Review of Husky Energy Proposal for The White Rose Extension Project Oil Spill Aspects

Merv Fingas

Spill Science

Edmonton, Alberta

For Environment Canada

February 2013

[redacted]

Review of Husky Energy Proposal for The White Rose Extension Project Oil Spill Aspects

Merv Fingas

Spill Science

Edmonton, Alberta

For Environment Canada

February 2013

Index

1 Summary

This is a review of the oil spill aspects of the Husky proposal for the Extension of the White Rose project which has phases offshore in the present White Rose area (WREP) and also at Placentia Bay.

The first step was to collect wind and current data for the two sites and then model the movement of the possible oil spills (crude and diesel) at both sites. Then as a second step a more detailed review of the proponents' oil spill component was carried out. These two were then compared.

In the Environment Canada models, it was found that that there is no predominant movement of spills at WREP although the most favoured are northeast and southeast. There is a lesser tendency to move northwest, southwest and east. There certainly is a tendency for oils to move around as both the currents and winds are quite variable.

At the sites in Placentia Bay, oils will always move south with the possibility of easterly or westerly tendencies. The winds are always out of the northeast. The currents are very weak inside the islands of the Bay and outside are tidal.

This was then compared to the proponent's modeling of the potential spills. For the offshore sites it was found that the trends were similar, however there were some differences. The proponents only used generalized winds which had predominant westerly components. This yielded scenarios which were slightly different from those of Environment Canada.

For the Placentia Bay scenarios, the proponents found that sometimes the diesel fuel entered further into the Bay. Environment Canada found that the oil predominantly went southerly. Further Environment Canada noted that the winds were almost always out of the northeast, thus explaining this movement.

The proponent suggested that the diesel oil spills had limited lifetimes due to natural dispersion, but did not model the movement and re-surfacing of the dispersed diesel fuel, suggesting that it was assimilated in the ocean. This may not affect the scenarios strongly.

2 Introduction

This is a review of the oil spill aspects of the proposal for the Extension of the White Rose project which has phases offshore in the present White Rose area (WREP) and also at Placentia Bay.

The approaches to this study were to:

a) Obtain the best data set for currents and winds
b) Obtain alternative but reliable data sets for these currents and winds
c) Study these data by plotting them and if they do not appear to be correct, get new sets
d) Obtain long data sets for the winds to ensure they truly represent the area
e) Obtain the data on the possible oils spilled, the best sources are empirical sources
f) Use a good (the best) state-of-the-art model to test the trajectories
g) Examine the fate of the oil using, if available, empirical data
h) Reassess the outputs of the model to ensure consistency.

3 Comments on the Proposals

3.1 Comments on Oil Spill Fate and Behaviour Modeling

Page 6 - Winds – The winds for Placentia Bay are given as being an average of 5 to about 11 m/s. This table appears to have incorrect directions. Analysis of daily winds from the National Climate Archive for two years shows winds almost always come from the North East. This would change many of the scenarios for Placentia Bay.

The two year average daily wind summary is shown below:

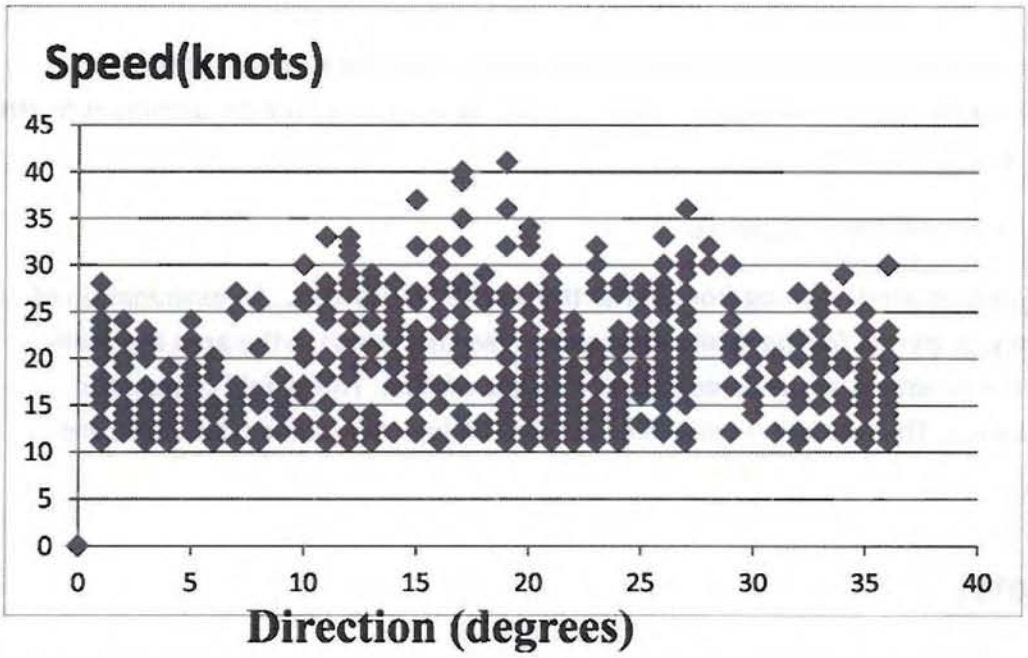


Figure 1 Daily plot of winds at the Argentia station Placentia Bay. Each data point represents one day's winds. Note that the winds are almost always out of the North East.

Page 6 – Spill Behaviour Average Environmental Conditions and following discussion

The SLR report states that "The following discussions assume that the spilled oil persists on the ocean surface and does not contact shore prior to loss of the surface slick"

This appears to be inconsistent with the modeling conducted in this review. The oil, here diesel fuel, contacts the shore several times. This would appear to be the case where there are differences in the amount naturally dispersed. However, If the diesel were naturally dispersed, one should then model the movement and resurfacing of the dispersed plume.

Page 8 Average conditions Trajectory Modeling

The modeling in the report shows the three slicks from sites A, B and C going north. Modeling for Environment Canada shows all slicks going south. It is suspected that this is caused by the difference in the currents and winds. The wind differences have been noted above, this is mostly a case of differences in direction. The current differences are unknown because the Husky report does not show the currents used.

It appears unlikely that the oil releases would go north because the currents through the islands in Placentia Bay are light and are tidal, i.e. go back and forth, thus the progress into the Bay would relatively be matched by progress out of the Bay. The winds are almost always from the north east; these would drive the oil south.

Page 14 Figure 2-9

The batch spill trajectory probabilities for Location A. This shows much of the oil heading further into the Bay. As noted earlier this is unlikely because of the predominant North East winds and the tidal currents.

Page 27 Winds for the offshore modeling.

Table 3-5 shows winds coming from either the west or southwest. An examination of winds over a two year period for the White Rose site shows that winds in the area are usally from varied directions with little persistence over a period of time. This would change the predicted trajectories. The two year winds from the Climatological Weather Data base are shown below.

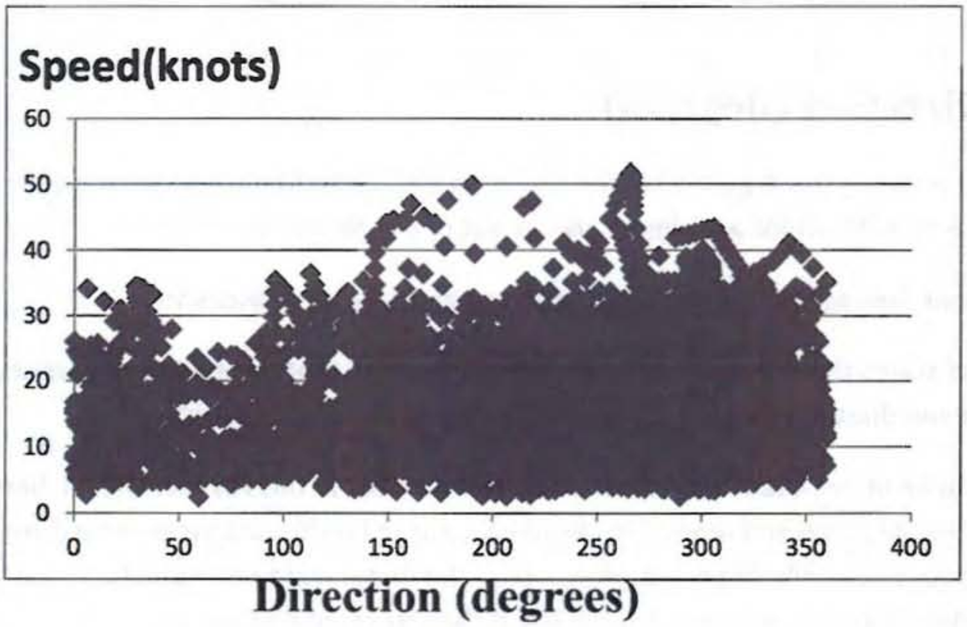


Figure 2 Autumn winds – points are hourly over a two year period. This shows that the winds are have very little predominant directions. Further data on these winds are presented later in this report.

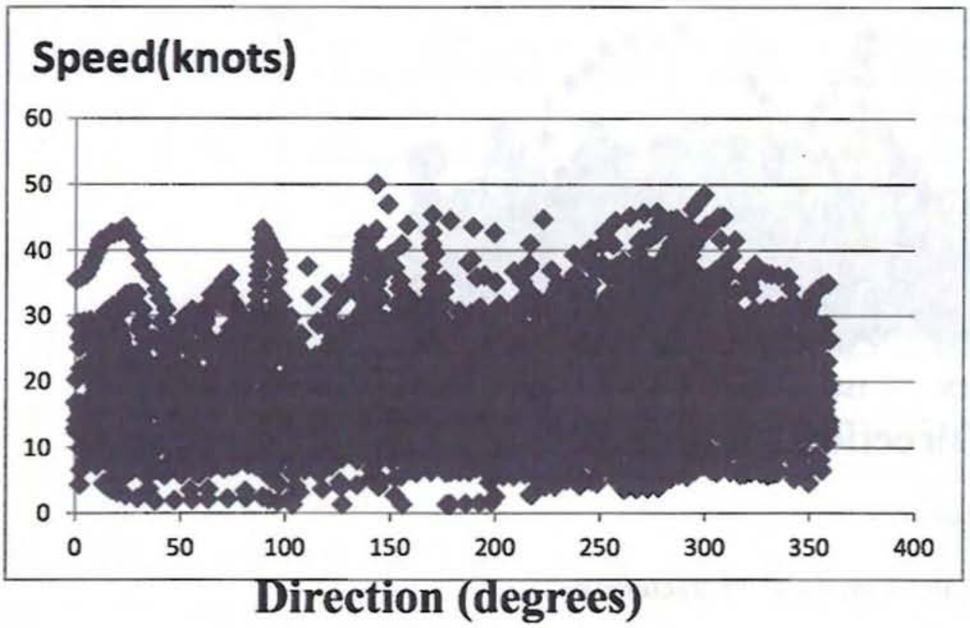


Figure 3 Winter winds for the White Rose site

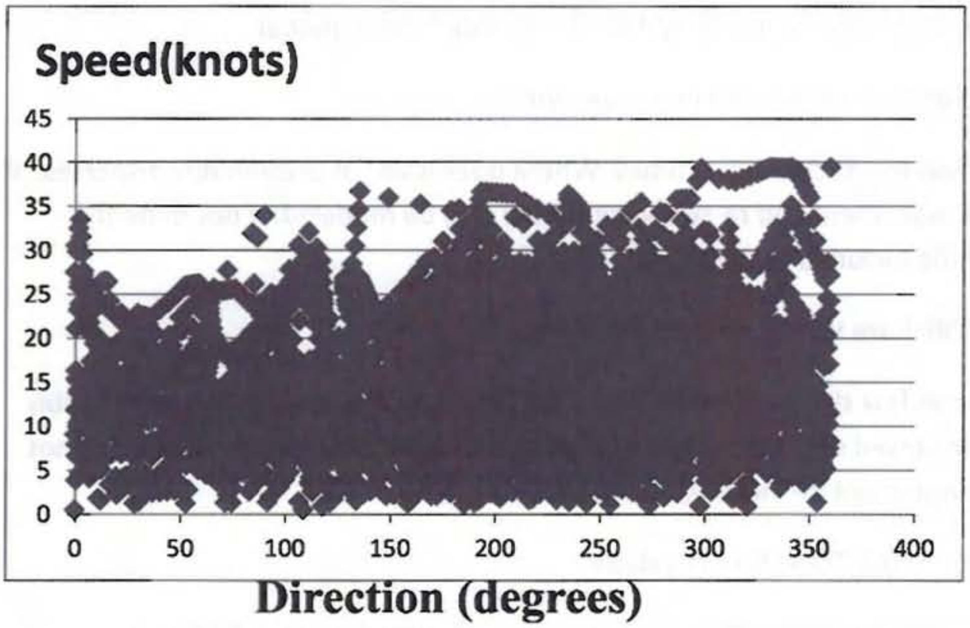


Figure 4 Spring winds for the White Rose site

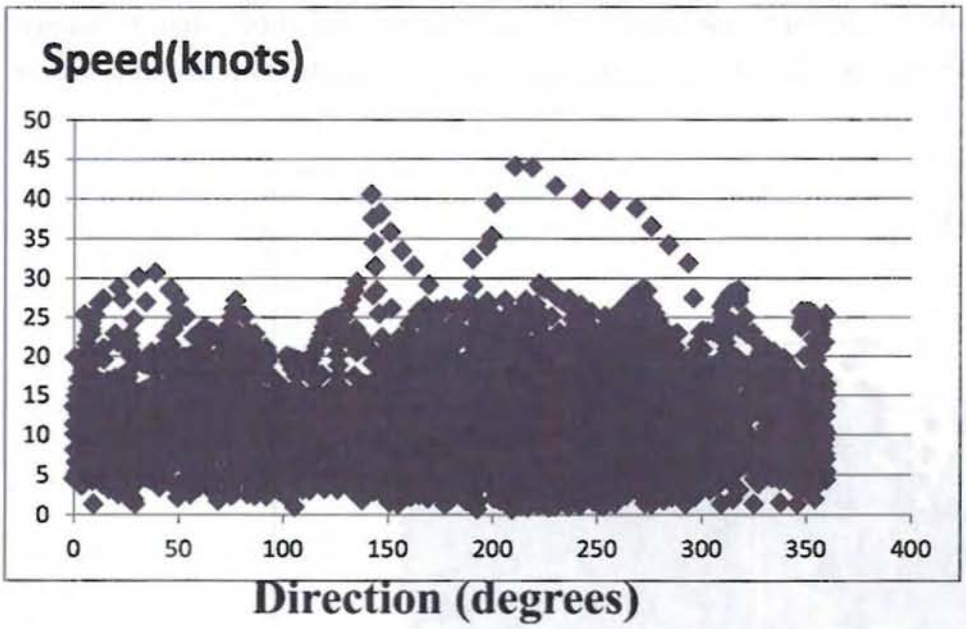


Figure 5 Winds for summer

Page 28 Table 3.6 Batch Diesel Spill Characteristics

This table shows the slick survival time ranges between 13 and 38 hours. Where does it go? It presumably disperses. If so the dispersed slick movement and re-surfacing should also be modeled. If not done the dispersion should not be included in the model.

Page 29 Figure 3-6 Offshore Summer Diesel Trajectories

This figure shows low slick survival times. Where does it go? It presumably disperses. If so the dispersed slick movement and re-surfacing should also be modeled. If not done the dispersion should not be included in the model.

Page 30 Figure 3-7 Offshore Winter Diesel Trajectories

This figure shows low slick survival times. Again, where does the oil go? It presumably disperses. If so the dispersed slick movement and re-surfacing should also be modeled. If not done the dispersion should not be included in the model.

Page 32 Figure 3-8 Summer Trajectory Envelope

This figure is approximately correct, however since the winds chosen had a predominately westerly direction, this is different from the projection in this study, shown below:

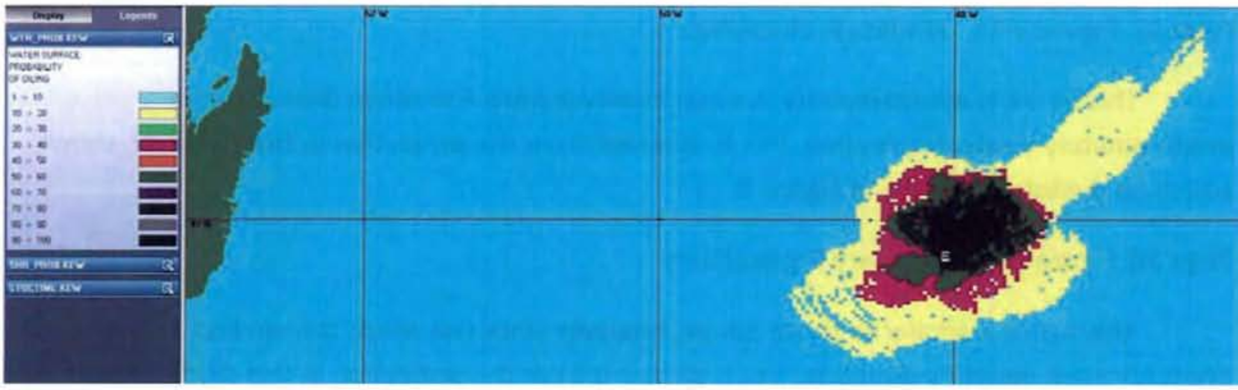


Figure 6 A stochastic trajectory prediction for a summer blowout scenario. Note that the probability of oil (also in the colour key) shows probabilities in both the Northeast and Southeast directions.

Page 33 Figure 3-9 Winter Trajectory Envelope

This figure is approximately correct, however since the winds chosen had a predominately westerly direction, this is different from the projection here, shown below:

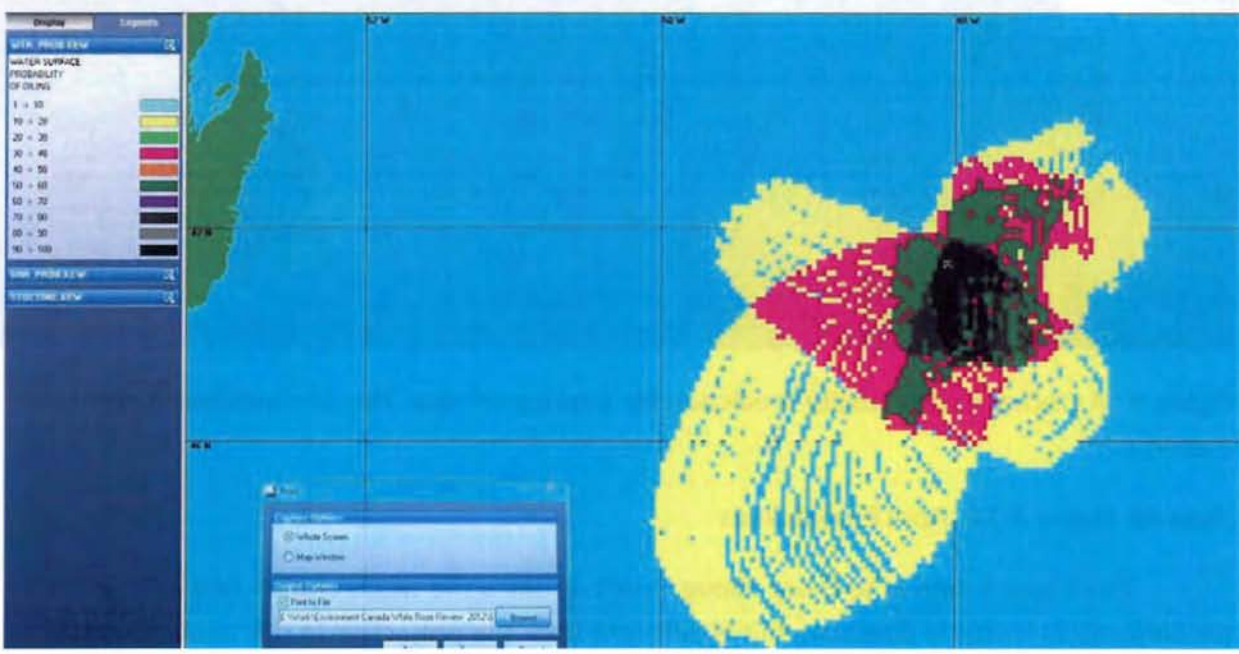


Figure 7 Stochastic probabilities calculated for Environment Canada for winter. Highest probabilities are in the Southeast and then about equally probable in the Northwest, Northeast and Southeast.

Page 37 Figure 3-11 January Probabilities

This figure is approximately correct, however since the winds chosen had a predominately westerly direction, this is different from the projection in the EC study, shown above for a winter scenario in Figure 7.

Page 38 Figure 3-12 February Probabilities

This figure is similar to those above, however since the winds chosen had a predominately westerly direction, this is different from the projection in this study, shown above for a winter scenario in Figure 7.

Page 39 Figure 3-13 March Probabilities

This figure is approximately correct, however since the winds chosen had a predominately westerly direction, this is different from the projection here, shown above for a spring scenario below.

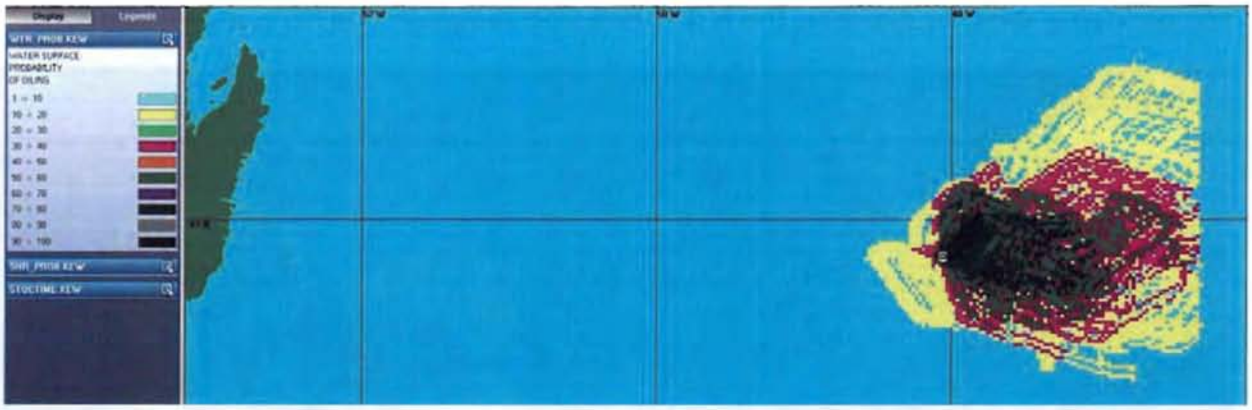


Figure 8 A stochastic probability prediction for a spring release. The predominant direction is easterly.

Page 40 Figure 3-14 April Probabilities

This figure is similar to those above, however since the winds chosen had a predominately westerly direction, this is different from the projection in this study shown above for a spring scenario in Figure 8.

Page 41 Figure 3-15 May Probabilities

This figure is approximately correct, however since the winds chosen had a predominately westerly direction, this is different from the projection here, shown above for a spring scenario in Figure 8.

Page 42 Figure 3-16 June Probabilities

This figure is approximately correct, however since the winds chosen had a predominately westerly direction, this is different from the EC projection, shown above for a summer scenario as shown below.

