Attachment: Environment Canada Comments on Oil Spill Trajectory Modeling

General Comments and Summary

Portions of the "Environmental Assessment of the Old Harry Prospect Exploratory Drilling Program" by Corridor Resources as relating to oil spills were reviewed as well as the "Modeling in Support of Corridor Resources Old Harry Exploratory Drilling Environmental Assessment. The reviewer also performed an independent review of the modelling using two separate models (Oilmap 4.3 & Oilmap 6.7.1) as well as some empirical data. Stochastic modeling, the most appropriate for impact assessment, provides the probabilities of oil using thousands of inputs of wind and currents. One Stochastic output is equivalent to tens of thousands of trajectory models. The Stochastic models were run using historical wind records for more than one year from the Magdalen Islands. Multi-year currents were also used. Several individual trajectory models were run in late March 2012 using actual wind and current data to compare to these trajectory models. The OilMap models used also had fate and behaviour models. These were compared to the SLR data and also to empirical data on the target oils - Diesel fuel and Cohasset crude.

Model Types & Algorithms

As noted above there are several types of models which can be used to describe oil movement. The most typically used are the stochastic and trajectory models. Trajectory models are used to predict the movement of a spill on a single set of data, be it for a few hours or a few days. Stochastic models, on the other hand, use the statistics of a wide set of wind and current observations to predict the probability that a certain area will be oiled. One Stochastic model is equivalent to tens of thousands of trajectory model runs. Stochastic models are the most appropriate models for environmental impact assessment.

State of the art models that combine the latest information on fate and behaviour and computer technology are at the core of what makes models work and what makes them work right or wrong. The models will be briefly reviewed in the following section. The references show many studies on algorithms and modeling.[4-10]

The models used are two different version of OilMap, Version 6.7.1 (very latest 2012 - edition) and Version 4.3 (used extensively from about 2002). These models are very similar but have slightly different approaches to certain facets such as horizontal diffusion. This will be highlighted later. Oil Version 4.3 is very rugged and has been tested very extensively. OilMap 6.7.1 contains more recent features, but has only be running for the past year. OilMap is a very common model in the world and is used in more than 100 countries by more than 250 groups. No other model is available that has such broad use. It should be noted that both versions have the properties and behavioural model inputs of both Diesel and Cohasset built in. It should be noted that the behaviour models differ in the two models in that the natural dispersion in the older

OilMap 4.3 is much higher. New Information has lowered natural dispersion effects in subsequent OilMap versions.

The operating inputs for this model are shown in the following table:

Parameters used in Modeling				
	Stochastic OilMap	**Trajectory OilMap**	**Empirical Evaporation**	**Fate OilMap**
Winds				
Daily	NA	CMC - daily wind field		
Spring	Hourly March-May Winds over Magdalen Islands - 2011 plus March 2012	NA		same as stochastic
Summer	Hourly June-August Winds over Magdalen Islands - 2011	Na		same as stochastic
Fall	Hourly Sept.-Nov. Winds over Magdalen Islands - 2011	NA		same as stochastic
Winter	Hourly December-Feb. Winds over Magdalen Islands - 2011	NA		same as stochastic
Currents				
Seasonal	Seasonal currents from Stantec rpt.	NA		same as stochastic
Daily		CMC - daily calculated tidal currents		
Tidal	Diurnal Tidal - time of high tide = 0	Actual		
Temperature	Seasonal temps from Stantec rpt.	10 °C	10 °C	10 °C
Volumes				
Diesel low	1000 L	1000 L	NA	
Diesel High	15.8 m^3		NA	15.8 m^3
Cohasset low	10,000L		NA	
Cohasset High	8176 m^3 (817.6 / day)			8176 m^3 (817.6 / day)
Days run	3 months	1 to 5 days	up to 13 days	10 days
	output 5 or 10 or 20 days			
Spill Duration				
Diesel fuel	0.2	0.2	NA	0.2
Cohasset	0.2	0.2	NA	0.2
Blowout	10 days		NA	10 days
(Cohasset)			NA	
Time Steps	Hourly	Hourly	Hourly	
Release Date	NA	on day	NA	01-Jun-11

