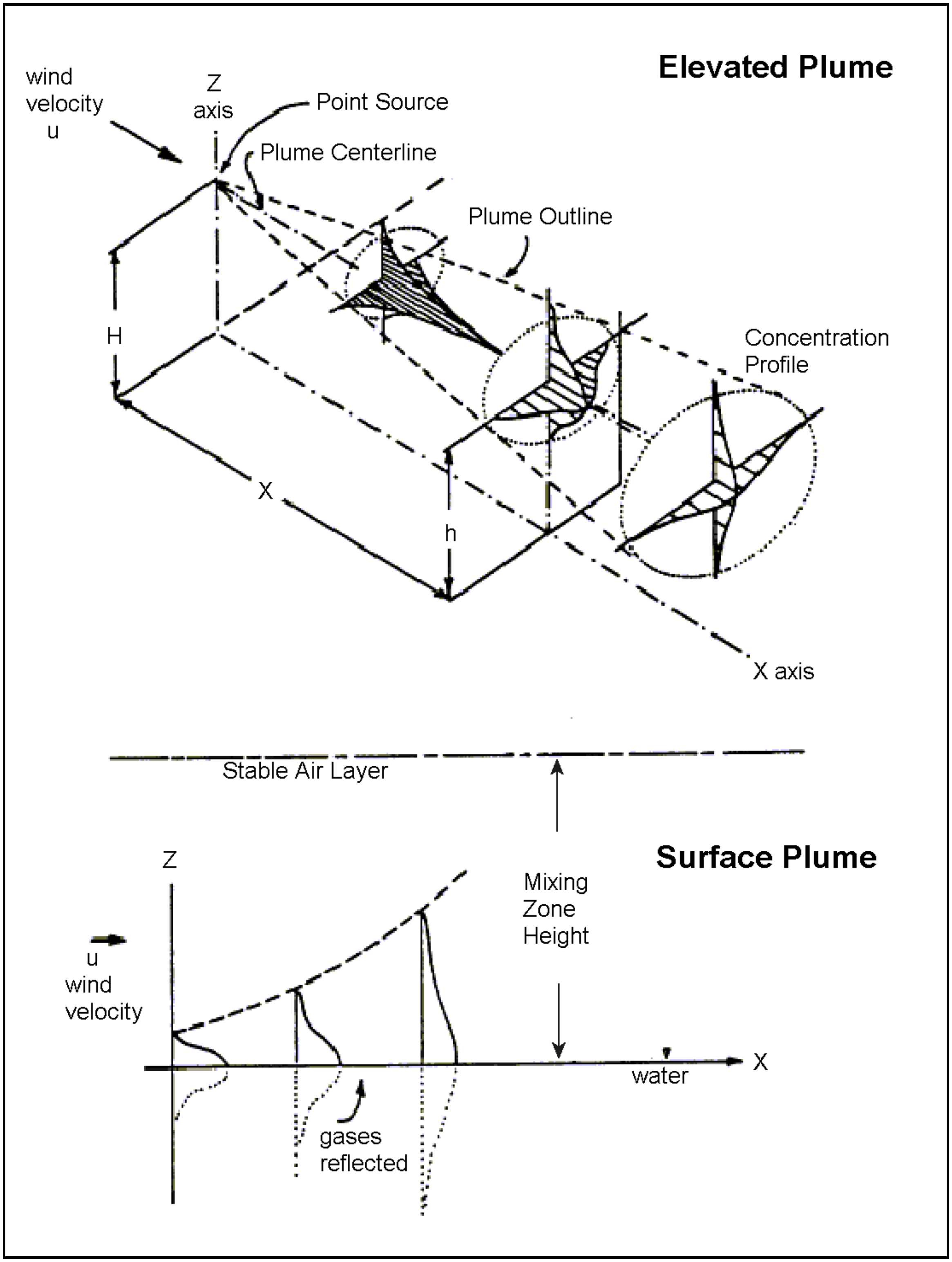


Figure 3-3 Plume Behaviour Schematic

3.2 Spill Modelling Inputs

The oil property data, spill flow rates and volumes, air and water temperatures, winds and water currents used in the spill behavior and trajectory model are described in the following sections.

3.2.1 Oil Properties

Husky Energy have indicated that the crude oil presently being produced from the existing White Rose operation will be representative of the crude likely to be encountered in the extension project. A November 2011 sample of White Rose crude oil was provided to SL Ross for weathering and physical property analysis to gather the information necessary to complete oil fate and behaviour modelling using the SL Ross oil spill model, SLROSM. Summaries of the measured fresh and weathered oil property data for the recent sample of White Rose crude oil are provided in Table 3-1.

Similar oil property data for diesel oil was taken from Environment Canada's online oil property database (www.etc-cte.gc.ca/databases/spills/oil_prop_e.html) for use in the diesel spill scenario modelling.

Table 3-2 shows the oil property modelling parameters derived from the fresh and weathered properties for the two oils that were used in the SLROSM.

Table 3-1 White Rose Crude Oil (Nov. 2011) Fresh and Weathered Properties

Spill-related properties		White Rose	API°=	31.53		
Evaporation (Volume %)		**0**		**4.70**		**14.12**
Density (g/cm^3)						
15	°C	0.869		0.877		0.887
30	°C	0.853		0.862		0.872
Dynamic Viscosity (mPa.s)	at approx 30 s^{-1} for 0° and 115 s^{-1} for 15°					
0	°C	928		1,461		2,146
15	°C	39		66		134
Kinematic Viscosity (mm^2/s)						
0	°C	1,068		1,666		2,419
15	°C	45		76		154
Interfacial Tension (dyne/cm)						
Oil/	Air	27.6		27.4		29.5
Oil/	Seawater	19.3		20.4		21.6
Pour Point (°C)						
		3		6		15
Flash Point (°C)						
		1		9		6
(gelled oil samples flashed as soon as stirrer activated)						
Emulsion Formation-Tendency and Stability @				0	°C	
Tendency		Likely		Likely		Unlikely
Stability		Stable		Stable		Gelled
Water Content		63%		61%		0%
Emulsion Formation-Tendency and Stability @				16.3	°C	
Tendency		Unlikely		Likely		Likely
Stability		Unstable		Entrained		Entrained
Water Content		0%		39%		47%
ASTM Modified Distillation						
		Evaporation (% volume)		Liquid Temperature (°C)		Vapour Temperature (°C)
		IBP		143.2		39.2
		5		180		64.3
		10		212		73.6
		15		245		86
		20		277		129.4
		25		304		148.9
		30		333		164.1
		40		377		172.1
		0		396		169

Table 3-2 Oil Property Parameters Used in SLROSM Spill Modelling

Oil Property	White Rose Crude	Diesel Fuel
Initial Density (kg/m3)	867.9	827.0
Standard Density Temperature (°C)	288.7	288.0
Density Constant 1	128.5	200.0
Density Constant 2	1.010	0.733
Initial Viscosity (cP)	38.7	5.0
Standard Viscosity Temperature (°C)	288.16	313.0
Viscosity Constant 1	7.14	8.755
Viscosity Constant 2	15833.7	1607.0
Oil Water Interfacial Tension (dynes/cm)	19.4	37.0
Water Interfacial Tension Constant	0.836	0.0
Oil Air Interfacial Tension (dynes/cm)	27.2	22
Air Interfacial Tension Constant	0.543	0.0
Initial Pour Point (°C)	275.72	243.0
Pour Point Constant	0.314	0.139
ASTM Distillation Constant A (slope)	609.98	285.0
ASTM Distillation Constant B (intercept)	425.4	473.0
Emulsification Delay	30000	99999999999
Fv Theta A	6.7	6.3
Fv Theta B	13.0	10.3

3.2.2 Discharge Volumes and Flow Rates

Instantaneous batch spills of 1.6 m^3 (10 barrels), 16 m^3 (100 barrels), 100 m^3 (630 barrels) and 350 m^3 (2200 barrels) have been modeled for marine diesel. The two smallest spill sizes were chosen as they are representative of small and medium sized platform spills based on historical records. The larger spill sizes were chosen to illustrate the behavior of large diesel spill sizes. The modelling of the continuous releases of gas and oil from well blowouts has been completed using the gas and oil flow rates shown in Table 3-3. The blowout flow rates identified in Table 3-3 were determined by Husky Energy engineers based on the best available reservoir information.

Table 3-3 Spill Flow Rates and Volumes Used in Modelling

Spill Type	Source	Flow	Gas-to-Oil Flow Ratio m^3/m^3
Crude Oil Well Blowout (Max Flow at Start of Blow)	Subsea	6,435 m^3/day (40,476 BOPD)	138
	Platform	6,435 m^3/day (40,476 BOPD)	138
Crude Oil Well Blowout (Flow after 120 Days)	Subsea	3,963 m^3/day (24,927 BOPD)	275
	Platform	3,963 m^3/day (24,927 BOPD)	275
Batch Oil Spills	Transfer	1.6 m^3 (100 bbl)	na
	Transfer	0.16 m^3 (10 bbl)	na
	Vessel Accident	100 m3 (630 bbl)	na
	Vessel Accident	350 m3 (2200 bbl)	na

3.2.3 Water Currents

Surface water current fields developed by the Ocean Sciences Division, Maritimes Region of Fisheries and Oceans Canada (Wu and Tang et.al. 2011) were used in the spill trajectory modelling in the offshore study area. Seasonal mean surface water velocities were provided by Fisheries and Oceans Canada and these were converted to a map format used by the SL Ross Oil Spill model (SLROSM). Surface water current maps for Spring (April to June), Summer (July to September), Fall (October to December) and Winter (January to March) seasons were used in the modelling. Coarse representations of the Summer and Winter vector fields for the offshore study area are provided in Figures 3-4 and 3-5, respectively. These water currents were combined with 3% of the average winds to determine the surface water currents influencing the initial formation and movement of the oil slicks.

Figure 3-4 Offshore Summer Surface Water Current Vectors

Figure 3-5 Offshore Winter Surface Water Current Vectors

3.2.4 Air and Water Temperatures

The monthly average air and water temperatures used in the fate modelling for the detailed fate and trajectory modelling for the offshore are shown in Table 3-4. Summer and winter average air temperatures of 12.9˚C and 0.1˚C, respectively, were used in the seasonal oil fate modeling. Summer and winter average water temperatures of 12.3˚C and 0.5˚C were used in the seasonal oil fate modelling.

Table 3-4 White Rose Extension Site: Average Monthly Air and Water Temperatures

	Average Temperatures (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air	0.1	-0.4	0.3	1.9	4.1	7.1	11.9	14.3	12.6	8.8	5.1	2.1
Water	1.0	0.3	0.3	1.0	3.0	5.9	10.5	13.7	12.7	9.1	5.5	2.7

(source: Oceans Ltd 2012. ICOADS air and surface water temperatures)

3.2.5 Winds

The MSC50 Wind data set (Swail et. al.2006) was used in the detailed spill trajectory modelling completed in this study. The data set has wind and wave data for 57 years from 1954 to 2010. Six-hourly wind speed and direction data were extracted from the full MSC 50 data set at grid points with 0.5 degree spacing over the study area. The seasonal spill behaviour modelling used summer and winter average wind speeds of 6.7 m/s (SW) and 10.6 m/s (W), respectively. Table 3-5 shows the average monthly wind speeds on a monthly basis near the offshore site.

