MONTARA WELL RELEASE

MONITORING STUDY S7.2

OIL FATE AND EFFECTS ASSESSMENT: MODELLING OF CHEMICAL DISPERSANT OPERATION

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EXECUTIVE SUMMARY

This document is a final report of Study S7.2 carried out in order to gain an understanding of the potential concentrations of dispersed oil in water which occurred in the Timor Sea as a result of chemical dispersant spraying operations during the spill response to the loss of well control at Montara throughout the later part of 2009.

The concentrations of dispersed oil are represented as hydrocarbon concentration in parts per million (ppm) and parts per billion (ppb) and are based on 50% and 100% dispersant effectiveness in order to provide a typical and upper bound on the in-water hydrocarbon concentrations following a chemical dispersant event.

Eleven dispersant events were simulated using three dimensional (3D) modelling. The eleven dispersant scenarios were selected on the basis of:

- those scenarios that would have the maximum area “impact zone”,
- their location (it was important to select dispersant events in different locations and directions around the Montara WHP including those closest to surrounding shoals), and;
- the amount of dispersant applied.

Of these eleven dispersant events, three events indicated some potential to reach some of the underwater shoals that exist in the Timor Sea, if mixing conditions were at the lower range of what is possible for the Timor Sea and dispersant efficiency was at a maximum of 100%. Thus, hypothetically, the modelling indicated very low level hydrocarbon concentrations might have been possible under these worst-case assumptions as follows:

- Two dispersant events resulted in a dispersed oil plume that potentially passed over Barracouta Shoal and;
- One dispersant event resulted in a dispersed oil plume that potentially passed over Goeree Shoal

Table 1 shows the model indicated concentration of hydrocarbons at the depth of the Shoal

Table 1: Hydrocarbon exposure to shoals

Location	Dispersant application date	Date and time of pass over shoal	Duration of pass over shoal	Maximum Hydrocarbon Concentration of pass (ppm)
Barracouta Shoal	01/09/2009	08/09/2009 02:00 am	2 hrs	0.001
		08/09/2009 08:00 pm	16 hrs	0.048
		09/09/2009 06:00 pm	6 hrs	0.025
Barracouta Shoal	02/09/2009	07/09/2009 10:00 pm	2 hrs	0.015
		08/09/2009 06:00 am	14 hrs	0.099
Goeree Shoal	17/09/2009	21/09/2009 12:00am	12 hrs	0.024

In summary, the 3D modelling indicated that the maximum concentration of hydrocarbons in the water column at any depth at any time following the dispersant events studied was 3.48ppm. This concentration was reached immediately after the dispersant event on the 1st October 2009 and was concentrated within the first metre of the water column.

The modeling indicated that the effect of the addition of the chemical dispersant to the oil spill of the Montara WHP caused an elevation of hydrocarbon concentrations in the water column that was extremely localized and of short duration.

1 INTRODUCTION

PTTEP Australasia (Ashmore Cartier) Pty Ltd (hereafter PTTEPAA) is the operator of the Montara oil field, located in the Timor Sea, approximately 200 km offshore from the Australian mainland (see Figure 1). Table 2 details the location of the Montara Well Head Platform (WHP).

The Montara WHP is located within a Commonwealth marine area as specified by the EPBC Act (1999). A number of small sub tidal sea mounts or pinnacles occur nearby. The nearest tidally exposed islands and reefs occur some 90 km to the west at Cartier Island, Ashmore Reef and Hibernia Reef. Cartier Island Marine Reserve and Ashmore Reef National Nature Reserve are both part of the National Representative System of Marine Protected Areas (NRSMPA) as defined by Environment Australia 2007.

The nearest sea mount[1] is Vulcan Shoal located 30 km to the south west of the Montara WHP. Other nearby sea mounts includes Goeree, Barracouta and Eugene McDermott Shoals.

On the 21st August 2009, Montara reservoir fluids and gases were accidently released from the Montara WHP (Figure 1) due to the accidental loss of control of the H1 well. As a result, crude oil was released to the environment as part of the uncontrolled flow. Liquids were released above the water surface at temperatures expected to exceed 80 degrees Celsius. At these temperatures it is estimated that condensates were gaseous and that liquid impacted the sea surface without its expected condensate composition, essentially as a pre-weather crude oil. The persistent components of the crude oil then fell to the ocean surface from the structures on site mostly via storm water drains without many of the lighter volatile hydrocarbons.

Over flight observations of the slick which developed on the water's surface within the first 24 hours indicated that the spill rate of the crude oil component of the uncontrolled release was initially 400 bbls per day (64,000L) as a 'worst-case' estimate.

The crude oil continued to be released for 72 days, until the well was brought under control on the 3rd November 2009.

The response to the spill was undertaken under the direction of the Australian Maritime Safety Authority (AMSA) and included both containment and recovery and dispersant application strategies. The spill response commenced on the morning of the 21st August, 2009 and was focussed around the Montara Well Head Platform in deep open waters.

Daily over flight observations, computer simulations (modelling) of slick trajectories and the use of satellite images were also undertaken by AMSA for planning and operational monitoring purposes throughout the incident. The surveillance and modelling indicated that surface oil was not detectable in the Timor Sea after the 15th November 2009.

During the response operations a number of monitoring activities were undertaken including the use of fluorometric equipment to monitor the dispersant operations by measuring the amount of fluorescence in the water column (AMSA 2009).

The AMSA (2009) report found no direct correlation between fluorometric data and hydrocarbons in the water. As such, it recommends that "for environmental effects assessment purposes, the distribution and concentration of dispersed oil should be modelled using available 3D models. Water quality data from study O.2.1 and if possible Study 04, should be used to check ("benchmark") model output." (AMSA 2009) Water quality data from these studies (sample analysis) has been used for comparison with the modelling output.

This document summarises the results of the dispersed oil modelling after the 11 most significant dispersant events (in terms of the location and amount of dispersant used). It will highlight the direction of the dispersed oil, the concentration of hydrocarbons in the water column and the potential impact to shoals (if any). When a shoal is contacted with any hydrocarbons the duration of that contact and the concentration modelled at that particular shoal is described. As much as possible, the results of the modelling will be correlated to the post-incident AMSA report entitled "Report 03 Dispersant Treated Oil Distribution" (AMSA 2009).

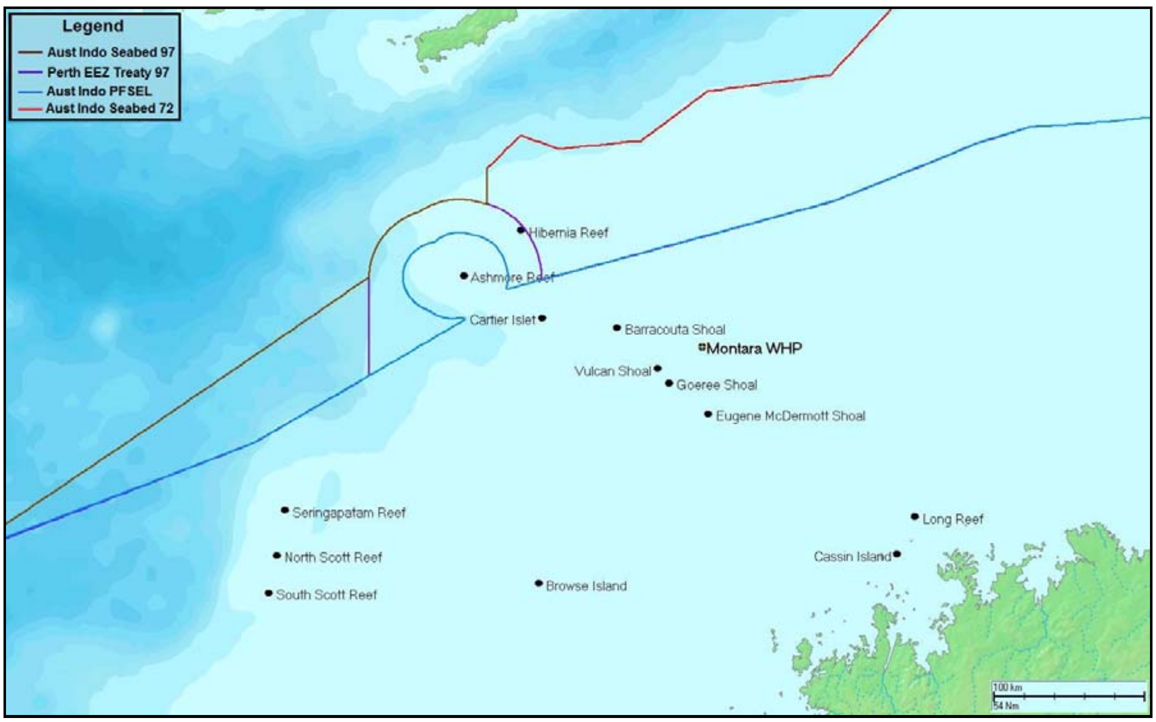

Figure 1: Map showing location of the Montara Well Head Platform (WHP), Timor Sea.

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[1] A sea mount is an underwater mountain rising above the ocean floor that does not reach the water surface and is thus not an island.

Table 2: Location of the Montara Well Head Platform.

Location	Latitude (South)	Longitude (East)	Water Depth (m)
Well Head Platform (Montara)	12° 40' 20.5"	124° 32' 22.3"	80 m

2 SCOPE OF WORK

The purpose of this study was to determine the concentration and movement of submerged oil in the Timor Sea after significant chemical dispersant application events (assuming 50% to 100% dispersant effectiveness) to quantify possible environmental exposure to surrounding habitats (such as submerged shoals surrounding the Montara WHP). The output included a time series of total in-water hydrocarbon concentrations, peak water column concentrations and how these dilute over time assuming low mixing conditions. The purposes of this study is to identify potential study sites and control sites for further monitoring if deemed appropriate.

3 METHODS

3.1 Overview of tides and winds

The modelling of dispersed oil plume for this study was undertaken using the Applied Science Associates Spill Impact Modelling System (SIMAP) software, which has been adopted under the US Natural Resource Damage Assessment methodology (NRDA) (see Appendix A).

The metocean datasets used for the hindcast simulation of the dispersant event are detailed in below and Appendix B.

In summary, SIMAP dispersed oil plume trajectories were undertaken using all combinations of available reanalysed metocean datasets, being NCOM+Tides, Oceanmaps+Tides (BLUElink), GLSA+Tides. Reanalysed winds from the National Oceanographic and Atmospheric Administration (NOAA) Global Forecast System (GFS) data provided the spatially varying wind fields for the duration of the event. These datasets were used, since the forecast version of NCOM, BLUElink and GFS was used throughout the response of the Montara Incident and were found to account for a significant amount of the observed drifts in the Timor Sea. GLSA is a hindcast dataset only. Spill model results using all datasets were examined to determine how well they agreed with each other. They were also then compared with over flight, satellite and ship observational data and a level of confidence was established for each dataset for each day of the incident.

Over flight data and ship positional data in GIS format was supplied by AMSA. This observational data included locations of highly weathered oil patches and solid wax rafts as well as fresh oil locations adjacent to the Montara WHP. Self Locating Datum Buoys (drifter

buoys) were also deployed by the response team on occasions throughout the response to independently check the current and wind data as additional quality control measures.

In summary, after extensive validation studies it was concluded that GFS winds were to be used throughout the SIMAP dispersed oil modelling and that GSLA +Tides was the most accurate current model between the 21st August 2009 and the 31st August 2009, after which it was found that Oceanmap+Tides (BLUElink) current model was most accurate. Appendix B provides a more in-depth description of the tidal and wind models used.

3.2 Model Inputs

AMSA Report 02.03 states that "in the absence of laboratory assessment of dispersant efficiencies of different dispersants under varying conditions and applied to varying oil weathering states … modelling should assume the "worst case" conditions for water column effects (i.e. 100% effectiveness)". As such, the SIMAP modelling has modelled both 50% dispersant effectiveness (most realistic scenario) and 100% dispersant effectiveness (hypothetical worst-case scenario) in order to provide bounds on the range of possible hydrocarbon concentrations predicted in the water column.

3.3 Dispersant Simulations

The amount of chemical dispersant that was appiled was obtained from AMSA data (Table 3). The amount of oil to be dispersed by one litre of dispersant was calculated at a ratio of 1:20 (1L of dispersant to 20L of oil dispersed as per manufacturers recommended dosage rates). As a consequence of this ratio, it is also possible to calculate the in water concentrations of the dispersant, being 1/20 of the concentration of hydrocarbon indicated by the mode at any given time.

The eleven dispersant events selected for this study encompass a range of locations and directions around the Montara WHP including outliers and high volume dispersant applications in order to get a range of distributions and concentrations that were representative of all the dispersant applications that occurred during the oil spill response.

The approximate area of where the dispersant was applied per day was extrapolated and determined from an AMSA figure (refer to Figure 2). The model was run using one and two days of oil release before the dispersant application[2].

The 100% dispersant efficiency indicates that depending on the volume of chemical dispersant used, all oil within the dispersant application area was dispersed (assuming enough dispersant was used on a 1:20 ratio). The 50% dispersant efficiency indicates that within the dispersant application area 50% of the oil was dispersed into the water column. This does mean that vast amounts of oil are still on the water surface (having not been dispersed) as no dispersant application would be able to reach all the oil.

[2] In the instances that a shoal was contacted the amount of oil released prior to the dispersant event was increased to 2 days worth. This was done in order to obtain a worst-case scenario of oil entering the water column (i.e. there was more oil available to disperse).

Table 3: Volume of dispersant used (L) on each day of the response operation. Dates highlighted in pink were selected for this study. (Source: AMSA)

Date	Volume of Dispersant (L) applied
23/08/2009	3300
24/08/2009	9000
25/08/2009	4000
26/08/2009	4000
27/08/2009	3600
28/08/2009	0
29/08/2009	4000
30/08/2009	4000
31/08/2009	0
1/09/2009	8000
2/09/2009	12120
3/09/2009	2000
4/09/2009	500
5/09/2009	0
6/09/2009	0
7/09/2009	0
8/09/2009	0
9/09/2009	600
10/09/2009	0
11/09/2009	2400
12/09/2009	2500
13/09/2009	500
14/09/2009	1800
15/09/2009	1000
16/09/2009	0
17/09/2009	8000
18/09/2009	1500
19/09/2009	3400
20/09/2009	1000
21/09/2009	1500
22/09/2009	0
23/09/2009	2500
24/09/2009	5500
25/09/2009	2400
26/09/2009	2800
27/09/2009	3300
28/09/2009	3250
29/09/2009	2000

Date	Volume of Dispersant (L) applied
30/09/2009	0
1/10/2009	7250
2/10/2009	0
3/10/2009	2000
4/10/2009	100
5/10/2009	1000
6/10/2009	4500
7/10/2009	3000
8/10/2009	5000
9/10/2009	3000
10/10/2009	4000
11/10/2009	1700
12/10/2009	1700
13/10/2009	600
14/10/2009	0
15/10/2009	2000
16/10/2009	1000
17/10/2009	0
18/10/2009	0
19/10/2009	3000
20/10/2009	3500
21/10/2009	0
22/10/2009	3000
23/10/2009	0
24/10/2009	1000
25/10/2009	0
26/10/2009	0
27/10/2009	1100
28/10/2009	0
29/10/2009	0
30/10/2009	0
31/10/2009	0
1/11/2009	600
2/11/2009	0
3/11/2009	0
4/11/2009	0

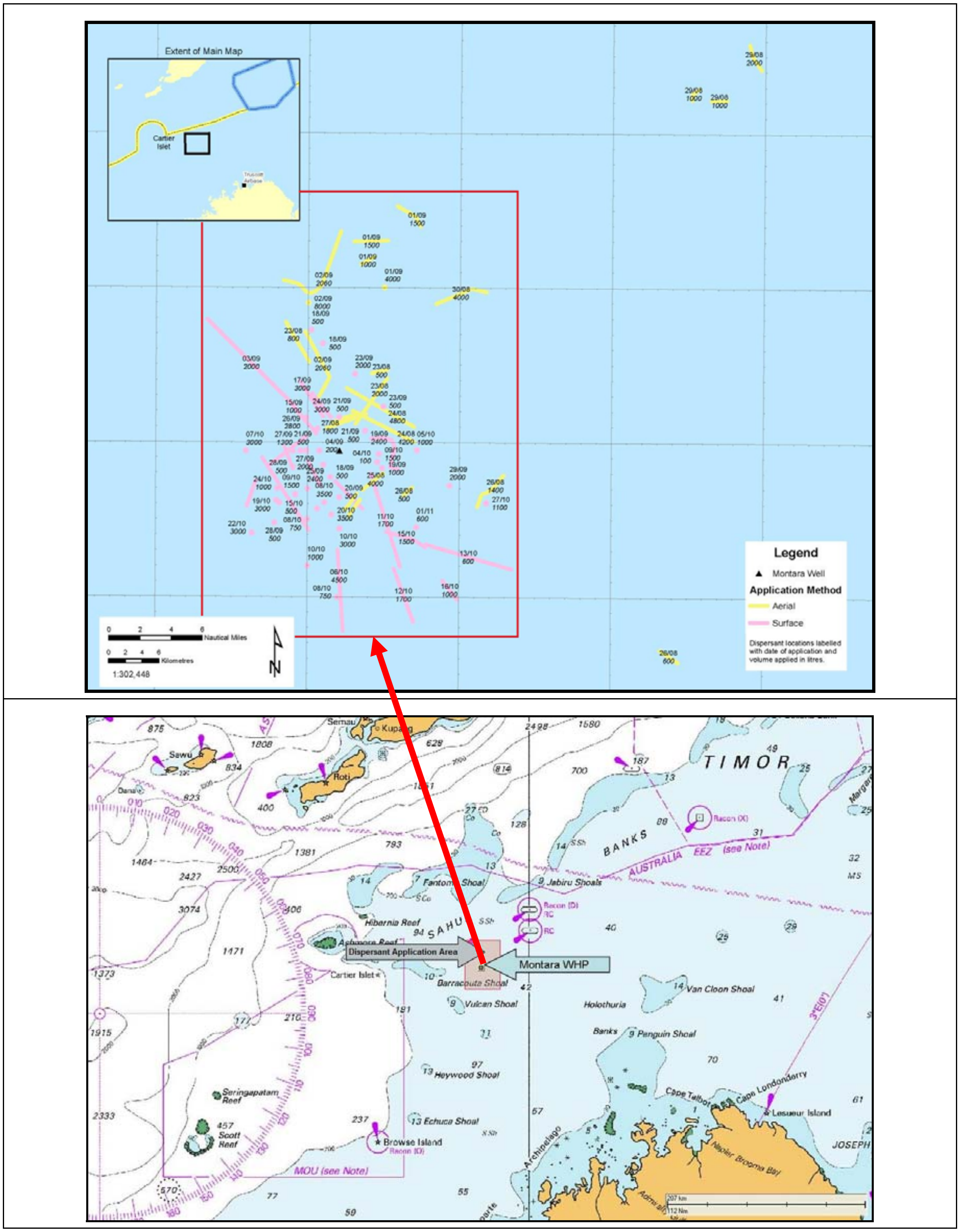


Figure 2: Location and extents of dispersant operations (dispersant application area) and the location of the Montara WHP.

4 RESULTS

In total, eleven dispersant events were selected for modelling based on the total amount of dispersant volume applied and the location of that application.

The tables which follow (Table 4 and Table 5) show;

- Concentration in parts per million (ppm) of hydrocarbons anywhere in the water column at 4 days after dispersant event
- Concentration (ppm) of hydrocarbons anywhere in the water column at 9 days after dispersant event
- 96 hour average modelled hydrocarbon concentrations (ppm) after dispersant event, and,
- Maximum concentration of hydrocarbons (ppm) in the water column after the dispersant event.

Hydrocarbon concentrations in the water column for the realistic scenarios (50% dispersant effectiveness) due to the eleven dispersant events ranged from maximum in-water elevations of 0.46 ppm to 2.93 ppm, and average 96hour concentrations between 0.16 ppm to 0.56 ppm (refer to Table 4).

Hydrocarbon concentrations in the water column for worst case scenarios (assuming 100% dispersant effectiveness) due to these eleven dispersant events ranged from maximum in-water elevations of 0.98 ppm to 3.48 ppm, and average 96 hour concentrations of 0.37 ppm to 0.90 ppm (refer to Table 5).

The concentration of hydrocarbons in the water drops rapidly due to natural dilution, falling below 0.17 ppm (for 50% dispersant effectiveness, refer to Table 4) or 0.31 ppm (for 100% dispersant effectiveness, refer to Table 5) within 4 days of all the dispersant events studied.

After nine days, the concentration of hydrocarbons in the water column approaches concentrations of 0.08 ppm and below in all of the dispersant events studied (refer to Table 4 and Table 5) even when assuming low mixing conditions prevailed over this length of time.

The modelling also indicated that in some cases (i.e. 1st September 2009, 24th September 2009 and 8th October 2009), a natural dispersion event, such as high winds (> 10 knots) could cause the entrainment of non-chemically treated surface oil into the water column. This often caused the concentrations of hydrocarbons in the water column to rise above the levels caused by the chemical dispersion event alone. These short term concentrations were formed near the surface following a moderate wind. These natural dispersion events were outside of the scope of this study.

Out of the eleven representative chemical dispersant events selected for this study, two of the dispersed oil plumes make contact at depth with Barracouta Shoal and one event made contact with Goeree Shoal, all at low concentrations and for short-periods of time due to tidal oscillations. These three dispersant events were investigated in detail and the comprehensive plume modelling outputs for each of the dispersant events follow.

Table 4: Realistic scenario - 50% dispersant effectiveness (all numbers in ppm)

Date	Concentration after 4 days	Concentration after 9 days	96 hr Average Concentration	Maximum Concentration
24 August 2009	0.17	0.05	0.50	1.66
25 August 2009	0.15	0.05	0.45	1.16
30 August 2009	0.14	0.04	0.54	1.53
01 September 2009	*0.03*	*0.04**	*0.16*	*0.78*
02 September 2009	*0.08*	*0.05*	*0.33*	*1.1*
17 September 2009	*0.12*	*0.11*[#]	*0.23*	*0.46*
24 September 2009	0.03	0.12*	0.19	1.03
01 October 2009	0.17	0.06	0.56	1.72
06 October 2009	0.10	0.06	0.54	2.93
08 October 2009	0.14	0.3*	0.28	1.18
10 October 2009	0.17	0.06	0.55	1.56

Table 5: Worst case scenario - 100% dispersant effectiveness (all numbers in ppm)

Date	Concentration after 4 days	Concentration after 9 days	96 hr Average Concentration	Maximum Concentration
24 August 2009	0.16	0.05	0.57	2.28
25 August 2009	0.27	0.06	0.71	2.32
30 August 2009	0.14	0.06	0.53	2.70
01 September 2009	*0.09*	*0.06**	*0.37*	*1.62*
02 September 2009	*0.15*	*0.08*	*0.59*	*2.01*
17 September 2009	*0.31*	*0.26*[#]	*0.53*	*0.98*
24 September 2009	0.04	0.07*	0.37	2.07
01 October 2009	0.21	0.08	0.77	3.48
06 October 2009	0.20	0.06	0.63	2.96
08 October 2009	0.14	0.53*	0.37	1.26
10 October 2009	0.30	0.12	0.90	1.71

* Indicates that this concentration is attributed to a natural dispersion event (high winds >10 knots)

[#] Indicates that this scenario could only be run for 5 days after the dispersant event as high winds produced unrealistically high in water concentrations after 5 days, which is not indicative of the dispersion which would have occurred due to dispersant application alone.

Entries in Italics indicate that the dispersed oil made contact with an underwater shoal in that scenario.

Figure 3 below shows the distribution of all eleven SIMAP model runs for all spillets at all depths of water with nearby reefs and shoals indicated. Each colour represents a different SIMAP model run with the index of dates provided in the figure key.

The dark yellow/orange model run moving to the east (24th September 2009) extends approximately 90km from the spill site.

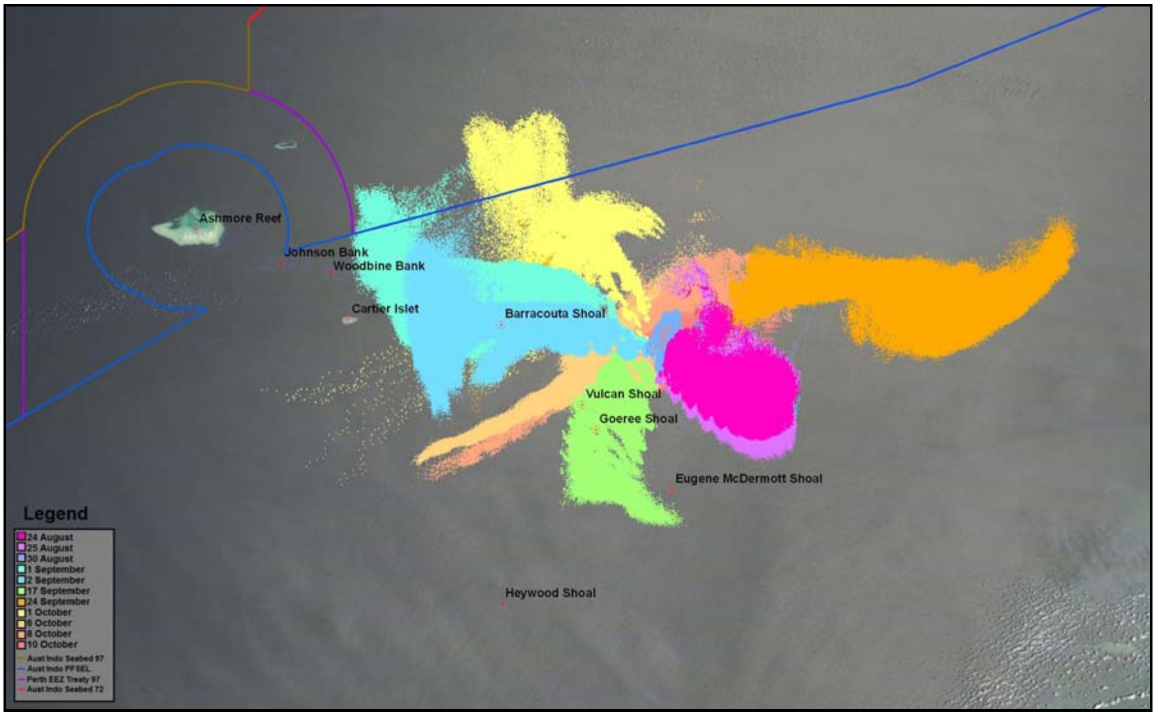


Figure 3: All eleven SIMAP scenarios showing all spillets at all depths - colour coded to each scenario date. Note that the coloured areas show the swept area of all spillets over the 10 day duration of each of the model scenario runs. The far field extents of these tracks indicate hydrocarbon concentrations down to less than 0.01 ppm (10 ppb).

The concentration of the modelled plume (using numerical spillets of hydrocarbon mass) reduces significantly with distance away from the spill site and depth (Figure 4). Figure 4 clearly indicates that there would have been no dispersed oil of any concentration at 100m depth.

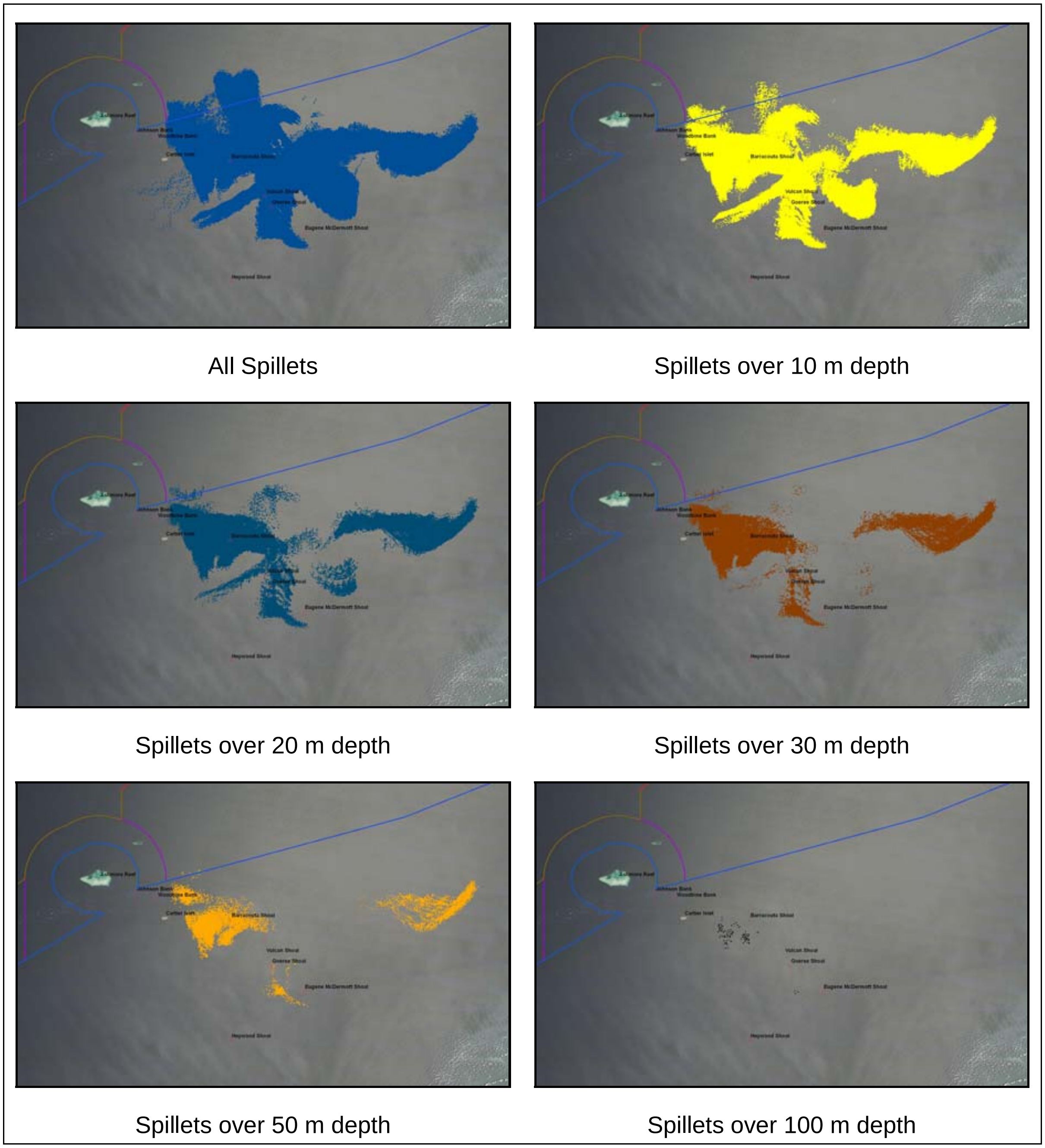


Figure 4: Model spillet distribution from all eleven model runs throughout the water column, shown as a function of depth. (Note how spillet footprint reduces as water depth increases)

Figure 5 provides a 3-D perspective of the combined spillets of all concentration for all 11 modelled simulations. Depths have been coloured to represent various intervals within the water column. The majority of the dispersed oil footprint is within the 0 to 25 metre depth.