The greatest difficulty and source of error in any modeling effort are the currents and the winds. To run the currents for this model several current grids were used. For the trajectories, a daily current grid was downloaded from the Canadian Meteorological Centre. This is a model that uses empirical data but is modeled to fill a grid and to correspond to the daily winds as well. To run the seasonal Stochastic models, a seasonal grid was set up and the currents from the generic averages as found in the Stantec report were used. The currents were then smoothed and spread out across the field using the models inside OilMap.

Winds for the Stochastic modeling were actual winds from the Magdalen Islands over the past year. More than 1600 hourly data points were used for each season. For the trajectories there were actual winds, spread over a wind field, from the Canadian Meteorological Centre. The remaining parameters are as noted in the above table.

Comparison of model results is provided in the following table:

Comparison of Model Output				
Diesel Discharge	**SLR**	**OilMap 4.3**	**OilMap 6.7.1**	**Empirical Data**
Small 1000 litre				
amount left after one day - %	0	20	80	80
amount left after two days	0	10	65	70
amount left after three days	0	10	50	60
amount left after five days	0	5	38	50
amount left after ten days	0	5	30	40
Primary direction(s) 5 days	NR	See seasonal at right		**Spring** SW, N
Primary direction(s) 10 days	NR	See seasonal at right		**Summer** E, N
Shoreline oiled - 5 days	NR	Cape Breton		**Fall** E, S
Shoreline oiled - 10 days	NR	Cape Breton , NFLD		**Winter** E
Large 15.6 m^3				
amount left after one day %	0	20	80	80
amount left after two days	0	10	65	70
amount left after three days	0	10	50	60
amount left after five days	0	5	38	50
amount left after ten days	0	5	30	40
Primary direction(s) 5 days	NR	See seasonal at right		**Spring** E
Primary direction(s) 10 days	NR	See seasonal at right		**Summer** circle
Shoreline oiled - 5 days	NR	NFLD		**Fall** E, S
Shoreline oiled - 10 days	NR	Cape Breton , NFLD		**Winter** NE
Cohasset Discharge	**Small 10000 litre**			
amount left after one day* %	0	99	99	95*
amount left after two days	0	97	97	92.5
amount left after three days	0	95	95	90
amount left after five days	0	94	94	86.3
amount left after ten days	0	92	92	83
Primary direction(s) 5 days	NR	See seasonal at right		**Spring** circle
Primary direction(s) 10 days	NR	See seasonal at right		**Summer** circle
Shoreline oiled - 5 days	NR	none		**Fall** circle
Shoreline oiled - 10 days	NR	none		**Winter** N, SE
Large 10-day blowout - 8176 m^3				
amount left after one day* %	0	99	99	95*
amount left after two days	0	97	97	92.5
amount left after three days	0	95	95	90
amount left after five days	0	94	94	86.3
amount left after ten days	0	92	92	83
Primary direction(s) 10 days	NR	See seasonal at right		**Spring** E, SE
Primary direction(s) 20 days	NR	See seasonal at right		**Summer** N, W
Shoreline oiled - 10 days	NR	Cape Breton , NFLD		**Fall** NW
Shoreline oiled - 20 days	NR	Newfoundland		**Winter** E, SE

* note this is a blowout scenario and fresh oil arrives over the entire period - hard to calculate without a continuous computer model

On the basis of this exercise, the following statements can be made about the possibility of oil spills from the Old Harry drilling site.

