Stantec

Stantec Consulting Ltd.
607 Torbay Road
St. John's, NL A1A 4Y6
Tel: (709) 576-1458
Fax: (709) 576-2126

Environmental Assessment of the Old Harry Prospect Exploration Drilling Program

Report Prepared for:

Corridor Resources Inc.
#301-5745 Spring Garden Road
Halifax, NS B3J 3T2

File: 121510468.500

February 2013

EXECUTIVE SUMMARY

This environmental assessment presents information on the proposed exploration drilling program, as proposed by Corridor Resources Inc. The proposed program would be conducted offshore western Newfoundland within the Laurentian Channel on the Old Harry Prospect, within Exploration Licence (EL) 1105. The Old Harry Prospect is located in the northeastern part of the Gulf of St. Lawrence (Gulf). Part of the prospect lies within waters under the jurisdiction of the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB), and the other part where a joint agreement between Quebec and Canada has recently been established. The proposed exploration well is located in lands administered by the C-NLOPB.

A description of the proposed program and the existing physical, biological and socio-economic environments is included. Valued Environmental Components (VECs) were identified to focus the environmental effects analysis. The VECs selected for this assessment were:

- Species at Risk;
- Marine Ecosystem;
- Marine Fish, Shellfish, and Habitat;
- Marine Birds;
- Marine Mammals and Sea Turtles;
- Sensitive Areas; and
- Commercial Fisheries and Other Users.

This environmental assessment includes consideration of the environmental effects of the proposed exploration well on each of the VECs, including the potential environmental effects of planned activities and potential unplanned (*e.g.*, accidental) events. It also considers potential cumulative environmental effects. Mitigation measures that are technically and economically feasible have been incorporated into the program design and planning. Monitoring programs are considered where appropriate. Provisions of relevant legislation and guidelines (*e.g.*, *Offshore Waste Treatment Guidelines* (National Energy Board *et al.* 2010)) have been identified and incorporated into the proposed exploration drilling program.

The environmental assessment predicts that no significant residual adverse environmental effects, including cumulative environmental effects, are likely to occur as a result of the Project.

Table of Contents

LIST OF APPENDICES

APPENDIX A Corridor Resources Inc. Old Harry Prospect Exploration Drilling Scoping Document

APPENDIX B Disposition Table of Regulatory Information Requests and Responses

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND UNITS OF MEASUREMENT

Acronym	Definition
2-D	Two-dimension
3-D	Three-dimension
AZMP	Atlantic Zone Monitoring Program
BOP	Blow-out preventer
BSF	Below seafloor
CAPP	Canadian Association of Petroleum Producers
CEAA	Canadian Environmental Assessment Act
CEA Agency	Canadian Environmental Assessment Agency
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CNSOPB	Canada-Nova Scotia Offshore Petroleum Board
Corridor	Corridor Resources Inc., the Operator
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CWS	Canadian Wildlife Service
DFO	Fisheries and Oceans Canada
DP	Dynamically-positioned
EBSA	Ecologically and Biologically Significant Area
ECSAS	Eastern Canadian Seabirds at Sea
EL	Exploration Licence
FEZ	Fisheries Exclusion Zone
FFAW	Fish, Food and Allied Workers
GOM	US Gulf of Mexico
HC	Hydrocarbon
HI	Hydrogen Index
HSE	Health, Safety and Environment
IBA	Important Bird Area
LOMA	Large Ocean Management Area
MAKMA	Mi'kmaq Alsumk Mowimsikik Koqoey Association
MODU	Mobile offshore drilling unit
MPA	Marine Protected Area
NAFO	Northwest Atlantic Fisheries Organization
NEB	National Energy Board
NMFS	United States National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OBIS	Ocean Biogeographic Information System
OCS	US Outer Continental Shelf
OWTG	Offshore Waste Treatment Guidelines
PIROP	Programme Integre de Recherches sur les Oiseaux Pelagiques
RV	Research vessel
SARA	*Species at Risk Act*
SBM	Synthetic-based mud
SEA	Strategic environmental assessment
SFA	Salmon Fishing Area
SLGO	St. Lawrence Global Observatory
TAC	Total allowable catch
TOC	Total organic carbon
The Gulf	The Gulf of St. Lawrence
VEC	Valued environmental component

VSP	Vertical seismic profile
WBM	Water-based mud

Symbol	**Unit of Measurement**
10^2	hundred
10^6	million
°C	degree Celsius
bopd	Barrels of oil per day
cm	centimetre
dB	decibel
g/kg	gram per kilogram
ha	hectare
Hz	Hertz
in^3	cubic inch
kg	kilogram
kHz	kilohertz
km	kilometre
km^2	square kilometre
km^3	cubic kilometre
L	litre
m	metre
m^2	square metre
m^3	cubic metre
m BSF	metres below seafloor
mg/kg	milligram per kilogram
mm	millimetre
MT	metric tonne
psi	pounds per square inch
t	metric tonne

1.0 INTRODUCTION

Corridor Resources Inc. (Corridor) is proposing to conduct one exploration well on the Old Harry prospect in the Gulf of St. Lawrence (Gulf) (Figure 1.1). The exploration well will be located within Exploration Licence (EL) 1105.

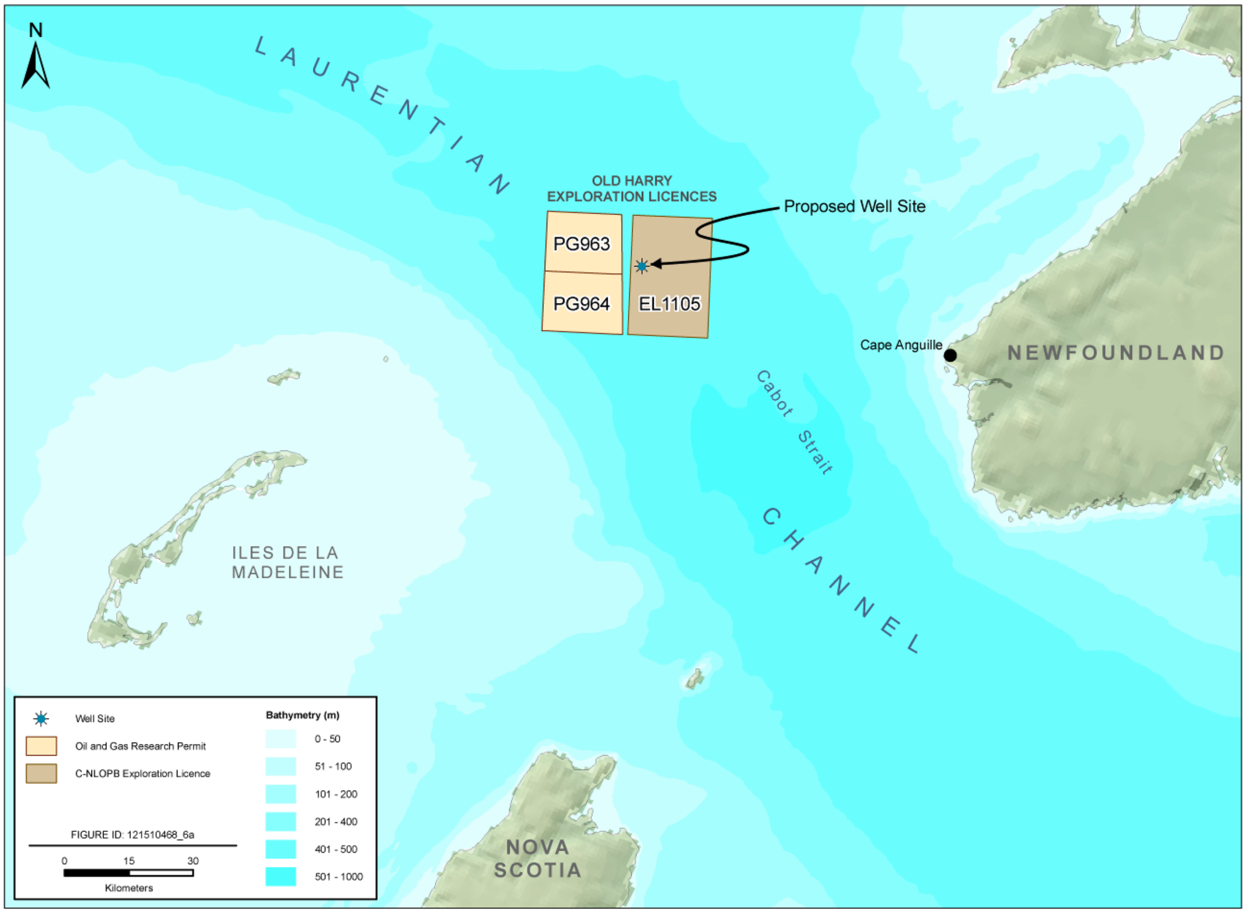


Figure 1.1 Location of Exploration Licence 1105 and Quebec Licences PG963 and PG964 Covering the Old Harry Prospect

The purpose of the exploration well is to obtain information that will assist Corridor in the ongoing evaluation of the hydrocarbon potential of the Old Harry prospect.

1.1 Project Overview

The official name of the Project is the Drilling of an Exploration Well on the Old Harry Prospect – EL 1105. EL 1105 is located in the Laurentian Channel portion of the Gulf, approximately 80 km west-northwest of Cape Anguille, Newfoundland and Labrador.

Corridor anticipates drilling one exploration well in EL 1105 on the western side of the licence, as illustrated in Figure 1.1. Depending on exploration drilling results, a decision will be made with respect to well testing. The drilling and testing program will be conducted in accordance with all Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) regulations and guidelines.

The information obtained from this well will assist Corridor in the ongoing evaluation of the hydrocarbon potential of the Old Harry prospect. This is an undrilled prospect and a well is required to confirm the hydrocarbon potential. If this exploration well provides encouraging results, a follow-up program may be developed and could include additional seismic or subsequent wells within EL 1105 or Corridor's other Old Harry Oil and Gas Research Permits. These activities, if conducted, would be covered under a separate regulatory process. This environmental assessment addresses the drilling of one well on EL 1105. The well is anticipated to take between 20 to 50 days to drill. A testing program could take up to several additional weeks on location depending on the geological and operational requirements.

The mobile offshore drilling unit (MODU) to be used for the exploration well is under consideration and could be a semi-submersible drilling rig or a drill ship. The MODU will be supported by a number of supply vessels and offshore helicopters. Vertical seismic profiling (VSP) activities may also be conducted in conjunction with the drilling activities.

1.2 The Proponent

Corridor, an Eastern Canadian company, is engaged in the exploration for and development and production of petroleum and natural gas resources onshore in New Brunswick and Quebec, and offshore in the Gulf. The company is headquartered in Halifax, Nova Scotia, with a production office for its McCully Field operations in Penobsquis, New Brunswick. Corridor has been producing natural gas from the McCully Field since 2003. In June 2007, following construction of a field gathering system, a gas plant and a pipeline lateral, the McCully Field was connected to markets through the Maritimes and Northeast Pipeline. Corridor safely and successfully conducted seismic programs at Old Harry in 1998 and 2002, a seismic program offshore west coast Cape Breton in 2003 and a geohazard survey at the Old Harry site in the fall of 2010.

Operator contacts for this Project are:

Dena Murphy
Quality, Health, Safety &
Environment Manager
Direct: (902) 406-8011
E-mail: dmurphy@corridor.ca

Paul Durling
Chief Geophysicist
Direct: (902) 406-8007
E-mail: pdurling@corridor.ca

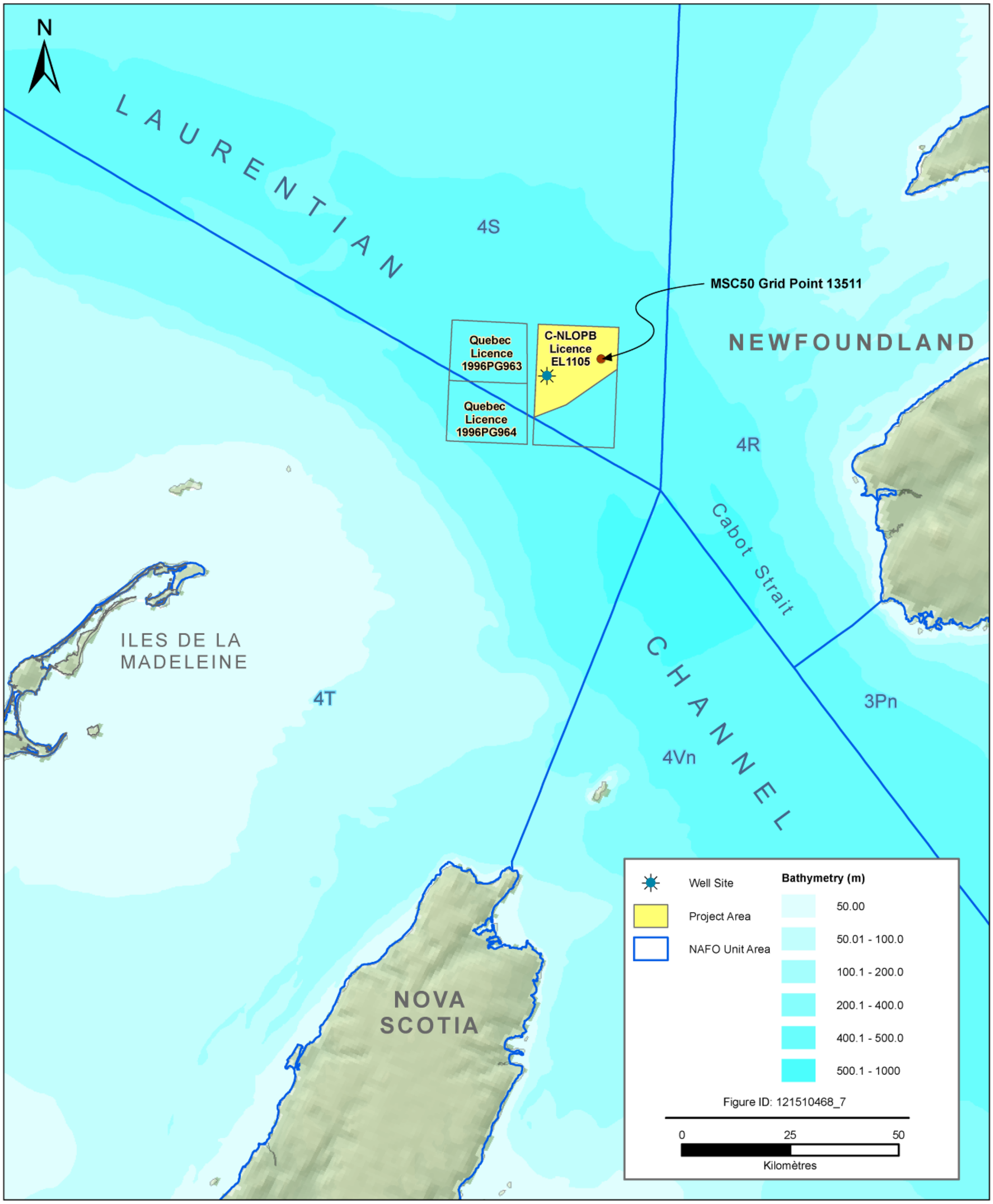


Figure 1.2 Old Harry Prospect Project Area

1.3 Regulatory Context

This exploration well occurs within EL 1105. Therefore, the activities associated with the exploration well will occur within the jurisdiction of the C-NLOPB.

The Project will require authorizations pursuant to Section 138(1)(b) of the *Canada-Newfoundland Atlantic Accord Implementation Act* and Section 134(1)(a) of the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act*, collectively known as the Accord Acts. A screening level environmental assessment pursuant to the *Canadian Environmental Assessment Act* (CEAA) was initiated on February 25, 2011 with the C-NLOPB as the Responsible Authority and Federal Environmental Assessment Coordinator. Federal Authorities involved in the review include Fisheries and Oceans Canada (DFO), Environment Canada (EC), and Department of National Defence (DND), all of whom have broad knowledge of the Gulf and have provided comment and direction on both the Scoping Document (C-NLOPB 2011a) and the environmental assessment. On July 6, 2012, CEAA was repealed when the *Canadian Environmental Assessment Act, 2012* (CEAA 2012) came into effect. However, as a designated project under CEAA 2012, the environmental assessment review of the Old Harry Project will continue under the previous CEAA as if it had not been repealed.

Prior to the issuance of EL 1105 to Corridor, the C-NLOPB commissioned a Strategic Environmental Assessment (SEA) of the Western Newfoundland Offshore Area (LGL 2005a) and an amendment area (including the Old Harry prospect) (LGL 2007), which included consultation with federal agencies and other stakeholders. On August 15, 2011, the federal Minister of the Environment requested an update of the 2007 SEA for the Western Newfoundland Offshore Area. The C-NLOPB has established a working group to oversee the process of updating the SEA for the Western Newfoundland Offshore Area and this process is well underway, with public consultation having been initiated in the summer of 2012 and a draft SEA report expected for public review in early spring 2013. This process will address broader policy issues associated with exploration activity in the Western Newfoundland Offshore Area.

Legislation that is relevant to the environmental aspects of this Project includes:

- the Accord Acts;
- *CEAA;*
- *Oceans Act;*
- *Fisheries Act;*
- *Navigable Waters Protection Act;*
- *Canada Shipping Act;*
- *Species at Risk Act (SARA);*
- *Migratory Birds Convention Act;* and
- *Canadian Environmental Protection Act.*

There is no federal funding of this Project. EL 1105 is administered by the C-NLOPB.

A finalized Scoping Document was issued by the C-NLOPB (with input from other regulatory agencies and the public) on August 17, 2011 (Appendix A). A screening-level environmental assessment was completed to fulfill the requirements of CEAA and the Scoping Document and submitted to the C-NLOPB on December 20, 2011. Comments were received from Federal Authorities during a regulatory review of the environmental assessment and have been addressed in this updated version of the environmental assessment. A disposition table of comments and responses is provided in Appendix B.

1.4 Rationale for the Project

The long-term goals of the Operator are to:

- conduct a safe and environmentally responsible exploration drilling program on the Old Harry prospect while meeting or exceeding all due diligence requirements;
- undertake the drilling of the Old Harry exploration well through the implementation of industry best practices and adherence to all applicable regulatory requirements and authorization conditions;
- establish and maintain positive relationships with regulators, other stakeholders, suppliers and contractors;
- explore and discover new oil and gas fields in Eastern Canada;
- create long-term benefits and enhance the energy infrastructure for Newfoundland and Labrador and the whole Eastern Canadian region; and
- execute a cost-effective program by phasing capital investment and carefully planning all aspects of the Project.

1.5 Document Organization

The environmental assessment is organized as follows:

- Section 1 introduces the project, proponent, regulatory context and rationale for the Project;
- Section 2 provides a description of the components of the proposed Project;
- Section 3 details the consultation conducted as part of the proposed Project;
- Section 4 describes the existing physical (geology, meteorology / oceanography and sea ice and icebergs) environment setting;
- Section 5 describes the existing biological (species at risk, fish and fish habitat, marine birds, marine mammals and sea turtles, special areas and commercial fisheries and other users) environment setting;
- Section 6 details the methodology used to conduct the environmental effects assessment;
- Section 7 is the environmental effects assessment;
- Section 8 is the accidental events environmental effects assessment;
- Section 9 is the cumulative environmental effects assessment;
- Section 10 provides a summary of the residual adverse environmental effects;
- Section 11 addresses monitoring and follow-up;
- Section 12 describes the potential effects of the environment on the Project;

- Section 13 describes the environmental management for this Project;
- Section 14 provides an overall summary and conclusion; and
- Section 15 provides literature cited in the preparation of the environmental assessment.

2.0 DESCRIPTION OF THE PROJECT

2.1 Background of the Project

The Old Harry Prospect is a large, doubly plunging anticline in the northeastern part of the Gulf approximately 30 km long and 12 km wide.

The southern Gulf is underlain by a large sedimentary basin that is up to 12 km deep and contains all of the necessary components for a viable petroleum system. The basin contains abundant sandstone reservoir rocks, shale and coal for hydrocarbon source rock and numerous geological structures for potential trapping of hydrocarbons. A recent petroleum resource assessment by the Geological Survey of Canada (Lavoie *et al.* 2009) estimates 39 trillion cubic feet of in-place natural gas and 1.5 billion barrels of in-place oil for the Maritimes Basin, which covers the southern Gulf and adjacent areas. These petroleum resource estimates were made, in part, through the analysis of previously drilled offshore wells in the Gulf.

2.2 History of Hydrocarbon Exploration in the Gulf of St. Lawrence

There is a long history of hydrocarbon exploration in the Gulf, starting with the first offshore exploration well drilled by the Island Development Company in Hillsborough Bay, Prince Edward Island, in 1944. Since that first well was drilled, nine more offshore wells were drilled and thousands of kilometres of seismic data were acquired (Table 2.1). The locations of the previous wells drilled and seismic programs conducted are shown in Figure 2.1. This extensive database of existing seismic and well information highlights the exploration potential of this area.

Table 2.1 Offshore Wells Drilled in the Gulf of St. Lawrence

#	Well	Year Drilled	Total Depth (m)
1	Hillsborough No.1	1944	4,479
2	Northumberland Strait F-25	1970	3,001
3	Cable Head E-95	1983	3,235
4	Beaton Point F-70	1980	1,734
5	East Point E-49	1974	3,526
6	East Point E-47	1980	2,662
7	St. Paul P-91	1983	2,885
8	Cap Rouge F-52	1973	5,059
9	Bradelle L-49	1973	4,421
10	St. George's Bay A-36	1996	3,240
Refer to Figure 2.1.			

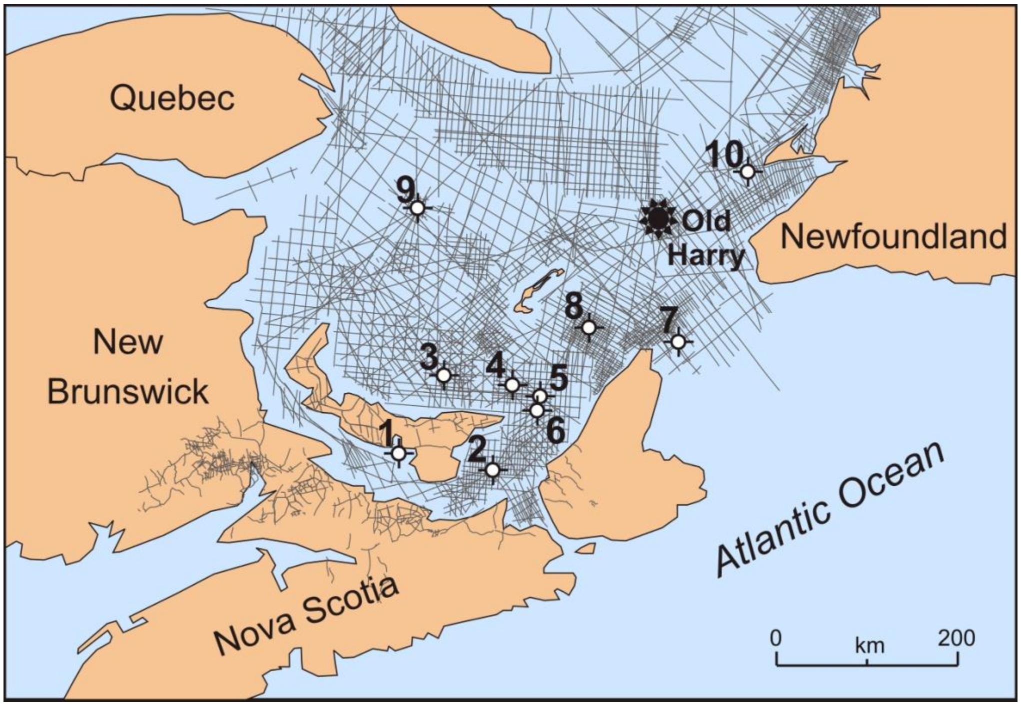


Figure 2.1 Location of Seismic Programs and Wells in the Gulf of St. Lawrence

Most of the offshore wells were drilled in the 1970s and early 1980s (see Table 2.1). At that time, the petroleum companies were seeking oil deposits, whereas the drilling results in the Gulf yielded indications of natural gas. Of the offshore wells drilled, five yielded no hydrocarbon shows, four had minor natural gas shows, and one well (East Point E-49) was reported as a significant natural gas discovery. A subsequent delineation well at this site (East Point E-47) was unsuccessful and only yielded minor hydrocarbon shows. The most recent drilling in the Gulf occurred in 1996 at the Bay St. George A-36 well. This well was located about 10 km southwest of Cape George and about 120 km northeast of the Old Harry prospect. This well was unsuccessful and was subsequently abandoned.

The southern Gulf is an extremely large area, spanning approximately 600 km in an east-west direction and 300 to 400 km north to south. However, only 10 offshore wells have been drilled in this vast, under-explored area, where the Old Harry prospect is just one of many geological structures with hydrocarbon exploration potential. The results of the 10 offshore wells indicate the presence of a viable petroleum system on the Old Harry prospect. Corridor previously completed an extensive work program at Old Harry to identify a well location, including the collection of 2-D seismic data in 1998 and 2002, as well as a geohazard site survey in October, 2010. Old Harry has multiple drilling targets, the potential for large hydrocarbon resources, and, if results from the exploration well are promising and lead to further activity, the potential to generate substantial economic benefits in Newfoundland and Labrador and the entire Eastern Canadian region.

2.3 Type of Oil Likely to be Found at Old Harry

Ten offshore wells have been drilled to date in the Gulf, an area encompassing approximately 140,000 km^2. Half of those wells encountered non-commercial quantities of natural gas and, with respect to oil, none encountered anything more than oil staining. For reasonable and appropriate oil spill modelling, an oil sample is required to determine the necessary oil properties (*e.g.*, density, viscosity, pour point). Since an oil sample is not available from the Old Harry structure to determine its properties, identification of a suitable surrogate oil is required.

The issue of identifying a suitable surrogate oil was remedied by applying a sequential scientific approach. First, Corridor undertook geochemical studies to identify the types and relative abundance of organic material that is preserved in the shale source rocks in the vicinity of Old Harry. This was followed by petroleum systems modelling to simulate the burial, maturation and generation of hydrocarbons from the organic material, followed by migration and trapping of hydrocarbons at Old Harry. Finally, the geological characteristics of the Old Harry area were compared to other areas with similar geological characteristics to identify a suitable surrogate for the hydrocarbons potentially trapped at Old Harry.

2.3.1 Geochemical Studies of Old Harry Source Rocks

Corridor hired an independent world-renowned organic geochemistry consultant (Dr. Prasanta Mukhopadhyay of Global Geoenergy Research) to complete geochemical studies of rock samples from the source rocks in the Brion Island No. 1 well, which is the closest well to the Old Harry prospect; located approximately 70 km to the west. The geochemical studies included measurements of total organic carbon (TOC), hydrogen index (HI) values (from Rock-Eval pyrolysis) and thermal maturity (vitrinite reflectance and thermal alteration index values). In addition, a scanning organic facies assessment (manual examination and classification of organic material using a high-powered microscope) was completed to determine the type of organic material in the source rocks. The results of geochemical analyses for 16 rock samples from the Brion Island well are provided in Table 2.2.

The first two columns in Table 2.2 indicate the depth of the rock sample studied in either feet (column 1) or metres (column 2). Column 3 shows the thermal maturation data with values that range between 0.6 to 1.0 percent Ro and show an advanced stage of thermal maturation. These sediments fall within the present day main phase of oil (oil window) to early condensate generation (gas window; see column 11). Columns 4 and 5 show the main geochemical results of the TOC, the HI and the production index. The interpretation of the present day TOC (ranges from 0.34 to 1.60; column 4) and HI values (ranges from 7 to 123 mg hydrocarbon (HC)/g TOC; column 4) would typically indicate a moderately organic-rich gas-prone Type III kerogen that is likely to generate only natural gas. However, a more in-depth investigation into the type of organic facies deposited in the rocks reveals a more oil-prone organic material.

Table 2.2 Reconstruction of Original Total Organic Carbon and Hydrogen Index Based on Organic Facies, Present Total Organic Carbon/Rock-Eval and Production Indices of the Brion Island #1 Well

Depth (ft)	Depth (m)	% Ro (Mean)	Present TOC/HI	Prod. Index	Scanning Organic Facies Assessment (approximate percentages; qualitative determination)	SR condition	Original TOC/HI	Kerogen Type	Maturity	HC Zones
4080	1252	0.58	0.34/18	0.5	mixtures of 50% spore, suberin, algae; 50% vitrinite + inertinite	depleted	1.0/225	II-III	mature	oil
4410	1353	0.64	0.36/33	0.33	mixtures of 30% spore, suberin, algae; 70% vitrinite + inertinite	depleted	0.8/150	II-III	mature	oil
4990	1531	0.71	1.09/91	0.12	mixtures of mainly 40% suberin, spore; 65% vitrinite + inertinite	depleted	2.0/200	II-III	mature	oil
5060	1552	0.75	1.6/123	0.06	mixtures of 50% cuticles and algae; 50% vitrinite + inertinite	depleted	2.5/250-300	II-III	mature	oil
5500	1687	0.8	1.51/64	0.11	mixtures of 60% AOM 2, spore, resin, algae; 40% vitrinite + inertinite	depleted	3.0/250-300	II-III	mature	oil
5690	1746	0.86	1.03/67	0.14	50% exinite; 10% algae; 10% AOM 2; 30% vitrinite + inertinite	depleted	2.5/250	II-III	mature	oil
5770	1770	0.86	0.73/45	0.15	20% exinite; 5% algae; 5% AOM 2; 70% vitrinite + inertinite	depleted	2.0/150-200	II-III or III	mature	oil
5930	1819	0.84	1.54/68	0.1	70% exinite; 5% algae; 5% AOM 2; and 20% vitrinite + inertinite	depleted	2.5/250-300	II-III	mature	oil
6760	2074	0.92	0.95/73	0.12	60% exinite; 5% algae; 5% AOM 2; and 30% vitrinite + inertinite	depleted	2.5/250	II-III	mature	oil
7030	2156	0.93	1.16/42	0.08	40% exinite; 5% algae; 5% AOM 2; 40% vitrinite + inertinite; 10% bitumen	depleted	2/150-200	II-III	mature	oil
7300	2240	0.9	0.58/19	0.21	30% exinite; 25% AOM 2; 20% vitrinite + inertinite; 10% bitumen	exhausted	2/200-250	II-III	mature	oil
7410	2273	0.94	0.96/53	0.12	50% exinite; 10% algae+AOM 2; 30% vitrinite + inertinite; 10% bitumen	exhausted	2/200	II-III	mature	oil
8370	2568	0.94	0.60/13	0.27	30% exinite; 15% AOM 2; 1-5% algae; 44-40% vitrinite + inertinite; 10% bitumen	exhausted	2/200-250	II-III	mature	oil
8570	2629	1.02	0.55/22	0.37	30% exinite; 25% AOM 2; 5% algae; 30% vitrinite + inertinite; 10% bitumen	exhausted	2.0/200-250	II-III	mature	condensate
8710	2672	1.05	0.59/19	0.31	20% exinite; 15% AOM 2; 45% vitrinite + inertinite; and 20% bitumen	exhausted	2.5/250	II-III	mature	condensate
8890	2727	1.08	0.34/7	0.43	30% AOM 2; 10% algae; 10% exinite; 30% vitrinite + inertinite; 20% bitumen	exhausted	3/250-300	II-III	mature	condensate

% Ro = mean random vitrinite reflectance for autochthonous vitrinite grains (main maturity)
TOC: total organic carbon content in wt %; **HI** = hydrogen index in mg HC/g TOC determined from Rock=Eval Pyrolysis
Prod. Index = production index (ratio of S1 and C2 curves) determined by Rock-Eval pyrolysis
exinite = exine rich organic components includes spore (sporinite), cutin (cutinite), and suberin (suberinite) - various lipid components derived from plants
AOM 2 = amorphous organic matter type 2 variety that are oil prone
Bitumen = solid bitumen - a secondary hydrocarbon transformation products derived from primary macerals (phytoclasts)
Original TOC/HI = the original TOC and HI was calculated based on present day TOC and HI, production indices, and organic facies reconstruction

Column 6 in Table 2.2 shows the results of the scanning organic facies assessment. The majority of the organics were derived from a terrestrial source (exinites and vitrinites). Vitrinite is basically the woody portion of plants and is generally by far the most abundant organic material in terrestrially-derived source rocks. Vitrinite is gas-prone Type III organic matter. However, in some deltaic deposits such those identified at Old Harry, much less vitrinite is deposited and the terrestrial lipid (oil- and gas-prone) organic components (exinites) can be dominant. These terrestrial lipid components are mainly Type II-III suberinite (plant suberin), resinite (plant resin) and cutinite (plant cuticles). These types of organic material usually generate liquid hydrocarbons within C17 to C27 normal alkanes during the early stages of thermal maturity (oil window) and, like all organics, will generate natural gas at higher stages of thermal maturity (gas window).

Other less abundant organic material found in the Brion Island source rocks is Type II amorphous liptinite (biodegraded algae). Together, all of the organic material in the Brion Island well form a Type II-III condensate-, oil- and gas-prone source rock. The C30+ hydrocarbons (mainly wax and asphaltene components) that are usually present within the botryococcus type lacustrine algae are absent in the various source rocks in the Brion Island well. These data suggest that asphaltene or wax-rich heavy oil is very unlikely at Old Harry because of the organic facies (nature of the terrestrial lipids) of the major source rocks and their thermal maturity.

Given that these rocks are greater than 250 million years old, it is reasonable to expect that at least some hydrocarbons would have been generated over geologic time. This is confirmed by the high production index. The various geochemical and organic facies data were assessed to determine the present-day condition of the source rocks, and column 7 lists the source rock condition. The fluorescence characteristics of the source rocks in the Brion Island well indicate that they have been depleted in liquid hydrocarbons. In general, the source rocks from the Brion Island well are depleted of their hydrocarbon generation potential above approximately 2,200 m depth and those below 2,200 m are exhausted. Since these source rocks are depleted or exhausted, the original source rocks prior to burial and thermal maturation would have had higher TOC and HI values. Therefore, the original TOC and HI values were recalculated on the basis of maturity, present day TOC, HI and production index values, and the scanning organic facies data. The recalculated values are presented in column 8 of Table 2.2.

2.3.2 Petroleum Systems Modelling

The organic facies and geochemical data were integrated with the interpreted 2-D seismic reflection data to develop a series of 2-D Petroleum System Models of the Old Harry structure. The Petroleum System Modelling was completed using the PetroMod 2D modelling software (version 11.04; Patch 3) of IES GmbH, Aachen, Germany (currently of Schlumberger Incorporated). A key part of petroleum systems modelling involves determining the development of the Old Harry structure through geologic time, including the stratigraphy, burial history, heat flow, hydrocarbon migration paths and other geological and geochemical information. The modelling incorporated the following information:

- lithology for each stratigraphic unit based on the Brion Island well and 2-D seismic interpretation;

- timing of erosion, palaeowater depths, and palaeotemperature (through time) from biostratigraphic analysis;
- heat flow in relation to basement structures;
- the hydrocarbon reservoirs and seals in relation to the structure;
- organic richness of various source rock intervals and hydrocarbon potential (HI values in mg HC/g TOC);
- trends of palaeoheat flow, palaeowater depths, and palaeotemperatures;
- multi-component kinetics of selected default source rocks; and
- oil and gas properties for each individual source rock, based on compositional analysis using pyrolysis-gas chromatography (Mukhopadhyay 2006) and the PetroMod 2D software database.

The stratigraphy, timing of sediment deposition, erosion, salt migration, folding and faulting were determined based on the interpretation of 2-D seismic reflection profiles. The seismic data were correlated to the Brion Island well to facilitate the identification of source rocks, reservoir and shale seal rocks. The stratigraphic ages of the individual formations were determined using the International Geological Time Scale of Ogg *et al.* (2008) and Giles and Utting (2003).

The palaeowater depth and palaeowater temperatures for each formation were incorporated in the models. The thermal maturity data (vitrinite reflectance and thermal alteration index values) indicates that the majority of the source rocks from the Brion Island #1 well are between 0.6 to 1.0 percent Ro (column 3 in Table 2.2). The calibration of the heat flow model used the measured vitrinite reflectance data points and their corresponding trend as seen in the Brion Island well. The heat flow calibration was later corroborated by one measured bottomhole temperature and Apatite Fission Track analysis by Grist *et al.* (1995).

As described above, the original TOC and HI values were recalculated on the basis of maturity, present day TOC, HI and production index values and the scanning organic facies data. Based on the early oil generation potential as seen from the scanning organic facies data, a range of source rock kinetics were selected for modelling. The kinetics of a source rock describes the generation of hydrocarbons from the source rock during thermal maturation (*i.e.*, when hydrocarbons are generated, what volume and whether oil or gas is generated). Three different classes of modelling simulations were completed to test the range of hydrocarbons that could be generated at Old Harry:

a. IES Gmbh default kinetics of kerogen Type II-III Monterrey source rock and Taranaki Basin Type II-III source rock;
b. Mahakam Delta Type III kinetics and Taranaki Basin kerogen Type II-III kinetics; and
c. IES default kinetics of kerogen Type II-III Monterrey source rock and Taranaki Basin Type II-III; however, higher TOC and HI values were used for source rocks in the deep basin to the south of the Old Harry structure.

The results of this modelling indicate that, at the present stage of thermal maturation of the source rocks, the hydrocarbons within the Old Harry structure, if present, are likely to comprise a very light, 45 to 56° API gravity oil with low to moderate gas-oil ratio. In fact, none of the model simulations indicated that the gravity of the hydrocarbons would be less than 50° API; however, oils with an API gravity of 45 to 56° API were included as a conservative estimate of the range of predicted hydrocarbons at Old Harry.

Various input parameters for the models were modified for each simulation to assess the change in hydrocarbon composition and saturation in the Old Harry reservoirs. The API gravity of the modelled hydrocarbons for all model simulations consistently fell within a narrow range, indicating the robust model results irrespective of variations in TOC and HI. However, it should be noted that increases in Type III kerogen relative to Type II kerogen in the modelled source rocks tends to decrease the amount of liquid hydrocarbons (oil) and increase the amount of gas, while the API gravity of the hydrocarbon liquids remains within the modelled range.

Note that the modelling cannot confirm that a structure is trapping and therefore the structure may contain no hydrocarbons and only water. As well, if hydrocarbons migrate from deeper within the basin where the organics are in the gas window, the structure could potentially be filled with natural gas.

2.3.3 Identification of Surrogate Oil

Petroleum Systems Modelling identified the potential range of hydrocarbons that could be trapped at Old Harry and the next step was to identify an appropriate surrogate oil for use during oil spill modelling. Corridor considered geological parameters such as depositional environment, the type of organic material (kerogen) and types of hydrocarbons encountered in several areas. Although only natural gas has been encountered in offshore Gulf wells, high API gravity oils have been identified in Gaspé (47° API), Port-au-Port, Newfoundland (51° API) and the Scotian Shelf (47 to 52° API). Several characteristics of the geology in the Maritimes Basin (Old Harry area) compare favourably to the geological conditions encountered in the Scotian Basin. as shown in Table 2.3. The clastic reservoir rocks in the fields on the Scotian Shelf typically comprise fluvial and shallow marine, stacked, sandstone sequences that are analogous to the fluvial sandstone reservoir rocks at Old Harry. Of particular note is the known kerogen type in both basins is Types II-III and III. In addition, light oil was produced from the Cohasset / Panuke / Balmoral Fields on the Scotian Shelf (Kidston *et al.* 2005). Consequently, Corridor geoscientists have selected the Cohasset oil from the Scotian Basin as an appropriate surrogate for the oil that could be found at Old Harry.

Table 2.3 Comparison of Geologic Characteristics of the Maritimes and Scotian Basins

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

2.4 Location and Water Depth

The proposed Project Area is located approximately 80 km west-northwest of Cape Anguille, Newfoundland and Labrador (see Figure 1.1). The Project Area is located within a physiographic feature called the Laurentian Channel. Water depths in the area are approximately 470 m.

2.5 Alternatives to and Within the Project

The alternative to this Project is to not drill on EL 1105. However, Corridor has been awarded rights to explore on EL 1105 through a regulated competitive bidding process and seeks to fulfill its commitments made as a part of the licencing process within the remaining time window.

Alternate means to be evaluated within the Project include the use of a semi-submersible drilling rig or a drill ship, both of which are considered MODUs. A harsh-environment jack-up rig is typically limited to water depths of approximately 120 m off the east coast of Canada and therefore will not be considered within this Project. Additional information regarding MODUs is provided in Section 2.8.

Other alternatives to be considered will be the drilling program, selection and use of drilling fluids, supply base location, helicopter support base location, waste management and program timing. Selection of the alternatives for the program will be guided by a consideration of safety, environmental, technical, community and economic factors.

2.6 Project Scheduling

This well is anticipated to take between 20 to 50 days to drill, (including rig mobilization and demobilization and any weather delays, and will occur when there is no ice present in the Gulf (no earlier than March and no later than November). If testing is conducted, the rig will spend up to several additional weeks on location. The temporal scope of the environmental assessment is year round to allow flexibility in the event of an ice-free year. Corridor intends to drill one exploration well between 2014 and 2015, with the specific timing dependent upon rig availability and regulatory approvals. Although the Project Description indicates a drilling start date as potentially mid-2012, this date is no longer achievable due to several protracted regulatory processes applied to this screening-level environmental assessment, including the implementation and subsequent cancellation of the Independent Review Process by the C-NLOPB.

All activities in EL 1105 will be conducted in accordance with stringent oil and gas regulatory requirements for working offshore Newfoundland and Labrador.

2.7 Project Personnel

The Project will be managed out of an office in Newfoundland and Labrador where the Project Team will be located and key decisions will be made. The drilling activities will be managed by a Drilling Manager located in this office. The Drilling Manager will have the authority to effectively manage the operational aspects of the Project. Day-to-day drilling operations will be directed by the Operator's drilling superintendents. Offshore, the management team consists of the Senior Drilling Supervisors (Operator's offshore representative), the designated Offshore Installation Managers and Supply Vessel Masters.

2.8 Mobile Offshore Drilling Units

For this environmental assessment, it is necessary to describe and consider two MODU types because rig and contractor selection is still in progress. While there are differences among the rig types, drilling, testing, well abandonment / suspension and discharges and emissions considerations are similar.

Drilling may be conducted from an anchored semi-submersible, a dynamically-positioned (DP) semi-submersible rig or a DP drill ship. Rig selection will be based on the characteristics of the well site, physical environment, well site water depth, expected drilling depth, logistical considerations (*e.g.*, rig availability, market conditions), and the mobility required based on well site weather and ice conditions (Canadian Association of Petroleum Producers (CAPP) 2001a), as well as other safety and environmental performance criteria.

A semi-submersible is a MODU where the drilling platform sits atop steel pontoons that are ballasted with water so that the unit floats with the main deck above water and the remainder below the water surface. Semi-submersibles are towed to the drilling site and are either moored to the bottom (with a series of 8 to 16 anchors which may extend up to 1 to 2 km from the rig) or are kept on station using a DP system (computer-controlled thrusters) in deeper waters (300 to 3,000 m). The maximum water depth is a function of many rig design criteria, including the length of the rig's riser, the main pressure containing pipe that runs from the blow-out preventer (BOP) on the seafloor to the MODU and through which drilling fluids and other material are conducted.

A drill ship is a MODU where a maritime vessel has been fitted with a drilling platform and station-keeping equipment. The vessel transits to location on its own power and is usually kept on location through a DP system.

These MODUs (semi-submersible and drill ship (Figure 2.2) are self-contained units, with derrick and drilling equipment, a moon pool, a helicopter pad, fire and rescue equipment and crew quarters. The operations and discharges are similar for both drilling units. While there are differences between rig types with respect to capabilities, treatment facilities and effluent discharge depths, the characteristic volumes and types of waste streams are similar among drill units.

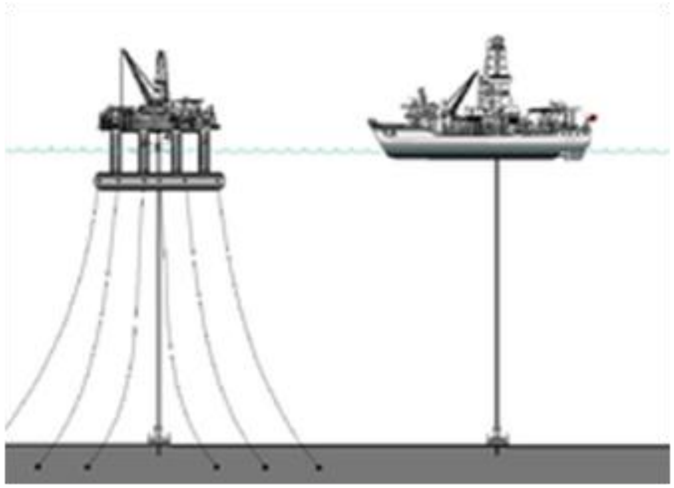


Figure 2.2 A Moored Semi-submersible and a Dynamically-positioned Drillship

2.9 Logistic Support

The Island of Newfoundland will be the base of operation and support centre for the Project. The Operator will engage a drill rig, supply vessels, helicopter and related goods and services on a direct hire or a contractual basis. To support these resources, the Operator will acquire marine support base, logistics and telecommunications services including, but not necessarily limited to, support vessels, meteorological and oceanographic services and emergency response services from third-party providers. All such goods and services will be acquired through a formal competitive process to the extent possible, which will be executed over a period of several months. The Operator will ensure that all selected contractors will meet the stringent competency requirements for working in the Newfoundland and Labrador offshore oil and gas sector.

2.9.1 Shorebase Facilities

The existing infrastructure and activity in Atlantic Canadian harbours enables the petroleum industry to optimize the use of supply vessels and other logistic assets. Existing facilities are capable of servicing multiple operations with the current infrastructure, including office space, crane support, bulk storage and consumable (fuel, water) storage and delivery capability. Additional harbours, which are not currently used by the industry but may be closer to the location of operations, will be investigated for suitability to supply the services necessary to support an offshore supply base. However, for a single exploration well, the main shorebase will likely be in St. John’s. There may be minor vessel traffic into Port aux Basques and/or Stephenville. The main helicopter shorebase will be in St. John’s with the potential for refuelling in Western Newfoundland (e.g., Port aux Basques and/or Stephenville). Warehouse facilities will be provided by third-party contractors as required and will consist primarily of storage for tubular goods and the equipment belonging to the drill rig, which can be stored onshore.

Operation and coordination service of all aeronautical and marine voice and data communication services will be provided from a central facility by a third-party contractor. The primary communications link between the drill rig and the Project Operations office will be via a dedicated satellite service. Independent backup communications systems will be provided by high quality high-frequency radio service, available through the coastal radio station.

2.9.2 Marine Support Vessels

Supply / standby vessels will be Canadian flagged and Canadian crewed and will be managed from the contractors' offices in Atlantic Canada. Letters of Compliance for each chartered supply / standby vessel will be in place prior to the onset of work. The vessels will be comparable to those presently operating on the Grand Banks in terms of power and capabilities. The supply boats (anchor-handling type) will have a range of 12,000 to 15,000 HP and be capable of storing and delivering drilling fluids, casing, deck cargo, water, cement, diesel fuel, and other bulk commodities. The vessels will be used for re-supply and safety standby. It is anticipated that two to three support vessel trips will be required per week (*e.g.*, one standby vessel and one to two supply vessels). Any support vessels that come from St. John's, Newfoundland, will use the recognized shipping lane through the Laurentian Channel.

