Modeling in Support of Corridor Resources Old Harry Exploratory Drilling Environmental Assessment

for

Corridor Resources Inc.

by

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Executive Summary

The objective of the modeling is to assess the behaviour and trajectory of oil spills that might occur during the exploration drilling activities being proposed by Corridor Resources Inc. in Exploration Licence 1105. The spills of concern for this proposed operation are sub-sea and surface drilling installation crude oil and natural gas blowouts and small spills of fuel oil from drilling installations or vessels.

Corridor geoscientists have selected the Cohasset oil from the Scotian Basin as an appropriate surrogate for the oil that could be found at Old Harry and the properties of this oil have been used in the oil spill fate and behaviour simulations.

Instantaneous batch spills of 1.59 m^3 and 15.9 m^3 have been modeled for marine diesel. The above-sea blowout rate of 817.6 m^3/day and the sub-sea rate of 2102.7 m^3/day used in the modeling were determined by Corridor Resource Inc. engineers based on the best available reservoir information.

Surface water current fields developed by the Ocean Sciences Division, Maritimes Region of Fisheries and Oceans Canada were used in the spill trajectory modeling.

The monthly average air and water temperatures used in the basic oil fate modeling were taken from the Western Newfoundland and Labrador Offshore Area Strategic Environmental Assessment.

The MSC50 Wind data set was used in the detailed spill trajectory modeling completed in this study.

Depending on the season and spill volume, the batch diesel spills modeled have a slick life of between 17 to 49 hours; between 27 to 40% evaporation and maximum dispersed oil concentrations of 0.2 to 1.0 ppm.

Subsea blowouts at this location are assumed to be driven by a gas bubble plume. This will result in initially wide (1478 to 2537 m) and thin (0.028 mm) surface slicks near the source with rapid dispersion. Depending on the season, between 16 to 29% of the oil will evaporate and the remaining will disperse to maximum concentrations near source of 0.7 to 0.8 ppm.

Surface blowouts will be much narrower (initial thick oil widths of 54 to 75 m) and thicker (initial thicknesses between 0.8 to 1.6 mm). Between 35 to 50% of the oil will evaporate and the remainder will disperse with maximum near-source dispersed oil concentrations in the 3.8 to 6 ppm range.

The crude oil surface slicks from the blowouts can be expected to persist on the surface up to about 5 km from the source prior to dispersion under average wind and wave conditions.

Dispersed oil plumes from the blowouts can be expected to sweep areas of between 18 to 22 km wide by 25 to 40 km long prior to concentrations dropping below 0.1 ppm.

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1. Introduction

The objective of this modeling is to assess the behaviour and trajectory of oil spills that might occur during the exploration drilling activities being proposed by Corridor Resources Inc. in Exploration Licence 1105 (EL 1105) shown in Figure 1. The spills of concern for this proposed operation are sub-sea and surface drilling installation crude oil and natural gas blowouts and small spills of fuel oil from drilling installations or vessels. The approach is to select a number of hypothetical spills that cover the main concerns and to describe their behaviour and trajectory in detail. These spill scenarios, involving various spill types and sizes, serve subsequently as the basis for impact assessment and countermeasures analyses.

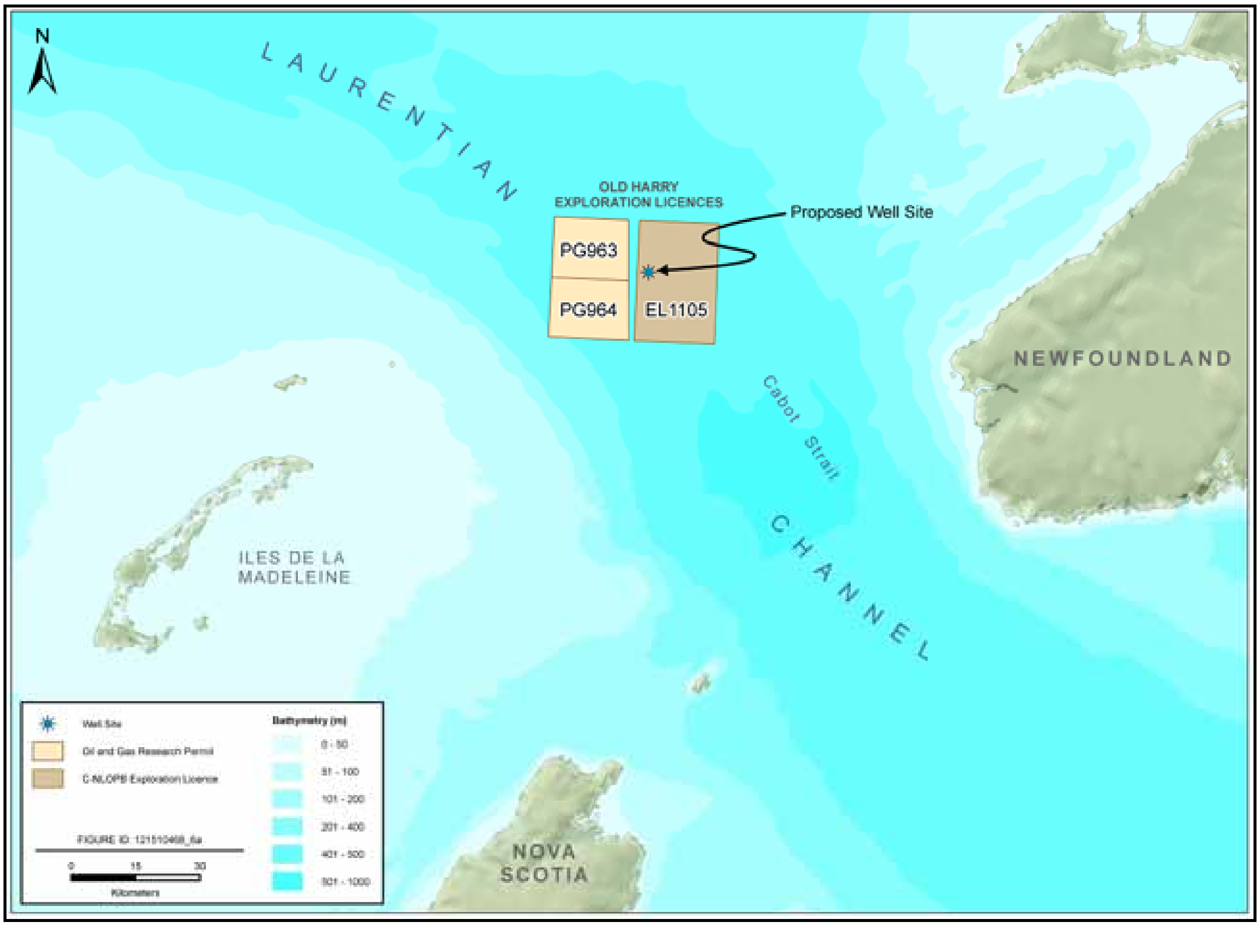

Figure 1. Drilling Area and Proposed Drilling Site

2. Oil Spill Scenarios and Modeling Inputs

2.1 General Oil Spill Behaviour

The following sections describe the general behaviour of oil associated with the key spill scenario types that may occur during an exploration drilling operation: small fuel oil batch spills; subsea crude oil blowouts; and above surface crude oil blowouts from exploration activities.

2.1.1 Small Batch Spills from the Drilling Installation

Small batch spills of diesel fuel from hose ruptures during transfer operations from a supply vessel or from drilling installation storage facilities are a possibility during drilling operations. These 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.

2.1.2 Subsea Blowouts

Well blowouts generally involve oil and natural gas where 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.

The behaviour of subsea blowouts can be very different depending on the water depth and temperature of the water at the release point. Because of this very different behaviour, they are often referred to as either shallow- or deep- water blowouts. Descriptions of the behaviour of the natural gas and oil released from these two situations follow.

Deep water blowouts are those where the natural gas exiting from the subsea release point quickly combines with water to form a solid ice-like substance known as hydrates. These form under high pressure and cold temperatures and deplete the volume of gas rising in the gas bubble plume. The natural gas volume may also be depleted through dissolution into the water. With the loss of natural 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 without the assistance of more buoyant gas. 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 close to the release point and smaller drops will be carried further down current away from the release point 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.

In 5°C waters deeper than about 700 to 800 m, complete conversion of the natural 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 2 provides guidance in the likely formation of hydrates as a function of water depth (pressure) and temperature. The phase diagram for methane is used since it is by far the most significant component (>90%) in natural gas. The formation of hydrates is also dependent on the actual composition of the natural 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 less than 500 m deep and the water temperature is 5°C or more, it has been assumed that a subsea blowout would behave as a shallow-water event in this situation and significant conversion of gas to hydrate will not occur. The behaviour of a shallow water gas and oil blowout is discussed below.

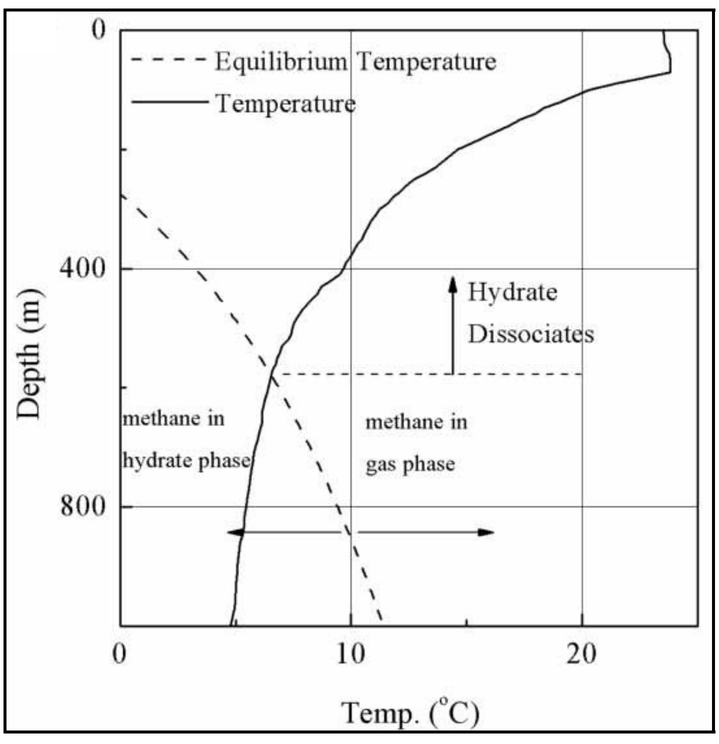

Figure 2. Methane Phase Diagram (from Yapa et al 2010)

In a shallow water blowout, the majority 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 side view). 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, a rapid loss of momentum occurs 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 created by the blowout turns and moves in a horizontal layer away from the center of the plume. The prevailing ocean surface water current pushes against this blowout-driven radial flow and turns it down-current to form a surface influence as illustrated in Figure 3 (above view). This surface influence carries the oil and spreads it over the surface up to the point where the water, oil and gas flow generated by the blowout 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 blowout driven plume and causes a surface disturbance identified by the arrows in the top view of Figure 3. At the surface, the oil is spread much faster than conventional batch oil spill spreading rates by the water flow generated by the gas bubble plume. This results in an initial slick that is larger in area but much thinner than would be experienced in a typical surface batch spill of oil.

If a blowout occurs under moving pack ice, the oil will thinly coat the underside of the ice and rise to the water surface between the ice pieces with a thickness and area similar to those for the open water condition. The oil present under the ice will travel with the ice and remain relatively fresh until released to the surface water when the ice melts. It is important to note that Corridor plans to drill during ice-free periods.

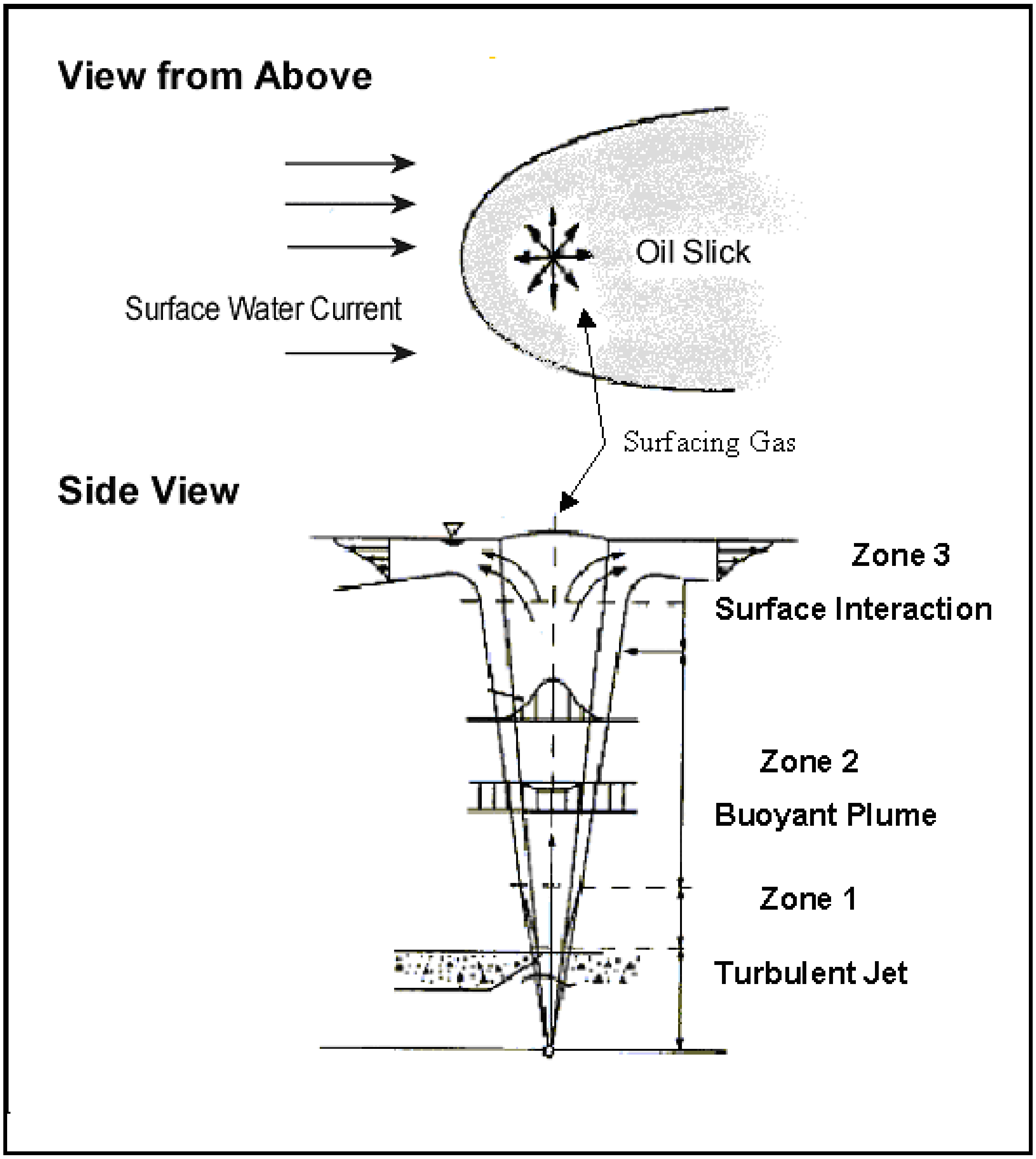

Figure 3. Subsea Blowout Schematic

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 modeling component of the SL Ross Oil Spill Model (SLROSM) used in this report to estimate the oil slick characteristics from shallow subsea blowouts.