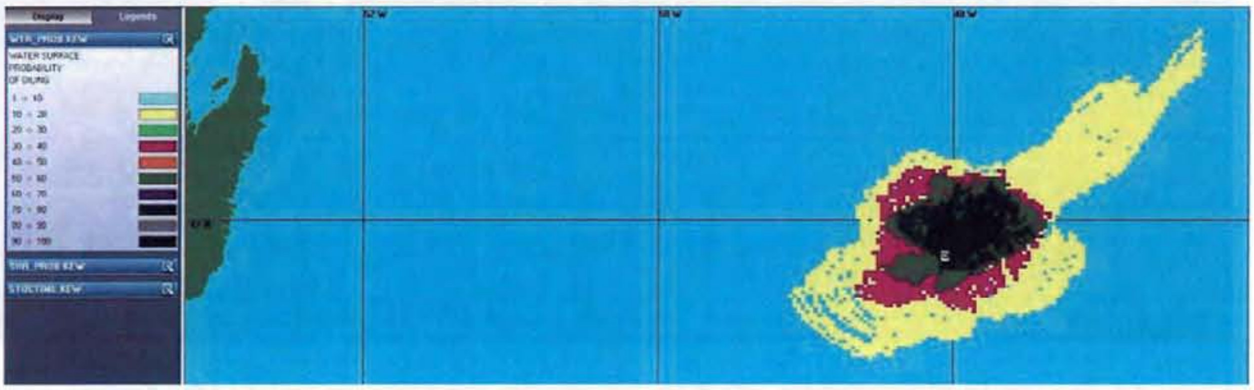


Figure 9 Prediction for a summer blowout release. The predominant direction of movement is to the Northeast with some movement to the Southwest.

Page 43 Figure 3-17 July Probabilities

This figure is approximately correct, however since the winds chosen had a predominately westerly direction, this is different from the projection in this study, shown above for a summer scenario as shown above.

Page 44 Figure 3-18 August Probabilities

This figure is approximately correct, however since the winds chosen had a predominately westerly direction, this is different from the projection here, shown above for a summer scenario as shown in Figure 9 above.

Page 45 Figure 3-19 September Probabilities

This figure is approximately correct, however since the winds chosen had a predominately westerly direction, this is different from the EC projection, shown above for a summer scenario as shown in Figure 10.

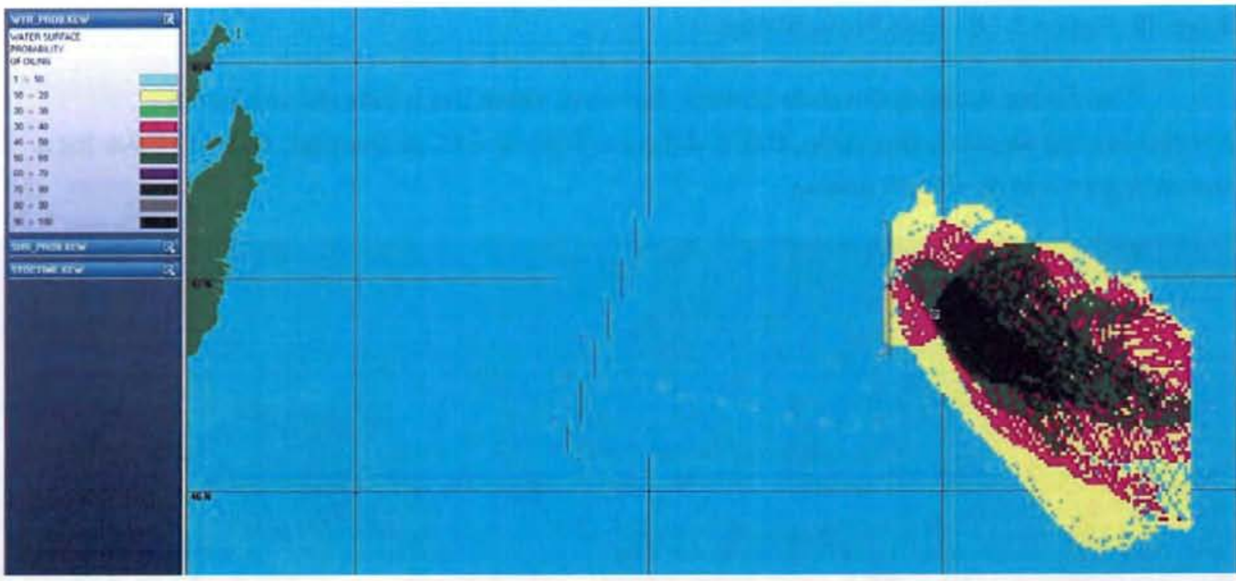


Figure 10 The stochastic probability of oil trajectories for autumn as calculated for Environment Canada

Page 46 Figure 3-20 October Probabilities

This figure is approximately correct, however since the winds chosen had predominately westerly direction, this is different from the Environment Canada projection, shown above for an autumn scenario as shown in Figure 10 above.

Page 47 Figure 3-21 - November Probabilities

This figure is approximately correct, however since the winds chosen had predominately westerly direction, this is different from the EC projection, shown above for a summer scenario as shown in Figure 10 above.

Page 484 Figure 3-22 December Probabilities

This figure is approximately correct, however since the winds chosen had predominately westerly direction, this is different from the projection in this study, shown above for a summer scenario as shown in Figure 7 above.

3.2 Comments on Section 16 Environmental Management

Page 16-5 Chemical Selection

What does 'domestic chemicals' refer to? Are these 'household chemicals'?

Page 16-16 Table 16-2

ISphere buoys are mentioned to follow oil. It is uncertain whether these buoys follow oil. There is no listing of testing (see: Fingas, M., "Buoys and Devices for Spill Tracking", in *Proceedings of the Thirty-fourth Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 213-228, 2011.). It should be noted that the same company does make oil spill tracking buoys that have been tested (Novatech spill tracking buoys).

Page 16-19 Section 16.11-4 Satellite Tracker Buoys

ISphere buoys are mentioned to follow oil. It is uncertain whether these buoys follow oil. There is no listing of testing (see: Fingas, M., "Buoys and Devices for Spill Tracking", in *Proceedings of the Thirty-fourth Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 213-228, 2011.). It should be noted that the same company does make oil spill tracking buoys that have been tested (Novatech spill tracking buoys).

Page 16-20 Section 16.12 CCG equipment

There is no section on how the CCG equipment might be put into play.

Page 16-22 Section 16.13.3 Dispersants

The main authority for dispersants is Environment Canada

4 Scenarios

This report is a review of proposals and an effort to model possible spills from oil and fuel spills from drilling at the both the Placentia Bay site off the south coast of Newfoundland and east off the coast of Newfoundland. Oil spill modeling is sometimes as much an art as a science; however in recent years extensive innovations have taken place in developing fate and behaviour algorithms and in the computer portions of the models themselves. What lags the art somewhat is the accuracy of the input parameters such as wind and currents. For contingency planning purposes the most accurate inputs are certainly the past actual measurements. This is easier with winds than currents as currents are not frequently measured in many locations. Only in those areas with continuous current monitoring buoys is this task much easier.

Today's sophisticated spill models combine the latest information on oil fate and behaviour with computer technology to predict where the oil will go and what state it will be in when it gets there. Their major limitation to accurately predicting an oil slick's movement is the lack of accurate data on water current and wind speeds along the predicted path. This is likely to remain a limitation in the future. In this case, historic winds were largely used to model the movement of the diesel fuel and crude oil likely to be released at these sites. Typically. hourly winds over two years were used. These are described later in this report. For trajectory models, accurate hourly winds for the day chosen were used to model the spills. These are obtained from CMC and generated specifically for modeling purposes.

Currents were used for this exercise from both historic generic sources (Wu and Fang, 2011)[1] as well as specific daily currents generated by CMC. In both areas, it was found the currents were generally not as important in moving the oil as was the wind.

Spill models operate in a variety of modes. The most typical is the trajectory mode which predicts the trajectory and weathering of the oil. The stochastic mode uses available data to predict a variety of scenarios for the oil spill, which includes the direction, fate, and property changes in the oil slick. 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. In another mode, often called the receptor mode, a site on the shore or water is chosen and the trajectory from the source of the oil is calculated. Increasingly, statistically-generated estimates are added to oil spill models to compensate for the lack of immediate data on winds and currents.

All modeling was carried out using OilMap 6.7.2.

The following table (Table 1) shows the model runs used in this report and summarizes the findings.

Table 1 Scenarios Summaries

Oil Type	Season/Date	Days run	Amount Fuel	Wind File	Current File	Spill time (hrs)	Results: Predominant Direction	Maximum Length (km)*	Time of Travel (days)	Hit Shoreline ?	Comments
Stochastic Scenarios - White Rose											
Crude	Autumn	10	20,000 bbls/day	2-yr autumn	seasonal	continuous	SW	222	10	no	
Diesel	Autumn	10	10,000 L batch	2-yr autumn	seasonal	2	SW	172	10	no	
Crude	Winter	10	20,000 bbls/day	2-yr winter	seasonal	continuous	SE &NE	328	10	no	on 2 axis
Diesel	Winter	10	10,000 L batch	2-yr winter	seasonal	2	SE &NE	233	10	no	on 2 axis
Crude	Spring	10	20,000 bbls/day	2-yr Spring	seasonal	continuous	NE	250	10	no	to end of grid
Diesel	Spring	10	10,000 L batch	2-yr Spring	seasonal	2	NE	168	10	no	
Crude	Summer	10	20,000 bbls/day	2-yr Spring	seasonal	continuous	NE	255	10	no	
Diesel	Summer	10	10,000 L batch	2-yr Spring	seasonal	2	NE	245	10	no	
Stochastic Scenarios - Pacentia Bay											
Diesel	first scenario	5	350 m^3 batch	2-yr annual	Feb-09	instantaneous	S	50	2	yes	Avalon Peninsula
Diesel	second scenario	5	350 m^3 batch	2-yr annual	average	instantaneous	S	50	2	yes	Avalon Peninsula
Diesel	west side release	5	350 m^3 batch	2-yr annual	average	instantaneous	S	10	1	yes	most grounds on Merasheen Island
Trajectories											
Diesel	100-day Trajec	100	10,000 L	2-yr Spring	seasonal	2	NE	55	100	no	
Crude	100-day Trajec	100	20,000 bbls	2-yr Spring	seasonal	2	NE	55	100	no	
Crude	Feb 6 - WREP	2	20,000 bbls	CMC daily	CMC daily	24	NE & NW	63	2	no	
Crude	Feb 7 - WREP	1	20,000 bbls	CMC daily	CMC daily	24	N	33	1	no	
Crude	Feb 8 - WREP	1	20,000 bbls	CMC daily	CMC daily	24	N	30	1	no	
Crude	Feb 9 - WREP	1	20,000 bbls	CMC daily	CMC daily	24	NW & SE	25	1	no	
Crude	Feb 10 - WREP	1	20,000 bbls	CMC daily	CMC daily	24	NW & SE	32	1	no	
Crude	Feb 11 - WREP	1	20,000 bbls	CMC daily	CMC daily	24	NW & SE	30	1	no	
Crude	Feb 12 - WREP	1	20,000 bbls	CMC daily	CMC daily	24	NW & SE	36	1	no	
Diesel	Feb 6 - WREP	1	350 m^3 batch	CMC daily	CMC daily	2	NE & NW	8	1	no	
Diesel	Feb 8 - WREP	1	350 m^3 batch	CMC daily	CMC daily	2	N	5	1	no	
Diesel	Feb 8-P. Bay	1	350 m^3 batch	CMC daily	CMC daily	1	SE	5.4	1	no	Avalon Peninsula
Diesel	Feb 9-P. Bay	1	350 m^3 batch	CMC daily	CMC daily	1	SW	3	1	no	mately would hit Burin Pen.
Diesel	Feb 10 -P. Bay	1	350 m^3 batch	CMC daily	CMC daily	1	SW	4	1	no	mately would hit Burin Pen.
Diesel	Feb 11 - P. Bay	1	350 m^3 batch	CMC daily	CMC daily	1	SE	8.5	1	yes	Avalon Peninsula
Diesel	Feb 12 - P. Bay	1	350 m^3 batch	CMC daily	CMC daily	1	SW	3.6	1	no	mately would hit Burin Pen.
Diesel	Feb 12-P. Bay	1	350 m^3 batch	CMC daily	CMC daily	1b more currents	SW	2	1	no	mately would hit Burin Pen.

*These are maximum values which includes spreading and uncertainty

4.1 Stochastic Scenarios

The stochastic scenarios are presented: first for the White Rose offshore site and then for the Placentia Bay site.

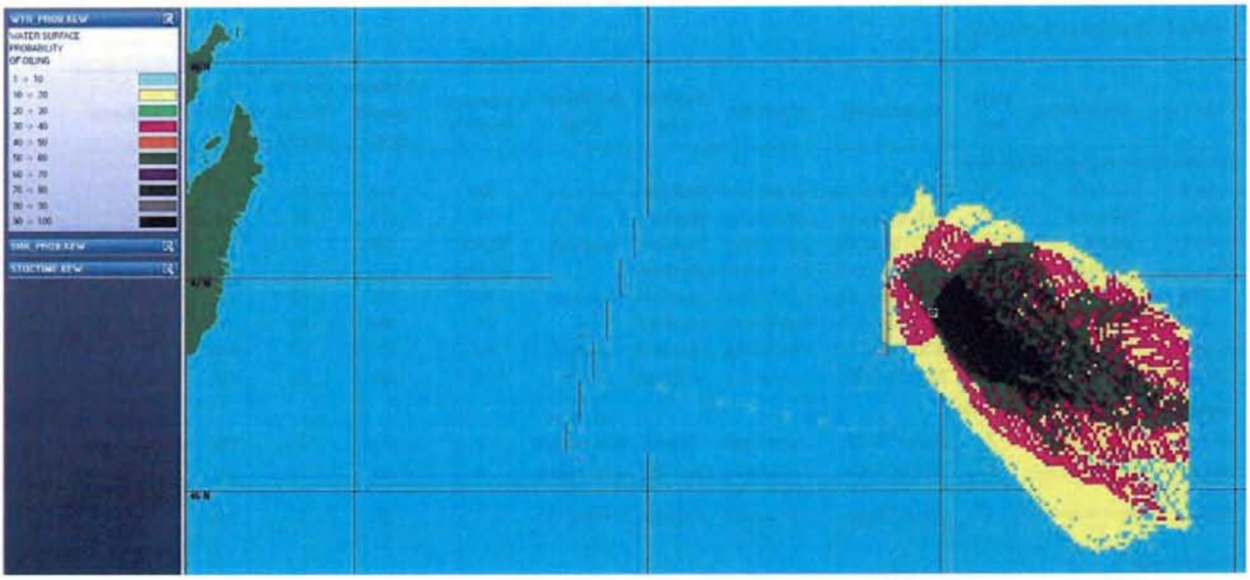


Figure 11 A stochastic probability of crude oil spills for the autumn months. The probability key is top left. Movement of oil is southeast.

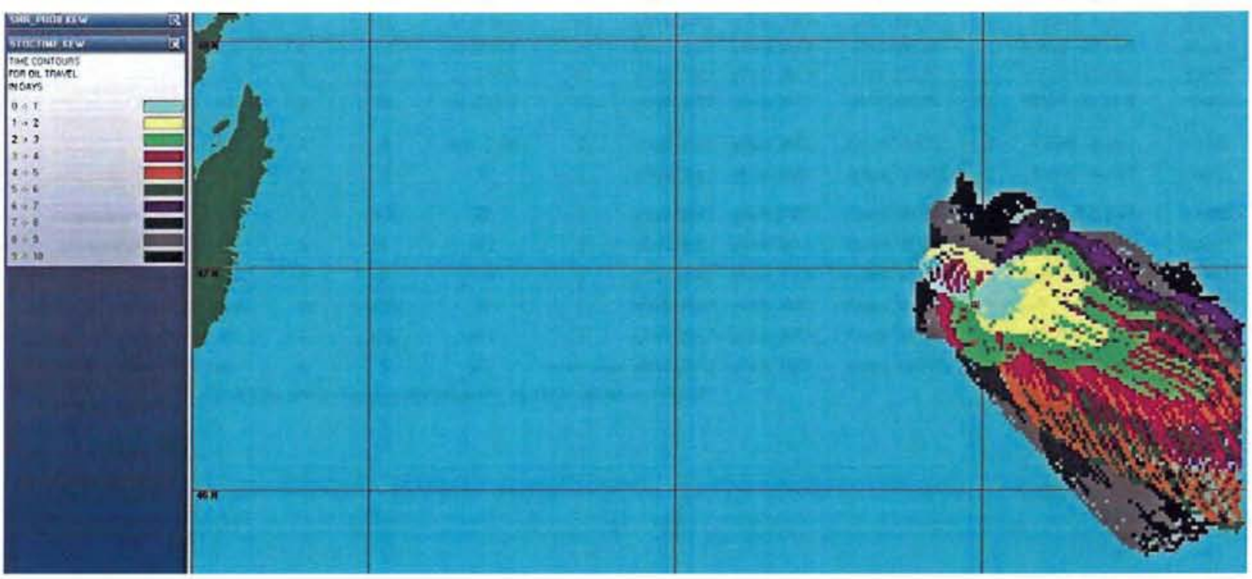


Figure 12 The time of travel for crude oil spills for autumn at the White Rose Expansion site. The time key is at the top left.

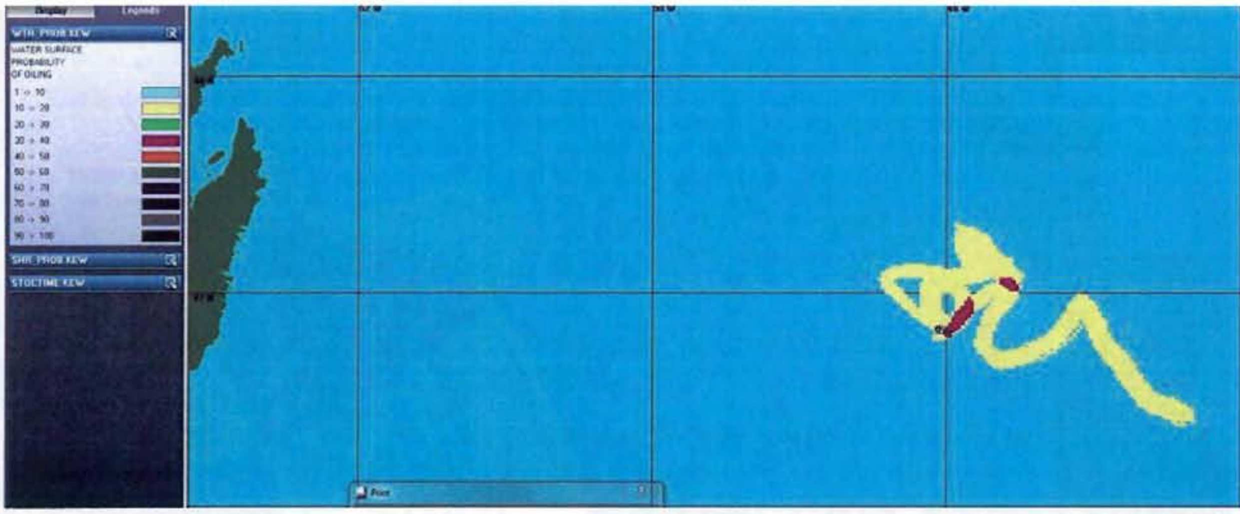


Figure 13 The stochastic movement of a batch spill of diesel fuel for autumn at the WREP site. The movement again is predominantly to the southeast; however, there is some looping to the north and northwest.

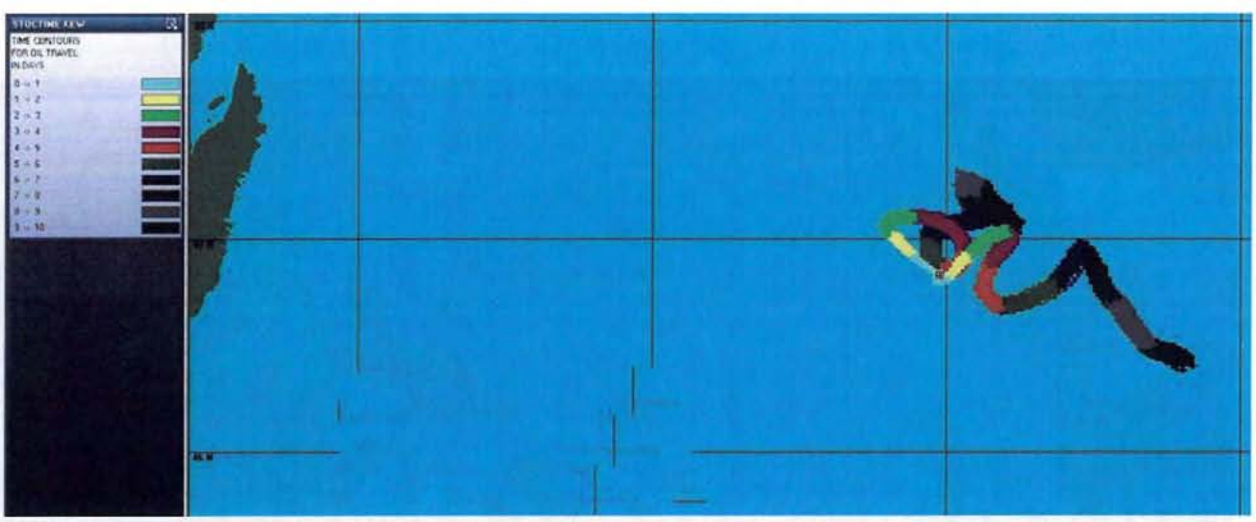


Figure 14 The stochastic travel time for diesel fuel as related to the above figure. This is for the autumn.

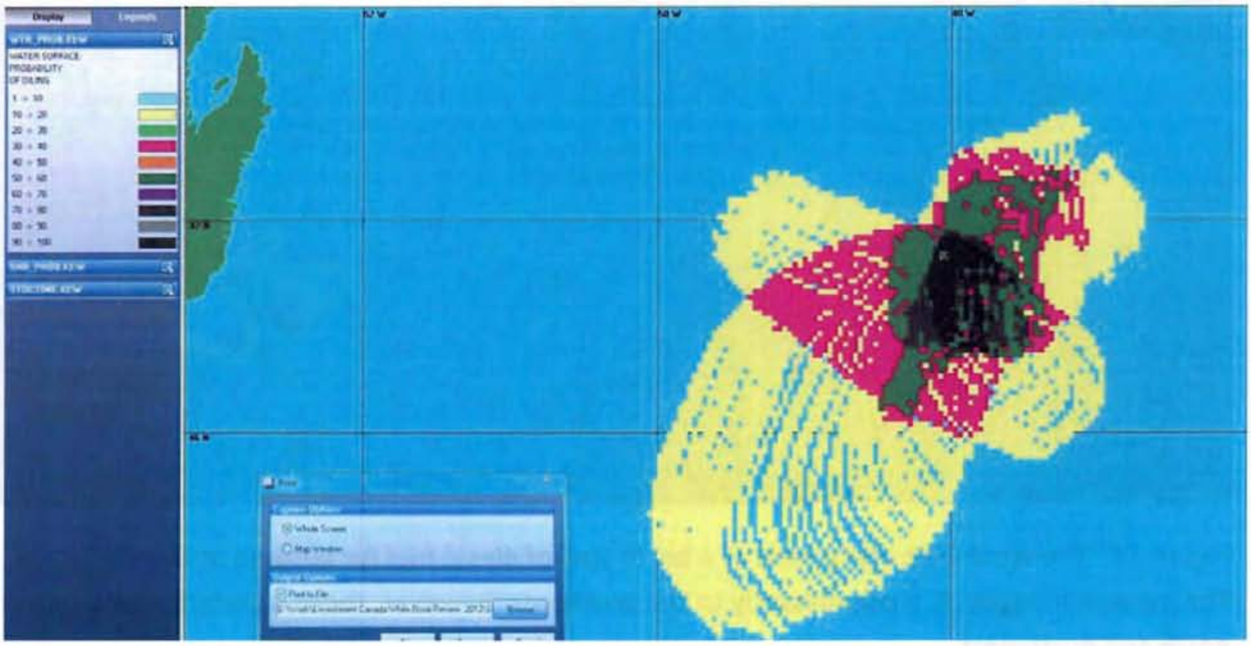


Figure 15 The stochastic probability of surface coverage for a crude oil spill in winter at WREP. Note that the majority of probability is to the southwest. Some travel to northwest, northeast and southeast could also occur.