2.9.3 Helicopter Support

Corridor is cognizant of the recent Offshore Helicopter Safety Inquiry report issued by Commissioner Robert Wells, Q.C., and the Transportation Safety Board of Canada's Aviation Investigation Report. Typical helicopter support for the Project may involve Sikorsky S-92, Sikorsky S-61 or Eurocopter AS332 aircraft. Auxiliary flight services, including First Response Equipment and technicians, alternate landing site facilities, weather station, aviation fuel, helicopter passenger transportation suits, aircraft maintenance, passenger loading terminal, and flight following services will be arranged. Contract helicopter support will be provided by offshore-rated helicopters. The helicopter contractor will also provide all auxiliary flight services for search and rescue, First Response equipment and technicians, alternate landing sites complete with weather station, aviation fuel, helicopter passenger transportation suits and an aircraft maintenance and passenger loading terminal located in Atlantic Canada. Several existing heliport locations will be investigated, with the most likely being located in St. John's. Potential refuelling may occur at a location in Western Newfoundland (*e.g.*, Port aux Basques and/or Stephenville). Helicopter support of approximately three trips per week will be required to transport personnel and light supplies and equipment.

2.10 Project Activities

A MODU will be contracted to drill one well within EL 1105. The MODU will be supplied and supported by vessels operating from a shorebase facility with the capability of storing and delivering drilling supplies, including drill fluids, casing, deck cargo, water, cement, diesel fuel and other bulk commodities including provisions.

Well design is currently in development, with some preliminary design information provided in Section 2.10.2. The actual hole sizes and casing setting depths will be finalized for the specific well requirements and design criteria.

Following completion of the exploration well, well abandonment / suspension will be conducted in accordance with recent *Drilling and Production Guidelines* (C-NLOPB and Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) 2011) and the *Newfoundland Offshore Petroleum Drilling and Production Regulations* (SOR/2009-316) under the *Canada-Newfoundland Atlantic Accord Implementation Act*.

2.10.1 Project Components

The Project will consist of the activities associated with a one well exploration program within EL 1105. These activities include the mobilization of a MODU and the drilling, evaluation and subsequent abandonment / suspension of the well. The evaluation of the well may occur over a few stages and could include wireline logging, VSP and well testing activities at a later date.

2.10.2 Exploration Drilling

The potential reservoir targets at the Old Harry structure are located between 850 and 2,000 m below the seafloor. The well would be started with a conductor hole either drilled or jetted to reach a depth typically 90 m below the seafloor (BSF). Following the cementing of this conductor pipe, a surface hole would likely be drilled without a marine riser to a depth between 300 to 600 m BSF and cemented back to the seafloor. The high-pressure wellhead housing would be installed on this string of pipe, facilitating the installation of the subsea BOPs. These two strings of steel pipe provide the structural support for the remainder of the drilling, as well as the pressure integrity required to reach the desired targets. The drilling fluids used from this point forward will be maintained as a closed loop system, with all fluids returned to the drilling unit through the BOPs and marine riser that connects the rig to the BOPs.

The intermediate hole would then be drilled to reach just above the upper reservoir targets and casing would be installed at this point. The final hole section to be drilled to total depth of the well would be the main hole section. A suite of evaluation logs would be run to gather data to confirm the presence of significant hydrocarbons. If the reservoir targets are hydrocarbon-bearing, a final production casing string or liner may be installed to enable future testing or production from the wellbore. If the well is deemed to be unsuccessful, it will likely be abandoned without the installation of the final string of casing / liner and the open hole abandoned using appropriate cement plugs in accordance with the *Drilling and Production Guidelines* (C-NLOPB and CNSOPB 2011).

An example hole size and casing profile for the Old Harry well is provided in Table 2.4. This design will be finalized as the engineering of the Project progresses.

Table 2.4 Description of Example Drill Hole and Casing Sizes

Hole Section	Hole Size (mm)	Casing Size (mm)	Setting Depth (m BSF)	Drilling Fluid Type	Drilling Fluid Return
Conductor	914	762	90	Seawater	Seafloor
Surface	660	508	300 to 600	Seawater with sweeps	Seafloor
Intermediate	444 to 311	340 to 245	800 to 1,200	SBM	Drilling Rig
Main / Production	311 to 216	245 to 178 (liner)	2,000 to 2,200	SBM	Drilling Rig

2.10.3 Vertical Seismic Profiling

VSP using an air-source array from a support vessel may be conducted as part of the exploration activities. The air-source array is similar to that employed by 2-D or 3-D seismic surveys, but is usually smaller and deployed in a small area for a limited amount of time (several days). An application for VSP activities may be included with the application to drill a well. For all geophysical surveys, the Operator will adhere to the *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2012).

2.10.4 Well Testing

A Well Data Acquisition Program will be submitted to the C-NLOPB in support of the well approval at least 21 days prior to the anticipated spud date. Other than declaring a significant discovery, any testing program that involves flowing the well will require its own approval. The Operator will include in the Well Data Acquisition Program its intention with respect to testing; however, the final decision to test, suspend or abandon the well will only be made once the well has been drilled to total depth and the initial geological evaluation completed. The decision to test a well is dependent on the quality, quantity and content of the hydrocarbon-bearing formations encountered. If well testing is warranted, the Operator could suspend the well and return to the location at a later date with all the necessary equipment.

During typical well testing operations, downhole test tools complete with perforating guns are run into the cased wellbore. There are additional tools placed across the subsea BOPs to ensure well control is maintained at all times. Once the well has been perforated, reservoir fluids are allowed to flow up the test string in the wellbore (tubing or drill pipe) to the deck of the drilling unit. On the deck of the rig, a temporary flow testing facility will have been installed, pressure and function tested, and certified to handle the flow of the fluids from the wellbore in a controlled manner. These fluids may contain hydrocarbons (oil and gas) and/or formation water. The hydrocarbons are measured and separated from the produced water in the test package. Hydrocarbons and small amounts of produced water are flared using high-efficiency burners to combust the hydrocarbons and minimize emissions. If produced water occurs, it will either be treated prior to ocean discharge or transported to shore for disposal in accordance with the *Offshore Waste Treatment Guidelines* (OWTG) (National Energy Board (NEB) *et al.* 2010). Once the testing is complete, the test string is removed from the well and, depending upon the results of the test, the well is either suspended or abandoned in accordance with the *Newfoundland Offshore Petroleum Drilling and Production Regulations* (SOR/2009-316). If a well is suspended, the well will be left in a safe state to prevent hydrocarbons from flowing out of the well until the well is re-entered in the future for additional testing or long term production.

2.10.5 Well Abandonment / Suspension

Depending on the preliminary information received during drilling, the exploration well may be suspended for future re-entry. The wellbore is plugged below the seafloor using mechanical and/or cement plugs in accordance with the *Drilling and Production Guidelines* (C-NLOPB and CNSOPB 2011). A suspension cap is installed to protect the wellhead connector for potential future re-use.

If the offshore well is abandoned, the wellhead may be removed or in some cases, approval may be granted for leaving the wellhead in place. When the wellhead is removed, the wellhead and associated equipment are removed to at least 1 m BSF. This is typically performed using mechanical cutters from the drilling unit. However, there are cases that require subsea cutting involving the use of shaped explosive charges. This option is employed only in instances where mechanical removal has failed. It is a requirement that operators have authorization from C-NLOPB before shaped charges are used. If approval is granted for leaving a wellhead in place, several factors are considered, including the occurrence and type of fishery in the area, as well as water depth at the location of the wellhead.

2.11 Waste Discharges, Air Emissions and Treatment

All discharges from the rig will be managed in compliance with the OWTG. Other requirements may be attached to individual authorizations from the C-NLOPB. Details are provided in the following sections on the discharges associated with exploratory drilling operations, which include drill muds and cuttings, produced water, grey and black water, ballast water, bilge water, deck drainage, discharges from machinery spaces, cement, BOP fluid (glycol / water) and air emissions.

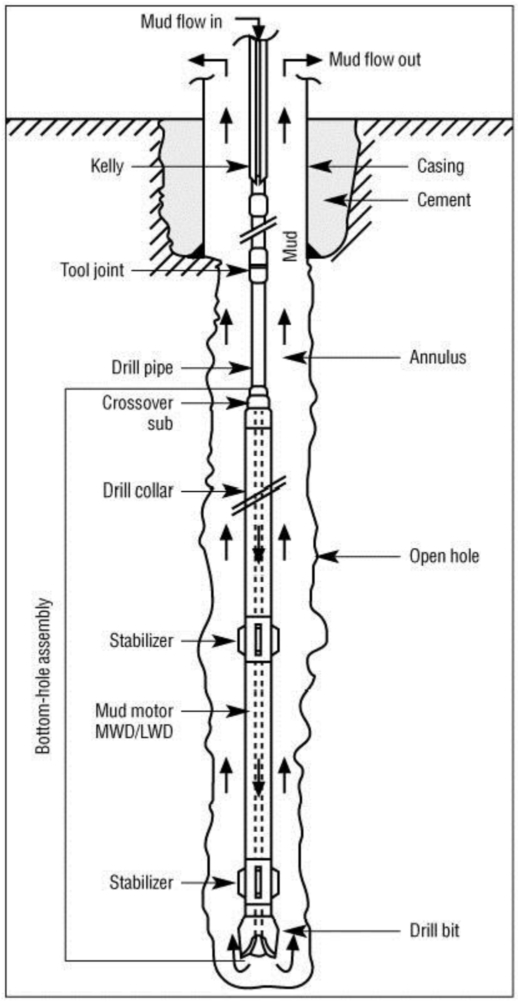
2.11.1 Drill Mud and Cuttings

The well at EL 1105 is planned to be drilled to depth using primarily synthetic oil-based mud (SBM), although water-based mud (WBM) will be used for the conductor and surface hole locations. Therefore, the environmental assessment for EL 1105 considers the use of both WBM and SBM.

Drilling uses a rotating drill bit attached to the end of a hollow drill pipe, referred to as the drill string. The rotation of the drill bit breaks off small chips (*i.e.*, cuttings) of the formation rock, deepening the borehole (*i.e.*, well). Drill mud is is circulated through the drill pipe and out through small jets or holes in the drill bit, picking up drill cuttings and lubricating the drill bit. The velocity and viscosity of the mud flushes drilled cuttings away from the bit, carrying them up to the surface through the annulus (space between the drill string and the borehole wall), as illustrated in Figure 2.3 (CAPP 2001a; Neff 2005).

At pre-determined intervals as described in Section 2.10.2, steel casing is cemented into the wellbore (see Figure 2.3), thereby providing a conduit that returns muds and cuttings to the drill unit for treatment. Drilling mud is removed from the cuttings in a series of successive separation phases that may use shakers, hydrocyclones and/or centrifuges. The cleaned cuttings are then discharged overboard via a cuttings chute. Drill mud is recovered and reconditioned for reuse as much as possible. However, some mud will remain on the drill cuttings and be discharged. Discharged drill cuttings are required to meet the limits outlined in the OWTG for the disposal of drill solids (no limit for WBM cuttings, 6.9 g of mud or less/100 g of cuttings for SBM cuttings overboard discharge).

The total volume of cuttings and drill mud discharged will be dependent upon the wellbore depth and drilling conditions encountered. Drilling of conductor and surface hole locations tend to be drilled with sea water and small amounts of WBM, with mud and cuttings discharged to the seafloor. For this well, the intermediate and production hole sections are planned to be drilled with SBM in a closed loop system, using a marine riser from the seafloor back to the drilling unit. SBM will be recycled, reused and brought to shore for environmentally safe disposal when spent. The exploration well is planned to be drilled vertically.



Source: CAPP 2001

Figure 2.3 Drill String Components Illustrating Drill Mud Circulation

The muds and the cuttings that meet the appropriate discharge limits are dispersed in the water column and settle to the seabed, with heavier cuttings and particles settling near the well bore and the fines dispersed at increasing distances from the MODU. The dispersion pattern for cuttings is irregular, largely dependent on water depth and current direction, as well as discharge intensity. Drill mud andcuttings and their potential environmental effects have been discussed in several studies (Husky 2000, 2001; CAPP 2001a; Hurley and Ellis 2004) and all confirm that exploratory drilling has no measureable environmental effect on the marine environment (refer to Section 7.1.2 for more information on environmental effects associated with drill muds and cuttings). Table 2.5 presents examples of drilling fluid components and drill cuttings discharge for an exploration well.

Table 2.5 Example of Drilling Fluid Components and Drill Cuttings Discharge

	Unit	Conductor	Casing Strings		
			Surface	Intermediate	Main
Hole Section	mm	914	660	445	311
Drilling Fluid System		Seawater / Gel	Seawater / Gel	SBM	SBM
Depth (See Notes)	M BSF	±90	±320	±850	±2,100
Volume Usage	m^3	340	530	765	±600
Wash Out	%	50%	30%	20%	10%
Products					
Barite	MT	150	100	20	20
Bentonite	MT	50	100	-	-
Caustic	kg	250	350	-	-
Fluid Loss Agent	kg	-	-	4,600	3,600
Potassium Chloride	kg	-	-	-	-
Glycol Inhibitor	L	-	-	-	-
Soda Ash	kg	250	375	-	-
Viscosifier	kg	-	1,135	15,300	12,000
Biocide	L	-	-	-	-
Wetting Agent	kg	-	-	1,530	1,200
Emulsifier	L	-	-	15,300	12,000
Lime	kg	-	-	13,800	10,800
Calcium Chloride	kg	-	-	41,300	32,400
Base Oil	m^3	-	-	581	456
Drilled Cuttings	kg	240,000	300,000	257,000	282,000
Volume of Cuttings	m^3	90	110	95	105

Notes:
1. The information provided is an example of a potential well design scenario. This will be finalized in the detailed design.
2. 914 mm (36-inch) and 660 mm (26-inch) hole sections will be drilled without a marine riser. It will have near seabed discharge of cuttings.
3. WBM is planned for the conductor and surface sections of the well.
4. The average water depth in the Project area is assumed to be 470 m.
5. All depths are measured bsf as the planned MODU has yet to be determined.

2.11.1.1 Water-based Muds

WBM employs freshwater or brines (salt water) as the continuous liquid phase and the solid phase is generally composed of barite, bentonite or other clays, silicates, lignite, caustic soda, sodium carbonate / bicarbonate, inorganic salts, surfactants, corrosion inhibitors, lubricants and other additives for unique drilling problems (Thomas *et al.* 1984; GESAMP 1993). The constituents of muds are screened via the *Offshore Chemical Selection Guidelines for Drilling and Production Activities on Frontier Lands* (NEB *et al.* 2009). Composition of an example of a typical mud formulation is presented in Table 2.5.

2.11.1.2 Synthetic-based Muds

SBM refers to a water-in-oil emulsion whose continuous phase is composed of one or more fluids produced by the reaction of a specific purified chemical feedstock, rather than the physical separation processes such as fractionation, distillation and minor chemical reactions. The synthetic-based fluids used in the preparation of SBM are water insoluble and, as such, the SBM does not disperse in water in the same manner as a WBM (Hurley and Ellis 2004). The discharge of whole SBM is not permitted. SBM cuttings may be discharged provided they do not exceed 6.9 g/100 g time weighted average of oil on wet solids (see Section 2.4 of the OWTG). Composition of an example of a typical SBM formulation is presented in Table 2.5.

The most commonly used SBM on the Grand Banks uses PureDrill IA-35 as the base fluid, together with weighting agents, wetting agents, emulsifiers and other additives. The SBM PureDrill IA-35 that is used on the Grand Banks is classified as a high purity synthetic alkane consisting of isoalkanes and cycloalkanes (Williams *et al.* 2002). PureDrill IA-35 has undergone an evaluation using the *Offshore Chemical Selection Guidelines for Drilling and Production Activities on Frontier Lands* (NEB *et al.* 2009). The fluid was screened from a facility, human health and environmental perspective (Williams *et al.* 2002). PureDrill IA-35 base oil is a component of a whole mud system called ParaDrill that received a Group E classification by the Offshore Chemical Notification System classification system used in the UK. The Group E classification is the best rating achievable under the Offshore Chemical Notification System and is assigned to chemicals that have relatively low toxicity and/or does not bioaccumulate or readily biodegrades. The components of ParaDrill-IA are presented in Table 2.6; a similar mud would be used for this Project.

Table 2.6 Composition of ParaDrill-IA

Component	Purpose
PureDrill IA-35	Base Fluid
NOVAMULL	Primary Emulsifier
NOVAMOD L	Rheology Modifier
NOVATHIN L	Thinner
MI-157	Wetting Agent
HRP	Rheology Modifier
TRUVIS	Viscosity
VERSATROL	Filtration Control
ECOTROL	Filtration Control (Alternative)
Lime	Alkalinity
Calcium Chloride	Salinity
Water	Internal Phase
Barite	Density
Source: Williams *et al.* 2002, in LGL Limited 2005a.	

2.11.2 Cement

The upper reaches of a well may be drilled into sediments with no casing by a process referred to as 'spudding'. The drill string is removed and a pipe (casing) is inserted and cemented into place. In order to avoid damaging subsurface equipment, excess cement from the conductor casing is not brought back to the drilling unit but discharged to the sea floor. The actual amount can only be estimated by remotely operated vehicle survey after the discharge. Additional cement returns from surface, intermediate and production casings may be discharged according to the OWTG. Cement components will also meet the *Offshore Chemical Selection Guidelines for Drilling and Production Activities on Frontier Lands* (NEB et al. 2009).

2.11.3 Produced Water

If hydrocarbons are present and flow testing is conducted, then small amounts of produced water may be discharged by atomizing with hydrocarbons and flaring. If the flare capacity is exceeded, then small amounts of treated produced water will be brought onshore for disposal.

2.11.4 Grey / Black Water

Typical drilling units will accommodate up to 150 personnel, depending upon the rig. Each rig will discharge up to approximately 50 m^3 of grey water per day. Black water or sewage will be macerated to 6 mm particle size or less and discharged as per the OWTG. Estimated amounts of black water are up to 25 m^3 per day per rig.

2.11.4 Machinery Space Discharges

Bilge drainage from machinery spaces (*e.g.*, where machinery leaks oil to a dedicated collection system) will be collected and sent to shore for disposal.

2.11.5 Bilge Water

Bilge water will be treated to OWTG standards so that residual oil concentration in discharged bilge water does not exceed 15 mg/L.

2.11.6 Deck Drainage

Any deck drainage, such as the rotary table floor and machinery spaces, will undergo treatment in accordance with the OWTG so that residual oil concentration does not exceed 15 mg/L.

2.11.7 Ballast Water

Water used for stability purposes in both supply boats and drilling rigs is stored in dedicated tanks and thus does not normally contain any oil. If oil is suspected in the ballast water, it will be tested and if necessary treated to OWTG standards so that the residual oil concentration does not exceed 15 mg/L.

2.11.8 Cooling Water

Electrical generation on most modern rigs is provided by large diesel-fired engines and generators. These engines are cooled by pumping water through a set of heat exchangers. The water is then discharged overboard in accordance with the OWTG. Other equipment is cooled through a closed loop system, which may use chlorine as a disinfectant. Water from closed systems will be tested prior to discharge and will comply with the OWTG. Any proposals for alternate biological control will be submitted to C-NLOPB for consideration prior to use. The EPP will describe the proposed biocide system and its management. If any form of biocide (chlorine or other) is to be used, it will be screened through the operator's chemical management system.

2.11.9 Solid Waste

All trash and garbage, including organic waste from galleys, will be containerized and transported to shore for disposal in approved landfills. Combustible waste such as oil rags and paint cans will be placed in hazardous materials containers for transport to shore. The rig will have a recycling program.

Any hazardous waste will be properly containerized, sealed, labelled and its disposal on shore at an approved facility will be the responsibility of a certified waste handler. All third-party waste management facilities will be assessed by the Operator to ensure they meet waste management standards.

2.11.10 Blow-out Preventer Fluid

With all subsea BOPs, the test fluid (glycol / water) is released at intervals. Chemicals potentially discharged offshore will be screened using the *Offshore Chemical Selection Guidelines for Drilling and Production Activities on Frontier Lands* (NEB *et al.* 2009). Excess chemicals or chemicals in damaged containers will not be discharged into the sea but returned to shore on a supply vessel. Any spent or excess acids will be neutralized as approved by the C-NLOPB and discharged.

2.11.11 Miscellaneous

The Operator's EPP will describe all proposed discharges. Any chemical to be released to the environment will be screened through the Operator's chemical management system. No substances will be discharged without prior notification and approval of the C-NLOPB.

2.11.12 Air Emissions

Exploration installations are usually in an area for a short duration (*e.g.*, 20 to 50 days for the Old Harry well). The main source of air emissions associated with routine activities of exploration drilling includes the burning of diesel fuel for power generation on the drill unit and flaring during any required well testing. Fugitive emissions will be a negligible source.

Typical emissions produced during a 20 to 50 day exploration drilling program would meet the stipulated air quality criteria in the short-term and in near-field and far-field locations. There will likely be no exceedances of the National Ambient Air Quality (NAAQ) Objectives.

Air emissions will be reported in accordance with the guidelines and the National Pollution Release Inventory. Sulphur dioxide, nitrogen oxides (NOx), hydrogen sulphide, particulate matter (PM), PM2.5, PM10 and volatile organic compounds are Criteria Air Contaminants, emissions of which must be reported to Environment Canada under the National Pollutant Release Inventory (NPRI) by June 1 annually. This reporting is required for production operations and development drilling but exploratory drilling operations are exempt from NPRI reporting.

The primary criteria air contaminants are carbon dioxide (CO_2), carbon monoxide (CO), sulphur oxides (SO_x), nitrogen oxides and particulate matter. It is estimated that a drilling rig consumes approximately 110 barrels of marine diesel per day (each barrel is assumed to hold approximately 42 US Gallons (159 L) of fuel). Additional assumptions made for the purposes of the estimate of emissions includes: the marine diesel used has a fuel sulphur content of 5,000 ppm (or 0.5 percent (typical for marine diesel)); and 1 gallon of diesel fuel produces approximately 139,000 Btu of energy.

The US EPA AP-42 Emission Factor Inventory was used, providing representative emissions factors for air contaminants released to the atmosphere by source type. In general, these emissions factors are understood to be representative of long-term averages for all facilities in the source category. For this estimate, AP-42, Fifth Edition, Volume 1, Chapter 3.4: Large Stationary Diesel and All Stationary Dual-fuel Engines was used, since the main domestic use of large stationary diesel engines (greater than 600 horsepower) is for the application of oil and gas exploration and production. As stated in the study, evaporative losses are nominal in diesel engines due to low volatility of diesel fuel; therefore, only air contaminant emissions emitted through exhaust were considered.

The emissions factors as prescribed by AP-42 for large stationary diesel internal combustion sources are shown in Table 2.7.

Table 2.7 Gaseous Emissions Factors for Large Stationary Diesel Internal Combustion Sources

Air Contaminant	Emission Factor (fuel input) (lb/MMBtu)
NO_x	3.2
CO	0.85
SO_x[A]	$1.01S_1$
CO_2	165
PM	0.1

[A] Assumes that all sulphur in the fuel is converted to SO_2. S_1 = % sulphur in fuel oil. Therefore, for this estimate, a sulphur fuel content of 0.5%, results in an emission factor of 0.505.

Daily air contaminant emissions for the case of consumption of 110 barrels of fuel per day were evaluated and are shown in Table 2.8. Whereas a formal analysis has not been conducted on air emissions from a semi-submersible, the resultant emissions would be slightly higher due to greater fuel consumption required for activities such as station-keeping. These emissions are comparable to emissions from a single large container ship of the type that commonly transits the area. There will be minimal effect on the health and safety of workers on the drill rig.

Table 2.8 Daily Criteria Air Contaminant Emissions for the Project Drilling Rig Consuming 100 Barrels of Fuel per Day

Air Contaminant	Diesel Fuel (# bbl/day)	# US Gallons/ day	Energy Produced Per Day (MMBtu)	Emission Factors (fuel input) (lb/MMBtu)	Air Contaminant Emissions (lbs/day)	Air Contaminant Emissions (tonnes/day)
NO_x	110	4,620	642	3.2	2,055	0.93
CO	110	4,620	642	0.85	546	0.25
SO_x^*	110	4,620	642	0.505	324	0.15
CO_2	110	4,620	642	165	105,960	48
PM	110	4,620	642	0.1	64	0.03
MMBtu = 1,000,000 Btu.						

There is ample assimilative capacity for emissions resulting from these activities because of the strong average winds at the site. As the drill rig will be more than 50 km from the nearest coastal community, there will be no effect on the coastal communities from the Project. The drilling rig would correspond to less than 0.2 percent of the greenhouse gas emissions for Newfoundland and Labrador (based on 2003 greenhouse gas emissions data).

2.12 Project-specific Model Inputs and Results

Corridor has conducted project-specific modelling to determine the areal extent of:

- drill cuttings dispersion; and
- hydrocarbon fate and behaviour spill trajectory.

2.12.1 Drill Cuttings

To estimate possible drill cuttings depositions, primarily the thicknesses and distances from the well site, a numerical model was employed which considered the proposed sequence of well sections to be drilled for the Project and an associated time history of cuttings discharges. The subsequent path of the discharged cuttings (with advection as a result of the ambient ocean current) to their ultimate fate on the seabed was predicted with a 3D sedimentation computer model.

Modelling of the dispersion of cuttings predicts the initial deposition of the cuttings only, not the subsequent weathering, erosion and fate of the material accumulated on the seabed over an extended period of time.

2.12.1.1 Model Inputs

Two publicly available sources of currents were used to serve as an input base for the Benthic Boundary Layer Transport model: the WebTide (DFO 2011a) and WebDrogue (DFO 2011b) model based velocity fields.

Tidal Currents

WebTide is initially a user interface designed to get the tidal predictions (elevation and velocities) at a (user selected) particular location. The tool uses the solutions of modelling studies performed over the years by DFO scientists and staff. The finite element mesh used for this study was the Northwest Atlantic Mesh described in Dupond *et al.* (2002).

Tidal solutions (elevation and currents) from the core program of WebTide (‘tidecor’) were interpolated on a regular grid to provide a time-series of spatial tidal velocity fields.

To provide a representative cycle, a full lunar month (30 days) of simulation was extracted and saved hourly over a grid covering from about 46.05°N to 50.05°N and 62.39°W to 58.39°W (2 degrees around the proposed drilling location).

Tidal current speeds and directions for all the phases of the tidal cycle are summarized in Table 2.9. The currents flow toward the direction given relative to true North.

Table 2.9 Tidal Currents at Drilling Site from Webtide Model Run

	Neap-Flood	Neap-Ebb	Spring-Flood	Spring-Ebb	Slack Water
Tidal current	0.07 m/s 320° N (to)	0.08 m/s 140° N (to)	0.21 m/s 320° N (to)	0.17 m/s 140° N (to)	0 m/s
Notes: magnitudes rounded to nearest cm/s and directions rounded to nearest 10° sector					

Seasonal Mean Current Fields from Webdrogue

WebDrogue is another user interface developed by DFO providing access to the results of numerical modelling of the general circulation in the Eastern Canada region of the Northwest Atlantic Ocean. The domain used for this study, covering the Gulf, was the one developed for DFO’s operational model to forecast currents, temperature, salinity and ice field over the Eastern Coast of Canada (DFO 2011c).

The seasonal current fields at the surface and the bottom were extracted from the model domain mesh for winter, spring, summer and fall, and interpolated on the same grid as for tidal currents (Section 2.12.1.1). In WebDrogue, the bottom layer is defined as “the average over the bottom 10 m” (DFO 2011c), and therefore representative of the benthic boundary layer. Seasonal mean currents are summarized in Table 2.10.

Table 2.10 Residual Currents at Drilling Site from WebDrogue Model Run

	Winter	Spring	Summer	Fall
Surface	0.04 m/s 130°N (to)	0.04 m/s 110°N (to)	0.06 m/s 150°N (to)	0.08 m/s 160°N (to)
Bottom	0.025 m/s 310°N (to)	0.05 m/s 300°N (to)	0.05 m/s 310°N (to)	0.03 m/s 330°N (to)
Notes: Magnitudes rounded to nearest .01 m/s and direction rounded to nearest 10° sector				

Stratification

Vertical stratification of the water column was derived from DFO monthly climatology of temperature and salinity for the region of the Gulf of St. Lawrence (DFO 2011d) around Old Harry. Density stratification resulting from temperature and salinity stratification is summarized for each season in Table 2.11.

Table 2.11 Disposal Site Water Column Physical Properties

Depth (m)	Density (kg/m^3)			
	Winter	Spring	Summer	Fall
0	1025.7	1025.5	1023.6	1024.3
200	1027.9	1028.0	1028.0	1027.8
400	1029.4	1029.4	1029.4	1029.4

Cuttings Particles Characterization

No cuttings particle size distributions that would quantify the composition of different mineral materials as a function of depth are available from the anticipated well to be drilled in EL 1105.

An overall estimation of the cuttings and sediment composition for the well is 38 percent sandstone, 49 percent shale, and 13 percent siltstone. Based on this limited knowledge, together with consideration of the cuttings sizes likely to be created from the drilling, it was assumed that most (perhaps 75 percent) of the cuttings will be large on the order of 1 to 3 cm, approximately 20 percent on the order of 0.5 to 1 cm, with the remainder less than 0.5 cm. For the two upper sections of the hole for which cuttings are discharged at the sea floor, this distribution was applied to the total in situ cuttings volume of 196 m^3. SBM will be used for drilling the deeper two sections and the discharge of the cuttings from the rig considered a similar distribution with one refinement applied to a total in situ cuttings volume of 211 m^3. To consider the presence of very fine particles that could be expected during drilling of the deeper well sections, a small amount, 5 percent, was moved from the larger particles to fines (Table 2.12). Discharged drill cuttings are required to meet the limits outlined in the OWTG for the disposal of drill solids (no limit for WBM cuttings, 6.9 g of mud or less/100 g of cuttings for SBM cuttings overboard discharge).

Table 2.12 Cuttings Particle Size Composition

Well Type/Section	Measured Weight Percent Material			
	Large Cuttings	Pebbles	Coarse Sand	Fines
Scenario 1: conductor and surface	75	20	5	0
Scenario 2: main and intermediate	70	20	5	5

It is assumed that the cuttings will enter the sea in a disaggregated form. The model considered the large cuttings, pebble, and sand materials to remain disaggregated in their fall to the seabed. Any fines were assumed to aggregate into flocs with an average size on the order of approximately 0.1 mm and settle with a constant speed.

Particle fall velocities, w, were estimated from the particle diameter using the following relationships from Sleath (1984):

$$w = 4.2\sqrt{D}, D > 0.0001m \quad (4)$$

$$w = 12x10^4 D^2, D \leq 0.0001m \quad (5)$$

For the four particle types considered, this yields the values reported in Table 2.13.

Table 2.13 Cuttings Particle Size Characterization

	Cuttings Material			
	Large Cuttings	Pebbles	Coarse Sand	Fines
Particle Diameter (mm)	20	7	1	0.1
Particle fall velocity (m/s)	0.594	0.351	0.133	0.0012

Ocean Currents

The seasonal bottom current fields from WebDrogue were combined with tidal current fields for use as Benthic Boundary Layer Transport current input. Thirty days of tidal currents were synthesized for each season. Subsequently, the corresponding residual current velocity was added to the tidal currents to yield separate composite current time-series representing each of winter, spring, summer, and fall conditions. For the near field models, currents are assumed to be uniform over the small model domain. For the mid and far field exercises with Benthic Boundary Layer Transport, currents vary in time and space and are representative of regional seasonal circulation patterns.

Long-term Dispersion Of Drilling Mud Discharge

Since barite (a weighting agent) and bentonite (a clay mineral) are the primary components of WBM and also are material of concern for the marine environment (Cranford and Gordon 1992;

Cranford 1995; Cranford *et al.* 1999), only these two components were considered in this study. Barite and bentonite have significantly different densities and settling velocities.

The files describing the mud discharge were created using the following information and assumptions:

- The drilling program was assumed to occur without any interruption between drilling and cementing of the sections of the hole. This represents a worst case scenario in terms of release of material into the environment. The overall discharge program was compressed and modelled to span a period of 15 days; in reality, drilling operations would span 20 to 50 days.
- Mud discharge was assumed to be continuous with material being added to the system in hourly time steps.
- In order to bracket the range of possible settling velocities, two values were retained for the simulations: 0.1 cm/s and 1 cm/s.

2.12.1.2 Model Results

Seafloor Discharge of Cuttings

A uniform depth of 470 m was assumed. The discharge included a total volume of 196 m^3 of drill cuttings. The cuttings deposition predicted following completion of the conductor and surface sections for the winter season is illustrated in Figure 2.4. Thicknesses of 1 mm, 1 and 2 cm, 10 and 20 cm, and 1 and 2 m are shown. There is very little difference in the pattern for spring, summer, and fall due to the discharge location being approximately 10 m above the seabed.

Model results indicate cuttings will be deposited up to approximately 30 m from the well site. The thickness of the deposit will be greatest immediately adjacent the well site with maximum thickness of about 4.7 m. From the well center outward to approximately 20 m, average thickness of the deposit is predicted to be about 220 mm. From 20 m outward to 50 m from the well center, the average thickness is predicted to be less than 1 mm.

Surface Discharge of Cuttings

A uniform depth of 470 m was assumed. The discharge included a total volume of 211 m^3 of WBM or SBM drill cuttings. Cuttings deposit thickness is greatest near the drill center, as large as 15 mm, due to the more rapid fall of the larger and heavier cuttings particles. Outward to approximately 100 m from the well center, predicted deposit thickness is as large as 6 mm but about 2 mm on average. Outward from 100 to 200 m, deposit thicknesses are as large as 6 mm but the average range is from about 0.5 to 1 mm. The cuttings deposition patterns on a 25 km x 25 km grid (with inset showing a finer resolution 500 m view to resolve the deposition of the larger, faster settling particles) is illustrated in Figure 2.5. A regional view of the deposit in the Gulf is provided in Figure 2.6. The oil concentration on the cuttings is approximately one to two times the oil thickness in microns (*e.g.*, if the thickness is 1,000 microns (1 mm), the oil concentration is approximately 1,000 to 2,000 mg/kg). The oil concentration within 50 m from the point of discharge, calculated for the one model grid cell immediately surrounding the well site, is predicted to be approximately 25 percent of that on the cuttings originally released, or

17,000 mg/kg. Within the band between 50 m and 100 m of well centre, the oil concentration drops to approximately 2,400 mg/kg (*i.e.*, a further reduction by a factor of seven). Outside the 200 m radius, the oil concentration on cuttings is 44 mg/kg or less. The predicted concentration is 3 mg/kg or less outside of 500 m.

Seafloor Discharge of Mud

The mud suspension will be diluted as it rises in a turbulent eject plume. A continuous drilling operation is considered to be comprised of a series of puffs of ejected material, the total of which will amount to 1,210 m^3. Each puff will experience dilution as its momentum mixes with the slower moving background currents and as a result of oceanic turbulence and shear dispersion as it is advected away from the well site by ambient currents.

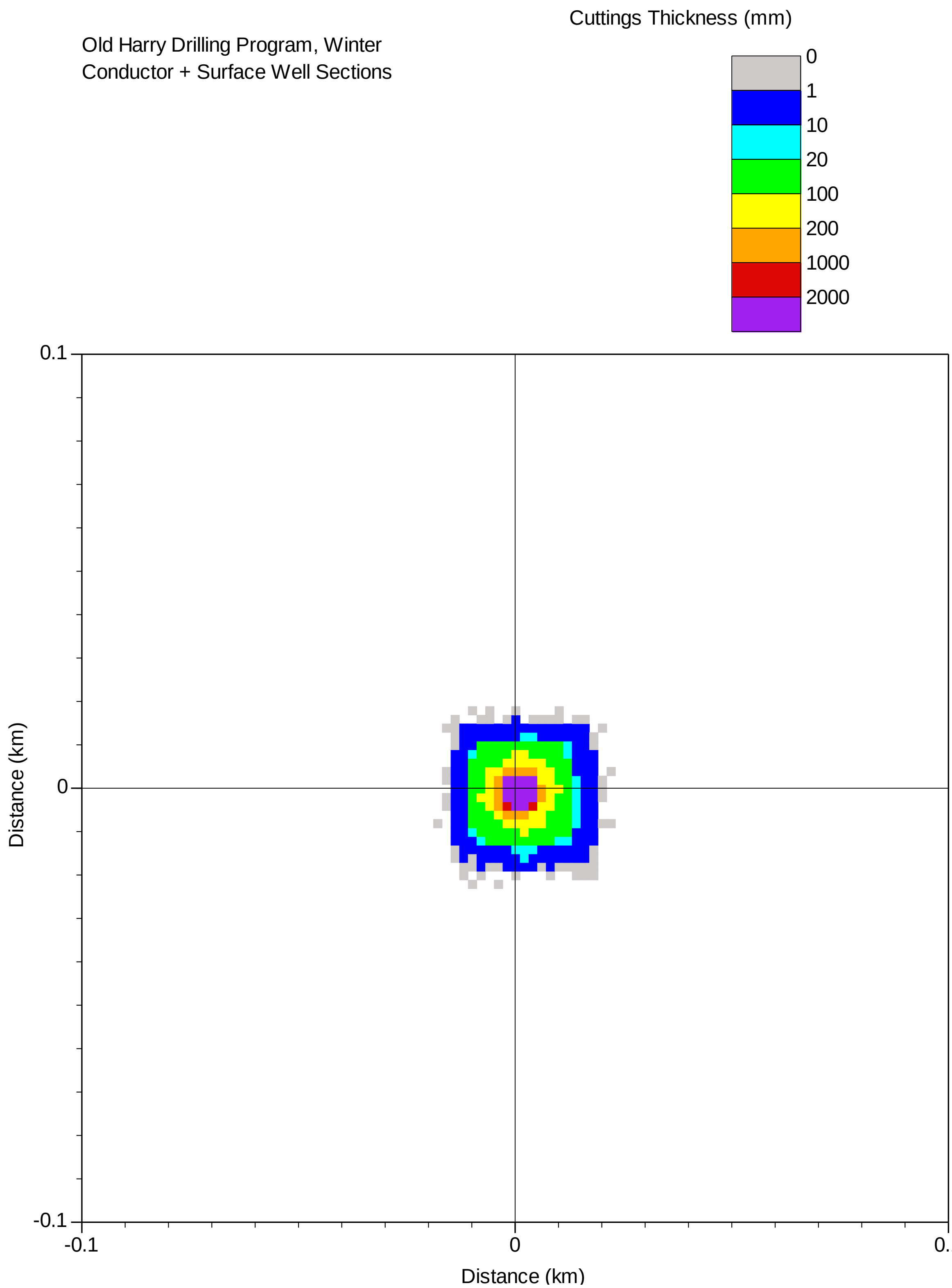
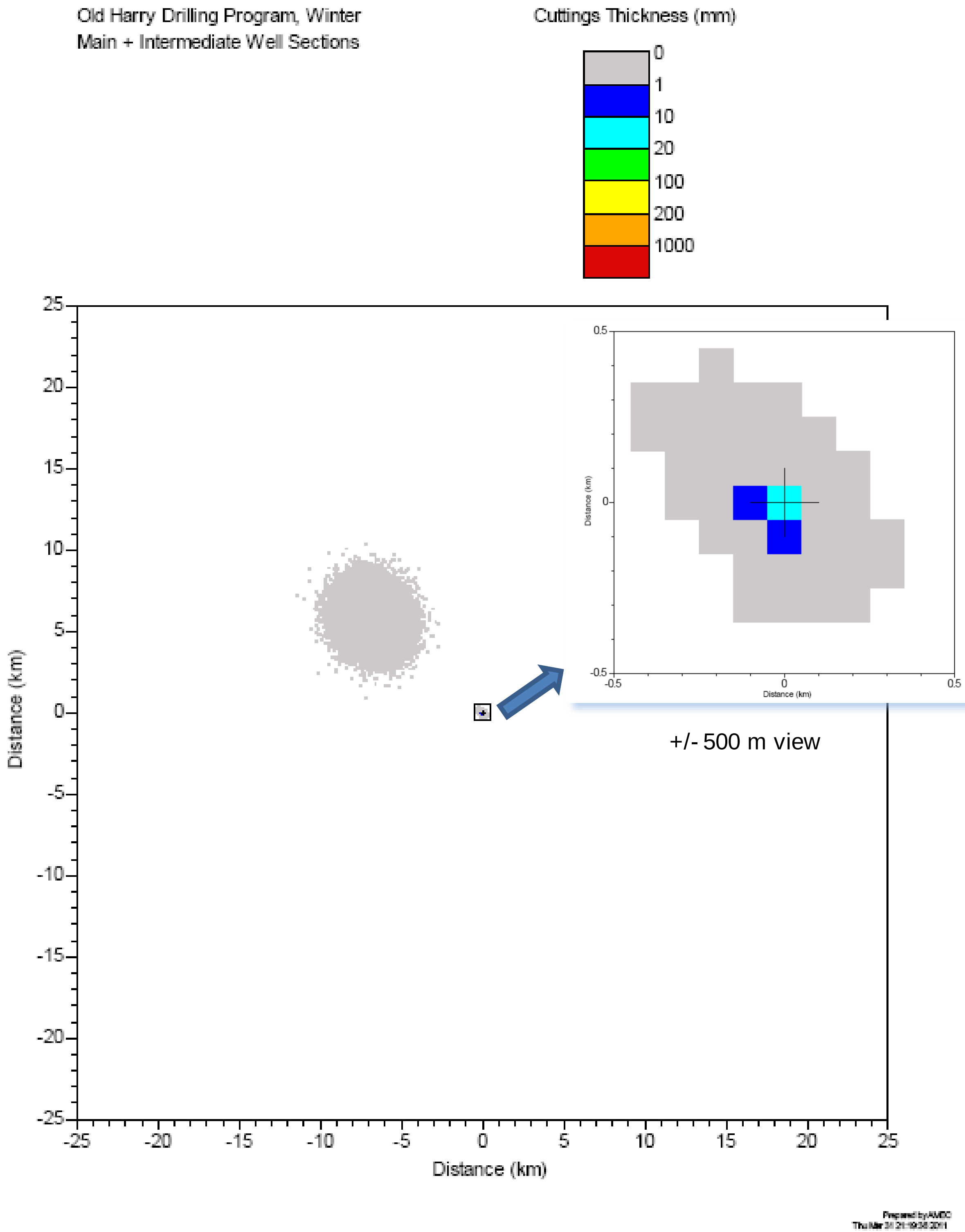
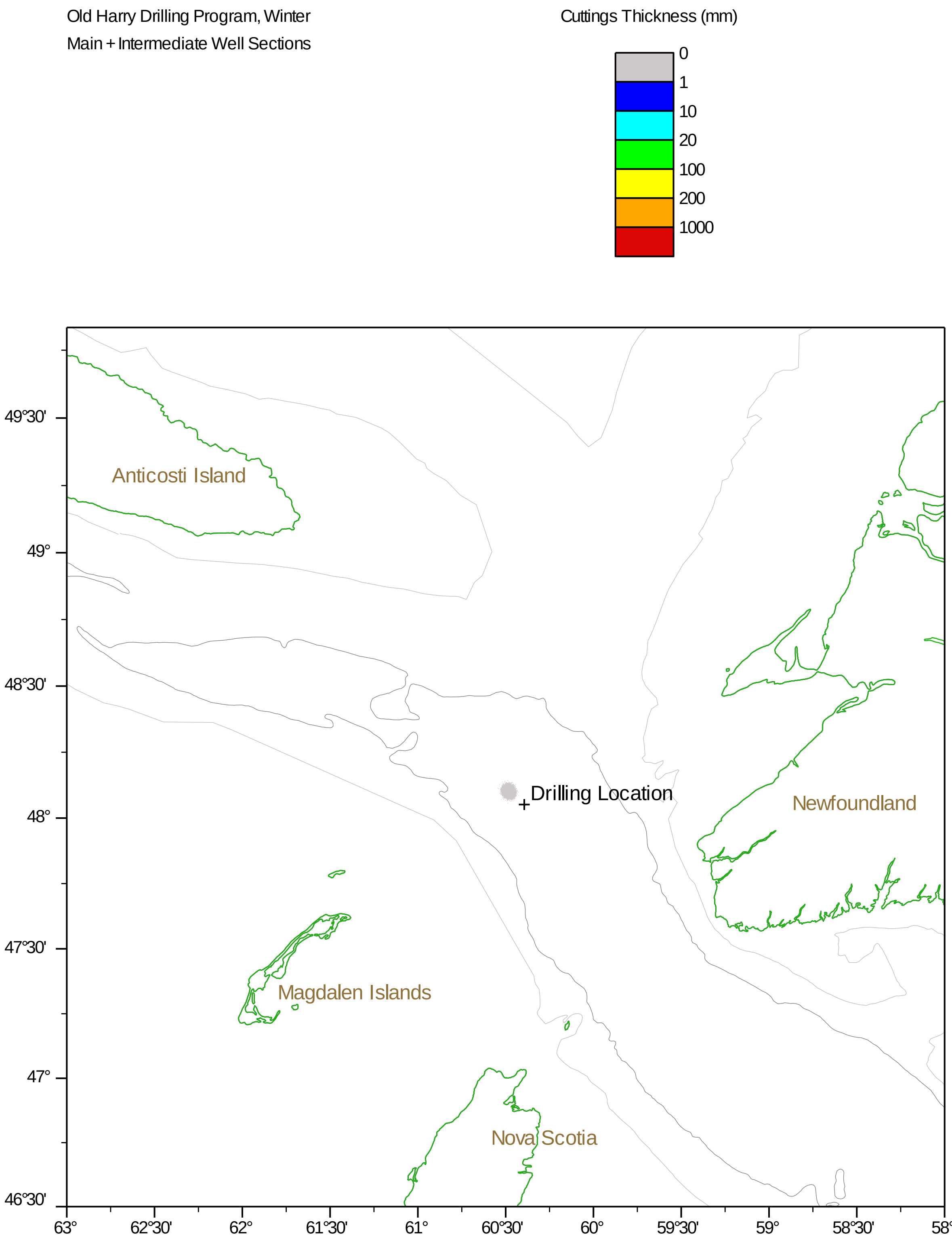


Figure 2.4 Cuttings Deposition Following Conductor and Surface Hole Section Drilling, Winter Season, 1 km view



Note: Inset shows a 500 m view centred on the wellsite

Figure 2.5 Cuttings Deposition Following Main and Intermediate Hole Section Drilling, Winter Season, 25 km View



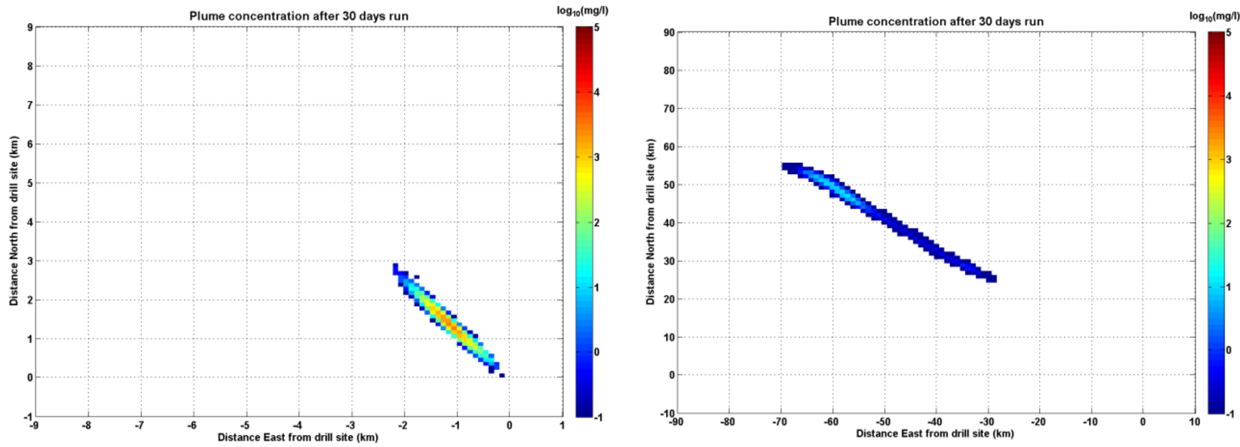
Note: 200 and 400 m Depth Contours Shown

Figure 2.6 Cuttings Deposition Following Main and Intermediate Hole Section Drilling, Winter Season, Gulf of St. Lawrence View

It is difficult to quantify the exact dispersion path that a particular puff will experience, but the process can be described in general terms based on the expected physical processes and the ambient current. For the purposes of this assessment, it is assumed that the WBM is forced out of the hole at speeds on the order of 1 m/s, while the ambient ocean currents are between 3 and 26 cm/s. Therefore, the initial dilution calculated from conservation of momentum is 4:1 to 33:1, depending on the phase of the tide. Because its density is larger than that of the ambient sea water, the diluted puff will tend to collapse into the benthic boundary layer. In the deep sea, this layer has a typical thickness on the order of 1 m (Wimbush and Munk 1970). Due to the current shear and turbulence in the boundary layer, the puff will tend to stay in suspension above the seabed. Assuming a pill-box shape for the initial plume, a discharge volume of 15 m^3 (a typical sweep volume), and an initial dilution of 4:1, the puff will have an average diameter of approximately 9 m at this time. As it is advected away, the diameter of the diluted puff will continue to grow and the mud concentrations will decrease due to dispersion and mixing. Based on a typical small scale horizontal diffusivity of 0.01 m^2/s (Okubo 1971), additional dilution by a factor of two will require on the order of two hours, at which time the cloud will have been advected by the ambient mean currents a distance between 200 and 1,700 m. Other factors not taken into account here, including the effects of seabed roughness and topography, will tend to provide additional dispersion. While necessarily not rigorous, the above description provides a reasonable picture of the process by which bottom releases of mud during jetting and drilling of the upper hole sections result initially in small clouds of fine particles in the benthic boundary layer. These clouds will continue to be diluted by turbulence and will be dispersed to the northwest of the well site as they are advected by the mean current.

