Comments on ASA and SL Ross Modelling Results

Prepared for:

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By

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September 17, 2012

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Batch spills of Cohasset crude and automotive diesel were modelled by ASA using Oilmap and by SL Ross using their in-house spill model (SLROSM) for comparison of outputs. The modelling by ASA was commissioned to provide independent results from the Oilmap product to verify the results prepared by Environment Canada that appeared to contain questionable natural dispersion predictions. Ten thousand litre instantaneous releases of Cohasset and 1,000 L instantaneous releases of diesel were modelled to provide predictions for comparison purposes. The Cohasset dataset identified by ASA as the one developed using Environment Canada data used the identical base Environment Canada oil property data as used in the SL Ross Cohasset dataset. This discussion focuses on the ASA results using the Environment Canada dataset (as opposed to the ADIOS sourced Cohasset data) as we feel this is the best data available and provides consistency between the two modeling efforts. (Note the discussion in the ASA report regarding the problems with the corrupted ADIOS Cohasset dataset.) The diesel oil data files used by the two models were not identical as slightly different diesel data sets in Oilmap and SLROSM were used in the two cases.

The SL Ross and ASA models use the same evaporation algorithms. The primary difference in the model's results for the Cohasset scenarios is due to the use of different dispersion algorithms by the two models. Oilmap uses the Delvigne algorithms and SL ROSM uses Audunson's.

The Audunson method used in SLROSM results in a more rapid dispersion with the loss of the Cohasset surface oil occurring in less than 2 hours under all wind conditions (from 10 to 20 knots). Due to this rapid dispersion the time available for the Cohasset oil to evaporate is limited so only 20 to 25% evaporates in the SL Ross model for the Cohasset scenarios.

The Delvigne dispersion method used in Oilmap results in loss of the Cohassett crude from the surface in less than about 24 hours for winds of 12 knots, 10.5 hours in 15 knot winds and about 5 hours in 20 knot winds. Approximately half of the surface oil was lost to evaporation and half to natural dispersion under these wind speeds. At 10 knots the Delvigne method resulted in surface oil persisting for up to about 5 days. We feel that this persistence is excessive since breaking waves still will be prevalent at these wind speeds. The Beaufort Scale indicates that wave crests will be breaking and scattered white horses will exist in winds from 7 to 10 knots. The Delvigne method assumes that no breaking waves occur at wind speeds below 5 m/s or 9.7 knots. As a result, the algorithm used by ASA for natural dispersion (Delvigne's) severely limits natural dispersion at wind speeds of 10 knots since this is very close to the 9.7 knot 'cutoff' for dispersion.

The estimated persistence of the Cohasset crude by the two models (Oilmap and SLROSM) is not too different from an offshore spill response and impact perspective, with the exception of the 10 knot wind speed results. The 5 day Oilmap predicted persistence in 10 knot winds is not realistic based on the 1984 Uniacke spill experience off Nova Scotia which involved oil very similar to Cohasset crude. No surface oil was observed during over flights the day after the Uniacke blowout was capped indicating that the oil persisted for less than 24 hours in this actual spill. (Martec Limited, 1984. Report on the Environmental Program associated with the blowout at Shell et al. Uniacke G-72 to Shell Canada Resources Limited). The winds from the time the blowout was killed (17:00 hrs on March 3rd) to the time of the over flight (12:00 hrs on March 4th) averaged about 15 km/hr or 8 knots (based on Sable Island wind station data).

The SL Ross results for the 1000L diesel spill show longer persistence than the Oilmap results for winds greater than 12 knots (SLROSM persistence of 12 to 24 hours versus 3 to 12 hours for Oilmap). These differences are likely primarily due to the different diesel data sets used in the modeling with the SLROSM diesel being slightly more persistent. The Oilmap surface oil persistence for diesel, in 10 knot winds, is higher than SLROSM due to differences in dispersion algorithms previously discussed.

Comparison of Previous Environment Canada Modelling Results to ASA Oilmap and SLROSM Modelling Results

The following table provides a brief summary of the on-water persistence predictions by Environment Canada, ASA and SL Ross for comparison. The Environment Canada results show a much higher persistence for the diesel and Cohasset crude than both the independent ASA results, that used the same oil spill model, and the SL Ross results. It is apparent that the Environment Canada modelling used an oil dataset that was in some way corrupted or incomplete based on the assessment presented by ASA.

Spill	Env. Can. OilMap 6.7.1	ASA OilMap 6.7.4		SLROSM	
		(at 10 knots)	(at 12 knots)	(at 10 knots)	(at 12 knots)
1000 L diesel	From Summary Table 30% remaining after 10 days	Less than 1% remaining after 5 days (ASA Figure 8)	Less than 1% remaining after 12 hrs (ASA Figure 8)	No surface oil after 38 hrs	No surface oil after 28 hrs
10,000 L Cohasset	From Summary Table 41% remaining after 10 days	Less than 1% remaining after 5 days (ASA Figure 6)	Less than 1% remaining after 24 hrs (ASA Figure 6)	No surface oil after 1.9 hrs	No surface oil after 1.5 hrs

FINAL REPORT

Results from Model Simulations of Cohasset Crude

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20 September, 2012

Table of Contents

Introduction

The OILMAP model system was used to simulate instantaneous spills of Cohasset Crude and diesel fuel under constant wind conditions. The goal of the simulations was to compare the oil mass balance for surface, evaporated and entrained oil between two different specifications of Cohasset Crude and one diesel product. Oil mass balance information is presented from each model simulation. OILMAP version 6.7.4 was used for all model simulations.