2.1.3 Above-Surface Blowouts

Oil released during a blowout from an offshore drilling installation 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 discharge location 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 4 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 4 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 under 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 are blowing through the drilling rig 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.

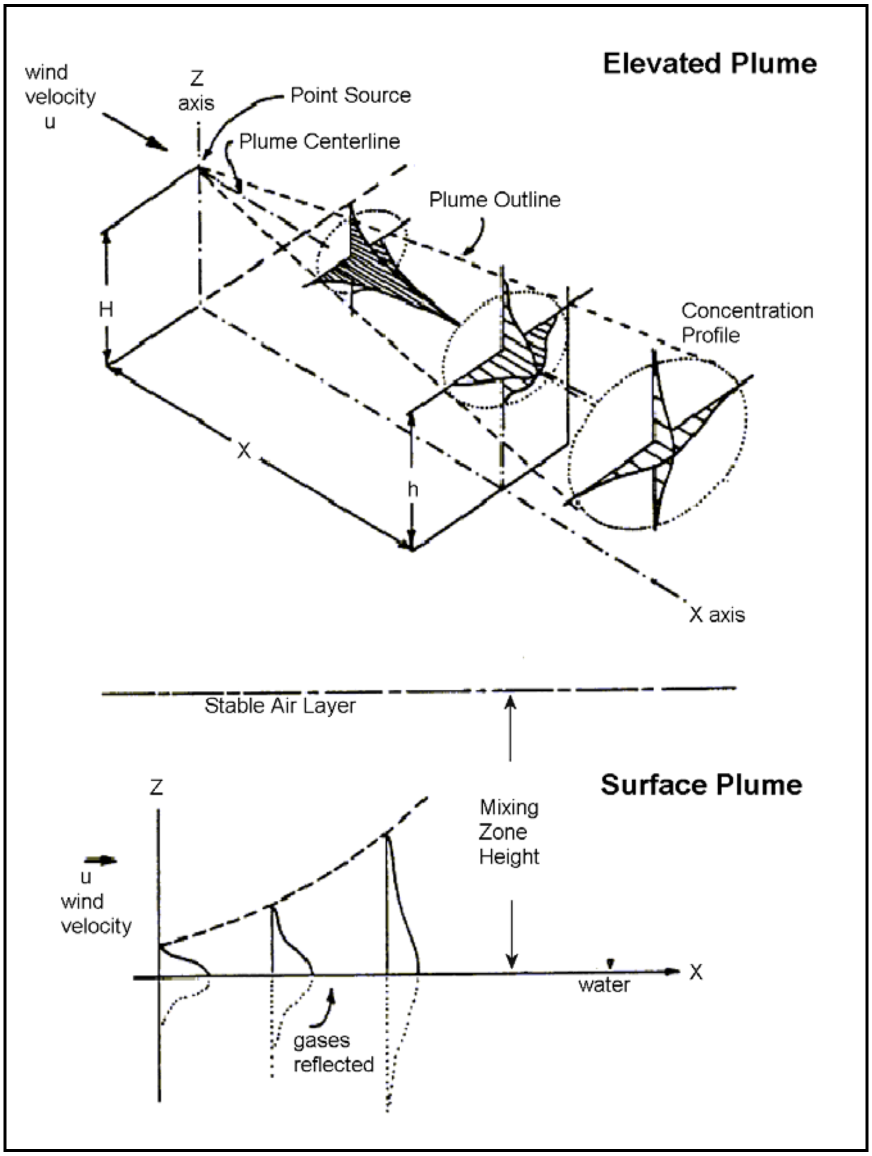

Figure 4. Above-sea Blowout Plume Behaviour Schematic

If the surface blowout occurs in the presence of pack or drift ice, some percentage of the oil will fall onto the surface of the ice passing by the blowout zone. The amount that reaches water or ice will depend on the ice cover concentration. Some portion of the oil will evaporate from the ice surface dependent on the amount of snow present and the remainder will be released to the water surface when the ice melts.

2.2 The Effect of the Presence of Pack or Drift Ice on Oil Spill Behaviour

Although Corridor intends to complete drilling operations during an ice-free period, a discussion of the effect of pack or drift ice on oil spill behaviour is included for completeness. It should be noted that this is drawn from a relatively limited knowledge base: two experimental spills in pack ice, and a few well-documented actual incidents of spills in ice conditions.

The Canadian Ice Service of Environment Canada provides a sea ice climate atlas online that provides ice summaries for the years 1981 through 2010 (www.ec.gc.ca/glaces-ice - East Coast Charts). Based on this 30-year analysis, thin first year or grey-white ice has been present in the vicinity of the proposed drill site from about mid-February to mid-March for about 22 of the 30 years of record. Drilling during these times of the year will be avoided.

2.2.1 The Effect of Pack or Drift Ice on the Four Main Oil Spill Processes

The effect of pack or drift ice on the four main spill processes of spreading, evaporation, dispersion and emulsification is briefly discussed first.

Oil spill spreading can be curtailed by the presence of pack or drift ice and brash ice. In high concentrations (greater than $5/10^{ths}$), oil spreading tends to be limited to the spaces between the floes. In general terms, the rate of spreading of an oil slick is not much affected by ice concentrations up to $3/10^{ths}$, is reduced by about half in concentrations between 3 and $7/10^{ths}$, and there is little spreading of slicks within an ice field of $7/10^{ths}$ or greater (SL Ross and DF Dickins 1987).

Oil spill evaporation is not greatly affected by the presence of ice unless the oil is trapped under or within the ice. Evaporation of volatile components will occur if the oil is exposed to the atmosphere, regardless of whether the oil rests on water or on ice. Oil will generally evaporate more slowly in pack ice than in open water, due to its increased thickness.

Oil spill dispersion and emulsification rates for oil spills on water depend on the mixing energy available at the sea surface (primarily in the form of breaking waves), and since the presence of ice tends to dampen the effects of wind on sea state, both dispersion and emulsification rates in pack or drift ice conditions would be expected to be less than the case in open water conditions, all other factors remaining the same.

2.2.2 Oil Spilled Within or Under Ice from Subsea Blowouts

Oil spilled in pack or drift ice conditions would be contained on water in the leads between floes and coat the bottom of ice floes if released from a subsea blowout. The oil will travel with the ice as it moves under the influence of winds and water currents. As spring melt proceeds and the ice pack diverges and ablates, the area of oil contamination would increase.

For the case of oil trapped within or under newly forming pancakes or sheet ice, the likely fate will be rapid encapsulation, with new ice quickly growing beneath the oil to entrap it. The oil sandwiched in the ice sheet would remain trapped until the spring, when the warming ice would result in the oil appearing on the surface of the floes and accumulating in melt pools.

The fate of oil trapped between floes will depend largely on the ice concentration and time of year. During freeze-up, the oil will most likely be entrained in the solidifying frazil ice and slush present on the water surface prior to forming coherent floes. Storm winds at this time often break up and disperse the newly forming ice, leaving the oil to spread temporarily in an open water condition until incorporated in the next freezing cycle (within hours or days depending on the air and water temperatures at the time).

In high ice concentrations, the oil is effectively prevented from spreading and is contained by the ice. As the ice cover loosens, more oil is able to escape into larger openings as the floes move apart. Eventually, as the ice concentration decreases to less than $3/10^{ths}$, the oil on the water surface behaves essentially as an open water spill, with localized oil patches being temporarily trapped by wind against individual floes. Any oil present on the surface of individual floes will move with the ice as it responds to winds and currents.

2.2.3 Oil Spilled on Top of the Ice from Above Sea Blowouts

The resulting area of contamination and oil thickness from a release of oil on top of ice will be influenced by a number of site-specific factors, such as wind speed, surface roughness, speed of the ice passing under the falling oil and the amount of snow cover on the ice. A number of process equations are available to predict the spreading and evaporation behaviour of oil in snow (Belore and Buist 1988). Key behavioural factors associated with oil spilled on snow can be summarized as follows (after Wotherspoon 1992):

- Evaporation rates in snow are substantially less than oil slicks on open water;
- Oil spreads very slowly in snow, and stops spreading much sooner than on open water (snow is a good sorbent for oil); and,
- Oil mixed with snow neither naturally disperses, nor forms emulsions.

The oil would remain on and move with the ice until spring melt when it would be released to the surface waters. The amount of oil loss to evaporation while the oil is contained on the ice/snow surface will depend on the surface ice and snow conditions, the prevailing weather and the duration of containment.

2.3 Spill Modeling Inputs

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

2.3.1 Oil Properties

Several characteristics of the geology in the Maritimes Basin (Old Harry area) compare favourably to the geological conditions encountered in the Scotian Basin (see Table A1 in Appendix A). The clastic reservoir rocks in the fields on the Scotian Shelf typically comprise fluvial and shallow marine, stacked, sandstone sequences that are analogous to the fluvial sandstone reservoir rocks at Old Harry. Of particular note is the known kerogen type in both basins is Types II-III and III. In addition, light oil was produced from the Cohasset/Panuke/Balmoral Fields on the Scotian Shelf. Consequently, Corridor geoscientists have selected the Cohasset oil from the Scotian Basin as an appropriate surrogate for the oil that could be found at Old Harry. See Appendix A for a detailed description of the rationale for the selection of Cohasset crude as a surrogate to Old Harry. Summaries of the fresh and weathered oil property data for Cohassett crude oil are provided in Table 1.

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 modeling.

Table 2 shows the oil property modeling parameters that were used in the SL Ross Oil Spill Model (SLROSM). These parameters were derived using the fresh and weathered oil property data shown in Table 1.

Table 1. Fresh and Weathered Properties of the Surrogate Cohasset Crude Oil

Cohassett Crude	API° gravity 47.5			
Oil Property	Temperature °C	Weathered State of Oil		
		0% Evaporated	11% Evaporated	26% Evaporated
Density (g/cm^3)	0	0.800	0.815	0.847
	15	0.790	0.805	0.837
Dynamic Viscosity (mPa.s)	0	3	4	7
	15	2	3	5
Kinematic Viscosity (mm^2/s)	0	4	5	8
	15	3	4	6
Interfacial Tension (dyne/cm)	Oil/Air	27.6	30.2	31.4
	Oil/Sea Water	17.2	16.7	17.5
Pour Point (°C)		-30	-18	-12
Flash Point (°C)		32	40	82
Emulsion Formation and Tendency				
	Tendency	Unlikely	Unlikely	Unlikely
	Stability	Unstable	Unstable	Unstable
	Water Content	0%	0%	0%
Data source: http://www.etc-cte.ec.gc.ca/databases/OilProperties/oil_C_e.html				

Table 2. Oil Property Parameters Used in SLROSM Spill Modeling

Oil Property	Surrogate Crude Oil	Diesel Fuel
Initial Density (kg/m3)	790.00	827.0
Standard Density Temperature (°K)	288.00	288.0
Density Constant 1	174.30	200.0
Density Constant 2	0.731	0.733
Initial Viscosity (cP)	2.607	5.0
Standard Viscosity Temperature (°K)	288.00	313.0
Viscosity Constant 1	3.350	8.755
Viscosity Constant 2	974.00	1607.0
Oil Water Interfacial Tension (dynes/cm)	15.0	37.0
Water Interfacial Tension Constant	-0.765	0.0
Oil Air Interfacial Tension (dynes/cm)	25.6	22
Air Interfacial Tension Constant	0.2280	0.0
Initial Pour Point (°C)	244.916	243.0
Pour Point Constant	0.1524	0.139
ASTM Distillation Constant A (slope)	244.9163	285.0
ASTM Distillation Constant B (intercept)	443.00	473.0
Emulsification Delay	999999999.	999999999.
Fv Theta A	6.3	Diesel Fuel
Fv Theta B	10.3	827.0

2.3.2 Discharge Volumes and Flow Rates

Instantaneous batch spills of 1.59 m^3 and 15.9 m^3 (10 and 100 petroleum barrels) have been modeled for marine diesel. These two spill sizes have been chosen as representative of medium and large sized batch spills from offshore drilling operations. To put these volumes in perspective, in the 14 years of operations at the Hibernia facility the maximum fuel oil spill size from a vessel transfer operation has been about 0.2 m^3 and the maximum fuel oil spill from all operations was about 2 m^3 (C-NLOPB, 2011).

The modeling of the continuous release of gas and crude oil from well blowouts has been completed using the gas and crude oil flow rates shown in Table 3. The blowout flow rates identified in Table 3 were determined by Corridor Resource Inc. engineers based on the best available reservoir information (see Appendix B - Corridor Reservoir/Production Engineering Note – February 25, 2011).

Table 3. Spill Flow Rates and Volumes Used in Modeling

Spill Type	Source	Flow	Gas-to-Oil Flow Ratio m^3/m^3
Crude oil Blowout	Subsea (470 m water depth)	(817.6 m^3/day) (5,143 BOPD)	89
	Surface Drilling Installation	(2102.7 m^3/day) (13,226 BOPD)	89
Batch Diesel Fuel Spills	Drilling Operations	1.6 m^3 (100 bbl)	na
	Vessel Transfer	0.16 m^3 (10 bbl)	na
BOPD = barrels of oil per day			

2.3.3 Water Currents

Surface water current fields developed by the Ocean Sciences Division, Maritimes Region of Fisheries and Oceans Canada (Tang et.al. 2008) were used in the spill trajectory modeling. 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). These water currents were combined with wind data to determine the initial slick characteristics and their subsequent movement.

2.3.4 Air and Water Temperatures

The monthly average air and water temperatures used in the detailed fate and trajectory modeling are shown in Table 4. Air and water temperatures used in the seasonal oil fate modeling are also shown in Table 4. These data are from the Western Newfoundland and Labrador Offshore Area Strategic Environmental Assessment (LGL 2007).

Table 4. Average Monthly and Seasonal Air and Water Temperatures

	Average Temperatures (°C)											
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air	-4.5	-6.5	-3.0	1.0	6.0	10.0	14.5	16.0	13.0	7.5	4.0	-2.5
Water	0.5	-1.0	-1.0	0.0	1.5	5.0	10.5	15.2	15.5	12.0	7.0	3.5
Season	Winter			Spring			Summer			Fall		
Air	-4.7			5.7			14.5			3.0		
Water	-0.5			2.2			13.7			7.5		

(source: derived from Figure 2.17, LGL 2007)

2.3.5 Winds

The MSC50 Wind data set (Swail et. al.2006) was used in the detailed spill trajectory modeling completed in this study. The data set has wind and wave data for the years 1954 to 2005. 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 modeling used the average wind speeds shown in Table 5. These data are from the Western Newfoundland and Labrador Offshore Area Strategic Environmental Assessment (LGL 2007).