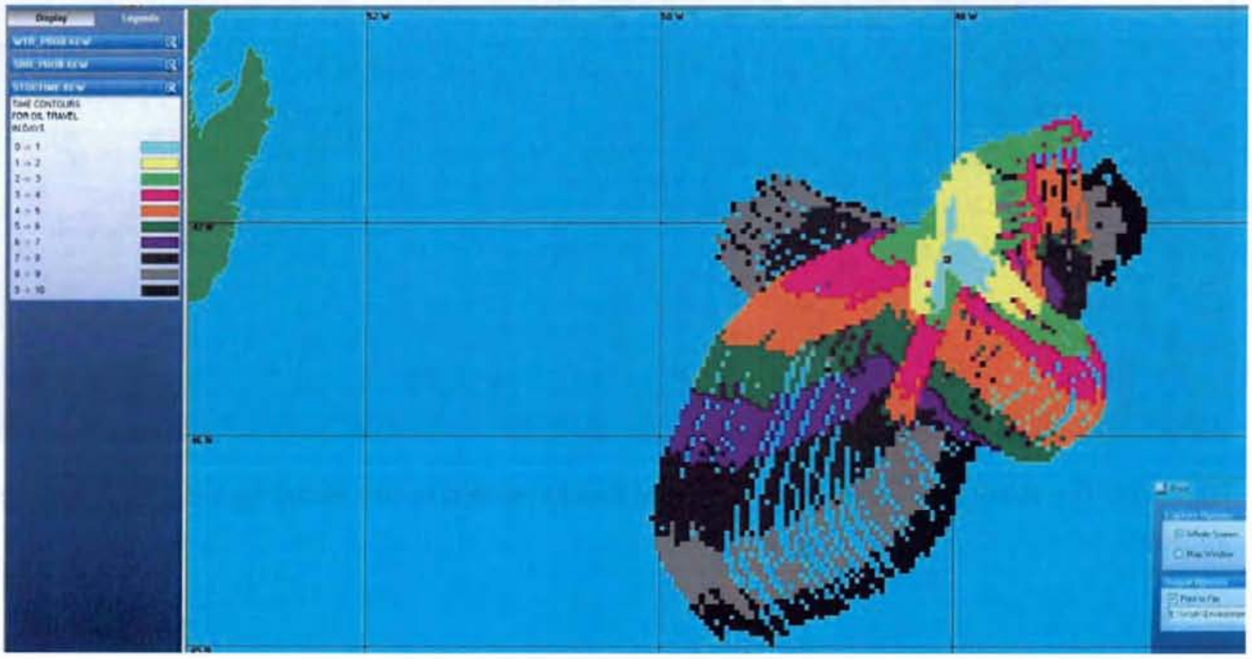


Figure 16 The travel times associated with a winter blowout of crude at WREP.

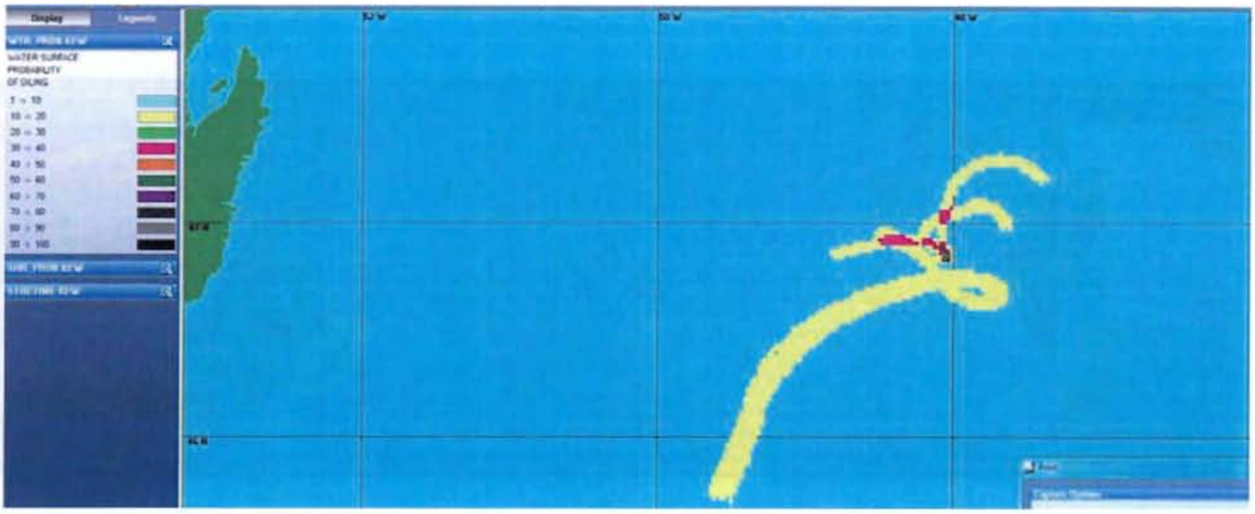


Figure 17 The stochastic trajectory of batch diesel spills for winter at WREP. The travel is the same as for crude, primarily to the southwest with some northwest and northeast travel.

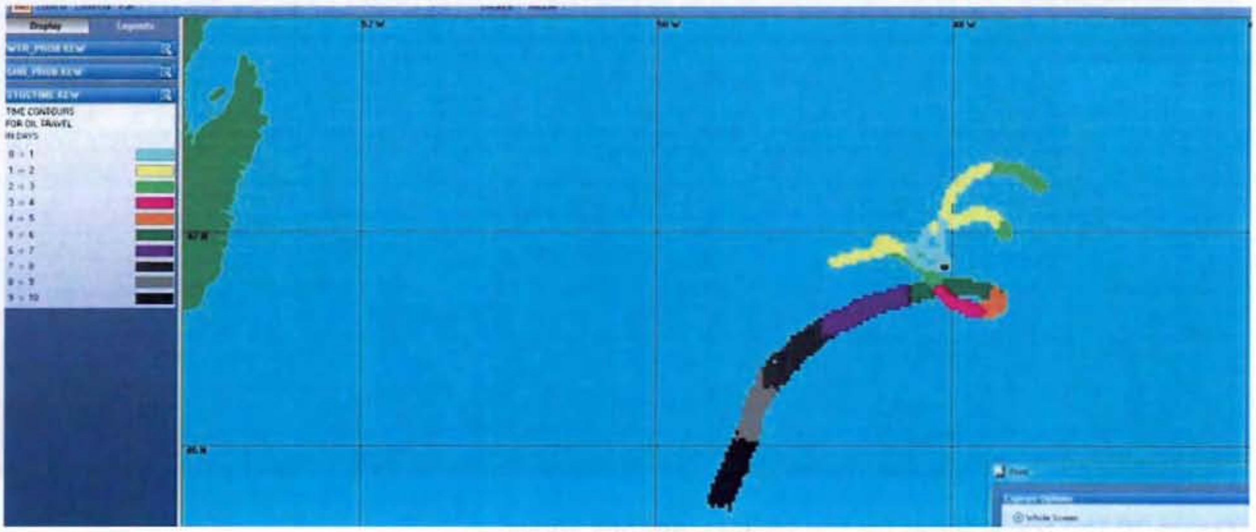


Figure 18 The travel times (days) for a batch diesel spill at WREP in winter.

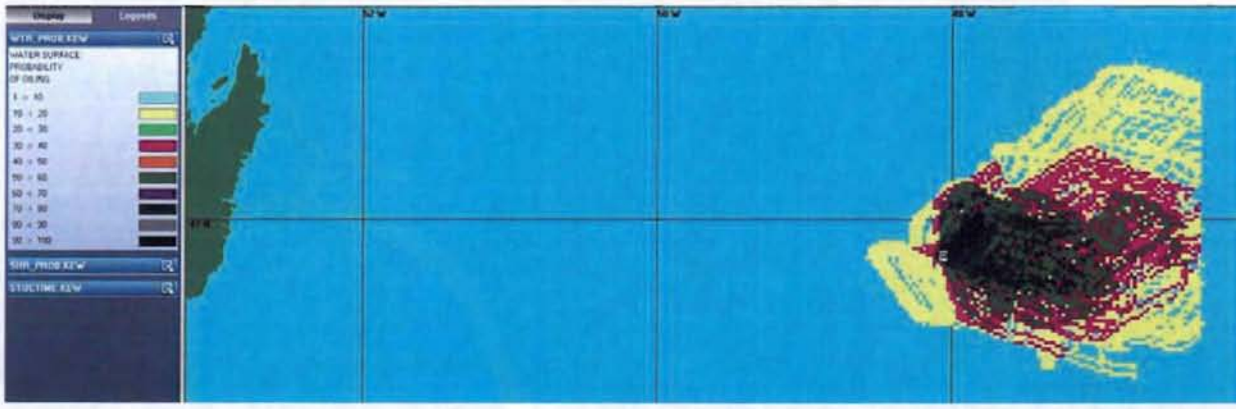


Figure 19 The spring stochastic scenarios for the WREP site. The prominent movement of oil is to the east.

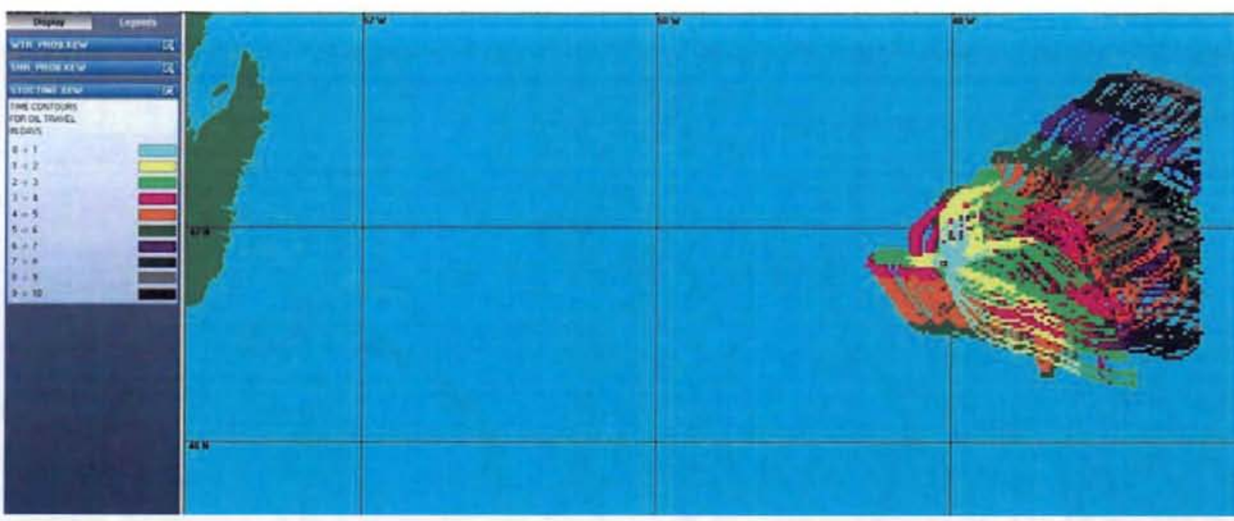


Figure 20 The travel times for the spring scenarios above.

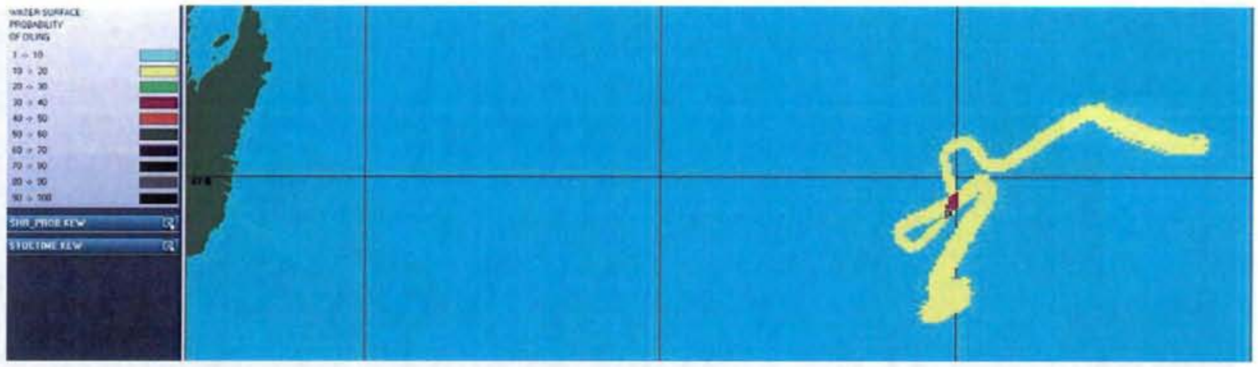


Figure 21 The Probabilities for a batch diesel spill at the WREP site in spring. The highest probabilities for travel are to the east and south.

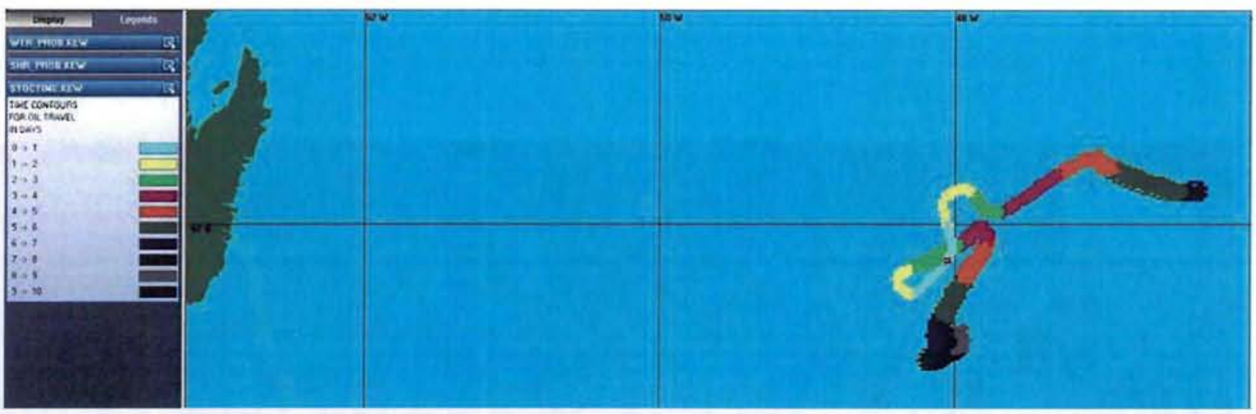


Figure 22 The travel times for a spring diesel spill at WREP.

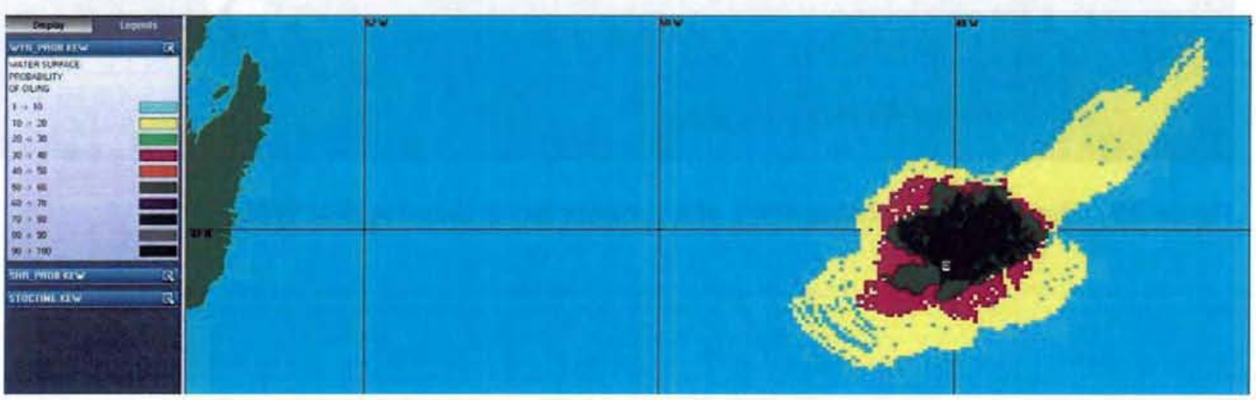


Figure 23 The stochastic probabilities for a summer crude oil blowout at WREP. The prominent travel would be to the northeast with some southwest and little southeast and northeast.

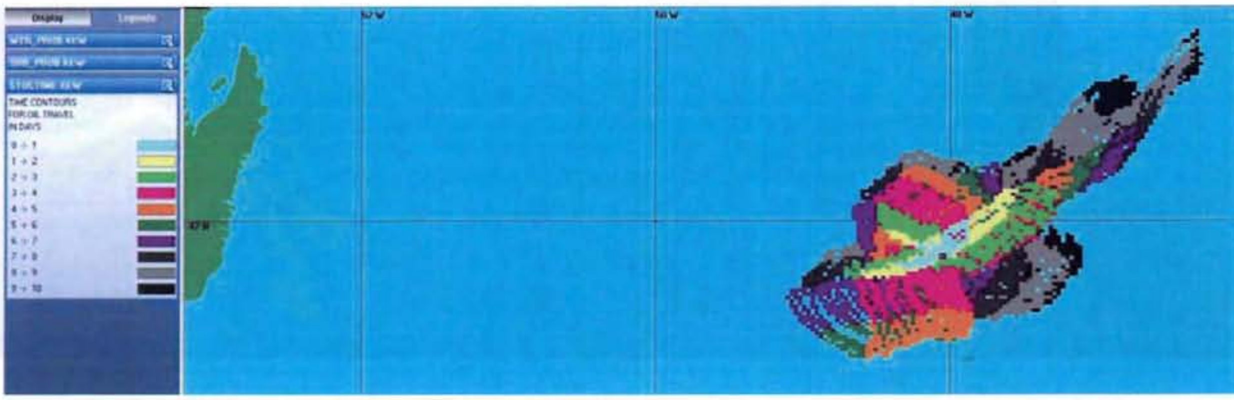


Figure 24 The travel times for a summer crude spill as described above.

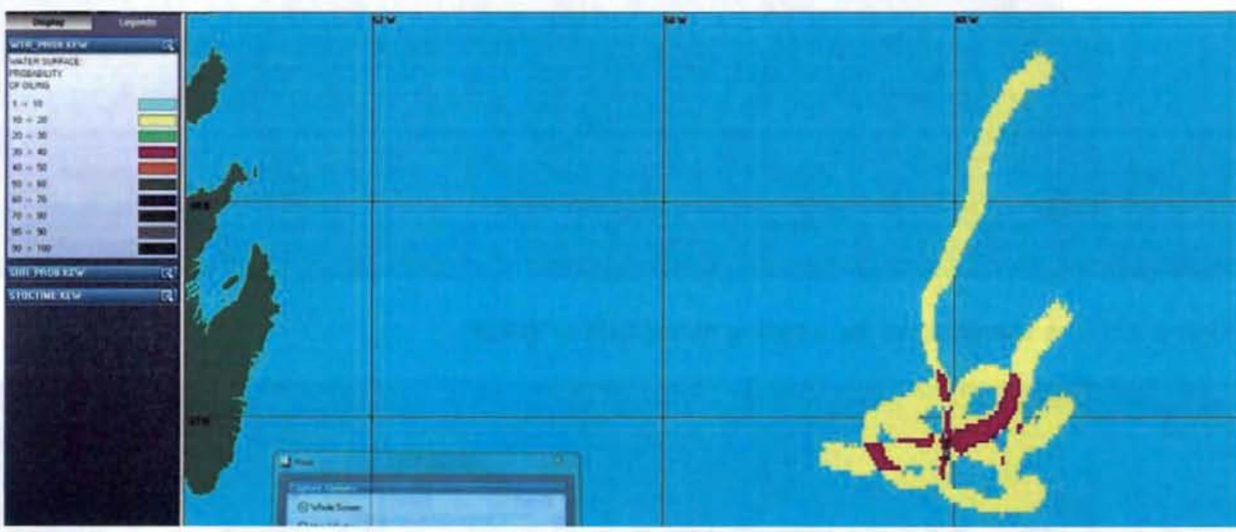


Figure 25 The stochastic probabilities of a summer batch diesel spill at WREP

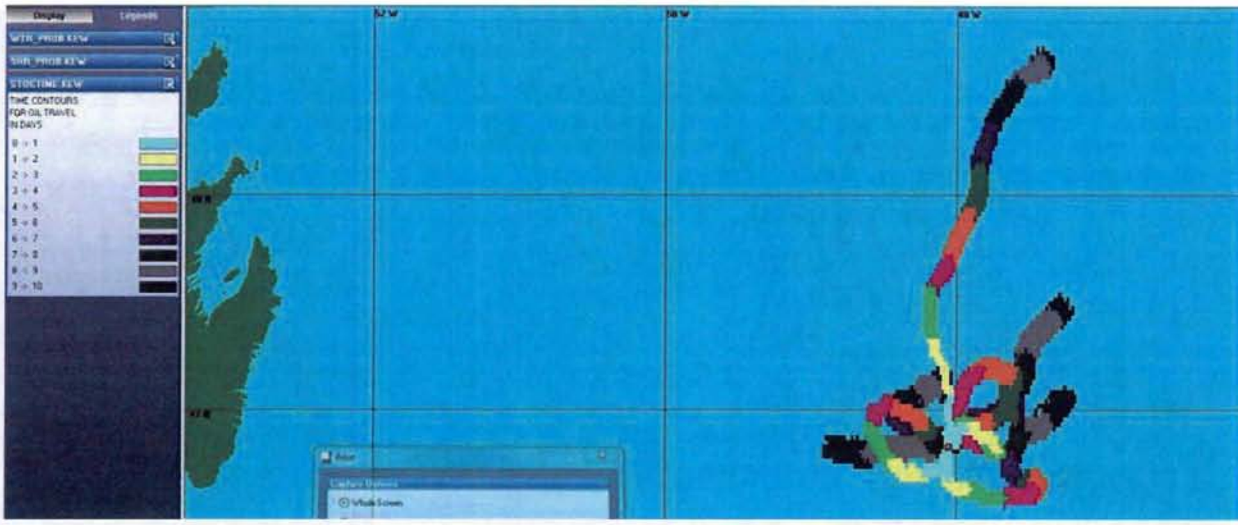


Figure 26 The travel times for the summer batch diesel spill at WREP.

