APPENDIX F

Spill Probability Analysis

Analysis of Probability of Potential Blowouts and Spills from Offshore Wells and Activities

Perspectives on Shelburne Basin Venture Exploration Drilling Project

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Executive Summary

The following document was prepared to provide a probability analysis of offshore spills and blowouts to support the Shelburne Basin Venture Exploratory Drilling Project (the Project). The report considers the probability of both continuous longer-term, larger scale blowouts, as well as smaller scale, shorter-term spill scenarios (batch spills) in association with the Project. In association with this analysis, this report considers relevant historical data on spills in order to evaluate the probability of occurrence of blowouts and spills associated with the Project. Additionally, this report provides information on general blowout and other exploratory well spillage to allow comparison to the modelled scenarios for this Project.

There are three important aspects to determining the "spill risk" associated with an offshore exploratory well operation:

- Determining the likelihood or probability that a well blowout or other well release will occur;
- Determining the potential oil spillage volumes that might occur and the probabilities that the spill will be a large-scale spill; and
- Determining the potential impacts of hypothetical spills.

This report only addresses the first two aspects of risk. The results of the analyses show that the probability of a well blowout or other release is very low – i.e., blowouts and other spills from offshore exploratory wells are quite rare. The analyses also show that if a blowout or other spill were to occur, the chances are great that it would be a small volume of spillage rather than a very large event with high consequences. This report reviews the available data and findings based on historical research on offshore spills to determine the probabilities for spills and the potential spill volumes that might be involved.

Well-related spills occur relatively infrequently during offshore operations. Most well spills involve releases of less than 100 barrels (bbl) over the course of less than one day. Additionally, large-scale exploratory well blowouts are very rare events. The greatest concern about blowout scenarios is for the potential volume that may be released into the environment. This concern has become particularly heightened after the 2010 Macondo MC-252 blowout in the US Gulf of Mexico. While this blowout released a large amount of oil, blowouts, in general, are infrequent and also are statistically shown to involve much smaller quantities of oil.

A blowout is defined as "a loss of well control or uncontrolled flow of formation or other fluids, including flow to an exposed formation (an underground blowout) or at the surface of the seabed (a surface blowout), flow through a diverter, or uncontrolled flow resulting from a failure of surface equipment or procedures." This definition encompasses incidents in which fluids other than oil are released. Only 41% of blowouts involve the release of any oil, as opposed to brine, water, or gas. The majority of surface blowouts from exploratory wells last less than five days.

The proposed Project wells would all be at water depths in the 1,000 to 3,000 metre range. Exploratory well blowouts statistically observed to be 30% less likely in water depths of 1,000 – 2,500 metres than at shallower depths; other well releases statistically observed to be 45% less likely at these depths. There have been no well blowouts or releases recorded at water depths over 2,500 metres.

The probability of a blowout from any specific exploratory well for the Project is estimated at 0.00078, or once in 1,287 years. With seven potential exploratory wells, the probability of a blowout from any of the wells increases to 0.0054, or once in 184 years.

The volume of spillage is dependent on the flow rate (bbl/day) and the duration of flow, which is dependent on the likelihood of natural bridging or the time that it would take to successfully intervene with the installation of a capping and containment system. The estimated probabilities of large well blowouts from the Project are summarized in Table ES-1. Return periods are the amount of time that would typically be required for an event to occur once. For example, a 100-year flood typically occurs once in 100 years. Note that the exploratory operations of the Project are expected to take five years in consideration of the initial exploration phase of the Project.

Table ES-1: Probabilities of Project Large Well Blowouts by Volume Category

Volume Category	Probability (Incidents per Well)	Return Period
Large (1,000 – 10,000 bbl)	0.0049	202 years
Very Large (10,000 – 150,000 bbl)	0.0045	222 years
Extremely Large (>150,000 bbl)	0.0018	541 years

Besides well blowouts and other releases from wells, other spills may potentially occur during offshore exploratory operations, including batch (or operational) spills of diesel from vessels, mobile offshore drilling units (MODUs), pumps, or hydraulic apparatus on rigs, or of synthetic-based mud (SBM), as shown in Tables ES-2 and ES-3.

As shown, spills of over 1 bbl are very unlikely to occur during the five-year Project time frame. There are, however, likely to be small (<1 bbl) spills occurring during the time frame of the Project. Moderate to Very Large category spills would tend to occur from the MODU, since this holds the greatest amount of oil. Small category spills could occur from the MODU or from other parts of the offshore operations other than the well itself.

Because the Moderate category covers such a broad range of volumes across three orders of magnitude (1 to 1,000 bbl) with highly varying probabilities of occurrence, the category has been further subdivided into Small/Moderate (1-10 bbl) and Moderate/Large (100 – 1,000 bbl) for the batch spill analysis.

Table ES-2: Probabilities of Project Batch Spillage by Volume Category

Volume Category	Probability		Return Period (years)
	1-Year	5-Year	
Small (< 1 bbl)	3.4	16.8	0.3
Small/Moderate (1 – 10 bbl)	0.02439	0.12194	41
Moderate/Large (100 – 1,000 bbl)	0.00124	0.00620	806
Large (1,000 – 10,000 bbl)	0.00006	0.00031	16,129
Very Large (10,000 – 150,000 bbl)	0.00001	0.00006	80,645
Extremely Large (>150,000 bbl)	0	0	n/a

Table ES-3: Probabilities of Project SBM Spillage by Volume Category			
Volume Category	**Probability**		**Return Period**
	1-Year	**5-Year**	
Small (< 1 bbl)	0.01116	0.05580	90
Moderate (1 – 1,000 bbl)	0.00062	0.00310	1,613
Large (1,000 – 10,000 bbl)	0.00012	0.00062	8,065
Very Large (10,000 – 150,000 bbl)	0	0	n/a
Extremely Large (>150,000 bbl)	0	0	n/a

The estimated probabilities of the specific spill volumes associated with the scenarios that were modelled for impacts are shown in Table ES-4. The blowout scenarios have return periods of about 3,700 and 18,000 years. Smaller diesel spills from mobile offshore drilling units (MODUs) have return periods of 41 for a 10-bbl spill and 806 years for a 100-bbl spill. No 100-bbl batch spills have occurred in the Nova Scotia offshore. Spills of synthetic-based mud (SBM) during operations for the volumes modelled are also unlikely, having return periods of at least 1,000 years.

Table ES-4: Probabilities of Project Scenario Spillage			
Scenario	**Volume (bbl)**	**Probability in Project Time**	**Return Period (years)**
Batch Spill-10 bbl (Diesel)	**10 bbl**	0.121940	41
Batch Spill-100 bbl (Diesel)	**100 bbl**	0.006200	806
SBM Spill-1	**377.4 bbl**	0.004960	1,008
SBM Spill-2	**3,604.2 bbl**	0.000620	8,065
Spill (Site-1) - Blowout	**1,474,500 bbl**	0.000054	18,392
Spill (Site-2) - Blowout	**747,000 bbl**	0.000270	3,678

During the 1990s, total inputs of oil from anthropogenic sources in coastal areas of Eastern Canada have averaged 9,000 barrels annually, and in offshore areas, 2,700 barrels annually, for a total of 11,700 barrels. Spill volumes off Nova Scotia have decreased significantly in the last decade to about 600 barrels. Offshore exploration and production facilities off Nova Scotia have spilled a total of 78 barrels of oil in 189 incidents over the last 15 years. Ninety-four percent of these incidents involved less than one barrel of oil. Overall, the probabilities of spillage are very low and if spillage does occur, the spill volumes are likely to be relatively small.

Occasional tanker spills have provided the greatest threat of oil spillage to the region in the past, though the remote possibility of a well blowout or other large spill exists. In addition to anthropogenic inputs from spills, urban runoff, and vessel and facility operations, natural seepage may also contribute to overall hydrocarbon inputs in the region. Several natural seeps have been identified in the region, though there are no quantifications of annual inputs from this source.

Project Scope

Environmental Research Consulting (ERC) has been tasked with providing an probability analysis of offshore oil well spills and blowouts as part of the environmental assessment required for the Shelburne Basin Venture Exploration Drilling Project application to the Canadian Environmental Assessment Agency (CEA Agency).

This report provides information and consideration of the following:

- Overall analysis of historical data on offshore oil exploration spillage;
  - Well spillage;
  - Offshore supply vessel spillage;
  - Operational discharges;
- Risk analysis of spillage from offshore wells due to causes other than blowouts;
  - History of offshore well spillage;
    - Causes;
    - Locations;
    - Spillage volumes (durations, flow rate, total spillage);
  - Probability of offshore well spillage;
  - Volume distributions for offshore well spillage;
- Risk analysis of offshore well blowouts;
  - History of offshore well blowouts;
    - Locations;
    - Spillage volumes (durations, flow rate, total spillage);
    - Method of stopping flow;
  - Probability of offshore well blowouts;
  - Volume distributions for offshore well blowouts;
- Analysis of Shell Shelburne modelled scenarios (blowouts and supply vessel spills);
  - Relative probability;
  - Volume probability;
- Natural oil seepage in the environment worldwide, in the northern Atlantic, and in the Shelburne area in particular; and
- Perspective on Shell Shelburne potential oil spillage in relation to other inputs;
  - Natural seepage;
  - Tanker spillage;
  - Non-tank vessel spillage;
  - Vessel operational discharges;
  - Offshore production operational discharges;
  - Coastal facility spillage; and
  - Urban runoff.

Glossary of Terms

Appraisal well: well drilled to determine the extent and size of a discovery.

Barrel (bbl): a unit of liquid measure, which is the equivalent of 42 US gallons, 35 Imperial gallons, or 0.159 cubic metres.

Batch spill: a small accidental spill that occurs during routine operations (also called “operational spill”).

Batch Spill-10 bbl: a hypothetical release of 10 bbl of diesel fuel from a MODU at Location 3 (42.2487, -63.4776)

Batch Spill-100 bbl: a hypothetical release of 100 bbl of diesel fuel from a MODU at Location 3 (42.2487, -63.4776)

Blowout: loss of well control or uncontrolled flow of formation or other fluids, including flow to an exposed formation (an underground blowout) or at the surface (a surface blowout), flow through a diverter, or uncontrolled flow resulting from a failure of surface equipment or procedures.

BOP: Blowout preventer

Bridging (Natural Bridging): stoppage of well flow without human intervention through sand or rock accumulation inside the wellbore, formation collapses due to high flowing rates and high drawdown pressure, or formation of hydrates blocking flow paths.

Exploration well: drilling for new reserves; includes both wildcat and appraisal wells.

Extremely Large Spill: spill that involves the release of more than 150,000 bbl (23,850 m^3)

HPHT well: high pressure/high temperature well.

Large Spill: spill that involves the release of more than 1,000 bbl (159 m^3) up to 10,000 bbl (1,590 m^3).

Macondo MC-252 Well Blowout: the well blowout that occurred in the US Gulf of Mexico during April – July 2010; also referred to as “Deepwater Horizon”, which is the name of the drilling ship involved. Macondo MC-252 refers to the well from which the oil originated. The US government’s estimate of the volume of oil released is 4.9 million bbl.[1]

Mobile Offshore Drilling Unit (MODU): facilities designed or modified to engage in drilling and exploration activities, including drilling vessels, semisubmersibles, submersibles, jack-ups, and similar facilities that can be moved without substantial effort. These facilities may or may not have self-propulsion equipment on board and may require dynamic positioning equipment or mooring systems to maintain their position.

MODU spill: spill of fuel from the vessels rather than well-sourced spillage potentially caused by MODU operations, which would be classified as a well spill. (MODU spills are also referred to as Batch Spills in this study.)

[1] Lubchenco et al. 2010.

Moderate Spill: spill that involves the release of more than 1 bbl (0.159 m^3) up to 1,000 bbl (159 m^3).

Return Period: the inverse of annual probability; the amount of time (generally in years) during which a particular event might be expected to occur once, on average; the return period for a 100-year flood is 100 years; if the probability of an event is 0.0005 (or 5×10^{-4}), the return period is 2,000 years.

SBM Spill-1: a hypothetical release of 60 m^3 (377.4 bbl) of synthetic-based mud (SBM) released at the sea surface at Location 1 (42.2760, -63.9990) and Location 2 (42.0730, -62.8830); this modelled scenario represents an accidental discharge of a full mud tank.

SBM Spill-2: a hypothetical release of 573 m^3 (3,604.2bbl) of synthetic-based mud (SBM) released from Location 1 (42.2760, -63.9990) and Location 2 (42.0730, -62.8830); this modelled scenario represents the disconnection of the riser at the blowout preventer.

Small Spill: spill that involves the release of less than 1 bbl (0.159 m^3).

Spill (Site-1): a hypothetical release of 49,150 bbl/day for 30 days for a total of 1,474,500 bbl released from Location 1 (42.2760, -63.9990).

Spill (Site-2): a hypothetical release of 24,900 bbl/day for 30 days for a total of 747,000 bbl released from Location 2 (42.0730, -62.8830).

Spillage rate: probability that an incident will result in the spillage of oil.

Surface blowout: an uncontrolled surface/subsea flow of fluids from a deep zone or shallow zone that enters the water column.

Synthetic-Based Mud (SBM): low-toxicity oil-based mud or drilling fluid in which the base fluid is a synthetic oil; SBM is used on offshore rigs due to the lower toxicity of fluid fumes.

Very Large Spill: spill that involves the release of more than 10,000 bbl (1,590 m^3) up to 150,000 bbl (23,850 m^3).

Underground blowout: underground (sub-bottom) flow of fluids that remains in the sediment or formation but does not enter the water column.

Well release: flow of oil (or gas) from a well from some point where flow was not intended; flow is stopped by the use of the barrier system that was available on the well at the time the incident started.

Well spill: incident of spillage due to blowout or other release causes; this term is used in this report to combine blowout incidents and releases from wells, and to distinguish these incidents from SBM spills or MODU spills

Note on numbering scale for integer powers of ten: In this report, the "short scale" is used, so that the term "billion" refers to 10^9, and trillion refers to 10^{12}.

Introduction

The proposed Shelburne Basin Venture Exploration Drilling Project (Shelburne Project) is located approximately 250 km south of Halifax, Nova Scotia, and is proposed to include up to seven exploration wells within the Exploration Drilling Project Area (Figure 1). In association with the Project the potential exists for oil spillage and discharge potential due to spills from offshore supply vessels and mobile offshore drilling units (MODU), permitted operational discharges, and from spills from the wells themselves, including blowouts. This report evaluates this spillage and discharge potential with respect to the likelihood or probability of an incident occurring as well as the range of potential spill or discharge volumes. Additionally, this report considers the spill and discharge potential in relation to other oil inputs in the region.

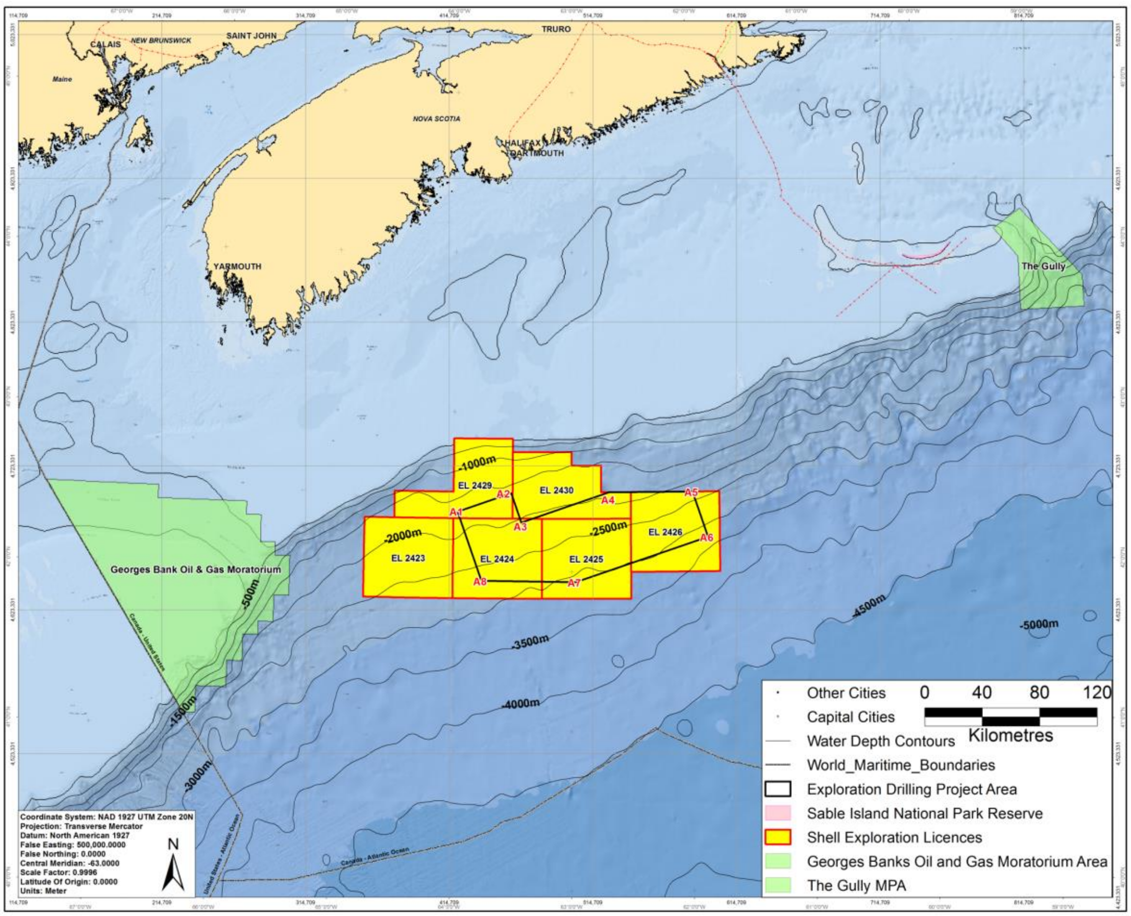

Figure 1: Proposed Shelburne Basin Venture Exploration Drilling Project[2]

In addition, this report complements the modelling and assessment of potential spill scenarios conducted as part of the Environmental Impact Statement (EIS) for the Project by providing a perspective on the probability of occurrence of the various scenarios (blowouts and batch spills) as well as the probability distributions of spill volumes. These modelled scenarios are discussed and assessed separately in the EIS.

[2] Shell Canada Ltd. and Stantec Consulting Ltd. 2013.

Spillage from Offshore Exploration – General Overview

Worldwide there are an estimated 1.7 x 10^{12} barrels of proved oil reserves[3] of which currently about 3.1 x 10^{10} are being produced. Offshore exploration activities involve occasional accidental events inclusive of wells, platforms, rigs, and support vessels. Spills as a result of offshore activities can include both larger-scale, longer-term incidents (i.e. blowouts) or instantaneous or short duration, smaller-scale incidents (i.e. batch spills). In Canada, there have been no large-scale spill events as a result of offshore exploration and production. As a result, offshore data from jurisdictions outside of Canada must be utilized to provide a general perspective on spillage from exploration and production activities. For these purposes, a recent analysis of US spills is presented below. This analysis is chosen for consideration in this report as it is considered the most comprehensive analysis currently available.

Note on "Deepwater Horizon"/Macondo MC-252 Oil Spill Volume

The August 2009 publication of *Analysis of US Oil Spillage* (API Publication 356),[4] which included spill data from the late 1960s through 2007 showed significant reductions in offshore exploration and production-related spillage. Since the release of that publication, a significant spill incident occurred with the blowout of the Macondo MC-252 well. This 2010 incident is often popularly referred to as the "Deepwater Horizon" spill after the rig that was drilling the well (MC-252) at the time of the blowout. This incident, which resulted in an oil spill lasting 86 days (20 April through 15 July 2010), will be referred to as "Macondo MC-252" for the purposes of this report.

At the time of the writing of this report, the exact total volume of spillage, the flow rate at different times during the 86-day period, and the amount of oil contained at the wellhead are in dispute as part of multidistrict litigation in Case MDL No. 2179 being heard in the US District Court, Eastern District of Louisiana, New Orleans, Louisiana, USA.

As a result, there are currently two different quantifications of the release from Macondo MC-252 – one from the responsible parties (BP/Anadarko) and one from the government; both of these volumes are summarized in Table 1. There is an absolute difference of 1,750,000 barrels between the BP/Anadarko and the US Government's estimates of the total release to water. The US Government estimated volume for the MC-252 spill is 71% higher than BP/Anadarko's estimate. Where consideration is given to the MC-252 incident in association with spill volumes, both volumes are provided to address this current uncertainty.

The volumes are important in considerations of such statistics as the average annual spillage volume or the number of barrels spilled per barrel produced.

The significance of the volume of spillage from the Macondo MC-252 well is that it slightly skews the volume distribution for historical spillage, though it does not increase the probability that there will be a blowout or other well release event.

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[3] Proved oil reserves are generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reserves under existing economic and operating conditions.

[4] Etkin 2009.

