Validation of the Two Models Developed to Predict the Window of Opportunity for Dispersant Use in the Gulf of Mexico

Final Report

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Executive Summary

In a previous US-BSEE-funded research project entitled: "*Identification of Window of Opportunity for Chemical Dispersants on Gulf of Mexico Crude Oils*" (SL Ross, 2007), two correlation models were developed to predict the "window of opportunity" (or "time-window") for successful chemical dispersant use in the Gulf of Mexico (GOM). The models consist of correlation relationships established using best-fit correlation between readily available fresh oil properties and the window of opportunity for successful chemical dispersant use estimated using data from GOM crude oils and spill volumes of 1,000 and 10,000 barrels. The study showed that combination of Sulfur, Saturate and Wax contents of the fresh oils correlated best with the time-window for dispersant use.

This study aims to validate and improve the two correlation models using a well know oil spill model OILMAP and adding 48 new oils to the initial 24 oils used by SL Ross to develop the models. Among the oils added are 24 crude oils from outside the GOM for which physical and chemical properties are available. The other 24 new crude oils are from the GOM and California for which physical and chemical properties have been measured in this study. The project also aims to conduct sensitivity analysis of the improved models to spill volume, water temperature, wind speed, and the cutoff viscosity used to determine the time-window and include their effects in the new improved models. A total of 9450 OILMAP simulations were performed for this sensitivity analysis using realistic spill and weather conditions obtained from the BURL1 NDBC-NOAA weather station. The final step in this study was to use existing data from large tank tests and data from Swirling Flask Test to test the final models developed in this study.

This study showed that time-window predicted using the SL Ross oil spill model SLROSM and the two correlation models were different from the time-window predicted using OILMAP oil spill model. The time-window predicted by OILMAP is not correlated with Sulfur and Wax contents, but showed some correlation with, Saturates content. Simple correlation and Principal Component Analysis (PCA) methods showed that the time-window predicted using OILMAP has strong correlated with oil viscosity measured at 15 °C. The data showed two distinct trends for viscous and less viscous oils. The separation occurs at a viscosity of about 33.5 cP. Based on orthogonal regression using PCA analysis, two models were developed to predict the time-window for oils with oil viscosity below and higher than this reference viscosity. Sensitivity analysis of these models showed that spill volume, wind speed, temperature, and cutoff viscosity have strong effects on the

time-window. The effects of these factors have been integrated into the new models. The new models to predict the time-window are show by the following equations.

where *TW* is the time-window in hours and C_f is a correction factor that includes the effects of spill volume, wind speed, temperature, and cutoff viscosity. It is given by the following equation:

$$C_f = 1.48 \left(\frac{V_o}{V_{o1}}\right)^{0.25} \left(\frac{\mu_{co}}{\mu_{or}}\right) e^{0.573\left(\frac{T}{T_1}\right)} e^{-0.97\left(\frac{W_s}{W_{s1}}\right)}$$

μ_o represents dynamic viscosity of the oil measured at 15 °C in cP, μ_{or} = 33.468 cP, μ_{co} the cutoff viscosity in cP, V_o the spill volume in bbl, V_{o1} =1000 bbl, T the air/water temperature in °C, T_1 = 23 °C, W_s the wind speed in knots, and W_{s1} = 12 knots.

The new models were validated using the large tank dispersant effectiveness tests conducted by SL Ross (2012) at Ohmsett – The National Oil Spill Response Research & Renewable Energy Test Facility. The results showed that the new models reproduced the measured time-window better than the two SL Ross correlation models. Further data are needed to validate and improve the new models.

It is of paramount importance to note that the development of the new models shown by the equations above was based on the data generated using OILMAP oil spill model. As such, the accuracy of the new models to predict the time-window for application of chemical dispersant is directly related to the accuracy of this model oil weathering under different weather conditions and for different oils.

$$TW = \begin{cases} 8.754\, C_f \left(\frac{\mu_o}{\mu_{or}}\right)^{-3.4201} & for \quad 0 \le \mu_o \le \mu_{or} \\ 8.754\, C_f \left(\frac{\mu_o}{\mu}\right)^{-0.3556} & for \quad \mu_{or} \le \mu_o < \mu_{co} \end{cases}$$

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1. Introduction

Crude oil has a pervasive presence in modern society. The widespread extraction, transportation and use of petroleum inevitably results in releases to the environment. It is therefore prudent to plan and prepare for the response to such releases. Research into countermeasures to mitigate the environmental impact of an oil spill is an essential component for informing spill responders on the optimum response (NRC 2005; Chapman et al., 2007). Chemical dispersants are a major countermeasure that may offer potential benefit to a response. The effectiveness of chemical dispersants is related to the physical and chemical properties of the crude oil. The properties are altered over time as the oil remains on the surface of the water due to the processes of weathering, including evaporation, emulsification, dissolution, and natural dispersion. As a consequence, the effectiveness of dispersants declines over time and eventually loses sufficient effect to offer benefit to the response. The duration of the anticipated time period for effective application of chemical dispersants on various oil types is a useful parameter in the planning for, and responding to, a spill. This time period is commonly called the *window of opportunity* or the *time-window of opportunity* (hereafter referred to as the "time-window"). Overall, this time-window is limited by the effects of weathering on the chemical and physical properties of the spilled oil, especially the increase in oil viscosity. It varies with spill conditions, oil types, environmental conditions prevailing during a spill, and the types of dispersants and the method of their application. For many oils this means that dispersants must be applied quickly to be effective. As such, it is crucial for decision makers to predict this time-window as quickly as possible using confident predictive models.

In a previously US-BSEE-funded research project entitled: "*Identification of Window of Opportunity for Chemical Dispersants on Gulf of Mexico Crude Oils*" (SL Ross, 2007), the objective was to develop best-fit correlations between readily available fresh oil properties and the time-window for successful chemical dispersant use using data from Gulf of Mexico (GOM) crude oils. The study showed that combination of Sulfur, Saturate and Wax contents of the fresh oils correlated best with the time-window for dispersant use for both the 1,000 and 10,000 barrels spill scenarios. The two proposed correlation models are:

for 1,000 barrel spill, the model is:

$$\text{Dispersant Time-Window (hr)} = \exp^{(-1.997657*\text{Sulfur}+0.107833*\text{Saturate}-0.326005*\text{Wax}-1.35108)} \quad (1)$$

(R^2 = 0.979, all input fresh oil property data in wt%)

for 10,000 barrel spill, the model is:

$$\text{Dispersant Time-Window (hr)} = \exp^{(-1.30926*\text{Sulfur} +0.05534*\text{Saturate} -0.28146*\text{Wax}+2.7153)} \quad (2)$$

($R^2 = 0.971$, all input fresh oil property data in wt%)

The approach undertaken to establish these two correlation models was based on the following conditions, methods and/or assumptions:

1. Twenty-four (24) fresh oils from the GOM Region of the United States Outer Continental Shelf. Detailed oil properties for these oils were obtained from the Environment Canada's oil properties database (Env. Can. 2006).
2. Average water temperature and wind speed for the US GOM were assumed.
3. SLROSM oil spill model (SL Ross 2000) was used to simulate oil behaviour as a function of oil type and environmental conditions.
4. The maximum time-window for chemical dispersant use estimated by the time that the SLROSM model predicts that the oil's (or emulsion) viscosity reaches 7,500 cP.
5. For oils that never reach the viscosity cutoff of 7,500 cP, a time-window of 1,000 hours was arbitrarily attributed to these oils.
6. Fresh oil properties data that were used to perform correlation studies were: gravity, flash point, pour point, viscosity, wax content, asphaltene content, resin content, boiling point distribution, sulfur, aromatics, and saturates.
7. Correlation study was performed using Oakdale Engineering's "DataFit" software.

From an operational perspective, application of such correlation models is very cost effective as it immediately provides decision-makers with key information about the time-window for using chemical dispersants during oil spills in the GOM. However, the models were not validated.

Recently, SL Ross used the National Oil Spill Response Research & Renewable Energy Test Facility (OHMSETT) to collect the first series of data to validate the models (SL, Ross, 2012). Several oils were subjected to long-term weathering in the Ohmsett tank considering various wave and wind conditions. The report concluded that the correlation models did not accurately predict the observed individual time-windows for the different oils used in the study. Additional Ohmsett tank experiments were recommended to improve the confidence in the dispersant modelling and the validation of the models.

This research project is to validate further the two correlation models (eqs. (1) and (2)).

2 Objectives and Goals

2.1 Objectives

The objective of this research is to validate further the two correlation models (eqs. (1) and (2)) proposed by SL Ross (SL Ross, 2007) to predict time-window for dispersant use in the GOM using a well known oil spill model OILMAP, including crude oils from outside the GOM for which physical and chemical properties are available in EC's oil property database, introducing 24 new oils from the GOM and other places for which physical and chemical properties were measured in this study, and using existing data from large tank tests and field trials/spills. The project also aims to evaluate the sensitivity of the models to water temperature, wind speed and the viscosity with the aim to include effects of these parameters into the models.

2.2 Goals

The goals of this research project are:

1. use OILMAP oil spill model to validate the time-window predicted by SL Ross for the 24 crude oils selected from the Environment Canada's oil properties database and using the SLROSM oil spill model. SL Ross used this data set of predicted time-window to develop the two correlations models shown by equations (1) and (2) above;
2. use OILMAP oil spill model to validate and to improve the two correlation models proposed by SL Ross (eq. (1) and (2)) using 24 additional crude oils outside the GOM for which physical and chemical properties are available in the Environment Canada's oil properties database;
3. use OILMAP oil spill model to validate and to improve the two correlations models using 24 new crude oils from the GOM and other places. Physical and chemical properties of these new oils will be measure in this study;
4. use OILMAP oil spill model to perform a sensitivity analysis of the correlation models to show how the time-window varies with temperature, wind speed, viscosity cutoff (threshold) and the spill volume;
5. to validate and to improve the correlation models using existing data from large tank tests;

6. to validate and to improve the correlation models using new experimental data using EC's Swirling Flask Test (SWT) method. The new SWT experiments were conducted in this project for 24 new oils analyzed in this study.

3 Validation of the time-window using the 24 source oils (Task 1)

SL Ross (2007) used the following steps to establish the two correlation models. In **step1**, SL Ross ran their oil spill model SLROSM to calculate the time history of the variations of the oil viscosity. In **step2**, the time-window for dispersant use was then selected from this time history considering a preset viscosity cutoff (threshold) above which dispersants become ineffective. The last **step3** consists of introducing the time-window obtained in step2 and the readily available fresh oil properties into a statistical model "DataFit" to determine the best correlations (eq. (1) and (2)).

This shows that results from step1 and step2 are crucial for the development of the correlation models. Any uncertainty in the results (calculation of the time-window for dispersant use) from these steps will directly affect the accuracy of the correlation models (eq. (1) and (2)). This is why we believe proper validation of equations (1) and (2) should start with the validation of the calculation of the time-window (step1 and step2) discussed above. For this, one should use a different oil spill model than the SLROSM used in the previous study (SL Ross, 2007). In this study, we propose using the well known OILMAP oil spill model (ASA, 2008) to calculate the time history of the variations of the oil viscosity. OILMAP model is used worldwide and has been validated on several real spills worldwide.

Specifically, this Task 1 aims to validate the two correlation models (eqs. (1) and (2)) using the 24 source crude oils on which SL Ross based their study to develop the correlation models (Appendix A). The task will be performed according to the following steps: 1) using the well known OILMAP oil spill model to recalculate the time-window for dispersant use using the 24 oils and the same weather and spill conditions; 2) comparing the new results (time-window) with those calculated by SL Ross and presented in their final report submitted to BSEE (last two columns in the table shown in Appendix A). If the difference between the results (time-window) is significant, the results obtained with OILMAP will be considered for the validation/improvement of the correlation models (eq. (1) and (2) above).

3.1 Results from OILMAP simulations

Version 6.9.3 of OILMAP oil spill model was used to run the simulations. Weather and spill conditions were kept the same to those used in the SL Ross study. For each of the 24 oil samples used in the SL Ross study to develop the two correlation equations, two oil spill scenarios (1,000 and 10,000 barrel) were run using average environmental conditions for the US GOM; 23 ºC (73 ºF) water temperature, 6 m/s (12 knots) wind speed (SL Ross 2007) and Cutoff viscosity of 7,500 cP. All simulations were run considering a GIS basemap for the Gulf of Mexico, a wind drift factor of 3.5% and a simulation duration of 1000 hours. Detailed modelling results are shown in Appendix B. and summary results are shown in Table 1.

Table 1. Time-window predicted using OILMAP oil spill model and the 24 oils used in the SL Ross study and listed in Appendix A.

Oil Name	Time-window (Hours)					
	SLROSS Oil Spill Model		SLROSS Correlation Models		Present OILMAP Model	
	1000 bbl	10,000 bbl	1000 bbl	10,000 bbl	1000 bbl	10,000 bbl
Eugene Island Block 32	1000	1000	82	92	656	1000
Eugene Island Block 43	61	87	83	111	656	1000
Garden Banks Block 387	16	24			230	414
Garden Banks Block 426	66	87			9999	1000
Green Canyon Block 65	5	6	0	8	5	6
Green Canyon Block 109	30	47	1	12	8	11
Green Canyon Block 184	1000	1000			8	11
Green Canyon Block 200	177	296	187	285	346	620
Louisiana	1000	1000	75	154	1000	1000
Main Pass Block 306	1000	1000	62	164	610	1000
Main Pass Block 37	1000	1000	36	73	1000	1000
Mars TLP (2004)	1000	1000	2	18	139	251
Mississippi Canyon Block 72	32	53			140	253
Mississippi Canyon Block 194	27	46	70	143	140	253
Mississippi Canyon Block 807	102	169			140	253
Morpeth Block EW921	77	146	13	64	12	19
Petronius Block VK87A	12	17	469	473	65	119
Ship Shoal Block 269	473	473	112	171	9999	9999
South Pass Block 60	50	83	32	74	362	648
South Timbalier Block 130	1000	1000	167	242	9999	9999
Viosca Knoll Block 826	20	30			216	389
Viosca Knoll Block 990	200	335	214	346	1000	1000
West Delta Block 97	1000	1000	1244	727	9999	9999
West Delta Block 143	9	14			12	20

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cutoff viscosity during the 1000 hours of simulation.

3.2 Comparison with SL Ross Predictions

Before comparing time-window data predicted by the SL Ross models with those obtained with OILMAP oil spill model, a comparison was made between the time-window predicted by the two correlations models (Eqs. 1 and 2) and the time-window predicted by the SL Ross oil spill model. This is shown in Figure 1. Contrary to the high values of the good correlation reported in SL Ross (2007), the agreement between the two predictions is not that good for both the 1000 and 10,000 bbl spill volumes. For many oils, correlation models predicted a much lower values for the time-window than those predicted by the SL Ross oil spill model.

A comparison between the time-window predicted by OILMAP oil spill model and the time-window predicted by the SL Ross oil spill model for the first 24 source oils (Table 1) is shown in Figure 2. There is no good agreement between the results of the two oil spill models. For time-window less than about 400 hours, OILMAP predicted a much higher values than the SL Ross model. The opposite trend is shown for time-window higher than 400 hours.

When compared with the predictions using the two correlation models proposed by SL Ross (Eqs. 1 & 2), OILMAP predicted higher values of the time-window for most oils (Figure 3).

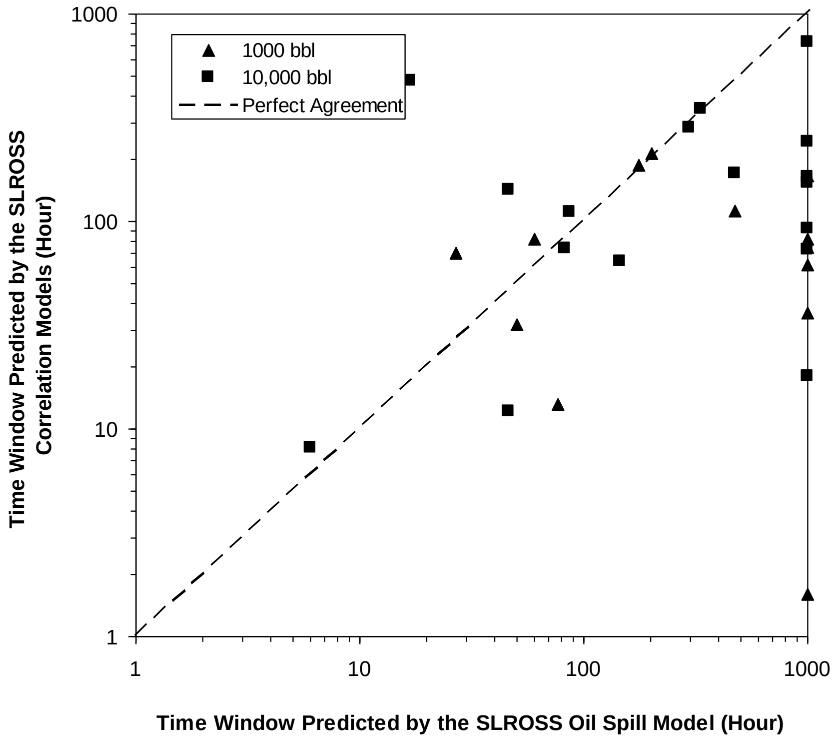


Figure 1: **Comparison between time-window predicted by the correlation models (equations 1 and 2) and time-window predicted by the SL Ross oil spill model (Task 1).**

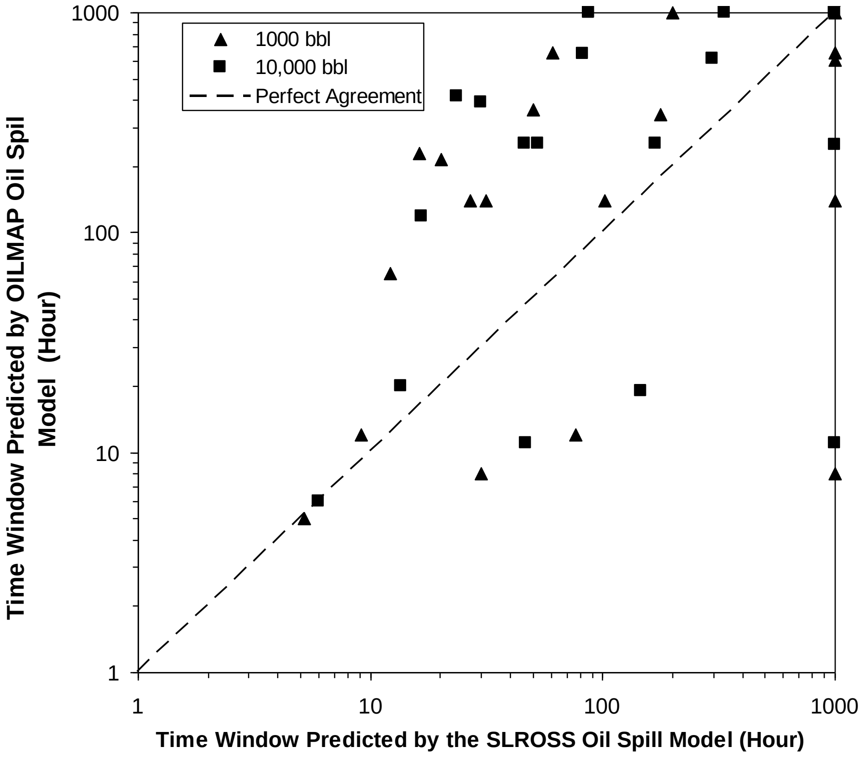


Figure 2: **Comparison between time-window predicted by the SL Ross oil spill model and the time-window predicted the OILMAP oil spill model (Task 1).**

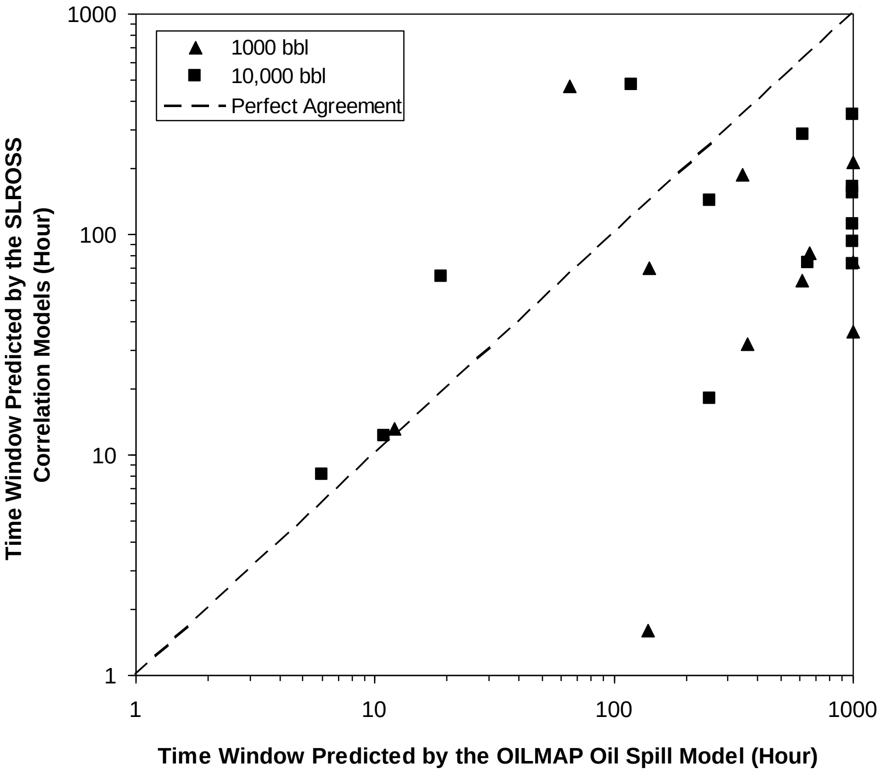


Figure 3: **Comparison between time-window predicted by the OILMAP oil spill model and the time-window predicted by the SLRoss correlation models (Eqs. 1 & 2).**

3.2 Conclusions for Task 1

Conclusions from the completion of Task 1 are:

1. The two correlations models proposed by SL Ross (2007) are not good predictors of the time-window initially predicted by SL Ross oil spill model.
2. For most of the 24 oils studied in Task 1, the values of the time-window predicted by OILMAP and the SL Ross oil spill models are very different.
3. For most of the 24 oils studied in Task 1, the two correlations models proposed by SL Ross (2007) underestimated the time-window predicted by OILMAP.
4. Values of the time-window predicted by OILMAP will be used to develop new models in Task 4.

4 Validation of the correlation models using crude oils from outside the US GOM for which physical and chemical properties exist (Task 2)

In this second task, the two correlation models (Eqs. 1 & 2) were validated using other oils, most of them are from outside the U.S. GOM, for which physical and chemical properties are available in the Environment Canada's oil properties database. Table 2 shows the list of the oils selected (a total of 24) to conduct this task and for which Environment Canada (EC) has measured physical and chemical properties.

4.1 Results from OILMAP simulations

Version 6.9.3 of OILMAP oil spill model was used to run the simulations. Weather and spill conditions were kept the same to those used in the SL Ross study. For each of the additional 24 oil samples listed in Table 2, two oil spill scenarios (1,000 and 10,000 bbl) were run using average environmental conditions for the US GOM; 23 ºC (73 ºF) water temperature, 6 m/s (12 knots) wind speed (SL Ross 2007) and Cutoff viscosity of 7,500 cP. All simulations were run considering a GIS basemap for the Gulf of Mexico, a wind drift factor of 3.5% and a simulation duration of 1000 hours Detailed modelling results are shown in Appendix C. and summary results are shown in Table 3.

Table 2. **List of the additional 24 oils selected to conduct Task 2. The physical and chemical properties were obtained from En. Can. (2006).**

Oil Name	Origin	API Gravity	Sulfur (wt %)	Dynamic Viscosity (cP)		Saturates (wt %)	Aromatics (wt %)	Resin (wt %)	Asphaltenes (wt %)	Wax (wt %)
				0°C	15°C					
Arabian Light (2000)	Saudi Arabia	31.30	1.93	33	13	75.5	15.2	5.7	3.6	2.7
Barrow Island	Australia	36.70	0.04	4	2	64.0	32.0	4.0	0.0	0.0
Carpinteria	California, USA	22.90	1.88	790	164	44.0	30.0	17.0	9.0	7.0
Chayvo #6	Russia (Exxon-Mobil)	37.91	0.34	19	4	87.9	8.6	3.4	0.2	5.0
Empire	Louisiana, USA	33.80	0.30	21	11	67.0	25.0	7.0	1.0	5.0
Federated (1998)	Alberta, Canada	38.90	0.34	9	5	72.0	22.0	4.0	2.0	2.0
Genesis	Gulf of Mexico, USA	28.40	1.38	48	26	59.0	29.7	9.7	1.6	0.9
Gullfaks	North Sea, Norway	31.00	0.30	25	13	60.0	35.0	5.0	1.0	4.0
Heidrun	Norwegian Sea, Norway	28.60	0.46	35	18	55.0	35.0	9.0	1.0	4.0
Hondo Monterey	California, USA	18.30	4.70	8064	1599	34.0	31.0	20.0	15.0	1.7
Iranian Heavy	Iran	30.00	1.20	43	20	53.0	30.0	11.0	6.0	5.0
Lucula	Angola	33.40	0.17	710	43	67.0	22.0	8.0	4.0	13.0
Malongo	Angola	31.00	0.20	1800	63	62.0	25.0	9.0	4.0	10.0
Odoptu	Alaska, USA	28.50	0.96	46	22	53.0	34.0	10.0	4.0	4.0
Oseberg	North Sea, Norway	34.40	0.28	22	10	65.0	25.0	8.0	2.0	5.0
Pitas Point	California, USA	38.00	0.61	3	2	80.0	18.0	3.0	0.0	0.0
Point Arguello Comingled	California, USA	21.40	3.64	2510	533	36.0	25.0	23.0	16.0	8.0
Prudhoe Bay (1995)	Alaska, USA	28.50	0.96	46	22	53.0	34.0	10.0	4.0	4.0
Sakhalin	Russia	32.30	0.25	6	4	61.0	32.0	6.0	1.0	0.6
Santa Clara	California, USA	22.10	2.85	1278	304	36.0	22.0	29.0	13.0	6.0
Statfjord	North Sea, Norway	37.80	0.26	31	6	68.0	26.0	6.0	2.0	8.0
Thevenard Island	Australia	48.60	0.01	2	1	85.0	13.0	2.0	0.0	1.0
West Texas Intermediate	Texas, USA	36.40	0.48	15	7	66.0	26.0	6.0	1.0	4.0
Zaire	Zaire	30.70	0.16	19200	362	64.0	22.0	9.0	5.0	20.0

Table 3. Time-window predicted using OILMAP oil spill model and the SLRoss correlation models (Eqs. 1 & 2) for the additional 24 oils listed in Table 2.

Oil Name	Time-window (Hours)			
	SLROSS Correlation Models (Eqs. 1 & 2)		Present OILMAP Model	
	1000 bbl	10,000 bbl	1000 bbl	10,000 bbl
Arabian Light (2000)	8	37	14	18
Barrow Island	238	495	9999	9999
Carpinteria	0	2	5	6
Chayvo #6	335	306	9999	9999
Empire	38	102	401	718
Federated (1998)	161	296	1000	1000
Genesis	7	50	314	562
Gullfaks	25	92	229	412
Heidrun	11	56	21	40
Hondo Monterey	0	0	3	3
Iranian Heavy	1	14	47	86
Lucula	4	13	13	22
Malongo	5	22	41	76
Odoptu	3	26	1000	1000
Oseberg	32	94	42	79
Pitas Point	427	569	9999	9999
Point Arguello Comingled	0	0	4	5
Prudhoe Bay (1995)	3	26	8	9
Sakhalin	93	269	1000	1000
Santa Clara	0	0	5	7
Statfjord	17	49	1000	1000
Thevenard Island	1752	1242	9999	9999
West Texas Intermediate	33	101	1000	1000
Zaire	0	2	2	2

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cutoff viscosity during the 1000 hours of simulation.

4.2 Comparison with SL Ross Correlation Models (Eqs. 1 & 2)

Values of the time-window predicted by OILMAP for the additional 24 oils were compared with those calculated using the two correlations models proposed by SL Ross (2007) and described by Equations (1) and (2) for both the 1000 and 10, 000 bbl spill volumes (Figure 4). Similarly to what was shown in Figure 3, the data in Figure 4 shows that the correlation models underestimate the time-window predicted by OILMAP for both spill volumes.

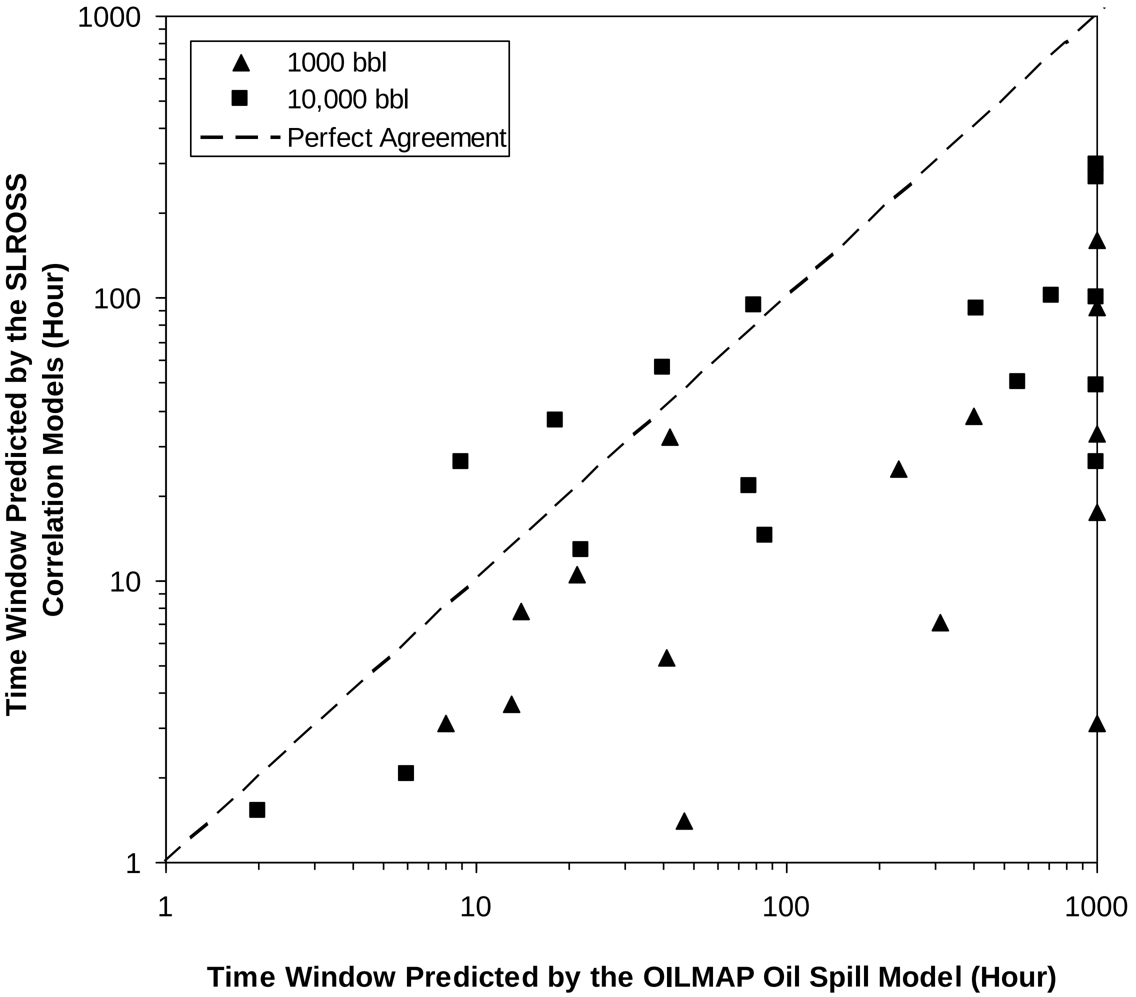


Figure 4: **Comparison between time-window predicted by the correlation models (Eqs. 1 and 2) and time-window predicted by the OILMAP oil spill model for the additional 24 oils (Task 2).**

4.3 Conclusions for Task 2

Conclusions from the completion of Task 2 are:

1. For most of the 24 additional oils studied in Task 2, the two correlations models proposed by SL Ross (2007) underestimated the time-window predicted by OILMAP.

2. Values of the time-window predicted by OILMAP will be used to develop new models in Task 4.

5 Validation of the correlation models using new crude oils from the US GOM (Task 3)

This task includes three steps. The first one consists of performing a detailed analyses of 24 oils, mostly newly produced crude oils from the US GOM, at the Environment Canada's Oil Spill Research laboratory. In these analyses, the following properties/process were be measured: Density, Flash Point, Pour Point, Dynamic Viscosity, Wax Content, Asphaltene Content, Resin Content, Boiling Point Distribution, Sulfur Content, Aromatics, Saturates, Interfacial Tensions, CCME Fractions and Evaporation test.

The second step in this task is to use OILMAP oil spill model to calculate the corresponding time-window considering the weather and spill conditions used in the previous SL Ross study. The final third step is to validate the correlation models against the new time-window data obtained from the previous step.

5.1 Measurement of the physical and chemical properties of the new oils samples

5.1.1 Oil Samples

Oil samples analyzed for this project were selected by US-BSEE and provided at their request to ESTS by the energy companies via MAR Inc. operating at the Ohmsett facility in Leonardo, NJ. In total, 24 samples were analyzed. The samples were tested as received, which in some cases required decanting prior to sampling. The oil identities, corporate sources, geographic locations of the oils, and the reported weathering when received are listed in Table 4.

Table 4. List of the 24 new oil samples analyzed in this study for Task 3.

Oil Identity	Reported weathering when received (%)	Origin
Alaska North Slope	none	Alaska
Alaska North Slope weathered	20.86	Prepared from Alaska North Slope oil above as small volume was received from previous Ohmsett experiments , Alaska
Arabian Medium	none	(replacement of Elly, July 2012), Saudi Arabia
DOBA	none	Chad
Dos Cuadras – Well HE-05	none	California
Dos Cuadras – Well HE-26	none	California
Ellen - Well A38	none	Well A38, Pacific Energy Resources, California
Ellen - Well A40	none	Well A40, Pacific Energy Resources, California
Endicott	none	Alaska
Endicott weathered	18.56	Prepared from Endicott oil above as small volume was received from previous Ohmsett experiments
Gail - Well E10	none	Well E10, Venoco Inc, California
Gail - Well E19	none	Well E19, Venoco Inc, California
Harmony	none	California
Heritage – Well HE-05	none	Well HE-05, ExxonMobil Corp., California
Heritage – Well HE-26	none	Well HE-26, ExxonMobil Corp., California
IFO-120	none	Fuel oil from from previous Ohmsett experiments
IFO-180	none	Fuel oil from from previous Ohmsett experiments
Independence Hub	none	Anadarko Petroleum Corp, Gulf of Mexico
Irene Lompoc	none	Lampoc Oil and Gas Facility, California
Irene Comingled	none	Comingled Exploration and Production, California
Neptune	none	BHP Billiton, Gulf of Mexico
North Star	none	Alaska
Rock	none	unknown
Terra Nova	none	East Coast Canada

5.1.2 Physical and chemical properties of the new oil samples

For each of the new oil samples listed above, the following properties/process were measured: Density, Flash Point, Pour Point, Dynamic Viscosity, Wax Content, Asphaltene Content, Resin Content, Boiling Point Distribution, Sulfur Content, Aromatics, Saturates, Interfacial Tensions, CCME Fractions and Evaporation test.

Detailed descriptions of the methods used to measure these properties/process and related results are given in Appendix D. A summary of the properties measured for the new 24 oil samples is given in Table 5a,b,c.

Table 5a. Summary of the physical and chemical properties of the 24 new oil samples analyzed in this study and listed in Table 4

Oil Sample	%Evap	Density (g/mL)		Viscosity (mPa·s)		Interfacial Tension (mN/m)					
	Loss	0 ºC	15 ºC	0 ºC	15 ºC	Air/Oil		Water/Oil		Brine/Oil	
	(%w/w)					0 ºC	15 ºC	0 ºC	15 ºC	0 ºC	15 ºC
ANS [2011]	0	0.8870	0.8754	30.2	15.4	28.4	27.9	21.7	21.2	21.1	20.1
ANS [2011]	20.86	0.9269	0.9159	561	133	31.9	29.9	25.5	22.7	24.5	22.3
ANS [2011]	30.67	0.9439	0.9316	4.80E+03	546	NM	30.1	NM	20.7	NM	20.5
Arabian Medium	0	0.8849	0.8738	62.6	21.6	29.3	27.4	24.9	26.7	25.7	27.0
Arabian Medium	31.35	0.9582	0.9454	2.23E+04	2.07E+03	NM	NM	NM	NM	NM	NM
DOBA	0	0.9423	0.9271	3.66E+04	3.11E+03	NM	NM	NM	28.2	NM	27.2
DOBA	14.13	0.9483	0.9372	6.10E+04	7.30E+03	NM	NM	NM	NM	NM	NM
Dos Cuadras HE-05	0	0.9184	0.9078	199	70.3	31.1	29.1	25.7	23.7	23.8	23.5
Dos Cuadras HE-05	23.40	0.9607	0.9491	2.77E+04	2.85E+03	NM	32.6	NM	29.8	NM	26.9
Dos Cuadras HE-26	0	0.8902	0.8785	56.2	20.6	28.3	28.6	NM	16.1	NM	16.1
Dos Cuadras HE-26	32.20	0.9487	0.9353	2.66E+04	1.14E+03	NM	33.3	NM	16.0	NM	17.5
Ellen A038	0	0.9694	0.9587	1.52E+04	3.10E+03	29.3	29.6	20.8	24.0	20.7	22.3
Ellen A038	15.88	1.0071	0.9981	2.31E+07	1.09E+06	NM	NM	NM	NM	NM	NM
Ellen A040	0	0.9889	0.9790	1.24E+05	1.97E+04	27.5	30.7	NM	15.3	NM	21.6
Ellen A040	14.57	1.0141	1.0058	4.63E+07	1.74E+06	NM	NM	NM	NM	NM	NM
Endicott [2011]	0	0.9142	0.9024	235	46.4	31.0	29.3	20.9	20.1	17.2	13.0
Endicott [2011]	18.56	0.9474	0.9357	9.57E+03	866	NM	31.2	NM	22.4	NM	20.3
Endicott [2011]	21.41	0.9518	0.9397	1.50E+04	1.36E+03	NM	31.2	NM	22.4	NM	20.3
Gail E010	0	0.9814	0.9709	6.72E+04	1.16E+04	29.0	29.8	19.0	21.8	22.0	23.6
Gail E010	16.92	1.0177	1.0086	9.65E+07	3.25E+06	NM	NM	NM	NM	NM	NM
Gail E019	0	0.9124	0.8996	147	51.7	28.3	26.4	NM	15.3	NM	17.6
Gail E019	24.42	0.9480	0.9346	1.55E+04	1.36E+03	NM	31.0	NM	NM	NM	NM
Harmony	0	0.9588	0.9456	2.20E+04	3.08E+03	NM	NM	NM	23.8	NM	16.6
Harmony	17.11	0.9996	0.9911	7.86E+07	1.82E+06	NM	NM	NM	NM	NM	NM
Heritage HE 05	0	1.0032	0.9922	3.03E+06	3.59E+05	NM	NM	NM	NM	NM	NM
Heritage HE 05	16.27	1.0253	1.0172	1.46E+09	3.80E+07	NM	NM	NM	NM	NM	NM
Heritage HE 26	0	0.9973	0.9859	1.91E+06	1.86E+05	NM	NM	NM	NM	NM	NM
Heritage HE 26	14.48	1.0213	1.0123	9.42E+08	2.74E+07	NM	NM	NM	NM	NM	NM
IFO-120 [2011]	0	0.9683	0.9567	9.16E+03	1.54E+03	NM	30.8	NM	31.9	NM	29.3
IFO-120 [2011]	9.54	0.9811	0.9701	1.38E+05	1.46E+04	NM	NM	NM	NM	NM	NM
IFO-180 [2011]	0	0.9794	0.9664	1.24E+05	1.92E+04	NM	NM	NM	NM	NM	NM
IFO-180 [2011]	6.86	0.9849	0.9782	1.41E+06	1.19E+05	NM	NM	NM	NM	NM	NM
Ind. Hub Atwater Valley 37	0	0.9255	0.9148	23.4	13.5	29.3	29.6	23.9	24.3	25.1	26.5
Ind. Hub Atwater Valley 37	22.07	0.9471	0.9370	126	40.2	30.6	31.4	19.2	15.5	17.0	18.0
Irene [Lompoc O&G Fac.]	0	0.9700	0.9591	6.83E+04	8.51E+03	30.2	28.7	20.8	19.6	19.0	23.4
Irene [Lompoc O&G Fac.]	17.41	1.0163	1.0073	3.15E+08	8.34E+06	NM	NM	NM	NM	NM	NM
Irene Comingled	0	0.9890	0.9787	4.45E+05	5.73E+04	27.1	26.6	NM	NM	NM	NM
Irene Comingled	20.26	1.0191	1.0107	6.16E+08	2.21E+07	NM	NM	NM	NM	NM	NM
Neptune [2011]	0	0.9354	0.9244	1.33E+03	402	30.1	30.4	35.3	31.6	31.7	30.7
Neptune [2011]	17.30	0.9758	0.9622	1.36E+05	2.07E+04	29.9	31.0	21.8	19.4	19.1	18.7
North Star	0	0.8687	0.8573	17.4	8.9	28.6	26.6	20.8	22.1	20.8	21.8
North Star	35.41	0.9284	0.9165	3.75E+03	201	NM	30.3	NM	21.4	NM	20.8
Rock	0	0.9776	0.9674	2.57E+04	4.36E+03	NM	NM	NM	26.1	NM	25.3
Rock	9.06	0.9964	0.9859	7.88E+05	7.14E+04	NM	NM	NM	NM	NM	NM
Terra Nova	0	0.8752	0.8624	47.6	17.5	NM	27.9	NM	24.4	NM	23.1
Terra Nova	28.55	0.9216	0.9114	1.65E+04	1.37E+03	NM	32.6	NM	24.4	NM	NM

NM: Not Measurable with the Pendant Drop method. The difficulty is due to the high viscosity of the oil.

Table 5b. Summary of the physical and chemical properties of the 24 new oil samples analyzed in this study and listed in Table 4 (continue)

Oil Sample	%Evap	Flash	Pour	Sulfur	Water	Disp.	Emulsion		
	Loss	Point	Point	Content	Content	Test	Stability	Water	Comp. Mod.
	(%w/w)	(ºC)	(ºC)	(%w/w)	(%w/w)	(% Eff.)	Class	(%w/w)	(Pa)
ANS [2011]	0	<-5	-15	0.91	0.1	67	Unstable	NM	NM
ANS [2011]	20.86	90	0	1.13	0.1	49	Meso	75.5	17
ANS [2011]	30.67	136	6	1.28	0.0	11	Stable	75.3	108
Arab. Med.	0	<0	<-24	2.70	0.1	53	Stable	85.5	1.06E+03
Arab. Med.	31.35	142	0	3.71	0.0	<10	Stable	75.8	975
DOBA	0	>60	-5	0.12	4.0	10	Entrained	43.0	47
DOBA	14.13	166	6	0.13	0.0	<10	Entrained	33.9	102
Dos Cuadras HE-05	0	0	-27	1.22	0.5	67	Unstable	NM	NM
Dos Cuadras HE-05	23.40	135	13	1.55	0.1	<10	Stable	76.4	457
Dos Cuadras HE-26	0	-1	-5	0.51	2.6	69	Unstable	NM	NM
Dos Cuadras HE-26	32.20	132	25	0.74	0.1	11	Stable	76.3	759
Ellen A038	0	40	-21	3.28	1.9	<10	Entrained	20.7	44
Ellen A038	15.88	154	12	3.69	0.5	<10	DNF	NM	NM
Ellen A040	0	104	-15	3.89	5.2	<10	Entrained	24.5	42
Ellen A040	14.57	161	3	4.25	0.9	<10	DNF	NM	NM
Endicott [2011]	0	<0	6	1.04	0.3	62	Unstable	NM	NM
Endicott [2011]	18.56	125	15	1.29	0.0	49	Entrained	71.6	676
Endicott [2011]	21.41	141	18	1.33	0.0	<10	Entrained	74.0	992
Gail E010	0	48	-6	5.94	4.3	<10	Entrained	43.9	258
Gail E010	16.92	147	9	6.79	1.4	<10	DNF	NM	NM
Gail E019	0	22	-3	1.90	3.7	43	Unstable	NM	NM
Gail E019	24.42	139	12	2.39	0.5	<10	Stable	77.9	752
Harmony	0	18	-9	4.73	0.3	<10	Entrained	59.5	942
Harmony	17.11	145	24	5.20	0.3	<10	DNF	NM	NM
Heritage HE 05	0	77	-3	7.20	6.6	<10	DNF	NM	NM
Heritage HE 05	16.27	150	33	7.64	1.3	<10	DNF	NM	NM
Heritage HE 26	0	72	-18	6.28	5.1	<10	DNF	NM	NM
Heritage HE 26	14.48	149	30	6.67	0.4	<10	DNF	NM	NM
IFO-120 [2011]	0	91	-9	0.96	0.3	12	Stable	69.6	171
IFO-120 [2011]	9.54	146	6	1.03	0.2	<10	Stable	59.6	505
IFO-180 [2011]	0	>60	15	0.46	1.7	<10	Entrained	42.1	144
IFO-180 [2011]	6.86	160	18	0.48	0.0	<10	Entrained	44.4	366
Ind. Hub Atwater Valley 37	0	40	<-30	0.65	0.1	77	Unstable	NM	NM
Ind. Hub Atwater Valley 37	22.07	124	<-30	0.72	0.0	66	Unstable	NM	NM
Irene [Lompoc O&G Fac.]	0	40	-9	5.21	2.6	<10	Entrained	48.9	381
Irene [Lompoc O&G Fac.]	17.41	150	33	5.85	1.4	<10	DNF	NM	NM
Irene Comingled	0	62	0	5.54	5.9	<10	Entrained	35.7	784
Irene Comingled	20.26	148	27	6.08	1.5	<10	DNF	NM	NM
Neptune [2011]	0	22	<-30	2.88	0.9	<10	Stable	80.5	171
Neptune [2011]	17.30	153	-6	3.47	0.2	<10	Stable	65.5	674
North Star	0	<-5	-16	0.70	0.0	74	Unstable	NM	NM
North Star	35.41	127	-3	1.06	0.0	43	Stable	78.3	416
Rock	0	42	-15	3.97	0.4	<10	Entrained	59.5	232
Rock	9.06	151	6	4.22	0.0	<10	Entrained	58.9	811
Terra Nova	0	<-5	9	0.57	0.0	43	Unstable	NM	NM
Terra Nova	28.55	136	21	0.80	0.0	<10	Stable	75.6	1.23E+03

DNF: Do Not Form

NM: Not Measurable because the emulsion did not form or was unstable.