Long-term Deposition

For the high settling velocity scenario, the final plume size is on the order of 2 to 3 km long and less than 1 km wide. Also, because of this high settling value and low currents on the order of a few cm/s, all the material stays within the first metre of the water column (Figure 2.7). Concentrations are in the range between 250 mg/l and 1 g/l. The highest concentration occurs at the centre of the plume, two to three orders of magnitude higher than at the margins. Overall, the averaged plume concentration time-series shows a stabilization of the concentration near approximately 250 mg/l after approximately 20 to 25 days of the 30 day modelling exercise.



Winter = High settling velocity; Summer = Low settling velocity.
Source: AMEC 2011

Figure 2.7 Greatest Extent of Drill Cuttings Deposition Modelling in Winter Season (left) and Summer Season (right)

2.12.1.3 Summary of Modelling Results

Information in this section is from AMEC (2011), which should be reviewed for more detail on the drill cuttings deposition model. Drilling operations could result in:

- sea floor discharge of 196 m^3 of cuttings;
- surface discharge of 211 m^3 of cuttings; and
- sea floor discharge of 1,210 m^3 of WBM of various density and composition.

Sea floor discharge of WBM cuttings is expected to result in a mound extending approximately 30 m from the well site, with cuttings thicknesses greatest immediately adjacent the well site. Average thickness is approximately 22 cm out to approximately 20 m from the well site; maximum thickness is approximately 4.7 m. From 20 to 50 m out from the well site, the average thickness is less than 1 mm.

Surface release of SBM cuttings is expected to produce a deposit with thickness greatest near the drill origin, due to the most rapid fall of the heavier pebble and sand cuttings particles, and is as thick as 15 mm directly below the point of origin. Out to approximately 100 m from the origin, thicknesses are approximately 2 mm on average with a maximum of approximately 6 mm. From 100 to 200 m, thicknesses average from approximately 0.5 to 1 mm, with a maximum of approximately 6 mm.

For cuttings released from the rig associated with SBM (that meet the 6.9 pecent oil on cuttings limit), maximum synthetic-based oil concentration within 50 m from the point of discharge is predicted to be approximately 25 percent of that of the original treated and released cuttings, or 17,000 mg/kg. Within 100 m, the concentration drops another factor of seven, to approximately

2,400 mg/kg. Outside of 200 m, the concentration is 44 mg/kg or less. Outside of 500 m, this concentration is 3 mg/kg or less.

Simulation of the long-term fate of all the mud released over the entire drilling program considered the conservative scenario where there is no interruption between each phase of drilling operations, in which case, all the mud would be released over a period of 15 days.

Results show that dispersion of the mud by the ambient tidal and mean currents result in an elongated plume varying from 2 to 3 km to approximately 40 km in length, depending on settling velocity, with widths from less than one to a few (numbers) kilometres, respectively. This variability is typical of the range of behaviour of drilling mud, and is consistent overall with other similar studies.

The concentration in those plumes, averaged over 1 m above the bottom, vary with their size and ranges from approximately 1 g/l initially for the high settling rate scenario a few kilometres away from the site down to approximately 1 mg/l for the low settling rate scenario a few tens of kilometres away from the drilling site. It was noted as well that the concentration varies greatly (one order of magnitude or more) within the plumes due to the suspension / deposition cycle induced by variations of current strength over the tidal cycle.

Considering the high settling velocity scenario, the particles are found to basically stay very close to the sea bed (less than 1 m). Were all the particles to settle on the sea floor, an area of approximately 1 km^2 would be covered by a very thin veneer of 64 µm.

Under the low settling velocity scenario, the particles are found to travel over relatively large distances of approximately 80 km over the 30-day simulation (Figure 2.7). Considering a 40 km long plume and a residual current of 2.5 cm/s, a fixed point within the trajectory of the plume would experience maximum continuous exposure to suspended material of the order of approximately 20 days.

If during the drilling program, interruptions of the order of a few hours to a few days were to take place, the plumes would be more elongated, more patchy, and their concentrations more variable in space and time; however, mean concentrations and exposure durations would not differ significantly from the results of the continuous discharge operation simulations considered herein.

Overall, the results of mud dispersion simulations presented in this study are found to be consistent with the results of previous generic and site-specific studies for similar discharges and receiving environment (Thomson *et al.* 2000; Hannah *et al.* 2003; Tedford *et al.* 2003).

2.12.2 Hydrocarbon Spill Fate and Behaviour Trajectory Modelling

Information in this section is from SL Ross (2011a, updated 2012), which should be reviewed for more detail on the fate and behaviour model. As well, a detailed description of the SL Ross Oil Spill Model (SLROSM) is available at www.slross.com/publications/ SLR/Description_of_SLROSM.pdf. Corridor geoscientists have selected Cohasset crude oil as a surrogate to the Old Harry oil (See Section 2.3). The Cohasset oil is high gravity oil (47° API) produced from the Cohasset / Panuke / Balmoral Fields on the Scotian Shelf (Kidston *et al.* 2005). The reservoir in these fields comprise fluvial and shallow marine, stacked, sandstone sequences that are analogous to the fluvial sandstone reservoir rocks at Old Harry. A detailed description of the rationale for the selection of Cohasset crude as a surrogate to Old Harry is provided in Appendix A of SL Ross (2011a, updated 2012).

2.12.2.1 General Oil Spill Behaviour

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

Small Batch Spills from the Drilling Installation

Small batch spills of diesel fuel from hose ruptures during transfer operations from a supply vessel or from drilling installation storage facilities are a possibility during drilling operations. These spills are considered instantaneous events and are modelled by considering the surface spreading, evaporation, dispersion, emulsification and drift of a single patch, or slick, of oil.

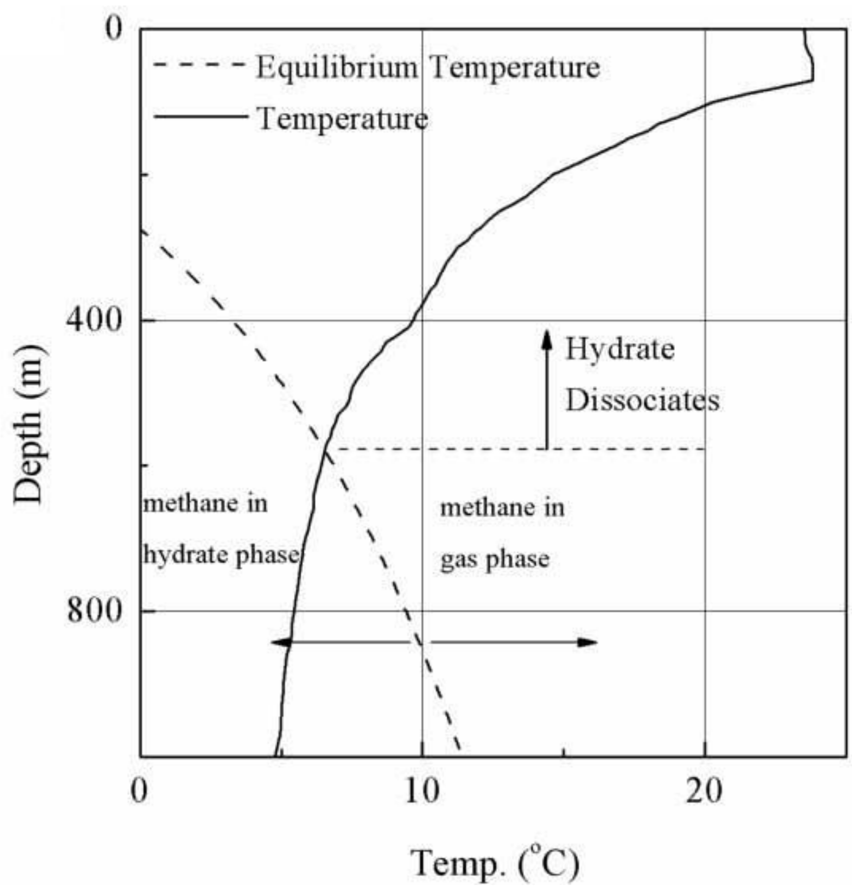
Subsea Blowouts

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

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

Deep water blowouts are those where the natural gas exiting from the subsea release point quickly combines with water to form solid ice-like substances known as hydrates. These form under high water pressure and cold temperatures and deplete the volume of gas rising in the gas bubble plume. The natural gas volume may also be depleted through dissolution into the water. With the loss of natural gas through either or both of these processes, the driving buoyancy of a rising gas bubble plume may be completely lost, which will result in the oil droplets rising slowly under gravity forces alone without the assistance of more buoyant gas (as was the case at the recent *Deepwater Horizon* or Macondo blowout in the Gulf of Mexico). The movement of the oil droplets is affected by cross currents during their rise. This will result in the separation of the oil droplets based on their drop size. The large diameter oil drops will surface first close to the release point and smaller drops will be carried further down current away from the release point prior to reaching the surface. Oceanic diffusion processes will result in additional separation of the oil drops due to their varying residence times in the water column.

In 5°C waters deeper than about 700 to 800 m, complete conversion of the natural gas to solid hydrates is likely whereas in 5°C waters less than about 500 m deep little hydrate formation is likely. The phase diagram for methane presented in Figure 2.8 provides guidance in the likely formation of hydrates as a function of water depth (pressure) and temperature. The phase diagram for methane is used since it is by far the most significant component (>90 percent) in natural gas. The formation of hydrates is also dependent on the actual composition of the natural gas and impurities in the gas and water so there is some uncertainty in the prediction of hydrate formation in water depths between 400 to 800 m. Because the water depth at the proposed drilling site is less than 500 m deep and the water temperature is 5°C or more, it has been assumed that a subsea blowout would behave as a shallow-water event in this situation and substantial conversion of gas to hydrate will not occur. The behaviour of a shallow water gas and oil blowout is discussed below.



Source: Yapa *et al.* 2010

Figure 2.8 Methane Phase Diagram

In a shallow water blowout, the majority of the gas does not convert to hydrates and a gas bubble plume develops that drives the movement of oil and gas and entrained water quickly to the water surface. Oil and gas released from a shallow subsea blowout pass through three zones of interest as they move to the sea surface (Figure 2.9 side view). The high velocity at the well head exit generates the jet zone dominated by the initial momentum of the gas. This highly turbulent zone is responsible for the fragmentation of the oil into droplets ranging from 0.5 to 2.0 mm in diameter (Dickins and Buist 1981). Because water is also entrained into the plume in this zone, a rapid loss of momentum occurs a few metres from the discharge location. In the buoyant plume zone, momentum is no longer significant relative to buoyancy, which becomes the dominant driving force for the remainder of the plume's rise to the surface. In this region, the gas continues to expand due to reduced hydrostatic pressures. As the gas rises, oil droplets and water in its vicinity are entrained in the flow and carried to the surface.

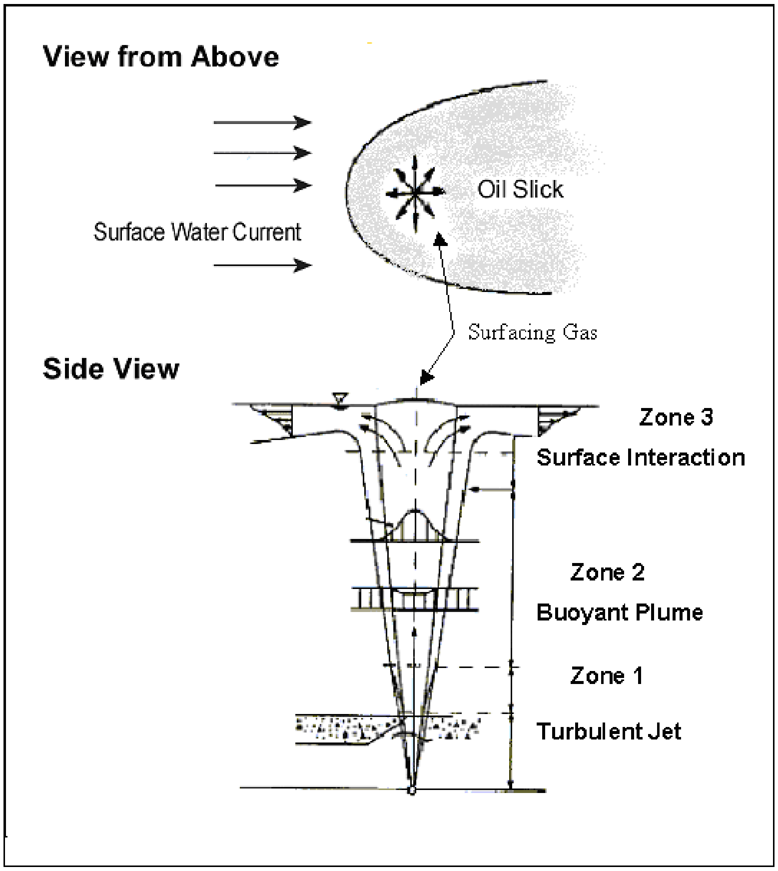


Figure 2.9 Subsea Blowout Schematic

Although the terminal velocity of a gas bubble in stationary water is only about 0.25 m/sec, velocities in the center of blowout plumes can reach 5 to 10 m/sec due to the pumping effect of the rising gas in the bulk liquid. That is, the water surrounding the upward moving gas is entrained and given an upward velocity, which is then increased as more gas moves through at a relative velocity of 0.25 m/sec. When the plume is fully developed, a considerable quantity of water containing oil droplets is pumped to the surface. The behavior of oil from a shallow blowout plume will be significantly different from a deep water blowout like the 2010 BP Macondo release in the Gulf of Mexico. The strong plume generated by the rising and expanding gas bubbles, in a shallow blowout, will move the oil quickly to the surface with little loss of oil to the surrounding waters. The rapid rise time will also result in only minimal deflection of the plume (usually a few hundreds of metres at most) as the gas, oil and entrained water makes its way to the surface. This behavior will be more similar to the Ixtoc blowout (Ross 1979).

In the surface interaction zone, the upward flow of water created by the gas bubbles turns and moves in a horizontal layer away from the center of the plume. The prevailing ocean surface water current pushes against this blowout-driven radial flow and turns it down-current to form a surface influence as illustrated in Figure 2.9 (above view). This surface influence carries the oil and spreads it over the surface up to the point where the water, oil and gas flow generated by the blowout no longer affects the surface water motion (between 1- to 1.5-slick widths down-current). At this point, the oil moves with the prevailing currents and spreads as any spill of oil would. The gas exits from the center of the blowout driven plume and causes a surface disturbance identified by the arrows in the top view of Figure 2.9. At the surface, the oil is initially spread outwards by the water flow generated by the gas bubble plume much faster than conventional batch oil spill spreading rates. This results in an initial slick that is wider but much thinner than would be experienced in a typical surface batch spill of oil.

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

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

Above-Surface Blowouts

Oil released during a blowout from an offshore drilling installation above the water's surface will behave differently than that from a subsea blowout. The gas and oil will exit at a high velocity from the discharge location and will be fragmented into a jet of fine droplets. The height that this jet rises above the release point will vary depending on the gas velocity and the prevailing wind velocity. Atmospheric dispersion processes and the settling velocity of the oil particles from the rising cloud of natural gas determine the fate of the oil at this point. The Uniacke blowout that occurred off Canada’s east coast is an example of a surface oil blowout.

A simple Gaussian model of this behaviour that can be used to predict the concentrations of oil and gas downwind from the release point is illustrated in Figure 2.10. Atmospheric dispersion is controlled in part by atmospheric turbulence that is influenced by solar radiation, wind speeds and temperatures. On clear, sunny days, with light winds, solar radiation will create highly turbulent conditions.

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

The atmospheric plume representation shown in Figure 2.10 can also be used to illustrate the behaviour of oil droplets by employing the following two modifications. The plume centerline is sloped down to account for the oil droplets' fall velocities. The oil will "rain" down, with the larger droplets falling closer to the release point. As oil drops fall, they will also be spread by atmospheric turbulence. A portion of the falling oil evaporates and the remainder eventually lands on the water and is carried down current. As water passes under the area of falling oil, it will be "painted" by the falling oil and an accumulation of oil over the width of the fallout zone will occur. Changing wind and water current directions will affect the ultimate distribution of the oil on the water surface in the fallout zone. If the gas and oil are blowing through the drilling rig derrick or some other obstruction, some of the oil droplets may agglomerate on the obstruction(s) and flow down onto the rig floor and eventually to the water surface. This portion of the oil will then behave more like a continuous surface release of oil.

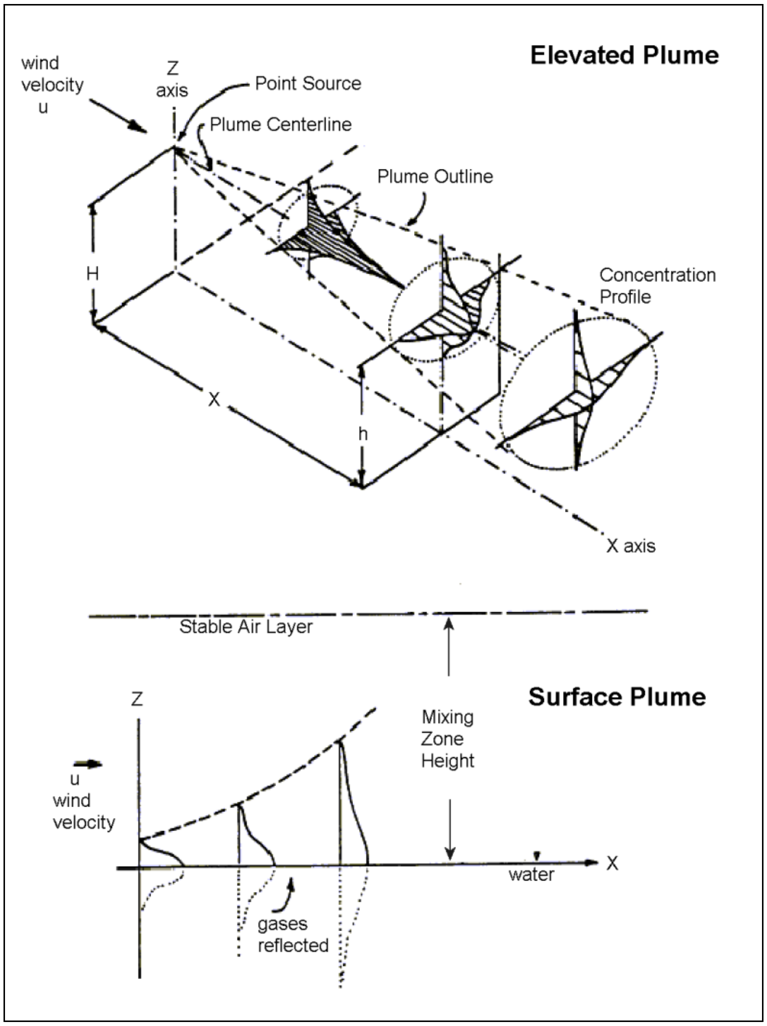


Figure 2.10 Above-sea Blowout Plume Behaviour Schematic

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

2.12.2.2 Fate and Behaviour Modelling Inputs

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

Oil Properties

Several characteristics of the geology in the Maritimes Basin (Old Harry area) compare favourably to the geological conditions encountered in the Scotian Basin. The clastic reservoir rocks in the fields on the Scotian Shelf typically comprise fluvial and shallow marine, stacked, sandstone sequences that are analogous to the fluvial sandstone reservoir rocks at Old Harry. Of particular note is the known kerogen type in both basins is Types II-III and III. In addition, light oil was produced from the Cohasset / Panuke / Balmoral Fields on the Scotian Shelf. Consequently, Corridor geoscientists have selected the Cohasset oil from the Scotian Basin as an appropriate surrogate for the oil that could be found at Old Harry. Summaries of the fresh and weathered oil property data for Cohasset crude oil are provided in Table 2.14.

Table 2.14 Fresh and Weathered Properties of the Surrogate Cohasset Crude Oil

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

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

The oil property modelling parameters that were used in the SLROSM are listed in Table 2.15. These parameters were derived using the fresh and weathered oil property data shown in Table 2.14.

Table 2.15 Oil Property Parameters Used in SLROSM Spill Modelling

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

Discharge Volumes and Flow Rates

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

The modelling of the continuous release of gas and crude oil from well blowouts has been completed using the gas and crude oil flow rates shown in Table 2.16. The blowout flow rates identified in Table 2.16 were determined by Corridor Resource Inc. engineers based on the best available reservoir information. The modeled blowout scenarios were run for one month (i.e., 30 days).

Table 2.16 Spill Flow Rates and Volumes Used in Modelling

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

Water Currents

Surface water current fields developed by the Ocean Sciences Division, Maritimes Region of DFO using the methods described by Tang *et al.* (2008) were used in the spill trajectory modelling. Seasonal mean surface water velocity data were provided by DFO from their modelling work that generated the Atlas of Ocean Currents in Eastern Canadian Waters (Wu 2011). As stated by Wu (2011), the model is driven by wind stress, heat and mostiure fluxes calculated from atmospheric parameters of North American Regional Reanalysis. The atmospheric variables include surface winds, air temperature, cloud cover, dew point temperature, air pressure and precipitation. These data were converted to a map format that was used by the SLROSM. Tidal currents were not considered in the assessment since their oscillatory movement results in little long-term net movement of surface oil. The water currents were combined with wind data (see below) to determine the initial slick characteristics and their subsequent movement.

Air and Water Temperatures

The monthly average air and water temperatures used in the detailed fate and trajectory modelling are shown in Table 2.17. Air and water temperatures used in the seasonal oil fate modelling are also shown in Table 2.17. These data are from LGL (2007).

Table 2.17 Average Monthly and Seasonal Air and Water Temperatures

Month	Average Temperatures (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air	-4.5	-6.5	-3.0	1.0	6.0	10.0	14.5	16.0	13.0	7.5	4.0	-2.5
Water	0.5	-1.0	-1.0	0.0	1.5	5.0	10.5	15.2	15.5	12.0	7.0	3.5
Season	Winter			Spring			Summer			Fall		
Air	-4.7			5.7			14.5			3.0		
Water	-0.5			2.2			13.7			7.5		
Source: derived from Figure 2.17, LGL 2007												

Winds

The MSC50 Wind data set (Swail *et al.* 2006) was used in the detailed spill trajectory modelling completed in this study. The MSC50 hind cast wind set is a long term data set with good spatial resolution over the entire Atlantic region. The data was developed by the Climate Research Division of Environment Canada and the Federal Program for Energy Research and Development. In the research paper describing the data set the authors state that "The wind and wave data are considered to be of sufficiently high quality to be used in the analysis of long return period statistics, and other engineering applications". This data set is the best available for offshore spill trajectory and behavior modelling as it provides spatially varying offshore wind velocities and historical wind variations rather than single point land-based weather data. The data set has wind and wave data for the years 1954 to 2005. Six-hourly wind speed and direction data were extracted from the full MSC 50 data set at grid points with 0.5 degree spacing over the study area. The seasonal spill behaviour modelling used the average wind speeds shown in Table 2.18. These data are from LGL (2007).

Table 2.18 Seasonal Average Wind Speeds

Average Wind Speeds by Season (m/s)			
Winter	Spring	Summer	Fall
7.96	5.72	5.72	8.59
Source: derived from Table 2.3, LGL 2007			

Additional details on the algorithms employed in the SLROSM spill model used in the simulations are provided in Tables 2.19 and 2.20. The modelling parameters provided in Table 2.15 were used in the oil property change relationships shown in Tables 2.19 and 2.20.

Table 2.19 Comparison of Model Oil Fate and Behaviour Equations

Batch Spill	Above-Sea Blowout	Subsea Blowout
INITIAL SLICK CHARACTERISTICS		
a) Initial thickness of thick slick = 2 cm	a) Volume mean diameter of oil spray droplets calculated using atomization equations of Deyson and Karian (1978) as described in S.L. Ross and Energetex (1985).	a) Volume mean diameter of oil droplets produced at wellhead calculated using atomization equations of Deyson and Karian (1978) as described in S.L. Ross and Energetex (1985)
b) Initial thick slick area = spill volume/2 cm	b) Atmospheric dispersion and settling of droplets estimated using Turner's (1970) equations	b) Initial width and thickness of slick downstream of blowout are calculated using subsea blowout plume equations of Fannelop and Sjoen (1980) as described in S.L. Ross (1982), using gas & oil flowrates, well depth and surface current
c) Initial thin slick area = 8 x thick area	c) Amount of evaporation of oil droplets in air circulated using modified evaporative exposure equation given in S.L. Ross and DMER (1988)	c) If the fresh oil's pour point exceeds the sea temperature, the slick consists as discrete droplets or "peas"

Table 2.19 Comparison of Model Oil Fate and Behaviour Equations

<table>
<tr><th>Batch Spill</th><th>Above-Sea Blowout</th><th>Subsea Blowout</th></tr>
<tr><td>d) Initial thin volume = thin area x 1µm</td><td>d) Initial oil properties are calculated based on initial evaporation and desired sea temperature</td><td>d) Initial evaporation, emulsification and natural dispersion are back-calculated from the release point to the time required to reach the initial width based on a geometric mean thickness between the two locations</td></tr>
<tr><td rowspan="2">e) Oil properties corrected to desired sea temperature</td><td>e) If the oil’s pour point exceeds the sea temperature, the oil does not form a slick on the sea surface but forms a series of discrete droplets or “peas”</td><td>e) The initial slicklet thickness is corrected to account for initial evaporation, emulsification, and natural dispersion</td></tr>
<tr><td>f) The initial width and thickness of the slick are calculated using a surface current, b) and c) above; a slicklet (of length 100s x surface current) is subsequently modelled</td><td>f) Initial oil properties area calculated based on initial evaporation, emulsification, and desired sea temperature</td></tr>
<tr><td colspan="3">SPREADING</td></tr>
<tr><td><u>Thick Slick</u>
Modified Mackay et al. (1980) equations, based on Fay gravity-viscous equation including emulsion viscosity; if oil’s pour point exceeds sea temperature the thick slick spreading ceases:
$\Delta A_{thick} = 2.2(1025 - \rho_o) \times 9.82 / (\rho_o \mu_o/10^3)^{1/2})^{2/3} (X_{thick})^{4/3} (A_{thick})^{1/3} \Delta t - (1 \times 10^{-6} \Delta_{thin}/X_{thick})$</td><td><u>Thick Slick</u>
Modified Fay “point source” surface tension-viscous equation (for lateral spreading only); include emulsion viscosity; if spreading coefficient falls below 0, thick slick spreading ceases:
$\Delta W_{thick} = \frac{3}{4} (\Theta)^{1/2}/(\Lambda_o \mu_o/10^3 t)^{1/2} \Delta t$</td><td><u>Thick Slick</u>
As per above-sea blowout</td></tr>
<tr><td><u>Thin Slick</u>
Modified Mackay et al. (1980) equations, based on Fay surface-tension viscous equation including oil viscosity; if spreading coefficient falls below 0, thin spreading stops; think slick ‘fed’ by thick slick:
$\Delta A_{thin} = 4.55 (\Theta/(\rho_o \mu_o/10^3)^{1/2})^{1/3} \exp(-0.003/X_{thick}) \Delta t$</td><td><u>Thin Slick</u>
As for thick slick, but using weathered oil properties, instead of emulsion properties</td><td><u>Thin Slick</u>
As per above-sea blowout</td></tr>
<tr><td colspan="3">EVAPORATION</td></tr>
<tr><td colspan="3">Uses modified evaporative exposure (Stiver and Mackay 1983) based on S.L. Ross and DMER 1988; includes internal mass transfer resistance if the oil’s pour point exceeds ambient temperature by 15°C</td></tr>
<tr><td colspan="3"><u>Thick Slick</u>
$\Delta F_v = (\Delta t/X_{thick}(HC/10^{-6} X_{thick} + (1/k))(\exp((6.3 - (10.3(T_0 + T_G F_v)/T_k)$

Where:
k= 0.0015 U0.78 (after Mackay et al. 1980)
C= 1 for slick
C= 6 for droplets of gelled oil
H= 0 if the oil’s pour point is less than 15°C above the sea temperature
H= exp $(6.3 - 10.3 (T_0 + T_G F_v)/T_k)$ if the oil’s pour point exceeds sea temperatures by 15°C or more.</td></tr>
<tr><td colspan="3"><u>Thin Slick</u>
Same as for thick slick, with C=1 and H=0 at all times. Initial fraction evaporated from the slick is 30%; maximum fraction evaporated from thin slick is 75%.</td></tr>
</table>

Table 2.19 Comparison of Model Oil Fate and Behaviour Equations

Batch Spill	Above-Sea Blowout	Subsea Blowout
NATURAL DISPERSION		
Thick Slick $\Delta F_{NDTHICK} = 2.78 \times 10^{-6}\ (U/8)^2\ \Delta t/(\theta_{o/w}\mu_0(1025 - \Lambda_0))X_{THICK}$ If the oil's pour point exceeds the sea temperature by 15°C or more, or the oil is present as droplets, then $\Delta F_{NDTHICK}=0$		
Thin Slick As above except using viscosity, density and thickness of thin slick; no pour point cut-off		
EMULSIFICATION		
Thick Slick $\Delta F_w = 2 \times 10^{-6}(U+1)^2\ (1-1.33F_w)\Delta t$ After Mackay & Zagorski 1982. Oil does not begin to emulsify until it has reached a specified degree of evaporative exposure determined based on analysis of oil (Bobra 1989), if the oil is in the form of droplets it does not emulsify.		
Thin Slick No emulsification of thin slick occurs.		

Table 2.20 Expressions Used to Relate Weathering and Temperature to Oil Property Changes in SL Ross Model

Property	Units	Expression
Density	Kg/m^3	$\Lambda_o[1\text{-C1}\ (T\text{-}T_o]\ (1\text{+C2F})$
Emulsion density	Kg/m^3	$\Lambda_o\ (1\text{-}F_w) + 1025\ F_w$
Viscosity	mPas (cp)	$\mu[\exp\ (C3\{1/T - 1T_o\})\ x\ \exp\ (C4F)]$
Emulsion Viscosity	mPas (cp)	$\mu[\exp\ (2.5F_w/\{1\text{-}0.65F_w\})]$
Aqueous solubility	g/m^3	S.exp (C5F)
Pour Point	°K	PP. (1+C6F)
Flash Point	°C	FIP. (1+C7F)
Fire Point	°C	FiP. (1+C8F)
Oil-Water Interfacial Tension	mN/m (dyne/cm)	$\theta_{ow}\ (1\text{+ C69F})$
Oil-Air Interfacial Tension	mN/m (dyne/cm)	$\theta_{oa}\ (1\text{+ C10F})$

2.12.2.3 Fate and Behaviour Modelling Results

Three spill types have been modelled: batch diesel spills, blowouts from the seabed and blowouts from the platform above the water surface. The behavior of the oil from these three types of spills, assuming average seasonal water currents and wind conditions, is summarized below. The survival time of the oil on the surface and approximate travel distance from source after spillage and the size and extent of dispersed oil clouds are provided. This provides a picture of the likely general behavior of the oil for use in spill impact assessment and spill countermeasures planning.

Instantaneous batch spills of 1.59 m^3 and 15.9 m^3 (10 and 100 barrels) have been modelled for marine diesel. These two spill sizes have been chosen as representative of medium- and large-sized batch spills from offshore drilling operations. To put these volumes in perspective, in the

14 years of operations at the Hibernia facility, the maximum fuel oil spill size from a vessel transfer operation has been approximately 0.2 m^3 (approximately 1.3 barrels) and the maximum fuel oil spill from all operations was approximately 2 m^3 (12.5 barrels) (C-NLOPB 2011b).

The modelling of the continuous releases of gas and crude oil from well blowouts has been completed using the gas and crude oil flow rates shown in Table 2.21. The blowout flow rates identified in Table 2.21 were determined by Corridor engineers based on the best available reservoir information.

Table 2.21 Spill Flow Rates and Volumes Used in Modelling

Spill Type	Source	Flow	Gas-to-Oil Flow Ratio (m^3/m^3)
Crude Oil Blowout	Subsea (470 m water depth)	817.6 m^3/day (5,143 bopd)	89
	Surface Drilling Installation	2,102.7 m^3/day (13,226 bopd)	89
Batch Diesel Fuel Spills	Drilling Platform Operations	15.9 m^3 (100 bbl)	na
	Vessel Transfer	1.59 m^3 (10 bbl)	na

Batch Diesel Spill Fate Modelling

The fate of the "batch" spills for the four seasons (using the average seasonal air and water temperatures and wind speeds described in SL Ross (2011a, updated 2012) are provided in Table 2.22. The ranges reported below reflect the differences due to seasonal temperature and wind variations. Winter-fall and spring-summer results are quite similar due to similar environmental conditions for these seasonal pairings.

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

Table 2.22 Batch Diesel Spill Characteristics

Spill Volume m^3 (bbl)	Season	Initial Slick Width (m)	Slick Survival Time (hr)	Max. Slick Width (m)	Total Evap. %	Dist. to Loss of Slick (km)	Peak Disp. Oil Conc. (ppm)	Time to Peak Conc. (hr)	Time to 0.1 ppm (hr)	Dispersed Oil Plume Width at 0.1 ppm (m)	Distance to 0.1 ppm (km)
1.59 (10)	Winter	10	20	55	27	20	0.42	2	7	490	7.0
1.59 (10)	Spring	10	36	58	36	26	0.20	1	4	275	2.8
1.59 (10)	Summer	10	32	56	40	17	0.21	1	4	275	2.3
1.59 (10)	Fall	10	17	52	30	18	0.47	1	7	490	7.5
15.9 (100)	Winter	32	30	133	27	31	0.92	3	24	2,020	24

Table 2.22 Batch Diesel Spill Characteristics

Spill Volume m^3 (bbl)	Season	Initial Slick Width (m)	Slick Survival Time (hr)	Max. Slick Width (m)	Total Evap. %	Dist. to Loss of Slick (km)	Peak Disp. Oil Conc. (ppm)	Time to Peak Conc. (hr)	Time to 0.1 ppm (hr)	Dispersed Oil Plume Width at 0.1 ppm (m)	Distance to 0.1 ppm (km)
15.9 (100)	Spring	32	49	139	35	35	0.43	3	14	1,140	10
15.9 (100)	Summer	32	43	134	38	24	0.43	3	13	1,060	7
15.9 (100)	Fall	32	25	127	29	26	1.02	3	25	2,140	26

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

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

Maximum in-water oil concentrations from the dispersed oil will reach 0.43 to 1.02 ppm within three hours after release for these larger diesel spills. The dispersed oil concentration in the water column will drop to 0.1 ppm within 13 to 25 hours. By the time the dispersed oil drops to 0.1 ppm, the dispersed oil zone will be 1,060 to 2,140 m in diameter, 30 m deep and will be between 7 and 26 km from the spill site.

Surface Blowout Fate and Behaviour Modelling

In this scenario, a blowout occurs on the surface drilling rig resulting in a discharge of 2,102.7 m^3/day of crude oil with a gas-to-oil ratio (GOR) of 89 m^3/m^3. The rig is not severely damaged and remains in position throughout the blowout period. The gas exits at the drill floor (21 m above the water surface) at high velocity and atomizes the crude oil into small diameter droplets. These droplets are propelled upward by the jet of gas, contact the derrick and agglomerate to a size of approximately 0.5 mm. This volume median drop size has been selected for the surface blowout modelling based on model calibration results using data from the Shell *Uniacke G-72* blowout that occurred off of Nova Scotia in 1984. These droplets rain down on the surface of the water downwind of the rig. Most of the droplets fall onto the water surface within a few hundred metres of the rig in a narrow swath and re-coalesce to form a thin slick. Minor differences in the initial slick characteristics and change in crude oil property over time will exist depending on the season (due to temperature and wind speed differences). The ranges of values reported below for the slick and dispersed plume characteristics reflect variations due to the seasonal environmental inputs. The results of the fate modelling are summarized in Table 2.23.

Table 2.23 Surface Crude oil Blowout Spill Characteristics

Spill Flow Rate m^3/day (bopd)	Season	Initial Slick Width (m)	Initial Slick Thick (mm)	Evap. In Air %	Slick Survival Time (hrs)	Total Evap. %	Peak Disp. Oil Conc. (ppm)	Time to 0.1 ppm Disp. Oil Conc. (hr)	Dispersed Oil Plume Width at 0.1 ppm Disp. Oil conc. (km)	Distance from Source at 0.1 ppm Disp. Oil (km)
Drill site located at 48.051471 N; -60.394274 W (release 21m above water surface)										
2,103 (13,226)	Winter	70	1.0	30	1.6	35	6.0	15	1.2	3.4
2,103 (13,226)	Spring	54	1.6	39	2.6	44	3.4	15	1.2	3.7
2,103 (13,226)	Summer	54	1.6	46	2.4	50	3.8	15	1.2	3.8
2,103 (13,226)	Fall	75	0.8	36	1.1	41	6.8	14	1.1	3.8

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

Subsea Blowout Fate and Behaviour Modelling

The crude oil flow rate modelled was 817.6 m^3/day and the GOR used was 89 m^3/m^3, as per Table 2.24. The fluids erupt from the seabed and the turbulent flow breaks the crude oil up into small droplets. These droplets are then quickly carried to the surface by the gas bubble plume. Since the water depth at the Old Harry site is less than 500 m, significant quantities of the gas are not likely to form hydrates and a bubble plume will develop as described in the shallow water subsea blowout description.

Table 2.24 Subsea Blowout Spill Characteristics

Spill Flow Rate m^3/day (bopd)	Season	Initial Slick Width (m)	Initial Slick Thick (mm)	Slick Survival Time (min)	Total Evap. %	Peak Disp. Oil Conc. (ppm)	Time to 0.1 ppm Disp. Oil Conc. (hr)	Dispersed Oil Plume Width at 0.1 ppm Disp. Oil conc. (km)	Distance from Source at 0.1 ppm Disp. Oil (km)
Drill site located at 48.051471 N; -60.394274 W (470 m water depth)									
817 (5,143)	Winter	1,647	0.028	1	16	0.8	30	4.5	5.1
817 (5,143)	Spring	2,165	0.028	2	25	0.7	35	5.7	6.6
817 (5,143)	Summer	2,537	0.028	2	29	0.7	38	6.4	8.1
817 (5,143)	Fall	1,478	0.028	1	19	0.7	27	4.0	6.3

At the surface, the crude oil drops spread to form a thin slick, since the ambient temperature in all seasons is well above the fresh crude oil's initial pour point. The entrained water flow creates an initial slick that extends away from the source. Near the source, there will be a localized zone of surface turbulence created by the exiting gas. The initial oil slick characteristics and ultimate fate of the surfacing oil are summarized in Table 2.24.

In general, the initial oil slicks from these subsea blowouts will be wide, thin and non-persistent due to the lateral spreading caused by the outflow of water brought to the surface by the gas bubble plume and the volatile, low-viscosity nature of the surrogate crude oil. The initial width of the slicks will vary between 1,478 and 2,537 m, depending on the combined wind-induced and residual surface currents for each season. These widths are estimated at the point where the surface water flow created by the blowout gas plume is no longer influencing the surface oil behaviour. The initial slick thicknesses will be only 0.028 mm, or 28 microns. Because of this very thin initial oil thickness, the model predicts that the surfacing light crude oil will completely evaporate and disperse into the water column within minutes. Traces of surface oil may persist for longer periods but it is unlikely that significant patches of thick oil will survive for extended periods assuming average seasonal environmental conditions.

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

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

2.12.2.4 Surface Oil Trajectory Modelling Results

Currents and wind will move spilled crude oil until it disperses into the water, evaporates or contacts land. As noted in the previous sections, spills of crude oil with characteristics similar to

Cohasset will not be persistent, and surface slick survival times of only a few hours at most are likely even under relatively calm winds.

Example surface slick trajectories from the proposed exploration site have been modelled for the four seasons to show the surface area that might be affected by month-long releases of crude oil. The average surface water current data utilized in the trajectories provides the seasonal trend in the surface water movement in the region (including wind stress effects). Tidal currents were not considered in the assessment since their oscillatory movement results in little long-term net movement of surface oil. When the seasonal average surface water current is combined with the 52 years of MSC50 wind data, the variation in trajectories possible from the drilling location are well represented for the purposes of impact assessment, especially for a spill of non-persistent crude oil. The wind induced movement of the surface slicks is also often more pronounced than the average surface water current effect.

The quantity of oil that would be released from six hours of a continuous above sea blowout has been introduced on the surface at the exploration site as a batch spill every six hours over month-long periods. This does not represent a scenario that would actually occur in a continuous blowout, from the standpoint of initial oil thickness estimates and rate of oil evaporation and dispersion, but rather, provides a reasonably conservative assessment of spill behaviour. A continuous release of oil, either from the surface or from the seabed, would generate thinner initial slicks than those modelled using the 6 hour batch quantities used in this assessment.

Each one of these six-hour quantities of oil has been tracked until the surface oil is completely evaporated and dispersed from the surface. All major oil spill processes are accounted for in the modelling (evaporation, emulsification and dispersion). The entire history of the movement of these six-hourly releases (initiated at the start of each month for February, May, August and November, respectively, and tracked until all of the surface oil is completely dispersed) are illustrated in Figures 2.11 to 2.14. These months were chosen because they represent the middle month in each of the four seasons. These plots do not represent the area of the ocean where crude oil is present at a point in time but merely show the total area that surface oil travelled over during each one-month release of oil.