Placentia Bay Stochastic Scenarios

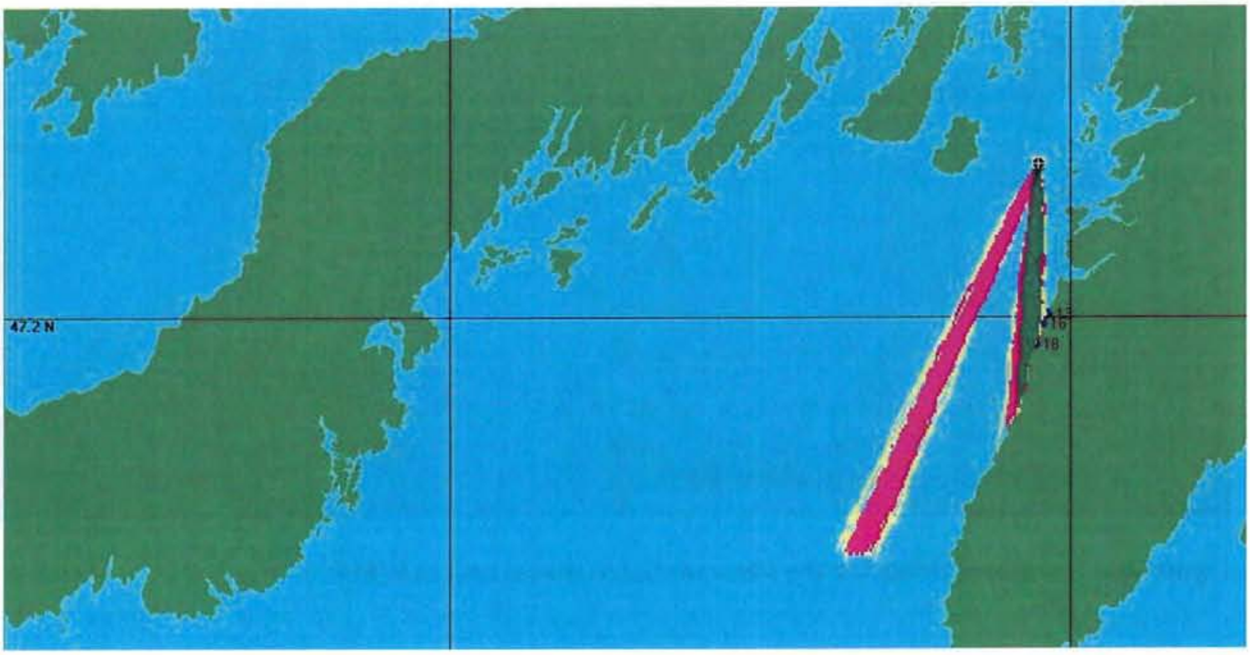


Figure 27 A stochastic scenario for a batch diesel spill at site A of Placentia Bay. The winds used were a daily wind over 2 years for 2011 and 2012.

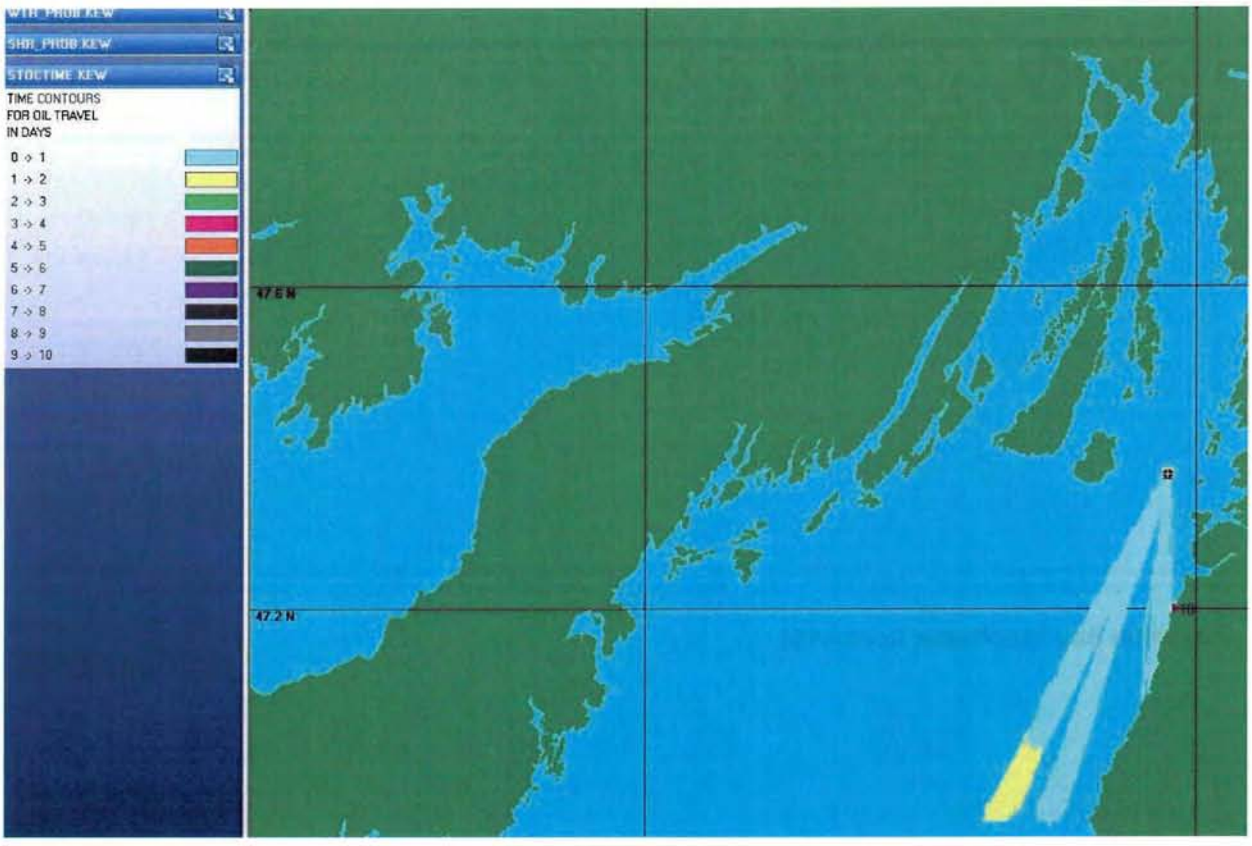


Figure 28 The travel times for the above stochastic scenario for Placentia Bay.

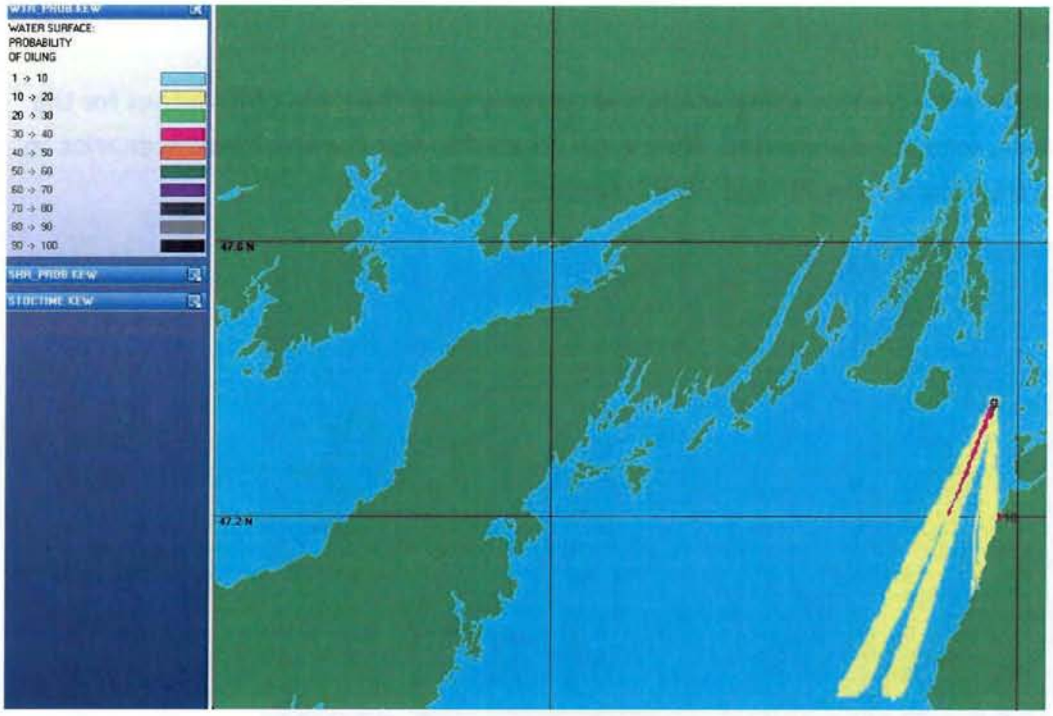


Figure 29 Another stochastic scenario for Placentia Site A. A slightly different current set was used with similar results to the above scenario.

Figure 30 A stochastic scenario for a diesel release at site C. Note that some of the oil lands on Merasheen Island

4.2 Trajectories

Trajectories were created using winds and currents from the daily CMC output for the small defined area, except where noted. They were created to test the stochastic scenarios to see if individual trajectories would yield similar results.

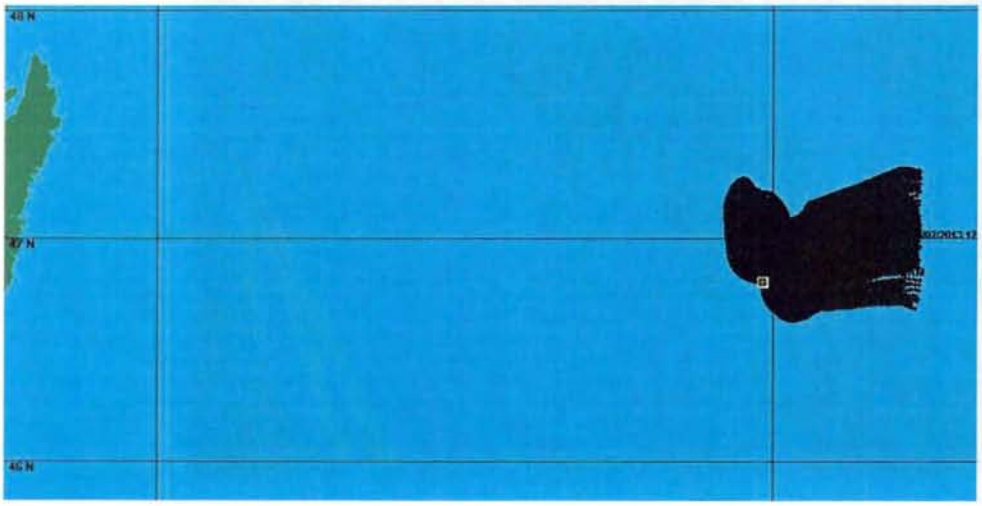


Figure 31 The February 6 crude oil blowout scenario for the WREP site. This includes 2 days whereas the other scenarios are typically 1 day.

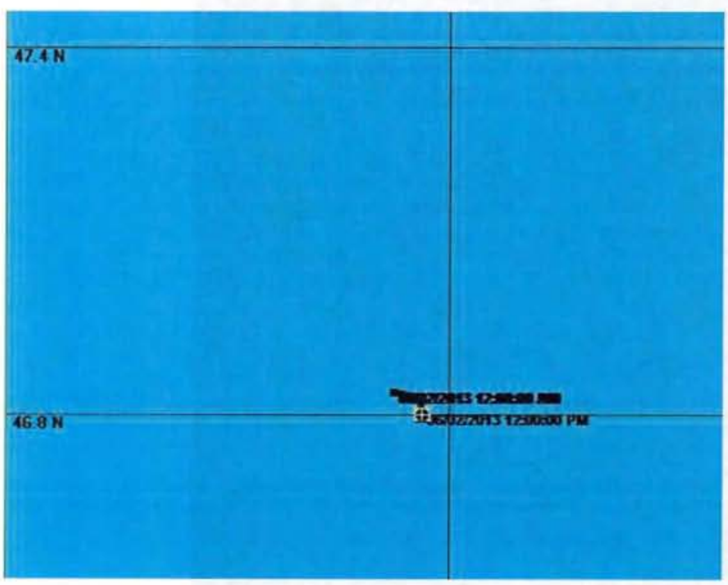


Figure 32 The February 6 diesel batch scenario at WREP.

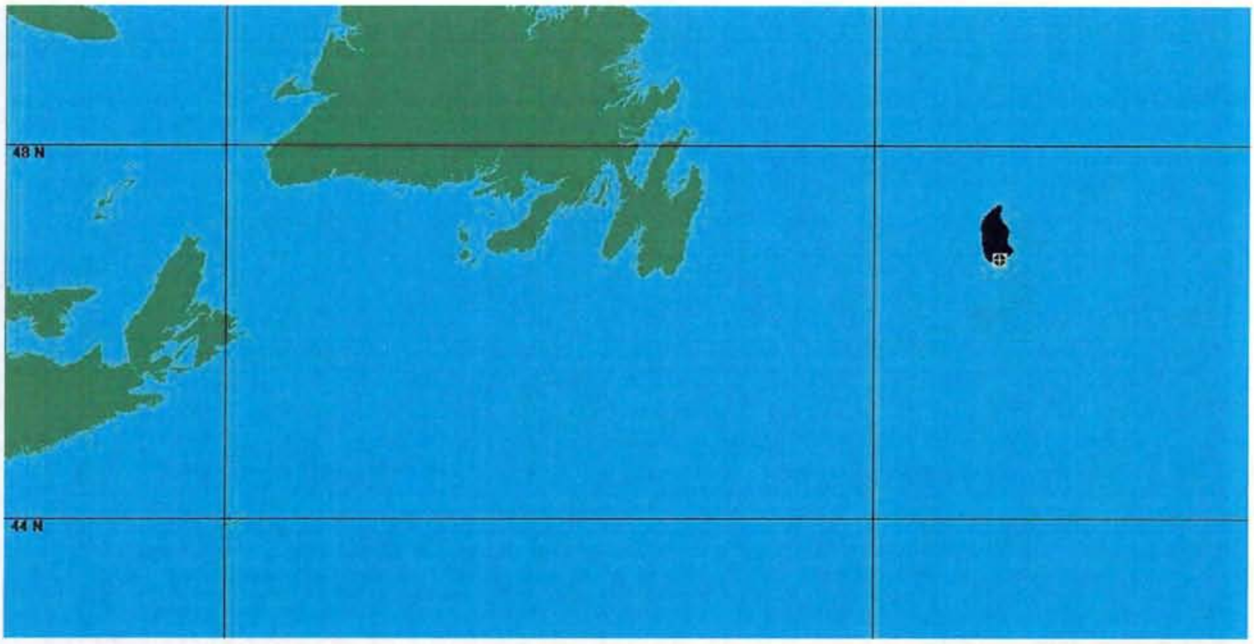


Figure 33 The February 7 crude blowout scenario at WREP

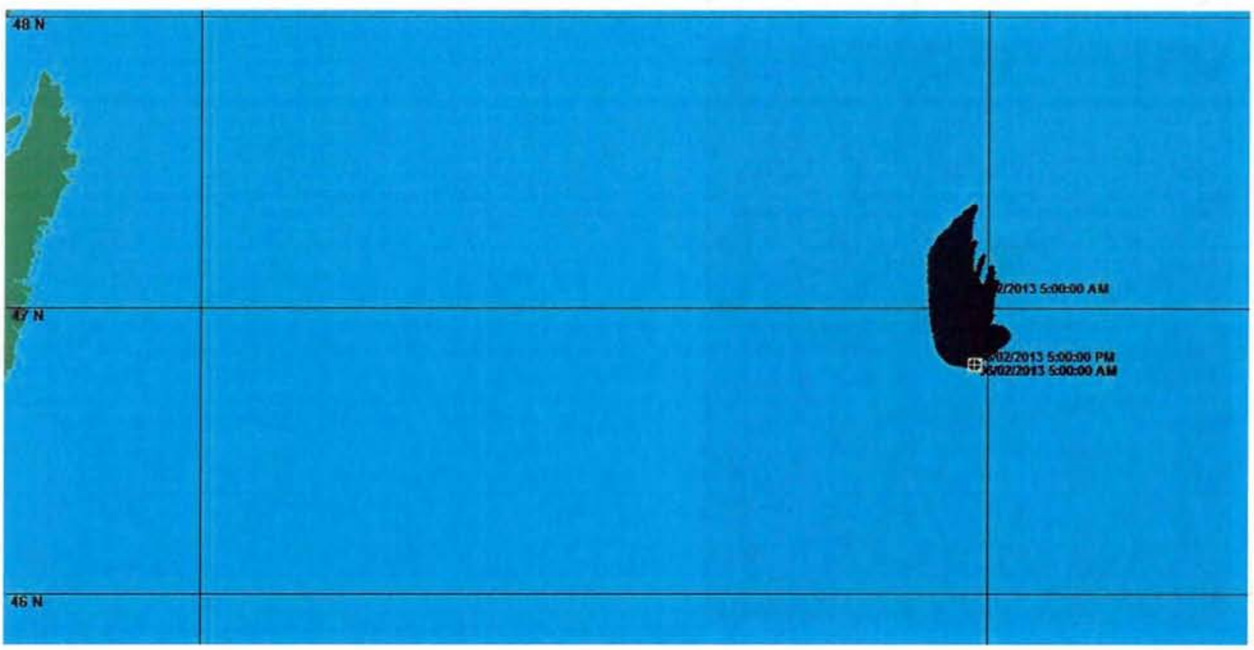


Figure 34 The February batch diesel trajectory at WREP. Note this is an expanded scale compared to the above figure.