Table 5. Seasonal Average Wind Speeds

Average Wind Speeds by Season (m/s)			
Winter	Spring	Summer	Fall
7.96	5.72	5.72	8.59

(source: derived from Table 2.3, LGL 2007)

3. Modeling Results

3.1 Batch Diesel Spill Fate Modeling

Two diesel fuel spill scenarios have been considered with spill volumes of 1.59 cubic metres and 15.9 cubic metres (10 and 100 barrels). Table 6 shows the fate of the "batch" spills for the four seasons using the average seasonal air and water temperatures and wind speeds provided in sections 2.3.4 and 2.3.5. A discussion of the modeling results are presented in the same order as they are reported in the columns of Table 6 starting with the smaller spill. The ranges reported below reflect the differences due to seasonal temperature and wind variations. Winter- fall and spring- summer results are quite similar due to similar environmental conditions for these seasonal pairings.

The small spills (1.59 m^3) have initial thick-oil slick widths of 10 m which grow to maximums of 52 to 58 m over the lives of the spills. The surface oil slicks from these small diesel spills will survive between 17 and 36 hours. The spring and summer discharges lose 36% and 40% of the diesel to evaporation while the winter and fall scenarios lose 27% and 30% by evaporation. The remaining oil is dispersed into the upper water layer where it further diffuses both laterally and with depth. The surface slicks will travel between 17 and 26 km from the source prior to dissipation from the surface (defined as the point at which the slick reaches a thickness of 10 µm or 0.01 mm).

The oil being dispersed into the water column under the slick will reach maximum concentrations of 0.2 to 0.47 ppm within 1 to 2 hours after release. It has been assumed that the oil will mix in the upper 30 m of water as this is the minimum surface water mixing depth reported in the literature for the region (Drinkwater & Gilbert 2004). The subsurface oil also diffuses laterally as it is moved away from the spill site by the prevailing surface water currents. The oil dispersed into the water column has been tracked until its concentration drops to 0.1 ppm of total petroleum hydrocarbon. This is the exposure concentration below which no significant biological effects are expected for sensitive marine resources (Trudel 1989, French-MacCay 2004). For the small diesel spills, the dispersed oil concentration in the water column will drop to 0.1 ppm within 4 to 7 hours. By the time the dispersed oil drops to 0.1 ppm, the dispersed oil zone will be 275 to 490 m in diameter, 30 m deep and will be between 2.3 and 7.5 km from the spill site.

The large spills modeled (15.9 m^3) have initial thick-oil slick widths of 32 m that grow to maximums of 127 to 139 m over the lives of the spills. The surface oil slicks from these larger diesel spills will survive between 25 and 49 hours. The spring and summer discharges lose 35% and 38% of the diesel to evaporation while the winter and fall scenarios lose 27% and 29% by evaporation. The remaining oil is dispersed into the upper water layer. The surface slicks will travel between 24 and 35 km from the source prior to dissipation from the surface.

Maximum in-water oil concentrations from the dispersed oil will reach 0.43 to 1.02 ppm within 3 hours after release for these larger diesel spills. The dispersed oil concentration in the water column will drop to 0.1 ppm within 13 to 25 hours. By the time the dispersed oil drops to 0.1 ppm, the dispersed oil zone will be 1060 to 2140 m in diameter, 30 m deep and will be between 7 and 26 km from the spill site.

Table 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. %	Dist. to Loss of Slick (km)	Peak Disp. Oil Conc. (ppm)	Time to Peak Conc. (hr)	Time to 0.1 ppm (hr)	Dispersed Oil Plume Width at 0.1 ppm (m)	Distance to 0.1 ppm (km)
1.58 (10)	Winter	10	20	55	27	20	0.42	2	7	490	7.0
1.58 (10)	Spring	10	36	58	36	26	0.20	1	4	275	2.8
1.58 (10)	Summer	10	32	56	40	17	0.21	1	4	275	2.3
1.58 (10)	Fall	10	17	52	30	18	0.47	1	7	490	7.5
15.8 (100)	Winter	32	30	133	27	31	0.92	3	24	2020	24
15.8 (100)	Spring	32	49	139	35	35	0.43	3	14	1140	10
15.8 (100)	Summer	32	43	134	38	24	0.43	3	13	1060	7
15.8 (100)	Fall	32	25	127	29	26	1.02	3	25	2140	26

3.2 Subsea Blowout Fate and Behaviour Modeling

The fate of crude oil from seasonal subsea blowout scenarios has been modeled using the methods outlined in Section 2.1.2 and the results are summarized below. As noted previously, oil properties from Cohassett crude oil have been used in this modeling as it is an applicable surrogate (Section 2.3.1).

The crude oil flow rate modeled was 817.6 m^3/day and the gas-to-oil ratio used was 89 m^3/m^3, as per Table 3. The fluids erupt from the seabed and the turbulent flow breaks the crude oil up into small droplets. These droplets are then quickly carried to the surface by the water being pumped to the surface by the gas bubble plume as illustrated in Figure 3. The seasonal average environmental conditions identified in Tables 4 and 5 were used in these subsea simulations.

At the surface, the crude oil drops spread to form a thin slick since the ambient temperature in all seasons is above the fresh crude oil's initial pour point. The entrained water flow creates an initial slick that extends away from the source as shown in Figure 3. Near the source, there will be a localized zone of surface turbulence created by the exiting gas. The initial oil slick characteristics and ultimate fate of the surfacing oil are summarized in Table 7. As in the previous section, these details are described in the order that they are presented in the table's columns. The ranges of values quoted below again reflect the differences due to varying seasonal environmental inputs.

In general, the initial oil slicks from these subsea blowouts will be wide, thin and non-persistent due to the radial spreading caused by the outflow of water brought to the surface by the gas bubble plume and the light nature of the crude oil. The initial width of the slicks will vary between 1478 and

2537 m. These widths are estimated at the point where the surface water flow created by the blowout gas plume is no longer influencing the surface oil behaviour. The initial slick thicknesses will be only 0.028 mm or 28 microns. Because of this very thin initial oil thickness, the model predicts that the surfacing light crude oil will completely evaporate and disperse into the water column within minutes. Traces of surface oil may persist for longer periods, but it is unlikely that significant patches of thick oil will survive for extended periods assuming average seasonal environmental conditions.

Between 16 and 29% of the crude oil will evaporate and the remainder will disperse. Surface slicks will not persist for any significant period of time but an in-water dispersed crude oil plume will be generated and move away from the source under the influence of the seasonal surface water currents. The plume will expand and diffuse to lower concentration as it moves away from the site. Maximum dispersed crude oil concentrations near the site are estimated to be between 0.7 and 0.8 ppm.

The dispersed oil plume widths where the in-water dispersed oil concentration drops to 0.1 ppm will vary from 4.0 to 6.4 km. The distances from the source where the dispersed oil plume drops to 0.1 ppm will vary from about 5.1 to 8.1 km.

Table 7. Subsea Blowout Spill Characteristics

Spill Flow Rate m^3/day (bopd)	Season	Initial Slick Width (m)	Initial Slick Thick (mm)	Slick Survival Time (min)	Total Evap. %	Peak Disp. Oil Conc. (ppm)	Time to 0.1 ppm Disp. Oil Conc. (hr)	Dispersed Oil Plume Width at 0.1 ppm Disp. Oil conc (km)	Distance from Source at 0.1 ppm Disp. Oil (km)
Drill site located at 48.051471 N –60.394274 W (470 m water depth)									
817 (5,143)	winter	1647	0.028	1	16	0.8	30	4.5	5.1
817 (5,143)	spring	2165	0.028	2	25	0.7	35	5.7	6.6
817 (5,143)	summer	2537	0.028	2	29	0.7	38	6.4	8.1
817 (5,143)	fall	1478	0.028	1	19	0.7	27	4.0	6.3

3.3 Surface Blowout Fate and Behaviour Modeling

In this scenario, a blowout occurs on the surface drilling rig resulting in a discharge of 2102.7 m^3/day of crude oil with a gas-to-oil ratio (GOR) of 89 m^3/m^3, as per Table 3. Cohassett crude oil properties have been used as the surrogate oil properties in the modeling (Section 2.3.1). The rig is not damaged and remains in position throughout the blowout period. The gas exits at the drill floor (21 m above the water surface) at high velocity and sprays the crude oil into small diameter droplets. These droplets are propelled upward by the jet of gas, contact the derrick and agglomerate to a size of about 0.5 mm. This volume median drop size has been selected for the surface blowout modeling based on model calibration results using data from the Shell Uniacke G-72 blowout that occurred off of Nova Scotia in 1984. 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 narrow swath and re-coalesce to form a thin slick. A Gaussian model of atmospheric plume behaviour (as illustrated in Figure 4) has been used to predict the concentrations of crude oil downwind from the release point of a surface blowout, following the method described by Turner (1970). The seasonal temperatures and wind speeds shown in Tables 4 and 5 have been used in the modeling of the fate of this crude oil. Minor differences in the initial slick characteristics and change in crude oil property over time will exist depending on the season (due to temperature and wind speed differences). The ranges of values reported below for the slick and dispersed plume characteristics reflect variations due to the seasonal environmental inputs. The results of the fate modeling are summarized in Table 8 and described below.

Using the flow rates, typical drilling rig height, pipe diameter and environmental conditions appropriate for the Old Harry drilling operation, the model estimates that the slick at source will be between 54 and 75 metres wide and 0.8 to 1.6 mm thick. The crude oil making up the slick will have lost between 30 and 46 % (depending on the season) of its volume through evaporation of the crude oil droplets in the air. The crude oil droplets will re-coalesce to form a thin slick on the water surface and this crude oil will immediately begin to disperse and continue to evaporate. The slicks will survive on the surface for a few hours at most (1.1 to 2.6 hours) as they move away from the spill source under the influence of winds and surface water currents. Peak in-water crude oil concentrations will be between 3.4 and 6.8 ppm and the dispersed oil plume will diffuse to 0.1ppm concentration within 14 to 15 hours. The dispersed oil plume will be 1.1 to 1.2 km wide at this point and will have travelled 3.4 to 3.8 km from the source.

Table 8. Surface Crude oil Blowout Spill Characteristics

Spill Flow Rate m^3/day (bopd)	Season	Initial Slick Width (m)	Initial Slick Thick (mm)	Evap. In Air %	Slick Survival Time (hrs)	Total Evap. %	Peak Disp. Oil Conc. (ppm)	Time to 0.1 ppm Disp. Oil Conc. (hr)	Dispersed Oil Plume Width at 0.1 ppm Disp. Oil conc (km)	Distance from Source at 0.1 ppm Disp. Oil (km)
Drill site located at 48.051471 N –60.394274 W (release 21m above water surface)										
2103 (13,226)	winter	70	1.0	30	1.6	35	6.0	15	1.2	3.4
2103 (13,226)	spring	54	1.6	39	2.6	44	3.4	15	1.2	3.7
2103 (13,226)	summer	54	1.6	46	2.4	50	3.8	15	1.2	3.8
2103 (13,226)	fall	75	0.8	36	1.1	41	6.8	14	1.1	3.8

4. Surface Oil Slick Trajectories

4.1 Introduction

Currents and wind will move spilled crude oil until it disperses into the water, evaporates or contacts land. As noted in the previous sections, spills of crude oil with characteristics similar to Cohassett will not be persistent, and surface slick survival times of only a few hours at most are likely even under relatively calm winds. The question then becomes: is there any chance that surface oil slicks from releases associated with the drilling of the exploration well will contact shore? This is the basic question to be addressed in this section. Another issue relates to the general sweep of surface oil from spills from the exploratory drilling program in relationship to fishing activities and surface resource distributions (birds and marine mammals).

4.2 Typical Monthly Surface Oil Slick Trajectories

Example surface slick trajectories from the proposed exploration site have been modeled for the four seasons to show the surface area that might be affected by month-long releases of crude oil. The quantity of oil that would be released from six hours of a continuous above sea blowout has been introduced on the surface at the exploration site as a batch spill every six hours over month-long periods. This does not represent a scenario that would actually occur in a continuous blowout situation but rather provides a reasonable worst-case assessment of spill behaviour. Each one of these six-hour quantities of oil has been tracked until the surface oil is completely evaporated and dispersed from the surface. This approach provides a worst-case estimate of surface slick extent from the site because the initial batch spill oil slick is thicker than would be produced by either an above-sea or subsea blowout. Figures 5 through 8 show the entire history of the movement of these six-hourly releases initiated at the start of each month for February, May, August and November 2005, respectively, and tracked until all of the surface oil is completely dispersed. These months were chosen because they represent the middle month in each of the four seasons. The year 2005 was selected randomly. The MSC50 wind data set and the average seasonal air and water temperatures in Table 4 were used to drive the trajectories. The circles in the figures represent the positions of 112 (28 days x 4 slicks per day) to 124 (31 days x 4 slicks per day) slicks of crude oil reported every 1.5 hours. The total areas of ocean surface that the slicks passed over (swept) during the one-month releases of crude oil, as represented by the composite line work shown in the close-up views, are relatively small. The radii of the total surface areas where surface oil passed through are only about 3 to 4 km from the spill source in all seasons. The areas swept by surface oil during the month-long releases are small because the light crude oil evaporates and disperses rapidly under typical weather conditions. These plots DO NOT represent the area of the ocean where crude oil is present AT ANY POINT IN TIME but merely show the total area that surface oil travelled over during each one-month release of oil. Each six-hourly release of oil is subjected to different wind speeds and directions so each surface slick will move along a different path. The following section looks in more depth at the possible movement of slicks using long-term historical wind data.