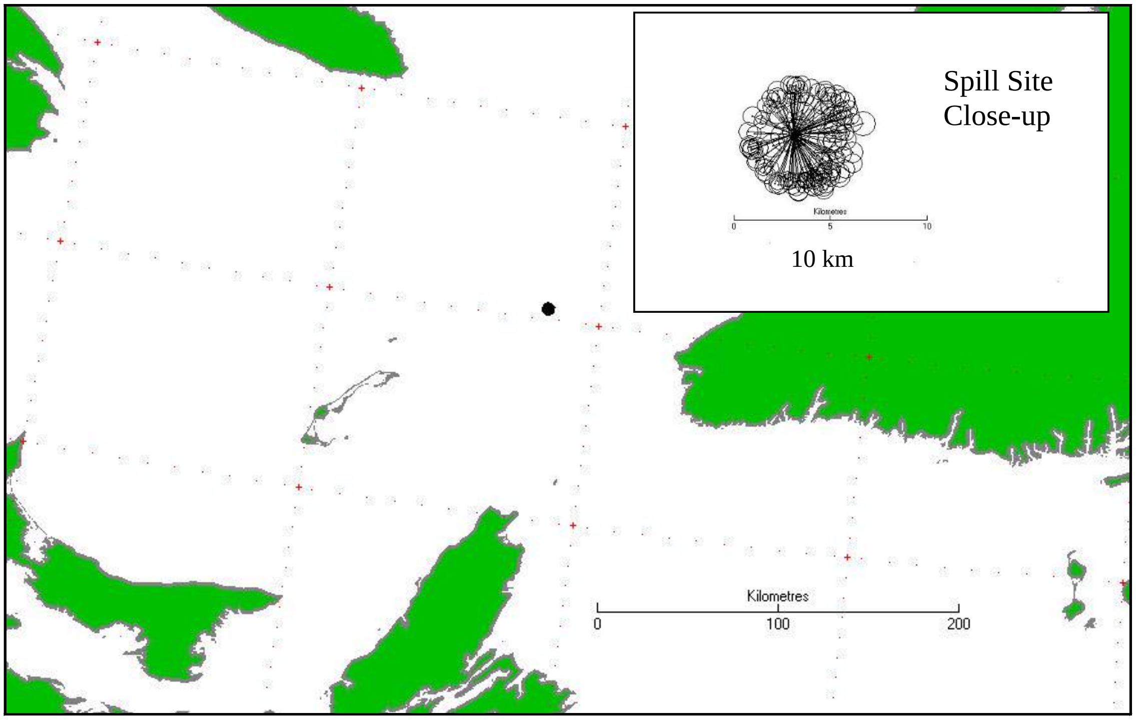


Figure 2.11 Surface Oil Trajectory Envelope for Surface Crude Oil: Based on Batch Releases of Six-hour Accumulations from the Blowout for the Month of February

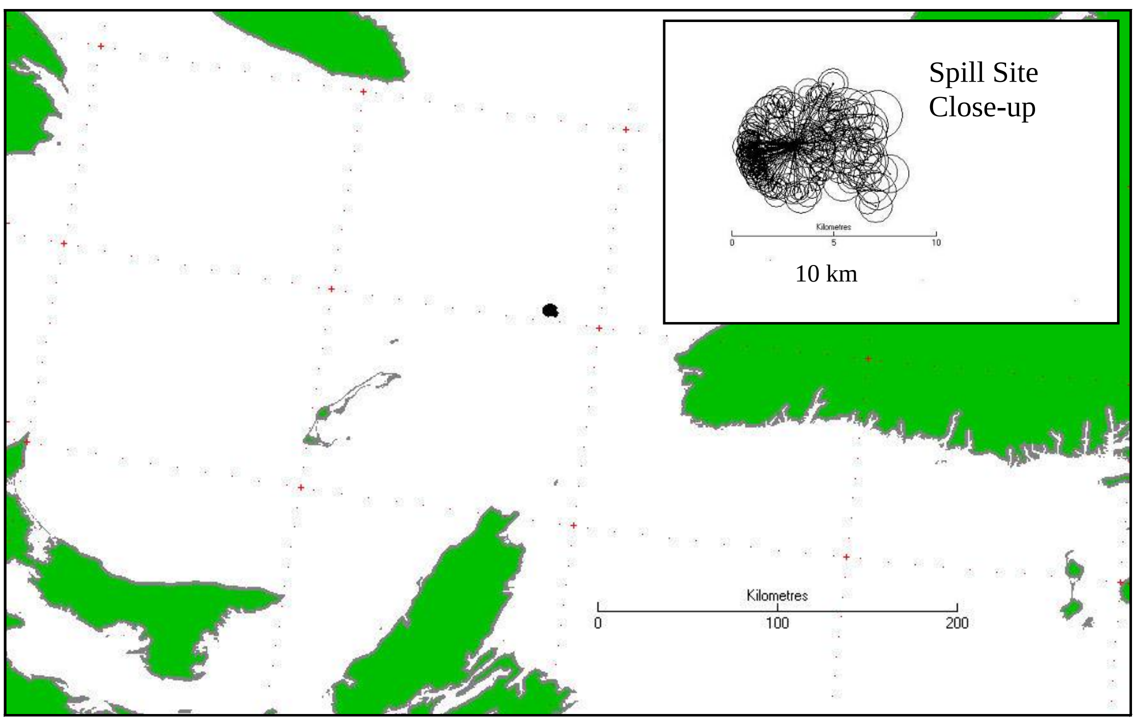


Figure 2.12 Surface Oil Trajectory Envelope for Surface Crude Oil: Based on Batch Releases of Six-hour Accumulations from the Blowout for the Month of May

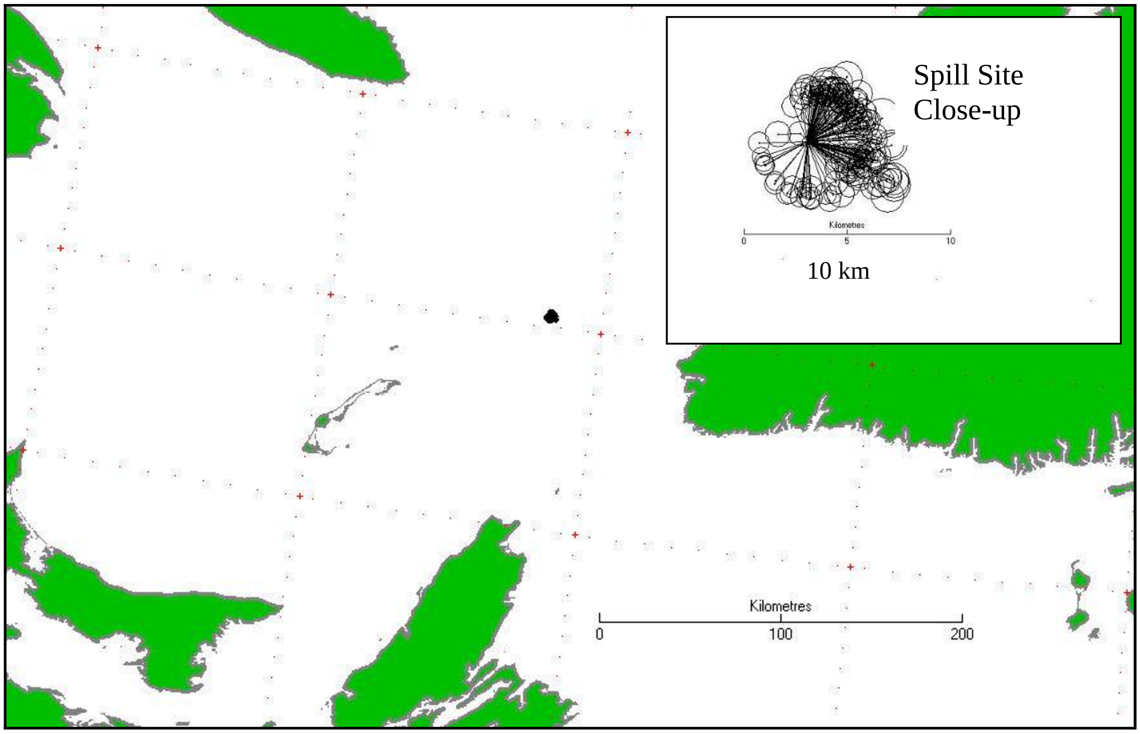


Figure 2.13 Surface Oil Trajectory Envelope for Surface Crude Oil: Based on Batch Releases of Six-hour Accumulations from the Blowout for the Month of August

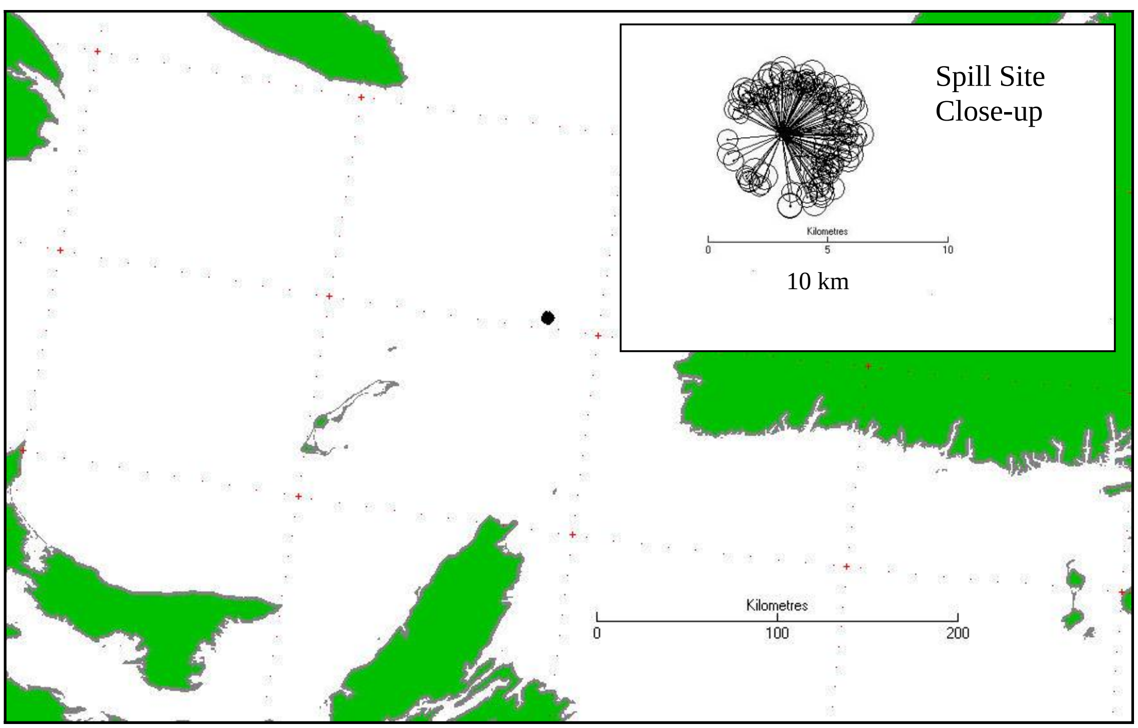


Figure 2.14 Surface Oil Trajectory Envelope for Surface Crude Oil: Based on Batch Releases of Six-hour Accumulations from the Blowout for the Month of November

The circles in the figures represent the positions of 112 (28 days x 4 slicks per day) to 124 (31 days x 4 slicks per day) slicks of crude oil reported every 1.5 hours. The total areas of ocean surface that the slicks passed over during the one-month releases of crude oil, as represented by the composite line work shown in the close-up views, are relatively small. The radii of the total surface areas where surface oil passed through are only approximately 3 km from the spill source in all seasons. The areas swept by surface oil during the month-long releases are small because the light crude oil evaporates and disperses rapidly under typical weather conditions. Each six-hourly release of oil is subjected to different wind speeds and directions so each surface slick will move along a different path.

SL Ross (2011a, updated 2012) also conducted an historical surface oil spill trajectory assessment for surface oil trajectory of above-sea blowouts (including alternative trajectory assessments using conservative above sea blowout and accumulated six-hour batch spills reasonably conservative oil fate modelling). The full trajectories (from source to complete loss of surface slick) of all 75,920 slicks (*i.e.*, the maximum modelled extent of the slick) are shown in Figures 2.15 and 2.16.

Even in the most conservative modelling approach, no oil slicks reached shore; 53 percent of the slicks survived for five hours or less and only 16 percent lasted for more than 10 hours (Table 2.25). As was the case for the conservative modelling approach, no crude oil slicks reached shore; 51 percent of the slicks survived for five hours or less and only 19.3 percent lasted for more than 10 hours (Table 2.25).

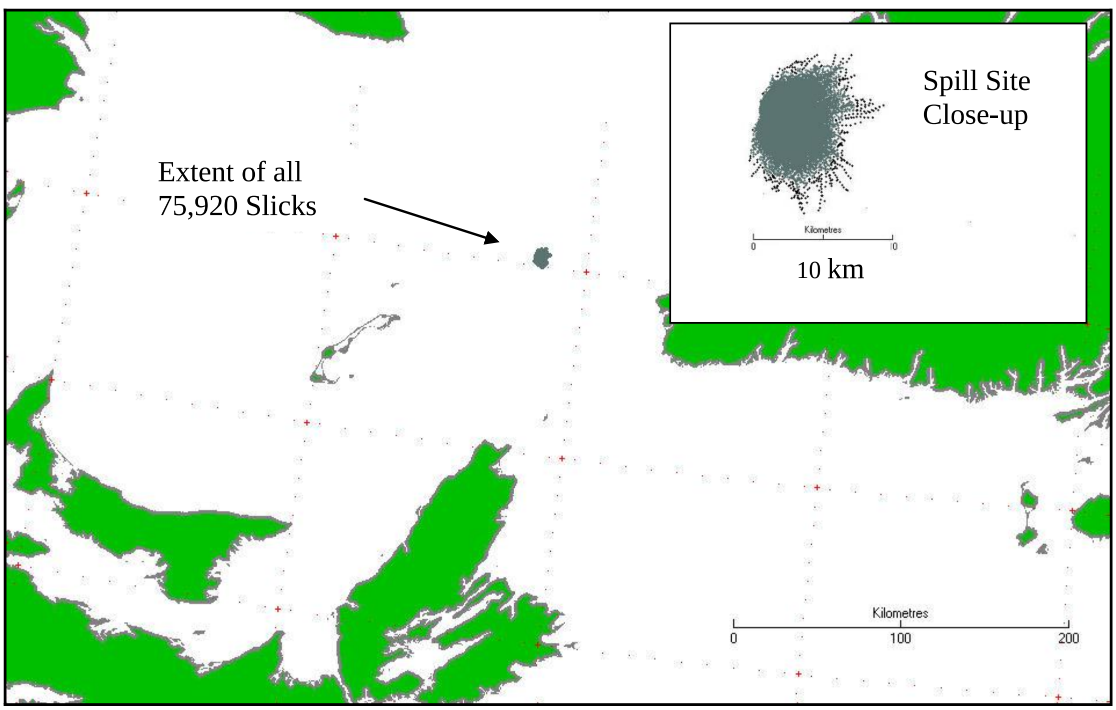


Figure 2.15 Maximum Area of Ocean Surface Swept by Oil from 52 Years of Above Sea Blowout Simulations

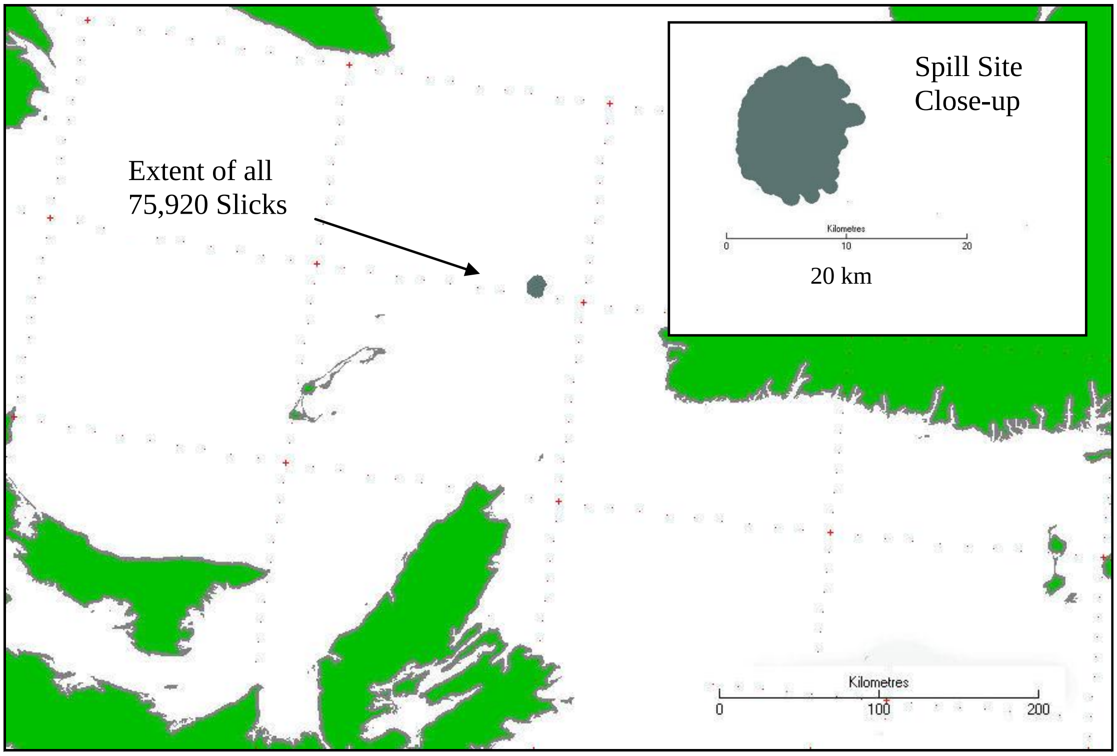


Figure 2.16 Maximum Area of Ocean Surface Swept by Oil from 52 Years of Simulations Using a Reasonable Conservative Modelling Approach

Table 2.25 Slick Shoreline Contact and Slick Life at Sea: Conservative and Reasonable Conservative Modelling Approach

Month	Number of Slicks Tracked	% of Slicks Tracked Reaching Shore		Minimum Slick Life at Sea (hours)		Maximum Slick Life at Sea (hours)	
		Conservative	Worst-Case	Conservative	Worst-Case	Conservative	Worst-Case
January	6,448	0.0	0.0	0.11	0.5	16.6	18.4
February	5,824	0.0	0.0	0.13	0.6	25.0	25.6
March	6,448	0.0	0.0	0.14	0.7	27.8	29.5
April	6,240	0.0	0.0	0.15	0.7	35.7	34.7
May	6,448	0.0	0.0	0.17	0.8	56.1	51.4
June	6,240	0.0	0.0	0.22	0.9	39.0	38.3
July	6,448	0.0	0.0	0.21	0.8	37.3	36.7
August	6,448	0.0	0.0	0.15	0.7	38.0	34.7
September	6,240	0.0	0.0	0.12	0.6	34.4	31.5
October	6,448	0.0	0.0	0.10	0.5	22.8	24.3
November	6,240	0.0	0.0	0.11	0.6	24.7	24.9
December	6,448	0.0	0.0	0.09	0.5	14.6	15.3

2.12.2.5 Typical Monthly Dispersed Oil Plume Trajectories Modelling Results

The movement and extent of the oil dispersed into the water column below the surface slicks is discussed in this section. The dispersed oil plumes resulting from the simulations described in Section 2.12.2.2 are discussed in this section. Example dispersed oil plume trajectories from the proposed exploration site have been modelled for the four seasons to show the subsea regions that might be affected by month-long releases of crude oil. In these simulations, the quantity of oil that would be released from six hours of a continuous above sea blowout has been introduced on the surface at the exploration site as a batch spill every six hours over month-long periods. As discussed previously, this does not represent a scenario that would actually occur in a continuous blowout situation (from an initial slick thickness standpoint) but rather provides a reasonably conservative assessment of dispersed oil behaviour.

The dispersed oil is assumed to mix into the upper 30 m water layer under the slick and is then diffused laterally by ocean diffusion processes. The entire histories of the movement of the dispersed oil plumes from these six-hourly releases during the months of February, May, August and November are illustrated in Figures 2.17 to 2.20, respectively. The total volumes of ocean swept by the plumes during the one-month releases of crude oil are represented by the areas shown in the close-up views (times the 30 m mixing depth). The dimensions of the swept areas in Figures 2.17 to 2.20 vary from 18 to 22 km for the plume widths and 25 to 40 km for the plume lengths. The spill source is located at the narrow end of the plots and the general direction of movement of the plumes reflects the direction of the seasonal surface water currents in the vicinity of the drilling site. Again, these plots do not represent the extent of the in-water oil plume at any given point in time.

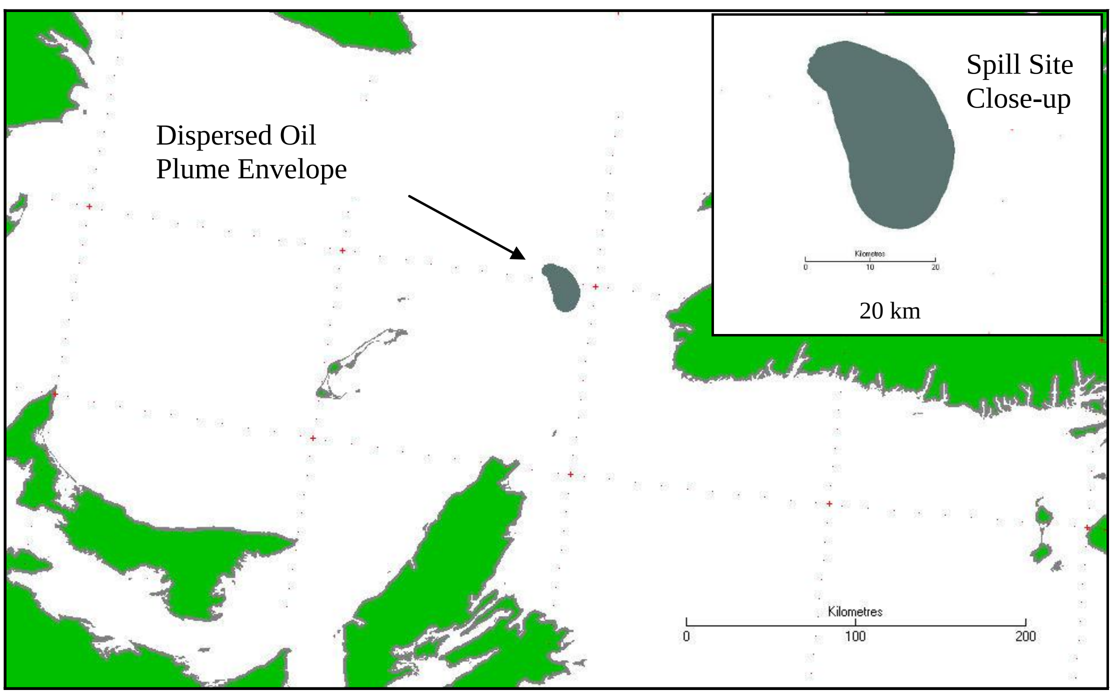


Figure 2.17 Reasonably Conservative Dispersed Oil Plume Trajectory Envelope: Based on Batch Releases of Six-hour Accumulations, for the Month of February

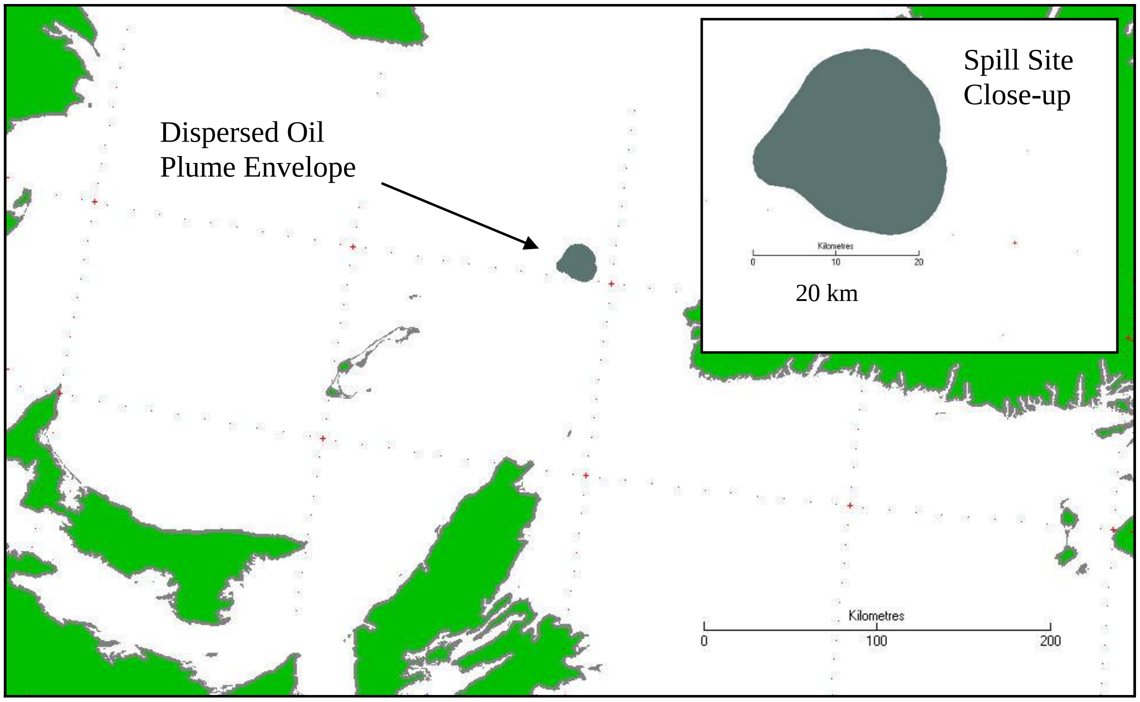


Figure 2.18 Reasonably Conservative Dispersed Oil Plume Trajectory Envelope: Based on Batch Releases of Six-hour Accumulations, for the Month of May

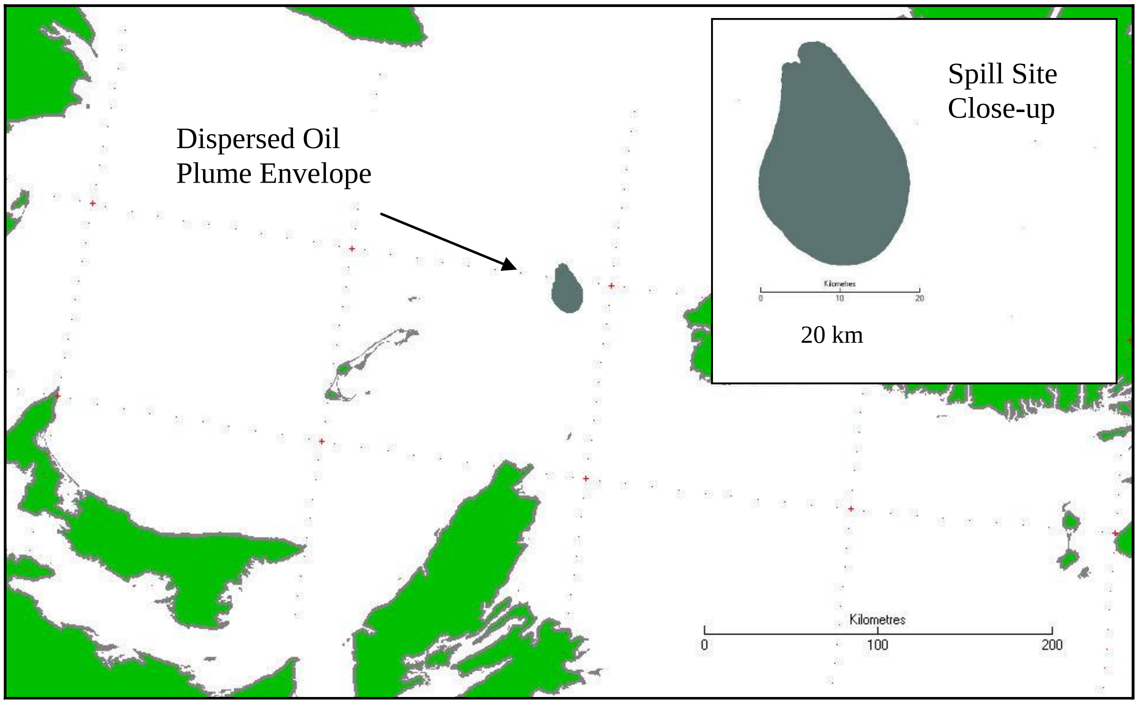


Figure 2.19 Reasonably Conservative Dispersed Oil Plume Trajectory Envelope: Based on Batch Releases of Six-hour Accumulations, for the Month of August

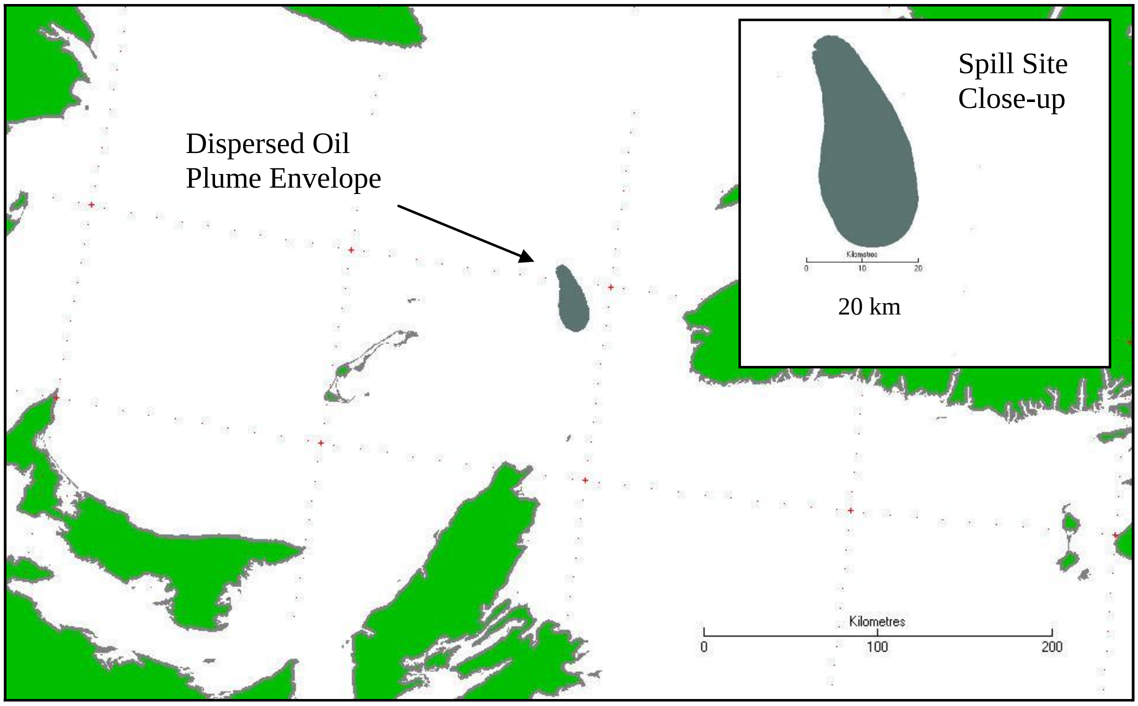


Figure 2.20 Reasonably Conservative Dispersed Oil Plume Trajectory Envelope: Based on Batch Releases of Six-hour Accumulations, for the Month of November

SL Ross (2011a, updated 2012) also conducted an historical dispersed oil plume trajectory assessment for dispersed oil plumes from above-sea blowouts. The same two sets of simulations reported for the surface slick trajectories, the above-sea blowout release and the reasonably conservative six-hourly batch releases, are also provided for the dispersed oil plumes (The full trajectories (from source to complete loss of surface slick) of all 75,290 slicks (*i.e.*, the maximum modelled extent of the slick) are shown in Figures 2.21 and 2.22.

The best estimate of the maximum possible region swept by the dispersed oil plume, out to 0.1 ppm is presented in Figure 2.21 and is based on the detailed modelling of an above-sea continuous blowout as described in Section 2.12.2.3. The areas do not represent the extent of the dispersed oil plume from a single blowout event; rather the area on Figure 2.21 shows the maximum extent of dispersed oil plumes with concentrations greater than 0.1 ppm for all of the 75,290 simulations completed using 52 years of wind data. Note that the surface footprint in Figure 2.22 is larger than the continuous above-sea blowout estimate provided in Figure 2.17 due to the larger volume of oil being considered in each six-hour release and the greater time required for the dispersed oil to diffuse to 0.1 ppm cutoff concentration.

The maximum modelled trajectory was superimposed on the Project Area (red rectangle) / Study Area (dotted line) to indicate the maximum extent to the spill in relation to these areas (Figure 2.23). As indicated in Figure 2.23, the predicted maximum extent of a spill only just extends beyond EL 1105 and does not extend much into the Study Area.

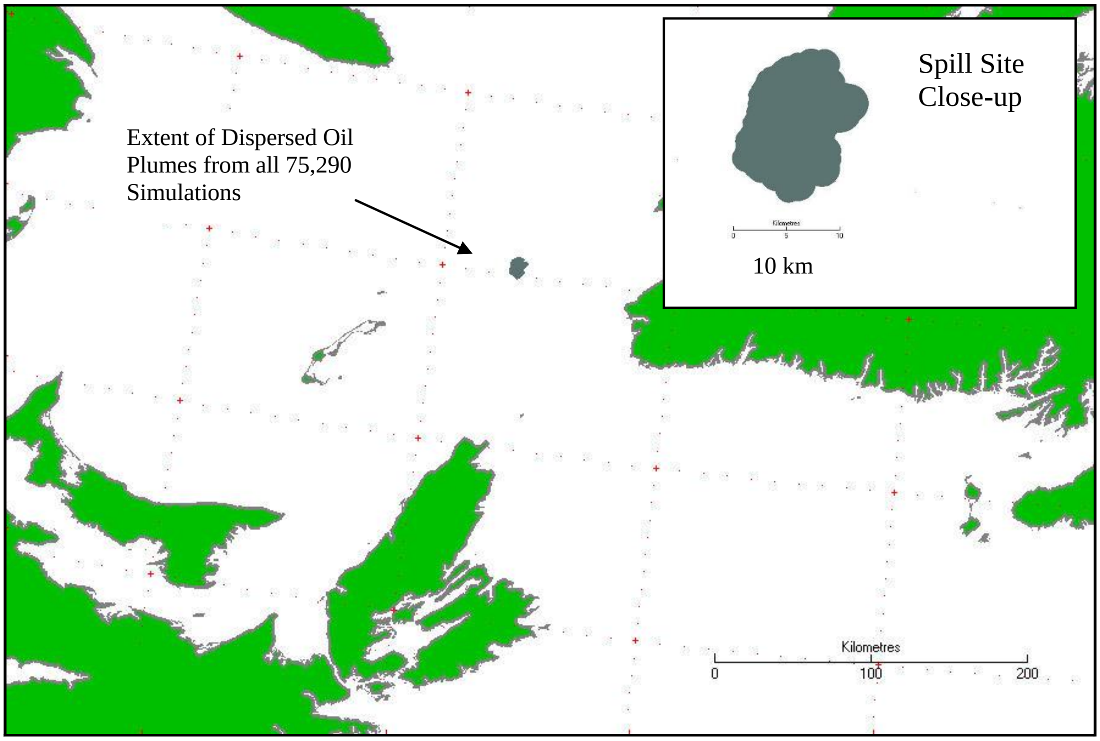


Figure 2.21 Maximum Extent of Ocean Swept by >0.1 ppm Dispersed Oil from 52 Years of Above Sea Blowout Simulations

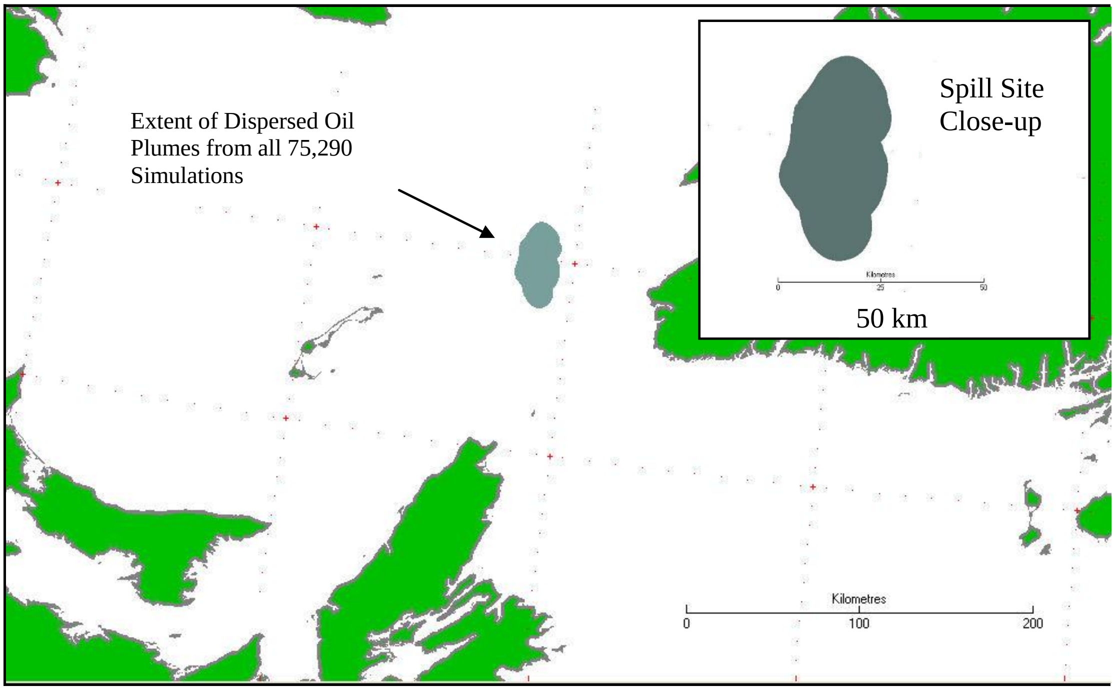


Figure 2.22 Maximum Extent of Ocean Swept by >0.1 ppm Dispersed Oil from 52 Years of Simulations Using a Conservative Modelling Approach: Six-hourly Accumulations Released as Batch Spills

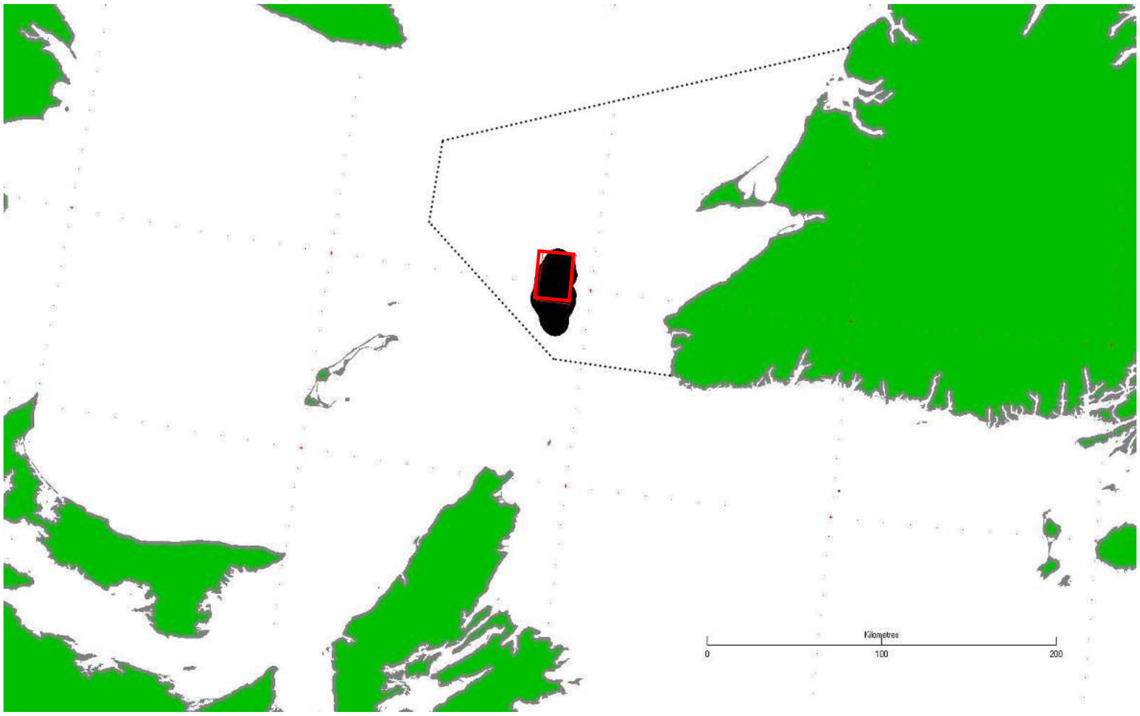


Figure 2.23 Predicted Maximum Extent of Oil Plume Trajectory in Relation to Exploration Licence 1105

3.0 STAKEHOLDER CONSULTATION

Corridor understands the importance of communicating with key stakeholders, including fisheries organizations, environmental organizations, First Nations representatives, regulators, provincial, federal and municipal governments, media and others. Corridor began the consultation process early and continues with its efforts throughout the Environmental Assessment process.

The Corridor website is also used as an information tool. A description of the proposed exploration well is posted, as well as regular updates.

Overall, the consultation for the proposed exploration project is designed to foster open, two-way dialogue with key stakeholders. Through this process, Corridor has identified important issues and reflected those in its planning for this proposed exploration well. The results of the public consultation program have been compiled in this Environmental Assessment report.

3.1 Legislated Requirements

CEAA requires that public consultation be conducted at three points during an Environmental Assessment:

- during the preparation of the Scoping Document;
- during the conduct of the Environmental Assessment; and
- during a review of the completed Environmental Assessment prior to the Minister's issuance of an Environmental Assessment decision statement.

The Scoping Document was made available by the C-NLOPB for public review and comment, for the period from February 25 to March 28, 2011. A public notice was placed on the Canadian Environmental Assessment Registry internet site (Registry reference number 11-01-60633) to initiate the public comment period; the public notice was also placed on the C-NLOPB internet site and was advertised in certain newspapers. The C-NLOPB, on behalf of the RAs, invited the public to comment on the draft Scoping Document for the Old Harry Project. Also, a notice was posted on the C-NLOPB web site and the draft Scoping Document and Project Description were made available electronically on the C-NLOPB website; hard copies were available from the C-NLOPB upon request. Comments were requested to be provided, either electronically or via post, by March 28, 2011. The majority of the comments received were outside the scope of the Environmental Assessment of a single exploration well within EL 1105 and instead focused on broader policy issues.

A consultation program was designed and carried out by Corridor during the preparation of the Environmental Assessment. Questions and issues relevant to the single exploration well proposal raised by stakeholders throughout the consultations are addressed in this Environmental Assessment.

The consultation program focused primarily on the geographic region most likely to be affected by the Project, the west coast of Newfoundland, as well as the Magdalen Islands due to their level of interest in the Project. The consultation program during the preparation of the Environmental Assessment involved:

- reviewing the SEA and Amendment prepared for the Western Newfoundland Offshore Area (LGL 2005b, 2007);
- reviewing issues raised during consultations held for the Western Newfoundland SEA;
- consulting community members, fishers, businesses and organizations, environmental non-governmental organizations and the general public;
- meetings with government departments and agencies;
- open houses;
- media communications and monitoring;
- distributing Project information through traditional and electronic media; and
- establishing a Project website [http://www.corridor.ca/oil-gas-exploration/gulf-of-saint-lawrence.html].

An important component of the consultation program was the recording of issues and comments raised at meetings and events. Consultations conducted to date during the preparation of the Environmental Assessment are detailed in the rest of this section. Corridor will continue open dialogue with interested stakeholders with questions or concerns.

On June 3, 2011, the C-NLOPB referred the Environmental Assessment to the Minister of the Environment with the recommendation for either a mediator or a review panel. On August 15, 2011, the Minister of Environment determined that the Environmental Assessment should proceed as a screening, but requested that extensive public consultation be conducted in conjunction with the screening-level environmental assessment. In addition, the Minister of Environment also requested an update of the 2007 Strategic Environment Assessment (SEA) for the Western Newfoundland Offshore Area. The C-NLOPB had established an independent review that was to focus on the potential environmental effects of the proposed drilling of a single exploration well on EL 1105, although this independent review was subsequently cancelled by the C-NLOPB.

The C-NLOPB established a working group to oversee the process of updating the SEA for the Western Newfoundland Offshore Area. An integral part of the SEA process is public consultation. This process provides the public with an opportunity to have input on broader policy issues associated with oil and gas exploration and development in the Western Newfoundland Offshore Area. A draft Scoping Document for the Western Newfoundland and Labrador Offshore Area SEA Update was published for public comment on December 21, 2011. Comments received were reviewed and incorporated as appropriate by the C-NLOPB into a Final Scoping Document which was released on February 21, 2012. Public consultation sessions were held as part of the SEA Update process in Newfoundland and Labrador, New Brunswick, Prince Edward Island, Nova Scotia, Magdalen Islands and Quebec in September and October, 2012. The next opportunity for public consultation on the SEA Update process will be a public review of a draft SEA Update report, expected to be released in early spring 2013. The final SEA Update is expected to be published in summer 2013.

3.2 Consultation in Local Municipalities

Corridor met with several local municipal governments on the west coast of Newfoundland and on the Magdalen Islands including:

- Zone 10 - Marine and Mountain Zone Corporation;
- Town of Channel-Port aux Basques;
- Port aux Basques Chamber of Commerce;
- Zone 9 - Long Range Regional Economic Development Board;
- Federation of Newfoundland Indians (currently known as the Qalipu Mi'kmaq First Nation Band);
- Corner Brook Board of Trade;
- City of Corner Brook; and
- Corner Brook Port Corporation.

Corridor also met with Magdalen Islands municipality representatives and made a presentation to the Hydrocarbon Working Committee. While not considered official consultation by the Working Committee, it provided Corridor with an opportunity to provide Project information and for Committee members to comment on the proposed Project.

3.3 Commercial Fisheries

Fisheries groups and civic leaders in Newfoundland and Labrador include One Ocean, the Fish Food and Allied Workers (FFAW), the Seafood Producers' Association, and fishers in Western Newfoundland. The Magdalen Islands also has a number of fishing associations (see Section 3.3.2).

3.3.1 One Ocean, FFAW and Other Fisheries Groups in Newfoundland

One Ocean is a liaison organization to facilitate communication between the fishing and oil and gas industries in Newfoundland and Labrador. Corridor met with One Ocean and FFAW in St. John's and also met with the west coast Newfoundland FFAW representative in Corner Brook. Both meetings included a presentation of the proposed Project and an opportunity for the organization representatives to ask questions and voice any issues or concerns about the Project. FFAW submitted comments on the December 2011 Old Harry EA Report indicating they had no issues with the documents (R. Saunders, FFAW, pers. comm. 2012).

3.3.2 Magdalen Island Fishing / Fisheries Representatives

In addition to the Magdalen Islands municipality representatives, Corridor met with the following Magdalen Island fishing organizations:

- Regroupement des Pecheurs Professionnels des Îles (RPPIM);
- Regroupement des Palangriers et Petoncliers Unique Madelinots (RPPUM);
- Association des pêcheurs propriétaires des Îles-de-la-Madeleine (APPIM); and

- Association of Inshore Fishermen of the Magdalen Islands.

The meetings included a presentation on the Project and it provided an opportunity for fishing representatives to comment on the proposed Project.

3.4 Meetings with Government Departments and Agencies

In order to assist in the scoping of the effects assessment, the identification of appropriate mitigation and addressing of any issues of concern, Corridor and its consultants undertook a consultation program with key regulatory stakeholders, including but not limited to:

- C-NLOPB;
- DFO (including A/Regional Manager - Environmental Assessment and Major Projects Newfoundland Region; an Environmental Assessment Analyst - Environmental Assessment and Major Projects Newfoundland Region; Regional Manager - Environmental Assessment and Major Projects Gulf Region; A Senior Advisor for Oil and Gas, Ecosystem Management Branch – Gulf Region; and an Analyste principale, Évaluation environnementale – Quebec Région. (note that this meeting was a presentation on the Project and did not include any discussion on the Environmental Assessment);
- Environment Canada in Newfoundland and Labrador;
- Transport Canada and Navigable Waters Protection in Newfoundland and Labrador;
- Canadian Environmental Assessment Agency (CEA Agency);
- National Energy Board;
- Assembly of First Nations' Chiefs in New Brunswick;
- Mi'kmaq Confederacy Prince Edward Island; and
- Government officials and elected representatives, in particular inside the provincial governments of Newfoundland and Labrador and Quebec, including the Newfoundland and Labrador Department of Natural Resources and Quebec Department of Natural Resources.

The Corridor Study Team have been consulting with key government officials and regulators both formally and informally on an ongoing basis. The objective of these consultations is to provide information and updates on the Project and the Environmental Assessment, and also to receive input and guidance as appropriate. The C-NLOPB and Federal Authorities have been regularly consulted since filing of the Project Description.

Corridor has met with the Premier of Newfoundland and Labrador and there have also been ongoing meetings with the Newfoundland and Labrador Minister of Natural Resources and the deputy ministers and assistant deputy ministers to keep them apprised of Project developments.

These consultations have involved one-on-one meetings (locally and in Ottawa), telephone conversations and e-mail correspondence.

3.5 Other Consultation Methods

Corridor held a series of open houses on the West Coast of Newfoundland. Corridor also provided information to the public and tracked issues using press releases and the Project website.

3.5.1 Open Houses

Open houses were held on the west coast of Newfoundland in Port aux Basques (14 attendees, including local media), Stephenville (9 attendees) and Corner Brook (6 attendees, including local media). The open houses consisted of a handout and display panels and the chance to discuss the information in the handouts / on the panels with representatives of Corridor and their environmental consultant (Stantec). All of the attendees expressed support for the Project.

3.5.2 Update Letters

Corridor has provided ongoing communication via letters to the following organizations:

- Atlantica Centre for Energy;
- City of Corner Brook;
- Corner Brook Board of Trade;
- Federation of Newfoundland Indians (currently known as the Qalipu Mi'kmaq First Nation Band);
- Mayor of Port Saunders;
- Mayor of the Town of Souris, PE;
- Newfoundland and Labrador Oil and Gas Industries Association (NOIA);
- Offshore / Onshore Technologies Association of Nova Scotia (currently the Maritimes Energy Association (MEA));
- Port-aux-Basques Chamber of Commerce;
- Port Harmon Authority Ltd.;
- Sustainable Development;
- Town of Channel-Port-aux-Basques;
- Zone 9: Long Range Regional Economic Development;
- Zone 10: Marine and Mountain Corporation; and
- Two First Nations groups (Assembly of First Nations' Chiefs in New Brunswick and Mi'kmaq Confederacy Prince Edward Island).

Corridor continues to provide updated information via letters.

3.5.3 Media Communication

Corridor responds to media inquiries as appropriate and has provided information about the project to local, national and international media. Corridor regularly monitors the provincial and national media, including print, broadcast and electronic news media.

3.5.4 Project Website

To increase accessibility and enhance communications with the general public, Corridor provides information on the Old Harry prospect on their website (http://www.corridor.ca/), which was widely advertised and promoted during presentations at workshops and open houses.

The website is updated regularly and the public are able to submit questions and issues through the Corridor email address or toll-free number.

3.6 Issues

Comments raised by stakeholders during the consultation / information exchange process are summarized in Table 3.1, which also indicates the section of the Environmental Assessment where each issue or concern is addressed.