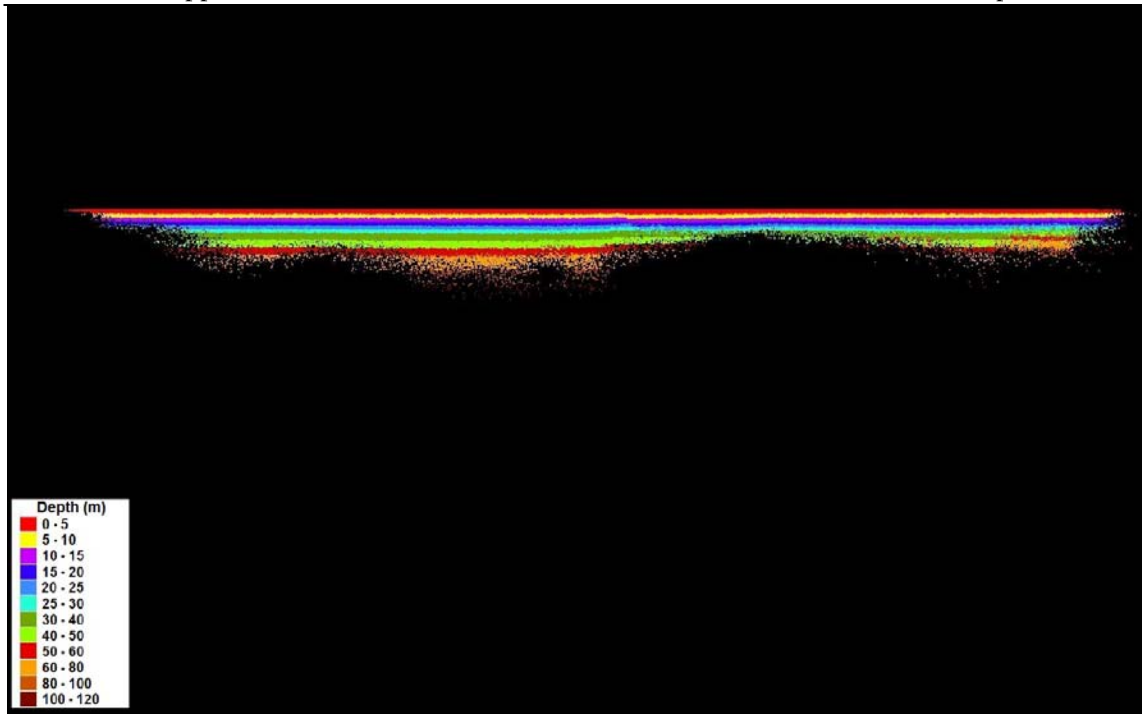


Figure 5: 3 Dimensional perspective of all modelled spillets (all scenarios) over a colour coded depth. Most of the dispersed oil spillets are concentrated in the first 25 metres of the water column. Note that the limits of the spill represent the maximum distance the spillets travelled over each 10 day scenario run.

<u>Barracouta Shoal</u>

On the two occasions where the modelling suggested that the oil plume moved over Barracouta Shoal (scenarios with dispersant application events on the 1st and 2nd September 2009), concentrations of hydrocarbons in the water column at any depth over the shoal reached a maximum of 0.048ppm and 0.099ppm respectively. These maximums were concentrated in the first metre of the water column thus did not make contact with the submerged shoal. In both these instances the duration of exposure was found to be less than 24 hours in any event due to tidal oscillations.

The concentrations also decreased significantly with depth. The model output indicated that the concentration of hydrocarbons at the depth of Barracouta Shoal was 0.001 ppm or 1 ppb (1st September 2009) and 0.003 ppm or 3 ppb (2nd September 2009) for less than 12 hours (See detailed model outputs in sections 4.4 and 4.5).

The persistence of subsurface hydrocarbons between 1 to 40 metre depth was relatively short-lived once contact was indicated and returned to levels of < 0.01 ppm or <10 ppb within 3 days. On the 1st and the 2nd of September the plume in layer 2 (between 1m and 40m) reached a distance of 52km and 70km (respectively) from the spill site before concentrations returned to zero.

Goeree Shoal

On the 17th September 2009 the model indicated that the dispersed oil plume moved towards Goeree Shoal causing an elevation in hydrocarbon concentration in the water column at any depth over the shoal of a maximum of 0.18 ppm (based on 100% dispersant effectiveness). This maximum concentration was found in the first metre depth of the water column and did not reached the depth of the shoal.

The concentration decreased significantly with depth. The model output indicated that the concentration of hydrocarbons at the depth of Goeree shoal was 0.010 ppm or 10 ppb for less than 18 hours duration.

4.1 Dispersant Event 24th August 2009

Table 6 shows a summary of the statistics for the dispersant event on the 24th August 2009. In this scenario the dispersed oil heads directly into an Easterly direction and does not make contact with any underwater shoals, as shown in Figure 7.

Table 6: Summary of results for dispersant event on the 24th August 2009

Parameter	50% dispersant effectiveness	100% dispersant effectiveness
Amount of dispersant used (L)	9000	
Current file used (validated)	GSLA	GSLA
Maximum concentration (ppm)	1.66	2.28
Average concentration over 96 hours after dispersant event (ppm)	0.50	0.57
Concentration of hydrocarbons 4 days after dispersant event (ppm)	0.17	0.16
Concentration of hydrocarbons 9 days after dispersant event (ppm)	0.05	0.05

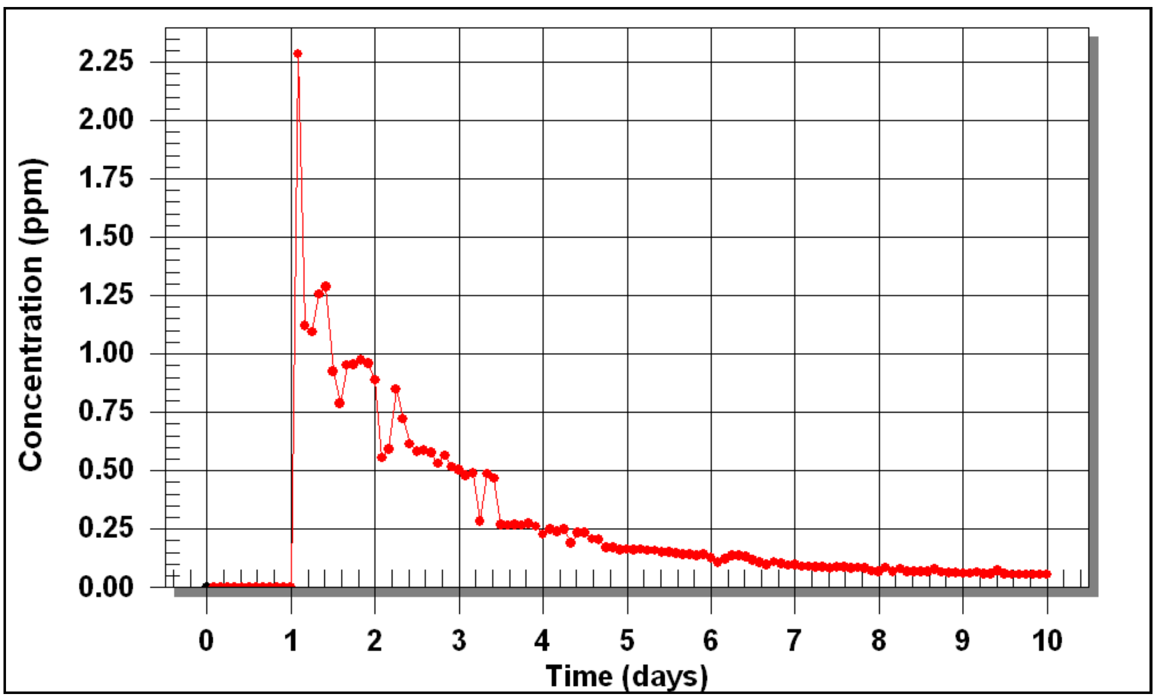
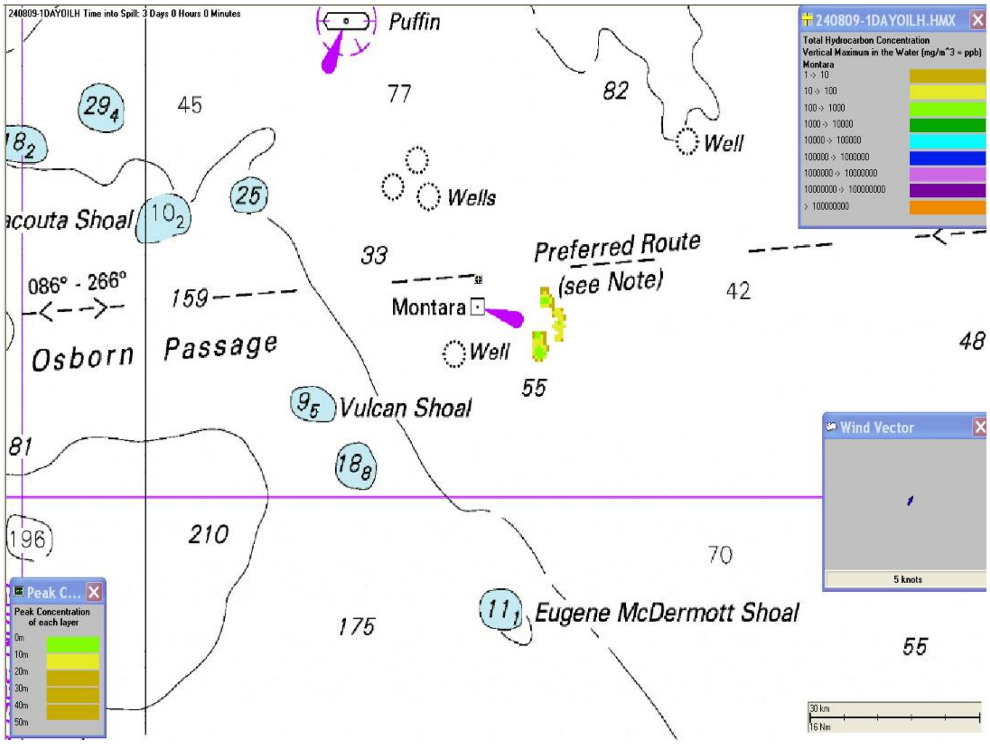
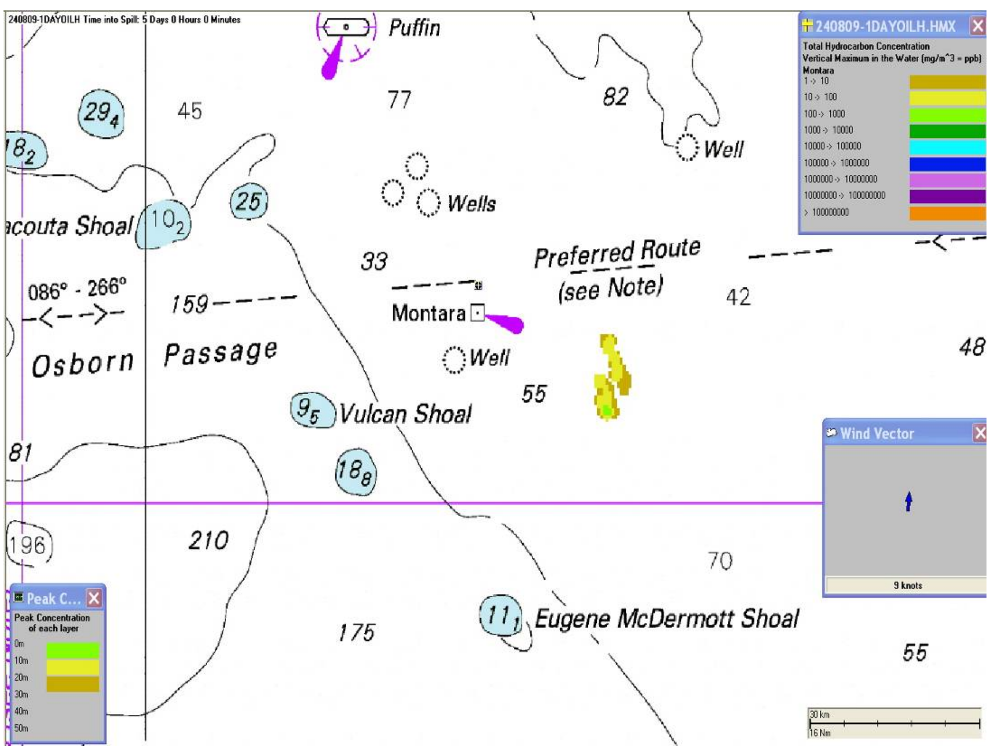


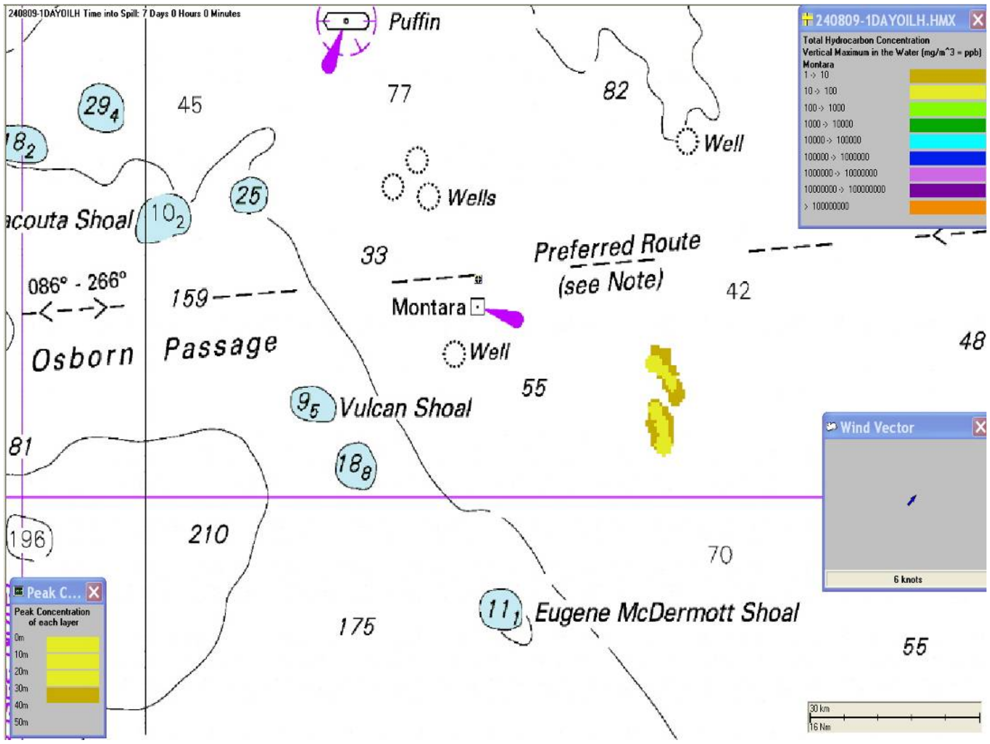
Figure 6: Maximum hydrocarbon concentration at any location, and at any depth within the model domain for the 100% dispersant effectiveness scenario, after a dispersant event on the 24th August 2009



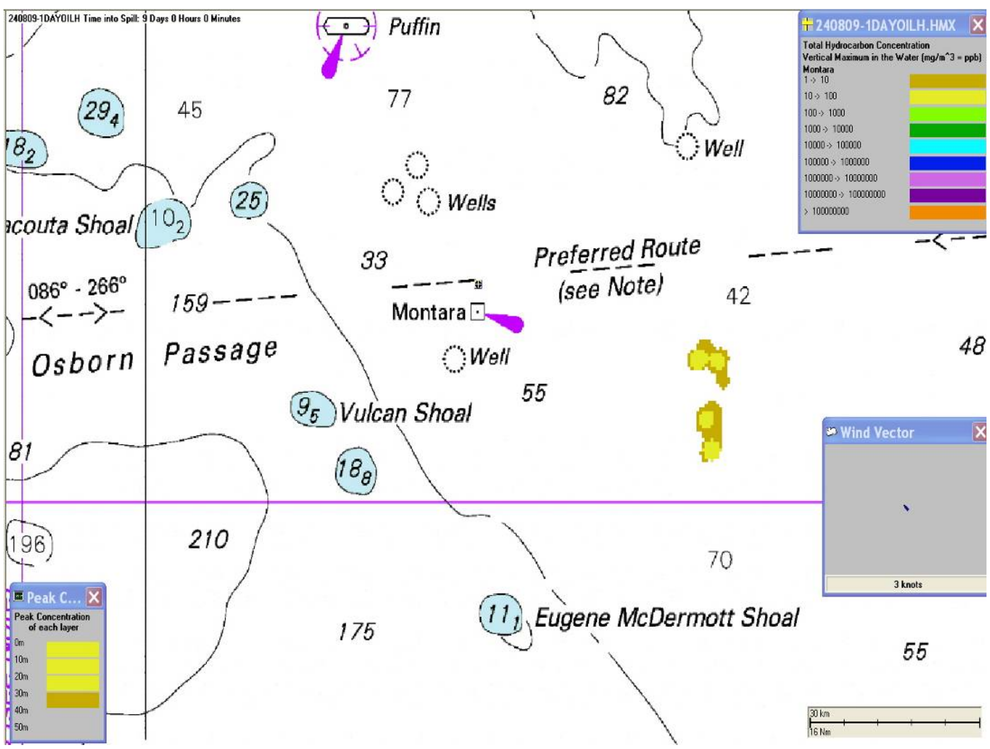
2 days after dispersant application (26/08/09)



4 days after dispersant application (28/08/09)



6 days after dispersant application (30/08/09)



8 days after dispersant application (01/09/09)

Figure 7: Movement and concentration of dispersed oil plume in the water column after a dispersant event on the 24th August 2009

4.2 Dispersant Event 25th August 2009

Table 7 shows a summary of the statistics for the dispersant event on the 25th of August 2009. In this scenario the dispersed oil heads directly in an East-South-Easterly direction and does not make contact with any underwater shoals, as shown in Figure 9.

Table 7: Summary of results for dispersant event on the 25th August 2009

Parameter	50% dispersant effectiveness	100% dispersant effectiveness
Amount of dispersant used (L)	4000	
Current file used (validated)	GSLA	GSLA
Maximum concentration (ppm)	1.16	2.32
Average concentration over 96 hours after dispersant event (ppm)	0.45	0.71
Concentration of hydrocarbons 4 days after dispersant event (ppm)	0.15	0.27
Concentration of hydrocarbons 9 days after dispersant event (ppm)	0.05	0.06

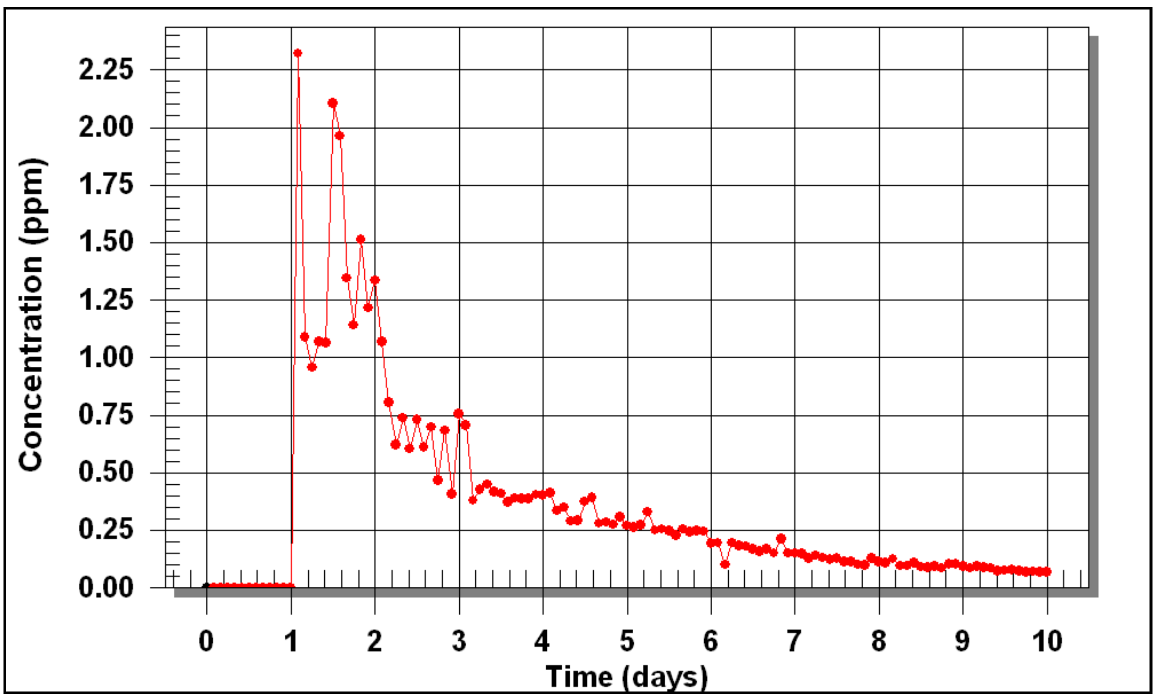
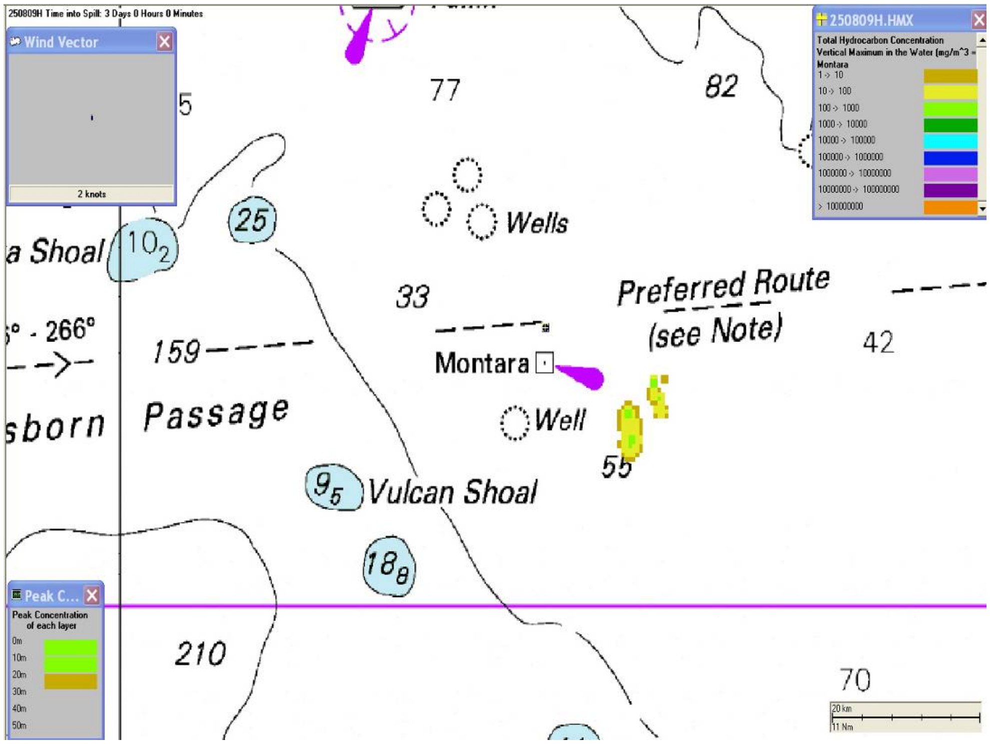
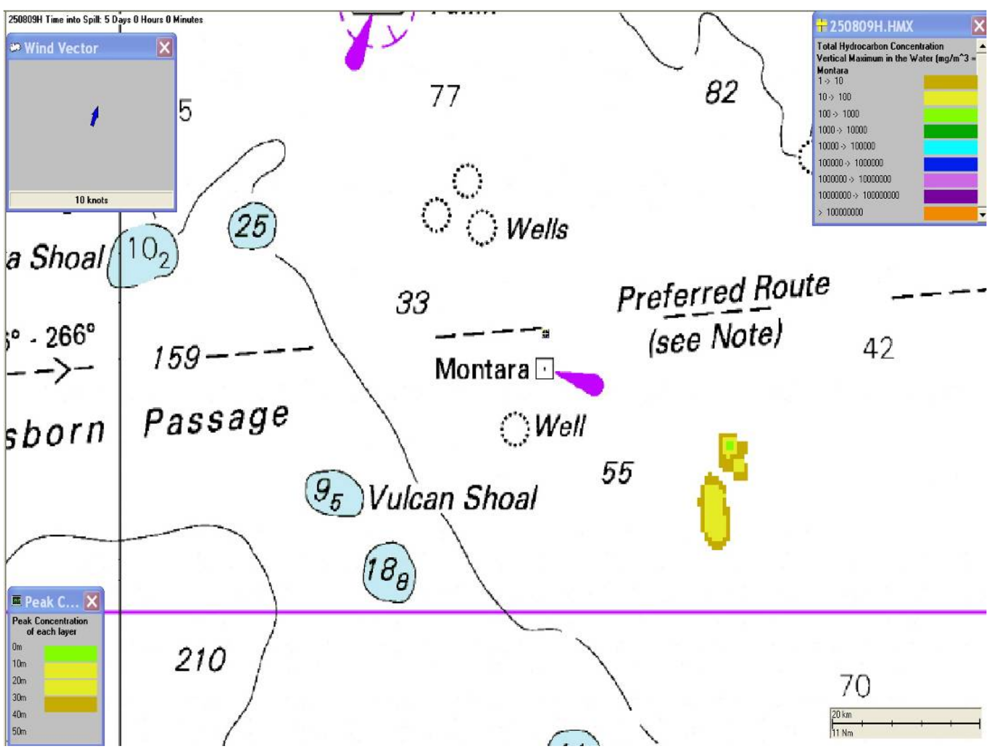


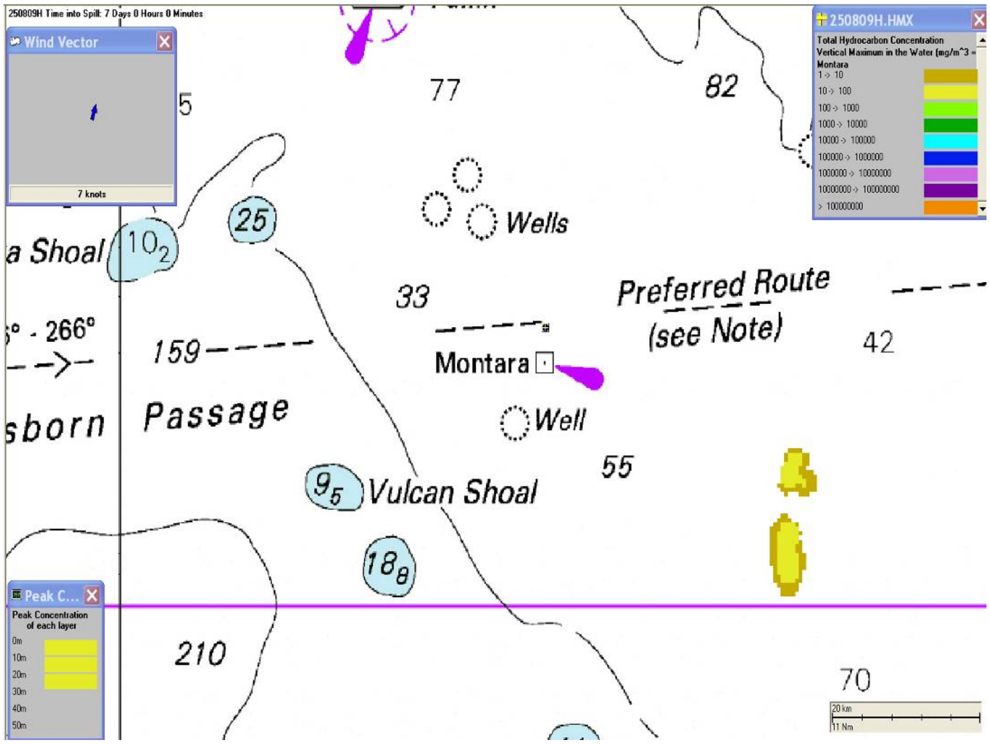
Figure 8: Maximum hydrocarbon concentration at any location, and at any depth within the model domain for the 100% dispersant effectiveness scenario, after a dispersant event on the 25th August 2009



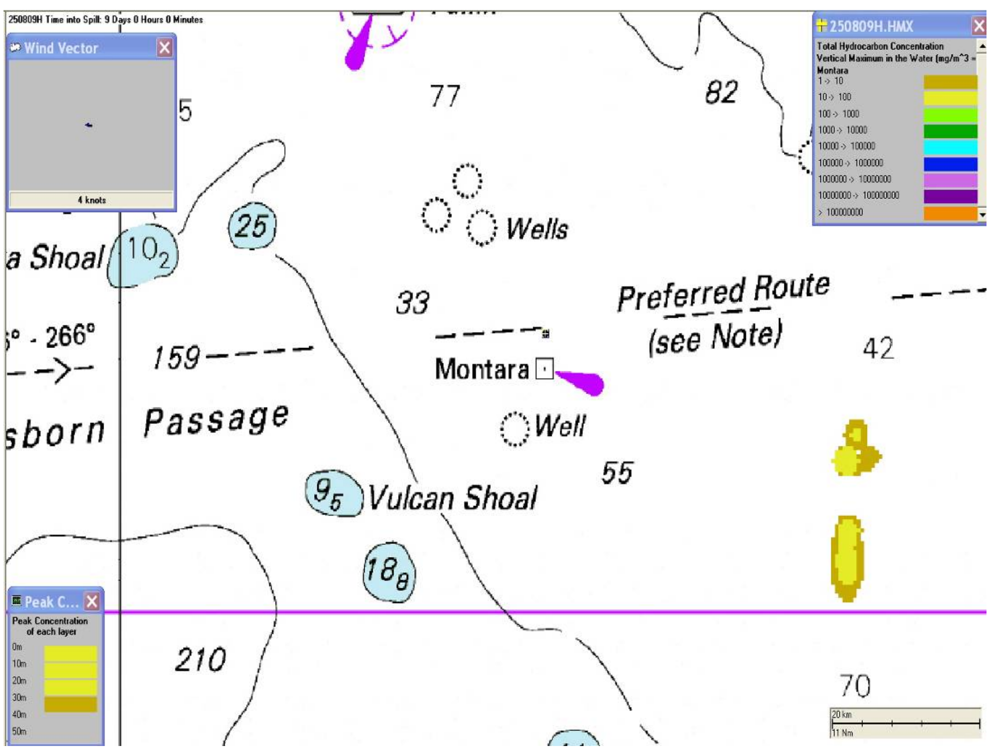
2 days after dispersant event (27/08/09)



4 days after dispersant event (29/08/09)



6 days after dispersant event (31/08/09)



8 days after dispersant event (02/09/09)

Figure 9: Movement and concentration of dispersed oil plume in the water column after a dispersant event on the 25th August 2009

4.3 Dispersant Event 30th August 2009

Table 8 shows a summary of the statistics for the dispersant event on the 30th August 2009. In this scenario the dispersed oil heads directly into an East-South-Easterly direction and does not make contact with any underwater shoals as shown in Figure 11.

