Appendix 7

Marine hydrocarbon spill modelling

ICHTHYS GAS FIELD DEVELOPMENT PROJECT

MARINE HYDROCARBON SPILL MODELLING

Prepared for INPEX Browse, Ltd.

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EXECUTIVE SUMMARY

INPEX Browse Ltd is proposing to develop and operate facilities to produce gas, liquefied petroleum gas (LPG) and condensate from the Ichthys reservoir, which is located within the Browse Basin. INPEX proposes to install sub-sea production equipment and a floating central processing facility (CPF) over the reservoir. The CPF will send a monoethylene glycol (MEG)/water/condensate mixture to a floating production, storage and offtake (FPSO) vessel. Offshore condensate stabilisation will take place on the FPSO, as will storage and offtake transfer through a loading hose to offtake tankers. Gas and associated condensate would be transported, via a seabed pipeline, to gas processing and export facilities within East Arm, Darwin Harbour. Liquefied natural gas (LNG), LPG and smaller amounts of condensate not removed offshore will be transferred to export ships via a jetty constructed off Blaydin Point for transport to customers. In addition to the longer-term operations, the development proposal includes dredging, pipe-laying and other marine operations at the field location, along the pipeline route and in the area of the shipping berths and channels. Many of these operations would involve the handling and storage of hydrocarbons, which could present some risk of spillage to the marine environment. The environmental consequences of an accidental oil spill will depend upon the probability that oil would be transported to sensitive habitats at sufficient concentration to be harmful.

Asia Pacific ASA was commissioned to model the spill scenarios and estimate the probability that a defined spill event would result in hydrocarbons (above defined threshold concentrations) reaching sensitive environmental resources, if a spillage of hydrocarbons were to occur in the first place. This assessment is intended to be a companion study to a quantification of the risk that the defined spill events could actually occur. The total risk to sensitive environmental resources will be the joint probability of the spill first occurring and then environmentally significant quantities of hydrocarbon reaching those resources.

This assessment used numerical modelling to simulate the trajectory and weathering of hydrocarbon spills for a series of defined spill scenarios. Spill scenarios were selected by INPEX to be representative of the various phases of the development, including the development and operation phases, and different operational areas (offshore and inshore). Scenarios accounted for where the hydrocarbons would be handled and the most realistic volumes that could be involved. .

The numerical simulations were carried out using a three-dimensional hydrocarbon spill trajectory and fates model that accounted for all significant weathering processes acting upon oil when released into the marine environment, including spreading, evaporation, emulsification, entrainment, dissolution, sedimentation and decay. Stochastic modelling was applied to repeatedly simulate each scenario, using objectively selected samples of weather data (current and wind fields) and climactic temperatures for the region. Probabilities of exposure from surface slicks and entrained and dissolved hydrocarbons were separately analysed for different seasonal weather samples.

The analysis considered spills of marine diesel and Ichthys condensate. Marine diesel is a mixture of volatile and non-volatile compounds and tends to spread rapidly and entrain into the upper water column. Ichthys condensate contains a high proportion (85% or more) of volatile compounds, which will evaporate rapidly on exposure to the atmosphere at the temperatures that prevail in the study area, leaving a non-volatile residual. After processing, this condensate is expected to evaporate completely within 12 hours of atmospheric exposure. Release of condensate below sea level will delay exposure to weathering and therefore extend the weathering period and enlarge the potential area exposed to slicks.

Simulation of spills at the proposed locations of the offshore facilities indicated that spills of condensate to the sea surface adjacent to the CPF and FPSO sites would generate very low probability of exposure (< 1% at > 1 g/m^2) to any of the offshore islands or reefs, due to the high volatility and dispersion rates of this product when exposed at the sea-surface at local ambient temperatures. Increased exposure probability (< 39%) to Browse Island, the Scott Reef complex and the Buccaneer Archipelago was indicated for large spills of condensate from the seabed (250 m below mean sea level) because the condensate would take time (hours to days) to surface and would drift within the water column with the prevailing currents, significantly extending weathering times. It should be noted that these probabilities have been calculated for conservatively low concentrations of hydrocarbon (appearing as yellowish brown/dull coloured film).

Simulations within Darwin Harbour indicated that the movement of any hydrocarbon slicks would be strongly affected by local tidal currents – advecting upstream and downstream over subsequent flooding and ebbing tidal cycles. Complicating these drift patterns, prevailing winds will act to spread slicks and to generate a net drift over longer durations than a tidal cycle. Seasonal wind patterns are predicted to generate an increased probability of expose to western shorelines during winter and to eastern shorelines during summer.

Shorelines and inter-tidal areas at risk of receiving hydrocarbon exposure will vary largely with the initial release point and the weathering rates of the hydrocarbon. Slicks generated within the harbour will have a high probability of being entrained by the strong tidal flows within the channels, limiting the influence of the wind on slick trajectories and extending the time before slicks can drift to shorelines. For the highly volatile condensates, where weathering times are relatively short, probabilities of shoreline oiling are estimated to be generally low as a result.

A condensate spill at the loading jetty was predicted to have a low probability of drifting out of the berth area before evaporating.

1 INTRODUCTION

INPEX Browse, Ltd. (INPEX) proposes to develop the natural gas and associated condensate contained in the Ichthys Field in the Browse Basin at the western edge of the Timor Sea about 200 km off Western Australia's Kimberley coast. The field is about 850 km west-south-west of Darwin in the Northern Territory.

The two reservoirs which make up the field are estimated to contain 12.8 tcf (trillion cubic feet) of sales gas and 527 MMbbl (million barrels) of condensate. INPEX will process the gas and condensate to produce liquefied natural gas (LNG), liquefied petroleum gas (LPG) and condensate for export to overseas markets.

For the Ichthys Gas Field Development Project (the Project), the company plans to install offshore facilities for the extraction of the natural gas and condensate at the Ichthys Field and a subsea gas pipeline from the field to onshore facilities at Blaydin Point in Darwin Harbour in the Northern Territory. A two train LNG plant, an LPG fractionation plant, a condensate stabilisation plant and a product loading jetty will be constructed at a site zoned for development on Blaydin Point. Around 85% of the condensate will be extracted and exported directly from the offshore facilities while the remaining 15% will be processed at and exported from Blaydin Point.

In May 2008 INPEX referred its proposal to develop the Ichthys Field to the Commonwealth's Department of the Environment, Water, Heritage and the Arts and the Northern Territory's Department of Natural Resources, Environment and the Arts. The Commonwealth and Northern Territory ministers responsible for environmental matters both determined that the Project should be formally assessed at the environmental impact statement (EIS) level to ensure that potential impacts associated with the Project are identified and appropriately addressed.

Assessment will be undertaken in accordance with the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act) and the *Environmental Assessment Act* (NT) (EA Act). It was agreed that INPEX should submit a single EIS document to the two responsible government departments for assessment.

Asia-Pacific ASA was commissioned to carry out marine hydrocarbon spill modelling as part of INPEX's preparation of the EIS, and this technical report has been prepared in fulfilment of that commission.

This marine hydrocarbon spill modelling study was carried out to quantify the secondary risk of exposure to surrounding environmental resources in the event of an accidental spill of hydrocarbons associated with the Ichthys Development. This study considered only the probability of exposure to environmental and other resources if the spill were to occur (Secondary risk), and is intended to complement the quantification of the risk of such accidents occurring (Primary risk). The Primary risk study is being prepared concurrently by Environmental Risk Solutions. The overall risk to sensitive resources will be the product of the Primary and Secondary risks. The two assessments together will allow INPEX to understand the environmental risks associated with different spill scenarios, and to develop appropriate oil spill contingency plans and consider improvements to facility designs.

Six credible scenarios were identified for the offshore operations:

1. A 100 m^3 seabed spill of condensate, at the CPF location, to represent the rupture of an export line close to the CPF
2. A 50 m^3 spill of diesel at the CPF, to represent a rupture of a storage tank on the CPF that overwhelmed the bunding and deck sumps on the CPF
3. A 730 m^3 seabed release of condensate, to represent the rupture of one of the flowlines midway between the CPF and the FPSO
4. A 1000 m^3 surface spill of condensate, to represent a ship collision with the FPSO that resulted in a leak from a condensate cargo tank on the ship
5. An instantaneous surface spill of 30 m^3 of condensate, to represent a spill from a loading hose failure at the FPSO
6. An instantaneous spill of 2.5 m^3 of diesel, at the surface at the CPF and near the boundary of the military training area, to represent an accident while refuelling a construction barge.

Table 1 and Figure 1 summarise the location of the sites assumed to be indicative release points for the offshore spill simulations.