Scenario Matrix

A total of 16 spill scenarios were simulated as defined in Table 1. Wind was held constant at the indicated speed for the entire 30 day simulation. All spills were modeled as instantaneous releases on the water surface.

Table 1. Spill scenarios.

Oil Type	Spill Volume (liters)	Wind Speeds (knots)	Water Temperature (°C)
Cohasset crude using Adios oil database (unmodified)	10,000	10, 12,15, 20	10
Cohasset crude using Adios oil database (modified for zero emulsification)	10,000	10, 12,15, 20	10
Cohasset crude using Environment Canada data (provided to ASA by SL Ross)	10,000	10, 12,15, 20	10
Diesel (automotive grade)	1,000	10, 12,15, 20	10

Oils Used in the Simulations

Table 2 lists the main oil properties for each product modeled. There are important differences between the two Cohasset oils used in the modeling. As noted in Table 2, the viscosity is different, particularly at 15°C. The other differences are that maximum water content and distillation data are not present for the Adios Cohasset. These differences have significance for how the model calculates entrainment and evaporation which are discussed more fully in the following sections. A complete listing of oil parameters used in the model simulations is provided in the Appendix.

Table 2. Cohasset crude properties for fresh oil.

Oil	Density of fresh oil (g/cm^3)	Dynamic Viscosity of fresh oil (cP)	Interfacial Tension (dyne/cm) {oil-seawater}	Maximum Water Content
Cohasset Crude (E.C.)	0.8002 @ 0° C 0.7900 @ 15° C	2.23 @ 0° C 1.63 @ 15° C	15.3	0
Cohasset Crude (Adios)	0.8002 @ 0° C 0.7900 @ 15° C	2.401 @ 0° C 2.370 @ 15° C	15.3	Not defined
Diesel	0.8310 @ 15° C	2.76 @ 15° C	27.5	0

The Adios Oil Database

The Adios database contains specifications for a large number of oils but many of the data fields contain no values. When data are missing from the database, both the Adios model and the OILMAP model utilize default values or calculations based on proxy oils that can have significant effects on the fate of the oil. In the simulations performed here we address the implications of the oil parameters that are missing from the Cohasset Crude specification in the Adios database. There is also the possibility that the Adios database file used by OILMAP can become corrupted in which case the model reads the oil specification from the database incorrectly and generates invalid oil mass balance results.

Corrupt Database File

During the course of modeling the Cohasset spills it was determined that a corrupt version of the Adios oil database was being used and that mass balance results, particularly for entrainment, were erroneous. When the spills of the Cohasset crude were simulated using the corrupted Adios database, the OILMAP model used incorrect oil parameters which affected the results. When the corrupt database was replaced with an uncorrupted version the oil mass balance results looked more reasonable and the comparison with the results using the Environment Canada Cohasset specification was better.

Missing Data

Some important parameters are missing from the Adios specification of Cohasset Crude oil that affects the oil mass balance predicted by OILMAP. The first is the distillation data used by OILMAP to calculate oil evaporation. The method used by OILMAP for calculating the distillation data and how the model deals with missing oil data are described below. The second important piece of information missing from Adios is the maximum water content of the oil which is used to calculate emulsification. The method used by the model to deal with this missing information is also discussed below.

Distillation Data and Evaporation

The OILMAP model uses the evaporative exposure model of Stiver and Mackay (1984) which is an analytical approach for predicting evaporation. It uses distillation data to estimate parameters needed for the analytic equation.

The fraction evaporated, F_v, is defined as

$$F_v = \ln[1 + B(T_G/T)\,\theta \exp(A - BT_0/T)][T/(BT_G)]$$

where

T_0 - initial boiling point of the modified distillation curve (K)
T_G - gradient of the modified distillation curve
T - environmental temperature (K)
A,B - dimensionless constants

t - time (sec)

θ - evaporative exposure.

The evaporative exposure, θ, is given by

$$\theta = \left(\frac{K_m A t}{V_o} \right)$$

where

K_m - mass transfer coefficient (m/sec)
A - slick area (m^2)
t - time (sec)
V_o - volume of oil spilled (m^3).

Distillation data (T_0, T_G, A, B) for many crude oils are available in Environment Canada's oil properties database (http://www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html).

If distillation data are present in the oil specification, OILMAP uses them, but if the data are missing, as is the case with the Adios Cohasset, the values used in the distillation calculations are determined using a method from the Adios version 1.0 technical documentation as follows:

T_0 = 532.98 - 3.1295 * API
T_g = 985.62 - 13.597 * API
A coeff = -0.572 - (0.016* T_g) + (0.045* T_0)
B coeff = 7.288 - (0.008* T_g) + (0.024* T_0)

Table 3 lists the oil distillation parameters used in the model simulations for both Cohasset oils. The values listed for the Adios oil were calculated using the formulas above, data for the Environment Canada oil were calculated using distillation data from the Cohasset Crude specification.