Table 8: Summary of results for dispersant event on the 30th August 2009

Parameter	50% dispersant effectiveness	100% dispersant effectiveness
Amount of dispersant used (L)	4000	
Current file used (validated)	GSLA	GSLA
Maximum concentration (ppm)	1.53	2.7
Average concentration over 96 hours after dispersant event (ppm)	0.54	0.53
Concentration of hydrocarbons 4 days after dispersant event (ppm)	0.14	0.14
Concentration of hydrocarbons 9 days after dispersant event (ppm)	0.04	0.06

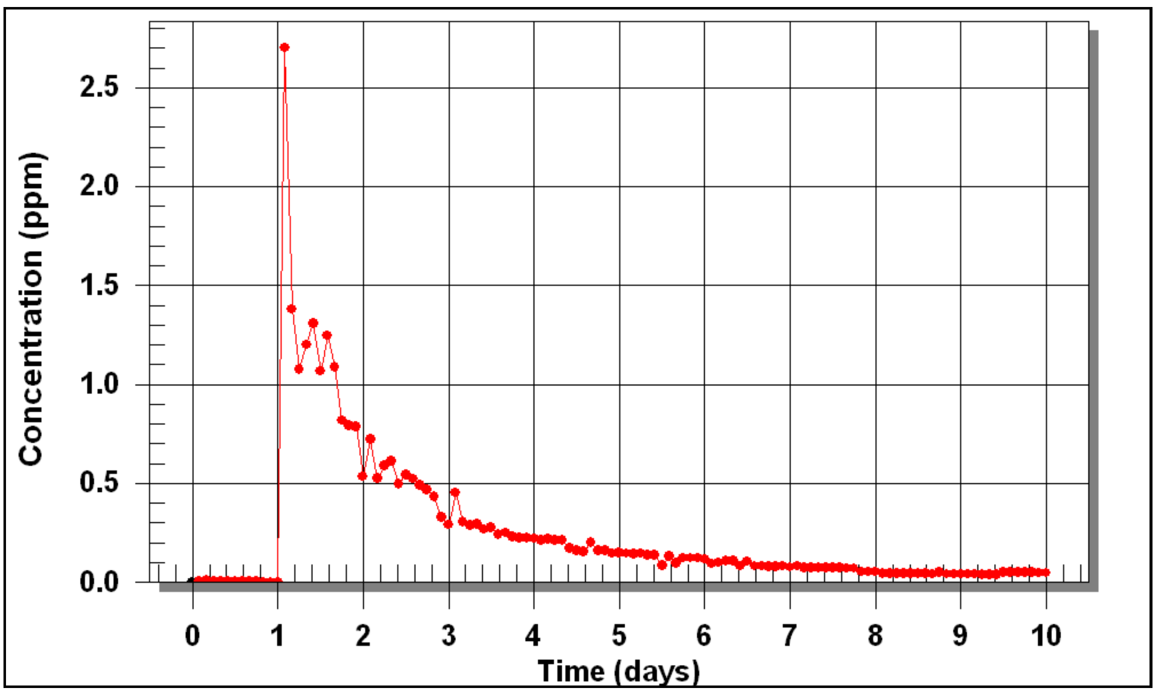
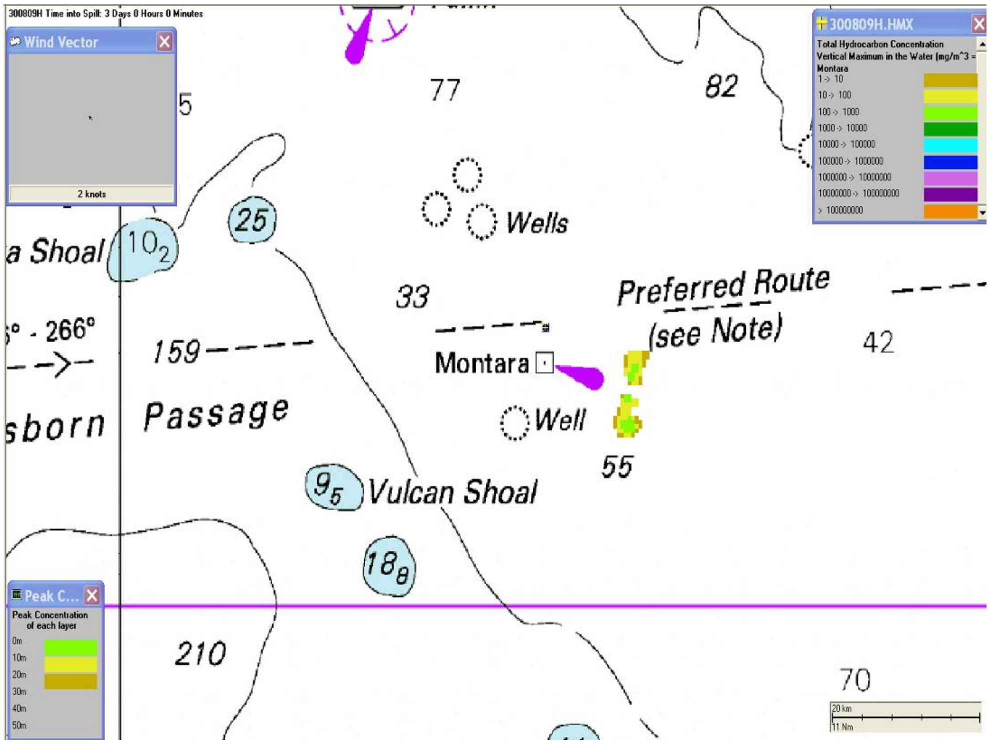
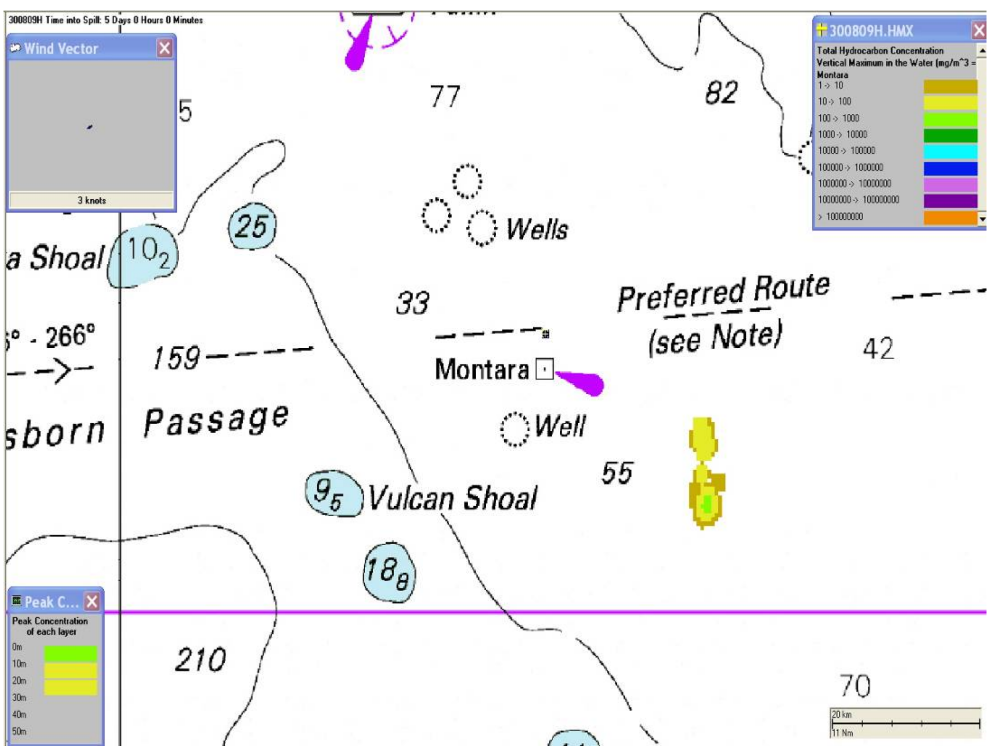


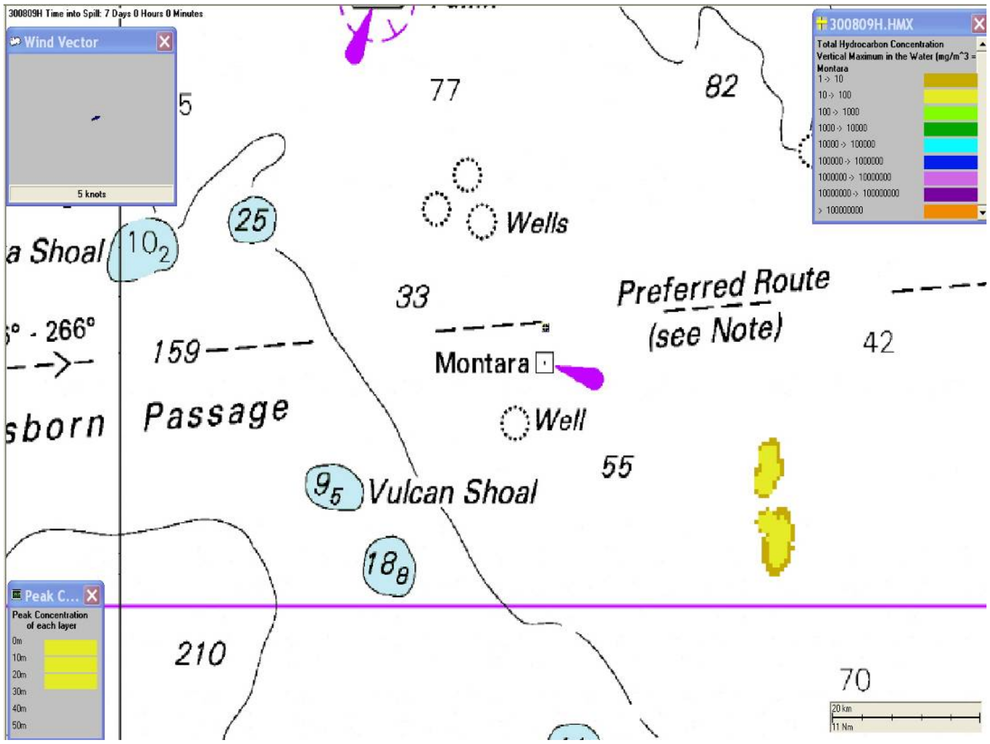
Figure 10: Maximum hydrocarbon concentration at any location, and at any depth within the model domain for the 100% dispersant effectiveness scenario, after a dispersant event on 30th August 2009



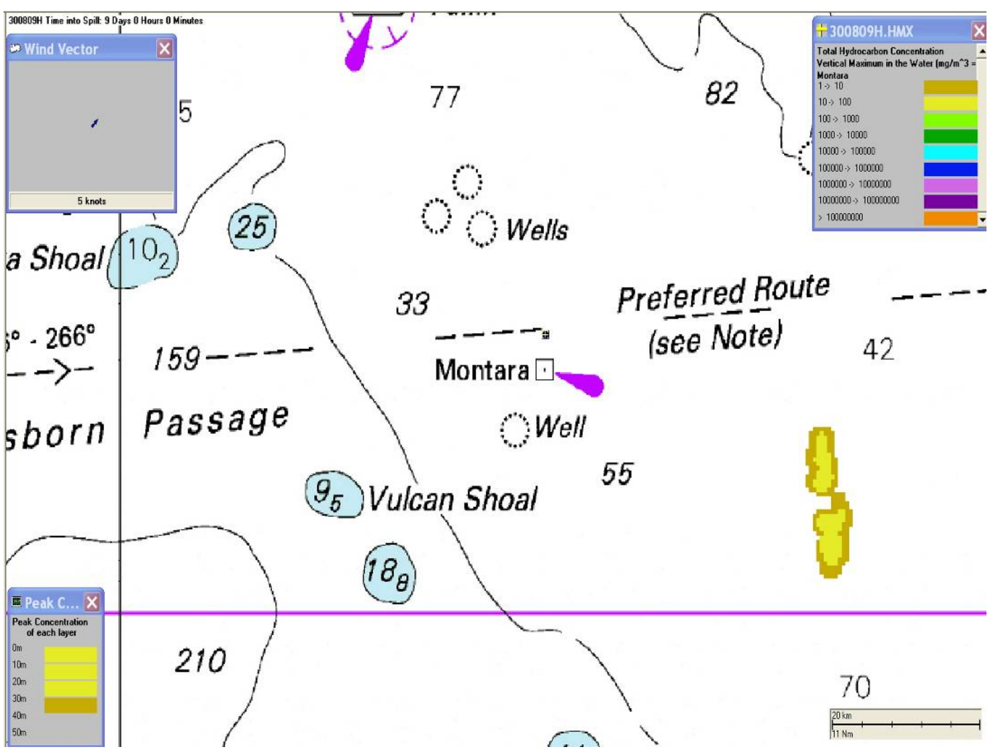
2 days after dispersant event (01/09/09)



4 days after dispersant event (03/09/09)



6 days after dispersant event (05/09/09)



8 days after dispersant event (07/09/09)

Figure 11: Movement and concentration of dispersed oil plume in the water column after a dispersant event on the 30th August 2009

4.4 Dispersant Event 1st September 2009

Table 9 shows a summary of the results of the dispersant event on the 1st September. The dispersant event on the 1st September 2009 caused a spike in hydrocarbon concentration of 1.62ppm (100% dispersant effectiveness) and 0.78ppm (50% dispersant effectiveness). After 8 days the hydrocarbon concentrations are at 0.07 (100% dispersant effectiveness) and 0.04 (50% dispersant effectiveness). Figure 12 shows the dispersant event on the 1st September causing a spike in hydrocarbon concentrations as high as 1.62ppm. Five days later, high winds (>11 knots) create a natural dispersion event causing hydrocarbon concentrations in the water column to reach as high as 2.7ppm.

Table 9: Summary of results for dispersant event on the 1st September 2009

Parameter	50% dispersant effectiveness	100% dispersant effectiveness
Amount of dispersant used (L)	8,000	
Current file used (validated)	Bluelink + tides	
Maximum concentration (ppm)	0.78	1.62
Average concentration over 96 hours after dispersant event (ppm)	0.16	0.37
Concentration of hydrocarbons 4 days after dispersant event (ppm)	0.03	0.06
Concentration of hydrocarbons 8 days after dispersant event (ppm)	0.09	0.07

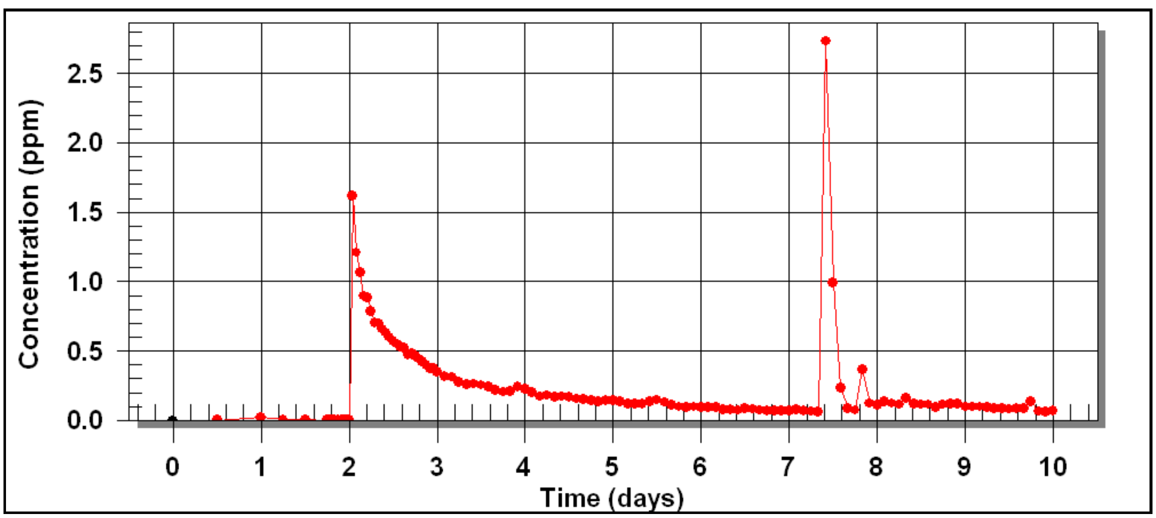


Figure 12: Maximum hydrocarbon concentration at any location, and at any depth within the model domain for the 100% dispersant effectiveness scenario. Note the high ppm caused by the 11 knot winds 7.5 days into the scenario.

The dispersed oil plume caused by the use of dispersants on the 1st September 2009 moves in a general west-ward direction (refer to Figure 18). It makes contact with Barracouta Shoal (56km to the west) 5.5 days after the dispersant event. Any organisms in the water column around the Shoal would be subjected to spikes in hydrocarbon concentrations of 0.05ppm for a short duration of time (<24hrs) after which concentrations drop down to zero.

Note that Figure 13 gives the maximum concentrations of hydrocarbons at the location of the Shoal at, any depth. The higher concentrations are concentrated to the first metre of water (Figure 14) while the concentration at the depth of the shoal itself was not seen to exceed 1ppb (Figure 15).

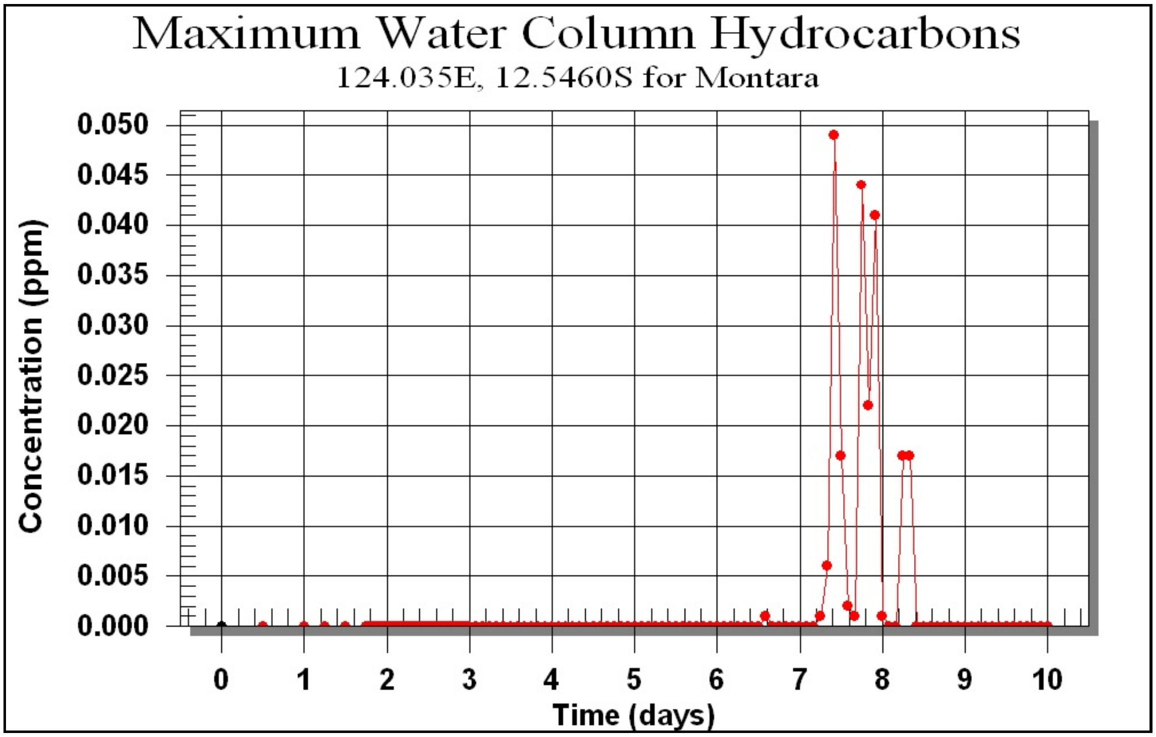


Figure 13: Maximum concentrations in the water column at any depth around Barracouta Shoal after a dispersant event on the 01/09/09 (based on 100% dispersant effectiveness – worst case scenario)

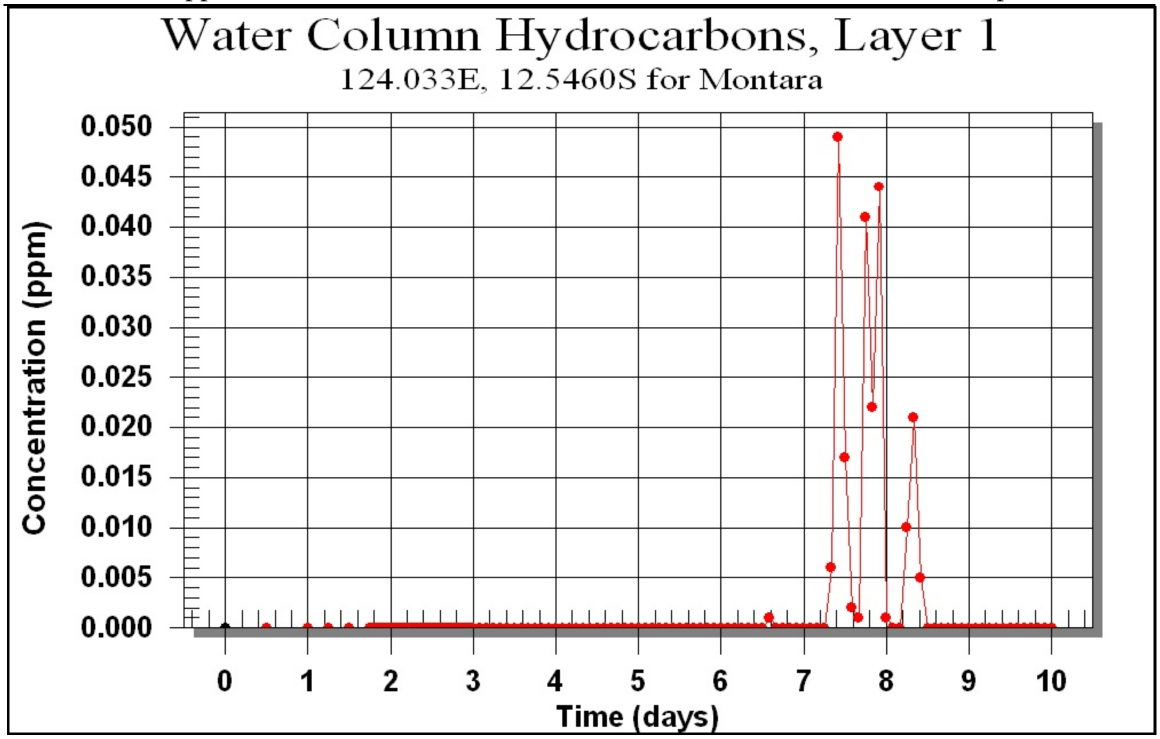


Figure 14: Maximum hydrocarbon concentration within layer 1 (0m – 1m) at Barracouta Shoal after a dispersant event on the 01/09/09

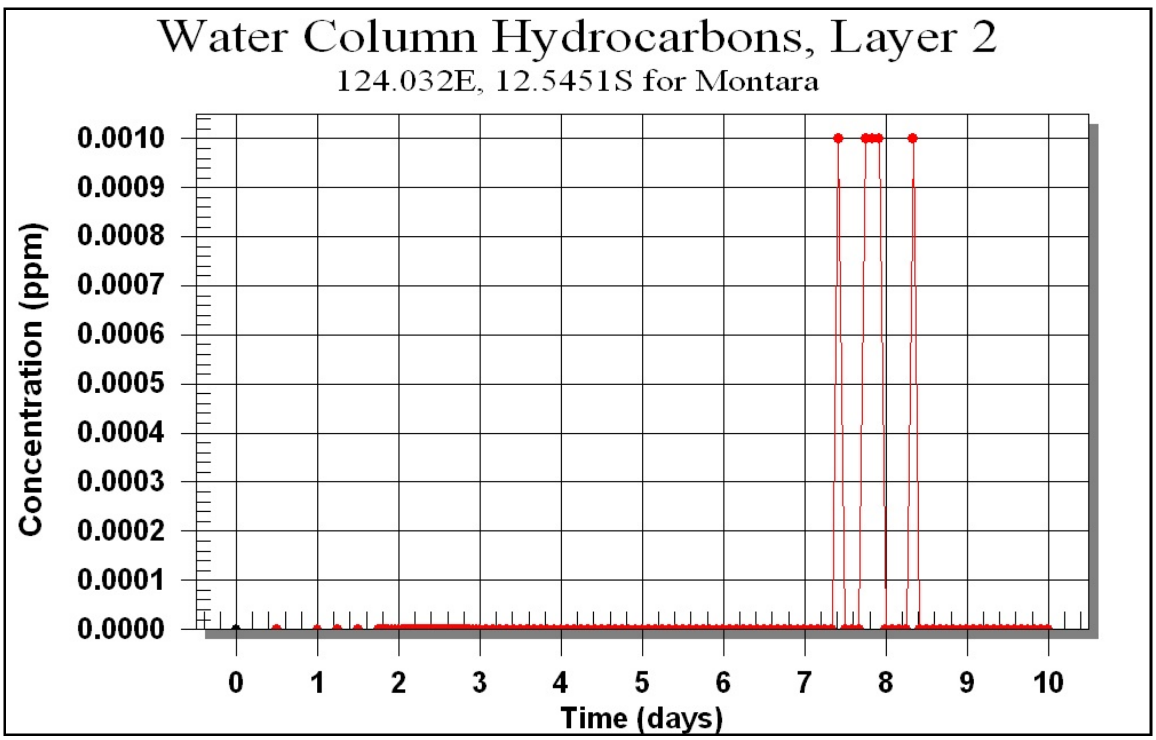


Figure 15: Maximum hydrocarbon concentration within layer 2 (1m - 40m), at Barracouta Shoal after a dispersant event on the 01/09/09

The dispersed oil plume within layer 2 of the water column (between 1m – 40m) travels as far as 51km from the spill site after which it dissipates. Any concentrations indicated after this time is concentrated to layer 1 (between 0m – 1m). Any benthic organisms living on the Shoal will be exposed to maximum concentrations of 1ppb for less than 18 hours (Figure 15).

Table 10: Comparison of hydrocarbon concentrations between water column depths

Layer	Max concentration at any location (max concentration found immediately after dispersant event) ppm
Layer 1 (<1m)	1.62
Layer 2 (between 1m – 40m)	0.098

A long-term model was undertaken in order to determine the persistence of the dispersed oil plume in the water column (layer 2). Regardless of whether the oil is dispersed by high winds or chemicals it becomes apparent that within 3 days or less of a dispersion event, the concentrations of hydrocarbons in the water column (layer 2) drop below 10ppb (Figure 17). Note that the oil plume moves westwards in a circular motion and thus some shoals may be affected a number of times as oil oscillates over the top.

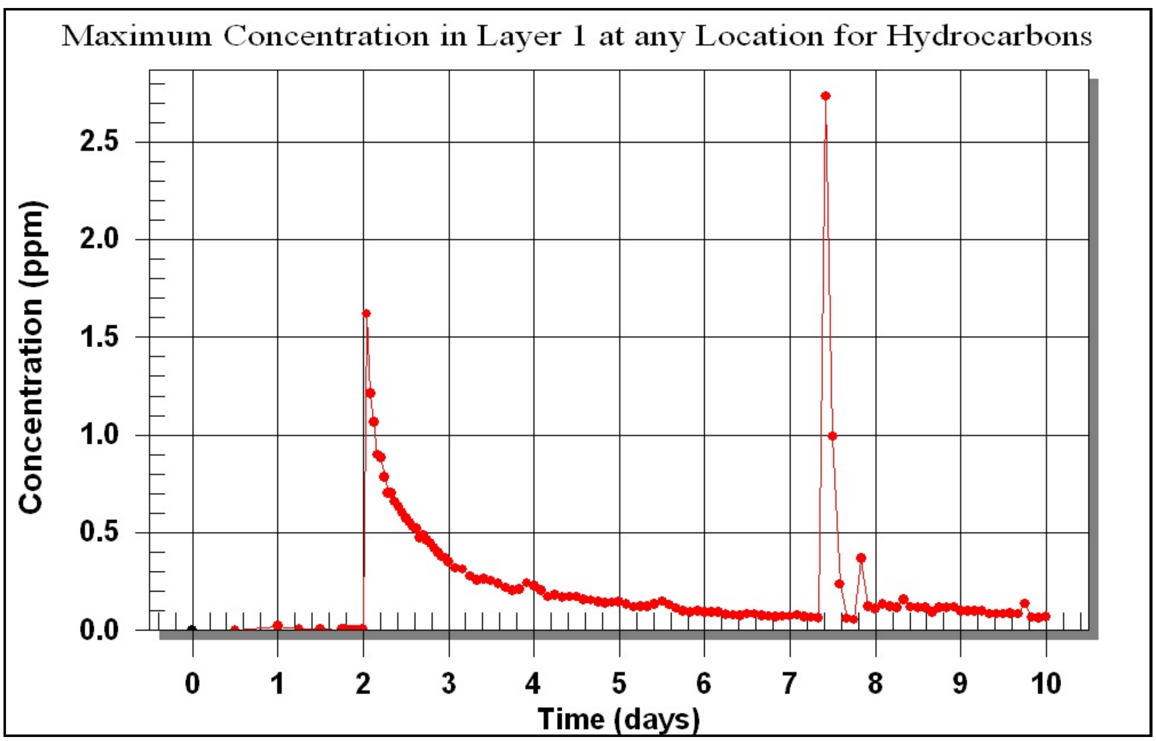


Figure 16: Maximum concentration of hydrocarbons at any location within layer 1 (0m - 1m).