Table 1: Quantification of Oil Release from Macondo MC-252		
Parameter	**Data Source**	
	BP and Anadarko[5]	**US Government**[6]
Total Quantity Discharged	3,260,000 bbl	5,000,000 bbl
Quantity Captured at Wellhead	810,000 bbl	800,000 bbl
Total Release to Water	**2,450,000 bbl**	**4,200,000 bbl**

Spillage from US Offshore Oil Exploration and Production Activities

Over the last 45 years, the US has produced a total of 15.6 trillion barrels of oil, about 411 million barrels annually. Of that amount an average of 1.2 to 1.8 barrels are spilled for every 10,000 barrels produced, or 0.012% to 0.018%. Over the last decade (2003 – 2012), the US produced an average of 528 million barrels of oil annually. Of that an estimated 0.042% to 0.072% has spilled, depending on the assumed amount of spillage for the MC-252 well blowout.

There are currently estimated to be about 3,400 offshore production facilities in the Gulf of Mexico and the Pacific Outer Continental Shelf (OCS) areas of the US.[7] There are also estimated to be over 30 exploratory wells in Alaskan OCS waters. Annual oil spillage from offshore platforms[8] in US OCS is shown in Figures 2 for 1968 – 2012. Figure 3 shows the data without the MC-252 spill. Figures 4 and 5 show average annual spill volumes from offshore platforms for the last decade with and without Macondo MC-252.

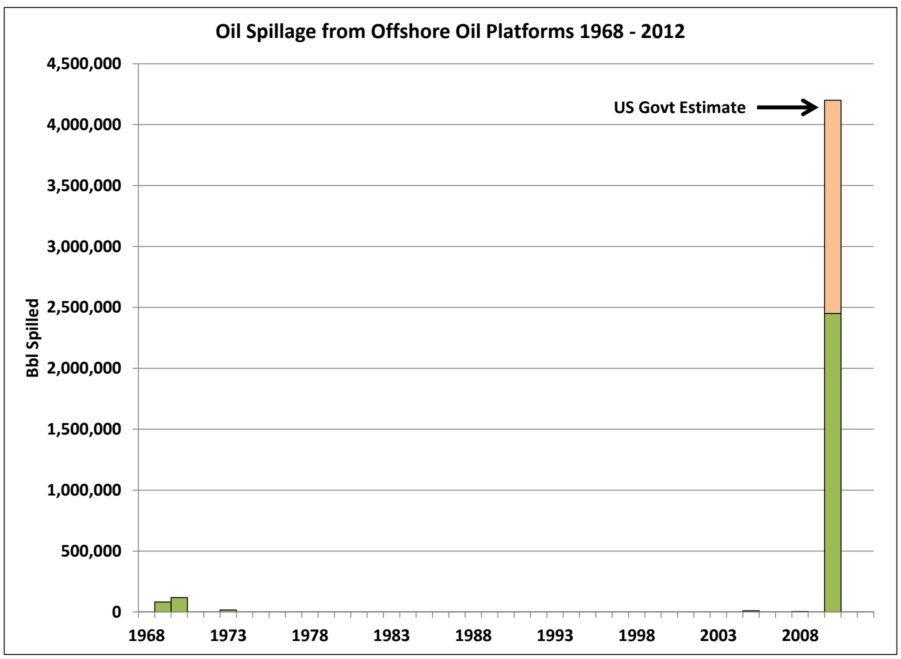

Figure 2: Annual US Offshore Oil Platform Spillage 1968-2012 (w/ Macondo MC-252)

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[5] Fitch et al. 2013.
[6] Hauck et al. 2013.
[7] US Bureau of Safety and Environmental Enforcement (BSEE).
[8] Spillage comes from the wells to which the platforms are connected. "Platform" spills include all spills associated with exploration and production wells.

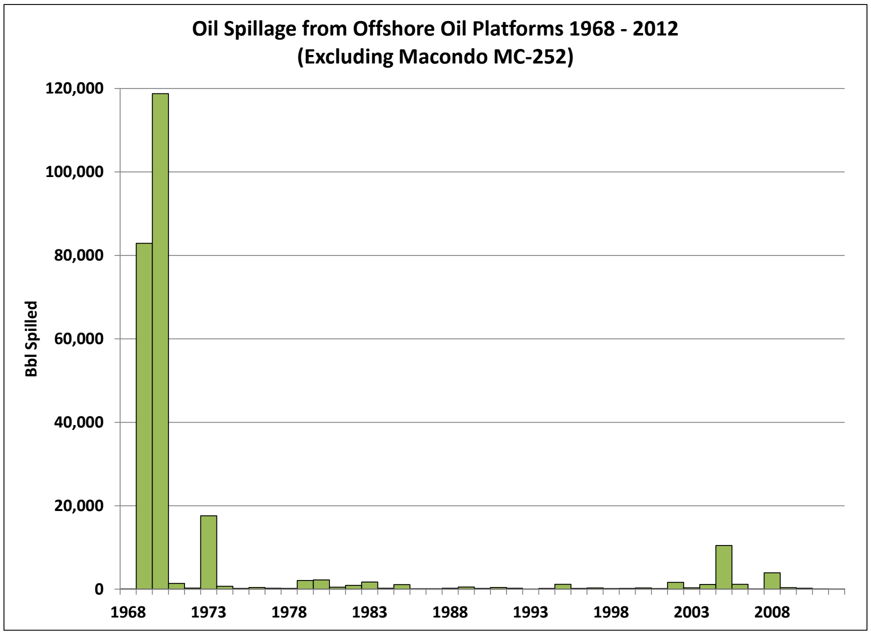

Figure 3: Annual Spillage from US Offshore Platforms 1968 – 2012 (w/o MC-252)

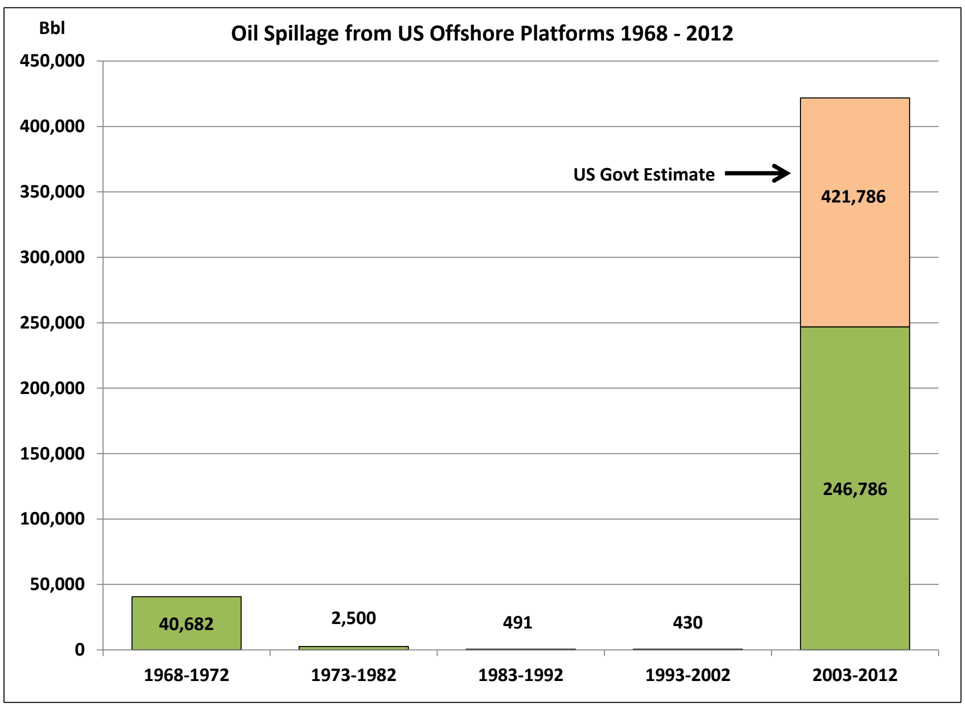

Figure 4: Average Annual Spillage from US Offshore Platforms (w/Macondo MC-252)

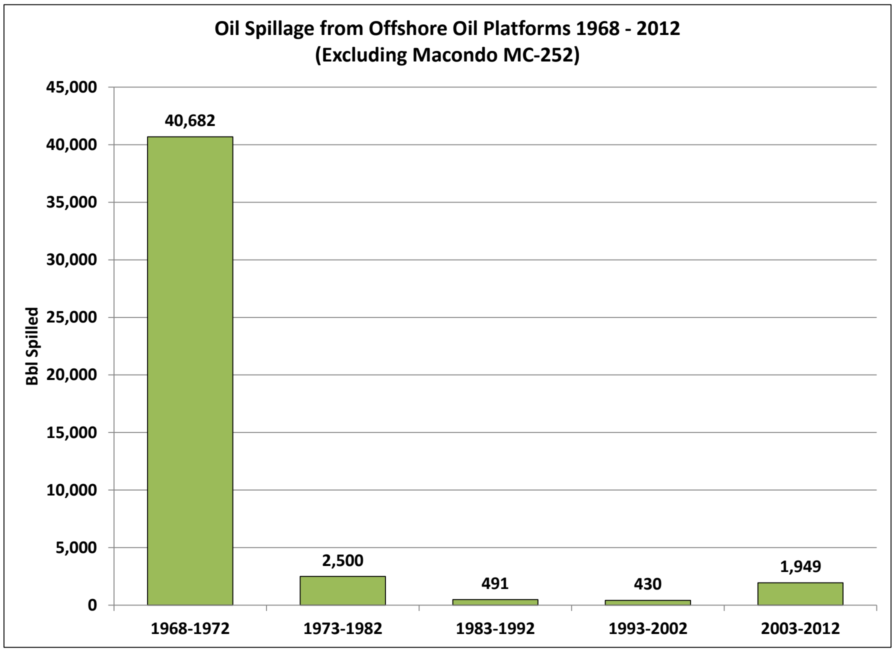

Figure 5: Average Annual Spillage from US Offshore Platforms (w/o Macondo MC-252)

Table 2 shows the numbers of incidents and volume spilled from offshore oil platforms[9] by year. (Note that this table includes some spills in state waters in addition to those in the OCS.) Over the last 45 years, an average of 60,000 to 99,000 barrels of oil has spilled annually from offshore platforms. Over the last decade, because of the Macondo MC-252 spill, the annual volume rose to an average of 247,000 to 422,000 barrels annually.

Table 2: Oil Spills from US Offshore Oil Exploration and Production Platforms

Year	Number (≥1 bbl)	Volume Spilled (bbl)		
		OCS	State Waters	Total
1968	1	85	0	**85**
1969	5	82,900	0	**82,900**
1970	6	118,773	0	**118,773**
1971	29	1,395	0	**1,395**
1972	15	256	0	**256**
1973	26	17,594	0	**17,594**
1974	14	691	0	**691**
1975	7	185	0	**185**
1976	10	419	0	**419**
1977	11	223	0	**223**
1978	6	181	524	**705**
1979	16	2,068	0	**2,068**
1980	9	2,216	0	**2,216**
1981	12	496	0	**496**
1982	8	924	0	**924**
1983	19	1,727	2,810	**4,537**
1984	7	243	690	**933**

[9] The data do not differentiate between exploration and production facilities.

Table 2: Oil Spills from US Offshore Oil Exploration and Production Platforms

Year	Number (≥1 bbl)	Volume Spilled (bbl)				
		OCS		State Waters	Total	
1985	11	1,099		0	**1,099**	
1986	5	114		0	**114**	
1987	5	131		0	**131**	
1988	6	239		0	**239**	
1989	6	526		810	**1,336**	
1990	6	198		953	**1,151**	
1991	7	404		0	**404**	
1992	5	224		12,262	**12,486**	
1993	1	19		0	**19**	
1994	5	182		740	**922**	
1995	7	1,165		0	**1,165**	
1996	6	184		0	**184**	
1997	8	301		0	**301**	
1998	4	168		0	**168**	
1999	6	207		107	**314**	
2000	4	287		0	**287**	
2001	2	141		0	**141**	
2002	7	1,643		0	**1,643**	
2003	3	321		0	**321**	
2004	11	1,125		0	**1,125**	
2005	45	10,467		0	**10,467**	
2006	17	1,162		0	**1,162**	
2007	4	77		0	**77**	
2008	38	3,947		0	**3,947**	
2009	12	381		0	**381**	
2010	7	2,450,230	4,200,230	0	**2,450,230**	**4,200,230**
2011	4	97		0	**97**	
2012	5	57		0	**57**	
Total	**447**	**2,705,387**	**4,455,387**	**18,896**	**2,724,283**	**4,474,283**
Avg 1968-1972	**14**	**40,682**		**0**	**40,682**	
Avg 1973-1982	**12**	**2,500**		**52**	**2,552**	
Avg 1983-1992	**8**	**491**		**1,753**	**2,243**	
Avg 1993-2002	**5**	**430**		**85**	**514**	
Avg 2003-2012	**15**	**246,786**	**421,786**	**0**	**246,786**	**421,786**
Avg 1968-2012	**10**	**60,122**	**99,010**	**420**	**60,542**	**99,430**

Most offshore oil spills are relatively small. Table 3 shows the probability distributions of spill volumes by time period and the percentile volume scenarios (e.g., spills of 1 million or more bbl make up 90% to 94% of the total spillage, whereas the more frequent spills of 10 – 99 bbl make up 0.2% to 0.4% of the total spillage). Figure 6 shows the probability distribution for the years 1968 through 2012. As illustrated by the data, a single large incident (i.e., MC-252) can dominate the spill volume statistics. The MC-252 spillage constitutes 90.5% to 94.2% of the total spillage during 1968 to 2012. Table 4 shows the percentile spill volumes during different time periods showing the effect of the MC-252 spillage.

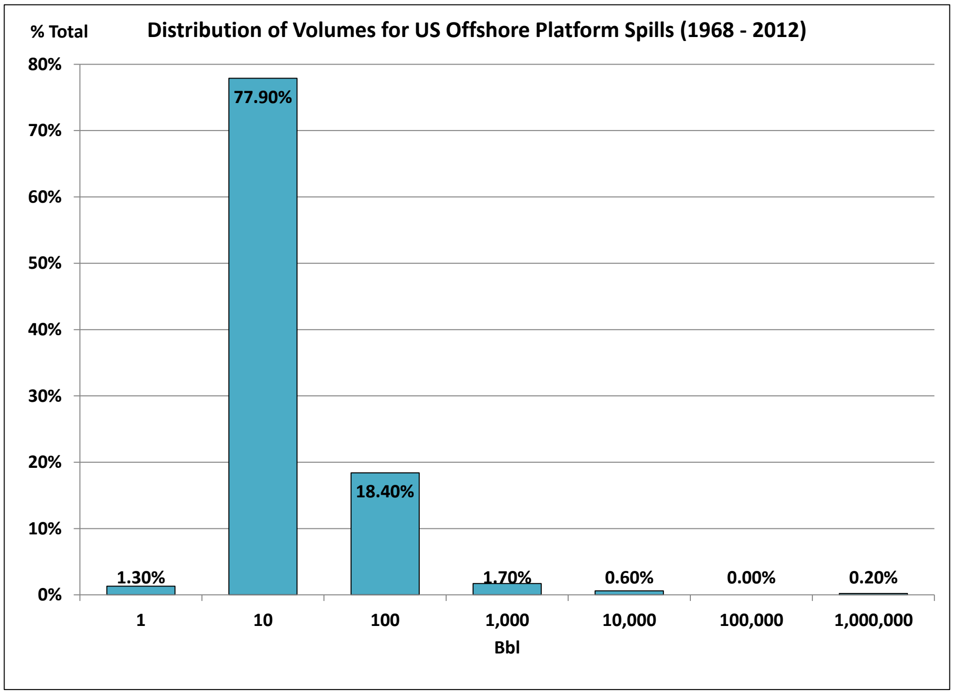

Figure 6: Probability Distribution of US Offshore Platform Spill Volumes (1968 – 2012)

Table 3: Volumes for Offshore Exploration & Production Spills (1968 – 2012)

Volume (bbl)	Number	% Total Number	Lower Macondo MC-252		Higher Macondo MC-252	
			Total Bbl[10]	% Total[11]	Total Bbl	% Total
1-9	6	1.3%	40	0.001%	40	0.001%
10-99	373	77.9%	10,221	0.377%	10,221	0.229%
100-999	88	18.4%	22,534	0.832%	22,534	0.505%
1,000-9,999	8	1.7%	27,457	1.014%	27,457	0.616%
10,000-99,999	3	0.6%	197,550	7.296%	197,550	4.432%
100,000-999,999	0	0.0%	0	0.000%	0	0.000%
1,000,000+	1	0.2%	2,450,000	90.479%	4,200,000	94.217%
Total	**479**	**100%**	**2,707,802**	**100.%**	**4,457,802**	**100%**

Table 4: US Offshore Oil Platform Spills: Probabilities of Spill Volumes (1968 – 2012)

Time Period	Spill Volume (bbl)[12]				
	50th percentile	90th percentile	95th percentile	Largest Spill	
				Lower Macondo MC-252 Estimate	Higher Macondo MC-252 Estimate
1983-1992	25	100	200	643	643
1993-2002	20	170	435	741	741
2003-2012	40	240	550	2,450,000	4,200,000
1968-2012	30	215	500	2,450,000	4,200,000

[10] Total volume in that size class (e.g., total volume of spillage made up by spills of 10 – 99 bbl is10,221 bbl).
[11] Percent that the volume from this size class makes up total spillage (e.g., spills of 1 million or more bbl make up 86% to 92% of the total spillage, whereas the more frequent spills of 10 – 99 bbl make 0.5% of the total spillage.
[12] A percentile spill volume is the percentage of spills that are that volume or less. e.g., a 90th percentile spill of 35 bbl means that 90% of spills are 35 bbl or less. Only 10% of spills are larger.

Synthetic-Based Mud (SBM) Spills

The available data on synthetic-based mud (SBM) spills are more limited. Only spills of 10 bbl or more are recorded. There were, on average, six SBM spills of 10 bbl or more, in the US OCS during 1999 through 2012 (Table 5). An average of 1,350 bbl of SBM spills from all 3,430 wells in the US OCS per year, or about 0.4 bbl per well. The number of incidents per well is about 0.00175 per year. This means that an individual well might be expected to have a spill of 10 bbl or more of SBM once in 572 years. Note that these estimates are based only on spills of 10 bbl or more. They do not include any smaller spills. Including smaller spills would increase the number of incidents, but only increase the total volume spilled by a relatively small percentage.

Table 5: Synthetic-Based Mud Spills from US Offshore Exploration & Development

Year[13]	Number ≥ 10 bbl	Volume (bbl)
1999	1	100
2000	7	2,520
2001	8	1,218
2002	8	2,768
2003	10	3,070
2004	9	2,093
2005	6	1,065
2006	7	938
2007	8	1,628
2008	4	1,922
2009	5	639
2010	5	185
2011	2	252
2012	7	503
Total	**87**	**18,901**
Average (1999 – 2012)	**6**	**1,350**

Vessel Spills

Offshore supply vessels and mobile offshore drilling units (MODUs) have had occasional spills during their servicing of US offshore facilities and drilling operations. Average total annual spillage from these vessels has been about 50 barrels (Table 6).

Table 6: Annual Oil Spillage (bbl) from US Offshore Vessels

Year	Volume (bbl)[14]
1968	0
1969	0
1970	0
1971	0
1972	0
1973	0
1974	25
1975	183
1976	0

[13] No spills of SBM were reported prior to 1999.

[14] All spills from offshore supply/service vessels are of refined product with the exception of one spill of 12 bbl of crude that occurred in 1996.

Table 6: Annual Oil Spillage (bbl) from US Offshore Vessels	
Year	**Volume (bbl)**[14]
1977	38
1978	47
1979	165
1980	408
1981	15
1982	21
1983	95
1984	0
1985	0
1986	0
1987	0
1988	0
1989	0
1990	58
1991	42
1992	0
1993	0
1994	148
1995	89
1996	140
1997	18
1998	0
1999	105
2000	0
2001	36
2002	16
2003	490
2004	0
2005	0
2006	25
2007	0
2008	0
2009	0
2010	49
2011	0
2012	0
Total	**2,213**
Avg 1968-1972	**0**
Avg 1973-1982	**90**
Avg 1983-1992	**20**
Avg 1993-2002	**55**
Avg 2003-2012	**56**
Avg 1968-2012	**49**

Spills from Offshore Oil Wells: Details

While blowouts tend to get more attention due to a small number of large-scale incidents, spills that are attributed to causes other than blowouts accounted for the vast majority (> 95%) of spills in US studies. These spills also tended to be relatively small, with an average volume of less than 200 bbl.

US Studies

Analyses of the causes of offshore platform spill incidents are shown in Table 7. In the last decade, the most common cause of platform and pipeline spills was hurricanes, but blowouts, and more specifically a single blowout (Macondo MC-252) contributed the vast majority of the total spill volume. While blowouts would generally present the greatest potential for high volume of spillage, they represented less than 5% of the spills over the last 45 years in the US. Blowouts and other releases are analyzed separately in the sections below.