Table 3. Oil distillation data used by OILMAP for the Adios and Environment Canada Cohasset oils.

Parameter	Adios Cohasset Oil	E.C. Cohasset Oil
T_0	384.33	453.75
T_g	339.76	196.91
A coefficient	11.29	13.91
B coefficient	13.79	15.51

Emulsification and Entrainment

Surface oil is entrained by breaking waves, and in the OILMAP model, breaking waves will occur if the wind speed exceeds 10 knots, so one would expect to see oil entrainment in the simulations performed here. In the OILMAP formulation for entrainment developed by Delvigne and Sweeney (1988), oils with higher viscosity entrain at lower rates than low viscosity oils.

Emulsification increases oil viscosity significantly so it can significantly slow the rate of entrainment. The OILMAP model uses a value for the maximum allowable water content specified in the oil database that sets an upper limit on oil emulsification. Oils with 0% water content specified will not emulsify, while oils with >0% water content will emulsify up to the specified limit.

The increase in the amount of oil entrained in the water column as wind speed increases is due to the increased energy that is transferred from the wind to the water surface causing the formation of breaking waves. As oil on the sea surface is exposed to wind and waves, it is entrained or dispersed into the water column (Figure 1). Entrainment incorporates small particles of oil into the water where they further break down and dissolve or disperse, or rise back to the surface. Entrainment is strongly dependent on turbulence and is greater in areas of high wave energy. Because all of the spills simulated here are instantaneous releases and because the wind used is constant, once oil is entrained, all but a very small fraction remains in the water column for the entire time in the simulation. Under changing wind conditions where wind speed drops below 10 knots the entrained oil could rise to the surface and form a slick.

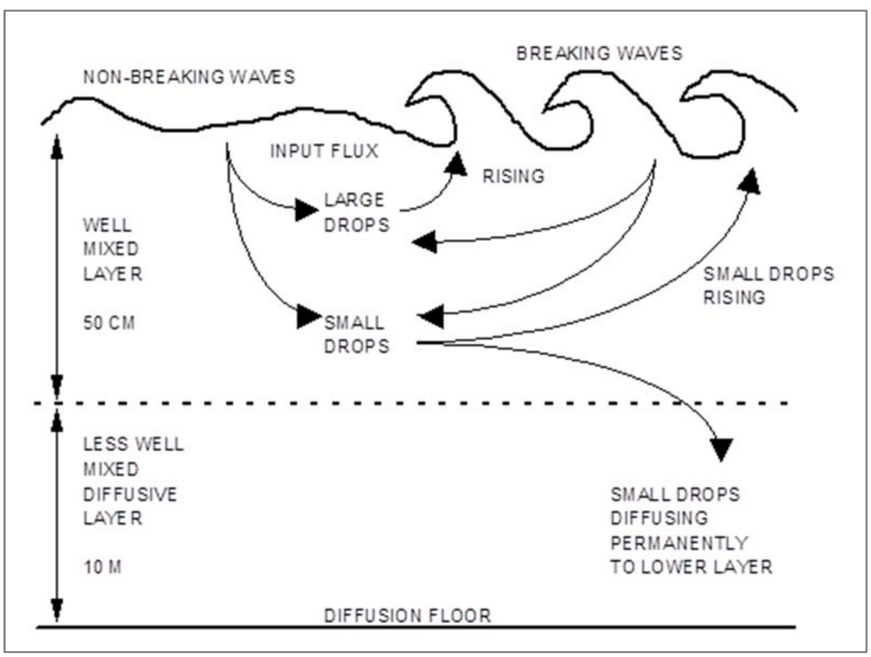


Figure 1. Schematic diagram if the oil entrainment process (Mackay, et al., 1980).

The Cohasset oil specification in the Adios database does not include a value for the maximum allowable water content. In the OILMAP model if the maximum water content is not specified a default value of 0.74 is used for crude oils and the oil is allowed to emulsify to this limit. A value of 0.74 is typical for a wide range of crude oils but Cohasset is at the very light end and this value is not really appropriate. The spill simulations of the Adios Cohasset presented here used the default maximum water content value of 0.74, but for purposes of comparison, additional simulations were run with a maximum water content of 0% assuming that the Cohasset oil does not emulsify. This is a reasonable assumption as the Environment Canada data indicate that the Cohasset Crude has a zero emulsion formation tendency up to 25.6 percent volume evaporation.

Model Results

The oil mass balance results from the model simulations are presented in graphs in Figures 2 through 6. Each page contains plots of oil mass balance from each wind speed for the entire 30 day period. It is not necessary to look at mass balance beyond about 200 hours under most wind speeds because the values for surface, evaporated and entrained oil are unchanged beyond this time. Table 4 lists the Figures containing the oil mass balance results.

Table 4. List of model output.