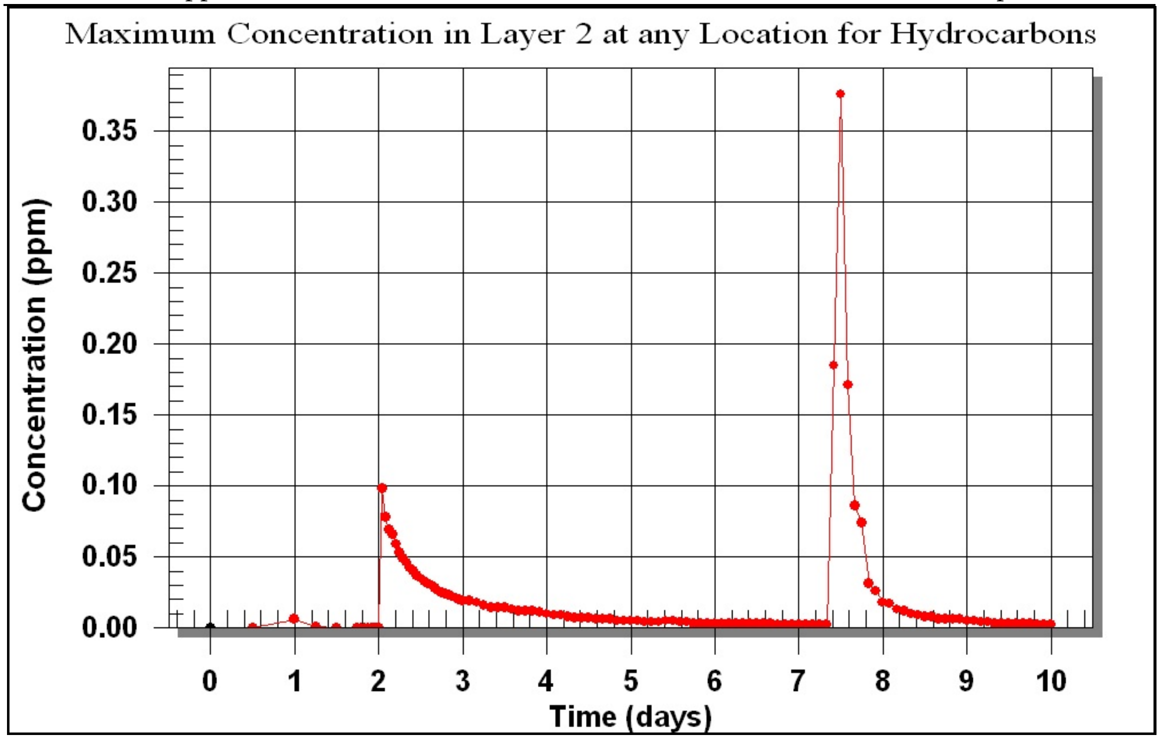
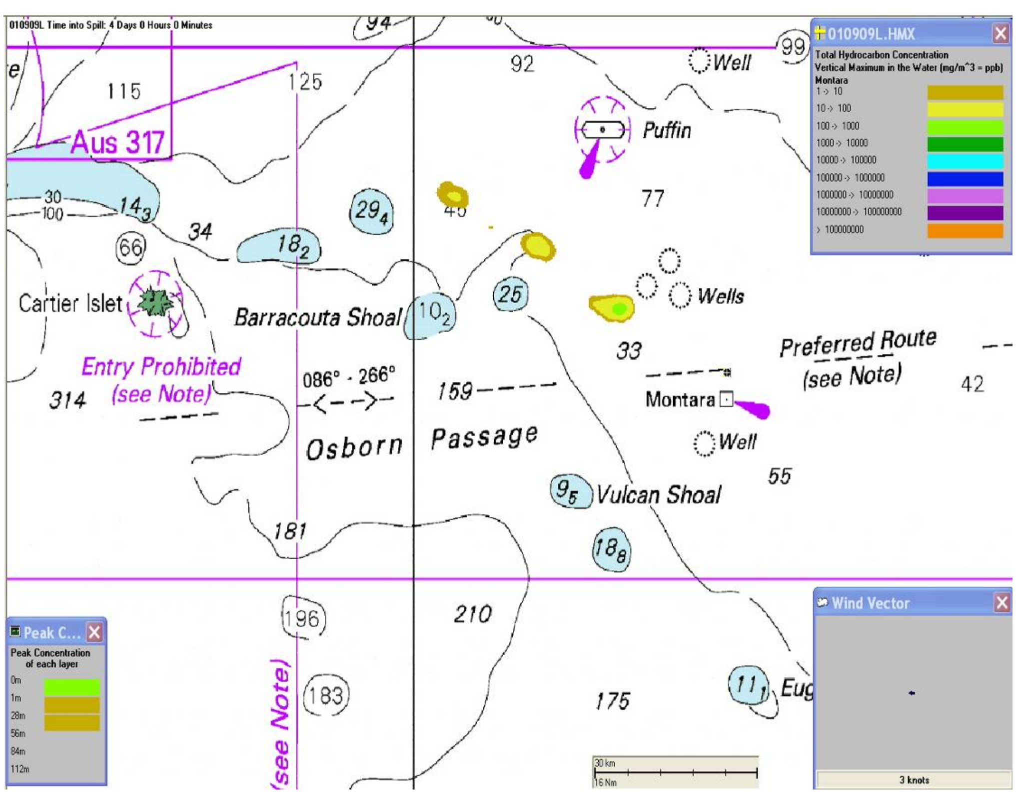
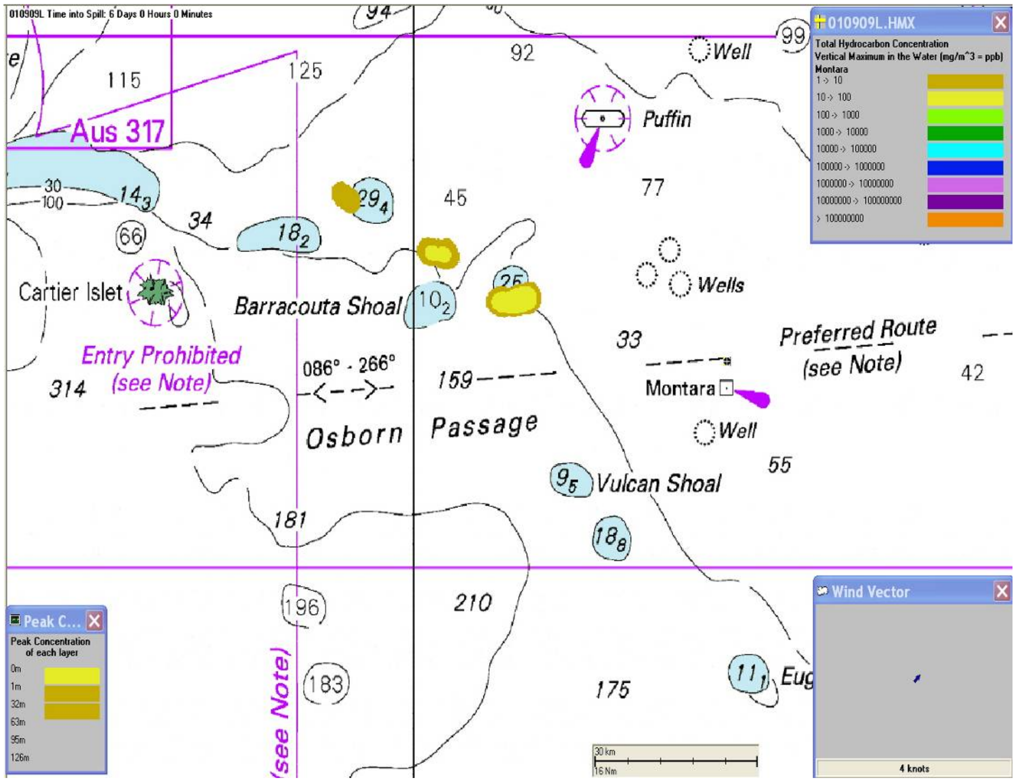


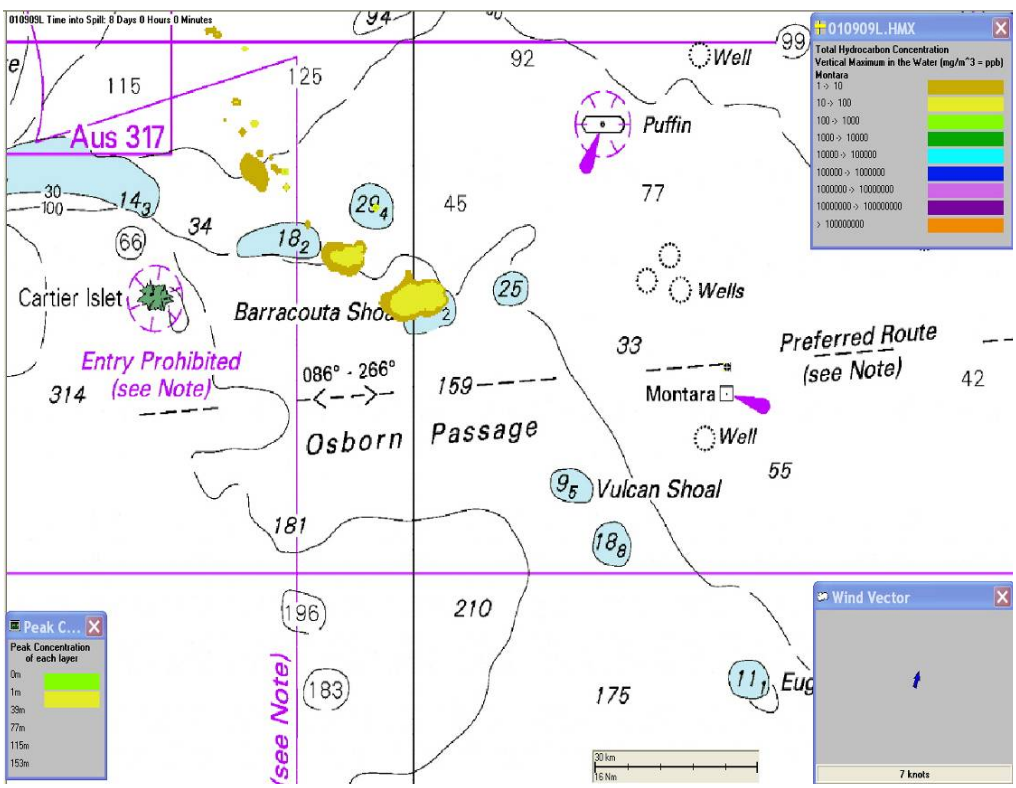
Figure 17: Maximum concentration of hydrocarbons at any location within layer 2 (1m - 40m). The first peak is caused by the chemical dispersion events while the other two peak is caused by natural dispersion events (i.e. high winds)



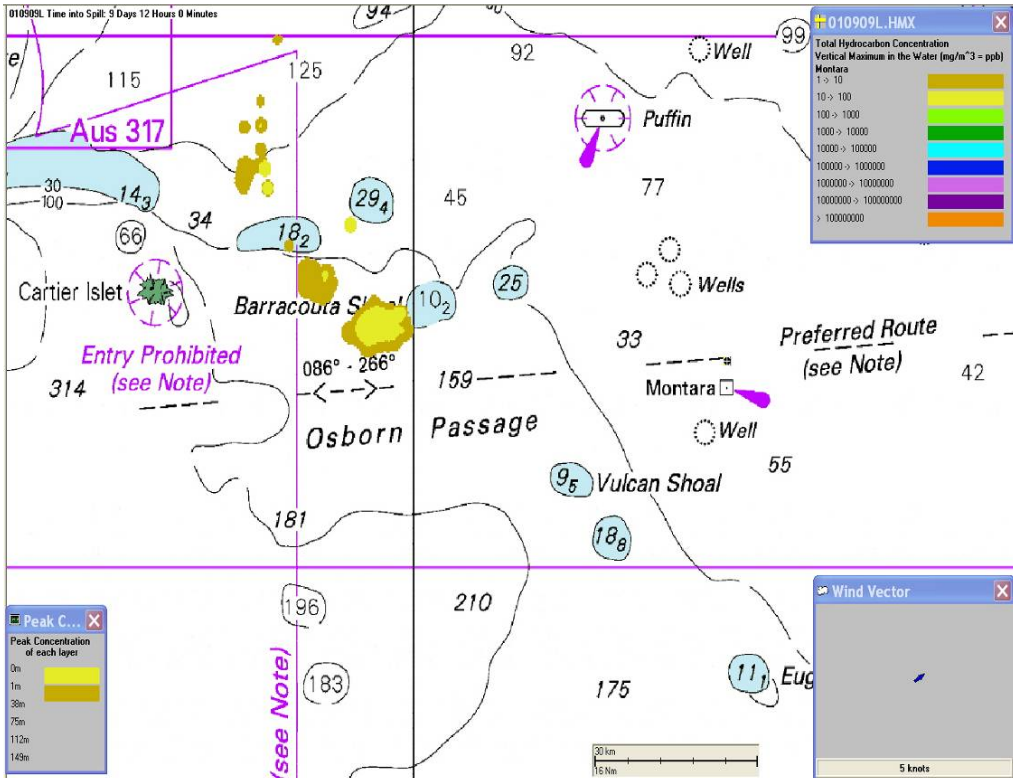
2 days after dispersant application (03/09/09)



4 days after dispersant application (05/09/09)



6 days after dispersant application (07/09/09)



8 days after dispersant application (09/09/09)

Figure 18: Movement and concentration of dispersed oil plume in the water column after a dispersant event on the 1st September 2009.

4.5 Dispersant Event 2nd September 2009

Table 11 shows a summary of the results of the dispersant event on the 2nd September. The dispersant event on the 2nd September 2009 caused a spike in hydrocarbon concentration of 2.01ppm (100% dispersant effectiveness) and 1.10ppm (50% dispersant effectiveness). After 8 days the hydrocarbon concentrations are at 0.08 (100% dispersant effectiveness) and 0.05 (50% dispersant effectiveness).

Table 11: Summary of results for dispersant event on the 1st September 2009

Parameter	50% dispersant effectiveness	100% dispersant effectiveness
Amount of dispersant used (L)	12120	
Current file used (validated)	Bluelink + tides	
Maximum concentration (ppm)	1.10	2.01
Average concentration over 96 hours after dispersant event (ppm)	0.33	0.59
Concentration of hydrocarbons 4 days after dispersant event (ppm)	0.08	0.15
Concentration of hydrocarbons 8 days after dispersant event (ppm)	0.05	0.08

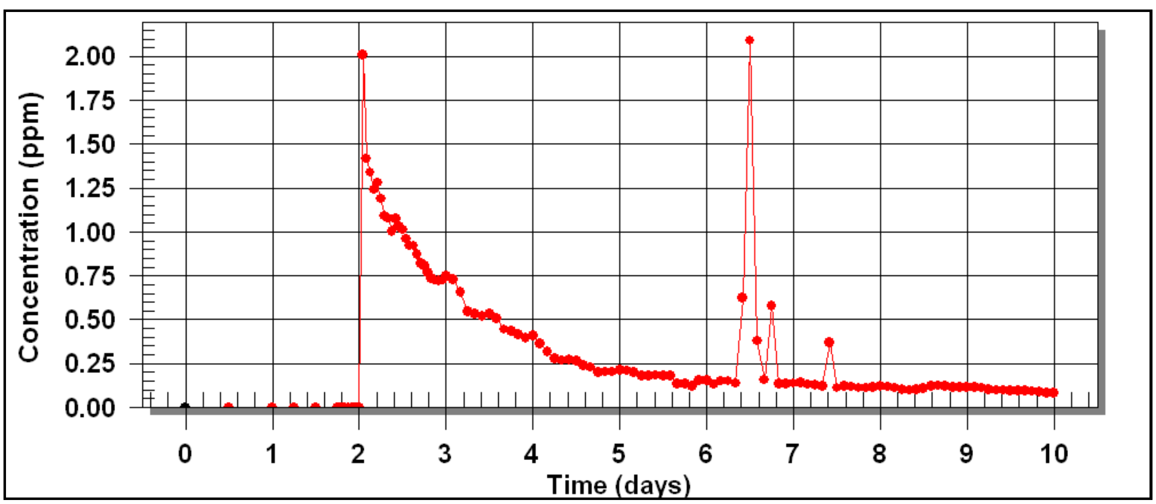


Figure 19: Maximum hydrocarbon concentration at any location, and at any depth within the model domain for the 100%dispersant effectiveness scenario. Note the high ppm caused by the 11 knot winds 6.5 days into the scenario

Figure 19 shows the dispersant event on the 2nd September causing a spike in hydrocarbon concentrations as high as 2.01ppm. this gradually decreases until four days later, when high winds over 11 knots cause a natural dispersion event which causes hydrocarbon concentrations in the water column as high as those caused by the chemical dispersant.

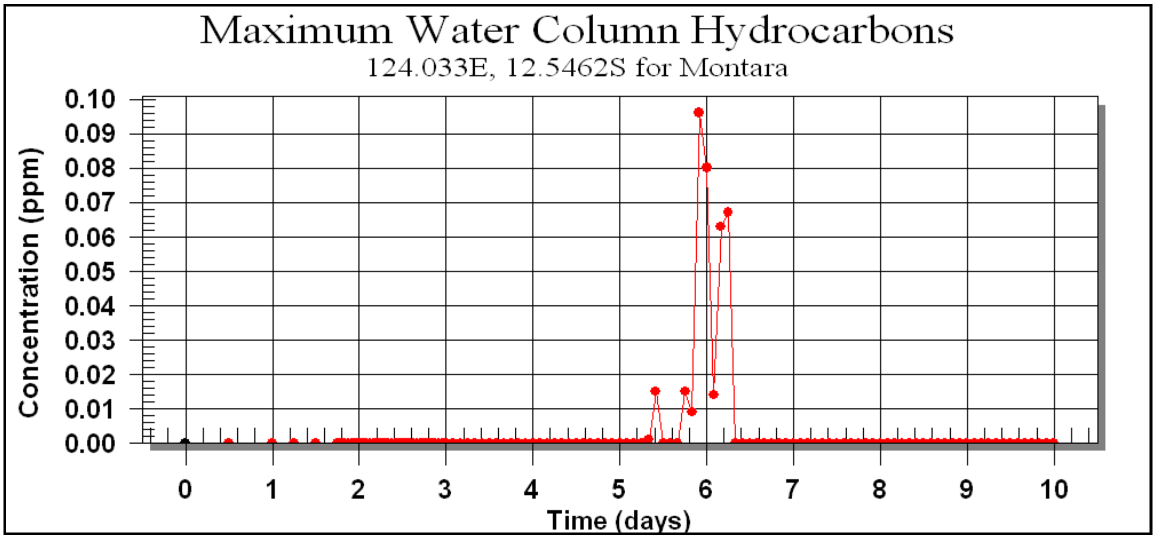


Figure 20: Maximum concentrations in the water column at any depth around Barracouta Shoal after a dispersant event on the 02/09/09 (based on 100% dispersant effectiveness – worst case scenario)

The dispersed oil plume caused by the use of dispersants on the 2nd September 2009 moves in a general west-ward direction. The oil plume travels westwards in a circular motion and thus some shoals may be affected a number of times as oil moves over the top and then moves over the top again.

The dispersed oil makes contact with Barracouta Shoal (56km to the west) 5.5 days after the dispersant event. Any organisms in the water column around the Shoal would be subjected to spikes in hydrocarbon concentrations of 0.1ppm for a short duration of time (<24hrs) after which concentrations drop down to zero.

Note that Figure 20 gives the concentrations of hydrocarbon at the location of the Shoal at any depth. The higher concentrations are concentrated in the first metre of water (Figure 21) while the concentration at the depth of the shoal itself (within 1m - 40m depth) was not seen to exceed 3ppb (Figure 22).

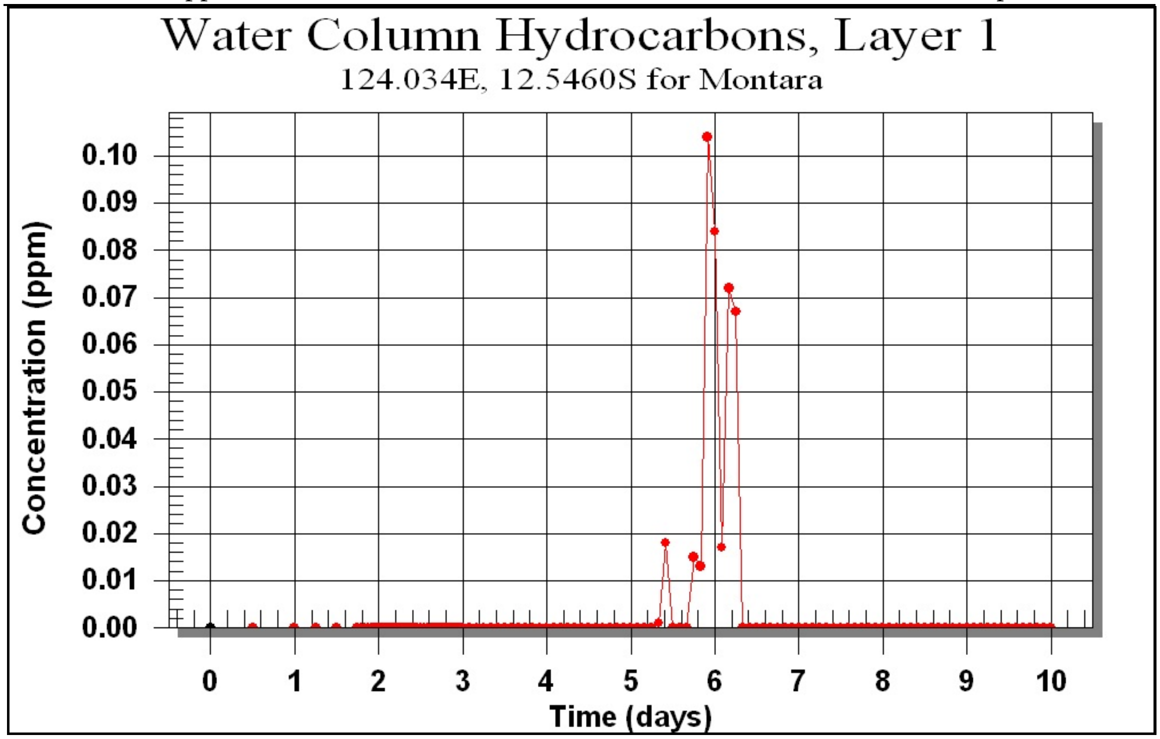


Figure 21: Maximum concentration at layer 1 (0m - 1m) at Barracouta Shoal after a dispersant event on the 02/09/09

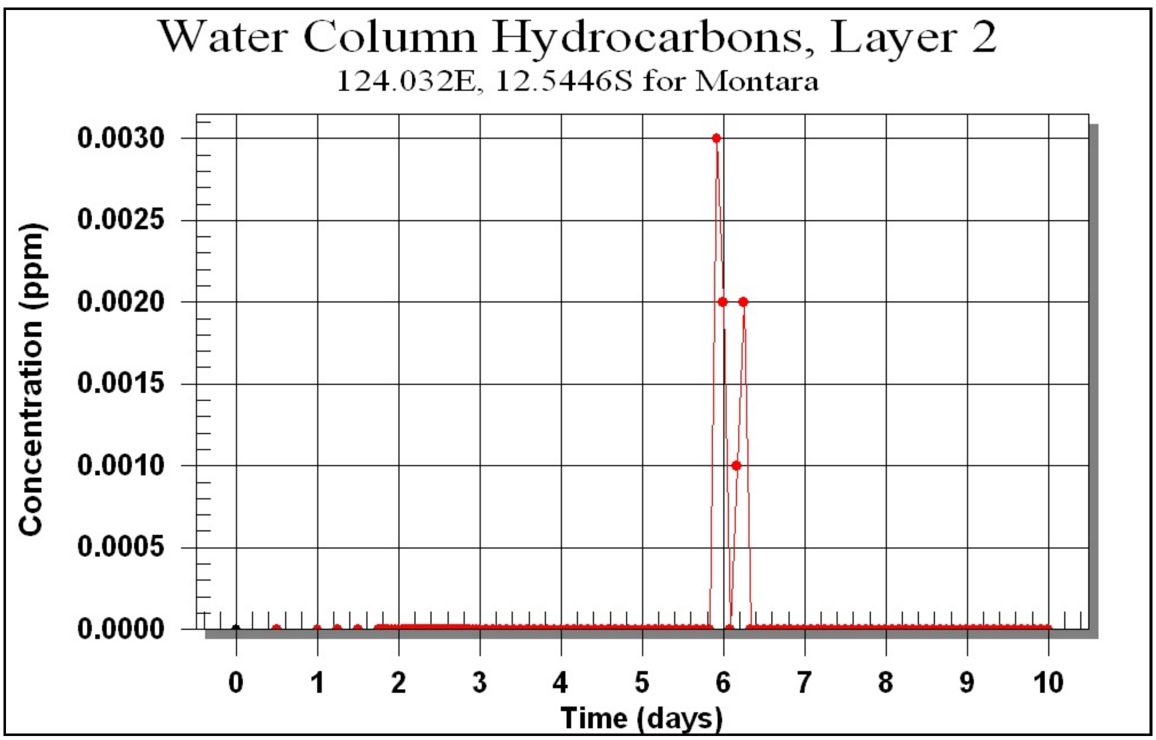


Figure 22: Maximum concentration at layer 2 (between 1m- 40m) at Barracouta Shoal after a dispersant event on the 02/09/09

The dispersed oil plume within layer 2 of the water column (between 1m – 40m) travels as far as 70km from the spill site after which it dissipates and disappears. Any concentrations seen after this time are concentrated in layer 1 (between 0m – 1m). Any benthic organisms living on the Shoal will be exposed to maximum concentrations of 3ppb for less than 18 hours (Figure 22).

Table 12: Comparison of hydrocarbon concentrations between water column depths

Layer	**Max concentration at any location (max concentration found immediately after dispersant event)** **ppm**
Layer 1 (<1m)	2.01
Layer 2 (between 1m – 40m)	0.024

A long-term SIMAP model was undertaken in order to determine the persistence of the dispersed oil plume in the water column (layer 2). Regardless of whether the oil is dispersed by high winds or chemicals it becomes apparent that within 2 days or less of the dispersion event the concentrations of hydrocarbons in the water column (layer 2) have dropped under 10ppb (Figure 24).

