Appendix F Oil Spill Modelling

Technical Report

Darwin Port Expansion EIS

Oil Spill Modelling

18 MARCH 2011

Prepared for

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Date:	**18 March 2011**
Reference:	42214000
Status:	Final

Executive Summary

As part of an Environmental Impact Statement (EIS) for the East Arm Wharf Expansion, URS/Scott Wilson has been commissioned to assess the potential for accidental oil spill in Darwin Harbour. Six oil spill scenarios have been identified for the study to represent potential accidents during the preparation and operation stages of the proposed development, including spills in 3 dredging areas from dredging plants, 2 accidents of pile driving plant and ship refuelling at the Tug Berth and Small Craft Mooring, and 1 catastrophic accident of rig tender collision.

The study follows a stochastic approach in which multiple simulations were conducted for each scenario by randomly selecting spill time. The hydrodynamic data used in this study covers a period of 4 months. A complete year of wind records at the Darwin Harbour Airport was also used. The objective of the stochastic investigation is to include the influence of variations in environmental conditions.

The diesel fuel and marine diesel will reduce in volume by approximately 10% and 30% respectively in the first day of accident due to evaporation. A 200 L spill of such oil around the project site is predicted to impact the water surface for a distance of a few kilometres from the initial spill location. Any such spill will disperse as it drifts away from the source location. The shoreline in the immediate vicinity of the project site will be at greatest risk of oiling. Other sections of the shore, particularly from Hudson Creek to Emery Point and from West Point to Talc Head could also be affected, although the probability will be relatively low (<10%).

The tender collision accident, which was assumed to release 1200 m^3 of heavy fuel oil, will be catastrophic for the Darwin Harbour and adjacent Beagle Gulf. The heavy fuel oil does not evaporate much and may also increase in volume by taking up a significant amount of water, further complicating clean-up operations.

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1 Introduction

As part of an Environmental Impact Statement (EIS) for the East Arm Wharf Expansion, URS/Scott Wilson has been commissioned to assess the potential consequences of accidental oil spills within Darwin Harbour. The associated environmental impacts are dealt with separately within the EIS.

Six oil spill scenarios have been identified for the study to represent potential accidents during the preparation and operation stages of the proposed development:

Scenario 1: dredge plant refuelling accident, spill of 200 L of marine diesel, 3 dredging locations:

Scenario 1a - Tug Berth and Small Craft Mooring,

Scenario 1b - Marine Supply Base,

Scenario 1c - Barge Ramp and Hardstand.

Scenario 2: pile-driving plant refuelling accident, spill of 200 L of diesel fuel oil, at the Central Berth.

Scenario 3: ship refuelling accident, spill of 200 L of marine diesel, at the Central Berth.

Scenario 4: rig tender collision accident when approaching berth, spill of 1200 m^3 of heavy fuel oil, randomised location near the Central Berth.

The locations of potential oil spill accidents are shown in Figure 1-1.

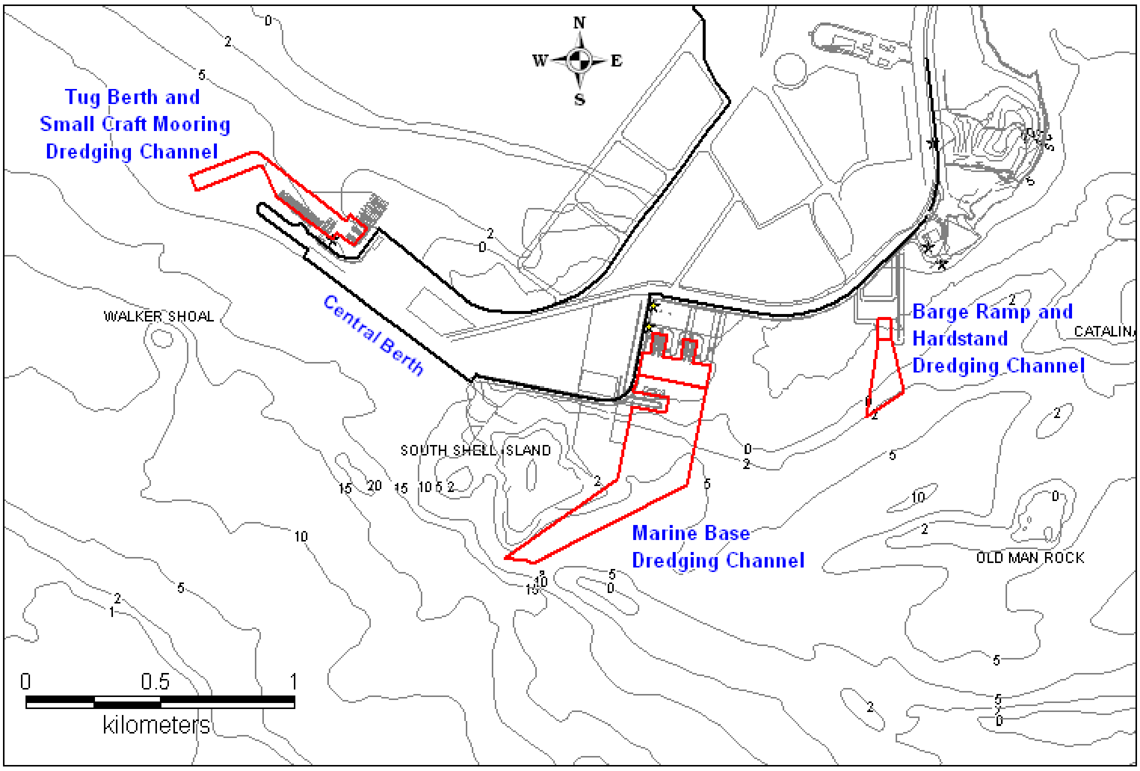

Figure 1-1: Locations of Potential Accidental Oil Spill Locations

The oil spill modelling is underpinned by a calibrated hydrodynamic model of Darwin Harbour. A stochastic approach has been applied in which a range of environmental conditions are considered for each of the spill accidents. A key objective is to map the risk probability associated with an accidental oil spill during the construction and operation phases of the proposed development.

This report describes the oil spill model applied to this study, the inputs to the risk assessment (Section 2), modelling results (Section 3) and a summary of the findings (Section 4).

2 Model Methodology

2.1 Modelling Approach

A stochastic approach has been applied to assess the risk probability in the Darwin Harbour and along its shoreline. For each identified oil spill accident scenario, 100 simulations have been carried out for randomly selected environmental conditions. This involved randomly selecting the timing of the initial oil spill. The hydrodynamic data is based on a 4 month simulation of hydrodynamics in Darwin Harbour. The wind is based on a complete year of measured data recorded at Darwin Airport. The selection of the applied hydrodynamic conditions and winds were considered to be independent and selected at random. This ensured the simulation covers spring-neap variation of ambient water flows and seasonal variation of wind to give a representative assessment of the likely impact.

Based on the results of all the stochastic simulations, the probability of oil slicks exceeding a defined threshold at every model cell was statistically calculated.

2.2 Description of the Oil Spill Model

The hydrodynamic model (HD) simulates water flows in Darwin Harbour driven by tides and winds. The oil spill analysis model simulates the drifting, spreading and weathering of oil.

The oil spill module Mike21 SA applies a Lagrangian discrete parcel method to represent discharged on water surface oil, which undergoes both:

- Spreading induced primarily by the oil properties (differences in the density of the oil and seawater, surface tension), and
- Dispersion induced by waves, wind and currents.

In the model, the oil is represented by a large ensemble of marked particles. The movement of each particle is affected by the physico-chemical processes. Once the parcels are released in the water body, their discrete path and mass are followed and recorded as a function of time relative to the reference grid system. Then the thickness/concentration distribution of the ensemble can be interpreted by counting the number/mass of particles within the grid cells.

The Lagrangian discrete parcel scheme calculates the displacement of each particle as the sum of an advective deterministic component and an independent, random Markovian component, which statistically approximates the random and/or chaotic nature of time-averaged tidal mixing. The advective displacement is a combined effect of current and wind drag. For depth integrated velocities, a logarithmic velocity profile can be established thus providing a quasi-three dimensional mode of calculations. The magnitude of the wind drift vector is commonly assumed to be proportional to the magnitude of the wind speed 10 m above the sea surface. Dispersion is treated as random walk which occurs in the horizontal and vertical directions.

To assess weathering, the following physicochemical processes are modelled:

- **Evaporation:** Evaporation from an oil spill is influenced by the composition of the oil, air and sea temperatures, spill area, wind speed, solar radiation, and slick thickness.
- **Emulsification:** One of the most important processes leading to the persistence of the oil at the sea surface is the formation of a water-in-oil emulsion (dispersed water

droplets in the oil), turning the oil into a very viscous mixture. Such an emulsion can contain up to 80% water. The ease of formation and the stability are highly dependent on the oil type and environmental conditions.

- **Entrainment (Vertical Dispersion) and Dissolution:** Transport into the water column can be accomplished by a number of mechanisms: dissolution, dispersion, accommodation, and sedimentation. Dispersion and accommodation are by far the most important mechanism during the first week of weathering. Dispersion is a mechanical process. Water turbulence tears off globules of oil and entrains them, forming an oil-in-water emulsion. These emulsions can be stabilised by surface active agents coating the oil-water interface and thus preventing the oil from coalescing. This formation of colloids is called accommodation. In hard weather the dominant dispersion mechanism is probably wave breaking, while in calm weather the most significant mechanism is probably the stretching of the slick, leading to droplet separation. The dissolution is calculated as the soluble components of the oil leaving the slick into the water column.

2.3 Model Setup

The model covers an area of 52 km by 34 km at a resolution of 50 m, as illustrated in Figure 2-1. The hydrodynamic conditions applied in the oil spill modelling were consistent with the calibrated flexible mesh model.