Table 7: Causes of Oil Spills from US Offshore Oil Exploration & Production Platforms[15]

Cause	Incidents 1968 – 2012			Incidents 2003 – 2012		
	#	%	#/yr	#	%	#/yr
Blowout[16]	20	4.5%	0.4	6	4.1%	0.6
Equipment Failure	231	51.6%	5.1	17	11.6%	1.7
Hurricane Damage	106	23.7%	2.4	99	67.3%	9.9
Human Error[17]	69	15.4%	1.5	5	3.4%	0.5
External Forces[18]	16	3.6%	0.4	16	10.9%	1.6
Vessel Allision[19]	2	0.4%	0.0	0	0.0%	0
Unknown	4	0.9%	0.1	4	2.7%	0.4
Total	**448**	**100%**	**10.0**	**147**	**100%**	**14.7**

As shown in Table 8, nearly 52% of platform spills are due to equipment failure. Another 24% are due to storms or hurricanes. Note that the fact that the vast majority of US platforms are in the Gulf of Mexico, a region prone to hurricanes, there is a higher percentage of hurricane-related spillage in the US than would be true for other parts of the world, including the North Atlantic. While the percentages of incidents attributed to various causes will be different in other regions of the world, due to different environmental factors, the volumes associated with each type of spill shown in Table 8 are relevant to other regions.

Table 8: Causes of Oil Spills from US Offshore Oil Platforms 1968 – 2012

Cause	Incidents			Volume					
				Lower Macondo MC-252 Estimate			Higher Macondo MC-252 Estimate		
	#	%	#/yr	Bbl	% Bbl	Avg. Bbl	Bbl	% Bbl	Avg. Bbl
Blowout	20	4.5%	0.4	2,652,331	98.02%	132,617	4,402,331	98.80%	220,117
Equipment	231	51.6%	5.1	29,468	1.09%	128	29,468	0.66%	128
Hurricane	106	23.7%	2.4	19,293	0.71%	182	19,293	0.43%	182
Human Error	69	15.4%	1.5	3,733	0.14%	54	3,733	0.08%	54
External	16	3.6%	0.4	383	0.01%	24	383	0.01%	24
Vessel	2	0.4%	0.0	219	0.01%	110	219	0.00%	110
Unknown	4	0.9%	0.1	547	0.02%	137	547	0.01%	137
Total	**448**	**100%**	**10.0**	**2,705,974**	**100%**	**6,040**	**4,455,974**	**100%**	**9,946**

[15] Includes exploration and production wells, but excludes pipelines and offshore supply vessels.
[16] Loss of well control or uncontrolled flow of formation or other fluids, including flow to an exposed formation (an underground blowout) or at the surface (a surface blowout), flow through a diverter, or uncontrolled flow resulting from a failure of surface equipment or procedures.
[17] e.g., refueling; improper operation.
[18] External force damage from weather (other than hurricane), mudslides, anchor dragging, etc.
[19] Vessel striking platform or well piping.

In another study focused specifically on the US state of Alaska, spills at coastal and offshore oil exploration and production facilities[20] in the Beaufort Sea, Chukchi Sea, Cook Inlet, Kodiak, and Aniakchak regions for the years 1995 through 2012 were analyzed.[21] The data are summarized in Table 9.[22] Note that no blowouts were reported.

Table 9: Oil Exploration and Production Spillage in Alaska 1995 – 2012

Cause	Crude Oil		Refined Product[23]		Total	
	Spills	Avg. Vol. (bbl)	Actual Spills	Avg. Vol. (bbl)	Actual Spills	Avg. Vol. (bbl)
Allision	18	3.1	35	0.4	**53**	**1.3**
Cargo Error	7	1.4	23	0.7	**30**	**0.9**
Containment Overflow	7	17.4	10	0.1	**17**	**7.2**
Discharge	2	0.02	12	0.06	**14**	**0.1**
Equipment Failure	117	2	397	0.7	**514**	**1.0**
Maintenance	2	0.02	1	0.02	**3**	**0.0**
Operator Error	47	1.6	154	2.4	**201**	**2.2**
Vessel Sinking	0	0	22	2.7	**22**	**2.7**
Structural Failure	185	3.3	523	1.2	**708**	**1.7**
Transfer Error	31	6.7	82	1.7	**113**	**3.1**
Vandalism	0	0	1	0.8	**1**	**0.8**
Other	21	0.4	25	0.7	**46**	**0.6**
Unknown	35	0.7	96	0.5	**131**	**0.6**
Total (All Causes)	**472**	**0.1**	**1,381**	**0.01**	**1,853**	**0.04**

The probability distribution of spill volumes is shown in Table 10 and Figure 7.

Table 10: Spill Volume Probability Distribution: Alaskan E&P (1995 – 2013)

Volume Category	Spill Volume	Number	% Total Spills
Very Small Spills	**0.001 – 0.009 bbl**	55	3.0%
	0.01 – 0.09 bbl	892	48.5%
	0.1 – 0.9 bbl	608	33.0%
Moderate Spills	**1 – 9 bbl**	226	12.3%
	10 – 99 bbl	54	2.9%
	100 – 999 bbl	6	0.3%
Large Spills	**1,000 – 9,999 bbl**	0	0.0%
Very Large Spills	**10,000 – 150,000 bbl**	0	0.0%
Extremely Large Spills	**> 150,000 bbl**	0	0.0%
Total		**1,841**	**100.0%**

[20] These data include all facets of the facilities – wells, rigs, supply vessels, temporary storage, and pipelines.
[21] Reich et al. 2012; Etkin 2012.
[22] Includes spills of less than 1 barrel and potential spills, differing from the overall US analysis previously shown.
[23] 98.9% of refined product spills involved diesel; the remainder involved distillates (gasoline) or heavy fuel.

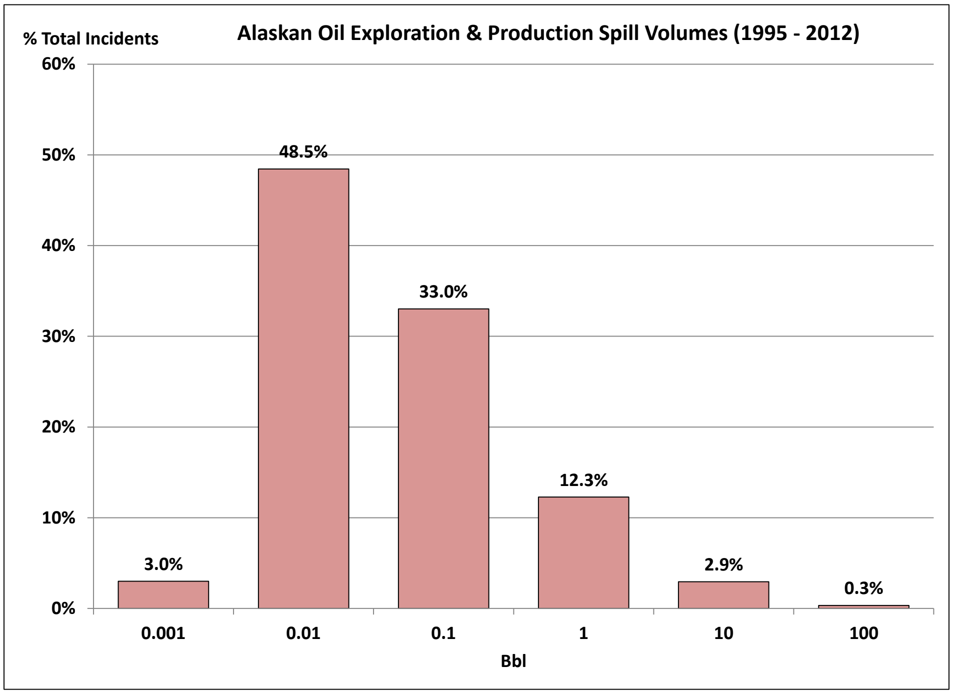

Figure 7: Probability Distribution of Volumes for Alaskan E&P Incidents (1995 – 2012)

Canada-Nova Scotia Offshore Petroleum Board Oil Spill Data Analysis

Oil exploration and production activity in Nova Scotia is very minimal in comparison with Gulf of Mexico or North Sea operations. There has been no new exploration for some time.

Data on spills from Nova Scotia platforms and wells as provided by the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) for the years 1999 through the present, were analyzed. These data include the discharge of chemicals, such as mono-ethylene glycol, and synthetic-based mud (SBM), which do not contain petroleum hydrocarbons. The data included much smaller spills (< 25 bbl) than were included in either the US or Alaska studies. Causes of spill incidents were not available for this data set. Table 11 shows the annual spillage of oils. There were 189 spills over the 15-year period, or 13 spills annually, on average, although there was a significant decrease in spill numbers in the latter years (Figure 8).

Table 11: Annual Spillage from Nova Scotia Offshore E&P Facilities (1999 – 2013)

Year	Number Spills	Volume (bbl)				
		Total	Minimum	Maximum	Average	Median[24]
1999	31	25.6	0.00002	10.7	0.83	0.06
2000	26	6.5	0.00063	2.2	0.25	0.025
2001	15	0.9	0.00038	0.3	0.06	0.013
2002	17	0.5	0.00063	0.4	0.03	0.002
2003	26	11.4	0.00063	3.6	0.4	0.094
2004	7	22.1	0.00063	22.0	3.2	0.003
2005	12	1.4	0.00063	0.6	0.1	0.003
2006	9	6.4	0.00063	5.0	0.7	0.126
2007	5	0.5	0.00063	0.5	0.1	0.003
2008	9	0.1	0.00063	0.1	0.02	0.013

[24] 50th percentile.

Table 11: Annual Spillage from Nova Scotia Offshore E&P Facilities (1999 – 2013)						
Year	**Number Spills**	**Volume (bbl)**				
		Total	**Minimum**	**Maximum**	**Average**	**Median**[24]
2009	6	0.3	0.00016	0.2	0.05	0.006
2010	8	0.03	0.00001	0.03	0.004	0.0006
2011	5	0.5	0.00001	0.3	0.1	0.0006
2012	6	0.9	0.00001	0.9	0.2	0.0009
2013	7	0.8	0.00001	0.6	0.1	0.03
Total	**189**	**78.2**	**0.00001**	**22.0**	**0.4**	**0.013**

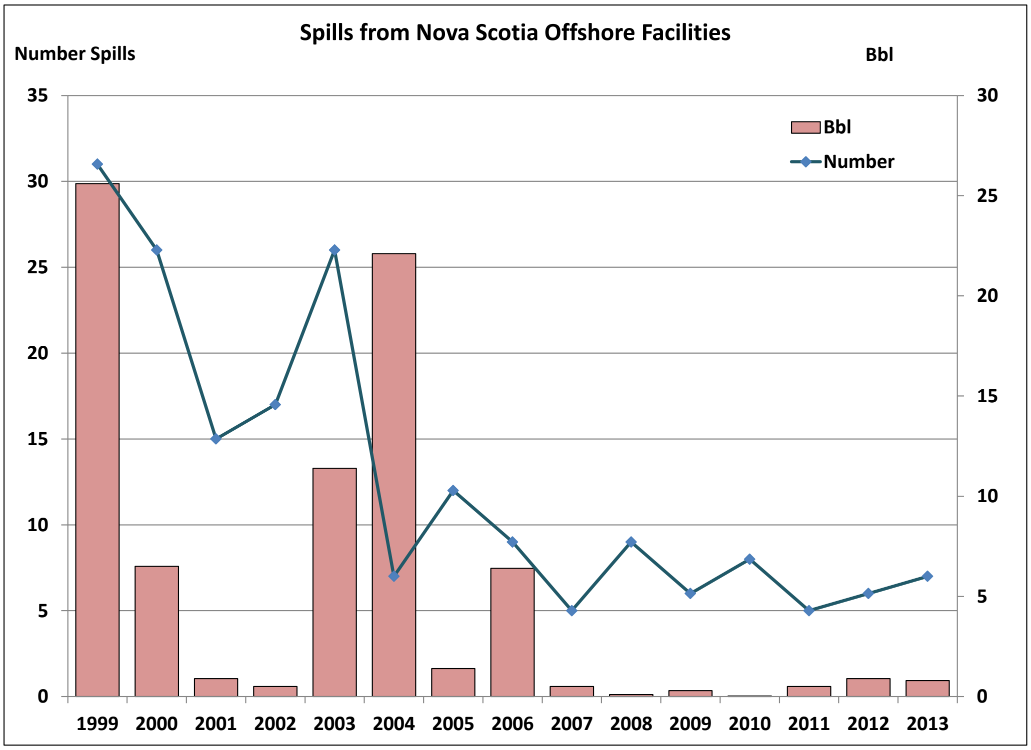

Figure 8: Oil Spills from Nova Scotia Offshore Facilities (1999 – 2013)

The largest spill was 22 barrels. The average spill volume was 0.4 barrels and the median (50th percentile) spill volume was 0.013 barrels. This means that the distribution of spill volumes is skewed towards the lower end, as shown in Figure 9 and Table 12. Percentile spills are shown in Table 13.

Table 12: Spill Volume Probability Distribution: Nova Scotia Offshore (1999 – 2013)			
Volume Category	**Spill Volume**	**Number of Spills**	**% Total Spills**
Small Spills	**0.00001 – 0.00009 bbl**	9	5%
	0.0001 – 0.0009 bbl	37	20%
	0.001 – 0.009 bbl	39	21%
	0.01 – 0.09 bbl	52	28%
	0.1 – 0.9 bbl	40	21%
Moderate Spills	**1 – 9 bbl**	10	5%
	10 – 99 bbl	2	1%
Total		**189**	**100%**

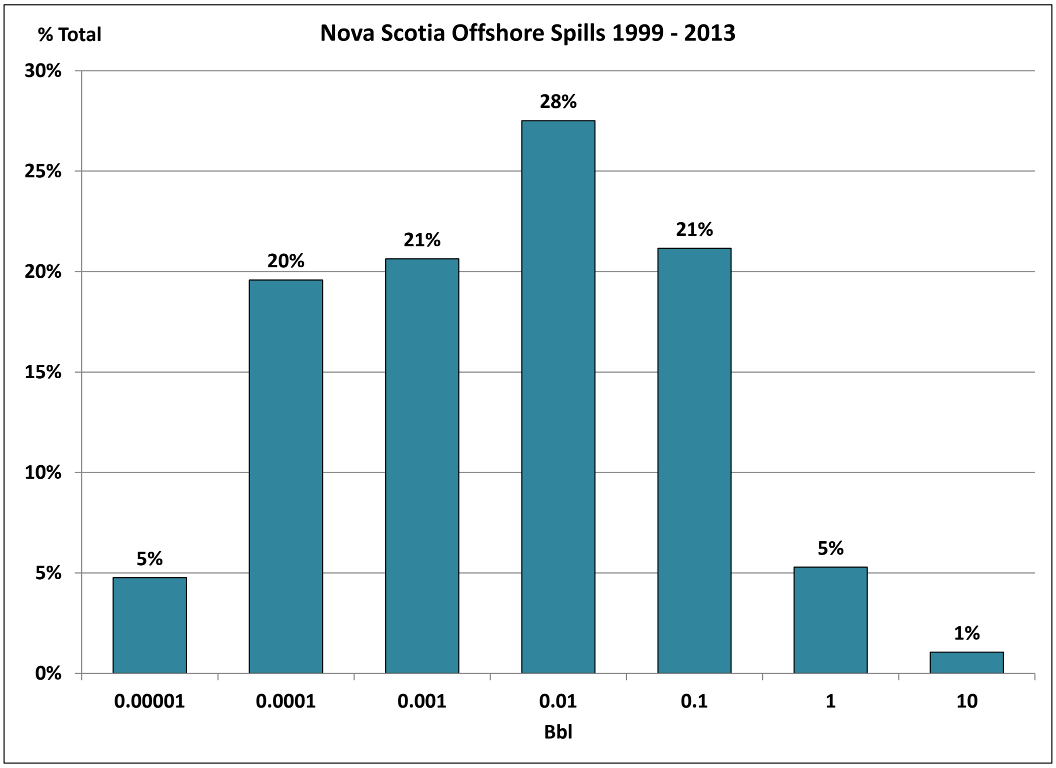

Figure 9: Probability Distribution of Volume of Nova Scotia Offshore Spills (1999 – 2013)

Table 13: Percentile Spill Volumes: Nova Scotia Offshore E&P Facilities (1999 – 2013)

Percentile	Spill Volume (bbl)
50th Percentile	0.013
75th Percentile	0.126
90th Percentile	0.503
95th Percentile	1.572
99th Percentile	5.032
Largest Actual Spill	22.014

Canada-Nova Scotia Offshore Petroleum Board SBM Spill Data

Synthetic-based mud (SBM) spills for Nova Scotia are shown separately in Table 14.

Table 14: Synthetic-Based Mud Spills in Nova Scotia

Year[25]	Number	Bbl	Average Bbl/Spill
2000	5	0.690	0.138
2001	3	0.270	0.090
2002	6	0.620	0.103
2003	1	3.877	3.877
2004	2	2,226.780	1,113.390
2005	1	0.001	0.001
Total	**18**	**2,232.238**	**124.013**
Average	**3**	**372**	**186**

[25] No SBM spills were reported during 2006 – 2013.

The majority (89%) of the spills were very small (<1 bbl), as shown in Table 15 and Figure 10.

Table 15: SBM Spill Volume Probability Distribution: Nova Scotia Offshore (2000 – 2005)

Volume Category	Spill Volume	Number of Spills	% Total Spills
Small Spills	**0.001 – 0.009 bbl**	6	33%
	0.01 – 0.09 bbl	3	17%
	0.1 – 0.9 bbl	7	39%
Moderate Spills	**1 – 9 bbl**	1	6%
	10 – 99 bbl	0	0%
	100 – 999 bbl	0	0%
Large Spills	**1,000 – 9,999 bbl**	1	6%
Total		**18**	**100%**

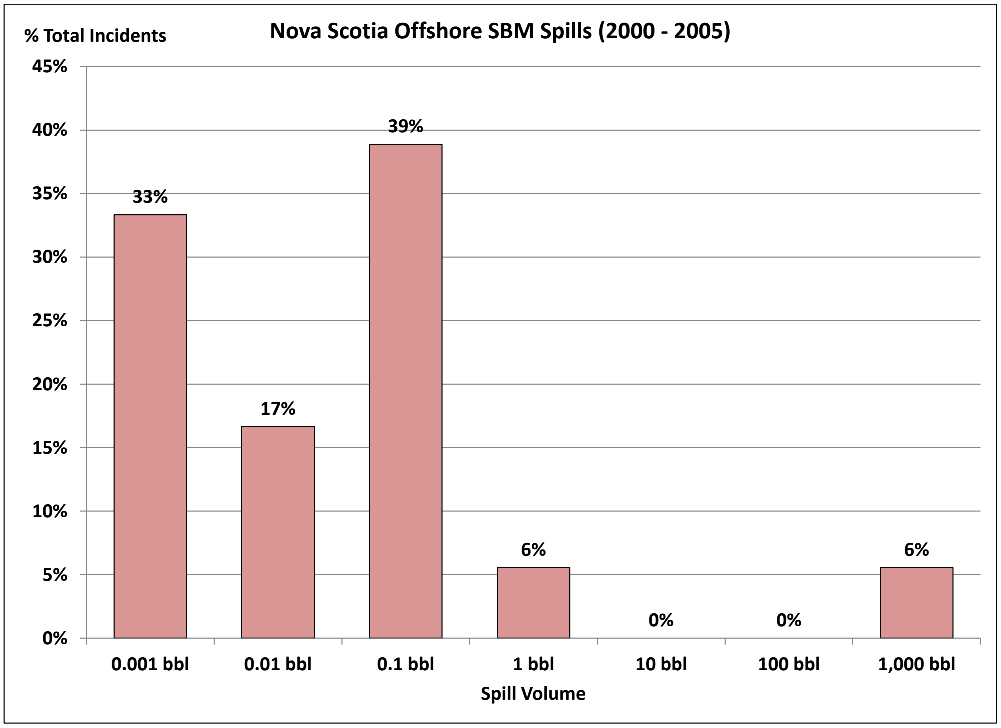

Figure 10: Volume Distribution of Nova Scotia Offshore SBM Spills (2000 – 2005)

Canada-Newfoundland and Labrador Offshore Petroleum Board Data

SBM spills during exploration drilling were reported by Canada-Newfoundland and Labrador Offshore Petroleum Board (CNLOFB) for the years 1997 through 2011, as shown in Table 16. There have been 16 incidents since 1997, the largest of which involved 4,655 bbl.

Table 16: Synthetic-Based Mud Spills in Newfoundland and Labrador

Year	Number Spills	Bbl	Average Bbl/Spill
1997	0	0	0
1998	0	0	0
1999	0	0	0
2000	0	0	0
2001	0	0	0
2002	0	0	0

Table 16: Synthetic-Based Mud Spills in Newfoundland and Labrador			
Year	**Number Spills**	**Bbl**	**Average Bbl/Spill**
2003	1	28	28
2004	0	0	0
2005	0	0	0
2006	1	4	4
2007	1	4,655	4,655
2008	0	0	0
2009	1	0	0
2010	0	0	0
2011	4	181	45
2012	8	678	85
Total	**16**	**5,544**	**347**
Average	**1**	**347**	**301**

Probability of Small Batch Spills from Offshore Facilities

Routine operations at offshore exploratory wells occasionally result in small spills (called "batch spills" or "operational spills") of various refined oil products not directly related to the wells themselves. These spills may result from the operation of pumps and hydraulic apparatus on the MODU, operations or fueling of offshore supply or service vessels, and other sources.