Table 3-5 White Rose Extension Site: Average Monthly Wind Speeds and Predominate Directions

	Average Wind Speeds and Predominate Direction											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Speed (m/s)	11.1	10.9	9.8	8.3	7.0	6.5	6.1	6.4	7.5	8.8	9.5	10.7
Direction	W	W	W	W	SW	SW	SW	SW	WSW	W	W	W

(source: Oceans Ltd 2012 MSC50 Grid Point 11034)

3.3 Oil Spill Fate Modelling Results

3.3.1 Diesel Batch Spill Fate Modelling

Four diesel fuel spill scenarios have been considered with spill volumes of 1.6, 16, 100 and 350 cubic metres. Table 3-6 shows the fate of the "batch" spills for the winter and summer seasons for the different spill volumes. The winter and summer scenarios were modeled using the average seasonal air and water temperatures and wind speeds provided in sections 3.2.4 and 3.2.5.

The summer discharges lose 36 to 38% of the diesel to evaporation while the winter scenarios lose about 25 to 27% by evaporation; this is due to a combination of the warmer summer temperatures and the more energetic winter conditions that disperse the oil more quickly thus reducing the opportunity for evaporation. The slicks in the winter are lost from the surface more quickly (13 to 37 hours in winter versus 25 to 62 hours in summer, depending on initial volume spilled) due to the higher winds and thus more energetic wave action. Surface oil will persist for 16 to 49 km from the source in the winter versus 22 to 62 km in the summer; the shorter distance in winter again due to the more rapid natural dispersion. The faster dispersion in the winter months results in higher peak in-water oil concentrations (0.6 to 3 ppm in winter versus 0.24 to 1.2 ppm in summer). The naturally dispersed oil in the water column is assumed to mix to a conservative depth of 30 metres. The clouds of dispersed oil from the winter spills will grow to widths of o 0.3 to 10.2 km at the point where the oil has diffused to below 0.1 ppm oil concentration. The winter dispersed oil clouds will sweep distances of 10 to 130 km prior to diffusing to a 0.1 ppm in-water oil concentration. The size of the summer spill clouds will be somewhat smaller (0.3 to 9.7 km) and they will sweep smaller distances (5 to 102 km). The in-water concentration of 0.1 ppm of total petroleum hydrocarbon is the exposure concentration below which no significant biological effects are expected (French-McCay 2004).

The maximum viscosity that the surface oil will reach in these batch spills is about 1700 cP in the winter and 3700 cP in the summer. The higher summer viscosity is due to the higher evaporation that results in a greater increase in viscosity than that caused by the colder winter water temperatures. These predicted maximum viscosities are significantly lower than viscosities that would hamper traditional containment and recovery countermeasures operations. Chemical dispersants also should remain effective on these diesel spills over the lifespan of the surface slicks.

Table 3-6 Batch Diesel Spill Characteristics

Spill Volume m^3 (bbl)	Season	Initial Slick Width (m)	Slick Survival Time (hr)	Max. Slick Width (m)	Total Evap. %	Max Oil Viscosity (cP)	Dist. to Loss of Slick (km)	Peak Disp. Oil Conc. (ppm)	Time to Peak Conc. (hr)	Time to 0.1 ppm (hr)	Cloud Width at 0.1 ppm (m)	Distance to 0.1 ppm (km)
1.6 (10)	Winter	10	13	50	26	1350	16	0.6	2	8	315	10
1.6	Summer	10	25	54	38	3700	22	0.24	2	4	275	5
16 (100)	Winter	32	19	120	27	1340	24	1.13	2	26	2,210	30
16	Summer	32	35	130	36	3070	31	0.5	2	18	1,490	17
100 (630)	Winter	80	28	247	25	1660	36	2.0	4	58	5,630	65
100	Summer	80	48	264	36	3075	45	0.8	4	54	5,210	55
350 (2200)	Winter	150	37	402	26	1320	49	3.0	6	98	10,400	130

350	Summer	150	62	430	36	2890	62	1.2	6	92	9,720	102

3.3.2 Offshore Diesel Spill Trajectories: Seasonal Average Environmental Conditions

Spill trajectories have been run from the White Rose platform location using average summer and winter wind speeds and prevailing water currents for the four diesel fuel spill volumes. The summer and winter trajectory results are shown in Figure 3-6 and 3-7, respectively. These basic trajectories illustrate the general movement of batch fuel oil spills from hypothetical spill at the offshore site. The locations where the surface oil slicks have completely evaporated and dispersed are marked on the figures as are the locations where the dispersed oil cloud concentrations drop to below 0.1 ppm concentration. For the smaller spills the plume concentrations are below this level prior to loss of the surface oil.

Section 3.4 provides more details on possible spill movements based on a detailed assessment using 57 year of historical winds.

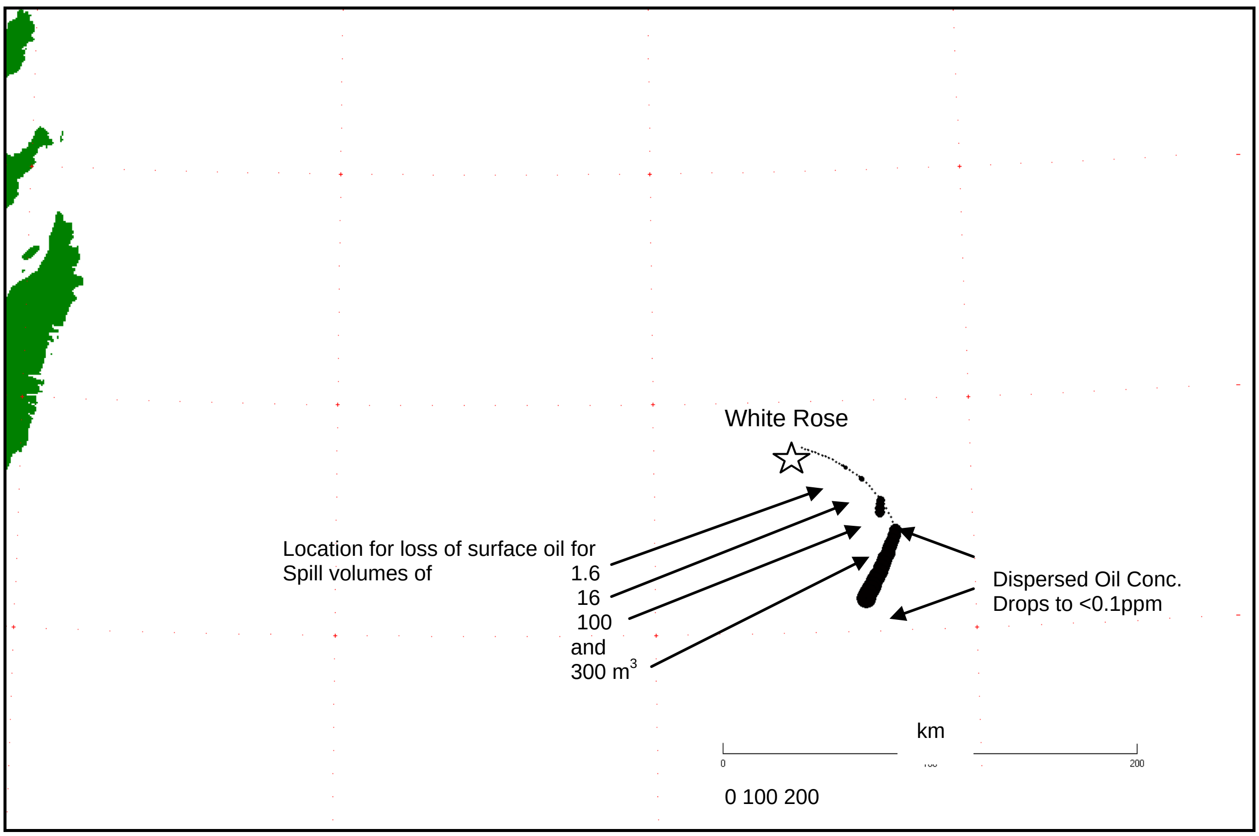


Figure 3-6 Offshore Summer Diesel Spill Trajectories: Average Environmental Conditions

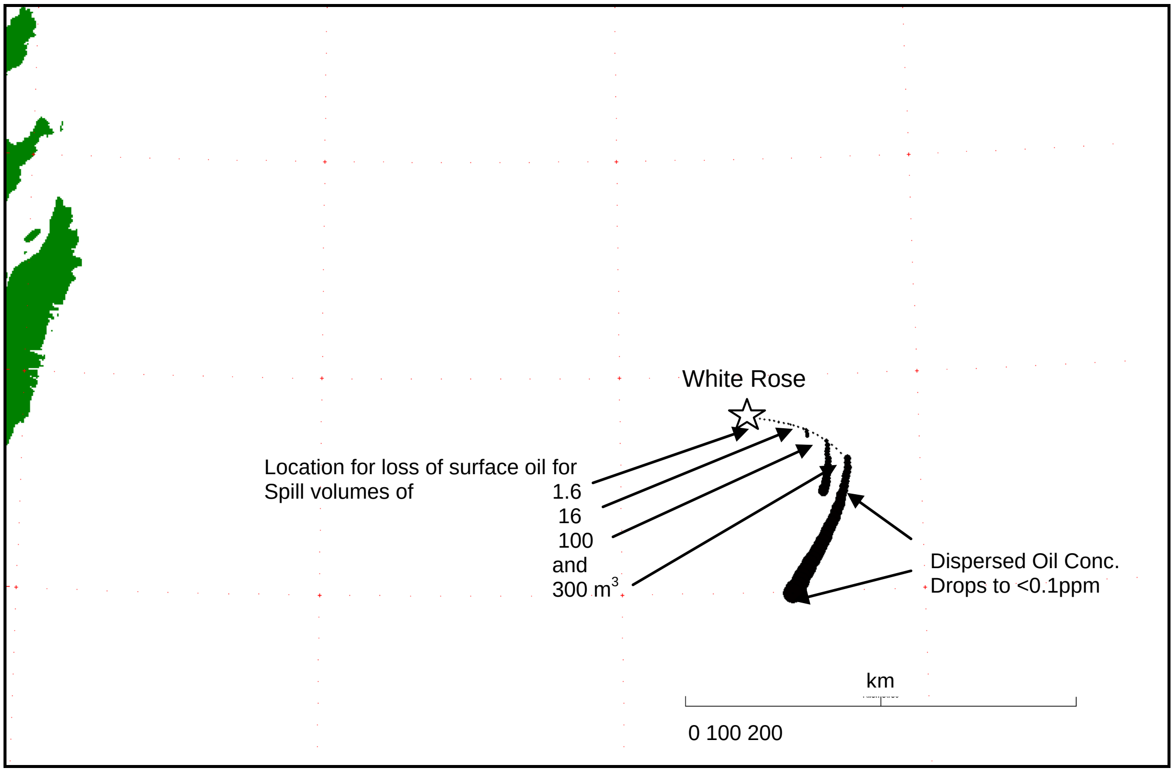


Figure 3-7 Offshore Winter Diesel Spill Trajectories: Average Environmental Conditions

3.3.3 Subsea Crude Oil Blowout Fate and Behaviour Modelling

The fate of crude oil from winter and summer subsea blowout scenarios has been modeled using the methods outlined in Section 3.1.2 and the results are summarized below. Oil properties of White Rose crude oil sampled and analyzed in the fall of 2011 have been used in this modelling.

Oil flow rates of 6,435 m^3/day and 3,963 m^3/day with gas-to-oil ratios (GOR) of 138 m^3/m^3 and 275 m^3/m^3 were used in the modelling. These flows represent the maximum oil flow rate estimated from the reservoir and the reduced flow expected after a 120 day release period (Husky Energy 2012). At the beginning of a blowout the oil fate will most closely match the results provided for the higher flow rate. By the end of a 120 day release the results presented for the lower flow rates will be more representative.