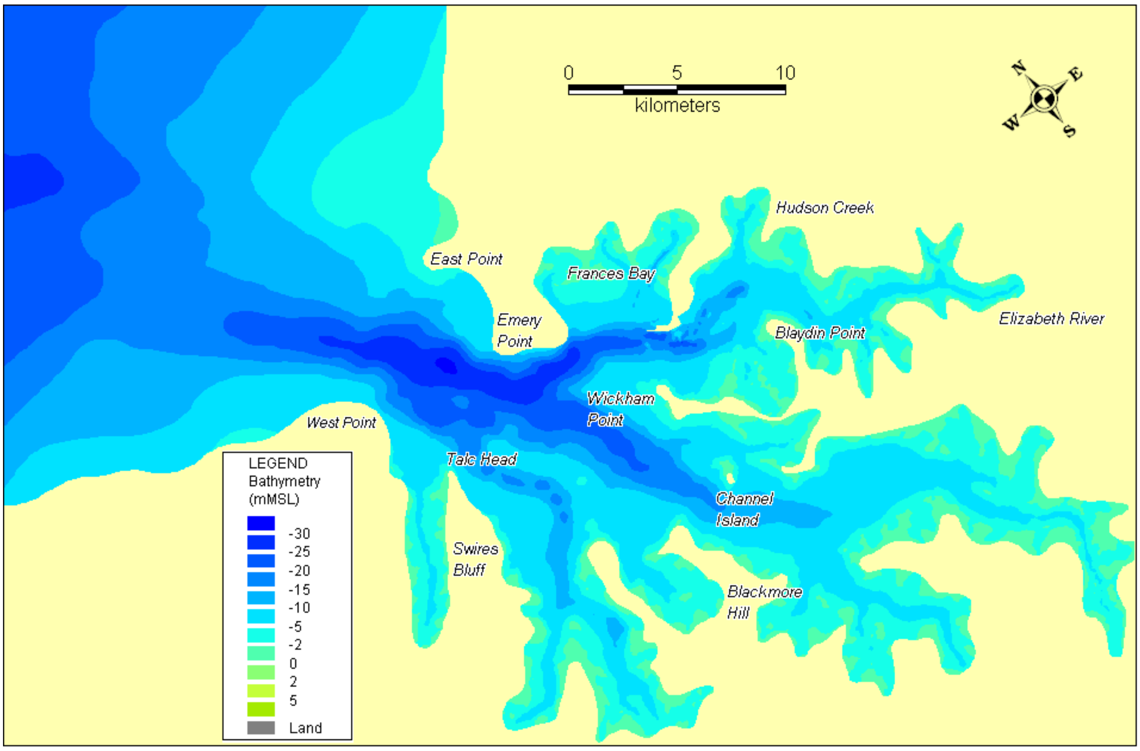

Figure 2-1: Bathymetry of Model Domain

2.4 Input Data

2.4.1 Hydrodynamics

Hydrodynamic conditions within Darwin Harbour were simulated for a period of 4 months, from mid-April to mid-August, 2008. The currents and water levels were recorded every 15 minutes in a hydrodynamic database to be read by the oil spill model. This database presents a sufficient variety of possible hydrodynamic conditions dominated by tidal currents.

Horizontal and vertical dispersion coefficients used in the simulations were 3 m^2/s and 0.01 m^2/s respectively, based on predicted conditions from the hydrodynamic model and supported by typical values found in literature.

2.4.2 Wind and Air Temperature

One year recorded wind at Darwin Airport was used to enable appropriate wind forcing to be applied within the oil spill model. The wind in the region is noted to vary seasonally with winds predominantly from westerly directions during summer months, from November to February. During winter, from April to August, wind directions shift from NE/E to SE. During transitional months, wind directions tend to be more variable (Figure 2-2 and 2-3).

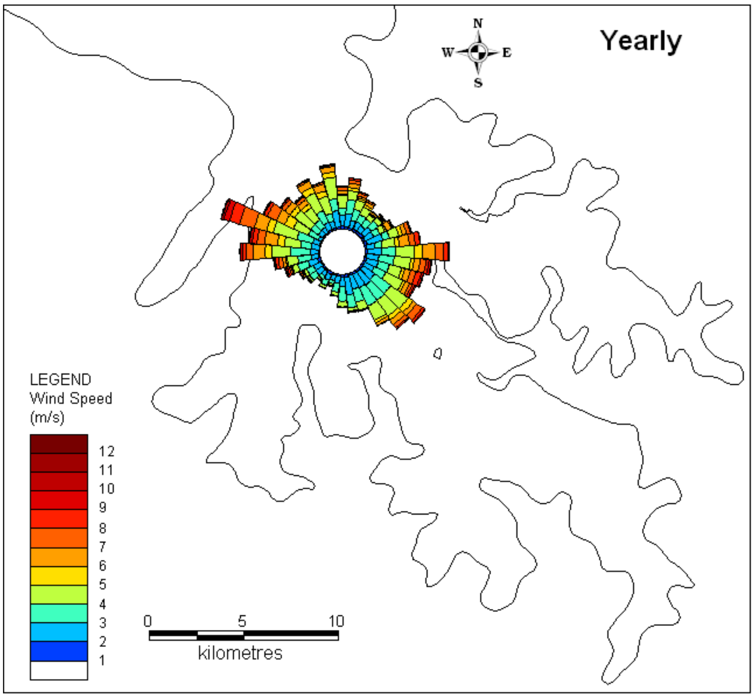

Figure 2-2: Yearly Wind Rose at Darwin Airport

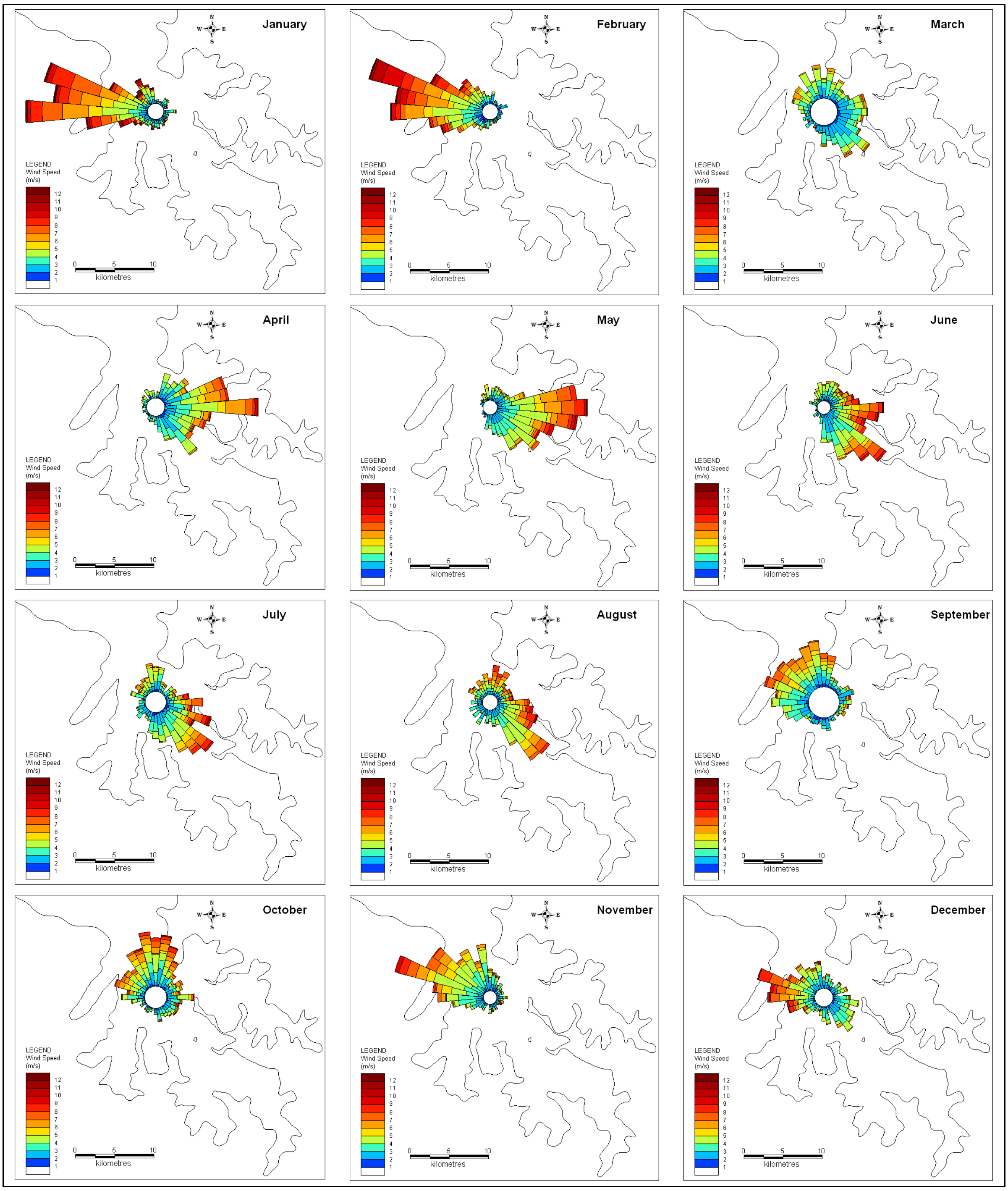

Figure 2-3: Monthly Wind Rose at Darwin Airport

The monthly average air temperature at Darwin Airport was obtained from the Bureau of Meteorology of Australian Government website:

http://www.bom.gov.au/climate/averages/tables/cw_014015.shtml.

The monthly temperature at 9 a.m. was used for the modelling, varying from 23°C in winter and 29°C in summer. The oil temperature is assumed to be the same as the air temperature.

2.4.3 Water Temperature and Salinity

The monthly average sea surface temperature and salinity of Darwin Harbour were obtained from the Department of Defence of Australian Government website:

http://www.metoc.gov.au/products/data/aussst.php

The sea surface temperatures vary seasonally from 26.6 °C in winter and 30.4 °C in summer. The salinity varies slightly throughout the year, from 34.3 ppt to 35.0 ppt. A conservative salinity of 34 ppt was defined in the model to allow more oil to be entrained as adopted in by a previous study (ASA, 2009).

2.4.4 Oil Properties and Weathering Characteristics

Oil is a mixture of hundreds of hydrocarbons, whose individual chemical properties vary widely. The properties of the oil as a whole depend on the properties of the individual constituents. Because these constituents weather at different rates, the slick properties will change with time. The properties of the oil are described in the oil spill module by dividing the oil into eight fractions, defined according to their distillation properties and their chemical structure (alkane or aromatic).

3 types of oil have been investigated in this study:

- Marine Diesel for dredging plants and ships;
- Diesel Fuel for pile driving plant; and
- Heavy Fuel Oil for a rig tender.