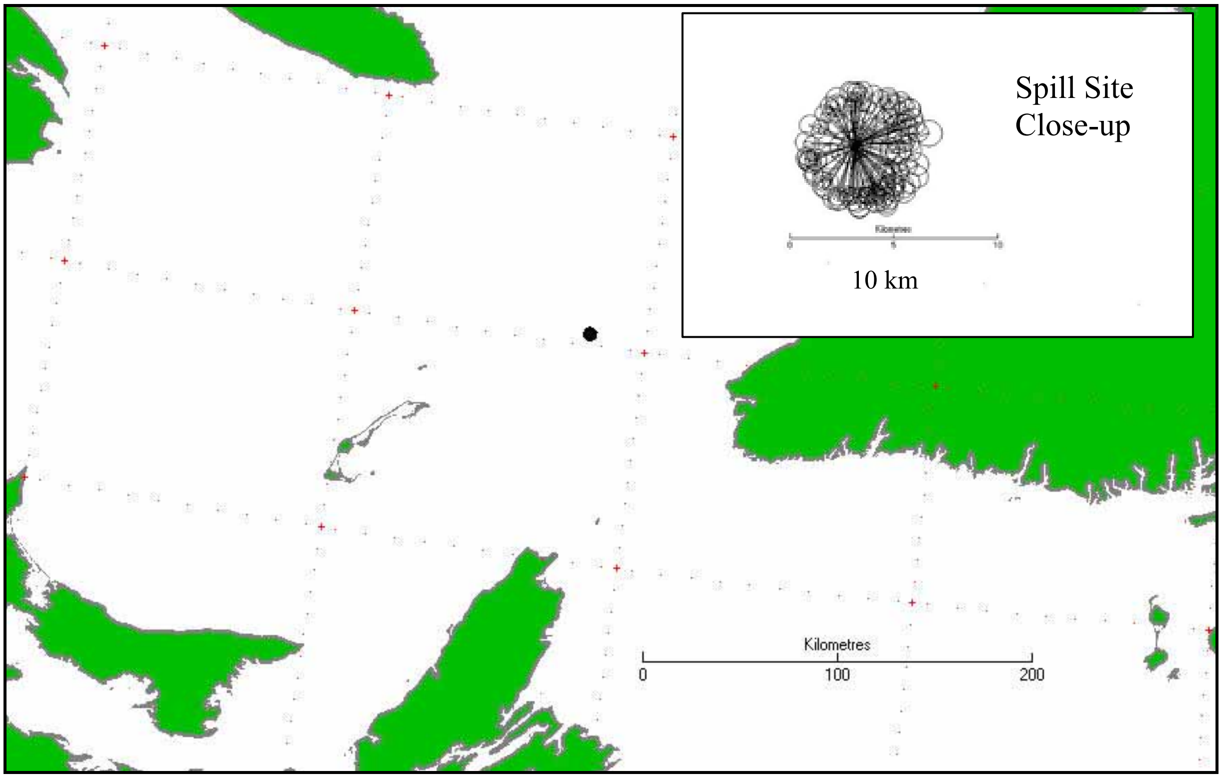

Figure 5. Surface Oil Trajectory Envelope for Surface Crude Oil: Based on Batch Releases of Six-Hour Accumulations from the Blowout, February 2005

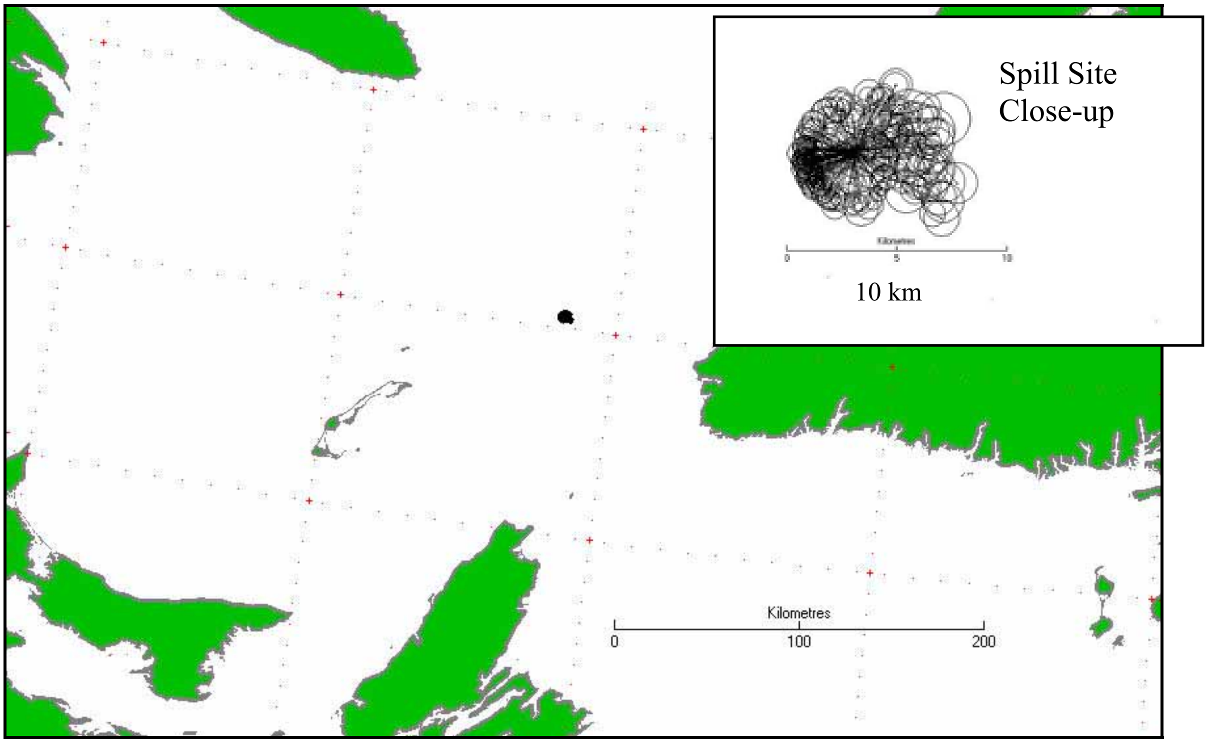

Figure 6. Surface Oil Trajectory Envelope for Surface Crude Oil: Based on Batch Releases of Six-Hour Accumulations from the Blowout, May 2005

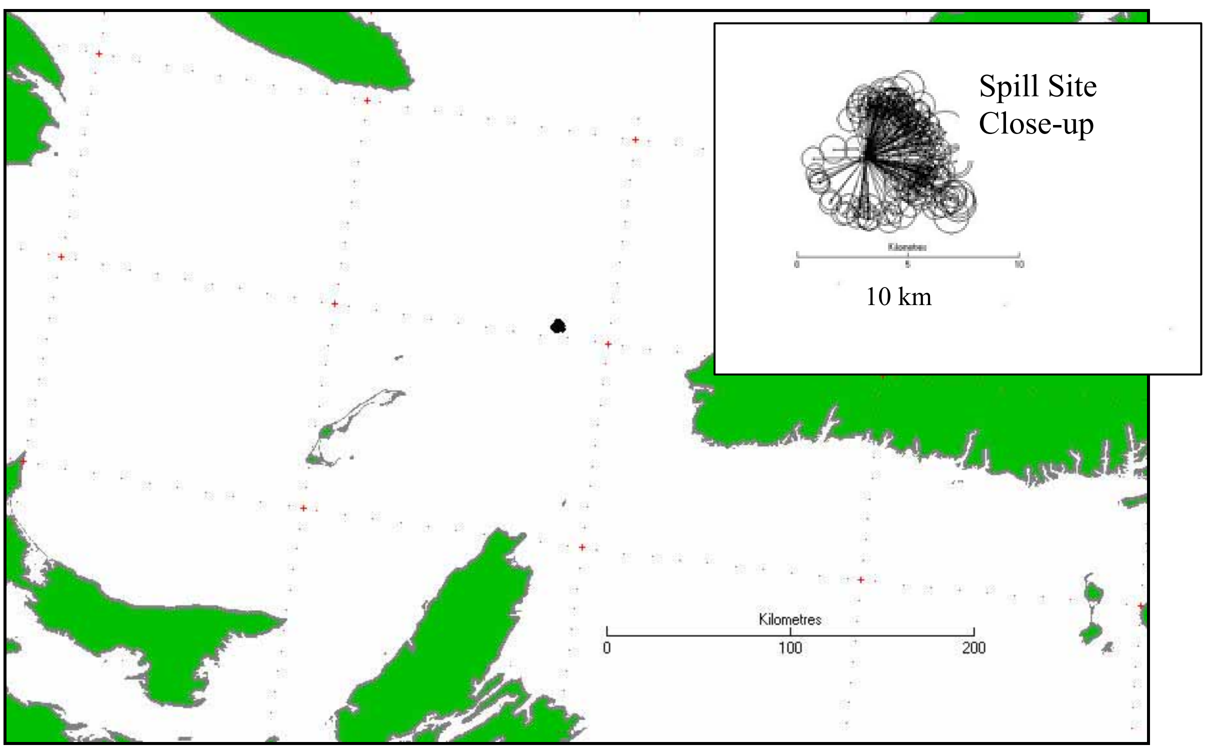

Figure 7. Surface Oil Trajectory Envelope for Surface Crude Oil: Based on Batch Releases of Six-Hour Accumulations from the Blowout, August 2005

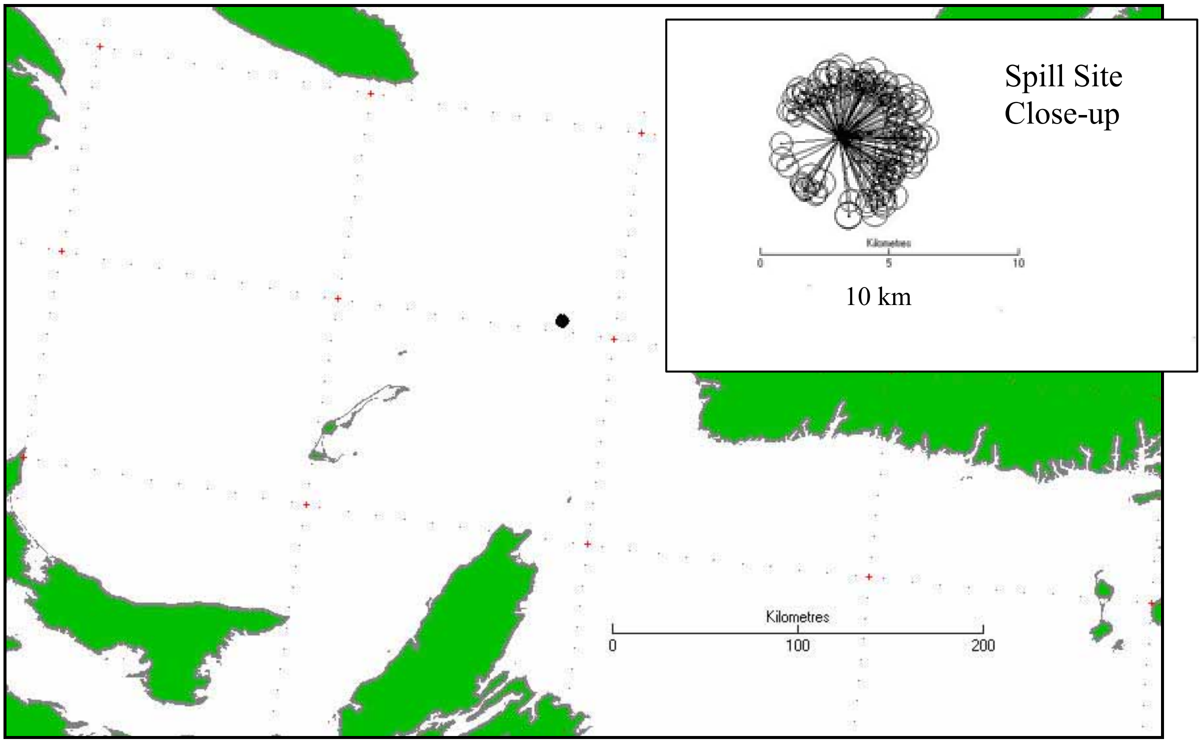

Figure 8. Surface Oil Trajectory Envelope for Surface Crude Oil: Based on Batch Releases of Six-Hour Accumulations from the Blowout, November 2005

4.3 Historical Surface Oil Spill Trajectory Assessment

In this section, the 52 years of historical wind data available in the MSC50 wind data set has been used to model the trajectory of surface oil slicks. This modeling has been completed to determine if spills from the exploration site are likely to reach land based on 52 years of historical data and to determine the likely extent of the ocean's surface that might be swept by surface oil from accidental releases from the exploration site. A good understanding of the movement of oil spilled at the drilling site is achieved by simulating the movement of the surface oil using the full 52 years of available wind data. The behaviour and fate of the surrogate crude oil from surface releases has been modeled in this assessment.

Two different approaches to this modeling have been investigated. The first is an analysis of the fate of oil from above sea blowouts as described in section 2.1.3. Above sea blowouts were selected instead of subsea releases because the oil persists on the surface longer in these types of blowouts. The second looks at a more conservative situation where 6-hour accumulations of oil (using the above sea blowout rate) are discharged as batch spills from the spill site every six hours. This approach results in longer slick survival times and higher in-water oil concentrations or more conservative estimates of oil fate. This assessment has been included to provide a reasonable worst-case oil fate estimate for any blowout situation from the drilling location.

4.3.1 Surface Oil Trajectory of Above Sea Blowouts

A total of 75,920 simulations from above sea blowouts using the methods outlined in Section 2.1.3 were run in this analysis. One volume of oil or slick from the blowout was initiated every 6 hours for the 52 year period of available winds (4 slicks per day x 365 days x 52 years = 75,920 slicks). These trajectories used the 52 years of wind data available from the MSC50 dataset. For months with 30 days, a total of 6240 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 6448 trajectories were modeled and 5824 spills were modeled for February. The spill release site used was 48.05147 N, 60.39427 W. Shoreline contact statistics on a monthly basis from these hypothetical spills are shown in Table 9. No slicks reached shore in any of the simulations completed using the 52 years of wind data. The length of time that each oil slick survived on the water surface, or the life of each surface slick, was recorded and the minimum and maximum survival times at sea are summarized in Table 9. Slick survival statistics for the complete set of 52 years of trajectories initiated every 6 hours are plotted in Figure 9. Over 40% of the slicks tracked survived at sea for less than 1 hour and only 11.5% survived for more than 10 hours.

The short life spans of the crude oil slicks results in a relatively small surface crude oil footprint. A detailed assessment of the movement of crude oil on a monthly basis, as has been traditionally done in these historical trajectory modeling exercises, is not warranted. The surface oil does not travel far enough from the site or sweep a broad enough area to justify the statistical assessment of which areas are more likely to be traversed by oil. A simpler and more instructive approach has been taken to identify the possible maximum area that surface oil could affect from a hypothetical long-term release of crude oil. The full trajectories (from source to complete loss of surface slick) of all 75,920 slicks have been drawn on one map (Figure 10) to identify the maximum surface area around the drilling site that might be swept by surface oil based on the 52 years of available wind data. The influence of surface oil from the drill site would be a maximum of about 8 km on the E-W axis and 12 km on the longer N-S axis based on this modeling.