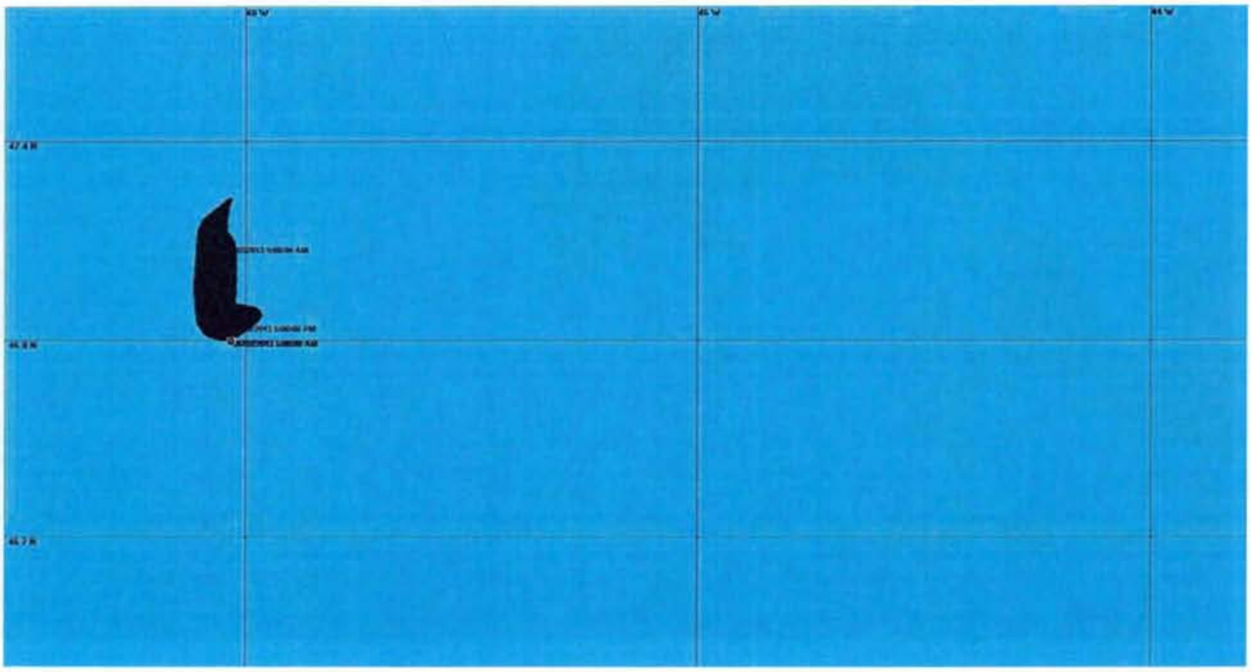


Figure 35 The trajectory of the February 8 crude oil blowout scenario at WREP

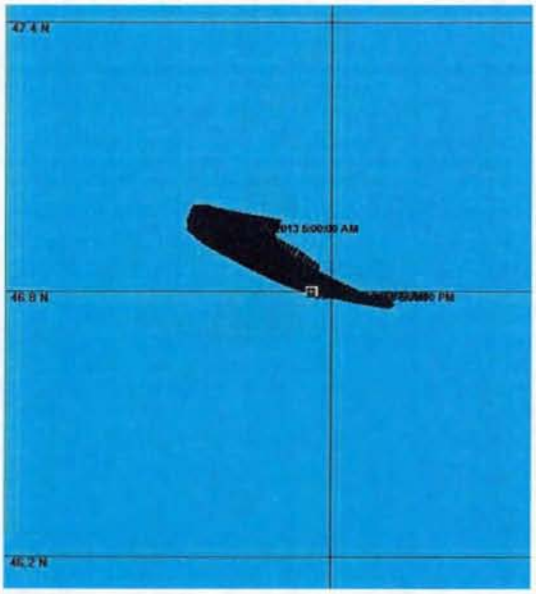


Figure 36 The trajectory of the February 9 crude oil blowout scenario at WREP

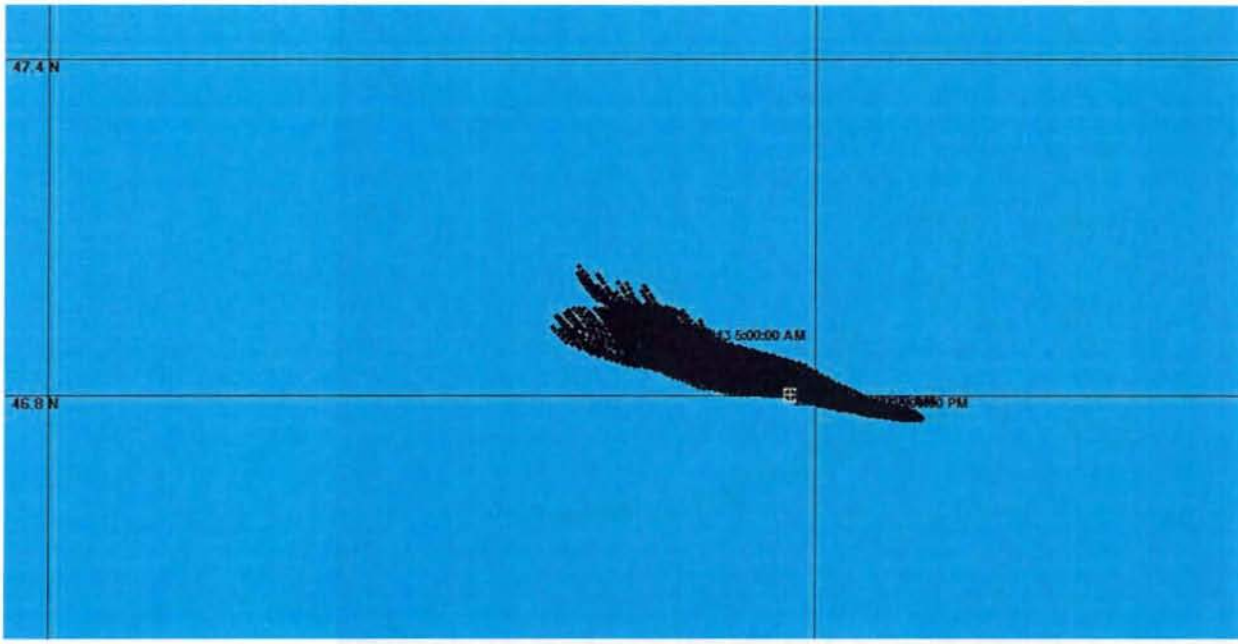


Figure 37 The trajectory of the February 10 crude oil blowout scenario at WREP

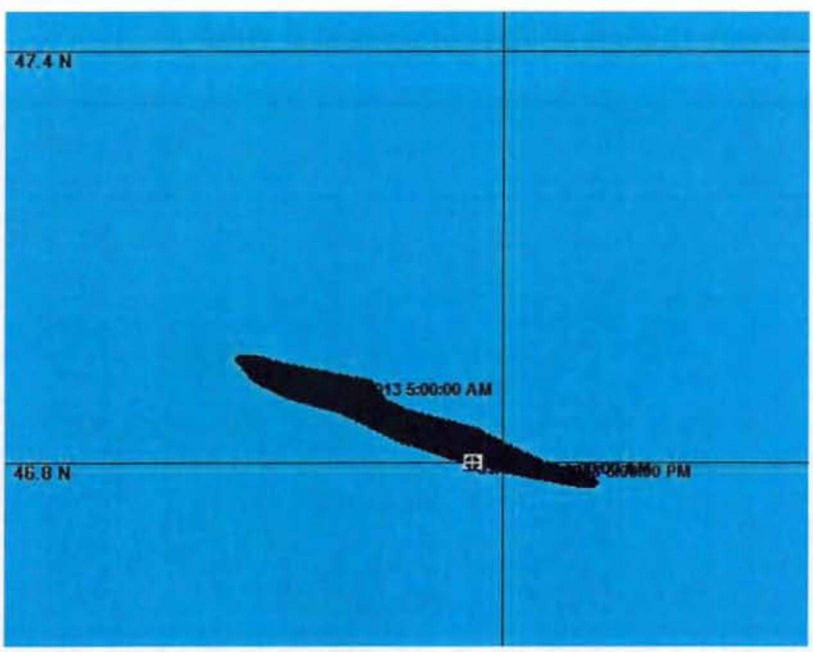


Figure 38 The trajectory of the February 11 crude oil blowout scenario at WREP

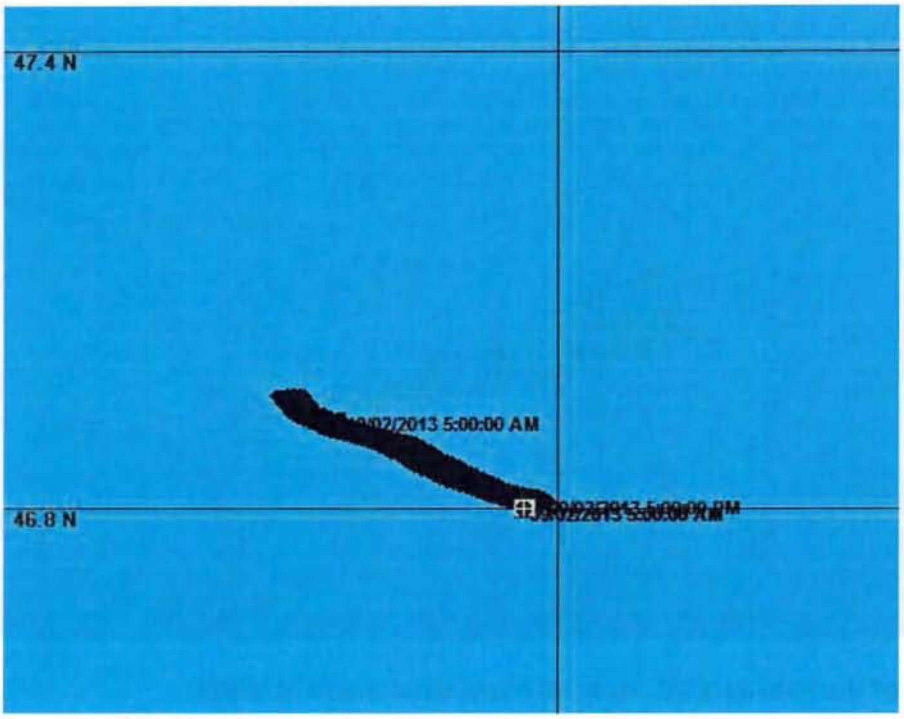


Figure 39 The trajectory of the February 12 crude oil blowout scenario at WREP

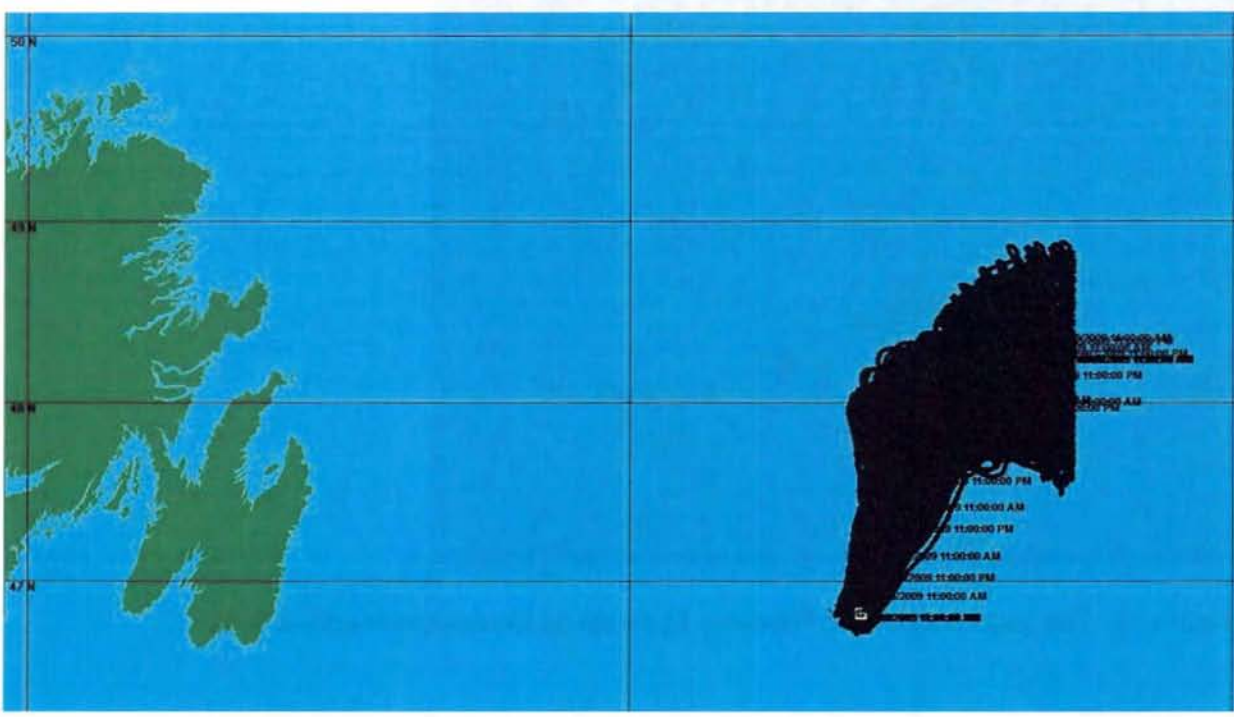


Figure 40 The trajectory of a 100-day crude oil blowout scenario using winds from 2010 and 2011. The start date was in January. The scenario appears typical of the area in that the oil often moved back and forth (north and south), but generally trended eastward during this time.

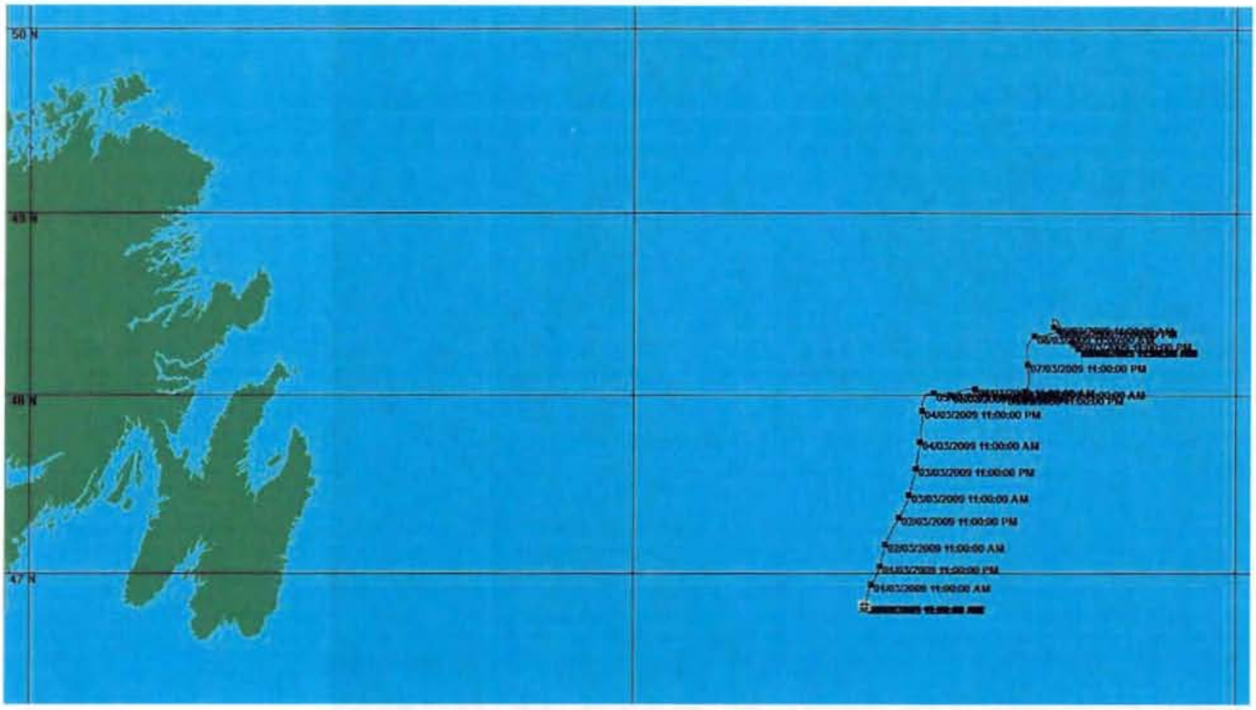


Figure 41 The trajectory of a 100-day batch diesel spill using winds from 2010 and 2011. The start date was in January. The slick area coverage is not shown, just the centroid of the slick.

Trajectories for Placentia Bay

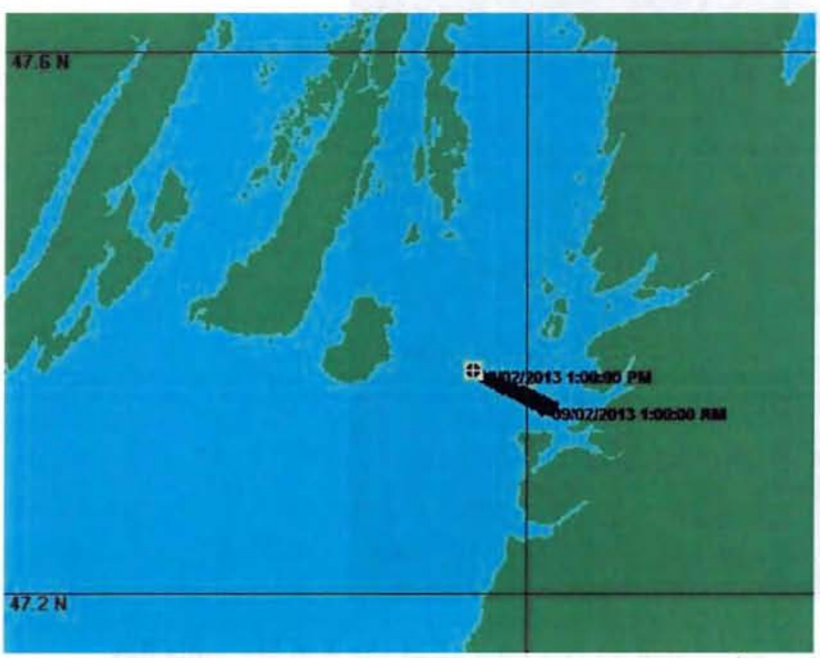


Figure 42 The trajectory for a batch diesel spill on February 8 at site A in Placentia Bay.

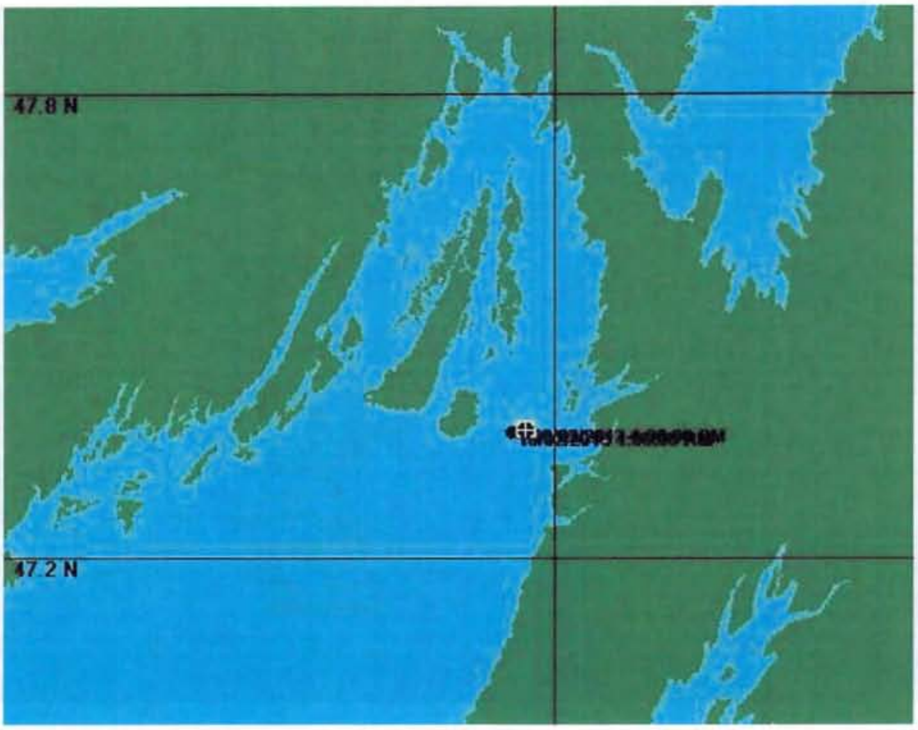


Figure 43 The trajectory for a batch diesel spill on February 9 at site A in Placentia Bay. On this particular day the slick did not move very far because of low winds and tidal movement.

Figure 44 The trajectory for a batch diesel spill on February 10 at site A in Placentia Bay.

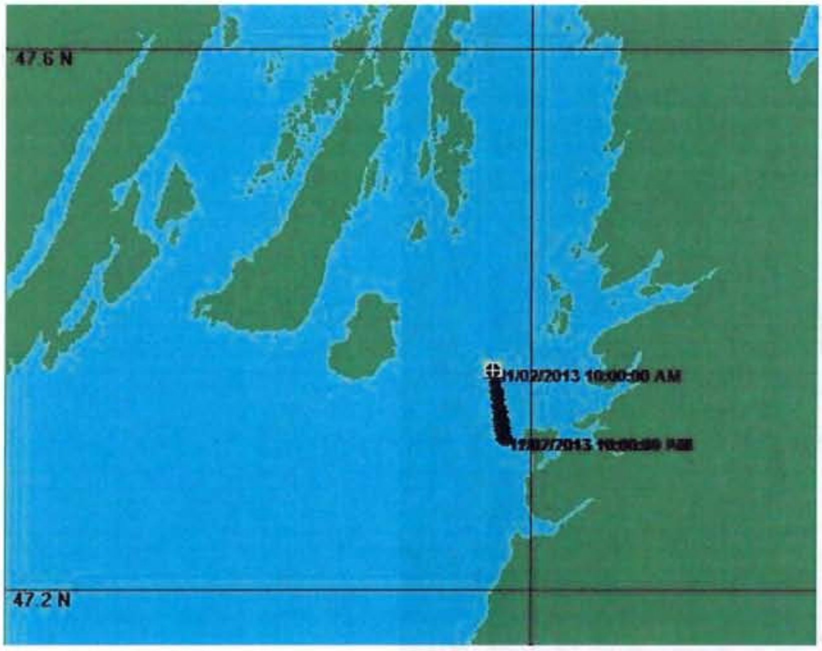


Figure 45 The trajectory for a batch diesel spill on February 11 at site A in Placentia Bay.

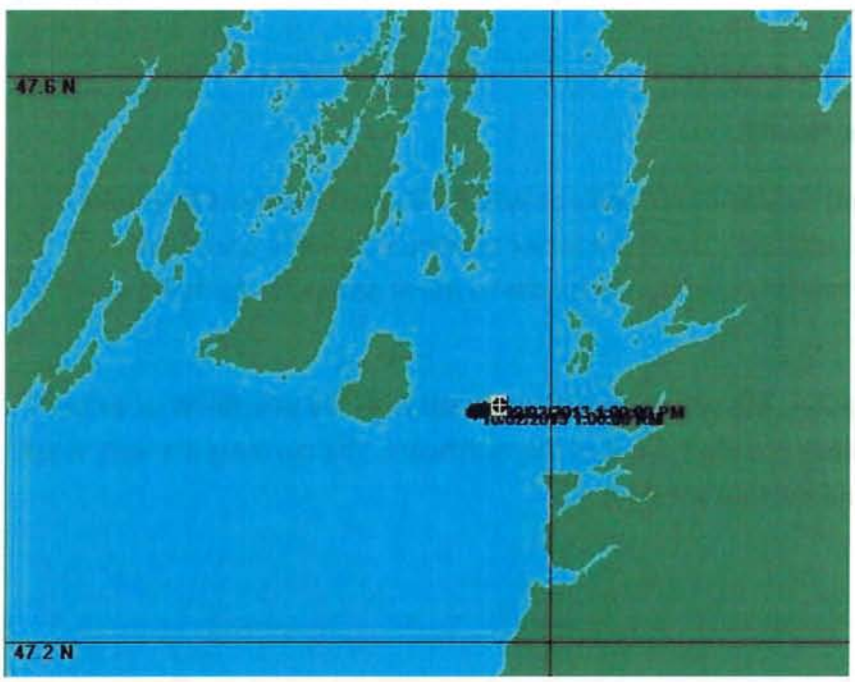


Figure 46 The trajectory for a batch diesel spill on February 12 at site A in Placentia Bay.

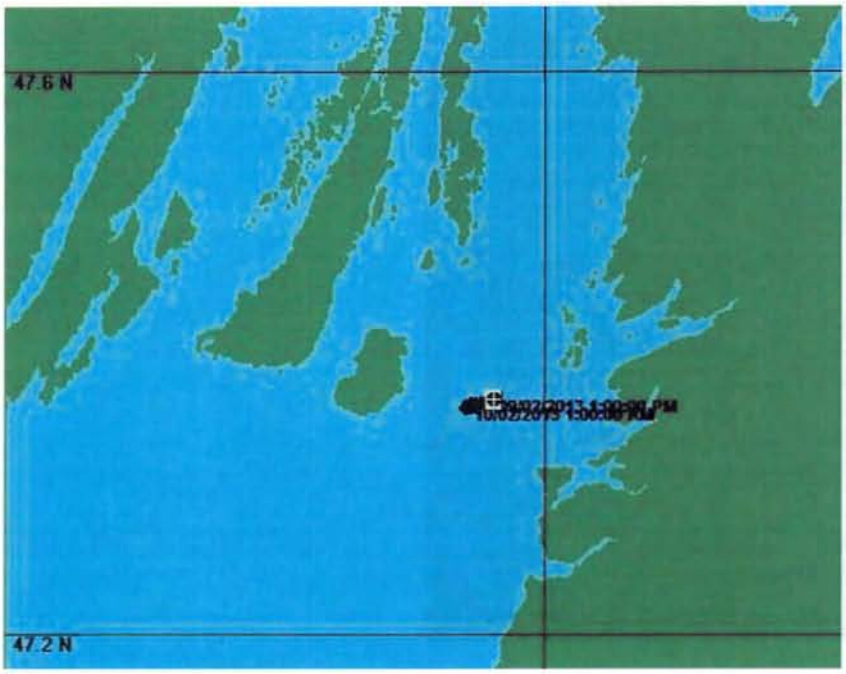


Figure 47 An alternate trajectory for a batch diesel spill on February 8 at site A in Placentia Bay.

4.3 Summary of the modeling results

There is no predominant movement of spills at WREP although the most favoured directions are northeast and southeast. There is a lesser tendency to move northwest, southwest and east. There certainly is a tendency for oils to move around as both the currents and winds are quite variable.

At the sites in Placentia Bay, oils will always move south with the possibility of easterly or westerly tendencies. The winds are always out of the northeast. The currents are very weak inside the islands of the Bay and outside are tidal.

5 Oil Behaviour

5.1 OilMap Fate Models

OilMap used in this study contains fate models. The differences between this and old models are largely on the amount of natural dispersion. Older models show more natural dispersion implemented. This is characteristic of older models (prior to 2000). In later years it was realized that oil simply does not naturally disperse so readily.

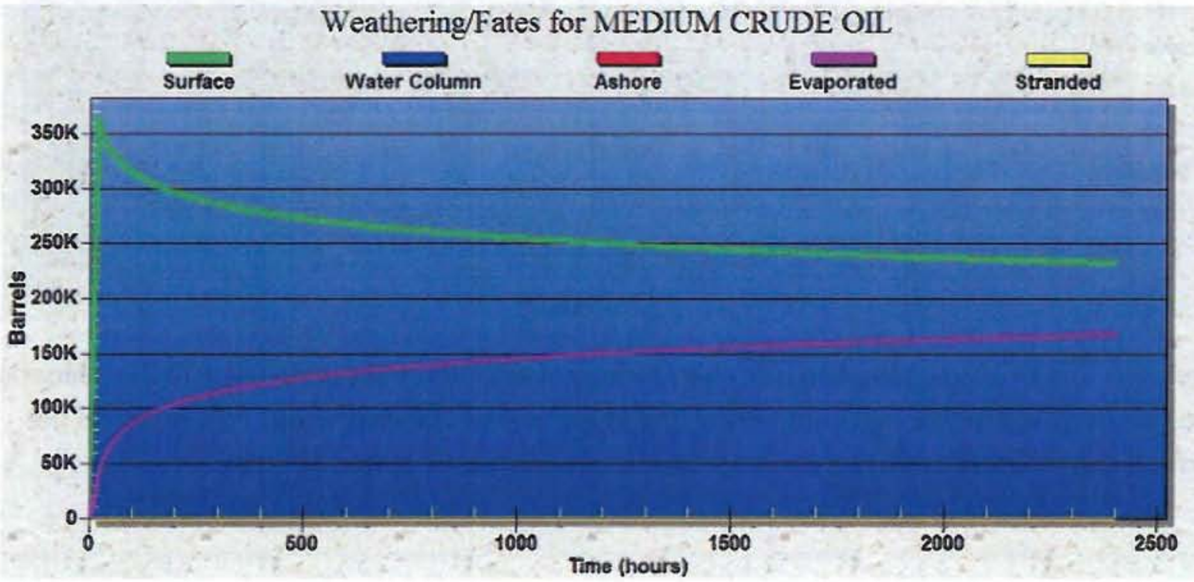


Figure 48 The OilMap-generated fate chart for crude oil as generated during the 100-day scenario. The spill occurred over a two hour period and at the end of 100 days about 70% is still on the surface, the only loss occurring via evaporation.