Table 1. Locations of release sites selected for the offshore spill simulations

Location Name	Longitude	Latitude	Water depth (m)
Central processing facility	123°17′52″E	13°56′20″S	256
Floating production, storage and offtake	123°18′34″E	13°57′57″S	256
Military boundary	128°00′59″E	12°31′59″S	117

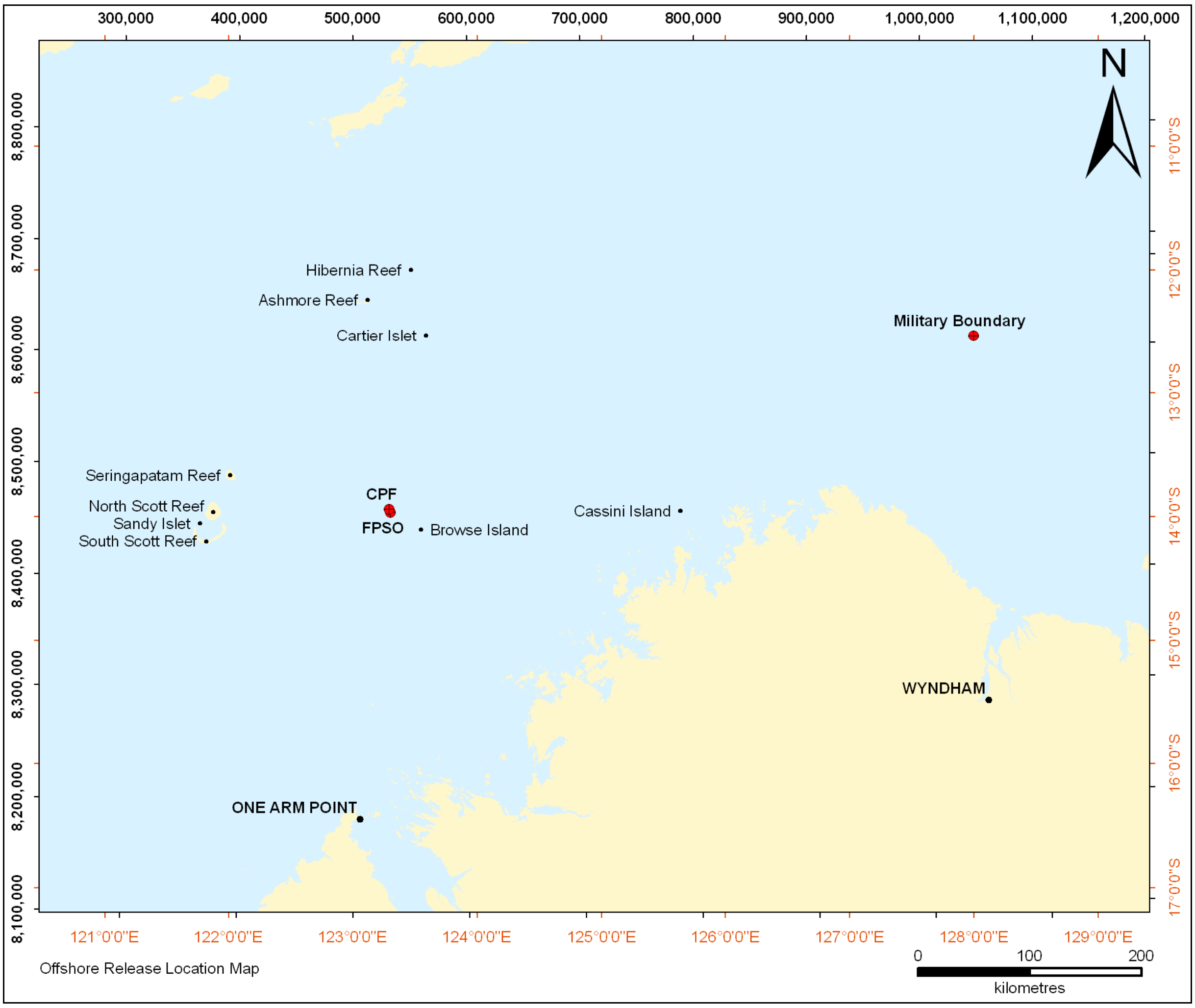


Figure 1. Locations of the release sites selected for the offshore oil spill simulations

A review by INPEX of the proposed Ichthys Development concluded that there were a further four credible hydrocarbon spill scenarios associated with the construction and operation phases within the inshore Darwin area (Darwin Harbour and entrance channel):

7. A 50 m^3 bottom release of condensate from the GEP to represent a full bore rupture
8. A 1 m^3 bottom release of condensate from the GEP to represent a 25 mm hole in the GEP
9. A 25 m^3 surface spill of condensate, to represent a product line or loading hose rupture at the export jetty
10. A 200 L surface spill of diesel fuel, to represent a refuelling incident at the East Arm Wharf.

Table 2 and Figure 2 summarise the location of the sites assumed to be indicative spill locations for each of these scenarios.

Table 2. Locations of release sites selected for the inshore spill simulations

Phase	Location Name	Longitude	Latitude	Water Depth (m)
All	GEP 1	130˚48′45.9″E	12˚29′26.9″S	15.0
All	GEP 2	130˚50′9.7″E	12˚31′52.7″S	15.0
Operations	Jetty	130˚54′31.7″E	12˚30′37.6″S	7.2
All	East Arm Wharf	130˚52′59.6″E	12˚29′36.7″S	11.8

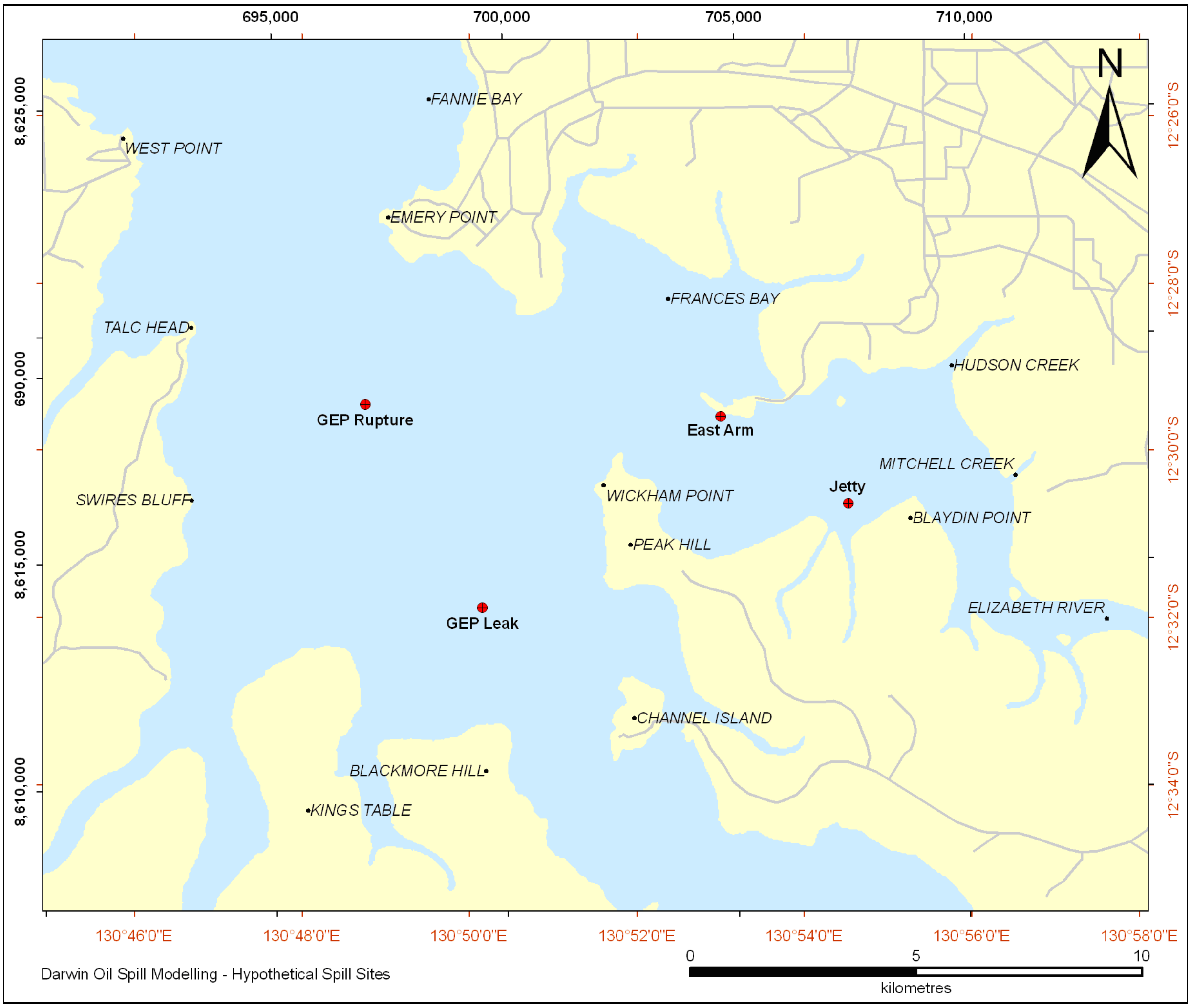


Figure 2. Locations of the release sites selected for the inshore oil spill simulations

2 METHODS

The spill modelling was carried out using a purpose-developed oil spill trajectory and fates model, SIMAP (Spill Impact Mapping and Assessment Program). This model is designed to simulate the transport and weathering processes that affect the outcomes of hydrocarbon spills to the sea, accounting for the specific oil type, spill situation and prevailing wind and current patterns. The SIMAP model is a three dimensional spill model and considers the fate of oil while on the surface and in the water column, in either entrained or dissolved form.

A stochastic modelling approach was applied to gain quantitative estimates of exposure risk for the different spill scenarios under investigation. This involves repeated simulation of each scenario, using different samples of metocean conditions each time. These samples of time varying conditions are selected randomly (and therefore objectively) from a database of historic current and wind data for the study area. The stochastic sampling approach provides an objective measure of the possible outcomes of a spill, because environmental conditions will be selected at a rate that is proportional to the likelihood that these conditions would occur for the area. The most commonly occurring conditions would be selected most often, while conditions that are more unusual are also represented.

Historic wind data were available from a combination of measured and modelled sources. Current data were simulated for the project using models developed to represent the appropriate forces for each of the areas of interest. For Darwin Harbour and approaches, where the harbour morphology is complex and the circulation patterns and potential areas of exposure are strongly affected by the tidal wetting and drying of the mudflats and fringing mangroves, a three-dimensional wetting and drying model was developed over a very fine grid (see Section 4). For the deep offshore waters, where wind and tide forces dominate the circulation and wetting and drying are insignificant, a simpler three-dimensional model (lacking wetting and drying) was developed over a larger-scale grid.