The oil types involved may include diesel, kerosene, hydraulic oil, and other miscellaneous oils, though not crude oil, which would come from the well reservoir itself.

The aggregated CNOSPB data presented in Tables 11 – 13 and Figures 8 – 9 above, along with data on the numbers of wells present in the Nova Scotia offshore area in the same time period, were analyzed to determine the rates of operational spills per well-year.

During the time period of 1999 through 2013, a total of 88 bbl of refined products were spilled, or about 6.3 bbl per year.[26] Table 17 shows the number of incidents and volume of spillage annually by well type.

Table 17: Batch Spills[27] for Nova Scotia Offshore Operations (CNOSPB Data)

Year	**Exploratory Wells**			**Development Wells**			**All Wells**		
	Number Spills	**Bbl**	**Average Bbl/Spill**	**Number Spills**	**Bbl**	**Average Bbl/Spill**	**Number Spills**	**Bbl**	**Average Bbl/Spill**
1999	0	0.000	0.000	23	19.802	0.861	23	19.802	0.861
2000	5	1.944	0.389	21	10.952	0.522	26	12.896	0.496
2001	1	0.013	0.013	13	1.421	0.109	14	1.434	0.102
2002	0	0.000	0.000	17	0.715	0.042	17	0.715	0.042
2003	13	7.944	0.611	13	3.436	0.264	26	11.380	0.438
2004	2	0.128	0.064	5	25.168	5.034	7	25.296	3.614
2005	0	0.000	0.000	12	1.134	0.095	12	1.134	0.095
2006	1	0.001	0.001	8	6.405	0.801	9	6.406	0.712
2007	0	0.000	0.000	5	0.469	0.094	5	0.469	0.094

[26] SBM spills were excluded from this analysis as these were separately analyzed as shown in Tables 14 – 15 and Figure 10. Other chemicals are incorporated into the aggregated CNOSPB data presented in Tables 11 – 13 and Figures 8 – 9.
[27] Excluding non-oil chemicals and SBM.

Table 17: Batch Spills[27] for Nova Scotia Offshore Operations (CNOSPB Data)									
Year	Exploratory Wells			Development Wells			All Wells		
	Number Spills	Bbl	Average Bbl/Spill	Number Spills	Bbl	Average Bbl/Spill	Number Spills	Bbl	Average Bbl/Spill
2008	2	0.050	0.025	7	6.448	0.921	9	6.498	0.722
2009	2	0.017	0.009	4	0.253	0.063	6	0.270	0.045
2010	4	0.034	0.009	4	0.001	0.000	8	0.035	0.004
2011	1	0.006	0.006	4	0.547	0.137	5	0.553	0.111
2012	1	0.001	0.001	5	0.926	0.185	6	0.927	0.155
2013	0	0.000	0.000	7	0.653	0.093	7	0.653	0.093
Total	**32**	**10.138**	**0.317**	**148**	**78.33**	**0.529**	**180**	**88.468**	**0.491**
Average	**2.13**	**0.676**	**0.317**	**9.87**	**5.222**	**0.529**	**12.00**	**5.898**	**0.491**

Table 18: Distribution of Spill Volumes for Batch Spills from Nova Scotia Wells		
Volume Class (bbl)	Number Spills	% Total
0.00000001	1	0.6%
0.0000001	1	0.6%
0.000001	3	1.7%
0.00001	13	7.2%
0.0001	26	14.4%
0.001	38	21.1%
0.01	46	25.6%
0.1	40	22.2%
1	10	5.6%
10	2	1.1%
Total	**180**	**100.0%**

The distribution of spill volumes for combined exploratory and development wells is shown in Table 18 and Figure 11. Note that in Figure 11, there is a significant drop in numbers of spills in the 1 x 10^{-3}-bbl down to 1 x 10^{-8}-bbl volume categories.

Statistically, it is highly unlikely that there are so many fewer incidents of these volumes, as generally the smallest spills would be the most frequent (and the largest ones the most infrequent). More likely, these very small spills, which represent about 0.02 liters (20 ml) down to 0.00002 ml (a small drop), are much more likely to be missed, overlooked, unseen, or not just reported. The incidents of this small volume that were reported were the ones that were noticed at the time of the incident and reported due to extreme precaution on the part of the operators.

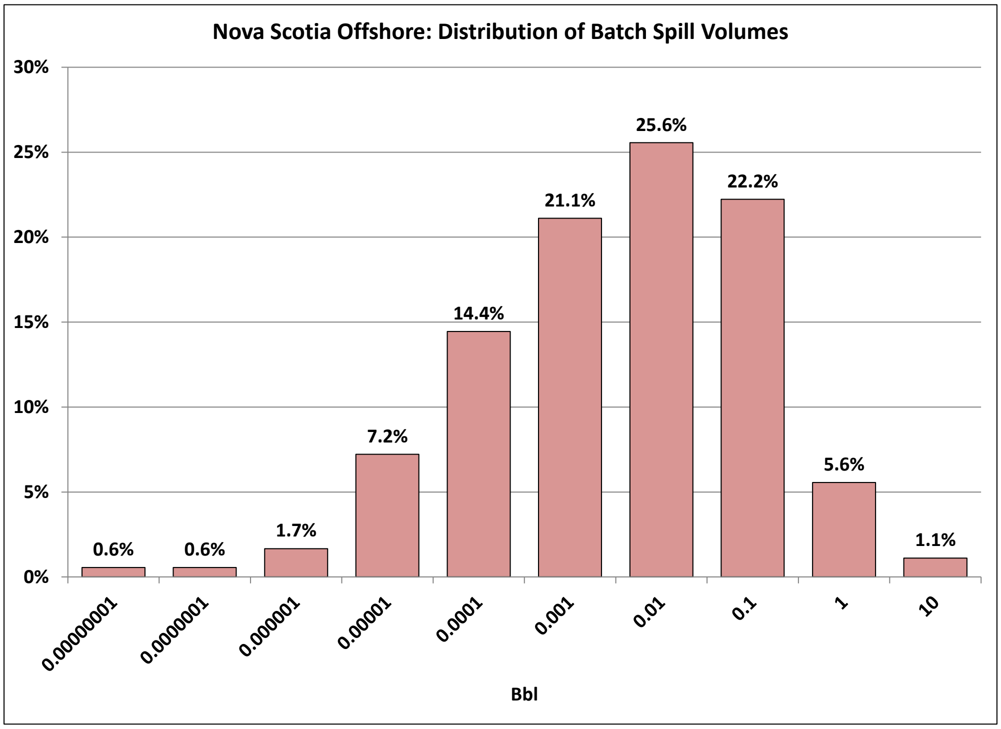

Figure 11: Batch Spill Volume Distribution for Nova Scotia Offshore

During this time period, there were 53 operating wells of which 27 were exploratory well, as summarized in Table 19. All of the wells were dry-hole or gas wells rather than oil wells. The analysis of batch spillage rate per exploratory well is relevant to the Project because the operations for gas wells are analogous to those for oil wells in that they involve the same types of drilling rigs, MODUs, and offshore supply vessels.

Table 19: Wells in Nova Scotia Offshore[28]

Year	Exploratory Wells	Development Wells	Total Wells
1999	3	11	**14**
2000	6	2	**8**
2001	6	1	**7**
2002	5	2	**7**
2003	6	4	**10**
2004	4	1	**5**
2005	3	2	**5**
2006	2	1	**3**
2007	0	0	**0**
2008	0	0	**0**
2009	0	2	**2**
2010	0	1	**1**

[28] Data from CNOSPB. Note that some wells were present over more than one year. There were no data available for wells during 2011 – 2013.

Batch spill rates per well-year are shown in Table 20. For exploratory well operations, there is an average rate of batch spillage of 0.52 per well-year. For development wells, there is a rate of 6.23 spills per well-year.

Table 20: Per-Well Year Batch Spill Rates in Nova Scotia Offshore

Year	Exploratory Wells	Development Wells	Total Wells
1999	0.00	2.09	**1.64**
2000	0.83	10.50	**3.25**
2001	0.17	13.00	**2.00**
2002	0.00	8.50	**2.43**
2003	2.17	3.25	**2.60**
2004	0.50	5.00	**1.40**
2005	0.00	6.00	**2.40**
2006	0.50	8.00	**3.00**
2007	n/a	n/a	**n/a**
2008	n/a	n/a	**n/a**
2009	n/a	2.00	**3.00**
2010	n/a	4.00	**8.00**
Average	**0.52**	**6.23**	**2.97**
Average <1 bbl	**0.48**	**5.79**	**2.76**

Extrapolating from exploratory well operations, for which there are 0.52 spills per well year, to the Project wells, which incorporate 35 well-years, i.e., seven wells for five years, there would be an expected 18.2 batch spills over the five year period, or 3.6 spills per year. This gives a return period of 0.3 years (or one spill every14 weeks. These spills are expected to be small. About 93% of the spills would be of 1 bbl or less; 71% would be less than one one-hundredth bbl (1.6 liters). The probability of a less than one bbl batch spill from the Project is estimated at 0.48 per well-year or 16.8 spills over 35 well-years. This is the equivalent of 3.4 spills annually or one spill approximately every 15 weeks. A one to 10-bbl batch spill from an exploratory well is likely to occur once in 41 years for all of the seven proposed exploratory wells in the Project.

Blowouts from Offshore Oil Wells

The greatest concern about spills or releases from oil wells is for blowout scenarios, because these incidents have the highest potential for large volumes of spillage. This concern is particularly heightened after the 2010 Macondo MC-252 blowout in the US Gulf of Mexico. While this blowout released a large amount of oil, blowouts, in general, tend to be infrequent and also tend to involve much smaller quantities of oil, which is supported by the statistics provided above.

History of Offshore Well Blowouts

A summary of the data available on the 20 largest historical well blowouts is shown in Table 21. The largest offshore well blowout is either the 1979 Ixtoc I incident, which involved 3.3 to 10.2 million barrels, or the Macondo MC-252 incident, which involved 2.45 to 4.2 million barrels, depending on which volume estimate is correct.

There was one gas well blowout off Sable Island, Nova Scotia in 1984 – Shell Canada's Uniacke G-72, which involved the release of about 1,500 bbl of gas condensate over the course of 10 days, as well as 1.11 to 1.83 x 10^6 m^3/day of natural gas.[29]

As shown in Table 21, where source control information was available, the majority (78%) of these incidents were shown to use capping and containment as the primary means of source control. Relief wells were identified as the source control for two incidents. Worldwide, it has been estimated that there have been 50,000 exploratory wells drilled. Of the 20 largest historical blowout incidents listed in Table 21, four have occurred during exploration drilling activities.

[29] Gill et al. 1985.

Table 21: Largest Offshore Well Blowouts[30]

Well	Start Date	Location	Bbl Spilled	Oil Type	Type of Well	Flow Rate (bbl/day)			Duration (days)	Source Control Method
						Peak	Avg.	Lowest		
Ixtoc I - HIGH	6/3/1979	Bahia del Campeche, Mexico	10,190,000	crude	exploratory	unknown	35,000	unknown	290	Well capped
Macondo MC-252- HIGH	4/20/2010	Gulf of Mexico	4,200,000	crude	exploratory	60,000	49,400	unknown	85	Well capped
Ixtoc I - LOW	6/3/1979	Bahia del Campeche, Mexico	3,300,000	crude	exploratory	30,000	20,000	10,000	290	Well capped
Macondo MC-252- LOW	4/20/2010	Gulf of Mexico	2,450,000	crude	exploratory	35,900	28,800	unknown	85	Well capped
Bull Run/ Atwood Oceanics	1/1/1973	Dubai, UAE	2,000,000	crude	development drilling	unknown	unknown	unknown	unknown	Unknown
Abkatun 91	10/1/1986	Bahia del Campeche, Mexico	247,000	crude	workover	unknown	unknown	unknown	unknown	Unknown
Montara - HIGH	9/21/2009	Timor Sea, Australia	214,300	crude	development drilling	2,000	400	400	74	Relief wells
Ekofisk Bravo B-14	4/20/1977	North Sea, Norway	202,381	crude	workover	28,080	28,080	28,080	7	Well capped
Funiwa 5	1/17/1980	Forcados, Nigeria	200,000	crude	development drilling	12,500	12,500	12,500	16	Well bridged naturally
Hasbah 6	10/2/1980	Gulf, Saudi Arabia	105,000	crude	exploratory	11,667	11,667	11,667	9	Well capped
Alpha Well 21 Platform A	1/28/1969	Pacific	100,000	crude	production	9,090	9,090	unknown	11	Well capped
Iran Marine Intl.	12/1/1971	Gulf, Iran	100,000	crude	development drilling	5,000	unknown	unknown	unknown	Unknown

[30] Two estimates are provided for Ixtoc I, Macondo MC-252, and Montara blowouts. The estimates are shown separately in decreasing order of volume.

Table 21: Largest Offshore Well Blowouts[30]

Well	Start Date	Location	Bbl Spilled	Oil Type	Type of Well	Flow Rate (bbl/day)			Duration (days)	Source Control Method
						Peak	Avg.	Lowest		
Main Pass Block 41-C	3/1/1970	Gulf of Mexico	65,000	crude	production	3,000	2,200	1,000	30	Well capped
Yum II/ Zapoteca	10/10/1987	Bahia del Campeche, Mexico	58,643	crude	exploratory	unknown	30,000	unknown	51	Well capped
South Timbalier B-26	12/1/1970	Gulf of Mexico	53,095	crude	wireline	unknown	unknown	unknown	unknown	Unknown
Trinimar Marine 327	8/8/1973	Gulf of Paria, Venezuela	36,650	crude	development drilling	unknown	2,000	unknown	5	Well capped
Montara - LOW	9/21/2009	Timor Sea, Australia	28,600	crude	development drilling	2,000	390	unknown	74	Relief wells
Ship Shoal 149/199	10/1/1964	Gulf of Mexico	11,847	crude	unknown	unknown	unknown	unknown	unknown	Unknown
Greenhill Timbalier Bay 251	9/29/1992	Gulf of Mexico	11,500	crude	production	3,120	1,440	120	14	Unknown
Hebert Bravo 1A	2/19/1979	Gulf of Mexico	3,500	condensate	unknown	unknown	unknown	unknown	unknown	Unknown
Uniacke G-72	2/22/1984	Nova Scotia	1,500	gas condensate	exploratory	300	unknown	unknown	10	Unknown
Ship Shoal 29	7/1/1965	Gulf of Mexico	1,690	crude	unknown	unknown	unknown	unknown	unknown	Unknown
Ship Shoal 72	3/16/1969	Gulf of Mexico	1,060	crude	unknown	unknown	unknown	unknown	unknown	Unknown

Blowout Probability Analysis

Worldwide, there have been about 50,000 exploratory wells drilled with two large blowouts – the 1979 Ixtoc I well blowout, and the 2010 Macondo MC-252 well blowout.

The probability of a well blowout occurring depends on a large number of factors related to the location, well characteristics, operating conditions, etc. For locations for which there are few, if any, offshore oil exploration and production wells, the only benchmarks are historical data from other regions. Estimates of the probability of well blowouts, measured as the frequency or rate per well, have varied by region, time period, and other factors. Various studies have investigated the probability of well blowouts per well as summarized in Table 22.

Table 22: Previous Estimates on Exploratory Well Blowout Probabilities

Location/Well Type	Blowout Probability per Well[31]			Data Source
	10th Percentile	Mean	90th Percentile	
Gulf of Mexico/North Sea Exploratory	0.00110	0.00250	0.00510	Holand 2006
Worldwide Exploration Deepwater High Pressure[32]	-	0.00190	-	
Worldwide Exploration Deepwater "Normal"	-	0.00031	-	
Beaufort Sea Exploratory	-	0.00250	-	Bercha 2010

Estimates for the probability of a particular exploratory well having a blowout over its productive lifespan vary from 0.0011 to 0.005 per well depending on factors such as depth, well pressure, location, and blowout cause. The mean blowout probability for exploratory wells is 0.025 per well. Analyses of international data [33] indicated that if a blowout does occur, there is a 56% chance of it lasting two days or less (i.e., bridging naturally), and only a 15% chance of it lasting more than two weeks.

US Studies in 1970s

In 1980, the US Department of the Interior Geological Survey[34] reported that during the 8-year period, 1971 – 1978, 46 blowouts occurred on the Outer Continental Shelf (OCS) of the US. Thirty of the blowouts occurred during drilling operations, however, most of these blowouts were reported to have been of short duration and had minimal effect. Of the 17 exploratory well blowouts, ten lasted for periods of 15 minutes to 24 hours. The remaining seven had durations of 21 days or less; only two lasted more than a week. Twelve of the 17 exploratory well blowouts "bridged" or sealed off naturally. The remaining five were controlled by pumping down mud or activating rams on the blowout preventer (BOP) stack. None of the wells required a relief well to regain control. All of these exploratory well blowouts involved the release of only gas. No oil was released.

The remaining 16 blowouts occurred during completion, production, and work-over operations. The blowouts that occurred during non-drilling operations were reported to have posed the greatest threat. During the eight-year study period, 7,533 new wells were started and one blowout occurred for every 250 wells drilled (0.004). Oil and condensate production amounted to 2.8 billion barrels with the total blowout

[31] Probability over lifetime of well.
[32] HPHT (high pressure/high temperature) wells.
[33] Holand 2006.
[34] Danenberger 1980.

spillage of less than 1,000 barrels (3.6 x 10^{-7} barrels spilled in blowouts per produced barrels). The blowout data are summarized in Table 23. Another US study from the 1970s showed that there was a blowout rate per well of 0.0072 (one blowout for 139 offshore wells) in Cook Inlet, Alaska.[35] A previous study for the time period 1953 – 1971 showed a blowout rate of one in 500 (0.002).

Table 23: Blowouts in US Offshore Operations 1971 – 1978[36]

Year	New Wells	Drilling Blowouts		Production Million bbl	Non-Drilling Blowouts					
		Expl.	Develop.		Production		Workover		Completion	
					#	Bbl	#	Bbl	#	Bbl
1971	841	2	0	418.5	2	450	1	0	0	0
1972	847	2	1	411.9	0	0	0	0	0	0
1973	820	2	1	394.7	0	0	0	0	0	0
1974	816	0	1	360.0	2	75	1	200	0	0
1975	882	4	0	330.2	0	0	1	0	1	0
1976	1,041	1	4	316.9	1	0	0	0	0	0
1977	1,158	2	2	303.9	0	0	3	0	2	0
1978	1,148	4	4	292.3	0	0	2	Minimal	0	0
Total	**7,553**	**17**	**13**		**5**	**525**	**8**	**200**	**3**	**0**

Studies for Canadian Offshore Projects

In a 2002 study, well blowout frequencies were calculated for US wells and worldwide as part of an analysis of the Northstar Project as shown in Table 24.

Table 24: Exploratory Well Blowout Frequency (SL Ross Northstar Study)[37]

Event Type	Historical Frequency	Time Period/Region
Gas blowout during exploration drilling	5.4 x 10^{-3}/well drilled	US OCS 1964 – 1995
Exploration drilling blowout with spill >10,000 bbl	1.5 x 10^{-4}/well drilled	Worldwide 1970 – 2002
Exploration drilling blowout with spill > 150,000 bbl	5.5 x 10^{-5}/well drilled	Worldwide 1970 – 2002

The Beaufort Sea Exploration Joint Venture Drilling Program[38] submitted a project description to the Environmental Impact Screening Committee in September 2013.[39] As part of the application, the group estimated the likelihood of blowouts and other oil spills, concluding:

- There have been no large offshore blowouts in Canada with nearly 400 wells (149 exploratory) in Newfoundland waters since 1966 and 83 wells in the Beaufort Sea since the 1970s and 1980s.
- The frequency of large blowouts is one per 25,000 or 0.00004 per well.
- The large blowout frequency is based on international data, including countries that do not generally have the regulatory standards as those in Canada, which suggests that the likelihood of a large well blowout is even lower in Canada.
- There have been very few large spills related to exploration and production.
- Based on Canadian offshore data, spills in the range of 8 m^3 to 159 m^3 (50 to 1,000 bbl) occur with a frequency of one every 540 wells (0.00185);

[35] Minerals Management Service 1986.
[36] Danenberger 1980.
[37] Bercha 2002; SL Ross 1998.
[38] Includes: Esso, Imperial Oil, ExxonMobil and BP.
[39] Imperial Oil Resources Ventures Limited. 2013.

- Spills of less than 8 m^3 (50 bbl) occurs at a frequency of one for every 37 wells (0.027).
- Very small spills of one to two liters occasionally occur on drilling units and support vessels.

Additional analyses on more comprehensive worldwide data on blowouts available in 2004 indicate that the probability of a well blowout occurring in an individual well are very small with the probability decreasing with increasing spillage volume (Table 25).

Table 25: Worldwide Blowout Probabilities[40]

Blowout Volume		Probability per Well	
bbl	**m^3**	**Crude or Condensate**	**Gas Only**
> 150,000 bbl	**> 24,000 m^3**	2.9×10^{-5}	6.7×10^{-3}
> 10,000 bbl	**> 1,600 m^3**	8.3×10^{-5}	6.7×10^{-3}
> 1 bbl	**> 0.2 m^3**	2.0×10^{-4}	6.7×10^{-3}

Labrador Sea Blowout Risk Evaluation

For a project for the Denmark Bureau of Minerals and Petroleum, the risk of blowout from exploratory wells was determined to be as shown in Table 26. These analyses were based on North Sea blowouts.