1. The contention that the oil studied here, Diesel fuel and Cohasset-like oil, survive at sea for only a few hours is not correct. This requires re-examination by the proponents. Further, the authors contend that no slicks survive for long at sea. This is untrue. The whole world of oil spill research and science revolves around oil spills arriving at shore and contaminating the intertidal zone. The Deepwater Horizon oil spill is certainly an example of this. This was a very light crude oil yet much of the oil survived the rise from 1500 m depth and a month travel over water to foul the shorelines of Louisiana, Alabama and Florida. Both Diesel and Cohasset-type oils will survive in part, for at least 30 days after being spilled at the site.

2. The direction of the trajectory depends mostly on the wind in the area as the currents are relatively stable and only change slightly with the season. For the most part, the direction of the slicks are in the easterly, northerly and southerly directions. Under some conditions oil will exit via the Cabot Strait. Also, the trajectories predicted for the oil are far too short. This may be as a result of the incorrect lifetime predictions as noted above.

3. Many of the algorithms used in the SLR model are quite old and represent first attempts to model oil as in the late 1970's and early 1980s.

4. The probability of oiling is very high for Newfoundland – particularly that portion of the coast northwest of Cabot Strait and secondly for Cape Breton, again northwest of the Cabot Strait. There is only a slight chance of oiling to the Magdalen Islands.

5. The proponents have provided little discussion of the effects of the oil on the environment including long term effects on biota.

Comments on the EA Report

Chapter 2
Section 2.12.2.2 Fate and Behaviour Modelling Inputs - Oil Properties

The oil properties were cited to be drawn from the Environment Canada Data base. The properties are quoted correctly except for the interfacial tensions. These appear to be misquoted.

	Comparison of Data Sources			
		0% Evaporated	**11% Evaporated**	**26% Evaporated**
SLR	Air	27.6	30.2	31.4
	Oil/Sea Water	17.2	16.7	17.5
Actual	Air	25.6	25.2	27.4
EC data	Sea Water	16.5	12.5	13

Interestingly these also do not correspond that that used in the model as quoted in Table 2.16.

Depending on how these values are used in the model, this may cause some variance.

Table 2.20 Comparison of Model Oil Fate and Behaviour equations

The following table was presented:

$(-0.003/X_{thick})1.t$
EVAPORATION
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
<u>Thick Slick</u> 1. $F_v = (1.t/X_{thick}(HC/10^{-6} X_{thick} + (1/k))(\exp((6.3 - (10.3(T_0 + T_G F_v)/T_k)$ 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.
<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%.
NATURAL DISPERSION
<u>Thick Slick</u> $1.F_{NDTHICK} = 2.78 \times 10^{-6} (U/8)^2 1.t/(8_{o/w}\mu_0(1025 - 1\backslash_0))X_{THICK}$ If the oil's pour point exceeds the sea temperature by 15°C or more, or the oil is present as droplets, then $1.F_{NDTHICK}=0$
<u>Thin Slick</u> As above except using viscosity, density and thickness of thin slick; no pour point cut-off

EMULSIFICATION
Thick Slick $1.F_w = 2 \times 10^{-6}(U+1)^2 (1-1.33F_w)1.t$ After Zagorski & Mackay 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.

The models are quite outdated and in all cases are initial models in the 1980's or earlier. In a subsequent section to this critique, an appraisal of models will be given and newer models summarized. This is a serious matter because the outcome of a model is entirely dependent on the model mechanism. If the model mechanism is incorrect, so is the output.

Section 2.12.2.3 Fate and Behaviour Modelling Results

The model outputs are based on the assumptions that the oils have a limited lifetime on the sea. This is not true and certainly there is no historical evidence that this occurs. Oil simply doesn't go away. Even in case where long time and travel are involved such as the Deepwater Horizon spill in the Gulf of Mexico, the oil survived to 70 km and 30 and more days.

The sub-surface oil well predictions such as listed on page 52 are relevant until the document talks about survival, however the document still says that: "*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.*"

A similar incorrect prediction is also made on page 53.