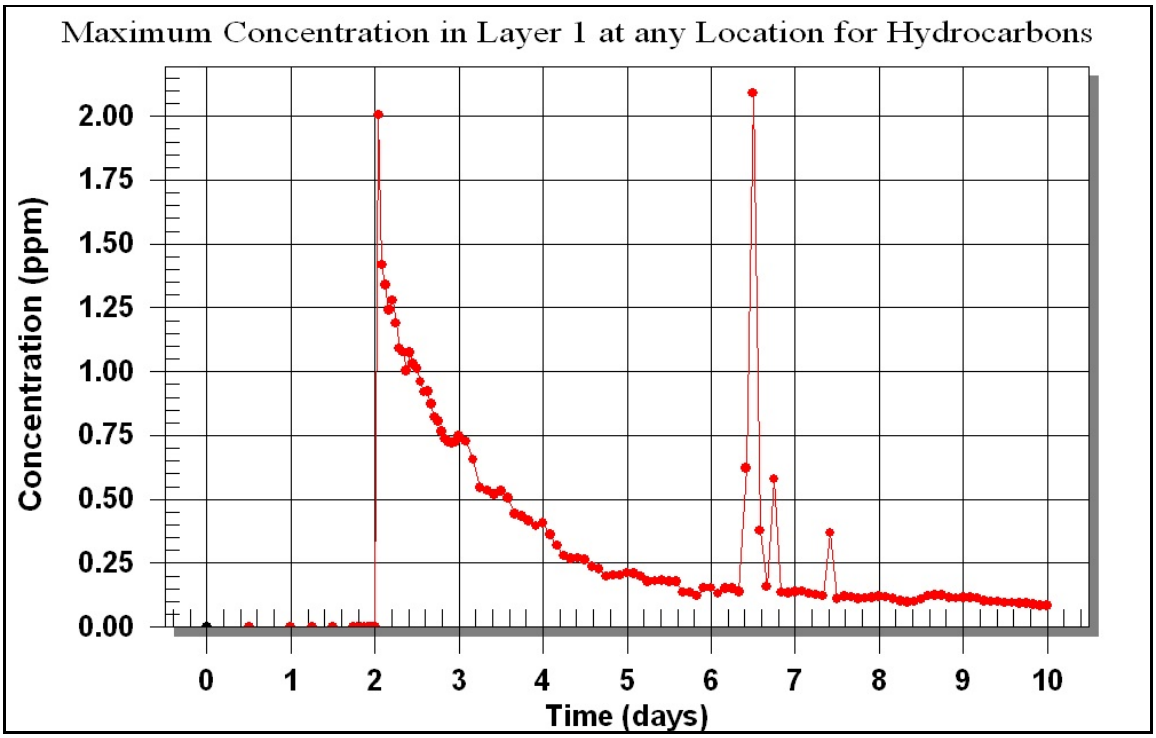


Figure 23: Maximum concentration of hydrocarbons in layer 1 (0m - 1m). The first peak in concentration is caused by the chemical dispersion event while the second peak is caused by a natural dispersion event (i.e. high winds)

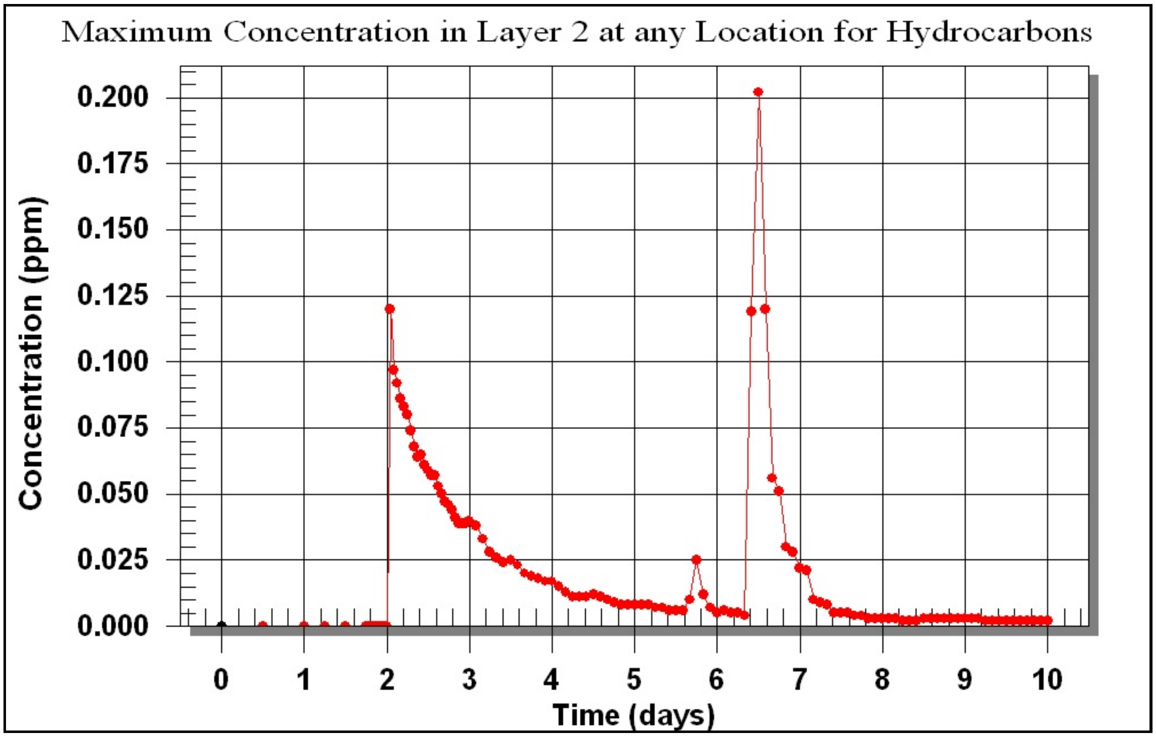
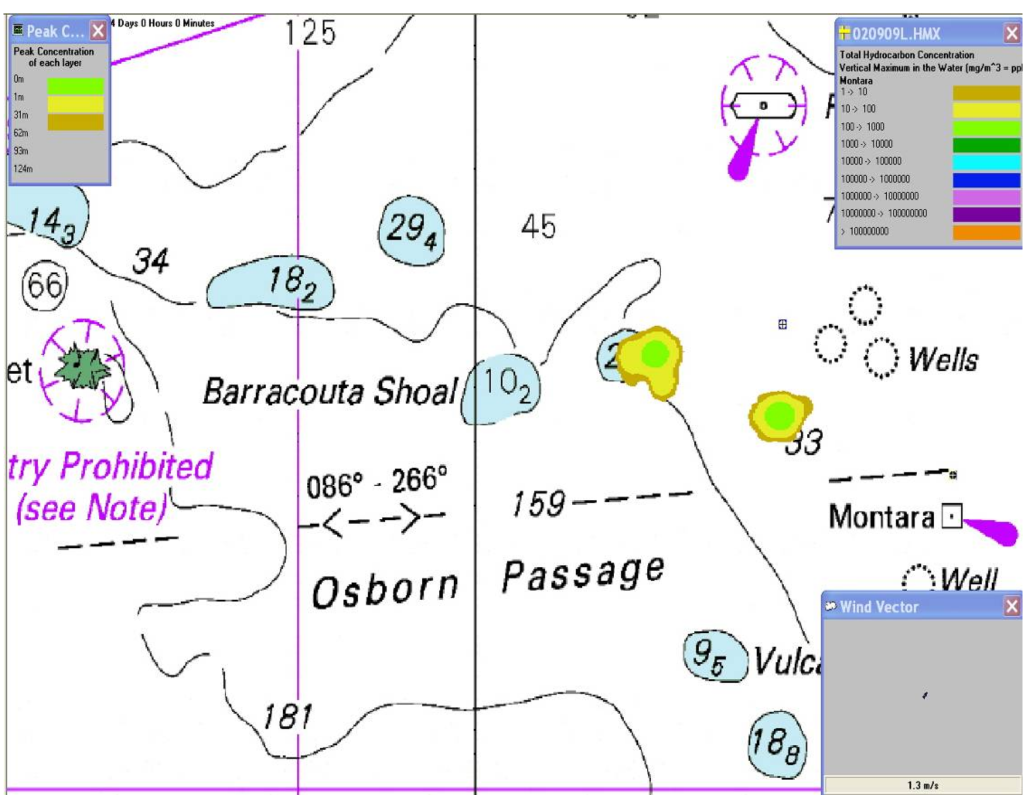
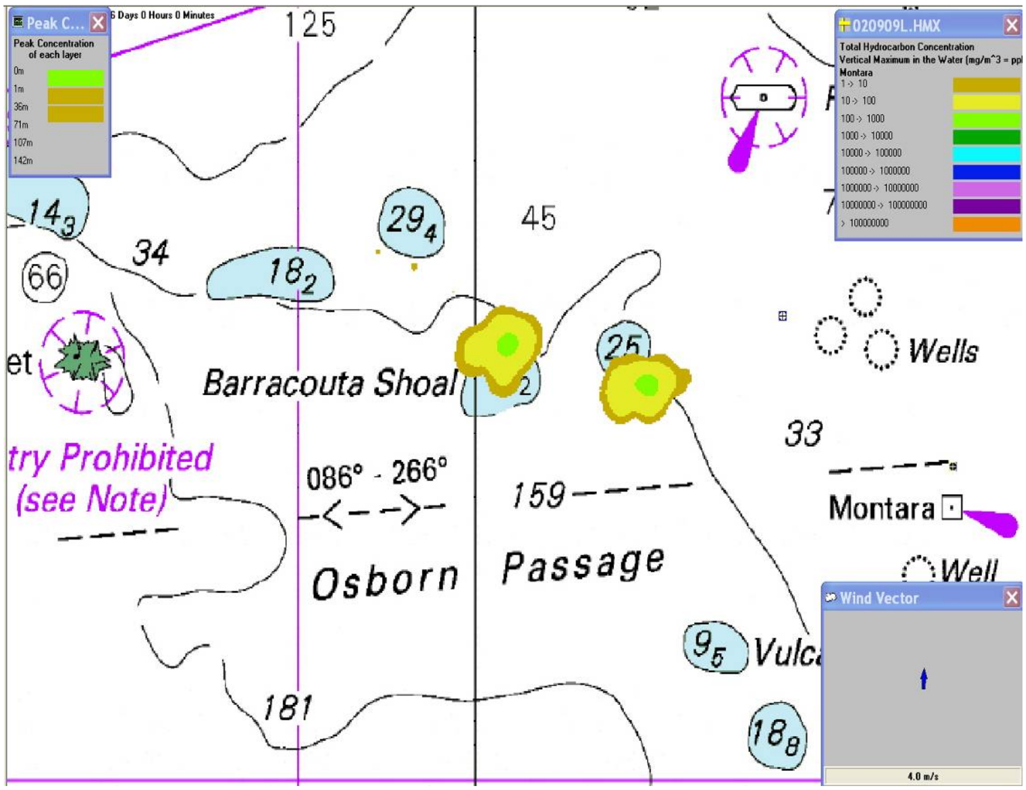


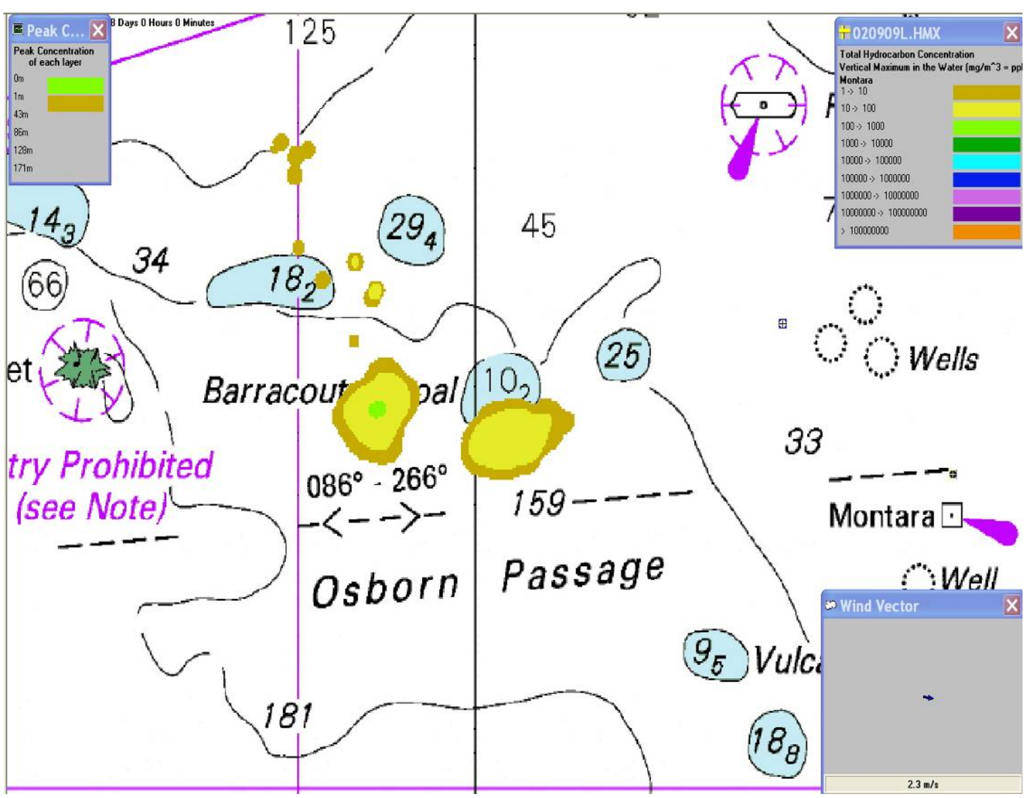
Figure 24: Maximum concentration of hydrocarbons in layer 2 (1-40m). The first peak in concentration is caused by the chemical dispersion event while the second peak is caused by a natural dispersion event (i.e. high winds)



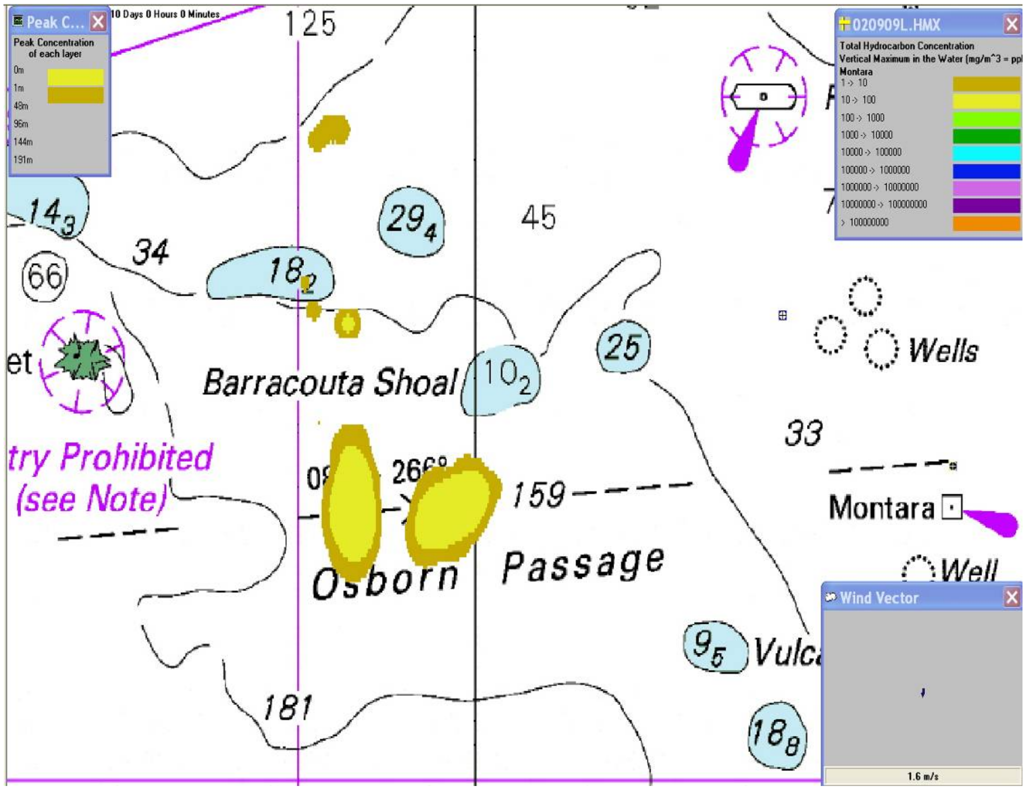
2 days after dispersant application (04/09/09)



4 days after dispersant application (06/09/09)



6 days after dispersant application (08/09/09)



8 days after dispersant application (010/09/09)

Figure 25: Movement and concentration of dispersed oil plume in the water column after a dispersant event on the 2nd September 2009.

4.6 Dispersant Event 17th September 2009

Table 13 shows a summary of the results of the dispersant event on the 17th September. The dispersant event on the 17th September 2009 caused a spike in hydrocarbon concentration of 0.98ppm (100% dispersant effectiveness) and 0.46ppm (50% dispersant effectiveness). After 5 days the hydrocarbon concentrations are at 0.26 (100% dispersant effectiveness) and 0.11 (50% dispersant effectiveness).

Table 13: Summary of results for dispersant event on the 17th September 2009

Parameter	50% dispersant effectiveness	100% dispersant effectiveness
Amount of dispersant used (L)	8000	
Current file used (validated)	Bluelink + tides	
Maximum concentration (ppm)	0.46	0.98
Average concentration over 96 hours after dispersant event (ppm)	0.23	0.53
Concentration of hydrocarbons 4 days after dispersant event (ppm)	0.12	0.31
Concentration of hydrocarbons 5* days after dispersant event (ppm)	0.11	0.26

*Could only be run for 5 days after dispersant application as a natural dispersion event caused a very large spike in the in water hydrocarbon concentrations due to pushing extra surface oil subsurface. No measurements in the field of natural dispersant events took place; hence no verification of this has been undertaken.

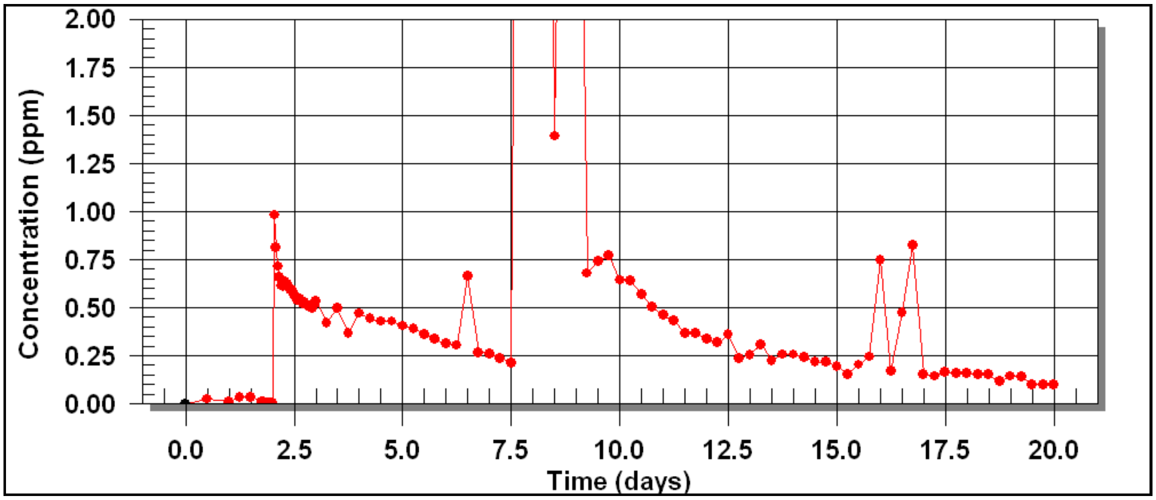


Figure 26: Maximum hydrocarbon concentration at any location, and at any depth within the model domain for the 100% dispersant effectiveness scenario.

A natural dispersion event at 7 days causes a spike in hydrocarbon concentrations as high as 70ppm (Figure 26). This quickly drops down to 5ppm within 24 hours and under 1ppm within 48 hours.

The dispersant event on the 17th September causes the dispersed oil plume to move over Goeree Shoal (approximately 31km south west of the spill site). The concentration of hydrocarbons at the location of the shoal was concentrated in the first metre of the water column. Maximum hydrocarbon concentrations in layer 1 (<1 metre) was 0.22ppm over Goeree Shoal (Figure 27). Maximum hydrocarbon concentrations in layer 2 (1m – 40m) were 10ppb over the Shoal (Figure 28). Any benthic organisms on Goeree Shoal would be exposed to 10ppb hydrocarbon concentrations for less than 24 hours.

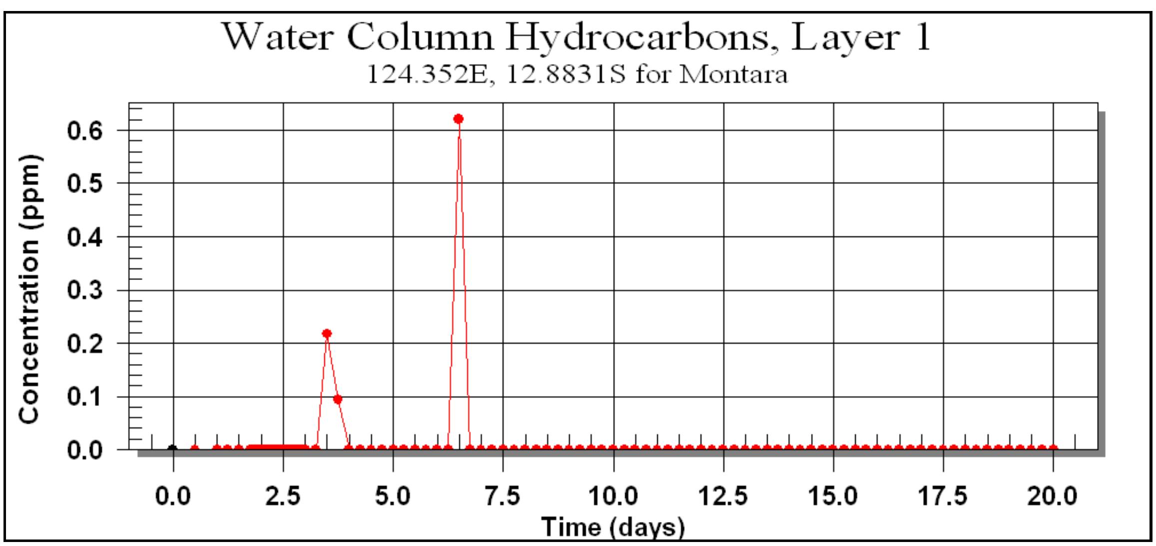


Figure 27: Maximum concentration of hydrocarbon at Goeree Shoal within layer 1 (<1 metre depth)

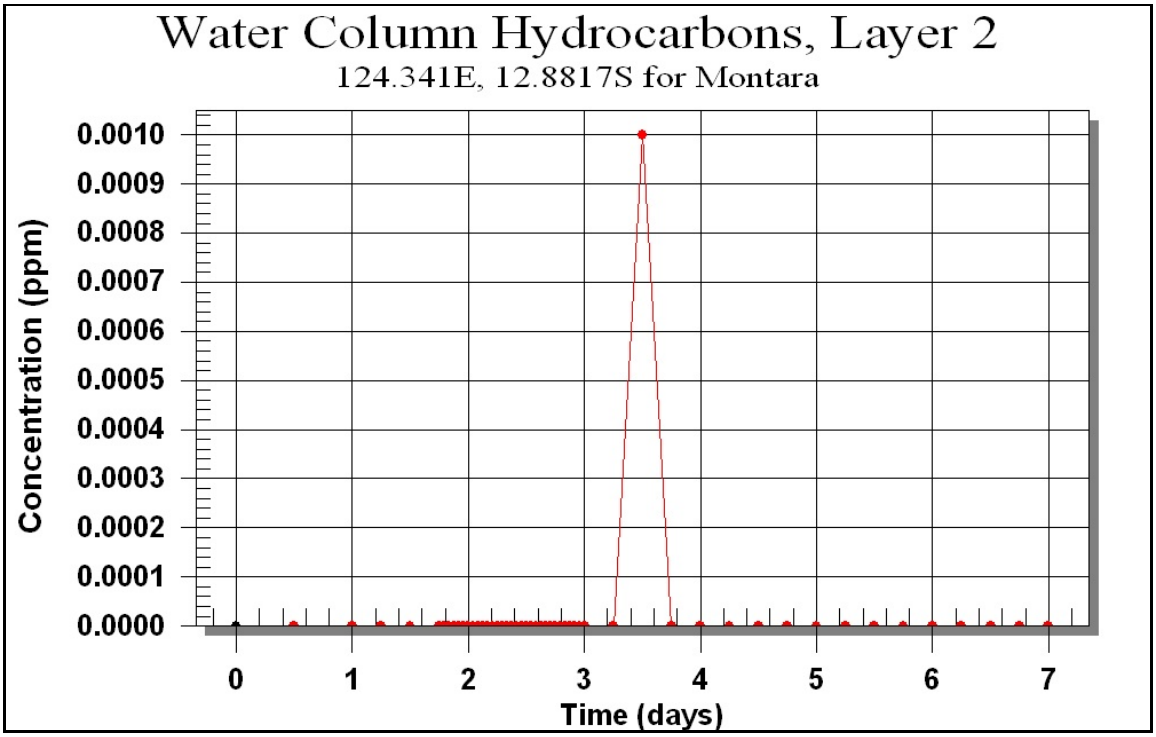
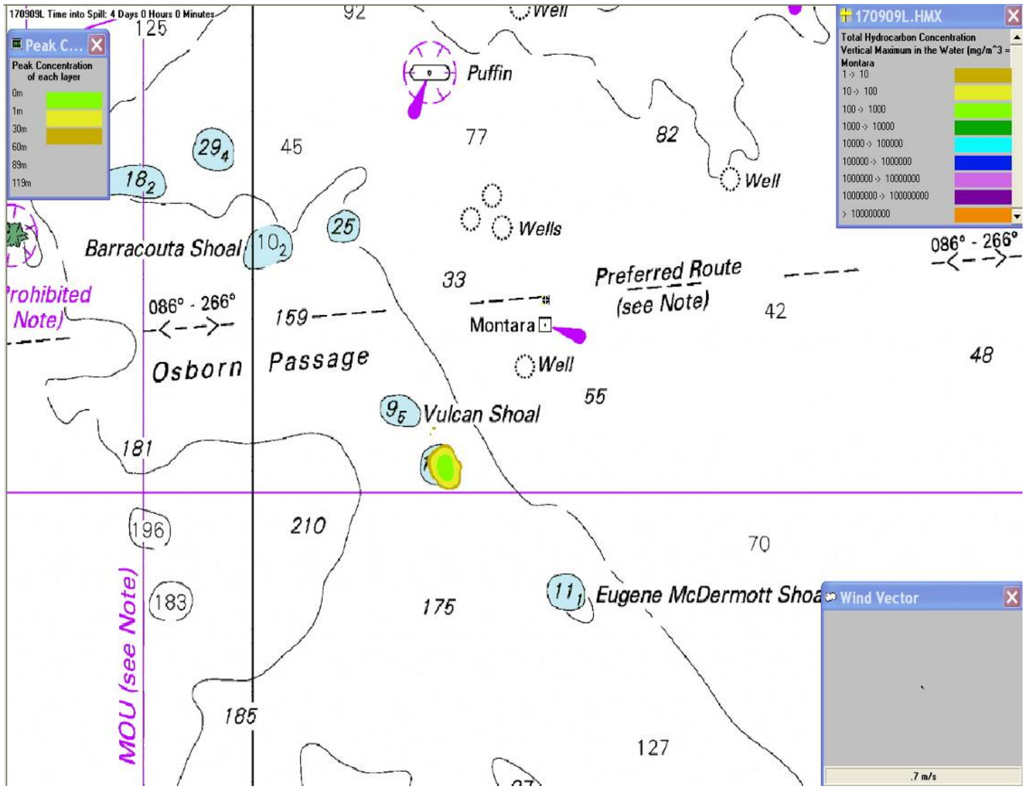


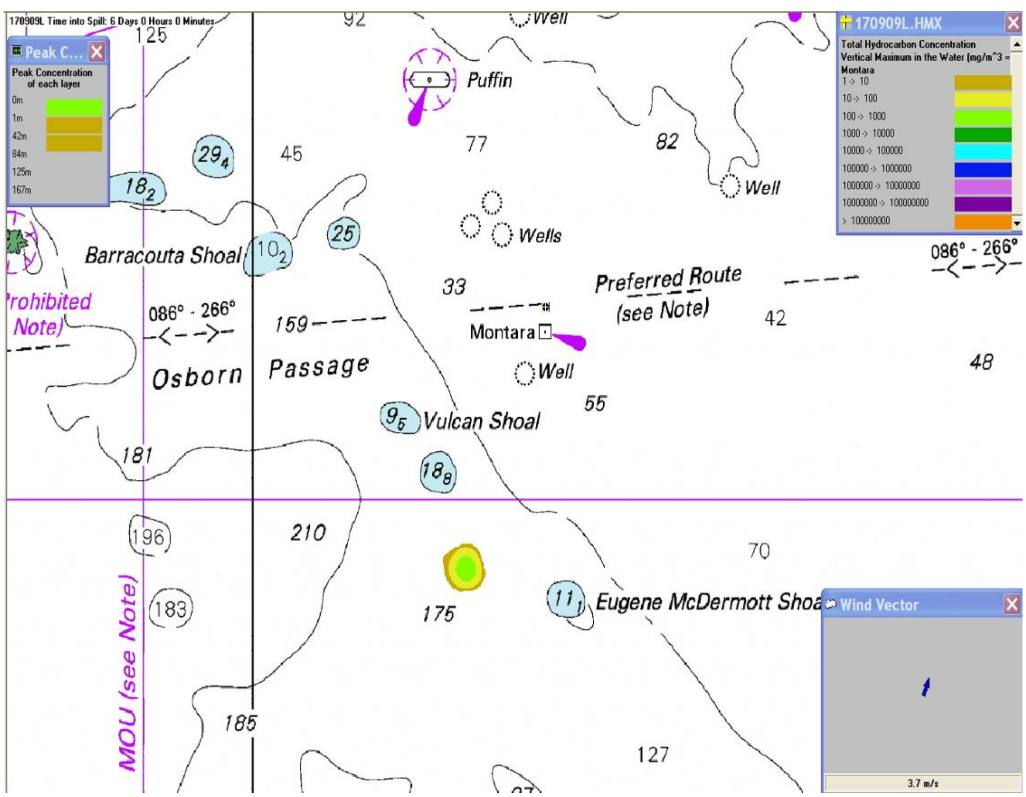
Figure 28: Maximum concentration of hydrocarbon at Goeree Shoal within layer 2 (1-40 metres)

Table 14: Maximum concentrations of hydrocarbon at depths at any location

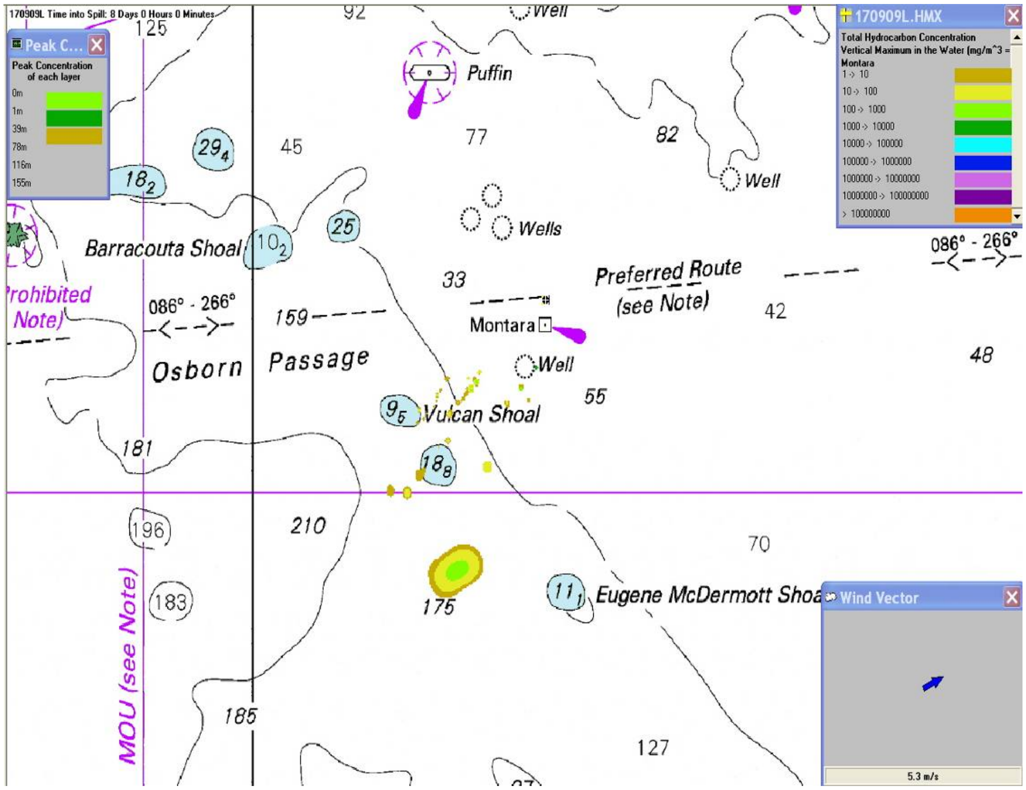
Layer	**Max concentration at any location (max concentration found immediately after dispersant event)** **ppm**
Layer 1 (<1m)	70 (caused by a natural dispersion event) 0.98 (caused by a chemical dispersion event)
Layer 2 (between 1m – 40m)	3.4 (caused by a natural dispersion event) 0.045 (caused by chemical dispersion event)



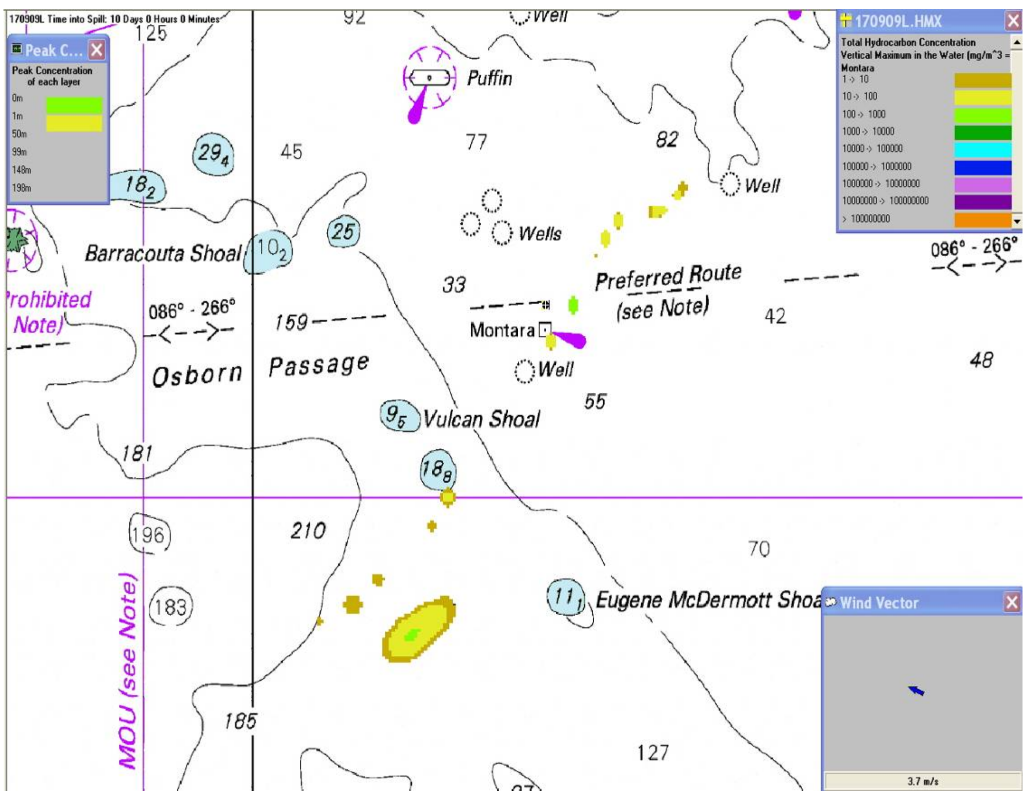
2 days after dispersant event (19/09/09)



4 days after dispersant event (21/09/09)



6 days after dispersant event (23/09/09)



8 days after dispersant event (25/09/09)

Figure 29: Movement and concentration of dispersed oil plume in the water column after a dispersant event on the 17th September 2009

4.7 Dispersant Event 24th September 2009

Table 15 shows a summary of the statistics for the dispersant event on the 24th September 2009. In this scenario the dispersed oil heads does not make contact with any underwater shoals as shown in Figure 31. Figure 30 indicates the maximum hydrocarbon concentration for all layers at any location in the grid for the 50% effectiveness scenario.