Description of the oil spill model

SIMAP is an evolution of the US EPA Natural Resource Damage Assessment model (French *et al*. 1996; French 1998; French *et al*. 1999) and is designed to simulate the fate and effects of spilled oils and fuels for both the surface slick and the three-dimensional plume that is generated in the water column. SIMAP includes algorithms to account for both physical transport and weathering processes. The latter are important for accounting for the partitioning of the spilled mass over time between the water surface (surface slick), water column (entrained oil and dissolved compounds), atmosphere (evaporated compounds) and land (stranded oil). The model also accounts for the interaction between weathering and transport processes.

The physical transport algorithms calculate transport and spreading by physical forces, including surface tension, gravity and wind and current forces for both surface slicks and oil within the water column. The fates algorithms calculate all of the weathering processes known to be important for oil spilled to marine waters. These include droplet and slick formation, entrainment by wave action, emulsification, dissolution of soluble components, sedimentation, evaporation, decay and shoreline interactions. These algorithms account for the specific oil type being considered. Evaporation rates vary over space and time dependent on the prevailing sea temperatures, wind and current speeds, the surface area of the slick and entrained droplets that are exposed to the atmosphere as well as the state of weathering of the oil. Evaporation rates will decrease over time, depending on the calculated rate of loss of the more volatile compounds. By this process, the model can differentiate between the fates of different oil types. Entrainment, dissolution and emulsification rates are correlated to wave energy, which is accounted for by estimating wave heights from the sustained wind speed and direction and the fetch (i.e. distance downwind from land barriers) at different locations in the domain. Dissolution rates are dependent upon the proportion of soluble, short-chained, hydrocarbon compounds, and the surface area at the oil/water interface of slicks. Dissolution rates are also strongly affected by the level of turbulence. For example, they will be relatively high at the site of the release for a deep-sea discharge at high pressure. In contrast, the release of hydrocarbons onto the water surface will not generate high concentrations of soluble compounds. However, subsequent wave action will enhance dissolution from surface slicks. Because the compounds that have high solubility also have high volatility. The processes of evaporation and dissolution will be in dynamic competition. Technical descriptions of the algorithms used in SIMAP and validations against real spill events are provided in e.g. French *et al*. (1996) and French (1998).

Input specifications for oil types include the density, viscosity, pour-point, distillation curve (volume of oil distilled off versus temperature) and the aromatic/aliphatic component ratios within given boiling point ranges. The model calculates a distribution of the oil by mass into the following components:

- Surface bound oil
- Entrained oil (non-dissolved oil droplets that are physically entrained by wave action)
- Dissolved hydrocarbons (principally the aromatic and short-chained aliphatic compounds)
- Evaporated hydrocarbons
- Sedimented hydrocarbons
- Decayed hydrocarbons.

The stochastic model within SIMAP performs a large number of simulations for a given spill site, randomly varying the spill time for each simulation. The model uses the spill time to select samples of current and wind data from a long time-series of wind and current data for the area. Hence, the transport and weathering of each slick will be subject to a different sample of wind and current conditions. During each simulation, the model records the grid cells (by horizontal and depth location) that were contacted by oil, as well as the amount of time that had elapsed prior to the contact or exposure.

Once the stochastic modelling is complete, the results are compiled from each of the sample trajectories to provide a statistical weighting to the likelihood of exposure for a given location. Results are summarised as:

1. Probability of exposure to locations at the water surface and shorelines, for slicks exceeding a defined threshold concentration

2. Probability of exposure to locations from entrained oil and dissolved aromatic hydrocarbons, for in-water concentrations exceeding a defined threshold concentration.

These estimates are calculated from the frequency of exposure during all simulations. To illustrate this process, Figure 3 shows a sample of the patch swept by surface oil during three independent simulations of a hypothetical 200 L diesel spill adjacent to the East Arm Wharf during the months spanning May to August. Each path represents the area swept by oil of any concentration (estimated to < 0.001 g m^{-2}) over a 5-day period using different, randomly selected, samples of wind and current data. Note how the path varies among the simulations but some areas were exposed in each case.

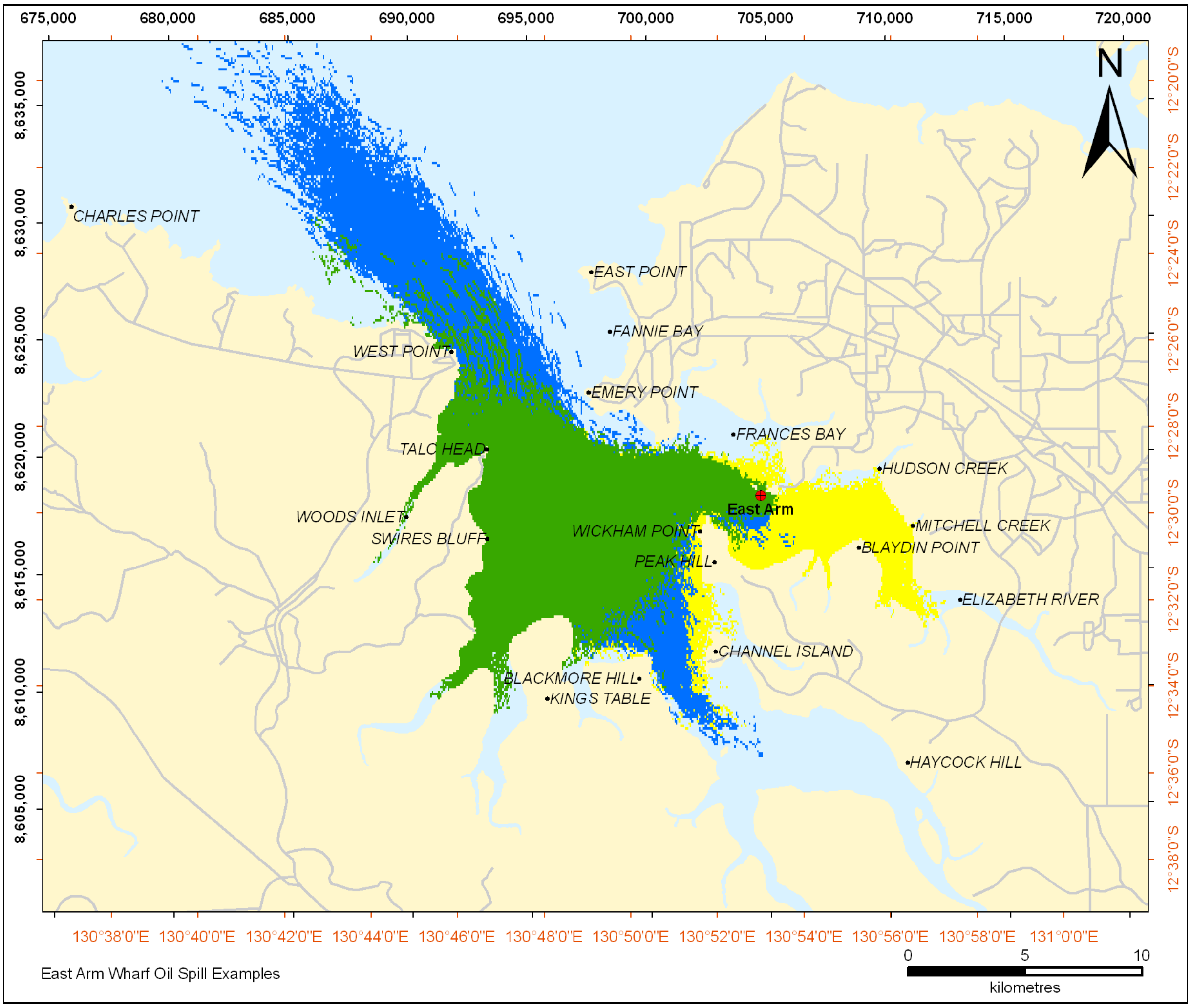


Figure 3. A sample of three single oil spill trajectories for a hypothetical 200 L diesel spill during the winter season (May - August).

Inputs to the offshore risk assessment

Offshore wind and current data

Wind information was available for the offshore development area from several sources. These data were compared to identify the longest set of uninterrupted data that correctly reflected observed seasonal trends at East Arm.

Wind records of variable duration and quality (some with multiple gaps) were obtained from several weather stations (Browse Island, Adele Island and Troughton Island, Kalumbaru and Truscott) and analysed (source: Bureau of Meteorology). An analysis of these wind measurements (Figure 4) shows that there are two prominent seasons:

- October till February, with prevailing westerly wind
- May till July, with prevailing easterly wind.

Two shorter transitional periods, with more variable wind directions usually during March–April and August–September, occur between these periods. These results are in good accord with findings of previous studies in the area (e.g. WNI 1997). The seasonal patterns were well reproduced in a longer data record produced by the NCEP/NCAR model re-analysis for 1999-2006 (Figure 5) which provided the advantage of representing spatial variation in wind patterns over the study area and was available as an uninterrupted data set covering 8 years. Consequently, the NCEP/NCAR data was applied to stochastic modelling for the offshore spill scenarios

For offshore oil spill modelling, current data were generated using an ocean/coastal circulation model, HYDROMAP. HYDROMAP simulates the flow of ocean currents within a model region due to forcing by astronomical tides, wind stress and bottom friction and can assimilate current vectors from other sources (e.g. large-scale drift currents). The model uses a “telescoping” grid structure, allowing definition of circulation at increasingly higher resolution into shallow waters. The model set up and validation for the offshore model is described in the companion report, Asia-Pacific ASA (2009).

Offshore water temperature and salinity settings

The WNI report (1997) for Browse Basin indicated that sea surface temperatures may vary seasonally within the limits 28 °C (winter and spring) – 30 °C (summer and autumn), while water salinity is almost constant and close to 35.0 parts per thousand (ppt) throughout the seasons. These data were applied to the offshore spill simulations.