The parameters of the above 3 types of oil (DHI, 2011; Verma, P., et al., 2008) are summarized in Table 2-1.

The fates of the spilled oil are very much dependent on the oil type. Figures 2-4 to 2-6 illustrate the weathering and fates of diesel fuel, marine diesel and heavy fuel oil respectively. For all 3 types of oil the weathering processes occur mostly within the first day. The diesel fuel evaporates about 30% in the first 18 hours, and 70% will remain in water or on land. The marine diesel is heavier and is less volatile, and approximately 10% evaporates within the first 14 hours. The diesel fuel and marine diesel do not contain asphaltenes and wax, and emulsification does not occur. Due to the calmness in Darwin Harbour, the amount of oil dispersed into water column and dissolution effects are not significant.

The heavy fuel oil contains about 8% of asphaltenes and 7% of wax. The emulsification is significant. By taking up water, the surface oil volume will be almost 4 times the total volume of spilled oil. Like the diesel fuel and marine diesel, evaporation happens in the first half day and about 5% of the volume is lost through evaporation. The vertical dispersion and dissolution are not significant for heavy fuel oil.

Table 2-1: Oil Properties

	Diesel Fuel	Marine Diesel	Heavy Fuel Oil
Composition of oil fractions (%)			
Paraffin (c6-C12)	15	6	4.3
Paraffin (c13-c25)	20	26	19.1
Cycloparaffin (c6-c12)	20	13	1.4
Cycloparaffin (c13-c23)	20	15	3.4
Aromatic (c6-c11)	15	2.1	1.8
Aromatic (c12-c18)	2	10	4.3
Naphtheon (c9-c25)	8	12.9	0
Residual	0	15	74.7
Asphaltene content (%)	0	0	8
Wax content (%)	0	0	7
Viscosity (cP)	3	4	211
Reference Temperature (^{o}C)	13	13	50

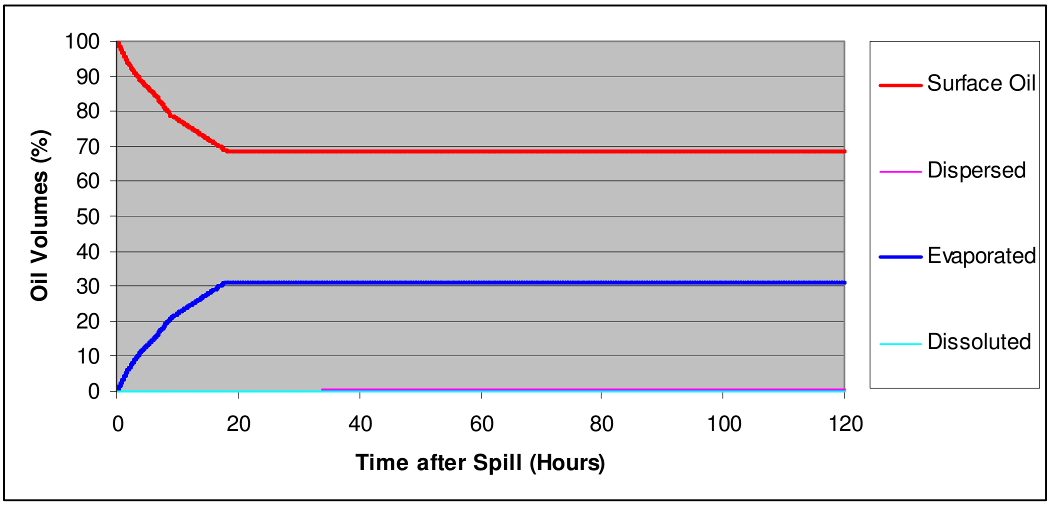

Figure 2-4: Weathering and Fates of Diesel Fuel

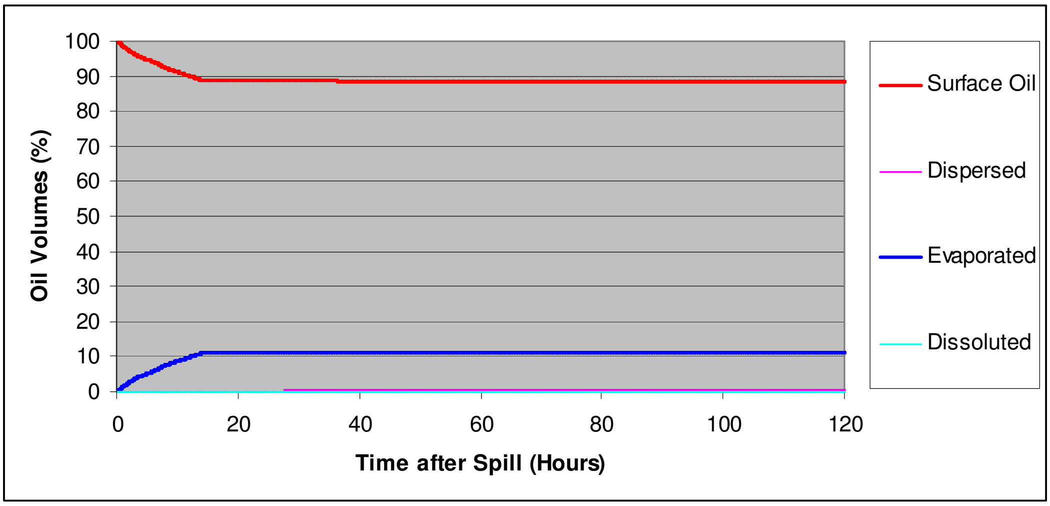

Figure 2-5: Weathering and Fates of Marine Diesel

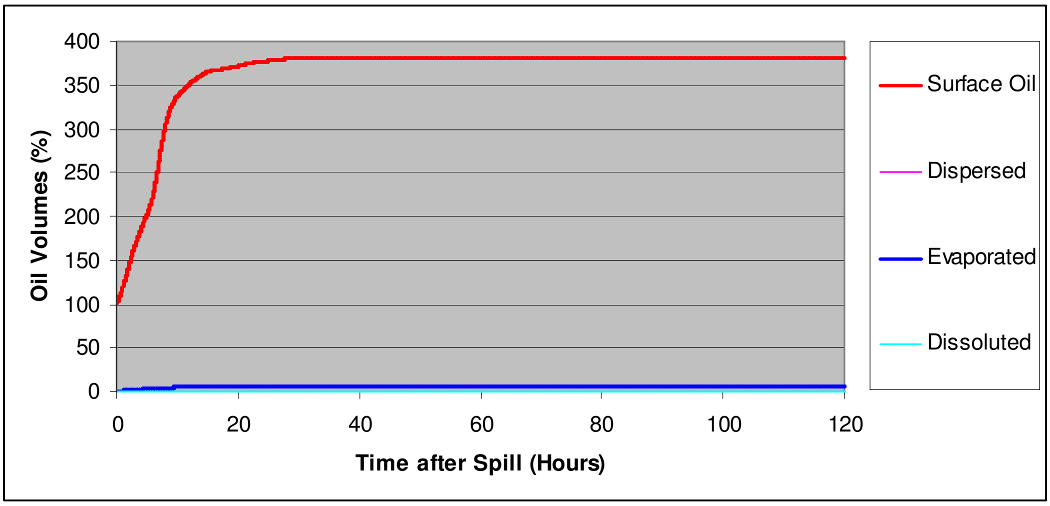

Figure 2-6: Weathering and Fates of Heavy Fuel Oil

3 Modelling Results

3.1 Modelling Scenarios

Six oil spill scenarios have been identified for the preparation and operation stages of the proposed development:

Scenario 1: dredge plant refuelling accident, spill of 200 L of marine diesel, 3 dredging locations:

Scenario 1a - Tug Berth and Small Craft Mooring,

Scenario 1b - Marine Supply Base,

Scenario 1c - Barge Ramp and Hardstand.

Scenario 2: pile-driving plant refuelling accident, spill of 200 L of diesel fuel oil, at the Central Berth location.

Scenario 3: ship refuelling accident, spill of 200 L of marine diesel, at the Central Berth location.

Scenario 4: rig tender collision accident when approaching berth, spill of 1200 m^3 of heavy fuel oil, randomised location near the Central Berth.

The spill locations are illustrated in Figure 1-1.

In scenarios 1, 2 and 3, 5000 particles were released instantly to represent the specified amount of oil. In scenario 4, 10000 particles were tracked considering the larger volume of the oil spill.

The time step of the oil spill simulations was 30 s. At the end of each simulation (5 days for scenarios 1, 2, 3; and 14 days for scenario 4), the maximum oil thickness/concentration that occurred during the simulation period at every model grid cell were calculated.

For each scenario, 100 simulations were conducted with a randomly selected initial spill time, in order to reflect the variation of hydrodynamic and atmospheric conditions. Based on these simulations, the probability of oil for each model cell as well as the thickness/concentration exceeding a threshold were calculated. The threshold was 0.001 mm, which is equivalent to 1 g/m^2 of un-emulsified oil, or dull coloured sheen according to NOAA HAZMAT, 1996 (Figure 3-1).

The area of oiled water surface and length of oiled shoreline were recorded and respective probabilities were mapped for all the scenarios.

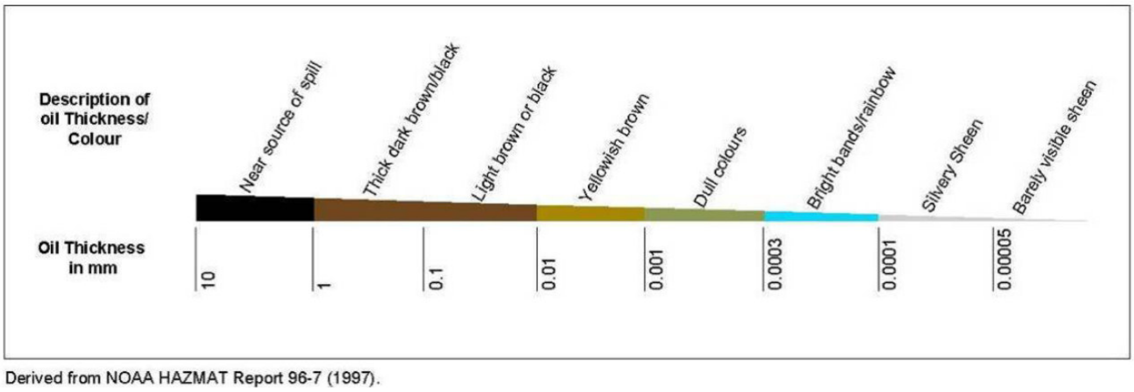

Figure 3-1: Surface Oil Colour and Thickness (source: NOAA HAZMAT Report 96-7)

3.2 Tug Berth and Small Craft Mooring Dredging Channel - Scenario 1a

This scenario assumes an instant release of 200 L of marine diesel from the dredging plant in the Tug Berth and Small Craft Mooring dredging channel during refuelling. The spill locations were randomly selected along the central route of the dredging operation.