In this scenario the fluids are assumed to erupt from the seabed with the formation of small oil droplets in the turbulent jet region of the discharge. The oil drops are then quickly carried to the surface with entrained water and gas. The average winter and summer seasonal temperatures and wind speeds presented in sections 3.2.4 and 3.2.5 are used in this modelling.

At the surface, the oil drops spread to form a slick in the summer since the ambient temperature is above the fresh oil's initial pour point, however, in the winter the oil is assumed to remain in the form of small drops of about 1 mm in diameter because the ambient water temperature is well below the oil's pour point. Because the oil drops are essentially semi-solid spheres it is assumed that they will not mix and coalesce into a traditional oil slick. The small drops have a larger surface area than a traditional slick and this allows for a more rapid evaporation and further increase in the oil's pour point and viscosity. If high concentrations of these droplets were to form offshore during a sunny day with calm conditions then solar radiation could warm the oil to the point where the drops might coalesce and form a more traditional oil slick. The entrained water flow from the blowout creates a hyperbolic-shaped oil distribution at the surface that extends several hundred metres up-current of the gas boil zone (located at the focus of the hyperbole, see Figure 3-2) and that is between about 1.7 to 2.8 kilometres wide down-current of the gas boil depending on the season (see initial slick width in Table 3-7).

The oil slicks are predicted to be very persistent due to the formation of water-in-oil emulsions in the summer and because the water is colder than the oil's pour point in the winter. As such the oil does not naturally disperse and will remain on the surface for an extended period of time.

After about 1 day of exposure on the water surface the oil will have lost between 18 to 21% of its volume to evaporation. The maximum amount expected to be removed through evaporation over the life of the surface oil is 31 to 36%.

The initial oil viscosity at the summer temperature is 65 cP, in winter it would be 712 cP. Under average summer conditions, evaporation and emulsification raises the viscosity of the oil to 10,000 cP after 9.7 to 15 hours (depending on the spill flow rate). The viscosity of the oil is predicted to increase to a maximum of between 39,350 to 45,600 cP by the end of the slick's life. In the winter the water temperature is more than 15 °C lower than the oil's pour point so the oil will remain in the form of drops, will not coalesce to for a slick and will not form water-in-oil emulsions. The maximum viscosity of the drops is estimated to be about 7,500 cP.

Natural dispersion will be minimal in all of the subsea blowout scenarios either due to emulsion formation or the high oil pour point and cold water. In-water oil concentrations from these spills will remain below 0.001ppm.

Table 3-7 Subsea Crude Oil Blowout Spill Characteristics

Spill Flow Rate m^3/day (bopd)	Season	Initial Slick Width (m)	Initial Slick Thick (mm)	Slick Survival Time (days)	% Evap after 1day	Total Evap. %	Peak Disp. Oil Conc. (ppm)	Time to 0.1 ppm Disp. Oil Conc. (hr)	Initial oil Viscosity (cP)	Time to Oil Viscosity of 10,000cP (hrs)	Maximum Oil Viscosity cP
6,435 (40,476)	winter	1670	1.0[2]	>30	18	31	<0.001	na[1]	712	na[1]	7,400[1]
6,435 (40,476)	summer	2600	0.18	>30	19	36	<0.001	na	65	15	39,350
3,963 (24,927)	winter	1790	1.0[2]	>30	18	33	<0.001	na	712	na[1]	7,400[1]
3,963 (24,927)	summer	2760	0.1	>30	21	33	<0.001	na	65	9.7	45,600

[1]Water temperature more than 15 °C lower than oil pour point – no natural dispersion and no emulsification assumed
[2] Oil remains as 'solid' drops with a 1 mm diameter due to high pour point and low water temperature in winter

3.3.4 Sample Subsea Blowout Spill Trajectories

Two random dates have been selected to provide sample trajectories of oil from a 120 day subsea blowout in the summer and winter months. The 6-hourly MSC50 wind data described in section 2.2.5 for September 2009 and February 2009 have been used to drive the trajectories. The spatially and temporally variable winds of the MSC50 data set are used here instead of seasonal average values to illustrate how the time-varying winds will affect the motion of slicklets that are released over the 120 day discharge period. Slicklets were released at the beginning of each day, starting on the first day of the month, over the 120 day releases. The position of each slicklet is plotted on the final graph after every 6 hours of movement. Average summer and winter air temperatures have been used in the modeling. The summer and winter model results are shown in Figues 3-8 and 3-9, respectively. These plots DO NOT represent the area of the ocean covered by oil at any given time but merely identify the area that would be influenced by the oil over the release period. The dots in the figures represent the positions of 28 or 31 slicks of oil reported every 6 hours. Each parcel was released at the start of each day in the month and then tracked for 120 days or until the average surface oil coverage dropped to below 1 g/25m^2. This level of contamination of highly weathered crude is considered innocuous to wildlife (French-McCay 2004).

The plots identify possible "zones of influence" of oil from a 120-day blowout at the drilling site for summer and winter conditions. Section 3.4 looks in more depth at the possible movement of slicks using long-term historical wind data.

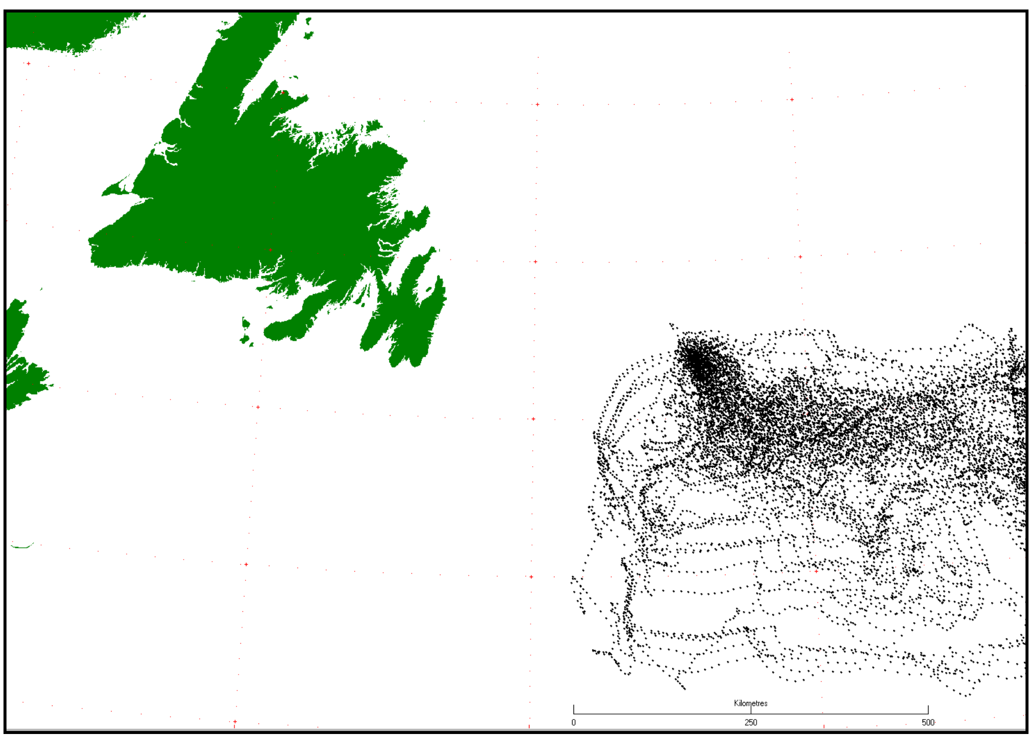


Figure 3-8 Trajectory Envelope for a 120 day Summer Subsea Blowout: started September 1, 2009

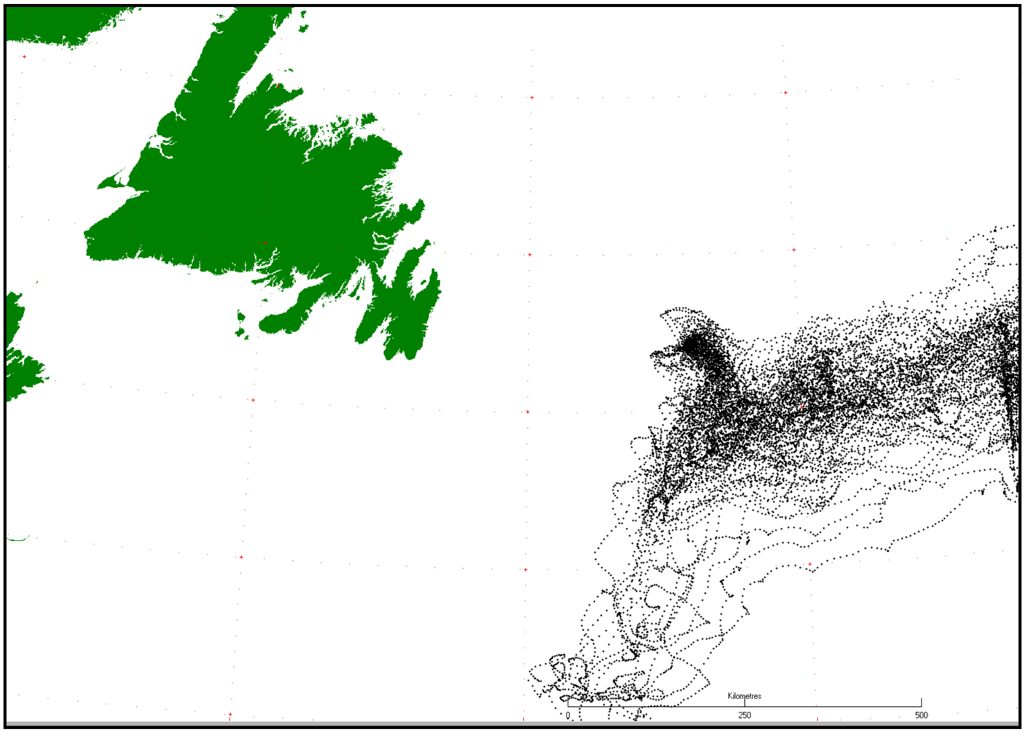


Figure 3-9 Trajectory Envelope for a 120 day Winter Subsea Blowout: started February 1, 2009

The zones of influence of the winter trajectories tend to smaller due to more persistent winds from the west. In the summer months the wind direction is more variable and this tends to move the slicklets over a wider area during a long term release.

3.3.5 Surface Crude Oil Blowout Fate and Behaviour Modelling

In this scenario, a blowout occurs on the on-site rig 43 m above the water surface resulting in a discharge of oil and gas into the air. Oil flow rates of 6,435 m^3/day and 3,963 m^3/day with gas-to-oil ratios (GOR) of 138 m^3/m^3 and 275 m^3/m^3 were used in the modelling. These flows represent the maximum oil flow rate estimated from the reservoir at the start of the release and the reduced flow expected after a 120 day release period (Husky Energy 2012). The platform and rig are not damaged and they remain in position throughout the blowout period. The gas exits 43 m above the water surface at high velocity and shatters the oil into small diameter droplets. These droplets are shot upward by the jet of gas, impact on the derrick and agglomerate to a size of about 0.75 mm. This median drop size has been selected for all surface blowout modelling based on model calibration results using data from the Ekofisk blowout. These droplets rain down on the surface of the water down-wind of the rig. Most of the droplets fall onto the water surface within a few hundred metres of the rig in a swath about 150 metres wide and re-coalesce to form a slick a 1 to 3.5 mm thick. A 'traditional' oil slick is assumed to form in both summer and winter in this above water blowout scenario. A Gaussian model of atmospheric plume behaviour (as illustrated in Figure 3-3) has been used to predict the concentrations of oil downwind from the release point of a surface blowout, following the method described by Turner (1970). Winter and summer seasonal temperatures and wind speeds have been used in the modelling of the fate of this oil. Minor differences in the initial slick characteristics and change in oil property over time will exist depending on the season (due to temperature and wind speed differences). The results of the fate modelling are summarized in Table 3-8 and described below.