Table 5c. Summary of the physical and chemical properties of the 24 new oil samples analyzed in this study and listed in Table 4 (continue)

Oil Sample	%Evap	Hydrocarbon Groups				Wax	% Evaporated
	Loss	Saturates	Aromatics	Resins	Asph.	Content	Equation
	(%w/w)	(%w/w)	(%w/w)	(%w/w)	(%w/w)	(%w/w)	(%Evap =)
ANS [2011]	0	58.7	31.3	7.6	2.4	4.9	-1.01 + 0.92 Ln(t+0.99)
ANS [2011]	20.86	56.6	26.3	13.7	3.4	7.3	-4.75 + 0.76 Ln(t+562.1)
ANS [2011]	30.67	50.1	26.5	20.2	3.2		
Arab. Med.	0	49.7	36.5	10.4	3.4	5.2	-1.27 +0.94 Ln(t+2.08)
Arab. Med.	31.35	47.2	29.1	17.8	5.9		
DOBA	0	65.2	20.2	10.2	4.5	2.7	-2.53 + 0.45 Ln(t+255.9)
DOBA	14.13	61.8	18.1	16.0	4.0		
Dos Cuadras HE-05	0	49.2	29.5	14.5	6.7	4.3	-1.72 + 0.87 Ln(t+5.83)
Dos Cuadras HE-05	23.40	33.6	28.6	26.7	11.1		
Dos Cuadras HE-26	0	57.2	31.0	8.9	2.8	6.4	-1.32 + 0.92 Ln(t+4.05)
Dos Cuadras HE-26	32.20	57.7	26.0	13.4	3.0		
Ellen A038	0	39.2	22.5	24.1	14.3	1.6	-14.5 + 3.03 Ln(t+152.2)
Ellen A038	15.88	35.2	22.1	27.5	15.2		
Ellen A040	0	42.6	18.6	24.5	14.3	1.2	-17.3 + 2.63 Ln(t+896.2)
Ellen A040	14.57	27.1	19.6	35.7	17.6		
Endicott [2011]	0	60.5	29.8	7.2	2.5	12.0	-1.34 + 0.64 Ln(t+8.11)
Endicott [2011]	18.56	50.1	32.2	14.4	3.4	15.6	-4.31 + 0.54 Ln(t+273.5)
Endicott [2011]	21.41	52.6	27.4	16.1	3.9		
Gail E010	0	37.4	14.2	25.4	23.1	2.3	-19.4 +3.43 Ln(t+350.0)
Gail E010	16.92	26.1	16.0	33.9	24.1		
Gail E019	0	64.1	18.8	11.4	5.8	15.0	-10.0 + 3.41 Ln(t+16.9)
Gail E019	24.42	59.2	20.8	12.5	7.5		
Harmony	0	36.8	20.6	31.2	11.4	5.8	-1.67 + 0.54 Ln(t+23.1)
Harmony	17.11	28.2	23.6	33.0	15.2		
Heritage HE 05	0	37.0	19.2	33.5	10.2	2.0	-5.0 + 0.97 Ln(t+271.6)
Heritage HE 05	16.27	22.1	12.7	50.8	14.4		
Heritage HE 26	0	35.9	24.9	28.5	10.7	3.1	-0.7 + 0.35 Ln(t+14.2)
Heritage HE 26	14.48	34.7	23.5	31.0	10.8		
IFO-120 [2011]	0	43.8	42.6	10.4	3.2	9.0	-4.17 + 0.63 Ln(t+807.5)
IFO-120 [2011]	9.54	45.7	32.5	18.7	3.1		
IFO-180 [2011]	0	49.3	31.9	14.8	4.0	20.0	-4.5 + 0.57 Ln(t+3184.0)
IFO-180 [2011]	6.86	39.5	33.4	21.2	5.9		
Ind. Hub Atwater Valley 37	0	72.6	22.8	4.6	0.0	0.2	-19.9 + 4.21 Ln(t+159.1)
Ind. Hub Atwater Valley 37	22.07	67.7	27.1	5.2	0.0		
Irene [Lompoc O&G Fac.]	0	37.7	10.6	32.7	19.0	1.7	-11.1 + 2.78 Ln(t+52.7)
Irene [Lompoc O&G Fac.]	17.41	23.1	12.8	37.7	26.4		
Irene Comingled	0	38.7	20.3	24.8	16.2	3.0	-26.0 + 4.0 Ln(t+787.0)
Irene Comingled	20.26	24.0	15.0	32.4	28.6		
Neptune [2011]	0	58.0	13.3	18.6	10.1	2.0	-7.6 + 2.48 Ln(t+23.5)
Neptune [2011]	17.30	55.2	15.0	18.7	11.2		
North Star	0	67.3	24.7	6.1	1.9	4.8	-1.38 + 1.07 Ln(t+1.14)
North Star	35.41	60.1	25.8	9.5	4.6		
Rock	0	29.5	23.5	40.5	6.5	3.0	-2.25 + 0.44 Ln(t+193.8)
Rock	9.06	28.7	21.3	41.1	8.9		
Terra Nova	0	67.8	19.1	12.4	0.7	20.5	-0.66 + 0.71 Ln(t+0.96)
Terra Nova	28.55	48.6	28.3	22.0	1.1		

5.2 Results from OILMAP simulations

Physical properties listed in Table 5 were introduced into OILMAP oil properties database and used to calculate the corresponding time-window considering the weather and spill conditions used in the previous SL Ross study. Version 6.9.3 of OILMAP oil spill model was used to run the simulations. Weather and spill conditions were kept the same to those used in the SL Ross study. For each of the additional 22 oil non weathered samples listed in Table 4, two oil spill scenarios (1,000 and 10,000 barrel) were run using average environmental conditions for the US GOM; 23 ºC (73 ºF) water temperature, 6 m/s (12 knots) wind speed (SL Ross 2007) and Cutoff viscosity of 7,500 cP. All simulations were run considering a GIS basemap for the Gulf of Mexico, a wind drift factor of 3.5% and a simulation duration of 1000 hours. Detailed modelling results are shown in Appendix E. and summary results are shown in Table 6.

Table 6. Time-window predicted using OILMAP oil spill model for the 24 new oil samples analyzed in this study and listed in Tables 4 and 5.

Oil Name	Time-window (Hours)			
	SLROSS Correlation Models		Present OILMAP Model	
	1000 bbl	10,000 bbl	1000 bbl	10,000 bbl
Alaska North Slope	5	30	10	15
Arabian Medium	0	2	6	8
DOBA	96	223	1000	1000
Dos Cuadras HE-05	1	14	5	6
Dos Cuadras HE-26	6	30	7	10
Endicott	0	4	12	21
Harmony	0	0	1	2
IFO-120	0	4	1	2
IFO-180	0	0	0	0
North Star	19	65	53	99
Rock	0	0	3	3
Terra Nova	0	1	13	22
Independence Hub A.V. Block 37	166	339	9999	9999
Irene Sampled from Lompoc	0	0	1	1
Neptune	0	5	4	5
Ellen A038	0	1	4	9
Ellen A040	0	1	0	0
Gail E010	0	0	1	1
Gail E019	0	1	7	10
Heritage HE 05	0	0	0	0
Heritage HE 26	0	0	0	0
Irene Comingled	0	0	0	0

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cutoff viscosity during the 1000 hours of simulation.

5.3 Comparison with SL Ross Correlation Models (Eqs. 1 & 2)

Figure 5 shows a comparison between time-window predicted by the correlation models (equations 1 and 2) and time-window predicted by OILMAP for the new oils shown in Table 6. Here again, the results show that for most oils the correlation models (Eqs. 1 & 2) underestimate the time-window predicted by OILMAP.

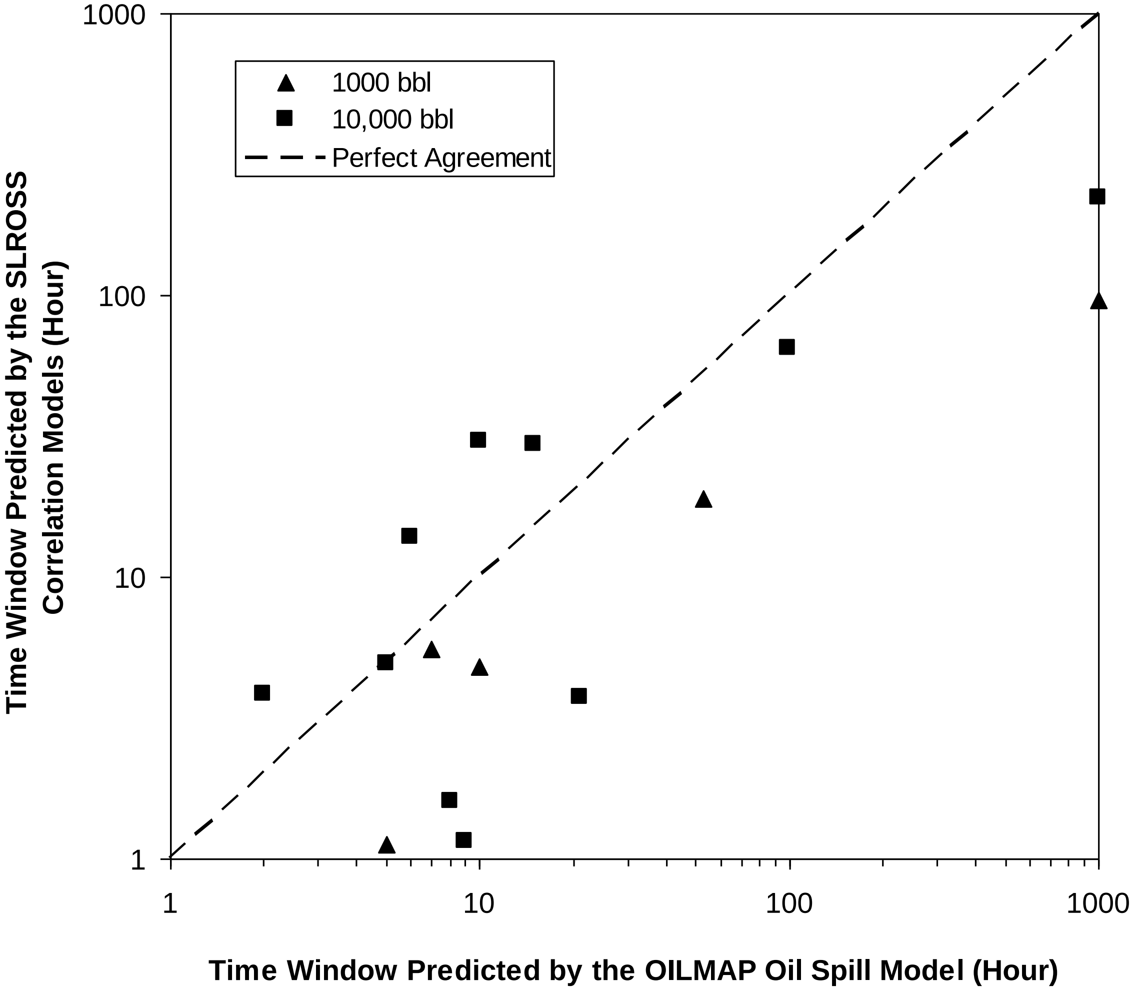


Figure 5: **Comparison between time-window predicted by the correlation models (equations 1 and 2) and time-window predicted by the OILMAP oil spill model for the new oils shown in Table 6 (Task 3).**

5.4 Conclusion for Task 3

Conclusions from the completion of Task 3 are:

1. For most of the new oils studied in Task 3 and listed in Table 6, the two correlations models proposed by SL Ross (2007) underestimated the time-window predicted by OILMAP.

2. Values of the time-window predicted by OILMAP will be used to develop new models in Task 4.

6 Model development and sensitivity analysis (Task 4)

The goals of this Task 4 are:

1. to use the data on time-window generated in Task 1 to 3 using OILMAP to develop new models to predict the time-window.
2. to use OILMAP to generate a much lager database on time-window by conducting new simulations using all non-weathered oils studies in Task 1 to 3 (70 in total), various wind speeds and air temperatures typical for the Gulf of Mexico water system, various spill volumes and various values for the cutoff viscosity.
3. to integrate the effects of spill volume, wind speed, air temperature and cutoff viscosity into the new models to predict the time-window.

6.1 Development of new predictive models using time-window data generated in Task 1 to 3.

Development of the new predictive models is presented in details in Appendix F. In summary, simple correlations and Principal Component Analysis of the multivariable problem have shown that the time-window calculated by the OILMAP oil spill model in Tasks 1 to 3 for spill volume of 1000 bbl can be predicted as a function of the oil viscosity only. Based on orthogonal regression using PCA analysis, the following models were developed to predict the time-window for application of chemical dispersant:

$\ln(\tau) = -3.4201 \ln(\mu)$, or $TW_1 = TW_r\,\mu^{-3.4201}$ for $0 \le \mu \le 1$ at 15 °C (3)

$\ln(\tau) = -0.3556 \ln(\mu)$, or $TW_2 = TW_r\,\mu^{-0.3556}$ for $1 \le \mu < K$ at 15 °C (4)

where

, represent the dimensionless time-window (5)

$$\tau = \frac{TW}{TW_r}$$

$\mu = \frac{\mu_o}{\mu_{or}}$ presents the dimensionless oil viscosity (6)

epresent a constant that depends mainly on the cutoff viscosity (7)

TW represents the time-window in hours, μ_o oil dynamic viscosity measured at 15 °C in cP, and TW_r and μ_{or} represent the reference time-window and reference oil dynamic viscosity, respectively, at which the data change the trend (slope). Precisely, this reference point is defined by the intersection of the regression models developed for the two regions before normalization of the variables (oil viscosity and the time-window). ln represents the natural logarithm function.

For the series of the data analyzed in Appendix F, the conditions used to generate the time-window data used to develop the models are as follows:
Oil spill volume = 1000 bbl
Water temperature = 23 °C
Wind speed = 12 knots
μ_{co} = 7500 cP

For these conditions, key parameters in equations (3) and (4) are:
μ_{or} = 33.468 cP
TW_r = 8.754 Hour

The calculations of TW_1 (time-window for the first region (group) of the oil viscosity) using equation (3) were limited to 1000 hours as imposed in the post-processing of the data generated from OILMAP simulations in which the cutoff viscosity was not reached during the 1000 hours simulation period. Furthermore, the applicability of the models shown by equations (3) and (4) to other spill conditions than those for which the models were developed is discussed in section 6.3 of this report.

Details on the orthogonal regression and the fitting to the data are shown on Figure 6.

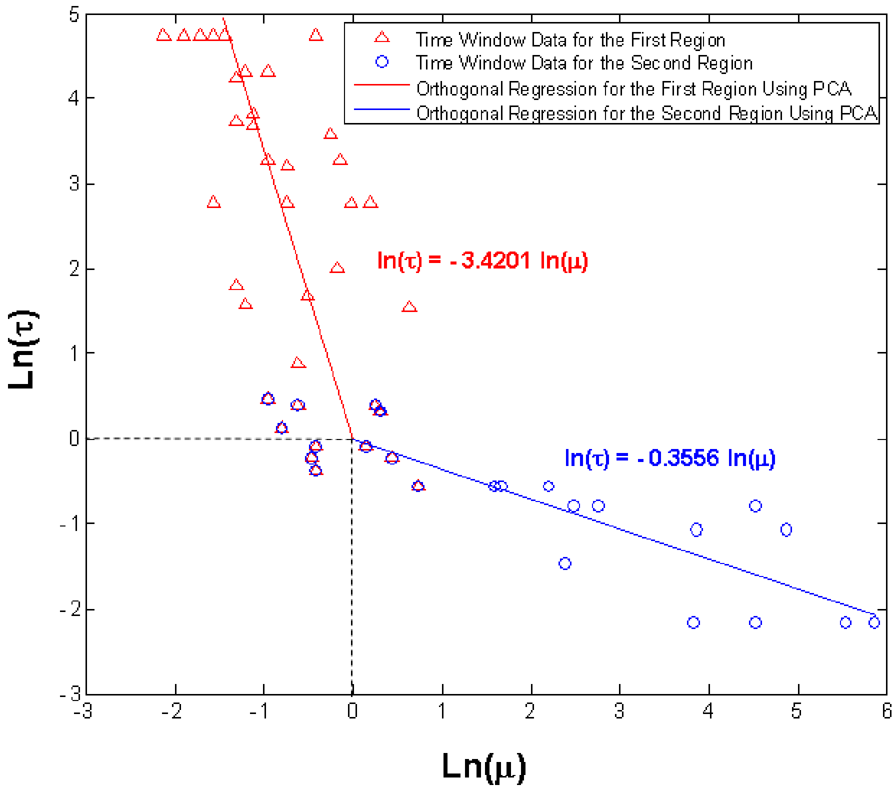


Figure 6: **Fitting linear models using orthogonal regression and principal components analysis on the two different groups of time-window data.**

6.2 Comparison between predicted time-window and the original data

Equations (3) and (4) were used to predict the time-window using oil viscosity data listed in Tables 5abc, wind speed of 12 knots, a spill volume of 1000 bbl, water temperature of 23 °C, and a cutoff viscosity of 7500 cP. The predictions were compared with the original data obtained by the OILMAP oil spill model using the same parameters. As it was done with the original data, the time-window was set to 1000 hour when the predictions exceeded this value. Results are shown in Figure 7.

While the agreement between the two predictions is not perfect, Figure 7 shows that overall the data show better agreement than with the previous correlations models. The results also show that further work is needed to improve the predictive models. What is also important to note is that the new models shown by equations (3) and (4) use oil viscosity only to predict the time-window with the goodness shown in Figure 7.

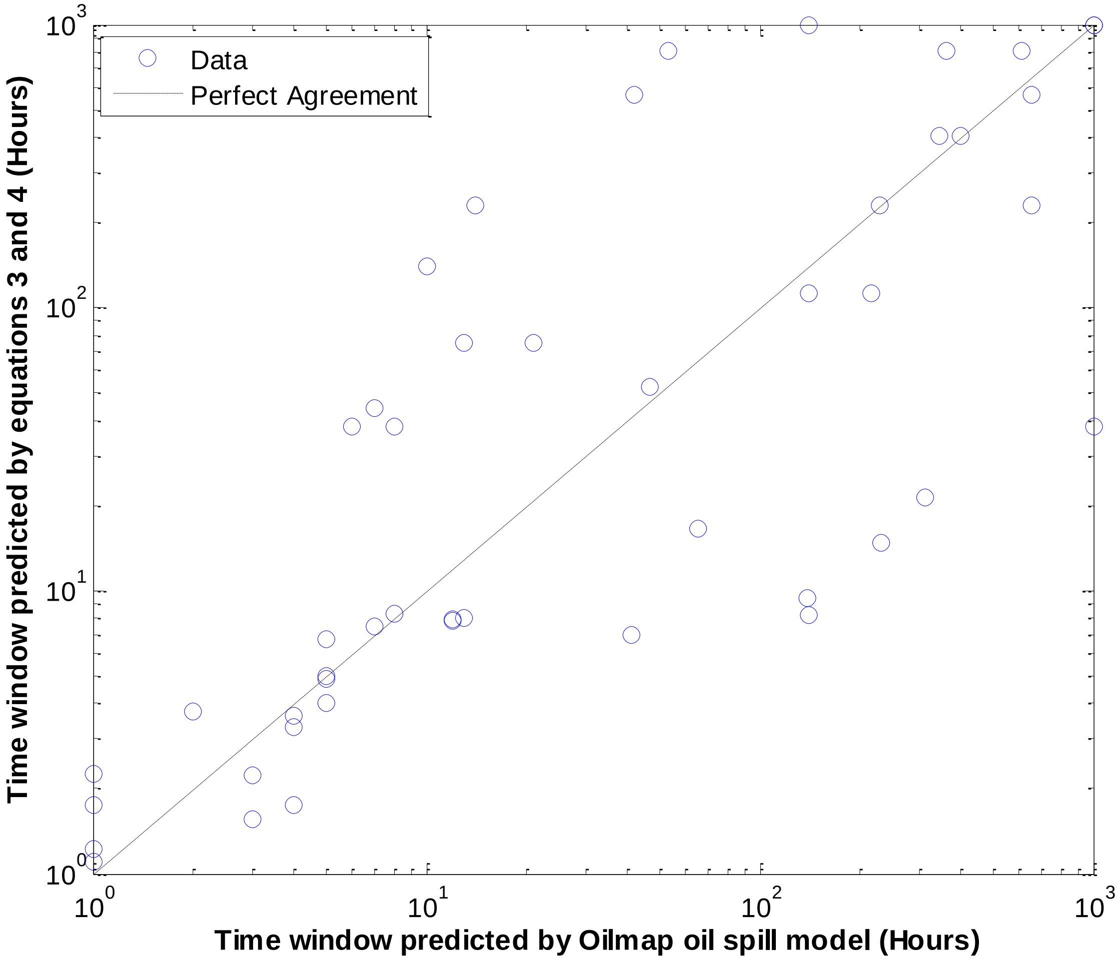


Figure 7: Comparison between predicted time-window using equations (3) and (4) and the original data predicted by OILMAP considering a spill volume of 1000 bbl, wind speed of 12 knots, water temperature of 23 °C, and cutoff viscosity of 7500 cP.

6.3 Sensitivity Analysis

The sensitivity of the new models shown by equations (3) and (4) to variations of the oil spill volume, wind speed, air temperature, and the cutoff viscosity was studied extensively in this project. Table 7 shows the values of the four variables used in this study. For each combination of these variables, the time-window was calculated using OILMAP oil spill model for all the non-weathered oil samples discussed in Tasks 1 to 3 (70 oils in total). The variables were then normalized using equation (5) and (6). In total, 9450 simulations were performed in this study. The results for all these simulations are shown in Appendices B, C and E. Results from these OILMAP simulations were then post-processed for the three cutoff viscosities shown in Table 7.

Table 7. Values of the variables used in the sensitivity analysis.

Variable	Values used in the sensitivity analysis study
Oil Spill Volume (bbl)	1000, 10000, 25000, 50000, 100000
Wind speed (knots)	8, 12, 15
Water temperature (°C)	13, 23, 29
Cutoff viscosity (cP)	5000, 7500, 10000

6.3.1 Effects of oil spill volume

As shown in Table 7, five oil spill volumes of 1000; 10,000; 25,000; 50;000 and 100;000 were used to study the sensitivity of the new models to this parameter. Wind speed, temperature and cutoff viscosity were kept constant to 12 knots, 23 °C and 7500 cP, respectively.

Results are shown in Figure 8. Overall the data showed that the time-window increases with the spill volume. The overall trend and the distinct separation between the two groups discussed previously are still shown by the additional four series of data obtained with spill volumes of 10,000; 25,000; 50,000; and 100,000 bbl. Ellen A038 and Santa Clara oils showed an unexpected increase of the time-window with oil viscosity.

A closer look at the results showed that the increase in the time-window with the spill volume is more important at viscosity lower than the reference viscosity μ_{or}. To clarify this, the same data shown in Figure 8 were normalized using the time-window data obtained with a spill volume of 1000 bbl and the reference viscosity μ_{or} discussed above. The results are shown in Figure 9. The following observations are made:

1. The increase of the time-window with the spill volume is higher in the first region of the data defined by oil viscosity smaller than the reference viscosity of 33.468 cP discussed above. In this region, most of the data showed that the increase is independent of oil viscosity.
2. In the second region defined by oil viscosity higher than 33.468 cP, the increase in time-window decreases with oil viscosity to finally vanish when oil viscosity reaches the cutoff viscosity of 7500 cP.

For oils with dynamic viscosity up to 33.468 cP and for which the time-window calculated with OILMAP was not cut to 1000 hours, effects of the spill volume are shown in Figure 10. The oils are identified by their initials in this figure. The time-window *TW* and the spill volume V_o were normalized by TW_1 and V_{o1}, the values of the same variables obtained with spill volume of 1000 bbl and the other parameters kept constant as discussed above. All the oils show similar trend of the spill volume effects on the time-window. The median increase is shown by the solid line in Figure 10. As shown on that figure, the equation of this fitting line is given by:

$$\frac{TW}{TW_1} = 1.00\left(\frac{V_o}{V_{o1}}\right)^{0.25} \qquad (8)$$

Comparisons between predicted time-window data using the new models given by equations (3), (4) and (8) and those predicted by OILMAP are shown on Figure 11.

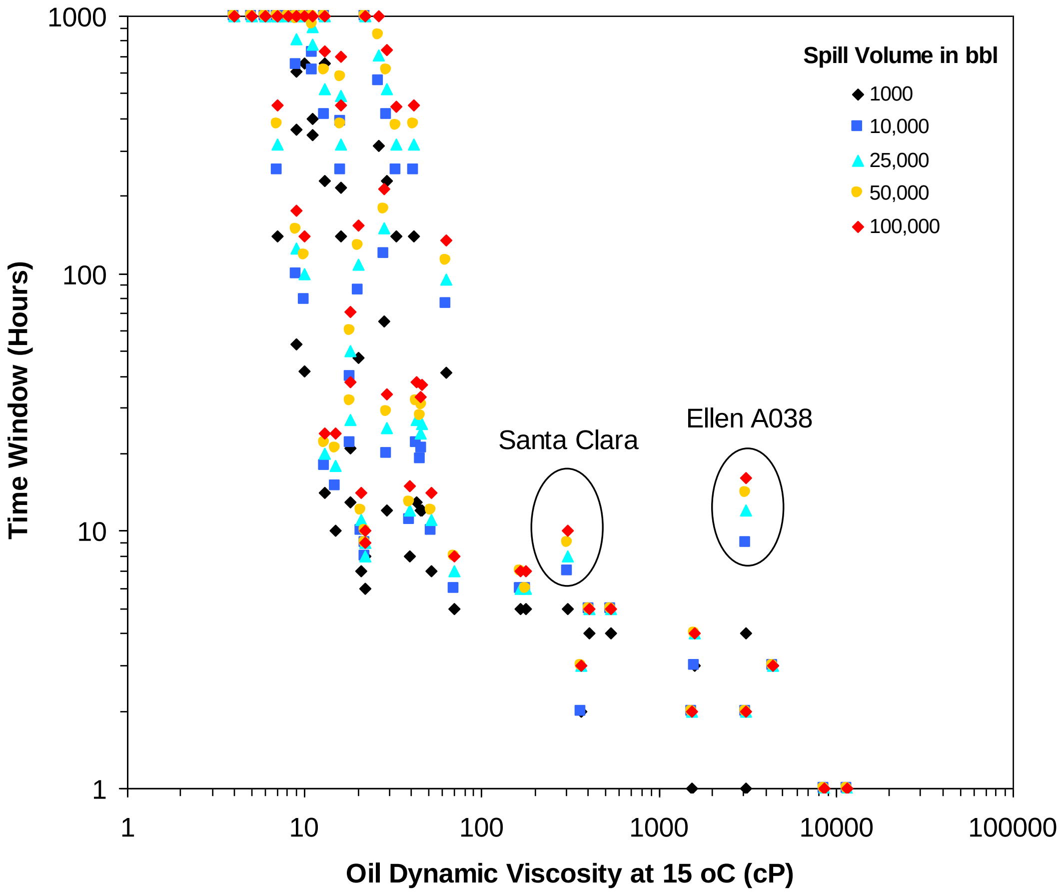


Figure 8: **Effects of the spill volume on the variations of the time-window with oil viscosity. The data were obtained from OILMAP simulations using the different spill volume indicated on the Figure, wind speed of 12 knots, water temperature of 23 °C, and cutoff viscosity of 7500 cP.**

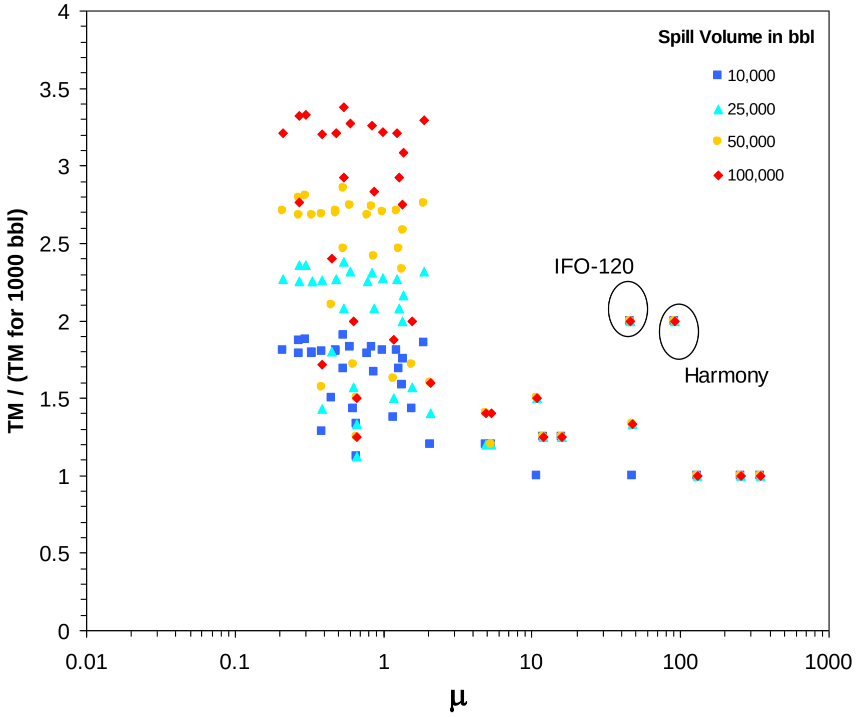


Figure 9: Data from Figure 8 with the time-window and oil viscosity normalized by the time-window obtained with a spill volume of 1000 bbl and the reference viscosity discussed above, respectively.

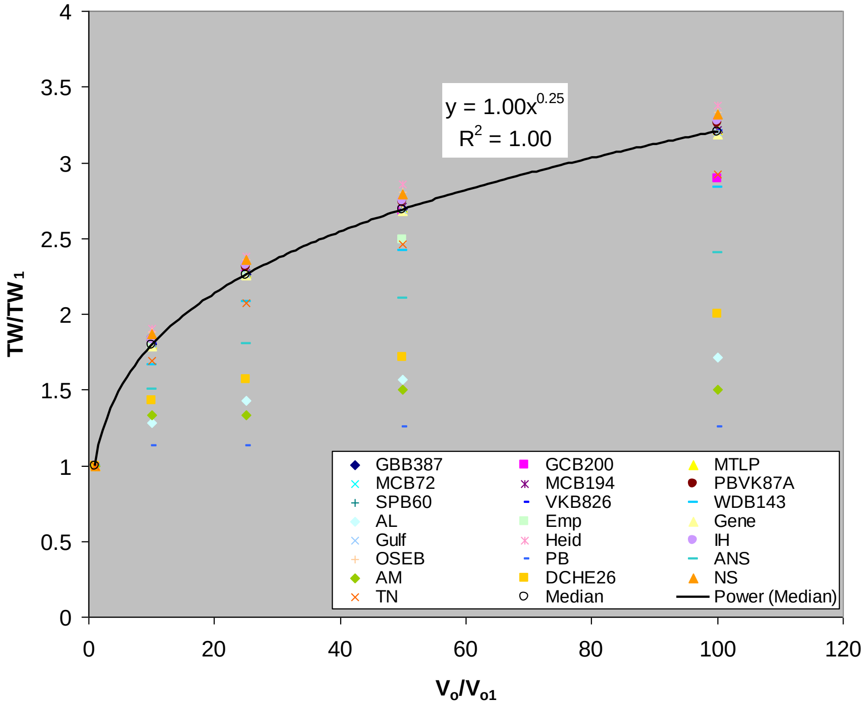


Figure 10: Variations of the increase of time-window with the spill volume for oils that have dynamic viscosity less than the reference viscosity of 33.468 cP. Each data series relates to different oil. The oils are referred by their initials. The solid line represents a curve fitting to the median variations.

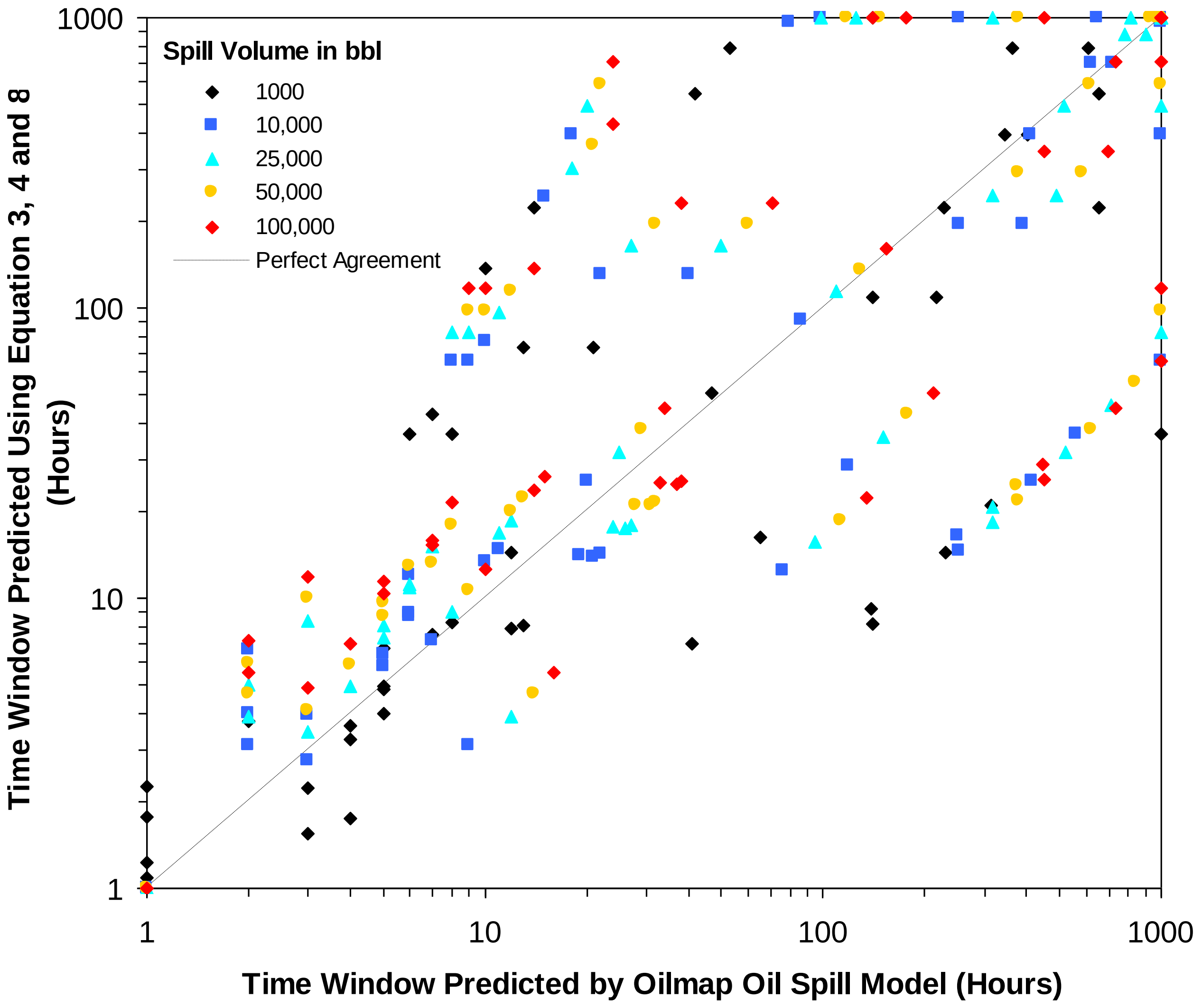


Figure 11: **Comparisons between predicted time-window using new models (equations 3, 4 and 8) and the original data predicted by OILMAP for different spill volumes wind speed of 12 knots, water temperature of 23 °C, and cutoff viscosity of 7500 cP.**

While the agreement between the predictions is not perfect, Figure 11 shows that the proposed models capture the overall effects of the spill volume. The improvement is obvious when comparing results shown in Figures 7 and 10. The results also show that additional research work is needed to improve the predictive models. Here again, it is important to note is that the new models shown by equations (3), (4) and (8) use oil viscosity only to predict the time-window with the goodness shown in Figures 7 and 10 for a wide variation of the spill volume.

6.3.2 Effects of water temperature

As shown in Table 7, three oil temperature of 13, 23, and 29 were used to study the sensitivity of the new models to this parameter. Wind speed, spill volume and cutoff viscosity were kept constant to 12 knots, 1000 bbl and 7500 cP, respectively. The 23 °C temperature was used in SL Ross (2007) study and the two other temperatures represent the monthly means (based on hourly data measurements) air temperature measured at the NDBC (BURL1) weather station of the NOAA National Data Buoy Center (http://www.ndbc.noaa.gov/). The 13 °C corresponds to the monthly average for the month of January and 29 °C is monthly average for August for that station. These values were obtained from processing hourly air temperature data observed from 1984 to 2007.

Results are shown in Figure 12. Overall the data showed that the time-window increases with the temperature. The overall trend and the distinct separation between the two groups discussed previously are still shown by the additional two series of data obtained with temperatures of 13 and 29 °C.

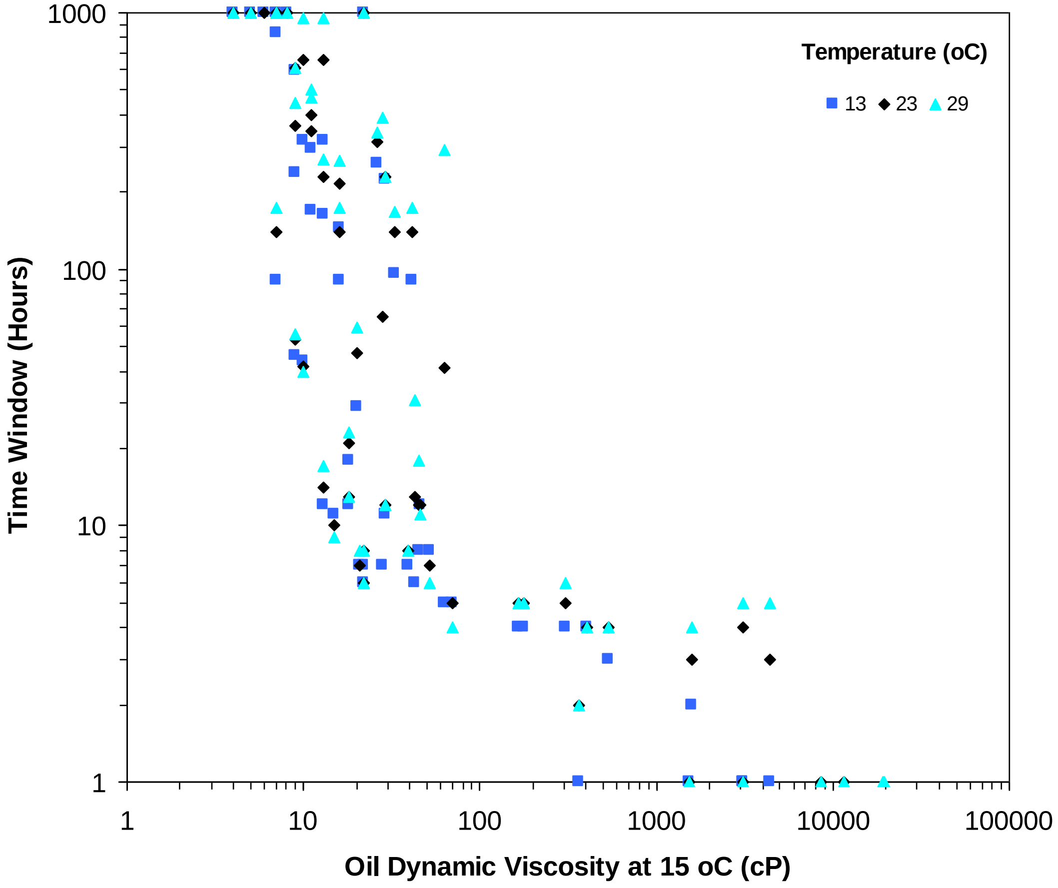


Figure 12: Effects of temperature on the variations of the time-window with oil viscosity. The data were obtained from OILMAP simulations using the three temperatures indicated on the Figure, spill volume of 1000 bbl, wind speed of 12 knots, and cutoff viscosity of 7500 cP.

Results shown in Figure 12 were normalized using the time-window data obtained with the temperature of 23 °C and the reference viscosity μ_{or} discussed above. The results are shown in Figure 13. Except for the Malongo, Petronius Block VK87A, and Lucula oils, the data showed similar increase of the time-window with temperature for most of the oils. For oils for which the time-window calculated with OILMAP was not cut to 1000 hours, effects of the temperature are shown in Figure 14. The oils are identified by their initials in this figure. The time-window TW and the air temperature T were normalized by TW_1 and T_1=23 °C, respectively. Most of the oils show similar trend of the temperature effects on the time-window. The median increase is shown by the solid line in Figure 14. As shown on that figure, the equation of this fitting line is given by:

$$\frac{TW}{TW_1} = 0.561\, e^{0.573\left(\frac{T}{T_1}\right)} \tag{9}$$

Comparisons between predicted time-window data using the new models given by equations (3), (4) and (9) those predicted using OILMAP are shown in Figure 15.

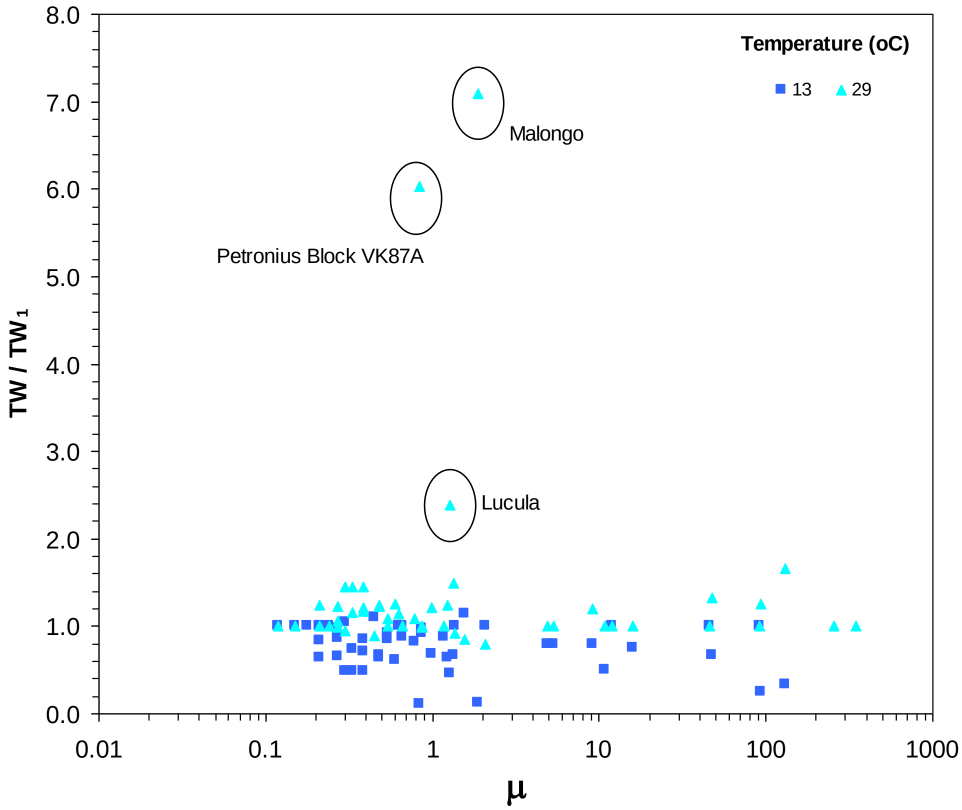
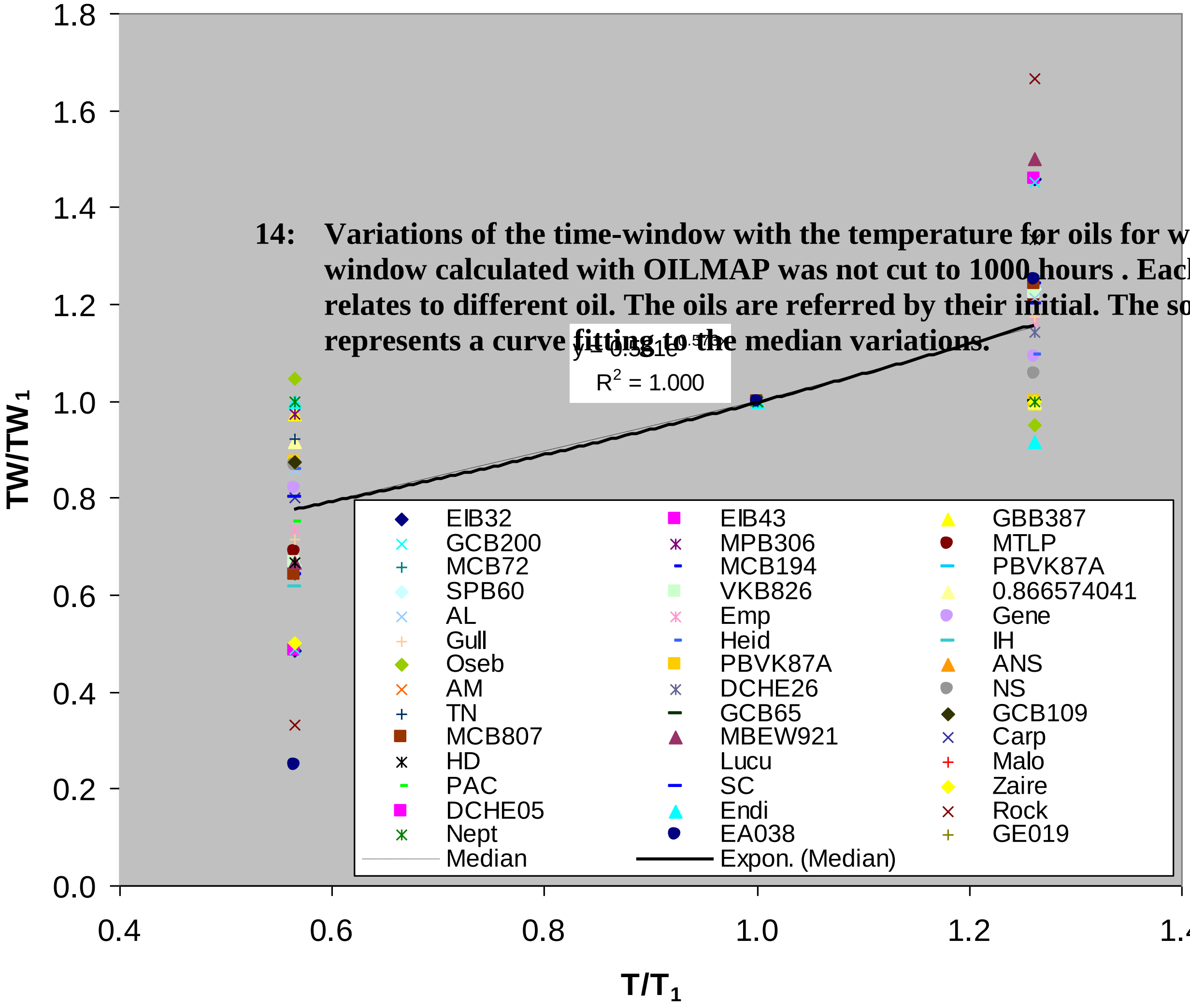


Figure 13: The same data as in Figure 12 with the time-window and oil viscosity normalized by the time-window obtained with a temperature of 23 °C and the reference viscosity discussed above, respectively.



14: Variations of the time-window with the temperature for oils for which the time-window calculated with OILMAP was not cut to 1000 hours . Each data series relates to different oil. The oils are referred by their initial. The solid line represents a curve fitting to the median variations.

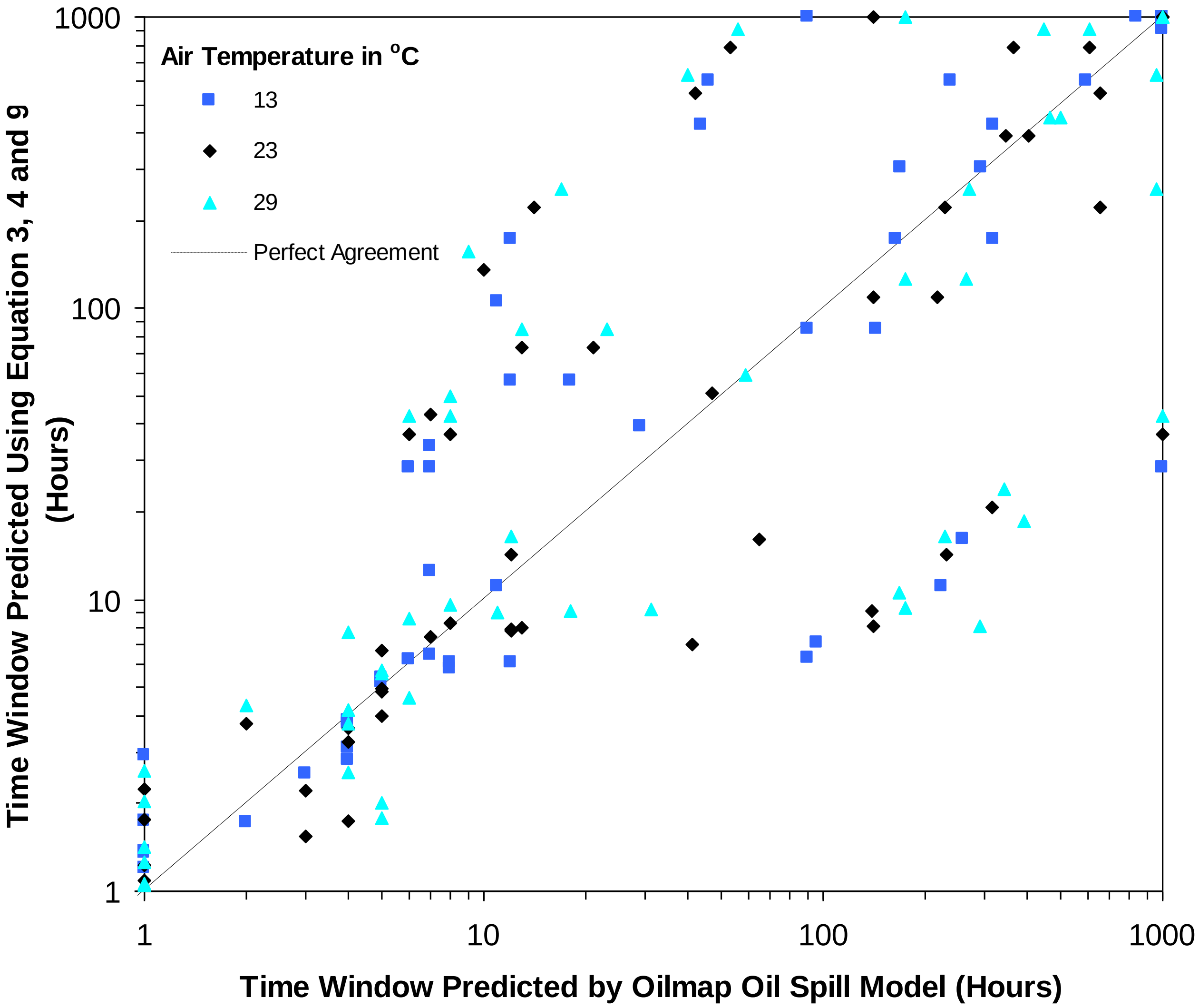


Figure 15: **Comparisons between predicted time-window using new models (equations 3, 4 and (9) and the original data predicted by OILMAP for different temperature, spill volume of 1000 bbl, wind speed of 12 knots, and cutoff viscosity of 7500 cP.**

While the agreement between the predictions is not perfect, Figure 15 shows that the proposed models capture the overall effects of temperature. The improvement is more obvious when comparing results shown in Figures 7 and 15. The results also show that further work is needed to improve the predictive models. Here again, it is important to note that the new models shown by equations (3), (4) and (9) use oil viscosity only to predict the time-window with the goodness shown in Figures 7 and 15 for different temperatures.