Section 2.12.2.4 Surface Oil Trajectory Modelling Results

Sample slick trajectories are presented starting on page 54. There are several problems with these. First, prediction for impact statement purposes should be carried out using a stochastic model, as opposed to a number of individual trajectories as shown here. This is for the reason that a simple individual trajectory takes into account one simple set of factors. Stochastic models use statistical methods to account for hundreds of possible outcomes. One stochastic model, properly applied, is worth thousands or tens of thousands of individual trajectories.

Second, the trajectories as shown on page 54 appear to go in a circle around the well source. This is not possible because the currents in the area are typically outward to the Cabot Straits, except for a short period of tidal flux the other direction. This is also noted on page 27 of this report.

Third, the lifetime of the trajectories are only 6 to 12 hours or until the "*slicks are entirely dispersed*". This as noted above is not correct and the oil certainly will survive until out the Cabot Strait or hits land.

Fourth, the scale of the mapping is such that little can be seen. The scale needs to be expanded greatly.

The statement on page 56 --"*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.*" This shows that the modeling carried out was inappropriate and not realistic. There is no historical record that slicks disappeared and especially that rapidly.

This is especially highlighted in Table 2.6 on page 28 - a clip of which appears below:

Minimum Slick Life at Sea (hours)		Maximum Slick Life at Sea (hours)	
Conservative	Worst-Case	Conservative	Worst-Case
0.11	0.5	16.6	18.4
0.13	0.6	25.0	25.6
0.14	0.7	27.8	29.5
0.15	0.7	35.7	34.7
0.17	0.8	56.1	51.4
0.22	0.9	39.0	38.3
0.21	0.8	37.3	36.7
0.15	0.7	38.0	34.7
0.12	0.6	34.4	31.5
0.10	0.5	22.8	24.3
0.11	0.6	24.7	24.9
0.09	0.5	14.6	15.3

Dispersed Oil Behaviour

The dispersed oil behaviour section (page 51 and on) provides little new information. The trajectories look very much like the surface releases. Again it is supposed that the oil evaporates and disperses completely. "*Each one of these six-hour quantities of oil has been tracked until the surface oil is completely evaporated and dispersed from the surface*." (p. 54) Unfortunately oil does not do that.

Again, the trajectories show a circular pattern which appears unlikely.
The trajectories from the dispersed oil plume appear to be similar to these surface equivalents.

Chapter 8
Section 8.0 Accidental Events

The report concludes that "*Based on modelling conducted by SL Ross (2011; see Section 2.12 for summary), the maximum extent of an oil spill that originates at the well site could extend up to 20 km from the point of origin of the spill, which is approximately 50 km away from the closest Newfoundland coast, approximately 70 km from the closest*

Nova Scotia coast and approximately 75 km away from the closest Magdalen Islands coast". As will be demonstrated later, it will be shown that this modeling approach is incorrect and that in fact under most environmental and spill conditions that the oil is persistent for many days and will, in fact, frequently hit Newfoundland, Cape Breton and possibly the Magdalen Islands.

Section 8.4.3 Spill Probabilities from Historical Statistics

Caution should certainly be exercised in using worldwide statistics on oil well blowouts. Reporting of accidents is not required in many jurisdictions and is notoriously inaccurate.[1]

Etkin provides the following table of oil spill accidents in the USA alone:[1]

Table 6. Average Annual Spillage from US Offshore Oil Platforms (ERC data)[1]

Years	Average Annual Spills One Tonne or More	Average Annual Tonnes Spilled
1969 – 1977	45	3,694
1978 – 1987	29	192
1988 – 1997	14	259
1998 – 2007	20	182
1969 – 2007	27	1,015

This does not include the spills from pipelines, supply ships etc. This certainly appears to have a higher probability that quoted on page 392 of the EIS.

Furthermore, the risk of blowouts for new wells into an unknown field (high probability) is not separated from wells drilled into a field where the substrates are already known (low probability). This is only separated on the basis of exploratory versus development which is a different division. It should be noted that the Macondo well in the Gulf was an exploratory well drilled into a new and unknown field. It would be wise to make these distinctions.