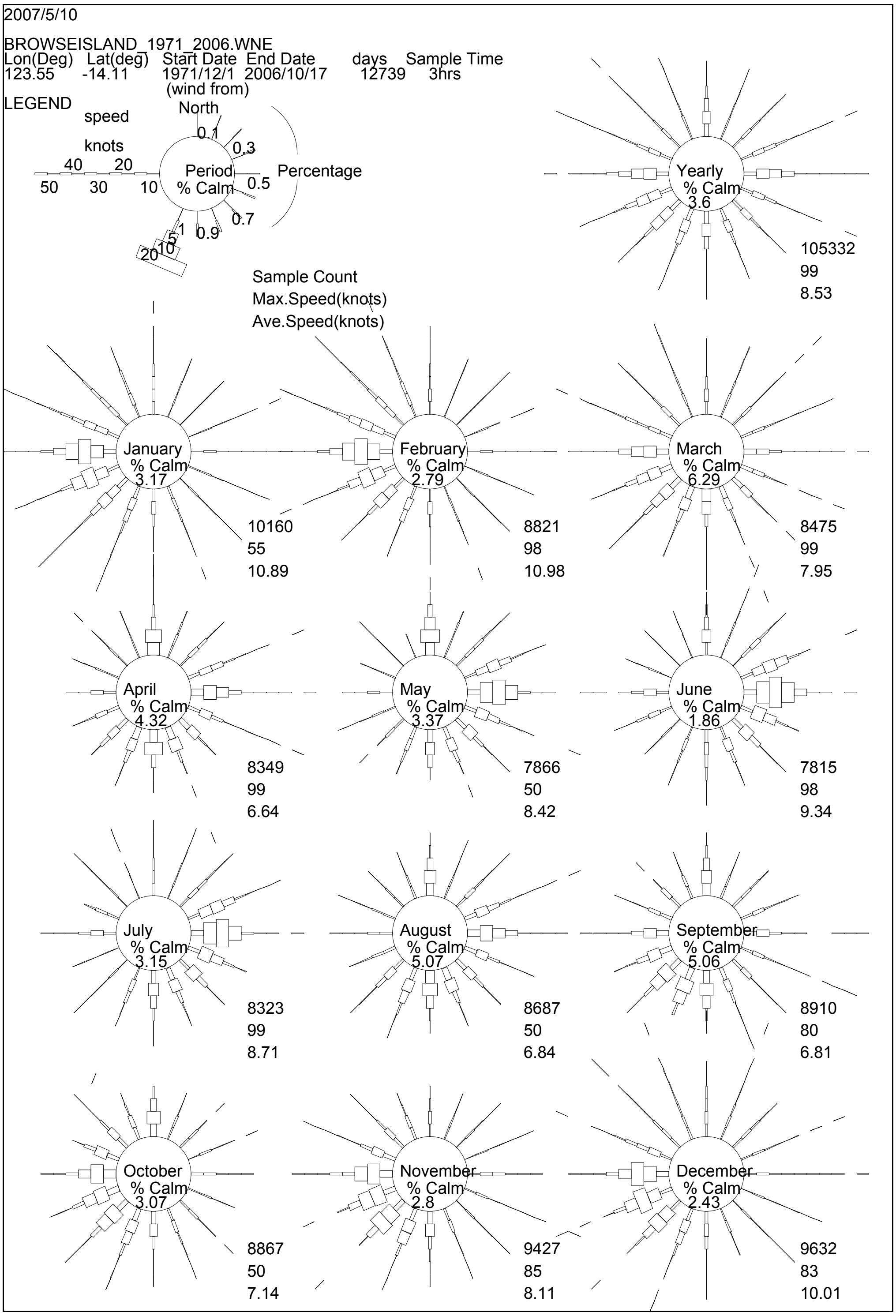


Figure 4. Monthly and yearly wind rose diagrams of the winds measured at Browse Island.

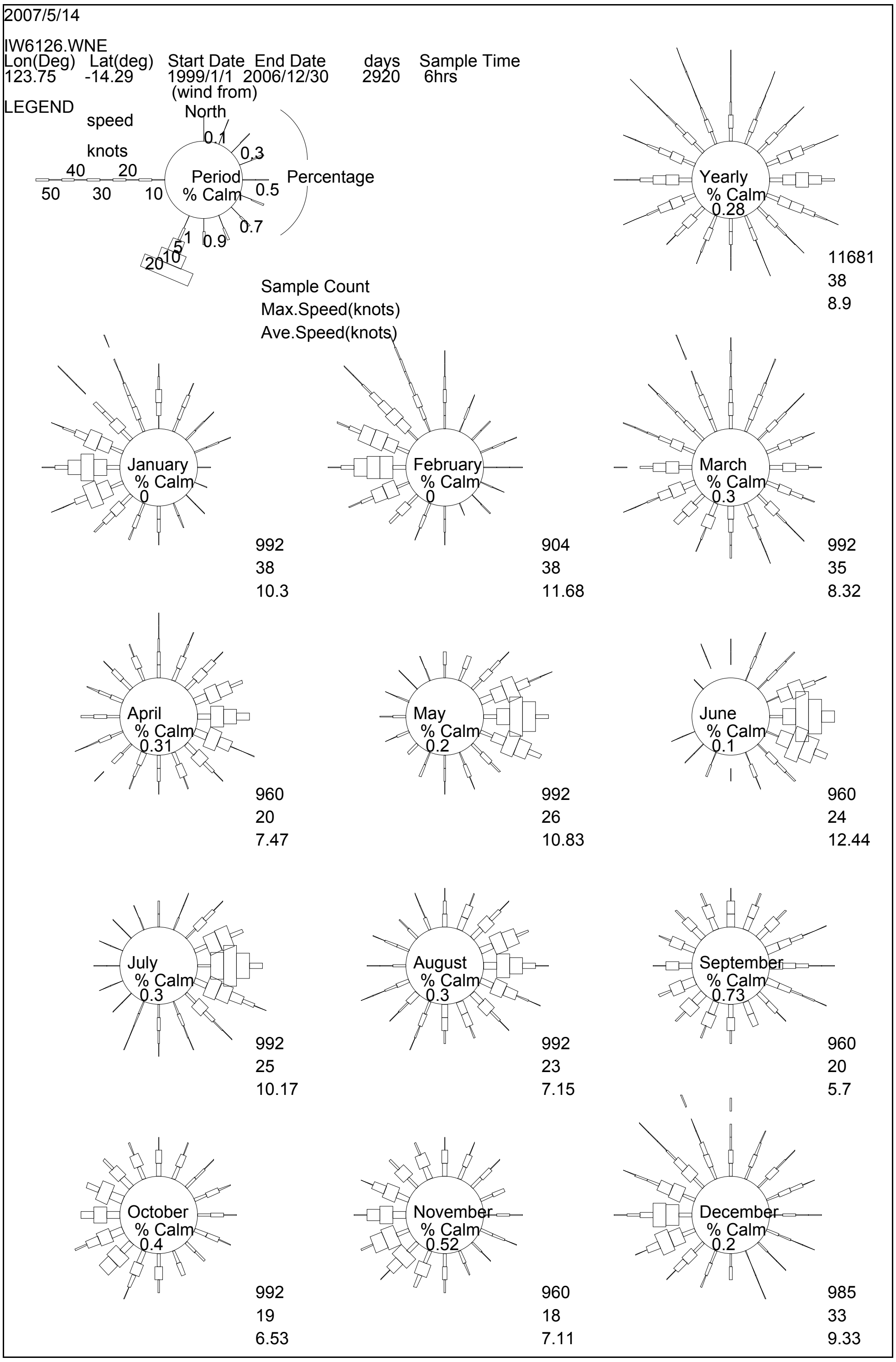


Figure 5. Monthly and yearly wind rose diagrams of the winds predicted at Browse Island by NCEP/NCAR model re-analysis.

Offshore scenario settings

Offshore spill trajectories were found to be more highly variable than the inshore trajectories, due to a larger effect of the wind offshore. For that reason, 200 simulations were completed per season and scenario combination (i.e. 600 per scenario, and 4200 in total) for the offshore risk assessment scenarios (Table 3).

Contact of oil on water or shoreline was only registered when the predicted thickness exceeded a threshold of 0.001 mm (1 µm or 1 g/m^2). This is equivalent to the lowest thickness where the oil will appear as a yellowish brown film (Figure 6) and the upper limit at which it will appear as a dull coloured sheen (NOAA HAZMAT 1996). Minimum thresholds for entrained and dissolved oil concentrations were set at 1 part per billion (ppb).

A horizontal dispersion coefficient of 10 m^2/s was used to account for the dispersive processes acting below the scale of resolution of the input current field, based on typical values for open waters (Okubo 1971).