6.3.3 Effects of wind speed

As shown in Table 7, three wind speeds of 8, 12, and 15 knots were used to study the sensitivity of the new models to this parameter. Water temperature, spill volume and cutoff viscosity were kept constant to 23 °C, 1000 bbl and 7500 cP, respectively. The 12 knots wind speed was used in SL Ross (2007) study and the two other wind speeds represent the monthly means (based on hourly data measurements) wind speed measured at the NDBC (BURL1) weather station of the NOAA National Data Buoy Center (http://www.ndbc.noaa.gov/). The 8 knots is close to the monthly average for the month of August and 15 knots is close to the monthly average for January for that station. These values were obtained from processing hourly wind speed data observed from 1984 to 2007.

Results are shown in Figure 16. The data showed that the time-window decreases with wind speed. The overall trend and the distinct separation between the two groups discussed previously are still shown by the additional two series of data obtained with wind speeds of 8 and 15 knots.

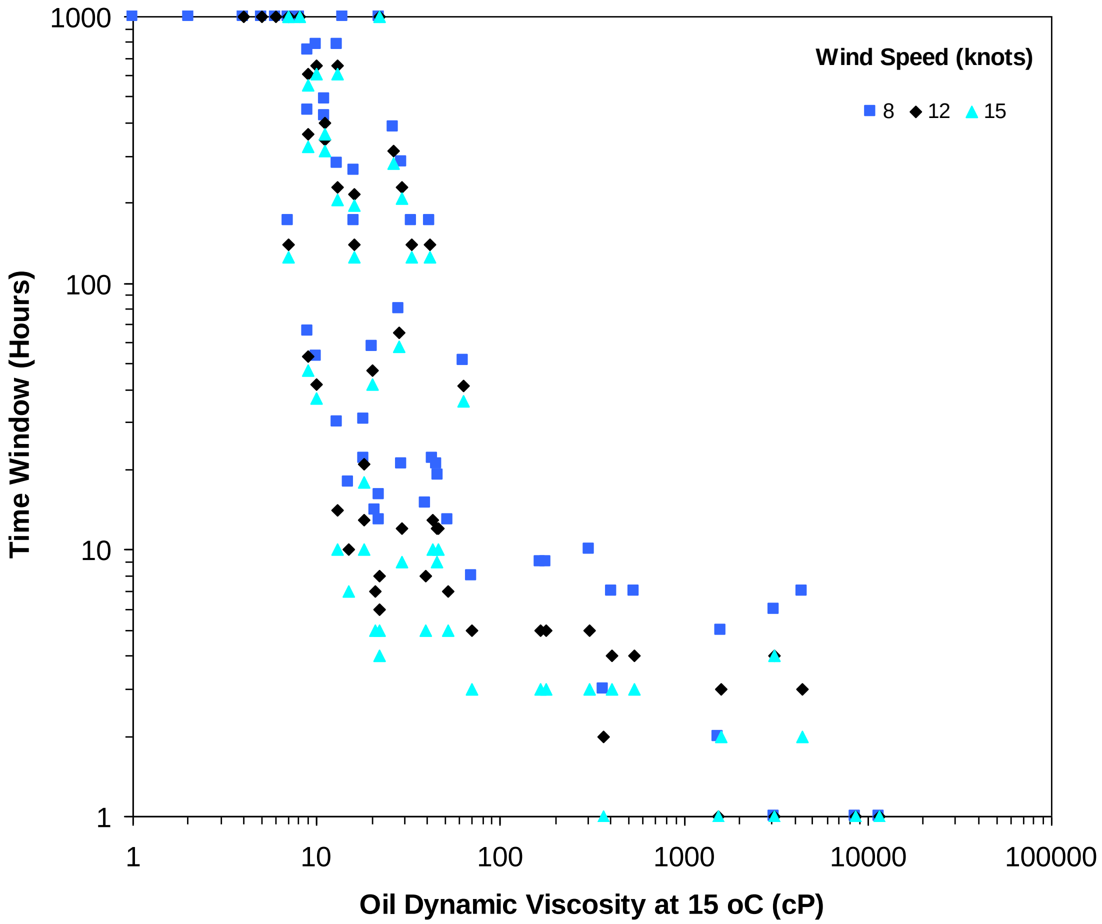


Figure 16: **Effects of wind speed on the variations of the time-window with oil viscosity. The data were obtained from OILMAP simulations using the three wind speeds indicated on the Figure, spill volume of 1000 bbl, water temperature of 23 °C, and cutoff viscosity of 7500 cP.**

The data shown in Figure 16 were normalized using the time-window data obtained with the wind speed of 12 knots and the reference viscosity μ_{or} of 33.468 cP, respectively. The results are shown in Figure 17. For oils for which the time-window calculated with OILMAP was not cut to 1000 hours, effects of the wind speed are shown in Figure 18. The oils are identified by their initials in this figure. The time-window *TW* and the wind seed W_s were normalized by TW_1 and W_{s1} =12 knots, respectively.

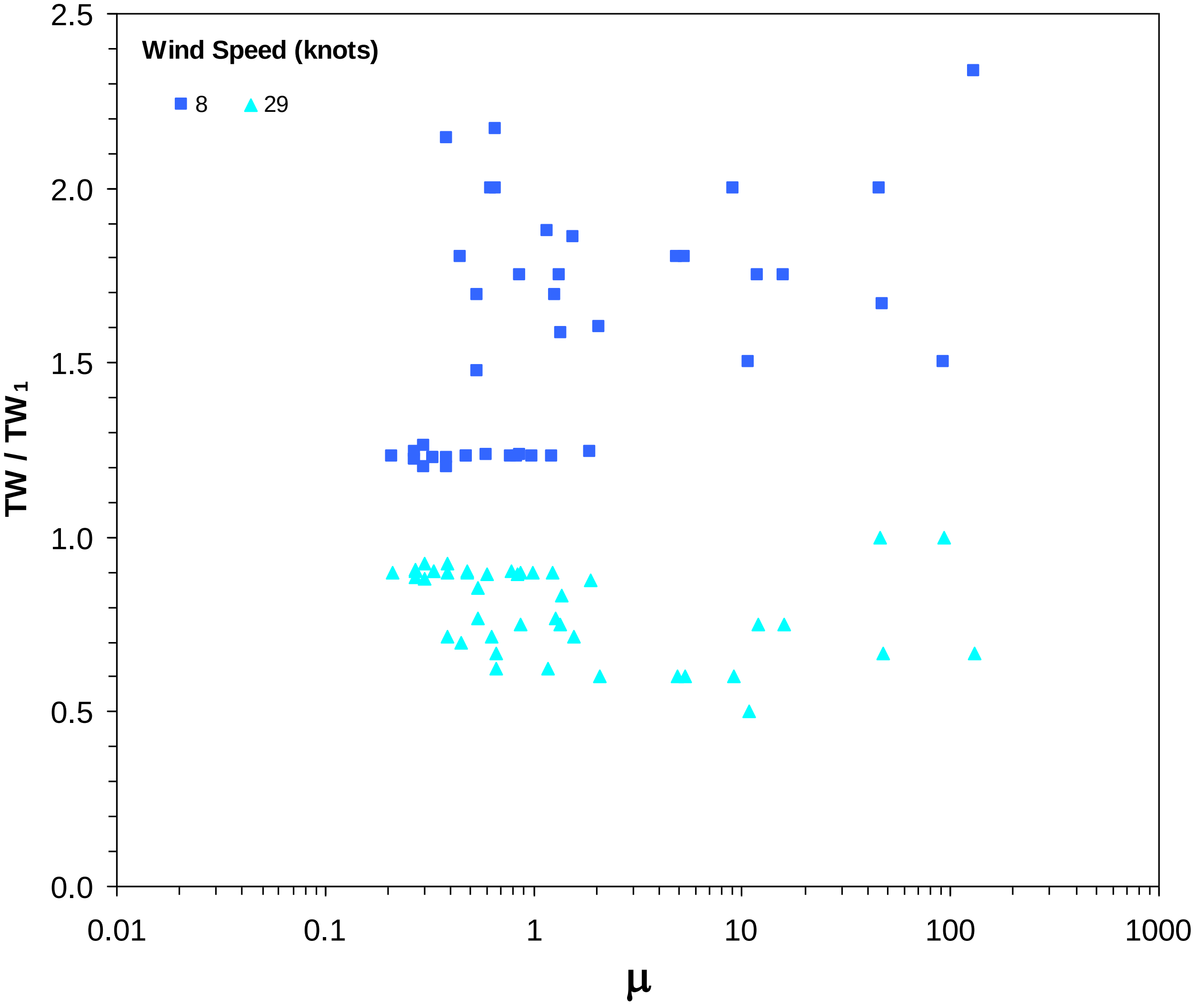


Figure 17: The same data as in Figure 15 with the time-window and oil viscosity normalized by the time-window obtained with a wind speed of 12 knots and the reference viscosity discussed above, respectively.

Most of the oils show similar trend of the wind effects on the time-window. The median effect is shown by the solid line in Figure 18. As shown on that figure, the equation of this fitting line is given by:

$$\frac{TW}{TW_1} = 2.64\, e^{-0.97\left(\frac{W_s}{W_{s1}}\right)} \tag{10}$$

Constant 2.8 was adjusted to 2.64 to obtain TW_1 when W_s=W_{s1}.

Comparisons between predicted time-window data using the new models given by equations (3), (4) and (10) and those predicted with OILMAP are shown on Figure 19.

While the agreement between the predictions is not perfect, Figure 19 shows that the proposed model capture the overall effects of wind speed. The improvement is more obvious when comparing results shown in Figures 7 and 19. The results also show that further work is needed to improve the predictive models. Here again, it is important to note that the new models shown by equations (3), (4) and (10) use oil viscosity only to predict the time-window with the goodness shown in Figures 7 and 19 for different wind speeds.

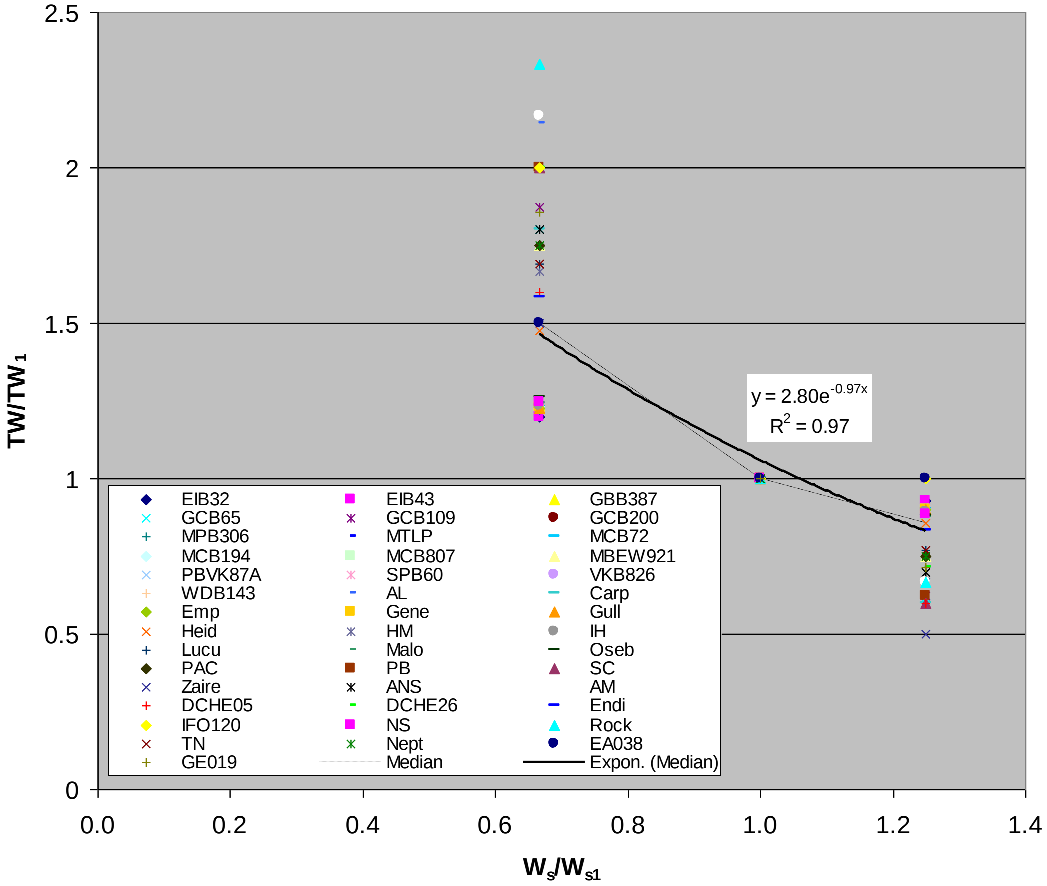


Figure 18: Variations of the time-window with the wind speed for oils for which the time-window calculated with OILMAP was not cut to 1000 hours. Each data series relates to different oil. The oils are referred by their initial. The solid line represents a curve fitting to the median variations.

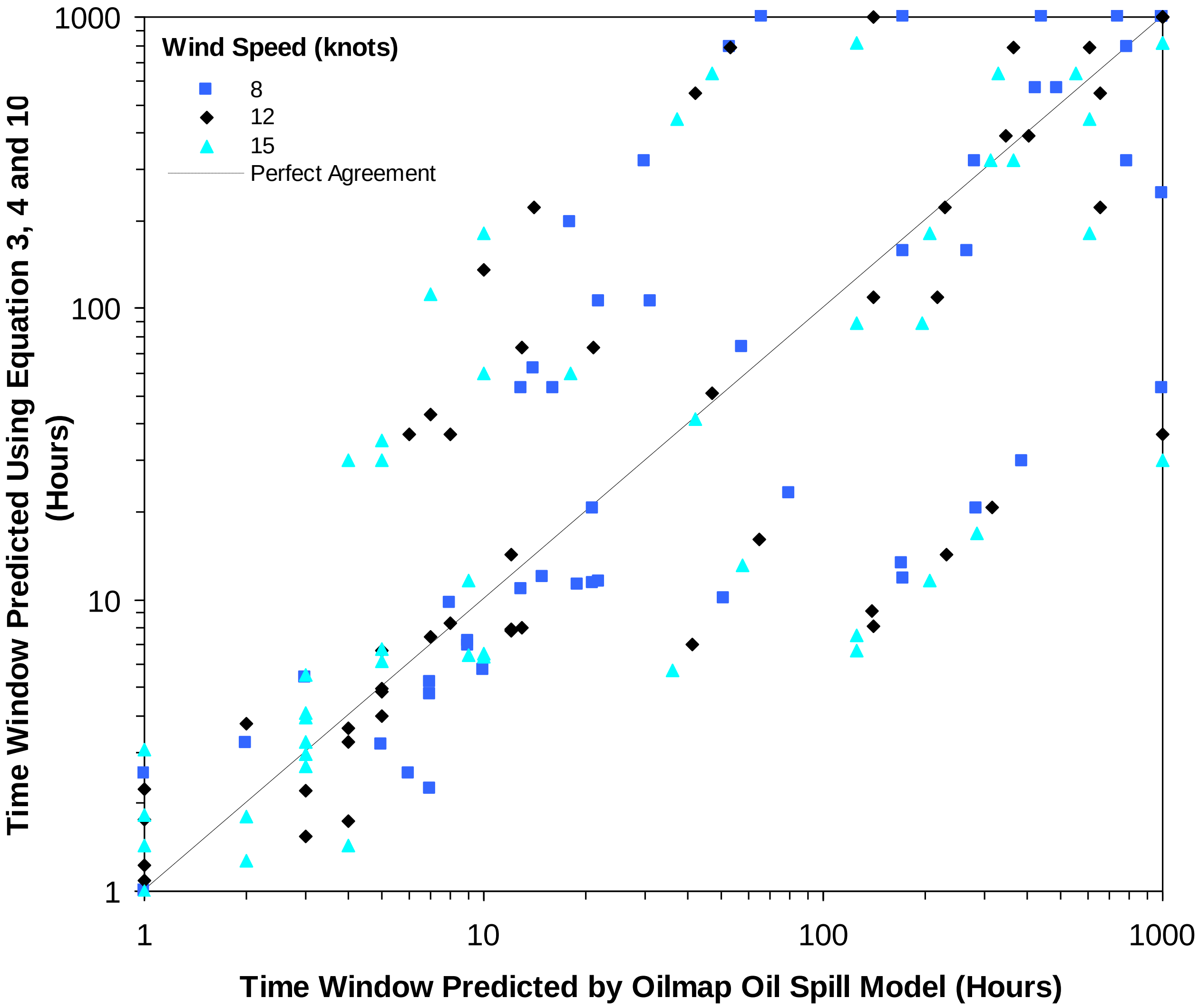


Figure 19: **Comparisons between predicted time-window using new models (equations 3, 4 and 10) and the original data predicted by OILMAP for different wind speed, spill volume of 1000 bbl, temperature of 23 °C, and cutoff viscosity of 7500 cP.**

6.3.4 Effects of the cutoff viscosity

As shown in Table 7, three cutoff viscosities of 5000, 7500 and 10,000 cP were used to study the sensitivity of the new models to this parameter. Water temperature, spill volume and temperature were kept constant at 12 knots, 1000 bbl and 23 °C, respectively. The 7500 cP cutoff viscosity was used in the SL Ross (2007) study and the two other cutoff viscosity represent lower and higher values of this parameter discussed in the literature (SL Ross, 2007).

Results are shown in Figure 20. As expected, the data showed that the time-window increases with the cutoff viscosity. The overall trend and the distinct separation between the two groups discussed previously are still shown by the additional two series of data obtained with cutoff viscosity of 5000 and 10,000 cP.

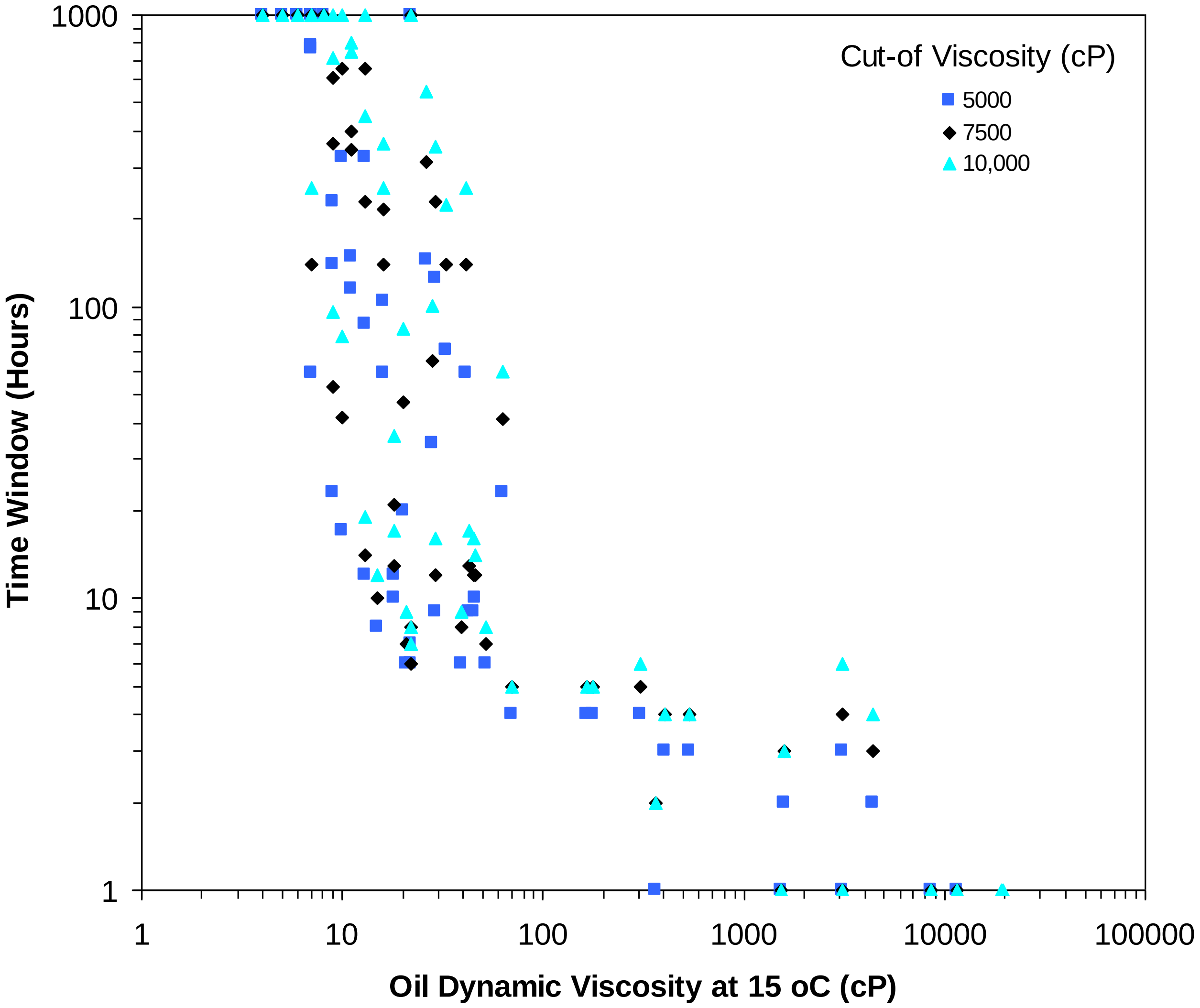


Figure 20: **Effects of cutoff viscosity on the variations of the time-window with oil viscosity. The data were obtained from OILMAP simulations using the three cutoff viscosities indicated on the Figure, spill volume of 1000 bbl, water temperature of 23 °C, and temperature of 23 °C.**

For oils for which the time-window calculated with OILMAP was not cut to 1000 hours, effects of the cutoff viscosity are shown in Figure 21. The oils are identified by their initials in this figure. The time-window *TW* and the cutoff viscosity μ_{co} were normalized by TW_1 and μ_{co1} =7500 cP.

Most of the oils show similar trend of the effects the cutoff viscosity on the time-window. The median effect is shown by the solid line in Figure 21. As shown on the figure, the equation of this fitting line is given by:

$$\frac{TW}{TW_1} = \frac{\mu_{co}}{\mu_{co1}} \qquad (11)$$

Comparisons between predicted time-window data using the new models given by equations (3), (4) and (11) and those predicted with OILMAP are shown on Figure 22.

While the agreement between the predictions is not perfect, Figure 22 shows that the proposed models capture the overall effects of the cutoff viscosity. The improvement is more obvious when comparing results shown in Figures 7 and 22. The results also show that further work is needed to improve the predictive models. Here again, it is important to note that the new models shown by equations (3), (4) and (11) use oil viscosity only to predict the time-window with the goodness shown in Figures 7 and 22 for different cutoff viscosity.

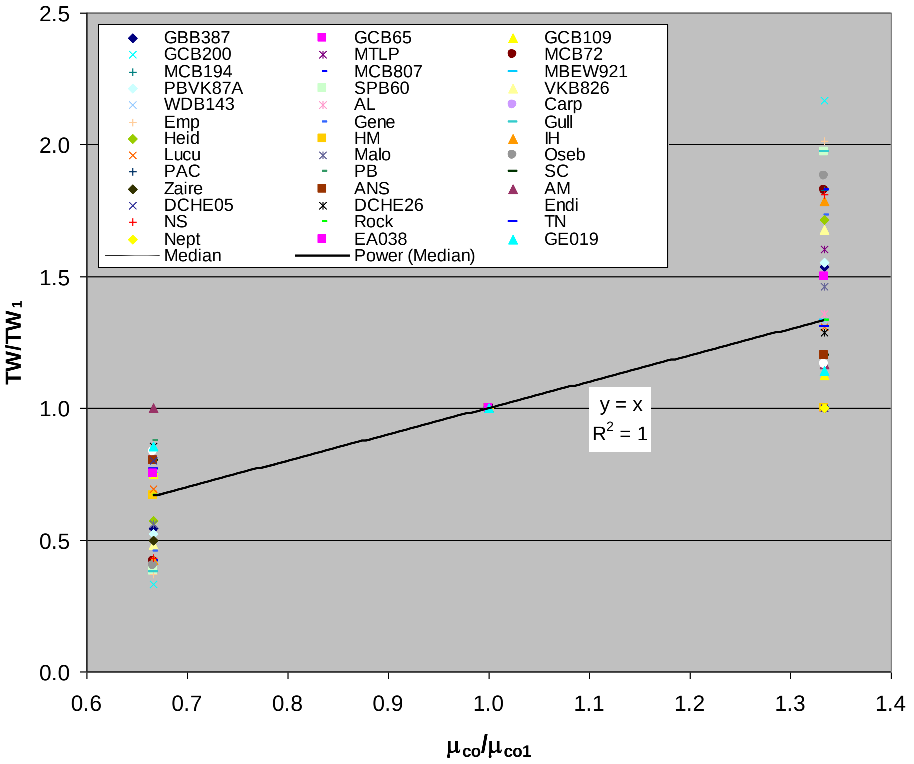


Figure 21: **Variations of the time-window with the cutoff viscosity for oils for which the time-window calculated with OILMAP was not cut to 1000 hours. Each data series relates to different oil. The oils are referred by their initial. The solid line represents a curve fitting to the median variations.**

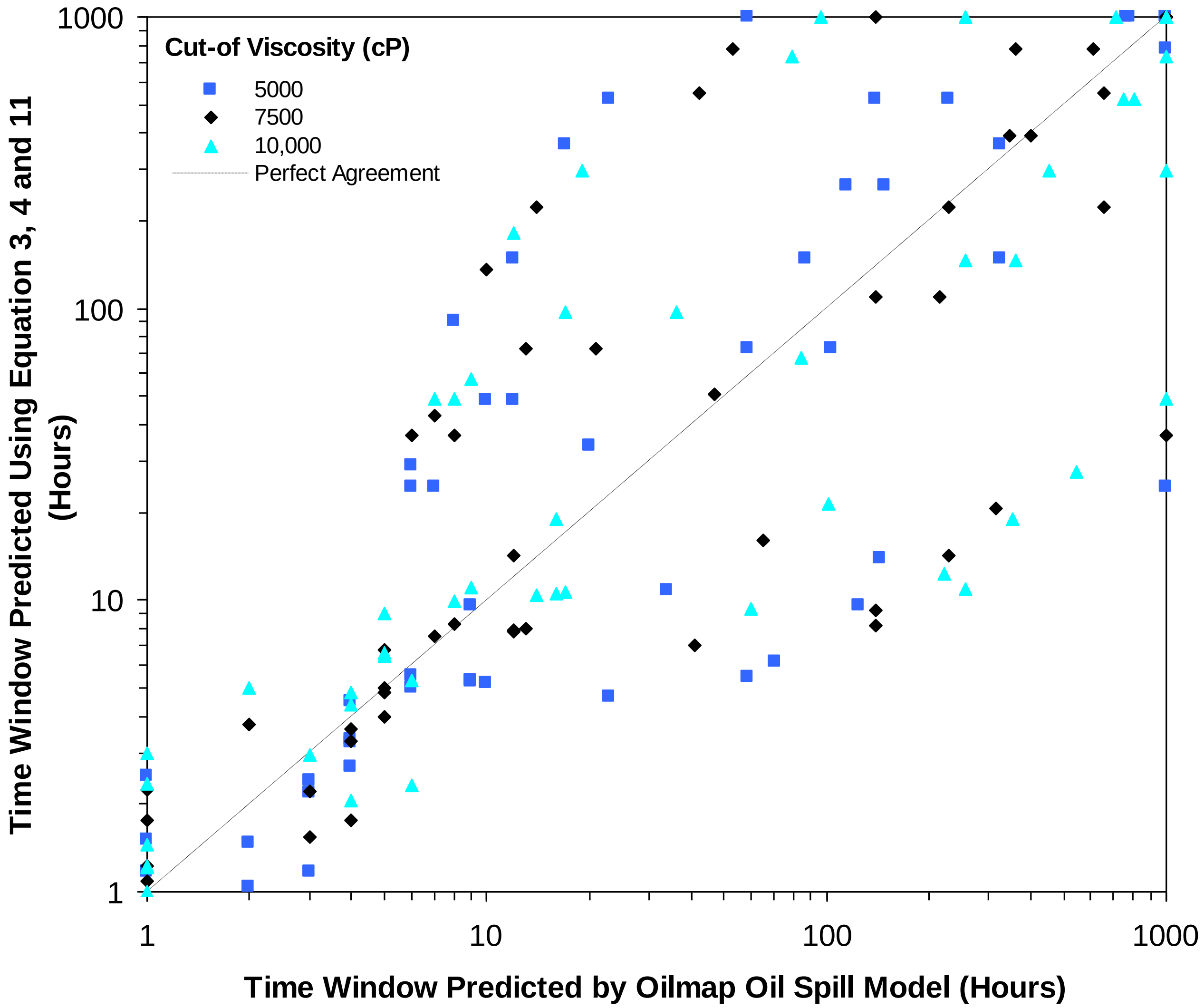


Figure 22: **Comparisons between predicted time-window using new models (equations 3, 4 and 11) and the original data predicted by OILMAP for different cutoff viscosities, spill volume of 1000 bbl, temperature of 23 °C, and wind speed of 12 knots.**

6.3.5 Simultaneous effects of spill volume, temperature, wind speed and cutoff viscosity.

The new models given by equations (3), (4), and (8) to (11) were tested by varying the four variables of spill volume, temperature, wind speed and cutoff viscosity in their entire ranges shown in Table 7. The predictions were compared to the time-window predicted using OILMAP and presented in Appendices B,C, and E. A total of 9450 simulations were run and processed to generate the same number of time-window data points. Results are shown in Figure 23.

As expected, the predictions using the new models are not in perfect agreement with the time-window data predicted using OILMAP. Specifically, two groups of data away from the perfect agreement line are clearly shown in the figure. In these groups of data the new models underestimate or overestimate in a consistent trend (almost parallel to the line of perfect agreement) the time-window predicted by OILMAP. This grouping is also shown in Figure 11, 15, 19, and 22. Apparently, these grouping are related to the data that were initially under or above the fitting line using orthogonal regression, as shown in Figure 24. More research work is needed to improve the models to capture the spreading of the data around the regression lines shown in Figure 24. The same remarks apply for the prediction of small values of the time widow (less than about 10 hours). The models overestimate the small values of the time-window in most of the simulations run in this study.

However, the predictions by the new models are in good agreement with the majority of the data shown in Figure 23. Considering the simplicity of the structure of the models, the wide ranges used in which the four parameters were varied, and the fact that the original data are in fact a prediction of OILMAP oil spill model, which not immune from uncertainty, the new models offered a new opportunity to improve the previous models (Eqs. 1 and 2) developed for very specific and limited conditions.

7 Validation of the new models (Tasks 5 and 6)

The goals of this Tasks 5 and 6 are:

1. to validate the final models to predict the time-window for application dispersant using existing data
2. to validate the final models to predict the time-window for application dispersant using the new data obtained in this study on dispersant effectiveness from the Swirling Flask Test (SWT).

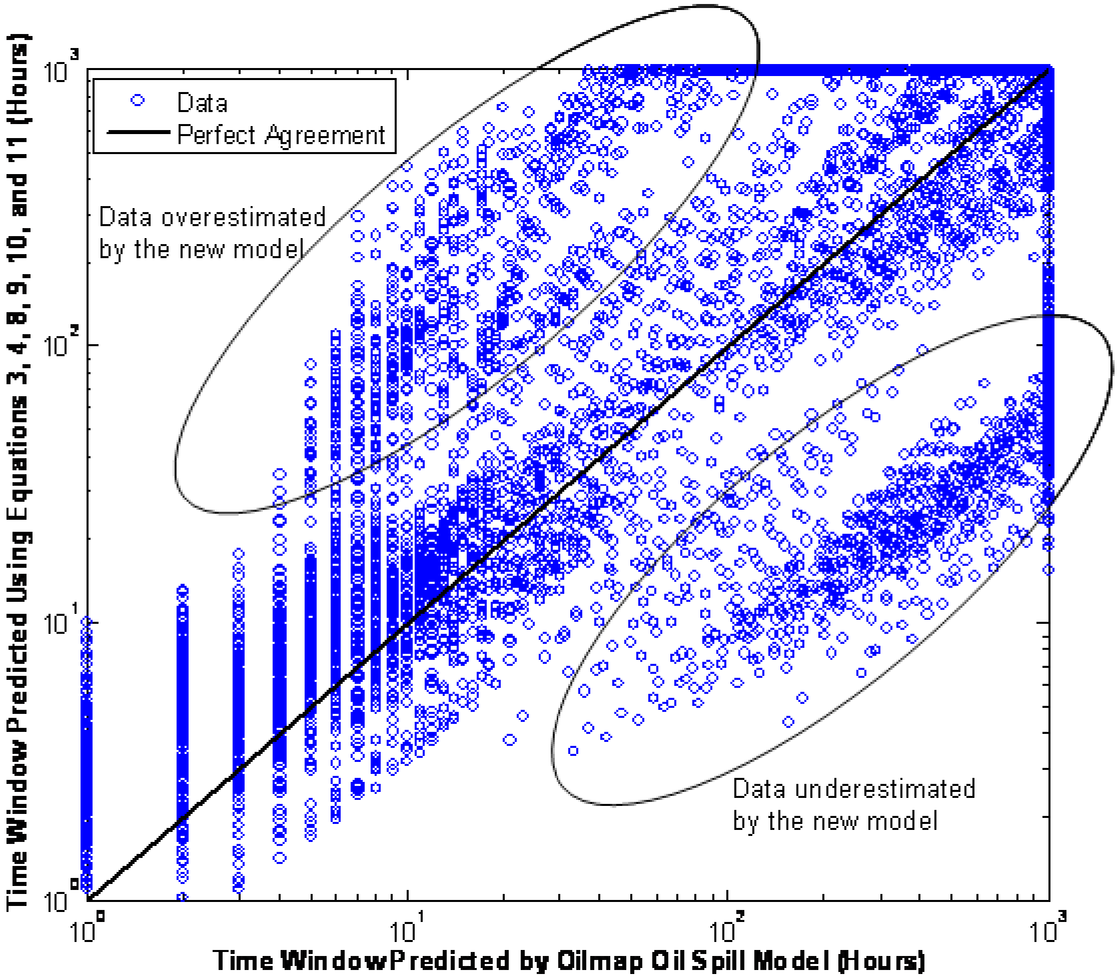


Figure 23: **Comparisons between predicted time-window using new models (equations 3, 4 and 8 to 11) and the original data predicted by OILMAP for all the spill volumes, temperatures, wind speeds and cutoff viscosities shown in Table 7. A total of 9450 simulations were performed and the results were processed to generate the same number of points shown in this figure.**

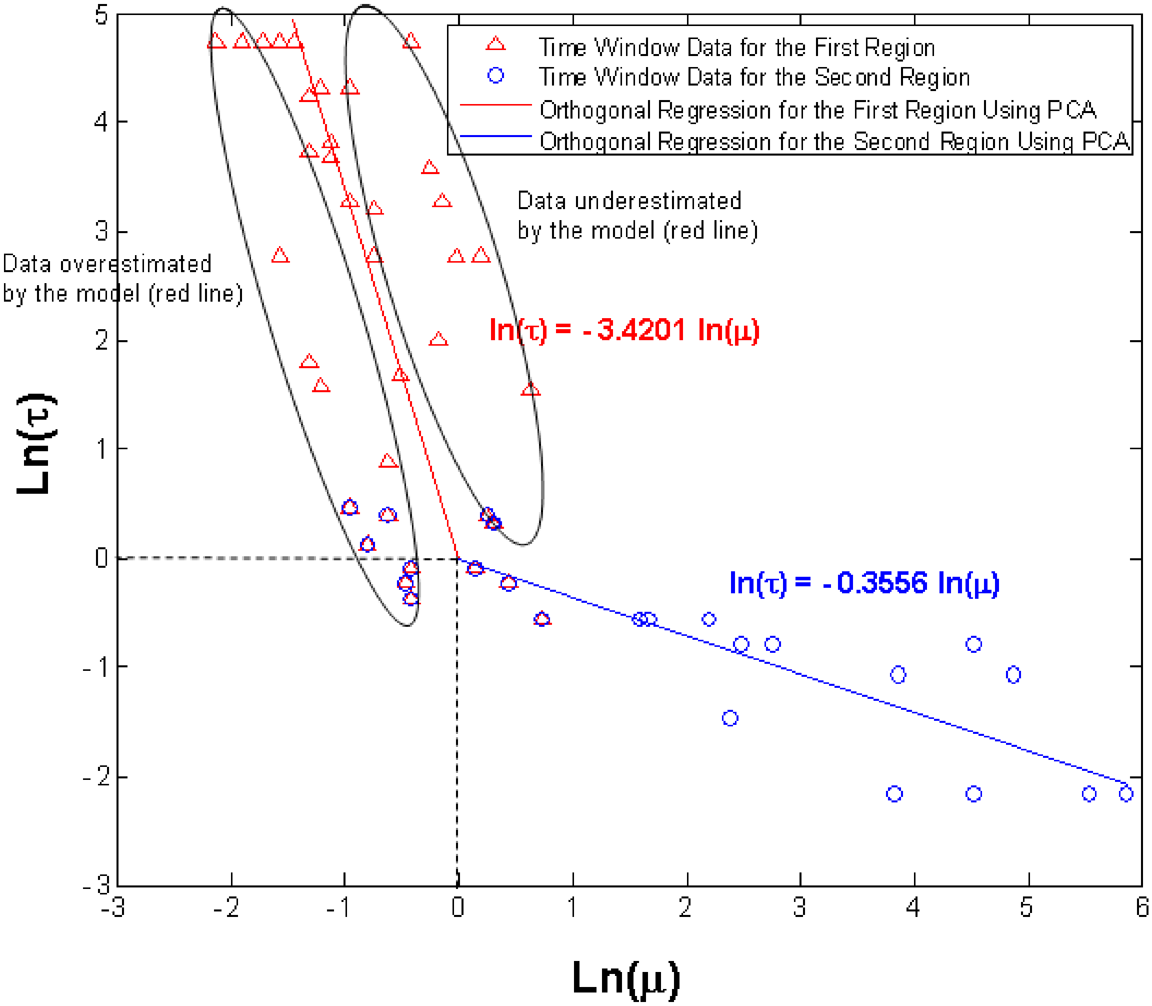


Figure 24: **Illustration of the two group of the original data for which the new models overestimate or underestimate the time-window predicted by OILMAP oil spill model.**

7.1 Validation of the final models using existing data

This study focused on using large tank dispersant effectiveness testing where weathering of the oil is tracked continuously for a long period of time (few days) and dispersant effectiveness was performed on the weathered oil periodically and used to determine the time-window. Such series of data are very rare. Related to this project, SL Ross (2012) conducted a series of large tank testing at Ohmsett – The National Oil Spill Response Research & Renewable Energy Test Facility (http://www.ohmsett.com/) to generate such data to validate their correlation models shown by equations (1) and (2). To our knowledge, these are the only series of large tank tests that provide most of the parameter needed to validate the new models. Data from the SL Ross report (SL Ross, 2012) were used to validate the new models described by equations (3), (4) and (8) to (11).

Conditions of the SL Ross Ohomsett tests and the corresponding measured and predicted values of the time-window are listed in Table 8. Values listed in this were obtained as follows:

1. Dynamic viscosity of fresh oils measured at 15 °C was obtained from this study. Some inconsistencies were found between the values listed in Table 1 in SL Ross (2012) and those obtained in this study (Tablees 5a and 5b above).
2. Values of the oil volumes used in each test (second column in Table 8) were obtained from SL Ross via US-BSEE and converted to bbl.
3. Average air temperature and wind speed were calculated in this study using information about the dates and times during which each test was run (Figures C1 to C7 in SL Ross, 2012) and weather conditions recorded at the Ohmsett Facility weather station. This information was also provided by SL Ross via US. BSEE.
4. The measured time-window was recalculated in this study using the data listed in Table 2 in SL Ross (2012). In most of the tests, the time-window was estimated form the data using extrapolation of the trend defined by the last two points in each series. As set in SL Ross (2012), the time-window was determined when dispersant effectiveness reaches 30%. These calculations were needed because some inconsistencies were found between the data listed in Table 2 and those shown in Figure 5 of the SLR (2012) report. A good example of relates to Anadarko oil. The measured time-window for this oil was set to 60 hours in Figure 5. A closer look at the related data in Table 2 in the SL Ross (2012) report showed that the average dispersant effectiveness for this oil reach 41.8% when 61.25 hours has elapsed. Then, it is clear that at 30% effectiveness, the time elapsed (time-window) would be much higher than 60 hours indicated in Figure 5. Our calculations showed that time-window for this oil is 86 hours or more.
5. The time-window predicted using the new models (last column in Table 8 below) was calculated using equations (3), (4) and (8) to (11). As such, the models take into account the effect of spill volume, air temperature, wind speed and the cutoff viscosity. Again, a closer look at the data in Table 2 of the SL Ross (2012) report showed that the cutoff viscosity is higher than 10,000 for all oils. This is the highest values of the cutoff viscosity we used in the development of the new models. As such, this value was used for the calculation of the time-window shown in the last column in Table 8.

Comparisons between measured and predicted values of the time-window are shown in Figure 24. The results shown in this figure and in Table 8 showed substantial improvements of the new models to predict the time-window compared to the correlation models given by equation (1) and (2). While many remarks can be made regarding the procedures used to conduct the large tank tests and the estimate the time-window from the Exdet dispersant effectiveness test, the following observations are worth mentioning:

1. The estimation of the time-window for Oseberg oil from the results of the tank tests listed in Table 2 of the SL Ross report is questionable. The dispersant effectiveness tests were stopped 22 hours only after the start of the test. At that time the dispersant effectiveness was still high at 78.8%. Extrapolation of the data to 30% cannot be accurate, especially given that this oil is the less viscous oil. As such, a time-window higher than what is estimated in Table 8 is expected for this oil. This means that the high value estimated by the new models is possibly much closer to the experimental value than what is shown in Figure 25.
2. Various techniques were used to contain the slick during the large tank experiment as indicated in the SL Ross (2012) report. This means that the spreading and dispersion of the oil was limited. While this may not have a significant impact on the two less viscous oils (Anadarko and Oseberg), it is expected to affect the predictions using the new models for the viscous oils because the volume of the spill is used as a parameter in the calculation and small volumes were used in most of the tests. Containment has similar effects than increasing the volume of the spill in term of thickness of the slick. As such, the small volumes used to predict the time-window for the viscous oils may not be appropriate, which may explains the underestimation of the time-window for these oil by the new models.

Table 8. **Conditions of the large tank testing conducted by SL Ross (2012) at Ohmsett Facility and measured and predicted time-window for application of chemical dispersant.**

Oil Tested	Dynamic viscosity of fresh oil measured at 15 °C (cP)	Volume spilled (bbl)	Average air temperature during the test (°C)	Average wind speed during the tests (knot)	Time-window measured at Ohmsett (Hour)	Time-window predicted using SL Ross correlations models (equation 1 and 2) (Hour)	Time-window predicted using the new models (equation 3,4 and 8 to 11) (Hour)
Endicott	46.4	2.38	24.3	3.5	22	3	4.7
Anadarko	13.5	1.90	21.1	7.3	86	178	75.5
Neptune	402	1.90	23.6	7.9	7	0.42	1.4
Venoco E-19 (Gail E019)	51.7	1.19	18.1	6.2	9	24	2.6
Oseberg	10	1.31	14.2	10.3	64	30	126.8
PER 038 (Ellen A038)	3100	0.95	18.6	2.9	2	0.03	0.8
Sockeye 2000	761	0.88	20.2	3.3	2	0	1.2

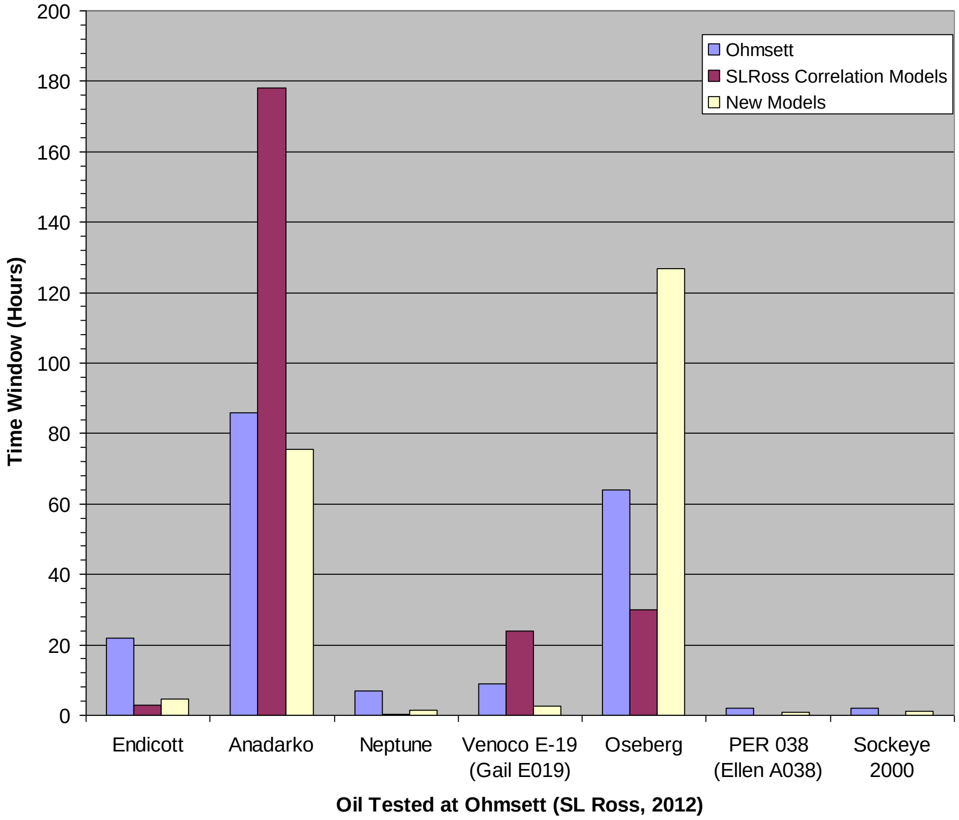


Figure 25: **Comparisons between measured time-window at the Ohmsett tank tests conducted by Sl Ross (2012) and the predictions using SL Ross correlation models (equations 1 and 2) and the new models (equation 3, 4 and 8 to 11)**

7.2 Validation of the final models using the new data obtained from the Swirling Flask Test (SFT)

While conscious of the limitations of using the results of the Swirling Flask Test (SFT) to estimate the time-window for application of chemical dispersant, an attempt was made to combine the results from the SFT experiments performed on two weathering percentages and the equation of evaporation to estimate the time-window and compare with the predictions of the new models. The procedure includes the following steps:

1. Using linear interpolation, estimate evaporation loss $EL_{30\%}$ at which dispersant effectiveness (DE) reaches 30% as suggested in SL Ross (2012). For this, results (Appendix B) of the SFT and the two weathering percentages tested in the lab were used.

2. Using the equation for the evaporation loss (Appendix B), calculate the time at which the evaporation loss reaches $EL_{30\%}$ and use this time as the experimental time-window for application dispersant.

3. Use the new models given equations (3) (4) and (8) to (11) to predict the time-window and compare it with the experimental time-window obtained from the previous step. For this, air temperature was set to 15 °C as used in the experiment, wind speed to 0 knots, spill volume to 1000 bbl as the evaporation experiment was conducted using pen procedure (oil contained), and cutoff viscosity to 7500 cP.