Table 9. Slick Shoreline Contact and Slick Life at Sea Details for Above Sea Blowouts

Month	Number of Slicks Tracked	% of Slicks Tracked Reaching Shore	Minimum Slick Life at Sea (hours)	Maximum Slick Life at Sea (hours)
January	6448	0.0	0.11	16.6
February	5824	0.0	0.13	25.0
March	6448	0.0	0.14	27.8
April	6240	0.0	0.15	35.7
May	6448	0.0	0.17	56.1
June	6240	0.0	0.22	39.0
July	6448	0.0	0.21	37.3
August	6448	0.0	0.15	38.0
September	6240	0.0	0.12	34.4
October	6448	0.0	0.10	22.8
November	6240	0.0	0.11	24.7
December	6448	0.0	0.09	14.6

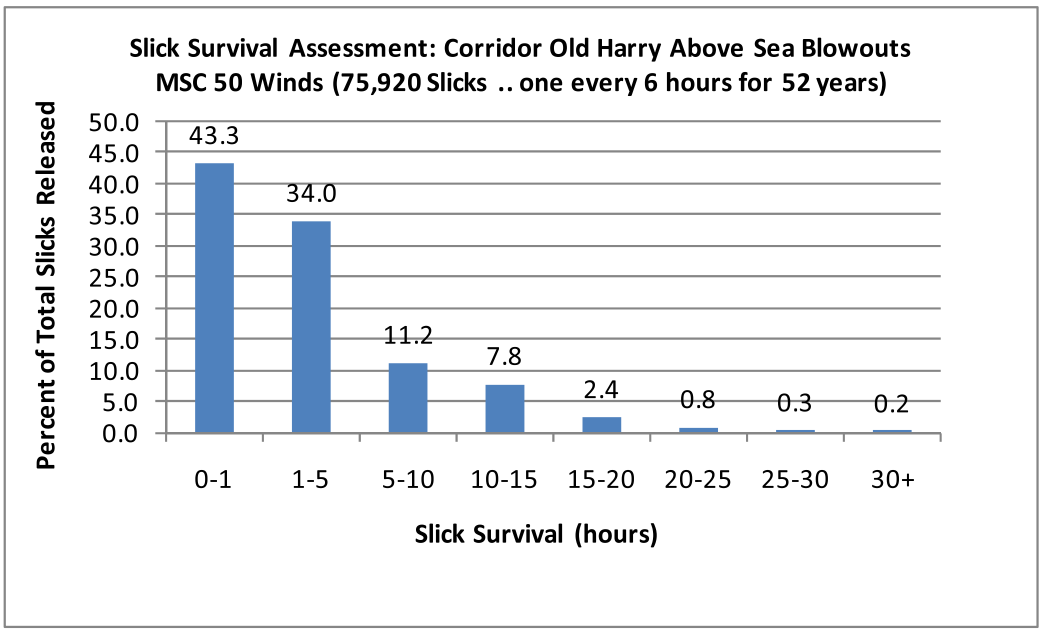

Figure 9. Slick Survival Time Statistics Above Sea Blowouts

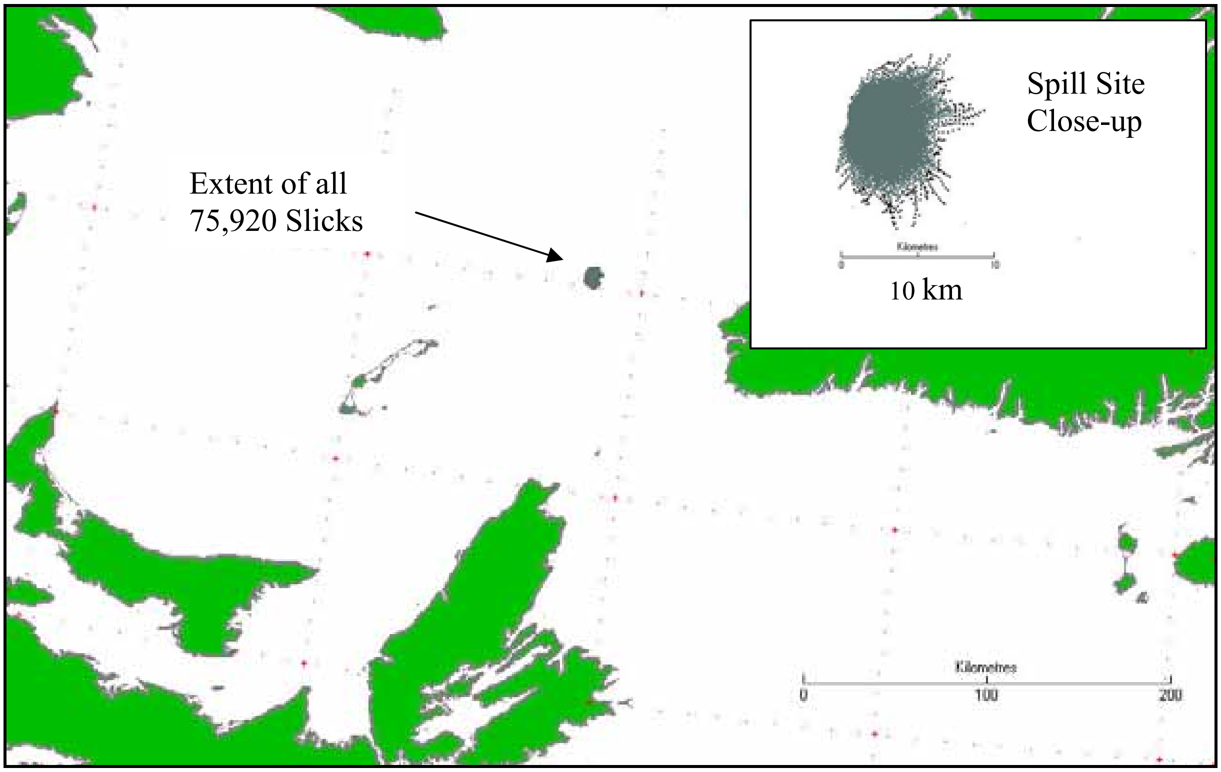

Figure 10. Maximum Area of Ocean Surface Swept by Oil from 52 Years of Above Sea Blowout Simulations

4.3.2 Alternative Trajectory Assessment: Using Conservative Oil Fate Modeling

A conservative approach to modeling the fate of crude oil from the drilling site has been used in this assessment to identify a reasonable worst-case ocean surface area that could be affected by a release from the drill site. The starting characteristics of the oil slick have been modified from that of the above sea blowout modeled in section 4.3.1. It has been assumed that six-hour accumulations of crude oil from a blowout are released at the surface as batch spills every six hours for the 52 years of available wind data to simulate the fate of this crude oil. The higher above sea flow rate of 2102.7 m^3/day was used in this assessment. This modeling is similar to the example trajectories shown in Section 4.2 but includes simulations for the entire 52 years of available wind data. In reality, the crude oil from either an above sea or subsea release would initially be thinner and evaporate and disperse from the surface more quickly than the batch slicks modeled in this section. As such, the results presented in this section provide a reasonable worst-case assessment of what the possible maximum extent of surface oil from crude oil blowouts from the drilling site using the surrogate oil properties and flow rates deemed appropriate for this formation. The data generated in these simulations have been processed in a similar manner to the above sea blowout results in section 4.3.1 and the results are provided in Table 10 and Figure 11.

As was the case for the above sea blowout modeling results, no crude oil slicks reached shore. The minimum and maximum slick survival times were similar in both cases. The six-hourly 'batch' releases generally lasted slightly longer than the above sea blowout slicks as would be expected due to the assumptions made in this modeling. Even with this reasonable worst-case modeling approach, 51 % of the slicks survived for 5 hours or less and only 19.3 % lasted for more than 10 hours.

Table 10. Slick Shoreline Contact and Slick Life at Sea: Reasonable Worst-Case Modeling Approach

Month	Number of Slicks Tracked	% of Slicks Tracked Reaching Shore	Minimum Slick Life at Sea (hours)	Maximum Slick Life at Sea (hours)
January	6448	0.0	0.5	18.4
February	5824	0.0	0.6	25.6
March	6448	0.0	0.7	29.5
April	6240	0.0	0.7	34.7
May	6448	0.0	0.8	51.4
June	6240	0.0	0.9	38.3
July	6448	0.0	0.8	36.7
August	6448	0.0	0.7	34.7
September	6240	0.0	0.6	31.5
October	6448	0.0	0.5	24.3
November	6240	0.0	0.6	24.9
December	6448	0.0	0.5	15.3

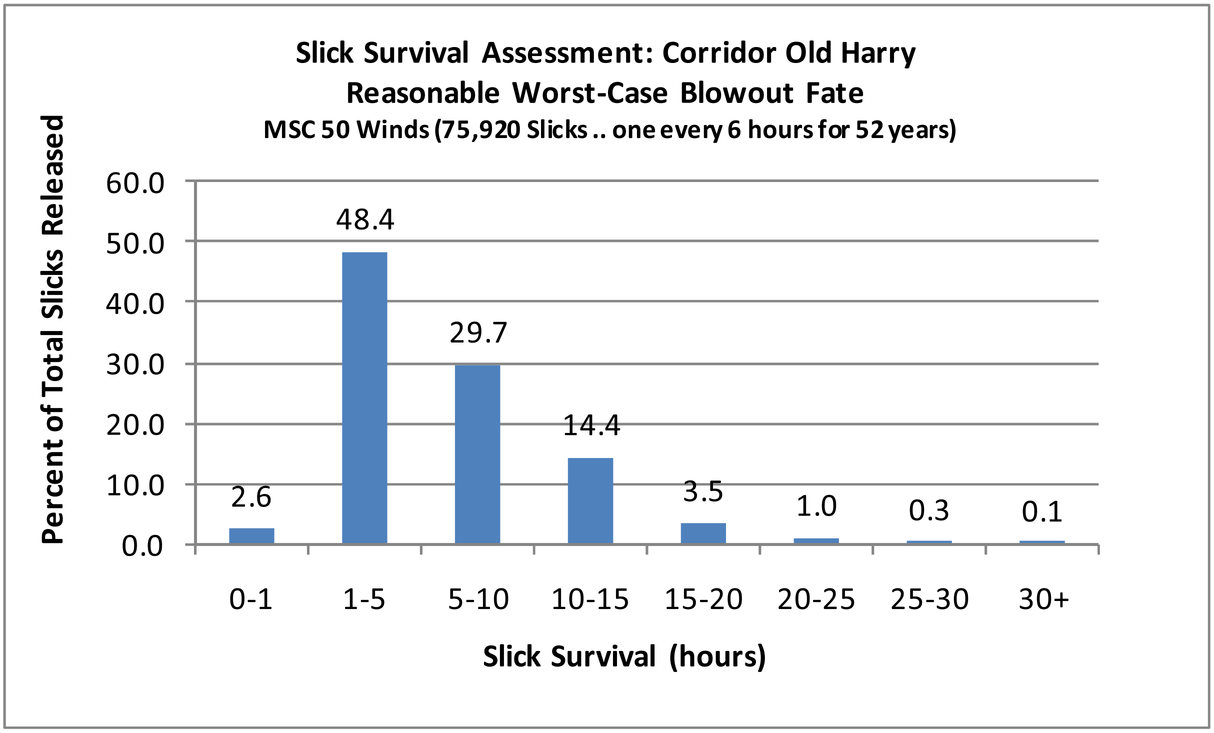

Figure 11. Slick Survival Time Statistics for Reasonable Worst-Case Modeling

As was done in the above sea blowout modeling, the trajectories of all 75,920 slicks have been drawn on one map (Figure 12) at the same time to identify the maximum ocean surface area that could possibly be swept by surface oil based on the 52 years of wind data available. As was the case for the above sea blowout modeling, a relatively small zone of influence exits even using this reasonable worst-case modeling approach. The ocean surface area that could be swept by surface oil would be about 10 km wide on the E-W axis and 13 km on the N-S axis. This is slightly larger than the above sea blowout results in section 4.3.1.

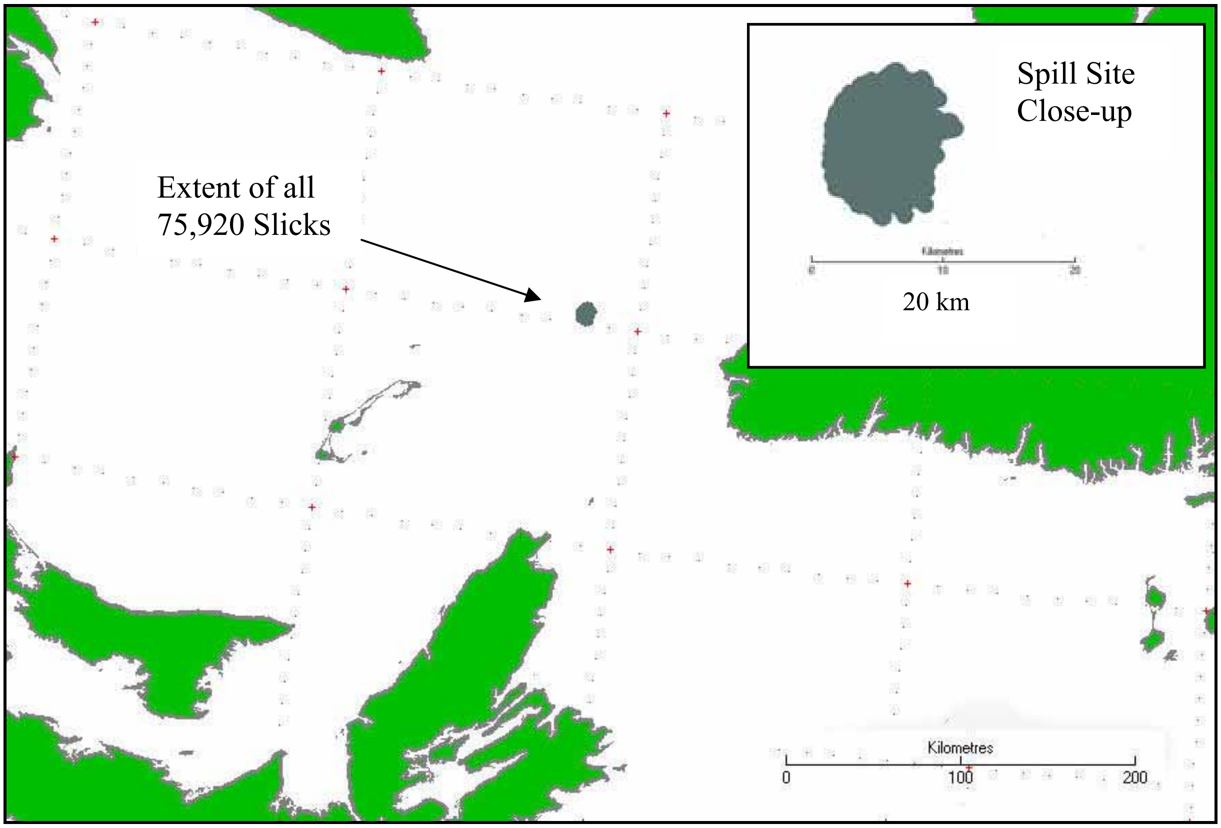

Figure 12. Maximum Area of Ocean Surface Swept by Oil from 52 Years of Simulations Using a Reasonable Worst-Case Modeling Approach

5. Dispersed Oil Plume Trajectories

5.1 Introduction

Section 4 dealt with the likely extent of surface oiling from two types of hypothetical blowouts from the Old Harry exploration operation. In this section, the movement and extent of the oil dispersed into the water column below the surface slicks from the same two hypothetical blowouts is discussed. The extent of the in-water oil plumes is of interest in determining potential effects of such spills on fisheries and non-commercial in-water resources.