Table 3.1 Comments Raised during the Consultation Program

Comment	Environmental Assessment Section Where Comment / Concern is Addressed
Accidental Events	
Is the oil spill model 2-D or 3-D?	The modelling was 2D. Refer to SL Ross 2011a (updated 2012) Supporting Document for modelling details.
The Gulf of Mexico spill occurred during exploration.	Section 8.4.2
Will copies of the Emergency Response Plan be available?	Section 13; the ERP will be made available
Birds	
Will seabird observers be stationed on the supply vessels and drilling platform?	Section 7.5.3
Commercial Fisheries	
Where is the crab grounds for Zone F on the Project Maps?	Figure 5.62[A]
Endangered or Special Status Species	
How does drilling noise affect species around the drilling platform?	Section 7.2.2.5
Fish and Fish Habitat	
What is the redfish larval extrusion zone?	Section 5.7.2
What are the pockmarks identified from the geohazard survey?	Discussed in the Geohazard Survey Report that was submitted to the C-NLOPB
Can the timing of the drilling program be scheduled to avoid migration and spawning	Table 5.11 indicates timing of migration and spawning
How does drilling noise affect species around the drilling platform?	Section 7.4.2.5
Marine Mammals	
How does drilling noise affect species around the drilling platform?	Section 7.6.2.5
Sensitive Areas	
Île Brion is a sensitive area	Section 5.7.3; Table 5.18
Public Involvement	
Consultation has been restricted to Newfoundland and the Magdalen Islands. Why not Prince Edward Island, Nova Scotia, New Brunswick?	Section 3.1
Why was there no formal "public consultation" in Magdalen Islands?	The presentations made on the Magdalen Islands are described in Section 3.3.2

Table 3.1 Comments Raised during the Consultation Program

Comment	Environmental Assessment Section Where Comment / Concern is Addressed
Technical / Project Description	
Is it just oil or is there gas?	Section 2.3
Will drilling be restricted to certain times of the year?	Section 2.6
Can the drilling platform withstand the environment	Section 12
What chemicals will be used during fracture gradient evaluation?	There will be no fracture stimulation of the well. This is a conventional oil and gas well. Any chemicals used will be evaluated under the OCSG as per Section 7.1.2.1
Miscellaneous	
Identified data gaps	Data gaps are acknowledged where applicable and taken into account when predicting environmental effects.
A Zone F is not specifically labelled in Figure 5.62; it is the snow crab harvesting area in NAFO Area 4Tf closest to EL 1105.	

3.7 Participation in Conferences

Corridor has also participated in the several conferences, including:

- 7th International Symposium on Oil and Gas Resources in Western Newfoundland in Corner Brook (September 12 to 14, 2012) – provided a presentation on the Old Harry Project, including a geological overview, oil spill modeling results, Project activities update and potential economic benefits;
- 6th International Symposium on Oil and Gas Resources in Western Newfoundland in Corner Brook (August 23 to 25, 2011) – provided a presentation on the one well exploration program and the hydrocarbon potential of Old Harry;
- 5th International Symposium on Oil and Gas Resources in Western Newfoundland in Corner Brook (September 21 to 24, 2010) – provided a presentation on the one well exploration program and results of the geohazard survey;
- Oil and Gas Forum in mid-April 2011 organized by the municipality of the Magdalen Islands – provided a presentation on its proposed one well exploration program;
- NOIA's Playing on the Edge Conference in St. John's (June 21 to 23, 2011) – provided a Project update; and
- CORE All Energy Conference and Trade Show in Halifax (October 3 to 6, 2011) – provided a Project update.

4.0 PHYSICAL ENVIRONMENT

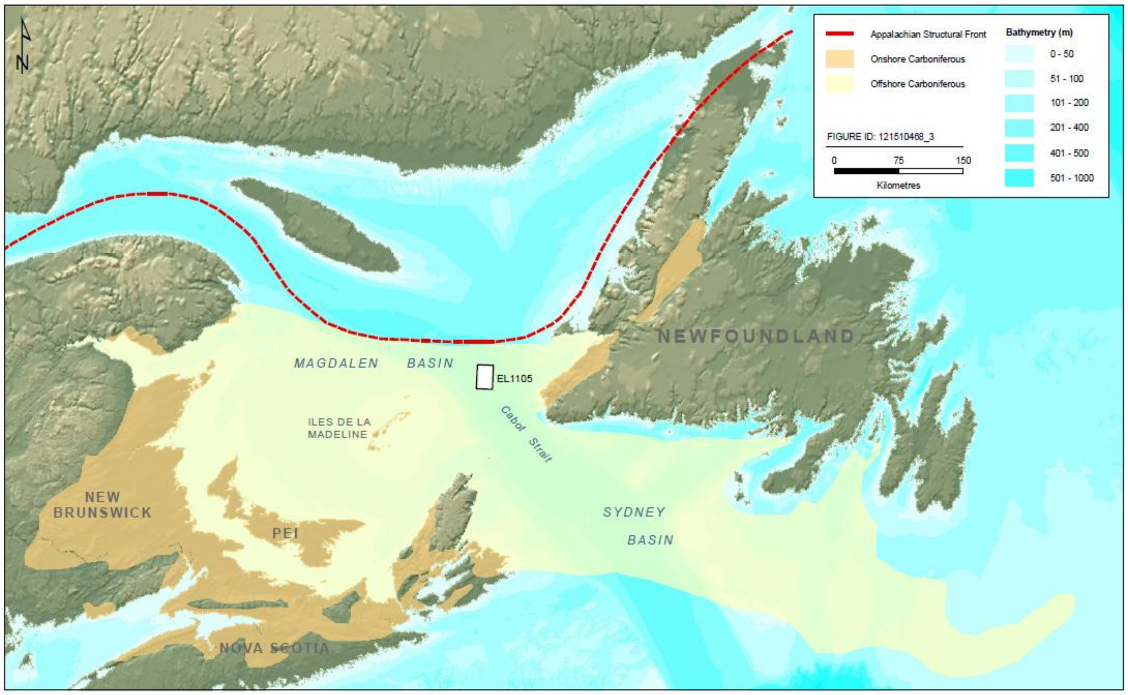
This section provides details of the physical environment related to the Old Harry prospect, including geology, physical oceanography and meteorology. A detailed discussion of the physical environment near the Project can be found in the 2005 Western Newfoundland and Labrador Offshore Area Strategic Environmental Assessment (SEA) (LGL 2005b) and the 2007 Western Newfoundland and Labrador Offshore Area SEA Amendment (LGL 2007). This SEA is currently being updated (refer to Section 3.1). The physical environment description in this document has been summarized using in part information from Western Newfoundland and Labrador Offshore Area SEA (LGL 2005b) and Corridor's geohazard survey environmental assessment (Stantec 2010), with more recent data and information included where available.

4.1 Geology

Geological formations in the Gulf are an essential component of marine habitats, as they influence oceanic circulation. The geological formations that form the foundations of the Gulf are millions of years old and straddle three major geological regions, including the Canadian Shield, the St. Lawrence Platform and the Appalachians. Some of these geological formations lay exposed to the ocean, while others are covered by sediment layers varying in depth from a few meters to hundreds of metres. Over the past two million years, four glacial and interglacial periods have transformed these geological formations as a result of erosion and sediment deposition. Natural phenomenon, including the movement of icebergs, and human activities (*i.e.*, fishing trawls) have also played a role in transforming the seafloor of the Gulf to how it exists today (DFO 2005a).

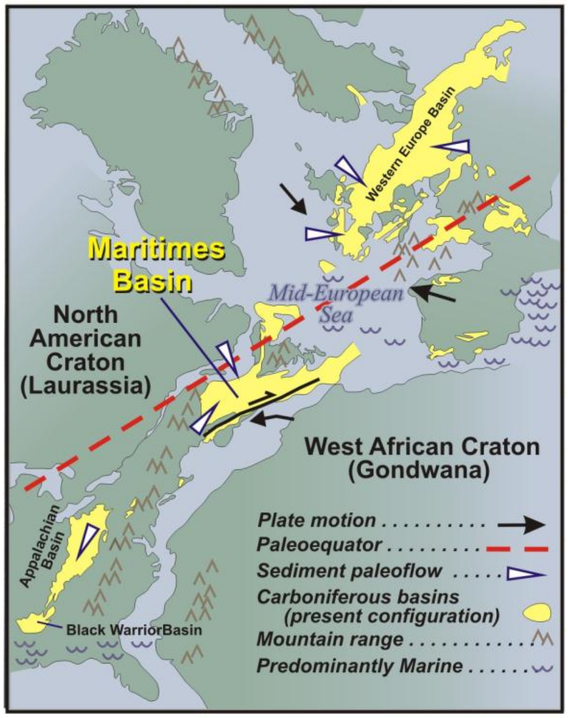
4.1.1 Maritimes and Magdalen Basin Geology

Underlying the Gulf, Cabot Strait, southwestern Grand Banks and northeastern Newfoundland continental shelves, including onshore extensions covering five eastern Canada provinces, is a large sedimentary basin known as the Maritimes Basin (Lavoie *et al.* 2009) (Figure 4.1). The basin developed in equatorial latitude, within a collision zone between the Laurassia and Gondwana cratons (Figure 4.2) during the final stages of assembly of the Pangea supercontinent (Lavoie *et al.* 2009). The rocks in the Maritimes Basin consist of mostly sandstone, siltstone and shale, with minor amounts of limestone, gypsum and salt. These rocks range in age from middle Devonian to Permian (Upper Paleozoic), but are generally regarded as mostly Carboniferous in age. Similar age rocks occur in the United States (Appalachian Basin) and in Western Europe (Figure 4.2). Hence, the Maritimes Basin is considered to be part of a series of sedimentary basins between Laurassia and Gondwana (Figure 4.2).



Source: Adapted from Lavoie *et al.* 2009.
Note: Maritimes basin is the light yellow and light brown shading / colours.

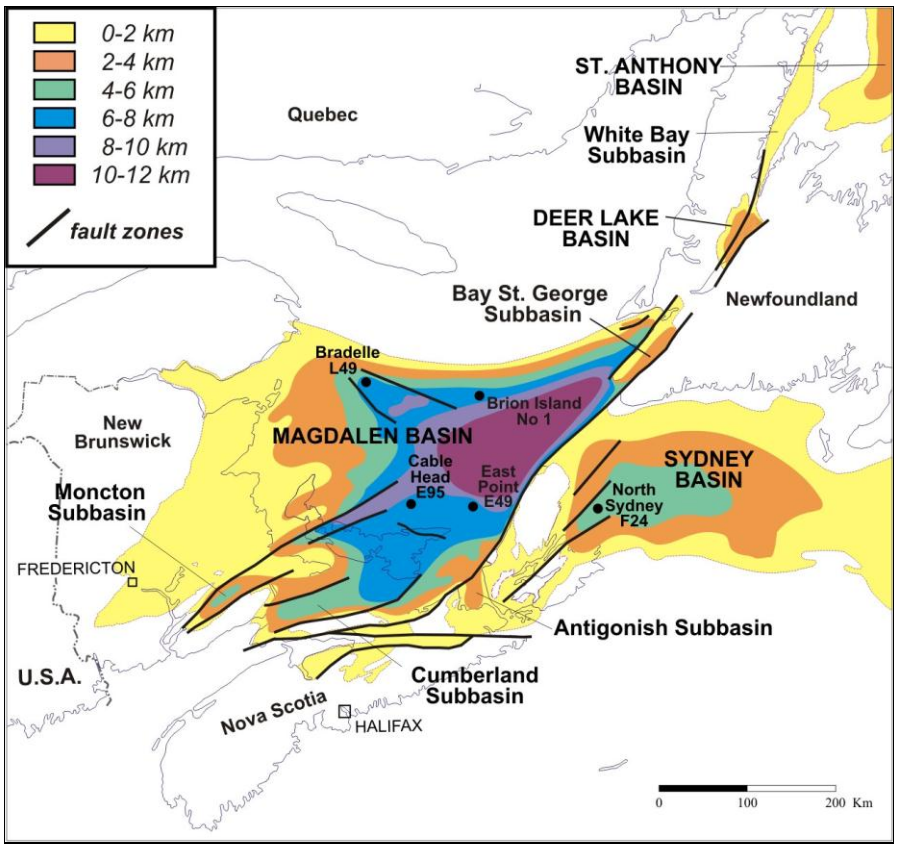
Figure 4.1 Regional Setting of the Maritimes Basin with Location of Magdalen Basin



Source: Lavoie *et al.* 2009.

Figure 4.2 Plate Tectonic Setting of the Maritimes Basin

The rocks of the Maritimes Basin underlie all of Prince Edward Island and the Magdalen Islands and extend onshore in eastern New Brunswick, northern Nova Scotia and Cape Breton Island and western Newfoundland (Figure 4.1) (Lavoie *et al.* 2009). The Maritimes Basin comprises several basins, including the Magdalen and Sydney Basins and local subbasins. It encompasses an area of 250,000 km^2, with approximately 75 percent of the basin offshore (Lavoie *et al.* 2009). The geological history of the Maritimes Basin includes extensional and strike-slip settings in the Late Devonian to Early Carboniferous, as well as a wrench-foreland basin setting in the Late Carboniferous to early Permian (Lavoie *et al.* 2009). The Maritimes Basin contains middle Devonian to early Permian continental and shallow marine strata of a thickness of approximately 12,000 m (Figure 4.3) (Lavoie *et al.* 2009). Today's Maritimes Basin is an erosional remnant of a more extensive cover of the Upper Paleozoic Strata (Lavoie *et al.* 2009). EL 1105 is located within the eastern part of the Magdalen Basin (Figure 4.1).



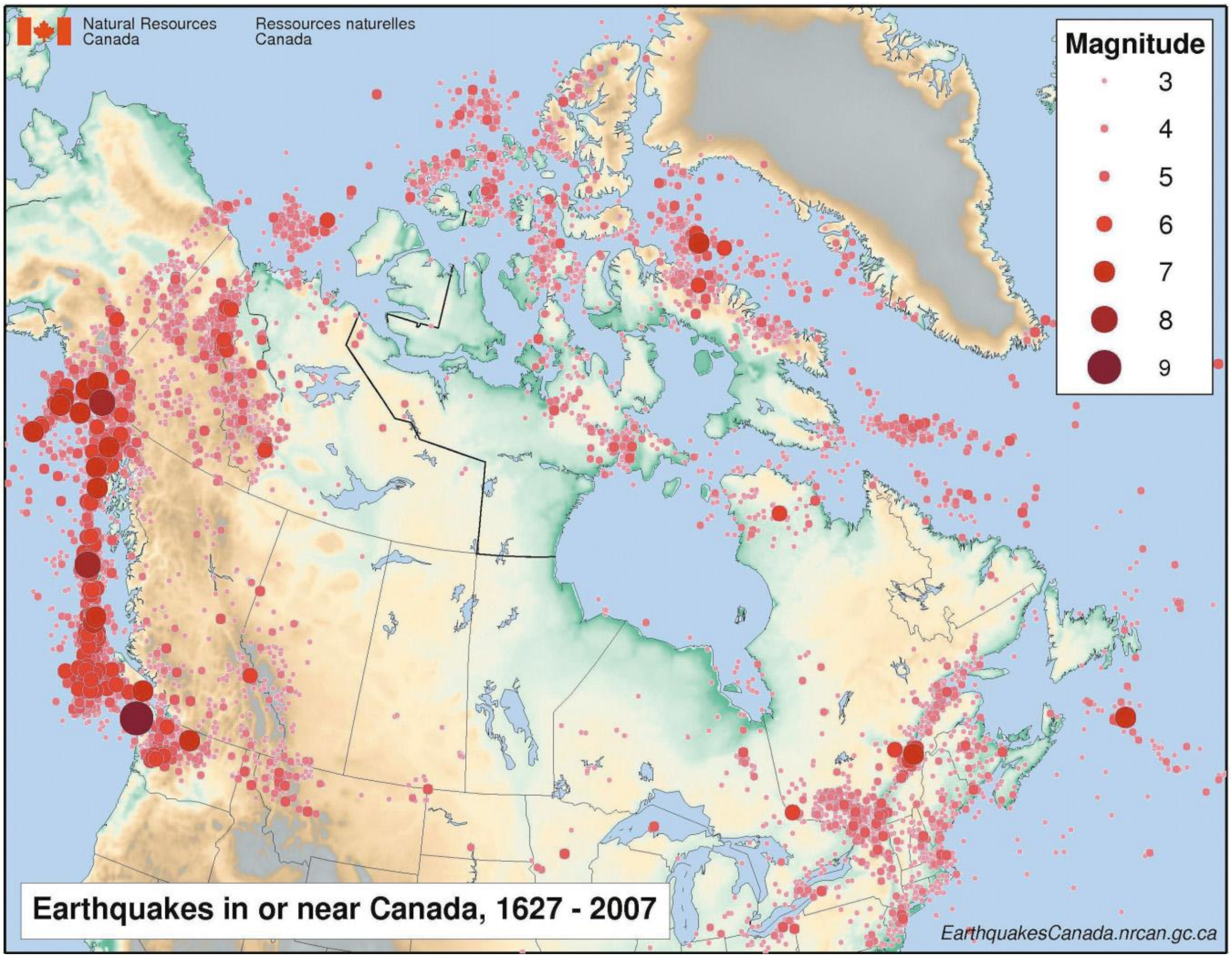
Source: Lavoie *et al.* 2009.

Figure 4.3 Isopach Map of Upper Paleozoic Strata in Maritimes Basin

4.1.2 Seismicity

Seismicity is the frequency or magnitude of earthquake activity in a given area. Global seismicity maps show that the regions where seismicity is the highest tend to correspond with the edges of the tectonic plates. The continual shifting of tectonic plates accounts for 97 percent of the world's earthquakes (Natural Resources Canada 2011). The causes of earthquakes in eastern Canada are not well understood. Eastern Canada is part of the stable interior of the North American Plate and as such, tectonic plate shifting is not the cause of most observed earthquakes in this region. Seismic activity in areas such as eastern Canada seems to be related to the regional stress fields, with the earthquakes concentrated in regions of crustal weakness (Natural Resources Canada 2011).

Peak accelerations and velocities define seismic zones throughout Canada (Natural Resources Canada 2011), that range from zero (Canadian Shield, which is a relatively aseismic area) to six (areas that are the most seismically active). EL 1105 is located within Zone 1 (based on the 1985 seismic zoning map), and is therefore considered to have a low seismicity (Natural Resources Canada 2011). The historic seismicity for Canada (1627 to 2007) is presented in Figure 4.4 and as indicated, there was no seismic activity ever recorded for in the vicinity of EL 1105.



Source: Mitchell *et al.* 2010.

Figure 4.4 Historical Seismicity in Canada

4.1.3 Sediment Type

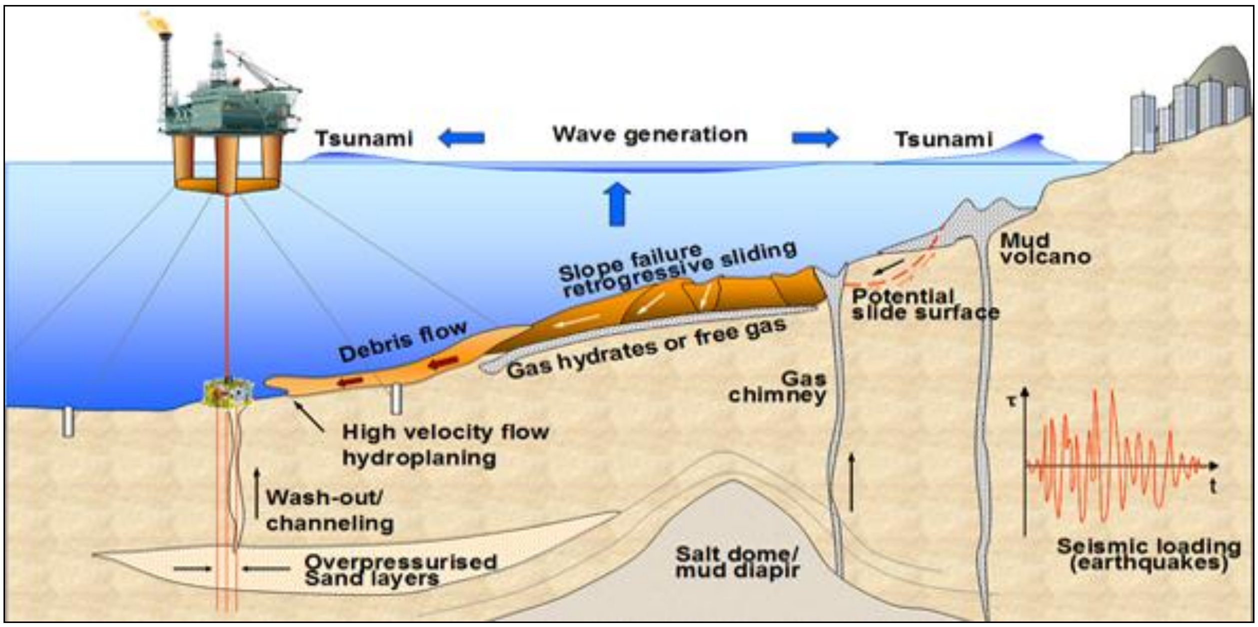
The three-dimensional configuration of the Quaternary sediments in the Gulf was studied by Josenhans and Lehman (1999) via an analysis of high-resolution seismic reflection data and core samples. The results were interpreted and the sediments were subdivided into three seismostratigraphic units, including glacial till-ice-contact sediments, glaciomarine sediments and postglacial sediments. The glacial till-ice-contact sediments lay above bedrock and other older till deposits and their thickness ranges from areas of thin discontinuous deposits to morainal deposits of up to 180 m thick. The glacial till-ice-contact unit was further interpreted to contain a stacking of multiple glacial till-ice-contact deposits, which were sub-divided into the lower, middle and upper till units. Samples taken from the lowermost till unit contained reddish-brown clayey silt with grit and large clasts of clay and pebbles. The middle till unit occurs along the eastern margin of the Magdalen Shallows (Figure 4.5) and extends down the southwestern flank of the Laurentian Channel. Sediments from this unit are dark brown in colour and made up of calcareous, silty-sandy muds with pebbles and red clayballs. The upper glacial till unit extends down the southwestern flanks of the Laurentian Channel and the sediments making up this unit consist of massive, dark grey clayey muds with clasts of limestone, black slate and igneous fragments. The glaciomarine sediments lie above the glacial till-ice-contact unit and consist of massive silty clays with gritty, pebbly sediments and rock fragments. The third seismostratigraphic unit, postglacial sediments, is the uppermost unit and consists of massive, grey clayey to sandy mud with some shell fragments. In general, the thickest deposits of glacial sediments have been deposited on the southwestward slope of the Laurentian Channel.

Source: Dufour and Ouellet 2007.

Figure 4.5 Physical Features Present in the Gulf of St. Lawrence

4.1.4 Natural Hazards Affecting the Seafloor

Natural hazards affecting the seafloor are referred to as geohazards. A geohazard is defined as "A geological state, which represents or has the potential to develop further into a situation leading to damage or uncontrolled risk". Geohazards are found in all parts of the Earth and are always related to specific geological conditions and geological processes, either recent or past. Important offshore geohazards include: (i) seabed instabilities and mass wasting processes including debris flows and gravity flows (submarine slope failures); (ii) pore pressure phenomena (*e.g.*, shallow gas accumulations, gas hydrates, shallow water flows, mud diapirism and mud volcanism, fluid vents, pockmarks); and (iii) seismicity (Figure 4.6).



Source ICG 2010.

Figure 4.6 Main Offshore Geohazards

A drilling hazards and constraints assessment of the proposed Old Harry exploration well was conducted in October 2010 (FGI 2010). Constraints are features or conditions that may affect drilling or installation operations, but do not constitute a safety hazard and include such items as localized near-surface boulders that might cause refusal during drilling or affect structural alignment of casing during installation, thereby requiring respud or reinstallation. A hazard by comparison may present a safety risk, such as the presence of over-pressured shallow gas within the “open hole” drilling interval, which would have potential to cause a blow-out. Hazards may be assessed qualitatively as having either low or high probability of occurrence, based on interpretation of the available geological and geophysical data. High probability is assessed if geologic conditions are conducive and the data support the presence of a specific hazard. In this case, the hazard occurrence is considered probable. In the case of low probability, the observed geologic conditions may be conducive and, although the data do not necessarily support the presence of a hazard, the data do not exclude the possibility of a hazard (FGI 2010).

High-resolution geophysical site survey data were acquired over the proposed well site for the purpose of a shallow drilling hazards assessment (FGI 2010). Geophysical data were acquired within a 22.5 km^2 rectangular survey site, aligned north-northwest-south-southeast. The site dimensions are 4.5 km (west-southwest-east-northeast) by 5 km (north-northwest-south-southeast). The assessment was performed to identify geological hazards and constraints on the seabed and in the shallow sub-surface relevant to the safety and efficiency of proposed exploration drilling operations. The assessment was limited to the "open hole" drilling interval (approximately 600 m below seafloor). Natural hazards that may affect the seafloor are described and discussed in the following sections, with results from the Old Harry geohazard survey (FGI 2010) included for appropriate site context.

4.1.4.1 Seabed Conditions

The regional surficial and shallow geology in EL 1005 reflects processes of Pleistocene glaciation and subsequent marine sedimentation (FGI 2010). The ultimate retreat of Late Wisconsinan ice from the Laurentian Channel is recorded by the near-surface sedimentary succession, which consists of glacial diamict (till), overlain by glaciomarine muds (Emerald Silt) and draped by Holocene surficial silty clays (LaHave Clay) (Fader *et al.* 1982; Grant and Morrison 1996). The LaHave Clays are distal equivalents of sand-rich slope deposits (Sambro Sands) on the flanks of the Laurentian Channel, which were derived from transgressive erosion of St. Pierre Bank and adjacent shelf areas as sea level rose from a post-glacial lowstand of -110 m (Fader *et al.* 1982; Josenhans and Lehman 1999; Quinlan and Beaumont 1981).

Josenhans and Lehman (1999) describe a typical succession of ice contact and till deposits, proximal and distal glaciomarine clay deposits and surficial marine muds. Three till sub-units relating to multiple glacial advances have been defined, with only the oldest (Lower Till) present in the region of the Old Harry prospect. The tills form a discontinuous cover over bedrock, and are draped by glaciomarine sediments and Holocene muds (FGI 2010).

The Old Harry prospect is situated within the Magdalen Basin (FGI 2010). Basin formation was initiated during the waning stages of the Acadian Orogeny in an extensional setting, with periods of dextral transpression (Williams 1995; Hayward *et al.* 2002). Within the Old Harry prospect area, the Basin hosts Upper Carboniferous sedimentary strata consisting of multi-storied channel sandstones interbedded with fine-grained siltstones, shales and mudstones (Giles and Utting 1999, 2003). The formerly flat-lying to gently dipping strata have been folded and faulted by salt-motivated tectonism, resulting in a system of fault-bounded anticlines and synclines, providing structural closure for prospective hydrocarbon systems (Hayward *et al.* 2002).

Within the Laurentian Channel, the strata have been deeply eroded by Pleistocene glaciation. In the Old Harry well site area, the shallow sedimentary succession comprises partially eroded, sandstone-dominant Cable Head Formation at the top, underlain by the finer grained Green Gables Formation, and the more interbedded Bradelle Formation, which is interpreted to host prospective reservoir quality sandstones (Hayward *et al.* 2002; Hu and Dietrich 2008, 2009;).

The Old Harry site is situated on the floor of the Laurentian Channel, a large-scale, glacially overdeepened u-shaped valley separating the Magdalen Shelf and the narrow shelf of southwest insular Newfoundland (FGI 2010). Water depths within the surveyed Old Harry well site area range from 462 m in the northwest to 482 m in the east; and the seabed dips regionally to the southeast at an average of less than 1°. The seabed displays a gently undulating topography with a broad, low relief “ridge” trending southeastward through the centre of the site, with low-lying troughs on each side. The proposed well surface location is situated near the crest of the “ridge” at 470 m water depth. The local seabed dip is <1° SSW (FGI 2010).

Seabed sediments in the Old Harry site investigation area consist mainly of soft glaciomarine to post-glacial muds with occasional coarse granular material derived from ice rafting (FGI 2010). The muds (>60 percent clay, >30 percent silt and <5 percent sand) are interpreted to have been deposited by gradual, deep-water pelagic sedimentation during the Late Wisconsinan to Holocene period. Far offset piston core data suggest that the surficial muds are bioturbated and contain occasional ice-rafted clasts. Seabed video images show a generally smooth mud seabed with common burrows formed by benthic infauna. Isolated clusters of ice-rafted pebbles are seen in places (FGI 2010).

Anchoring conditions are considered to be generally favourable within the Old Harry well site area. There are no identified or charted man-made features or obstructions to drilling and anchoring in the well site area (FGI 2010).

Boulders

There is potential for occasional ice-rafted cobbles and/or boulders within the near-surface deposits, down to the Base Quaternary glacial unconformity. Holocene surficial marine mud deposits vary from approximately 9 to 28 m thick across the Old Harry site, and are estimated to be 15 m thick at the proposed well location. Potential for coarse granular material generally increases below the Holocene surficial marine muds, within the proximal glaciomarine sediments and basal tills. There may be potential for fragmented bedrock on the glacially eroded, buried bedrock surface. While isolated boulders may occur, there is considered to be a low probability of drilling refusal or casing problems caused by near-surface boulders at the Old Harry well site (FGI 2010).

Faults

A southwest-northeast trending system of normal faults occurs in the southern part of the site investigation area (see Figure 4.8), forming a graben-like structure (FGI 2010). Faulting was likely associated with salt-motivated tectonism and uplift. These faults are not considered active. It is noted that the proposed well site at Old Harry is located approximately 1,200 m northwest of the fault system and does not intersect interpreted faults.

4.1.4.2 Pore Pressure Phenomena

The pore pressure phenomena considered in this report include shallow gas accumulations, gas hydrates, shallow water flows, mud diapirism, mud volcanism, fluid vents and pock marks. While all are individual phenomena, they are related, and are an expression of former or present day activities of fluid flow related to conduits such as faults or sedimentary discontinuities. Fluid flow within sediments, exploiting pathways of permeable sediments or faults, results in upward migration of gas and water expelled from sediments at depth. The end result of these extrusions is pockmarks and mud volcanoes and diapirisms, which form where entrained sediment erupt at the seafloor. These processes are related to excess pore pressure at depth, which decreases sediment strength and increases slope failure potential. Generally speaking, high-resolution seafloor mapping tools are being used worldwide for the identification of submarine slides, pockmarks, mud volcanoes and active faults in unprecedented detail. The morphologic evidence suggests that all these features should be considered as common rather than exceptional on the seafloor (Cochonat *et al.* 2007).

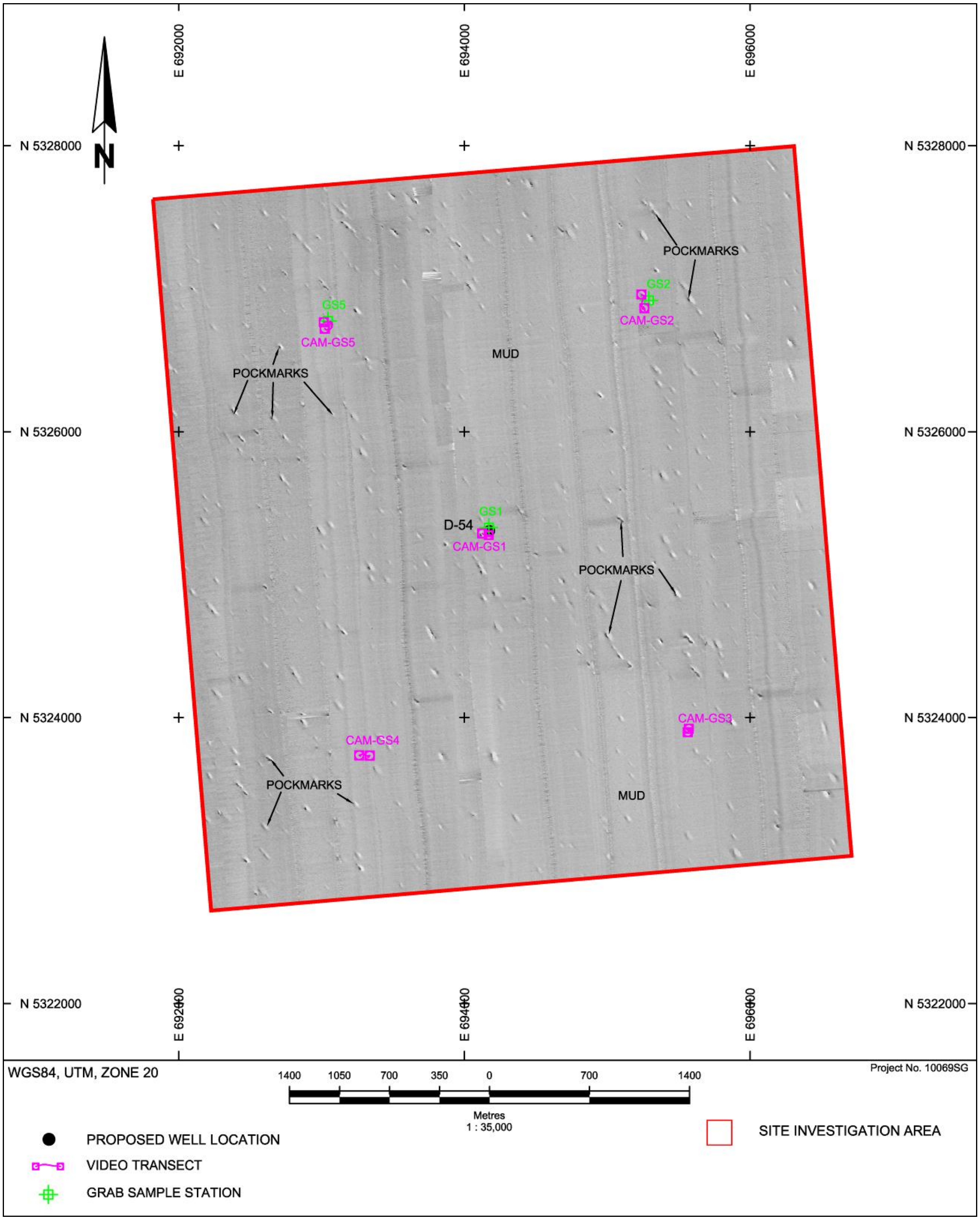
Pockmarks

Pockmarks are concave, crater-like features on the seafloor, generally up to several hundreds of metres in diameter and tens of metres in relief (King and MacLean 1970; Kelley *et al.* 1994). The formation of pockmarks is mostly caused by the seepage of thermogenic and biogenic gases (Rogers *et al.* 2006) and the release of pore water (Harrington 1985). Pockmarks have been described in areas that have been affected by the up-drift of ice that detached from the sub-seafloor (Paull *et al.* 1999) and decomposing gas hydrates (Solheim and Elverhøi 1993). Pockmarks are also induced by grounded moving icebergs or anthropogenic activities such as trawling and ship anchoring (Harrington 1985; Fader 1991).

Approximately 250 seabed pockmark depressions occur across the Old Harry survey site (FGI 2010) and their distribution is shown in multibeam and side scan sonar imagery (Figure 4.7). The features are asymmetrical with a dominant elongation to the south-southeast, in the direction of prevailing bottom currents. They are typically on the order of 50 m wide and 100 m long, and commonly less than 2 m deep. The smallest pockmark features imaged by multibeam data are approximately 20 m in diameter. Isolated pockmark features reach depths of approximately 5 m below the surrounding seabed. The inner sidewall slopes of pockmarks are typically <2° but exceed 5° in places (FGI 2010).

The areal density of pockmarks within the survey site is approximately 11/km^2. The pockmark distribution does not show well-defined patterns, though they appear to be most abundant southeast of the proposed Old Harry well location (FGI 2010). A few of the pockmark features are aligned with each other and have coalesced to form longer seabed depressions oriented with the dominant current direction, as seen mainly in the northeast part of the site. It is not known whether any of the features are actively venting; however, some are distinct while others appear muted and are potentially older (FGI 2010). Fluid expulsion would likely be gradual and intermittent (Grant and Morrison 1996).

Side-scan sonar imagery shows locally high acoustic reflectance in many of the pockmark depressions, suggesting that accumulations of coarse granular material may have formed at the base of the features, due to progressive winnowing of fine-grained sediments by fluid expulsion (FGI 2010). The coarse granular (ice-rafted) material, previously embedded in a mud / clay matrix, settled to the bottom of the pockmarks as the fine sediments were suspended by venting and then transported down-current. Some of the pockmark features show local seabed mounding on the down-current fringes, where some of the suspended sediment load has been rapidly deposited close to source (FGI 2010).



Source: FGI 2010

Figure 4.7 Side Scan Sonar Mosaic Depicting Pockmarks at Old Harry

Pockmarks should be avoided when selecting well spud locations. In the event that an anchored MODU is used for drilling, the deepest pockmarks should be avoided during anchor placement.

Shallow Gas Accumulations

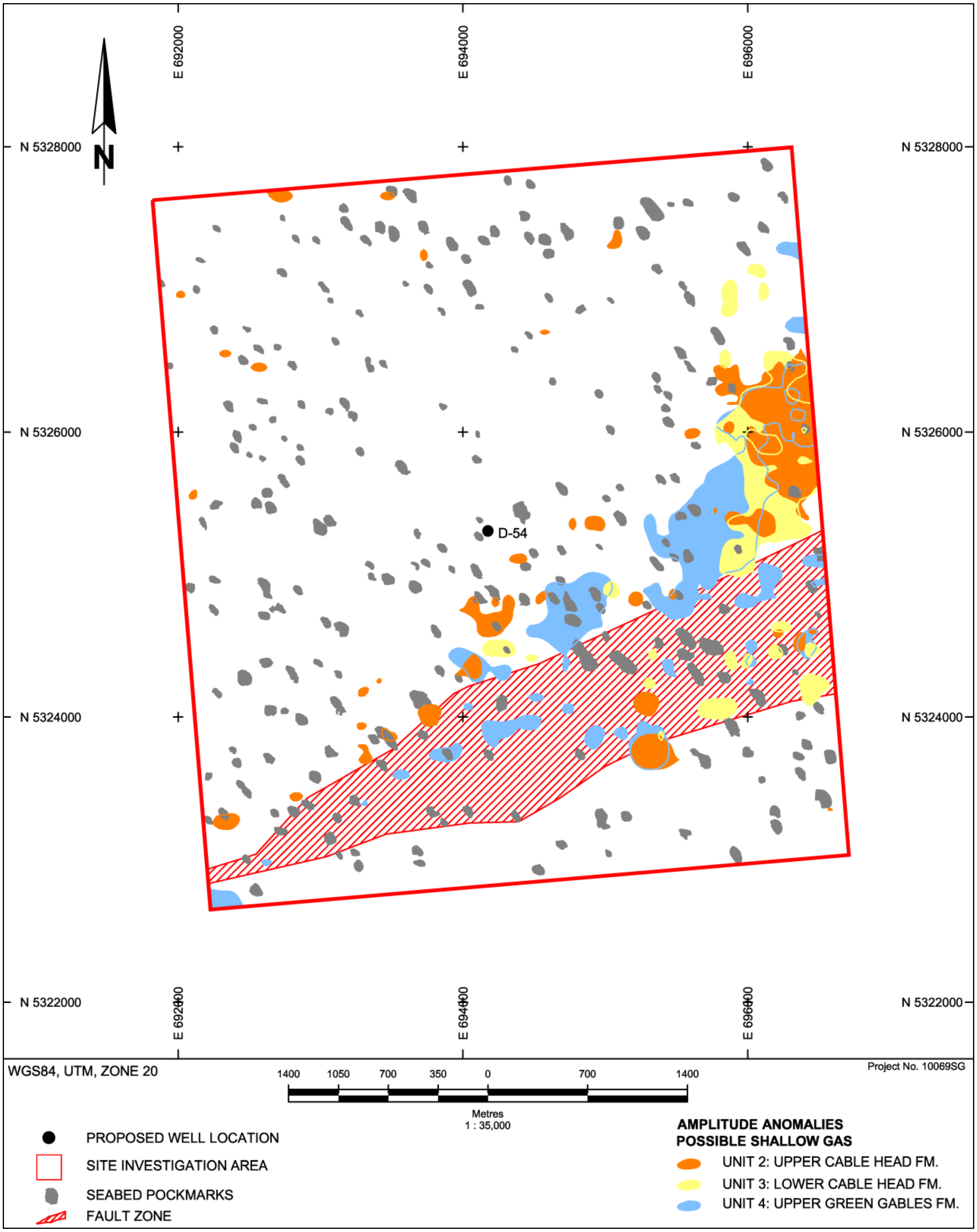
Shallow gas, which occurs at depths less than 1,000 m below seafloor (Floodgate and Judd 1992), may pose a hazard to offshore open-hole or riserless drilling operations, such as geotechnical drilling or drilling of the tophole section of oil and gas wells. There are two different types of shallow gas, defined by origin: thermogenic and biogenic. Thermogenic gas forms at depth under high temperatures and pressures. It may be present in the shallow subsurface where it has migrated up from a deeper reservoir (Floodgate and Judd 1992). Thermogenic gas can migrate upward along natural pathways, through porous strata or along faults, or along leaking wells. Biogenic gas forms at shallow depths through bacterial activity.

Biogenic gas is by far the most common gas in shallow sediments (Lin *et al.* 2004). Biogenic gas requires a sufficient supply of organic matter and a rapid sedimentation rate to bury organic material before it is oxidized. The gas accumulates when it can migrate in a free gas phase (Rice 1993), with this occurring when the concentration in the pore fluid exceeds gas solubility, or when gas exsolves due to reduction of hydrostatic pressure, which could be caused by erosion of the seabed or a fall in relative sea level.

Shallow gas accumulations require a reservoir, a seal and gas. Shallow gas reservoirs are most commonly formed by coarser-grained materials such as sand, and seals by fine-grained sediments such as clay (Kortekaas *et al.* 2011).

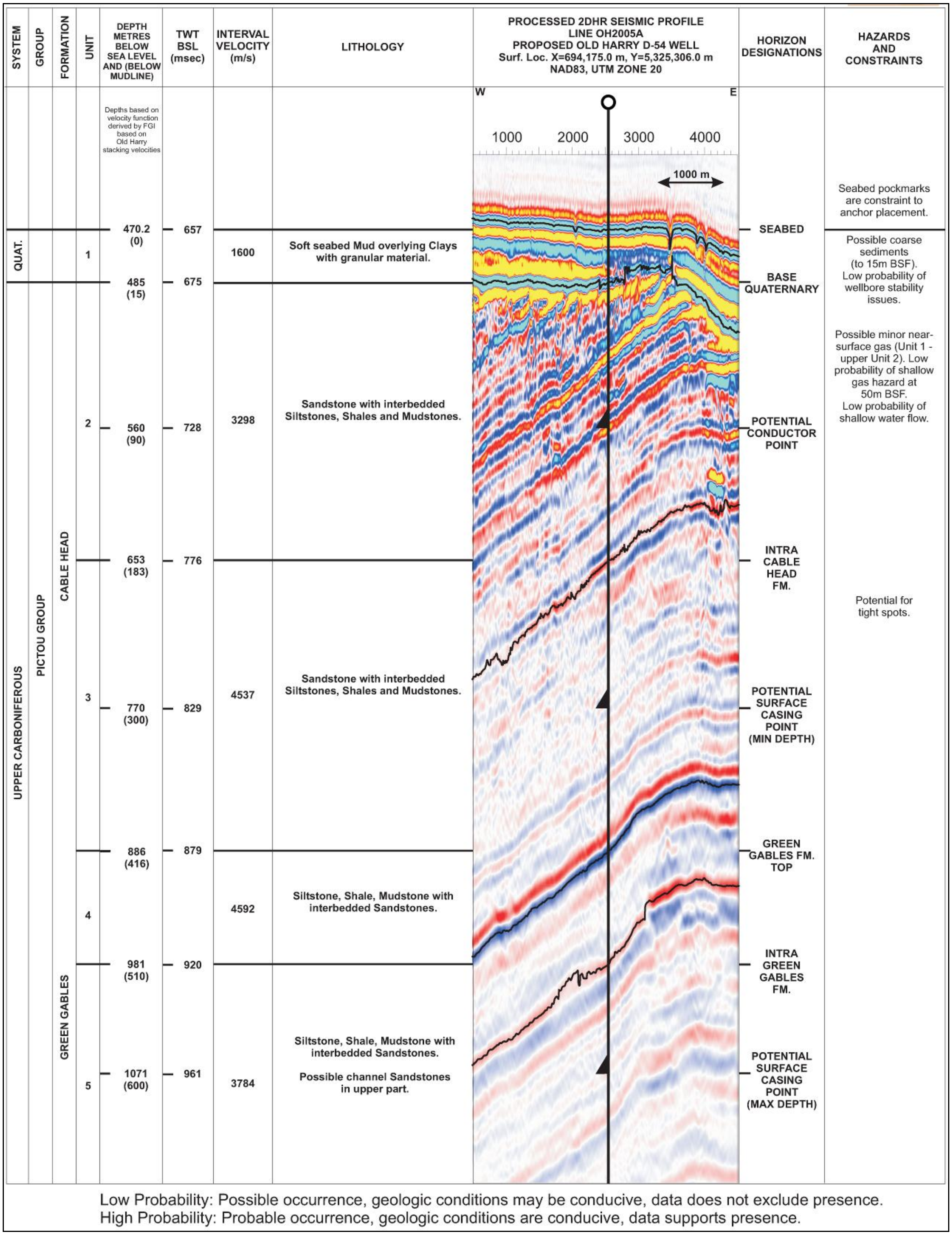
Geophysical observations suggest that there is possible near-surface gas in places within the Old Harry survey site, as indicated by seabed pockmarks and localized columns of attenuated amplitudes in Huntec sub-bottom profiler data, which commonly occur below the pockmark features (FGI 2010). Acoustic attenuation in proximity to pockmarks suggests the possible occurrence of gas (probably methane) within the dominantly fine-grained near-surface sediments, with potential seepage at the seabed. However, it is noted that the possible near-surface gas interpreted within the Old Harry survey area does not produce widespread acoustic wipe-out with loss of acoustic stratigraphy and structure, which typically occurs in high frequency sub-bottom profiler data where shallow sediments are extensively gas-charged.

Localized, subsurface high amplitude anomalies indicative of possible shallow gas have been mapped within the Old Harry survey site (FGI 2010). These anomalies occur within shallow Carboniferous bedrock along a southwest-northeast trend through the southern part of the site; mostly coincident with the mapped fault zone along the anticlinal structure that shallows to the north-northeast (see Figure 4.8). High amplitude anomalies indicative of possible gas occur more than 200 m southeast of the well site location. These anomalies display a number of gas attributes, including trough-over-peak reflection pairing, sharp lateral gradients and possible frequency effects (FGI 2010). The anomalies occur up-dip of the proposed well site, within the truncated anticlinal structure. These anomalies, delineated on the hazards and constraints map, do not pose a hazard to drilling at the proposed well site (Figures 4.8 and 4.9) (FGI 2010).



Source: FGI 2010

Figure 4.8 Hazards and Constraints Map of Old Harry Study Area



Source: FGI 2010

Figure 4.9 Hazards and Constraints at Old Harry Proposed Drill Site

It is noted that anomalous amplitudes occur near the up-dip limit of the trough reflector (Figure 4.9), which implies the possibility of gas migration up-dip along bedding planes (FGI 2010). The possibility of communication between the moderate amplitude bedding, the shallow amplitude anomalies (up-dip) and apparent fluid or gas escape pockmark features at the seabed suggests that the presence of gas cannot be excluded on the basis of the available data. However, the observed seismic attributes do not appear to be indicative of an overpressured gas zone below the Old Harry proposed well site. The reflector below the well site is therefore interpreted to have a low probability for shallow gas that is hazardous to drilling. As potential for shallow gas at the proposed well location cannot be excluded, it is suggested that mitigation options be considered (FGI 2010).

Gas Hydrates

Gas hydrates occur naturally onshore in permafrost and at or below the seafloor in sediments where water and gas combine at low temperatures and high pressures to form an ice-like solid substance. Methane, or natural gas, is typically the dominant gas in the hydrate structure. In a gas hydrate, frozen water molecules form a cage-like structure around high concentrations of natural gas; specifically, they are non-stoichiometric, solid compounds similar to ice crystals (Sloan 1998).