Key parameters used, the estimated experimental time-window and the predictions using the new models are shown in Table 9. As shown from the last two columns, while there is some agreement between the data and the predictions, it is difficult to conclude on the validation of the models using such a series of data. As discussed above, the use of data from the SFT tests remain questionable. For instance, the use of 30% effectiveness to determine the time-window is not necessarily valid with this test. Also, as shown in the SL Ross (2012) study, dispersant effectiveness does not necessarily decreases linearly with time as it was assumed here. But, with further testing and calibration, the results of the SFT test can be made useful to generate data on the time-window and to validate the models. Further research is needed to explore this possibility.

Table 9. Time-window estimated using the results of the SFT tests and the equation of evaporation loss compared to time-window predicted using the new models.

Oil Name	Dynamic Viscosity at 15 °C (cP)	Evaporative loss at weathering 1 (%)	Evaporative loss at weathering 2 (%)	DE at weathering 1 (%)	DE at weathering 2 (%)	Estimated weathering at DE of 30% (%)	Estimated time-window estimated using the equation to predict evaporation (Hours)	Time-window predicted using the new models (Hours)
Alaska North Slope	15	0	30.67	67	11	20.3	10	268
Arabian Medium	22	0	31.35	53	10	16.8	6	84
DOBA	3110	0	14.13	10	<10	N/A	0	4
Dos Cuadras HE-05	70	0	23.4	67	10	15.2	13	14
Dos Cuadras HE-26	21	0	32.2	69	11	21.7	15	99
Endicott	46	0	21.41	62	10	13.2	10	17
Harmony	3080	0	17.11	<10	<10	N/A	0	4
North Star	9	0	35.41	74	43	50.3	18906	1748
Rock	4360	0	9.06	<10	<10	N/A	0	3
Terra Nova	18	0	28.55	43	10	11.2	1	173
Neptune	402	0	17.3	<10	<10	N/A	0	8
Ellen A038	3100	0	15.88	<10	<10	N/A	0	4

8 Conclusions

This study included two major parts. In first one physicochemical properties of 24 oils from the Gulf of Mexico and California were measured for further use in the validation of the two correlations models developed in a previous study conducted by SL Ross (2007) to predict the time-window for application of chemical dispersant for spill volumes of 1000 and 10,000 bbl. The second part was to validate and improve these correlation models using a total of 70 oils and to conduct a sensitivity analysis for the improved/new models to spill volume, temperature, wind speed, and cutoff viscosity. The main conclusions of this study are:

1. Time-window predicted using the SL Ross oil spill model SLROSM and the two correlation models were very different from the time-window predicted using OILMAP oil spill model.

2. Time-window predicted using OILMAP is not correlated with wax and sulfur contents and shows some correlation with saturates content.

3. Simple correlation and Principal Component Analysis (PCA) techniques showed that the time-window predicted using OILMAP is strongly correlated with oil viscosity measured at

15 °C. The data showed two distinct trends for viscous and less viscous oils. The separation occurs at a viscosity of about 33.5 cP. Based on orthogonal regression using PCA analysis, two models were developed to predict the time-window for oils with oil viscosity below and higher than this reference viscosity. The models are shown by equations (3) to (7).

4. Sensitivity study of the new models to oil spill volume, wind speed, temperature and cutoff viscosity was conducted. A total of 9450 OILMAP simulations were run and the data processed to develop models to take into account the effects of these parameters on the prediction of the time-window. These models are shown by equation (8) to (11). These models were tested using the 9450 data points for the time-window.

5. The new models were validated using dispersant effectiveness tests conducted by SL Ross (2012) at the Ohmsett facility. Results showed that the new models perform better than the original correlation equations proposed by SL Ross (2007).

6. This study showed also that further research is needed to improve the prediction of the time-window using physicochemical properties of the oil. This requires, among others, conducting additional large tank tests where both the weathering and the effectiveness of oil are tracked for a long period of time.

7. More importantly, it is of paramount importance to note that that development of the new models shown by equations (3) to (11) was based on the data generated using OILMAP oil spill model. As such, the accuracy of the new models to predict the time-window for application of chemical dispersant is directly related to the accuracy of this model oil weathering under different weather conditions and for different oils.

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Appendix A

List of fresh oil properties used in the SL Ross study (Table 2 in SL Ross, 2007)

Oil Filename	Fresh Oil Properties																Time Window (hr)	
	API Gravity	Sulfur (wt %)	Flash point (°C)[1]	Pour Point (°C)	Viscosity (cP)	Saturates (wt %)	Aromatics (wt %)	Resin (wt %)	Asphaltenes (wt %)	Wax (wt %)	BP<200 °C (wt %)	BP<250 °C (wt %)	BP<300 °C (wt %)	BP<350 °C (wt %)	BP < 400 °C (wt %)	BP<450 °C (wt %)	1,000 Barrel	10,000 Barrel
Green Canyon Block 65	19.5	1.9	-4	-28	102	38	40	14	8	1	11	18	26	34	43	52	5.2	6
West Delta Block 143	29.1				20	61	27	9	3.6								9.1	13.6
Morpeth Block EW921	25.1	1.73	-10	-65	30	71	17	8	4	0.7	14	20	26	34	40	48	12.1	16.7
Garden Banks Block 386	29.5	1.52	-28	-39	19	53	36	10	1		17	24	33	43	53	62	16.2	23.6
Viosca Knoll Block 826	31.6	0.29	-2	-4	11	66	26	6	2		19	29	40	51	62	72	20.2	30
Mississippi Canyon Block 72	32	0.39	-5	-28	12	64	27	7	2		20	29	39	49	59	68	27	46
Green Canyon Block 109	27	1.89	0	-36	25	51	39	9	1	2	15	22	30	39	48	57	30	46.5
Mars TLP (2004)	27.6	2.1	-26	-28	24	60	24	11	5.5	1.5	11	16	22	28	35	42	31.5	53
South Pass Block 60	35.8	0.28	-4	-9	5	71	20	8	1	7	27	39	51	62	71	79	50	82.6
Eugene Island Block 43	36.8	0.18	12	0	7	81	16	3	0	8	16	27	43	58	71	83	60.6	87
Garden Banks Block 426	40.8	0.94	-24	-22	5	70	24	5	1		29	39	49	59	67	75	65.6	109
Mississippi Canyon Block 807	27.5	2.2	-35	-34	29	47	35	12	6		21	28	36	45	53	62	76.5	146
Mississippi Canyon Block 194	35.2	0.21	-6	-40	5	71	25	4	0	5	23	37	52	66	75	84	102	169
Green Canyon Block 200	33.9	0.87	0	-10	11.4	82	10	6.9	0.8	1.7	27	35	44	53	61	69	177	296
Viosca Knoll Block 990	38.1	0.22	-17	-32	5	73	22	4	1	2.2	26	36	46	57	66	74	200.4	335
Petronius Block VK87A	30	0.34	-10	-19	20	84	9	6	1.6	2.7	17	25	34	44	53	61	473	473
Eugene Island Block 32	36.9	0.02	21	7	6	84	14	2	1		10	23	46	69	82	91	1000	1000
Green Canyon Block 184	39.4	0.94	-18	-44	4	69	24	6	1		29	39	48	58	66	74	1000	1000
South Louisiana Crude	34.5	0.45	-11	-28	5	73	21	4	1	4	21	33	46	59	69	78	1000	1000
Main Pass Block 306	32.8	0.28	-35	-53	7	65	29	5	1	3	26	37	49	60	70	79	1000	1000
Main Pass Block 37	33	0.16	-6	-3	4	73	21	5	1	8	29	41	53	65	74	83	1000	1000
Ship Shoal Block 269	38.7	0.41	-7	-42	4	79	15	6	0	5	30	43	56	68	77	84	1000	1000
South Timbalier Block 130	35.1	0.32	5	-27	5	78	16	5	0	4	25	39	54	66	76	84	1000	1000
West Delta Block 97	50.2	0.07	-35	-27	1	92	7	1	0	4	55	72	86	95	99	100	1000	1000

[1] °C *(9/5)+32 = °F

Appendix B

Time-Window (in Hours) for Dispersant Application Predicted Using Oilmap Version 6.9.3 and the 24 oils from Task 1 and Different Oil Spill Volume, Water Temperature, Wind Speed, and Cutoff Viscosity for Sensitivity Analysis (Task4)

```
Table C1: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 8 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
        EUGENE ISLAND BLOCK 32     190     343     432     515      612
        EUGENE ISLAND BLOCK 43     190     343     432     515      612
        GARDEN BANKS BLOCK 387     148     268     338     402      479
        GARDEN BANKS BLOCK 426    1000    1000    1000    1000     1000
         GREEN CANYON BLOCK 65       6       8       9       9        9
        GREEN CANYON BLOCK 109      12      15      16      17       18
        GREEN CANYON BLOCK 184      12      15      16      17       18
        GREEN CANYON BLOCK 200      66     122     154     183      218
                     LOUISIANA     856    1000    1000    1000     1000
           MAIN PASS BLOCK 306     266     480     605     720      857
            MAIN PASS BLOCK 37     354     638     804     957     1000
                      MARS TLP      59     108     136     162      192
   MISSISSIPPI CANYON BLOCK 72      46      85     107     127      151
  MISSISSIPPI CANYON BLOCK 194      46      85     107     127      151
  MISSISSIPPI CANYON BLOCK 807      46      85     107     127      151
           Morpeth Block EW921      13      15      16      17       18
        Petronius Block VK786A      12      15      15      16       17
          SHIP SHOAL BLOCK 269    1000    1000    1000    1000     1000
           SOUTH PASS BLOCK 60     109     200     252     300      357
     SOUTH TIMBALIER BLOCK 130    1000    1000    1000    1000     1000
        VIOSCA KNOLL BLOCK 826      84     153     193     230      273
        VIOSCA KNOLL BLOCK 990    1000    1000    1000    1000     1000
           WEST DELTA BLOCK 97    9999    9999    9999    9999     9999
          WEST DELTA BLOCK 143      17      21      23      24       26
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------
```

```
Table C2: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 8 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
        EUGENE ISLAND BLOCK 32     390     702     884    1000     1000
        EUGENE ISLAND BLOCK 43     390     702     884    1000     1000
```

GARDEN BANKS BLOCK 387	155	280	353	421	500
GARDEN BANKS BLOCK 426	1000	1000	1000	1000	1000
GREEN CANYON BLOCK 65	7	9	10	10	11
GREEN CANYON BLOCK 109	12	16	17	18	19
GREEN CANYON BLOCK 184	12	16	17	18	19
GREEN CANYON BLOCK 200	142	258	325	387	461
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	281	507	639	761	906
MAIN PASS BLOCK 37	917	1000	1000	1000	1000
MARS TLP	88	160	202	240	286
MISSISSIPPI CANYON BLOCK 72	73	134	169	201	239
MISSISSIPPI CANYON BLOCK 194	73	134	169	201	239
MISSISSIPPI CANYON BLOCK 807	73	134	169	201	239
Morpeth Block EW921	17	22	24	26	28
Petronius Block VK786A	44	79	100	119	141
SHIP SHOAL BLOCK 269	1000	1000	1000	1000	1000
SOUTH PASS BLOCK 60	170	309	390	464	552
SOUTH TIMBALIER BLOCK 130	1000	1000	1000	1000	1000
VIOSCA KNOLL BLOCK 826	128	233	294	350	416
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	17	21	24	26	28

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C3: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 5000 cP
Wind Speed = 8 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	567	1000	1000	1000	1000
EUGENE ISLAND BLOCK 43	567	1000	1000	1000	1000
GARDEN BANKS BLOCK 387	156	282	356	423	503
GARDEN BANKS BLOCK 426	1000	1000	1000	1000	1000
GREEN CANYON BLOCK 65	8	10	11	11	12
GREEN CANYON BLOCK 109	12	16	17	18	19
GREEN CANYON BLOCK 184	12	16	17	18	19
GREEN CANYON BLOCK 200	210	380	479	570	678
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	284	513	646	769	915
MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	108	195	246	293	349
MISSISSIPPI CANYON BLOCK 72	92	169	213	253	301
MISSISSIPPI CANYON BLOCK 194	92	169	213	253	301
MISSISSIPPI CANYON BLOCK 807	92	169	213	253	301
Morpeth Block EW921	21	29	33	37	42
Petronius Block VK786A	261	472	594	708	842
SHIP SHOAL BLOCK 269	1000	1000	1000	1000	1000
SOUTH PASS BLOCK 60	212	385	486	578	688
SOUTH TIMBALIER BLOCK 130	1000	1000	1000	1000	1000
VIOSCA KNOLL BLOCK 826	158	288	363	432	513
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000

WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	17	22	24	26	28

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C4: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 5000 cP
Wind Speed = 12 knots
Water Temperature = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	156	280	352	419	498
EUGENE ISLAND BLOCK 43	156	280	352	419	498
GARDEN BANKS BLOCK 387	120	217	274	326	387
GARDEN BANKS BLOCK 426	1000	1000	1000	1000	1000
GREEN CANYON BLOCK 65	3	4	4	5	5
GREEN CANYON BLOCK 109	6	8	9	9	10
GREEN CANYON BLOCK 184	6	8	9	9	10
GREEN CANYON BLOCK 200	54	99	125	148	176
LOUISIANA	707	1000	1000	1000	1000
MAIN PASS BLOCK 306	218	391	492	585	695
MAIN PASS BLOCK 37	290	520	654	778	924
MARS TLP	47	87	110	131	155
MISSISSIPPI CANYON BLOCK 72	37	69	87	103	122
MISSISSIPPI CANYON BLOCK 194	37	69	87	103	122
MISSISSIPPI CANYON BLOCK 807	37	69	87	103	122
Morpeth Block EW921	6	8	8	9	9
Petronius Block VK786A	6	7	8	8	8
SHIP SHOAL BLOCK 269	9999	9999	9999	9999	9999
SOUTH PASS BLOCK 60	89	162	205	243	289
SOUTH TIMBALIER BLOCK 130	9999	9999	9999	9999	9999
VIOSCA KNOLL BLOCK 826	68	124	156	186	221
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	9	12	13	15	16

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C5: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 5000 cP
Wind Speed = 12 knots
Water Temperature = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	324	579	728	865	1000
EUGENE ISLAND BLOCK 43	324	579	728	865	1000
GARDEN BANKS BLOCK 387	125	227	286	340	405

GARDEN BANKS BLOCK 426	9999	1000	1000	1000	1000
GREEN CANYON BLOCK 65	4	5	5	5	5
GREEN CANYON BLOCK 109	6	8	9	10	11
GREEN CANYON BLOCK 184	6	8	9	10	11
GREEN CANYON BLOCK 200	115	209	264	314	373
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	230	413	520	618	735
MAIN PASS BLOCK 37	765	1000	1000	1000	1000
MARS TLP	71	130	163	194	231
MISSISSIPPI CANYON BLOCK 72	59	109	137	163	193
MISSISSIPPI CANYON BLOCK 194	59	109	137	163	193
MISSISSIPPI CANYON BLOCK 807	59	109	137	163	193
Morpeth Block EW921	9	12	14	16	19
Petronius Block VK786A	34	64	81	96	114
SHIP SHOAL BLOCK 269	9999	9999	9999	9999	9999
SOUTH PASS BLOCK 60	139	251	317	376	447
SOUTH TIMBALIER BLOCK 130	9999	9999	9999	9999	9999
VIOSCA KNOLL BLOCK 826	104	189	238	284	337
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	9	12	14	16	18

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C6: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 5000 cP
Wind Speed = 12 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	474	845	1000	1000	1000
EUGENE ISLAND BLOCK 43	474	845	1000	1000	1000
GARDEN BANKS BLOCK 387	126	229	288	343	407
GARDEN BANKS BLOCK 426	9999	1000	1000	1000	1000
GREEN CANYON BLOCK 65	4	5	5	6	6
GREEN CANYON BLOCK 109	6	8	9	10	11
GREEN CANYON BLOCK 184	6	8	9	10	11
GREEN CANYON BLOCK 200	171	309	389	462	549
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	232	417	525	625	742
MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	87	159	200	238	282
MISSISSIPPI CANYON BLOCK 72	75	137	172	205	243
MISSISSIPPI CANYON BLOCK 194	75	137	172	205	243
MISSISSIPPI CANYON BLOCK 807	75	137	172	205	243
Morpeth Block EW921	12	19	24	28	33
Petronius Block VK786A	214	385	484	576	685
SHIP SHOAL BLOCK 269	9999	9999	9999	9999	9999
SOUTH PASS BLOCK 60	173	313	395	469	558
SOUTH TIMBALIER BLOCK 130	9999	9999	9999	9999	9999
VIOSCA KNOLL BLOCK 826	129	234	294	350	416
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999

WEST DELTA BLOCK 143	9	12	14	16	19

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C7: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 5000 cP
Wind Speed = 15 knots
Water Temperature = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	141	252	317	376	447
EUGENE ISLAND BLOCK 43	141	252	317	376	447
GARDEN BANKS BLOCK 387	108	195	245	292	346
GARDEN BANKS BLOCK 426	9999	9999	9999	9999	9999
GREEN CANYON BLOCK 65	2	3	3	3	3
GREEN CANYON BLOCK 109	4	6	6	7	7
GREEN CANYON BLOCK 184	4	6	6	7	7
GREEN CANYON BLOCK 200	48	88	111	132	157
LOUISIANA	650	1000	1000	1000	1000
MAIN PASS BLOCK 306	197	351	441	525	623
MAIN PASS BLOCK 37	263	468	588	698	830
MARS TLP	42	78	98	116	138
MISSISSIPPI CANYON BLOCK 72	33	61	77	92	109
MISSISSIPPI CANYON BLOCK 194	33	61	77	92	109
MISSISSIPPI CANYON BLOCK 807	33	61	77	92	109
Morpeth Block EW921	4	5	6	6	6
Petronius Block VK786A	4	5	5	5	6
SHIP SHOAL BLOCK 269	9999	9999	9999	9999	9999
SOUTH PASS BLOCK 60	80	145	183	217	258
SOUTH TIMBALIER BLOCK 130	9999	9999	9999	9999	9999
VIOSCA KNOLL BLOCK 826	61	111	140	166	197
VIOSCA KNOLL BLOCK 990	9999	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	6	9	10	12	14

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C8: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 5000 cP
Wind Speed = 15 knots
Water Temperature = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	298	528	664	788	937
EUGENE ISLAND BLOCK 43	298	528	664	788	937
GARDEN BANKS BLOCK 387	113	204	256	305	362
GARDEN BANKS BLOCK 426	9999	9999	9999	9999	9999

```
          GREEN CANYON BLOCK 65       3       3       3       4        4
         GREEN CANYON BLOCK 109       4       6       7       7        8
         GREEN CANYON BLOCK 184       4       6       7       7        8
         GREEN CANYON BLOCK 200     104     187     236     280      333
                      LOUISIANA     981    1000    1000    1000     1000
           MAIN PASS BLOCK 306     208     371     467     554      659
            MAIN PASS BLOCK 37      711    1000    1000    1000     1000
                       MARS TLP      64     116     146     174      206
    MISSISSIPPI CANYON BLOCK 72      53      97     122     145      172
   MISSISSIPPI CANYON BLOCK 194      53      97     122     145      172
   MISSISSIPPI CANYON BLOCK 807      53      97     122     145      172
            Morpeth Block EW921       6      10      12      14       16
         Petronius Block VK786A      30      57      72      86      101
          SHIP SHOAL BLOCK 269     9999    9999    9999    9999     9999
           SOUTH PASS BLOCK 60      125     225     283     337      400
      SOUTH TIMBALIER BLOCK 130    9999    9999    9999    9999     9999
         VIOSCA KNOLL BLOCK 826      94     170     213     254      301
         VIOSCA KNOLL BLOCK 990    9999    9999    9999    9999     9999
            WEST DELTA BLOCK 97    9999    9999    9999    9999     9999
           WEST DELTA BLOCK 143       6       9      12      13       16
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table C9: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 15 knots
Water Temperature      = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
         EUGENE ISLAND BLOCK 32     442     781     982    1000     1000
         EUGENE ISLAND BLOCK 43     442     781     982    1000     1000
         GARDEN BANKS BLOCK 387     113     205     258     307      365
         GARDEN BANKS BLOCK 426    9999    9999    9999    9999     9999
          GREEN CANYON BLOCK 65       3       3       4       4        4
         GREEN CANYON BLOCK 109       4       6       7       7        8
         GREEN CANYON BLOCK 184       4       6       7       7        8
         GREEN CANYON BLOCK 200     154     277     348     413      491
                      LOUISIANA    1000    1000    1000    1000     1000
           MAIN PASS BLOCK 306     210     375     471     560      665
            MAIN PASS BLOCK 37     1000    1000    1000    1000     1000
                       MARS TLP      79     142     179     212      252
    MISSISSIPPI CANYON BLOCK 72      67     122     154     183      217
   MISSISSIPPI CANYON BLOCK 194      67     122     154     183      217
   MISSISSIPPI CANYON BLOCK 807      67     122     154     183      217
            Morpeth Block EW921       9      17      21      25       29
         Petronius Block VK786A     192     345     434     517      615
          SHIP SHOAL BLOCK 269     9999    9999    9999    9999     9999
           SOUTH PASS BLOCK 60      156     281     353     420      499
      SOUTH TIMBALIER BLOCK 130    9999    9999    9999    9999     9999
         VIOSCA KNOLL BLOCK 826     116     209     263     313      372
         VIOSCA KNOLL BLOCK 990    9999    9999    9999    9999     9999
            WEST DELTA BLOCK 97    9999    9999    9999    9999     9999
           WEST DELTA BLOCK 143       6      10      12      14       16
```

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C10: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 7500 cP
Wind Speed = 8 knots
Water Temperature = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	388	698	879	1000	1000
EUGENE ISLAND BLOCK 43	388	698	879	1000	1000
GARDEN BANKS BLOCK 387	277	498	627	747	888
GARDEN BANKS BLOCK 426	1000	1000	1000	1000	1000
GREEN CANYON BLOCK 65	8	10	10	11	11
GREEN CANYON BLOCK 109	14	18	20	21	23
GREEN CANYON BLOCK 184	14	18	20	21	23
GREEN CANYON BLOCK 200	207	375	473	563	670
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	724	1000	1000	1000	1000
MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	118	214	269	321	381
MISSISSIPPI CANYON BLOCK 72	111	203	256	305	363
MISSISSIPPI CANYON BLOCK 194	111	203	256	305	363
MISSISSIPPI CANYON BLOCK 807	111	203	256	305	363
Morpeth Block EW921	15	19	20	21	23
Petronius Block VK786A	14	17	18	19	20
SHIP SHOAL BLOCK 269	1000	1000	1000	1000	1000
SOUTH PASS BLOCK 60	293	530	668	795	946
SOUTH TIMBALIER BLOCK 130	1000	1000	1000	1000	1000
VIOSCA KNOLL BLOCK 826	178	321	405	482	574
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	21	28	32	36	41

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C11: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 7500 cP
Wind Speed = 8 knots
Water Temperature = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	786	1000	1000	1000	1000
EUGENE ISLAND BLOCK 43	786	1000	1000	1000	1000
GARDEN BANKS BLOCK 387	284	510	643	765	910
GARDEN BANKS BLOCK 426	1000	1000	1000	1000	1000
GREEN CANYON BLOCK 65	9	11	12	12	13

GREEN CANYON BLOCK 109	15	19	21	22	24
GREEN CANYON BLOCK 184	15	19	21	22	24
GREEN CANYON BLOCK 200	424	763	961	1000	1000
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	744	1000	1000	1000	1000
MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	171	310	390	465	553
MISSISSIPPI CANYON BLOCK 72	172	312	393	468	557
MISSISSIPPI CANYON BLOCK 194	172	312	393	468	557
MISSISSIPPI CANYON BLOCK 807	172	312	393	468	557
Morpeth Block EW921	21	29	33	38	43
Petronius Block VK786A	80	146	185	220	262
SHIP SHOAL BLOCK 269	1000	1000	1000	1000	1000
SOUTH PASS BLOCK 60	443	797	1000	1000	1000
SOUTH TIMBALIER BLOCK 130	1000	1000	1000	1000	1000
VIOSCA KNOLL BLOCK 826	266	479	604	718	855
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	21	29	33	38	44

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C12: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 7500 cP
Wind Speed = 8 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	1000	1000	1000	1000	1000
EUGENE ISLAND BLOCK 43	1000	1000	1000	1000	1000
GARDEN BANKS BLOCK 387	282	508	640	762	906
GARDEN BANKS BLOCK 426	1000	1000	1000	1000	1000
GREEN CANYON BLOCK 65	9	12	12	13	14
GREEN CANYON BLOCK 109	15	19	21	23	25
GREEN CANYON BLOCK 184	15	19	21	23	25
GREEN CANYON BLOCK 200	613	1000	1000	1000	1000
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	740	1000	1000	1000	1000
MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	207	373	471	560	666
MISSISSIPPI CANYON BLOCK 72	213	386	486	579	689
MISSISSIPPI CANYON BLOCK 194	213	386	486	579	689
MISSISSIPPI CANYON BLOCK 807	213	386	486	579	689
Morpeth Block EW921	28	42	52	62	73
Petronius Block VK786A	478	858	1000	1000	1000
SHIP SHOAL BLOCK 269	1000	1000	1000	1000	1000
SOUTH PASS BLOCK 60	544	979	1000	1000	1000
SOUTH TIMBALIER BLOCK 130	1000	1000	1000	1000	1000
VIOSCA KNOLL BLOCK 826	324	583	735	875	1000
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	21	29	34	39	45

```
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table C13: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 12 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
        EUGENE ISLAND BLOCK 32     319     570     717     852     1000
        EUGENE ISLAND BLOCK 43     319     570     717     852     1000
        GARDEN BANKS BLOCK 387     224     404     508     605      719
        GARDEN BANKS BLOCK 426    1000    1000    1000    1000     1000
         GREEN CANYON BLOCK 65       4       5       5       5        6
        GREEN CANYON BLOCK 109       7      10      11      12       14
        GREEN CANYON BLOCK 184       7      10      11      12       14
        GREEN CANYON BLOCK 200     169     304     383     456      542
                     LOUISIANA    1000    1000    1000    1000     1000
           MAIN PASS BLOCK 306     594    1000    1000    1000     1000
            MAIN PASS BLOCK 37     838    1000    1000    1000     1000
                      MARS TLP      96     173     218     259      308
   MISSISSIPPI CANYON BLOCK 72      90     165     207     247      293
  MISSISSIPPI CANYON BLOCK 194      90     165     207     247      293
  MISSISSIPPI CANYON BLOCK 807      90     165     207     247      293
           Morpeth Block EW921       8      10      11      12       13
        Petronius Block VK786A       7       9       9      10       10
          SHIP SHOAL BLOCK 269    9999    9999    9999    9999     9999
           SOUTH PASS BLOCK 60     239     430     541     644      766
     SOUTH TIMBALIER BLOCK 130    9999    9999    9999    9999     9999
        VIOSCA KNOLL BLOCK 826     144     261     328     390      464
        VIOSCA KNOLL BLOCK 990    1000    1000    1000    1000     1000
           WEST DELTA BLOCK 97    9999    9999    9999    9999     9999
          WEST DELTA BLOCK 143      11      18      23      27       31
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table C14: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 12 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
        EUGENE ISLAND BLOCK 32     656    1000    1000    1000     1000
        EUGENE ISLAND BLOCK 43     656    1000    1000    1000     1000
        GARDEN BANKS BLOCK 387     230     414     521     620      737
        GARDEN BANKS BLOCK 426    9999    1000    1000    1000     1000
         GREEN CANYON BLOCK 65       5       6       6       6        7
        GREEN CANYON BLOCK 109       8      11      12      13       15
```

GREEN CANYON BLOCK 184	8	11	12	13	15
GREEN CANYON BLOCK 200	346	620	780	928	1000
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	610	1000	1000	1000	1000
MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	139	251	316	376	447
MISSISSIPPI CANYON BLOCK 72	140	253	318	379	450
MISSISSIPPI CANYON BLOCK 194	140	253	318	379	450
MISSISSIPPI CANYON BLOCK 807	140	253	318	379	450
Morpeth Block EW921	12	19	24	28	33
Petronius Block VK786A	65	119	150	178	212
SHIP SHOAL BLOCK 269	9999	9999	9999	9999	9999
SOUTH PASS BLOCK 60	362	648	816	971	1000
SOUTH TIMBALIER BLOCK 130	9999	9999	9999	9999	9999
VIOSCA KNOLL BLOCK 826	216	389	490	582	693
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	12	20	25	29	34

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C15: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity   = 7500 cP
Wind Speed   = 12 knots
Water Temperature   = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	956	1000	1000	1000	1000
EUGENE ISLAND BLOCK 43	956	1000	1000	1000	1000
GARDEN BANKS BLOCK 387	229	412	519	617	734
GARDEN BANKS BLOCK 426	9999	1000	1000	1000	1000
GREEN CANYON BLOCK 65	5	6	6	7	7
GREEN CANYON BLOCK 109	8	11	12	14	15
GREEN CANYON BLOCK 184	8	11	12	14	15
GREEN CANYON BLOCK 200	502	895	1000	1000	1000
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	607	1000	1000	1000	1000
MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	168	303	381	454	539
MISSISSIPPI CANYON BLOCK 72	174	313	394	469	557
MISSISSIPPI CANYON BLOCK 194	174	313	394	469	557
MISSISSIPPI CANYON BLOCK 807	174	313	394	469	557
Morpeth Block EW921	18	33	42	50	59
Petronius Block VK786A	392	701	882	1000	1000
SHIP SHOAL BLOCK 269	9999	9999	9999	9999	9999
SOUTH PASS BLOCK 60	446	798	1000	1000	1000
SOUTH TIMBALIER BLOCK 130	9999	9999	9999	9999	9999
VIOSCA KNOLL BLOCK 826	264	474	596	710	844
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	12	20	25	30	35

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C16: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 7500 cP
Wind Speed = 15 knots
Water Temperature = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	291	514	646	767	911
EUGENE ISLAND BLOCK 43	291	514	646	767	911
GARDEN BANKS BLOCK 387	202	362	455	542	644
GARDEN BANKS BLOCK 426	9999	9999	9999	9999	9999
GREEN CANYON BLOCK 65	3	3	4	4	4
GREEN CANYON BLOCK 109	5	7	9	10	11
GREEN CANYON BLOCK 184	5	7	9	10	11
GREEN CANYON BLOCK 200	152	272	342	407	483
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	539	954	1000	1000	1000
MAIN PASS BLOCK 37	765	1000	1000	1000	1000
MARS TLP	86	155	195	231	275
MISSISSIPPI CANYON BLOCK 72	81	147	185	220	261
MISSISSIPPI CANYON BLOCK 194	81	147	185	220	261
MISSISSIPPI CANYON BLOCK 807	81	147	185	220	261
Morpeth Block EW921	5	7	8	9	10
Petronius Block VK786A	5	6	6	7	7
SHIP SHOAL BLOCK 269	9999	9999	9999	9999	9999
SOUTH PASS BLOCK 60	216	385	484	576	684
SOUTH TIMBALIER BLOCK 130	9999	9999	9999	9999	9999
VIOSCA KNOLL BLOCK 826	130	233	293	348	414
VIOSCA KNOLL BLOCK 990	9999	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	9	16	20	24	28

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C17: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 7500 cP
Wind Speed = 15 knots
Water Temperature = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	608	1000	1000	1000	1000
EUGENE ISLAND BLOCK 43	608	1000	1000	1000	1000
GARDEN BANKS BLOCK 387	207	371	467	555	660
GARDEN BANKS BLOCK 426	9999	9999	9999	9999	9999
GREEN CANYON BLOCK 65	3	4	4	4	4
GREEN CANYON BLOCK 109	5	8	9	11	12
GREEN CANYON BLOCK 184	5	8	9	11	12

```
        GREEN CANYON BLOCK 200     312     555     698     830      986
                     LOUISIANA    1000    1000    1000    1000     1000
           MAIN PASS BLOCK 306     554     981    1000    1000     1000
            MAIN PASS BLOCK 37    1000    1000    1000    1000     1000
                      MARS TLP     125     225     283     336      399
   MISSISSIPPI CANYON BLOCK 72     126     226     284     338      401
  MISSISSIPPI CANYON BLOCK 194     126     226     284     338      401
  MISSISSIPPI CANYON BLOCK 807     126     226     284     338      401
           Morpeth Block EW921       9      17      21      25       30
        Petronius Block VK786A      58     106     134     159      188
          SHIP SHOAL BLOCK 269    9999    9999    9999    9999     9999
           SOUTH PASS BLOCK 60     327     582     731     869     1000
     SOUTH TIMBALIER BLOCK 130    9999    9999    9999    9999     9999
        VIOSCA KNOLL BLOCK 826     195     349     438     521      619
        VIOSCA KNOLL BLOCK 990    9999    9999    9999    9999     9999
           WEST DELTA BLOCK 97    9999    9999    9999    9999     9999
          WEST DELTA BLOCK 143       9      17      22      26       30
---------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
---------------------------------------------------------------------------


Table C18: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 15 knots
Water Temperature      = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
---------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
---------------------------------------------------------------------------
         EUGENE ISLAND BLOCK 32    903    1000    1000    1000     1000
         EUGENE ISLAND BLOCK 43    903    1000    1000    1000     1000
        GARDEN BANKS BLOCK 387     206     369     465     553      658
        GARDEN BANKS BLOCK 426    9999    9999    9999    9999     9999
         GREEN CANYON BLOCK 65       3       4       4       5        5
        GREEN CANYON BLOCK 109       5       8      10      11       13
        GREEN CANYON BLOCK 184       5       8      10      11       13
        GREEN CANYON BLOCK 200     453     804    1000    1000     1000
                     LOUISIANA    1000    1000    1000    1000     1000
           MAIN PASS BLOCK 306     551     977    1000    1000     1000
            MAIN PASS BLOCK 37    1000    1000    1000    1000     1000
                      MARS TLP     152     271     341     406      482
   MISSISSIPPI CANYON BLOCK 72     156     280     352     419      497
  MISSISSIPPI CANYON BLOCK 194     156     280     352     419      497
  MISSISSIPPI CANYON BLOCK 807     156     280     352     419      497
           Morpeth Block EW921      15      30      37      44       52
        Petronius Block VK786A     353     631     794     945     1000
          SHIP SHOAL BLOCK 269    9999    9999    9999    9999     9999
           SOUTH PASS BLOCK 60     404     718     903    1000     1000
     SOUTH TIMBALIER BLOCK 130    9999    9999    9999    9999     9999
        VIOSCA KNOLL BLOCK 826     238     425     535     636      756
        VIOSCA KNOLL BLOCK 990    9999    9999    9999    9999     9999
           WEST DELTA BLOCK 97    9999    9999    9999    9999     9999
          WEST DELTA BLOCK 143       9      18      22      26       31
---------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
```

```
--------------------------------------------------------------------------


Table C19: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 8 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
        EUGENE ISLAND BLOCK 32     645    1000    1000    1000     1000
        EUGENE ISLAND BLOCK 43     645    1000    1000    1000     1000
        GARDEN BANKS BLOCK 387     430     772     972    1000     1000
        GARDEN BANKS BLOCK 426    1000    1000    1000    1000     1000
         GREEN CANYON BLOCK 65       9      11      12      12       13
        GREEN CANYON BLOCK 109      16      21      24      26       28
        GREEN CANYON BLOCK 184      16      21      24      26       28
        GREEN CANYON BLOCK 200     462     829    1000    1000     1000
                     LOUISIANA    1000    1000    1000    1000     1000
           MAIN PASS BLOCK 306    1000    1000    1000    1000     1000
            MAIN PASS BLOCK 37    1000    1000    1000    1000     1000
                      MARS TLP     192     347     437     520      619
   MISSISSIPPI CANYON BLOCK 72     208     376     474     565      672
  MISSISSIPPI CANYON BLOCK 194     208     376     474     565      672
  MISSISSIPPI CANYON BLOCK 807     208     376     474     565      672
           Morpeth Block EW921      17      22      24      26       28
        Petronius Block VK786A      16      20      21      22       24
          SHIP SHOAL BLOCK 269    1000    1000    1000    1000     1000
           SOUTH PASS BLOCK 60     589    1000    1000    1000     1000
     SOUTH TIMBALIER BLOCK 130    1000    1000    1000    1000     1000
        VIOSCA KNOLL BLOCK 826     302     544     685     815      970
        VIOSCA KNOLL BLOCK 990    1000    1000    1000    1000     1000
           WEST DELTA BLOCK 97    9999    9999    9999    9999     9999
          WEST DELTA BLOCK 143      25      37      45      53       62
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table C20: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 8 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
        EUGENE ISLAND BLOCK 32    1000    1000    1000    1000     1000
        EUGENE ISLAND BLOCK 43    1000    1000    1000    1000     1000
        GARDEN BANKS BLOCK 387     435     780     983    1000     1000
        GARDEN BANKS BLOCK 426    1000    1000    1000    1000     1000
         GREEN CANYON BLOCK 65      10      12      13      14       15
        GREEN CANYON BLOCK 109      17      22      25      27       30
        GREEN CANYON BLOCK 184      17      22      25      27       30
        GREEN CANYON BLOCK 200     918    1000    1000    1000     1000
```

LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	1000	1000	1000	1000	1000
MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	275	494	623	741	882
MISSISSIPPI CANYON BLOCK 72	314	566	714	849	1000
MISSISSIPPI CANYON BLOCK 194	314	566	714	849	1000
MISSISSIPPI CANYON BLOCK 807	314	566	714	849	1000
Morpeth Block EW921	26	38	46	54	64
Petronius Block VK786A	124	226	285	340	404
SHIP SHOAL BLOCK 269	1000	1000	1000	1000	1000
SOUTH PASS BLOCK 60	873	1000	1000	1000	1000
SOUTH TIMBALIER BLOCK 130	1000	1000	1000	1000	1000
VIOSCA KNOLL BLOCK 826	444	798	1000	1000	1000
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	26	39	48	56	67

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C21: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity   = 10000 cP
Wind Speed   = 8 knots
Water Temperature   = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	1000	1000	1000	1000	1000
EUGENE ISLAND BLOCK 43	1000	1000	1000	1000	1000
GARDEN BANKS BLOCK 387	430	771	971	1000	1000
GARDEN BANKS BLOCK 426	1000	1000	1000	1000	1000
GREEN CANYON BLOCK 65	11	13	14	15	16
GREEN CANYON BLOCK 109	17	22	25	27	30
GREEN CANYON BLOCK 184	17	22	25	27	30
GREEN CANYON BLOCK 200	1000	1000	1000	1000	1000
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	1000	1000	1000	1000	1000
MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	328	590	744	885	1000
MISSISSIPPI CANYON BLOCK 72	385	693	873	1000	1000
MISSISSIPPI CANYON BLOCK 194	385	693	873	1000	1000
MISSISSIPPI CANYON BLOCK 807	385	693	873	1000	1000
Morpeth Block EW921	36	62	78	93	110
Petronius Block VK786A	732	1000	1000	1000	1000
SHIP SHOAL BLOCK 269	1000	1000	1000	1000	1000
SOUTH PASS BLOCK 60	1000	1000	1000	1000	1000
SOUTH TIMBALIER BLOCK 130	1000	1000	1000	1000	1000
VIOSCA KNOLL BLOCK 826	537	964	1000	1000	1000
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	26	40	49	57	68

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C22: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 12 knots
Water Temperature = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	531	945	1000	1000	1000
EUGENE ISLAND BLOCK 43	531	945	1000	1000	1000
GARDEN BANKS BLOCK 387	349	626	788	938	1000
GARDEN BANKS BLOCK 426	1000	1000	1000	1000	1000
GREEN CANYON BLOCK 65	5	6	6	6	6
GREEN CANYON BLOCK 109	9	12	15	17	19
GREEN CANYON BLOCK 184	9	12	15	17	19
GREEN CANYON BLOCK 200	376	673	847	1000	1000
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	1000	1000	1000	1000	1000
MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	156	281	353	421	500
MISSISSIPPI CANYON BLOCK 72	169	305	384	457	543
MISSISSIPPI CANYON BLOCK 194	169	305	384	457	543
MISSISSIPPI CANYON BLOCK 807	169	305	384	457	543
Morpeth Block EW921	9	12	14	16	18
Petronius Block VK786A	8	10	11	12	13
SHIP SHOAL BLOCK 269	9999	9999	9999	9999	9999
SOUTH PASS BLOCK 60	481	859	1000	1000	1000
SOUTH TIMBALIER BLOCK 130	9999	9999	9999	9999	9999
VIOSCA KNOLL BLOCK 826	245	440	555	660	785
VIOSCA KNOLL BLOCK 990	1000	1000	1000	1000	1000
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	15	28	36	42	50

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C23: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 12 knots
Water Temperature = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	1000	1000	1000	1000	1000
EUGENE ISLAND BLOCK 43	1000	1000	1000	1000	1000
GARDEN BANKS BLOCK 387	353	633	797	948	1000
GARDEN BANKS BLOCK 426	9999	1000	1000	1000	1000
GREEN CANYON BLOCK 65	5	6	7	7	8
GREEN CANYON BLOCK 109	9	13	16	18	21
GREEN CANYON BLOCK 184	9	13	16	18	21
GREEN CANYON BLOCK 200	750	1000	1000	1000	1000
LOUISIANA	1000	1000	1000	1000	1000

```
           MAIN PASS BLOCK 306    1000    1000    1000    1000     1000
            MAIN PASS BLOCK 37    1000    1000    1000    1000     1000
                      MARS TLP     223     401     504     600      713
   MISSISSIPPI CANYON BLOCK 72     256     459     578     688      818
  MISSISSIPPI CANYON BLOCK 194     256     459     578     688      818
  MISSISSIPPI CANYON BLOCK 807     256     459     578     688      818
           Morpeth Block EW921      16      29      36      43       51
        Petronius Block VK786A     101     184     231     275      327
          SHIP SHOAL BLOCK 269    9999    9999    9999    9999     9999
           SOUTH PASS BLOCK 60     714    1000    1000    1000     1000
     SOUTH TIMBALIER BLOCK 130    9999    9999    9999    9999     9999
        VIOSCA KNOLL BLOCK 826     362     648     816     971     1000
        VIOSCA KNOLL BLOCK 990    1000    1000    1000    1000     1000
           WEST DELTA BLOCK 97    9999    9999    9999    9999     9999
          WEST DELTA BLOCK 143      16      30      38      45       54
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table C24: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 12 knots
Water Temperature      = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
        EUGENE ISLAND BLOCK 32    1000    1000    1000    1000     1000
        EUGENE ISLAND BLOCK 43    1000    1000    1000    1000     1000
        GARDEN BANKS BLOCK 387     348     625     787     936     1000
        GARDEN BANKS BLOCK 426    9999    1000    1000    1000     1000
         GREEN CANYON BLOCK 65       5       7       7       8        8
        GREEN CANYON BLOCK 109       9      13      16      18       21
        GREEN CANYON BLOCK 184       9      13      16      18       21
        GREEN CANYON BLOCK 200    1000    1000    1000    1000     1000
                     LOUISIANA    1000    1000    1000    1000     1000
           MAIN PASS BLOCK 306    1000    1000    1000    1000     1000
            MAIN PASS BLOCK 37    1000    1000    1000    1000     1000
                      MARS TLP     267     479     602     717      853
   MISSISSIPPI CANYON BLOCK 72     314     562     708     842     1000
  MISSISSIPPI CANYON BLOCK 194     314     562     708     842     1000
  MISSISSIPPI CANYON BLOCK 807     314     562     708     842     1000
           Morpeth Block EW921      26      50      63      75       89
        Petronius Block VK786A     601    1000    1000    1000     1000
          SHIP SHOAL BLOCK 269    9999    9999    9999    9999     9999
           SOUTH PASS BLOCK 60     874    1000    1000    1000     1000
     SOUTH TIMBALIER BLOCK 130    9999    9999    9999    9999     9999
        VIOSCA KNOLL BLOCK 826     438     783     986    1000     1000
        VIOSCA KNOLL BLOCK 990    1000    1000    1000    1000     1000
           WEST DELTA BLOCK 97    9999    9999    9999    9999     9999
          WEST DELTA BLOCK 143      16      31      39      46       55
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------
```

```
Table C25: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 15 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
        EUGENE ISLAND BLOCK 32     484     854    1000    1000     1000
        EUGENE ISLAND BLOCK 43     484     854    1000    1000     1000
        GARDEN BANKS BLOCK 387     314     561     706     841     1000
        GARDEN BANKS BLOCK 426    9999    9999    9999    9999     9999
         GREEN CANYON BLOCK 65       3       4       4       4        4
        GREEN CANYON BLOCK 109       6      10      12      14       17
        GREEN CANYON BLOCK 184       6      10      12      14       17
        GREEN CANYON BLOCK 200     339     602     757     900     1000
                     LOUISIANA    1000    1000    1000    1000     1000
           MAIN PASS BLOCK 306    1000    1000    1000    1000     1000
            MAIN PASS BLOCK 37    1000    1000    1000    1000     1000
                      MARS TLP     140     251     316     375      446
   MISSISSIPPI CANYON BLOCK 72     152     273     343     407      484
  MISSISSIPPI CANYON BLOCK 194     152     273     343     407      484
  MISSISSIPPI CANYON BLOCK 807     152     273     343     407      484
           Morpeth Block EW921       6       9      11      13       15
        Petronius Block VK786A       5       7       8       9       10
          SHIP SHOAL BLOCK 269    9999    9999    9999    9999     9999
           SOUTH PASS BLOCK 60     434     770     968    1000     1000
     SOUTH TIMBALIER BLOCK 130    9999    9999    9999    9999     9999
        VIOSCA KNOLL BLOCK 826     220     394     496     589      700
        VIOSCA KNOLL BLOCK 990    9999    1000    1000    1000     1000
           WEST DELTA BLOCK 97    9999    9999    9999    9999     9999
          WEST DELTA BLOCK 143      13      25      32      38       44
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table C26: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 15 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
        EUGENE ISLAND BLOCK 32    1000    1000    1000    1000     1000
        EUGENE ISLAND BLOCK 43    1000    1000    1000    1000     1000
        GARDEN BANKS BLOCK 387     317     567     714     850     1000
        GARDEN BANKS BLOCK 426    9999    9999    9999    9999     9999
         GREEN CANYON BLOCK 65       3       4       5       5        5
        GREEN CANYON BLOCK 109       6      11      13      16       18
        GREEN CANYON BLOCK 184       6      11      13      16       18
        GREEN CANYON BLOCK 200     678    1000    1000    1000     1000
                     LOUISIANA    1000    1000    1000    1000     1000
           MAIN PASS BLOCK 306    1000    1000    1000    1000     1000
```

MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	201	358	451	536	637
MISSISSIPPI CANYON BLOCK 72	230	411	516	614	730
MISSISSIPPI CANYON BLOCK 194	230	411	516	614	730
MISSISSIPPI CANYON BLOCK 807	230	411	516	614	730
Morpeth Block EW921	13	26	32	38	45
Petronius Block VK786A	90	164	206	245	291
SHIP SHOAL BLOCK 269	9999	9999	9999	9999	9999
SOUTH PASS BLOCK 60	646	1000	1000	1000	1000
SOUTH TIMBALIER BLOCK 130	9999	9999	9999	9999	9999
VIOSCA KNOLL BLOCK 826	326	581	731	869	1000
VIOSCA KNOLL BLOCK 990	9999	9999	9999	9999	9999
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	14	27	34	40	48

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table C27: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 15 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
EUGENE ISLAND BLOCK 32	1000	1000	1000	1000	1000
EUGENE ISLAND BLOCK 43	1000	1000	1000	1000	1000
GARDEN BANKS BLOCK 387	313	561	706	839	998
GARDEN BANKS BLOCK 426	9999	9999	9999	9999	9999
GREEN CANYON BLOCK 65	4	5	5	5	6
GREEN CANYON BLOCK 109	6	11	14	16	19
GREEN CANYON BLOCK 184	6	11	14	16	19
GREEN CANYON BLOCK 200	971	1000	1000	1000	1000
LOUISIANA	1000	1000	1000	1000	1000
MAIN PASS BLOCK 306	1000	1000	1000	1000	1000
MAIN PASS BLOCK 37	1000	1000	1000	1000	1000
MARS TLP	241	429	539	641	762
MISSISSIPPI CANYON BLOCK 72	282	503	633	752	894
MISSISSIPPI CANYON BLOCK 194	282	503	633	752	894
MISSISSIPPI CANYON BLOCK 807	282	503	633	752	894
Morpeth Block EW921	24	44	56	67	79
Petronius Block VK786A	543	968	1000	1000	1000
SHIP SHOAL BLOCK 269	9999	9999	9999	9999	9999
SOUTH PASS BLOCK 60	795	1000	1000	1000	1000
SOUTH TIMBALIER BLOCK 130	9999	9999	9999	9999	9999
VIOSCA KNOLL BLOCK 826	395	703	885	1000	1000
VIOSCA KNOLL BLOCK 990	9999	9999	9999	9999	9999
WEST DELTA BLOCK 97	9999	9999	9999	9999	9999
WEST DELTA BLOCK 143	14	27	35	41	48