Table 26: Exploratory Well Blowout Risk Analysis for Danish Labrador Sea Project[41]

Drilling Operation	Well Category	Blowout Frequency Per Well		
		Average	**Gas Well**	**Oil Well**
Exploration	**Normal**	1.12×10^{-4}	1.02×10^{-4}	1.23×10^{-4}
	HPHT	6.92×10^{-4}	6.32×10^{-4}	7.65×10^{-4}

SINTEF Well Blowout Database

The most comprehensive database on well blowouts is that maintained by SINTEF, [42] which includes data on 607 offshore blowouts and well releases that have occurred worldwide since 1955. The SINTEF database includes data from 43 nations. Over 59% of the data are from the US, including the Gulf of Mexico, California, and Alaska. Nearly 13% are from the North Sea. Only 0.3% are from Eastern Canada.

An analysis conducted in 2006[43] of the SINTEF data concluded that for exploratory wells that met the North Sea Standard,[44] which would apply to the Project, blowout frequencies are as shown in Table 27.

Table 27: Offshore Exploratory Well Blowout/ Release Frequencies (North Sea Standard)

Operation	Category	Frequency (per drilled well)
Exploration drilling deep normal wells	**Blowout**	2.5×10^{-4}
	Well release	2.0×10^{-3}
Exploration drilling deep HPHT wells	**Blowout**	1.5×10^{-3}
	Well release	1.2×10^{-2}

[40] Data from 2004, assuming pre-2004 blowout prevention technologies and operating standards (Imperial Oil Resources Ventures Limited. 2013.)
[41] Dyb et al. 2012.
[42] http://www.sintef.no/home/Technology-and-Society/Projects/Projects-SINTEF-TS-2001/SINTEF-Offshore-Blowout-Database/
[43] Scandpower 2006; OGP 2010.
[44] Operating with a blowout preventer (BOP) installed including shear ram and two barrier principle followed.

In a 2013 report on the SINTEF data, a number of findings were reported with respect to the frequency of blowouts and well releases by operational phase (Tables 28 and 29).[45] About 34% of blowouts and releases occur during exploration, based on post-1980 data.

Table 28: Distribution of Blowout/Well Releases by Operational Phase[46]

Period	Percent Incidents by Operational Phase								
	Develop Drill	Expl. Drill	Un-known	Com-pletion	Work-over	Produc-tion	Wire-line	Other	Total
Before 1980	24.3%	42.4%	0.6%	6.8%	10.2%	11/3%	1.7%	2.8%	**100%**
1980 - 2011	22.7%	34.4%	2.2%	6.2%	16.3%	11.5%	2.2%	4.5%	**100%**
Total	**23.2%**	**36.8%**	**1.7%**	**6.4%**	**14.5%**	**11.4%**	**2.0%**	**4.0%**	**100%**

Table 29: Blowout/Well Release Frequencies for Exploratory Appraisal Wells[47]

Release Category	Well Depth[48]	Incidents per Drilled Well
Blowout (Surface Flow)	**Deep**	1.28×10^{-3}
	Shallow	1.54×10^{-3}
Blowout (Underground Flow)	**Deep**	1.3×10^{-4}
Diverted Well Release	**Deep**	0
	Shallow	6.4×10^{-4}
Well Release	**Deep**	3.9×10^{-4}
	Shallow	1.3×10^{-4}
Unknown	**Deep**	1.3×10^{-4}
All	**Deep**	1.93×10^{-3}
	Shallow	2.31×10^{-3}

Blowout Potential with Water Depth

The blowout potential as a function of water depth was evaluated using the SINTEF data, as shown in Tables 30 and 31, and Figures 12 and 13.

These analyses indicate that blowouts from exploratory were statistically observed to be 30% less likely to occur in water depths of 1,000 – 2,500 metres compared with exploratory wells in less than 1,000 metres water depth. There have been no reported blowouts from the 42 exploratory wells in water depths over 2,500 metres.

Other well releases were statistically observed to be 45% less likely in exploratory wells at 1,000 – 2,500 metres water depth. There have also been no well releases in the over-2,500 metre exploratory wells. Total exploratory well incidents (blowouts and releases) were statistically observed to be 34% less likely in deeper wells.

[45] Holand 2013.
[46] Holand 2013.
[47] Based on data in Holand 2013.
[48] Well depth refers to the drilling depth into the substrate not the water depth.

Table 30: Detailed Analysis of Exploratory Well Spills by Water Depth 1980 – 2011[49] (Incidents/Well)

Water Depth (m)	Number of Exploratory Wells	Blowout Surface Flow (Deep)	Blowout Surface (Shallow)	Blowout Underground (Deep)	Blowout Underground Flow (Shallow)	Diverted Well Release (Deep)	Diverted Well Release (Shallow)	Well Release (Shallow)	Well Release (Deep)	Total
<50	6,291	0.002066	0.001431	0.000477	0.000000	0.000318	0.000000	0.000000	0.000000	**0.004292**
50-100	2,589	0.002317	0.004249	0.001159	0.000000	0.002704	0.002704	0.000772	0.000386	**0.011587**
100-200	848	0.002358	0.007075	0.000000	0.000000	0.002358	0.002358	0.001179	0.000000	**0.014151**
200-400	484	0.000000	0.004132	0.004132	0.000000	0.002066	0.002066	0.004132	0.000000	**0.016529**
400-600	364	0.002747	0.005495	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.008242**
600-1,000	659	0.001517	0.001517	0.000000	0.001517	0.000000	0.000000	0.000000	0.000000	**0.004552**
1,000-1,500	566	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001767	0.000000	**0.001767**
1,500-2,500	456	0.002193	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002193**
2,500-3,000	39	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
>3,000	3	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
Total	**12,299**	**0.001951**	**0.002521**	**0.000650**	**0.000081**	**0.000976**	**0.000976**	**0.000488**	**0.000081**	**0.006911**

Table 31: Summary of Analysis of Exploratory Well Blowouts/Releases by Water Depth 1980 – 2011[50] (Incidents/Well)

Water Depth (m)	Number of Exploratory Wells	Blowouts	Well Releases	Total
<50	6,291	0.003974	0.000318	0.004292
50-100	2,589	0.007725	0.006566	0.011587
100-200	848	0.009434	0.005896	0.014151
200-400	484	0.008264	0.008264	0.016529
400-600	364	0.008242	0.000000	0.008242
600-1,000	659	0.004552	0.000000	0.004552
1,000-1,500	566	0.000000	0.001767	0.001767
1,500-2,500	456	0.002193	0.000000	0.002193
2,500-3,000	39	0.000000	0.000000	0.000000
>3,000	3	0.000000	0.000000	0.000000
Total	**12,299**	**0.005204**	**0.002521**	**0.006911**
Wells < 1,000 m	**11,235**	**0.005607**	**0.001780**	**0.007388**
Wells 1,000 – 2,500 m	**1,022**	**0.003914**	**0.000978**	**0.004892**
Wells > 2,500 m	**42**	**0.000000**	**0.000000**	**0.000000**

[49] Based on data in Holand 2013 (SINTEF Database); Analysis by ERC.
[50] Based on data in Holand 2013 (SINTEF Database); Analysis by ERC.

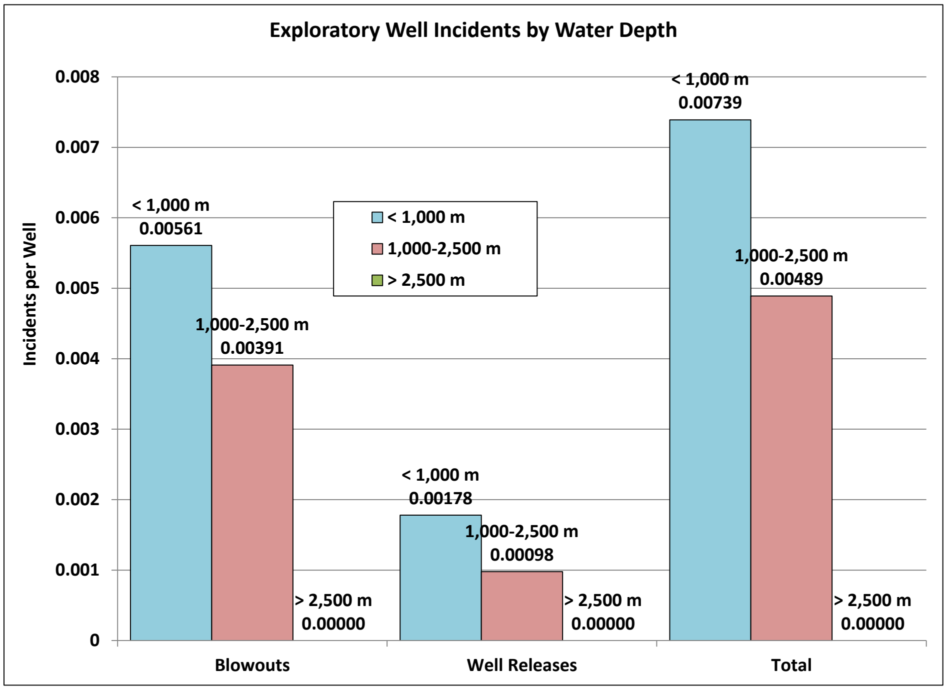

Figure 12: Exploratory Well Blowouts/Releases by Water Depth (1980 – 2011)

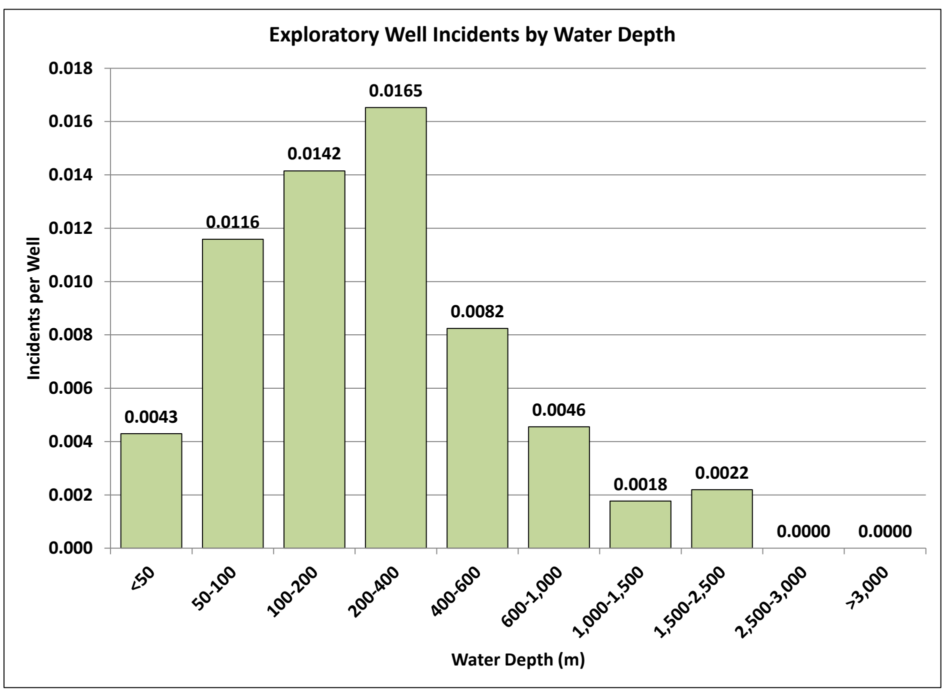

Figure 13: Exploratory Well Spill Incidents by Water Depth (1980 – 2011)

Volume of Well Spillage

The total volume of spillage, regardless of cause, is ultimately the concern with respect to potential spill impacts and response preparedness. In this analysis, spill volumes were grouped into five categories:

- Small Spills: less than 1 bbl
- Moderate Spills: 1 – 1,000 bbl
- Large Spills: >1,000 – 10,000 bbl
- Very Large Spills: >10,000 – 150,000 bbl
- Extremely Large Spills: >150,000 bbl

Overall Well Blowout Volumes

Clearly the spill volume is of greatest concern when considering potential blowout scenarios. As with most other spill causes, the volume of spillage from blowouts tends to be skewed towards smaller volumes, with large volumes of release being less frequent. A number of studies were reviewed to derive the probability distribution of spill volumes for blowouts. Table 32 and Figure 14 show the distribution of spill volumes for blowouts in the US OCS.

Table 32: Spill Volume Distribution of US Oil Well Blowouts

Volume Category	Volume	Number	% Total
Moderate Spills	**1-9 bbl**	1	3%
	10-99 bbl	10	32%
	100-999 bbl	10	32%
Large Spills	**1,000-9,999 bbl**	5	16%
Very Large Spills	**10,000-99,999 bbl**	4	13%
Extremely Large Spills	**100,000-999,999 bbl**	0	0%
	1,000,000+ bbl	1	3%
Total		**31**	**100%**

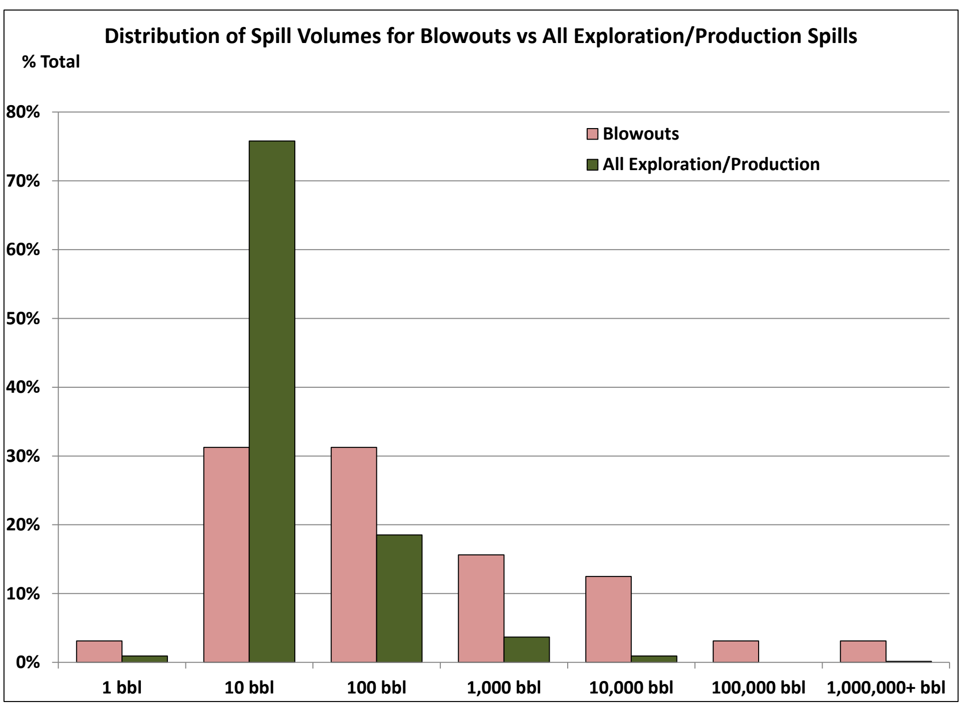

Figure 14: Distribution of Spill Volumes for Blowouts in US OSC Waters

Blowout volume data derived from studies conducted for Canadian projects are summarized in Table 33.

Table 33: Distribution of Well Blowout Volumes for Canadian Projects					
Spill Volume (bbl)	Northstar Project[51]			Hebron Project[52]	
	Development	Exploration	Production	Development	Production
1 bbl	-	-	65.0%	-	27.1%
10,000 bbl	66.7%	68.2%	25.0%	71.3%	52.1%
150,000 bbl	33.3%	31.8%	10.0%	28.7%	20.8%

Blowout and Release Durations for Exploratory Wells

The volume of a blowout (or other well release) is dependent on the flow rate and the duration of flow:

[1]

$$Spill_{volume} = flow \cdot duration$$

$$Spill_{volume}(bbl) = \frac{bbl}{day} \cdot days$$

Flow rates and release durations are considered separately here. The results of analyses of the SINTEF data for the duration of blowouts or releases from exploratory wells are summarized in Tables 34 and 35, and Figure 15. Generally, the duration of flow for blowouts and other releases is relatively short, which would limit the total volume of spillage. Nearly 40% of blowouts from exploratory wells flow for less than five days; 95% of other releases flow for less than five days. There are no specific data on durations of flow after five days. If the exploratory well blowout or release lasts for more than five days, it may flow until a capping and containment system is effectively installed. Note that preparations for intervention with capping and containment would commence with the first notification of spillage. According to the analysis in Holand 2013, the maximum time for capping and containing the well was determined to be 25 days, with 10 days to collect and prepare the appropriate equipment and 15 days for the actual operation. A 30-day release scenario takes this timing into account.

Table 34: Distribution Exploratory Well Blowout/Well Release Duration[53]									
Spill Type	Duration								
	≤10 min	10 min - ≤40 min	40 min - ≤ 2 hrs	2 hrs - ≤12 hrs	12 hrs - ≤2 days	2 days - ≤5 days	> 5 days	Unknown	Total
Blowout Deep Surface	0%	0%	4%	8%	21%	13%	29%	25%	100%
Blowout Shallow Surface	0%	3%	6%	13%	6%	22%	25%	25%	100%
Blowout Deep Underground	0%	0%	0%	13%	0%	13%	50%	25%	100%
Deep Diverted Release	100%	0%	0%	0%	0%	0%	0%	0%	100%
Shallow Diverted Release	8%	8%	8%	42%	17%	8%	0%	8%	100%
Deep Well Release	71%	14%	0%	14%	0%	0%	0%	0%	100%
Shallow Well Release	0%	0%	0%	0%	0%	0%	50%	50%	100%

[51] Bercha 2002; SL Ross 1998.
[52] Stantec et al. 2010.
[53] Based on data in Holand 2013.

Table 35: Probability of Exploratory Well Blowout/Release Duration of 5 Days or Less	
Release Type	**% Duration of 5 Days or Less[54]**
Blowout Deep Surface Flow	61%
Blowout Shallow Surface Flow	67%
Blowout Deep Underground Flow	34%
Deep Diverted Release	100%
Shallow Diverted Release	100%
Deep Well Release	100%
Shallow Well Release	0%
Average	**66%**
Blowouts (Surface and Underground Flow)	**40%**
Blowouts (Surface Only)	**64%**
Other Releases	**95%**

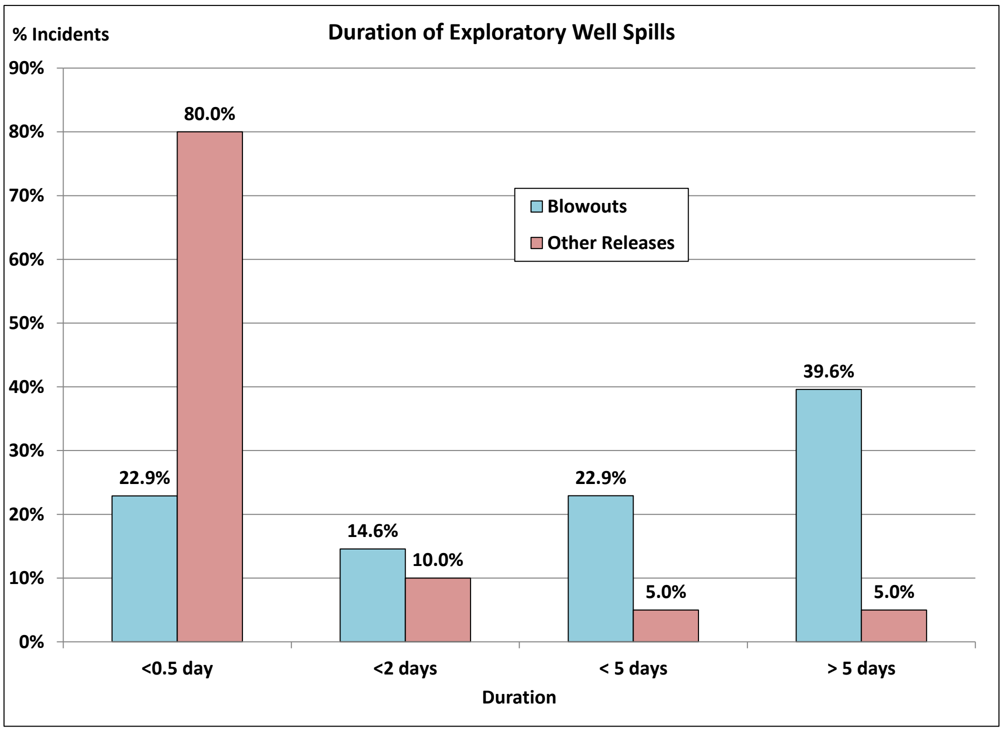

Figure 15: Duration of Exploratory Well Spills[55]

Blowout and Release Flow Rates

According to the SINTEF data,[56] blowout release or flow rates are generally poorly documented. For some blowouts flow-rate figures do exist, but for most blowouts they do not exist. Even for very well-studied blowout scenarios, such as the Macondo MC-252 incident, there are varying estimates of average and peak flow. Table 36 shows reported estimates of flow rates for a number of historical well blowouts. Note that these incidents are larger events. For smaller incidents, there are rarely flow rate calculations. But, the fact that, as shown in Table 32 and Figure 14 above, the total spillage volume is less than 1,000

[54] Based on SINTEF data for incidents for which there are known flow durations.
[55] Based on Holand 2013 (SINTEF data).
[56] Holand 2006; Holand 2013.

bbl for 67% of US blowout incidents and 83% are less than 10,000 bbl indicates that flow rates for most incidents are generally considerably less than 10,000 bbl or even 1,000 bbl per day.