Table 3. Summary of the offshore oil spill scenarios

Number	Scenario	Spill Location	Spilled Fluid	Volume	Spill Duration	Simulation period
1	Seabed flowline rupture	CPF (sub-surface)	Condensate	100 m^3	1 hour	10 days
2	Storage tank rupture	CPF	Diesel	50 m^3	Instantaneous	10 days
3	Product line rupture	Midway between CPF and FPSO (sub-surface)	Condensate	730 m^3	12 hours	10 days
4	Product lost from export ship following collision with the FPSO	FPSO (release from 10 km radius)	Condensate	1000 m^3	12 hour	10 days
5	Loading hose failure	FPSO	Condensate	30 m^3	Instantaneous	5 days
6A	Spill during refuelling of construction barge	CPF	Diesel	2500 L	Instantaneous	10 days
6B	Spill during refuelling of construction barge	Military Boundary	Diesel	2500 L	Instantaneous	10 days

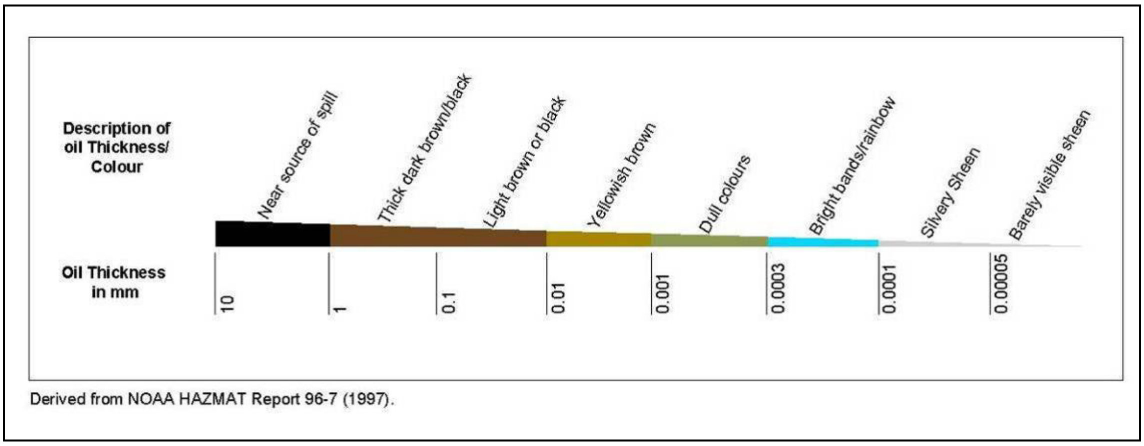


Figure 6. Surface oil colour description as a function of surface oil layer thickness (source: NOAA HAZMAT Report 96-7)

Inputs to the inshore risk assessment

Inshore wind and current data

Historic wind data for the region were available from electronic measurements collected at Darwin Airport by the Bureau of Meteorology, at hourly intervals. The suitability of this data for the harbour was confirmed by comparison to a 4 month sample of wind data measured by APASA at the East Arm Wharf.

Figure 7 shows the yearly and monthly wind roses summarising the distribution of wind speeds and directions according to the measured data. Note that the axes indicate the direction the wind blew from, (e.g. an axis pointing up the page from the centre of the wind-rose designates winds from the north). The width of each segment within a branch is proportional to the frequency of winds within the corresponding range of speeds from that direction.

The wind roses indicate that average and maximum measured non-cyclonic winds at Darwin are 4 m/s and 14 m/s, respectively, and that predominant wind directions vary seasonally. For the inshore risk assessment, wind seasons were classified into three periods, as shown in Table 4. During the summer months (November to February), the winds are most frequently from the west. The winds throughout the winter months (May to August) are most frequently from the eastern sector, shifting between the northeast to southeast. During the transitional months (March-April and September-October), wind directions are more variable and all directions are represented over shorter durations.

Current data for Darwin Harbour and approaches were generated using a three-dimensional estuarine/coastal circulation model, BFHYDRO, which uses a flexible cell grid to maximise spatial resolution.

BFHYDRO produces three-dimensional current estimates, thereby representing changes in current speed and direction as a function of depth. The model also represented the change in the water and shoreline area due to tidal wetting and drying over the wide inter-tidal zones within Darwin Harbour. This model capability was considered critical to account for the full tidal exchange between Darwin Harbour and the open sea, as well as the variability in the position of the potential shoreline-stranding locations as the tide changed. The model set up and validation for the inshore model, as well as proof of the suitability of the Darwin Airport wind data are described in the companion report, Asia-Pacific ASA (2009).

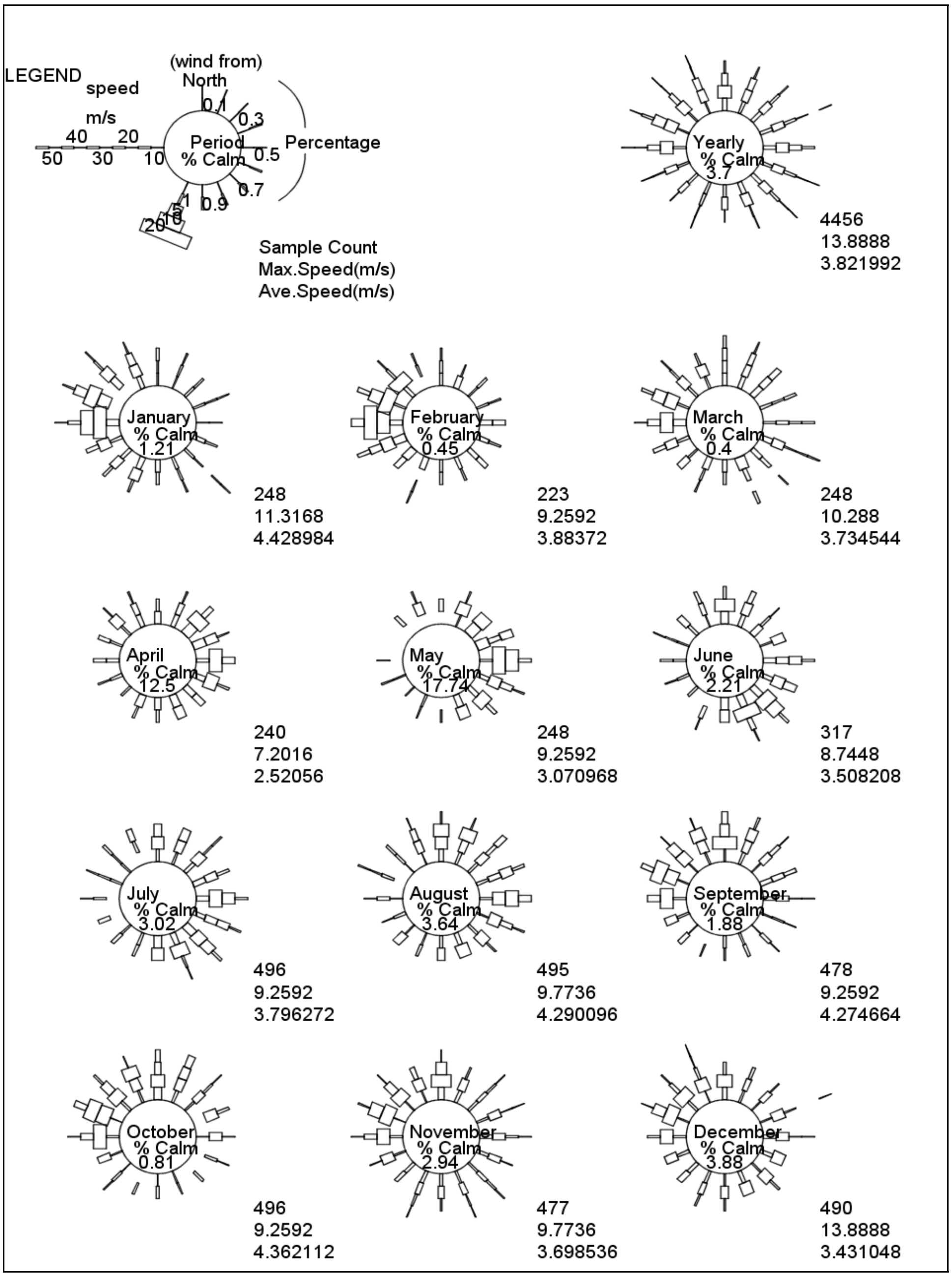


Figure 7. Monthly and yearly wind rose diagrams of the winds measured at Darwin Airport (sample data are January to December 2005)

Table 4. Classification of seasons, based on the local wind data

Season	Period	Number of Months
Summer	November to February	4
Transitional	March–April, September–October	4
Winter	May to August	4

Inshore water temperature and salinity settings

Sea surface temperatures influence the evaporation rate of oil slicks. The Department of Defence Directorate of Oceanography and Meteorology (DDDOM; www.metoc.gov.au) report that sea surface temperatures vary seasonally within Darwin harbour, from a minimum of 26 °C in winter to a maximum of 30 °C in summer.

Water salinity influences the buoyancy of oil slicks, with increased chance of oil entraining with a decrease in salinity. DDDOM data indicated that surface salinity varies only slightly (34.3 ppt to 35.0 ppt) throughout the year so a conservative salinity (34.0 ppt) was defined allowing for more oil to be entrained.

Inshore scenario settings

Table 5 provides a summary of the four unique spill scenario and location combinations that were investigated for release points inside the harbour.

One hundred single random trajectories were simulated per season/scenario/location combination (i.e. 300 per scenario, and 1200 in total).

Surface contact was registered for contact by slicks at a conservatively lower concentration than was selected for the offshore scenarios. In this case, contact was recorded for thickness estimates exceeding a threshold of 0.001 mm (1 µm), approximately equivalent to a surface concentration of 1 g/m^2. This is equivalent to the lowest thickness where the oil will appear as a yellowish brown film and the upper limit at which it will appear as a dull coloured sheen (NOAA HAZMAT 1996, Figure 6). The threshold for shoreline exposure was also set to a thickness of 0.001 mm (1 µm or 1 g/m^2), which is the thickness that the oil could be observed on shorelines (as a dull yellow colour). This thickness remains below the level required for oil to be physically collected (Bonn Agreement Oil Appearance Code) and is also considered to be conservatively low for ecological consequence. Minimum thresholds for entrained and dissolved oil concentrations were set at a conservatively low value of 1 ppb, based on a review of the toxicity thresholds related to oil exposure to marine organisms (French *et al*. 1996).

Table 5. Summary of the inshore oil spill scenarios

No.	Scenario	Spill Location	Spilled Fluid	Volume	Spill Duration	Simulation period
7	GEP full bore rupture	GEP	Condensate	50 m^3	3 hours	5 days
8	GEP 25mm hole	GEP	Condensate	1 m^3	24 hours	5 days
9	Product line or loading hose rupture	Jetty	Condensate	25 m^3	Instantaneous	5 days
10	Refuelling spill	East Arm Wharf	Diesel	200 L	Instantaneous	5 days

Spill simulations were carried out using wind samples from three major wind seasons, based on the wind analysis.