5.2 Typical Monthly Dispersed Oil Plume Trajectories

The dispersed oil plumes resulting from the simulations described in section 4.2 are discussed in this section. Example dispersed oil plume trajectories from the proposed exploration site have been modelled for the four seasons to show the subsea regions that might be affected by month-long releases of crude oil. In these simulations, the quantity of oil that would be released from six hours of a continuous above sea blowout has been introduced on the surface at the exploration site as a batch spill every six hours over month-long periods. As discussed previously, this does not represent a scenario that would actually occur in a continuous blowout situation but rather provides a reasonable worst-case assessment of dispersed oil behaviour. Each one of these six-hour quantities of oil has been tracked until the subsea oil plume concentration has dropped to 0.1 ppm, the minimum concentration that is considered lethal to the more sensitive marine resources (Trudel 1989, French-MacCay 2004). The initial movement of the dispersed oil plume is assumed to be due to a combination of winds and surface water currents. The prevailing surface water currents alone are assumed to drive the dispersed oil plume once the surface slick is depleted. This generates worst-case estimates of dispersed oil concentrations as all of the dispersed oil is assumed to remain and accumulate under the slick even if the subsurface currents are actually moving the dispersed oil away from the surface slick.

The seasonal water current maps described in section 2.3.3 have been used for the movement of the oil plume. Because these maps only reflect seasonal average water currents, the variations in movements of the dispersed oil plumes are minimal once the slick is completely dispersed and the wind influence on the plume motion is no longer considered. The dispersed oil is assumed to mix into the upper 30 m water layer under the slick and is then diffused laterally by ocean diffusion processes. Figures 13 through 16 show the entire histories of the movement of the dispersed oil plumes from these six-hourly releases during the months of February, May, August and November 2005, respectively. These plots DO NOT represent the extent of the in-water oil plume at any given point in time. The total ocean region swept by the plumes during the one-month release of crude oil is represented by the areas shown in the close-up views. It has been assumed that the dispersed oil extends down to a 30 m depth. The dimensions of the swept areas in Figures 13 through 16 vary from 18 to 22 km for the plume widths and 25 to 40 km for the plume lengths.

The spill source is located at the narrow end of the plots and the general direction of movement of the plumes reflects the direction of the seasonal surface water currents in the vicinity of the drilling site.

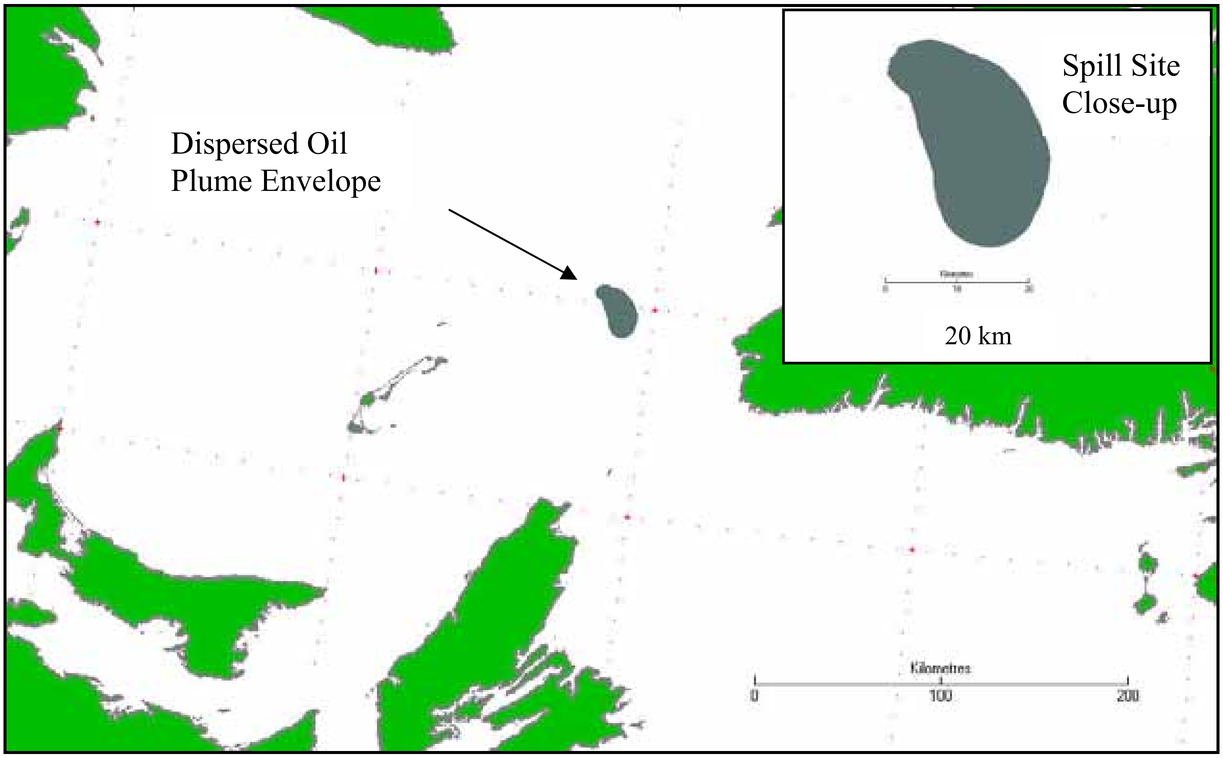

Figure 13. Reasonable Worst-Case Dispersed Oil Plume Trajectory Envelope: Based on Batch Releases of Six-Hour Accumulations, February 2005

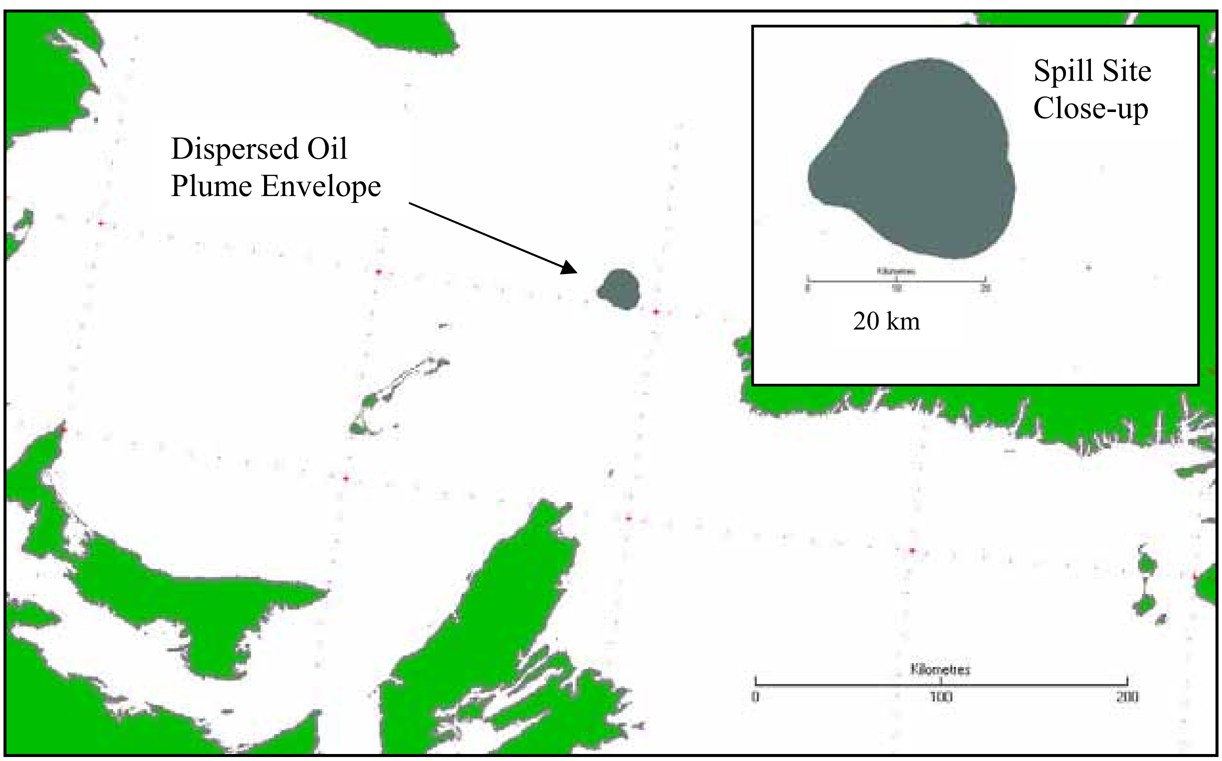

Figure 14. Reasonable Worst-Case Dispersed Oil Plume Trajectory Envelope: Based on Batch

Releases of Six-Hour Accumulations, May 2005

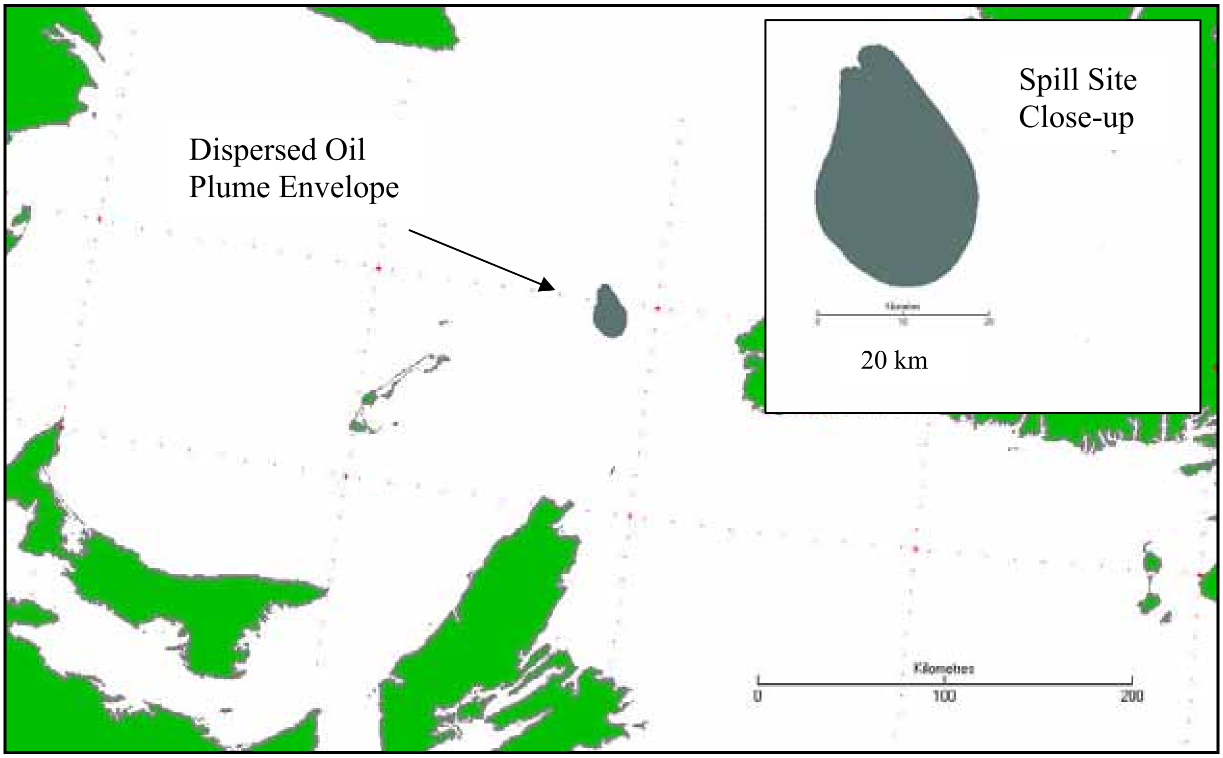

Figure 15. Reasonable Worst-Case Dispersed Oil Plume Trajectory Envelope: Based on Batch Releases of Six-Hour Accumulations, August 2005

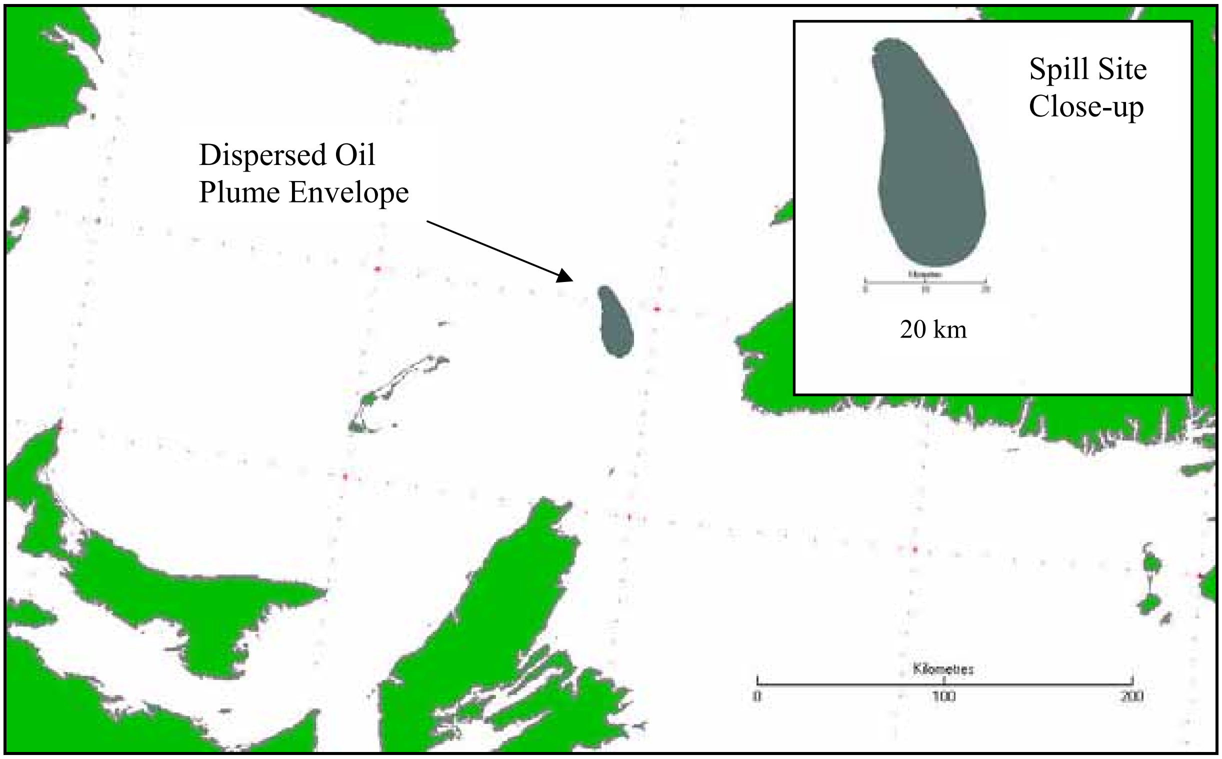

Figure 16. Reasonable Worst-Case Dispersed Oil Plume Trajectory Envelope: Based on Batch Releases of Six-Hour Accumulations, November 2005

5.3 Historical Dispersed Oil Plume Assessment

This modeling has been completed to determine the maximum likely extent of the ocean's upper 30 m mixing layer that might be contacted by dispersed oil from accidental releases from the exploration site. The full 52 years of MSC50 wind data and the seasonal water current maps have been used in these simulations. In section 5.2 only month-long oil releases for a specific year are considered to provide a "typical' oil footprint. The behaviour and fate of the surrogate crude oil from surface releases has been modeled in this assessment. The same two sets of simulations reported for the surface slick trajectories, the above sea blowout release and the reasonable worst-case 6-hourly batch releases are also provided for the dispersed oil plumes.