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Appendix C

Time-Window (in Hours) for Dispersant Application Predicted Using Oilmap Version 6.9.3 and the 24 oils from Task 2 and Different Oil Spill Volume, Water Temperature, Wind Speed, and Cutoff Viscosity for Sensitivity Analysis (Task4)

```
Table D1: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 8 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)      21      23      24      25       25
                 BARROW ISLAND    1000    1000    1000    1000     1000
                   CARPINTERIA       5       7       7       8        8
                      Chayvo#6    1000    1000    1000    1000     1000
                        EMPIRE     129     236     297     354      421
              FEDERATED (1998)    1000    1000    1000    1000     1000
                       GENESIS     142     257     324     386      459
                      GULLFAKS      74     137     172     205      244
                       HEIDRUN      20      26      29      32       36
                HONDO MONTEREY       2       3       3       3        3
                 IRANIAN HEAVY      24      33      39      45       52
                        LUCULA      10      12      13      13       14
                       MALONGO       8      10      11      11       12
                        Odoptu    1000    1000    1000    1000     1000
                       OSEBERG      29      43      53      63       74
                   PITAS POINT    9999    9999    9999    9999     9999
      POINT ARGUELLO COMINGLED       4       5       6       6        6
            Prudhoe Bay (1995)      13      15      16      16       17
                      SAKHALIN    1000    1000    1000    1000     1000
                   SANTA CLARA       5       7       8       8        8
                     STATFJORD    1000    1000    1000    1000     1000
              THEVENARD ISLAND    1000    1000    1000    1000     1000
       WEST TEXAS INTERMEDIATE     536     964    1000    1000     1000
                         ZAIRE       1       1       1       1        1
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------
```

```
Table D2: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 8 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)      25      27      29      30       30
                 BARROW ISLAND    1000    1000    1000    1000     1000
                   CARPINTERIA       7       9      10      11       11
```

Chayvo#6	1000	1000	1000	1000	1000
EMPIRE	183	331	418	497	592
FEDERATED (1998)	1000	1000	1000	1000	1000
GENESIS	177	321	404	481	572
GULLFAKS	107	196	247	294	350
HEIDRUN	22	29	33	37	42
HONDO MONTEREY	4	5	6	6	6
IRANIAN HEAVY	30	48	59	70	83
LUCULA	17	23	26	28	31
MALONGO	32	55	69	82	97
Odoptu	1000	1000	1000	1000	1000
OSEBERG	28	42	52	61	72
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	6	8	8	8	9
Prudhoe Bay (1995)	14	16	16	17	18
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	8	10	11	12	12
STATFJORD	1000	1000	1000	1000	1000
THEVENARD ISLAND	1000	1000	1000	1000	1000
WEST TEXAS INTERMEDIATE	940	1000	1000	1000	1000
ZAIRE	2	3	4	4	4

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D3: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 5000 cP
Wind Speed = 8 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	27	31	32	34	35
BARROW ISLAND	1000	1000	1000	1000	1000
CARPINTERIA	9	11	12	12	13
Chayvo#6	1000	1000	1000	1000	1000
EMPIRE	216	391	493	587	699
FEDERATED (1998)	1000	1000	1000	1000	1000
GENESIS	197	356	448	533	635
GULLFAKS	129	234	295	352	418
HEIDRUN	23	31	35	40	46
HONDO MONTEREY	6	7	7	8	8
IRANIAN HEAVY	35	60	75	90	106
LUCULA	27	43	54	64	76
MALONGO	211	381	481	572	681
Odoptu	1000	1000	1000	1000	1000
OSEBERG	28	41	51	60	70
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	7	9	10	10	10
Prudhoe Bay (1995)	14	16	17	17	18
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	9	12	13	15	16
STATFJORD	1000	1000	1000	1000	1000
THEVENARD ISLAND	1000	1000	1000	1000	1000
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000

ZAIRE	3	5	5	5	6

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D4: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 5000 cP
Wind Speed = 12 knots
Water Temperature = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	10	11	11	11	12
BARROW ISLAND	9999	9999	9999	1000	1000
CARPINTERIA	3	4	4	4	4
Chayvo#6	1000	1000	1000	1000	1000
EMPIRE	105	191	241	287	341
FEDERATED (1998)	1000	1000	1000	1000	1000
GENESIS	115	208	262	312	371
GULLFAKS	60	111	140	166	197
HEIDRUN	11	16	19	22	26
HONDO MONTEREY	1	2	2	2	2
IRANIAN HEAVY	14	24	30	35	41
LUCULA	5	6	6	7	7
MALONGO	4	5	5	6	6
Odoptu	1000	1000	1000	1000	1000
OSEBERG	18	34	43	51	60
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	2	3	3	3	3
Prudhoe Bay (1995)	6	7	8	8	8
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	3	4	4	4	4
STATFJORD	1000	1000	1000	1000	1000
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	441	787	990	1000	1000
ZAIRE	1	1	1	1	1

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D5: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 5000 cP
Wind Speed = 12 knots
Water Temperature = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	12	13	14	14	15
BARROW ISLAND	9999	9999	9999	9999	9999
CARPINTERIA	4	5	5	5	6
Chayvo#6	9999	9999	9999	9999	1000

EMPIRE	149	269	339	403	479
FEDERATED (1998)	1000	1000	1000	1000	1000
GENESIS	144	260	327	389	463
GULLFAKS	87	159	200	238	283
HEIDRUN	12	19	24	28	33
HONDO MONTEREY	2	3	3	3	3
IRANIAN HEAVY	20	38	48	57	67
LUCULA	9	14	16	19	22
MALONGO	23	44	56	66	79
Odoptu	1000	1000	1000	1000	1000
OSEBERG	17	33	42	49	58
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	3	4	4	4	4
Prudhoe Bay (1995)	7	8	8	8	9
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	4	5	6	6	7
STATFJORD	1000	1000	1000	1000	1000
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	783	1000	1000	1000	1000
ZAIRE	1	2	2	2	2

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D6: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 5000 cP
Wind Speed = 12 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	13	15	16	17	18
BARROW ISLAND	9999	9999	9999	9999	9999
CARPINTERIA	4	6	6	6	7
Chayvo#6	9999	9999	9999	9999	9999
EMPIRE	176	318	400	476	566
FEDERATED (1998)	1000	1000	1000	1000	1000
GENESIS	160	289	363	432	514
GULLFAKS	105	190	240	285	338
HEIDRUN	12	21	26	31	36
HONDO MONTEREY	3	4	4	4	4
IRANIAN HEAVY	25	48	61	72	86
LUCULA	18	34	43	52	61
MALONGO	172	311	392	466	554
Odoptu	1000	1000	1000	1000	1000
OSEBERG	17	32	40	48	56
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	4	5	5	5	5
Prudhoe Bay (1995)	7	8	8	9	9
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	5	7	8	8	9
STATFJORD	9999	9999	1000	1000	1000
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	2	3	3	3	3

```
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table D7: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 15 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)       6       7       7       7        7
                 BARROW ISLAND    9999    9999    9999    9999     9999
                   CARPINTERIA       2       3       3       3        3
                      Chayvo#6    9999    9999    1000    1000     1000
                        EMPIRE      95     171     215     256      304
              FEDERATED (1998)    1000    1000    1000    1000     1000
                       GENESIS     104     187     235     279      332
                      GULLFAKS      54      99     125     148      176
                       HEIDRUN       8      13      17      20       23
                HONDO MONTEREY       1       1       1       1        1
                 IRANIAN HEAVY      11      21      26      31       37
                        LUCULA       3       4       4       5        5
                       MALONGO       3       3       4       4        4
                        Odoptu    1000    1000    1000    1000     1000
                       OSEBERG      15      30      38      45       53
                   PITAS POINT    9999    9999    9999    9999     9999
      POINT ARGUELLO COMINGLED       2       2       2       2        2
            Prudhoe Bay (1995)       4       5       5       5        5
                      SAKHALIN    9999    1000    1000    1000     1000
                   SANTA CLARA       2       2       3       3        3
                     STATFJORD    1000    1000    1000    1000     1000
              THEVENARD ISLAND    9999    9999    9999    9999     9999
       WEST TEXAS INTERMEDIATE     401     711     894    1000     1000
                         ZAIRE       1       1       1       1        1
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table D8: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 15 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)       7       8       9       9       10
                 BARROW ISLAND    9999    9999    9999    9999     9999
                   CARPINTERIA       3       3       4       4        4
                      Chayvo#6    9999    9999    9999    9999     9999
                        EMPIRE     134     241     303     360      428
```

FEDERATED (1998)	9999	1000	1000	1000	1000
GENESIS	130	233	293	349	414
GULLFAKS	78	142	179	213	252
HEIDRUN	9	17	21	25	29
HONDO MONTEREY	2	2	2	2	2
IRANIAN HEAVY	18	34	43	51	60
LUCULA	7	11	14	17	19
MALONGO	21	39	50	59	70
Odoptu	1000	1000	1000	1000	1000
OSEBERG	15	29	37	44	52
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	2	3	3	3	3
Prudhoe Bay (1995)	4	5	5	5	6
SAKHALIN	9999	1000	1000	1000	1000
SANTA CLARA	3	4	4	4	5
STATFJORD	9999	9999	9999	1000	1000
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	727	1000	1000	1000	1000
ZAIRE	1	1	2	2	2

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D9: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 5000 cP
Wind Speed = 15 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	8	10	11	12	13
BARROW ISLAND	9999	9999	9999	9999	9999
CARPINTERIA	3	4	4	4	5
Chayvo#6	9999	9999	9999	9999	9999
EMPIRE	159	285	358	426	506
FEDERATED (1998)	9999	1000	1000	1000	1000
GENESIS	145	259	326	387	460
GULLFAKS	94	170	214	254	302
HEIDRUN	9	18	23	27	32
HONDO MONTEREY	2	2	3	3	3
IRANIAN HEAVY	23	43	54	64	76
LUCULA	16	31	39	46	54
MALONGO	155	279	352	418	498
Odoptu	1000	1000	1000	1000	1000
OSEBERG	14	28	36	43	50
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	3	3	3	3	3
Prudhoe Bay (1995)	4	5	5	6	6
SAKHALIN	9999	1000	1000	1000	1000
SANTA CLARA	3	5	6	6	7
STATFJORD	9999	9999	9999	9999	9999
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	995	1000	1000	1000	1000
ZAIRE	1	2	2	2	2

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D10: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 7500 cP
Wind Speed = 8 knots
Water Temperature = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	25	28	29	30	31
BARROW ISLAND	1000	1000	1000	1000	1000
CARPINTERIA	7	8	9	9	10
Chayvo#6	1000	1000	1000	1000	1000
EMPIRE	360	647	816	971	1000
FEDERATED (1998)	1000	1000	1000	1000	1000
GENESIS	318	571	719	856	1000
GULLFAKS	202	365	460	547	651
HEIDRUN	28	42	52	61	72
HONDO MONTEREY	3	4	4	4	5
IRANIAN HEAVY	39	68	86	103	122
LUCULA	11	14	15	16	17
MALONGO	10	12	13	13	14
Odoptu	1000	1000	1000	1000	1000
OSEBERG	55	102	129	154	182
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	5	7	7	7	7
Prudhoe Bay (1995)	15	17	18	19	20
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	7	9	9	10	11
STATFJORD	1000	1000	1000	1000	1000
THEVENARD ISLAND	1000	1000	1000	1000	1000
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	1	2	2	2	2

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D11: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 7500 cP
Wind Speed = 8 knots
Water Temperature = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	30	35	37	39	41
BARROW ISLAND	1000	1000	1000	1000	1000
CARPINTERIA	9	11	12	13	13
Chayvo#6	1000	1000	1000	1000	1000
EMPIRE	491	883	1000	1000	1000
FEDERATED (1998)	1000	1000	1000	1000	1000

```
                       GENESIS     386     693     873    1000     1000
                      GULLFAKS     281     507     639     761      905
                       HEIDRUN      31      50      62      74       88
                HONDO MONTEREY       5       7       7       7        8
                 IRANIAN HEAVY      58     107     134     160      190
                        LUCULA      22      30      36      41       48
                       MALONGO      51      93     118     140      167
                        Odoptu    1000    1000    1000    1000     1000
                       OSEBERG      53      97     123     146      173
                   PITAS POINT    9999    9999    9999    9999     9999
      POINT ARGUELLO COMINGLED       7       9       9      10       10
            Prudhoe Bay (1995)      16      18      19      20       21
                      SAKHALIN    1000    1000    1000    1000     1000
                   SANTA CLARA      10      13      14      15       16
                     STATFJORD    1000    1000    1000    1000     1000
              THEVENARD ISLAND    1000    1000    1000    1000     1000
       WEST TEXAS INTERMEDIATE    1000    1000    1000    1000     1000
                         ZAIRE       3       4       5       5        5
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table D12: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 8 knots
Water Temperature      = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)      34      42      46      50       56
                 BARROW ISLAND    1000    1000    1000    1000     1000
                   CARPINTERIA      10      13      14      15       16
                      Chayvo#6    1000    1000    1000    1000     1000
                        EMPIRE     571    1000    1000    1000     1000
              FEDERATED (1998)    1000    1000    1000    1000     1000
                       GENESIS     422     758     954    1000     1000
                      GULLFAKS     330     595     750     893     1000
                       HEIDRUN      32      54      68      81       96
                HONDO MONTEREY       7       8       9       9       10
                 IRANIAN HEAVY      72     133     168     200      238
                        LUCULA      39      71      90     107      127
                       MALONGO     355     639     805     959     1000
                        Odoptu    1000    1000    1000    1000     1000
                       OSEBERG      50      93     117     140      166
                   PITAS POINT    9999    9999    9999    9999     9999
      POINT ARGUELLO COMINGLED       9      10      11      12       12
            Prudhoe Bay (1995)      16      19      20      20       21
                      SAKHALIN    1000    1000    1000    1000     1000
                   SANTA CLARA      12      16      18      20       22
                     STATFJORD    1000    1000    1000    1000     1000
              THEVENARD ISLAND    1000    1000    1000    1000     1000
       WEST TEXAS INTERMEDIATE    1000    1000    1000    1000     1000
                         ZAIRE       4       6       6       7        7
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
```

```
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table D13: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 12 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)      12      13      14      14       15
                 BARROW ISLAND    9999    9999    9999    1000     1000
                   CARPINTERIA       4       4       5       5        5
                      Chayvo#6    1000    1000    1000    1000     1000
                        EMPIRE     294     526     662     787      936
              FEDERATED (1998)    1000    1000    1000    1000     1000
                       GENESIS     258     463     583     693      824
                      GULLFAKS     164     296     373     443      527
                       HEIDRUN      18      33      41      49       58
                HONDO MONTEREY       2       2       2       2        2
                 IRANIAN HEAVY      29      55      70      83       98
                        LUCULA       6       7       8       8        9
                       MALONGO       5       6       6       7        7
                        Odoptu    1000    1000    1000    1000     1000
                       OSEBERG      44      83     104     124      147
                   PITAS POINT    9999    9999    9999    9999     9999
      POINT ARGUELLO COMINGLED       3       3       4       4        4
            Prudhoe Bay (1995)       7       8       9       9       10
                      SAKHALIN    1000    1000    1000    1000     1000
                   SANTA CLARA       4       5       5       5        6
                     STATFJORD    1000    1000    1000    1000     1000
              THEVENARD ISLAND    9999    9999    9999    9999     9999
       WEST TEXAS INTERMEDIATE    1000    1000    1000    1000     1000
                         ZAIRE       1       1       1       1        1
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table D14: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 12 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)      14      18      20      22       24
                 BARROW ISLAND    9999    9999    9999    9999     9999
                   CARPINTERIA       5       6       6       7        7
                      Chayvo#6    9999    9999    9999    9999     1000
                        EMPIRE     401     718     903    1000     1000
              FEDERATED (1998)    1000    1000    1000    1000     1000
                       GENESIS     314     562     708     842     1000
```

GULLFAKS	229	412	518	616	733
HEIDRUN	21	40	50	60	71
HONDO MONTEREY	3	3	4	4	4
IRANIAN HEAVY	47	86	109	129	154
LUCULA	13	22	27	32	38
MALONGO	41	76	95	113	135
Odoptu	1000	1000	1000	1000	1000
OSEBERG	42	79	99	118	140
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	4	5	5	5	5
Prudhoe Bay (1995)	8	9	9	10	10
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	5	7	8	9	10
STATFJORD	1000	1000	1000	1000	1000
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	2	2	3	3	3

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D15: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 7500 cP
Wind Speed = 12 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	17	25	31	36	42
BARROW ISLAND	9999	9999	9999	9999	9999
CARPINTERIA	5	7	7	8	8
Chayvo#6	9999	9999	9999	9999	9999
EMPIRE	467	834	1000	1000	1000
FEDERATED (1998)	1000	1000	1000	1000	1000
GENESIS	343	615	774	921	1000
GULLFAKS	269	483	608	724	860
HEIDRUN	23	44	55	65	77
HONDO MONTEREY	4	4	4	5	5
IRANIAN HEAVY	59	108	136	162	192
LUCULA	31	58	73	87	103
MALONGO	291	522	657	782	930
Odoptu	1000	1000	1000	1000	1000
OSEBERG	40	75	95	113	134
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	4	5	6	6	6
Prudhoe Bay (1995)	8	9	10	10	11
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	6	10	11	13	15
STATFJORD	9999	9999	1000	1000	1000
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	2	3	3	3	4

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

```
--------------------------------------------------------------------------


Table D16: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 15 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)       7       8       9       9       10
                 BARROW ISLAND    9999    9999    9999    9999     9999
                   CARPINTERIA       2       3       3       3        3
                      Chayvo#6    9999    9999    1000    1000     1000
                        EMPIRE     265     471     592     704      837
              FEDERATED (1998)    1000    1000    1000    1000     1000
                       GENESIS     232     415     522     620      737
                      GULLFAKS     148     265     333     395      470
                       HEIDRUN      15      29      37      44       52
                HONDO MONTEREY       1       2       2       2        2
                 IRANIAN HEAVY      26      49      62      74       87
                        LUCULA       4       5       5       6        6
                       MALONGO       3       4       4       5        5
                        Odoptu    1000    1000    1000    1000     1000
                       OSEBERG      40      74      93     111      131
                   PITAS POINT    9999    9999    9999    9999     9999
      POINT ARGUELLO COMINGLED       2       2       2       2        2
            Prudhoe Bay (1995)       5       6       6       6        6
                      SAKHALIN    9999    1000    1000    1000     1000
                   SANTA CLARA       2       3       3       4        4
                     STATFJORD    1000    1000    1000    1000     1000
              THEVENARD ISLAND    9999    9999    9999    9999     9999
       WEST TEXAS INTERMEDIATE    1000    1000    1000    1000     1000
                         ZAIRE       1       1       1       1        1
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table D17: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 15 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)      10      13      15      17       20
                 BARROW ISLAND    9999    9999    9999    9999     9999
                   CARPINTERIA       3       4       4       4        5
                      Chayvo#6    9999    9999    9999    9999     9999
                        EMPIRE     362     644     810     963     1000
              FEDERATED (1998)    9999    1000    1000    1000     1000
                       GENESIS     283     505     634     754      897
                      GULLFAKS     206     368     463     551      654
```

HEIDRUN	18	36	45	53	63
HONDO MONTEREY	2	2	2	2	3
IRANIAN HEAVY	42	77	97	115	137
LUCULA	10	19	24	29	34
MALONGO	36	67	85	101	120
Odoptu	1000	1000	1000	1000	1000
OSEBERG	37	70	88	105	124
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	3	3	3	3	3
Prudhoe Bay (1995)	5	6	6	6	7
SAKHALIN	9999	1000	1000	1000	1000
SANTA CLARA	3	5	6	7	8
STATFJORD	9999	9999	9999	1000	1000
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	1	2	2	2	2

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D18: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 7500 cP
Wind Speed = 15 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	12	21	27	32	37
BARROW ISLAND	9999	9999	9999	9999	9999
CARPINTERIA	4	5	5	5	6
Chayvo#6	9999	9999	9999	9999	9999
EMPIRE	422	749	942	1000	1000
FEDERATED (1998)	9999	1000	1000	1000	1000
GENESIS	310	552	694	825	981
GULLFAKS	242	433	544	647	769
HEIDRUN	20	39	49	58	68
HONDO MONTEREY	2	3	3	3	3
IRANIAN HEAVY	52	96	121	144	171
LUCULA	27	52	65	77	91
MALONGO	262	469	591	704	838
Odoptu	1000	1000	1000	1000	1000
OSEBERG	36	67	85	100	119
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	3	3	4	4	4
Prudhoe Bay (1995)	5	6	6	7	7
SAKHALIN	9999	1000	1000	1000	1000
SANTA CLARA	5	8	10	11	13
STATFJORD	9999	9999	9999	9999	9999
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	2	2	2	2	2

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

```
Table D19: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 8 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)      29      32      34      36       37
                 BARROW ISLAND    1000    1000    1000    1000     1000
                   CARPINTERIA       8      10      10      11       11
                      Chayvo#6    1000    1000    1000    1000     1000
                        EMPIRE     740    1000    1000    1000     1000
             FEDERATED (1998)     1000    1000    1000    1000     1000
                       GENESIS     560    1000    1000    1000     1000
                      GULLFAKS     406     730     920    1000     1000
                       HEIDRUN      40      71      89     106      126
                HONDO MONTEREY       4       5       5       5        6
                 IRANIAN HEAVY      68     125     157     187      222
                        LUCULA      13      16      17      18       19
                       MALONGO      11      13      14      15       16
                        Odoptu    1000    1000    1000    1000     1000
                       OSEBERG     105     192     242     288      343
                   PITAS POINT    9999    9999    9999    9999     9999
     POINT ARGUELLO COMINGLED        6       7       8       8        8
           Prudhoe Bay (1995)       17      19      20      21       22
                      SAKHALIN    1000    1000    1000    1000     1000
                   SANTA CLARA       8      10      11      12       13
                     STATFJORD    1000    1000    1000    1000     1000
              THEVENARD ISLAND    1000    1000    1000    1000     1000
      WEST TEXAS INTERMEDIATE     1000    1000    1000    1000     1000
                         ZAIRE       2       2       3       3        3
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table D20: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 8 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)      36      45      51      58       66
                 BARROW ISLAND    1000    1000    1000    1000     1000
                   CARPINTERIA      10      13      14      14       15
                      Chayvo#6    1000    1000    1000    1000     1000
                        EMPIRE     989    1000    1000    1000     1000
             FEDERATED (1998)     1000    1000    1000    1000     1000
                       GENESIS     668    1000    1000    1000     1000
                      GULLFAKS     554     994    1000    1000     1000
                       HEIDRUN      46      84     106     126      150
```

HONDO MONTEREY	6	8	8	9	9
IRANIAN HEAVY	104	190	239	285	339
LUCULA	26	40	50	59	70
MALONGO	74	136	172	204	243
Odoptu	1000	1000	1000	1000	1000
OSEBERG	98	179	226	269	320
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	8	10	11	11	11
Prudhoe Bay (1995)	17	20	21	22	23
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	11	15	17	19	20
STATFJORD	1000	1000	1000	1000	1000
THEVENARD ISLAND	1000	1000	1000	1000	1000
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	4	5	5	6	6

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D21: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 8 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	45	66	83	98	116
BARROW ISLAND	1000	1000	1000	1000	1000
CARPINTERIA	12	15	16	17	18
Chayvo#6	1000	1000	1000	1000	1000
EMPIRE	1000	1000	1000	1000	1000
FEDERATED (1998)	1000	1000	1000	1000	1000
GENESIS	723	1000	1000	1000	1000
GULLFAKS	643	1000	1000	1000	1000
HEIDRUN	49	91	115	136	162
HONDO MONTEREY	8	10	10	11	11
IRANIAN HEAVY	129	235	296	352	419
LUCULA	56	103	130	155	184
MALONGO	514	922	1000	1000	1000
Odoptu	1000	1000	1000	1000	1000
OSEBERG	92	170	214	255	303
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	10	12	12	13	13
Prudhoe Bay (1995)	18	21	22	23	24
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	14	20	23	26	29
STATFJORD	1000	1000	1000	1000	1000
THEVENARD ISLAND	1000	1000	1000	1000	1000
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	5	7	7	7	8

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

```
Table D22: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 12 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)      14      16      17      18       20
                 BARROW ISLAND    9999    9999    9999    1000     1000
                   CARPINTERIA       4       5       5       6        6
                      Chayvo#6    1000    1000    1000    1000     1000
                        EMPIRE     604    1000    1000    1000     1000
              FEDERATED (1998)    1000    1000    1000    1000     1000
                       GENESIS     455     814    1000    1000     1000
                      GULLFAKS     331     592     745     887     1000
                       HEIDRUN      30      57      72      86      101
                HONDO MONTEREY       2       3       3       3        3
                 IRANIAN HEAVY      55     101     127     151      179
                        LUCULA       7       8       9      10       11
                       MALONGO       5       7       7       8        8
                        Odoptu    1000    1000    1000    1000     1000
                       OSEBERG      85     156     196     233      277
                   PITAS POINT    9999    9999    9999    9999     9999
    POINT ARGUELLO COMINGLED         3       4       4       4        4
           Prudhoe Bay (1995)        8       9      10      10       11
                      SAKHALIN    1000    1000    1000    1000     1000
                   SANTA CLARA       4       5       6       6        7
                     STATFJORD    1000    1000    1000    1000     1000
              THEVENARD ISLAND    9999    9999    9999    9999     9999
     WEST TEXAS INTERMEDIATE      1000    1000    1000    1000     1000
                         ZAIRE       1       2       2       2        2
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table D23: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 12 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
          ARABIAN Light (2000)      19      30      37      44       52
                 BARROW ISLAND    9999    9999    9999    9999     9999
                   CARPINTERIA       5       7       7       8        8
                      Chayvo#6    9999    9999    9999    9999     1000
                        EMPIRE     808    1000    1000    1000     1000
              FEDERATED (1998)    1000    1000    1000    1000     1000
                       GENESIS     544     971    1000    1000     1000
                      GULLFAKS     452     807    1000    1000     1000
                       HEIDRUN      36      68      86     102      121
                HONDO MONTEREY       3       4       4       4        4
```

IRANIAN HEAVY	84	154	194	230	274
LUCULA	17	32	40	47	56
MALONGO	60	110	139	165	196
Odoptu	1000	1000	1000	1000	1000
OSEBERG	79	145	183	217	258
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	4	5	5	5	6
Prudhoe Bay (1995)	8	10	11	11	12
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	6	9	10	12	14
STATFJORD	1000	1000	1000	1000	1000
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	2	3	3	3	3

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D24: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 12 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	28	53	67	79	94
BARROW ISLAND	9999	9999	9999	9999	9999
CARPINTERIA	6	8	9	9	10
Chayvo#6	9999	9999	9999	9999	9999
EMPIRE	929	1000	1000	1000	1000
FEDERATED (1998)	1000	1000	1000	1000	1000
GENESIS	588	1000	1000	1000	1000
GULLFAKS	524	936	1000	1000	1000
HEIDRUN	39	73	93	110	131
HONDO MONTEREY	4	5	5	5	5
IRANIAN HEAVY	105	190	239	285	338
LUCULA	45	83	105	125	148
MALONGO	421	753	948	1000	1000
Odoptu	1000	1000	1000	1000	1000
OSEBERG	75	137	173	206	245
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	5	6	6	6	7
Prudhoe Bay (1995)	9	10	11	12	12
SAKHALIN	1000	1000	1000	1000	1000
SANTA CLARA	8	13	16	19	23
STATFJORD	9999	9999	1000	1000	1000
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	3	4	4	4	4

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D25: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 15 knots
Water Temperature = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	9	11	12	13	15
BARROW ISLAND	9999	9999	9999	9999	9999
CARPINTERIA	3	3	4	4	4
Chayvo#6	9999	9999	1000	1000	1000
EMPIRE	545	967	1000	1000	1000
FEDERATED (1998)	1000	1000	1000	1000	1000
GENESIS	410	730	918	1000	1000
GULLFAKS	298	530	666	792	942
HEIDRUN	27	51	64	76	90
HONDO MONTEREY	2	2	2	2	2
IRANIAN HEAVY	49	90	113	135	160
LUCULA	4	6	7	7	8
MALONGO	4	5	5	5	6
Odoptu	1000	1000	1000	1000	1000
OSEBERG	76	139	175	208	246
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	2	3	3	3	3
Prudhoe Bay (1995)	5	6	7	7	7
SAKHALIN	9999	1000	1000	1000	1000
SANTA CLARA	3	4	4	4	5
STATFJORD	1000	1000	1000	1000	1000
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	1	1	1	1	1

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D26: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 15 knots
Water Temperature = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	14	26	33	39	46
BARROW ISLAND	9999	9999	9999	9999	9999
CARPINTERIA	3	5	5	5	6
Chayvo#6	9999	9999	9999	9999	9999
EMPIRE	732	1000	1000	1000	1000
FEDERATED (1998)	9999	1000	1000	1000	1000
GENESIS	491	872	1000	1000	1000
GULLFAKS	407	723	908	1000	1000
HEIDRUN	32	61	76	91	107
HONDO MONTEREY	2	3	3	3	3
IRANIAN HEAVY	76	137	173	205	244

LUCULA	14	28	36	42	50
MALONGO	54	98	124	147	175
Odoptu	1000	1000	1000	1000	1000
OSEBERG	71	130	163	194	230
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	3	3	3	4	4
Prudhoe Bay (1995)	6	7	7	8	8
SAKHALIN	9999	1000	1000	1000	1000
SANTA CLARA	4	7	9	10	12
STATFJORD	9999	9999	9999	1000	1000
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	2	2	2	2	2

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table D27: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 15 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
ARABIAN Light (2000)	25	47	60	71	84
BARROW ISLAND	9999	9999	9999	9999	9999
CARPINTERIA	4	6	6	7	7
Chayvo#6	9999	9999	9999	9999	9999
EMPIRE	842	1000	1000	1000	1000
FEDERATED (1998)	9999	1000	1000	1000	1000
GENESIS	532	944	1000	1000	1000
GULLFAKS	473	839	1000	1000	1000
HEIDRUN	35	66	83	98	116
HONDO MONTEREY	3	3	3	3	4
IRANIAN HEAVY	94	170	213	254	301
LUCULA	40	74	94	111	132
MALONGO	379	679	855	1000	1000
Odoptu	1000	1000	1000	1000	1000
OSEBERG	67	123	154	183	218
PITAS POINT	9999	9999	9999	9999	9999
POINT ARGUELLO COMINGLED	3	4	4	4	4
Prudhoe Bay (1995)	6	7	8	8	9
SAKHALIN	9999	1000	1000	1000	1000
SANTA CLARA	6	11	14	17	20
STATFJORD	9999	9999	9999	9999	9999
THEVENARD ISLAND	9999	9999	9999	9999	9999
WEST TEXAS INTERMEDIATE	1000	1000	1000	1000	1000
ZAIRE	2	2	3	3	3

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Appendix D

Detailed descriptions of the methods used to measure physical and chemical properties/process of the 24 new oil samples listed in Table 4 and related results.

1. Description of Oil Characteristics

1.1 Bulk Properties of Crude Oil

Physical properties of the almost limitless variety of crude oils are generally correlated with aspects of chemical composition. Some of these key properties for determining fate and behaviour of oil and petroleum products in the environment are viscosity, density, flash point, pour point, distillation, and interfacial tension. The properties for the oils and comparison to common fuels are listed in Table B.1.

Table B1 Typical Oil and Fuel Properties at 15°C

Property	Units	Gasoline	Diesel	Light Crude	Heavy Crude	Intermediate Fuel Oil	Bunker C	Crude Oil Emulsion
Viscosity	m.Pa·s	0.5	2	5 to 50	50 to 50,000	1,000 to 15,000	10,000 to 50,000	20,000 to 100,000
Density	g/mL	0.72	0.84	0.78 to 0.88	0.88 to 1.00	0.94 to 0.99	0.96 to 1.04	0.95 to 1.0
Interfacial Tension	mN/m	27	27	10 to 30	15 to 30	25 to 30	25 to 35	N/A
Flash Point	℃	-35	55 to 65	-30 to 30	-30 to 60	80 to 100	>100	>80
Pour Point	℃	N/A	-60	-55 to 0	-30 to 30	-10 to 10	5 to 20	>50

1.1.1 Viscosity

Viscosity is the internal resistance to flow in a liquid. The lower the viscosity, the more readily the liquid flows. The viscosity of an oil is a function of its composition, therefore crude oil has a wide range of viscosities. For example, the viscosity of Federated oil from Alberta is 5 mPa·s, while a Sockeye oil from California is 45 mPa·s at 15°C . In general, the greater the fraction of saturates and aromatics and the lower the amount of asphaltenes and resins, the lower the viscosity. As oil weathers, the evaporation of the lighter components leads to increased viscosity.

As with other physical properties, viscosity is affected by temperature, with higher temperatures reducing the viscosity. For most oils, the viscosity varies approximately exponentially with temperature. Oils that flow readily at high temperature can become a slow-moving, viscous mass at low temperature. In terms of oil spill cleanup, viscous oils do not spread rapidly, do not penetrate soils readily, and affect the ability of pumps and skimmers to handle the oil. The dynamic viscosity of an oil can be measured by a viscometer using a variety of standard cup-and-spindle sensors at controlled temperatures.

1.1.2 Density

Density is the mass of a unit volume of oil, usually expressed as grams per millilitre (g/mL) or, equivalently, as kilograms per cubic metre (kg/m^3). It is used by the petroleum industry to grade light or heavy crude oils. Density is also important because it indicates whether a particular oil will float or sink in water. As the density of water is 1.0 g/mL at 15°C and the density of most oils range from 0.70 to 0.99 g/mL, oils typically float on water. As the density of seawater is 1.03 g/mL, even heavier oils will usually float on it. Only a few bitumens have densities greater than water at higher temperatures. However, as water has a maximum density at 4°C and oils will continue to contract as temperature decreases, heavier oils, including heavy crudes and residual fuel oils, may sink in freezing waters. Furthermore, as density increases as the light ends of the oil evaporate off, a heavily-weathered oil, long after a spill event may sink, or be prone to overwashing, where the fresh oil, immediately after the spill, may have floated readily.

1.1.3 Interfacial Tension

Interfacial tensions are the net stresses at the boundaries between different substances. They are expressed as the increased energy per unit area (relative to the bulk materials), or equivalently as force per unit length. The SI units for interfacial tension are milliNewtons per meter (mN/m). Surface tension is thought to be related to the final size of a slick. The lower interfacial tension of oil with water, the greater the extent of spreading and thinner terminal thickness of oil. In actual practice, the interfacial tension alone does not appear account for spreading behaviour; environmental effects and other effects seem to be dominant.

1.1.4 Flash Point

The flash point of an oil is the temperature at which the vapour over the liquid can be ignited. A liquid is considered to be flammable if its flash point is less than 60°C. Flash point is an important consideration for the safety of spill cleanup operations. Gasoline and other light fuels can ignite under most ambient conditions and therefore are a serious flammability hazard when spilled. Many freshly spilled crude oils also have low flash points until the lighter components have evaporated or dispersed. On the other hand, Bunker C and heavy crude oils generally are not flammable when spilled.

1.1.5 Pour Point

The pour point of an oil is the temperature at which no flow of the oil is visible over a period of five seconds from a standard measuring vessel. The pour point of crude oils range from -60°C to 30°C. Lighter oils with low viscosities generally have lower pour points. As oils are made up of hundreds of compounds, some of which may still be liquid at the pour point, the pour point is not the temperature at which an oil will no longer flow. Due to factors such as high wax content, that may crystallize and form a “crust”, the pour point does not represent the point of solidification; the bulk oil may continue to be fluid and can evaporate to a significant degree.

1.2 Chemical Composition

Crude oil is an extremely complex and variable mixture of hydrocarbons. The fate and behaviour of crude oils are strongly influenced by their chemistries. Oil hydrocarbons range from small, volatile compounds to very large, non-volatile compounds. The oil hydrocarbons are characterized and classified by their structures, including saturates, aromatics, and the polar compounds comprising the sub-groups resins and asphaltenes.

1.2.1 Saturates

Saturates are a group of hydrocarbons composed of only carbon and hydrogen with no double bonds or aromaticity. They are said to be “saturated” with hydrogen. They may by straight-chain (normal), branched or cyclic. Typically, however, the group of “saturates” refers to the aliphatics generally including alkanes, as well as a small amount of alkenes. The lighter saturates, those less than ~C_{18}, make up the components of an oil most prone to weathering. The larger saturates, generally those heavier than C_{18}, are termed waxes.

1.2.2 Aromatics

Aromatics are cyclic organic compounds that are stabilized by a delocalized π-electron system. They include such compounds as BTEX (benzene, toluene, ethylbenze and the three xylene isomers), polycyclic aromatic hydrocarbons (PAHs, such as naphthalene), and some heterocyclic aromatics such as the dibenzothiophenes. Benzene and its alkylated derivatives can constitute several percent in crude oils. PAHs and their alkylated derivatives can also make up as much as a percent in crude oils.

1.2.3 Polar Compounds: Asphaltenes and Resins

Polar compounds are those with distinct regions of positive and negative charge, as a result of bonding with atoms such as oxygen, sulphur, or nitrogen. The polarity derived from the charge that the compounds carry result in behaviour that, under some circumstances, is different from non-polar compounds. This is especially significant for the behaviour of the oil on water, as the polar compounds interact with water, which is itself a polar molecule. In the petroleum industry, the smaller polar compounds are called “resins” and the larger polar compounds are called “asphaltenes”, so named because they often compose the largest percentage of the asphalt commonly used for road construction.

The resins include hetero-substituted aromatics (typically oxygen- or nitrogen-containing PAHs), acids, ketones, alcohols, monoaromatic steroids, and sulphur compounds. Because of their polarity, these compounds are more soluble in polar solvents than the non-polar compounds, such as waxes and aromatics, of similar molecular weight. Sulphur is often a very abundant element in petroleum and may be found in many forms, such as hydrogen sulphide, mercaptans, thiophenes, and dibenzothiophenes.

Asphaltenes are a complex mixture of very large organic compounds which precipitate from oils and bitumen by natural processes. Despite a considerable volume of relevant analytical data, very little is known about the molecular configuration of asphaltenes. From X-ray diffraction patterns of solid asphaltenes, it has been inferred that crystallographic organization can be represented by an asphaltene “macromolecule”, in which clusters of partly ordered aromatic matter carrying aliphatic chains of varying length are associated in micelles or particles. If abundant in oil, they have a significant effect on oil behaviour.

1.3 Effects of Evaporative Weathering on Oil Properties

Long experience has shown that the physical characteristics and chemical fingerprint of a crude oil can change greatly over the course of a spill incident. These changes have a profound effect on the fate, behaviour, and effects of an oil in the environment. The oil may transmute to other states, evaporating, dissolving in water, or condensing to a semi-solid residue, each new state having unique behaviours and eventual fates. In order to aid in the estimation and prediction of spill behaviour, it is useful to know not only the characteristics of the fresh crude oil, but also those of oils at different stages of “weathering” in the environment. Previous work has shown that immediately after a spill, the dominant process of oil weathering is evaporation. The following discussion will focus on the effects of evaporative weathering on changes of oil physical properties and chemical compositions.

1.3.1 Weathering

When oil is spilled, on either water or land, a number of transformation processes operate on the oil. In general, there are two types of transformation processes: the first is weathering, and the second is a group of processes (including spreading, transport, sinking, and over-washing) related to the movement of oil in the environment. Weathering and movement processes overlap, with weathering strongly influencing how oil moves in the environment and vice versa. These processes depend very much on the type of oil spilled and the weather conditions during and after the spill. Thoroughly understanding the behaviour of spilled oil in the environment is extremely important for development of oil spill models. Today's sophisticated spill models combine the latest information on oil fate and behaviour with computer technology to predict where the oil will go, what state it will be in, and when it will get there.

"Weathering" refers to the wide variety of physical, chemical and biological processes of a spilled oil in the environment. The weathering processes include evaporation, emulsification, natural dispersion, dissolution, microbial degradation, photooxidation, and other processes such as sedimentation, and oil-suspended particle interactions.

Weathering has a very significant effect on most bulk oil properties and relative proportions of chemical compounds. Unlike the chemical compositions, however, where environmental parameters only affect the rate and type of weathering, bulk properties of the oil are also highly variable depending on the physical conditions. Most important of these is temperature, but other factors such as pressure and the materials with which the oil is in contact also play a role.

As an oil loses mass and changes in composition several general trends in physical property changes can be observed:

- Density increases approximately linearly with increasing weathering. Density decreases approximately linearly with temperature.
- Viscosity increases with increasing weathering, but a simple functional relationship is not easy to develop. Viscosity increases approximately exponentially with decreasing temperature.
- Surface and interfacial tensions tend to increase slightly with increasing weathering.

2 Summary of Quality Assurance and Quality Control (QA/QC) Plan

2.1 Quality Assurance Statement

As a federal government science and technology institute it has been one of our fundamental operating principles that the Oil Research Laboratory of the Emergencies Science and Technology Section (ESTS) of Environment Canada should set an example by adopting the most stringent standards possible for our work. A critical part of our official Mission Statement is to provide "specialized sampling and analytical expertise and services of the highest standards". Quality management has always been a fundamental element of our programs. We continue to refine our quality procedures and protocols whenever new information and processes become available. Our quality program is certified through SCC-CALA, the Standards Council of Canada/Canadian Analytical Laboratories Association. Participation in the SCC-CALA accreditation program provides us a systematic, internationally recognized quality system. A quality web site has been created which provides staff with easy and fast access to all current and approved quality system documentation. The Emergencies Science and Technology Section QA/QC system includes the following:

- Laboratory profile, mission and organization;
- Quality system;

- Personnel;
- Methodology;
- Service, equipment and supplies;
- Facilities;
- Sample management;
- Data management;
- Work load management.

2.2 Quality Assurance in Chemical Composition Methods

The Oil Research Laboratory at Emergencies Science and Technology Division presently performs the following chemical measurements for crude oils, oil products, and oil-spill-related environmental samples: total petroleum hydrocarbons (TPH), total saturates, total aromatics, *n*-alkane distribution, oil-characteristic alkylated PAH homologous series, and other EPA priority PAHs, BTEX and alkyl-benzene compounds, biomarker triterpanes and steranes. The methods of *"Analytical Method for Identification of BTEX Compounds and Alkyl Benzenes and Direct Determination of BTEX and (BTEX + C3-benzenes) in Oils and Refined Products by Gas Chromatography/Mass Spectrometry" and "Analytical Method for the Determination of Individual n-Alkanes and Isoprenoids and Total Petroleum Hydrocarbons (TPH), Polycyclic Aromatic Hydrocarbons (PAHs), and Biomarker Triterpanes and Steranes in Oils, Petroleum Products, and Oil-spill-related Environmental Samples"* have been approved by SCC and CALA.

Chromatographic techniques are used for analyses of oil chemical compositions. In addition to a formal quality control program, a number of specific measures have been added to the processing of oil samples to monitor quality control and to aid in assessment of the data quality with respect to the project objectives. An important part of this is the evaluation of specific QC samples for accuracy, precision, and potential contamination. Before sample analysis, a five point initial calibration composed of the target oil components (for example, n-alkanes) are established, demonstrating the linear range of the analyses. Check standards at the mid-point of the established calibration curves are run before and after each analytical batch of samples (7-10 samples) to validate the integrity of the initial calibration. The method of internal standards using the average relative response factors (RRF) generated from the linear initial calibration is used to quantify the target oil compounds. The RRF stability is a key factor in maintaining the quality of the analysis. Mass discrimination, that is the reduced response of high molecular weight components, must be carefully monitored. If there is a problem with mass discrimination, it can be minimized by trimming the capillary column and by replacing the quartz liner in the injection port. All samples and quality control samples are spiked with appropriate surrogate compounds to measure individual sample matrix effects associated with sample preparation and analysis. Method detection limits (MDL) studies of target compounds are performed according to the procedure described in the EPA protocol titled "Definition and Procedure for the Determination of the Method Detection Limit" (Code of Federal Regulations 40 CFR Part 136). Control charts of standards are prepared and monitored. Validations of analytes in the control chart should be no more than 25% from historical average.

2.3 Quality Assurance in Physical Property Methods

The ESTS Oil Research Laboratory performed the following physical property measurements on crude oils and oil products: boiling point distribution, density, dispersibility, evaporation equation determination, flash point, hydrocarbon group analysis, sulphur content, surface and interfacial tensions, viscosity, and water content. Many of these procedures are ASTM standard methods, and must meet the reproducibility and repeatability of the appropriate method. Others, however, are methods developed in-house and control systems are defined for them in the standard operating procedures (SOP) for those methods. Table B.2 details the measurement procedures.

Table B2: Measurement Procedures

Boiling Point Distribution	Commercial Package, conforming to ASTM D2887
Density	ASTM D5002
Dispersibility	ASTM F2059
Evaporation Equation	In-house method
Flash Point	ASTM D7094
Hydrocarbon Groups	In-house method
Pour Point	ASTM D5853
Sulphur Content	ASTM D4294
Interfacial Tension	Pendant drop method
Viscosity	In-house method
Water Content	ASTM D4377

Pour point is considered semi-quantitative. For this method, although the range of variability in the results is closely monitored, no calibrations, blanks or check standards are preformed. Note that while pour point is measured according to ASTM D5853, no calibration or check standard is specified by that method. While the ASTM D5853 reproducibility requirements are achieved, no further controls for pour point are used in the Emergencies Science and Technology Section Oil Research Laboratory.

Several physical property methods rely on a single instrument and involve a simple measurement with little sample manipulation. These measurements include: density, the development of the evaporation equation, flash point, sulphur content, surface and interfacial tensions, viscosity and water content. For all of these methods, the instruments are calibrated as directed by the manufacturer or the appropriate ASTM method with chemical and/or gravimetric standards as appropriate. In addition, instrumental and operator performance is monitored by periodic measurement of check standards. A log is kept for each instrument, in which calibration and check standard measurements are recorded. The check standard measurements are monitored closely. Failure of the check standard measurement to fall within the smaller of either a historical 95% confidence limit or the appropriate ASTM required repeatability results in an investigation of the procedure. This investigation includes recalibration and measurement of the check standard until the desired precision and accuracy is reached.

Finally, the last class of physical property methods involve significant sample preparation, followed by a measurement by gas chromatography or gravimetry. These methods include: boiling point distribution, dispersibility, and hydrocarbon group analysis. The boiling point distribution is measured using a commercial package provided by Agilent Technologies. The quality control for this procedure involves the minimization of the variance of a check sample chromatogram. The dispersibility test is defined by ASTM F2059 and uses the calibration and standard procedure defined by that method. The hydrocarbon group analysis is carried out under the same protocols as described for the other chromatographic techniques previously.

3 Materials and Instruments

3.1 Instruments

The major instruments used to determine the oil properties are the following:

- Oil Weathering System (Buchi Rotovapor R-220)
- GC-FID (Agilent 6890 with 7683 autosampler)
- X-ray Spectrofluorometer (Spectro Titan)
- Viscometer (ThermoHaake VT550, RheoStress RS300)
- Density meter (Anton Paar DMA 5000)
- Flash point analyzer (Grabner MiniFlash FLP and MiniFlash FLPL)
- Karl Fischer automatic titrator (Metrohm Titrino KF703)
- Pendant drop image analyzer (KSV CAM 200)

3.2 Materials

Solvents were distilled-in-glass quality and used without further purification. Calibration standards were from certified sources, traceable to the National Institute of Standards and Technology (NIST) where available. Lab grade purified water was generated from a dedicated reverse osmosis filtration system.

4 Methods

4.1 Evaporation (Weathering) of Oils

A laboratory oil-weathering technique by rotary evaporation is used by ESTS to artificially weather oils. The oil-weathering system consists of a Buchi Rotovapor R-220 with a 10 L flask, an integral water bath (capacity 14 L), a Brinkmann Lauda 3200 circulating bath and a Millipore vacuum pump. The bath temperature can be set from 20℃ to 100℃ ± 0.5℃. The rotation speed can be continuously varied from 10 to 135 rpm.

The following evaporation procedure is used to evaporate oils:

(1) The water bath of distilled water is brought to a temperature of 80℃.
(2) The empty rotary flask is weighed, approximately 2 L of oil added and the flask reweighed.
(3) The flask is mounted on the apparatus and the flask partially immersed in the water bath and spun at full speed, 135 rpm. A constant flow of air of 13 L/min through the flask is maintained by the vacuum pump.
(4) At set intervals, the sample flask is removed and weighed. Periodically, a sample of about 1 g is removed for chemical analysis.
(5) When evaporation is stopped (i.e. overnight and weekends), the flask is sealed and stored at 5℃. After removal and prior to restarting, the flask is weighed to ensure that no evaporation has occurred during storage.

The initial weathering period is 48 hours, a duration chosen to simulate a highly weathered state of an oil in the environment.