1. Summer (November to February)
2. Transitional period (March–April, September–October)
3. Winter months (May to August).

A horizontal dispersion coefficient value of 3 m^2/s was used to account for dispersive processes that occur below the scale of resolution of the current field, based on typical values reported for estuaries with a large tidal exchange (Okubo 1971).

Oil properties and weathering characteristics

Characteristic oil properties were defined for the diesel and condensate that would be handled within the inshore and offshore regions. Diesel oil was characterised using the formulation of a commercial fuel determined for a similar operational temperature to the Browse Basin. This formulation would have an initial API of 37.6 (or 829.1 kg/m^3) and a viscosity of 4 centipoise (cP). Diesel is a mixture of volatile and semi-persistent hydrocarbons, with approximately 60–75% by mass predicted to evaporate over the first day or two, depending upon the prevailing conditions. The remainder will not readily evaporate. The heavier components of diesel have a density closer to sea water and will tend to entrain into the upper water column as oil droplets in the presence of waves. This oil is not dissolved and can refloat to the surface if wave energies abate. Figure 8 shows predictions for the weathering of this oil type, given an instantaneous release of 200 L at the surface. The weathering simulation was under varying current and wind conditions. Note the dynamic balance that is predicted to develop between the surfaced and entrained (water column) component. The entrained diesel will be concentrated in the upper water column and, thus, can be transported by near-surface currents onto sensitive locations.

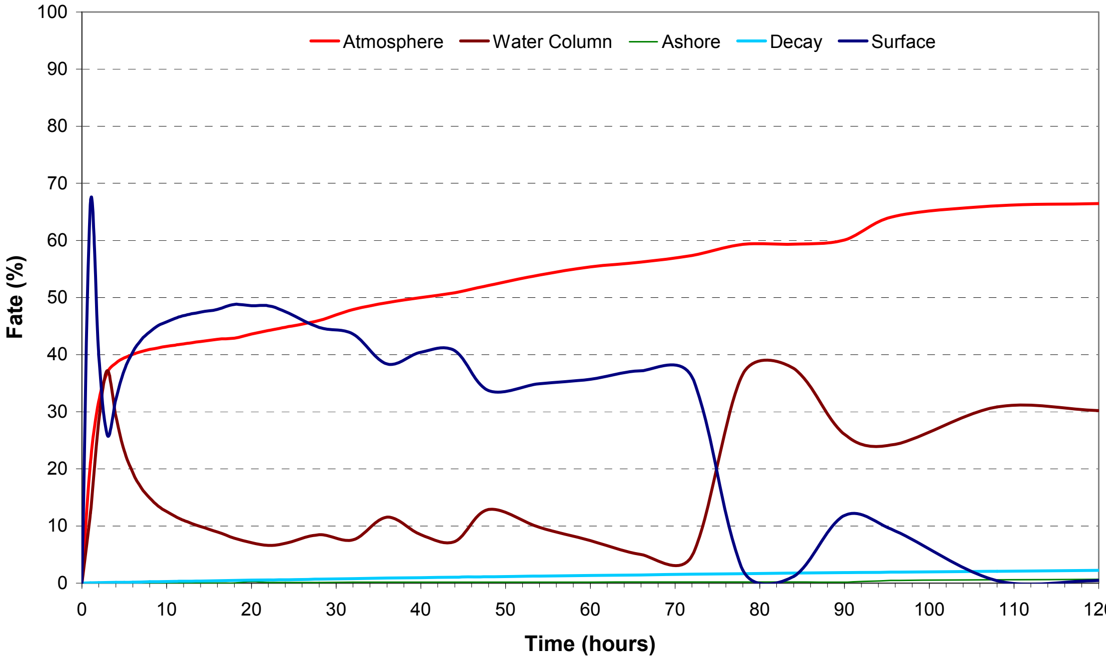


Figure 8. Weathering and fates graph for an instantaneous 200 L surface release of diesel tracked for 5 days, under varying current and wind conditions

Expected properties for the condensate that would be handled during the operational phase of the Ichthys Development were provided by INPEX. Condensate, which could be spilled at the offshore facilities, would be a light oil (API of 58.7, density of 744 kg/m^3) with low viscosity of 0.754 cP and a relatively low proportion of aromatic hydrocarbons (3.1%). Simulations of the evaporation of this condensate indicate that a high proportion of the mass (70–80%) would evaporate within the first day of release. Evaporation would then slow, leaving a non-volatile residual (~15%) that would resist evaporation (Figure 9).

In the case of pressurised releases at the seabed (scenarios 1, 5, 7, 8 and 9, see Table 3 and 5), the condensate would be atomised into droplets of variable size by the gas escaping under pressure from the pipeline. Smaller droplets will rise more slowly than larger droplets, hence the supply of condensate to the surface will be extended. In turn, the weathering period will be extended (French 2000). Figure 10 shows the weathering predictions for a release of offshore condensate (730 m^3) as fine droplets from 250 m below sea level. A relatively high proportion of the mass remained entrained for up to 4 days, and the volatile components took up to seven days to evaporate. About 40% of the mass was predicted to remain in the water column as fine droplets after this period.

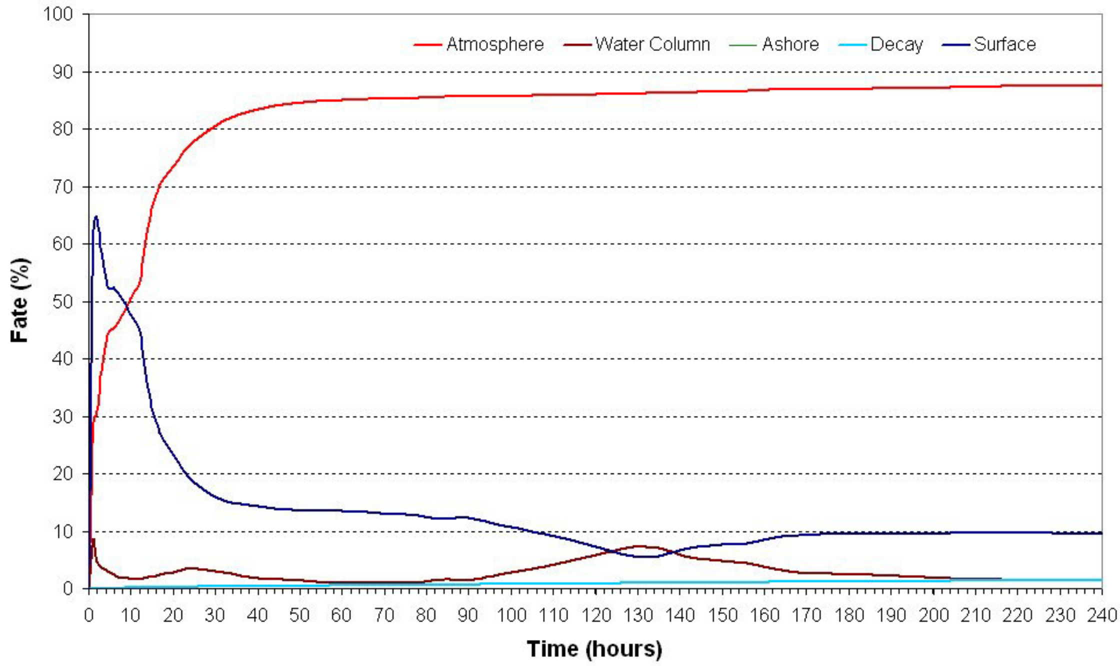


Figure 9. Weathering and fates graph for a 1000 m^3 surface release of offshore condensate (over 12 hours) tracked for 10 days, under varying current and wind conditions

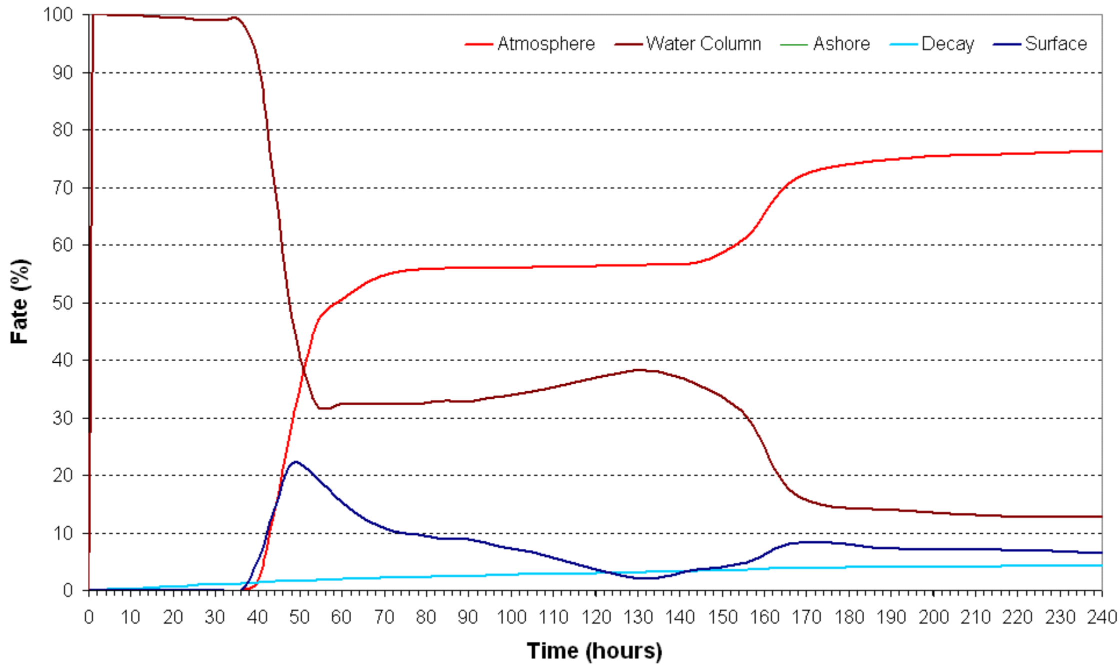


Figure 10. Weathering and fates graph for a 730 m^3 sub-surface of condensate (over 12 hours) tracked for 10 days, under varying current and wind conditions

Onshore condensate that would be transferred to export ships at the East Arm Jetty would have marginally lower density (API of 75.7, density of 682.9 kg/m^3) and viscosity (0.296 cP) but a higher aromatic content (6.4%) than the offshore condensate. This hydrocarbon type is predicted to be highly volatile, with complete evaporation occurring within 12 hours, if spilled at the sea surface (Figure 11).