The slick at source will be between 116 and 160 metres wide and 1.0 to 3.4 mm thick. The oil making up the slick will have lost between 4 and 7 percent (depending on the season) of its volume through evaporation of the oil droplets in the air. The oil droplets will re-coalesce to form a slick on the water surface and this oil will immediately begin to emulsify. The initial oil will have a viscosity of 110 cP in the summer scenario and 960 cP in the winter.

After about 1 day of exposure on the water surface, the slicks will have lost between 10 to 13% of their volume to evaporation; this increases to a maximum of about 27% over the life of the surface oil slicks.

Evaporation and emulsification raises the viscosity of the slicks to 10,000 cP within 1 hour in the winter and between 136 and 190 hours in the summer, depending on the spill flow rate. The viscosity will increase to maximums of about 21,000 cP in the summer and 195,000 cP in the winter; the higher winter viscosities are due to the colder conditions.

Under both average summer and winter conditions the model predicts that the surface slicks will persist for periods greater than 30 days with very little natural dispersion. As the oil drifts from the site, wave action will break the slicks up into viscous particles of oil that move away from each other under the influence of oceanic turbulence. The makeup of this oil will depend on the harshness of the environment over this period. It is likely that after a several weeks of exposure to the energetic conditions of the North Atlantic Ocean the oil will be broken into small tar-balls spread over a large area, with the oil particles separated by large expanses of water.

Table 3-8 Above Sea Crude Oil Blowout Spill Characteristics

Spill Flow Rate m^3/day (bopd)	Season	Initial Slick Width (m)	Initial Slick Thick (mm)	Slick Survival Time (days)	% Evap in Air	% Evap after 1day	Total Evap. %	Peak Disp. Oil Conc. (ppm)	Time to 0.1 ppm Disp. Oil Conc. (hr)	Initial oil Viscosity (cP)	Time to Oil Viscosity of 10,000cP (hrs)	Maximum Oil Viscosity cP
6,435 (40,476)	winter	150	1.7	>30	4	10	22	<0.001 ppm	na	950	1	170,000
6,435 (40,476)	summer	116	3.4	>30	7	12	27	<0.001 ppm	na	108	190	20,000
3,963 (24,927)	winter	160	1.0	>30	4	12	24	<0.001 ppm	na	960	1	195,000
3,963 (24,927)	summer	126	1.9	>30	7.4	13	26	<0.001 ppm	na	110	136	21,000

3.3.6 Typical Surface Blowout Spill Trajectories

The trajectories for the surface blowout scenarios will be identical to those from the subsea discharges because the oil from both types of spills will be very persistent. The starting slicklet sizes and oil thicknesses will be different but the paths that the slicklets take will not vary. The trajectories provided in section 3.3.4 are thus indicative of typical trajectories for the surface blowouts as well.

3.4 Historical Spill Trajectory Assessment

3.4.1 Introduction

As noted in the previous sections, spills of White Rose crude oil will tend to be very persistent and surface slick survival times of many weeks is likely. The modelling in this section looks at which surface areas on the Grand Banks are more likely to be swept by surface oil and the likelihood of crude oil slicks released from the drilling block reaching Newfoundland shorelines. Because the oil is very persistent the mode in which it is released (subsea or surface blowout or batch spill) is not a critical factor in determining the long term trajectory of spills. We have chosen to represent long term releases from the production site as discrete batches of oil released at six-hour intervals. Each batch of oil contains the full quantity of oil that would have been released during the six hour period by a blowout flowing at the maximum discharge rate. This ensures that all of the oil spilled is accounted for and provides a reasonable separation between batches (6 hours) for the assessment of variations in trajectory as a result of variations in wind speed and direction.

A total of 83,220 trajectories were run in this analysis from a spill release site of 46.800728 N, 48.063392 W. These trajectories used the 57 years of wind data available from the MSC50 dataset described in section 2.2.5. For months with 30 days a total of 6840 individual slick trajectories were followed, one released every 6 hours starting at the beginning of the first day in the month. For months with 31 days a total of 7068 trajectories were modelled and 6384 spills were modelled for February.

3.4.2 Shoreline Contact

Shoreline contact statistics on a monthly basis from these hypothetical spills is provided in Table 3-9. A small number of slicks came to shore only in the months of March (9 slicks), October (29 slicks) and November (1 slick). This amounts to only 0.04% of the 83,220 oil slicks tracked that reached shore as seen in Figure 3-10. The slicks arrived at shore between 45 and 92 days after release.

Table 3-9 Slick Shoreline Contact from White Rose Offshore Releases

Month	Number of Slicks Tracked	# of Slick's Centres Reaching Shore	% of Slick's Centres Reaching Shore	Minimum Time to Shore		Maximum Time to Shore	
				Hours	Days	Hours	Days
January	7,068	0	0	-	-	-	-
February	6,384	0	0	-	-	-	-
March	7,068	9	0.13	1638	68	2220	92.5
April	6,840	0	0	-	-	-	-
May	7,068	0	0	-	-	-	-
June	6,840	0	0	-	-	-	-
July	7,068	0	0	-	-	-	-
August	7,068	0	0	-	-	-	-
September	6,840	0	0	-	-	-	-
October	7,068	26	0.37	1080	45	1746	73

November	6,840	1	0.01	1410	59	1410	59
December	7,068	0	0	-	-	-	-

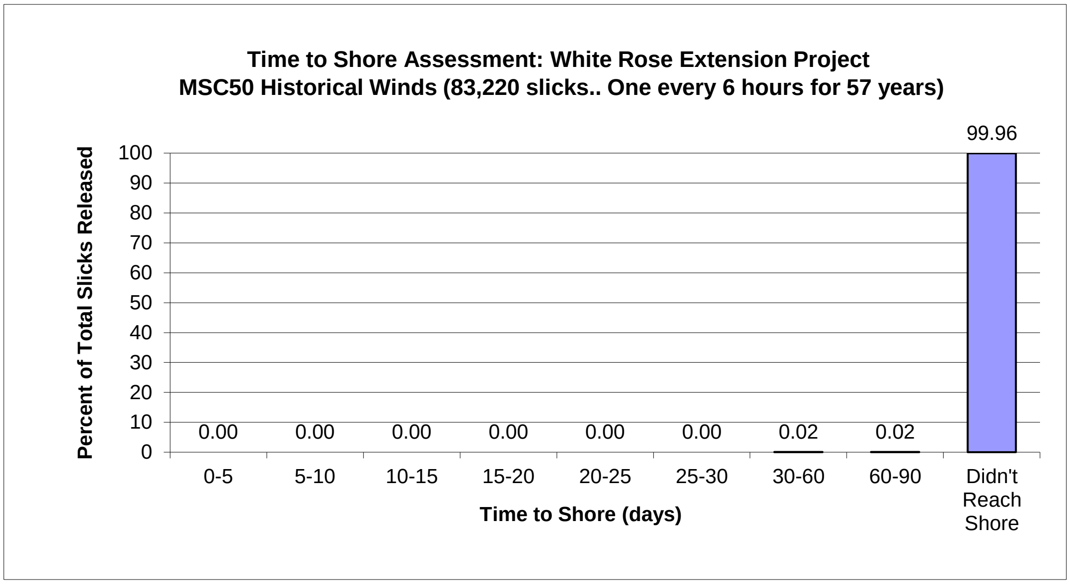


Figure 3-10 Slick Survival Time Statistics for WREP: All Months and Years

3.4.3 Spill Trajectory Probabilities

The data has been further processed, on a monthly basis, to identify the probability of a slick reaching specific areas in the offshore. The slick movements for all spills released in a given month of the year, for the 57 years of data, have been processed to identify the percent of the spills released in the month that enter each cell in a 1 km x 1 km grid placed over the study area. The results are shown in Figures 3-11 through 3-22. The total sweep area of the slicks (as defined using an oceanic diffusion model, Okubo 1971) has been used in this assessment. The contours on the following graphs represent the boundaries where 0 to 1% of the slicks will pass 1 to 5%, 5 to 10%, 10 to 25%, 25 to 50%, and 50 to 100%. These graphs provide insight into the most likely path of oil over when spilled in a given month based on the 57 years of available wind data.

Trajectories have been run for 120 days or until the oil evaporates and disperses from the surface or the average oil concentration on the surface has dropped below 1 gram per 25 square metres This level of contamination of highly weathered crude is considered innocuous to wildlife (French-McCay 2004).

It cannot be stressed enough that our confidence in accurately modelling the fate of crude oil on the open ocean past a few weeks is not high. Very little data has ever been collected on the long-term fate of different oil types in the offshore (past even one-week of exposure). A study completed for the US Minerals Management Service reviewed the worldwide data on the persistence of crude oil spills on open water (SL Ross et al, 2003). The study found that the persistence of large spills (> 1000 barrels) was predicted best with the following equation:

$$PD = 0.0001S - 1.32T + 33.1$$

Where: PD= spill persistence in days
S= spill size in barrels
T = Water temperature in degrees Celsius

If the single day's release of oil is considered as a unique slick with a volume of 40,500 barrels then its long term persistence would be about 34 days in the winter and about 20 days in the summer. These estimated surface slick persistence values (based on the equation above) are somewhat shorter than those predicted in the detailed spill modeling prepared for this report and are presented only to provide additional insight into the possible survival time of surface slicks based on historical records.