5.3.1 Dispersed Oil Plumes from Above Sea Blowouts

The dispersed oil plume envelope resulting from the 52 years of above sea blowout simulations has been plotted on Figure 17. This figure represents our best estimate of the maximum possible region swept by the dispersed oil plume, out to 0.1 ppm, based on the detailed modeling of an above sea continuous blowout as described in section 4.3.1. The areas do not represent the extent of the dispersed oil plume from a single blowout event; rather the area on this figure shows the maximum extent of dispersed oil plumes with concentrations greater than 0.1 ppm for all of the 75,290 simulations completed using 52 years of wind data.

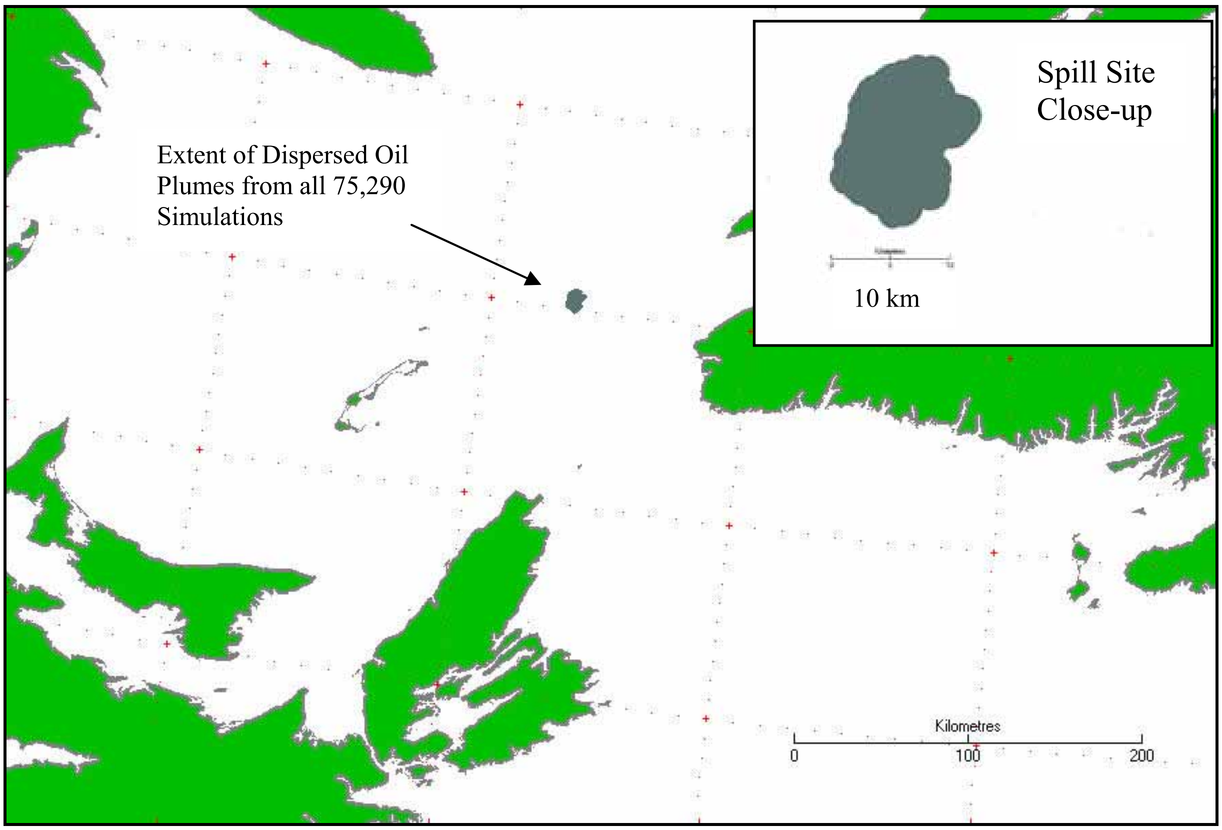

Figure 17. Maximum Extent of Ocean Swept by > 0.1 ppm Dispersed Oil from 52 Years of Above Sea Blowout Simulations

5.3.2 Alternative Dispersed Oil Plumes: Using Reasonable Worst-Case Oil Fate Modeling

Figure 18 shows the dispersed oil plume extent for the spill simulations described in section 4.3.2 where six-hour accumulations of oil from the blowout are released as batch spills. The surface footprint for this case is larger than the continuous above sea blowout estimate provided in section 5.3.1 due to the larger volume of oil being considered in each 6-hour release.

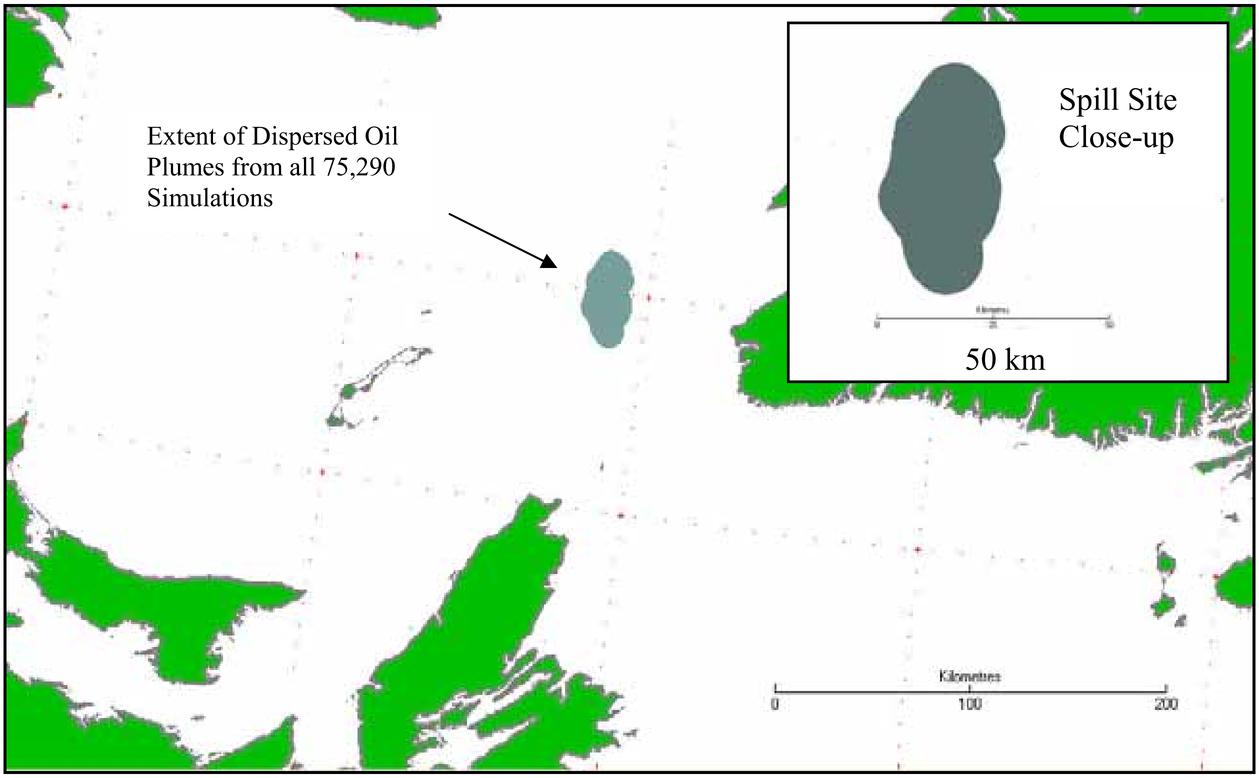

Figure 18. Maximum Extent of Ocean Swept by > 0.1 ppm Dispersed Oil from 52 Years of Simulations Using Reasonable Worst-Case Modeling Approach: Six-Hourly Accumulations Released as Batch Spills

7. References

Belore, R.C. and I.A. Buist. 1988. Modeling of oil spills in snow. Proceedings of the 11th Arctic and Marine Oilspill Program Technical Seminar.

Corridor Resources Inc. 2011. Project Description for the Drilling of an Exploration Well on the Old Harry Prospect – EL 1105.

Dickins, D.F. and I.A. Buist. 1981. Oil and gas under sea ice study. Report to the Canadian Offshore Oil Spill Research Association, Calgary.

Drinkwater, K.F., D. Gilbert. 2004. Hydrographic Variability in the Waters of the Gulf of St. Lawrence, the Scotian Shelf and the Eastern Gulf of Maine (NAFO Subarea 4) During 1991-2000. J. Northw. Atl. Fish. Sci., Vol. 34: 83-99.

C-NLOPB. 2011. Canada-Newfoundland and Labrador Offshore Petroleum Board Spill Statistics. www.cnlopb.nl.ca/env_stat.shtml. Data accessed January 2011. CNLOPB. St. John's.

Fannelop, T.K., Sjoen, K. 1980. Hydrodynamics of Underwater Blowouts. AIAA 18th Aerospace Sciences Meeting. Pasadena California. 1980. AIAA-80-0219.

French-MacCay, D.P. 2004. Oil spill impact modeling: Development and validation. Environmental Toxicology and Chemistry 23(10)-2441-2456.

LGL 2007. Western Newfoundland and Labrador Offshore Area Strategic Environmental Assessment. Prepared for Canada-Newfoundland and Labrador Offshore Petroleum Board. LGL Limited Environmental Research Associates. November 2007.

SL Ross, Alun Lewis Oil Spill Consultancy, Bercha Group, PCCI. 2003. Persistence of Crude Oil Spills on Open Water. Project Number 1435-01-02-RP-85091. Report Prepared for US Department of the Interior, Minerals Management Service, Alaska Outer Continental Shelf Region.

S.L. Ross Environmental Research Limited and D.F. Dickins Associates Ltd. 1987. Field research spills to investigate the physical and chemical fate of oil in pack ice. Environmental Studies Revolving Funds, Report No. 062, Ottawa.

Swail, V.R., V.J. Cardone, M. Ferguson, D.J. Gummer, E.L. Harris, E.A. Orelup, A.T. Cox. 2006. The MSC50 Wind ans Wave Reanalysis. 9th International Workshop on Wave Hindcasting and Forecasting. Victoria, B.C., Canada.

Tang, C.L., T. Yao, W. Perrie. B.M. Detracey, B. Toulany, E. Dunlap, Y. Wu. 2008. Canadian Technical Report of Hydrography and Ocean Science No. 261, BIO Ice-Ocean and Wave Forecasting Models and Systems for Eastern Canadian Waters. Ocean Sciences Division, Maritimes Region, Fisheries and Oceans Canada.

Trudel, B.K., R.C. Belore, B.J. Jessiman, S.L. Ross. 1989. A Mico-computer Based Spill Impact Assessment System for Untreated and Chemically Dispersed Oil Spills in the U.S. Gulf of Mexico. 1989 International Oil Spill Conference.

Turner, D.B. 1970. Workbook of Atmospheric Dispersion Estimates. US Environmental Protection Agency.

Yapa, Poojitha D. , Dasanayaka, Lalith K. , Bandara, Uditha C. and Nakata, Kisaburo. 2010. A model to simulate the transport and fate of gas and hydrates released in deepwater, Journal of Hydraulic Research, 48: 5, 559-572.

Wotherspoon & Associates. 1992. Detection of oil in ice & burning of oil spills in winter conditions: State of the art review. Prepared for PROSCARAC Inc., Calgary, Alberta.

Appendix A. Type of Oil Likely to be found at Old Harry

Ten offshore wells have been drilled to date in the Gulf of St. Lawrence; half of those wells encountered non-commercial quantities of natural gas and none encountered oil. An oil sample that is representative of the type of oil potentially trapped in the Old Harry structure is required to determine the necessary oil properties (density, viscosity, pour point, etc.) for oil spill modeling. Since an oil sample is not available from the Old Harry structure to determine its properties, identification of an appropriate surrogate oil is required.

Corridor hired a world renowned contractor (Global Geoenergy Research) to complete source rock studies. These studies were used to determine the most likely type of oil to be potentially encountered at Old Harry. The source rock studies involved geochemical analysis and thermal maturity determinations of rock samples from the Brion Island No. 1 well (Mukhopadhyay, 2011). The Brion Island well is the closest well to the Old Harry prospect; located about 70 kilometers to the west. The geochemical studies identified the type of organic material, its main characteristics, and the depositional environment of the source rocks in the Old Harry area. The data clearly indicated that most of the organic material in the source rocks near the Old Harry structure was derived from mixed fluvial-lacustrine oil prone amorphous lipids (Type II) or terrestrial liptinite (Type III) organic matter. These source rocks typically generate mainly oil at the early stages of thermal maturation and natural gas at later stages. Due to the present stage of thermal maturation of the source rocks, the hydrocarbons within the Old Harry structure, if present, are likely to comprise a very light, 45-56 degree API gravity oil with low to moderate gas-oil ratio (Mukhopadhyay, 2011).

To assist in the identification of a surrogate oil for Old Harry, Corridor considered geological parameters such as depositional environment, the type of organic material (kerogen) and types of hydrocarbons encountered in several areas. Although only natural gas has been encountered in offshore Gulf of St. Lawrence wells, high API gravity oils have been identified in Gaspe (47^{o} API); Port-au-Port, Newfoundland (51^{o} API); and the Scotian Shelf (47-52^{o} API). Several characteristics of the geology in the Maritimes Basin (Old Harry area) compare favourably to the geological conditions encountered in the Scotian Basin as shown in Table A1. The clastic reservoir rocks in the fields on the Scotian Shelf typically comprise fluvial and shallow marine, stacked, sandstone sequences that are analogous to the fluvial sandstone reservoir rocks at Old Harry. Of particular note is the known kerogen type in both basins is Types II-III and III. In addition, light oil was produced from the Cohasset/Panuke/Balmoral Fields on the Scotian Shelf. Consequently, Corridor geoscientists have selected the Cohasset oil from the Scotian Basin as an appropriate surrogate for the oil that could be found at Old Harry.