Figure	Spill Volume (liters)	Oil Type	Wind
2	10,000	Cohasset Adios (unmodified)	Wind = 10, 12, 15 and 20kts
3	10,000	Cohasset Adios (unmodified)	Wind = 15kts
4	10,000	Cohasset Adios (max water content = 0)	Wind = 10, 12, 15 and 20kts
5	10,000	Cohasset E.C.	Wind = 10, 12, 15 and 20kts
6	1,000	Diesel Fuel	Wind = 10, 12, 15 and 20kts

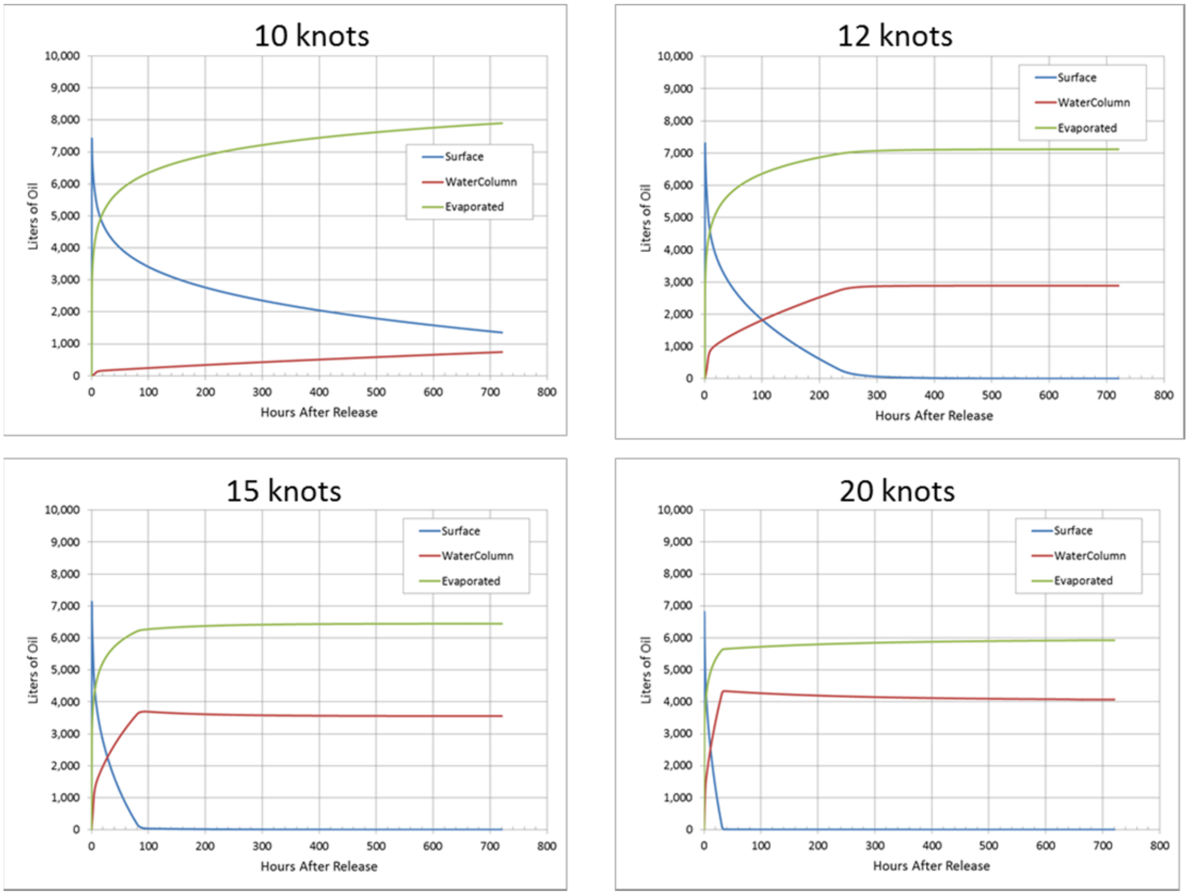


Figure 2. Oil mass balance for 30 days under 4 constant wind speeds using the unmodified Cohasset Crude specification from the Adios oil database. These results include emulsification up to a 74%.

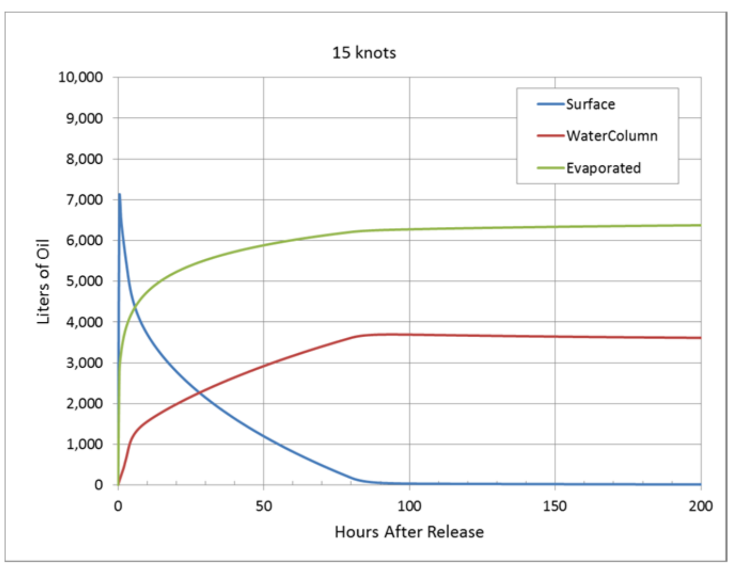


Figure 3. Oil mass balance for 200 hours under 15 knot constant wind using the unmodified Cohasset Crude specification from the Adios oil database. These results include emulsification up to a 74%.