Gas hydrates are found abundantly worldwide in the top few hundred metres of sediment beneath continental margins at water depths between a 100 and 1,000 m (few hundred and a few thousand feet). The gas hydrate stability zone in the marine environment is determined by water depth, seafloor temperature, pore pressure, thermal gradient and the gas and fluid composition. The base of the zone in which hydrate can exist is limited by the increase in temperature with depth beneath the seabed (Sloan 1998). Currently, the principal indicator of marine methane hydrates is the detection of bottom-simulating reflectors on seismic data (CGG Veritas 2011).

The presence of pockmarks at the seabed and locally attenuated amplitudes in sub-bottom data suggests potential for localized near-surface gas within the Old Harry site. If temperature and pressure conditions are favourable, there would be potential for gas hydrate formation (FGI 2010). Estimated parameters for the Old Harry site were plotted on the phase equilibrium curve(s) to provide an indication of potential for gas hydrate formation. Water depth at the Old Harry well site is 470 m. A water bottom temperature (near seabed) of 5°C was found at the Old Harry site. The subsurface geothermal gradient is not well constrained for the well site area. These parameters and assumptions confine the Old Harry site to the shallow limit of the gas hydrate phase equilibrium curve(s). For the “saline water” case, the geothermal trend is nearly tangential to the upper limb of the phase equilibrium curve and does not intersect, suggesting that conditions for hydrate formation are not satisfied. Given that near-surface sediment pore waters at Old Harry are likely to be saline to some depth, there is considered to be a low probability of gas hydrates forming and remaining stable on or near the seabed (FGI 2010).

In addition, near-surface (Quaternary) sediments within the well site area are interpreted to be predominantly fine-grained with a clay matrix, and therefore lack sufficient porosity for the development of massive hydrates. Also, there is no apparent bottom-simulating reflector that would indicate the presence of free gas accumulation beneath a potential gas hydrate stability zone (FGI 2010).

If gas hydrates are present, they are likely localized and disseminated within the fine-grained sediment in the form of small crystals, small to large nodules, lenses and partings, or thin veins. If free-phase gas (or mixed gas and hydrate) are present locally in the unconsolidated near-surface sediments, it is not expected to be overpressured (FGI 2010).

Potential hazards associated with gas hydrates include ground subsidence, methane release, seabed and slope instability. Offshore drilling operations that disturb gas hydrate-bearing sediments could fracture or disrupt the bottom sediments and compromise the wellbore, pipelines, rig supports and other equipment involved in oil and gas production from the seafloor. Problems stem from decreases in pressure and/or increases in temperature, which can cause the gas hydrate to dissociate and rapidly release large amounts of gas into the well bore during a drilling operation (Folger 2008). However, as noted above, there is a low probability associated with gas hydrates forming and remaining stable on or near seabed at Old Harry (FGI 2010).

Shallow Water Flow

Shallow water flow is defined as water flowing within and around the outside of structural well casing to the seabed (Alberty *et al.* 1997). Shallow water flows occur when fluids under greater than hydrostatic pressures are present in unconsolidated sands between approximately 90 and 500 m (300 and 5,000 feet) below the mudline. These highly permeable sands are widely referred to as shallow water flows because they are sufficiently geopressured to force water and sand into the lower-pressured well bores (Von Flatern 1997). Common deepwater shallow sediment traits are low fracture gradients with pore pressures greater than a seawater gradient. The high pore pressure relative to the fracture gradient causes difficult drilling conditions in the shallow regions of the well.

In the Old Harry well site area, the shallow stratigraphy comprises thin (<20 m) unconsolidated clay-dominant Quaternary deposits overlying truncated and dipping Carboniferous sandstone and mudstone beds. The sandstones may be sufficiently porous to host pore fluids. However, the Quaternary deposits are too thin to exert substantial overburden pressure, and the lithified sandstones are effectively incompressible. Any potential for shallow flow would likely arise from deeper geopressures causing upward fluid migration through porous (or fractured) sandstone beds. There is interpreted to be a low probability of shallow water flow associated with the high amplitude beds in the conductor interval at the Old Harry site (FGI 2010).

Other Pore Pressure Phenomena

Mud diapirism and volcanoes are other pore pressure phenomena that may occur but are not expected to occur at the Old Harry site, based on the Old Harry Geohazard Survey (FGI 2010). A brief description of these pore pressure phenomena are included for completeness.

Mud diapirism is the extrusion of fluid rich, fine-grained sediment through an overlying lithologic succession with seismicity and/or hydrocarbon generation causing the timing and amount of extruded material (Yassir 1989). The actual location of the mud upwelling is often directed by confining structural elements or pre-existing weak zone (faults), which serve as dewatering pathways and conduits (Shipley *et al.* 1990).

Mud volcanoes can be large and long-lived geological structures that morphologically resemble magmatic volcanoes. Mud volcanoes are of two types, those associated with magmatic complexes and those related to petroleum provinces. The presence of mud volcanoes is distributed throughout the globe in both passive and predominantly active margins, often located along faults, fault-related folds and anticline axes. Mud volcanoes act as the preferential pathway by which deep fluids gather and ultimately reach the surface. Mud volcanoes episodically experience violent eruptions of large amounts of gas mixed with water, oil, mud and rock fragments, forming the ‘‘mud breccia’’. The periodic eruptions can produce volcano-shaped mountains that can reach kilometres in size (Mazzini 2009). The main cause of the eruptions is overpressured methane rising from source rocks and hydrocarbon reservoirs at greater depths.

Mud volcanoes may pose a geohazard for drilling and platform constructions due to the potentially violent release of large amounts of hydrocarbons and mud breccia. Eruption of greenhouse gases via mud volcanoes may influence global climate regimes and several attempts to estimate their contribution have been made. Offshore mud volcanoes are frequently associated with the presence of gas hydrates (Mazzini 2009).

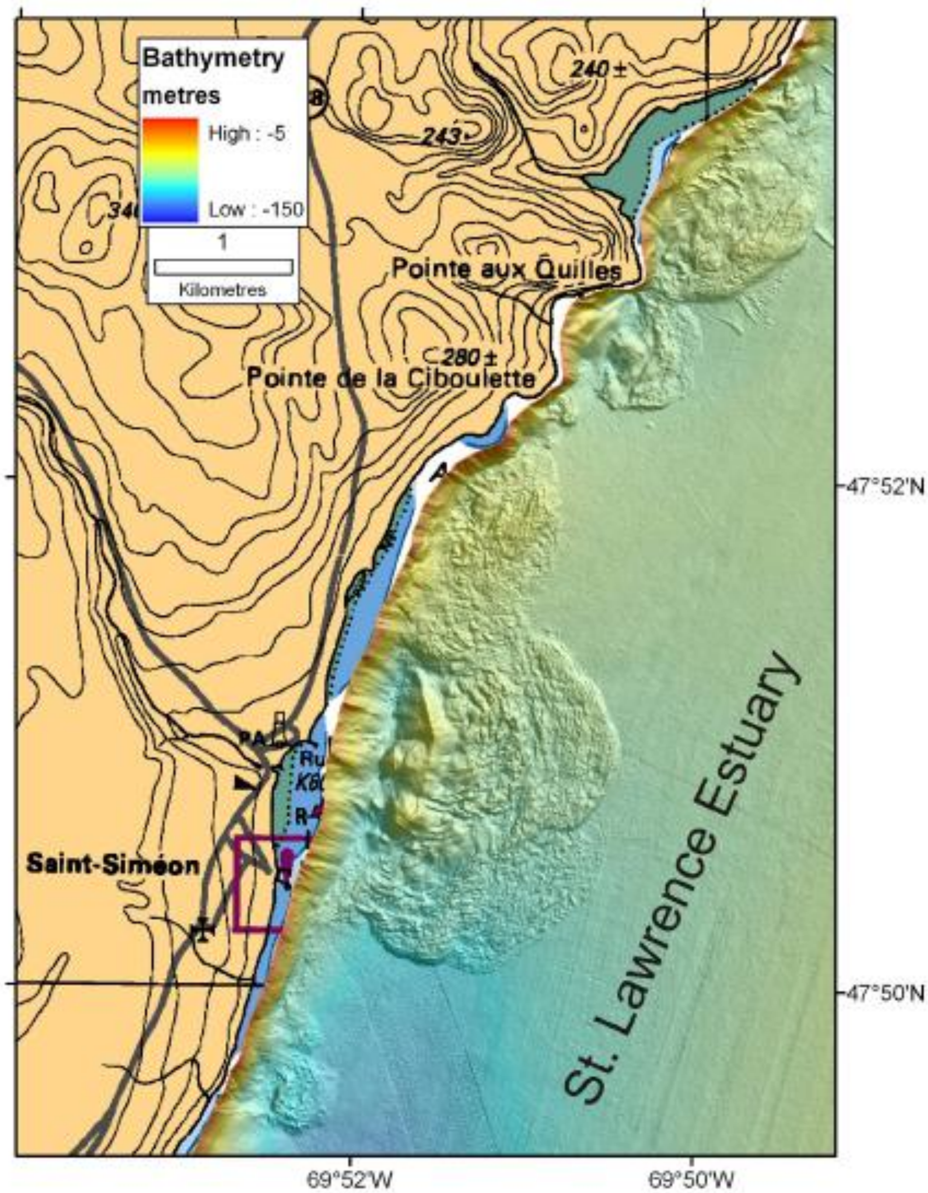
4.1.4.3 Other Geohazards

Canada’s coastline is over 243,000 km long, which is the longest in the world. As noted in Section 4.1.4.1, important offshore geohazards include seabed instabilities, pore pressure phenomena (discussed in Section 4.1.4.2), and seismicity (Section 4.1.2). Seabed instabilities including submarine slope failure is the most serious geohazard on both local and regional scales. Seabed instabilities have not been well researched because of their inaccessibility and general lack of direct societal consequence. With increasing awareness of the potential for offshore seabed instabilities (including slope failures) to potentially generate tsunami, there is a need for better understanding of offshore seabed instability processes and potential (Locat and Lee 2002). The seabed instability geohazards are included for completeness and are not anticipated to occur at the Old Harry site for reasons noted below.

Seabed Instabilities

Seabed instabilities may occur near a coastal region and along continental slopes. Coastal seabed instabilities present a particular hazard as a result of their potential for tsunami generation as well as proximity to societal infrastructure. Coastal regions often exhibit a variety of factors that could result in the establishment of conditions for sediment mass-failure (Mosher 2008). As a result of wave, long-shore current and glacial erosion, coastal regions may have steep slopes. Coastal sediments arising from quaternary glaciations deposition have mixed lithologies that often lack cohesive strength as well as having endured episodes of sea level rise and fall, thus the sediments are of marine and lacustrine origin. This history results in sediments of variable adjacent geotechnical competency.

After British Columbia, the second highest earthquake prone area in Canada is the Laurentian Valley of Quebec (Mazzotti *et al.* 2005), which is located approximately 700 km from Old Harry. Numerous examples of sediment failure (Figure 4.10) can be found along the banks and submarine slope of the St. Lawrence estuary and the Saguenay Fjord (Urgeles *et al.* 2001; Levesque *et al.* 2006; Cauchon-Voyer *et al.* 2007). Most of the sediment failures are pre-historic but a few are recent events, 1663 and circa 1860 (Cauchon-Voyer *et al.* 2007). Depending upon conditions of failure and location, a modern instability event in these areas could readily cause damage to underwater structures and generate waves that will damage coastal infrastructure within a limited area.



Source:Mosher 2009.

Figure 4.10 Physical Features Present in the Gulf of St. Lawrence

It should be noted that the Old Harry site is not considered to be located in a coastal area as it is in the Gulf, approximately 80 km west of Cape Anguille, western Newfoundland, and 88 km northeast of the Magdalen Islands, Quebec, at a water depth of approximately 470 m (FGI 2010). The seabed slope at Old Harry is not steep, with the seabed dipping regionally to the southeast at an average of less than 1° (FGI 2010). The seabed at the Old Harry site displays a gently undulating topography with a broad, low relief "ridge" trending southeastward through the centre of the site, with low lying troughs on each side. The proposed well surface location is situated near the crest of the "ridge" at 470 m water depth and the local seabed dip is <1° south-southwest (FGI 2010).

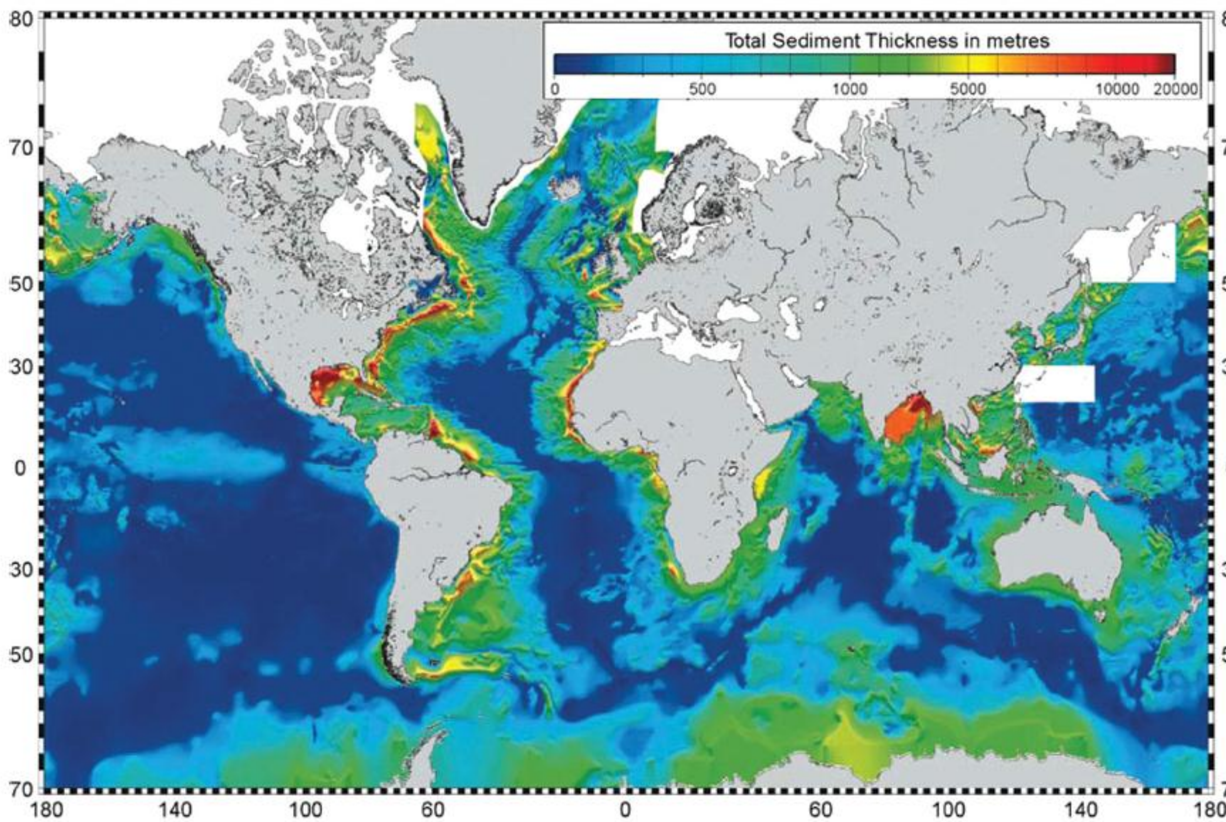
Continental Shelf Seabed Instabilities

Canada's underwater landmass below the 200 m (approximate depth of the shelf break) and above the 3,000 m isobath represents an area of 2,960,000 km^2, which is the largest of any country in the world. The seabed slope angles within this zone typically range between <1° and 4°, although canyon and channel wall or subduction thrust ridge slope angles can exceed 45° (Mosher *et al.* 2004a). The continental slope typically supports a stable, thick, unconsolidated sediment overburden (Mosher *et al.* 1994). Other factors that may affect seabed and slope instability potential include interstitial biogenic or hydrocarbon free gas, gas hydrate, salt mobility, high sedimentation rates (*e.g.*, deglacial periods), high pore pressures and vertical lithologic (porosity / permeability) variability (Mosher *et al.* 2004b). Lykousis *et al.* (2007) indicate that for continental margin settings, seismicity, or ground shaking due to earthquakes, is required to initiate seabed instability. It is acknowledged that the main triggering mechanisms of sediment failures are seismic shaking, overloading, gas hydrate dissolution and excess pore pressure (coastal flow regime), wave loading, erosion and human activities such as coastal construction (Locat and Lee 2009).

Canada's eastern continental margin is a tectonically-passive margin where seismicity is rare (Adams and Halchuk 2003). However, earthquakes up to M7+ can be expected (Mazzotti and Adams 2005) and have occurred, such as the 1929 M7.2 event off the southern tail of the Grand Banks (Bent 1995). In the past, seismicity was probably more common due to deglacial isostatic rebound, or periods when possible ocean basin scale tectonism was active (Weaver 2003). The 1929 Grand Banks landslide is perhaps the most famous historic submarine mass-transport deposit. It led to the first formal recognition of naturally-occurring turbidity currents (Piper *et al.* 1988), and the recognition that seafloor displacements due to seabed sediment failure can cause damaging tsunamis at great distance from their source (Ruffman and Tuttle 1995; Ruffman 2001; Fine *et al.* 2005).

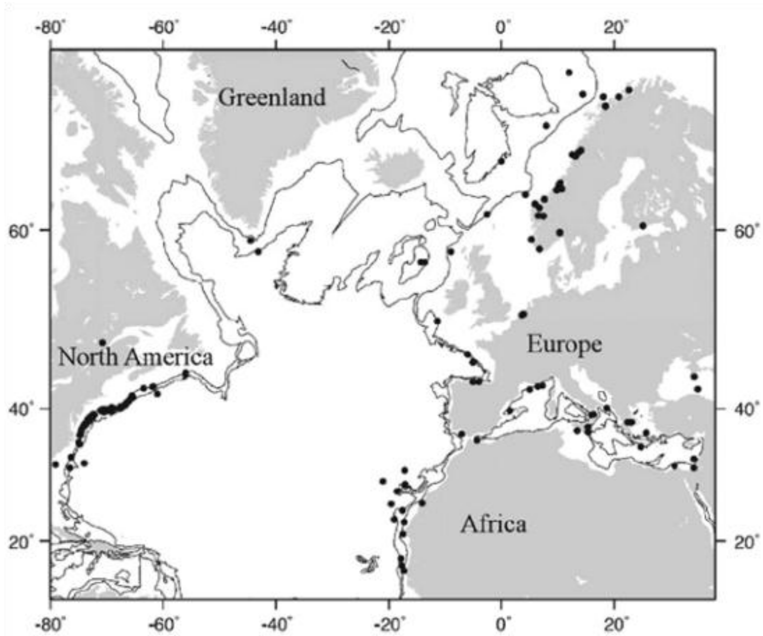
Lee *et al.* (2007) noted that submarine landslides (sediment instabilities) are not distributed uniformly over the world's oceans, but instead tend to occur commonly where there are thick bodies of soft sediment, where the slopes are steep and where the loads exerted by the environment are high. It should be noted that Old Harry is not situated in an area with this type of seabed morphology. A compilation of sediment thickness for the main oceans is illustrated in Figure 4.11 (areas coloured red denote a zone of substantial deltaic accumulation (such as the Gulf of Mexico) or thick glacial sequences (that would be found off the eastern coast of Canada)). The St. Lawrence Estuary is located in a glaciated area in which the land has risen faster than sea level, resulting in large terraces that were cut and are now exposed. A compilation of landslide distribution for the North Atlantic had been described in Hunerbach and Masson (2004) and is presented in Figure 4.12. Since the production of this figure, the St. Lawrence estuary was mapped and more than 30 slides were identified in that area (Campbell *et al.* 2008).

Slope instabilities occur mainly in two settings, on open continental margins and on oceanic island flanks, which appears to be a function of specific aspects of the geology and morphology of these areas. Slope failures associated with continental margin slopes are typically of low gradient with gentle topography; however, the 'drop' from shelf edge to basin floor can be up to 5 km over distances of a few hundred kilometres (Masson *et al.* 2006). Parallel-bedded sediment sequences with little variability over large areas characterize their subsurface structure, with the result that, should the conditions for slope failure occur, they can simultaneously affect large areas.



Source: Locat and Lee 2009

Figure 4.11 Total Sediment Thickness for Main Oceans



Source: Locat and Lee 2009

Figure 4.12 Slope Failures in Western and Eastern North Atlantic and Adjacent Seas

The hazard posed by submarine landslides will vary according to landslide scale, location, type and process and are such that even small submarine landslides can be dangerous when they occur in coastal areas. Slope failures can be divided into two types, those related to the geological characteristics of the landslide material (*e.g.*, overpressure due to rapid deposition or the presence of a weak layer) and those driven by transient external events (*e.g.*, earthquakes or climate change).

Many sedimented slopes prone to submarine landslides show a history of landslides that extends back through geological time. This observation can often be applied at quite local scales, with areas showing stacked landslide deposits sharply demarcated from those showing long-term stability (Solheim *et al.* 2005). The importance of tsunamis generated by slope instabilities has only become widely recognized during the last 15 years or so, when it became apparent that a landslide source could explain the unusual run-up distributions and propagation characteristics of certain particularly deadly tsunami, such as the 1998 PNG event (Ward 2001; Okal and Synolakis 2004).

Seabed Instabilities Generated Tsunamis

Considerable evidence suggests that ‘unusual’ tsunamis, particularly those with high near-field run-ups that decay rapidly away from source, are directly caused by seabed and slope failures (landslides) (Bardet *et al.* 2003; Okal and Synolakis 2004). Rotational slides (often referred to as slumps), where a thick slide block with a steep headwall can move rapidly downward, may be particularly effective in generating tsunamis, even when the lateral distance moved is small and little effect is seen on the seafloor downslope of the immediate landslide site. As noted previously, the Old Harry site displays a gently undulating topography with a broad, low relief “ridge” trending southeastward through the centre of the site, with low lying troughs on each side. The proposed well surface location is situated near the crest of the “ridge” at 470 m water depth and the local seabed dip is <1° south-southwest (FGI 2010). This type of topography generally does not support seabed or slope failures.

Slope failure volume, velocity, initial acceleration, length and thickness all contribute to the determination of tsunami character (Masson *et al.* 2006). The best indicator of tsunamigenic potential is the product of volume and initial acceleration (Lovholt *et al.* 2005). An abrupt deceleration might also contribute to larger surface elevations. The slide length affects both the wavelength and the maximum surface elevation (Haugen *et al.* 2005), while the wavelength is also determined by the travel time or run-out distance of the slide. Submarine slides are normally clearly subcritical, implying that the tsunami will run away from the wave-generating slide, limiting the build-up of the wave. Slides in shallow waters are more critical, since the speed of wave propagation is lower. Moreover, shallower water normally means less distance to the coast and a shorter distance available for radial damping (Masson *et al.* 2006). In contrast, tsunamis generated by earthquakes are more critical when the seabed displacement occurs in deeper waters, as the initial wave will become shorter and more dangerously amplified when propagating from deeper to shallower waters (Masson *et al.* 2006). The area in which Old Harry is located is of low seismicity potential and in an area with gentle undulating topography, so slope failures in the immediate area would not be expected.

4.2 Physical Oceanography

The Gulf is a semi-enclosed sea (Koitutonsky and Bugden 1991), having two openings to the Atlantic Ocean, the Cabot Strait and the Strait of Belle Isle (Figure 4.5). The Gulf has a surface area of approximately 236,000 km^2, a volume of 35 000 km^3, an average depth of 152 m and maximum depths up to 535 m (Dufour and Ouellet 2007; Dufour *et al.* 2010). The Gulf exchanges salt water with the North Atlantic Ocean and receives considerable input of fresh water from the St. Lawrence River and other nearby rivers. As a consequence, the Gulf acts like a large estuary where Coriolis effects (from force generated by the Earth’s rotation), geostrophic currents, baroclinic processes, formation of eddies and wind stress effects are all important.

Present within the Gulf are numerous shallow areas and deep troughs. One particularly well-known trough, called the Laurentian Channel, is a long, continuous trough that has a maximum depth of 535 m and extends approximately 1,500 km from the continental shelf in the Atlantic Ocean to its end point in the St. Lawrence Estuary. Two secondary troughs are also located in the Gulf: the Esquiman and the Anticosti Channels. Another predominant feature is the Magdalen Shallows, which is a plateau located in the southern Gulf (Dufour and Ouellet 2007). The physiographical features of the Gulf greatly influence the circulation, mixing and characteristics of water masses within this area (Dufour and Ouellet 2007).

4.2.1 Bathymetry

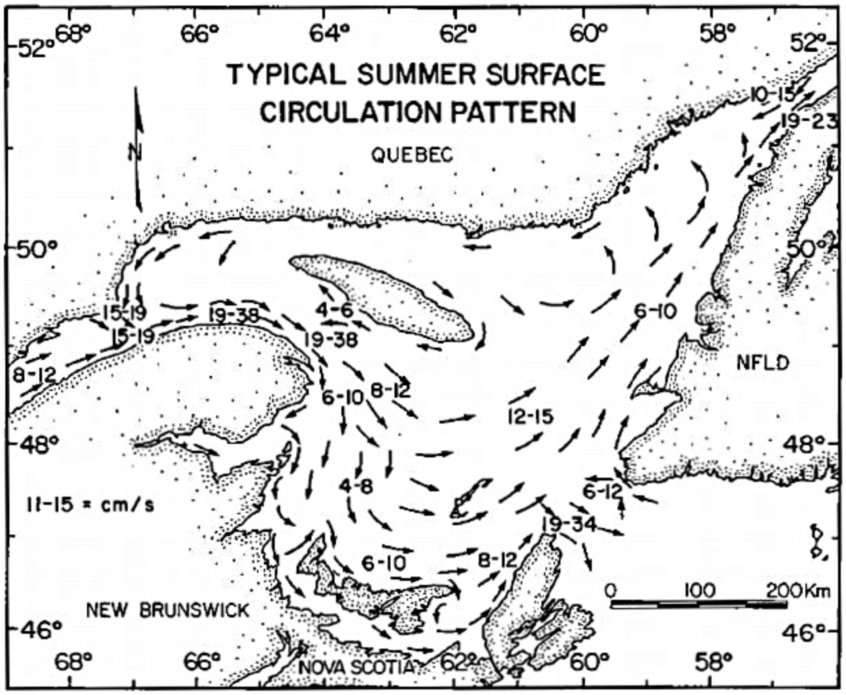
Water depths within EL 1105 and the vicinity of the Project range from 400 to 500 m (see Figure 1.2).

4.2.2 Ocean Currents

Knowledge of ocean currents is essential to the planning of oil and gas related operations in any area. Currents in the Gulf are influenced by a number of factors, including tides, regional meteorological events, freshwater runoff and water exchange through the Strait of Belle Isle and the Cabot Strait. There are large, seasonally-variable runoffs of fresh water into the Gulf, mainly from the St. Lawrence River and rivers of the northern shore and southern shores, which strongly influence the circulation of the Gulf.

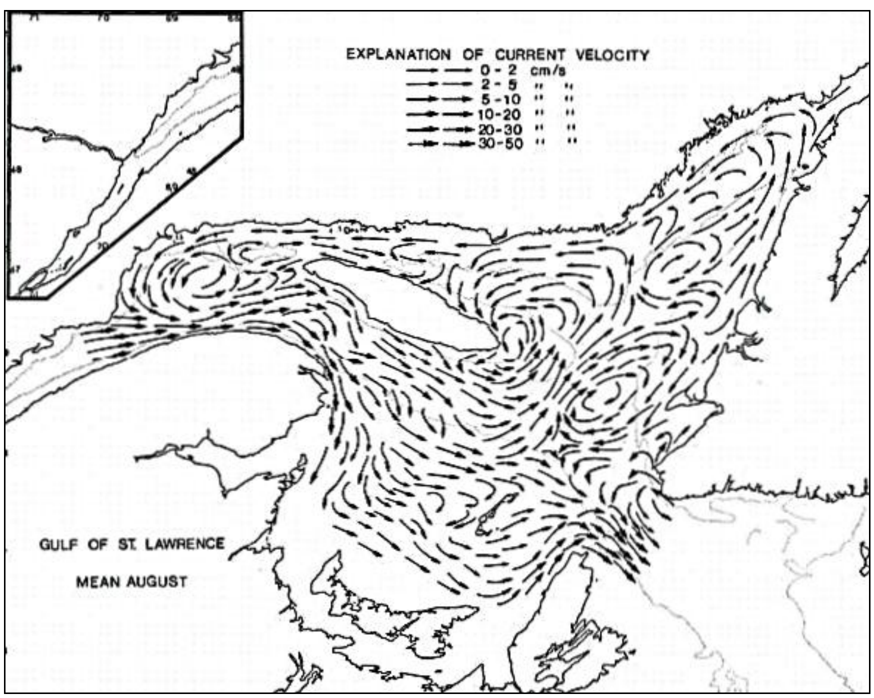
The strongest currents in the Gulf are located 2 to 12 nm offshore of Gaspé Peninsula and average 6 to 10 nm per day. From there, the water spreads across the Magdalen Shallows towards the Cabot Strait with some water traveling through the Laurentian Channel across the Gulf. Currents over the Magdalen Shallows are generally 3 to 5 nm per day. Rates of flow north of Cape Breton Island are typically 5 to 7 nm and 2 to 4 nm along the west coast of Newfoundland (Environment Canada 2011).

Cold, dense water flows into the Gulf through the Strait of Belle Isle from northern latitudes via the Labrador Current. Waters from the Atlantic Ocean enter the Gulf via the Cabot Strait, in the Laurentian Channel (Figure 4.13). The surface circulation of the Gulf exhibits strong features such as coastal currents, gyres, large eddies in the Estuary and tidal fronts (Dufour and Ouellet 2007). The St. Lawrence River outflow produces a strong coastal current that flows along the length of the Gaspé Peninsula (the Gaspé Current), flowing seaward and dispersing the St. Lawrence runoff in the northwestern and the southern Gulf (Dufour and Ouellet 2007). The waters of the southern Gulf (between the Magdalen Islands, Prince Edward Island and the western side of Cape Breton) form the main outflow of the Gulf on the western side of Cabot Strait. On the eastern side of Cabot Strait, an inflow from the Atlantic flows northeastward along the west coast of Newfoundland (Dufour and Ouellet 2007). The waters from the Strait of Belle Isle move westward along the northeastern shore (Dufour and Ouellet 2007) (Figure 4.14).



Source: Trites 1972, in LGL 2005b.

Figure 4.13 Typical Summer Circulation in the Gulf of St. Lawrence

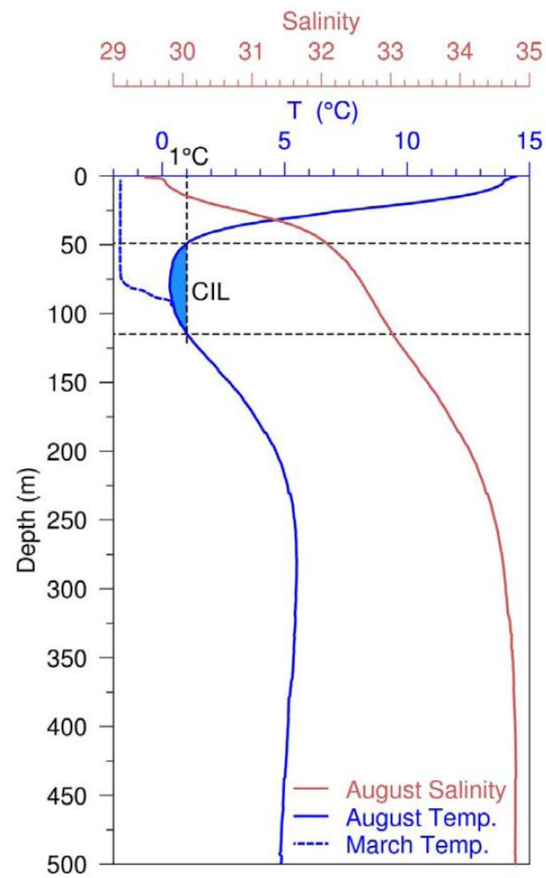


Source: LGL 2005b.

Figure 4.14 Geostrophic Surface Currents in the Gulf of St. Lawrence in August

The surface circulation is cyclonic, that is, the surface current moves in a counter-clockwise fashion (Figure 4.13). The similarities between this cyclonic circulation pattern and the surface salinity distributions in the Gaspé and Magdalen Shallows regions indicate that the surface currents are a result of the geostrophic balance (Figure 4.14) between the horizontal pressure gradient field and Coriolis effects (Koutitonsky and Bugden 1991) and are indicative of a complex circulation pattern.

Oceanographic conditions in the Gulf are complex. Masses of water with acutely contrasting temperature and salinity come together and mix. The Gulf can be considered a three-layer system (Figure 4.15) during summer (surface layer, cold intermediate layer and deep water layer); the two upper layers undergo seasonal variations and become one during the winter months (DFO 2005a; Dufour and Ouellet 2007). Surface temperatures typically reach maximum values in mid-July to mid-August (Galbraith *et al.* 2011). Gradual cooling occurs thereafter, and wind mixing during the fall leads to a progressively deeper and cooler mixed layer, eventually encompassing the cold intermediate layer. During winter, the surface layer thickens as a result of buoyancy loss (due to cooling and reduced runoff) and brine rejection associated with sea-ice formation. However, the primary force driving the surface layer thickening is wind-driven mixing prior to ice formation (Galbraith 2006).



Source: Galbraith *et al.* 2011.

Figure 4.15 Typical Depth Profile of Temperature and Salinity Observed during the Summer in the Gulf of St. Lawrence (based on 2007-2008 data)

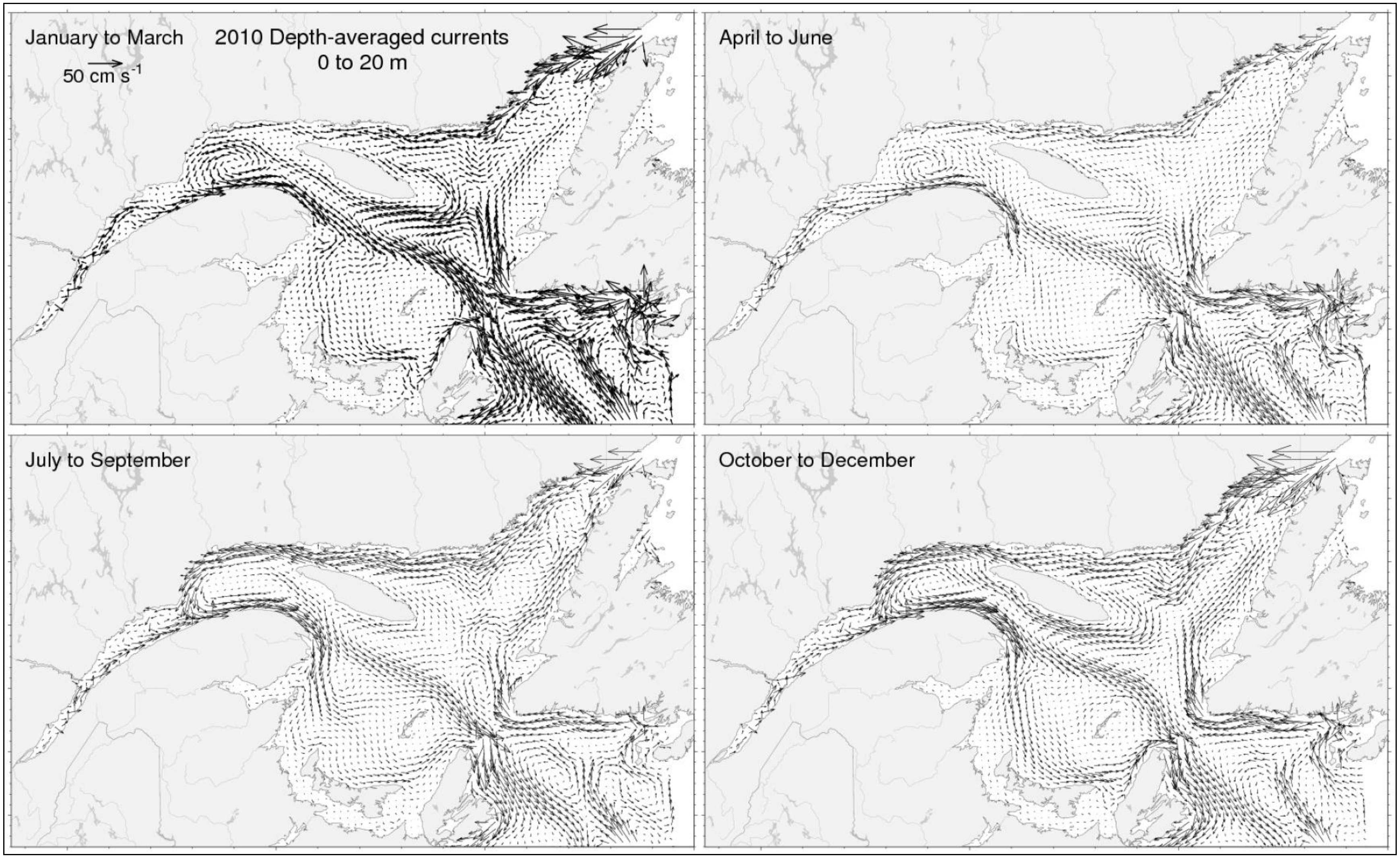
The surface winter layer reaches an average depth of 75 m with depths up to 150 m and deeper in the northeast Gulf, where waters from the Labrador Shelf at the Strait of Belle Isle may intrude into the Gulf and extend the surface winter layer from the surface to the bottom (>200 m) in Mécatina Trough by the end of March. The surface winter layer exhibits temperatures near freezing (-1.8 to 0ºC) (Galbraith 2006). The warmer, low salinity surface layers are produced during the spring when an increase in freshwater flow enters the Gulf via the St. Lawrence River, the Saguenay River and other smaller rivers along the shores. The surface layer flows out of the Gulf into the Atlantic. Additional freshwater runoff occurs in the fall, driving circulation patterns in the Gulf, and causing the area to show properties of an estuarine environment (Dufour and Ouellet 2007). At the start of winter the warmer, low salinity surface layer flowing into the Atlantic becomes less buoyant, due to the drop in air temperature and ice formation, and moves downward in the water column. Once spring arrives, a new summer surface layer is created causing the winter layer to be trapped below. This is referred to as the Cold Intermediate Layer (Dufour and Ouellet 2007).

Currents are strongest in the surface mixed layer, generally 0 to 20 m, except in winter months when the 20 to 100 m averages are almost as strong (the surface layer and cold intermediate layer have merged as one layer) and the deep layer (100 m to the bottom) averages are very high. Currents are strongest along the slopes of the deep channels. The Anticosti Gyre is always evident but strongest during winter months, when it even extends strongly into the bottom-average currents (Galbraith *et al.* 2011). Figure 4.16, 4.17 and 4.18 present the seasonal depth-averaged currents for 0 to 20 m, 20 to 100 m, and 100 m to the bottom for 2010 (Galbraith *et al.* 2011).

Maurice Lamontagne Institute, Canadian Hydrographic Service and DFO issue ocean forecasts for the Gulf (St. Lawrence Global Observatory (SLGO) 2011). The surface current forecast is extracted from a three-dimensional numerical model computing the oceanic circulation under the influence of tides, the St. Lawrence River fresh water runoff, atmospheric forcing and the sea ice drift, growth and melt (SLGO 2011). This model has been validated under a series of scientific and operational research and development programs within DFO. The validation process was done against a number of oceanographic observations including currents, water level, water temperature and salinity (SLGO 2011). This online program allows for daily forecast of surface currents. The surface currents for EL 1105 are illustrated in Figure 4.19 and is an example output of the model described above is presented for September 29, 2011 @ 0800 hours.

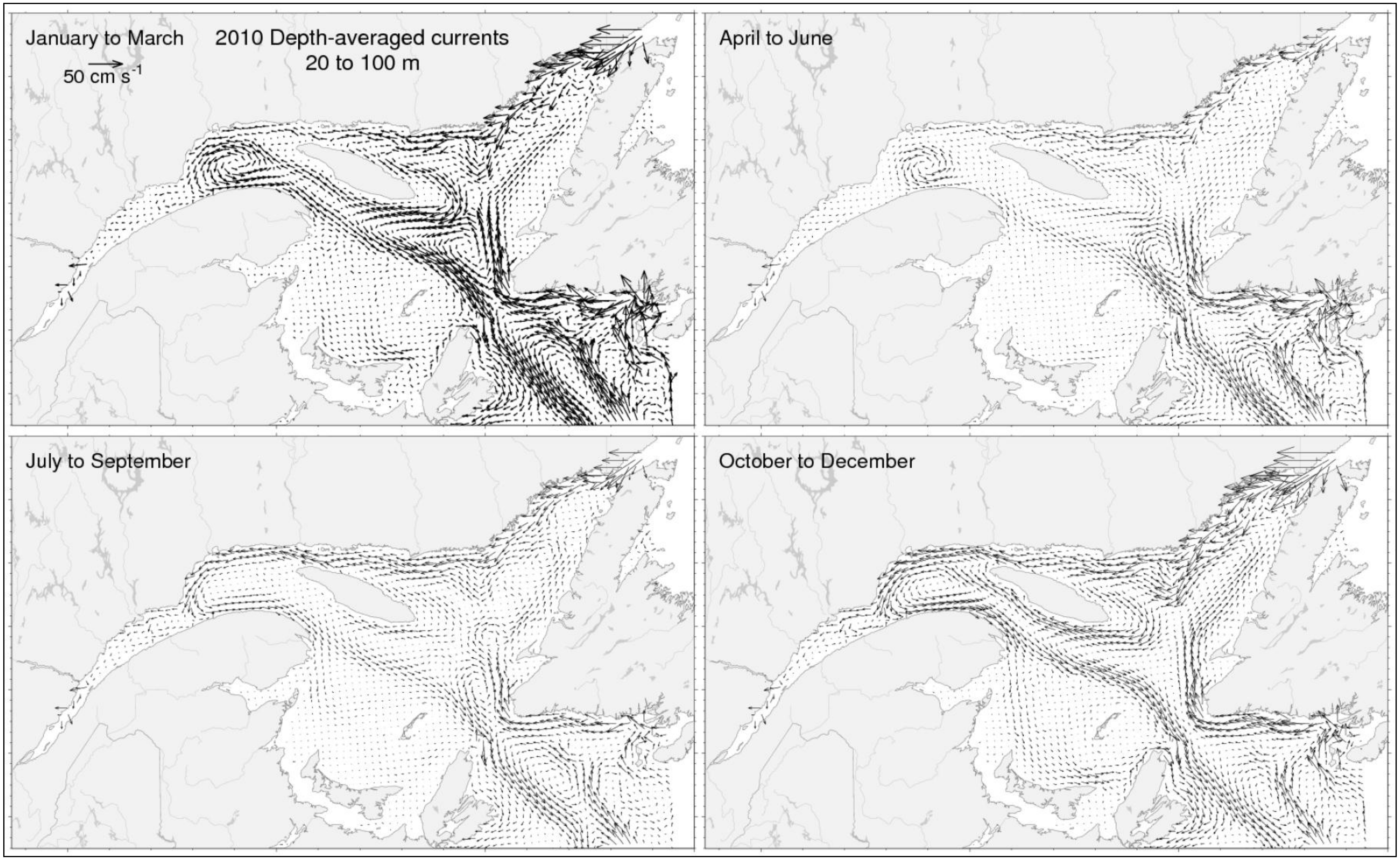
Vertical mixing is an important process affecting water masses as it plays an important role in marine habitats, thereby directly affecting productivity and biodiversity. Tides propagating over the sills at the head of the Laurentian Channel produce strong mixing of the different water masses that converge in this area (Dufour and Ouellet 2007). Tidal mixing is also a permanent and dominant modifier of the intermediate and deeper waters near the head of Jacques Cartier Strait and in the Strait of Belle Isle (Saucier *et al.* 2003). The wind-driven mixing coupled with the tidal regime and the local stability of the surface waters will determine the deepening of the summer and winter surface layers (Saucier *et al.* 2003). A water mass can reside in the Gulf for a few months near the surface or up to a few years in the colder, bottom waters.

Atmospheric conditions in the Gulf also play an important role in the circulation of water, as they have an effect on cloud cover, precipitation, evaporation and air temperature.