The Cohasset oil is high gravity oil (47.5^{o} API) produced from the Cohasset/Panuke/Balmoral Fields on the Scotian Shelf (Kidston et al., 2005). The source rocks that generated the Cohasset oil are reported to have been generated from Types I to II source rocks (Mukhopadhyay, 1993). Source rocks of this type have never been encountered in any well drilled to date in the Scotian Basin. The only known source rocks in the Scotian Basin comprise Types II-III and III (Kidston et al., 2005), the same classification of the source rocks found at Old Harry.

Table A1. Comparison of Geologic Characteristics of the Maritimes and Scotian Basins.

	Maritimes Basin (Old Harry)	**Scotian Basin**
Tectonic Environment	Strike-Slip Rift	Extensional Rift
Depositional Environment	Fluvial-Deltaic	Fluvial-Deltaic to Shallow Marine
Kerogen Type	Types II-III and III	Types II, II-III and III
Hydrocarbon Types	Natural Gas	Natural Gas and Light Oil

Kidston A.G., Brown, D.E., Smith, B.M. and Altheim, B. 2005. The Upper Jurassic Abenaki Formation Offshore Nova Scotia: A Seismic and Geologic Perspective. Canada-Nova Scotia Offshore Petroleum Board, 169 p.

Mukhopadhyay, P.K. 1993. *Analyses and interpretation of geochemical and source rock data from Scotian Shelf wells.* Geological Survey of Canada Open File Report No.2804.

Mukhopadhyay, P.K. 2011. Genesis of Reservoir Hydrocarbons and Migration of Oil and Gas within Old Harry Prospect: Two Dimensional Petroleum System Modelling Using 2-D Seismic Lines (98-23-K50 and 98-32). Corridor Resources Internal Report, Contract Number 2010-160, 30 p.

Appendix B. Reservoir/Production Engineering Note – February 25, 2011
Old Harry Conceptual Development – Oil Well Blowout Modeling

1. Introduction

Old Harry is an offshore prospect located in the Laurentian Channel of the Gulf of St. Lawrence (refer to Figure B1).

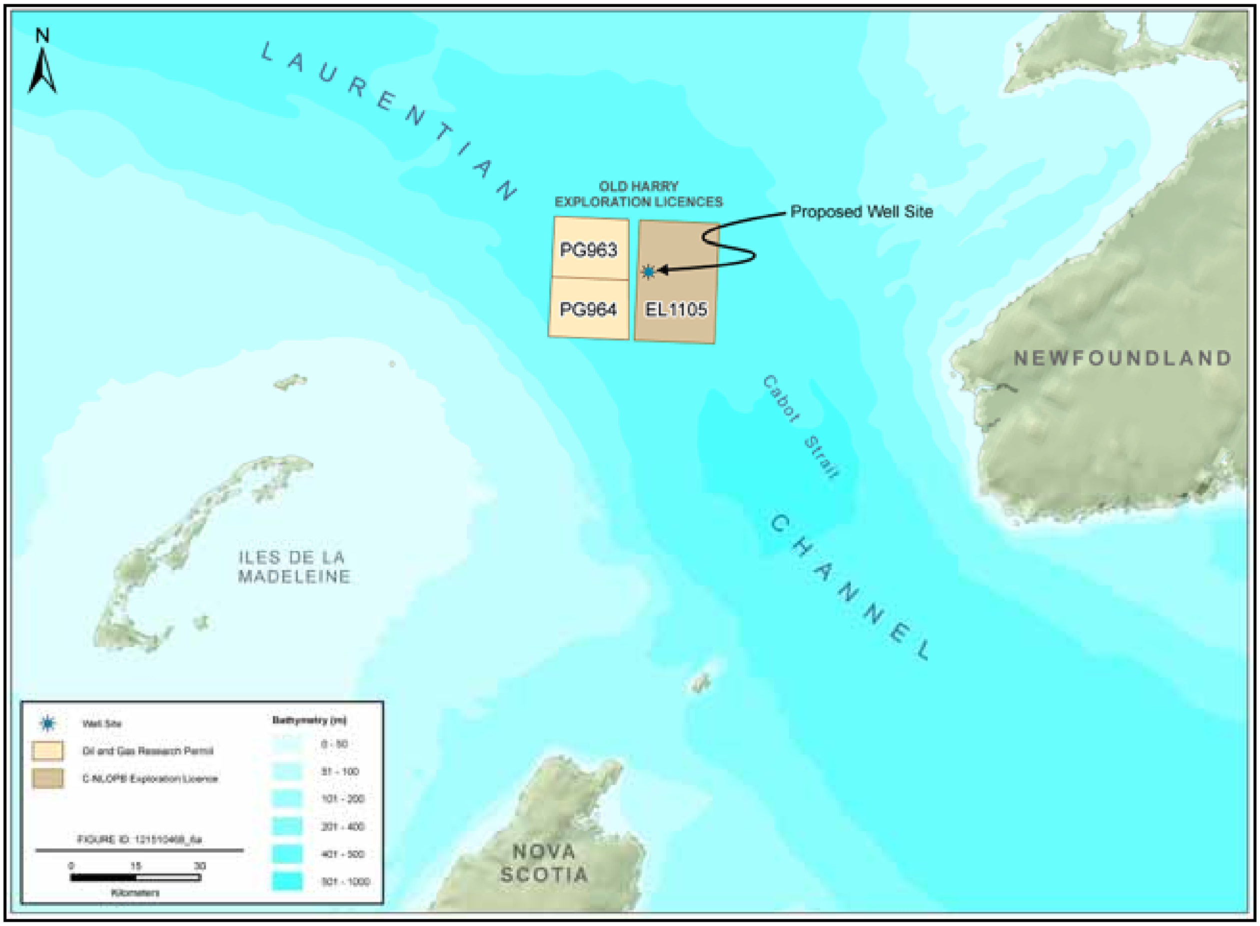

Figure B1: Location of Old Harry

In order to assist with modeling the environmental impact of a well drilling problem that included an uncontrolled well problem (blowout), a production model was constructed using the IPM (Integrated Production Model) software from Petroleum Experts Limited to model unconstrained oil flow from a well blowout in the Old Harry reservoir.

2. Old Harry Blowout Production Model

The integrated production model includes a number of oil wells in order to model unconstrained flow for varying the reservoir parameters. Figure B2 presents the blowout production model constructed for this exercise.

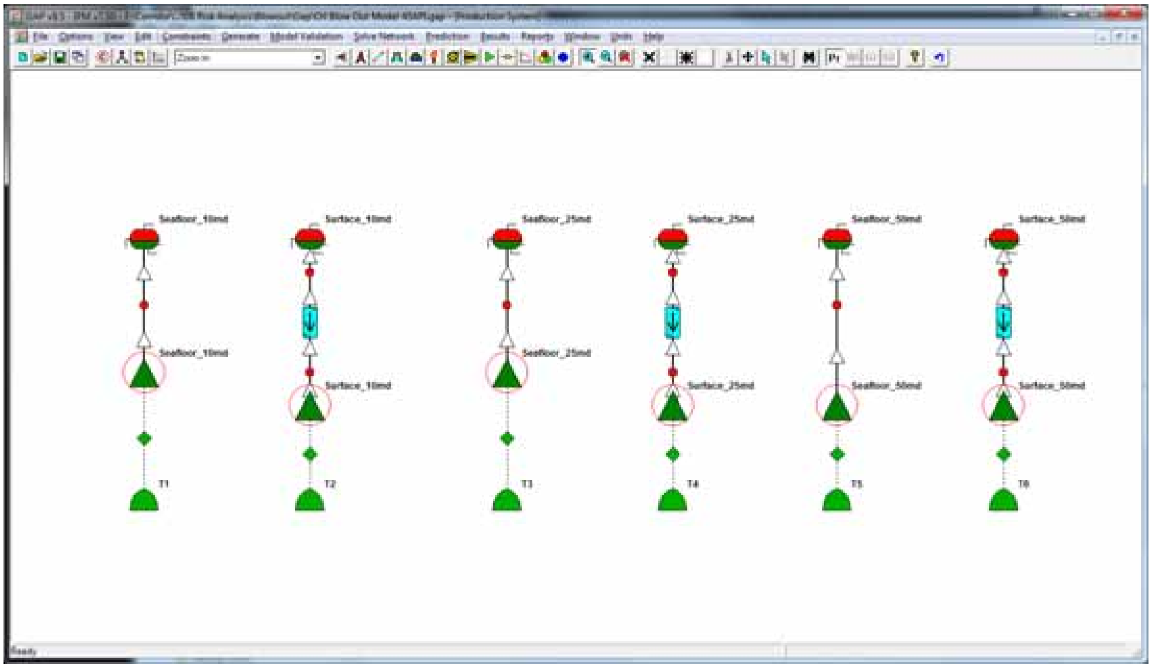

Figure B2: Old Harry Blowout Model – Oil Wells

Three type wells were included to cover the assumed range of reservoir quality expected to be encountered at Old Harry. Table B1 lists the reservoir parameters used in the model.

Blowout Model - Well Parameters	
Permeability (md)	10 / 25 / 50
Pay Thickness (m)	30
Well PI (bpd/psi)	1.6 / 3.9 / 7.8
Oil API	55
Well GOR (scf/bbl)	500
Well OOIP (MMbbl)	50
Pressure (psi)	2350
Temperature (C)	30
Pay Depth (m)	1500
Water Depth (m)	470

Table B1 – Well Parameters

For modeling purposes, based on hydrocarbon source modeling, a 55° API oil was assumed to exist in the Old Harry structure. The closest equivalent crude is Cohasset crude at 47.5° API. Cohasset crude is an extremely under saturated crude, but for purposes of this exercise, the Old Harry oil was considered to be moderately under saturated.

The production model was used to evaluate an uncontrolled flow situation where the flow outlet point was either at the seafloor or on the rig. A seafloor blowout would be constrained by the pressure exerted by a 470m column of water and for this exercise was set at 660psi. A blowout on the rig was assumed to occur at 25m above sea level with no pressure constraint. Completion of the wells assumed a 12.25" open hole with a 21.25" riser to the rig floor.

3. Old Harry Oil Blowout Potential

To model the unconstrained flow from the wells, two locations were assumed: seafloor and surface. For flow at the seafloor, the constraint on the well was equivalent to the pressure exerted by 470m of water. Flow at surface assumed a 25m height above sea level with an unconstrained flow to atmosphere.

The production model was used to forecast 30 days of flow. Figure B3 presents the results of the 30 day forecast for a seafloor blowout and Figure B4 presents the results for surface blowout.

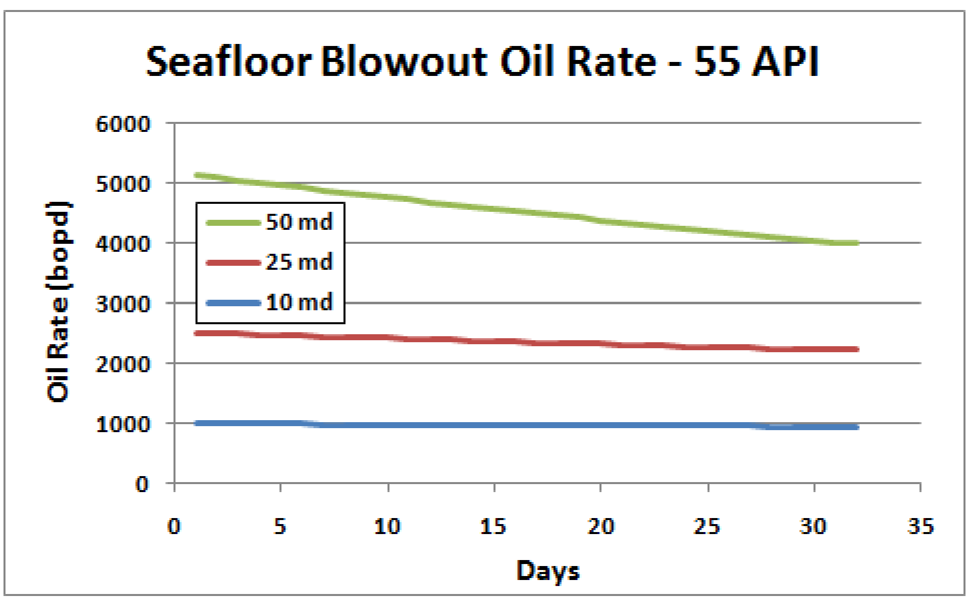

Figure B3: Old Harry Blowout Model – Subsea Blowout

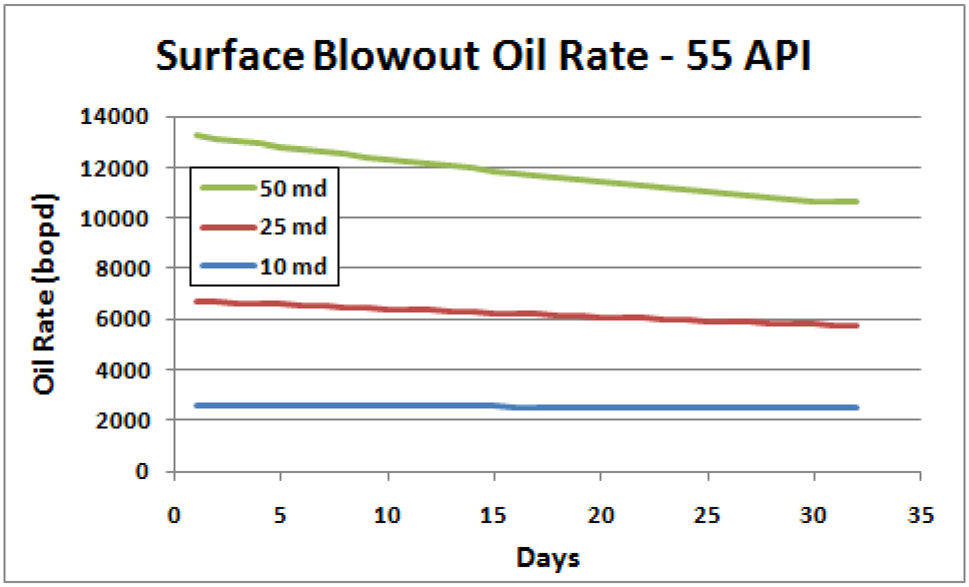

Figure B4: Old Harry Blowout Model – Surface Blowout

Table B2 presents the day 1 oil rate for the different blowout scenarios.

Day 1 Potential Rate 55 API (bopd)		
Quality	**Seafloor**	**Surface**
10 md	991	2608
25 md	2514	6719
50 md	5143	13226

Table B2 – Day 1 Unconstrained Oil Rates

4. Old Harry Blowout Potential: Conclusion

The magnitude of the unconstrained flow of oil from the Old Harry structure is a function of the location of the problem and the quality of the reservoir.

For a problem at the sea floor, the blowout rate would be in the range of 1000 bopd – 5000 bopd depending on the reservoir permeability.

For a problem at the surface, the blowout rate would be in the range of 2500 bopd – 13,000 bopd depending on the reservoir permeability.