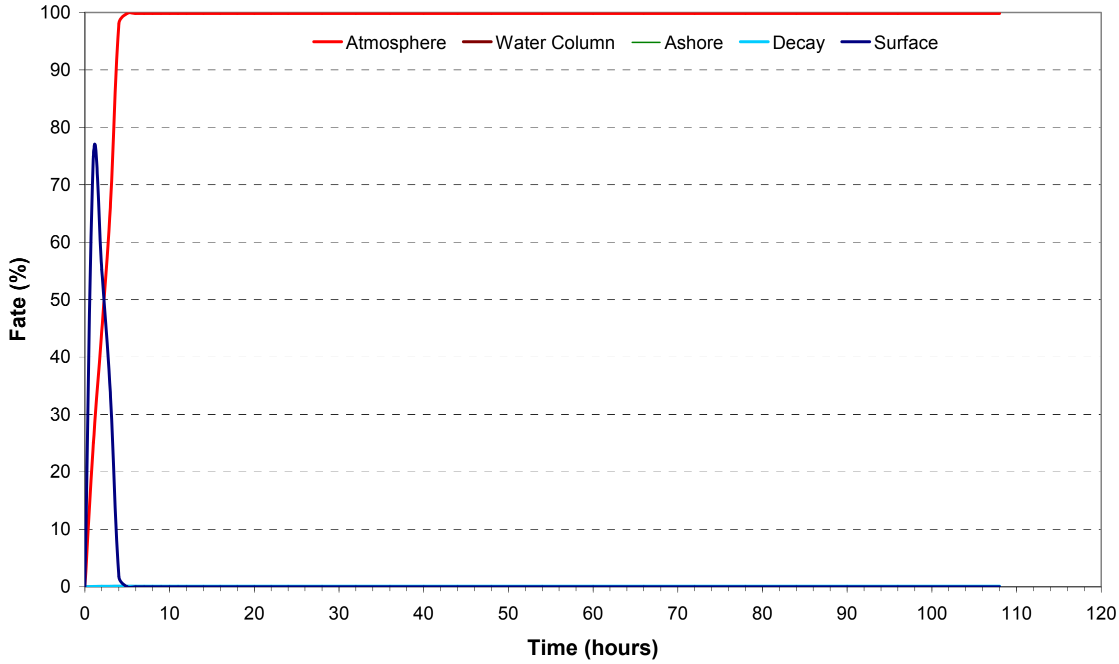


Figure 11. Weathering and fates graph for an instantaneous 80 m^3 surface release of onshore condensate tracked for 5 days, under varying current and wind conditions

Sub-surface oil behaviour

It should be noted that sub-surface (or entrained) oil drifts differently to surface bound oil. Surface bound oil is influenced both by winds and surface currents, whilst sub-surface oil is only influenced by sub-surface currents. Sub-surface oil can have a different speed and direction to surface bound oil and may impact coastal cells within the SIMAP model, while surface bound oil does not. SIMAP's coastal cells are considered the inter-tidal area, or foreshore, and any oil entering these cells, either as surface or sub-surface oil, is considered a shoreline strike. Therefore, SIMAP modelling results can indicate water surface oiling probabilities adjacent to coastal cells lower than the probability of shoreline oiling.

3 MODEL RESULTS

Results for offshore spill scenarios

The following section summarises the probabilities of exposure to shorelines and subsurface plumes to submerged habitats for each of the scenarios.

Scenario 1: Discharge of condensate from a seabed flowline rupture adjacent to CPF

Well fluids and gas produced from the Ichthys wells will be conducted through seabed flowlines to the CPF. In the event of a rupture of one of these flowlines, INPEX estimates that condensate loss would be limited by the ability to shut-in and isolate the line. A maximum loss volume of approximately 100 m^3 and duration of one hour were specified by INPEX for this scenario. A rupture of one of these lines would liberate pressurised gas; therefore it was assumed that the condensate would be atomised (median droplet size approximately 200 µm).

Simulations of this scenario indicated that the condensate would rise towards the surface over time. The larger droplets would surface relatively quickly (< one hour), generating thin slicks and sheens close to the release location, while the smaller droplets may be trapped and rise to the surface more slowly, while drifting with the prevailing currents. The predicted probability of surface oil exposure (above 1 µm) are shown for each season in Figure 12 to Figure 14. Results relative to shorelines are summarised in Table 6.Highest concentrations of entrained (145 ppb) and dissolved (48 ppb) hydrocarbons were predicted for winter conditions, when transport is least likely to be toward Browse Island. Figure 18 shows the maximum entrained hydrocarbon concentrations, calculated for each grid cell (above 1 ppb), from all of the simulations (200 single trajectories) during the winter months.

Table 6. Scenario 1: probability of shoreline oil exposure

Season	Number of cases impacting shorelines (%)	Maximum probability of shoreline exposure at a single location (%)	Maximum oil on shore (%)	Minimum time to shore (hours)	Maximum length of oiled shoreline (km)
Summer	10	9	3	79	15
Transitional	4	3	2	132	4
Winter	22	6	1	145	48

The modelling showed that, during the summer months, slicks would most likely drift towards the east due to the influence of the westerly winds (Figure 12) reaching the shore in 10% of cases. The maximum probability of exposure of any shoreline was 9%, with a minimum travel time (to Browse Island) of about 79 hours.

During the transitional months, the direction of drift is expected to be more variable, with a 3% probability predicted for condensate slicks to reach either Browse Island or Seringapatam Reef in 4% of cases.

Results for the winter months indicate there is a high likelihood that slicks will drift west towards Seringapatam Reef and the Scott Reef group and impact the shoreline for 22% of cases. However, due to the distance to these reefs from the release site (~130 km) and the highly evaporative nature of the condensate, only a small percentage (1% of the spill volume or less) is expected to arrive. Browse Island was predicted to have low risk of exposure (~1%) during winter.

Probability plots for the concentrations of entrained oil and dissolved aromatics exceeding 1 ppb are shown in Figure 15 to Figure 17. The results for all three seasons indicate that plumes of entrained and dissolved hydrocarbons will reduce in concentration to less than 1 ppb within 15 km from the release point and, therefore, would not reach any of the significant island or reef structures surrounding the CPF.

Highest concentrations of entrained (145 ppb) and dissolved (48 ppb) hydrocarbons were predicted for winter conditions, when transport is least likely to be toward Browse Island. Figure 18 shows the maximum entrained hydrocarbon concentrations, calculated for each grid cell (above 1 ppb), from all of the simulations (200 single trajectories) during the winter months.