The simulation results suggest that water surface within a distance of 4 km from the spill location would be affected (Figure 3-2). As slicks move further away, the oil becomes progressively more dispersed.

There is a 95% probability that spilled oil would reach any location at the shoreline, as the dredging location is close to the shore (Table 3-1). The maximum probability of shoreline exposure at a single location is about 55%, which is found at the western end of the Central Berth quay wall.

Sections with probability of shoreline oiling below 10% extend from Hudson Creek to Emery Point and around the Talc Head, reaching so far due to the predominant wind direction (Figure 3-2).

Table 3-1: Oil on water surface and on shore – Scenario 1a

Maximum Area of Oil on Water Surface (km^2)	Maximum Length of Oiled Shoreline (km)	Probability of Shoreline Exposure (%)	Maximum Probability of Shoreline Exposure at a Single Location (%)
1.26	3.25	95	55

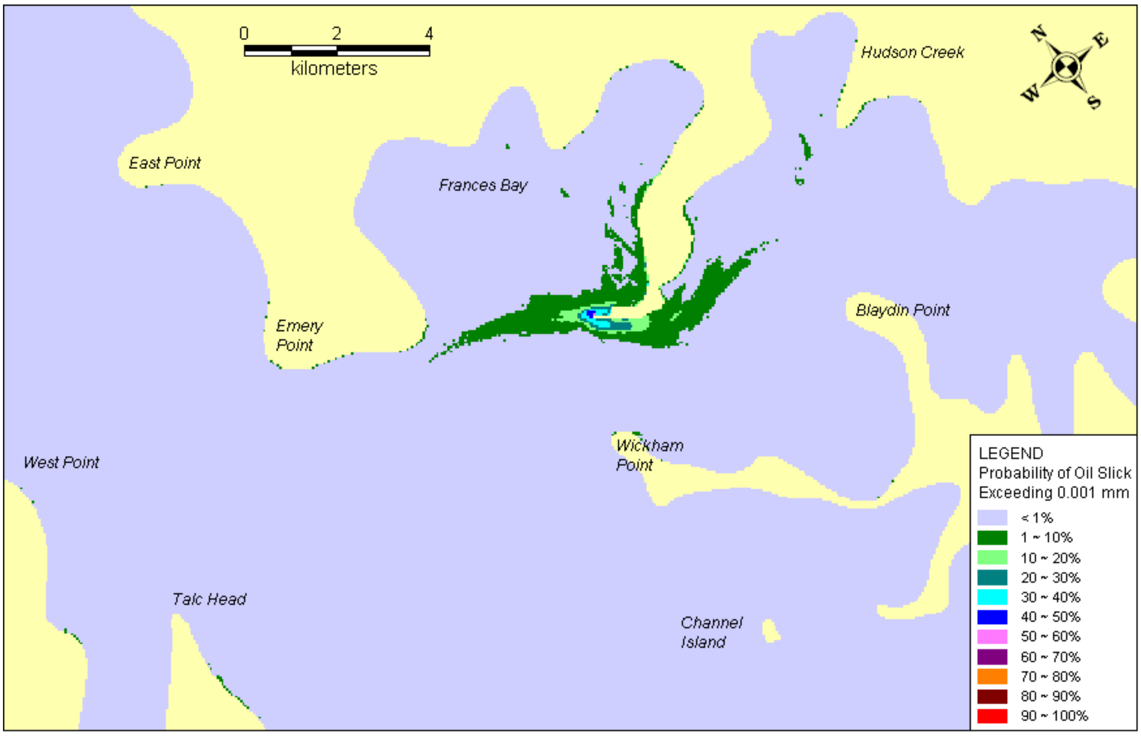

Figure 3-2: Probability of oil exceeding 0.001 mm on Water Surface – Scenario 1a

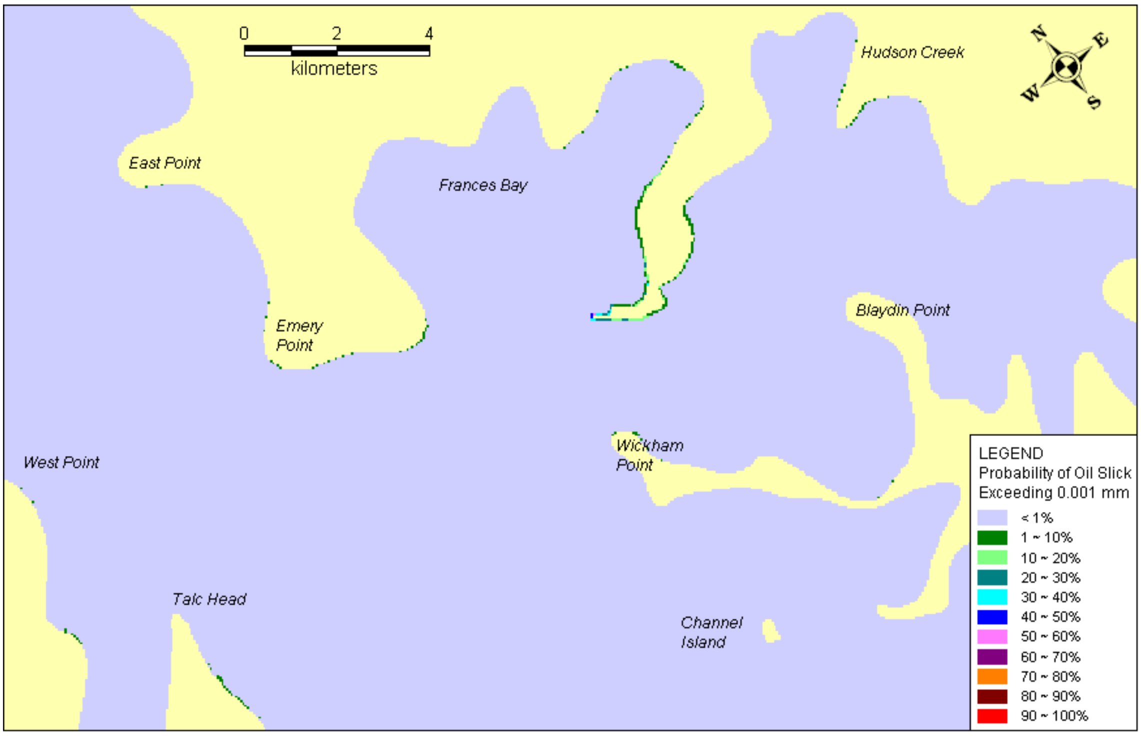

Figure 3-3: Probability of oil exceeding 0.001 mm on Shoreline – Scenario 1a

3.3 Marine Supply Base Dredging Channel - Scenario 1b

This scenario assumes an instant release of 200 L marine diesel from a dredging plant in the Marine Supply Base dredging channel during refuelling. The spill locations were randomly selected along the central route of the dredging operation.

The simulation results suggest that an extent water surface up to 6 km from the spill location might be affected (Figure 3-4) due to the exposure of this site to strong flood and ebb currents.

Shoreline oiling would be at a probability of 89%, as the dredging location is near-shore. The maximum probability of shoreline exposure at a single location was about 31%, for the nearest section of shoreline (Table 3-2).

The highest probabilities of the shoreline oiling would be observed near the spill location (Figure 3-5). A section of the tidal flat around Hudson Creek would have a probability of oiling at or below 10%. Oil may reach as far as West Point and Talc Head under modelled wind conditions (Figure 3-5).

Table 3-2: Oil on water surface and on shore – Scenario 1b

Maximum Area of oil on Water Surface (km^2)	Maximum Length of oiled Shoreline (km)	Probability of Shoreline Exposure (%)	Maximum Probability of Shoreline Exposure at a Single Location (%)
1.30	3.2	89	31