Table 36: Reported Well Blowout Flow Rates

Scenario[57]	Peak Flow (bbl/day)	Average Flow (bbl/day)
Alpha 21-A (Santa Barbara)	-	9,090
Ekofisk Bravo B-14	-	28,080
Funiwa 5	12,500	-
Greenhill TB-251	3,120	1,440
Hasbah 6	-	11,667
Iran Marine Intl	5,000	-
Ixtoc I -HIGH	-	35,000
Ixtoc I -LOW	20,000	30,000
Macondo MC-252-HIGH	60,000	49,400
Macondo MC-252-LOW	35,900	2,880
Macondo MC-252-Oldenburg[58]	60,000	56,000
Macondo MC-252-McNutt[59]	70,000	50,000
Main Pass 41-C	3,000	2,200
Montara -HIGH	2,000	400
Montara - LOW	2,000	390
Trinimar Marine 327	-	2,000
Yum II/Zapoteca	-	30,000

Project Spill Risk

The risk of spills and blowouts of various volumes from the Project is determined by evaluating the probability of occurrence and the probability distribution of potential spill volumes. Generally, "risk" is the probability of the occurrence of an event times the consequence of that event. The probability of the event is the relative frequency of the event, in this case, the relative frequency (rate per well or well-year) of spills or blowouts. In this case the "consequence" is the relative volume of spillage.

Probability of Project Well Blowouts and Releases

The probability of various kinds of potential spill releases and well blowouts and their respective volumes were analyzed for the Project with the application of a fault tree analysis and Monte Carlo simulation, as described in Appendix A. This methodology allows for incorporation of uncertainty in fault tree estimate inputs, as well as the incorporation of distributions of probabilities of various outcomes.

The overall probability of a spill from each individual or specific well is, on average, 0.000866, or once in 1,154 years. For seven wells (i.e., a spill from any one of the seven wells in the Project), the probability is 0.006064, once in 165 years. For blowouts specifically, the probability is 0.000777 per well or once in 1,287 years. For any of the seven wells, the probability is 0.005437 or once in 184 years. For other non-blowout releases, the probability per well is 0.00009 or once in 11,146 years. For a release from any of the seven wells, the probability is 0.000628 or once in 1,592 years (Tables 37 and 38).

[57] For details on blowout incidents, see Table 17.
[58] Oldenburg et al. 2012.
[59] McNutt et al. 2012a; McNutt et al. 2012b.

Table 37: Probabilities of Well Spillage per Specific Individual Well						
Statistical Parameter	Blowouts Only		Other Well Releases Only		All Well Spills	
	Probability per Well	Return Period per Well	Probability per Well	Return Period per Well	Probability per Well	Return Period per Well
Mean	0.000777	1,287	0.000090	11,146	0.000866	1,154
Median	0.000732	1,366	0.000087	11,438	0.000822	1,217
Std. Deviation	0.000380	2,632	0.000019	52,632	0.000381	2,628
Minimum	0.000051	19,499	0.000053	18,717	0.000116	8,621
Maximum	0.003146	318	0.000202	4,950	0.003258	307

Table 38: Probabilities of Well Spillage for Any Well or Multiple Wells						
Number Wells[60]	Blowouts Only		Other Well Releases Only		All Well Spills	
	Probability	Return Period	Probability	Return Period	Probability	Return Period
1[61]	5.437×10^{-3}	1.839×10^{2}	6.280×10^{-4}	1.592×10^{3}	6.064×10^{-3}	1.649×10^{2}
2	2.956×10^{-5}	3.383×10^{4}	3.944×10^{-7}	2.536×10^{6}	3.677×10^{-5}	2.719×10^{4}
3	1.607×10^{-7}	6.222×10^{6}	2.477×10^{-10}	4.038×10^{9}	2.230×10^{-7}	4.485×10^{6}
4	8.739×10^{-10}	1.144×10^{9}	1.555×10^{-13}	6.429×10^{12}	1.352×10^{-9}	7.395×10^{8}
5	4.751×10^{-12}	2.105×10^{11}	9.768×10^{-17}	1.024×10^{16}	8.200×10^{-12}	1.220×10^{11}
6	2.583×10^{-14}	3.871×10^{13}	6.134×10^{-20}	1.630×10^{19}	4.972×10^{-14}	2.011×10^{13}
7	1.404×10^{-16}	7.120×10^{15}	3.852×10^{-23}	2.596×10^{22}	3.015×10^{-16}	3.317×10^{15}

Probability of Project MODU Batch Diesel Spill

There are no specific data from which to derive probabilities of MODU spills[62] per se. Most of the data on vessel-sourced spills have involved offshore supply or service vessels. For vessels (offshore supply vessels and MODUs) associated with US Gulf of Mexico operations, there have been 0.0018 vessel spill incidents per well per year.[63] This is a return period of 557 years.

To more closely reflect the experience in the Nova Scotia offshore, the batch spill data from CNOSPB during 1999 – 2013 were analyzed. These data include vessel spills and other small spills associated with the operations at exploratory wells. The probability (incident rate) of a small (< 1 bbl) spill during the five-year project period is 17 such spills. For spills of one to 10 bbl, the probability is 0.12 in five years, or once in 41 years.

Probability of Project SBM Spill

The average number of incidents of SBM spills is estimated to be 0.00175 incidents per well per year, or one incident in 571 years, based on the data in Table 5 above. Applying this statistic to seven wells and 5 years for the Project, gives an expected frequency of 0.062 for the duration of the five-year Project.

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[60] The probability of multiple wells spilling during the five-year exploratory period. The probability for one well is the probability of *any* well spilling. The probabilities in Table 33 are the probabilities for each specific well.
[61] Probability of spillage from any one of the seven wells.
[62] MODU spills are spills of fuel from the vessels rather than well-sourced spillage potentially caused by MODU operations, which would be classified as well spills.
[63] Based on data from Etkin 2009.

Project Spill Volume Probabilities: Wells

In the unlikely event that a spill does occur, the spill will not necessarily involve the maximum amount of outflow. In fact, most spills are small and only very rarely does a spill result in a volume that would be classified as Very Large or Extremely Large. If a spill does occur from the well, there is a distribution of potential spill volumes ranging from Small to Extremely Large. Non-blowout releases tend to involve relatively small volumes of considerably less than one bbl to about 100 bbl, because they, by definition, do not involve uncontrolled flow. Blowouts, on the other hand, involve flow at a certain rate for a few hours to a number of days, depending on the time to natural bridging or successful intervention through capping. The total volume is dependent on the duration of flow and flow rate, the latter of which varies from a few barrels per day to as high as 49,150 bbl/day, the estimated maximum flow rate for the Project.

Tables 39 and 40 show the statistics for the expected distribution of potential blowouts from the wells based on application of the Monte Carlo simulation for spill volumes described in Appendix A. The lowest volume is based on a hypothetical flow rate of 100 bbl/day for 0.02 days. The highest volume is based on a hypothetical flow rate of 49,150 bbl/day for 30 days.

Table 39: Summary Expected Volumes for Project Well Blowouts

Statistical Parameter	Value (bbl)	
	Natural Bridging	Capping/Containment
Mean	39,210	279,398
Median	29,591	227,952
Standard Deviation	33,948	217,941
Minimum	65	1,816
Maximum	245,750	1,474,500

Table 40: Summary Expected Volume Percentile for Project Well Blowouts

Percentile Spill Volume	Volume (bbl)		
	Natural Bridging	Capping/Containment	All Stoppage Methods
0 Percentile (Minimum)	2	1,816	2
10th Percentile	5,300	45,736	1,800
20th Percentile	10,274	85,620	15,000
30th Percentile	15,817	128,164	30,000
40th Percentile	22,034	175,382	47,000
50th Percentile (Median)	29,590	227,951	75,000
60th Percentile	38,529	288,114	128,000
70th Percentile	49,666	359,167	225,000
80th Percentile	64,390	450,349	288,000
90th Percentile	87,398	589,524	450,000
100th Percentile (Maximum)	245,750	1,474,500	1,474,500

Combining this probability distribution of blowout volumes with the probability that a blowout will occur, the probability of a 747,000-bbl spill *volume*, as in Spill (Site-2) based on 24,900 bbl/day for 30 days, is 0.00027, or once in 3,678 years. The probability of a 1,474,500-bbl *volume*, as in Spill (Site-1) based on 49,150 bbl/day for 30 days, is 0.000054, or once in 18,392 years. Combining the probabilities of occurrence and volume provides the probabilities of well spills by volume category are shown in Table 41.

Table 41: Probabilities of Project Well Blowouts by Volume Category		
Volume Category	**Probability (Incidents per Well)**	**Return Period**
Large (1,000 – 10,000 bbl)	0.0049	202 years
Very Large (10,000 – 150,000 bbl)	0.0045	222 years
Extremely Large (>150,000 bbl)	0.0018	541 years

Project Spill Volume Probabilities: MODU Batch Spills (Diesel)

The best estimate for volumes for MODU diesel spills is based on the distribution of vessel spills for the US Gulf of Mexico OCS[64] as shown in Table 42.

Table 42: Summary Expected Volume Percentile for Project MODU Batch Spills	
Percentile Spill Volume	**Volume (bbl)[65]**
0 Percentile (Minimum)	1
10th Percentile	1.5
20th Percentile	3
30th Percentile	3.5
40th Percentile	4
50th Percentile	5
60th Percentile	6
70th Percentile	10
80th Percentile	15
90th Percentile	47
95th Percentile	100
100th Percentile (Maximum)	643

Based on this, the probability of a 10-bbl spill *volume* (as in Batch Spill-10 bbl), is 0.30, since it is in the 70th percentile (only 30% of spills are this volume or larger). The probability of a 100-bbl *volume* (as in Batch Spill-100 bbl), is 0.05, since it is in the 95th percentile (only 5% of spills are this volume or larger). Theoretically, a spill of as much as 25,000 bbl might occur from a MODU with that large a fuel capacity, though this has never yet occurred. It is assumed that this type of spillage would occur in 0.1% of cases.

As shown in Table 43, spills of over 1 bbl are very unlikely to occur during the five-year Project time frame. There are, however, likely to be small (<1 bbl) spills occurring during the time frame of the Project. Moderate to Very Large category spills would tend to occur from the MODU, since this holds the greatest amount of oil. Small category spills could occur from the MODU or from other parts of the offshore operations other than the well itself.

Because the Moderate category covers such a broad range of volumes across three orders of magnitude (1 to 1,000 bbl) with highly varying probabilities of occurrence, the category has been further subdivided into Small/Moderate (1-10 bbl) and Moderate/Large (100 – 1,000 bbl) for the batch spill analysis.

64 Etkin 2009.
65 Spills under 1 bbl not recorded.

Table 43: Probabilities of Project MODU Batch Spillage by Volume Category			
Volume Category	**Probability**		**Return Period (years)**
	1-Year	**5-Year**	
Small (< 1 bbl)	3.4	16.8	0.3
Small/Moderate (1 – 10 bbl)	0.02439	0.12194	41
Moderate/Large (100 – 1,000 bbl)	0.00124	0.00620	806
Large (1,000 – 10,000 bbl)	0.00006	0.00031	16,129
Very Large (10,000 – 150,000 bbl)	0.00001	0.00006	80,645
Extremely Large (>150,000 bbl)	0	0	n/a

Project Spill Volume Probabilities: SBM Spills

The best estimate for the volume distribution of spill volumes for SBM incidents for the Project is based on a combination of data from the US OCS and Nova Scotia offshore data. Table 44 applies the percentage of small (under 1 bbl) spills – i.e., 89% – from the Nova Scotia data (Table 19) to the larger data set from the US OCS[66], which does not include any spills of less than one bbl. Based on this, the probability of a 377.4-bbl spill, as in the SBM Spill-1 scenario, is 0.05. The probability of a 3,600-bbl spill, as in the SBM Spill-2 scenario, is 0.01.

Table 44: Summary Expected Volume Percentile for Project SBM Spills	
Percentile Spill Volume	**Volume (bbl)[67]**
0 Percentile (Minimum)	0.001
10th Percentile	0.005
20th Percentile	0.007
30th Percentile	0.009
40th Percentile	0.01
50th Percentile	0.09
60th Percentile	0.1
70th Percentile	0.5
80th Percentile	0.07
90th Percentile	1
95th Percentile	500
100th Percentile (Maximum)	3,600

Note that this volume probability is independent of the probability that an SBM spill will occur. That probability, addressed in a previous section, is 0.0124 in one year and 0.062 over 5 years. Combining the probabilities of occurrence and volume provides the probabilities of MODU spills, as shown in Table 45.

Table 45: Probabilities of Project SBM Spillage by Volume Category			
Volume Category	**Probability**		**Return Period (years)**
	1-Year	**5-Year**	
Small (< 1 bbl)	0.01116	0.05580	90
Moderate (1 – 1,000 bbl)	0.00062	0.00310	1,613
Large (1,000 – 10,000 bbl)	0.00012	0.00062	8,065
Very Large (10,000 – 150,000 bbl)	n/a[68]	n/a	n/a
Extremely Large (>150,000 bbl)	n/a[69]	n/a	n/a

[66] Based on BSEE data through 2013.
[67] Spills under 1 bbl not recorded.
[68] A spill of this volume would not occur because this exceeds the SBM capacity of the MODUs.
[69] A spill of this volume would not occur because this exceeds the SBM capacity of the MODUs.

Probabilities of Modelled Scenarios

The estimated probabilities of the specific spill volumes associated with the modelled scenarios are shown in Table 46.

Table 46: Probabilities of Project Scenario Spillage

Scenario	Volume (bbl)	Probability per Well-Year[70]	Return Period (years)
Batch Spill-10 bbl	**10 bbl**	0.121940	41
Batch Spill-100 bbl	**100 bbl**	0.006200	806
SBM Spill-1	**377.4 bbl**	0.004960	1,008
SBM Spill-2	**3,604.2 bbl**	0.000620	8,065
Spill (Site-1)	**1,474,500 bbl**	0.000054	18,392
Spill (Site-2)	**747,000 bbl**	0.000270	3,678

Other Oil Inputs in the Region

Any potential spillage or discharge from the Shelburne Project should be considered in relation to other oil inputs in the region, including: natural seeps, other spills from vessels and facilities, operational inputs from vessels, and urban runoff in the region.

Natural Oil Seepage

Canada has proved oil reserves[71] of about 173.6 billion barrels,[72] nearly 10% of the world's reserves.[73] Some of this crude oil is naturally discharged each year from "natural seeps", natural springs from which liquid and gaseous hydrocarbons (hydrogen-carbon compounds) leak out of the ground. Oil seeps are fed by natural underground accumulations of oil and natural gas.[74] Oil from sub-marine (and inland subterranean) oil reservoirs comes to the surface each year, as it has for millions of years due to geological processes.

Natural discharges of petroleum from submarine seeps have been recorded throughout history going back to the writings of Herodotus[75] and Marco Polo.[76] Archaeological studies have shown that products of oil seeps were used by Native American groups living in California - including the Yokuts, Chumash, Achomawi, and Maidu tribes - well before the arrival of European settlers.[77] Aboriginal people were reported to have sealed their canoes with tar-like residues from natural oil seeps. In 1714, Hudson Bay Company's fur traders James Knight and Henry Kelsey were said to have found petroleum seeps from river banks. Oil seeps in Ontario and Alberta led geologists to significant petroleum discoveries that

70 Incidents expected in the five-year time period.
71 Proved oil reserves are estimated quantities that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions.
72 *Oil & Gas Journal* 2012.
73 *BP Statistical Review 2013*.
74 http://geomaps.wr.usgs.gov/seeps.
75 Lees 1950.
76 Levorson 1954.
77 Hodgson 1987.

started the first registered oil companies in North America.[78] Oil seeps were also reported in Canada by other explorers in the late 18th century.[79]

Oil seeps can occur on the ocean floor as well as on land. When oil seeps onto land, it may form pockets or pools of oil on the surface, such as in the La Brea Tar Pits in California. Oil that seeps from the ocean floor can become incorporated into sediment or it can rise to the surface where it forms sheens and tar balls that may be deposited on beaches.[80] In many locations with natural sea-floor seeps, chemosynthetic communities have become established. The organisms in these communities convert carbon molecules from methane and other compounds into organic matter using oxidation of inorganic molecules, such as hydrogen sulfide.[81] The presence of oil seeps also fosters the development of populations of microbes that metabolize hydrocarbons. The oil-degrading microorganisms (bacteria) appear to adapt to the specific types of crude oil being released. This also demonstrates the tremendous adaptability of these microbial communities and ecosystems in dealing with the incursion of the large volume of oil spilled.[82]

In recent times, the locations of natural seeps have been used for exploration purposes to determine feasible locations for oil extraction. The magnitude of natural seeps is such that, according to prominent geologists, Kvenvolden and Cooper (2003), "*natural oil seeps may be the single most important source of oil that enters the ocean, exceeding each of the various sources of crude oil that enters the ocean through its exploitation by humankind.*" Worldwide, natural seepage totals from about 4.2 million barrels to as much as 14 million barrels annually. In North American waters, natural seeps are also the largest source of oil inputs.

While regional assessments of natural seepage have been conducted in some locations, particularly nearshore in California,[83] the Indian Ocean,[84] and in the US Gulf of Mexico,[85] the most comprehensive worldwide assessment of natural seepage is still the study conducted by Wilson et al. (1974) (Figure 16). Even the two more recent international assessments of oil inputs into the sea[86] relied heavily on the estimates of natural oil seepage conducted by Wilson et al. (1974), having found no more recent comprehensive studies.

Assessments for natural oil seepage involve few actual measurements, though certain seep locations along the southern California Pacific coast in the US have been studied to some extent. Natural seep studies have also included identification of hydrothermically-sourced hydrocarbons (especially polycyclic aromatic hydrocarbons) in sediments. The most well-known studies have relied on estimation methodologies based on field data, observations, and various basic assumptions.

Wilson et al. (1974) estimated that total *worldwide* natural seepage ranged from 1.4 to 42.0 x 10^6 barrels annually, with the best estimate being 4.2 x 10^6 barrels, based largely on observations of seepage rates off

78 Bott 2012.
79 http://www.geohelp.net/history.html
80 Lorensen et al. 2009; Farwell et al. 2009.
81 Sassen et al. 1993; MacDonald et al. 1995.
82 Hazen et al. 2010.
83 Allen et al. 1970; Hornafius et al. 1999; Kvenvolden and Simoneit. 1990; Farwell et al. 2009.
84 Chernova et al. 2001; Gupta et al. 1980; Venkatesan et al. 2003.
85 MacDonald, 1998.
86 GESAMP 2007; NRC 2003.

California and western Canada. Estimates of the areas of ocean with natural seeps are shown in the table below. Estimates of seepage rates by ocean are shown in Tables 47 and 48.

Table 47: Seepage-prone Areas of the World's Oceans[87]

Ocean	Number of 1,000-Square Kilometres		
	High-Potential Seepage	Moderate-Potential Seepage	Low-Potential Seepage
Pacific	1,943	9,285	4,244
Atlantic	1,303	10,363	11,248
Indian	496	7,928	3,010
Arctic	0	5,636	2,456
Southern	0	486	458
Total	**3,741**	**33,697**	**21,416**

Table 48: Summary of World Seepage Rates[88]

Ocean	Estimated Oil Seepage (bbl per year)[89]		
	Case I, P_{16}[90]	Case II, $P_{1.0}$[91]	Case III, $P_{0.3}$[92]
Pacific	19,810,000	1,883,000	482,300
Atlantic	14,420,000	1,372,000	352,800
Indian	6,510,000	619,500	159,600
Arctic	1,498,000	16,100	36,400
Southern	131,600	121,800	3,157
Total	**42,369,600**	**4,012,400**	**1,034,257**

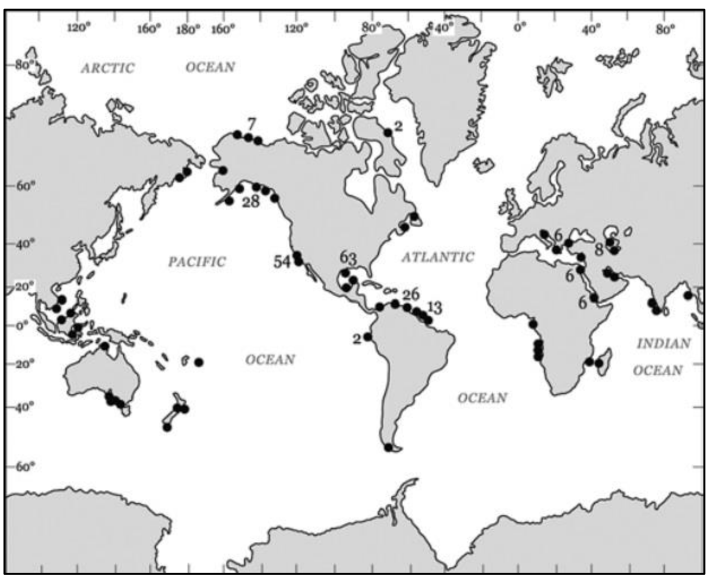

Figure 16: Worldwide Reported Natural Oil Seeps[93]

[87] Based on Wilson et al. 1974
[88] Based on Wilson et al. 1974
[89] Three probability levels were examined.
[90] Probability percentile 16 with a worldwide estimate of 42 x 10^6 bbl annually, likely a high estimate.
[91] Probability percentile 1.0 with a worldwide estimate of 4.2 x 10^6 bbl annually
[92] Probability percentile 0.3 with a worldwide estimate of 1.4 x 10^6 bbl annually, likely a minimal estimate.
[93] From Kvenvolden and Cooper 2003, based on Wilson et al. 1973 (The numbers refer to the reported number of major seeps in each location.)