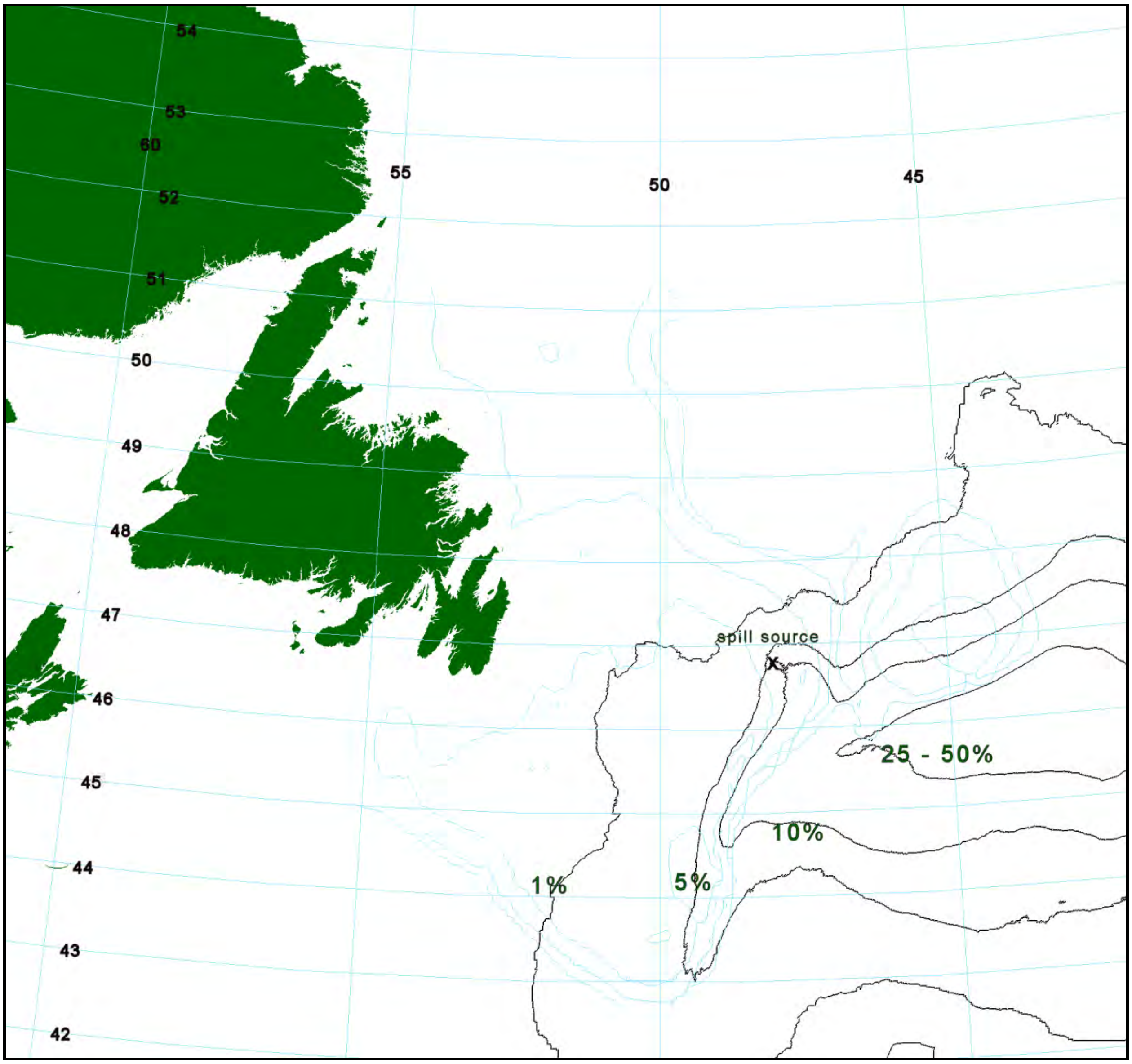


Figure 3-11 Spill Trajectory Probabilities for Releases from White Rose: January

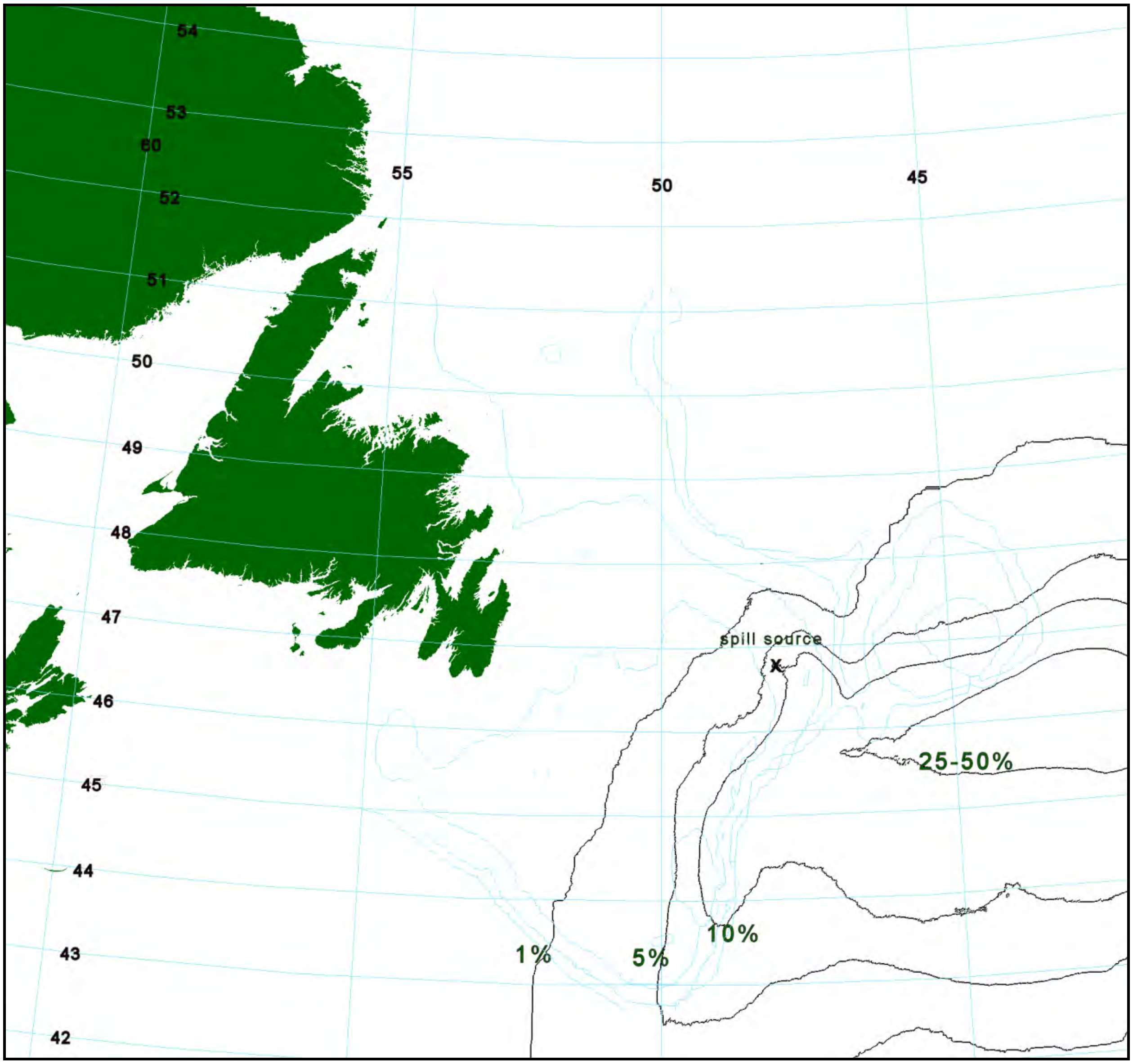


Figure 3-12 Spill Trajectory Probabilities for Releases from White Rose: February