Table 15: Summary of results for dispersant event on the 24th September 2009

Parameter	50% dispersant effectiveness	100% dispersant effectiveness
Amount of dispersant used (L)	5500	
Current file used (validated)	Bluelink + tides	
Maximum concentration (ppm)	1.03	2.07
Average concentration over 96 hours after dispersant event (ppm)	0.19	0.37
Concentration of hydrocarbons 4 days after dispersant event (ppm)	0.03	0.04
Concentration of hydrocarbons 9 days after dispersant event (ppm)	0.12	0.07

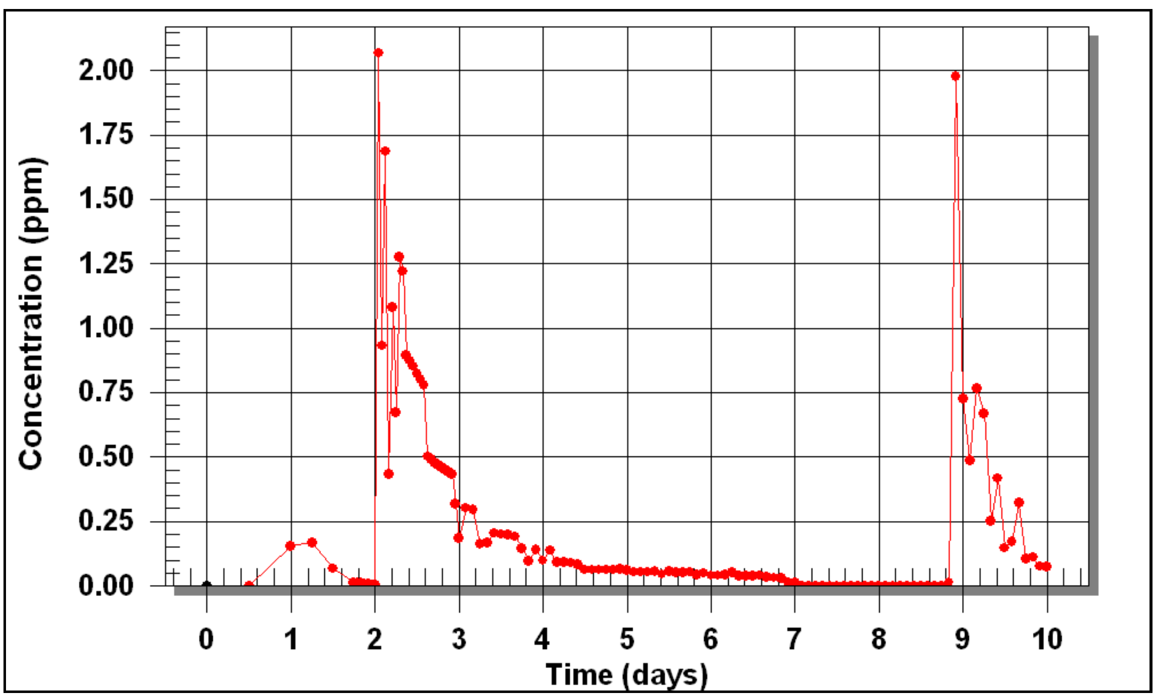
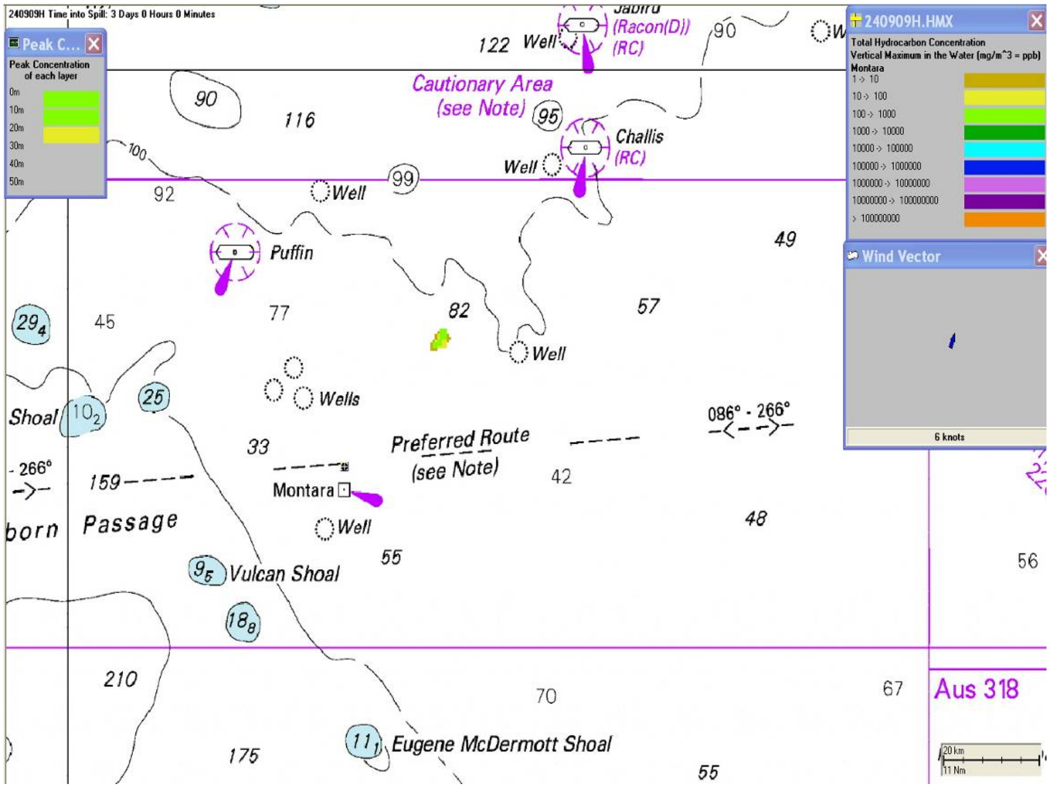
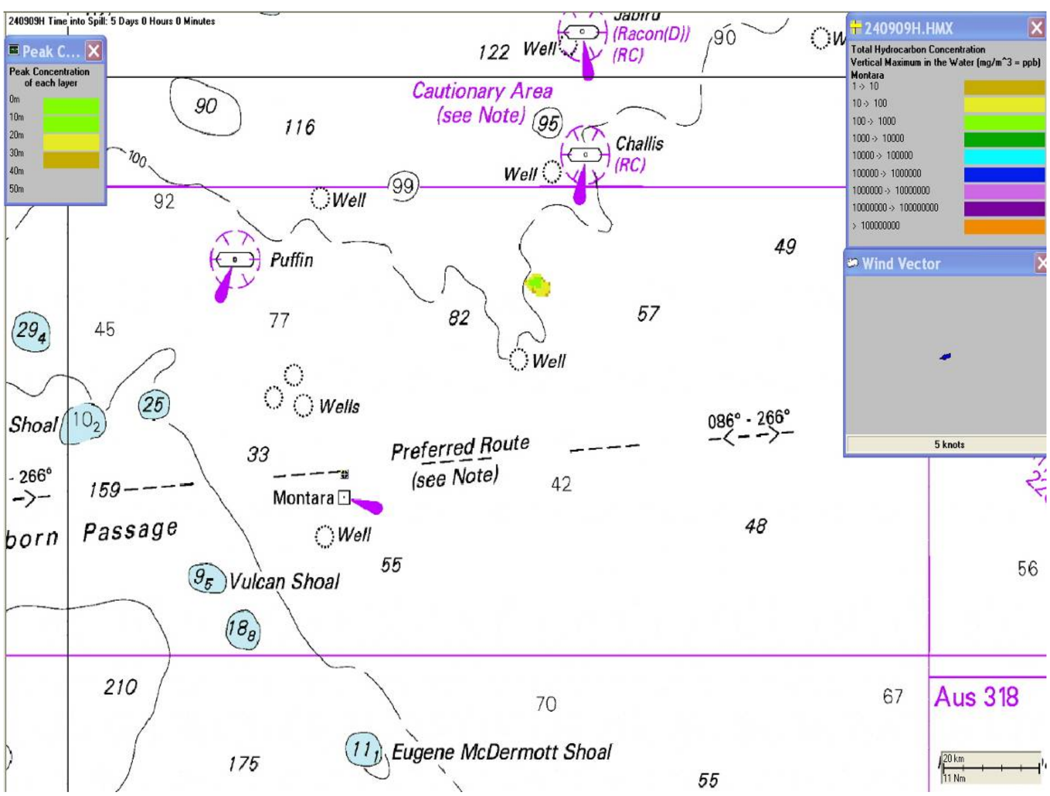


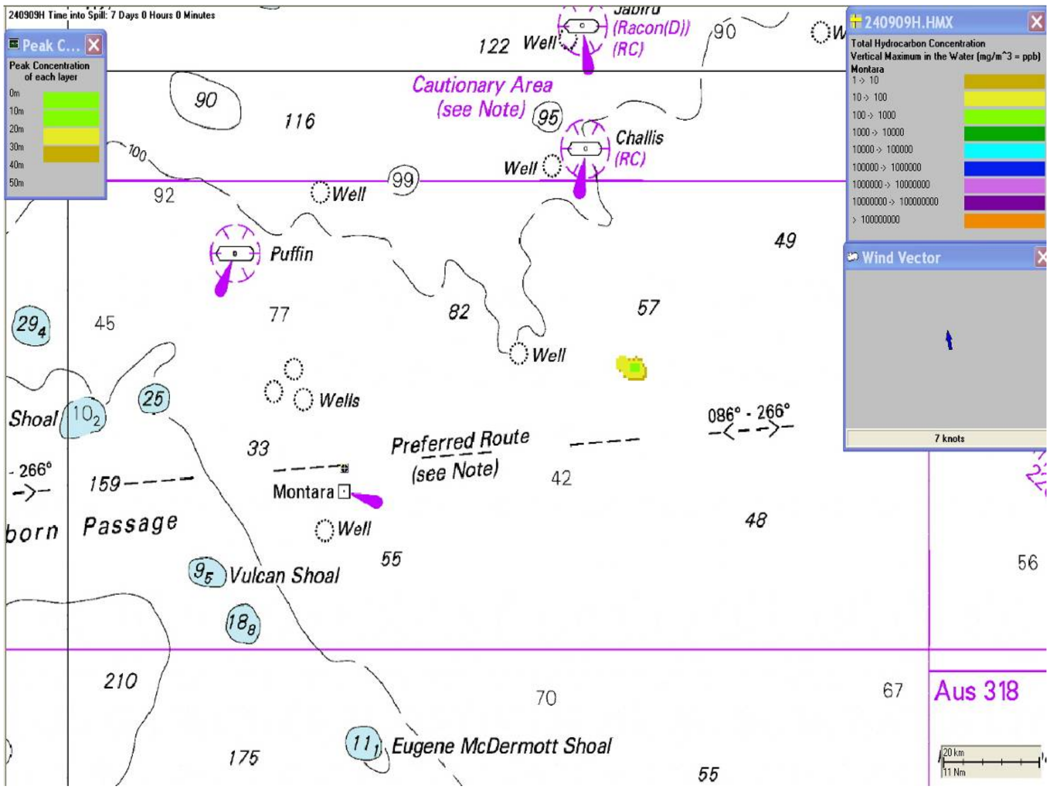
Figure 30: Maximum hydrocarbon concentration at any location, and at any depth within the model domain for the 100%% dispersant effectiveness scenario after a dispersant event on the 24th September 2009



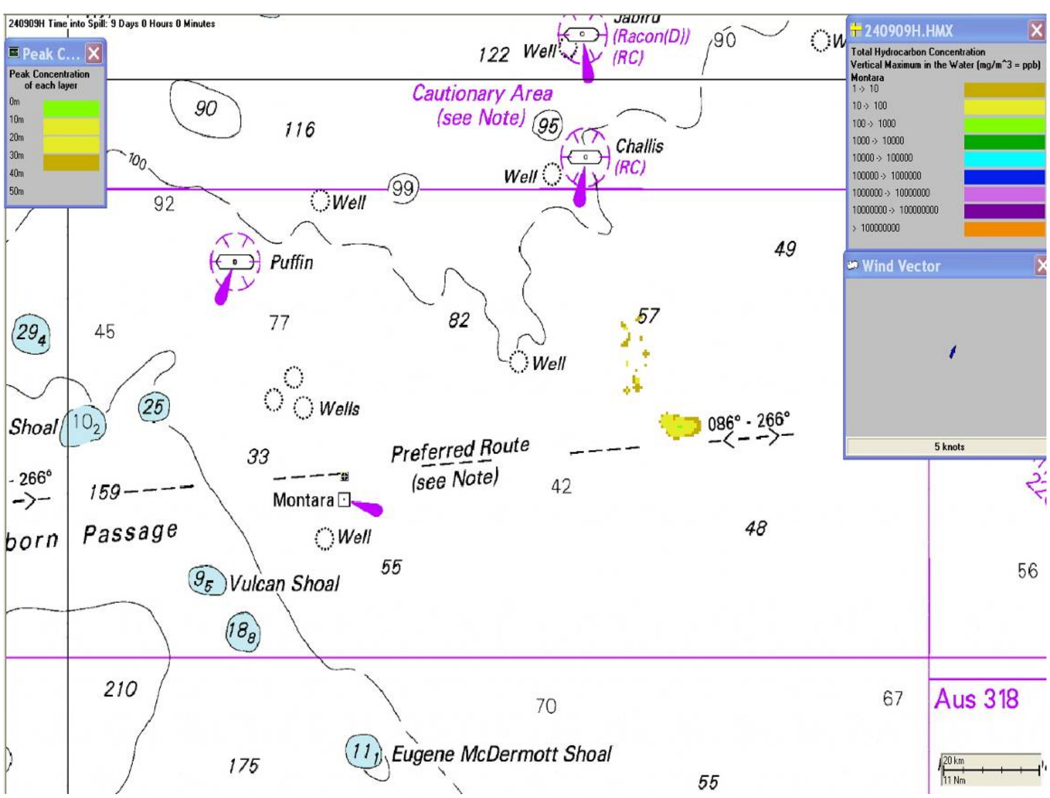
2 days after dispersant event (26/09/09)



4 days after dispersant event (28/09/09)



6 days after dispersant event (30/09/09)



8 days after dispersant event (02/10/09)

Figure 31: Movement and concentration of dispersed oil plume in the water column after a dispersant event on the 24th September 2009

4.8 Dispersant Event 1st October 2009

Table 16 shows a summary of the statistics for the dispersant event on the 1st October 2009. In this scenario the dispersed oil heads directly in a North-north-westerly direction and does not make contact with any underwater shoals as shown in Figure 33. Figure 32 indicates the maximum hydrocarbon concentration for all layers at any location in the grid for the 50% effectiveness scenario.

Table 16: Summary of results for dispersant event on the 1st October 2009

Parameter	50% dispersant effectiveness	100% dispersant effectiveness
Amount of dispersant used (L)	7250	
Current file used (validated)	Bluelink + tides	
Maximum concentration (ppm)	1.72	3.48
Average concentration over 96 hours after dispersant event (ppm)	0.56	0.77
Concentration of hydrocarbons 4 days after dispersant event (ppm)	0.17	0.21
Concentration of hydrocarbons 9 days after dispersant event (ppm)	0.06	0.08

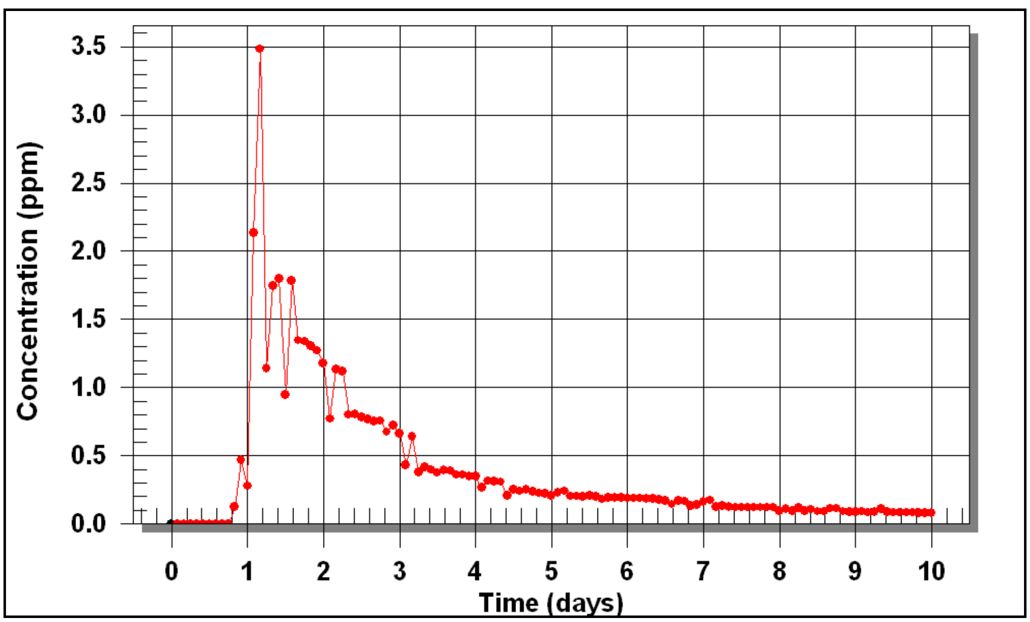
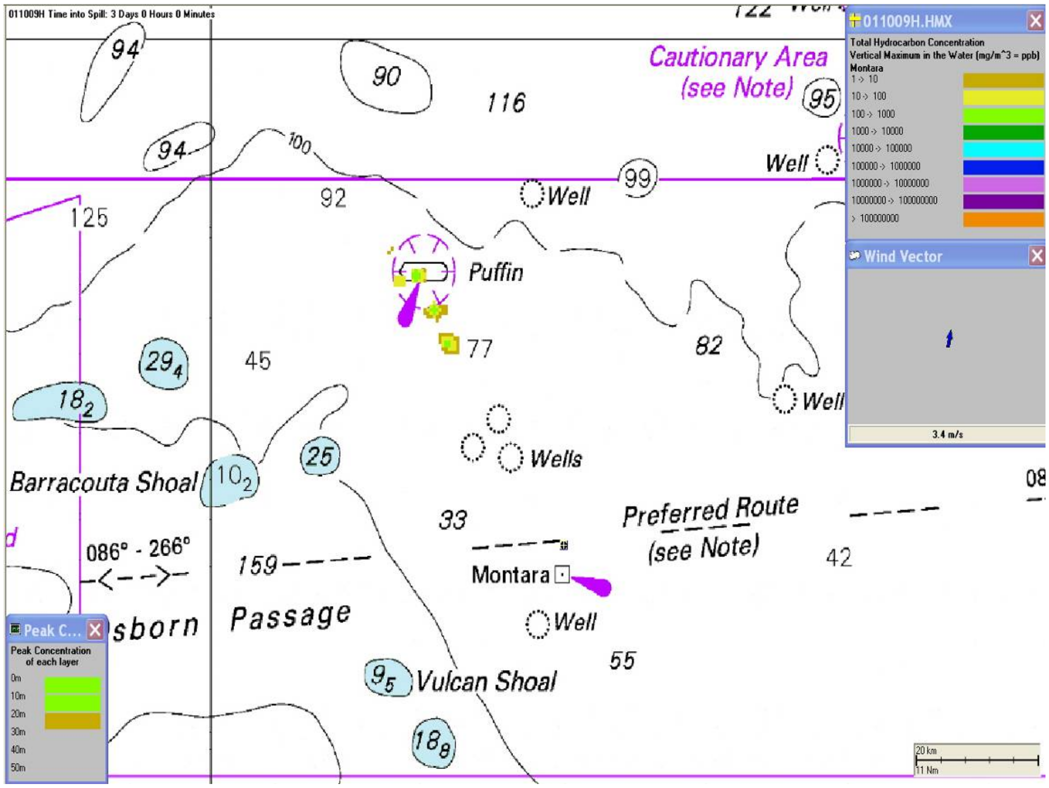
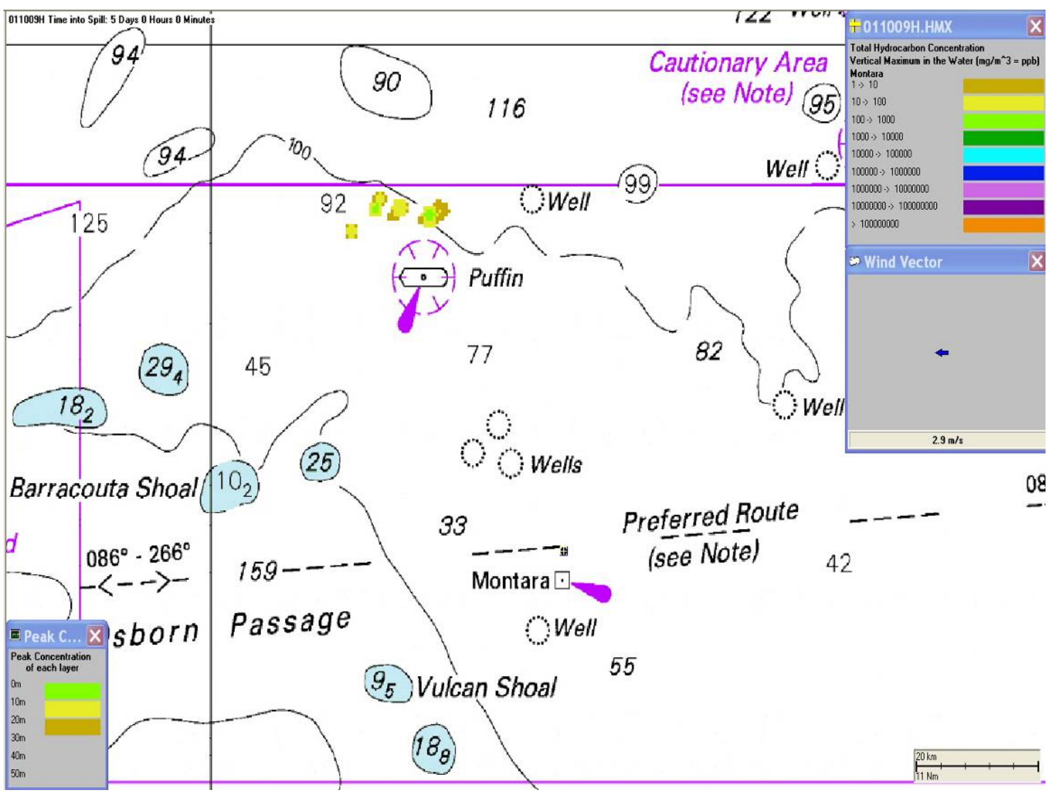


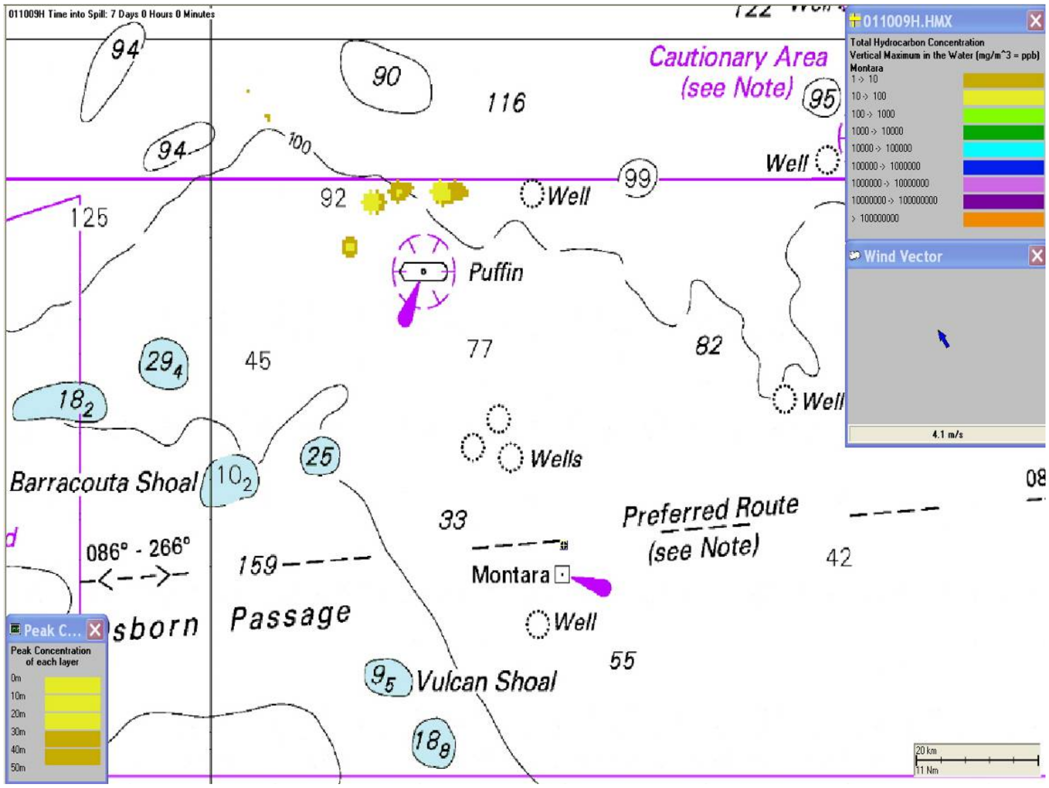
Figure 32: Maximum hydrocarbon concentration at any location, and at any depth within the model domain for the 100% dispersant effectiveness scenario after a dispersant event on the 1st October 2009



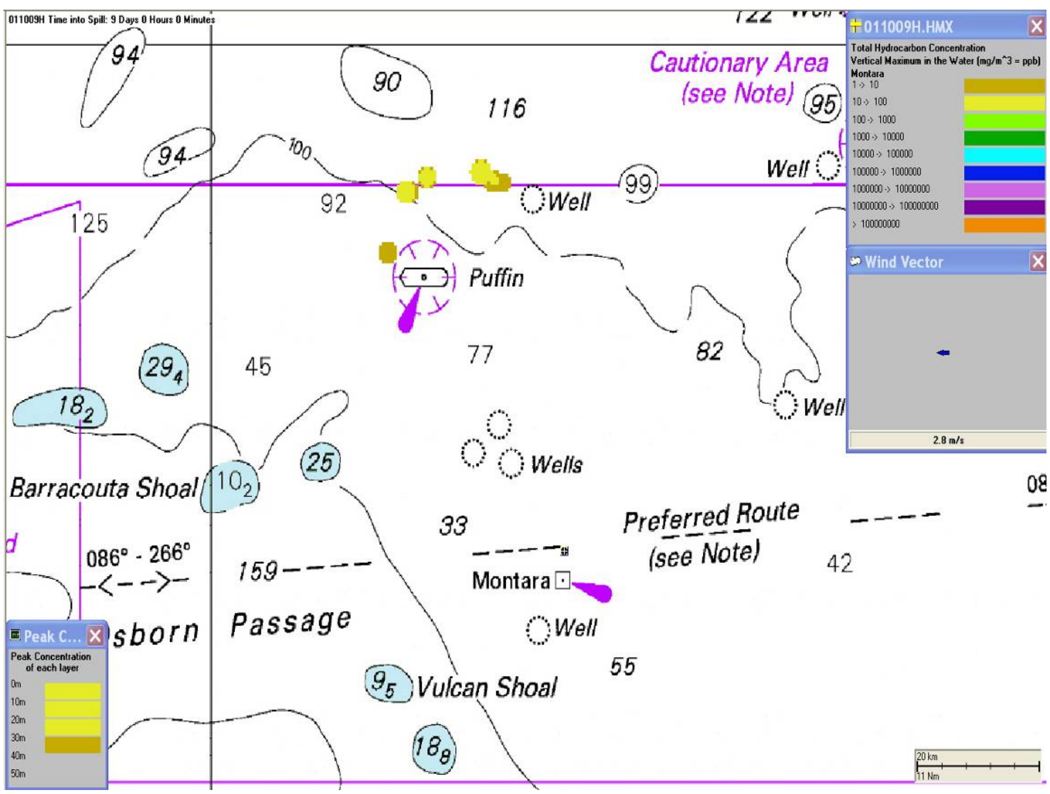
2 days after dispersant event (03/10/09)



4 days after dispersant event (05/10/09)



6 days after dispersant event (07/10/09)



8 days after dispersant event (09/10/09)

Figure 33: Movement and concentration of dispersed oil plume in the water column after a dispersant event on the 1st October 2009

4.9 Dispersant Event 6th October 2009

Table 17 shows a summary of the statistics for the dispersant event on the 6th October 2009. In this scenario the dispersed oil heads directly in a South-Westerly direction and does not make contact with any underwater shoals as shown in Figure 35. Figure 34 indicates the maximum hydrocarbon concentration for all layers at any location in the grid for the 50% effectiveness scenario.