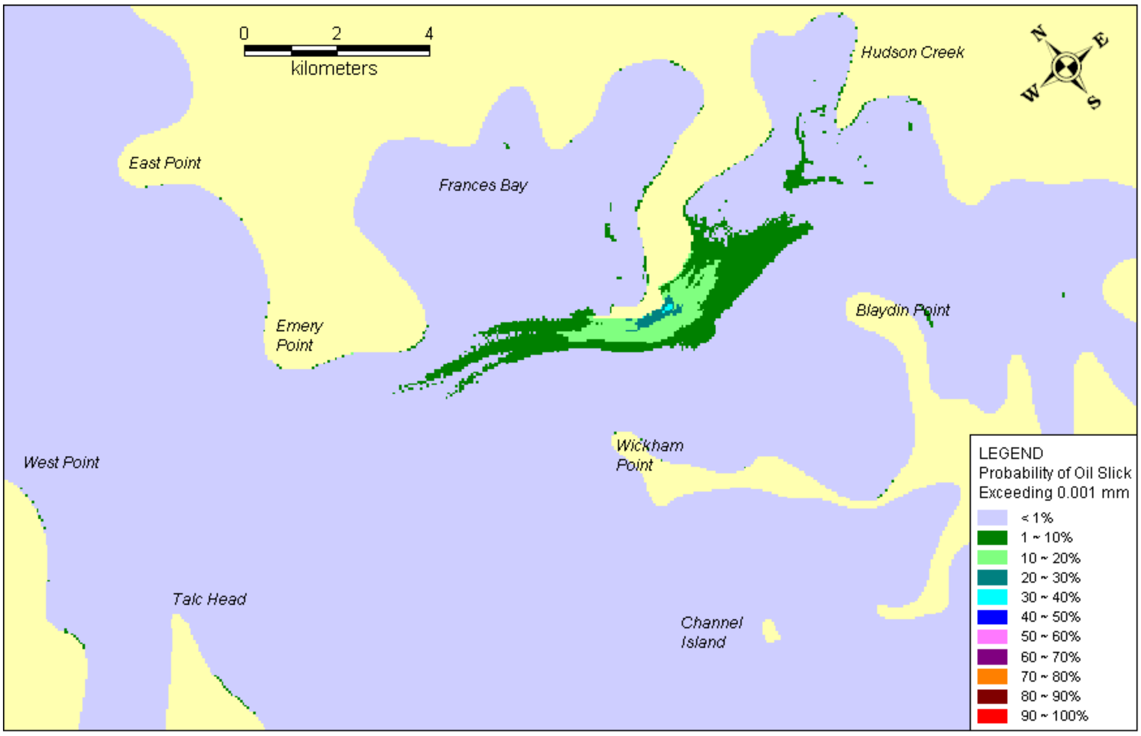

Figure 3-4: Probability of oil exceeding 0.001 mm on Water Surface – Scenario 1b

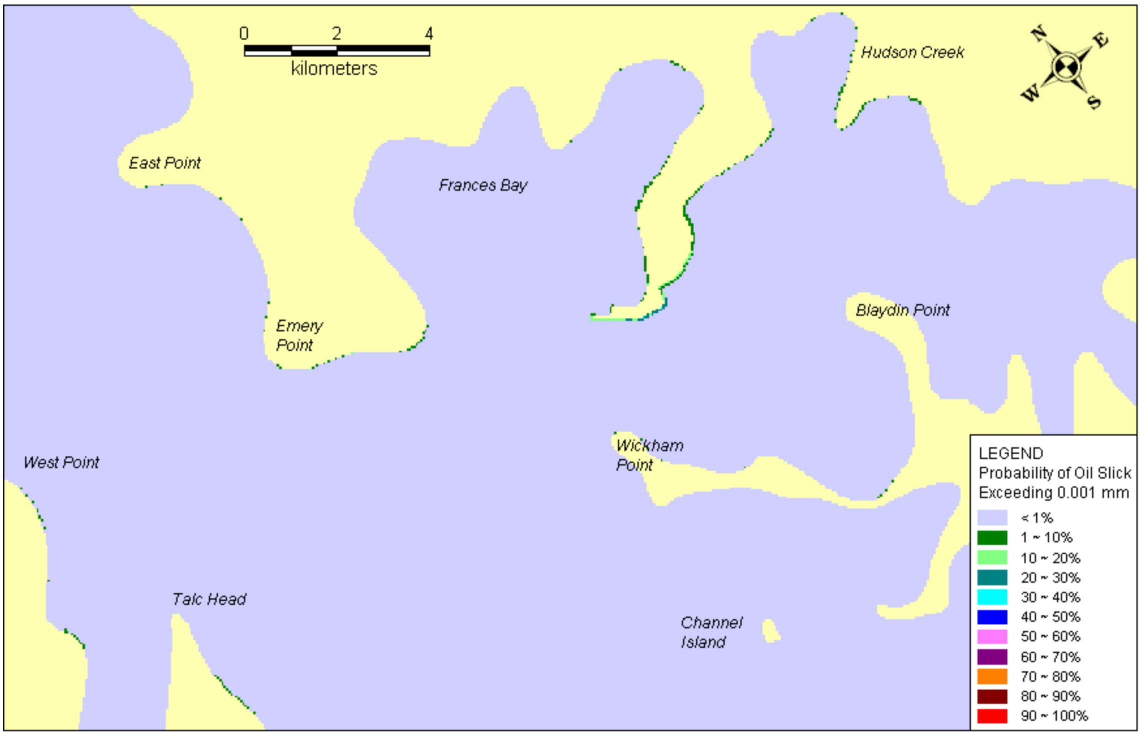

Figure 3-5: Probability of oil exceeding 0.001 mm on Shoreline – Scenario 1b

3.4 Barge Ramp and Hardstand Dredging Channel - Scenario 1c

This scenario assumes an instant release of 200 L marine diesel from the dredging plant refuelling in the Barge Ramp and Hardstand dredging channel. The spill locations were randomly selected along the central route of the dredging operation.

The maximum extent of the slick trajectories would be around 5 km from the spill location (Figure 3-6). This is slightly smaller than in the case of the Marine Supply Base dredging channel because the currents at the Barge Ramp and Hardstand are sheltered to a certain degree by the surrounding shoreline. The probability of shoreline oiling would be 95% and the maximum probability at a single location 38%.

Similarly with the previous scenario, Hudson Creek would have a probability of oiling at or below 10%. Oil may reach as far as West Point and Talc Head under modelled wind conditions (Figure 3-7).

Table 3-3: Oil on water surface and on shore – Scenario 1c

Maximum Area of oil on Water Surface (km^2)	Maximum Length of oiled Shoreline (km)	Probability of Shoreline Exposure (%)	Maximum Probability of Shoreline Exposure at a Single Location (%)
1.04	3.4	95	38

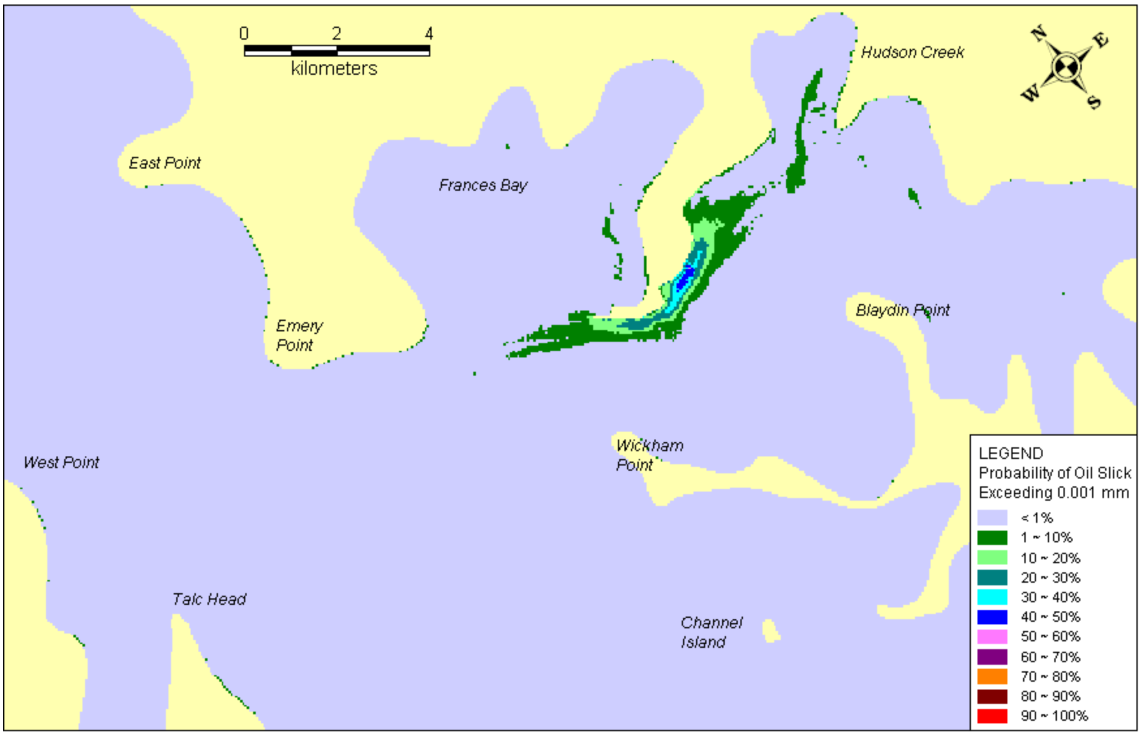

Figure 3-6: Probability of oil exceeding 0.001 mm on Water Surface – Scenario 1c

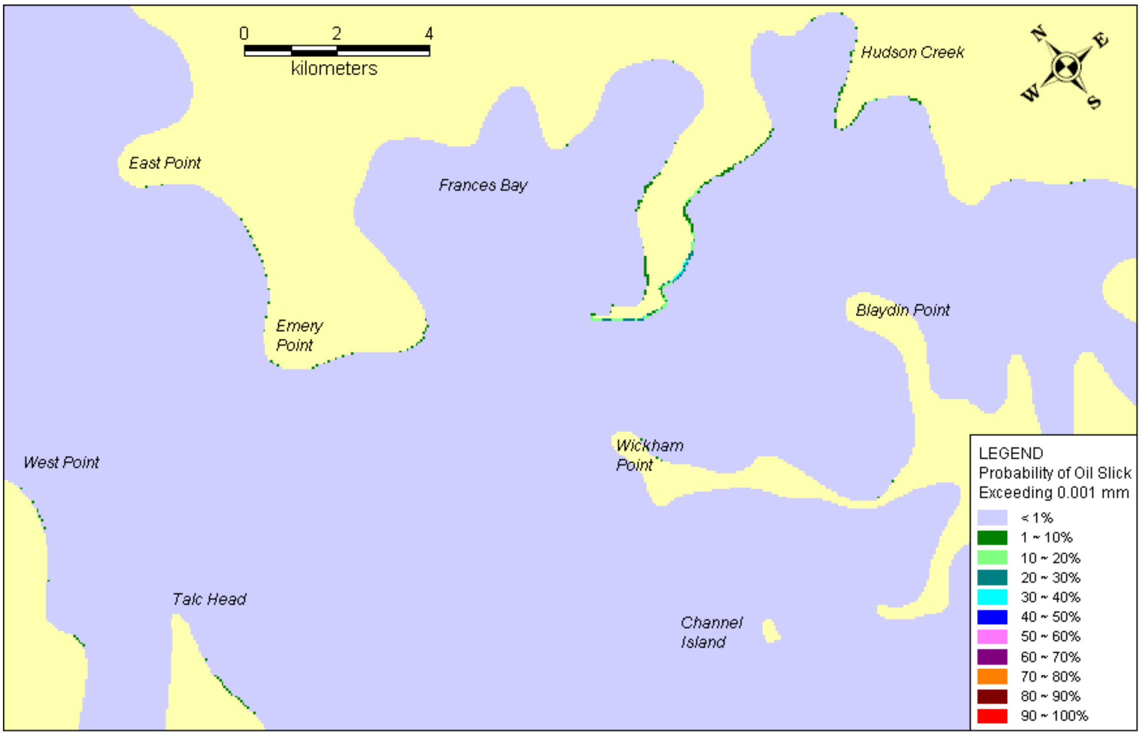

Figure 3-7: Probability of oil exceeding 0.001 mm on Shoreline – Scenario 1c

3.5 Pile Driving Plant Refuelling Accident - Scenario 2

This scenario assumes an instant release of 200 L of diesel fuel from the pile driving plant refuelling. The location of the spill was fixed in the middle of the Central Berth.