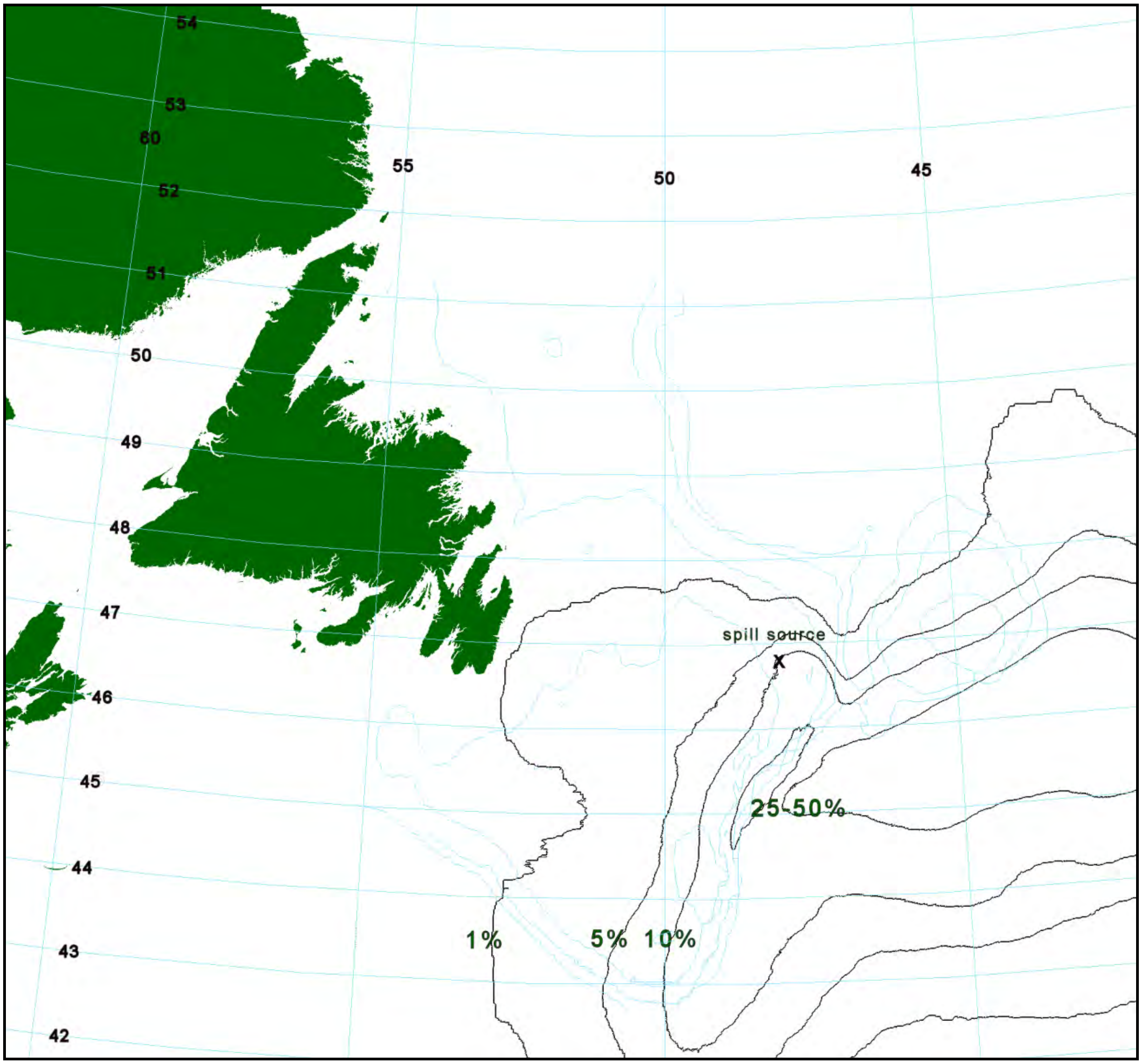


Figure 3-13 Spill Trajectory Probabilities for Releases from White Rose: March

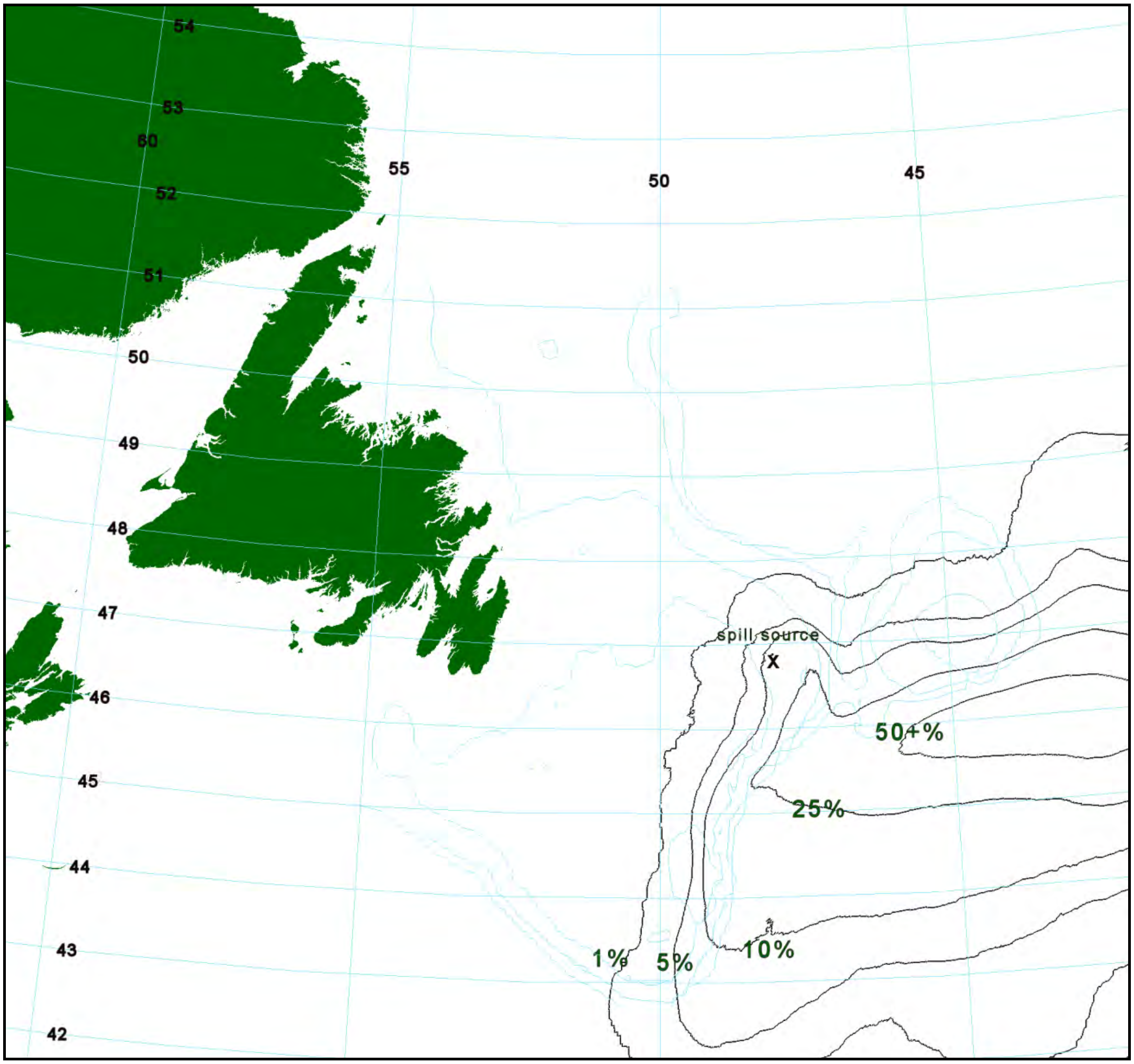


Figure 3-14 Spill Trajectory Probabilities for Releases from White Rose: April

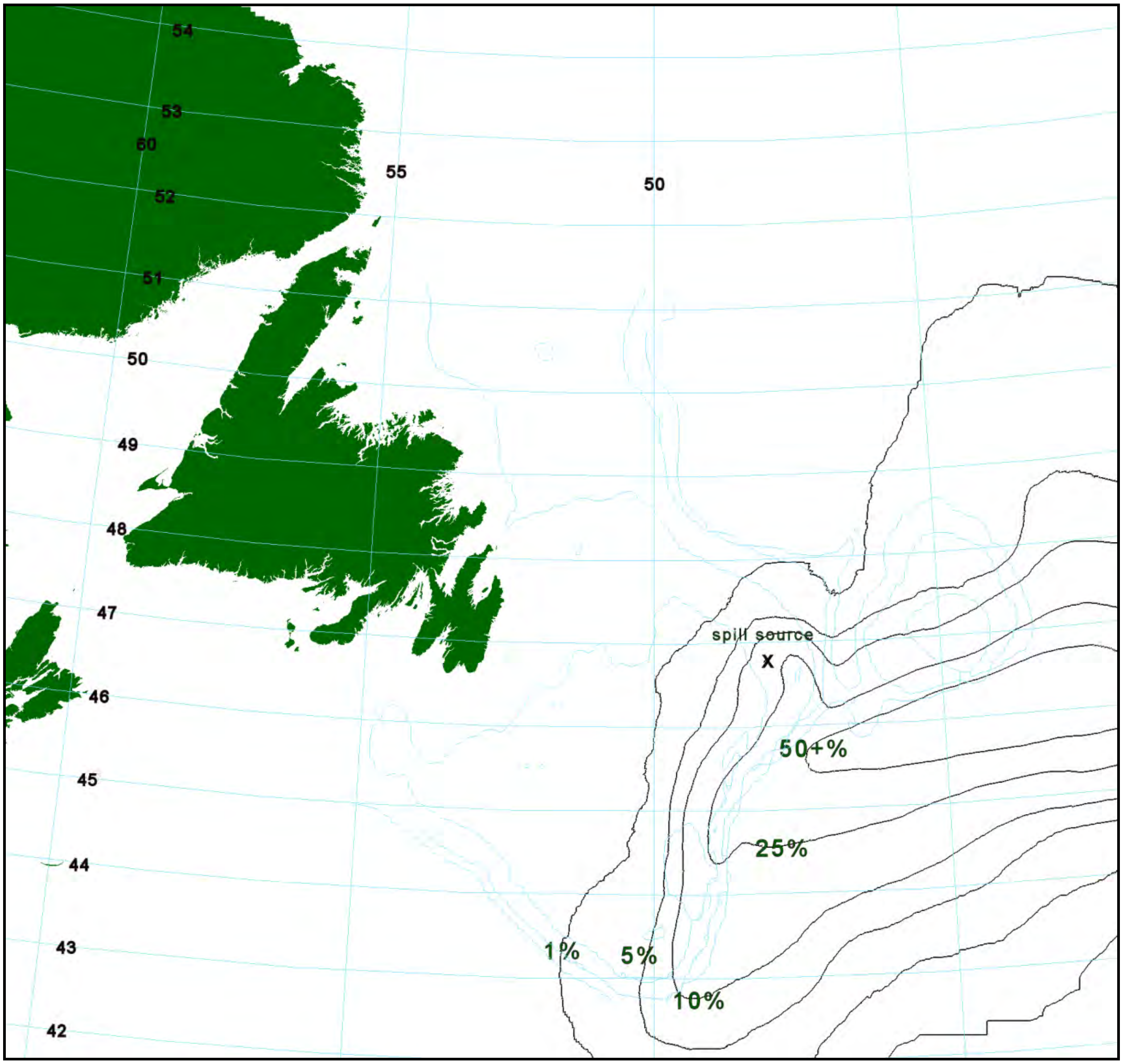


Figure 3-15 Spill Trajectory Probabilities for Releases from White Rose: May

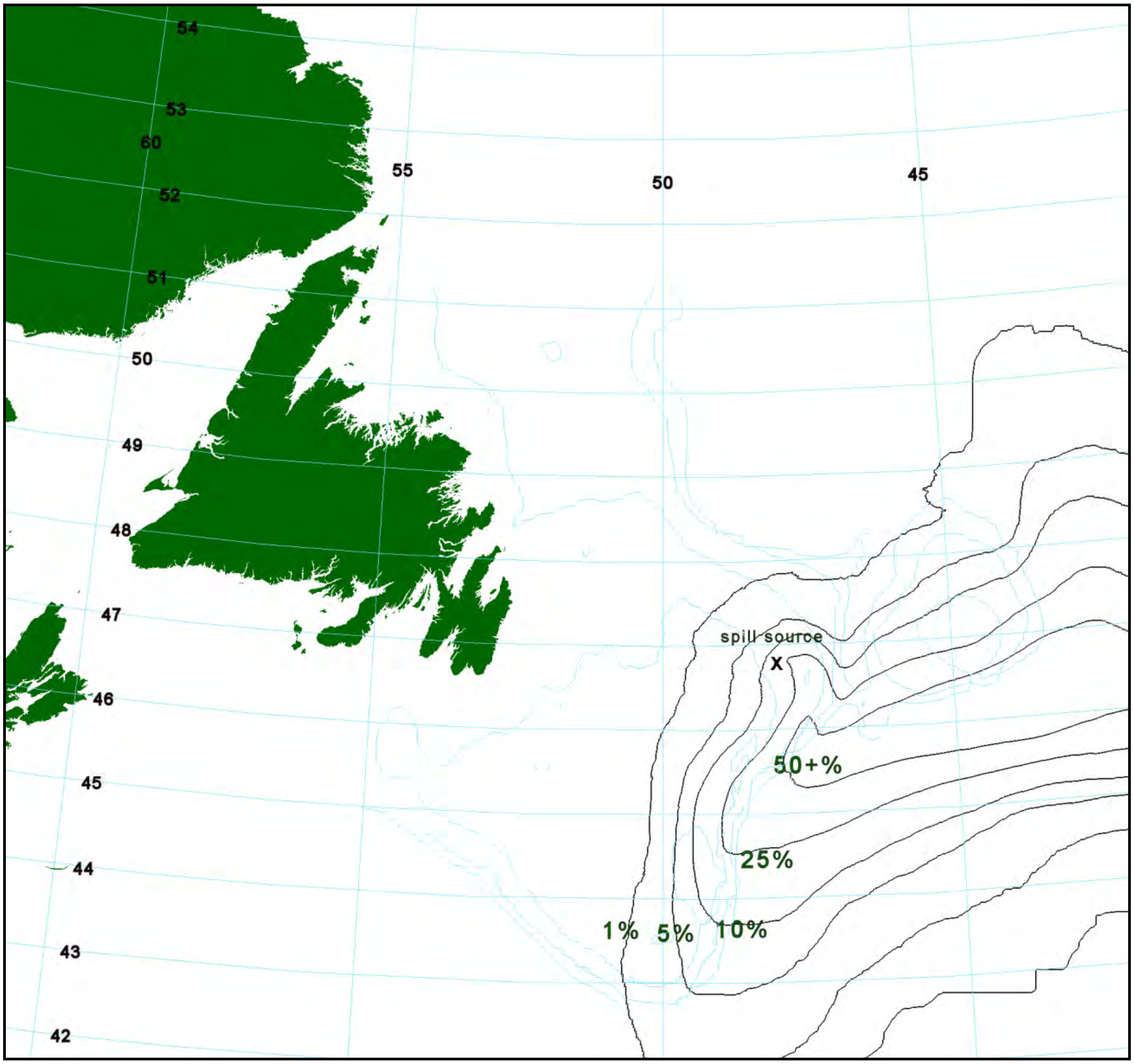