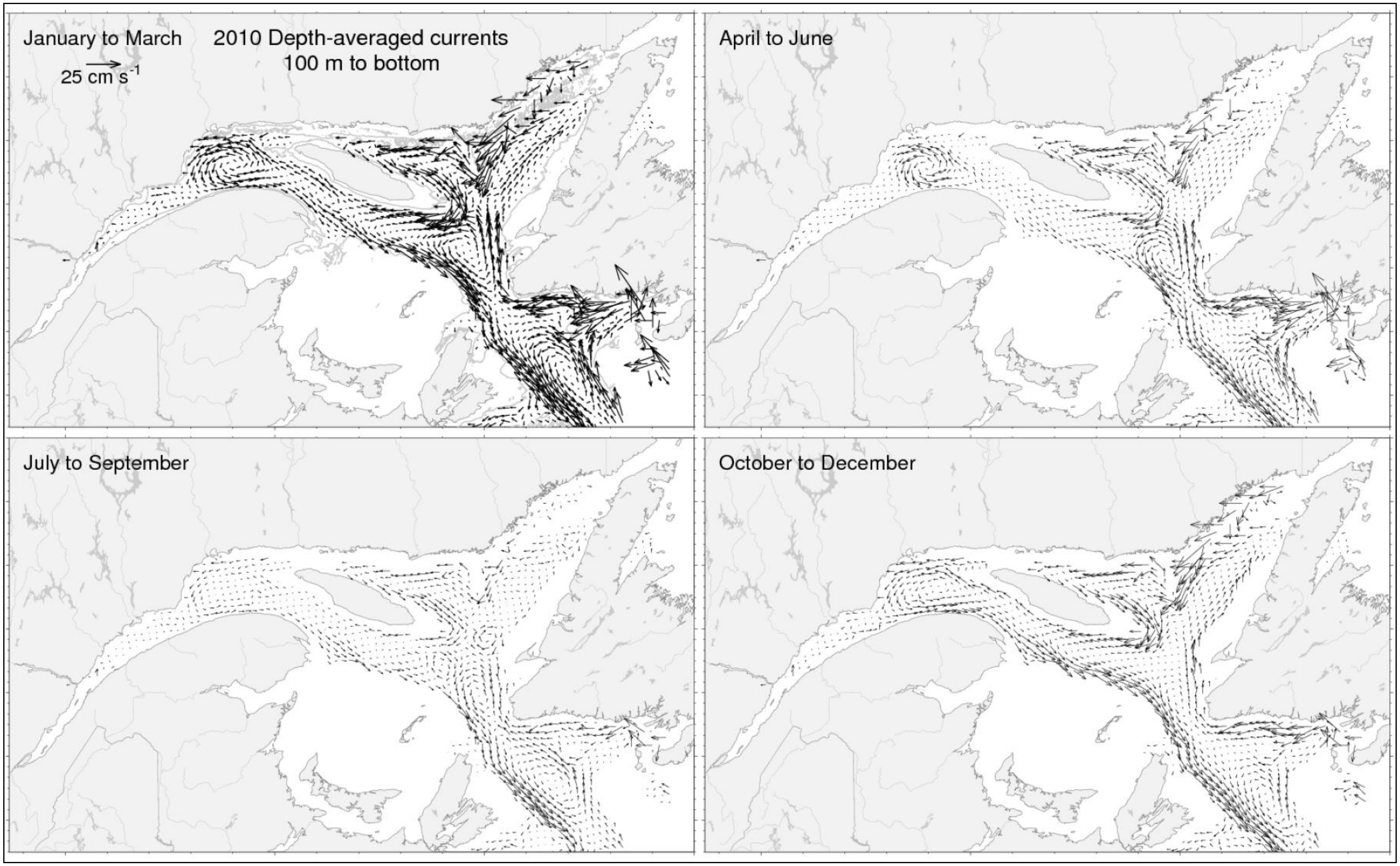
Source: Galbraith *et al.* 2011

Figure 4.16 Depth-averaged Currents from 0 to 20 m for each Three-month Period of 2010



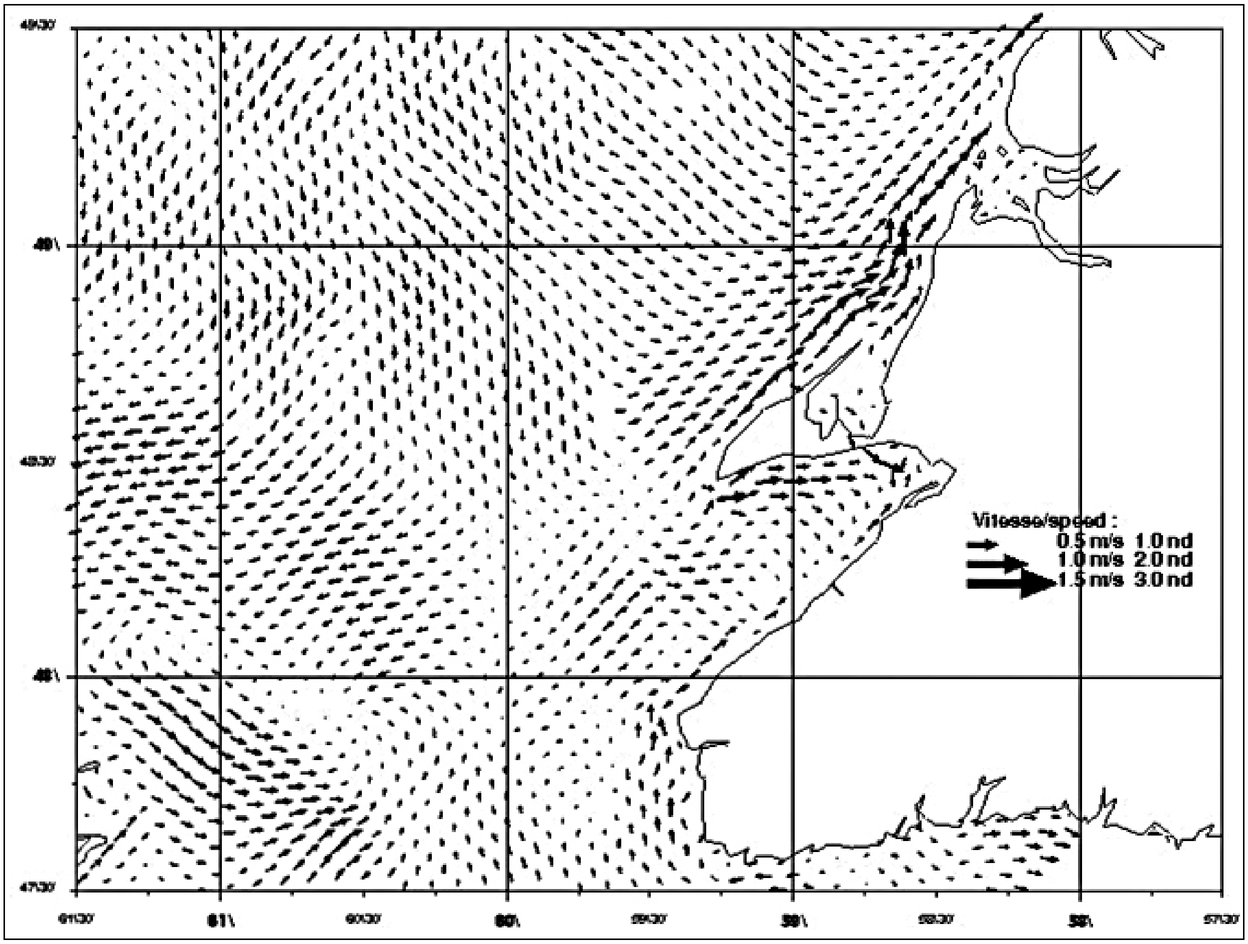
Source: Galbraith *et al.* 2011

Figure 4.17 Depth-averaged Currents from 20 to 100 m for each Three-month Period of 2010



Source: Galbraith *et al.* 2011

Figure 4.18 Depth-averaged Currents from 100 m to Bottom for each Three-month Period of 2010



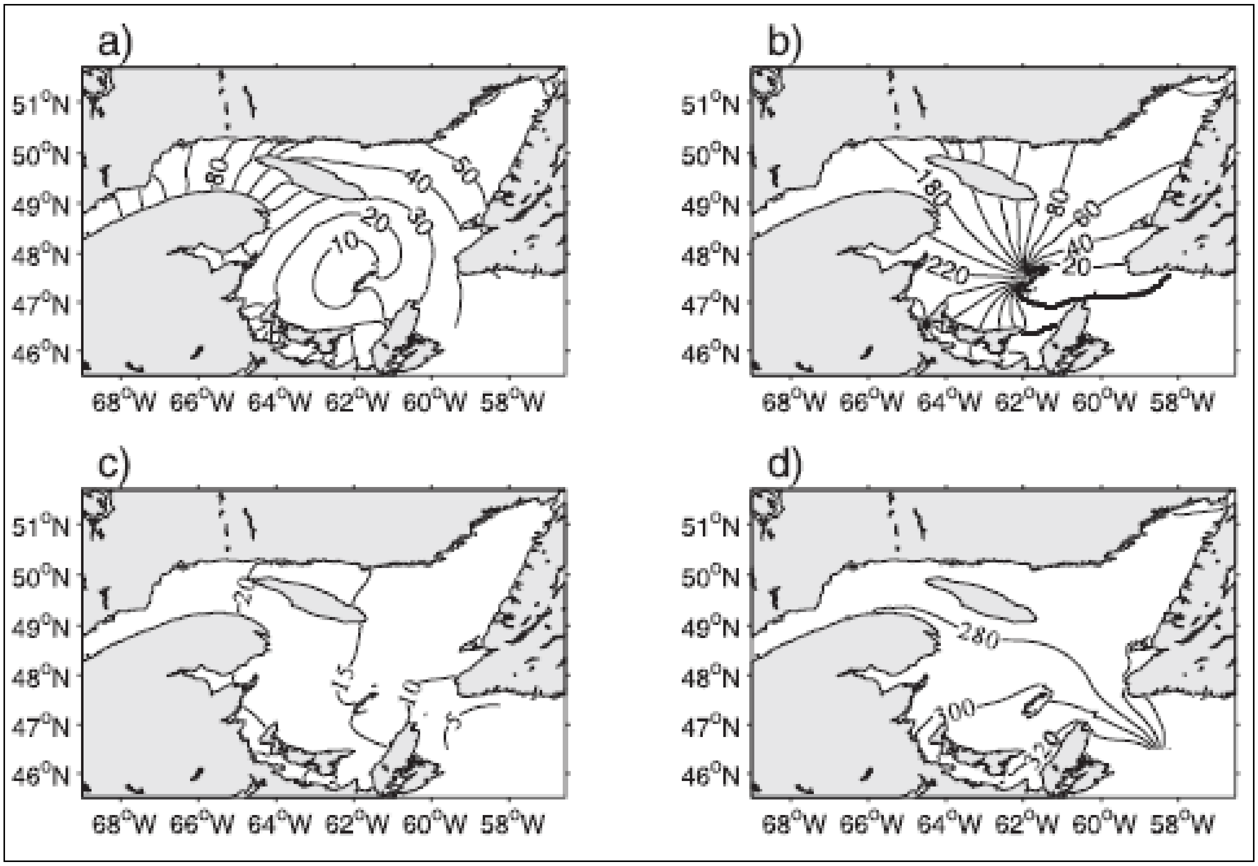
Source: SLGO 2011.

Figure 4.19 Surface Currents in the Gulf of St. Lawrence (September 29, 2011 @ 0800 hours)

Source: Environment Canada 2011

4.2.3 Tides

The tides in the Gulf are mixed in the centre of the Gulf (LGL 2005b). Tides are forced through the Cabot Strait with minor contributions from the Strait of Belle Isle and direct gravitational forcing (Lu et. al. 2001). The tides in the Magdalen Islands average approximately 0.7 m. The main tidal surge flows counter-clockwise around a point west of the Magdalen Islands (Figure 4.20). It enters at the Cabot Strait and average tide ranges vary from 0.8 to 1.5 m. In the Northumberland Strait the tidal pattern becomes more complex. The area west of the Strait has one tide per day, while in the east there are the typically two tides with ranging from 1.2 to 1.8 m. The Strait of Belle Isle has tides in the 0.8 to 0.9 m range (Environment Canada 2011). Tidal currents seldom exceed 30 cm/sec (Koutitonsky and Bugden 1991).



Source: Lu *et al.* 2001.
Amplitudes are in cm, and phases are in degrees relative to midnight GMT.
Note: a and c are coamplitude lines; b and d are cophase lines.

Figure 4.20 Semidiurnal (M2) and Diurnal Tide (K1) Lines Calculated using a Complex Model

4.2.4 Waves

The wave climate in the Gulf can be affected by extra-tropical storms occurring from October to March. Tropical storms can also occur between August and October; however, hurricanes tend to have reduced to tropical or extra-tropical storms by the time they have reached the Gulf waters (LGL 2005b). The wave climate in the Gulf was assessed by means of the MSC50 data set for grid point 13511 (within the Project Area). The minimum, maximum, mean and standard deviations of significant wave heights for each season are presented in Table 4.1. Significant wave height is defined as the mean wave height of the highest 1/3 of all individual waves from trough to crest (NOAA 2011). Maximum significant wave heights were greatest during the fall and winter seasons. The percent occurrence of peak wave period against significant wave heights for grid point 13511 for each season is presented in Tables 4.2 to 4.5. Peak wave period refers to the period associated with most energetic waves in the nondirectional wave spectrum at a specific point (NOAA 2011). Wind data from the same grid point are provided in Section 4.3.2.

Table 4.1 Minimum, Maximum, Mean and Standard Deviation of Significant Wave Height at Grid Point 13511 by Season

Season	Minimum Wave Height (m)	Maximum Wave Height (m)	Mean Wave Height (m)	Standard Deviation (m)
Fall (Sept to Nov)	0.15	9.29	1.95	1.09
Winter (Dec to Feb)	0	9.46	2.41	1.35
Spring (March to May)	0	7.05	1.41	0.92
Summer (June to Aug)	0.1	7.56	1.14	0.63

Table 4.2 Percent Occurrence of Peak Wave Period against Significant Wave Height for Grid Point 13511: September, October and November

Significant Wave Height (m)	Peak Wave Period(s)										Total
	1	3	5	7	9	11	13	15	17	19	
0 to 0.99	<0.01	2.05	9.82	2.25	2.19	0.72	0.67	0.13	0.02	<0.01	**17.9**
1 to 1.99	<0.01	0.46	25.1	13.2	2.58	0.95	0.61	0.2	0.05	<0.01	**43.1**
2 to 2.99	<0.01	<0.01	0.81	20.6	1.29	0.29	0.22	0.01	0.01	<0.01	**23.2**
3 to 3.99	<0.01	<0.01	<0.01	4.04	5.94	0.12	0.07	<0.01	<0.01	<0.01	**10.2**
4 to 4.99	<0.01	<0.01	<0.01	0.07	3.76	0.07	0.03	<0.01	<0.01	<0.01	**3.92**
5 to 5.99	<0.01	<0.01	<0.01	<0.01	0.95	0.31	0.01	<0.01	<0.01	<0.01	**1.27**
6 to 6.99	<0.01	<0.01	<0.01	<0.01	0.02	0.29	<0.01	<0.01	<0.01	<0.01	**0.31**
7 to 7.99	<0.01	<0.01	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	<0.01	<0.01	**0.08**
8 to 8.99	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	**0.03**
9 to 9.99	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	**<0.01**
Total	**<0.01**	**2.51**	**35.7**	**40.2**	**16.7**	**2.87**	**1.6**	**0.35**	**0.08**	**<0.01**	**100**

Table 4.3 Percent Occurrence of Peak Wave Period against Significant Wave Height for Grid Point 13511: December, January and February

Significant Wave Height (m)	Peak Wave Period(s)										Total
	1	3	5	7	9	11	13	15	17	19	
0 to 0.99	0.07	2.25	5.22	0.34	1.19	1.03	0.69	0.03	0.01	0.01	**10.9**
1 to 1.99	<0.01	0.44	19.9	9.95	2.07	1.99	0.68	0.09	<0.01	<0.01	**35.1**
2 to 2.99	<0.01	<0.01	1.66	21.9	1.44	0.94	0.36	0.06	<0.01	<0.01	**26.3**
3 to 3.99	<0.01	<0.01	0.01	6.72	8.04	0.4	0.17	0.01	<0.01	<0.01	**15.4**
4 to 4.99	<0.01	<0.01	<0.01	0.27	6.84	0.22	0.07	<0.01	<0.01	<0.01	**7.41**
5 to 5.99	<0.01	<0.01	<0.01	<0.01	2.28	0.78	0.02	<0.01	<0.01	<0.01	**3.07**
6 to 6.99	<0.01	<0.01	<0.01	<0.01	0.17	0.97	0.02	<0.01	<0.01	<0.01	**1.16**
7 to 7.99	<0.01	<0.01	<0.01	<0.01	<0.01	0.48	0.01	<0.01	<0.01	<0.01	**0.49**
8 to 8.99	<0.01	<0.01	<0.01	<0.01	<0.01	0.2	<0.01	<0.01	<0.01	<0.01	**0.2**
9 to 9.99	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	**0.04**
Total	**0.07**	**2.7**	**26.8**	**39.2**	**22**	**7.05**	**2.03**	**0.19**	**0.01**	**0.01**	**100**

Table 4.4 Percent Occurrence of Peak Wave Period against Significant Wave Height for Grid Point 13511: March, April and May

Significant Wave Height (m)	Peak Wave Period(s)											Total
	1	3	5	7	9	11	13	15	17	19	21	
0 to 0.99	0.63	7.59	15	6.95	5.48	1.93	1.66	0.11	0.04	0.02	0.01	**39.4**
1 to 1.99	<0.01	0.62	24.7	9.29	3.25	1.39	0.27	0.03	<0.01	<0.01	<0.01	**39.5**
2 to 2.99	<0.01	<0.01	0.9	12.3	0.97	0.32	0.08	<0.01	<0.01	<0.01	<0.01	**14.6**
3 to 3.99	<0.01	<0.01	<0.01	2.53	1.9	0.09	0.05	<0.01	<0.01	<0.01	<0.01	**4.57**
4 to 4.99	<0.01	<0.01	<0.01	0.05	1.29	0.03	0.02	<0.01	<0.01	<0.01	<0.01	**1.39**
5 to 5.99	<0.01	<0.01	<0.01	<0.01	0.37	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	**0.44**
6 to 6.99	<0.01	<0.01	<0.01	<0.01	0.02	0.07	<0.01	<0.01	<0.01	<0.01	<0.01	**0.08**
7 to 7.99	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	**<0.01**
Total	**0.63**	**8.21**	**40.6**	**31.1**	**13.3**	**3.89**	**2.09**	**0.14**	**0.04**	**0.02**	**0.01**	**100**

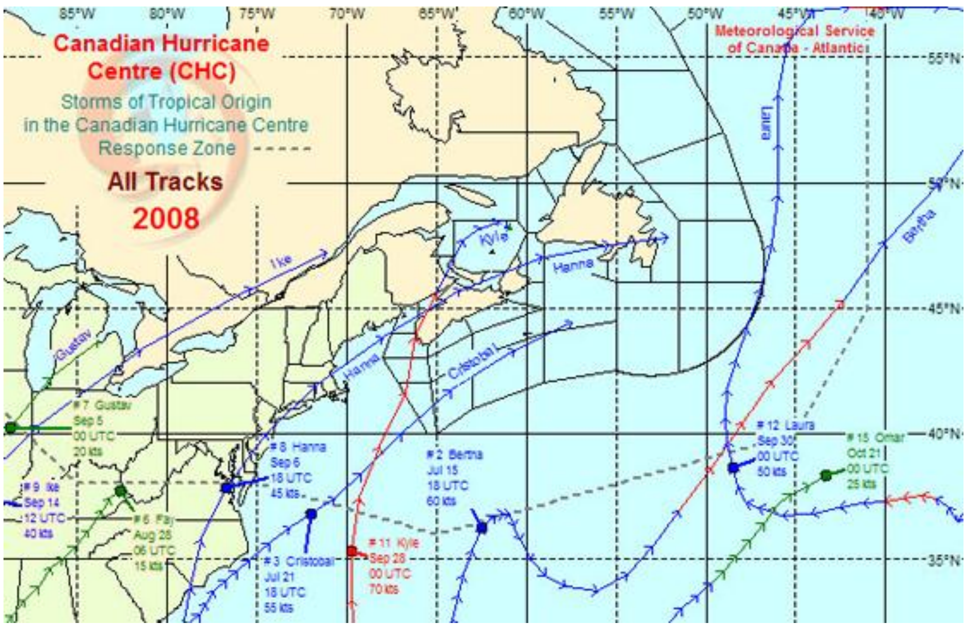
Table 4.5 Percent Occurrence of Peak Wave Period against Significant Wave Height for Grid Point 13511: June, July and August

Significant Wave Height (m)	Peak Wave Period(s)										Total
	1	3	5	7	9	11	13	15	17	19	
0 to 0.99	<0.01	7.74	24.5	11.3	4.26	1	0.89	0.34	0.19	0.02	**50.3**
1 to 1.99	<0.01	0.43	27.8	9.87	1.31	0.53	0.05	0.07	0.03	0.01	**40.1**
2 to 2.99	<0.01	<0.01	0.26	7.73	0.25	0.07	<0.01	0.01	<0.01	<0.01	**8.32**
3 to 3.99	<0.01	<0.01	<0.01	0.54	0.58	0.02	<0.01	<0.01	<0.01	<0.01	**1.14**
4 to 4.99	<0.01	<0.01	<0.01	<0.01	0.17	<0.01	<0.01	<0.01	<0.01	<0.01	**0.17**
5 to 5.99	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	**0.02**
6 to 6.99	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	**<0.01**
7 to 7.99	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	**<0.01**
Total	**<0.01**	**11.2**	**52.6**	**29.5**	**6.59**	**1.63**	**0.94**	**0.41**	**0.23**	**0.03**	**100**

The majority of the significant wave heights during the fall and winter occurred at 1 to 1.99 m and at 0 to 0.99 m m during the summer. The majority of significant wave heights for spring were evenly divided between 0 to 0.99 m and 1 to 1.99 m. Generally, the winter months experienced the highest wave heights. The typical peak period is approximately 7 seconds during the fall and winter months and 5 seconds during the spring and summer months.

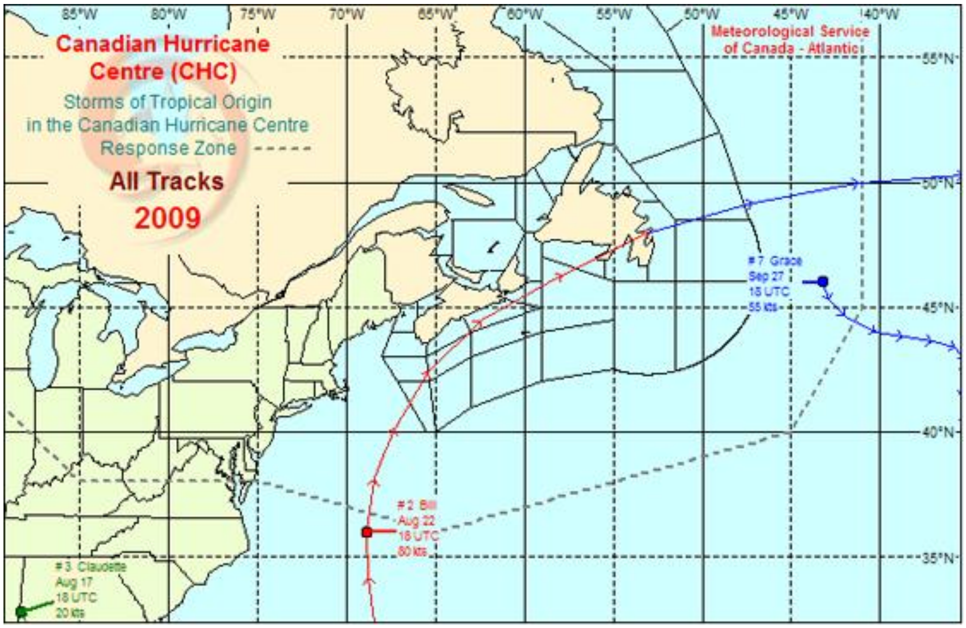
4.2.5 Storm Tracks in the Gulf of St. Lawrence

Weather systems tend to move along preferred paths over Canadian waters. Major tracks pass through the St. Lawrence Lowlands, with storms developing and moving out to sea in a northeasterly direction over the Grand Banks of Newfoundland and the Labrador Sea. In the Gulf of St. Lawrence, a cyclone season occurs from June to November, peaking in August through September. Major polar storm tracks during the summer months from 2008 to 2011 are shown in Figure 4.21 to 4.24. The important weather features affecting the North Atlantic during winter are a low pressure area, the Icelandic Low, centred southeast of Greenland; and a continental high pressure system which develops west of Hudson Bay. While the most common polar storm tracks are illustrated in Figures 4.21 to 4.24, individual storms may behave quite differently. As shown in the figures, it is common to encounter severe weather conditions resulting from low pressure systems that move northward along the United States Eastern Seaboard into the Gulf and onto the Grand Banks. These variations in normal weather patterns can result in large departures from typical seasonal weather conditions, affecting wind speed and direction, air temperature, precipitation and visibility, and can produce unseasonal ice conditions for a given region (DFO 1999a). The frequency of extratropical storm tracks during 1998 are illustrated in Figures 4.25 to 4.28.



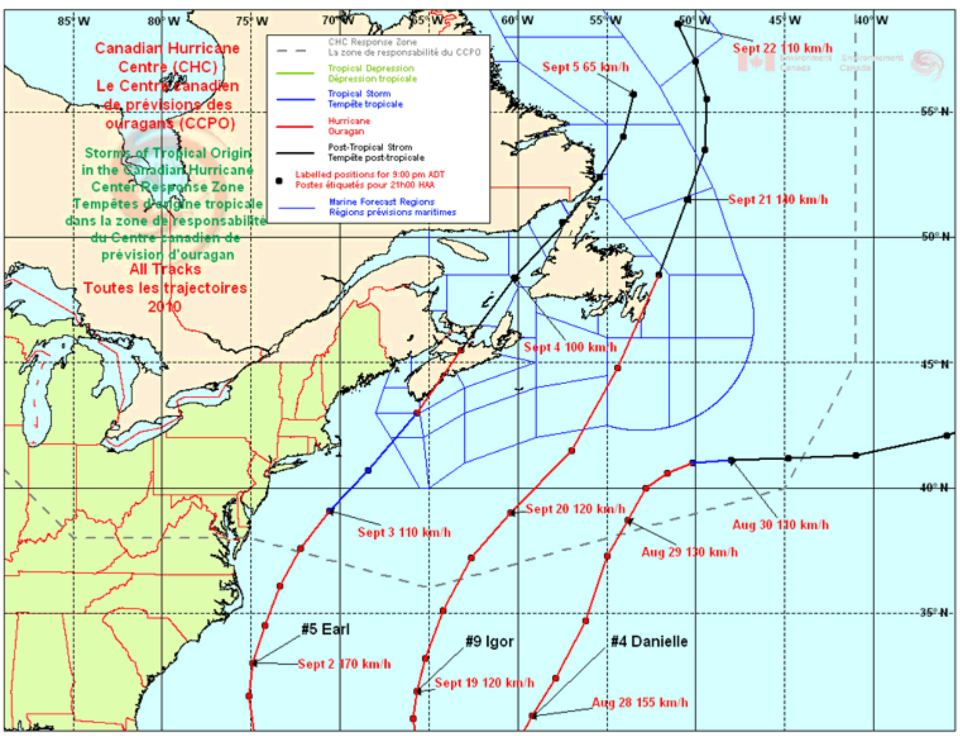
Source: Environment Canada 2012a

Figure 4.21 2008 Atlantic Canada Extratropical Storm Tracks



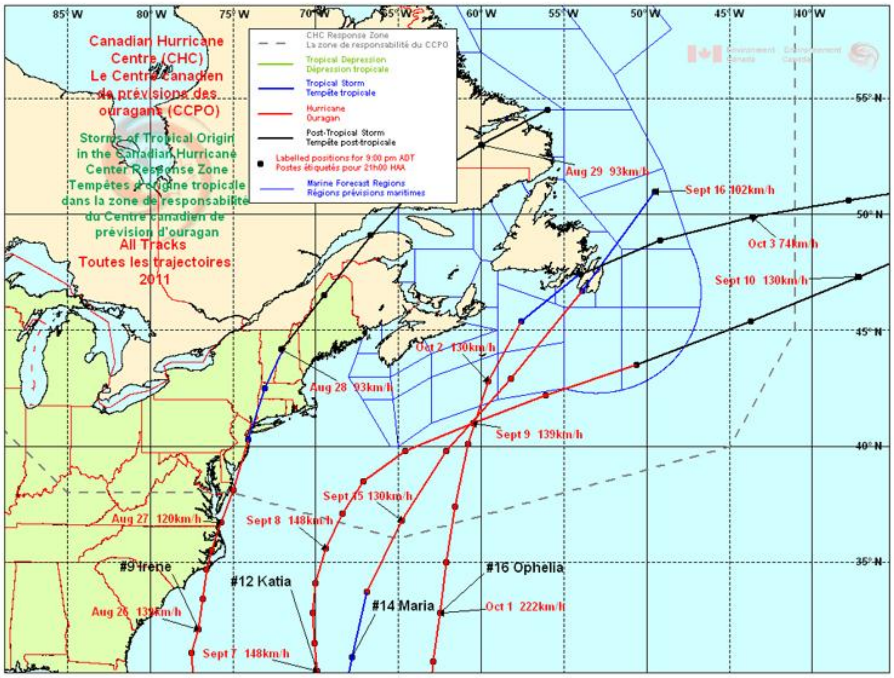
Source: Environment Canada 2012a

Figure 4.22 2009 Atlantic Canada Extratropical Storm Tracks



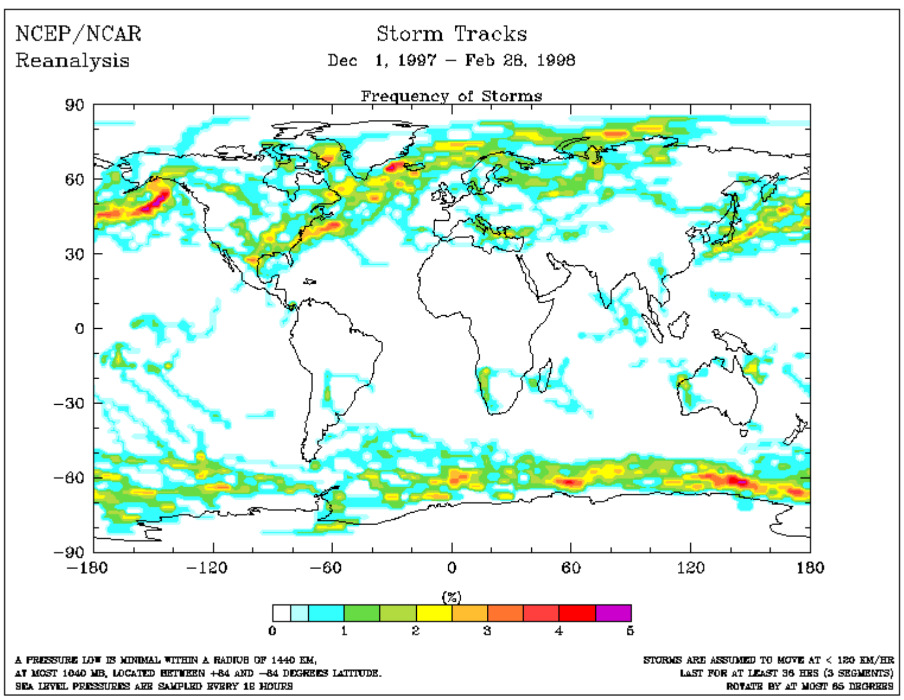
Source: Environment Canada 2012a

Figure 4.23 2010 Atlantic Canada Extratropical Storm Tracks



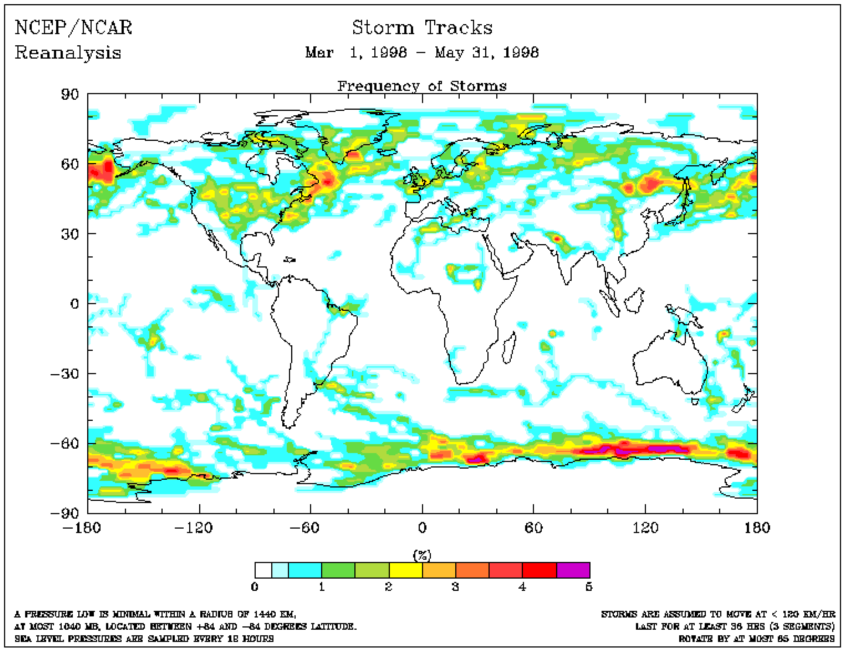
Source: Environment Canada 2012a

Figure 4.24 2011 Atlantic Canada Extratropical Storm Tracks



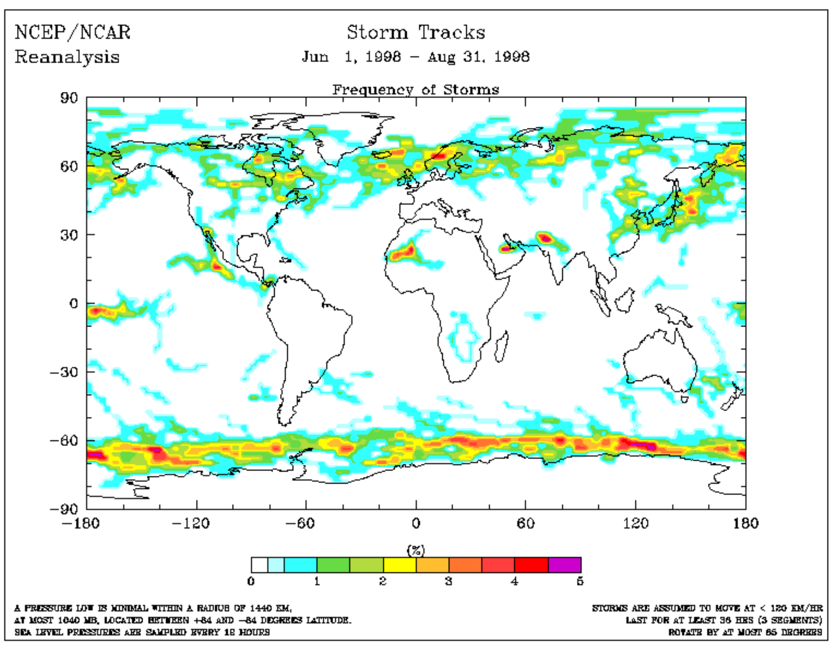
Source: NOAA No Date.

Figure 4.25 Frequency of Extratropical Storms, Dec. 1, 1997 – Feb. 28, 1998



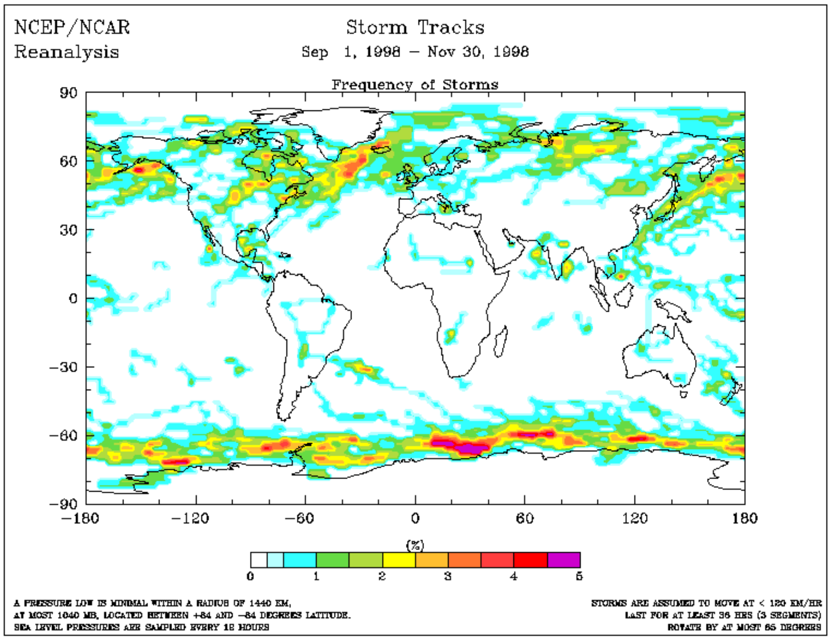
Source: NOAA No Date.

Figure 4.26 Frequency of Extratropical Storms, Mar. 1, 1998 – May 31, 1998



Source: NOAA No Date.

Figure 4.27 Frequency of Extratropical Storms, Jun. 1, 1998 – Aug. 31, 1998

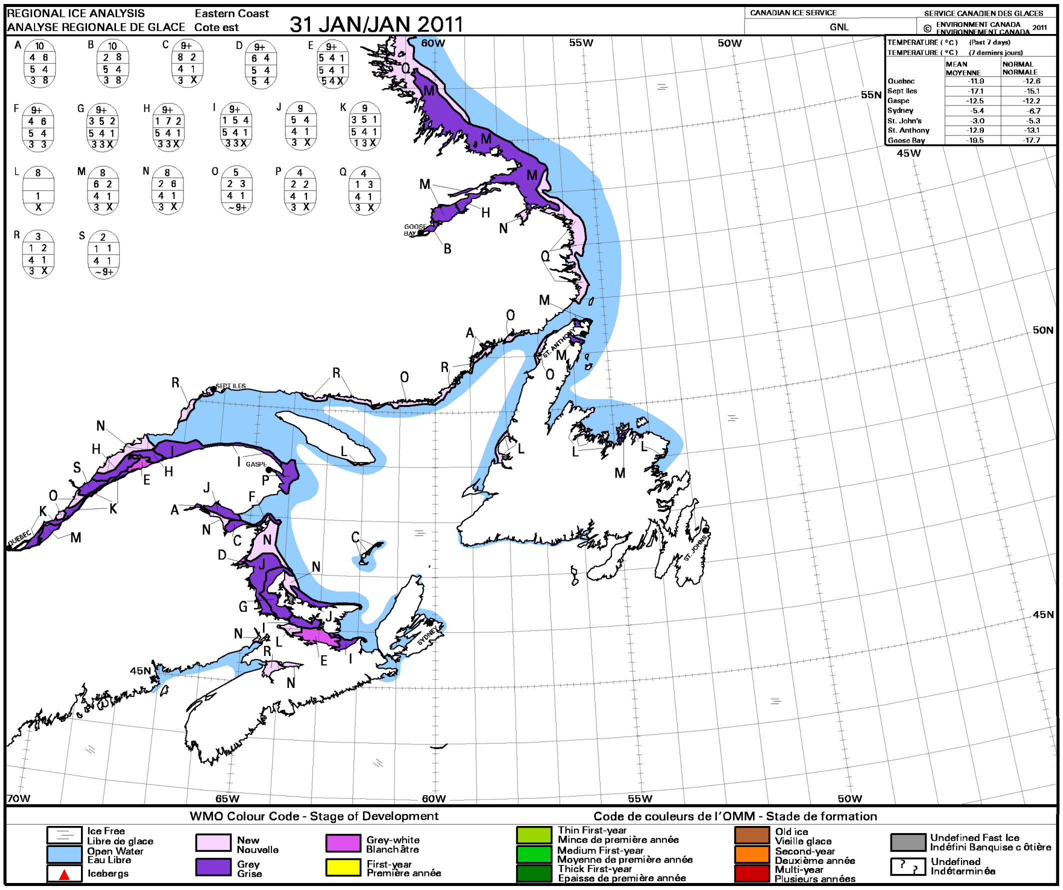


Source: NOAA No Date.

Figure 4.28 Frequency of Extratropical Storms, Sep. 1, 1998 – Nov. 30, 1998

4.2.6 Ice

Ice forms in the Gulf every winter; however, there tends to be a lot of variation in ice cover, thickness and break-up times from year to year. Floating ice is present in two forms in the marine environment - sea ice and icebergs. Both types pose a potential hazard to marine vessels and drilling rigs. Ice found in EL 1105 is a result of ice that has primarily formed in the Gulf. All sea ice in EL 1105 is seasonal ice, described as new ice, grey ice and grey-white ice in Figure 4.29. Undeformed ice thicknesses for these stages of development are less than 10 cm, 10 to 15 cm, and 15 to 30 cm, respectively. Ice thicknesses greater than 30 cm (thin first-year ice to medium first-year ice) are typically not seen until March or early April, near the end of the ice season for the Gulf of St. Lawrence.



Source: Environment Canada 2011.

Figure 4.29 Regional Ice Analysis for the Gulf of St. Lawrence (January 31, 2011)

Currents, tides, and bathymetry are the main oceanographic factors influencing ice formation in the Gulf of St. Lawrence. The bathymetry of the Gulf is dominated by a deep trench, the Laurentian Channel. It runs from the Cabot Strait to the Saguenay River and reaches depths of 500 m. The trench also extends into Jacques Cartier Passage and the Northeast Arm of the Gulf where it can be as deep as 275 m. Northumberland Strait has water depths of only 17 to 65 m with the deepest waters located to each end. The Strait of Belle Isle is as shallow as 50 m at some points and the southwestern part of the Gulf averages less than 75 m in depth (Environment Canada 2011). A description of the currents and tides is provided in Section 4.2.2 and 4.2.3, respectively.

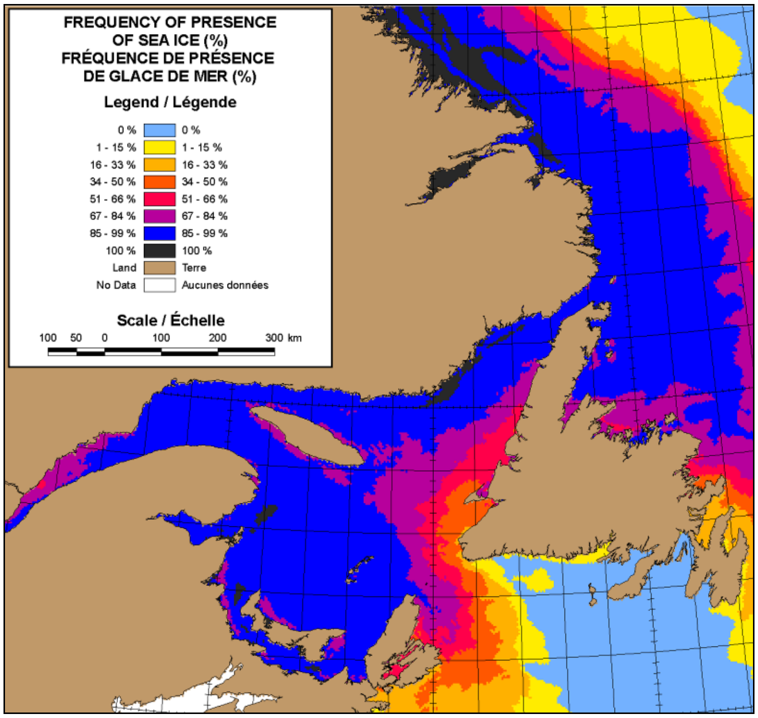
Tidal forces impact the ice regime through moving the ice back and forth as the tides rise and fall. This motion can be clearly seen in the upper Estuary and Chaleur Bay. As a result of the tidal influences and shallowness of these areas, large areas of fast ice can form (Environment Canada 2011).

Temperature and winter winds are the two key climatic factors that affect ice coverage in the Gulf. The average temperatures during the winter typically remain around the freezing point resulting in colder or milder than average winters having a huge impact on total ice cover.

Winter winds from the west to north directions are generally cold and dry while those from the west to northeast are mild and moist (Environment Canada 2011).

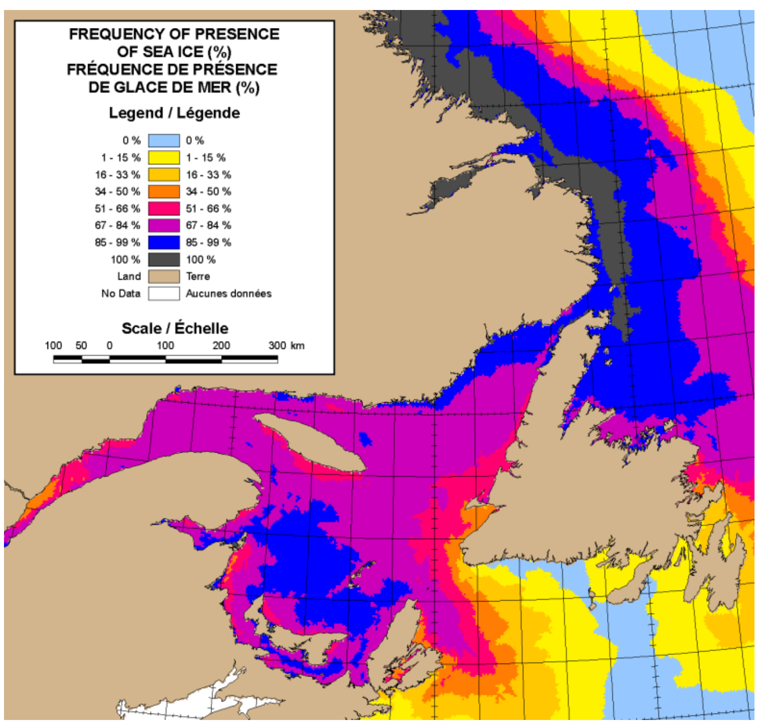
Ice forms in the Gulf each year beginning in the near-shore areas of the St. Lawrence River. In early February, the ice moving south through the Gulf will reach Sydney, Nova Scotia and affect shipping for the remainder of the season. By late February, most of the remaining areas of the Gulf are covered. The exception is a 10 to 30 km coastal lead along the Newfoundland coast south of Cape Saint George (Environment Canada 2011).

At the beginning of February, grey-white and grey ice predominates with thin first year ice gradually developing over the course of the month. By the end of the third week of February, thin first year ice is found in Northumberland Strait, along the northwest coast of Cape Breton, along the north coast of the Magdalen Islands, along the west coast of Newfoundland as well as along the south shores of Chaleur Bay and the Estuary (Environment Canada 2011). Over the northern portions of the St. Lawrence Estuary and Gulf, the predominant ice type remains new and grey because offshore winds push the ice southward. From the later part of February until the middle of March, the ice in the Gulf will have reached its maximum extent and much of the ice continues to grow to the first-year stage of development. As a result of the continuous southward drift of the pack ice in the Gulf, the ice remains at the grey-white stage over the northwestern portions of the Gulf. The lead along the Western Newfoundland coast, particularly north of the Port-au-Port Peninsula, is closed and there can be ice drifting into the Cabot Strait. For the period 1981 to 2010, the most ice encountered in a single season in the Gulf occurred in 1989/1990 with the least amount of ice occurred in 2009/2010. The ice coverage varies considerably from year to year but in general, there were above normal conditions from 1980/1981 to 1994/1995 and then below normal conditions from 1995/1996 to 2009/2010. The maximum pack ice extent in the Gulf in February, March and April, based on a 30-year median of ice concentration, is displayed in Figures 4.30, 4.31 and 4.32, respectively (Environment Canada 2011).



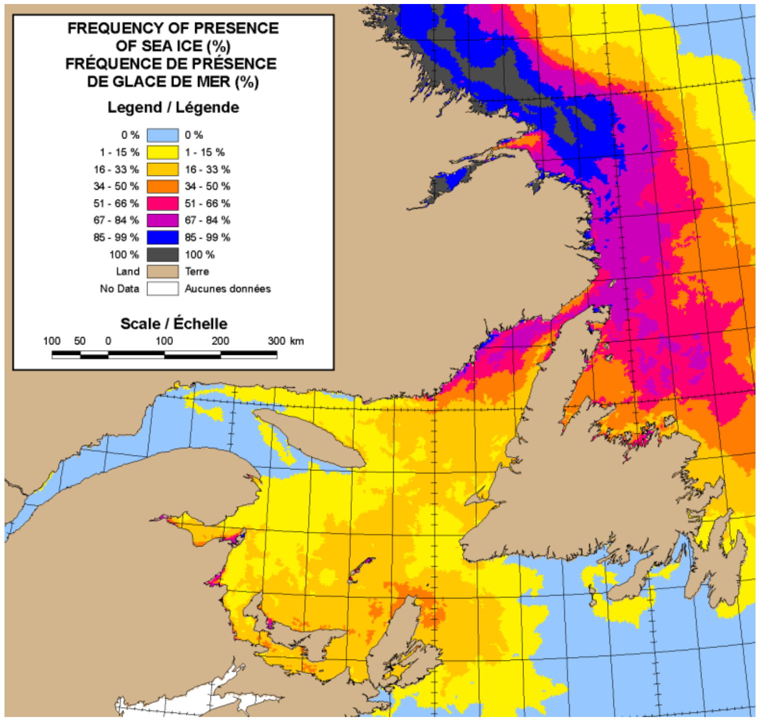
Source: Environment Canada 2011.

Figure 4.30 Maximum Pack Ice Extent in February (1981 to 2010)



Source: Environment Canada 2011.

Figure 4.31 Maximum Pack Ice Extent in March (1981 to 2010)

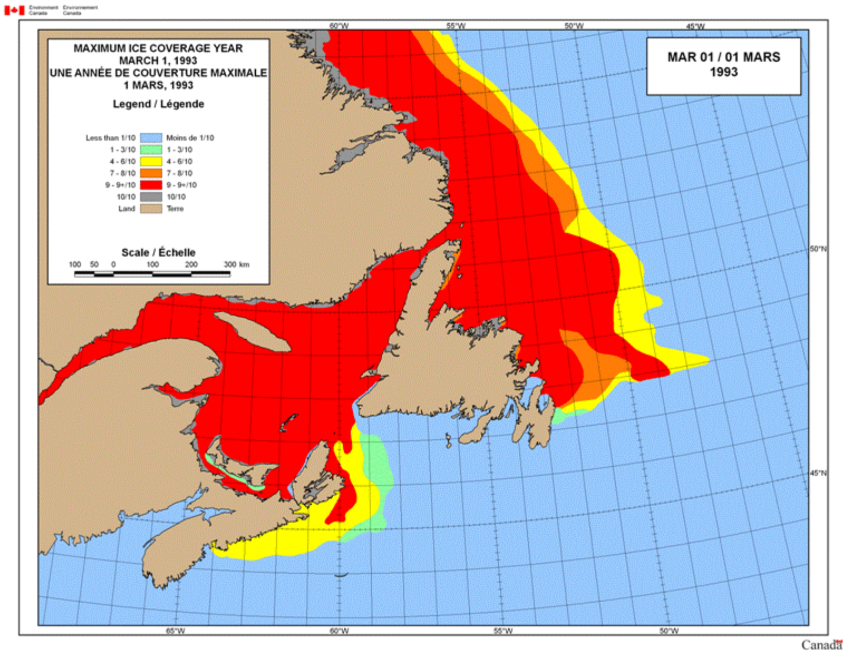


Source: Environment Canada 2011.