Section 8.5 Nearshore Spills

On page 399 the report states that "*In high-energy environments (NOAA 2000), oil is generally held offshore by wave reflection, and any oil that is deposited is rapidly removed by wave action. Environmental effects to inter-tidal communities are expected be short term. In medium-energy environments, which are essentially an intermediate stage between high-energy and low-energy environments with tide pools, there is usually a small accumulation of soil sediment at high tide mark coexisting with gravel beaches.*"

These statements are not correct. If this were true, oil spills would not be a problem and would not come ashore in high energy environments. The whole history of oil spills is filled with oil coming ashore, effects on the intertidal community and shoreline cleanup.

Further the discussion on diesel effects on page 399 and 400 contains outdated references, many from the 1970's.

Section 8.7.1.2 Marine Bird Species at Risk

On page 402 the report states that "*The oil spill modelling of the diesel and oil (condensate) spills at the wellsite (reported in SL Ross (2011) and summarized in Section 2.12.3) indicate that there would be no fuel remaining after 30 days and it would not reach any shorelines*" is again incorrect. With the correction, the marine bird species at risk would have to be re-assessed.

Section 8.7.6 Sensitive Areas

On page 410 the statement that "*The oil spill modelling indicates that the furthest extent of a blow-out or spill from the Project site would extend approximately 20 km from the well location (not much beyond the borders of EL 1105)*" is incorrect. Use of correct modeling data requires that the impact on sensitive areas be re-assessed.

Comments on the “Modeling in Support of Corridor Resources Old Harry Exploratory Drilling Environmental Assessment” Report by S.L. Ross Environmental Research Ltd.

Section 2.12 - Subsea blowouts

The prediction that all of the natural gas at depths below 700 to 800 m would all convert to gas hydrates is not really correct. The example of the Macondo well is clear, the solubility of gas components in the sea water at depth is so great that they (gases) become dissolved in the sea water rather than form hydrates. This may depend on other circumstances; however, hydrates have not formed in recent deep well blowouts. At best this may be a research topic.

The study of subsea blowouts by several researchers have shown that droplet sizes may vary from the size of the opening (not really a droplet) to the smaller droplets historically predicted.[2] This implies a much faster rise time in the oil than traditionally predicted. This faster rise time was observed at the Macondo well site.

Section 2.3.1 Oil Properties

The oil properties were cited to be drawn from the Environment Canada Data base. The properties are quote are correct except for the interfacial tensions. These appear to be misquoted.

	Comparison of Data Sources			
		0% Evaporated	11% Evaporated	26% Evaporated
SLR	Air	27.6	30.2	31.4
	Oil/Sea Water	17.2	16.7	17.5
Actual	Air	25.6	25.2	27.4
EC data	Sea Water	16.5	12.5	13

Later it was noticed that differing values from either set were used in the model (Table 2). It is not known how this affects the SLR model results.

Section 2.3.3 Water Currents
It was noted on page 16 of the report that water currents were taken from Tang et al. (2008). Perusal of this report shows only a model report not actual currents. Data may have been derived by this method by Tang?

Section 2.3.5 Wind Data
Similarly, it was noted on page 17, that winds were derived from Swail et al. (2006). The Swail report contains large scale summaries only. Data must have been taken from another source.

It is unclear from the paragraph on page 17 what type of wind data was actually used in the models as in the same paragraph 6-hour winds are discussed and then seasonal average winds from the LGL reports. These are quite different.

Section 3.1 Batch Diesel Spill Fate Modelling
The report states on page 18 and 19 that "*The small spills (1.59 m^3) have initial thick-oil slick widths of 10 m which grow to maximums of 52 to 58 m over the lives of the spills. The surface oil slicks from these small diesel spills will survive between 17 and 36 hours*." This is far too small a swath and far too short a life span.

The discussion on water column concentrations for surface spills is not relevant as natural dispersion would not result in such high concentrations. The discussion on this in the second volume, will clarify this situation.