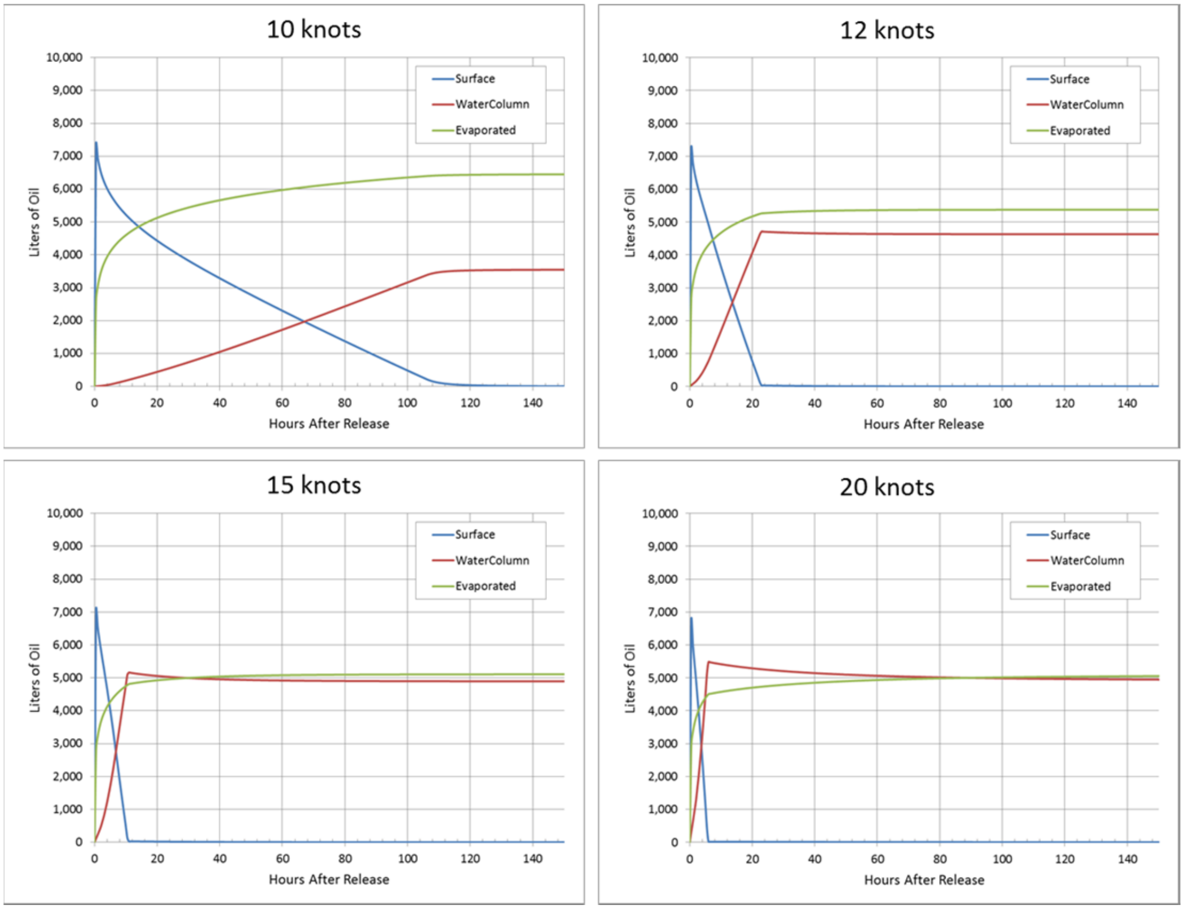


Figure 4. Oil mass balance for 30 days under 4 constant wind speeds using Cohasset Crude specification from the Adios oil database with maximum water content set to zero.