Table 17: Summary of results for dispersant event on the 6th October 2009

Parameter	50% dispersant effectiveness	100% dispersant effectiveness
Amount of dispersant used (L)	4500	
Current file used (validated)	Bluelink + tides	
Maximum concentration (ppm)	2.93	2.96
Average concentration over 96 hours after dispersant event (ppm)	0.54	0.63
Concentration of hydrocarbons 4 days after dispersant event (ppm)	0.10	0.20
Concentration of hydrocarbons 9 days after dispersant event (ppm)	0.06	0.06

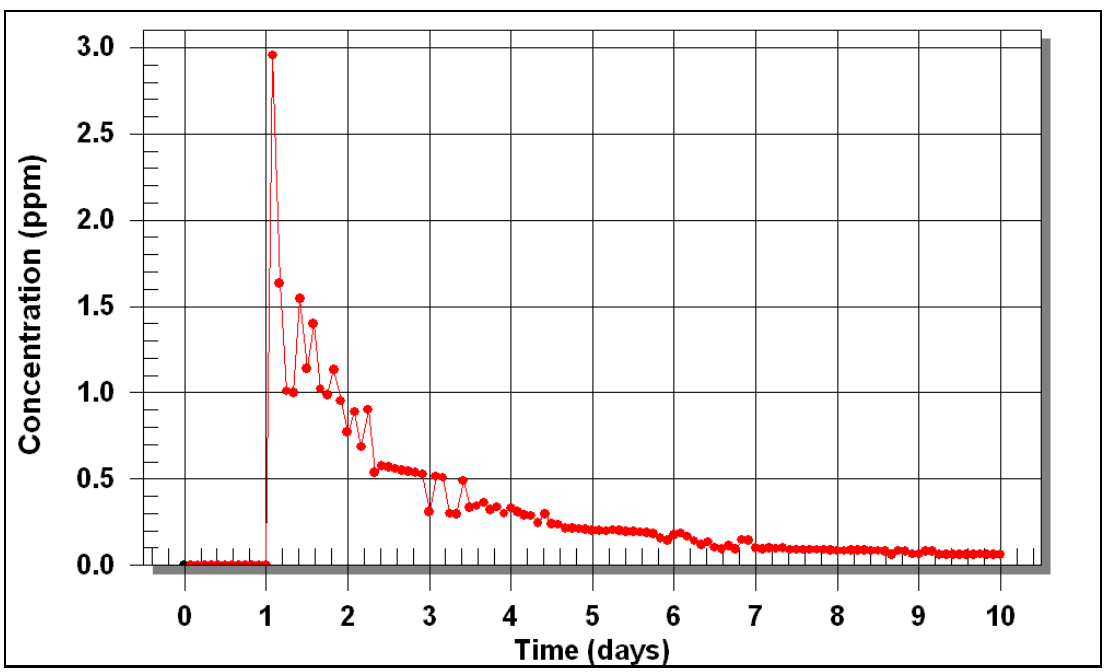
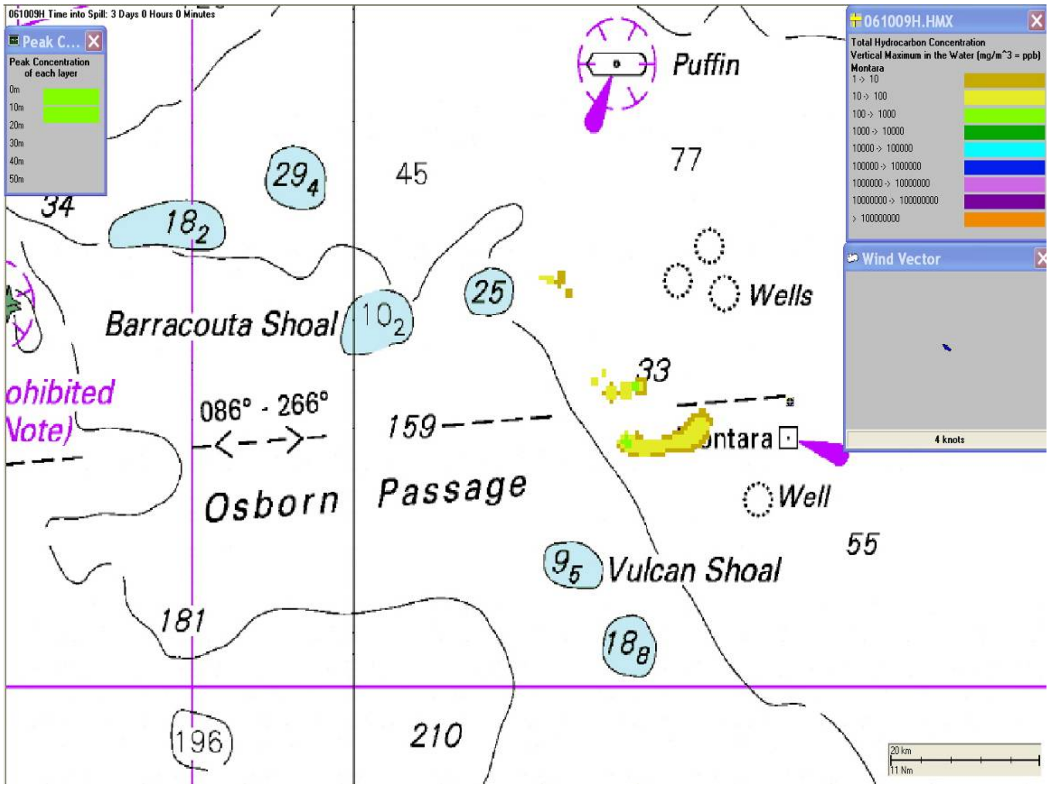
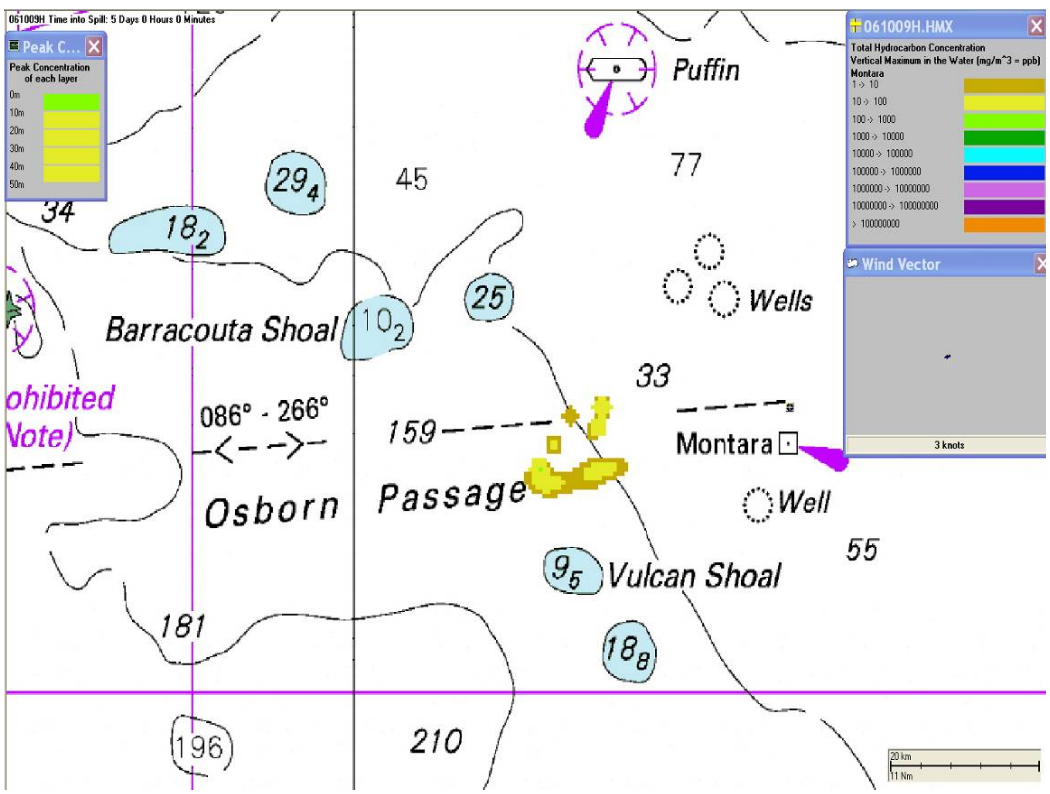


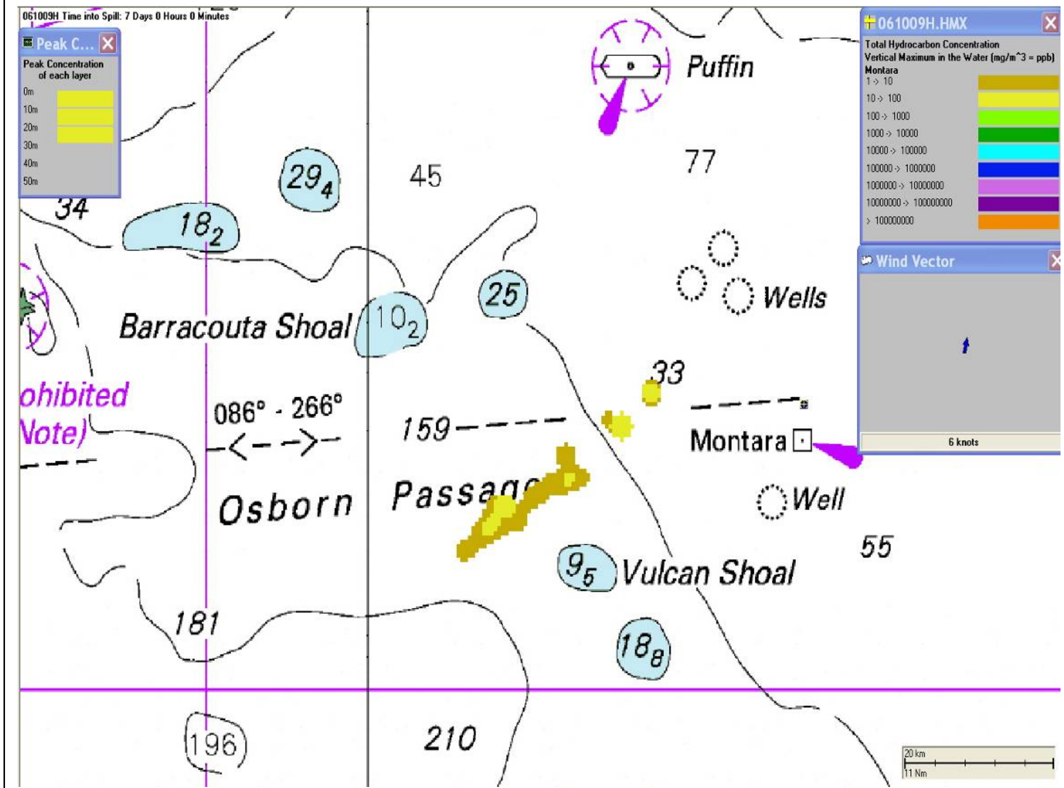
Figure 34: Maximum hydrocarbon concentration at any location, and at any depth within the model domain for the 100% dispersant effectiveness scenario after a dispersant event on the 6th October 2009



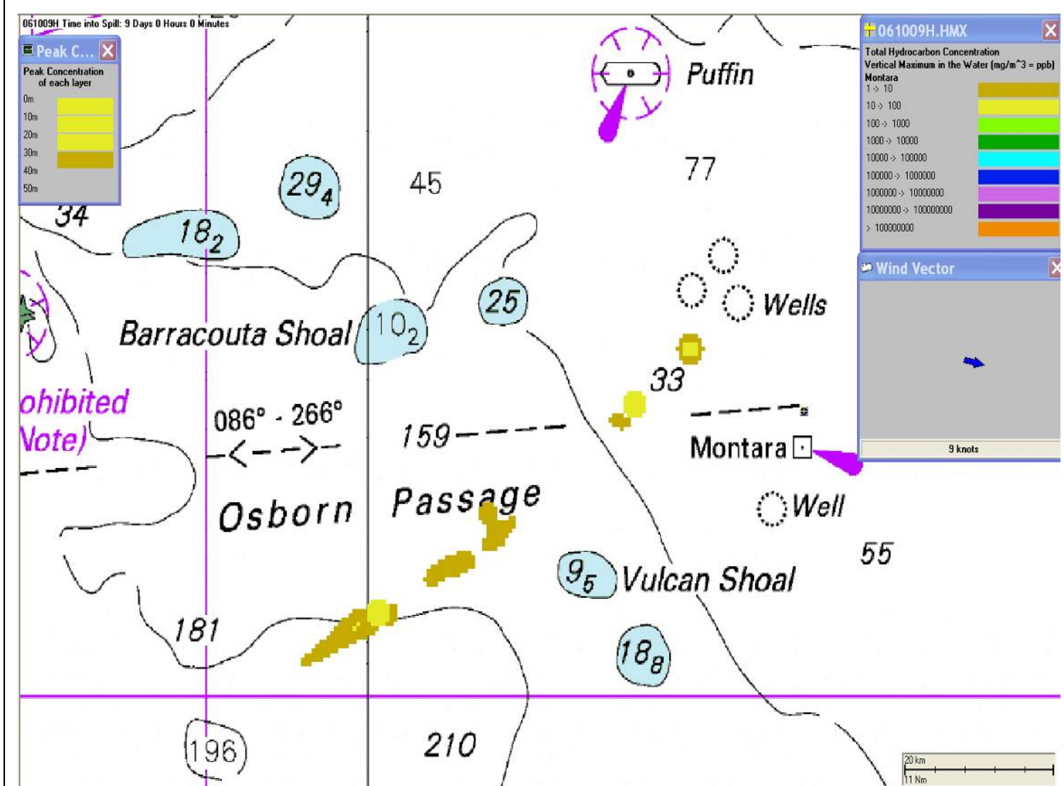
2 days after dispersant event (08/10/09)



4 days after dispersant event (10/10/09)



6 days after dispersant event (12/10/09)



8 days after dispersant event (14/10/09)

Figure 35: Movement and concentration of dispersed oil plume in the water column after a dispersant event on the 6th October 2009

4.10 Dispersant Event 8th October 2009

Table 18 shows a summary of the statistics for the dispersant event on the 8th October 2009. In this scenario the dispersed oil travels directly in a South-Westerly direction and does not make contact with any underwater shoals as shown in Figure 37. Figure 36 indicates the maximum hydrocarbon concentration for all layers at any location in the grid for the 50% effectiveness scenario.

Table 18: Summary of results for dispersant event on the 8th October 2009

Parameter	50% dispersant effectiveness	100% dispersant effectiveness
Amount of dispersant used (L)	5000	
Current file used (validated)	Bluelink + tides	
Maximum concentration (ppm)	1.18	1.26
Average concentration over 96 hours after dispersant event (ppm)	0.28	0.37
Concentration of hydrocarbons 4 days after dispersant event (ppm)	0.14	0.14
Concentration of hydrocarbons 9 days after dispersant event (ppm)	0.30	0.53

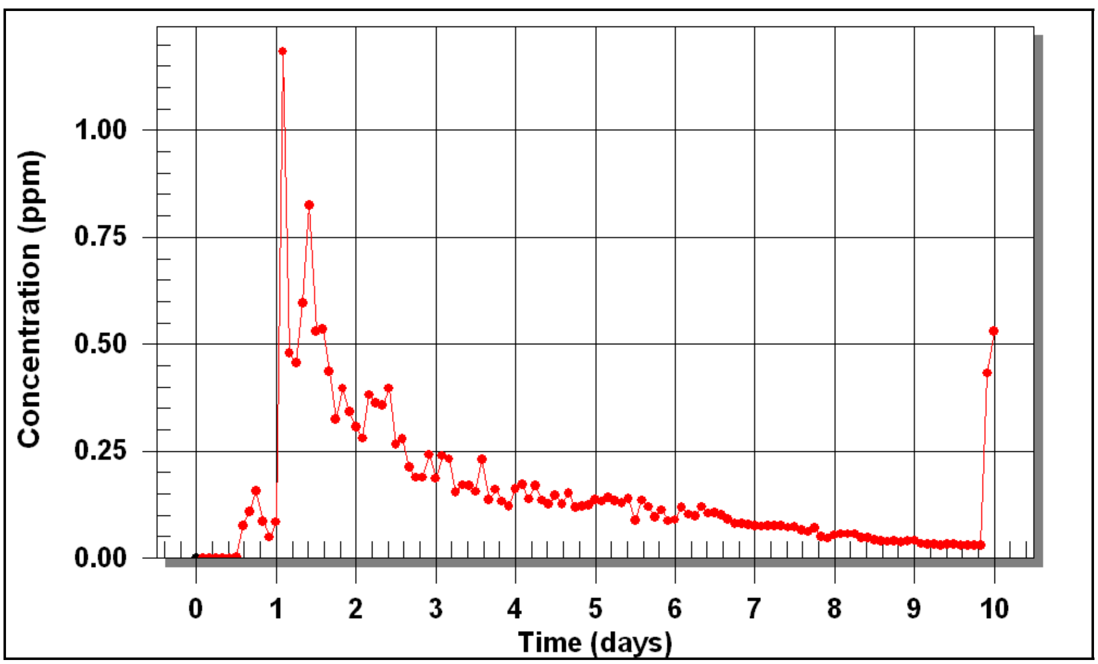
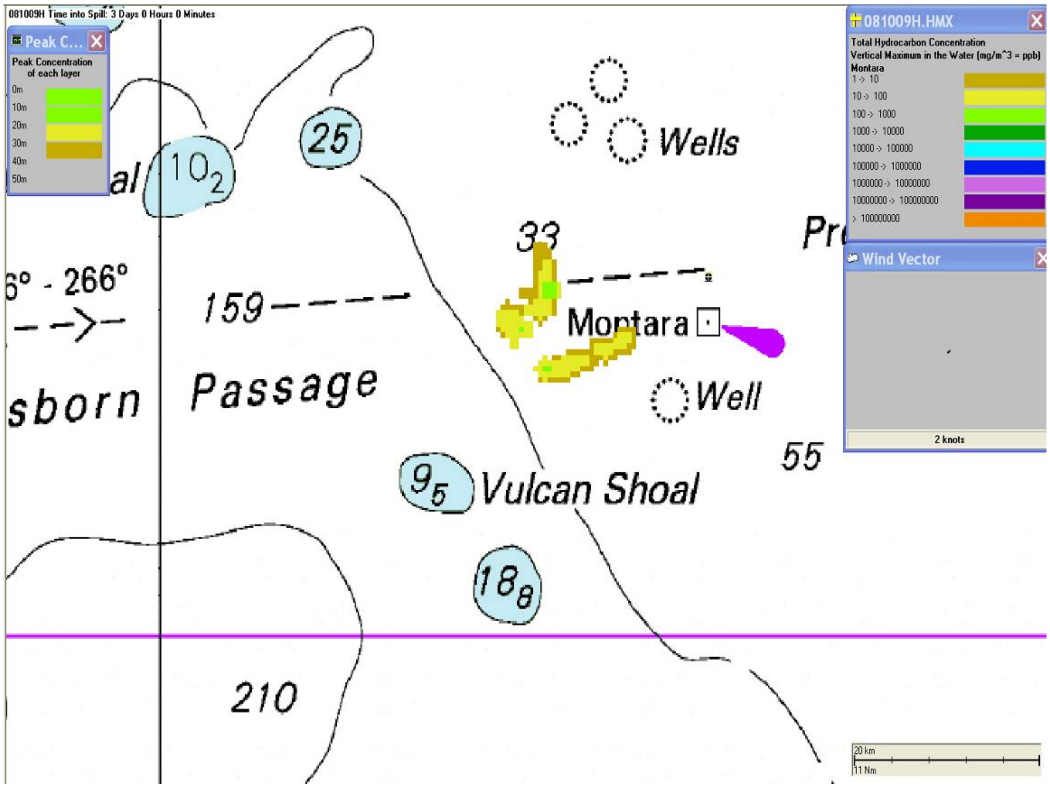
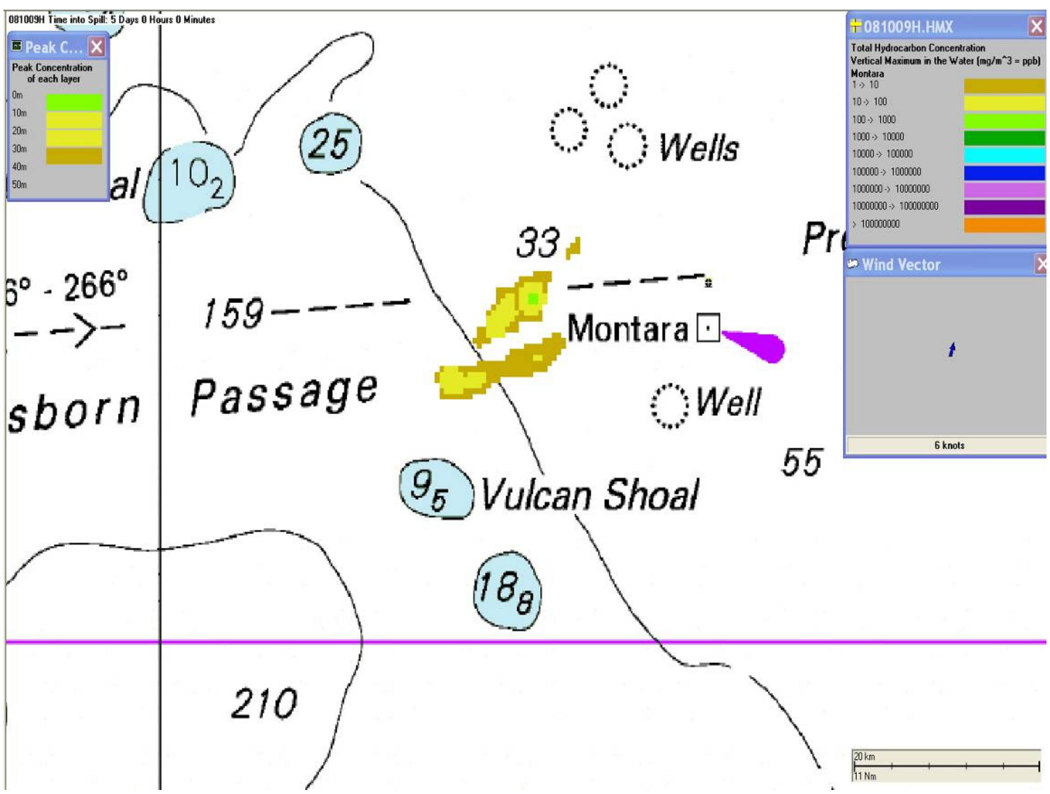


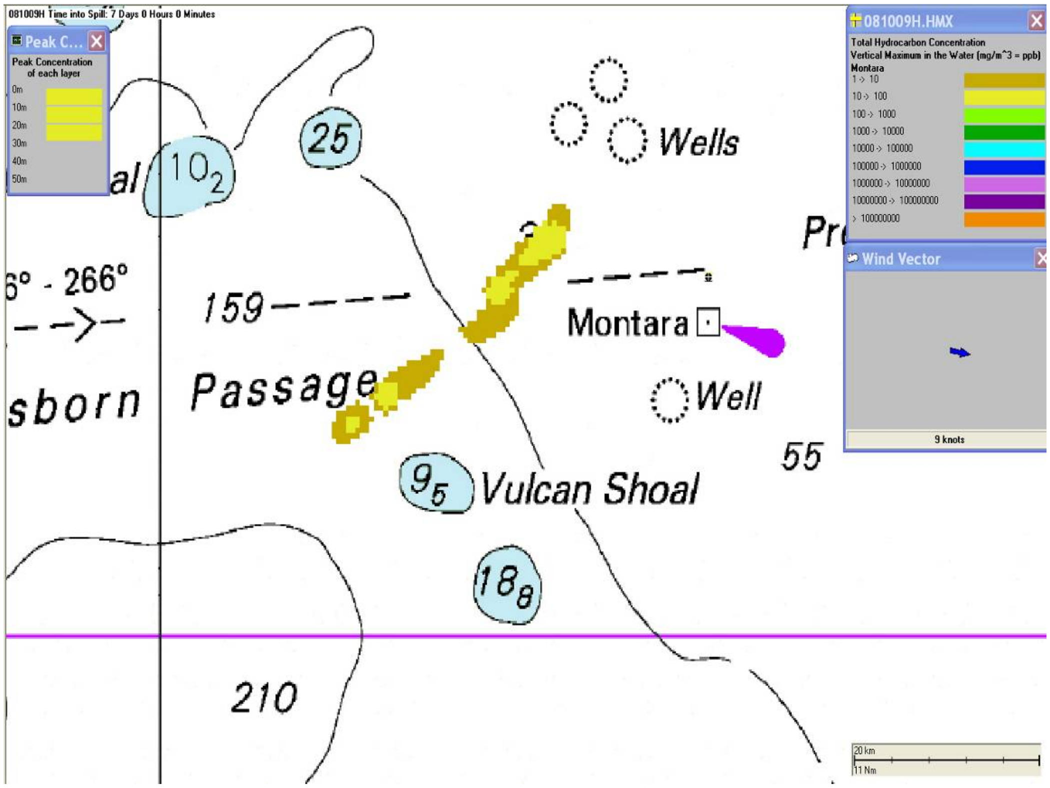
Figure 36: Maximum hydrocarbon concentration at any location, and at any depth within the model domain for the 100% dispersant effectiveness scenario after a dispersant event on the 8th October 2009



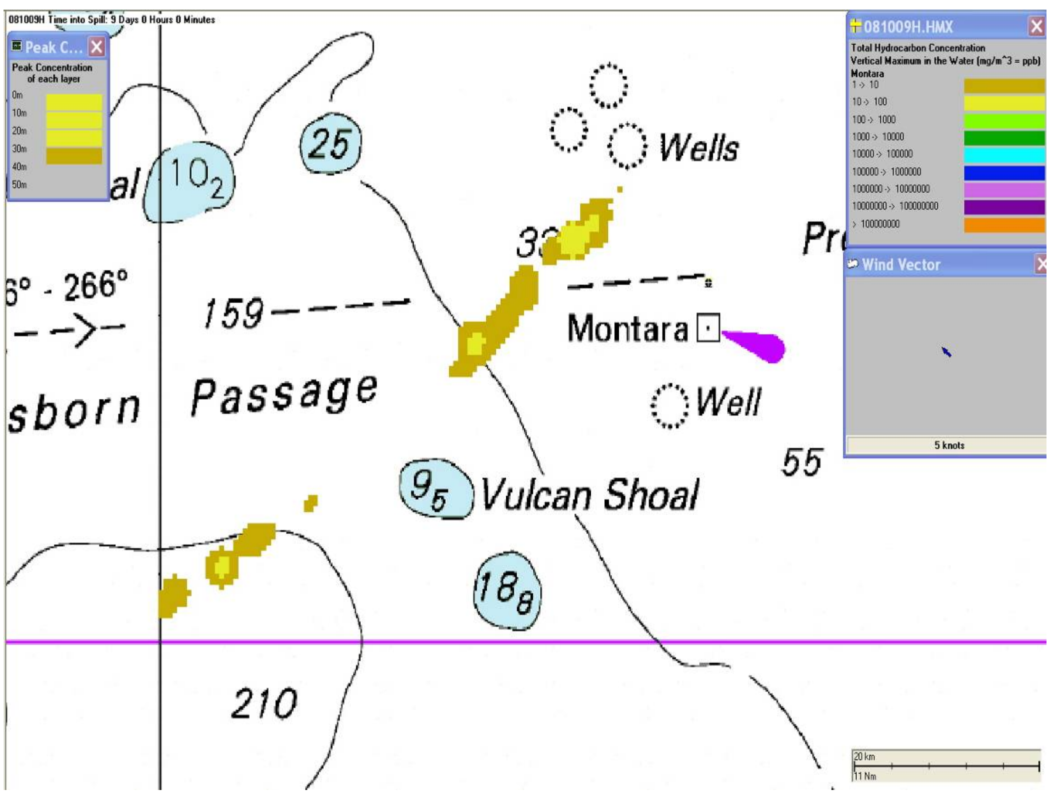
2 days after dispersant event (10/10/09)



4 days after dispersant event (12/10/09)



6 days after dispersant event (14/10/09)



8 days after dispersant event (16/10/09)

Figure 37: Movement and concentration of dispersed oil plume in the water column after a dispersant event on the 8th October 2009

4.11 Dispersant Event 10th October 2009

Table 19 shows a summary of the statistics for the dispersant event on the 10th October 2009. In this scenario the dispersed oil initially heads in a North-Westerly direction before oscillating back and forth with the tidal currents. It does not make contact with any underwater shoals as shown in Figure 39. Figure 38 indicates the maximum hydrocarbon concentration for all layers at any location in the grid for the 50% effectiveness scenario.