Figure 3-16 Spill Trajectory Probabilities for Releases from White Rose: June

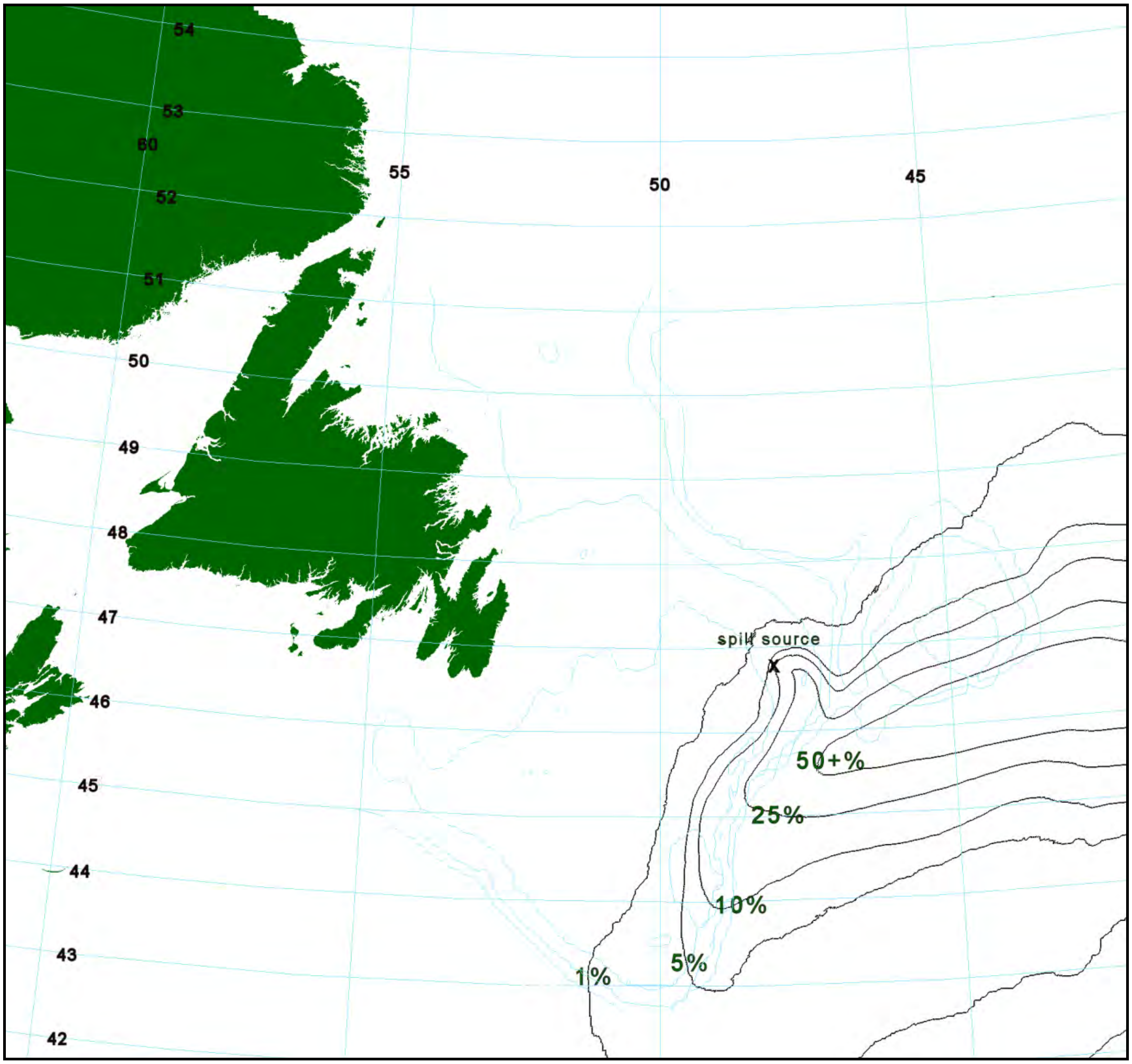


Figure 3-17 Spill Trajectory Probabilities for Releases from White Rose: July

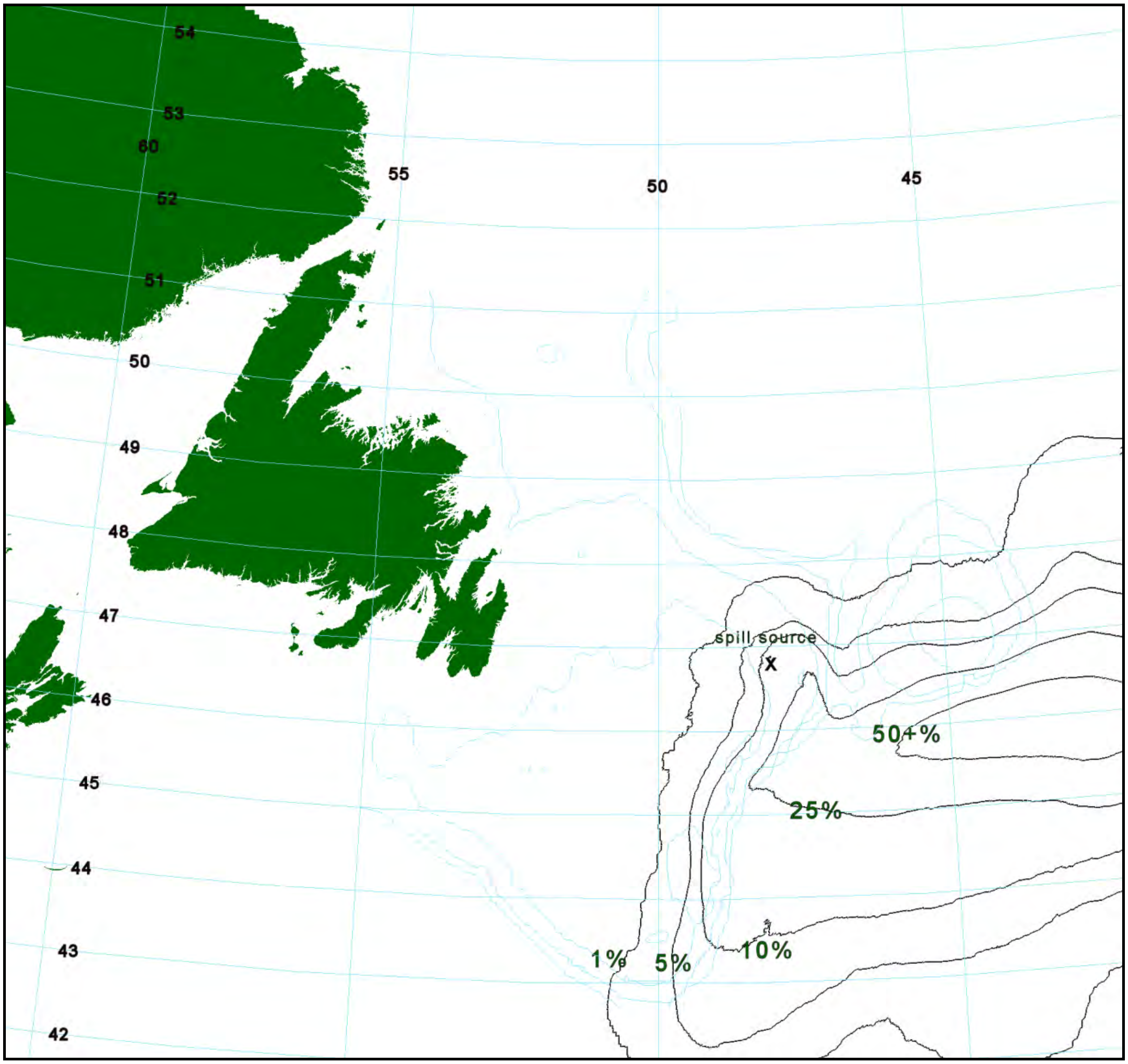


Figure 3-18 Spill Trajectory Probabilities for Releases from White Rose: August

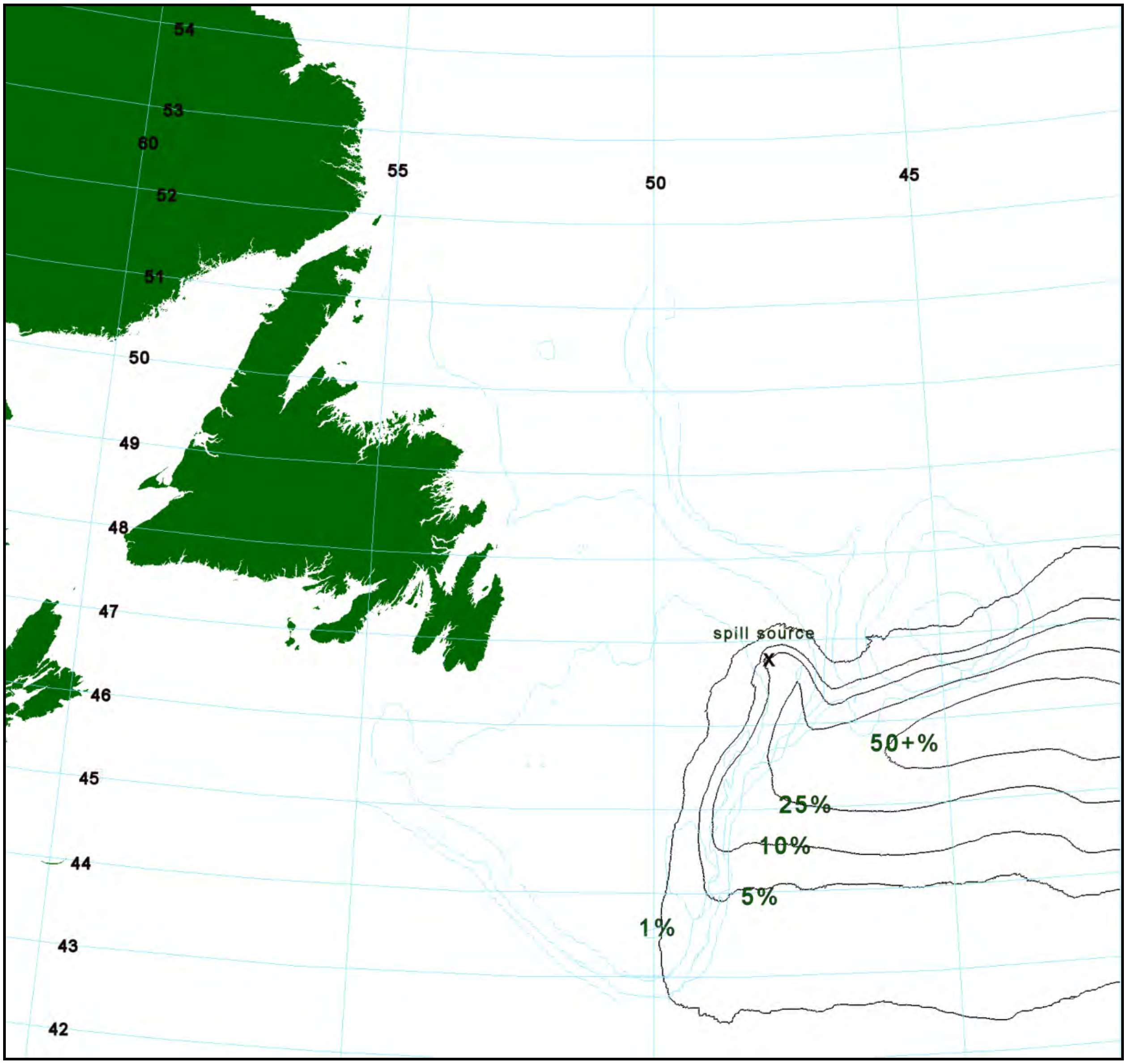


Figure 3-19 Spill Trajectory Probabilities for Releases from White Rose: September