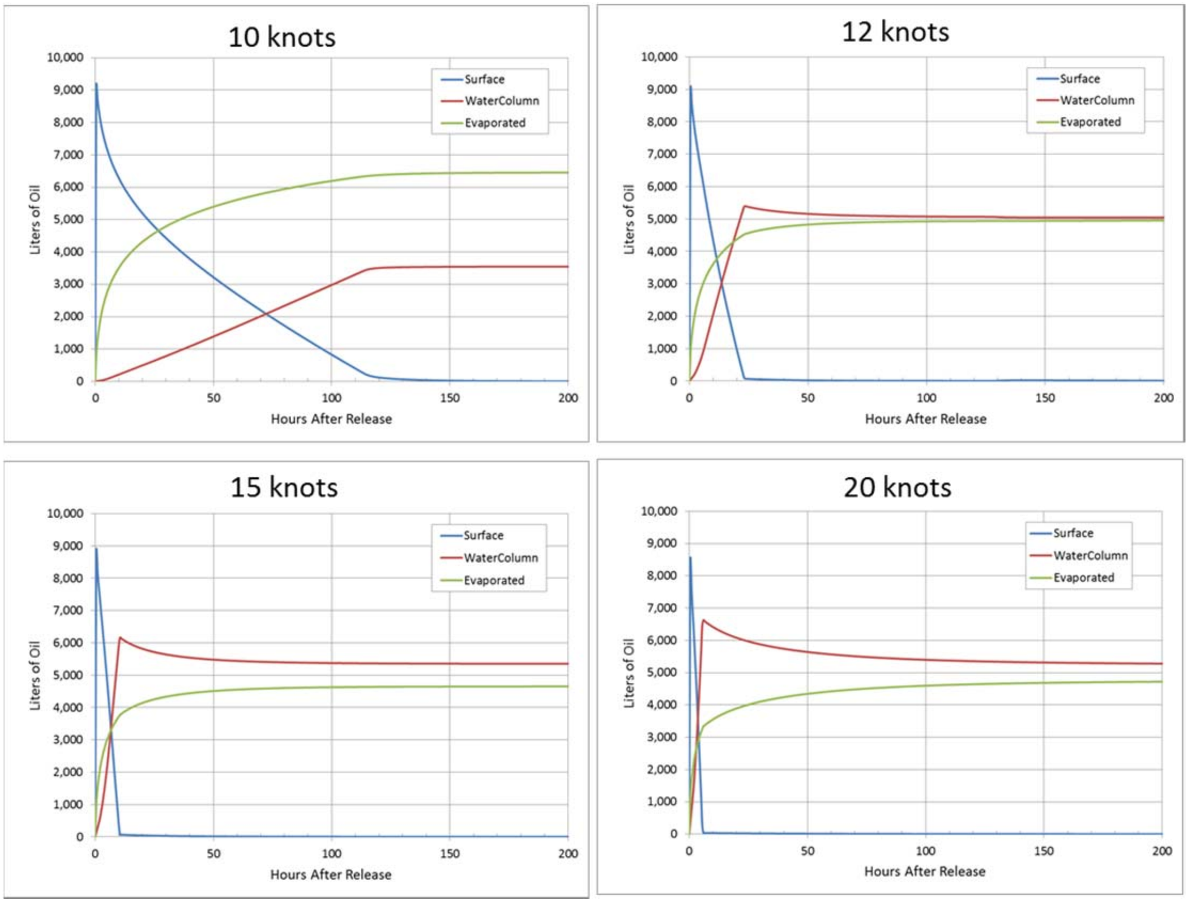


Figure 5. Oil mass balance for 30 days under 4 constant wind speeds using the Cohasset Crude specification provided by Environment Canada.