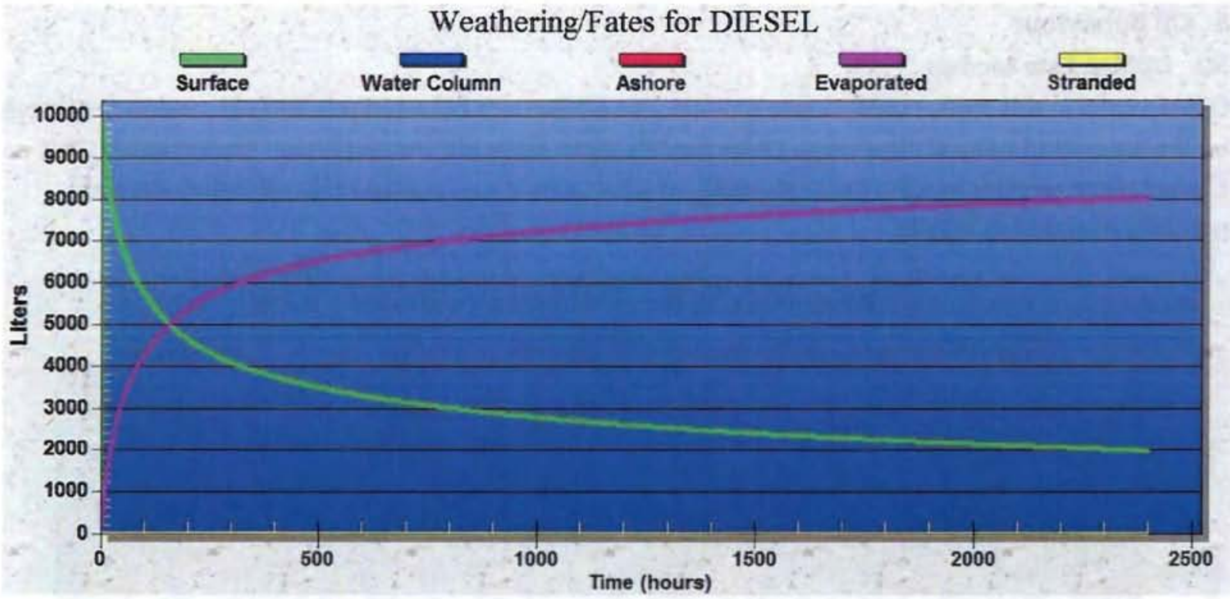


Figure 49 The OilMap-generated fate chart for diesel as generated during the 100-day scenario. The spill occurred over a two hour period and at the end of 100 days about 20% is still on the surface, the only loss occurring via evaporation (probably over-stated at 80%).

5.2 Empirical Weathering Data

There exist empirical evaporation models for both diesel and some crude oils.[9] The empirical data can be used to compare the actual evaporation (under controlled conditions) of these oils to the various predictions given. It is noted from the figure below that empirical data shows only about 40% is evaporated at about 5°C compared to about 80% in the OilMap model.

	Diesel evaporation					
time - hou	Percent Evaporate	20 degrees	15 degrees	5 degrees	time	days
1	5	6	5	4	60	0
2	7	8	8	6	120	0.1
3	9	10	9	7	180	0.1
4	10	12	11	8	240	0.2
5	11	13	12	9	300	0.2
8	14	17	15	11	480	0.3
10	16	19	17	12	600	0.4
12	17	21	19	14	720	0.5
24	24	29	27	19	1440	1
36	30	36	33	24	2160	1.5
72	42	51	46	34	4320	3
96	49	58	54	39	5760	4
120	54	65	60	43	7200	5
144	59	72	66	47	8640	6
168	64	77	71	51	10080	7
192	69	83	76	55	11520	8
216	73	88	80	58	12960	9
240	77	92	85	61	14400	10
264	81	97	89	64	15840	11
288	84	101	93	67	17280	12
316	88	106	97	70	18960	13.2

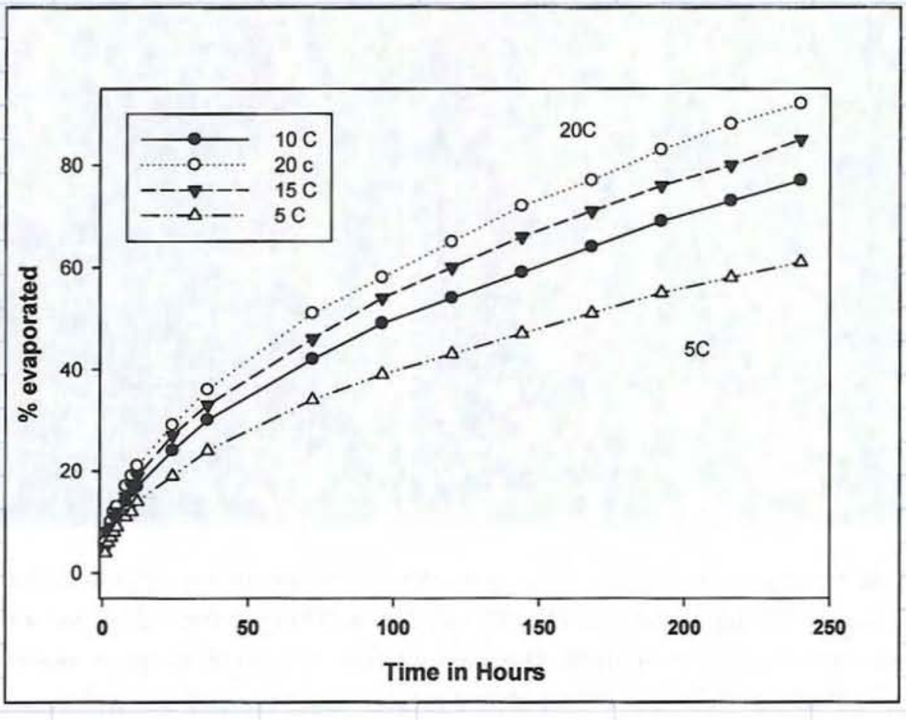


Figure 50 Empirical data for the evaporation of diesel[9]

6.1 Winds – White Rose Offshore Site

The winds for stochastic modeling of the offshore site were chosen as wind from the Atlantic Climate Centre and from International Comprehensive Ocean and Atmosphere Dataset (ICOADS). These are generated from ships and platforms operating in the areas. Exact hourly data for the White Rose expansion site are available from 1954 to the end of 2011. Data were used from the start of 2009 to the end of 2011. These generally contain about 6500 data points.

Winds for the daily trajectory modeling were from the Canadian Meteorological Centre service for modeling. These span a one-day period. These winds are unique in that they are in the format of a wind field and span the entire selected area. An example is shown in Figure 51 below.

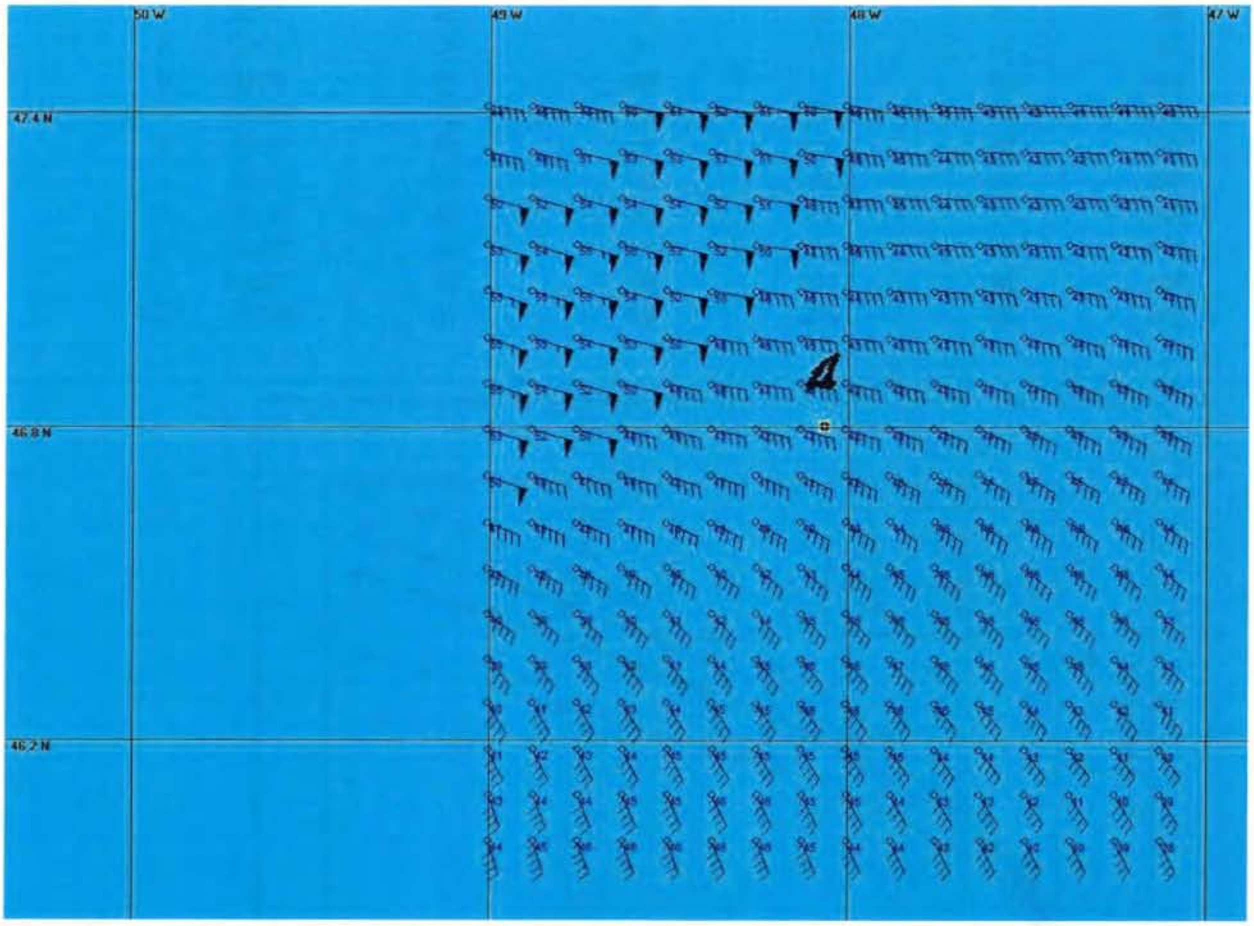


Figure 51 The wind field from February 8, 2013. This shows the advantages of a wind field in that over the field there are different wind speeds and directions, lend a great reality to the model. Most models typically have a uniform wind over the entire field. The black object in the centre of the image is the crude oil trajectory for February 8. Note that the wind field rotates about the well site within one day.

Characterization of the Winds

The winds at the site are rather unique in that they tend to change quite quickly. Analysis of the winds show that they have a tendency to range from about 3 to 40 knots with no predominate direction. This is shown in the following figures.

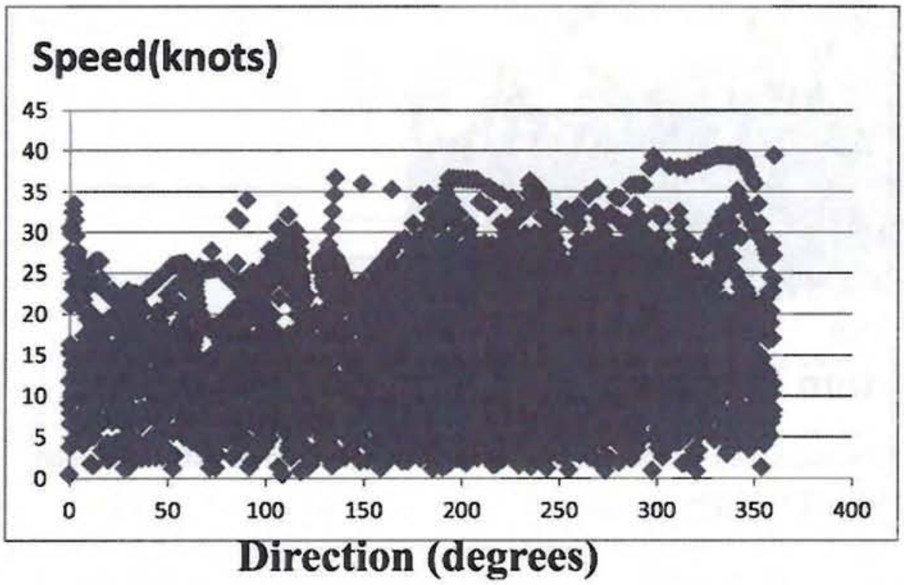


Figure 52 This shows a distribution of the about 6500 data points from 2009 to 2011 of the spring winds (March to May). This shows that there is little tendency to the winds.

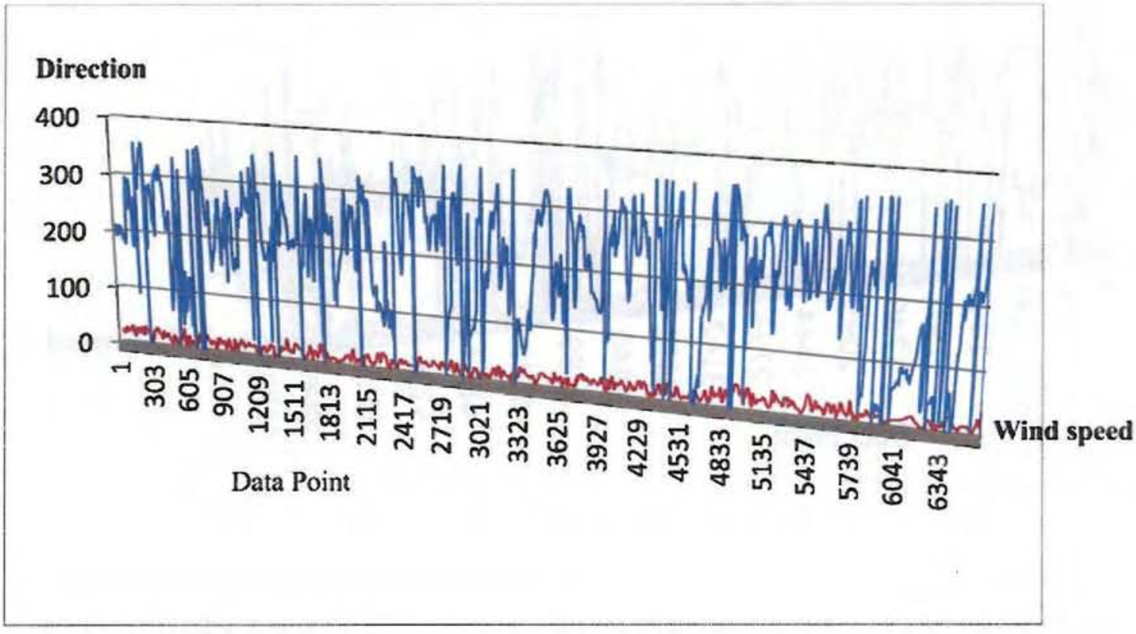


Figure 53 This is another representation of the spring winds, again showing little tendency or correlation between directions, persistence and wind speed.

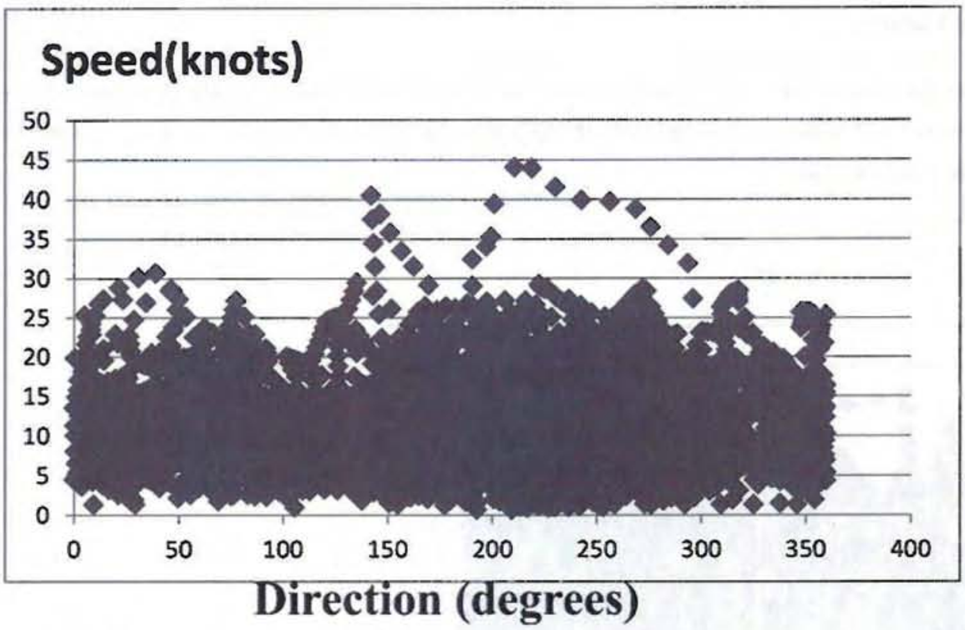


Figure 54 A view of the direction and speed for the summer winds. This again shows little correlation between directions, persistence and wind speed.

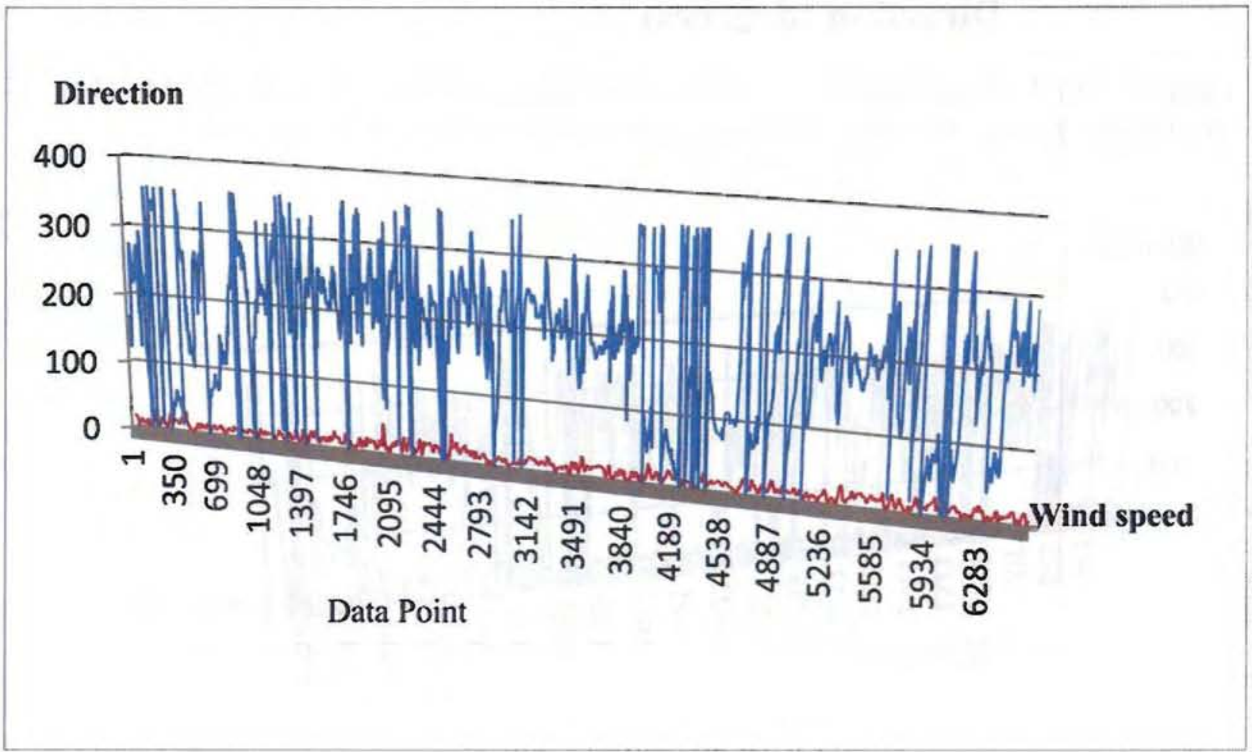


Figure 55 Another view of the direction and speed for the summer winds for about 6300 data points from 2009 to 2011.

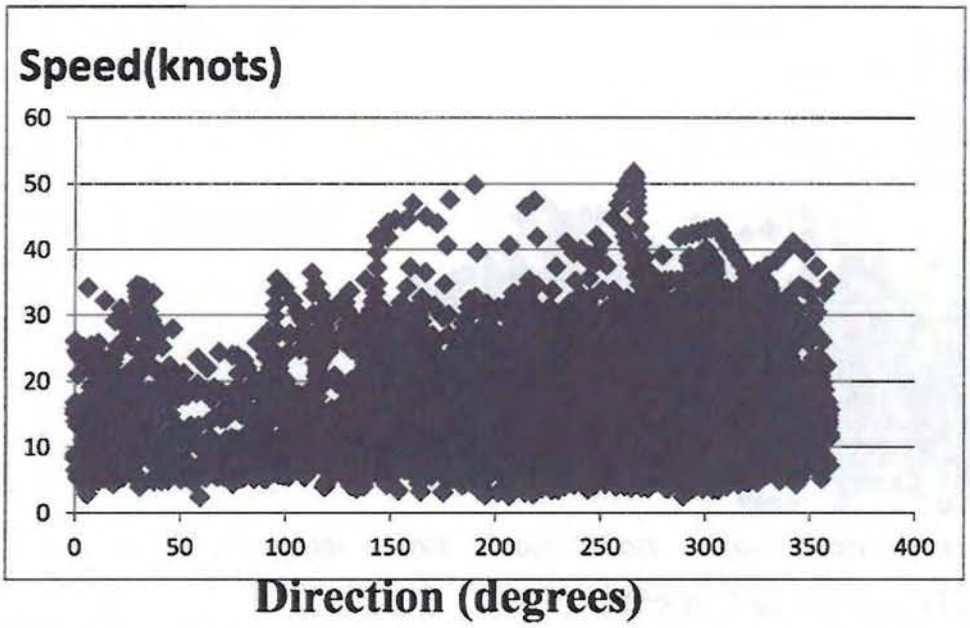


Figure 56 A view of the winds for autumn. This, like the other seasons, shows little correlation between directions, persistence and wind speed. It might be noted that the north-easterly winds may be a little lighter than the others.