Wilson et al. (1974) based their estimates on five basic assumptions (Figure 17):

- More seeps exist in offshore basins than have been observed;
- Factors that determine seepage rate in a particular area are related to general geological structural type and the stage of sedimentary basin evolution;
- Seepage is dependent on the area of exposed rock rather than on rock volume;
- Most marine seeps are clustered at continental margins; and
- Seepage rates are log-normally distributed.

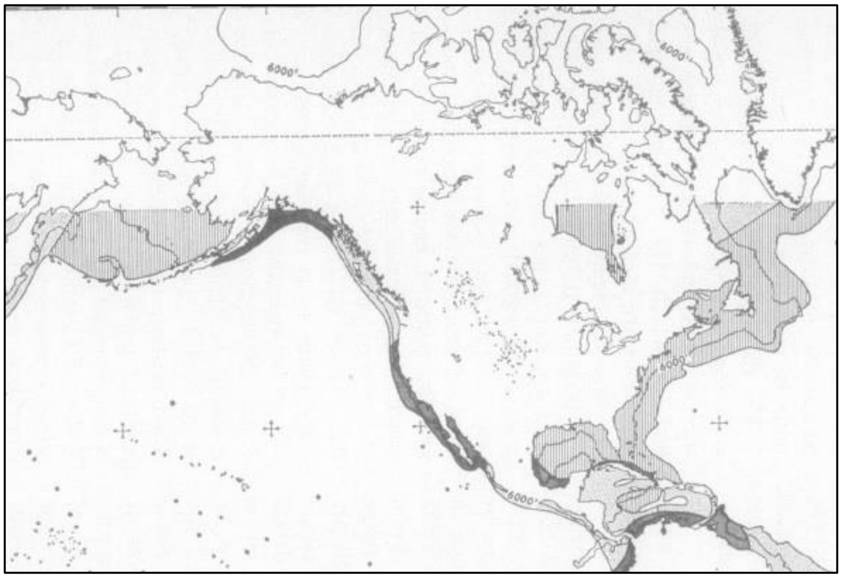

Figure 17: Oil Seepage Potential[94]

Kvenvolden and Harbaugh (1983) concluded that the minimal worldwide estimate (1.4 x 10^6 barrels annually) from the Wilson et al. (1974) study is most likely to be correct and that an error margin of an order of magnitude above and below this value should be applied (i.e., 0.14 x 10^6 to 14.0 x 10^6 barrels annually). Their theory was based on a reduced value for the assumed and known oil resources that would be available for seepage.

NRC 2003 presented a worldwide estimate of natural seepage into the marine environment of between 0.14 x 10^6 to 14.0 x 10^6 barrels annually, with a "best estimate" of 4.2 million barrels. These estimates[95] were made based on the Kvenvolden and Harbaugh (1983) reassessment of the estimates made by Wilson et al. (1974), as well as an acceptance of the original estimates of Wilson et al. (1974), resulting from a "new appreciation" for the magnitude of natural seepage, particularly in the Gulf of Mexico. Relying largely on the Wilson et al. (1974) and Kvenvolden and Harbaugh (1983) studies, the 2007 GESAMP also included an estimate of the range of natural seepage as 0.14 x 10^6 to 14.0 x 10^6 barrels annually.

[94] Wilson et al. 1974. This figure shows the potential for natural oil seepage in and around US waters. The darkest areas have the highest potential for seepage.

[95] The Oil in the Sea III natural seep estimates were made by Dr. Keith Kvenvolden, one of the co-authors of the Kvenvolden and Harbaugh (1983) reassessment.

With the technology available today a more comprehensive assessment of natural seepage, or at least a verification of the Wilson et al. (1974) study or the Kvenvolden and Harbaugh (1983) re-evaluation of that study, is theoretically possible. Due to the considerable resources that might be required to conduct this on a global or even regional scale, the most likely funding would, however, come from industry sources interested in exploration of any areas that contain potentially high levels of oil rather than for the purpose of assessing impacts to the world's oceans. Figure 17 shows areas of oil seepage potential in and around North America.

In the 2003 National Academy of Sciences "Oil in the Sea" study, which covered all of North America, scant data were found on oil seeps in the Canadian regions, so that no estimates of seepage-related inputs were developed for these regions. However, additional research was conducted for this report to find evidence of natural seeps off Canada, and in particular the region near the Shelburne Basin.

Oil seeps have been reported in Arctic regions of Canada, off the Mackenzie River in the Beaufort Sea region and Scott Inlet,[96] Buchan Gulf,[97] and Davis Strait[98] near Baffin Island, Hudson Bay and Foxe Basin.[99]

Different studies have looked at seeps in other parts of the Atlantic. In 1979, the US National Oceanic and Atmospheric Administration (NOAA)[100] reported the discovery of a large natural oil seep in the southwestern portion of the North Atlantic. In that report, NOAA estimated that the seep detected 1,129 km north of the Antilles island chain contained nearly twice the amount of oil (0.6 million tons – or 4.2 million barrels) that scientists were using to describe global inputs to oceans from natural sources at that time. More recently, Reahard et al. (2010) reported on potential natural seeps in the mid-Atlantic Ocean off North Carolina and Virginia, though the visual evidence was inconclusive.

Wilson (1973) reported the presence of at least two natural seeps off the eastern provinces of Canada, though there were no estimates of input volumes. Late in 2010, Nalcor Energy and Gas conducted a study to map regional oil seeps off Newfoundland and Labrador, though the results have not been made publicly available.

Seeps offshore of Nova Scotia have been reported by the Offshore Energy Technology Research Association[101] in its Play Fairway Analysis (PFA).[102] The PFA identified rich hydrocarbon potential offshore of Nova Scotia of about 8 billion barrels of oil. Much of this is based on data on seeps, as shown in Figures 18 – 20. There are rank-2 thermogenic oil seeps , reported "oil shows", and other indications of seepage in the Shelburne area and several rank-1 thermogenic oil seeps and "oil shows" over 100 km to the west-northwest of Shelburne.[103] There are no estimates of the annual amount of seepage.

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[96] Levy 1978; Blasco et al. 2010.
[97] Levy and Ehrhardt 1981.
[98] Decker et al. 2013a.
[99] Decker et al. 2013b.
[100] Anon. 1979.
[101] http://www.epmag.com/item/Deepwater-oil-potential-puts-offshore-Nova-Scotia-radar_106258.
[102] Beicip-Franlab. 2011.
[103] The ranking system is based on observations of remote sensing images. Rank 1 = overlap of the upwind ends of slicks in two or more images; Rank 2 = overlap of slick ends regardless of wind direction; Rank 3 = ends of slicks

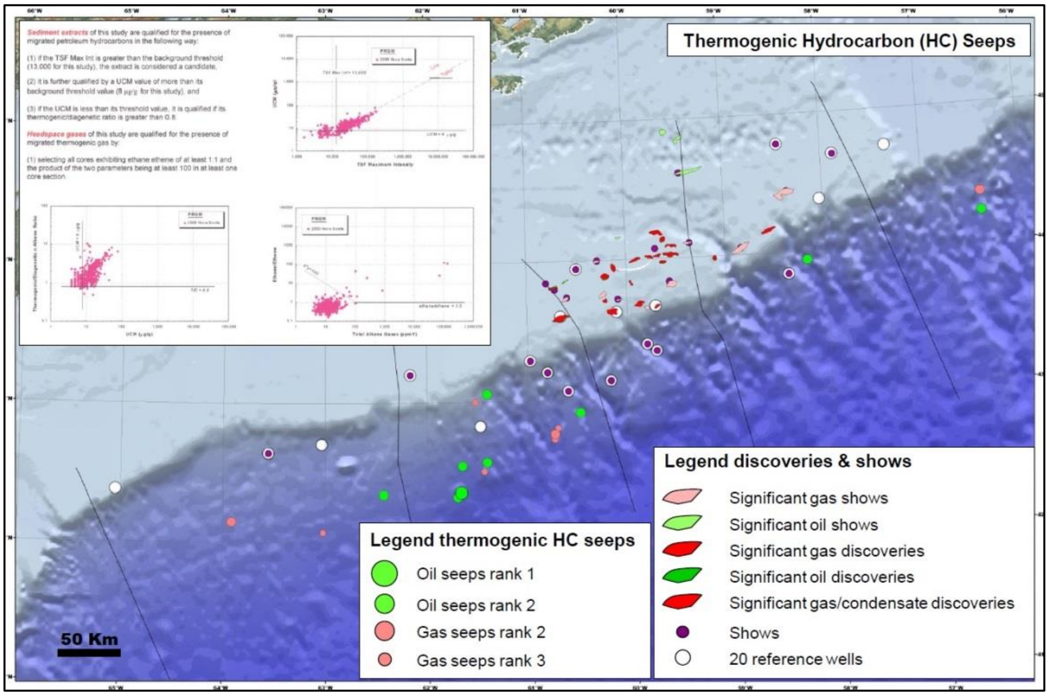

Figure 18: Significant Oil Discoveries and Thermogenic Hydrocarbon Seeps (DHI)[104]

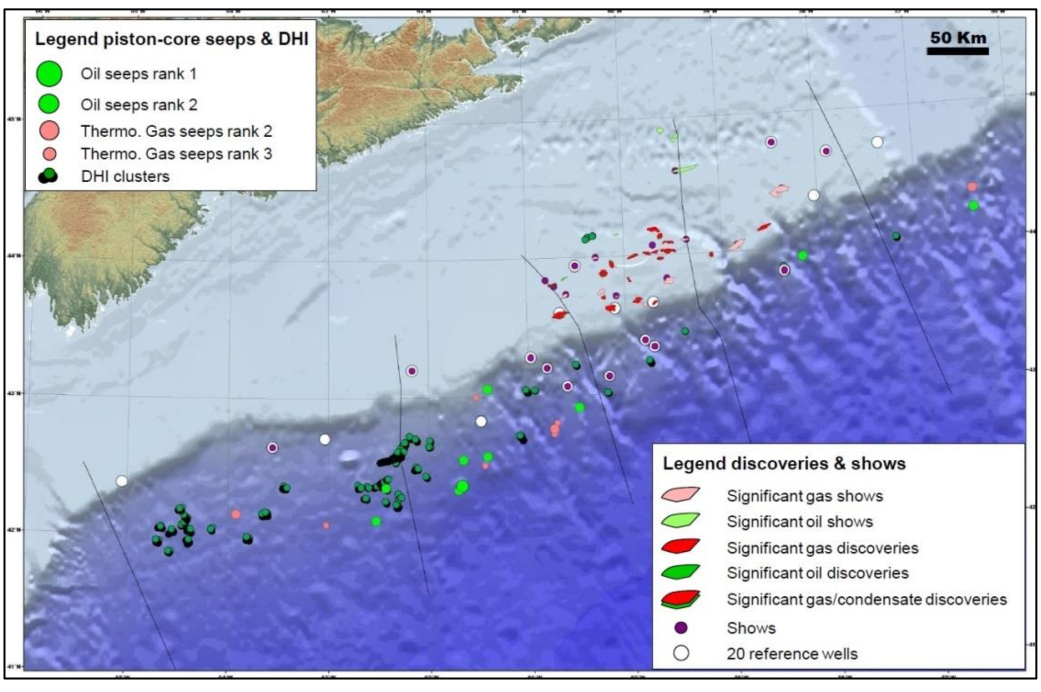

Figure 19: Significant Oil Discoveries and Thermogenic Hydrocarbon Seeps (Satellite)[105]

within 2 km of each other; Rank 4 = overlap of any portion of slick polygons in two or more images. (Liu et al. 2009; MacDonald et al. 1996).

[104] Beicip-Franlab. 2011, based on Bernard et al. 2000 from direct hydrocarbon indicators (DHI).

[105] Beicip-Franlab. 2011, based on Bernard et al. 2000 from DHI and satellite oil slick data.

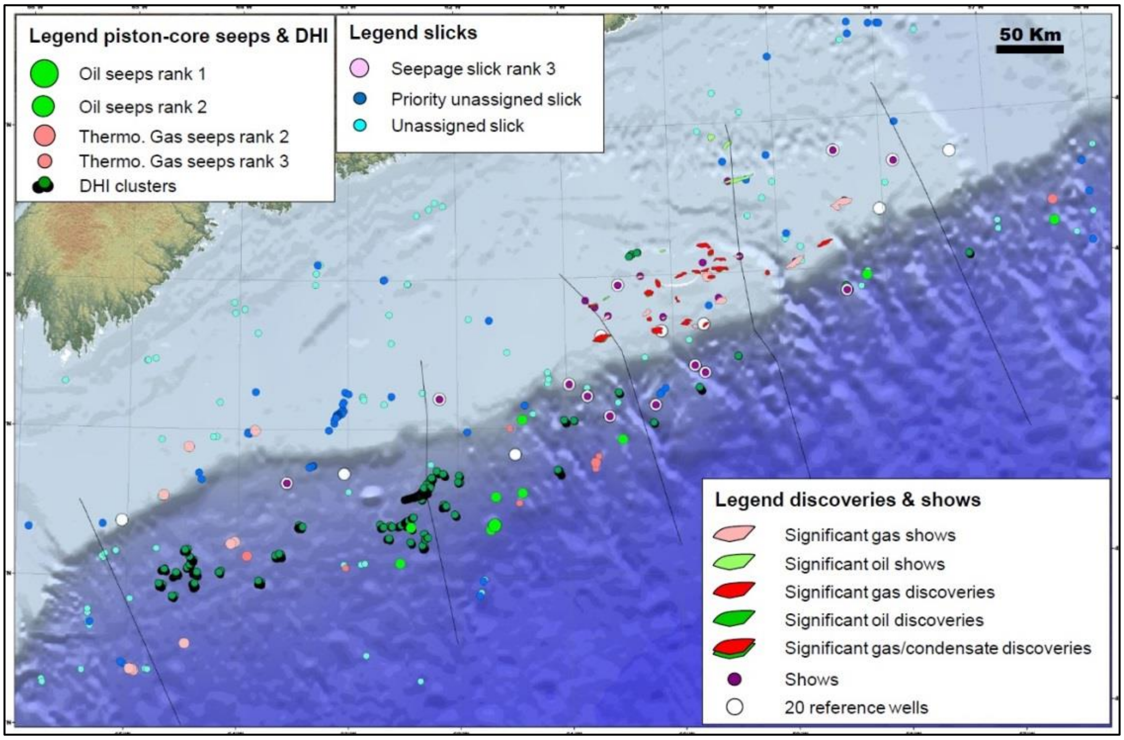

Figure 20: Significant Oil Discoveries and Thermogenic Hydrocarbon Seeps[106]

Other Spillages and Inputs

In addition to the unknown inputs of natural seeps in the region, other oil inputs occur from spillages originating from other oil exploration and production facilities, vessels, including tank vessels that carry oil as cargo and non-tank vessels (e.g., cargo ships and fishing vessels) that carry oil only as fuel and for operations.

The 2003 National Academy of Sciences “Oil in the Sea” Study, which covered the years 1990 through 1999, concluded that in eastern Canada, the annual oil inputs to coastal and offshore waters were as shown in Table 49. Total inputs from anthropogenic sources in this region were estimated to be 9,000 barrels annually in coastal areas, and 2,700 barrels annually in offshore areas. Note that this assessment includes a much larger area of eastern Canada than the immediate area near Shelburne Basin.

Table 49: Average Annual Oil Input (1990 – 1999) in Eastern Canada

Category	Source	Estimated Annual Input (bbl)		
		Coastal	Offshore	Total
Oil Extraction	Platforms	0	196	**196**
	Atmospheric Deposition	0	0	**0**
	Produced Water[107]	0	434	**434**
Oil Transportation	Pipelines	0	0	**0**
	Tank Vessels	0	0	**0**
	Coastal Facilities	39	0	**39**
	Atmospheric Deposition	39	0	**39**

[106] Beicip-Franlab. 2011, based on Bernard et al. 2000.
[107] Oil content only.

Table 49: Average Annual Oil Input (1990 – 1999) in Eastern Canada				
Category	Source	Estimated Annual Input (bbl)		
		Coastal	Offshore	Total
Oil Consumption	Land-Based (Urban Runoff)	3,500	0	3,500
	Recreational Vessels	0	23	23
	Vessels >100 GT[108] (Spills)	1,820	21	1,841
	Vessels >100 GT (Operational Discharges)	1,820	21	1,841
	Vessels <100 GT (Operational Discharges)	1,820	21	1,841
	Atmospheric Deposition	0	1,120	1,120
	Aircraft (Jettisoning)	0	840	840
Total Extraction		0	630	630
Total Transportation		39	0	39
Total Consumption		8,960	2,046	11,006
Total Anthropogenic		8,999	2,676	11,675

Based on an analysis of data for the years 1970 through 2009,[109] average oil spillage from various sources in coastal and offshore Nova Scotia is summarized in Table 50.

Table 50: Annual Oil Spillage in Nova Scotia Coastal and Offshore Waters (1970 – 2009)						
Source Type	Total (bbl)	Average Annual Spillage (bbl)				
		1970s	1980s	1990s	2000s	1970 - 2009
Coastal Facility	1,454	8	121	19	1	145
Fishing Vessel	674	43	0	24	1	67
Non-Tank Vessel	5,805	3	263	311	4	581
Oil Storage Terminal	1,915	48	143	1	0	192
Pipeline	5	0	0	0	0	1
Production Facility	3,524	0	352	0	0	352
Refinery	27	0	0	1	2	3
Tank Barge	74	0	0	0	7	7
Tanker (Tank Ship)	575,659	42,538	395	14,072	561	57,566
Unknown	476	0	0	48	0	48
Total	589,613	42,639	1,274	14,474	577	58,961

Based on this assessment, annual spillage could be expected to be about 600 barrels annually, with the possibility of a larger input from a large tanker spill or a large spill or potential blowout from another offshore facility.

Other than a major blowout from an offshore exploration or production facility, the greatest potential volume of spillage exists from oil tankers. There have been several significant oil tank vessel spills off Nova Scotia and Newfoundland in the past (Table 51).

Table 51: Largest Tanker and Tank Barge Spills in and near Eastern Canadian Waters[110]			
Tanker Name	Date	Location	Bbl
Odyssey	11/10/1988	Off Nova Scotia	1,026,190
Athenian Venture	4/22/1988	Off Newfoundland	252,429
Pegasus	2/8/1968	NW Atlantic Ocean	228,500

[108] Gross tonnage.
[109] ERC oil spill databases.
[110] Includes oil tanker spills that occurred in the US Exclusive Economic Zone (EEZ) or affected those waters.

Table 51: Largest Tanker and Tank Barge Spills in and near Eastern Canadian Waters[110]			
Tanker Name	**Date**	**Location**	**Bbl**
Texaco Oklahoma	3/26/1971	NW Atlantic Ocean	225,000
Grand Zenith	12/30/1976	Off Nova Scotia	212,571
Spartan Lady	4/4/1975	NW Atlantic Ocean	142,857
Berge Broker	11/15/1990	Off Nova Scotia	140,000
Arrow	2/4/1970	Chedabucto Bay, NS	77,000
Kurdistan	3/15/1979	Cabot Str, NS	49,690
Irving Whale	7/26/1970	Gulf of St. Lawrence, PEI	7,905

According to Transport Canada,[111] there are 10,000 vessel movements on the east coast of Canada each year, but tankers account for about a third (3,000) of these transits. Over 161 million barrels of petroleum and refined products are moved in and out of 23 ports in Atlantic Canada, about 75% of which goes though Come-by-Chance, Newfoundland and Labrador, Port Hawkesbury, Nova Scotia, and Saint John, New Brunswick.

Conclusions

During the 1990s, total inputs of oil from anthropogenic sources in coastal areas of Eastern Canada have averaged 9,000 barrels annually, and in offshore areas, 2,700 barrels annually, for a total of 11,700 barrels. Spill volumes off Nova Scotia have decreased significantly in the last decade to about 600 barrels. Occasional tanker spills have provided the greatest threat to the region in the past.

Offshore exploration and production facilities have spilled a total of 78 barrels of oil in 189 incidents over the last 15 years in Nova Scotia. Ninety-four percent of these incidents involved less than one barrel of oil.