Table 19: Summary of results for dispersant event on the 10th October 2009

Parameter	50% dispersant effectiveness	100% dispersant effectiveness
Amount of dispersant used (L)	4000	
Current file used (validated)	Bluelink + tides	
Maximum concentration (ppm)	1.56	1.71
Average concentration over 96 hours after dispersant event (ppm)	0.55	0.9
Concentration of hydrocarbons 4 days after dispersant event (ppm)	0.17	0.3
Concentration of hydrocarbons 9 days after dispersant event (ppm)	0.06	0.12

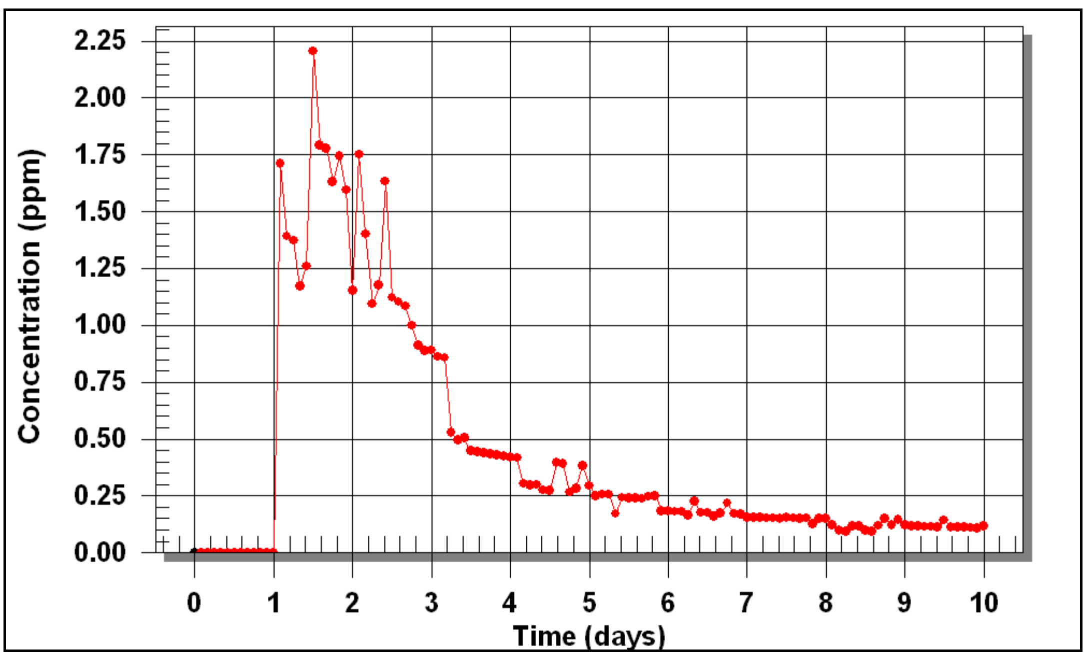
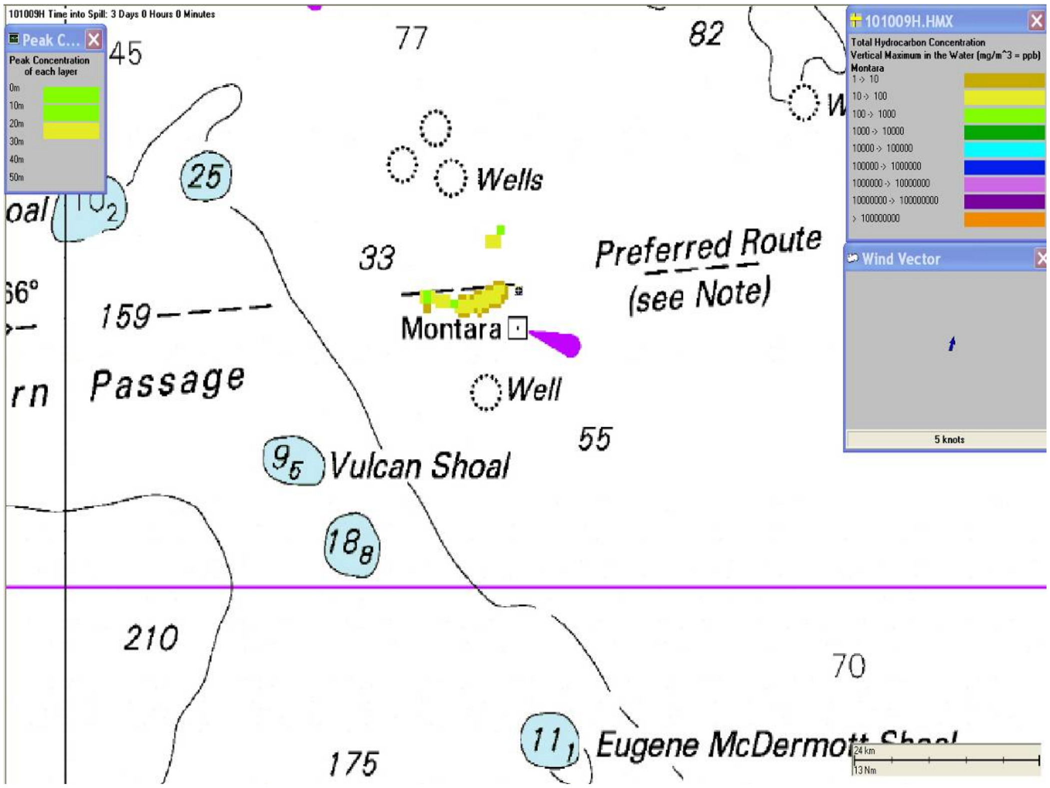
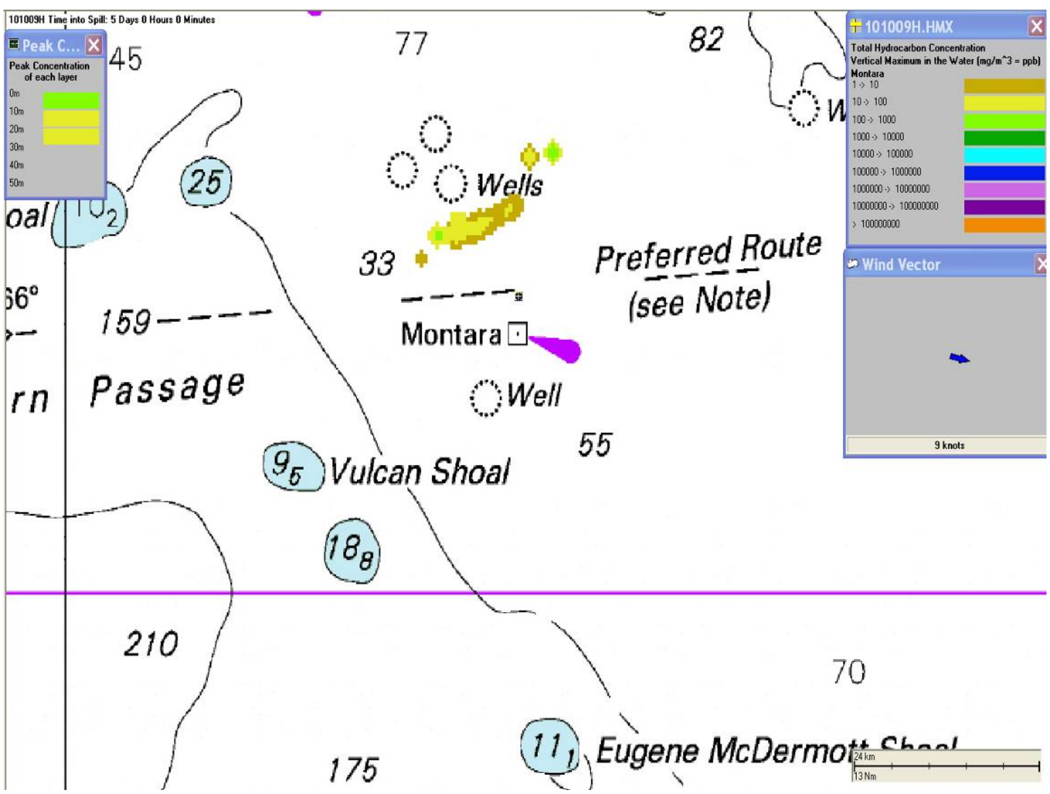


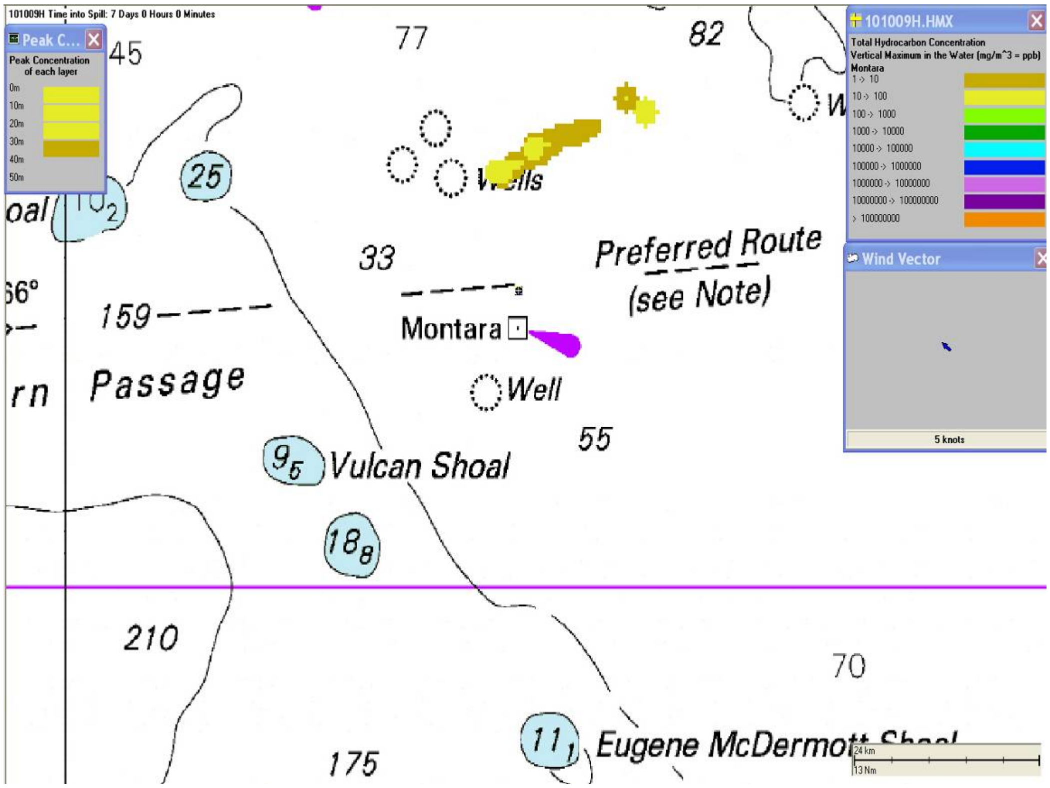
Figure 38: Maximum hydrocarbon concentration at any location, and at any depth within the model domain for the 100% dispersant effectiveness scenario after a dispersant event on the 10th October 2009



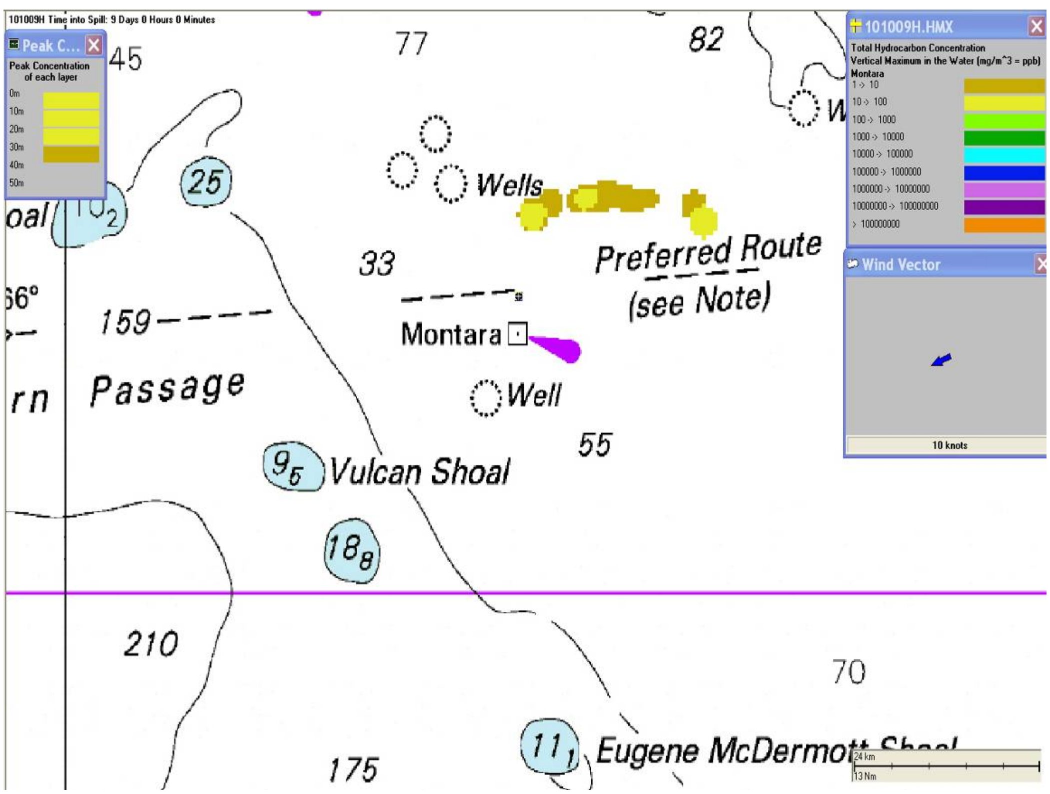
2 days after dispersant event (12/10/09)



4 days after dispersant event (14/10/09)



6 days after dispersant event (16/10/10)



8 days after dispersant event (18/10/09)

Figure 39: Movement and concentration of dispersed oil plume in the water column after a dispersant event on the 10th October 2009

5 DISCUSSION

The results of the 3D modelling of the dispersant events indicate that the chemical dispersant caused elevations in hydrocarbon concentrations in the water column, mostly within the first metre of the water column. The concentration of hydrocarbons reduced quickly with time, depth and distance from the dispersant application site.

It was found that at depths of over one metre, the dispersed oil plume would reduce below concentrations of 0.010 ppm or 10 ppb at a distance of 70 km from the dispersant application site indicating a localized concentration of hydrocarbons centered around the spill site.

The results of this 3D modelling study are in line with the laboratory results from the AMSA 02.03 (AMSA 2009) report. The average and maximum peak concentrations fall within the range that was analysed in the laboratory where TPH (total petroleum hydrocarbon) levels reached a high of 3.5 ppm at one metre depth (see Figure 1, AMSA 2009). The maximum hydrocarbon concentrations found with 3D modelling was 3.48 ppm (worst case scenario). This peak event was due to the lower advection and mixing associated with neap tides that occurred at this time.

The duration of exposure is also consistent with the AMSA 02.03 report which states that "the chemical analysis of sampled waters suggest that concentrations of dispersed oil below treated slicks are low (<5 ppm) and are rapidly diluted over depth and time (to <1 ppm)". The 3D modelling conducted for this study indicates that 4 days after the dispersant was applied, hydrocarbon concentrations in the water column were found to be below 1 ppm in all the dispersant events modeled and analysed. An average concentration was calculated over the 4 days (96 hours) after the dispersant event. All the dispersant events had 4 day averages less than 1 ppm of HYDROCARBON concentrations.

Three dispersant events created elevated concentrations of hydrocarbons over submerged shoals. The 3D modelling demonstrated that the concentrations reached (at the depth of the shoal) were very low (< 0.010 ppm or < 10 ppb) and for durations of less than 18 hours. The modelling also demonstrated that the highest concentration of hydrocarbons after a dispersant event would be within the first metre of the water column, directly after a dispersion event and would naturally dilute rapidly with both time and depth.

Even in the worst case scenario of 100% dispersant effectiveness the hydrocarbon concentrations in the water column caused by the chemical dispersant were considered to be low in comparison to hydrocarbon concentrations in the water column caused by natural dispersion events, and also in comparison to the overboard discharge clean water specifications of 30 mg/L daily oil content (Petroleum (Submerged Lands) (Management of Environment) Regulation 1999).

The eleven chemical dispersant events were chosen as a representation of the worst case dispersant application events (either in terms of maximum dispersant volume, proximity to shoals, or maximum areal extent) that took place during the response to the Montara WHP oil spill response. In summary, the effect of the addition of the chemical dispersant to the oil spill of the Montara WHP caused elevations in hydrocarbon concentrations in the water column that were extremely localized and of short duration.

6 REFERENCES

AMSA, 2009. Montara Well Release Timor Sea. Operational Monitoring Study 02. Monitoring of Oil Character Fate and Effects. Report 03 Dispersant Treated Oil Distribution. Document Number AMSA 02-03. November 8th 2009.

Barron, C. N., Rhodes, R. C., Smedstad, L. F., Rowley, C. D., and P. J. Martin., 2003. Global ocean nowcasts and forecasts with the Navy Coastal Ocean Model". Ocean Science and Technology, *NRL Review*: 175-178.

Barron, C. N., Kara, B., Rhodes, R., Rowley, C., and L. Smedstad., 2007. Validation test report for the 1/8^{o} global navy coastal ocean model forecast system. A report by the Naval Research Laboratory NRL/MR/7320—070-9019.

Burns, K., Codi, S., Furnas, M., Heggie, D., Holdway, D., King, B., F. McAllister, 1999. Dispersion and Fate of Produced Formation Water Constituents in an Australian Northwest Shelf Shallow Water Ecosystem. *Mar. Pollut. Bull*., 38 (7): 593-603.

Davies, A.M 1977. The Numerical Solution of the Three-Dimensional Hydrodynamic Equations, Using a B-spline Representation of the Vertical Current Profile. *Elsevier Oceanography Series*, *Volume 19*, *1977*, *Pages 1-25*

Davies, A.M 1977. Three-Dimensional Model with Depth-Varying Eddy Viscosity *Elsevier Oceanography Series*, *Volume 19*, *1977*, *Pages 27-48*

Environment Australia. 2007. Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve Management Plans. Dept of Environment and Heritage. Federal Register of Legislative Instruments F2007/B00982

Fox, A., Haines, K., De Cuevas, B., and D. Webb., 2002. Altimeter Assimilation in the OCCAM Global Model, Part II: TOPEX/POSEIDON and ERS1 Data. *J. Marine Syst.*, 26: 323-347.

Gordon, W.B. A uniform asymptotic analysis of dispersive wave motion across a space-time shadow boundary. *Wave Motion*, *Volume 4, Issue 4*, *October 1982*, *Pages 349-369*

Gulec, I. and D. A. Holdway. 2000. Toxicity of crude oil and dispersed crude oil to ghost shrimp *Palaemon serenus* and larvae of Australian bass *Macquaria novemaculeata*. Enivonmental Toxicology 15:2: pp91-98.

Isaji, T. and M. Spaulding, 1984. A Model of the Tidally Induced Residual Circulation in the Gulf of Maine and Georges Bank, published in: *J. Phys. Ocean*., 14: 1119-1126.

King, B. and F.A. McAllister, 1998. Modelling the dispersion of produced water discharges. *APPEA Journal. 681-691*.

Martin, P.J., G. Peggion, and K.J. Yip, (1998): A comparison of several coastal ocean models.NRL Report No. NRL/FR/7322/97/9692, 96pp. [Available from NRL, Code7322, Bldg. 1009, Stennis Space Center, MS 39529-5004, USA.]

Martin, P.J., (2000): Description of the Navy Coastal Ocean Model Version 1.0. NRL Report No. NRL/FR/7322/00/9962, 45pp. [Available from NRL, Code7322, Bldg. 1009, Stennis Space Center, MS 39529-5004, USA.]

Petroleum (Submerged Lands) (Management of Environment) Regulations 1999. Federal Register of Legislative Instruments F2005C00878.

PTTEPAA. 2009. Monitoring Plan for the Montara Well Release, Timor Sea as agreed between PETTEP Australasia (Ashmore Cartier) Pty. Ltd. and the Department of the Environment, Water Heritage and the Arts.

Owen, A., 1980. A three-dimensional model of the Bristol Channel. *Journal of Physical Oceanography*., 10: 1290-1302

SINTEF 2008. Oil Spill Dispersants. SINTEF Applied Chemistry, Environmental Engineering. Norway

Zigic, S., M. Zapata., T. Isaji., B. King and C. Lemckert. 2003. Modelling of Moreton Bay using an ocean/coastal circulation model. *Coast and Ports Australiasian Conference, 9 -12 September Auckland, New Zealand, paper 170*.

7 APPENDIX A – SIMAP DESCRIPTION

SIMAP MODEL DESCRIPTION

Below are brief descriptions of the SIMAP fates and effects models. Detailed descriptions of the algorithms and assumptions in the model are in published papers (French McCay 2002, 2003, 2004). The model has been validated with more than 20 case studies, including the Exxon Valdez and other large spills (French and Rines, 1997; French McCay, 2003, 2004; French McCay and Rowe, 2004) as well as test spills (French et al., 1997).

The three-dimensional physical fates model estimates distribution (as mass and concentrations) of whole oil and oil components on the water surface, on shorelines, in the water column, and in sediments. Processes simulated include spreading (gravitational and by shearing), evaporation of volatiles from surface oil, transport on the surface and in the water column, randomized dispersion, emulsification, entrainment of oil as droplets into the water (natural and facilitated by dispersant), dissolution of soluble components, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended sediments, adsorption of soluble and semi-soluble aromatics to suspended sediments, sedimentation, stranding on shorelines, and degradation. The algorithms and assumptions of the 3-d fates model are described in French McCay (2004).

The biological effects model (French et al., 1996; French McCay, 2003, 2004, 2009) estimates short term (acute) exposure of biota of various behaviour types to floating oil and subsurface contamination (in water and subtidal sediments), resulting percent mortality, and sublethal effects on production (somatic growth). For each wildlife behaviour group, a portion of the animals in the area swept by surface oil over a threshold thickness is assumed to die, based on probability of encounter with the oil on the water surface multiplied by the probability of mortality once oiled. Toxicity to aquatic biota in the water column and subtidal sediments is estimated from dissolved aromatic concentrations and exposure duration, using laboratory-based bioassay data for oil hydrocarbon mixtures (French McCay, 2002). Losses are estimated by species or species group for fish, invertebrates and wildlife by multiplying percent loss by abundance.

References

French, D., M. Reed, K. Jayko, S. Feng, H. Rines, S. Pavignano, T. Isaji, S. Puckett, A. Keller, F. W. French III, D. Gifford, J. McCue, G. Brown, E. MacDonald, J. Quirk, S. Natzke, R. Bishop, M. Welsh, M. Phillips and B.S. Ingram, 1996. The Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), Technical Documentation. Final Report, submitted to the Office of Environmental Policy and Compliance, U.S. Dept. of the Interior, Washington, DC, April, 1996, Contract No. 14-0001-91-C-11.

French, D.P., and H. Rines, 1997. Validation and use of spill impact modeling for impact assessment. In: Proceedings, 1997 International Oil Spill Conference, Fort Lauderdale, Florida, American Petroleum Institute Publication No. 4651, Washington, DC, pp.829-834.

French, D.P., H. Rines and P. Masciangioli, 1997. Validation of an Orimulsion spill fates model using observations from field test spills. In: Proceedings of the Twentieth Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Vancouver, Canada, June 10-13, 1997, Emergencies Science Division, Environment Canada, Ottawa, Ontario, Canada, pp.933-961.

French McCay, D.P., 2002. Development and application of an oil toxicity and exposure model, OilToxEx. Environmental Toxicology and Chemistry 21(10): 2080-2094.

French McCay, D.P., 2003. Development and application of damage assessment modeling: Example assessment for the North Cape oil spill. Marine Pollution Bulletin, Volume 47, Issues 9-12, September-December 2003, pp. 341-359.

French McCay, D.P., 2004. Oil spill impact modeling: Development and validation. Environmental Toxicology and Chemistry 23(10): 2441-2456.

French McCay, D.P., and J.J. Rowe, 2004. Validation of the SIMAP Oil Spill Model Using Historical Oil Spill Cases. In Proceedings of the 27th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada, pp. 421-452.

French-McCay, D.P, 2009. State-of-the-Art and Research Needs for Oil Spill Impact Assessment Modeling. In Proceedings of the 32nd AMOP Technical Seminar on Environmental Contamination and Response, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada, pp. 601-653.

8 APPENDIX B: CURRENT AND WIND MODELS

Tides

HYDROMAP's model formulations and predicted current (current speed/direction) and sea levels outputs have been verified through various field investigations globally during the past 26 years (Isaji and Spaulding,1984; Zigic et al., 2003). In fact, HYDROMAP tidal current data has been used as input to forecast (in the future) and hindcast (in the past) previous spills in Australian waters and forms part of the Australian national oil spill emergency response system operated by AMSA. The model is also the hydrodynamic engine used by the Western Australian marine search and rescue system (WA Police).

The numerical solution methodology of HYDROMAP follows that of Davies (1977a, b) with further developments for model efficiency by Owen (1980) and Gordon (1982). A more detailed presentation of the model can be found in Isaji and Spaulding (1984).

Figure 40 shows a time-series graph of the predicted surface tidal current speed and direction from August to November 2009. The current speeds had an average and maximum of 0.286 m/s and 0.591 m/s, respectively. The major tidal axis at the site was essentially elliptical.

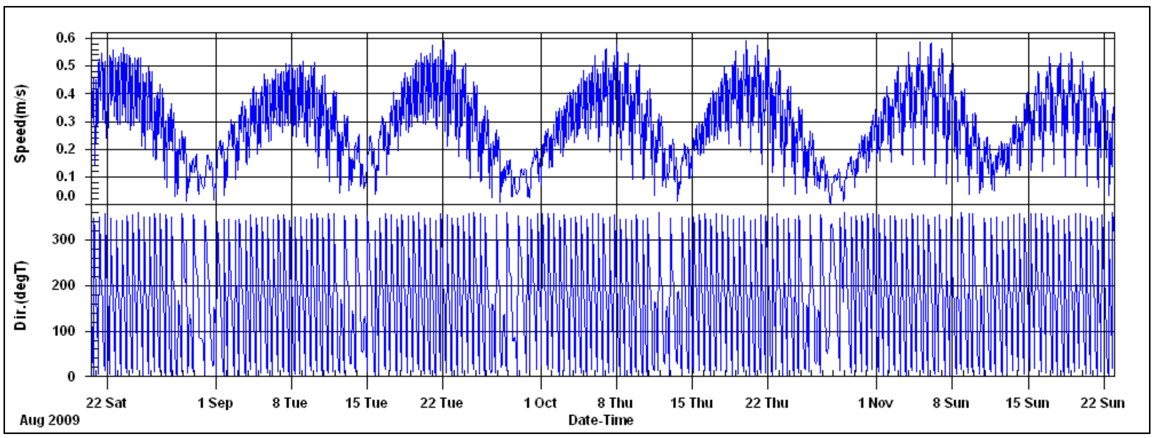


Figure 40: Time-series graph of the predicted surface tidal current speeds and directions for August to November (2009).

Satellite Derived Currents - Gridded Sea Level Anomaly Model

This dataset comprised of the Gridded Sea Level Anomaly (GSLA) deep ocean surface currents combined with the HYDROMAP tides. GSLA is primarily measured satellite derived data generated by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The GSLA model includes altimeter estimates of sea level mapped in near-real-time to a lat-long grid. The model takes into account the geostrophic surface velocity which would result from satellite measured sea-level anomalies. This dataset is typically daily, but mapped hourly onto the tidal component.

NCOM+Tides – Navy Coastal Ocean Model incorporating Tides

The NCOM+Tides dataset provides deep ocean and continental shelf surface currents from the USA Navy Coastal Ocean Model (NCOM) and HYDROMAP tides. NCOM is a relatively

new source of data that describes medium to large scale surface-currents over wide regions. There is a forecast version and a hindcast version. NCOM is a 1/8° global model developed at the U.S. Naval Research Laboratory (NRL) for transition to operations at the Naval Oceanographic Office (Barron et al., 2003). This dataset is typically 6 hourly, but mapped hourly onto the tidal component.

The physics and numerics of the NCOM model (Martin 2000) are fundamentally based on the Princeton Ocean Model (POM), with some features adopted from the Sigma/Z-level model (Martin et al., 1998) and a number of additional features. The boundary conditions for NCOM are hindcast winds, satellite measured sea levels, air temperature, water and salinity flux and solar radiation. The NCOM domain extends over continental shelves, coastal regions and the Arctic, providing global coverage with a minimum bottom depth of 5 m (Baron et al., 2007).

The model is spun-up from rest using surface and in-situ measured climatological data as initial conditions and forcings. The model data is then assimilated and compared to: mean sea surface height; kinetic energy; sea-surface temperature; and sea surface salinity with time series from tide gauge data, buoy data and Pathfinder sea surface temperature (SST) data (National Oceanic and Atmospheric Administration, National Oceanographic Data Center). The model has been validated for numerous locations around the world (Barron et al., 2003, Barron 2007) and was successfully used to predict the fate of the spill of oil from the Pacific Adventurer spill offshore Brisbane in March 2009.

Ocean Model Analysis and Prediction System - OceanMAPS

The OCEANMAPS+Tides dataset provides ocean surface current data from the Ocean Model Analysis and Prediction System plus tides. OceanMaps was developed by a partnership between the Royal Australian Navy, the CSIRO and Australia's Bureau of Meteorology. The system is based on the Ocean Forecast Australia Model (OFAM), the BLUElink Ocean Data Assimilation System (BODAS), a data management system and enhanced surface winds from numerical wind prediction (NWP) and high-resolution SST products. This dataset is typically daily, but mapped hourly onto the tidal component. There is a forecast and hindcast version of this dataset, the forecast version was used extensively throughout the response effort. The hindcast version was used for this study extensively as well. This dataset was also successfully used to predict the fate of the spill of oil from the Pacific Adventurer spill offshore Brisbane in March 2009.

Winds: Global Forecast System (GFS)

The Global Forecasting System (GFS) is a global spectral numerical model operationally run by the US National Oceanic and Atmospheric Administration (NOAA). The version used in this study provides global coverage with a horizontal resolution of 1/2° with 64 unequally spaced vertical layers. This dataset was also successfully used to predict the fate of the spill of oil from the Pacific Adventurer spill offshore Brisbane in March 2009. There is a forecast and hindcast version of this dataset. The temporal resolution is 6 hours. The wind data from GFS was regularly compared with the wind measurements from Browse Island and Troughton Island to ensure it was representative of the wind fields over the Timor Sea.