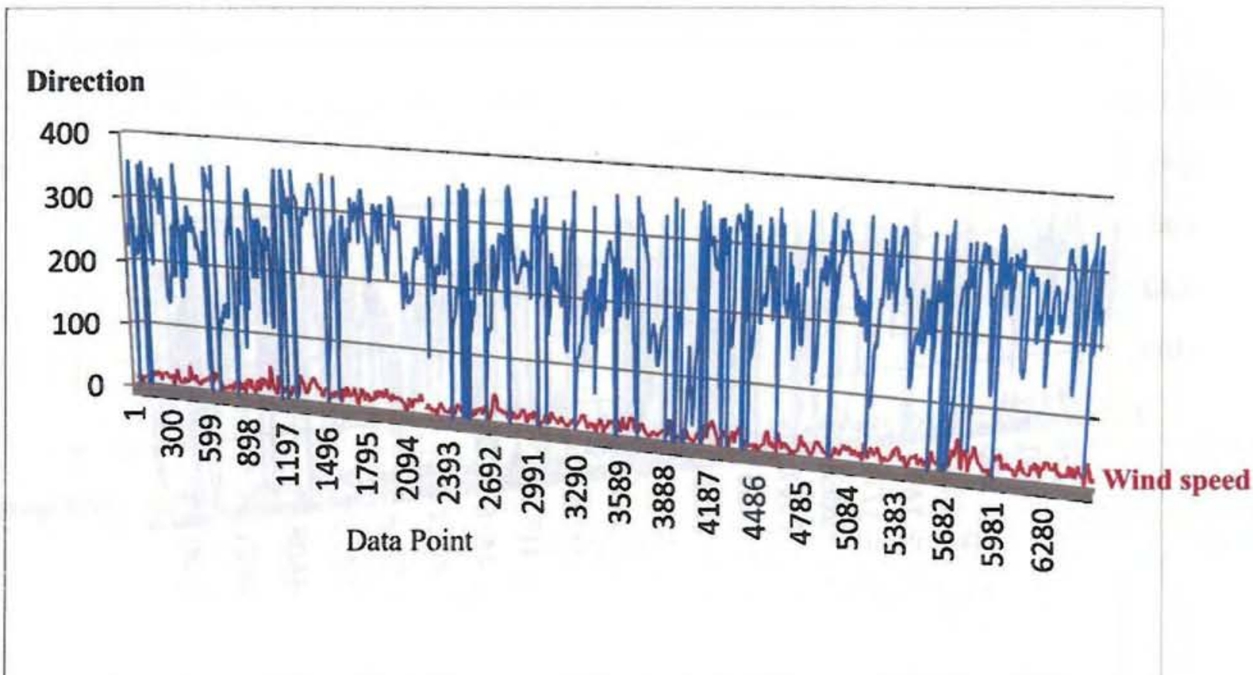


Figure 57 Another view of the autumn winds plotted by the about 6500 data points from 2009 to 2011

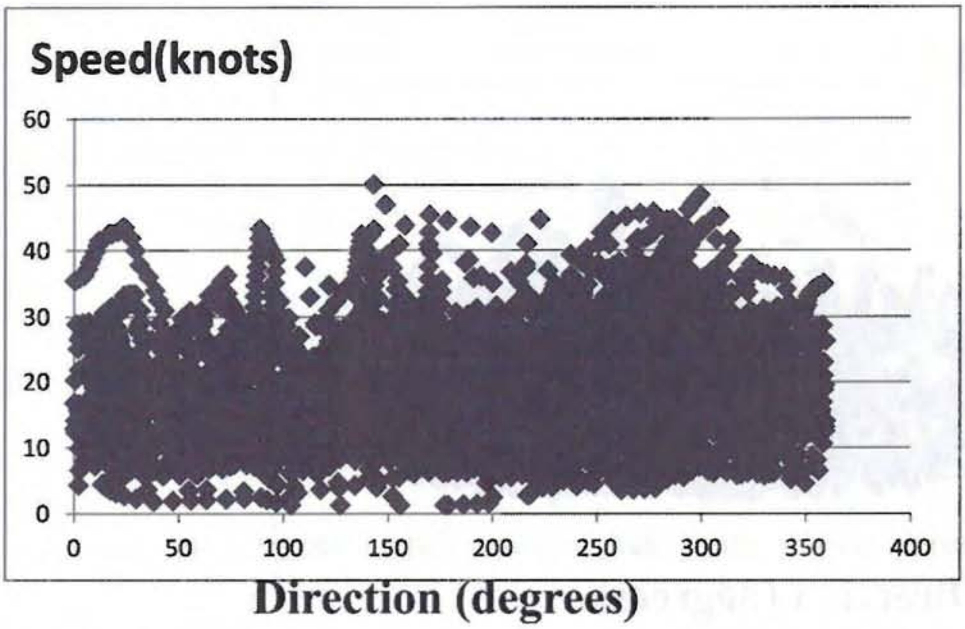


Figure 58 A view of the speed versus direction for the winter winds at the White Rose expansion site. This again shows little correlation between directions, persistence and wind speed.

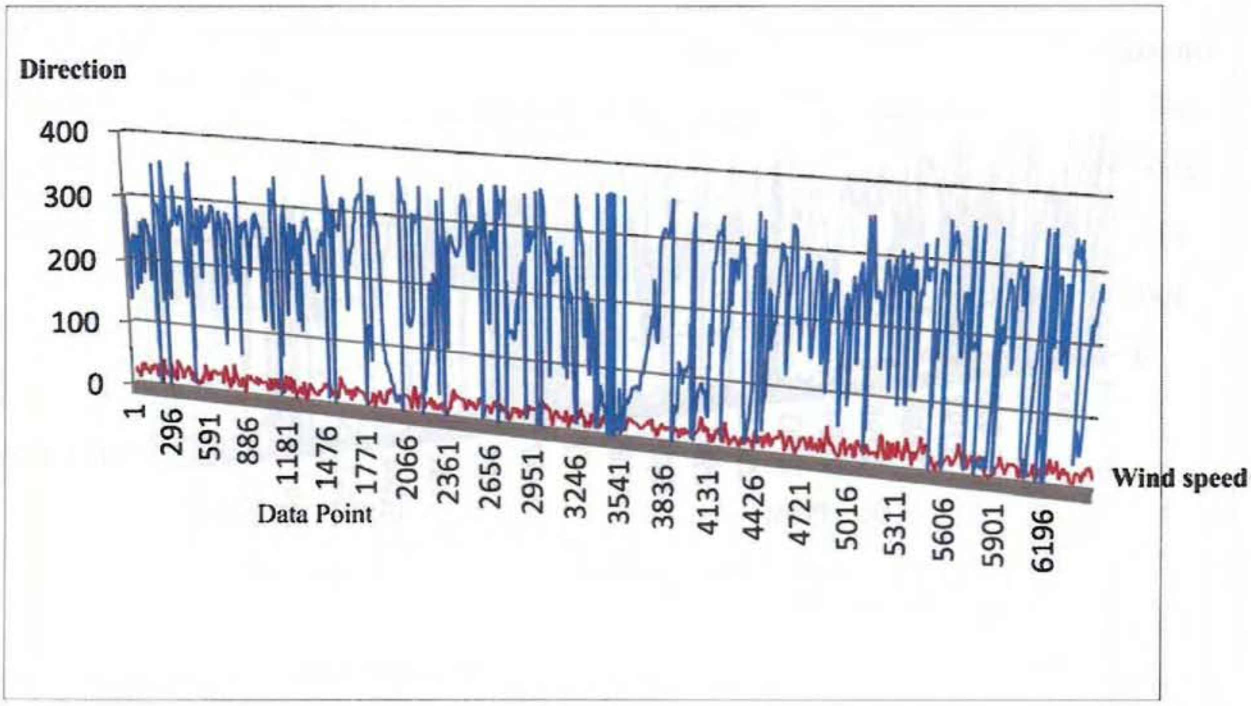


Figure 59 Another view of the winter winds plotted by the approximately 6500 data points from 2009 to 2011.

6.1 Winds – Placentia Bay

The winds for Placentia Bay modeling were taken from the Canadian Meteorological Service climatological set. Winds were taken on a daily basis for 2 years.

Winds for the daily trajectory modeling were from the Canadian Meteorological Centre service for modeling. These span a one-day period. These winds are unique in that they are in the format of a wind field and span the entire selected area.

The winds for the Placentia Bay are unique in that winds from the northeast predominate year around. This can be seen in the following figures.

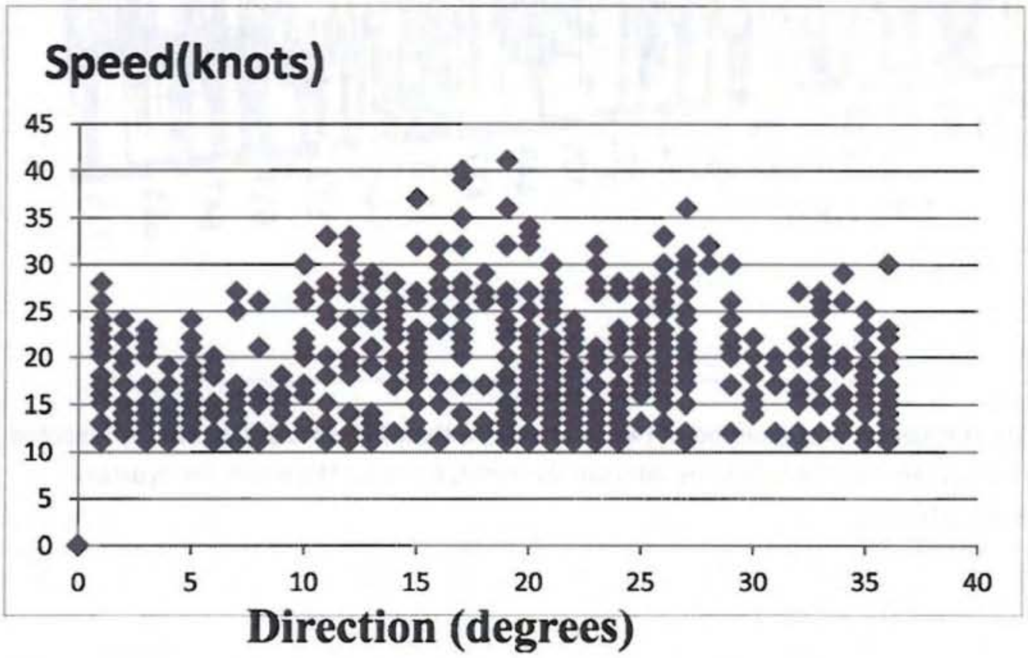


Figure 60 This shows the unique winds in the Placentia Bay over a period of two years, with one point per day. All winds are from the northeast. The wind station was at Argentia. Similar data sets were extracted for hourly winds as well. They show exactly the same trend. The following figure will show each data point.

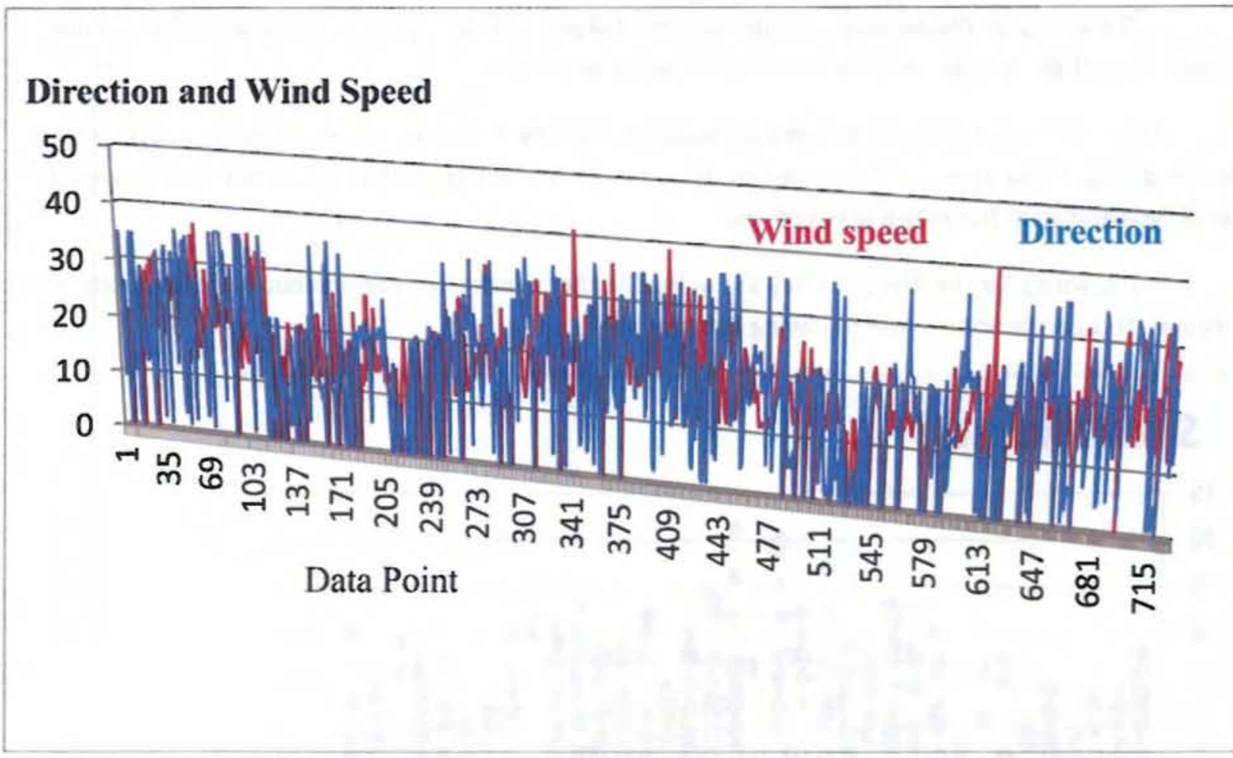
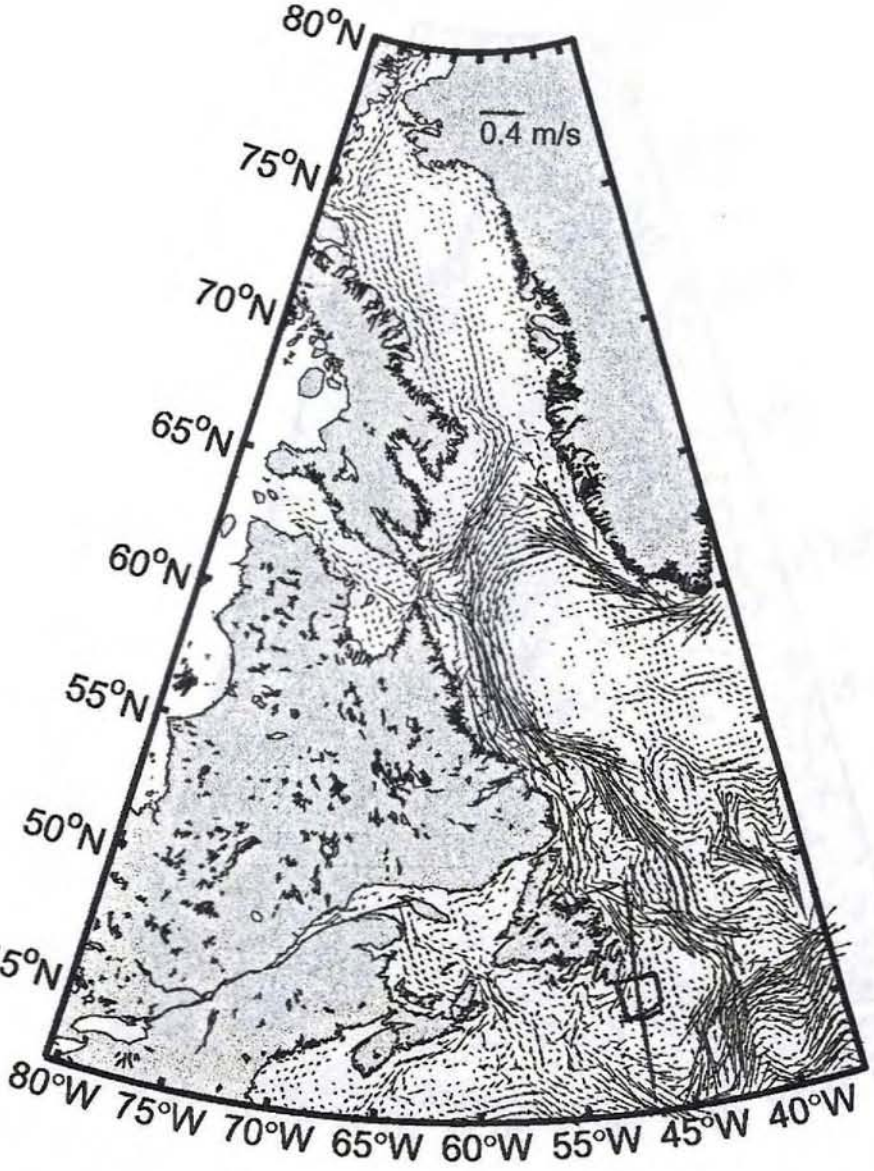


Figure 61 The winds at Argentia over a period of two years. More than 720 data points are represented here, one per day. It is noted that the winds are all from the North East and the winds are typically moderate compared to offshore.

7 Currents

7.1 Currents – Offshore at White Rose

The currents for the offshore scenarios were taken from two places, the seasonal data from Wu and Tang (2011)[1] and higher resolution data from the CMC daily forecasts. The offshore in the White Rose area is noted for low currents with generally no predominant direction. The direction is not particularly seasonal either. The seasonal currents from Wu and Tang (2011) are shown in the following diagrams.



Velocity field at 0 m for autumn

Figure 62 The autumn currents for the east coast. The area of White Rose is sketched in. The area has low currents with minimal directionality.

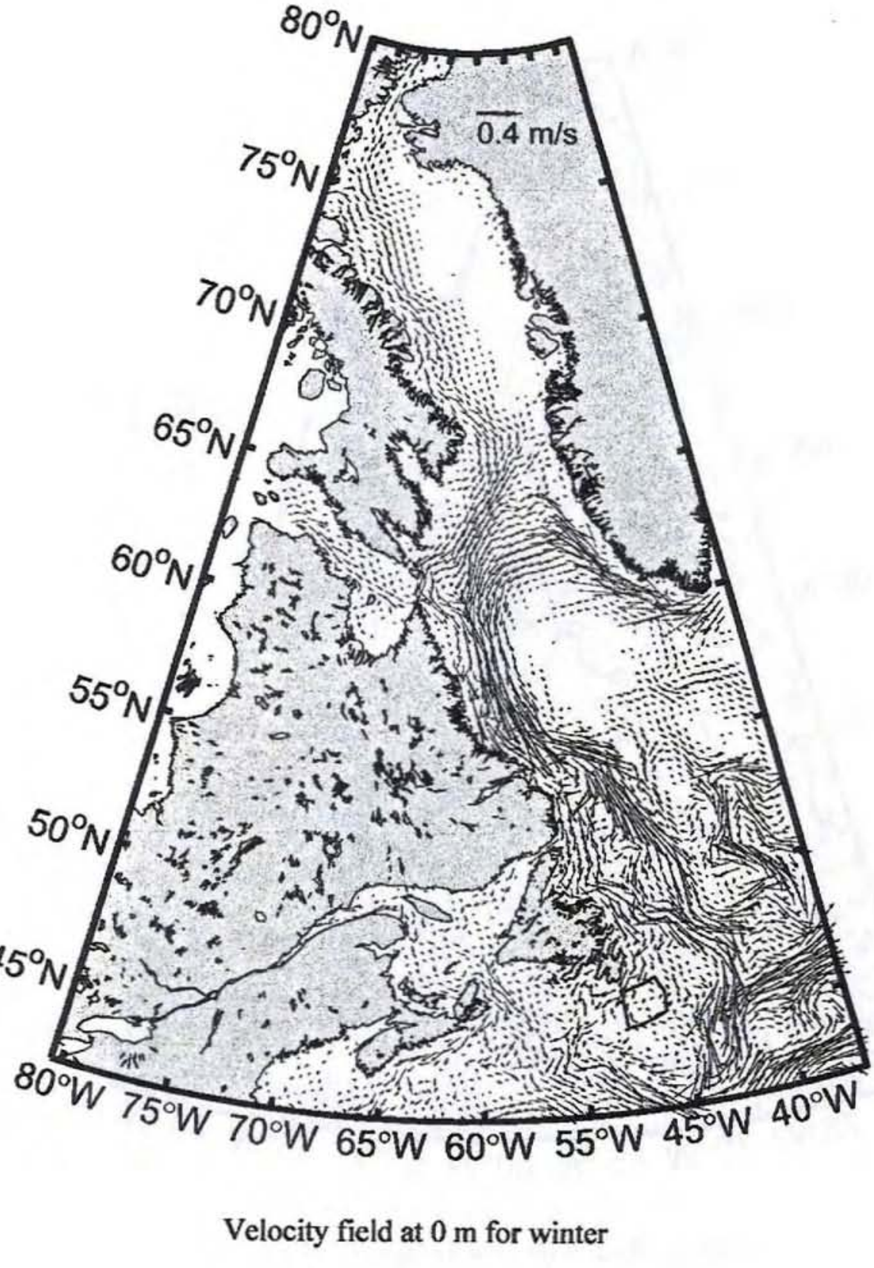
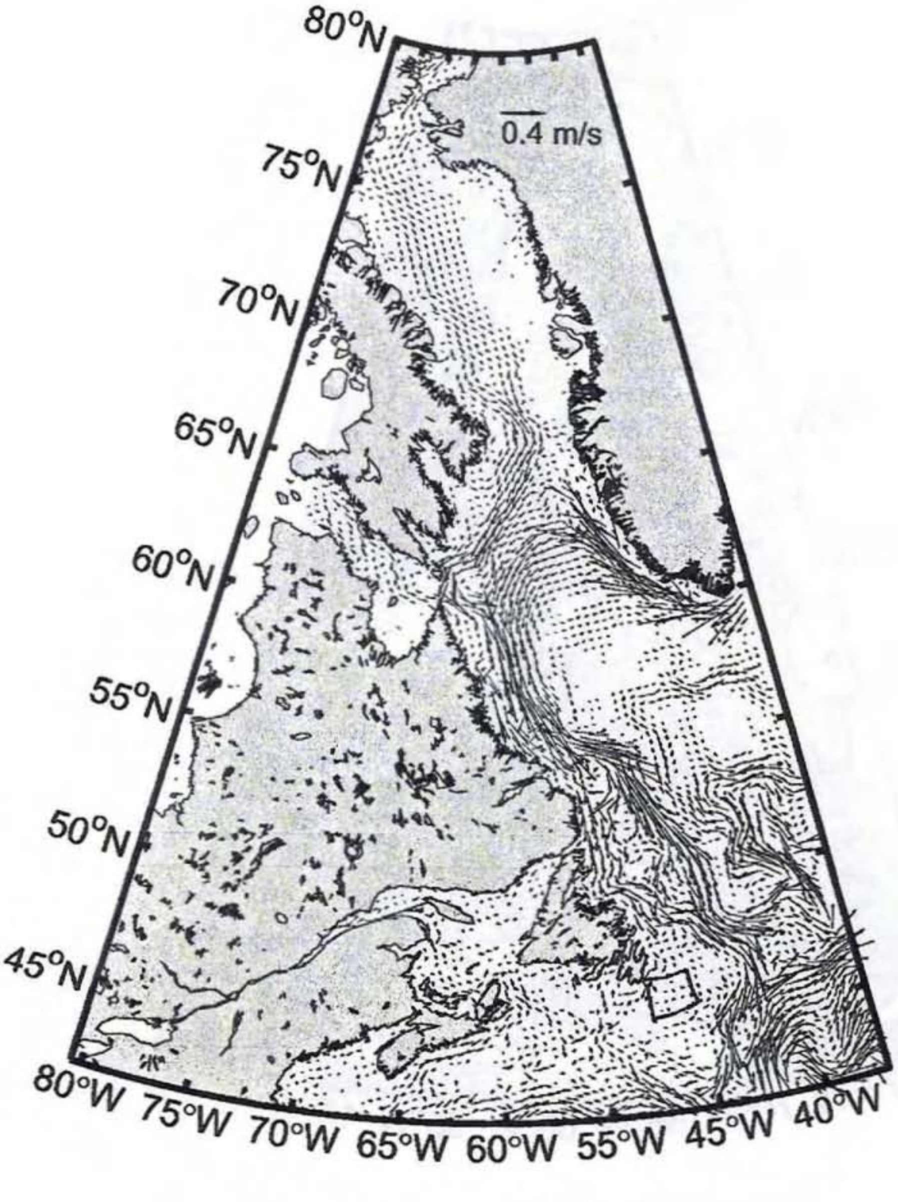


Figure 63 The winter currents from Wu and Tang (2011). The White Rose area is sketched in.