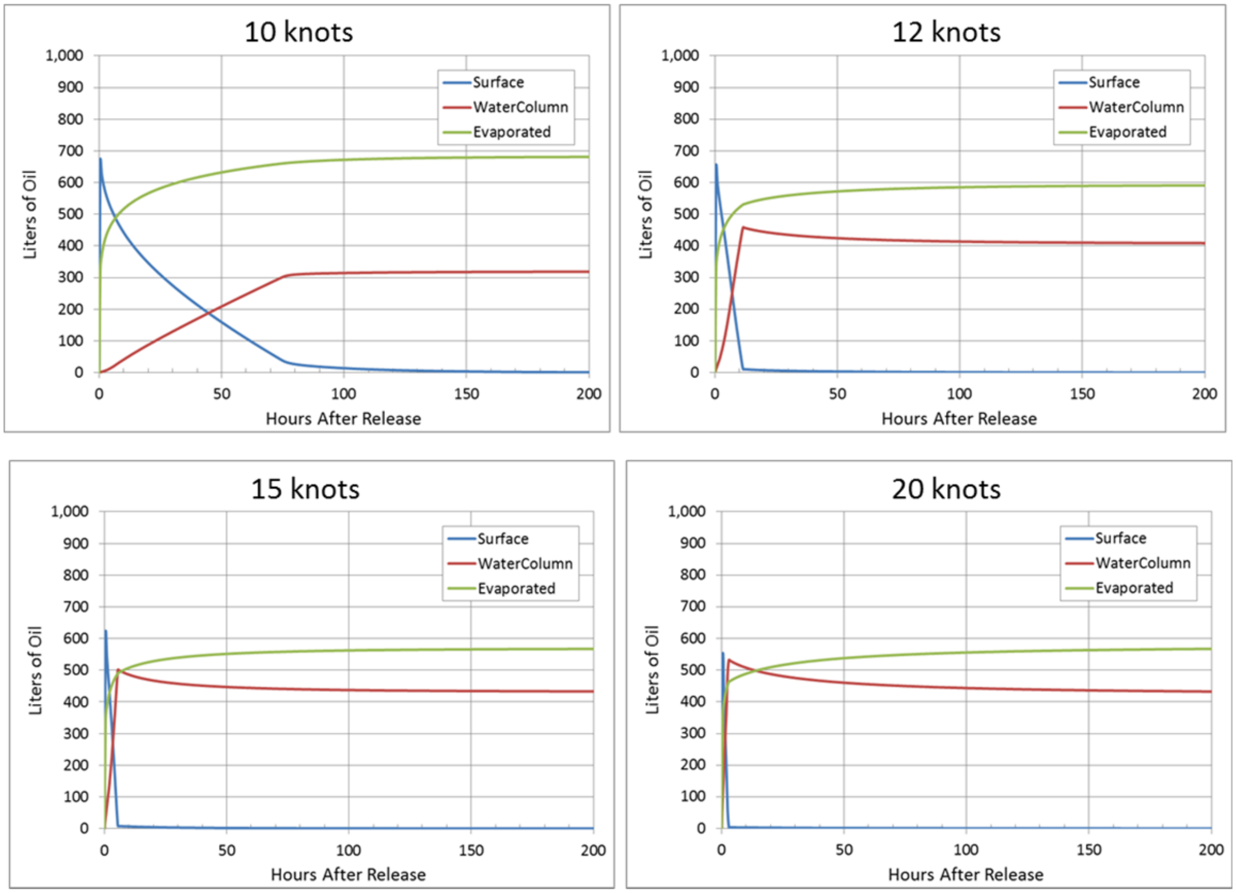


Figure 6. Oil mass balance for 30 days under 4 constant wind speeds using a Diesel fuel specification.

Summary

Simulations of instantaneous releases were performed using three different specifications of Cohasset Crude and one diesel fuel under 4 constant wind speeds:

1. Cohasset from Adios (unaltered)
2. Cohasset from Adios (assuming no emulsification)
3. Cohasset from Environment Canada
4. Diesel fuel

The quantities of oil entrained in the water column and left on the water surface for all Cohasset oils are what one would expect for light crude oils under these environmental conditions. The different oil properties of the Environment Canada Cohasset Crude and the Adios Cohasset Crude account for the differences seen in the oil mass balance predicted by OILMAP.

The difference in oil evaporation rate between the Environment Canada Cohasset oil specification and the Adios Cohasset oil specification is due to the different distillation data for each oil. The Adios database does not contain distillation data so it is calculated by the OILMAP model. This results in different evaporation rates for these different oil specifications.

The difference in oil entrainment between the Environment Canada Cohasset oil specification and the Adios Cohasset oil specification is due to emulsification of the oil as it weathers and the subsequent increase in viscosity. The Adios oil database does not include water content data for Cohasset Crude so the OILMAP model uses a default value of 0.74 which results in a significant reduction of entrainment and prolonged surface oil transport. Model results using the Adios Cohasset oil with the maximum water content set equal to zero show remarkably good agreement with the results using the Environment Canada Cohasset Crude. The data from the Environment Canada database indicate that Cohasset does not emulsify.

The time required for surface oil to go below 1% of the total spill volume under a 15 knot wind:

Oil Type	**Hours to < 1% Surface Oil**	
Adios Cohasset	84	Assumes maximum water content up to 74%
Adios Cohasset (assuming no emulsification)	11	Assumes 0% water content
Environment Canada Cohasset	10.5	
Diesel	5.5	

References

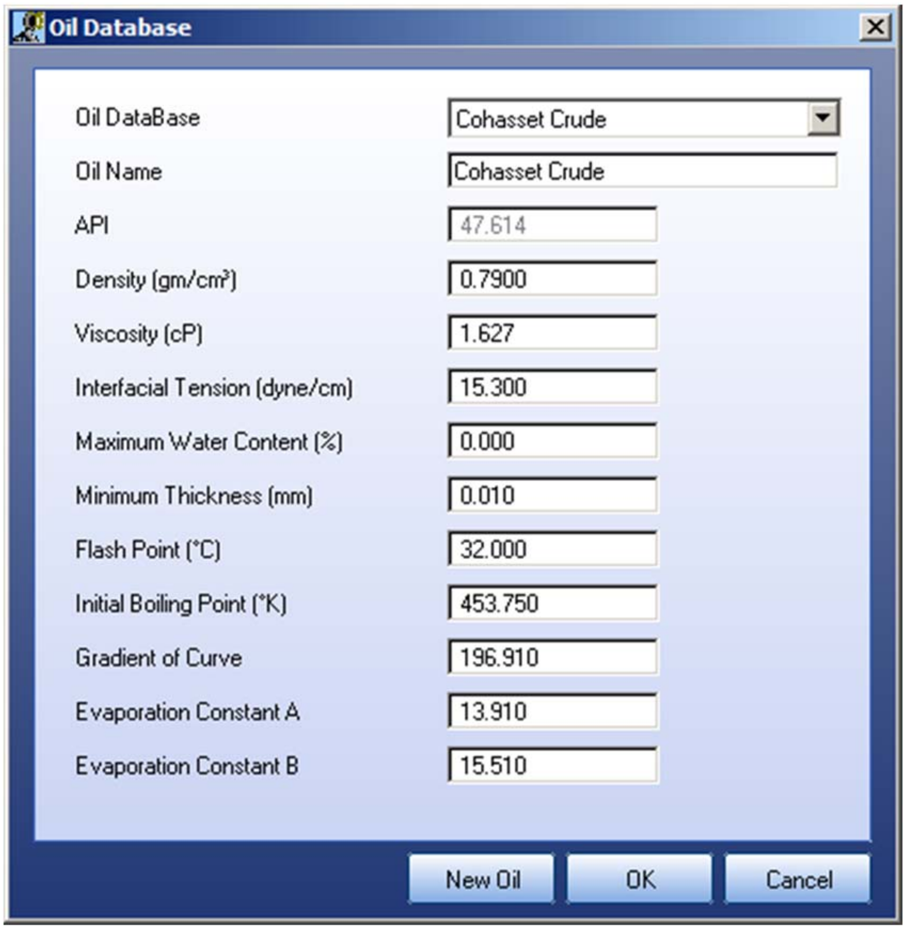
Delvigne, G.A.L. and C.E. Sweeney, 1988. Natural dispersion of oil. Oil and Chemical Pollution, 4:281-310.