The simulation results suggest the oil trajectories extending up to 3 km from the spill location (Figure 3-8). As it moves further away, the oil would become more dispersed; approximately 30% of the spilled diesel would evaporate in the first 18 hours.

Diesel would reach the shoreline with a 100% probability with the berth having the greatest risk of exposure (Table 3-4). Beyond the Central Wharf Berth, the probability of exposure would reduce to less than 50% (Figure 3-9); for the shores of Frances Bay, Hudson Creek and Talc Head it would not exceed 10%.

Table 3-4: Oil on water surface and on shore – Scenario 2

Maximum Area of oil on Water Surface (km^2)	Maximum Length of oiled Shoreline (km)	Probability of Shoreline Exposure (%)	Maximum Probability of Shoreline Exposure at a Single Location (%)
0.74	3.15	100	100

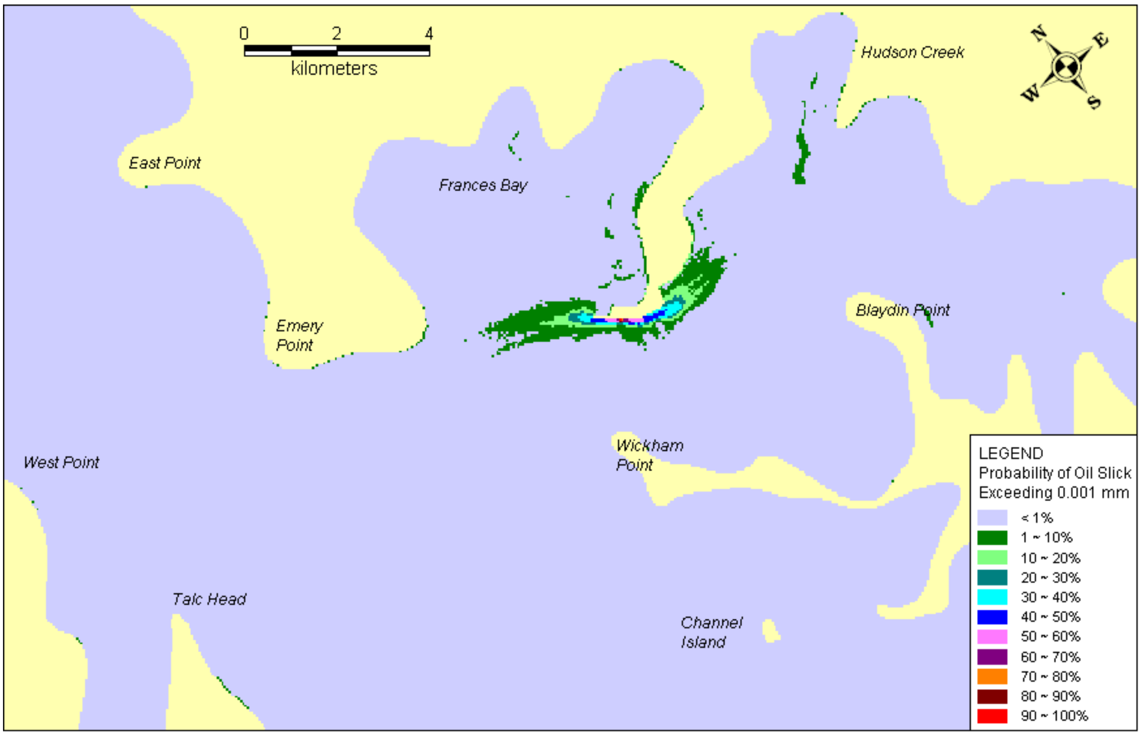

Figure 3-8: Probability of oil exceeding 0.001 mm on Water Surface – Scenario 2

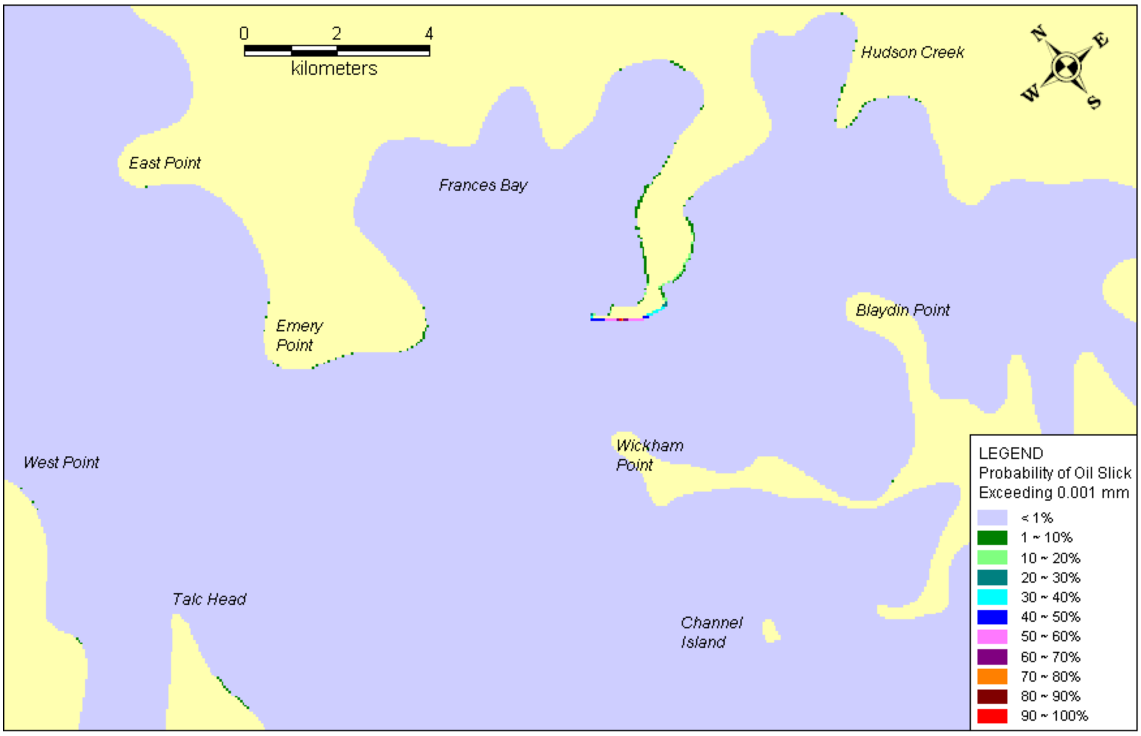

Figure 3-9: Probability of oil exceeding 0.001 mm on Shoreline – Scenario 2

3.6 Ship Refuelling Accident - Scenario 3

This scenario assumes an instant release of 200 L marine diesel from a ship refuelling at the Central Berth. The assumptions for this scenario are the same as for scenario 2 except the type of oil is marine diesel instead of diesel fuel. The marine diesel is heavier than diesel fuel, thus less of this oil will evaporate (see weathering curves in Figures 2-4 and 2-5).

Oil trajectories from this spill would spread within 3 km from the initial spill location (Figure 3-10). The adjacent to the berth shoreline has a 100% probability of oiling (Table 3-5). Apart from the shoreline around the project site and the south-eastern shore of Frances Bay, other sections of Darwin Harbour are at a lower (below 20%) risk of exposure (Figure 3-11).

Table 3-5: Oil on water surface and on shore – Scenario 3

Maximum Area of oil on Water Surface (km^2)	Maximum Length of oiled Shoreline (km)	Probability of Shoreline Exposure (%)	Maximum Probability of Shoreline Exposure at a Single Location (%)
0.76	3.35	100	100