Section 3.2 Subsea Blowout Fate and Behaviour Modelling
The report states on page 19 that "*The large spills modeled (15.9 m^3) have initial thick-oil slick widths of 32 m that grow to maximums of 127 to 139 m over the lives of the spills. The surface oil slicks from these larger diesel spills will survive between 25 and 49 hours*." This is incorrect and far too small slick widths and far too short a life span. Calculations in the second volume of this set of comments show that lifetimes for both diesel fuel and Cohasset oil extend well beyond 20 days.

Section 3.3 Surface Blowout Fate and Behaviour Modeling
The OST states on page 21 that "*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*."

Calculations in the independent modeling referenced above show that life times for both diesel fuel and Cohasset oil extend well beyond 30 days. This is irrespective of the source. It makes only a small difference to the fate of the oil whether it is released on the surface or the sub-sea. In the sub-sea release, a portion of the oil is dissolved and a portion dispersed, but the remaining oil will persist on the sea surface. This certainly was the case during the Macondo Well blowout in the Gulf in 2010. The oil in the Macondo case was heavier than a Cohasset type, but certainly was a very light crude oil.

Section 4.2 Typical Monthly Surface Oil Slick Trajectories

The standard method for predicting the movement and translocation of oil spills for impact analysis is to use Stochastic modeling. One Stochastic model run is equivalent to tens of thousands of single trajectory runs. A stochastic model calculates the probability of every possible trajectory and position given a broad set of wind and current data. Trajectory models are useful for actual accident prediction, for creating an exercise or for examining further the possibilities for an EI given that stochastic modeling has already been done.

The plots of Figures 5 to 8 of the OST have very limited usefulness as the predicted lives of the slicks are not realistic. This yields a poor scale and a limited view of where the slicks would actually go.

Section 4.3.1 Surface Oil Trajectory of Above Sea Blowouts

The above-sea blowout scenarios are unrealistic due to the unrealistic oil survival times. Table 9 from the report shows these times to vary typically up to only a few hours. The scenarios then in Figure 10 are not meaningful.

Section 4.3.2 Alternative Trajectory Assessment: Using Conservative Oil Fate Modeling

Again the results of this OST exercise show that no slicks reach shore. This is not correct and is a result of the algorithms used initially to look at the fate of oil. In the independent modeling where the slicks were modeled using different types of models and different data, it was seen that the oil spilled from the Old Harry site will frequently hit shore. The summary results of the OST model are shown in the following diagram taken from the OST text.