Mackay, D., S. Paterson and K. Trudel, 1980a. A mathematical model of oil spill behavior. Department of Chemical and Applied Chemistry, University of Toronto, Canada.

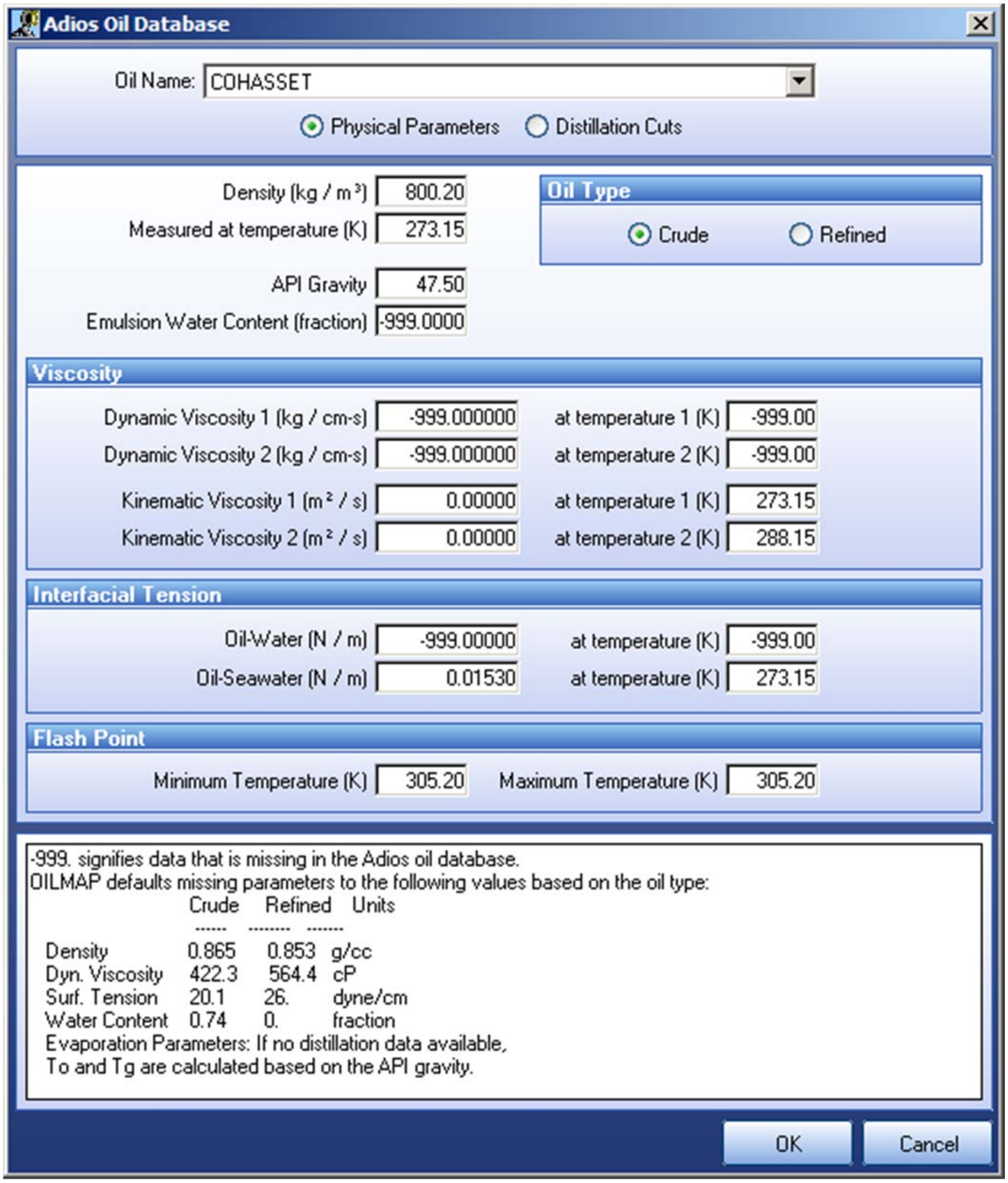
Stiver, W. and D. Mackay, 1984. Evaporation rate of spills of hydrocarbons and petroleum mixtures. Environmental Science and Technology, 18:834-840.

Appendix – Oil Specifications

Cohasset Crude properties defined using Environment Canada database



Cohasset Crude properties defined in Adios oil database



Diesel Fuel oil properties