This technique allows for precise control of the evaporative weight loss for a target oil, and can be directly correlated to compositional changes of the target weathered oil. The weathering percentage is calculated by the equation below, where, %weathering is the percentage evaporative mass-loss over the 48 hour period, m_i is the initial mass of the flask and oil, m_f is the final mass of the flask and oil, and m_e is the mass of the empty flask. A graph of %weathering as a function of time is plotted using the interval weighing data.

$$\%\text{weathering} = (m_i - m_f) / (m_i - m_e) \times 100\%,$$

4.2 Equation for Predicting Evaporation

The evaporation kinetics, reported as percentage mass loss as a function of time, are determined for each oil by measuring the weight loss over time from a shallow dish (Fingas, 2001). Approximately 20 g of oil is weighed into a 139mm petri dish. Measurements are conducted in a climate-controlled chamber at 15℃. Temperatures are monitored by a digital thermometer. The oil weight is recorded by an electronic Mettler Toledo balance (model Excellence XS2002S) accurate to 0.01 g at every minute and stored on a computer. All evaporation experiments were run for a minimum of five days.

The data series showing the time versus weight loss were then analyzed for best curve fit using a variety of known predefined behavior functions provided in the SigmaPlot software. The results reveal the following simple equation describe best the variations of the evaporation mass loss with time measured observed at 15 ^{o}C for all the ten oils:

$$\%Ev = A + B \ln (t + C)$$

where: %Ev is weight-percent evaporated, t is time (in minutes), and A, B and C are constants fitted to the measured data.

Equations proposed by Fingas (2001) were considered in this study. Both the logarithmic and power law equations he proposed did not perform better than the proposed equation above. In addition, the proposed equation gives more realistic values when the time approaches zero than in the Fingas logarithmic model. The equation of the curve fit to the evaporation data is listed as part of the oil properties.

4.3 Method for Determining Density

The density of an oil sample, in g/mL, is measured using an Anton Parr DMA 5000 digital density meter following ASTM method D 5002. Measurements are performed at 0.0℃ and 15.0℃. The instrument is checked daily using air and Type 1 water at each temperature. Method and operator performance is monitored by periodic measurement of a NIST traceable standard. A method control chart is kept of these measurements. Densities are corrected for sample viscosity, as specified by the instrument manufacturer. Measurements are repeated in triplicate and the mean reported as the density.

4.4 Method for Determining Dynamic Viscosity

The dynamic viscosity of an oil sample, in mPa.s or cP, is measured using a ThermoHaake VT550 viscometer or the ThermoHaake RheoStress RS300 rheometer. Measurements are made at 0.0℃ and 15.0℃. The instrument is calibrated with ASTM-traceable viscosity standards at 15.0℃. Check standards are run daily. Control charts are kept for each set of sensors.

For oils between 0 and 50,000 mPa.s, the VT550 is selected with either the NV or the SV1 sensor system. The NV sensor is used for oils with viscosities below 100 mPa.s, the SV1 sensor for oils above 70 mPa.s. The sample is allowed to thermally equilibrate until a stable reading is observed for several minutes by the temperature monitor.

The rotational shear rate is set at 500/s for the NV sensor, the SV1 sensor at 100/s. The sensors are ramped up to speed over a period of one minute. The viscosity is measured for a subsequent five minutes, calculated once per second. The viscosity reported is the average over the constant-shear rate interval. Triplicate measurements are averaged and the mean reported as the apparent dynamic viscosity.

For samples above 50,000 mPA.s, the RheoStress RS300 rheometer is employed with a 35 mm cone-plate sensor system in controlled rate mode. Sufficient sample is loaded onto the base plate and raised to the working gap with the cone sensor. The sample is then trimmed to a square edge for measurement. At 0.0℃, a cover is put in place to enable thermal equilibration to be reached. The shear rate is assigned at the high end of the working range of the sensor, which is typically 0.1 s^{-1} for viscosity values in the millions, and 1 s^{-1} for lower viscosities.

4.5 Pendant/Rising Drop Determination of Interfacial Tensions

The interfacial tension is determined by calculation with comparison to the shape of a drop hanging from the end of a needle. A camera is used to photograph a picture of a drop hanging from a needle. The digital picture is analyzed by software, then a parameterized curve shape is developed, from which the surface tension is calculated (Song 1996).

In the case of a liquid-liquid interfacial tension, the surrounding fluid must be clear, so that a good image may be generated. For oil in water this requires that the oil be suspended in water. However, as most oils are less dense than water, the rising oil bubble, rather than the pendant drop must be measured. In this case, the image is inverted in software and, instead of the force of gravity, the buoyant force, determined as the fraction of gravity based on the specific gravity of the oil is used:

$$b = g\,(\rho_{\mathrm{water}} - \rho_{\mathrm{oil}}) / \rho_{\mathrm{water}}$$

where b is the buoyant force, g is the acceleration due to gravity, ρ_{water} is the density of water at the measurement temperature and ρ_{oil} is the oil density.

4.6 Method for Determining Sulphur Content

The mass fraction of atomic sulphur in oil is determined using X-ray fluorescence closely following ASTM method D 4294.

The XRF spectrometer is calibrated using a duplicate series of six NIST sulphur-in-oil standards. A linear calibration chart is prepared from the twelve standard measurements. Single element standards are used to calibrate and remove chlorine interference in the sulphur signal. Instrument and operator performance is monitored by a triplicate measurement of a check standard consisting of a known crude oil. Check standard measurements are tracked on a quality control chart.

Approximately 3 g of oil is weighed out into 31mm HDPE XRF cells, sealed with 0.25 mm thick mylar film. The sealed cells are measured on a Spectro Titan XRF spectrometer. Each unknown is measured in triplicate and the mean reported as the final value.

4.7 Method for Determining Water Content

The mass fraction of water in oil or an emulsion, expressed as a percentage, is determined by Karl Fischer titration using a Metrohm KF Titrino 703 automatic titrator. The method used closely follows ASTM method D 4377. The Karl Fischer reaction is an amine-catalyzed reduction of water in a methanolic solution:

$$CH_3OH + SO_2 + RN \rightarrow [RNH]+ [SO_3CH_3]-$$
$$2RN + H_2O + I_2 + [RNH]SO_3CH_3 \rightarrow [RNH]+ [SO_4CH_3]- + 2\ [RNH]+ I-$$

The amine, RN, or mixture of amines is proprietary to each manufacturer.

A sample of oil or emulsion in the range of 50 to 100 mg is accurately weighed and introduced to the reaction vessel of the autotitrator. A solution of 1:1:2 (by volume) mixture of methanol:chloroform:toluene is used as a working fluid. The autotitrator is loaded with 5-mg/mL, pyridine-free Karl Fischer reagent from a certified supplier. Samples are repeated in triplicate and the mean reported as the water percentage. The titrant value is calibrated by a series of five replicate titrations of 25 µL of distilled, deionized water.

4.8 Method for Determining Flash Point

The flash point of the oils were determined by ASTM method D 7094 using one of two method apparatus, depending on the flash point range. Flash points below 60°C were performed on a MiniFlash FLPL by Grabner Instruments. A flow of cooling water is required to reach temperatures as low as -5°C. Flash points above 60°C were performed on a MiniFlash FLP. In both cases, a 2 mL sample is loaded into the apparatus, moved into position to form a sealed chamber, and sequentially tested for the flash point in one degree increments by automated heating and spark ignition. The flash point is reached when the vapours in the chamber combust, as detected by a spike in the internal pressure.

Samples are repeated in triplicate and the mean reported, with an allowable deviation of 2°C for individual tests. Flash points below -10°C or above 200°C are confirmed in duplicate and reported as outside of the measurable temperature range.

Reagent-grade hexanol is periodically measured by both instruments as a check on instrument and operator performance. A control chart is kept of the results.

4.9 Method for Determining Pour Point

The pour point of an oil sample, in degrees Celsius, is determined by following ASTM method D 5853. Two aliquots of sample are poured into test jars (as described by ASTM D 5853), stopped and fixed with ASTM 5C or 6C thermometers, as appropriate.

Pour point is determined, as described in ASTM D5853, by tilting the test jar to the horizontal and observing the flow of the sample past the fill mark on the jar. If no flow is visible after 5 seconds, the pour point is considered to have been reached. When the pour point is reached, 3°C is added to the temperature recorded. The average of the two measurements is reported as the pour point.

4.10 Method for the Evaluation of the Stability of Emulsions Formed from Saline and Oils and Oil Products

Water-in-oil emulsions are formed in 2.2-litre fluorinated vessels on an end-over-end rotary mixer (Associated Design, VA) at a nominal rotational speed of 50 RPM (Fingas and Fieldhouse, 2009).

(1) A 600-mL volume of salt water (3.3% w/v NaCl) is dispensed into a mixing vessel.
(2) A 30-mL aliquot of oil is added to each vessel for a 1:20 oil:water ratio.
(3) The vessels are sealed and placed in the rotary mixer such that the cap of each mixing vessel follows, rather than leads, the direction of rotation. The rotary mixer is kept in a temperature controlled cold room at 15℃ .
(4) The vessels and their contents are allowed to stand for approximately 4 hours before rotation begins, then mixed continuously for 12 hours.
(5) At the conclusion of the mixing time, the emulsions are collected from the vessels for measurement of water content, viscosity and the complex modulus. The emulsions are stored in the cold room at 15℃ for one week, then observed for changes in physical appearance.

Water content for the emulsions is measured using method 5.7 Method for Determining Water Content. The complex modulus is measured on an RS300 RheoStress rheometer using a 35 mm plate-plate geometry. A stress sweep is performed in the range 100 to 10,000 mPa at a frequency of 1 Hz. The complex modulus value in the linear viscoelastic region is reported. The emulsions are monitored over the week for changes and measurements repeated to assess changes and assign the stability class.

4.11 Method for Determining the Chemical Dispersibility of an Oil or Oil Product

This method determines the relative ranking of effectiveness for the dispersibility of an oil sample by the surfactant Corexit 9500. This method follows closely ASTM F2059, modified to include enhanced quantification methods and performed at 15ºC at the request of MMS.

A pre-mix of 1:25 dispersant:oil is made up by adding oil to 100mg of dispersant to make approximately 2.5mL of pre-mix in total. The ratio must be within 0.5% of the target.

Six side-spout Erlenmeyer flasks, as described in ASTM F2059, containing 120 mL of 33‰ brine are placed into an incubator-shaker. An aliquot of 100 μL of premix is added to the surface of the liquid in each flask, care being taken to not disturb the bulk brine. The flasks are mechanically mixed on an oscillating table with 2.5 cm orbit at a rotation speed of 150 rpm for exactly 20 minutes. The solutions are allowed to settle for 10 minutes.

Using the side spout, 30 mL of the oil-in-water phase is transferred to a 250 mL separatory funnel, first clearing the spout by draining 3 mL of liquid. The 30 mL aliquot is extracted with 3 volumes of 5 mL of 70:30 (v:v) dichloromethane:pentane, collected into a 25-mL graduated cylinder and made up to a 15 mL volume.

Sample analysis is performed using a gas chromatograph with flame ionization detector (GC-FID) to determine the oil concentration in the solvent. A 900 μL aliquot of the 15-mL solvent extract is combined with 100 μL of internal standard (200 ppm of 5-α-androstane in hexane) in a 2 mL injection vial and shaken well. Total petroleum hydrocarbon content of the sample is quantified by the internal standard method using the following equation:

$$\mathrm{TPH} = A_{TPH}/A_{IS}/\mathrm{RRF}*C_{IS}*67$$

where:

TPH = total petroleum hydrocarbon in μg,
A_{TPH} = the total baseline-corrected peak area,

A_{IS} = the internal standard peak area,
C_{IS} = concentration of the internal standard in the sample in μg
RRF = the average relative response factor for a series of alkane standards covering the analytical range, determined separately

The method is calibrated using a series of six oil-in-solvent mixtures prepared from the premix for each oil. The volume of premix dispersant/oil solution for each standard is selected to represent a percentage efficiency of the dispersed oil, 100 μL representing 100% effectiveness. The volume of the premix is carefully applied to the surface of the brine in a shaker flask and shaken exactly as one of the samples, as described previously. Upon removal from the shaker and following the settling time however, the entire contents of the flask is transferred to the separatory funnel. This is extracted with 3 volumes of 20 mL of 70:30 (v:v) dichloromethane to pentane and made up to 60 mL. Chromatographic quantitation is then performed using the same formula as for the samples above.

The %Effectiveness for the calibration set is plotted as a function of TPH to determine the linear equation. The TPH values for the samples are then substituted to determine the effectiveness of the individual samples, and averaged to provide the overall effectiveness value for the oil and dispersant.

4.12 Hydrocarbon Groups

4.12.1 Saturate and Aromatic Chromatographic Determination

This method is adapted and simplified from a previously published method (Wang 1994) for crude oil and petroleum product determination.

An 80 mg/mL solution of oil is prepared in hexane. A 3.0 g column of activated silica-gel is prepared, topped with 0.5 cm anhydrous sodium sulphate. The column is conditioned with 20 mL of hexane.

An amount of 200 μL of the oil solution, approximately 16 mg of oil, is quantitatively transferred onto the column using an additional 3 mL of hexane to complete the transfer. The eluent is also discarded. Just prior to exposure of the sodium sulphate to the air, 12 mL of hexane is added to the column. The eluent is labeled fraction “F1”. F1 is considered to contain all the saturates, including the waxy components in the oil.

The column is then eluted with 15 mL of 1:1 (volume:volume) benzene/hexane or dichloromethane/hexane. The eluent is collected and labeled fraction “F2”. F2 is considered to contain the aromatic compounds in the oil, including the BTEX compounds, other akylated benzene species, PAHs and the alkylated PAH homologues.

Half of fractions F1 and F2 are combined. This composite fraction is labeled “F3”. This fraction is used for analysis of total petroleum hydrocarbons (TPH).

All the three fractions are concentrated under dry nitrogen. The fractions are then spiked with the internal standard, 100 μL of 200 ppm 5-α-androstane, and made up with hexane to 1 mL .

The analysis for total petroleum hydrocarbons and saturates is performed by high resolution capillary GC/FID using the following conditions:

Column: 30 m x 0.32 mm ID HP DB5-HT fused silica column

(0.10 μm film thickness);
Carrier Gas: Helium, 3.0 mL/min, constant flow;
Injection volume: 1.0 μL;
Injector temperature: 290 °C;
Detector temperature: 325 °C;
Oven program: 40 °C for 2 minutes, followed by 25 °C/minute to a final temperature of 340 °C, then held for 15 minutes. The total run time is 29 minutes.

The concentration of petroleum hydrocarbons are calculated using the following equation:

$$\textit{Concentration}\ (\mu g/g) = A_S * W_{IS} * D \,/\, A_{IS} * RRF * W_S$$

where:

A_S = Detector response for the analyte in the sample, units in area count
A_{IS} = Detector response for the internal standard in the sample, same units
W_{IS} = Mass in mg of internal standard added to the sample
W_S = Mass of the sample in g
D = Dilution factor of the solvent

To calculate the concentration of hydrocarbons in each fraction, the area response attributed to the petroleum hydrocarbons must be determined. This area includes all of the resolved peaks and unresolved “hump”. This total area must be adjusted to remove the area response of the internal standards and GC column bleed (baseline)
Column bleed is the reproducible baseline shift that occurs during the oven cycle of the GC. To determine this area, a hexane blank injection is analyzed before and after every 10 samples to determine the baseline response. The integration baseline is then set at a stable reproducible point just before the solvent peak. This baseline area for the blank run is subtracted from the actual sample run.

The total areas of the chromatograms of F1, F2 and F3 are obtained by integration of all peaks, corrected by removal of the baseline and internal standard. The F3 fraction is used to calculate the total petroleum hydrocarbon (TPH) values for the oil (Wang 1994). The F1 and F2 fractions are used to calculate the total saturate (TSH) and total aromatic (TAH) contents. Note that TPH should be within 10% of TSH + TAH.

As not all the oil is passed through the GC column, a simple sum of TSH, TAH, resin and asphaltene contents will not sum to 100%. This missing portion of the oil, which does not precipitate or get analyzed by the GC method is approximated by proportionally dividing it into the saturate and aromatic portions. Thus the saturate content of the oil is comuted using:

$$\%\ \textit{Saturates} = TSH \,/\, (\,TSH + TAH)\ (1 - \%\ \textit{Asphaltenes} - \%\ \textit{Resins})$$

Likewise, the aromatic content is computed using:

$$\%\ \textit{Aromatic} = TAH \,/\, (\,TSH + TAH)\ (1 - \%\ \textit{Asphaltenes} - \%\ \textit{Resins})$$

For crude oils or products with high water content, it is necessary to dry the sample prior to the gravimetric determination of the hydrocarbon group contents. If a Karl-Fischer water content determination can be made, then the composition of the original product can be reported, adjusted for the observed water content. If not, the values should be reported as for dried product only.

4.12.2 Resin and Asphaltene Thin-layer Chromatography Determination

A standard method is not available for this technique, however it has the advantages over previously used gravimetric methods by being much faster, requiring less oil and being more reproducible. It has the disadvantage of requiring a sophisticated instrument, a thin-layer chromatograph (TLC) with a flame ionization detector (FID).

A thin-layer chromatograph which quantifies analystes developed on silica gel-coated glass rods, such as the Iatroscan Mark 6, is necessary for this method. An aliquot of sample dissolved in dichloromethane at a concentration of 1 mg/mL is spotted at a point, the origin, near one end of a rod closest to the base of a rod rack in which the rods are mounted. The rods are then developed by immersion of the base into a series of solvents to separate the four hydrocarbon groups as the solvents travel up the rods by capillary action. The origin points must remain above the liquid surface, but the base end of the rods must be immersed sufficiently to allow solvent travel.

The first solvent used is n-hexane to develop the saturates. Toluene develops the aromatics. Finally, a 95%-dichloromethane, 5%-methanol mixture is used to develop the resins. The asphaltenes remain at the spotting origin. The hydrocarbon groups which are not quantified by this method, the saturates and aromatics, are removed by pyrolysis. A known standard is then applied to the chromarod and then quantified using a flame ionization detector (FID) and an internal standard. A sample of 1-octadecanol at 1 mg/mL concentration is a convenient internal standard. This is spotted on the rod just prior to measurement, on the part of the rod pyrolyzed to remove the saturate and aromatic fractions.

The development of the chemicals on the rods critically depends on the conditions. The rods must be developed in tanks to control the vapours in the atmosphere. Also, temperature and humidity must remain as consistent as possible to achieve reproducible results. When drying after each development, the rods must rest in a controlled humidity chamber.

Resin and asphaltene contents are determined as follows:

$$\%\text{Resin} = C_{IS} * V_{IS} * A_R / A_{IS}$$

$$\%\text{Asphaltene} = C_{IS} * V_{IS} * A_A / A_{IS}$$

Where :

C_{IS} = Internal standard concentration
V_{IS} = Internal standard volume
A_{IS} = Internal standard area from TLC integration
A_R = Resin area from TLC integration
A_A = Asphaltene area from TLC integration

Note that while saturate and aromatic fractions are separated by the development process, and could, in principle be measured by TLC-FID, the drying process between development stages requires significant evaporation. This level of evaporation is of sufficient magnitude to remove most of the volatile components, which includes a large fraction of both saturates and aromatics (but not the resins or asphaltenes). For this reason this TLC-FID method is not suitable for saturate or aromatic determination.

4.13 Calculation of Total Petroleum Hydrocarbon Distributions

The quantification of total petroleum hydrocarbon (TPH) in the oil samples, the proportionality of saturates and aromatics, as well as the proportionality of TPH segments defined by *n*-alkane carbon number ranges, are determined from the same chromatograms and by the same calculations as described above for the determination of saturate and aromatic hydrocarbon groups. TPH determination is a mass quantification, while the remainder are relative percentages. The distribution of hydrocarbons within the four fractions defined by the C_8, C_{10}, C_{16} and C_{34} n-alkane elution times are calculated by integrating the resolved and unresolved hydrocarbon response after removing the baseline and internal standard peak. The hydrocarbon range from $C_8 – C_{10}$ is generally the volatile components, C_{10} to C_{16} the semi-volatiles, C_{16} to C_{34} are the non-volatiles, while the remaining fraction is high-boiling residue.

4.14 Method for Determining the Simulated Boiling Point Distribution

This analysis is performed on an Analytical Controls SIMDIS analyser, a modified Hewlett-Packard 5890 series II gas chromatograph. The system has a custom cryogenically-cooled inlet and a high-temperature column. Reference and calibration mixtures are run according to Analytical Controls specifications.

Oil samples are made up as 2% (m/m) solutions in carbon disulphide. An aliquot of 0.5 μL is injected into the inlet. The inlet temperature program runs from 40℃ to 430℃ a 70℃ per minute. The oven temperature program runs from -20℃ for 1 min, ramp at 10℃/min to 430℃, and hold for 3 minutes at this final temperature. The flame ionization detector operates at 430℃.

The Ultra Scientific Software outputs the boiling point temperature at which a cumulative fixed mass percentage of sample has been removed under this simulation.

4.15 Measurement of Wax Content

4.15.1 Analytical Procedure

The analytical procedure used to measure wax content is based on the gravimetric method (precipitation). The analysis involves the removal of asphaltenes using precipitation and filtration from *n*-pentane. The de-asphaltened oil (maltenes) is then dissolved in a 1:1 mixture of Dichloromethane (DCM) and Methyl Ethyl Ketone (MEK) and chilled overnight at -30 C. On the next day, the precipitated waxes are filtered from the cold solution, air-dried, and weighed. The following steps explain the details of the procedure.

1. A 5 mL sample of crude oil is mixed with 2mL of Toluene, swirled manually and left for 2 minutes.
2. 125mL of Pentane are added to the oil solution and shaken for 1 hour at 100 RPM at Room Temperature.
3. The precipitated asphaltenes are collected on a tared 0.45-μm membrane filter by vacuum filtration.
4. The filtered asphaltenes are left in a desiccator overnight to allow evaporation of any remaining solvent. Asphaltene content can be determined gravimetrically by dividing the mass difference of the filter by the initial mass of the oil sample.
5. The eluent (maltenes) is transferred to a tared 500mL boiling flask and the n-pentane removed by rotary evaporation at 30 °C.

6. A minimum amount of dichloromethane (DCM) is used to rinse the filtration container and ensure that all of the maltenes were transferred to the boiling flask. Rotary evaporation is used to remove the DCM at 40 °C.
7. The maltenes are stored loosely covered in the fume hood overnight.
8. The de-asphaltened oil is transferred to a 250 mL Teflon Erlenmeyer flask using 50mL of a 1:1 volume mixture of DCM and methyl ethyl ketone (MEK). The flask is stoppered and put on the shaker for 30 minutes.
9. The sample is then stored in a freezer at -30 °C overnight, along with additional filtration apparatus and solvent, including a Buchner funnel, filtering flask, and a squeeze bottle of DCM/MEKOn the following day, a tared Whatman GF/C 5.5cm glass microfiber filter is placed in the chilled Buchner filtration apparatus. Working as quickly as possible to minimize warming, the precipitated wax crystals are filtered from the oil solution and rinsed with chilled solvent.
10. The Teflon flask is rinsed with chilled DCM/MEK and poured onto the filter to ensure complete transfer of the waxes. Aspiration continues for five minutes following filtration to dry the filter. A final weight of the waxes from the oil sample is obtained by mass difference of the filter.
11. The percentage wax content is determined gravimetrically by dividing the mass of wax by the initial mass of the oil sample.

4.15.2 Quality Control

1. A duplicate test is performed for each sample and the wax content is calculated as the average of the weight percents of precipitated wax to original oil weight. A third measurement was conducted to validate the results of the first two measurements when relatively large difference was obtained from the first measurements.
2. Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and the analysis of reference standards as a continuing check on performance.
3. The laboratory is required to maintain performance records to define the quality of data that is generated. Ongoing performance checks must be compared with established performance criteria to determine if the results of analyses are within accuracy and precision limits expected of the method.
4. Before performing any analysis, the analyst must demonstrate the ability to generate acceptable accuracy and precision with this method. This involves performing a test measuring the wax content of the check standard, Western Sweet Blend crude oil, to determine both the precision and accuracy of the operator and method.

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6 Oil Properties of Select Oils

The tables below summarize the properties of the 24 new U.S. outer continental shelf oils analyzed as part of this project.

Table B3 Oil Properties of Alaska North Slope

		%Evaporative Mass Loss	
		0.0%	30.67%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	$\%Ev = -1.01 + 0.92\ \mathrm{Ln}(t+0.99)$		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	$\%Ev = (2.47 + 0.045T)\ \ln(t)$		
Density (g/mL)	0ºC	0.8870	0.9439
	15ºC	0.8754	0.9316
Dynamic Viscosity (mPa·s)	0ºC	30.2	4.80E+3
	15ºC	15.4	546
Surface Tension (mN/m)	0ºC	28.4	NM*
	15ºC	27.9	30.1
Interfacial Tension - Oil/Water (mN/m)	0ºC	21.7	NM*
	15ºC	21.2	20.7
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	21.1	NM*
	15ºC	20.1	20.5
Sulfur Content (%w/w)		0.91	1.28
Water Content (%w/w)		0.1	0
Flash Point (ºC)		<-5	136
Pour Point (ºC)		-15	6
Emulsion Formation	Visual Stability	Unstable	Meso
	Complex Modulus (Pa)	NM	108
	Water Content (%w/w)	NM	75.3
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	67%	11%
Hydrocarbon Groups (%w/w)	Saturates	58.7	50.1
	Aromatics	31.3	26.5
	Resins	7.6	20.2
	Asphaltenes	2.4	3.2
Wax Content (%w/w)		4.9	
GC-TPH Distributions	Total GC-TPH (mg/g)	511	515
	GC-Saturates/GC-TPH (%)	65.2	65.4
	GC-Aromatics/GC-TPH (%)	34.8	34.6
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	12.3	1.3
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	28.1	23.3
	$nC_{16} <$ to $\leq nC_{34}$	50.5	65.5
	nC_{34} +	9.1	10.0

Note:
NM - Not Measured
*Too viscous

%Evaporative Mass Loss
0.0% 30.67%

	% Mass	°C	°C
Boiling Point Distribution	IBP	34	216
(Cumulative Weight Fraction)	5	86	247
	10	111	264
	15	133	278
	20	151	293
	25	174	305
	30	200	318
	35	224	332
	40	247	346
	45	267	361
	50	287	375
	55	308	390
	60	329	404
	65	351	419
	70	372	433
	75	394	447
	80	417	462
	85	439	479
	90	462	497
	95	488	515
	99.5	512	535

Note:
IBP - Initial Boiling Point

Table B4 Oil Properties of Alaska North Slope weathered 20.86%

		%Evaporative Mass Loss
		0.0%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	%Ev = -4.75 + 0.76 Ln(t+562.1)	
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	%Ev = (-0.57 + 0.045T) ln(t)	
Density (g/mL)	0ºC	0.9269
	15ºC	0.9159
Dynamic Viscosity (mPa·s)	0ºC	561
	15ºC	133
Surface Tension (mN/m)	0ºC	31.9
	15ºC	29.9
Interfacial Tension - Oil/Water (mN/m)	0ºC	25.5
	15ºC	22.7
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	24.5
	15ºC	22.3
Sulfur Content (%w/w)		1.13
Water Content (%w/w)		0.1
Flash Point (ºC)		90
Pour Point (ºC)		0
Emulsion Formation	Visual Stability	Meso
	Complex Modulus (Pa)	17
	Water Content (%w/w)	75.5
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	49%
Hydrocarbon Groups (%w/w)	Saturates	56.6
	Aromatics	26.3
	Resins	13.7
	Asphaltenes	3.4
Wax Content (%w/w)		7.3
GC-TPH Distributions	Total GC-TPH (mg/g)	639
	GC-Saturates/GC-TPH (%)	68.3
	GC-Aromatics/GC-TPH (%)	31.7
GC-TPH in Ranges:	$nC_8 \le$ to $\le nC_{10}$	4.2
(%w/w)	$nC_{10} <$ to $\le nC_{16}$	28.3
	$nC_{16} <$ to $\le nC_{34}$	55.6
	nC_{34} +	11.9

		%Evaporative Mass Loss
		0.0%
	% Mass	°C

Boiling Point Distribution	IBP	150
(Cumulative Weight Fraction)	5	191
	10	215
	15	233
	20	251
	25	266
	30	282
	35	299
	40	314
	45	330
	50	345
	55	362
	60	379
	65	396
	70	413
	75	431
	80	448
	85	466
	90	486
	95	507
	99.5	528

Note:
IBP - Initial Boiling Point

Table B5 Oil Properties of Arabian Medium

		%Evaporative Mass Loss	
		0.0%	31.35%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	$\%Ev = -1.27 + 0.94\,\mathrm{Ln}(t+2.08)$		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	$\%Ev = (2.18 + 0.045T)\ln(t)$		
Density (g/mL)	0ºC	0.8849	0.9582
	15ºC	0.8738	0.9454
Dynamic Viscosity (mPa·s)	0ºC	62.6	2.23E+4
	15ºC	21.6	2.07E+3
Surface Tension (mN/m)	0ºC	29.3	NM*
	15ºC	27.4	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	24.9	NM*
	15ºC	26.7	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	25.7	NM*
	15ºC	27.0	NM*
Sulfur Content (%w/w)		2.70	3.71
Water Content (%w/w)		0.1	0
Flash Point (ºC)		<0	142
Pour Point (ºC)		<-24	0
Emulsion Formation	Visual Stability	Stable	Stable
	Complex Modulus (Pa)	1062	975
	Water Content (%w/w)	85.5	75.8
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	53%	<10%
Hydrocarbon Groups (%w/w)	Saturates	49.7	47.2
	Aromatics	36.5	29.1
	Resins	10.4	17.8
	Asphaltenes	3.4	5.9
Wax Content (%w/w)		5.2	
GC-TPH Distributions	Total GC-TPH (mg/g)	412	544
	GC-Saturates/GC-TPH (%)	57.6	61.8
	GC-Aromatics/GC-TPH (%)	42.4	38.2
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	5.3	0.8
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	28.4	19.2
	$nC_{16} <$ to $\leq nC_{34}$	57.1	69.7
	nC_{34} +	9.3	10.3

Note:
NM - Not Measured
*Too viscous

%Evaporative Mass Loss
0.0% 31.35%

	% Mass	°C	°C
Boiling Point Distribution	IBP	57	87
(Cumulative Weight Fraction)	5	97	206
	10	125	249
	15	148	269
	20	170	285
	25	192	300
	30	215	315
	35	235	329
	40	257	343
	45	279	357
	50	302	372
	55	322	388
	60	344	403
	65	366	419
	70	388	434
	75	411	450
	80	434	465
	85	457	482
	90	481	499
	95	507	517
	99.5	534	536

Note:
IBP - Initial Boiling Point

Table B6: Oil Properties of DOBA

		%Evaporative Mass Loss	
		0.0%	14.13%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	$\%Ev = -2.53 + 0.45 \ln(t+255.9)$		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	$\%Ev = (-0.11 + 0.013T) \sqrt{t}$		
Density (g/mL)	0ºC	0.9423	0.9483
	15ºC	0.9271	0.9372
Dynamic Viscosity (mPa·s)	0ºC	3.66E+4	6.10E+4
	15ºC	3.11E+3	7.30E+3
Surface Tension (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*	NM*
	15ºC	28.2	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*	NM*
	15ºC	27.2	NM*
Sulfur Content (%w/w)		0.12	0.13
Water Content (%w/w)		4.0	0
Flash Point (ºC)		>60	166
Pour Point (ºC)		-5	6
Emulsion Formation	Visual Stability	Entrained	Entrained
	Complex Modulus (Pa)	47	102
	Water Content (%w/w)	43.0	33.9
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	10%	<10%
Hydrocarbon Groups (%w/w)	Saturates	65.2	61.8
	Aromatics	20.2	18.1
	Resins	10.2	16.0
	Asphaltenes	4.5	4.0
Wax Content (%w/w)		2.7	
GC-TPH Distributions	Total GC-TPH (mg/g)	382	363
	GC-Saturates/GC-TPH (%)	76.4	77.4
	GC-Aromatics/GC-TPH (%)	23.6	22.6
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	3.2	1.7
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	19.0	12.6
	$nC_{16} <$ to $\leq nC_{34}$	63.8	65.4
	nC_{34} +	14.0	20.3

Note:
NM - Not Measured
*Too viscous

	%Evaporative Mass Loss	
	0.0%	14.13%

	% Mass	˚C	˚C
Boiling Point Distribution	IBP	94	120
(Cumulative Weight Fraction)	5	199	260
	10	239	285
	15	264	307
	20	284	325
	25	306	342
	30	326	358
	35	344	373
	40	361	388
	45	378	403
	50	395	416
	55	410	428
	60	424	440
	65	437	451
	70	450	462
	75	462	472
	80	474	484
	85	487	495
	90	499	506
	95	512	518
	99.5	525	532

Note:
IBP - Initial Boiling Point

Table B7: Oil Properties of Dos Cuadras HE-05

		%Evaporative Mass Loss	
		0.0%	23.40%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	$\%Ev = -1.72 + 0.87\,\mathrm{Ln}(t+5.83)$		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	$\%Ev = (1.61 + 0.045T)\ln(t)$		
Density (g/mL)	0ºC	0.9184	0.9607
	15ºC	0.9078	0.9491
Dynamic Viscosity (mPa·s)	0ºC	199	2.77E+4
	15ºC	70.3	2.85E+3
Surface Tension (mN/m)	0ºC	31.1	NM*
	15ºC	29.1	32.6
Interfacial Tension - Oil/Water (mN/m)	0ºC	25.7	NM*
	15ºC	23.7	29.8
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	23.8	NM*
	15ºC	23.5	26.9
Sulfur Content (%w/w)		1.22	1.55
Water Content (%w/w)		0.5	0.1
Flash Point (ºC)		0	135
Pour Point (ºC)		-27	13
Emulsion Formation	Visual Stability	Unstable	Entrained
	Complex Modulus (Pa)	NM	457
	Water Content (%w/w)	NM	76.4
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	67%	<10%
Hydrocarbon Groups (%w/w)	Saturates	49.2	33.6
	Aromatics	29.5	28.6
	Resins	14.5	26.7
	Asphaltenes	6.7	11.1
Wax Content (%w/w)		4.3	
GC-TPH Distributions	Total GC-TPH (mg/g)	477	460
	GC-Saturates/GC-TPH (%)	62.6	54.0
	GC-Aromatics/GC-TPH (%)	37.4	46.0
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	5.1	0.4
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	15.0	22.4
	$nC_{16} <$ to $\leq nC_{34}$	63.8	67.3
	nC_{34} +	16.1	10.0

Note:
NM - Not Measured
*Too viscous

%Evaporative Mass Loss
0.0% 23.40%

	% Mass	˚C	˚C
Boiling Point Distribution	IBP	69	196
(Cumulative Weight Fraction)	5	108	242
	10	137	260
	15	166	277
	20	191	294
	25	217	305
	30	238	318
	35	259	333
	40	280	349
	45	302	364
	50	318	380
	55	340	395
	60	361	411
	65	383	425
	70	405	438
	75	426	450
	80	443	463
	85	461	479
	90	483	495
	95	505	510
	99.5	525	525

Note:
IBP - Initial Boiling Point

Table B8: Oil Properties of Dos Cuadras HE-26

		%Evaporative Mass Loss	
		0.0%	32.20%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	$\%Ev = -1.32 + 0.92 \mathrm{Ln}(t+4.05)$		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	$\%Ev = (2.52 + 0.045T) \ln(t)$		
Density (g/mL)	0ºC	0.8902	0.9487
	15ºC	0.8785	0.9353
Dynamic Viscosity (mPa·s)	0ºC	56.2	2.66E+4
	15ºC	20.6	1.14E+3
Surface Tension (mN/m)	0ºC	28.3	NM*
	15ºC	28.6	33.3
Interfacial Tension - Oil/Water (mN/m)	0ºC	13.1	NM*
	15ºC	16.1	16.0
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	12.6	NM*
	15ºC	16.1	17.5
Sulfur Content (%w/w)		0.51	0.74
Water Content (%w/w)		2.6	0.1
Flash Point (ºC)		-1	132
Pour Point (ºC)		-5	25
Emulsion Formation	Visual Stability	Unstable	Stable
	Complex Modulus (Pa)	NM	759
	Water Content (%w/w)	NM	76.3
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	69%	11%
Hydrocarbon Groups (%w/w)	Saturates	57.2	57.7
	Aromatics	31.0	26.0
	Resins	8.9	13.4
	Asphaltenes	2.8	3.0
Wax Content (%w/w)		6.4	
GC-TPH Distributions	Total GC-TPH (mg/g)	546	554
	GC-Saturates/GC-TPH (%)	64.8	68.9
	GC-Aromatics/GC-TPH (%)	35.2	31.1
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	13.0	1.2
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	17.7	23.8
	$nC_{16} <$ to $\leq nC_{34}$	31.9	67.6
	nC_{34} +	37.4	7.4

Note:
NM - Not Measured
*Too viscous

%Evaporative Mass Loss
0.0% 32.20%

	% Mass	˚C	˚C
Boiling Point Distribution	IBP	60	148
(Cumulative Weight Fraction)	5	95	234
	10	118	253
	15	139	270
	20	162	286
	25	184	300
	30	210	311
	35	232	324
	40	253	340
	45	275	355
	50	300	369
	55	318	384
	60	342	400
	65	366	415
	70	390	429
	75	414	441
	80	436	454
	85	456	469
	90	481	486
	95	509	503
	99.5	539	518

Note:
IBP - Initial Boiling Point

Table B9: Oil Properties of Endicott

		%Evaporative Mass Loss	
		0.0%	21.41%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	%Ev = -1.34 + 0.64 Ln(t+8.11)		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	%Ev = (1.39 + 0.045T) ln(t)		
Density (g/mL)	0ºC	0.9142	0.9518
	15ºC	0.9024	0.9397
Dynamic Viscosity (mPa·s)	0ºC	235	1.50E+4
	15ºC	46.4	1.36E+3
Surface Tension (mN/m)	0ºC	31.0	NM*
	15ºC	29.3	31.2
Interfacial Tension - Oil/Water (mN/m)	0ºC	20.9	NM*
	15ºC	20.1	22.4
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	17.2	NM*
	15ºC	13.0	20.3
Sulfur Content (%w/w)		1.04	1.33
Water Content (%w/w)		0.3	0
Flash Point (ºC)		<0	141
Pour Point (ºC)		6	18
Emulsion Formation	Visual Stability	Unstable	Entrained
	Complex Modulus (Pa)	NM	992
	Water Content (%w/w)	NM	74.0
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	62%	<10%
Hydrocarbon Groups (%w/w)	Saturates	60.5	52.6
	Aromatics	29.8	27.4
	Resins	7.2	16.1
	Asphaltenes	2.5	3.9
Wax Content (%w/w)		12.0	
GC-TPH Distributions	Total GC-TPH (mg/g)	517	522
	GC-Saturates/GC-TPH (%)	67.0	65.7
	GC-Aromatics/GC-TPH (%)	33.0	34.3
GC-TPH in Ranges:	$n\mathrm{C}_8 \le$ to $\le n\mathrm{C}_{10}$	10.5	0.9
(%w/w)	$n\mathrm{C}_{10} <$ to $\le n\mathrm{C}_{16}$	24.5	21.2
	$n\mathrm{C}_{16} <$ to $\le n\mathrm{C}_{34}$	58.6	68.8
	$n\mathrm{C}_{34}$ +	6.4	9.2

Note:
NM - Not Measured
*Too viscous

		%Evaporative Mass Loss	
		0.0%	21.41%

	% Mass	˚C	˚C
Boiling Point Distribution	IBP	72	97
(Cumulative Weight Fraction)	5	120	224
	10	154	253
	15	185	271
	20	215	287
	25	238	304
	30	261	319
	35	281	334
	40	302	350
	45	320	365
	50	340	380
	55	359	394
	60	378	410
	65	397	424
	70	416	438
	75	434	452
	80	452	468
	85	472	484
	90	493	501
	95	516	520
	99.5	543	541

Note:
IBP - Initial Boiling Point

Table B10: Oil Properties of Endicott weathered 18.56%

		%Evaporative Mass Loss
		0.0%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	%Ev = - 4.31+ 0.54 Ln(t+273.5)	
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	%Ev = (-0.16 + 0.013T) √t	
Density (g/mL)	0ºC	0.9474
	15ºC	0.9357
Dynamic Viscosity (mPa·s)	0ºC	9.57E+3
	15ºC	866
Surface Tension (mN/m)	0ºC	NM*
	15ºC	31.2
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*
	15ºC	22.4
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*
	15ºC	20.3
Sulfur Content (%w/w)		1.29
Water Content (%w/w)		0
Flash Point (ºC)		125
Pour Point (ºC)		15
Emulsion Formation	Visual Stability	Entrained
	Complex Modulus (Pa)	676
	Water Content (%w/w)	71.6
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	49%
Hydrocarbon Groups (%w/w)	Saturates	50.1
	Aromatics	32.2
	Resins	14.4
	Asphaltenes	3.4
Wax Content (%w/w)		15.6
GC-TPH Distributions	Total GC-TPH (mg/g)	534
	GC-Saturates/GC-TPH (%)	60.9
	GC-Aromatics/GC-TPH (%)	39.1
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	0.6
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	22.3
	$nC_{16} <$ to $\leq nC_{34}$	68.8
	nC_{34} +	8.3

Note:
NM - Not Measured
*Too viscous

%Evaporative Mass Loss
0.0%

	% Mass	˚C
Boiling Point Distribution	IBP	106
(Cumulative Weight Fraction)	5	216
	10	243
	15	262
	20	279
	25	297
	30	312
	35	328
	40	343
	45	358
	50	373
	55	389
	60	404
	65	419
	70	434
	75	448
	80	464
	85	480
	90	498
	95	516
	99.5	539

Note:
IBP - Initial Boiling Point

Table B11: Oil Properties of Harmony

		%Evaporative Mass Loss	
		0.0%	17.11%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	%Ev = - 1.67+ 0.54 Ln(t+23.1)		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	%Ev = (0.85 + 0.045T) ln(t)		
Density (g/mL)	0ºC	0.9588	0.9996
	15ºC	0.9456	0.9911
Dynamic Viscosity (mPa·s)	0ºC	2.20E+4	7.86E+7
	15ºC	3.08E+3	1.82E+6
Surface Tension (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*	NM*
	15ºC	23.8	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*	NM*
	15ºC	16.6	NM*
Sulfur Content (%w/w)		4.73	5.20
Water Content (%w/w)		0.3	0.3
Flash Point (ºC)		18	145
Pour Point (ºC)		-9	24
Emulsion Formation	Visual Stability	Entrained	DNF
	Complex Modulus (Pa)	942	NM
	Water Content (%w/w)	59.5	NM
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	<10%	<10%
Hydrocarbon Groups (%w/w)	Saturates	36.8	28.2
	Aromatics	20.6	23.6
	Resins	31.2	33.0
	Asphaltenes	11.4	15.2
Wax Content (%w/w)		5.8	
GC-TPH Distributions	Total GC-TPH (mg/g)	380	167
	GC-Saturates/GC-TPH (%)	64.1	54.4
	GC-Aromatics/GC-TPH (%)	35.9	45.6
GC-TPH in Ranges:	$n\mathrm{C}_{8} \leq$ to $\leq n\mathrm{C}_{10}$	11.5	3.4
(%w/w)	$n\mathrm{C}_{10} <$ to $\leq n\mathrm{C}_{16}$	25.6	20.2
	$n\mathrm{C}_{16} <$ to $\leq n\mathrm{C}_{34}$	51.4	58.5
	$n\mathrm{C}_{34}$ +	11.6	17.9

Note:
DNF – Did not form
NM - Not Measured
*Too viscous

%Evaporative Mass Loss

		0.0%	17.11%
	% Mass	°C	°C
Boiling Point Distribution	IBP	64	99
(Cumulative Weight Fraction)	5	110	146
	10	138	184
	15	163	217
	20	186	245
	25	209	266
	30	230	286
	35	251	305
	40	271	323
	45	293	343
	50	312	361
	55	332	380
	60	353	398
	65	373	416
	70	409	434
	75	432	451
	80	453	468
	85	475	486
	90	498	504
	95	520	520
	99.5	543	534

Note:
IBP - Initial Boiling Point

Table B12: Oil Properties of IFO-120

		%Evaporative Mass Loss	
		0.0%	9.54%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	$\%Ev = - 4.17 + 0.63\ \mathrm{Ln}(t+807.5)$		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	$\%Ev = (-0.11 + 0.013T)\sqrt{t}$		
Density (g/mL)	0ºC	0.9683	0.9811
	15ºC	0.9567	0.9701
Dynamic Viscosity (mPa·s)	0ºC	9.16E+3	1.38E+5
	15ºC	1.54E+3	1.46E+4
Surface Tension (mN/m)	0ºC	NM*	NM*
	15ºC	30.8	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*	NM*
	15ºC	31.9	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*	NM*
	15ºC	29.3	NM*
Sulfur Content (%w/w)		0.962	1.03
Water Content (%w/w)		0.3	0.2
Flash Point (ºC)		91	146
Pour Point (ºC)		-9	6
Emulsion Formation	Visual Stability	Stable	Stable
	Complex Modulus (Pa)	171	505
	Water Content (%w/w)	69.6	59.6
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	12%	<10%
Hydrocarbon Groups (%w/w)	Saturates	43.8	45.7
	Aromatics	42.6	32.5
	Resins	10.4	18.7
	Asphaltenes	3.2	3.1
Wax Content (%w/w)		9.0	
GC-TPH Distributions	Total GC-TPH (mg/g)	313	291
	GC-Saturates/GC-TPH (%)	50.7	58.5
	GC-Aromatics/GC-TPH (%)	49.3	41.5
GC-TPH in Ranges:	$n\mathrm{C}_8 \leq$ to $\leq n\mathrm{C}_{10}$	6.1	1.5
(%w/w)	$n\mathrm{C}_{10} <$ to $\leq n\mathrm{C}_{16}$	32.2	25.6
	$n\mathrm{C}_{16} <$ to $\leq n\mathrm{C}_{34}$	44.0	55.6
	$n\mathrm{C}_{34}$ +	17.7	17.4

Note:
NM - Not Measured
*Too viscous

	%Evaporative Mass Loss	
	0.0%	9.54%

	% Mass	˚C	˚C
Boiling Point Distribution	IBP	109	81
(Cumulative Weight Fraction)	5	180	178
	10	204	231
	15	225	253
	20	238	268
	25	253	281
	30	268	295
	35	281	305
	40	295	317
	45	305	329
	50	318	342
	55	330	356
	60	344	371
	65	360	390
	70	379	412
	75	403	440
	80	439	470
	85	479	497
	90	507	517
	95	526	537
	99.5	545	559

Note:
IBP - Initial Boiling Point

Table B13: Oil Properties of IFO-180

		%Evaporative Mass Loss	
		0.0%	6.86%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	%Ev = - 4.5 + 0.57 Ln(t+3184.0)		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	%Ev = (-0.15 + 0.013T) √t		
Density (g/mL)	0ºC	0.9794	0.9849
	15ºC	0.9664	0.9782
Dynamic Viscosity (mPa·s)	0ºC	1.24E+5	1.41E+6
	15ºC	1.92E+4	1.19E+5
Surface Tension (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Sulfur Content (%w/w)		0.46	0.48
Water Content (%w/w)		1.7	0
Flash Point (ºC)		>60	160
Pour Point (ºC)		15	18
Emulsion Formation	Visual Stability	Entrained	Entrained
	Complex Modulus (Pa)	144	366
	Water Content (%w/w)	42	44
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	<10%	<10%
Hydrocarbon Groups (%w/w)	Saturates	49.3	39.5
	Aromatics	31.9	33.4
	Resins	14.8	21.2
	Asphaltenes	4.0	5.9
Wax Content (%w/w)		20.0	
GC-TPH Distributions	Total GC-TPH (mg/g)	312	320
	GC-Saturates/GC-TPH (%)	60.7	54.2
	GC-Aromatics/GC-TPH (%)	39.3	45.8
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	3.4	1.5
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	17.8	26.7
	$nC_{16} <$ to $\leq nC_{34}$	59.0	60.4
	nC_{34} +	19.8	11.3

Note:
NM - Not Measured
*Too viscous

	%Evaporative Mass Loss	
	0.0%	6.86%

	% Mass	°C	°C
Boiling Point Distribution	IBP	80	70
(Cumulative Weight Fraction)	5	167	129
	10	213	167
	15	243	201
	20	264	231
	25	283	256
	30	302	278
	35	320	298
	40	339	316
	45	355	334
	50	368	352
	55	381	368
	60	394	383
	65	406	398
	70	420	413
	75	433	429
	80	449	445
	85	466	463
	90	487	484
	95	508	505
	99.5	528	525