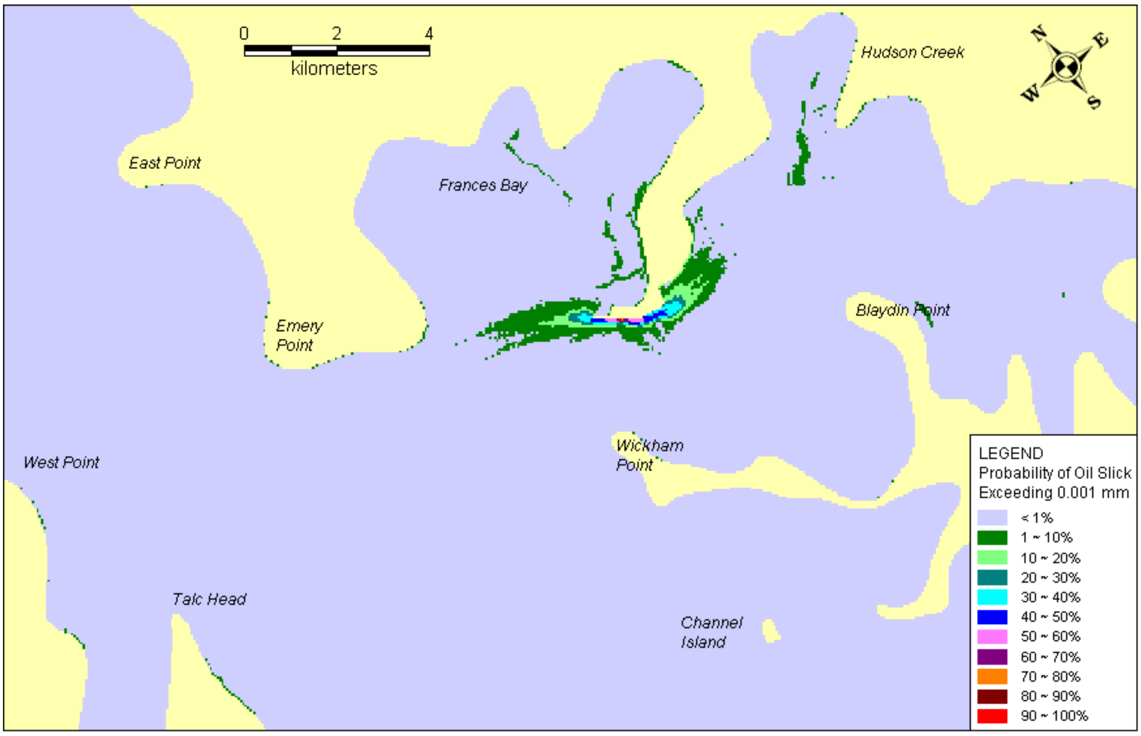

Figure 3-10: Probability of oil exceeding 0.001 mm on Water Surface – Scenario 3

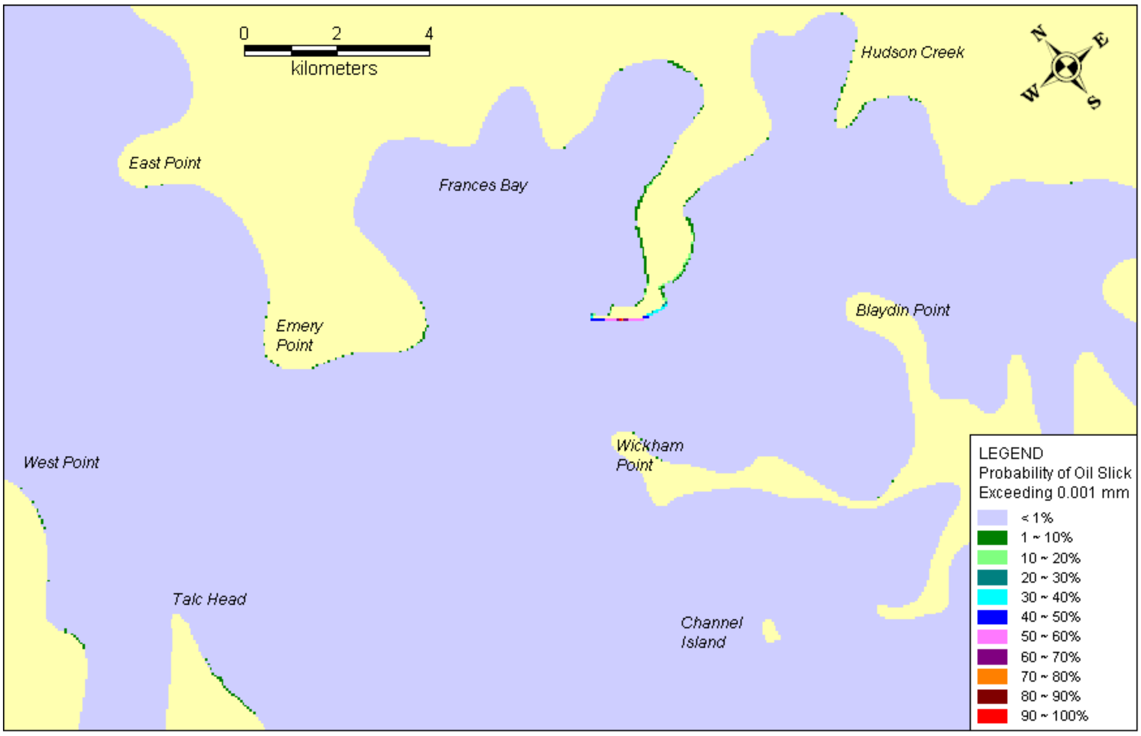

Figure 3-11: Probability of oil exceeding 0.001 mm on Shoreline – Scenario 3

3.7 Rig Tender Collision Accident - Scenario 4

This scenario assumes an instant release of 1,200 m^3 of heavy fuel oil from a Rig Tender Collision accident near the Central Berth. The exact locations of spills were randomly selected within a 200 m radius of the mid-point along the Central Berth. Heavy fuel oil looses only around of 5% of the spilled volume due to evaporation (see Figure 2-6). Due to the high content of ashphaltene and wax, the surface oil may uptake significant amounts of water and expand in volume by a factor of up to four (Figure 2-6).

All three arms of the harbour would have higher than 50% probability of oil on water surface thicker than 0.001 mm, with probabilities higher than 90% in the vicinity of Emery Point, Wickham Point, and near East Arm Wharf (Figure 3-12). Depending on the prevailing wind direction, oil slicks may be forced to one side of the harbour or another (for examples see Figures 3-13 - 3-15). Oil slick trajectories from this scenario were traced beyond the harbour area, and into Beagle Gulf.

The probability of oil thicker than 0.001 mm on shore would range from higher than 90% in the vicinity of the spill site to below than 10% in the upper reaches of arms and outside of the harbour (Figure 3-16). The maximum oiled water surface area and shoreline length would be over 650 km^2 and 320 km respectively (Table 3-6).