In considering international and national historical spill data, well blowouts and other well-related spills from offshore drilling activities are considered *rare events*. The estimated probability that a specific individual exploratory well from the Project would have a blowout with oil spillage is 0.00077, or once in 1,287 years. With seven potential wells, this probability increases to 0.00544 that any one of the wells would have a blowout involving the spillage of oil.

The probability that there would be a spill from causes other than a well blowout is estimated to be 0.00009 per exploratory well, or once in 11,146 years. For a non-blowout release from any of the potential seven wells, the probability is 0.00063, or once in 1,592 years. Well spillage probability for any cause is estimated to be 0.00087, or once in 1,154 years; for all seven wells, the probability is 0.0061, or once in 165 years. The probabilities of well blowouts by volume category are shown in Table 52.

Table 52: Probabilities of Project Well Blowouts by Volume Category		
Volume Category	**Probability (Incidents per Well)**	**Return Period**
Large (1,000 – 10,000 bbl)	0.0049	202 years
Very Large (10,000 – 150,000 bbl)	0.0045	222 years
Extremely Large (>150,000 bbl)	0.0018	541 years

[111] http://www.tc.gc.ca/eng/marinesafety/menu-4100.htm#b

In the very unlikely event that a blowout with oil spillage occurs, the expected probability distribution of spill volumes from blowouts is shown in Table 53.

Table 53: Expected Spill Volume Percentile for Blowouts (All Stoppage Methods)

Percentile Spill Volume	Value (bbl)
0 Percentile (Minimum)	2
10th Percentile	1,800
20th Percentile	15,000
30th Percentile	30,000
40th Percentile	47,000
50th Percentile (Median)	75,000
60th Percentile	128,000
70th Percentile	225,000
80th Percentile	288,000
90th Percentile	450,000
100th Percentile (Maximum)	1,474,500

Other spills may potentially occur from offshore operations, including spills of diesel from vessels and MODUs, as shown in Tables 54 and 55.

Table 54: Summary Expected Volume Percentile for Project MODU Batch Spills

Percentile Spill Volume	Volume (bbl)[112]
0 Percentile (Minimum)	1
10th Percentile	1.5
20th Percentile	3
30th Percentile	3.5
40th Percentile	4
50th Percentile	5
60th Percentile	6
70th Percentile	10
80th Percentile	15
90th Percentile	47
95th Percentile	100
100th Percentile (Maximum)	643

Table 55: Probabilities of Project Batch Spillage by Volume Category

Volume Category	Probability		Return Period (years)
	1-Year	5-Year	
Small (< 1 bbl)	3.4	16.8	0.3
Small/Moderate (1 – 10 bbl)	0.02439	0.12194	41
Moderate/Large (100 – 1,000 bbl)	0.00124	0.00620	806
Large (1,000 – 10,000 bbl)	0.00006	0.00031	16,129
Very Large (10,000 – 150,000 bbl)	0.00001	0.00006	80,645
Extremely Large (>150,000 bbl)	0	0	n/a

Another potential type of spill from offshore exploratory operations involves synthetic-based mud (SBM), as shown in Tables 56 and 57.

[112] Spills under 1 bbl not recorded.

Table 56: Summary Expected Volume Percentile for Project SBM Spills	
Percentile Spill Volume	**Volume (bbl)**
0 Percentile (Minimum)	0.001
10th Percentile	0.005
20th Percentile	0.007
30th Percentile	0.009
40th Percentile	0.01
50th Percentile	0.09
60th Percentile	0.1
70th Percentile	0.5
80th Percentile	0.07
90th Percentile	1
95th Percentile	500
100th Percentile (Maximum)	3,600

Table 57: Probabilities of Project SBM Spillage by Volume Category			
Volume Category	**Probability**		**Return Period (years)**
	1-Year	**5-Year**	
Small (< 1 bbl)	0.01116	0.05580	90
Moderate (1 – 1,000 bbl)	0.00062	0.00310	1,613
Large (1,000 – 10,000 bbl)	0.00012	0.00062	8,065
Very Large (10,000 – 150,000 bbl)	0	0	n/a
Extremely Large (>150,000 bbl)	0	0	n/a

The estimated probabilities of the specific spill volumes associated with the modelled scenarios are shown in Table 58.

Table 58: Probabilities of Project Scenario Spillage			
Scenario	**Volume (bbl)**	**Probability**	**Return Period (years)**
Batch Spill-10 bbl	**10 bbl**	0.121940	41
Batch Spill-100 bbl	**100 bbl**	0.006200	806
SBM Spill-1	**377.4 bbl**	0.004960	1,008
SBM Spill-2	**3,604.2 bbl**	0.000620	8,065
Spill (Site-1) Blowout	**1,474,500 bbl**	0.000054	18,392
Spill (Site-2) Blowout	**747,000 bbl**	0.000270	3,678

Overall, the probabilities of spillage are very low and if spillage does occur, the spill volumes are likely to be relatively small.

In addition to anthropogenic inputs from spills, urban runoff, and vessel and facility operations, natural seepage may also contribute to overall hydrocarbon inputs in the region. Several natural seeps have been identified in the region, though there are no quantifications of annual inputs from this source.

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Appendix A: Probability Modelling Methodology

Fault Tree Analysis Methodology

The probability of a failure event is typically dependent on a constant failure rate, λ, and the exposure time, *t*, as in equations 2 and 3:

[2]
$$P = 1 - \exp(-\lambda t)$$

[3]
$$P \approx \lambda t, \lambda t < 0.1$$

The probabilities can be calculated as the incident rate of the scenario on an annual basis. This can then be calculated as the probability of the scenario occurring over the course of a longer period of time, such as over the course of 20 to 30 years, as in Equation 4. The incident rates can also be expressed in "return years" (*RY*), which is the amount of time (in years) that it would generally take for the incident to occur once, as in Equation 5.

[4]
$$P(event)_t = \frac{N_{event}}{t}$$

[5]
$$RY = \frac{1}{N_{event}}, t = 1 year$$

The series of event probabilities is analyzed by means of a "fault tree", which is based on Boolean logic, i.e., a statement (e.g., "There was an oil spill," or "a blowout occurred.") is either true or false, except that there are also probabilities associated with the "true" and "false" determinations. The fault tree combines a series of lower-level failure events to determine the likelihood of a "system failure". With the exploration wells and drilling process, the system functions properly when there is no spillage. That is, there are no errors or other precipitating events that could potentially cause a spill or blowout to occur. If one of the components of the system "fails", there is the possibility of oil spillage.

In a simple fault tree, there are events that have probabilities of occurrence (Figure A-1).

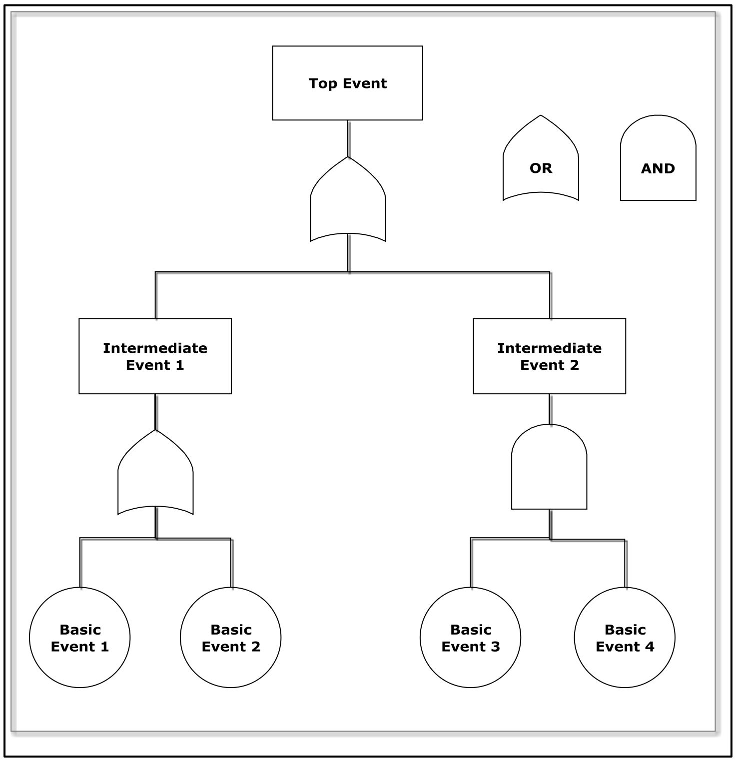

Figure A-1: Basic Fault Tree Design

The probabilities of a series of events occurring are characterized by "gates" that represent whether two or more events are all required for the failure to occur ("AND" gate), or if the events independently can cause the failure to occur ("OR" gate). The probability that both events occur is the product of the probabilities of the two events, as in Equation 6.

[6] $$P(AandB) = P(A \cap B) = P(A) \cdot P(\mathrm{B})$$

The probability that two independent events occur to cause a failure ("or" gate) is represented by equations 7 and 8:

[7] $$P(AorB) = P(A \cup B) = P(A) + P(B) - P(A \cap B)$$

[8] $$P(AorB) = P(A) + P(B), \mathrm{P(A \cap B)} \approx 0$$

The probabilities of the output event of the OR- and AND-gates are calculated according to the equations below, where P_i is the probability of the input events (i) to the gates, as in Equations 9 and 10.

[9] $$P_{occurrenceOR} = 1 - \prod_i (1 - P_i)$$

[10]

$$P_{occurrenceAND} = \prod_i P_i$$

Monte Carlo Simulation Methodology

Given that there is some uncertainty and variability in the probabilities that are incorporated into the fault tree analysis, an additional step of Bayesian statistical approach needs to be added. Bayesian statistical methodologies take into account the variability and distributions of inputs as opposed to point values for probabilities. A Monte Carlo simulation[114] can be used to incorporate variable inputs into a basic fault tree analysis, as in Figure A-2.

The Monte Carlo simulation was applied using Decisioneering Oracle Crystal Ball® software. This allowed for incorporation of variable probabilities for each of the series of events to determine the overall probability of each of the spillage scenarios.

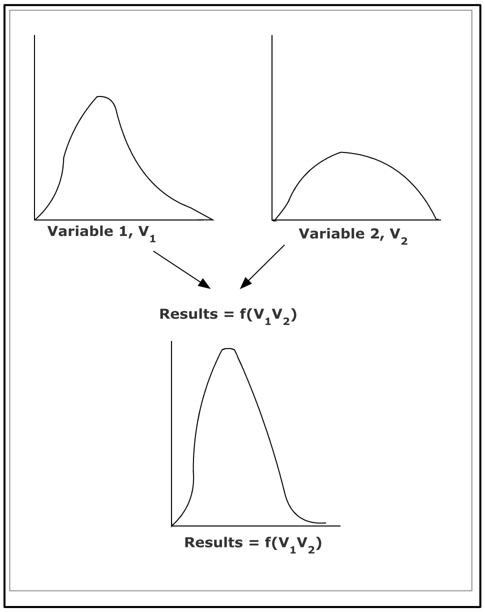

Figure A-2: Monte Carlo Simulation Basis[115]

Fault Tree Design for Project Analysis

The probability of a spill from the exploratory wells in the Project depend on a series of probabilities as outlined in the fault tree in Figure A-3 and described in Table A-1. In addition to the probability of events, for each spillage event there is a probability distribution function of spill volumes applied in the Monte Carlo Simulation. For the blowout events, the volume is determined by the multiplication of the flow rate and the duration of flow. For non-blowout well releases, there is a simple distribution of volumes applied.

[114] Monte Carlo simulation is a problem solving technique used to approximate the probability of certain outcomes by running multiple trial runs, called simulations, using random variables.
[115] Uncertainties of input variables are included in the result which is a function of v1 and v2.

For the variables in Table A-1 for which there are ranges or distributions of values, the values are based on the low to high estimates derived from the references cited. This applies a measure of variability and uncertainty in the estimates. In other words, one cannot be certain of the exact value of probability to apply for Shell's Project, because past studies are based on exploratory wells and projects in other locations that may have somewhat different circumstances than would be applicable to the Project. And given that there is no direct historical record of incidents for the Project, applying a range of possible values represents the potential error in the estimation process.

Table A-1: Variables in Fault Tree Analysis for Project Well Spill Probability Analysis

Variable	Assumed Value(s)	Basis/Reference	Distribution Type[116]
Exploratory Drilling Well[117]	7 wells	Shell Canada/Stantec 2013	Discrete value
Exploration Time Period	5 years	Shell Canada/Stantec 2013	Discrete value
Non-Blowout Release Causal Event Probability	1.3×10^{-4} to 3.9×10^{-4} per well	Table 25 (based on data in Holand 2013)	Uniform
Blowout Causal Event Probability	1.23×10^{-4} to 5.1×10^{-3} per well	Tables 18, 20, 21, 22, 23, and 25 (Holand 2013; Bercha 2010; SL Ross 1998; Imperial Oil Resources Ventures Limited. 2013; Dyb et al. 2012.)	Uniform
Non-Blowout No-Spillage Probability[118]	0.59	Scandpower 2006; OGP 2010	Discrete value
Non-Blowout Spillage Probability	0.41	Scandpower 2006; OGP 2010	Discrete value
Blowout No-Spillage Probability[119]	0.59	Scandpower 2006; OGP 2010	Discrete value
Blowout Spillage Probability	0.41	Scandpower 2006; OGP 2010	Discrete value

[116] Variable distribution for application in Monte Carlo analysis. A normal distribution is one in which the mean value is the most likely. The distribution is symmetrical around the mean. A value is more likely to be closer to the mean than further away from it. A log-normal distribution is one in which the upper value is unlimited but values cannot fall below zero. The natural logarithm of the distribution is a normal distribution. The distribution is positively skewed with most values near the lower limit. An extreme value distribution describes the largest value of a response over time. This is typically used to describe earthquake and flooding events. An exponential distribution describes the distribution of times between events that occur randomly. Each event is independent of the previous events. A Weibull distribution is a slightly positively skewed normal distribution. This type of distribution is typically applied for failure time in a reliability study (e.g., corrosion). A uniform distribution has equal likelihood for all values in the designated range.
[117] The exploratory drilling well number and exploration time period are required for determining the well-years and final expected values and distributions of spillage over the exploratory time period.
[118] Non-blowout no-spillage probability is based on probability that there will only be gas flow rather than oil spillage.
[119] Blowout no-spillage probability is based on probability that there will only be gas flow rather than oil spillage.

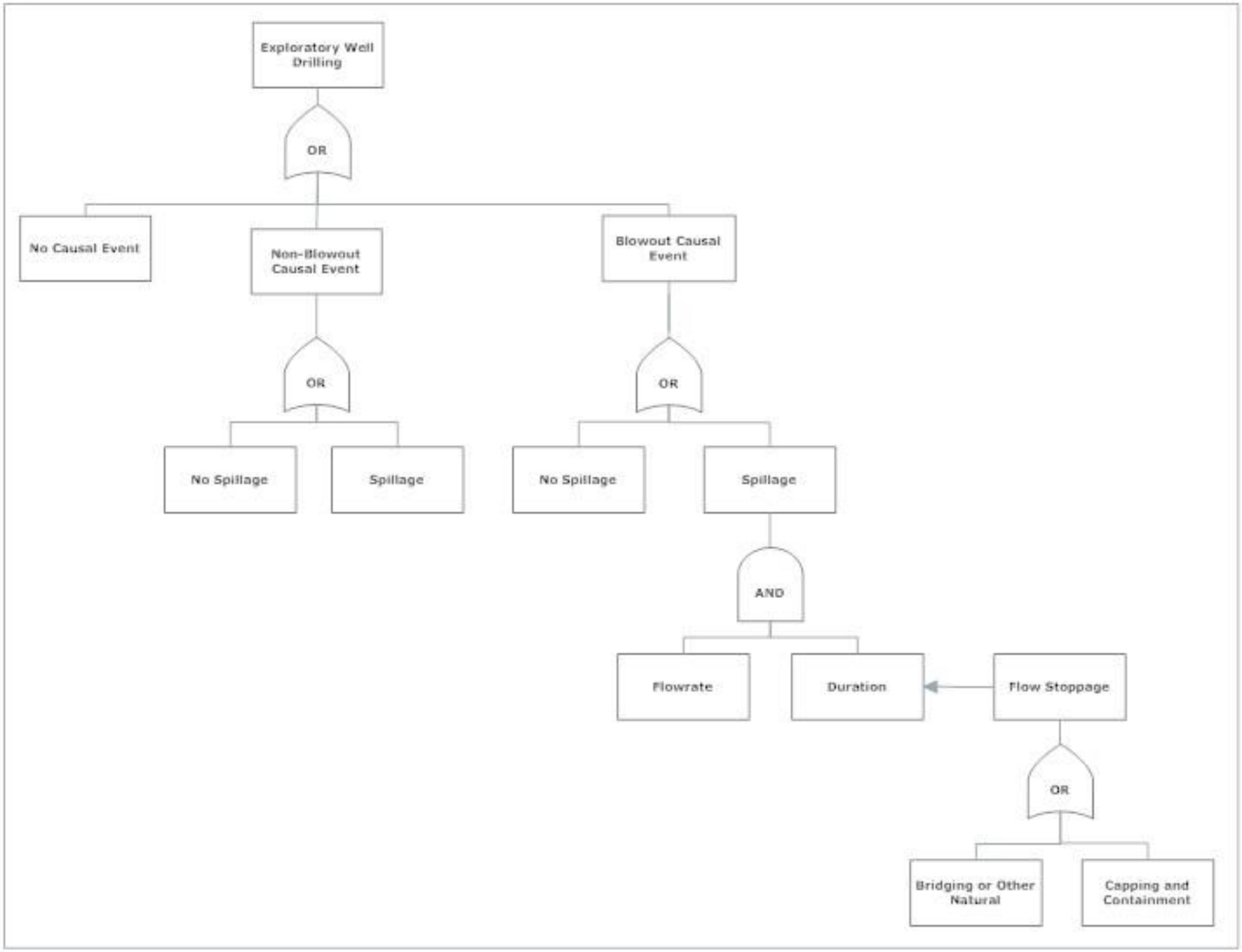

Figure A-3: Basic Fault Tree for Shelburne Blowout Probability Analysis

Monte Carlo Forecast Model Simulation Results for Shelburne Project

The probability equation applied in the Monte Carlo forecast model[120] to determine the likelihood of spills was in Equation 11:

$$P_s = (P_{nbe} \cdot P_{nbs}) + (P_{be} \cdot P_{bs}) \quad [11]$$

Where, P_s = probability of spill

P_{nbe} = probability of non-blowout event

P_{nbs} = probability of non-blowout oil spillage given event

P_{be} = probability of blowout event

P_{bs} = probability of oil spillage given blowout event

This only determined the likelihood that there would be a well-related spill of any kind. The probability distribution of volumes was calculated separately.

Spill Volume Distribution Modelling

The distribution of spill volumes was based on the flow rate and the duration of flow with probabilities for different types of events (blowout or non-blowout release) based on the previous modelling results and inputs. Table A-2 shows the assumptions and inputs for the modelling of the spill volume distributions.

Table A-2: Variables for Exploratory Well Spill Volume Distribution Simulation

Variable	Assumed Value(s)	Basis/Reference	Distribution Type[121]
Non-Blowout Spill Volume	0.000001 – 100 bbl	Table 12 and Figure 9 (CNSOPB data)	Log-Normal
Blowout Flowrate	100 – 49,150 bbl/day	Maximum based on Shell Canada/Stantec 2013	Log-Normal
Blowout Bridging Time[122]	0.02 – 5 days	Holand 2013.	Weibull
Blowout Capping/Containment Time	5 – 30 days	Dyb et al. 2012	Weibull
Blowout Bridging Probability	0.55	Holand 2013	Discrete value
Blowout Capping/Containment Probability	0.45	Holand 2013	Discrete value

[120] 1,000 simulations were run.

[121] Variable distribution for application in Monte Carlo analysis. A normal distribution is one in which the mean value is the most likely. The distribution is symmetrical around the mean. A value is more likely to be closer to the mean than further away from it. A log-normal distribution is one in which the upper value is unlimited but values cannot fall below zero. The natural logarithm of the distribution is a normal distribution. The distribution is positively skewed with most values near the lower limit. An extreme value distribution describes the largest value of a response over time. This is typically used to describe earthquake and flooding events. An exponential distribution describes the distribution of times between events that occur randomly. Each event is independent of the previous events. A Weibull distribution is a slightly positively skewed normal distribution. This type of distribution is typically applied for failure time in a reliability study (e.g., corrosion). A uniform distribution has equal likelihood for all values in the designated range.

[122] It is assumed that any well that stops flowing within 5 days has not been stopped by a containment cap or relief well.

The distribution of spill volumes for blowouts was developed through a Monte Carlo forecast model[123] applying Equation 12:

[12] $$V_s = F \cdot t_s$$

Where, V_s = volume of spill (in bbl)

F = flowrate (in bbl/day)

t_s = duration of flow (in days) for stoppage method, s[124]

s = bridging (*br*) or capping/containment (*c*)

[123] 100,000 simulations were run for volume forecasts.

[124] Stoppage method is either natural bridging or capping and containment. Relief wells are not considered an appropriate or necessary intervention measure.