Note:
IBP - Initial Boiling Point

Table B14: Oil Properties of North Star

		%Evaporative Mass Loss	
		0.0%	35.41%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	$\%Ev = -1.38 + 1.07\, Ln(t+1.14)$		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	$\%Ev = (2.93 + 0.045T)\, ln(t)$		
Density (g/mL)	0ºC	0.8687	0.9284
	15ºC	0.8573	0.9165
Dynamic Viscosity (mPa·s)	0ºC	17.4	3.75E+3
	15ºC	8.9	201
Surface Tension (mN/m)	0ºC	28.6	NM*
	15ºC	26.6	30.3
Interfacial Tension - Oil/Water (mN/m)	0ºC	20.8	NM*
	15ºC	22.1	21.4
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	20.8	NM*
	15ºC	21.8	20.8
Sulfur Content (%w/w)		0.70	1.06
Water Content (%w/w)		0	0
Flash Point (ºC)		<-5	127
Pour Point (ºC)		-16	-3
Emulsion Formation	Visual Stability	Unstable	Stable
	Complex Modulus (Pa)	NM	416
	Water Content (%w/w)	NM	78.3
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	74%	43%
Hydrocarbon Groups (%w/w)	Saturates	67.3	60.1
	Aromatics	24.7	25.8
	Resins	6.1	9.5
	Asphaltenes	1.9	4.6
Wax Content (%w/w)		4.8	
GC-TPH Distributions	Total GC-TPH (mg/g)	672	591
	GC-Saturates/GC-TPH (%)	73.1	69.9
	GC-Aromatics/GC-TPH (%)	26.9	30.1
GC-TPH in Ranges:	$nC_{8} \leq$ to $\leq nC_{10}$	15.0	1.4
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	26.7	25.1
	$nC_{16} <$ to $\leq nC_{34}$	51.0	64.0
	nC_{34} +	7.2	9.5

Note:
NM - Not Measured
*Too viscous

	%Evaporative Mass Loss	
	0.0%	35.41%

	% Mass	°C	°C
Boiling Point Distribution	IBP	56	168
(Cumulative Weight Fraction)	5	93	235
	10	113	253
	15	134	267
	20	155	279
	25	175	292
	30	198	304
	35	220	317
	40	240	330
	45	260	344
	50	279	357
	55	301	372
	60	318	388
	65	342	404
	70	365	421
	75	389	438
	80	416	456
	85	444	475
	90	474	497
	95	510	520
	99.5	555	547

Note:
IBP - Initial Boiling Point

Table B15: Oil Properties of Rock

		%Evaporative Mass Loss	
		0.0%	9.06%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	%Ev = - 2.25 + 0.44 Ln(t+193.8)		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	%Ev = (-0.11 + 0.013T) $\sqrt{t}$		
Density (g/mL)	0ºC	0.9776	0.9964
	15ºC	0.9674	0.9859
Dynamic Viscosity (mPa•s)	0ºC	2.57E+4	7.88E+5
	15ºC	4.36E+3	7.14E+4
Surface Tension (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*	NM*
	15ºC	26.1	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*	NM*
	15ºC	25.3	NM*
Sulfur Content (%w/w)		3.97	4.22
Water Content (%w/w)		0.4	0
Flash Point (ºC)		42	151
Pour Point (ºC)		-15	6
Emulsion Formation	Visual Stability	Entrained	Entrained
	Complex Modulus (Pa)	232	811
	Water Content (%w/w)	59.5	58.9
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	<10%	<10%
Hydrocarbon Groups (%w/w)	Saturates	29.5	28.7
	Aromatics	23.5	21.3
	Resins	40.5	41.1
	Asphaltenes	6.5	8.9
Wax Content (%w/w)		3.0	
GC-TPH Distributions	Total GC-TPH (mg/g)	317	312
	GC-Saturates/GC-TPH (%)	55.6	57.4
	GC-Aromatics/GC-TPH (%)	44.4	42.6
GC-TPH in Ranges:	$n\mathrm{C}_8 \leq$ to $\leq n\mathrm{C}_{10}$	3.9	2.5
(%w/w)	$n\mathrm{C}_{10} <$ to $\leq n\mathrm{C}_{16}$	20.8	22.1
	$n\mathrm{C}_{16} <$ to $\leq n\mathrm{C}_{34}$	58.9	60.9
	$n\mathrm{C}_{34}$ +	16.5	14.5

Note:
NM - Not Measured
*Too viscous

	%Evaporative Mass Loss	
	0.0%	9.06%

	% Mass	°C	°C
Boiling Point Distribution	IBP	74	74
(Cumulative Weight Fraction)	5	142	151
	10	185	204
	15	217	242
	20	241	265
	25	263	286
	30	284	304
	35	304	321
	40	322	339
	45	342	356
	50	360	373
	55	379	390
	60	397	407
	65	415	423
	70	432	437
	75	448	452
	80	463	466
	85	480	482
	90	497	497
	95	513	512
	99.5	528	525

Note:
IBP - Initial Boiling Point

Table B16: Oil Properties of Terra Nova

		%Evaporative Mass Loss	
		0.0%	28.55%
Equation for predicting evaporation (mass loss) based on best fit of the data to the three-parameter logarithmic function	$\%Ev = -0.66 + 0.71\,\mathrm{Ln}(t+0.96)$		
Equation for predicting evaporation (mass loss) based on best fit of the data to Fingas 01 equations	$\%Ev = (2.32 + 0.045T)\ln(t)$		
Density (g/mL)	0ºC	0.8752	0.9216
	15ºC	0.8624	0.9114
Dynamic Viscosity (mPa·s)	0ºC	47.6	1.65E+4
	15ºC	17.5	1.37E+3
Surface Tension (mN/m)	0ºC	NM*	NM*
	15ºC	27.9	32.6
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*	NM*
	15ºC	24.4	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*	NM*
	15ºC	23.1	NM*
Sulfur Content (%w/w)		0.571	0.8
Water Content (%w/w)		0	0
Flash Point (ºC)		<-5	136
Pour Point (ºC)		9	21
Emulsion Formation	Visual Stability	Unstable	Stable
	Complex Modulus (Pa)	NM	1230
	Water Content (%w/w)	NM	75.6
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	43%	<10%
Hydrocarbon Groups (%w/w)	Saturates	67.8	48.6
	Aromatics	19.1	28.3
	Resins	12.4	22.0
	Asphaltenes	0.7	1.1
Wax Content (%w/w)		20.5	
GC-TPH Distributions	Total GC-TPH (mg/g)	512	539
	GC-Saturates/GC-TPH (%)	78.0	63.2
	GC-Aromatics/GC-TPH (%)	22.0	36.8
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	15.7	0.9
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	27.7	19.3
	$nC_{16} <$ to $\leq nC_{34}$	46.7	66.7
	nC_{34} +	9.9	13.2

Note:
NM - Not Measured
*Too viscous/below pour point

%Evaporative Mass Loss
0.0% 28.55%

	% Mass	˚C	˚C
Boiling Point Distribution	IBP	56	189
(Cumulative Weight Fraction)	5	97	243
	10	124	261
	15	150	276
	20	174	290
	25	198	304
	30	223	317
	35	246	331
	40	267	346
	45	287	361
	50	308	376
	55	329	391
	60	351	406
	65	372	421
	70	394	434
	75	416	448
	80	437	462
	85	457	478
	90	479	495
	95	503	513
	99.5	526	531

Note:
IBP - Initial Boiling Point

Table B17: Oil Properties of Independence Hub Atwater Valley Block 37

		%Evaporative Mass Loss	
		0.0%	22.07%
Equation for predicting evaporation	%Evaporated = -19.9 + 4.21 Ln(t+159.1), t in minute		
Density (g/mL)	0ºC	0.9255	0.9471
	15ºC	0.9148	0.9370
Dynamic Viscosity (mPa·s)	0ºC	23.4	126
	15ºC	13.5	40.2
Surface Tension (mN/m)	0ºC	29.3	29.6
	15ºC	30.6	31.4
Interfacial Tension - Oil/Water (mN/m)	0ºC	23.9	19.2
	15ºC	24.3	15.5
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	25.1	17.0
	15ºC	26.5	18.0
Sulfur Content (%w/w)		0.65	0.72
Water Content (%w/w)		0.1	0
Flash Point (ºC)		40	124
Pour Point (ºC)		<-30	<-30
Emulsion Formation	Visual Stability	Unstable	Unstable
	Complex Modulus (Pa)	NM	NM
	Water Content (%w/w)	NM	NM
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	77%	66%
Hydrocarbon Groups (%w/w)	Saturates	72.6	67.7
	Aromatics	22.8	27.1
	Resins	4.6	5.2
	Asphaltenes	0	0
Wax Content (%w/w)		0.2	
GC-TPH Distributions	Total GC-TPH (mg/g)	707	785
	GC-Saturates/GC-TPH (%)	76.1	71.4
	GC-Aromatics/GC-TPH (%)	23.9	28.6
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	3.9	0
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	37.4	29.2
	$nC_{16} <$ to $\leq nC_{34}$	56.6	68.4
	nC_{34} +	2.1	2.4

Note:
NM - Not Measured

		%Evaporative Mass Loss	
		0.0%	22.07%
	% Mass	°C	°C
Boiling Point Distribution	IBP	77	213
(Cumulative Weight Fraction)	5	156	237
	10	189	250
	15	213	258

	20	231	266
	25	243	274
	30	254	282
	35	263	292
	40	272	301
	45	282	310
	50	294	319
	55	305	330
	60	317	342
	65	330	356
	70	346	372
	75	365	390
	80	388	411
	85	415	435
	90	440	447
	95	455	458
	99.5	490	494

Note:
IBP - Initial Boiling Point

Table B18: Oil Properties of Irene Sampled from Lompoc O&G Facility

		%Evaporative Mass Loss	
		0.0%	17.41%
Equation for predicting evaporation	%Evaporated = -11.1 + 2.78 Ln(t+52.7), t in minute		
Density (g/mL)	0ºC	0.9700	1.0163
	15ºC	0.9591	1.0073
Dynamic Viscosity (mPa·s)	0ºC	6.83E+4	3.15E+8
	15ºC	8.51E+3	8.34E+6
Surface Tension (mN/m)	0ºC	30.2	NM*
	15ºC	28.7	NM*
Interfacial Tension – Oil/Water (mN/m)	0ºC	20.8	NM*
	15ºC	19.6	NM*
Interfacial Tension – Oil/Brine, 33‰ NaCl (mN/m)	0ºC	19.0	NM*
	15ºC	23.4	NM*
Sulfur Content (%w/w)		5.21	5.85
Water Content (%w/w)		2.6	1.2
Flash Point (ºC)		40	150
Pour Point (ºC)		-9	33
Emulsion Formation	Visual Stability	Entrained	DNF
	Complex Modulus (Pa)	381	NM
	Water Content (%w/w)	48.9	NM
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	<10	<10
Hydrocarbon Groups (%w/w)	Saturates	37.7	23.1
	Aromatics	10.6	12.8
	Resins	32.7	37.7
	Asphaltenes	19.0	26.4
Wax Content (%w/w)		1.7	
GC-TPH Distributions	Total GC-TPH (mg/g)	294	305
	GC-Saturates/GC-TPH (%)	78.0	64.4
	GC-Aromatics/GC-TPH (%)	22.0	35.6
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	8.4	0.3
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	22.2	13.2
	$nC_{16} <$ to $\leq nC_{34}$	50.7	63.2
	nC_{34} +	18.7	23.3

Note:
DNF - Did not form
NM - Not Measured
* - Too viscous

		%Evaporative Mass Loss	
		0.0%	17.41%
	% Mass	°C	°C
Boiling Point Distribution	IBP	29	189
(Cumulative Weight Fraction)	5	93	236
	10	125	255
	15	152	271
	20	181	286
	25	209	299
	30	233	311

35	258	323
40	282	336
45	305	349
50	328	362
55	351	375
60	373	388
65	396	402
70	417	415
75	436	427
80	454	438
85	473	450
90	493	462
95	512	474
99.5	530	486

Note:
IBP - Initial Boiling Point

Table B19: Oil Properties of Neptune

		%Evaporative Mass Loss	
		0.0%	17.30%
Equation for predicting evaporation	%Evaporated = -7.6 + 2.48 Ln(t+23.5), t in minute		
Density (g/mL)	0ºC	0.9354	0.9758
	15ºC	0.9244	0.9622
Dynamic Viscosity (mPa•s)	0ºC	1.33E+3	1.36E+5
	15ºC	402	2.07E+4
Surface Tension (mN/m)	0ºC	30.1	29.9
	15ºC	30.4	31.0
Interfacial Tension - Oil/Water (mN/m)	0ºC	35.3	21.8
	15ºC	31.6	19.4
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	31.7	19.1
	15ºC	30.7	18.7
Sulfur Content (%w/w)		2.88	3.47
Water Content (%w/w)		0.9	0.2
Flash Point (ºC)		22	153
Pour Point (ºC)		<-30	-6
Emulsion Formation	Visual Stability	Stable	Stable
	Complex Modulus (Pa)	171	674
	Water Content (%w/w)	80.6	65.5
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	<10	<10
Hydrocarbon Groups (%w/w)	Saturates	58.0	55.2
	Aromatics	13.3	15.0
	Resins	18.6	18.7
	Asphaltenes	10.1	11.2
Wax Content (%w/w)		2.0	
GC-TPH Distributions	Total GC-TPH (mg/g)	478	243
	GC-Saturates/GC-TPH (%)	81.4	78.7
	GC-Aromatics/GC-TPH (%)	18.6	21.4
GC-TPH in Ranges:	$nC_{8} \leq$ to $\leq nC_{10}$	5.7	0.2
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	20.3	9.6
	$nC_{16} <$ to $\leq nC_{34}$	53.7	64.3
	nC_{34} +	20.4	25.9

		%Evaporative Mass Loss	
		0.0%	17.30%
	% Mass	°C	°C
Boiling Point Distribution	IBP	31	227
(Cumulative Weight Fraction)	5	103	262
	10	138	281
	15	173	298
	20	207	313
	25	233	328
	30	257	343
	35	279	356
	40	301	370
	45	321	384
	50	342	398
	55	361	411

60	380	423
65	400	435
70	418	447
75	435	458
80	451	471
85	468	484
90	486	497
95	505	511
99.5	525	526

Note:
IBP - Initial Boiling Point

Table B20: Oil Properties of Ellen A038

		%Evaporative Mass Loss	
		0.0%	15.88%
Equation for predicting evaporation	%Evaporated = -14.5 + 3.03 Ln(t+152.2), t in minute		
Density (g/mL)	0ºC	0.9694	1.0071
	15ºC	0.9587	0.9981
Dynamic Viscosity (mPa·s)	0ºC	1.52E+4	2.31E+7
	15ºC	3.10E+3	1.09E+6
Surface Tension (mN/m)	0ºC	29.3	NM*
	15ºC	29.6	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	20.8	NM*
	15ºC	24.0	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	20.7	NM*
	15ºC	22.3	NM*
Sulfur Content (%w/w)		3.28	3.69
Water Content (%w/w)		1.9	0.5
Flash Point (ºC)		40	154
Pour Point (ºC)		-21	12
Emulsion Formation	Visual Stability	Entrained	DNF
	Complex Modulus (Pa)	44	NM
	Water Content (%w/w)	20.7	NM
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	<10	<10
Hydrocarbon Groups (%w/w)	Saturates	39.2	35.2
	Aromatics	22.5	22.1
	Resins	24.1	27.5
	Asphaltenes	14.3	15.2
Wax Content (%w/w)		1.6	
GC-TPH Distributions	Total GC-TPH (mg/g)	348	257
	GC-Saturates/GC-TPH (%)	63.6	61.4
	GC-Aromatics/GC-TPH (%)	36.4	38.6
GC-TPH in Ranges:	$n\mathrm{C}_8 \le$ to $\le n\mathrm{C}_{10}$	5.9	0.3
(%w/w)	$n\mathrm{C}_{10} <$ to $\le n\mathrm{C}_{16}$	20.4	10.3
	$n\mathrm{C}_{16} <$ to $\le n\mathrm{C}_{34}$	55.2	67.0
	$n\mathrm{C}_{34}$ +	18.5	22.4

Note:
DNF - Did not form
NM - Not Measured
*Too viscous

		%Evaporative Mass Loss	
		0.0%	15.88%
	% Mass	°C	°C
Boiling Point Distribution	IBP	37	219
(Cumulative Weight Fraction)	5	112	258
	10	147	279
	15	182	297
	20	215	312
	25	240	326
	30	265	342
	35	287	356

40	307	370
45	327	384
50	348	398
55	368	412
60	387	424
65	406	435
70	423	445
75	438	455
80	452	467
85	467	480
90	484	494
95	503	508
99.5	521	524

Note:
IBP - Initial Boiling Point

Table B21: Oil Properties of Ellen A040

		%Evaporative Mass Loss	
		0.0%	14.57%
Equation for predicting evaporation	%Evaporated = -17.3 + 2.63 Ln(t+896.2), t in minute		
Density (g/mL)	0ºC	0.9889	1.0141
	15ºC	0.9790	1.0058
Dynamic Viscosity (mPa·s)	0ºC	1.24E+5	4.63E+7
	15ºC	1.97E+4	1.74E+6
Surface Tension (mN/m)	0ºC	27.5	NM*
	15ºC	30.7	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*	NM*
	15ºC	15.3	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*	NM*
	15ºC	21.6	NM*
Sulfur Content (%w/w)		3.89	4.25
Water Content (%w/w)		5.2	0.9
Flash Point (ºC)		104	161
Pour Point (ºC)		-15	3
Emulsion Formation	Visual Stability	Entrained	DNF
	Complex Modulus (Pa)	42	NM
	Water Content (%w/w)	24.5	NM
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	<10	<10
Hydrocarbon Groups (%w/w)	Saturates	42.6	27.1
	Aromatics	18.6	19.6
	Resins	24.5	35.7
	Asphaltenes	14.3	17.6
Wax Content (%w/w)		1.2	
GC-TPH Distributions	Total GC-TPH (mg/g)	364	334
	GC-Saturates/GC-TPH (%)	69.6	58.0
	GC-Aromatics/GC-TPH (%)	30.4	42.0
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	4.6	0
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	19.0	9.7
	$nC_{16} <$ to $\leq nC_{34}$	57.0	67.7
	nC_{34} +	19.4	22.6

Note:
DNF - Did not form
NM - Not Measured
*Too viscous

		%Evaporative Mass Loss	
		0.0%	14.57%
	% Mass	°C	°C
Boiling Point Distribution	IBP	65	186
(Cumulative Weight Fraction)	5	138	259
	10	183	283
	15	221	303
	20	247	318
	25	270	335
	30	293	352
	35	311	367

40	330	383
45	349	398
50	367	412
55	384	425
60	402	436
65	418	446
70	432	456
75	444	468
80	455	480
85	469	493
90	485	503
95	502	514
99.5	522	524

Note:
IBP - Initial Boiling Point

Table B22: Oil Properties of Gail E010

		%Evaporative Mass Loss	
		0.0%	16.92%
Equation for predicting evaporation	%Evaporated = -19.4 + 3.43 Ln(t+350.0), t in minute		
Density (g/mL)	0ºC	0.9814	1.0177
	15ºC	0.9709	1.0086
Dynamic Viscosity (mPa•s)	0ºC	6.72E+4	9.65E+7
	15ºC	1.16E+4	3.25E+6
Surface Tension (mN/m)	0ºC	29.0	NM*
	15ºC	29.8	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	19.0	NM*
	15ºC	21.8	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	22.0	NM*
	15ºC	23.7	NM*
Sulfur Content (%w/w)		5.94	6.79
Water Content (%w/w)		4.3	1.4
Flash Point (ºC)		48	147
Pour Point (ºC)		-6	9
Emulsion Formation	Visual Stability	Entrained	DNF
	Complex Modulus (Pa)	258	NM
	Water Content (%w/w)	43.9	NM
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	<10	<10
Hydrocarbon Groups (%w/w)	Saturates	37.4	26.1
	Aromatics	14.2	16.0
	Resins	25.4	33.9
	Asphaltenes	23.1	24.1
Wax Content (%w/w)		2.3	
GC-TPH Distributions	Total GC-TPH (mg/g)	350	310
	GC-Saturates/GC-TPH (%)	72.5	62.0
	GC-Aromatics/GC-TPH (%)	27.5	38.0
GC-TPH in Ranges:	nC_{8} ≤ to ≤ nC_{10}	6.5	0.1
(%w/w)	nC_{10} < to ≤ nC_{16}	22.7	12.6
	nC_{16} < to ≤ nC_{34}	51.4	63.9
	nC_{34} +	19.4	23.4

Note:
DNF - Did not form
NM - Not Measured
*Too viscous

		%Evaporative Mass Loss	
		0.0%	16.92%
	% Mass	°C	°C
Boiling Point Distribution	IBP	34	200
(Cumulative Weight Fraction)	5	112	244
	10	147	262
	15	179	275
	20	208	289
	25	232	302
	30	254	315
	35	278	326

40	301	339
45	321	352
50	343	364
55	363	377
60	384	390
65	404	403
70	424	416
75	441	429
80	458	441
85	477	452
90	496	465
95	512	479
99.5	529	491

Note:
IBP - Initial Boiling Point

Table B23: Oil Properties of Gail E019

		%Evaporative Mass Loss	
		0.0%	24.42%
Equation for predicting evaporation	%Evaporated = -10.0+ 3.41 Ln(t+16.9), t in minute		
Density (g/mL)	0ºC	0.9124	0.9480
	15ºC	0.8996	0.9346
Dynamic Viscosity (mPa•s)	0ºC	147	1.55E+4
	15ºC	51.7	1.36E+3
Surface Tension (mN/m)	0ºC	28.3	NM*
	15ºC	26.4	31.0
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*	NM*
	15ºC	15.3	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*	NM*
	15ºC	17.6	NM*
Sulfur Content (%w/w)		1.90	2.39
Water Content (%w/w)		3.7	0.5
Flash Point (ºC)		22	139
Pour Point (ºC)		-3	12
Emulsion Formation	Visual Stability	Unstable	Stable
	Complex Modulus (Pa)	NM	752
	Water Content (%w/w)	NM	77.9
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	43%	<10%
Hydrocarbon Groups (%w/w)	Saturates	64.1	59.2
	Aromatics	18.8	20.8
	Resins	11.4	12.5
	Asphaltenes	5.8	7.5
Wax Content (%w/w)		15.0	
GC-TPH Distributions	Total GC-TPH (mg/g)	652	475
	GC-Saturates/GC-TPH (%)	77.3	74.0
	GC-Aromatics/GC-TPH (%)	22.7	26.0
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	6.4	0.1
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	26.0	14.6
	$nC_{16} <$ to $\leq nC_{34}$	51.8	65.3
	nC_{34} +	15.9	20.0

Note:
DNF - Did not form
NM - Not Measured
*Too viscous

		%Evaporative Mass Loss	
		0.0%	24.42%
	% Mass	°C	°C
Boiling Point Distribution	IBP	37	218
(Cumulative Weight Fraction)	5	119	250
	10	154	268
	15	179	283
	20	204	298
	25	227	310
	30	247	323
	35	265	337

40	284	351
45	303	365
50	320	379
55	341	392
60	359	408
65	379	422
70	400	436
75	421	449
80	440	464
85	460	480
90	482	496
95	506	513
99.5	532	533

Note:
IBP - Initial Boiling Point

Table B24: Oil Properties of Heritage HE 05

		%Evaporative Mass Loss	
		0.0%	16.27%
Equation for predicting evaporation	%Evaporated = -5.0 + 0.97 Ln(t+271.6), t in minute		
Density (g/mL)	0ºC	1.0032	1.0253
	15ºC	0.9922	1.0172
Dynamic Viscosity (mPa·s)	0ºC	3.03E+6	1.46E+9
	15ºC	3.59E+5	3.80E+7
Surface Tension (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*	NM*
	15ºC	16.8	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*	NM*
	15ºC	13.5	NM*
Sulfur Content (%w/w)		7.20	7.64
Water Content (%w/w)		6.6	1.3
Flash Point (ºC)		77	150
Pour Point (ºC)		-3	33
Emulsion Formation	Visual Stability	DNF	DNF
	Complex Modulus (Pa)	NM	NM
	Water Content (%w/w)	NM	NM
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	<10	<10
Hydrocarbon Groups (%w/w)	Saturates	37.0	22.1
	Aromatics	19.2	12.7
	Resins	33.5	50.8
	Asphaltenes	10.2	14.4
Wax Content (%w/w)		2.0	
GC-TPH Distributions	Total GC-TPH (mg/g)	247	216
	GC-Saturates/GC-TPH (%)	65.8	63.5
	GC-Aromatics/GC-TPH (%)	34.2	36.5
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	6.8	0.4
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	22.0	13.5
	$nC_{16} <$ to $\leq nC_{34}$	51.8	62.7
	nC_{34} +	19.4	23.5

Note:
DNF - Did not form
NM - Not Measured
*Too viscous

		%Evaporative Mass Loss	
		0.0%	16.27%
	% Mass	°C	°C
Boiling Point Distribution	IBP	49	178
(Cumulative Weight Fraction)	5	126	240
	10	156	265
	15	185	284
	20	215	302
	25	237	317
	30	261	331
	35	282	347

40	303	361
45	320	376
50	342	390
55	359	404
60	377	417
65	395	429
70	412	441
75	428	452
80	442	463
85	456	476
90	471	488
95	486	500
99.5	499	510

Note:
IBP - Initial Boiling Point

Table B25: Oil Properties of Heritage HE 26

		%Evaporative Mass Loss	
		0.0%	14.48%
Equation for predicting evaporation	%Evaporated = -0.7 + 0.35 Ln(t+14.2), t in minute		
Density (g/mL)	0ºC	0.9973	1.0213
	15ºC	0.9859	1.0123
Dynamic Viscosity (mPa•s)	0ºC	1.91E+6	9.42E+8
	15ºC	1.86E+5	2.74E+7
Surface Tension (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Sulfur Content (%w/w)		6.28	6.67
Water Content (%w/w)		5.1	0.4
Flash Point (ºC)		72	149
Pour Point (ºC)		-18	30
Emulsion Formation	Visual Stability	DNF	DNF
	Complex Modulus (Pa)	NM	NM
	Water Content (%w/w)	NM	NM
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	<10	<10
Hydrocarbon Groups (%w/w)	Saturates	35.9	34.7
	Aromatics	24.9	23.5
	Resins	28.5	31.0
	Asphaltenes	10.7	10.8
Wax Content (%w/w)		3.1	
GC-TPH Distributions	Total GC-TPH (mg/g)	240	214
	GC-Saturates/GC-TPH (%)	59.0	59.6
	GC-Aromatics/GC-TPH (%)	41.0	40.4
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	0.7	0.4
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	22.5	13.5
	$nC_{16} <$ to $\leq nC_{34}$	55.7	62.5
	nC_{34} +	21.2	23.5

Note:
DNF - Did not form
NM - Not Measured
*Too viscous

		%Evaporative Mass Loss	
		0.0%	14.48%
	% Mass	°C	°C
Boiling Point Distribution	IBP	56	189
(Cumulative Weight Fraction)	5	132	242
	10	165	265
	15	197	285
	20	226	302
	25	251	317
	30	272	333
	35	296	350

40	316	366
45	337	381
50	357	396
55	376	412
60	395	426
65	414	439
70	431	451
75	447	464
80	462	478
85	479	491
90	495	502
95	510	511
99.5	524	518

Note:
IBP - Initial Boiling Point

Table B26: Oil Properties of Irene Comingled

		%Evaporative Mass Loss	
		0.0%	20.26%
Equation for predicting evaporation	%Evaporated = -26.0 + 4.0 Ln(t+787.0), t in minute		
Density (g/mL)	0ºC	0.9890	1.0191
	15ºC	0.9787	1.0107
Dynamic Viscosity (mPa•s)	0ºC	445,133	6.164E+08
	15ºC	57,347	2.209E+07
Surface Tension (mN/m)	0ºC	27.1	NM*
	15ºC	26.6	NM*
Interfacial Tension - Oil/Water (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Interfacial Tension - Oil/Brine, 33‰ NaCl (mN/m)	0ºC	NM*	NM*
	15ºC	NM*	NM*
Sulfur Content (%w/w)		5.54	6.08
Water Content (%w/w)		5.9	1.5
Flash Point (ºC)		62	148
Pour Point (ºC)		0	27
Emulsion Formation	Visual Stability	Entrained	DNF
	Complex Modulus (Pa)	784	NM
	Water Content (%w/w)	35.7	NM
Chemical Dispersibility by Swirling Flask Test	Corexit 9500	<10	<10
Hydrocarbon Groups (%w/w)	Saturates	38.7	24.0
	Aromatics	20.3	15.0
	Resins	24.8	32.4
	Asphaltenes	16.2	28.6
Wax Content (%w/w)		3.0	
GC-TPH Distributions	Total GC-TPH (mg/g)	245	231
	GC-Saturates/GC-TPH (%)	65.6	61.6
	GC-Aromatics/GC-TPH (%)	34.4	38.4
GC-TPH in Ranges:	$nC_8 \leq$ to $\leq nC_{10}$	6.8	0.3
(%w/w)	$nC_{10} <$ to $\leq nC_{16}$	22.5	13.2
	$nC_{16} <$ to $\leq nC_{34}$	53.4	64.4
	nC_{34} +	17.3	22.1

Note:
DNF - Did not form
NM - Not Measured
*Too viscous

		%Evaporative Mass Loss	
		0.0%	20.26%
	% Mass	°C	°C
Boiling Point Distribution	IBP	53	168
(Cumulative Weight Fraction)	5	122	235
	10	158	255
	15	184	271
	20	212	287
	25	234	302
	30	255	315
	35	278	327

40	300	341
45	319	354
50	340	368
55	361	381
60	381	395
65	401	409
70	419	422
75	436	434
80	452	446
85	469	457
90	487	470
95	504	483
99.5	522	495

Note:
IBP - Initial Boiling Point

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Appendix E

Time-Window (in Hours) for Dispersant Application Predicted Using Oilmap Version 6.9.3 and the 24 oils from Task 3 and Different Oil Spill Volume, Water Temperature, Wind Speed, and Cutoff Viscosity for Sensitivity Analysis (Task 4)

```
Table E1: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 8 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]      16      20      22      24       26
                Arabian Medium      11      13      14      15       16
                          DOBA       1       1       1       1        1
            DOS Cuadras HE-05       8      11      12      13       14
            DOS Cuadras HE-26      12      15      16      17       18
                      Endicott      16      23      26      28       32
                       Harmony       1       1       1       1        1
                       IFO-120       1       1       2       2        2
                       IFO-180       0       0       0       0        0
                    North Star      31      47      59      69       82
                          Rock       0       0       0       0        0
                    Terra Nova      18      23      25      27       30
Independence Hub A.V. Block 37    1000    1000    1000    1000     1000
     Irene Sampled from Lompoc       0       0       0       0        0
                      Nepturne       6       7       8       8        8
                    Ellen A038       1       1       2       2        2
                    Ellen A040       0       0       0       0        0
                     Gail E010       0       0       0       0        0
                     Gail E019      13      17      18      20       21
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------
```

```
Table E2: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 8 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]      15      19      21      23       24
                Arabian Medium      11      14      15      15       16
                          DOBA    1000    1000    1000    1000     1000
            DOS Cuadras HE-05       7      10      11      12       13
            DOS Cuadras HE-26      12      15      17      18       19
                      Endicott      16      23      27      30       35
```

```
                       Harmony       1       2       2       2        2
                       IFO-120       1       2       2       3        3
                       IFO-180       0       0       0       0        0
                    North Star      34      55      69      82       97
                          Rock       5       5       5       5        5
                    Terra Nova      18      23      26      29       32
Independence Hub A.V. Block 37    1000    1000    1000    1000     1000
     Irene Sampled from Lompoc       1       1       1       1        1
                      Nepturne       6       8       8       9        9
                    Ellen A038       4       7       9      10       12
                    Ellen A040       0       0       0       0        0
                     Gail E010       1       1       1       1        1
                     Gail E019      11      15      17      18       19
                 Heritage HE 05      0       0       0       0        0
                 Heritage HE 26      0       0       0       0        0
              Irene Comingled        0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E3: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 8 knots
Water Temperature      = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]      15      19      20      22       24
                Arabian Medium      11      14      15      15       16
                          DOBA    1000    1000    1000    1000     1000
             DOS Cuadras HE-05       7       9      10      11       12
             DOS Cuadras HE-26      12      16      17      18       19
                      Endicott      16      23      26      30       34
                       Harmony       1       2       2       3        3
                       IFO-120       1       2       3       3        3
                       IFO-180       1       1       1       1        1
                    North Star      35      59      74      88      104
                          Rock       7       8       8       8        8
                    Terra Nova      18      24      27      29       33
Independence Hub A.V. Block 37    1000    1000    1000    1000     1000
     Irene Sampled from Lompoc       1       1       1       1        2
                      Nepturne       5       7       8       9        9
                    Ellen A038       4       8      11      12       14
                    Ellen A040       1       1       1       1        1
                     Gail E010       1       2       2       2        2
                     Gail E019      10      14      15      16       18
                 Heritage HE 05      0       0       0       0        0
                 Heritage HE 26      0       0       0       0        0
              Irene Comingled        0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------
```

```
Table E4: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 12 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]       8      11      13      14       16
                Arabian Medium       6       7       7       7        8
                          DOBA       1       1       1       1        1
             DOS Cuadras HE-05       5       6       7       7        7
             DOS Cuadras HE-26       6       8       8       9       10
                      Endicott       9      14      17      20       23
                       Harmony       1       1       1       1        1
                       IFO-120       1       1       1       1        1
                       IFO-180       0       0       0       0        0
                    North Star      20      37      47      56       66
                          Rock       0       0       0       0        0
                    Terra Nova       9      13      15      18       20
Independence Hub A.V. Block 37    9999    9999    9999    9999     9999
     Irene Sampled from Lompoc       0       0       0       0        0
                      Nepturne       3       4       4       4        4
                    Ellen A038       1       1       1       1        1
                    Ellen A040       0       0       0       0        0
                     Gail E010       0       0       0       0        0
                     Gail E019       7       9      10      11       11
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E5: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 12 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]       8      11      12      13       15
                Arabian Medium       6       7       7       8        8
                          DOBA    1000    1000    1000    1000     1000
             DOS Cuadras HE-05       4       6       6       7        7
             DOS Cuadras HE-26       6       8       9       9       10
                      Endicott      10      16      19      23       27
                       Harmony       1       1       1       1        1
                       IFO-120       1       1       2       2        2
                       IFO-180       0       0       0       0        0
                    North Star      23      44      56      66       78
                          Rock       2       2       2       2        2
                    Terra Nova      10      14      17      19       22
Independence Hub A.V. Block 37    9999    9999    9999    9999     9999
```

```
     Irene Sampled from Lompoc       1       1       1       1        1
                      Nepturne       3       4       4       5        5
                    Ellen A038       3       6       7       8        9
                    Ellen A040       0       0       0       0        0
                     Gail E010       1       1       1       1        1
                     Gail E019       6       8       9      10       11
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E6: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 12 knots
Water Temperature      = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]       8      10      12      13       14
                Arabian Medium       6       7       7       8        8
                          DOBA    1000    1000    1000    1000     1000
             DOS Cuadras HE-05       4       5       6       6        7
             DOS Cuadras HE-26       6       8       9      10       10
                      Endicott       9      15      19      22       26
                       Harmony       1       1       2       2        2
                       IFO-120       1       2       2       2        2
                       IFO-180       1       1       1       1        1
                    North Star      24      47      60      71       84
                          Rock       3       4       4       4        4
                    Terra Nova      10      14      17      20       23
Independence Hub A.V. Block 37    9999    9999    9999    9999     9999
     Irene Sampled from Lompoc       1       1       1       1        1
                      Nepturne       3       4       4       5        5
                    Ellen A038       3       7       8      10       11
                    Ellen A040       1       1       1       1        1
                     Gail E010       1       1       1       1        1
                     Gail E019       6       8       9       9       10
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E7: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 15 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
```

```
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]       6       8      10      12       13
                Arabian Medium       4       5       5       5        5
                          DOBA       1       1       1       1        1
            DOS Cuadras HE-05        3       4       5       5        5
            DOS Cuadras HE-26        4       5       6       6        7
                      Endicott       7      12      15      18       21
                       Harmony       1       1       1       1        1
                       IFO-120       1       1       1       1        1
                       IFO-180       0       0       0       0        0
                    North Star      17      33      42      50       59
                          Rock       0       0       0       0        0
                    Terra Nova       6      10      13      15       18
Independence Hub A.V. Block 37    9999    9999    9999    9999     9999
     Irene Sampled from Lompoc       0       0       0       0        0
                      Nepturne       2       3       3       3        3
                    Ellen A038       1       1       1       1        1
                    Ellen A040       0       0       0       0        0
                     Gail E010       0       0       0       0        0
                     Gail E019       5       6       7       8        8
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E8: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 15 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]       5       8       9      11       12
                Arabian Medium       4       5       5       5        5
                          DOBA    1000    1000    1000    1000     1000
            DOS Cuadras HE-05        3       4       4       5        5
            DOS Cuadras HE-26        4       6       6       7        7
                      Endicott       7      14      17      20       24
                       Harmony       1       1       1       1        1
                       IFO-120       1       1       1       1        1
                       IFO-180       0       0       0       0        0
                    North Star      20      39      49      59       69
                          Rock       1       1       1       1        1
                    Terra Nova       7      12      14      17       20
Independence Hub A.V. Block 37    9999    9999    9999    9999     9999
     Irene Sampled from Lompoc       1       1       1       1        1
                      Nepturne       2       3       3       3        3
                    Ellen A038       2       5       6       7        8
                    Ellen A040       0       0       0       0        0
                     Gail E010       1       1       1       1        1
                     Gail E019       4       6       7       8        8
                Heritage HE 05       0       0       0       0        0
```

```
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E9: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 5000 cP
Wind Speed             = 15 knots
Water Temperature      = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]       5       7       9      10       11
                Arabian Medium       4       5       5       5        5
                          DOBA    1000    1000    1000    1000     1000
             DOS Cuadras HE-05       3       4       4       4        5
             DOS Cuadras HE-26       4       6       6       7        8
                      Endicott       7      13      17      20       23
                       Harmony       1       1       1       1        1
                       IFO-120       1       1       1       2        2
                       IFO-180       1       1       1       1        1
                    North Star      21      42      53      63       74
                          Rock       2       2       2       2        2
                    Terra Nova       7      12      15      18       20
Independence Hub A.V. Block 37    9999    9999    9999    9999     9999
     Irene Sampled from Lompoc       1       1       1       1        1
                      Nepturne       2       3       3       3        3
                    Ellen A038       3       6       7       9       10
                    Ellen A040       1       1       1       1        1
                     Gail E010       1       1       1       1        1
                     Gail E019       4       6       6       7        8
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E10: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 8 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]      19      26      29      32       36
                Arabian Medium      13      15      16      17       18
                          DOBA       3       3       3       3        3
             DOS Cuadras HE-05      10      13      14      15       16
             DOS Cuadras HE-26      14      18      19      21       22
```

```
                      Endicott      19      28      34      39       45
                       Harmony       1       1       1       2        2
                       IFO-120       1       2       2       2        2
                       IFO-180       0       0       0       0        0
                    North Star      57     106     133     159      189
                          Rock       2       2       2       2        2
                    Terra Nova      21      29      34      39       45
Independence Hub A.V. Block 37    1000    1000    1000    1000     1000
     Irene Sampled from Lompoc       0       0       0       0        0
                      Nepturne       7       9       9      10       10
                    Ellen A038       3       4       5       5        6
                    Ellen A040       0       0       0       0        0
                     Gail E010       0       0       0       0        0
                     Gail E019      15      19      22      23       25
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E11: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 8 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]      18      24      27      30       34
                Arabian Medium      13      16      17      17       18
                          DOBA    1000    1000    1000    1000     1000
             DOS Cuadras HE-05       8      12      13      14       15
             DOS Cuadras HE-26      14      18      20      21       23
                      Endicott      19      28      34      39       46
                       Harmony       1       2       3       3        3
                       IFO-120       2       3       3       3        3
                       IFO-180       0       0       0       0        0
                    North Star      66     122     154     183      218
                          Rock       7       7       7       7        7
                    Terra Nova      22      31      36      42       48
Independence Hub A.V. Block 37    1000    1000    1000    1000     1000
     Irene Sampled from Lompoc       1       1       1       1        1
                      Nepturne       7       9      10      10       11
                    Ellen A038       6      11      14      17       20
                    Ellen A040       0       0       0       0        0
                     Gail E010       1       1       2       2        2
                     Gail E019      13      17      19      21       22
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------
```

```
Table E12: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 8 knots
Water Temperature      = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
---------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
---------------------------------------------------------------------------
     Alaska North Slope [2011]      18      23      26      29       32
                Arabian Medium      13      16      17      17       18
                          DOBA    1000    1000    1000    1000     1000
            DOS Cuadras HE-05        8      11      12      13       14
            DOS Cuadras HE-26       14      18      20      22       23
                      Endicott      18      27      32      37       44
                       Harmony       1       3       3       3        3
                       IFO-120       2       3       3       4        4
                       IFO-180       1       1       1       1        1
                    North Star      70     130     164     195      232
                          Rock      10      11      12      12       12
                    Terra Nova      22      31      37      43       49
Independence Hub A.V. Block 37    1000    1000    1000    1000     1000
     Irene Sampled from Lompoc       1       2       2       2        2
                      Nepturne       6       9       9      10       10
                    Ellen A038       6      12      15      18       21
                    Ellen A040       4       4       4       4        4
                     Gail E010       1       2       3       3        3
                     Gail E019      11      16      17      19       20
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
---------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
---------------------------------------------------------------------------
```

```
Table E13: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 12 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
---------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
---------------------------------------------------------------------------
     Alaska North Slope [2011]      11      16      20      23       27
                Arabian Medium       6       8       8       9        9
                          DOBA       1       1       1       1        1
            DOS Cuadras HE-05        5       7       8       8        9
            DOS Cuadras HE-26        7      10      11      12       13
                      Endicott      12      20      26      30       36
                       Harmony       1       1       1       1        1
                       IFO-120       1       1       1       1        2
                       IFO-180       0       0       0       0        0
                    North Star      46      86     108     128      152
                          Rock       1       1       1       1        1
                    Terra Nova      12      20      25      30       35
```

Independence Hub A.V. Block 37	9999	9999	9999	9999	9999
Irene Sampled from Lompoc	0	0	0	0	0
Nepturne	4	4	5	5	5
Ellen A038	1	2	3	3	4
Ellen A040	0	0	0	0	0
Gail E010	0	0	0	0	0
Gail E019	8	11	13	14	16
Heritage HE 05	0	0	0	0	0
Heritage HE 26	0	0	0	0	0
Irene Comingled	0	0	0	0	0

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table E14: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 7500 cP
Wind Speed = 12 knots
Water Temperature = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
Alaska North Slope [2011]	10	15	18	21	24
Arabian Medium	6	8	8	9	9
DOBA	1000	1000	1000	1000	1000
DOS Cuadras HE-05	5	6	7	8	8
DOS Cuadras HE-26	7	10	11	12	14
Endicott	12	21	26	31	37
Harmony	1	2	2	2	2
IFO-120	1	2	2	2	2
IFO-180	0	0	0	0	0
North Star	53	99	125	148	176
Rock	3	3	3	3	3
Terra Nova	13	22	27	32	38
Independence Hub A.V. Block 37	9999	9999	9999	9999	9999
Irene Sampled from Lompoc	1	1	1	1	1
Nepturne	4	5	5	5	5
Ellen A038	4	9	12	14	16
Ellen A040	0	0	0	0	0
Gail E010	1	1	1	1	1
Gail E019	7	10	11	12	14
Heritage HE 05	0	0	0	0	0
Heritage HE 26	0	0	0	0	0
Irene Comingled	0	0	0	0	0

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table E15: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 7500 cP
Wind Speed = 12 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

```
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]       9      14      17      19       22
                Arabian Medium       6       8       8       9        9
                          DOBA    1000    1000    1000    1000     1000
             DOS Cuadras HE-05       4       6       7       7        8
             DOS Cuadras HE-26       8      10      11      13       14
                      Endicott      11      20      25      29       35
                       Harmony       1       2       2       2        2
                       IFO-120       1       2       2       2        2
                       IFO-180       1       1       1       1        1
                    North Star      56     105     133     158      187
                          Rock       5       5       5       5        5
                    Terra Nova      13      22      28      33       39
Independence Hub A.V. Block 37    9999    9999    9999    9999     9999
     Irene Sampled from Lompoc       1       1       1       1        1
                      Nepturne       4       5       5       5        6
                    Ellen A038       5      10      12      14       17
                    Ellen A040       1       1       1       1        1
                     Gail E010       1       1       2       2        2
                     Gail E019       6       9      10      11       12
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------
```

```
Table E16: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 15 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]       8      14      17      21       24
                Arabian Medium       4       5       5       6        6
                          DOBA       1       1       1       1        1
             DOS Cuadras HE-05       4       5       6       6        6
             DOS Cuadras HE-26       5       7       8       9       10
                      Endicott       9      18      23      27       32
                       Harmony       1       1       1       1        1
                       IFO-120       1       1       1       1        1
                       IFO-180       0       0       0       0        0
                    North Star      41      76      96     114      136
                          Rock       1       1       1       1        1
                    Terra Nova       9      18      22      26       31
Independence Hub A.V. Block 37    9999    9999    9999    9999     9999
     Irene Sampled from Lompoc       0       0       0       0        0
                      Nepturne       3       3       3       3        3
                    Ellen A038       1       2       3       3        3
                    Ellen A040       0       0       0       0        0
                     Gail E010       0       0       0       0        0
                     Gail E019       6       8      10      12       13
```

```
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E17: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 15 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]       7      12      16      18       21
                Arabian Medium       4       5       6       6        6
                          DOBA    1000    1000    1000    1000     1000
             DOS Cuadras HE-05       3       5       5       6        6
             DOS Cuadras HE-26       5       7       8      10       11
                      Endicott      10      19      23      28       33
                       Harmony       1       1       1       1        1
                       IFO-120       1       1       1       2        2
                       IFO-180       0       0       0       0        0
                    North Star      47      88     111     132      157
                          Rock       2       2       2       2        2
                    Terra Nova      10      19      24      29       34
Independence Hub A.V. Block 37    9999    9999    9999    9999     9999
     Irene Sampled from Lompoc       1       1       1       1        1
                      Nepturne       3       3       3       4        4
                    Ellen A038       4       8      10      12       14
                    Ellen A040       0       0       0       0        0
                     Gail E010       1       1       1       1        1
                     Gail E019       5       7       9      10       11
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E18: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 7500 cP
Wind Speed             = 15 knots
Water Temperature      = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]       7      12      14      17       20
                Arabian Medium       4       5       6       6        6
                          DOBA    1000    1000    1000    1000     1000
             DOS Cuadras HE-05       3       4       5       5        6
```

```
             DOS Cuadras HE-26       5       7       9      10       11
                      Endicott       9      18      22      26       31
                       Harmony       1       1       1       2        2
                       IFO-120       1       2       2       2        2
                       IFO-180       1       1       1       1        1
                    North Star      50      94     118     140      166
                          Rock       3       3       3       3        3
                    Terra Nova      10      20      25      30       35
Independence Hub A.V. Block 37    9999    9999    9999    9999     9999
     Irene Sampled from Lompoc       1       1       1       1        1
                      Nepturne       3       3       3       4        4
                    Ellen A038       4       8      11      13       15
                    Ellen A040       1       1       1       1        1
                     Gail E010       1       1       1       1        1
                     Gail E019       5       7       8       9       10
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E19: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 8 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]      23      32      38      44       52
                Arabian Medium      14      17      18      19       20
                          DOBA       5       5       5       5        5
             DOS Cuadras HE-05      11      14      16      17       18
             DOS Cuadras HE-26      16      20      22      24       26
                      Endicott      22      34      42      49       58
                       Harmony       1       2       2       2        2
                       IFO-120       1       2       3       3        3
                       IFO-180       0       0       0       0        0
                    North Star     103     190     240     285      339
                          Rock       3       3       3       3        3
                    Terra Nova      26      38      46      54       64
Independence Hub A.V. Block 37    1000    1000    1000    1000     1000
     Irene Sampled from Lompoc       0       0       0       0        0
                      Nepturne       8      10      10      11       11
                    Ellen A038       5      10      12      14       16
                    Ellen A040       0       0       0       0        0
                     Gail E010       0       0       0       0        0
                     Gail E019      16      22      25      27       30
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------
```

```
Table E20: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 8 knots
Water Temperature      = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]      22      30      35      40       46
                Arabian Medium      14      17      18      19       20
                          DOBA    1000    1000    1000    1000     1000
             DOS Cuadras HE-05       9      13      14      15       16
             DOS Cuadras HE-26      16      21      23      25       27
                      Endicott      21      33      41      48       57
                       Harmony       2       3       3       3        3
                       IFO-120       2       3       4       4        4
                       IFO-180       1       1       1       1        1
                    North Star     118     216     273     325      386
                          Rock       9       9       9       9        9
                    Terra Nova      26      40      50      58       69
Independence Hub A.V. Block 37    1000    1000    1000    1000     1000
     Irene Sampled from Lompoc       1       1       2       2        2
                      Nepturne       7      10      11      11       12
                    Ellen A038       8      15      19      23       26
                    Ellen A040       1       1       1       1        1
                     Gail E010       1       2       2       2        2
                     Gail E019      14      19      21      23       25
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E21: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 8 knots
Water Temperature      = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]      21      28      33      37       43
                Arabian Medium      14      17      18      19       20
                          DOBA    1000    1000    1000    1000     1000
             DOS Cuadras HE-05       9      12      13      14       15
             DOS Cuadras HE-26      16      21      24      26       28
                      Endicott      20      31      38      45       53
                       Harmony       2       3       3       4        4
                       IFO-120       2       4       4       4        5
                       IFO-180       1       1       2       2        2
                    North Star     124     228     287     342      407
                          Rock      13      15      16      16       17
```

```
                    Terra Nova      26      41      50      60       70
Independence Hub A.V. Block 37    1000    1000    1000    1000     1000
     Irene Sampled from Lompoc       1       2       2       2        2
                      Nepturne       7       9      10      11       12
                    Ellen A038       8      15      19      22       26
                    Ellen A040      18      34      43      51       61
                     Gail E010       2       3       3       3        4
                     Gail E019      13      17      19      21       23
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E22: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 12 knots
Water Temperature      = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl
--------------------------------------------------------------------------
    Oil Name \ OilVolume (bbl)    1000   10000   25000   50000   100000
--------------------------------------------------------------------------
     Alaska North Slope [2011]      13      23      29      35       41
                Arabian Medium       7       8       9       9       10
                          DOBA       2       2       2       2        2
             DOS Cuadras HE-05       6       8       9      10       10
             DOS Cuadras HE-26       8      11      13      15       16
                      Endicott      14      26      33      39       46
                       Harmony       1       1       1       1        1
                       IFO-120       1       2       2       2        2
                       IFO-180       0       0       0       0        0
                    North Star      84     154     194     231      274
                          Rock       1       1       1       1        1
                    Terra Nova      16      29      37      44       52
Independence Hub A.V. Block 37    9999    9999    9999    9999     9999
     Irene Sampled from Lompoc       0       0       0       0        0
                      Nepturne       4       5       5       5        5
                    Ellen A038       4       8       9      11       13
                    Ellen A040       0       0       0       0        0
                     Gail E010       0       0       0       0        0
                     Gail E019       9      13      16      18       21
                Heritage HE 05       0       0       0       0        0
                Heritage HE 26       0       0       0       0        0
               Irene Comingled       0       0       0       0        0
--------------------------------------------------------------------------
9999 means that the spilled oil has naturally dispersed and/or evaporated
before reaching the Cut-off viscosity during the 1000 hours of simulation.
--------------------------------------------------------------------------


Table E23: Time Window (in Hours) for Dispersant Application Predicted
           Using Oilmap 6.9.3 and the following Parameters
Cutoff Viscosity       = 10000 cP
Wind Speed             = 12 knots
Water Temperature      = 23 oC
```

Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
Alaska North Slope [2011]	12	21	26	31	36
Arabian Medium	7	9	9	10	10
DOBA	1000	1000	1000	1000	1000
DOS Cuadras HE-05	5	7	8	9	9
DOS Cuadras HE-26	9	12	14	16	18
Endicott	14	26	32	38	45
Harmony	1	2	2	2	2
IFO-120	1	2	2	2	2
IFO-180	1	1	1	1	1
North Star	96	175	221	263	312
Rock	4	4	4	4	4
Terra Nova	17	31	40	47	55
Independence Hub A.V. Block 37	9999	9999	9999	9999	9999
Irene Sampled from Lompoc	1	1	1	1	1
Nepturne	4	5	6	6	6
Ellen A038	6	12	15	18	21
Ellen A040	1	1	1	1	1
Gail E010	1	1	1	1	1
Gail E019	8	11	13	15	17
Heritage HE 05	0	0	0	0	0
Heritage HE 26	0	0	0	0	0
Irene Comingled	0	0	0	0	0

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table E24: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 12 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
Alaska North Slope [2011]	12	19	24	28	33
Arabian Medium	7	9	9	10	10
DOBA	1000	1000	1000	1000	1000
DOS Cuadras HE-05	5	7	7	8	9
DOS Cuadras HE-26	9	12	14	16	18
Endicott	13	24	30	36	42
Harmony	1	2	2	2	2
IFO-120	1	2	2	3	3
IFO-180	1	1	1	1	1
North Star	101	185	233	277	329
Rock	6	7	7	7	7
Terra Nova	17	32	40	48	57
Independence Hub A.V. Block 37	9999	9999	9999	9999	9999
Irene Sampled from Lompoc	1	1	1	2	2
Nepturne	4	5	6	6	6
Ellen A038	6	12	15	18	21
Ellen A040	14	27	35	41	48
Gail E010	1	2	2	2	2

Gail E019	7	10	12	13	14
Heritage HE 05	0	0	0	0	0
Heritage HE 26	0	0	0	0	0
Irene Comingled	0	0	0	0	0

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table E25: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 15 knots
Water Temperature = 13 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
Alaska North Slope [2011]	11	21	26	31	36
Arabian Medium	5	6	6	6	7
DOBA	1	1	1	1	1
DOS Cuadras HE-05	4	6	6	7	8
DOS Cuadras HE-26	6	9	10	12	14
Endicott	12	23	30	35	41
Harmony	1	1	1	1	1
IFO-120	1	1	1	1	1
IFO-180	0	0	0	0	0
North Star	75	138	173	206	244
Rock	1	1	1	1	1
Terra Nova	13	26	33	39	46
Independence Hub A.V. Block 37	9999	9999	9999	9999	9999
Irene Sampled from Lompoc	0	0	0	0	0
Nepturne	3	3	3	3	3
Ellen A038	3	7	8	10	11
Ellen A040	0	0	0	0	0
Gail E010	0	0	0	0	0
Gail E019	6	11	13	16	18
Heritage HE 05	0	0	0	0	0
Heritage HE 26	0	0	0	0	0
Irene Comingled	0	0	0	0	0

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table E26: Time Window (in Hours) for Dispersant Application Predicted
Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 15 knots
Water Temperature = 23 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
Alaska North Slope [2011]	9	18	23	27	32
Arabian Medium	5	6	6	7	7
DOBA	1000	1000	1000	1000	1000

DOS Cuadras HE-05	4	5	6	6	7
DOS Cuadras HE-26	6	9	11	13	15
Endicott	12	23	29	34	40
Harmony	1	1	1	2	2
IFO-120	1	2	2	2	2
IFO-180	1	1	1	1	1
North Star	86	157	197	234	278
Rock	2	2	2	2	2
Terra Nova	14	28	35	42	49
Independence Hub A.V. Block 37	9999	9999	9999	9999	9999
Irene Sampled from Lompoc	1	1	1	1	1
Nepturne	3	4	4	4	4
Ellen A038	5	11	13	16	19
Ellen A040	1	1	1	1	1
Gail E010	1	1	1	1	1
Gail E019	6	9	11	12	14
Heritage HE 05	0	0	0	0	0
Heritage HE 26	0	0	0	0	0
Irene Comingled	0	0	0	0	0

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Table E27: Time Window (in Hours) for Dispersant Application Predicted Using Oilmap 6.9.3 and the following Parameters

Cutoff Viscosity = 10000 cP
Wind Speed = 15 knots
Water Temperature = 29 oC
Oil Spill Volume (bbl) = 1000, 10000, 25000, 50000, and 100000 bbl

Oil Name \ OilVolume (bbl)	1000	10000	25000	50000	100000
Alaska North Slope [2011]	9	17	21	25	29
Arabian Medium	5	6	6	7	7
DOBA	1000	1000	1000	1000	1000
DOS Cuadras HE-05	3	5	5	6	6
DOS Cuadras HE-26	6	10	12	14	16
Endicott	11	21	27	32	38
Harmony	1	1	2	2	2
IFO-120	1	2	2	2	2
IFO-180	1	1	1	1	1
North Star	90	165	208	247	293
Rock	4	4	4	4	4
Terra Nova	14	28	36	43	50
Independence Hub A.V. Block 37	9999	9999	9999	9999	9999
Irene Sampled from Lompoc	1	1	1	1	1
Nepturne	3	4	4	4	4
Ellen A038	5	11	13	16	18
Ellen A040	13	24	31	36	43
Gail E010	1	1	1	1	1
Gail E019	5	8	9	11	12
Heritage HE 05	0	0	0	0	0
Heritage HE 26	0	0	0	0	0
Irene Comingled	0	0	0	0	0

9999 means that the spilled oil has naturally dispersed and/or evaporated before reaching the Cut-off viscosity during the 1000 hours of simulation.

Appendix F

Identification of the key variables controlling variations of the time-window and development of new predictive models (Task 4)

1 Correlation of the time window with the key oil properties

Data on time window (TW) for spill volumes of 1000 discussed in Tasks 1 to 3 were used to search for possible correlation of this variable with the following oil properties: API gravity, sulfur content, dynamic viscosity at 15 oC, saturates content, aromatics content, resin content, asphaltenes content and median boiling point (MBP). The time window data are those discussed in Tasks 1 to 3 for oil volume 1000 bbl, water temperature of 23 oC, wind speed of 12 knots and a cut-of viscosity of 7500 cP. Simple plots of the variations of the TW with each of these oil properties are shown in Figures F1 to F8.

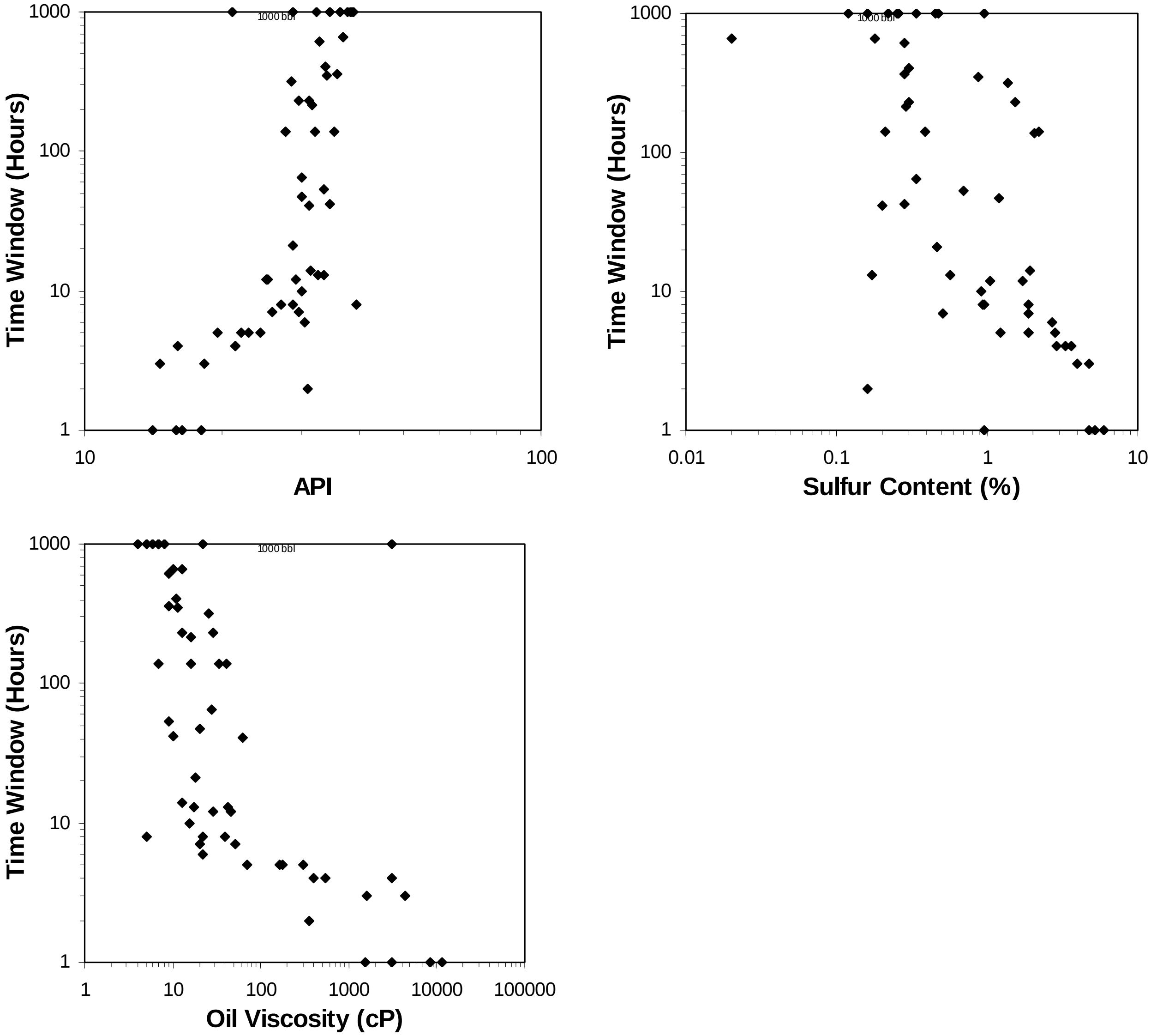

Figure F1: Variations of the time window with API, sulfur content and oil viscosity.

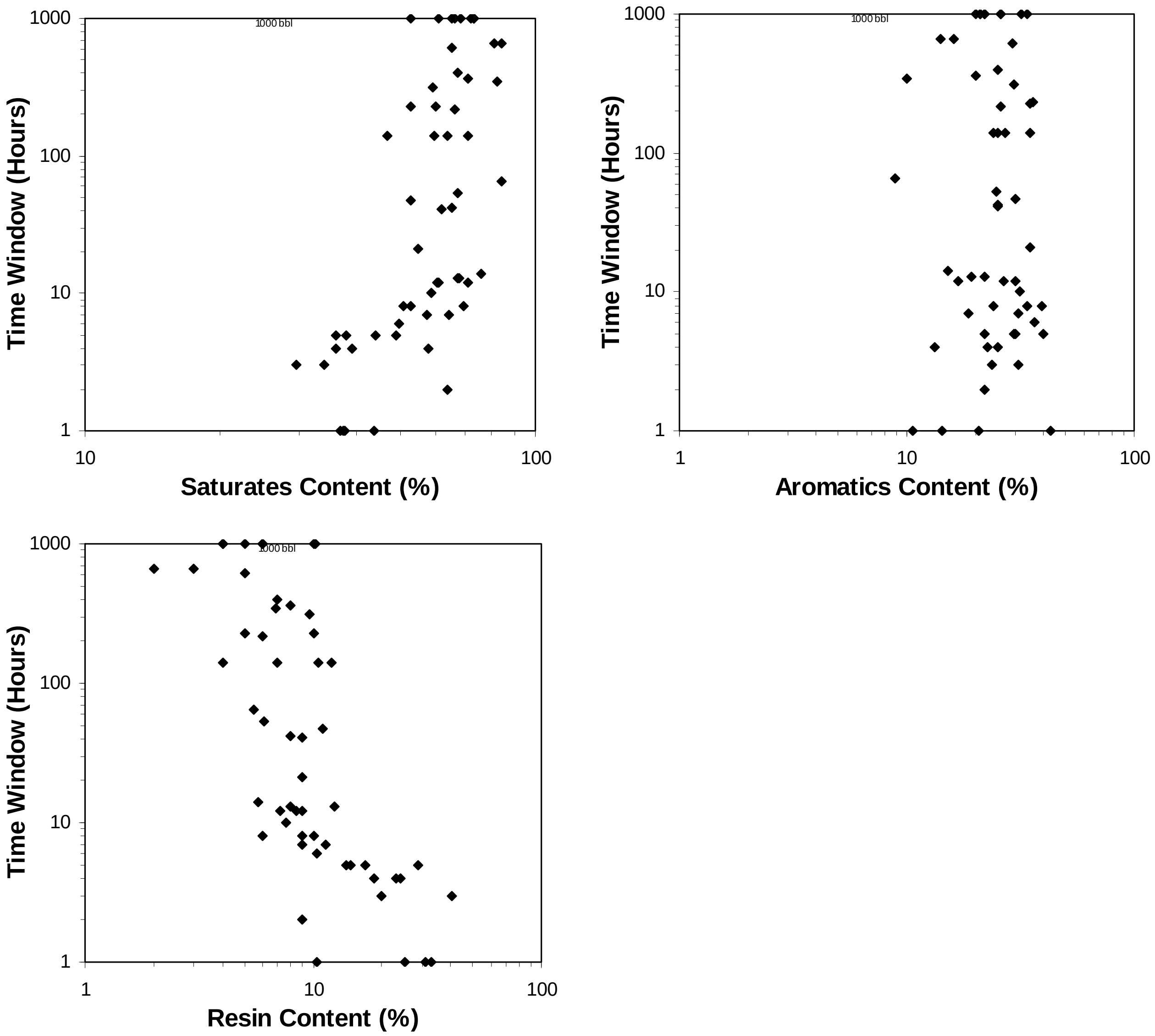

Figure F2: Variations of the time window with saturates content, aromatics content and resin content.

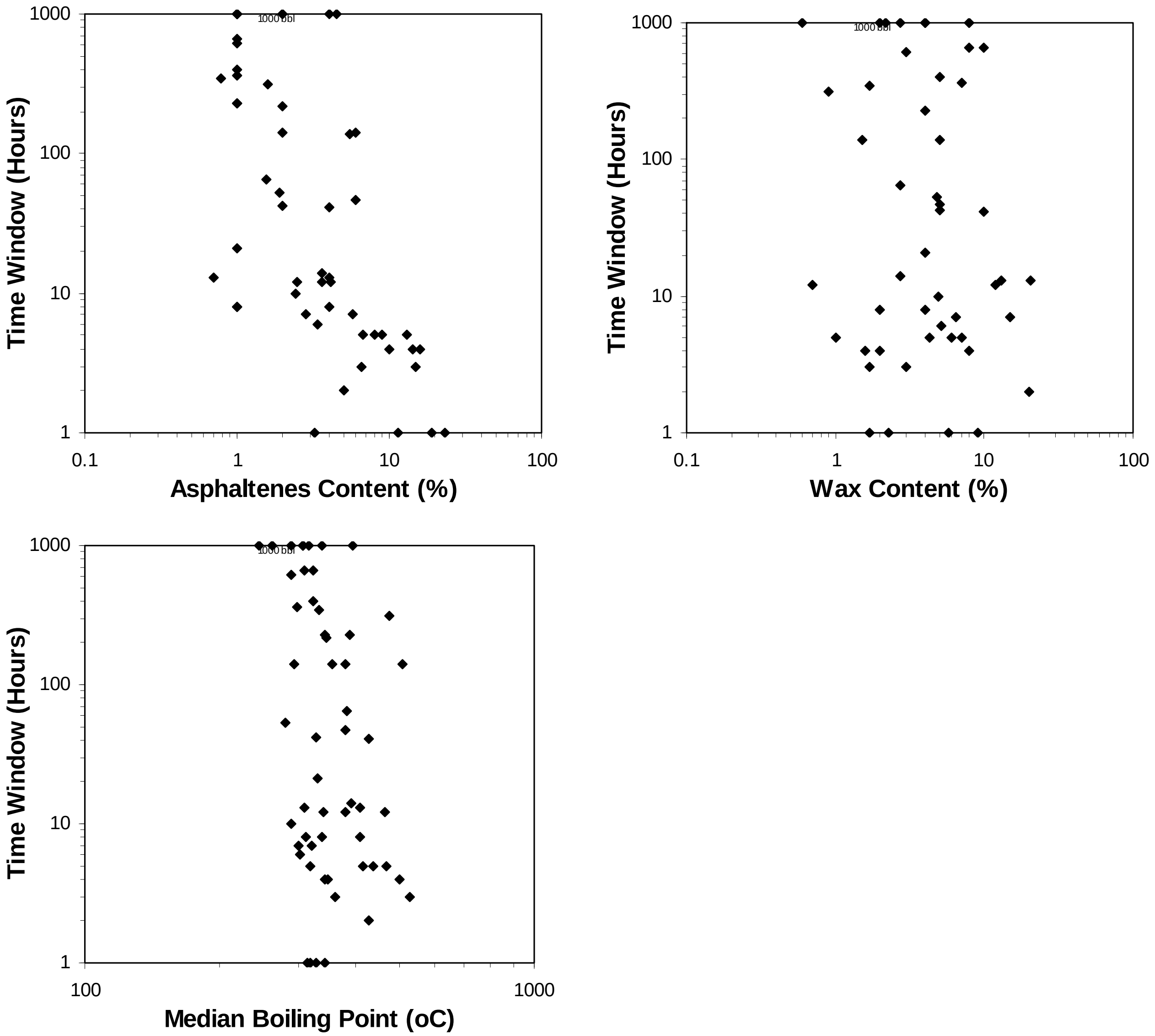

Figure F3: Variations of the time window with asphaltenes content, and wax content and median boiling point.

Figures F1 to F3 show some evidence that the time window (TM) is mostly correlated with the API gravity and oil viscosity, with some correlation with saturates, asphaltenes and resins. No evidence of existing correlation between TM and sulphur and wax.

2 Principal Component Analysis

As many of the variables discussed above are dependant, principal component analysis (PCA) technique was used to investigate further on possible reduction of the number of variables and to identify key oil properties that control the variations of the time window.

First, PCS has been applied considering the sulfur, saturates and wax as the controlling variables as suggested by SL Ross (2007). The TM was set as the fourth variable in the analysis.

Table F1 show the coefficients obtained for the four principal components. The percent of the total variability explained by each component is also shown in the last row of the table. A projection of the data onto the first two principal components (main ones) is shown in Figure F4. No useful information can be concluded from this analysis except that wax content is showing the least impact on the variability of the data as opposed to fulfur.

Table F1: principal components obtained from the PCA analysis considering sulfur, saturates wax, and TM variables.

Principal component #	1st PC	2nd PC	3rd PC	4th PC
Coefficient	0.6182	-0.1209	0.244	0.7373
	-0.6111	0.0245	-0.4356	0.6605
	-0.1686	0.8553	0.4738	0.1248
	-0.4648	-0.5033	0.7254	0.0671
Percent of the total variability explained by each component	54.6	28.4	11.4	5.6

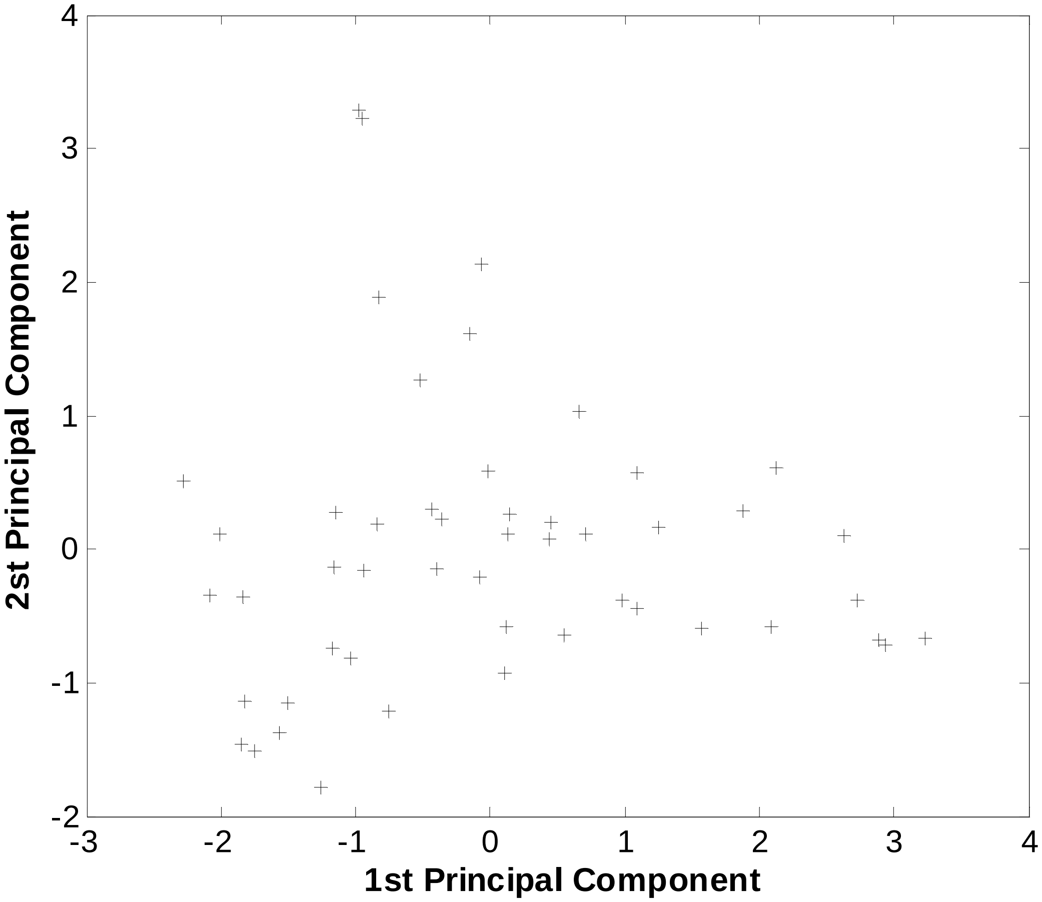

Figure F4: Sulfur, saturates, wax and TM data projected onto the first two principal components shown in Table D1.

Several additional PCS analyses have been performed considering the whole set of variables. The most interesting results where obtained when considering API gravity and oil viscosity with TM. Figure F5 shows API and TM data projected onto the two principal components obtained from the OCS analysis using these two variables only. Equivalent data are shown in Figure F6 for the results obtained from PCA analysis using oil viscosity and TM data.

This PCA analysis confirms that TM is mostly correlated with the oil viscosity and API data, as it was shown from the simple plots discussed above (Figure F1 to F3). Figure F5 shows that the variations of TM with API can be grouped in three categories: two are shown by the linear correlation and the third one relates to the data shown by the scatter points located between the two first groups. However, results obtained with the oil viscosity and TM data (Figure F6) showed a clear grouping of the data into two categories defined by the linear trend in Figure 6 (Group 1 and Group 2), except for DOBA oil which is outside of these two groups. Furthermore, it is well established that oil viscosity and API are highly correlated. As shown in Figure F7, the present data do show such strong correlation between these two variables. From this, it is concluded that the correlations of TM data with API gravity and with oil viscosity represent the same information. Based on these results, efforts have been concentrated on developing the new models to predict the time window as a function of oil viscosity. This is discussed in more details in the next section.

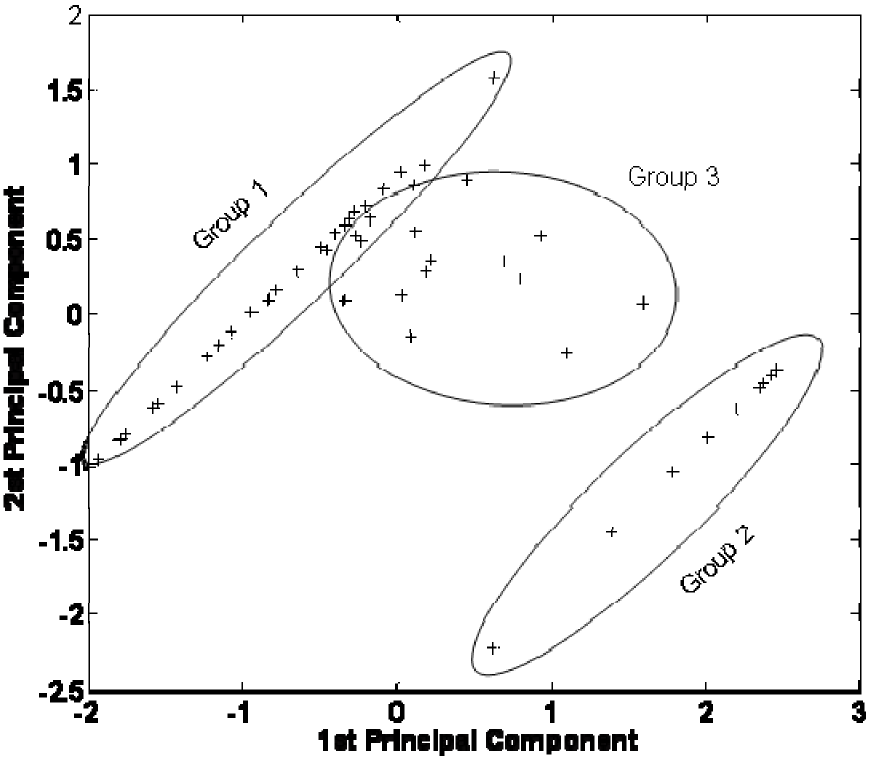

Figure F5: API gravity and TM data projected onto the first two principal components calculated using these two variables.

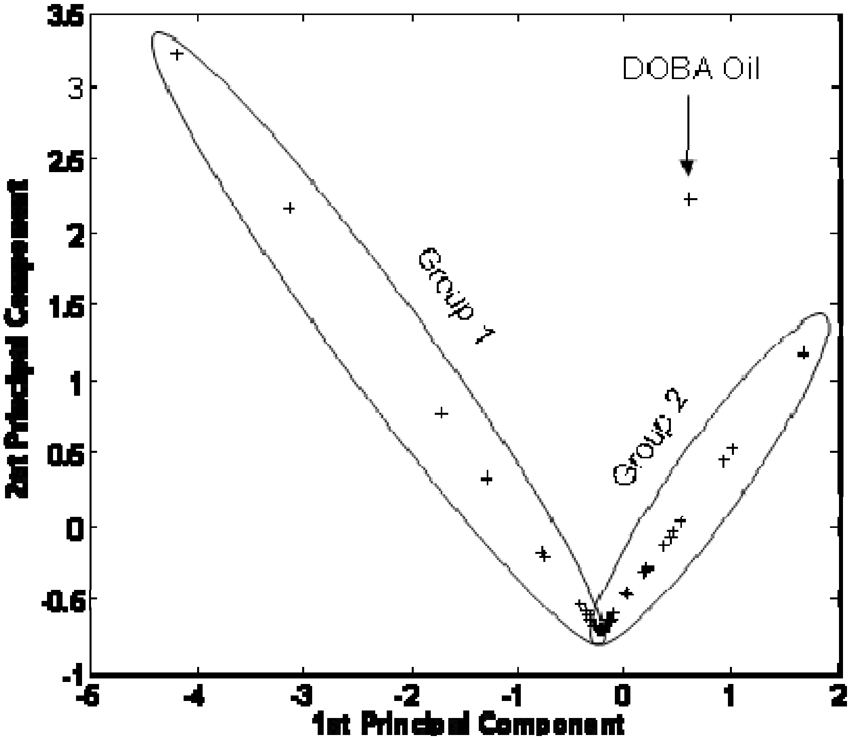

Figure F6: Oil viscosity and TM data projected onto the first two principal components calculated using these two variables.

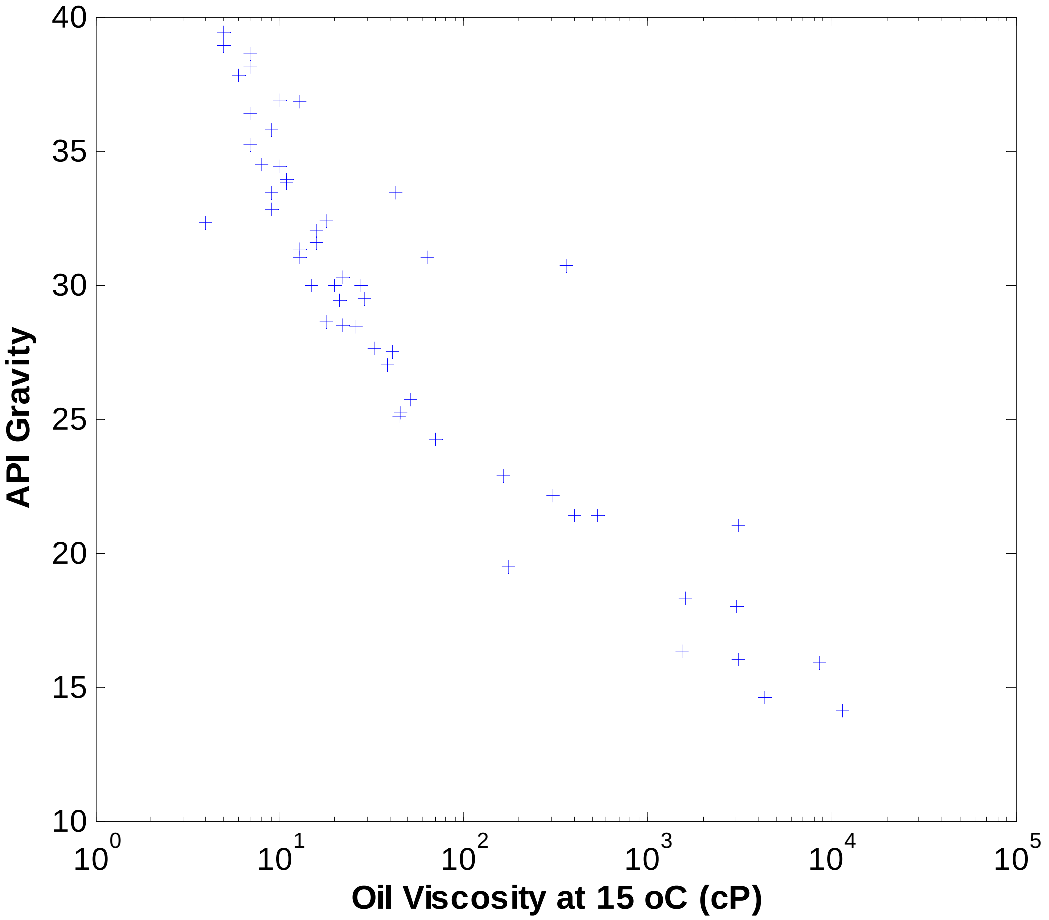

Figure F7: Variations of API gravity as a function of the oil viscosity

3 Development of the new predictive models

Further investigation of the results of the PCA analysis shown in Figure F6 showed that the grouping of the oils into two distinct groups is exactly the same as the grouping shown on the simple plot of TM vs oil viscosity shown in Figure F8. Based on this finding, orthogonal regression using PCA analysis was performed on each group separately. DOBA and green Canyon Block 184 oils were not considered in this regression. Figure F9 illustrate in more details the results and how the data were separated in two different groups shown by the red and blue symbols. These equations obtained from the orthogonal regression constitute the backbone of the new models developed in this study to predict the time window as a function of the oil viscosity measured at 15 oC. Results are summarized in Table F2.

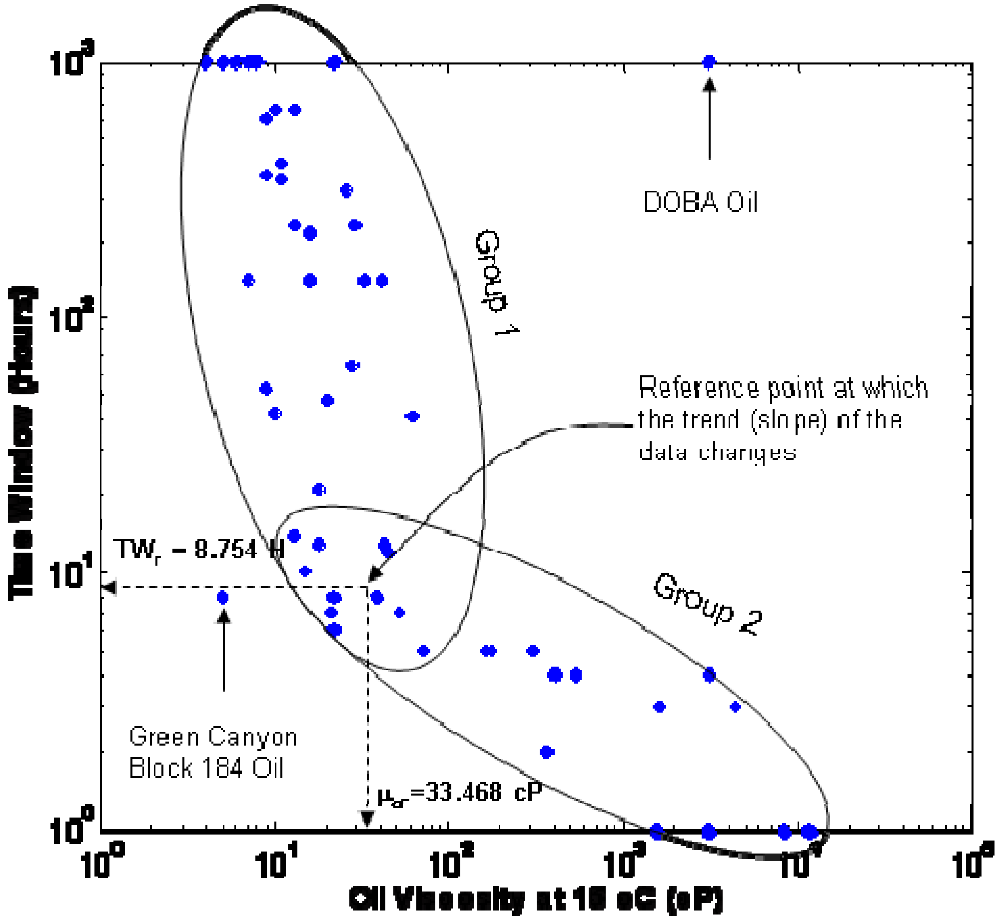

Figure F8: Simple plot of the variations of the time window data with oil viscosity to show evidence of distinct grouping of the data and its relationship with the grouping obtained from PCA analysis shown in Figure F6

For consistency with the dimensional analysis and considering the distinct two linear (in log scale) trends shown by the data in Figures F6 and F8, the controlling variables were normalized as follows:

Dimensionless Time Window, $$\tau = \frac{TW}{TW_r} \qquad \text{(F1)}$$

Dimensionless Oil Viscosity, $$\mu = \frac{\mu_o}{\mu_{or}} \qquad \text{(F2)}$$

where *TW* represents the time window in hours, μ_o is the oil dynamic viscosity measured at 15 oC, and TW_r and μ_{or} represent the reference time window and reference oil dynamic viscosity, respectively, at which the data change the trend (slope). Precisely, this reference point is defined by the intersection of the regression models developed for the two regions before normalization of the variables (oil viscosity and the time window).

Based on this normalization of the controlling variables and as shown in Table F2 and Figure F9, the new models to predict the time window for application of chemical dispersant are as follows:

$\mathbf{ln(\tau) = -3.4201\ ln(\mu)}$, or $\boldsymbol{TW_1 = TW_r\, \mu^{-3.4201}}$ for $\mu \leq 1$ at 15 oC (F4)

$\boldsymbol{TW_1 = 1000\ Hours}$ if $TW_r\, \mu^{-3.4201} > 1000$ Hours

$\mathbf{ln(\tau) = -0.3556\ ln(\mu)}$, or $\boldsymbol{TW_2 = TW_r\, \mu^{-0.3556}}$ for $1 \leq \mu \leq \frac{\mu_{co}}{\mu_{or}}$ at 15 oC (F5)

where μ_{co} if the cut-of viscosity used to calculate the time window data. For the series of data analyzed in this Appendix F, the conditions used to generate the time window data used to develop the models are as follows:
Oil spill volume = 1000 bbl
Water temperature = 23 oC
Wind speed = 12 knots
μ_{co} = 7500 cP

For these conditions, key parameters in equations F4 and F5 are:
μ_{or} = 33.468 cP
TW_r = 8.754 H

The limitation of TW_1 (time window for the first region (group) of the oil viscosity) to 1000 hours is as imposed in the post-processing of the data generated from Oilmap simulations in which the cut-of viscosity was not reached during the 1000 hours simulation period. Furthermore, the applicability of the models shown by equations F4 and F5 to other spill conditions is discussed in section 6.3 of the main report.

Table F2: New Models Developed using Principal Components Analysis and Orthogonal Regression.

Region	Main principal component considering $\boldsymbol{\mu_r}$ and $\boldsymbol{\tau}$ variables	Variance covered by the main principal component (%)	Linear fitting using orthogonal regression	Range of validity
First region: low oil viscosity	-0.281 0.960	93.3	$\boldsymbol{TW_1 = TW_r\, \mu^{-3.4201}}$	$\boldsymbol{\mu} \leq 1$ at 15 oC
Second region: high oil viscosity	0.942 -0.335	97.3	$\boldsymbol{TW_2 = TW_r\, \mu^{-0.3556}}$	$1 \leq \boldsymbol{\mu} \leq \frac{\mu_{co}}{\mu_{or}}$ at 15 oC where μ_{co} represent the cut-of viscosity used to calculate the time window

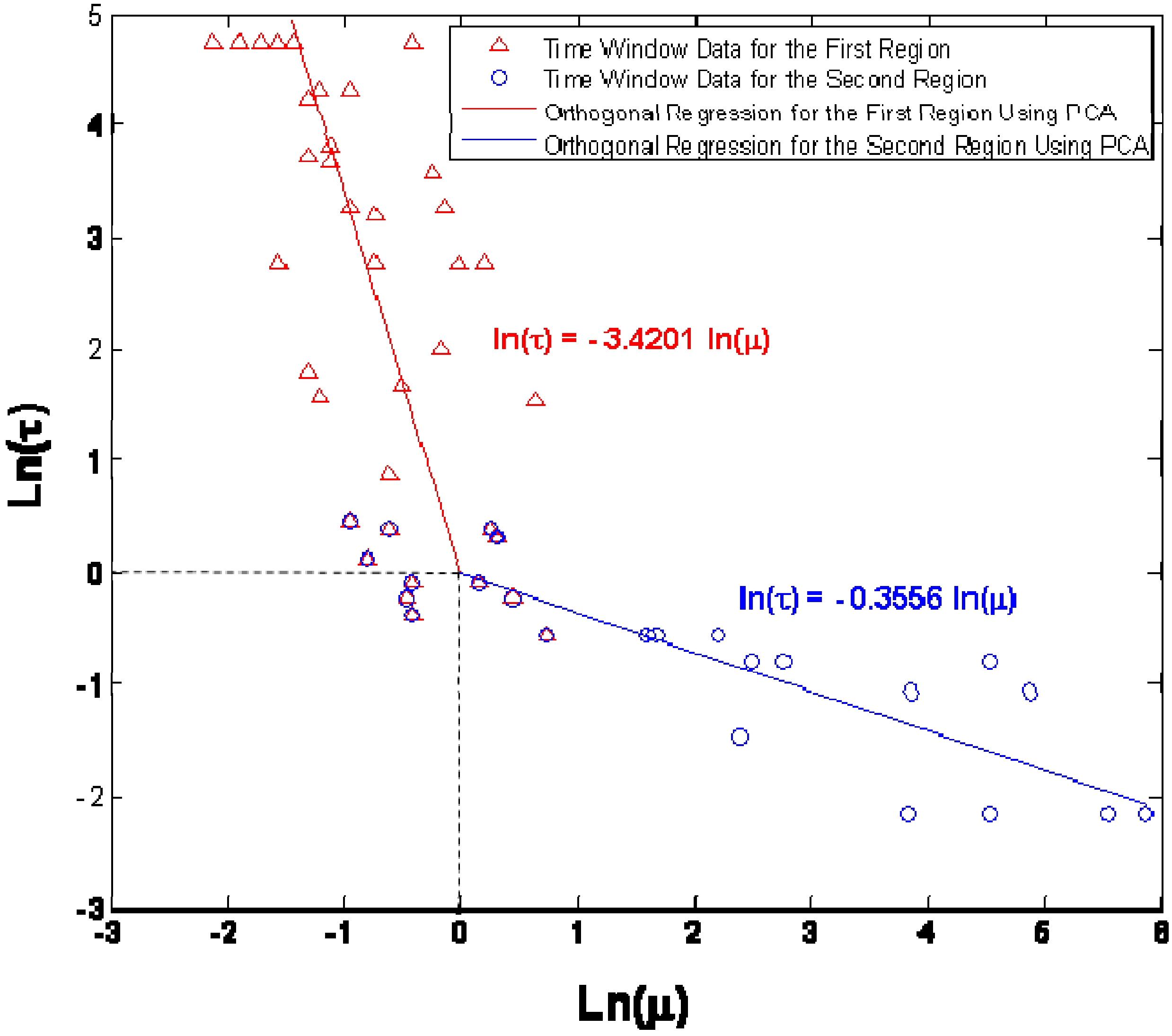

Figure F9: Fitting Linear Models using Orthogonal Regression and Principal Components Analysis on the two different groups.

4 Comparison between predicted time window and the original data

Equations F4 and F5 were used to predict the time window using oil viscosity, wind speed of 12 knots, a spill volume of 1000 bbl, water temperature of 23 oC, and a cut-of viscosity of 7500 cP. The predictions were compared with the original data obtained by the Oilmap oil spill model using the same parameters. As it was done with the original data, the time window was set to 1000 hour when the predictions exceed this value. Results are shown in Figure F10.

While the agreement between the two predictions is not prefect, Figure F10 shows that overall the data show better agreement than with the previous correlations models. The results also show that further work is needed to improve the predictive models. What is also important to note is that the new models shown by equations F4 and F5 use only oil viscosity to predict the time window with the goodness shown in Figure F10.

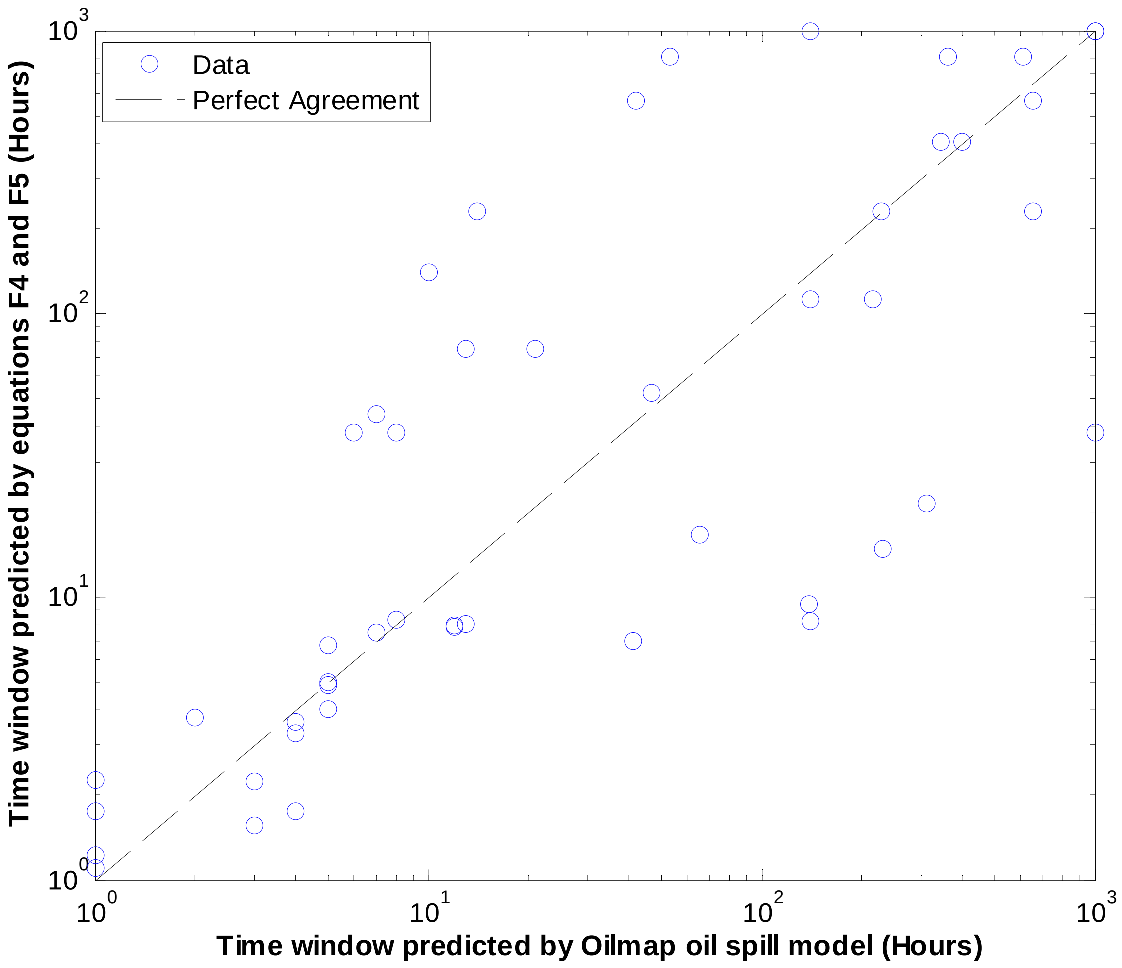

Figure F10: Comparison between predicted time window using equations F4 and F5 and the original data predicted by Oilmap considering a spill volume of 1000 bbl, wind speed of 12 knots, water temperature of 23 oC, and cut-of viscosity of 7500 cP.