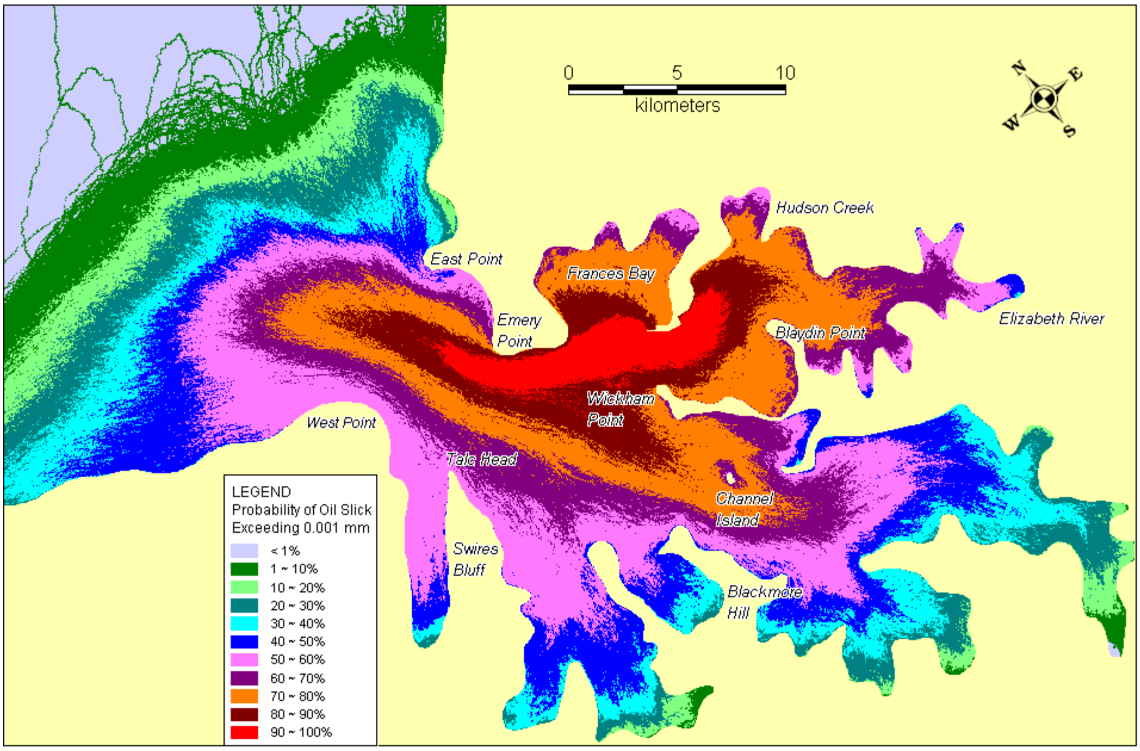

Figure 3-12: Probability of oil exceeding 0.001 mm on Water Surface – Scenario 4

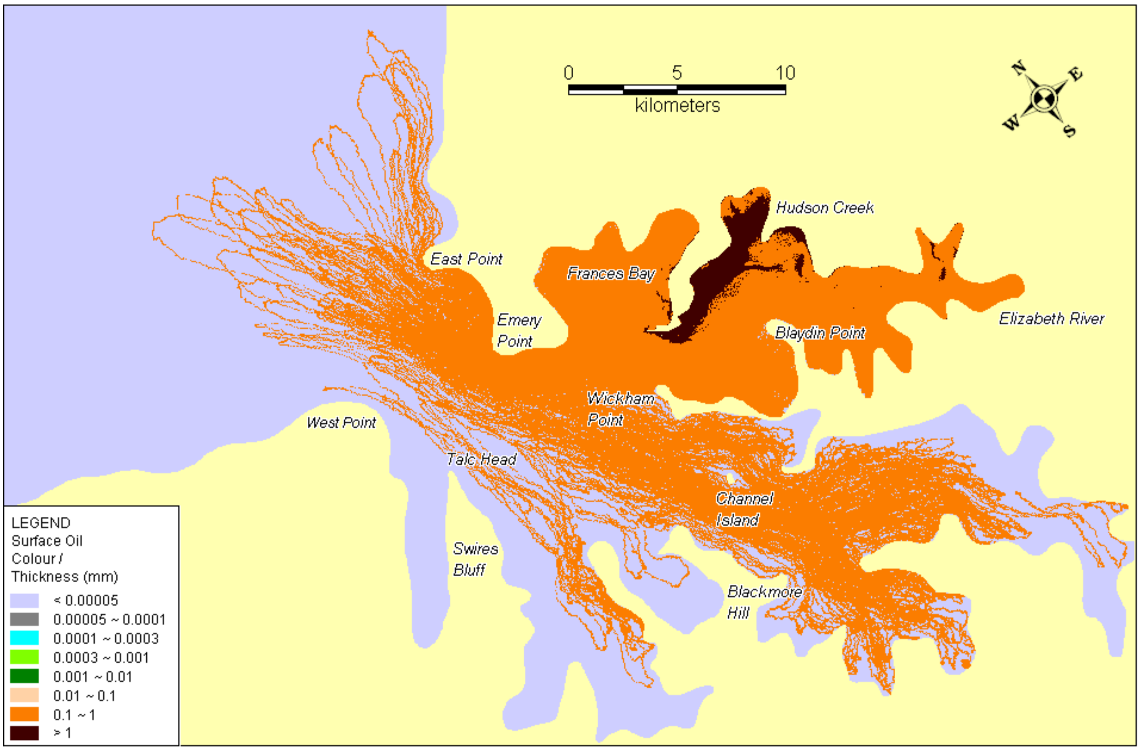

Figure 3-13: An Example of Oil Spill Trajectories in 14 Days – Westerly Wind

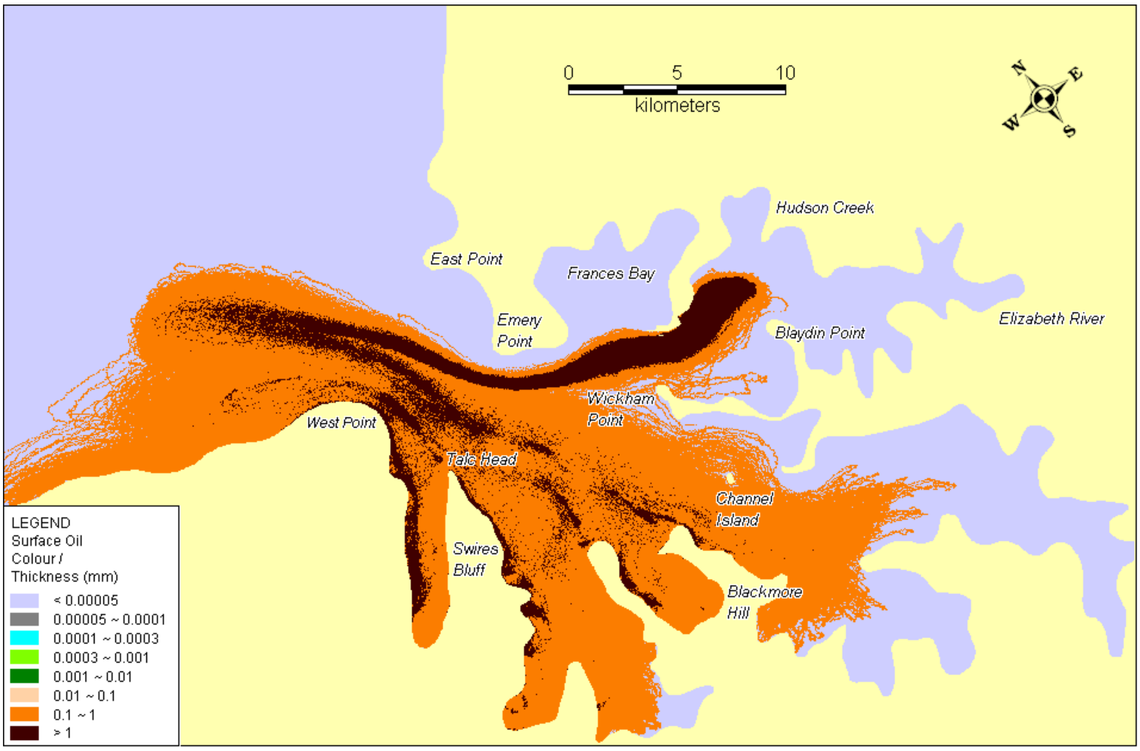

Figure 3-14: An Example of Oil Spill Trajectories in 14 Days – Easterly Wind

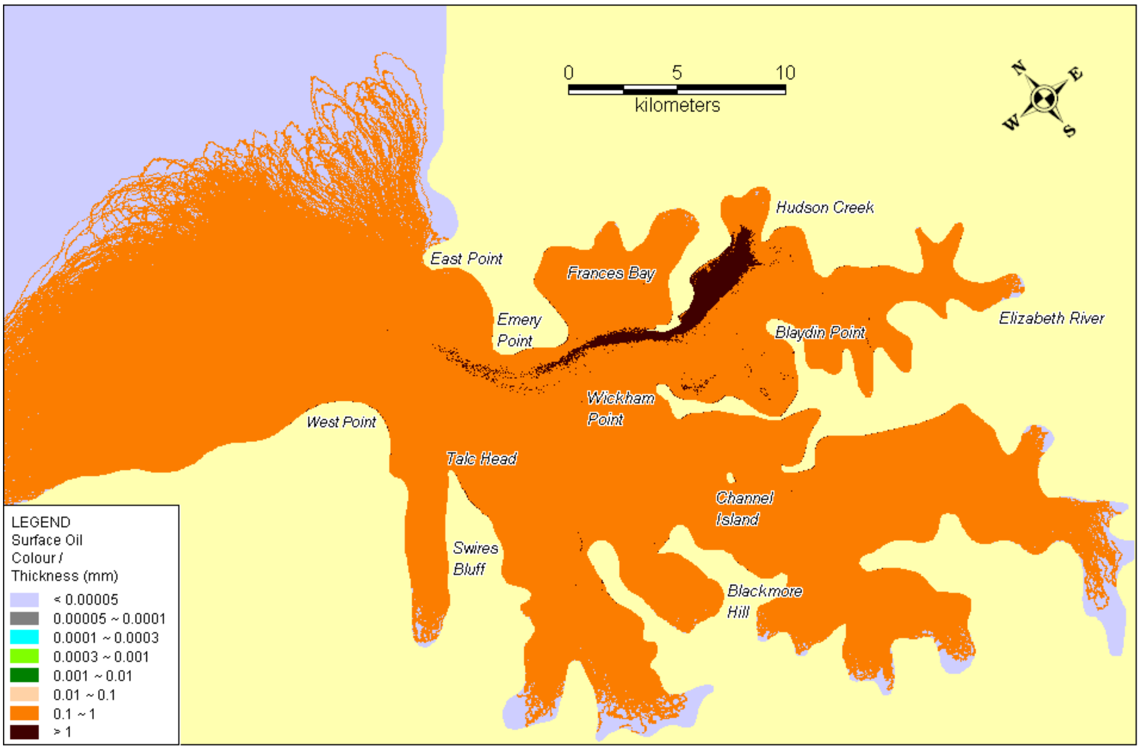

Figure 3-15: An Example of Oil Spill Trajectories in 14 Days – Varying Wind

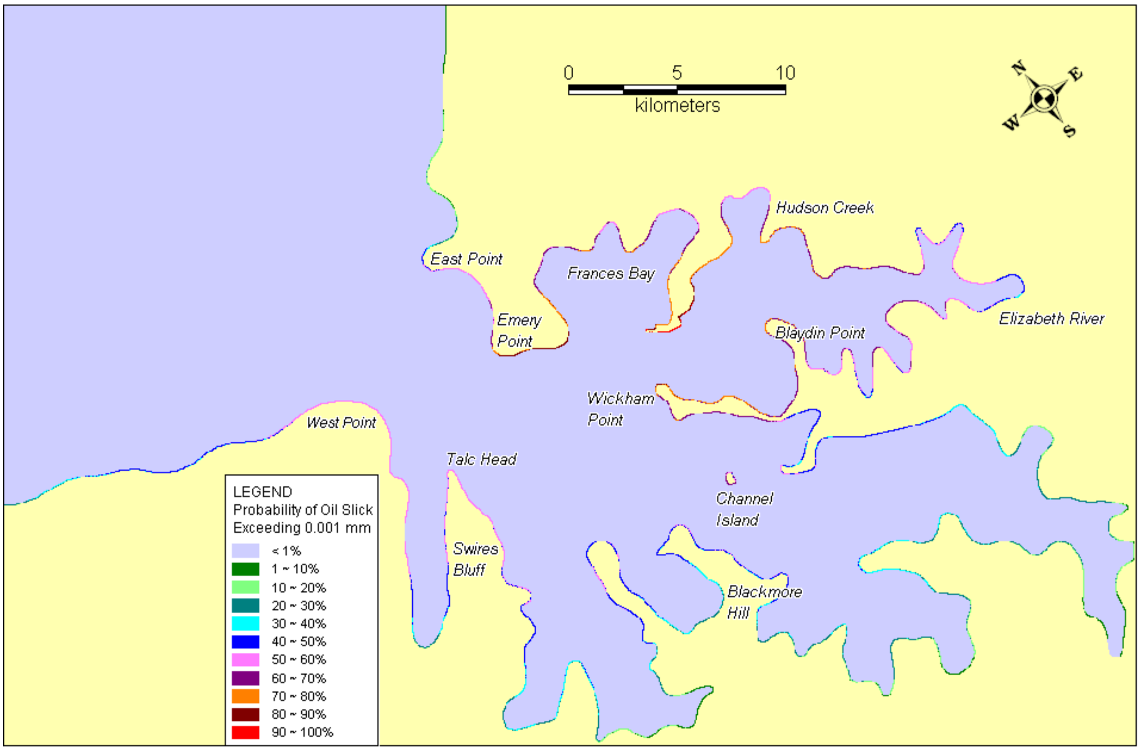

Figure 3-16: Probability of oil exceeding 0.001 mm on Shoreline – Scenario 4

Table 3-6: Oil on water surface and on shore – Scenario 4

Maximum Area of Oil on Water Surface (km^2)	Maximum Length of Oiled Shoreline (km)	Probability of Shoreline Exposure (%)	Maximum Probability of Shoreline Exposure at a Single Location (%)
663	341	100	100

4 Summary

Six oil spill scenarios have been simulated for the preparation and operation stages of the East Arm Wharf Expansion project. The scenarios were as follows:

Scenario 1: dredge plant refuelling accident, spill of 200 L of marine diesel, 3 different dredging locations:

Scenario 1a - Tug Berth and Small Craft Mooring,

Scenario 1b - Marine Supply Base,

Scenario 1c - Barge Ramp and Hardstand.

Scenario 2: pile-driving plant refuelling accident, spill of 200 L of diesel fuel oil, Central Berth location.

Scenario 3: ship refuelling accident, spill of 200 L of marine diesel, Central Berth location.

Scenario 4: rig tender collision accident when approaching berth, spill of 1200 m^3 of heavy fuel oil, randomised location near the Central Berth.

Probabilities of oil on water surface and oil on shore have been assessed following a stochastic approach. This approach allows to account for variable hydrodynamic and wind conditions; the results are summarised in Table 4-1.

Table 4-1: Oil on water surface and on shore – All Scenarios

Scenario	Maximum Area of Impacted Water Surface (km^2)	Maximum Length of Impacted Shoreline (km)	Probability of Shoreline Exposure (%)	Maximum Probability of Shoreline Exposure at a Single Location (%)
1a	1.26	3.25	95%	55
1b	1.30	3.2	89%	31
1c	1.04	3.4	95%	38
2	0.74	3.15	100%	100
3	0.76	3.35	100%	100
4	663	341	100%	100

Limitations

The findings presented in this report are limited by the reliability of the information applied within the study. The hydrodynamic conditions used are limited to a 4 month period and wind data to a 1 year record. The limited duration of these datasets may not therefore capture the full range of variability in environmental conditions. The approach adopted is however expected to provide an adequate representation of potential environmental impacts since construction activities would most probably be suspended under more extreme conditions.

5 References

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