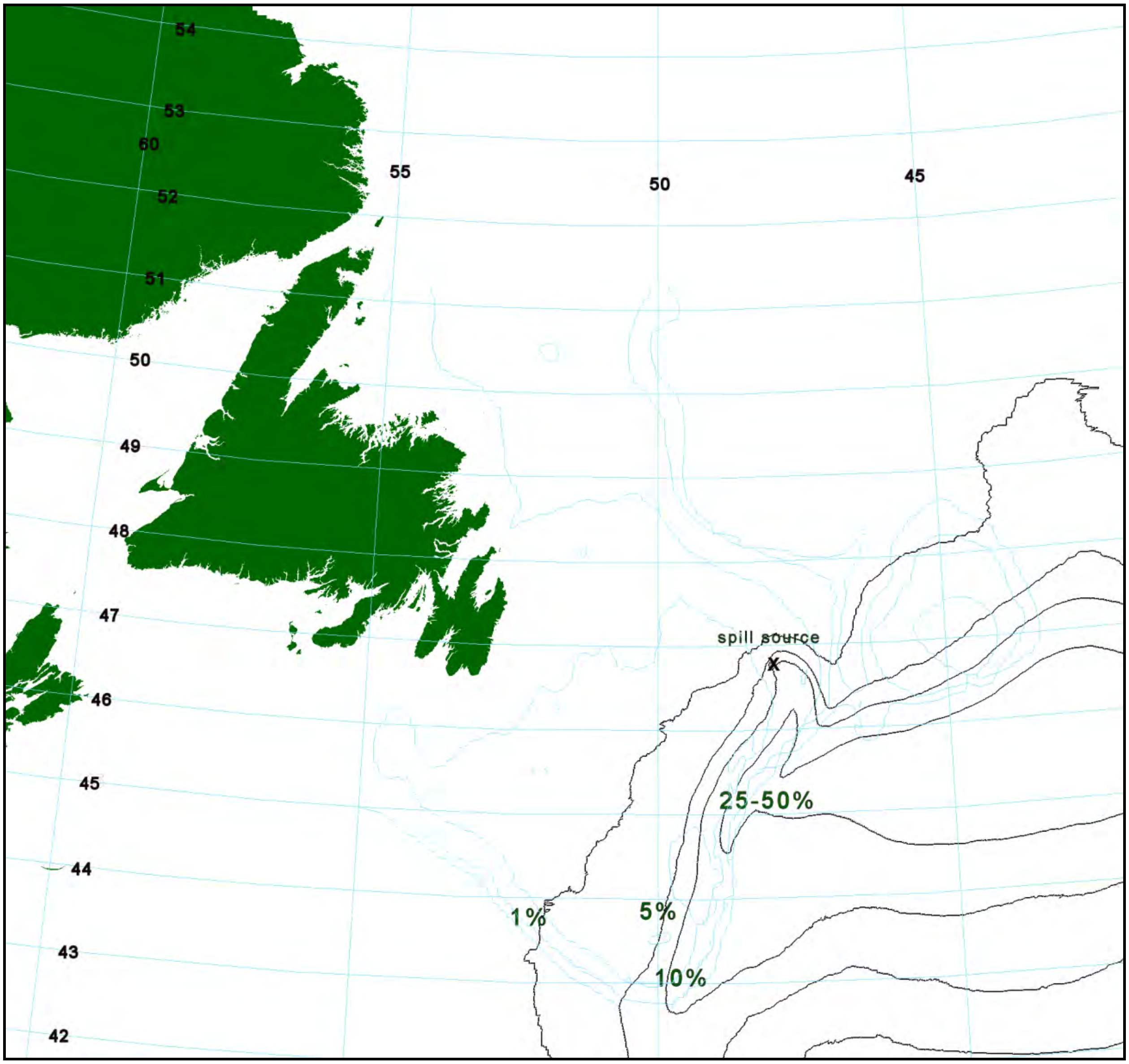


Figure 3-20 Spill Trajectory Probabilities for Releases from White Rose: October

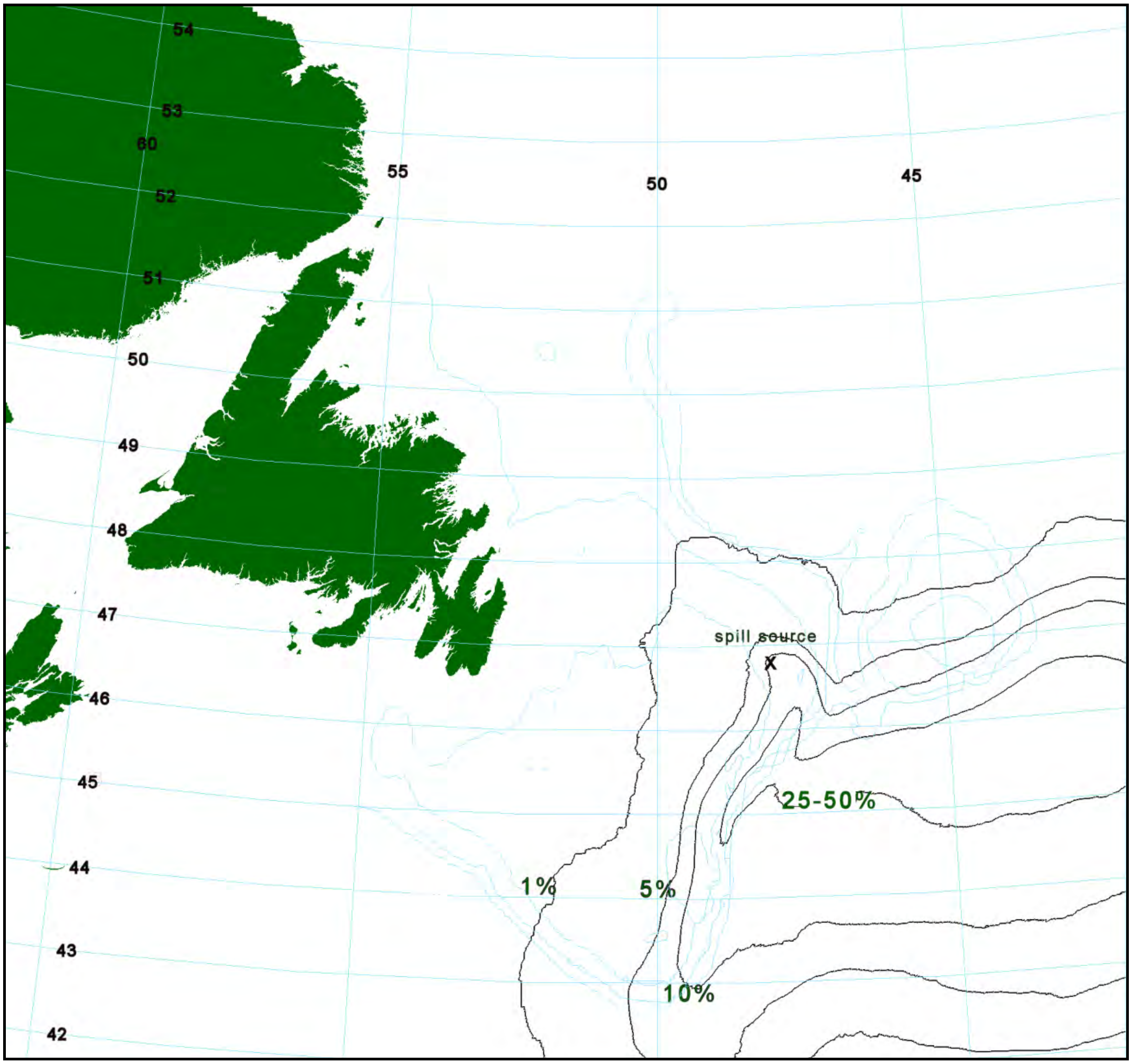


Figure 3-21 Spill Trajectory Probabilities for Releases from White Rose: November

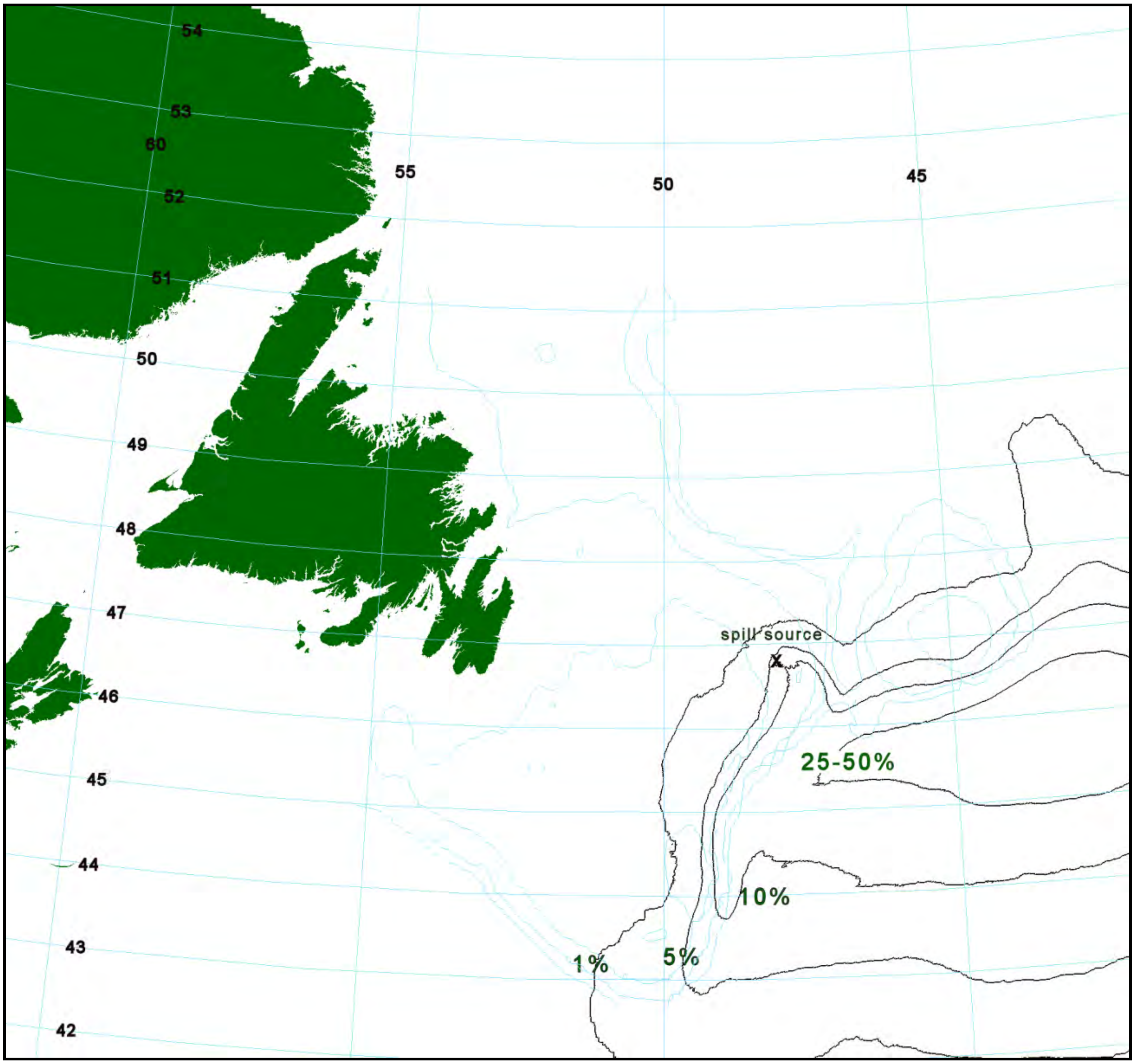


Figure 3-22 Spill Trajectory Probabilities for Releases from White Rose: December

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5.0 Acronyms

Term	Description
ADW	Approval to Drill a Well
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
bcf	billion cubic feet
Bbl/d	barrels per day
CDC	Central Drill Centre
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CSA	Canadian Standards Association
DA	Development Application
DGPS	Differential Global Positioning System
DNV	Det Norske Veritas
DST	drill stem test
EEM	environmental effects monitoring
FEED	Front End Engineering Design
Fm	formation
FPSO	Floating Production, Storage and Offloading Facility
FVF	formation volume factor
GOR	gas oil ratio
GR	gamma ray
ISO	International Standards Organization
kPa	kilopascals
LWD	logging while drilling
Ma	million years
md	millidarcies
MDT	modular dynamic formation tester
MMbbls	million barrels
mmscf/d	million standard cubic feet per day
MODU	Mobile Offshore Drilling Unit
m/s	metres per second
mTVDss	metres true vertical depth subsea
NADC	North Amethyst Drill Centre
NDC	Northern Drill Centre
N:G	net to gross ratio
NPV	net present value

Term	Description
OGIP	original gas in place
OOIP	original oil in place
OWC	Oil / water contact
PVT	pressure, volume, temperature
Psi	pounds per square inch
ROV	remotely operated vehicle
Rs	solution gas-oil ratio
Rw	resistivity of water
RVP	Reid vapour pressure
s	seconds
SWRX	South White Rose Extension Tie-back
Sw	water saturation
TVD	true vertical depth
WREP	White Rose Extension Project
WWRX	West White Rose Extension
XTree	Christmas (xmas) tree