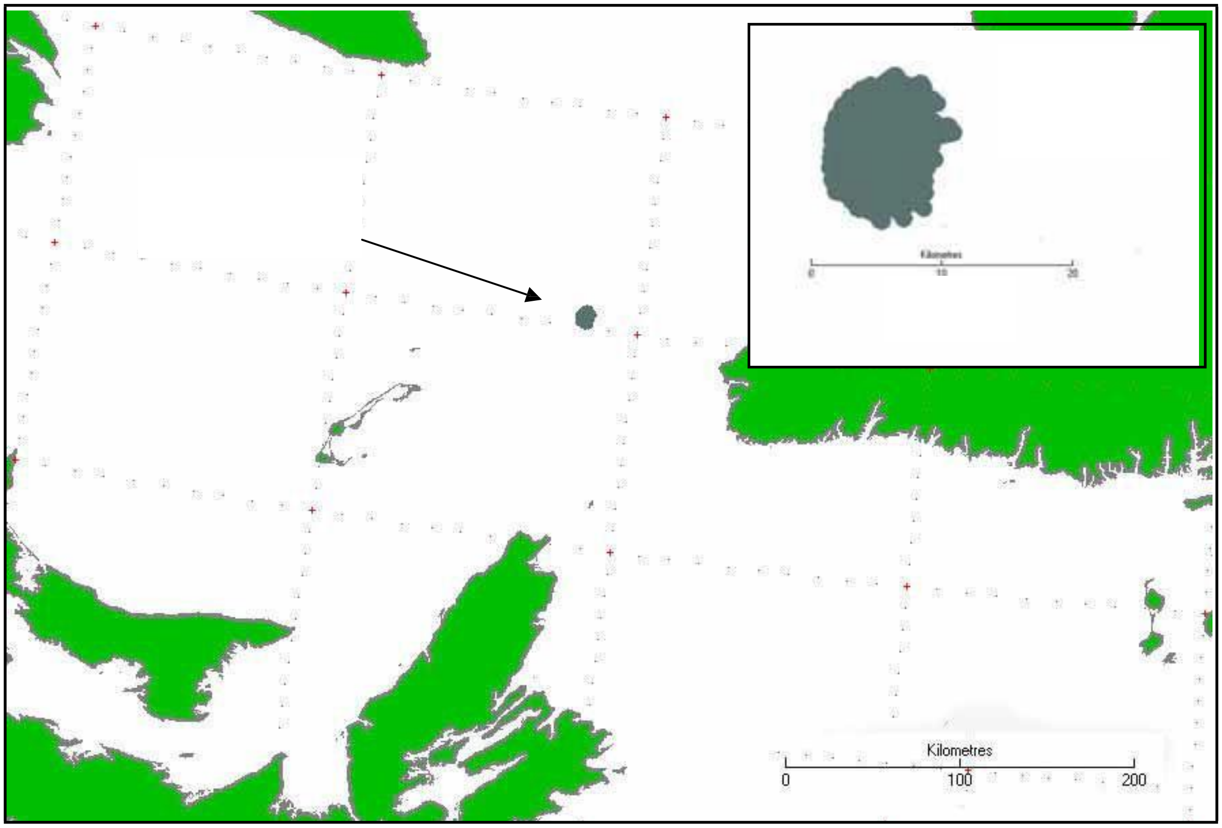

Figure 12. Maximum Area of Ocean Surface Swept by Oil from 52 Years of Simulations Using a Reasonable Worst-Case Modeling Approach

Section 5 Dispersed Oil Plume Trajectories

As the plumes are over-predicted, the trajectories are not believed to be relevant.

Section 5.3.1 Dispersed Oil Plumes from Above Sea Blowouts

The above sea spill trajectories are again under-predicted as noted in the diagram from the report as noted below:

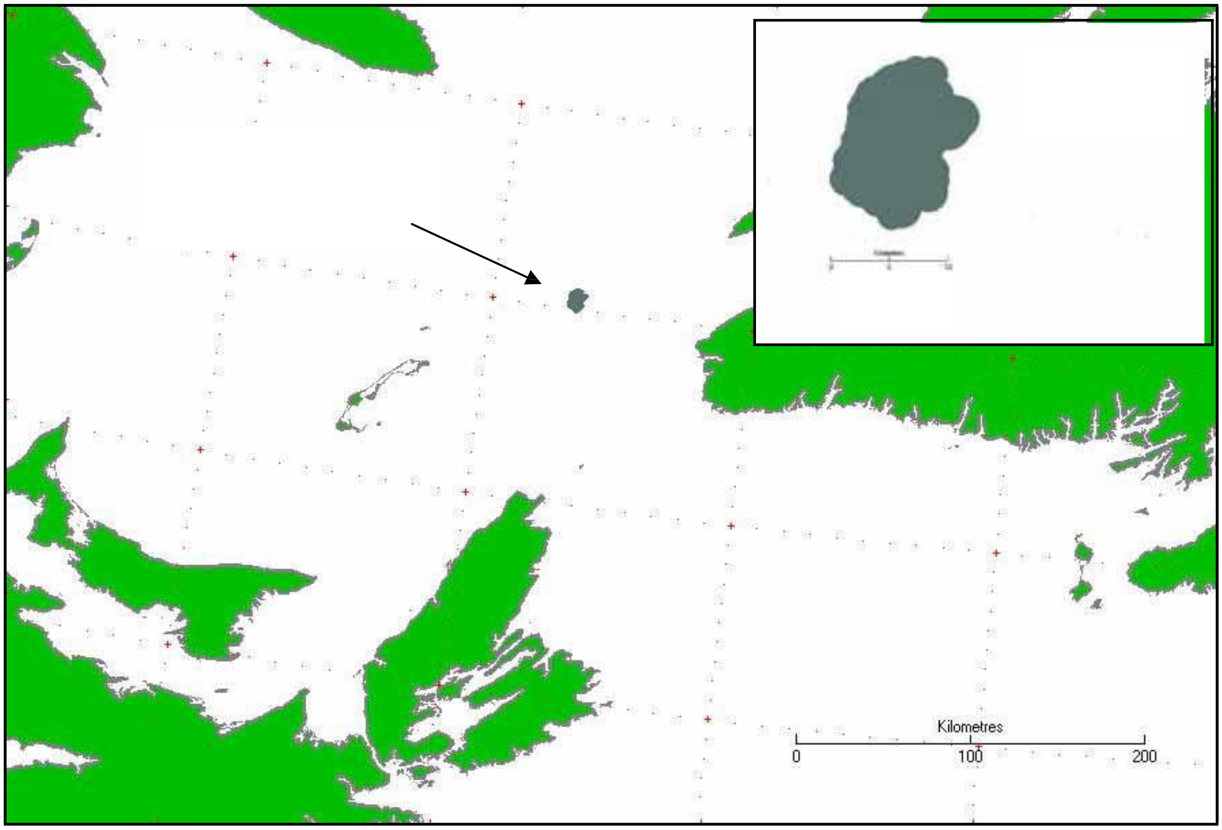

Figure 17. Maximum Extent of Ocean Swept by > 0.1 ppm Dispersed Oil from 52 Years of Above Sea Blowout Simulations

This will again have to be modeled again to yield a realistic scenario.

References

1 Etkin, D.S., Overview of Spill Occurrences, Chapter 2, in *Oil Spill Science and Technology,* M. Fingas, Editor, Gulf Publishing Company, NY, NY, pp. 7-47, 2011.

2 Adams, E. E. and S. A. Socolofsky, "Review of Deep Oil Spill Modeling Activity Supported by The DeepSpill JIP and Offshore Operators Committee," Technical Report, submitted to C. Cooper and the U.S. Dept. Interior, Minerals Management Service, (last revision) February, 2005.

3 Danchuk, S., and C.S. Willson, Numerical Modeling of Oil Spills in the Inland Waterways of the Lower Mississippi River Delta, IOSC, 887, 2008.

4 Spaulding, M.L., A State-of-the-art Review of Oil Spill Trajectory and Fate Modeling, Oil Chem. Poll. Vol. 4, pp. 39-55, 1988.

5 Stiver, W. and D. Mackay, Evaporation Rate of Spills of Hydrocarbons and Petroleum Mixtures. Environmental Science and Technology, pp. 834-840, 1984.

6 Delvigne, G.A.L., *Experiments on Natural and Chemical Dispersion of Oil in Laboratory and Field Circumstances*, Publication No. 327, Delft Hydraulic Laboratory, Delft, The Netherlands, 24 p, 1984.

7 French McCay, D.P., Modeling Impacts of Oil and Chemical Releases, *Sea Technology*, 21, 2006.

8 French-McCay, D., Modeling as a Scientific Tool in NRDA for Oil and Chemical Spills, *IOSC*, 2008.

9 Fingas, M., "Introduction to Oil Spill Modeling", Chapter 8, in *Oil Spill Science and Technology,* M. Fingas, Editor, Gulf Publishing Company, NY, NY, pp. 187-200, 2011.

10 Fingas, M., "Oil and Petroleum Evaporation", in *Proceedings of the Thirty-fourth Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 426-459, 2011.