Velocity field at 0 m for spring

Figure 64 The spring currents from Wu and Tang, 2011. The White Rose area is in the box.

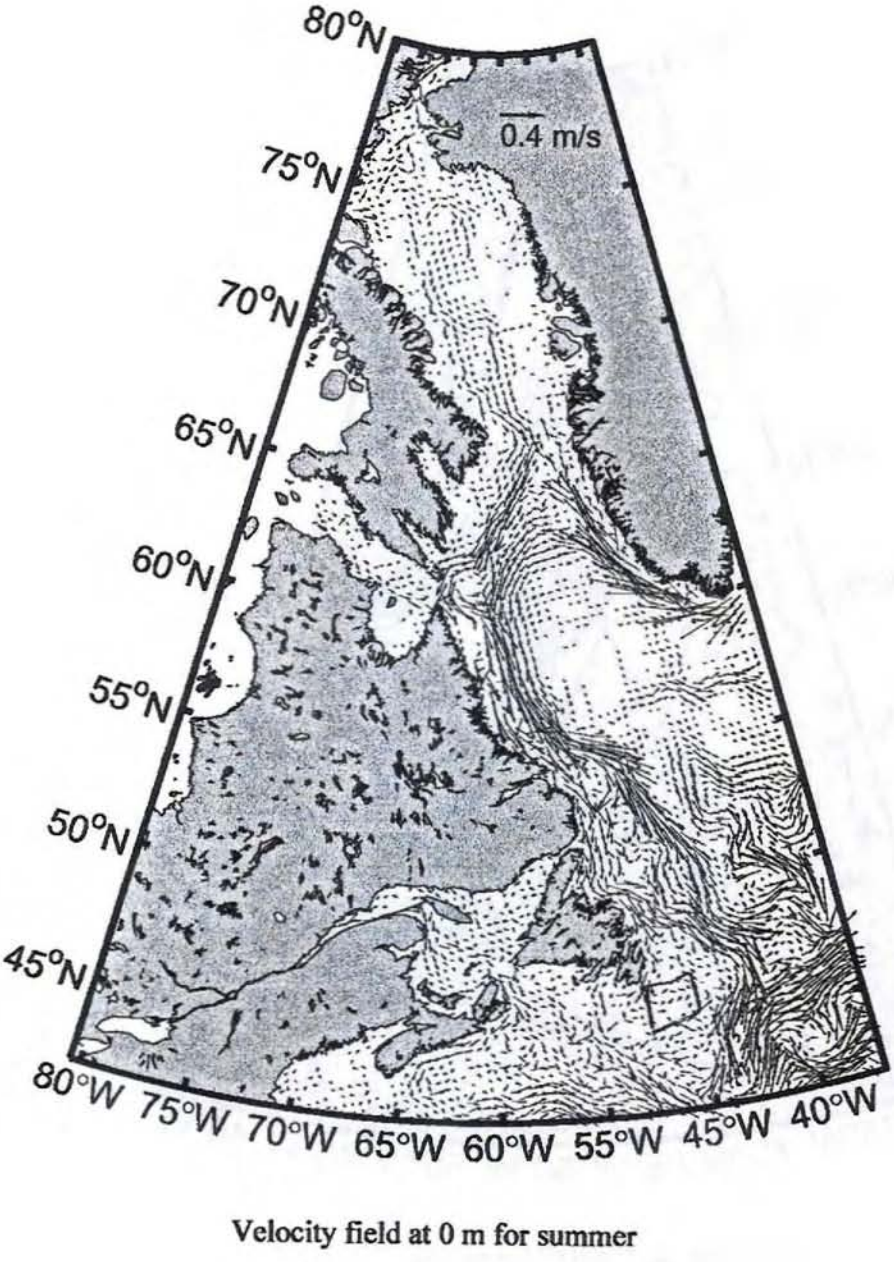


Figure 65 The summer currents for the East Coast of Canada from Wu and Tang (2011). The area for the White Rose Extension is in the drawn-in square. Again it is noted that the currents are light with little predominant direction.

The CMC model provides detailed currents for specific areas. These currents were used for daily trajectories as discussed earlier. These are provided on a matrix-type area as specified around the projected spill site. The following figure is an example of one of these current fields.

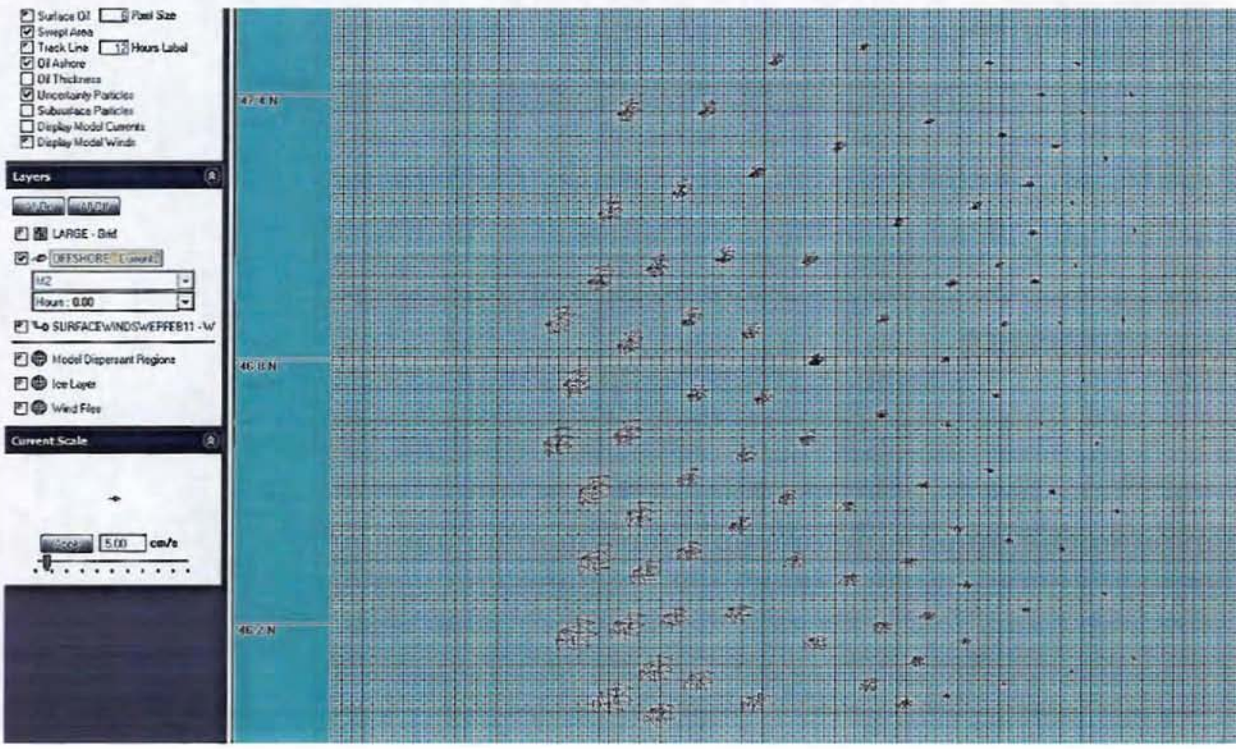


Figure 66 A sample of more detailed currents as created by CMC daily modeling. The arrows (sometimes overlaid in this image) represent the direction and velocity of the current at geographic location.

7.2 Currents in Placentia Bay

The currents in Placentia Bay were similarly taken from generic data and from the daily CMC tidal current model inputs. The generic tidal currents were taken from an oil spill incident inside Placenta Bay some years ago. These were based on movement observations at the time. The Wu and Tang (2011)[1] currents are not detailed enough to provide insight into the movement of oil inside the bay. These generalized currents show a typical tidal flux with a slight clockwise circulation overall.

An example of the CMC currents is shown below.

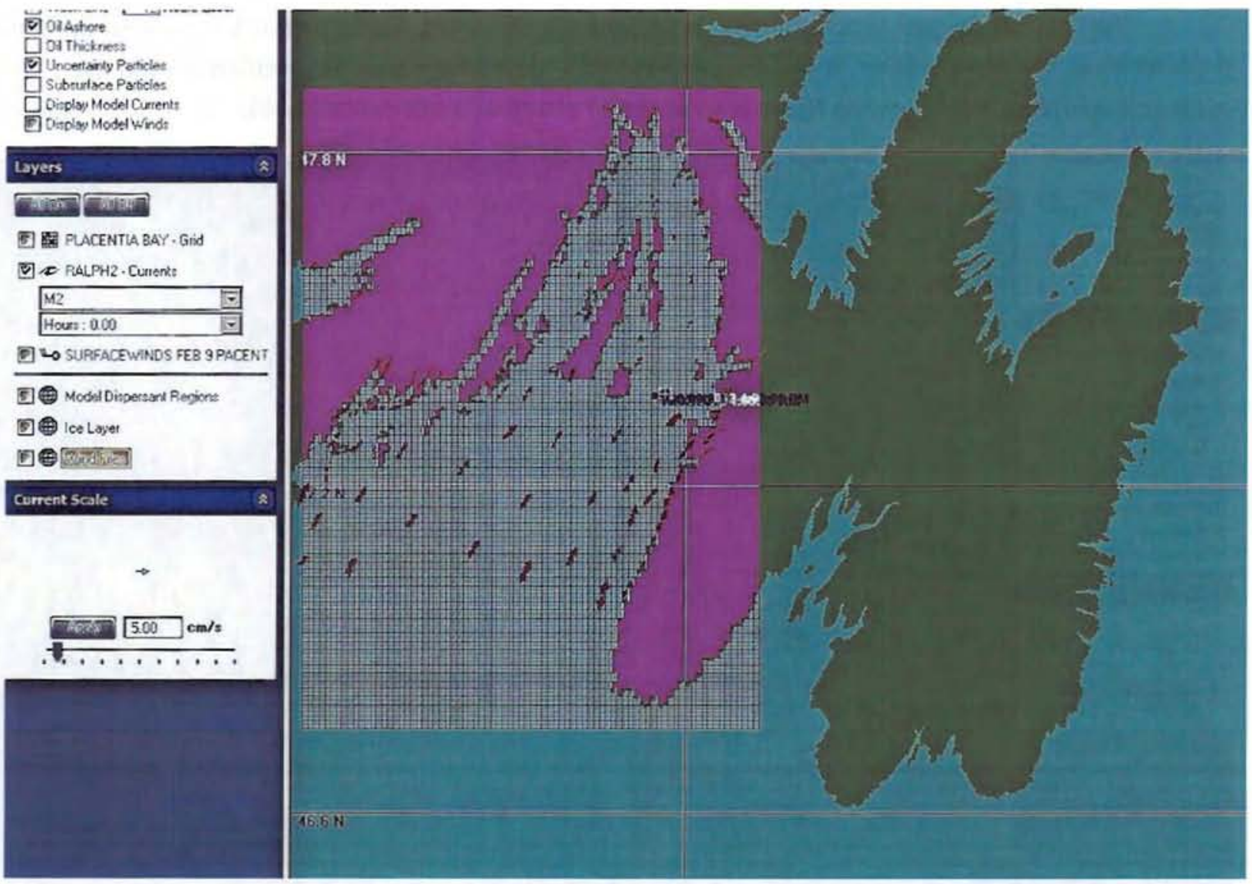


Figure 67 An example of the CMC daily currents used for modeling the movement of oil in Placentia Bay. The arrows represent the currents. Some of these are double-sided arrows showing the effect of tidal reversal. This is a partial set only. The features show that the interior of the Bay is subject to only small currents.

8 Modeling and Behaviour Overview

8.1 Model types

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.

8.2 Model Algorithms

Model algorithms are the core of what makes models work and what makes them work right or wrong. The algorithms will be briefly reviewed in the following section. The references show many works on algorithms and modeling.[2-8]

8.3 Movement of Oil Slicks

In addition to their natural tendency to spread, oil slicks on water are moved along the water surface, primarily by surface currents and winds. If the oil slick is close to land and the wind speed is less than 10 km/h, the slick generally moves at a rate that is 100% of the surface current and approximately 3% of the wind speed. In this case, wind does not generally play an important role. If the wind is more than about 20 km/h, however, and the slick is on the open sea, wind predominates in determining the slick's movement. Both the wind and surface current must be considered for most situations. In an area like the White Rose site in the Atlantic Ocean, usually the wind predominates. Thus a good model becomes very important for correct prediction.

When attempting to determine the movement of an oil slick, a major factor affects accuracy. The more significant factor is the inability to obtain accurate wind and current speeds at the time of a spill.

8.4 Spreading

After an oil spill on water, the oil tends to spread into a slick over the water surface. This is especially true of the lighter products such as gasoline, diesel fuel, and light crude oils, which form very thin slicks. Heavier crudes and Bunker C initially spread to slicks several millimetres thick. Heavy oils may also form tar balls and tar mats and thus may not go through progressive stages of thinning. Oil spreads horizontally over the water surface even in the complete absence of wind and water currents. This spreading is caused by the force of gravity and the interfacial tension between oil and water. The viscosity of the oil opposes these forces. As time passes, the effect of gravity on the oil diminishes, but the force of the interfacial tension continues to spread the oil. The transition between these forces takes place in the first few hours after the spill occurs.

As a general rule, an oil slick on water spreads relatively quickly immediately after a spill. The outer edges of a typical slick are usually thinner than the inside of the slick at this stage so that the slick may resemble a 'fried egg'. After a day or so of spreading, this effect diminishes.

Winds and currents also spread the oil out and speed up the process. Oil slicks will elongate in the direction of the wind and currents, and as spreading progresses, take on many shapes depending on the driving forces. Oil sheens often precede heavier or thicker oil concentrations. If the winds are high (more than 20 km/h), the sheens may separate from thicker slicks and move downwind.

A slick often breaks into 'windrows' on the sea under the influence of either waves or zones of convergence or divergence. Oil tends to concentrate between the crests of waves simply due to the force of gravity. There are often vertical circulation cells in the top 20 m of the sea. When two circulation cells meet, a zone of convergence is formed. When two currents diverge, it forms a zone of divergence. Oil moving along these zones is alternately concentrated and spread out by the circulation currents to form ribbons or windrows of oil rather than continuous slicks. In some locations close to shore, zones of convergence and divergence often occur in similar locations so that oil spills may appear to have similar trajectories and spreading behaviour in these areas.

The specific behaviour processes that occur after an oil spill determine how the oil should be cleaned up and its effect on the environment. For example, if oil evaporates rapidly, cleanup is less intense, but the hydrocarbons in the oil enter the atmosphere. An oil slick could be carried by surface currents or winds to the vicinity of a bird colony or to a shore where seals are breeding and severely affect the wildlife and their habitat. On the other hand, a slick could be carried out to sea where it disperses naturally and has less direct effect on the environment.

The fate and effects of a particular spill are determined by the behaviour processes which are in turn almost entirely determined by the type of oil and the environmental conditions at the time of the spill. Spill responders need to know the ultimate fate of the oil in order to take measures to minimize the overall impact of the spill.

8.5 Weathering

Oil spilled on water undergoes a series of changes in physical and chemical properties which in combination are termed 'weathering'. Weathering processes occur at very different rates, but begin immediately after oil is spilled into the environment. Weathering rates are not consistent throughout the duration of an oil spill and are usually highest immediately after the spill. Both weathering processes and the rates at which they occur depend more on the type of oil than on environmental conditions. Most weathering processes are highly temperature-dependent, however, and will often slow to insignificant rates as temperatures approach zero degrees.

The processes included in weathering are evaporation, emulsification, natural dispersion, dissolution, photooxidation, sedimentation, adhesion to materials, interaction with mineral fines, biodegradation, and the formation of tar balls. These processes are listed in order of importance in terms of their effect on the percentage of total mass balance, i.e., the greatest loss from the slick in terms of percentage, and what is known about the process. Modern models combine the weathering algorithms with the movement algorithms. This then yields a picture of what the oil properties will be and where it will go.

8.6 Evaporation

Evaporation is usually the most important weathering process. It has the greatest effect on the amount of oil remaining on water or land after a spill. Over a period of several days, a light fuel such as gasoline evaporates almost completely at typical ambient temperatures, whereas only a small percentage of heavier Bunker C oil evaporates. The rate at which an oil evaporates depends primarily on the oil's composition. The more volatile components an oil or fuel contains, the greater the extent and rate of its evaporation. Many components of heavier oils will not evaporate at all, even over long periods of time and at high temperatures.

Oil and petroleum products evaporate in a slightly different manner than water and the process is much less dependent on wind speed and surface area. Oil evaporation can be considerably slowed down, however, by the formation of a 'crust' or 'skin' on top of the oil. This happens primarily on land or in calm areas where the oil layer does not get mixed. The skin or crust is formed when the smaller compounds in the oil are removed leaving the larger compounds, such as waxes and resins, at the surface. This crust then seals off the remainder of the oil and slow evaporation. Stranded oil from old spills has been re-examined over many years and it has been found that when this crust has formed, there is no significant evaporation in the oil underneath. When this crust has not formed, similar oil could be weathered to the hardness of wood over the same amount of years.

The rate of evaporation is very rapid immediately after a spill and then slows considerably. About 80% of evaporation that will take place, occurs in the first two days after a spill. The evaporation of most oils follows a logarithmic curve with time. Some oils such as diesel fuel, however, evaporate as the square root of time, at least for the first few days. This means that the evaporation rate slows very rapidly in both cases after a few days.

The properties of oil can change significantly with the extent of evaporation. If about 40% (by weight) of an oil evaporates, its viscosity could increase by as much as a thousand-fold. Its density could rise by as much as 10% and its flash point by as much as 400%. The extent of evaporation can be the most important factor in determining properties of an oil at a given time after the spill and in changing the behaviour of the oil.

8.7 Emulsification

Emulsification is the process by which one liquid is dispersed into another one in the form of small droplets.[7] Water droplets can remain in an oil layer in a stable form and the resulting material is completely different. These water-in-oil emulsions are sometimes called 'mousse' or 'chocolate mousse', as they resemble this dessert. In fact, both the actual version of chocolate mousse and butter are common examples of water-in-oil emulsions.

The mechanism of emulsion formation is not yet fully understood, but it probably starts with sea energy forcing the entry of small water droplets, about 10 to 25 µm (or 0.010 to 0.025 mm) in size, into the oil. If the oil is somewhat viscous, these small droplets will not leave the oil quickly. On the other hand, if the oil is too viscous, droplets will not enter the oil to any significant extent. Once in the oil, the droplets slowly gravitate to the bottom of the oil layer. Asphaltenes and resins in the oil will interact with the water droplets to stabilize them. Depending on the quantity of asphaltenes and resins, as well as other conditions, an emulsion may be formed. The conditions required for emulsions of any stability to form may only be reached after a period of evaporation. Evaporation increases the viscosity to the critical value and increases the resin and asphaltene percentage in the oil.

Water can be present in oil in four ways. First, some oils contain about 1% water as soluble water. This water does not significantly change the physical or chemical properties of the oil. The second way is called 'entrainment', whereby water droplets are simply held in the oil by its viscosity to form an unstable emulsion. These are formed when water droplets are incorporated into oil by the sea's wave action and there are not enough asphaltenes and resins in the oil. Unstable emulsions break down into water and oil within minutes or a few hours, at most, once the sea energy diminishes. The properties and appearance of the unstable emulsion are almost the same as those of the starting oil, although the water droplets may be large enough to be seen with the naked eye.

Meso-stable emulsions represent the third way water can be present in oil. These are formed when the small droplets of water are stabilized to a certain extent by a combination of the viscosity of the oil and the interfacial action of asphaltenes and resins. These emulsions generally break down into oil and water or sometimes into water, oil, and stable emulsion within a few days. Meso-stable emulsions are viscous liquids that are reddish-brown in colour.

The fourth way that water exists in oil is in the form of stable emulsions. These form in a way similar to meso-stable emulsions except that the oil contains a sufficient amount of resins and asphaltenes to stabilize the water droplets. The viscosity of stable emulsions is 700 to 1000 times higher than that of the starting oil and the emulsion will remain stable for weeks and even months after formation. Stable emulsions are reddish-brown in colour and appear to be nearly solid. Because of their high viscosity and near solidity, these emulsions do not spread and tend to remain in lumps or mats on the sea or shore.

The formation of emulsions is an important event in an oil spill. First, and most importantly, it substantially increases the actual volume of the spill. Emulsions that contain about 70% water triple the volume of the oil spill. Even more significantly, the viscosity of the oil increases by as much as 1000 times, depending on the type of emulsion formed. For example, an oil that has the viscosity of motor oil can triple in volume and become almost solid through the process of emulsification.

These increases in volume and viscosity make cleanup operations more difficult. Emulsified oil is difficult or impossible to disperse, to recover with skimmers, or to burn. Emulsions can be broken down with special chemicals in order to recover the oil with skimmers or to burn it. It is thought that emulsions break down into oil and water by further weathering, oxidation, and freeze-thaw action.

Meso- or semi-stable emulsions are relatively easy to break down, whereas stable emulsions may take months or years to break down naturally, if they ever do break down naturally.

Emulsion formation also changes the fate of the oil. It has been noted that when oil forms stable or meso-stable emulsions, evaporation slows considerably. Biodegradation also appears to slow down. The dissolution of soluble components from oil may also cease once emulsification has occurred.

Despite the important of emulsion formation to many spills, it may be relevant in the case of the White Rose well site. The oil is predicted to be a medium oil with asphaltenes and thus could form some type of emulsion.

9 References

1 Wu, Y.S., C.L. Tang. 2011. Atlas of Ocean Currents in Eastern Canadian Waters. Ocean Sciences Division, Maritimes Region, Fisheries and Oceans Canada.

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

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

4 Stiver, W. and D. Mackay, Evaporation Rate of Spills of Hydrocarbons and Petroleum Mixtures. Env. Sci. Tech., 834, 1984

5 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

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

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

8 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.

9 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