Figure 4.32 Maximum Pack Ice Extent in April (1981 to 2010)

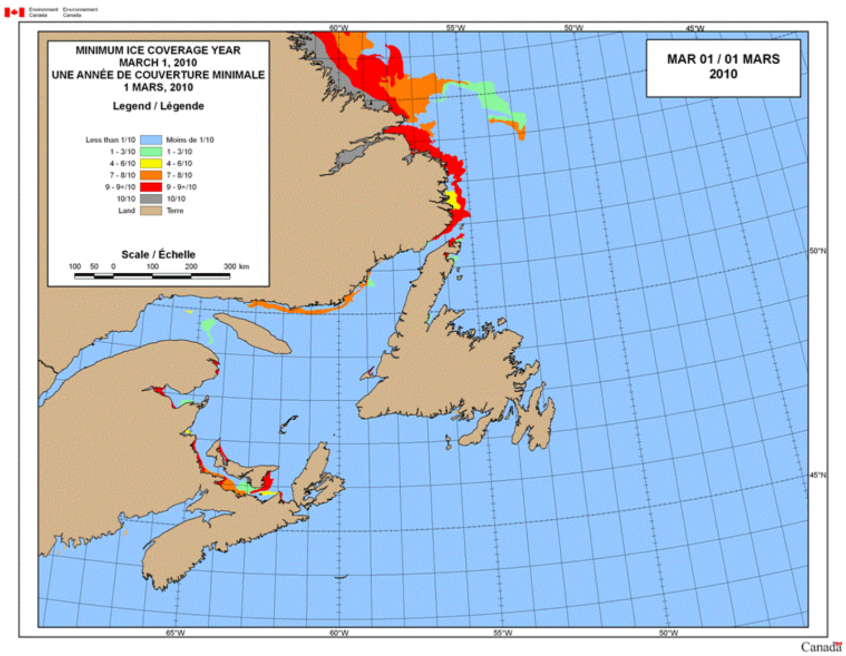
The 30-year frequency of sea ice presence in the Project Area ranges from 51 to 84 percent in late February to less than 15 percent by the end of April. The maximum ice coverage year was March 1, 1993 (Figure 4.33) and the minimum ice coverage year was March 1, 2010 (Figure 4.34). EL 1105 is located in the area that has an average ice freeze up date of January 29 (Figure 4.35). The normal ice free period for EL 1105 extends from April 9th to February 12th of the following winter, and in extreme cold winters the ice free period is shorter and extends only from May 7th to January 15th. For mild winters, the ice may not reach EL 1105. This has happened six times in the past 30 years, with most incidents experienced since the late 1990s for which an overall warming trend has been observed (Environment Canada, pers. comm. 2011).

When the pack ice reaches EL 1105, the ice thicknesses are typically in the range of 10 to 30 cm. As the winter progresses, the ice thickens to the 30 to 70 cm range. Ice ridges could occasionally form in the area; these ridges can result in ice thicknesses that could be substantially higher than the 30 to 70 cm range. The ice concentration could vary a lot but it is often close to the 80 to 100 percent range with lower concentration at the beginning of the ice season. Strong ice pressure could occasionally develop because of high winds associated with winter storms which are quite frequent in the Gulf area. Such ice pressure can have substantial impacts on shipping activities (Environment Canada, pers. comm. 2011).



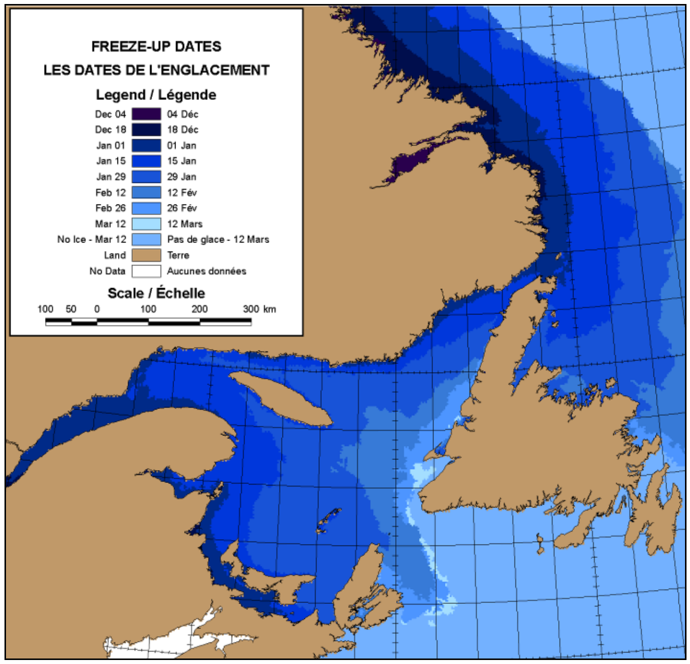
Source: http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=9453F6C9-1.

Figure 4.33 Maximum Ice Coverage Year



Source: http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=4B65BC3E-1.

Figure 4.34 Minimum Ice Coverage Year



Source: Environment Canada 2011.

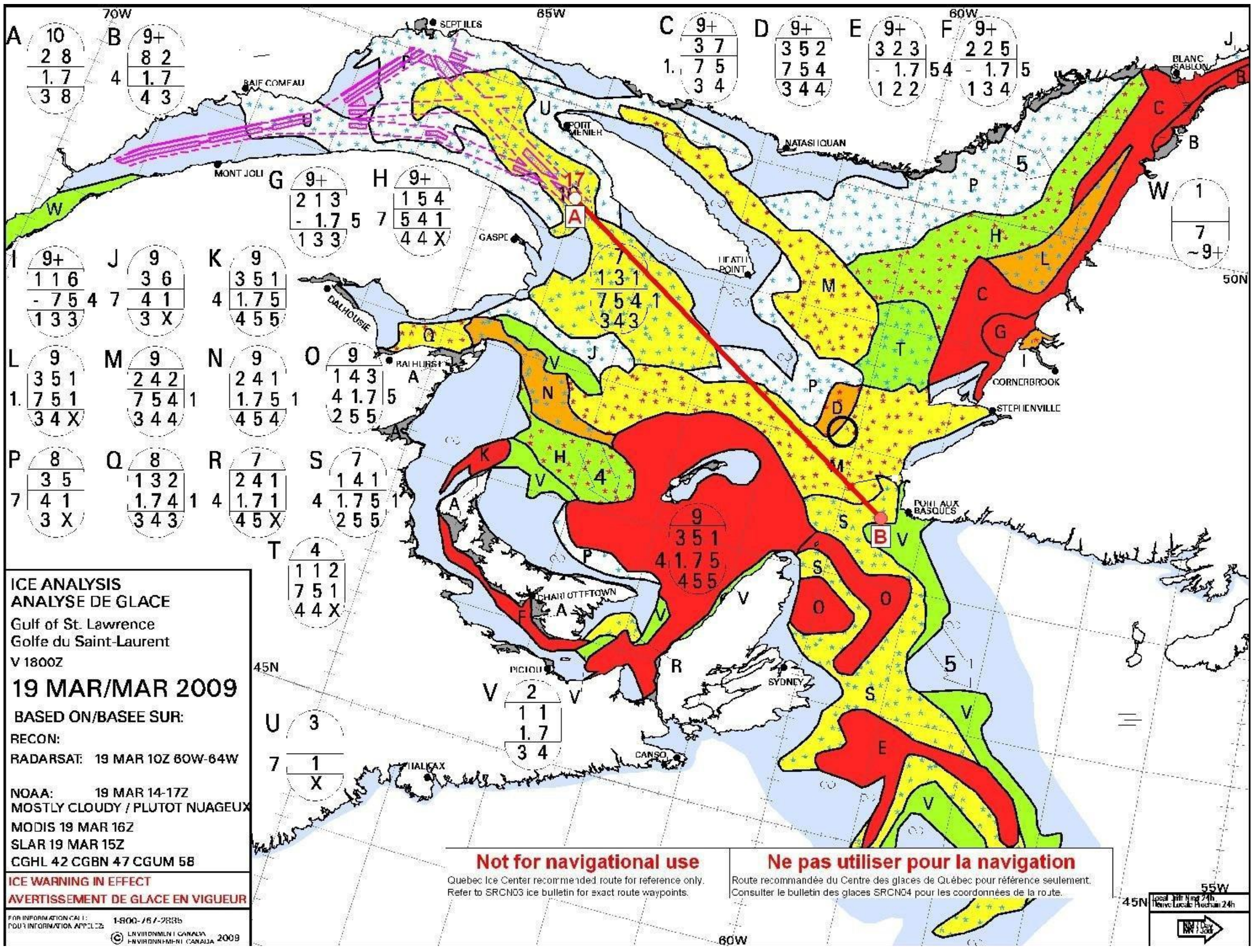
Figure 4.35 Dates of Freeze-up (1981 to 2001)

Dispersal of the ice is first evident near the end of February and by mid-March extensive open water areas can be seen in several places within the Gulf. A combination of tidal upwelling of warm water and rising air temperatures begin the break-up near the mouth of the Saguenay River. Open water develops next south of Anticosti Island, as well as along the north end of the St. Lawrence Estuary and the north shore to Natashquan. By the end of March, the thinner ice formations are melting quickly, decreasing the median ice concentrations in the main shipping route through the central Gulf of St. Lawrence (Environment Canada 2011).

The estuary and main shipping route clear in early April. The two main remaining ice areas at this point are the southwestern Gulf in the region surrounding Cape Breton and the area from the Port-au-Port Peninsula to the Strait of Belle Isle. No new ice barriers to navigation in either the Estuary or the main shipping route occur after this point and the remaining ice has generally cleared by mid-April (Environment Canada 2011).

During the peak of the ice season, new ice formation and a general southeastward progression of existing ice combine to create a thick ice cover from Gaspé Passage to Cape Breton Island. This thick ice cover builds up along the coasts of Cape Breton and the northwestern parts of the Magdalen Islands. These large floes of thick ice are generally kept clear of the Prince Edward Island and New Brunswick coasts due to prevailing winds. These winds can also lead to a congestion of thick and deformed ice in the Bay of Islands area and north of the Port-au-Port Peninsula area. Fracturing of the ice floes in the Cabot Strait area can sometimes occur during times of high ice coverage due to swells from Atlantic Ocean storms. Old ice can sometimes enter the Northeast Arm but is not generally significant in the Gulf of St. Lawrence (Environment Canada 2011).

A recommended shipping route is maintained by the Canadian Coast Guard during the peak of the ice season. It is published daily by Ice Quebec during the season and ships are expected to follow that route through the Gulf for the day (Figure 4.36). During time of ice congestion along the south side of Anticosti Island, the winter shipping route can sometimes be shifted to the north side of the Island (Environment Canada 2002a).



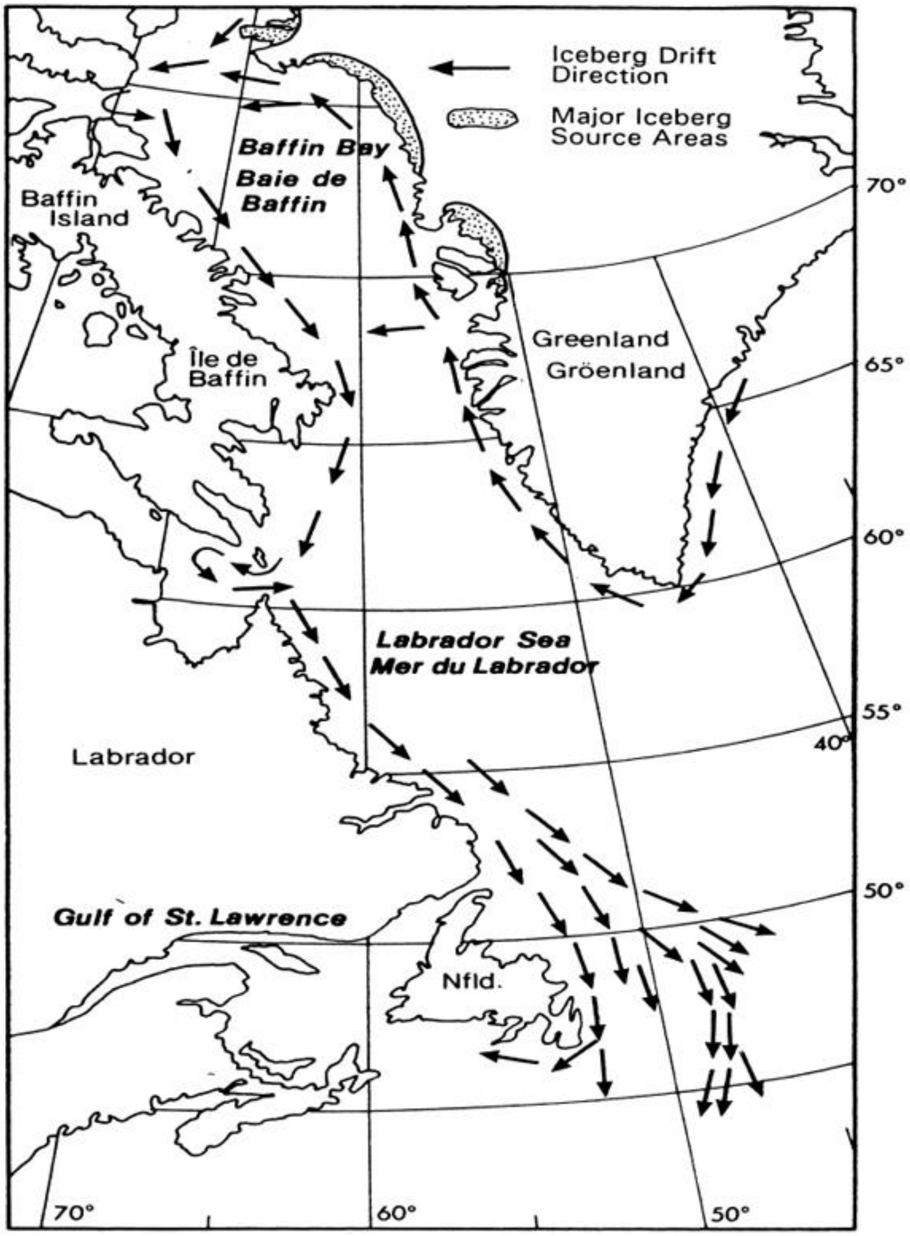
Source : Environment Canada

Figure 4.36 Ice Analysis Daily Report (Sample)

4.2.7 Icebergs

Occasionally icebergs enter the Gulf, passing through the Strait of Belle Isle. These icebergs are generally small, as the water depths in the Strait (55 m) limit iceberg draught. Most icebergs entering the Gulf tend to go aground along the Quebec shore, east of Harrington Harbour, although a few have been observed as far west as Anticosti Island and in the Bay of Islands area along the west coast of Newfoundland. A considerable number of icebergs can remain grounded in the Strait of Belle Isle (Canadian Coast Guard 1999).

While icebergs have been spotted in the Strait of Belle Isle during every month of the year over the past 25 years, further intrusion into the Gulf of St. Lawrence is uncommon. No icebergs have been sighted south of Anticosti Island and no iceberg south of Newfoundland has ever been spotted west of 59° W. Primary currents in these waters prevent iceberg migration from the east (Environment Canada 2011). For these reasons, the Project Area is unlikely to be impacted by icebergs from any direction. The sources and main tracks of icebergs in Eastern Canadian waters are presented in Figure 4.37.



Source: Canadian Coast Guard 1999

Figure 4.37 Sources and Tracks of Icebergs in Eastern Canadian Waters

4.3 Meteorology

Meteorology is discussed below in terms of climate, wind and visibility.

4.3.1 Climate

The climate in the vicinity of EL 1105 is dominated by the effects of the Gulf water that surrounds it and also by the eastward movement of continental air masses and their associated pressure systems. The climate is categorized as maritime temperate. Due to the severe winters experienced in the Gulf, the presence of buoys is limited. To assess the historical climate conditions in EL 1105, data were obtained from the Port Aux Basques weather station, located on the southwestern coast of Newfoundland approximately 100 km from the Project Area. The data are summarized in Table 4.6.

Table 4.6 Temperature and Precipitation Climate Data, 1971 to 2000, Port Aux Basques, Newfoundland

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)												
Daily Average	-5.2	-6.4	-3.5	1	5.2	9.5	13.7	15	11.6	7	2.6	-2.2
Daily Maximum	-1.9	-3	-0.4	3.7	8.3	12.8	16.7	18.3	15	10	5.2	0.8
Daily Minimum	-8.4	-9.8	-6.6	-1.7	2.1	6.2	10.6	11.7	8.2	3.9	-0.1	-5.1
Extreme Maximum	9.9	8.9	11.2	18.2	22.2	25.3	27.8	27.2	30	25	15	10.7
Extreme Minimum	-23.3	-26.1	-24.1	-13.3	-6.7	-1.1	3.5	2.8	0	-4	-11.3	-21.2
Precipitation (mm)												
Rainfall	52.8	39.2	61	101.8	124.2	114.1	115.3	114.1	123.1	147	126.2	97
Snowfall (cm)	93.5	75	51.7	21.5	3.4	0	0	0	0	3.4	19.6	75.3
Precipitation	146.4	115.1	113.9	126.5	128.2	114.1	115.3	114.2	123.1	150.5	147.6	174.7
Extreme Daily Rainfall	74.2	67.3	60	89.9	85.9	66.8	111.4	83.8	96.6	65.3	101.1	88.9
Extreme Daily Snowfall (cm)	57.4	45.7	36.8	31	11.4	0.5	0	0	2.8	14.7	30.5	43
Days with Precipitation												
>= 0.2 mm	24.9	20.8	18.9	16.1	15.4	15	15.8	14.7	16.2	17.7	19.5	8.6
>= 5 mm	8.9	6.5	6.6	6.7	6.7	6.3	6.2	6	7.1	8.3	8.6	4.7
>= 10 mm	4.6	3.7	3.7	4	4.4	4	3.6	3.7	4	4.8	4.9	3.3
>= 25 mm	0.96	0.74	0.78	1.1	1.2	1.1	1.1	1.1	1.2	1.6	1.4	0.92
Source: Environment Canada 2010a.												

Average daily temperatures in the vicinity of EL 1105 ranged from -6.4°C in February to 15°C in August. Above-zero average temperatures were recorded for all months except December, January, February and March. The highest amount of precipitation was recorded for the month of December and the least amount for the month of March. October was the month that recorded the highest amount of days (1.6) with rainfall greater than 25 mm.

In 2008, the average monthly air temperatures for several land-based weather stations surrounding the Gulf (including Sept-Îles, Natashquan, Blanc-Sablon, Daniel's Harbour, Port Aux Basques, Charlottetown, Magdalen Islands, Mont-Joli and Gaspé) were generally normal or slightly higher than temperatures recorded in 2007 (DFO 2009a). However, the southern and eastern portions of the Gulf did exhibit greater abnormalities than the other areas, and March was an exceptionally cold month for all weather stations. The temperatures recorded for September, October and November in 2008 at the Port Aux Basques and Magdalen Islands weather stations were all above 0°C. The months that recorded temperatures below 0°C included December, January, February and March for both stations (DFO 2009a). Air temperatures in the Gulf have been above the 1971 to 2000 normal between November 2009 and December 2010 except for the near normal month of June (Galbraith *et al.* 2011). Gulf-wide monthly above-average air temperatures were record highs (since 1945) in February, April, and December 2010. The average of the several land-based weather stations provides an overall temperature index for the entire Gulf, which was above normal in 2010 by 2.4°C (+2.5 SD) - a record-high since 1945, breaking the previous 2006 record of 1.6°C (+1.6 SD). The last negative annual anomaly occurred in 2002 (Galbraith *et al.* 2011). The 2010 annual and winter conditions were a record high with the third-warmest spring conditions and above-normal summer conditions. The 2010 fall conditions were also a record high since 1945, characterized by very warm air temperatures in December 2010 that did not even fall below 0°C averaged over nine land-based weather stations (Galbraith *et al.* 2011).

In terms of sea surface temperatures, the minimum mean temperatures for February and March are approximately -0.8 °C and the maximum mean temperatures occur in August and September at approximately 15°C (LGL 2005b). Sea-surface temperature averages for the first 28 days of each month of 2009 as observed with National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) remote sensing are provided in Figure 4.38 (the white areas have no data for the period due to ice cover) (Galbraith *et al.* 2011).

Icing on vessels can result from freshwater moisture such as fog, freezing rain, drizzle, wet rain and snow, or from salt water sources such as freezing spray and wave wash (Canadian Coast Guard 2012). Icing from advection and evaporating fog can be a problem during the fog months. Icing from precipitation generally occurs when there is a steep drop in air temperatures and is generally limited to the spring and fall months.

In the Gulf, freezing spray is the most frequently reported cause of vessel icing (Canadian Coast Guard 2012). Freezing precipitation and supercooled fog are less frequent but still cause vessel ice build up in the Gulf. Freezing spray can occur any time from November to April in the Gulf, with higher conentrations of events occurring from December to February. Potential icing conditions from spray are encountered more than 50 percent of the time during January. Freezing rain can occur from December to April in the Gulf. Supercooled fog can create icing conditions from January to March. For more information on freezing spray, refer to Section 12.1.

The Project will require helicopter support consisting of three trips per week to transport personnel, and light supplies and equipment. Climate can have immense effects on air transport. The area from Deer Lake to Port Aux Basques is unprotected from the effects of the

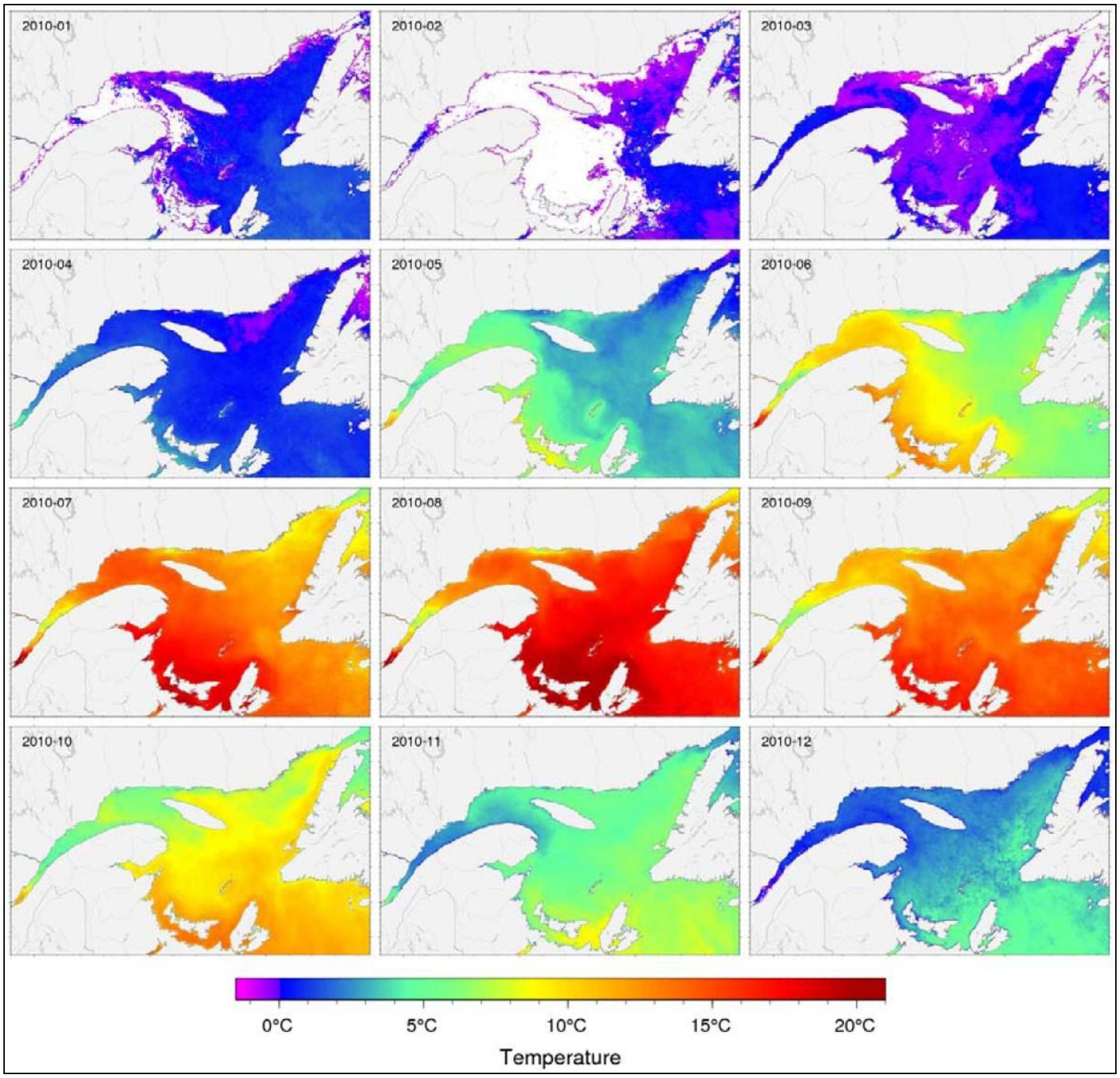
Gulf year round. During the fall months, air passing over the Gulf becomes cooler, while the ocean remains relatively warm (Robichaud and Mullock 2001). This combination of cool air and warm surface heating creates flat, stratocumulus clouds providing relatively high ceiling for flight. During late November, snow showers and streamers develop in cold west to northwest winds creating a relatively low ceiling and reduced visibility. Local visibility of ¼ mile (0.40 km) or less and vertical instability of 100 feet (30 m) is not uncommon during this time of year. If winds are from the west-northwest, Anticosti Island acts as a barrier for the development of snow shower activity and clear skies can be found downwind as far as the west coast of Newfoundland, including Stephenville airport (Robichaud and Mullock 2001).

Fog in the Gulf becomes frequent by mid spring and remains frequent until late summer. A well known hazard exists from eastward and southeast winds from St. Andrews to Cape Ray (Robichaud and Mullock 2001). These are the extremely strong downslope winds known as 'Wreckhouse Winds". These winds can cause extreme turbulence near and below the crest of the hills on the lee side. Funneling can further enhance these winds. Severe turbulence, strong whirlwinds and downdrafts can be expected in these areas which local pilots agree can cause a light aircraft to break up in flight.

4.3.2 Wind Climate

Wind is an important aspect related to planning due to its role in current and wave generation, which in turn could produce forces on vessels, the drilling platform and other related equipment. Knowledge of the frequency of occurrence of wind speed is necessary for the planning of operations. From autumn through the winter and spring, many extra-tropical storm disturbances pass through or near the Gulf. These storms can produce gale-force winds that may persist for many hours and in some cases, for several days (as described in Section 4.2.5). During the summer months when the tracks of cyclonic activity are displaced farther north, the persistent strong wind becomes less frequent over the Gulf.

The parameters used to describe the wind characteristics most commonly are wind speed and wind direction. Data on percent wind speed by wind direction from 1954 to 2008 were acquired from the MSC50 data set for grid point 13511 (UTM – Northing, 5,331,208 m; Easting, 708,455 m) and are presented in Tables 4.7 to 4.10 for each season. Corresponding wind roses over the same time period and seasons are presented in Figures 4.39 to 4.42.



and

Source: Galbraith *et al.* 2011

Figure 4.38 Sea-Surface Temperature Averages (2010)

Table 4.7 Percent Wind Speed by Direction for Grid Point 13511: September, October and November 1954-2008

Wind Speed (m/s)	Wind Direction												Total
	15	45	75	105	135	165	195	225	255	285	315	345	
0 to 4.99	1	0.89	0.95	0.87	0.97	1.26	1.6	1.93	2.14	1.91	1.62	1.24	16.4
5 to 9.99	2.49	2.03	1.85	1.61	2.16	3.44	5.41	6.81	6.42	6.59	5.63	3.74	48.2
10 to 14.99	1.34	1.2	0.87	0.86	1.31	2.12	2.95	3.63	3.73	4.91	3.79	24	29.1
15 to 19.99	0.37	0.22	0.21	0.27	0.4	0.5	0.39	0.34	0.62	1.2	0.96	0.53	6.01
20 to 24.99	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0	0.03	0.07	0.09	0.03	0.33
25 to 29.99	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**5.23**	**4.37**	**3.89**	**3.62**	**4.85**	**7.34**	**1.04**	**12.71**	**12.9**	**14.7**	**12.1**	**7.94**	**100**

Table 4.8 Percent Wind Speed by Direction for Grid Point 13511: December, January and February 1954-2008

Wind Speed (m/s)	Wind Direction												Total
	15	45	75	105	135	165	195	225	255	285	315	345	
0 to 4.99	1.03	0.84	0.79	0.65	0.59	0.76	0.9	1.2	1.31	1.51	1.48	1.35	12.4
5 to 9.99	2.91	2.28	1.82	1.59	1.74	2.14	2.65	4.03	5.12	6.86	5.78	4.24	41.2
10 to 14.99	2.06	1.34	1.3	1.18	1.07	1.39	2	2.82	4.49	7.17	5.71	3.07	33.6
15 to 19.99	0.62	0.49	0.52	0.54	0.5	0.55	0.38	0.59	1.38	2.78	1.92	0.94	11.2
20 to 24.99	0.03	0.09	0.03	0.09	0.1	0.08	0.03	0.06	0.24	0.37	0.28	0.16	1.56
25 to 29.99	0	0	0	0	0	0	0	0	0.01	0	0.01	0	0.02
Total	**6.65**	**5.04**	**4.46**	**4.05**	**4**	**4.92**	**5.96**	**8.71**	**12.6**	**18.7**	**15.2**	**9.77**	**100**

Table 4.9 Percent Wind Speed by Wind Direction for Grid Point 13511: March, April and May 1954-2008

Wind Speed (m/s)	Wind Direction												Total
	15	45	75	105	135	165	195	225	255	285	315	345	
0 to 4.99	2.42	2.39	2.3	2.09	2.06	2.41	2.97	3.22	2.97	2.97	2.74	2.55	31.1
5 to 9.99	4	3.25	2.7	2.57	2.7	3.95	4.87	4.73	3.95	4.15	4.56	4.37	45.8
10 to 14.99	1.96	1.92	1.29	1.24	1.21	1.42	1.72	1.41	1.42	2.1	1.93	1.78	19.4
15 to 19.99	0.42	0.6	0.24	0.26	0.21	0.16	0.12	0.09	0.24	0.5	0.36	0.32	3.52
20 to 24.99	0.04	0.03	0.01	0.02	0	0	0	0	0.01	0.02	0.02	0.02	0.18
Total	**8.84**	**8.19**	**6.55**	**6.18**	**6.19**	**7.95**	**9.68**	**9.44**	**8.59**	**9.74**	**9.61**	**9.03**	**100**

Table 4.10 Percent Wind Speed by Wind Direction for Grid Point 13511: June, July and August 1954-2008

Wind Speed (m/s)	Wind Direction												Total
	15	45	75	105	135	165	195	225	255	285	315	345	
0 to 4.99	1.84	1.66	0.18	1.96	2.38	3.89	5.94	7.19	5.58	3.68	2.48	2.13	40.5
5 to 9.99	1.51	1.32	1.51	0.15	2.49	5.95	11	10.5	5.83	3.82	2.61	1.91	50
10 to 14.99	0.39	0.32	0.28	0.37	0.44	1.36	2.49	1.38	0.69	0.7	0.52	0.42	9.23
15 to 19.99	0.04	0.01	0	0	0.02	0.04	0.02	0	0.02	0.03	0.02	0.04	0.26
20 to 24.99	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**3.78**	**3.21**	**3.58**	**3.84**	**5.34**	**11.2**	**19.5**	**19.1**	**12.1**	**8.22**	**5.63**	**4.51**	**100**

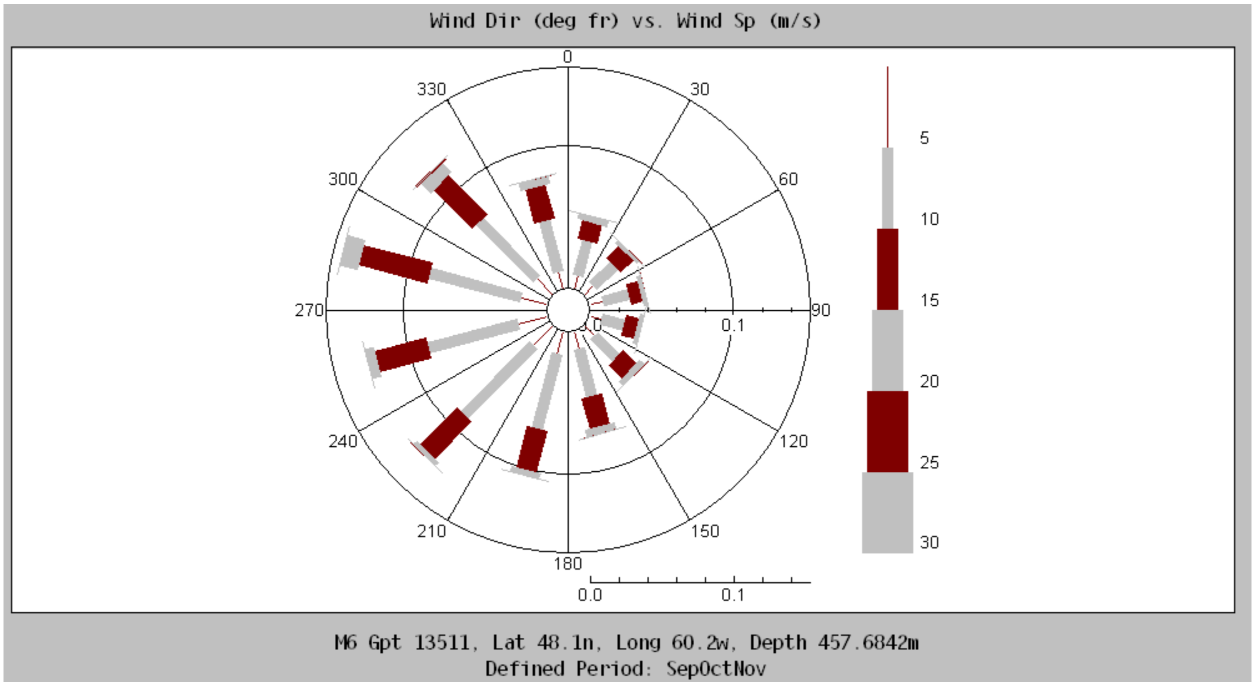


Figure 4.39 Wind Rose for September, October and November 1954-2008

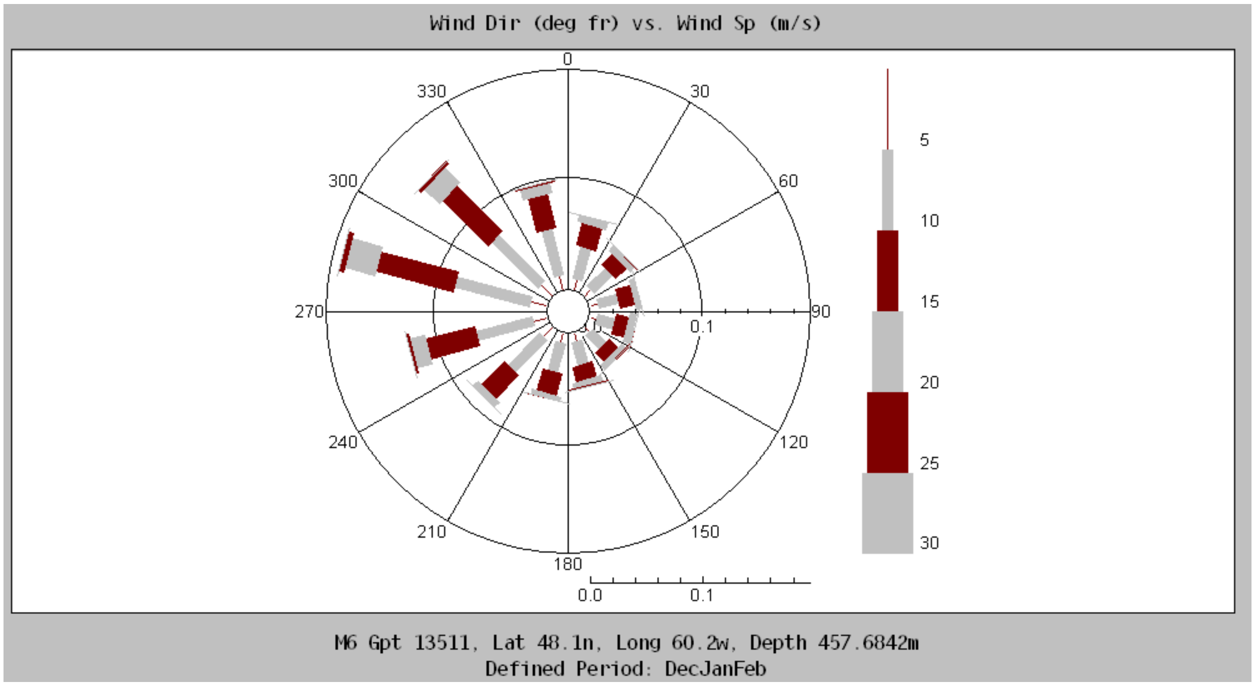


Figure 4.40 Wind Rose for December, January and February 1954-2008

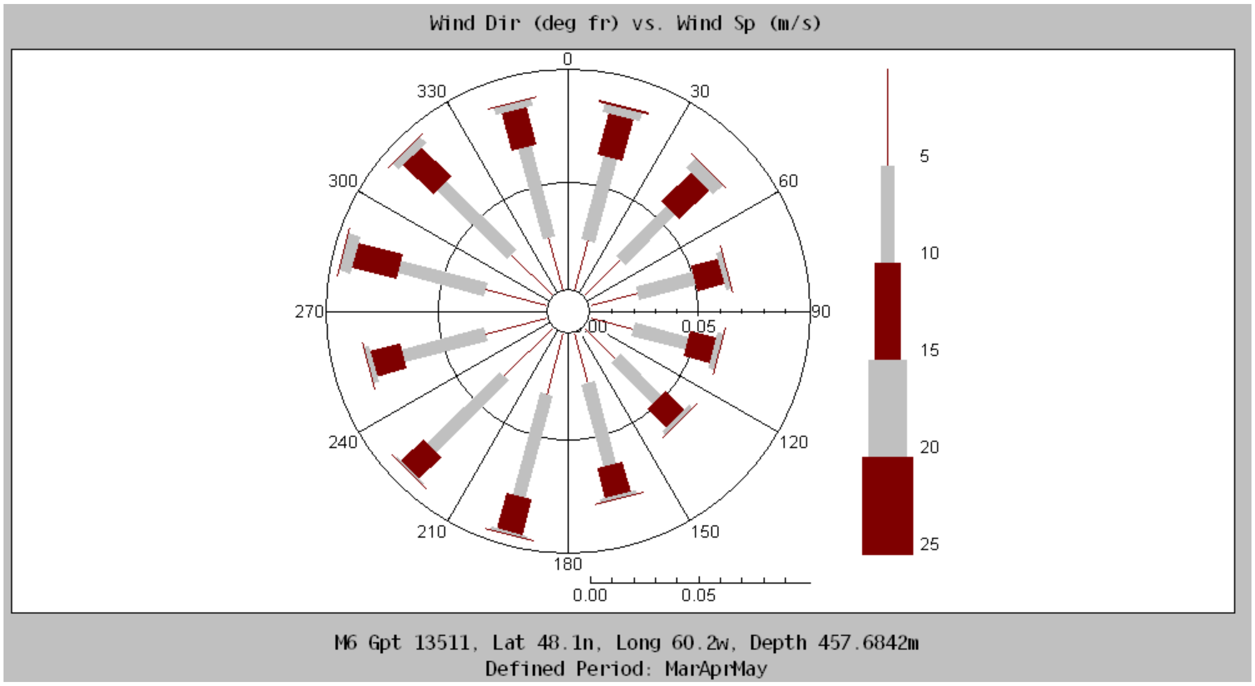


Figure 4.41 Wind Rose for March, April and May 1954-2008

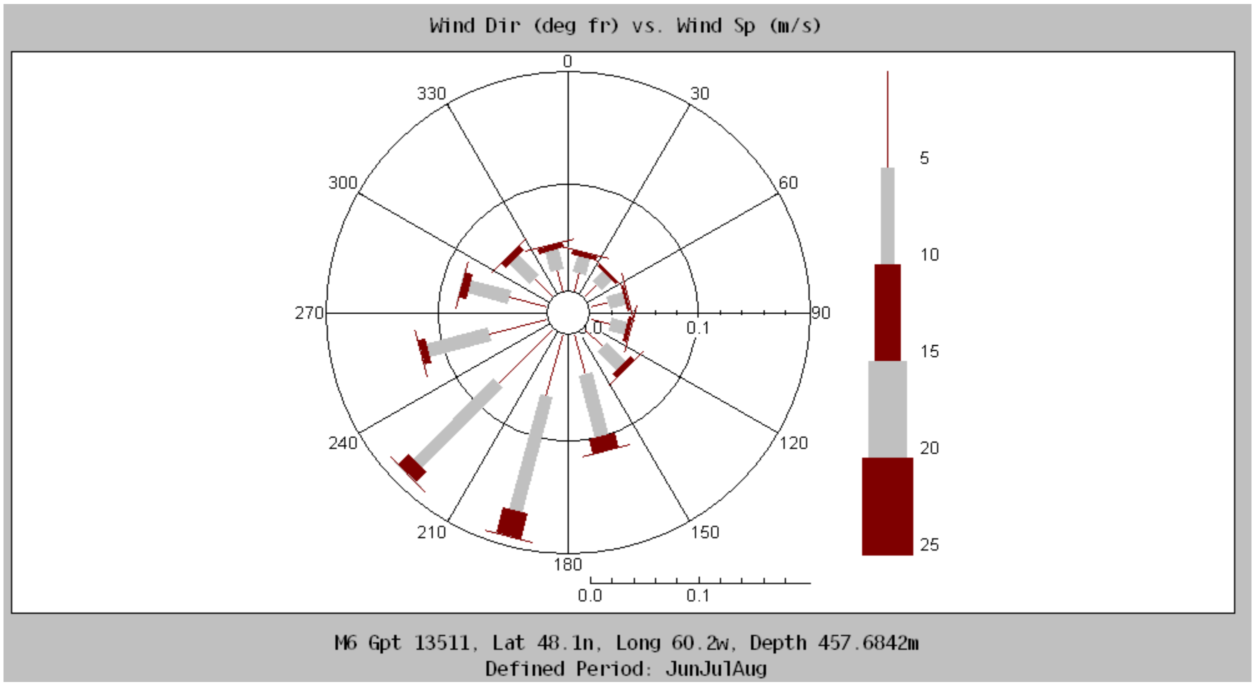


Figure 4.42 Wind Rose for June, July and August 1954-2008

Most wind speeds at grid point 13511 during the fall (September to November), winter (December to February) and spring (March to May) are between 5 and 9.9 m/s and are from the west-northwest direction. Approximately 50 percent of the wind speeds during the summer (June to August) are also between 5 and 9.9 m/s; however, the winds are most commonly from the southwest direction. There was no wind speed reported during the summer greater than 20 m/s. Wind speeds between 20 and 24.9 m/s were experienced during the fall, winter and spring months and the highest percentage was reported during the winter, at less than 2 percent.

4.3.3 Visibility and Fog

Fog is an important weather condition that results in poor visibility for the ships, helicopters and aircraft operating offshore. Sea fog can be dense and may often cover large areas.

Historical data for visibilities were acquired from the Port Aux Basques weather station and are presented in Table 4.11.

Table 4.11 Hours of Visibility per Month Recorded at the Port Aux Basques Weather Station, 1971 to 2000

	Jan	Feb	Mar	Apr	May	Jun	Jul	Oct	Sep	Oct	Nov	Dec
<1 km	51.9	45.7	47.4	54.4	84.8	106.6	138.6	78.2	33.3	32	27.7	37.4
1 to 9 km	208.6	160.8	139.8	140.3	134.3	132.5	154.1	114.7	76.9	83.4	104.4	182
>9 km	483.6	471	556.9	525.3	525	480.9	451.3	551.1	609.8	628.7	588	524.7

During the averaging period from 1971 to 2000, the number of hours with visibility less than 1 km was greatest during June and July. The number of hours with visibility greater than 9 km was highest during September, October and November.

Existing visibility conditions in the Gulf were assessed in the 2005 SEA report (LGL 2005b) using information available near AES-40 data set at grid point 5817, which is located offshore Newfoundland and Labrador slightly north of Cape St. George. There was an occurrence of 8 to 10 percent of reduced visibilities (less than 1 km) in January, February and March, due to snow. By April to July, as the sea surface air temperature increases and warm, moist air from southern North America (with high relative humidity (high dew points)) floods the area, and the temperature of the ocean remains cooler, the air becomes cooled by the ocean and saturated, resulting in fog. An 11 percent reduced visibility (less than 1 km) was recorded for the month of July. As fall approaches, the temperature difference between the air and the ocean lessens and cool, dry air (low dew points) from the north floods the region, reducing the amount of fog, with October reporting the lowest occurrences of reduced visibility, approximately 2 percent (LGL 2005b).

4.4 Climate Change

It is generally accepted that a warming world will result in a rise in the global sea level and that sea surface temperatures will increase by 1°C to 2°C over the next several decades if global warming continues. Meteorological drivers of the long-term trends in global sea level rise were examined (Kolker and Hameed 2007) and a major fraction of the variability and trend since 1900 at five Atlantic Ocean tide gauges can be explained by atmospheric indices like the North Atlantic Oscillation. Kolker and Hameed (2007) state that “debate has centred on the relative contribution of fresh water fluxes, thermal expansion and anomalies in Earth’s rotation”. When factors such as the North Atlantic Oscillation were subtracted out from their analysis of the long-term rise, the “residual” sea level rise was between 0.49±0.25 and 0.93±0.39 mm per year, which could be due to rising global temperatures (Kolker and Hameed 2007).

Between 1961 and 2003, the global average sea level rose at an average rate of 1.8 (1.3 to 2.3) mm per year (Intergovernmental Panel on Climate Control (IPCC) 2007); a worldwide increase of 18 to 58 cm is predicted by 2100 (IPCC 2007). Based on emission scenarios from the 2007 IPCC assessment, Vermeer and Rahmstorf (2009) estimated sea-level rise projections over the next century using a semi-empirical model and compared the results to a relationship between historical global temperature and sea-level rise. This semi-empirical method implicitly accounts for the effects of the recent rapid glacial melt.

Sea levels off the northeast coast of North America could rise by 30 to 51 cm more than other coastal areas due to moderate to high rates of ice melt from Greenland (Hu *et al.* 2009). Since ocean dynamics would push water in different directions, oceans will not rise uniformly as the Earth warms (Hu *et al.* 2009).

Estimates of the global sea level rise over the next 100 years due to global warming alone are from 5 cm to as much as 190 cm. Based on a rate of 1.7 cm per year (as per Vermeer and Rahmstorf (2009)), the expected total rise has a central estimate of 45 cm and an upper limit of approximately 70 cm over the time period of 2010 to 2050. Information on trends in storm events and ice formation is provided in Sections 4.25 and 4.26, respectively.