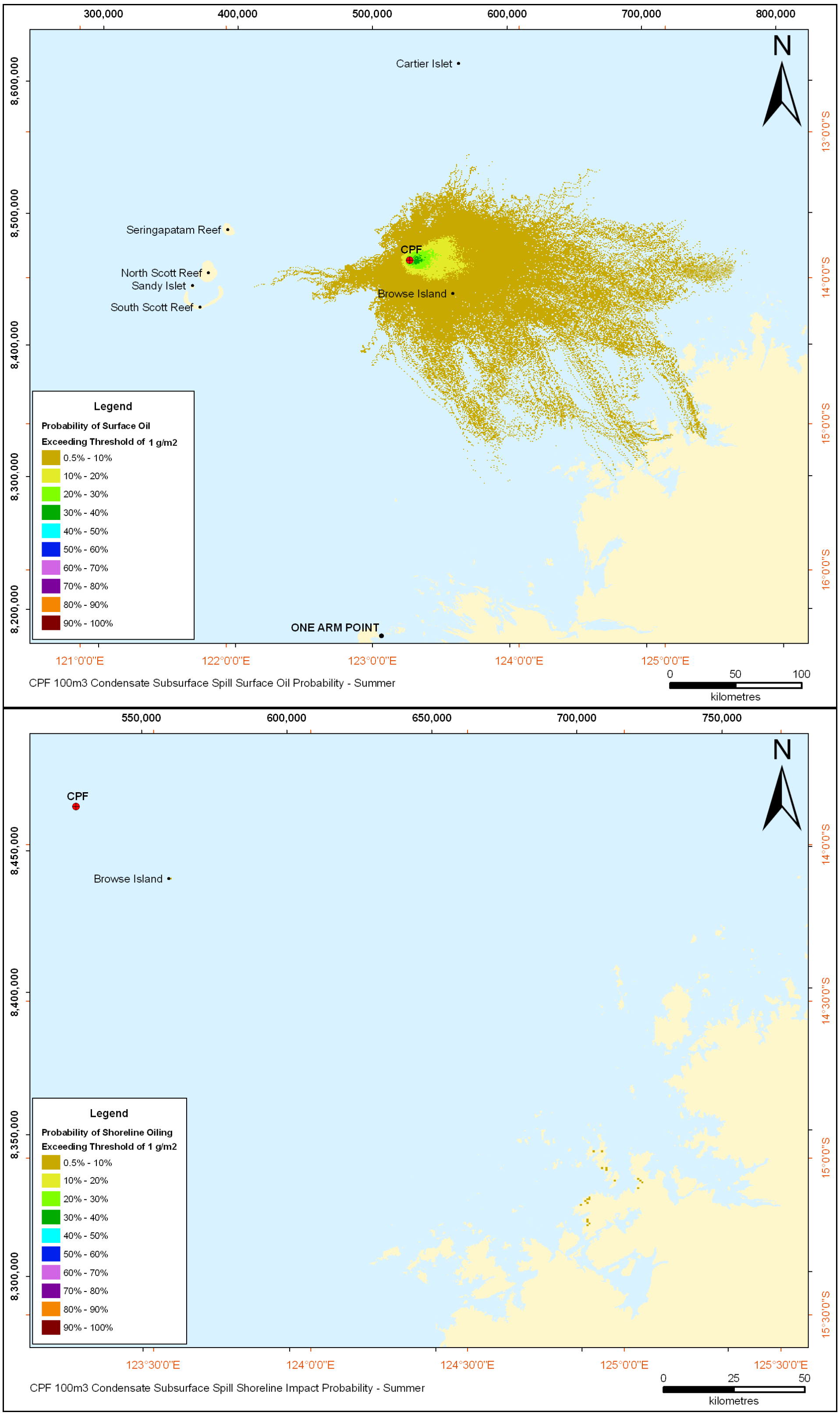


Figure 12. Scenario 1: predicted probability of oil exposure to the water surface(top) and shoreline oil exposure (bottom) above 1 g/m^2 (1 μm) as a result of a 100 m^3 release of condensate under summer conditions. Probability of shoreline exposure to Browse Island was indicated

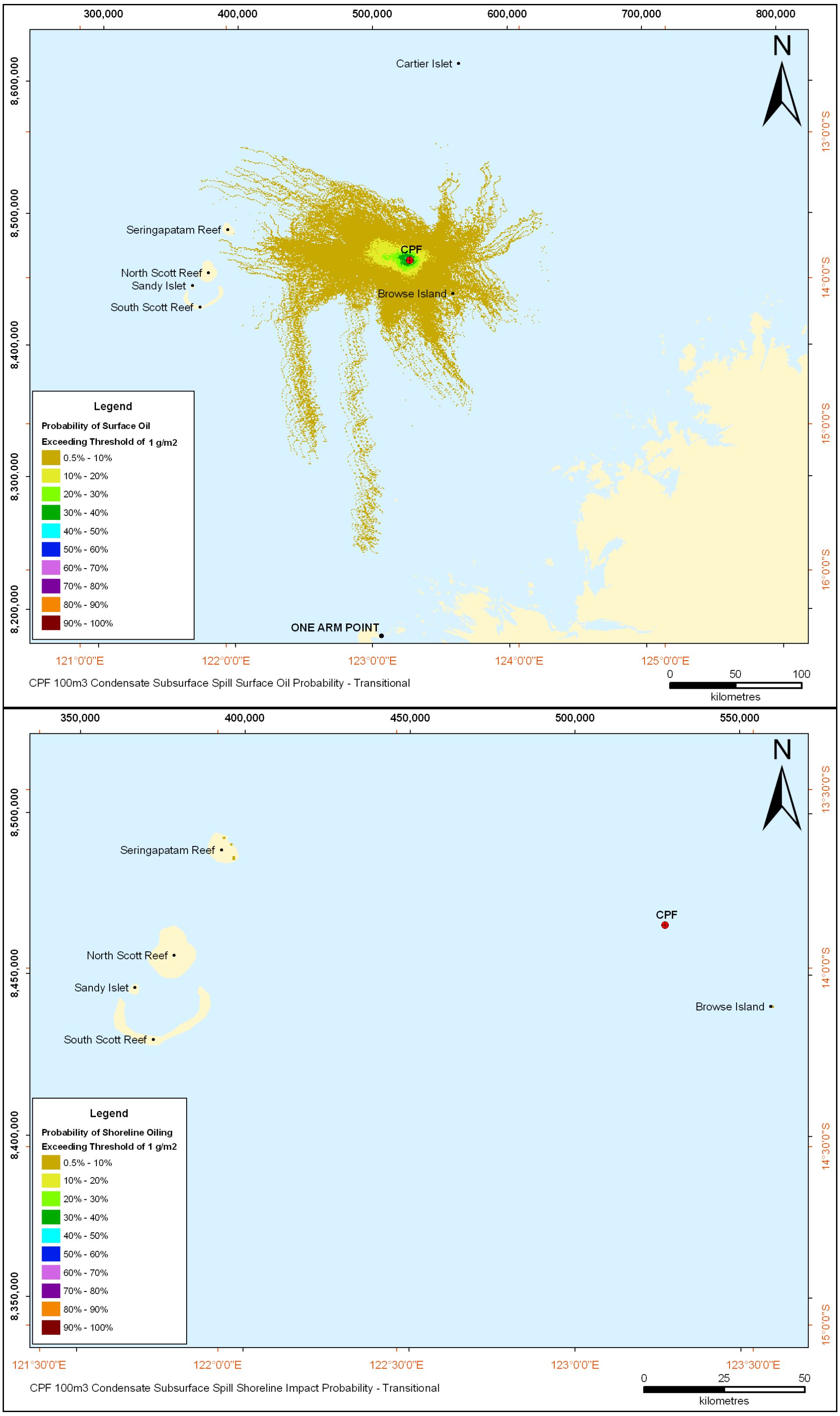


Figure 13. Scenario 1: predicted probability of oil exposure to the water surface (top) and shoreline oil exposure (bottom) above 1 g/m^2 (1 µm) as a result of a 100 m^3 release of condensate under transitional conditions. Probability of shoreline exposure to Browse Island was indicated

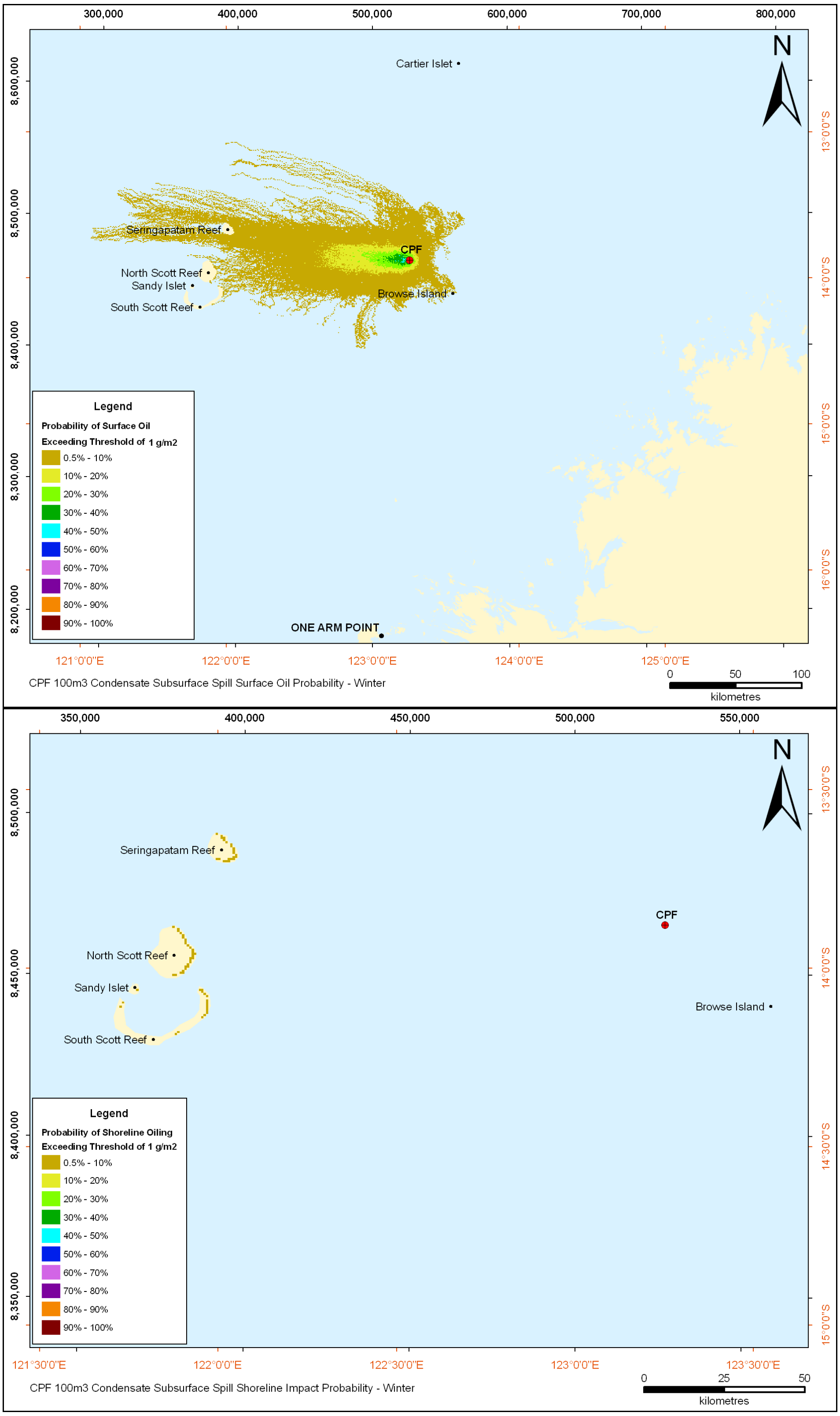


Figure 14. Scenario 1: predicted probability of oil exposure to the water surface(top) and shoreline oil exposure (bottom) above 1 g/m^2 (1 µm) as a result of a 100 m^3 release of condensate under winter conditions. Probability of shoreline exposure to Browse Island was indicated

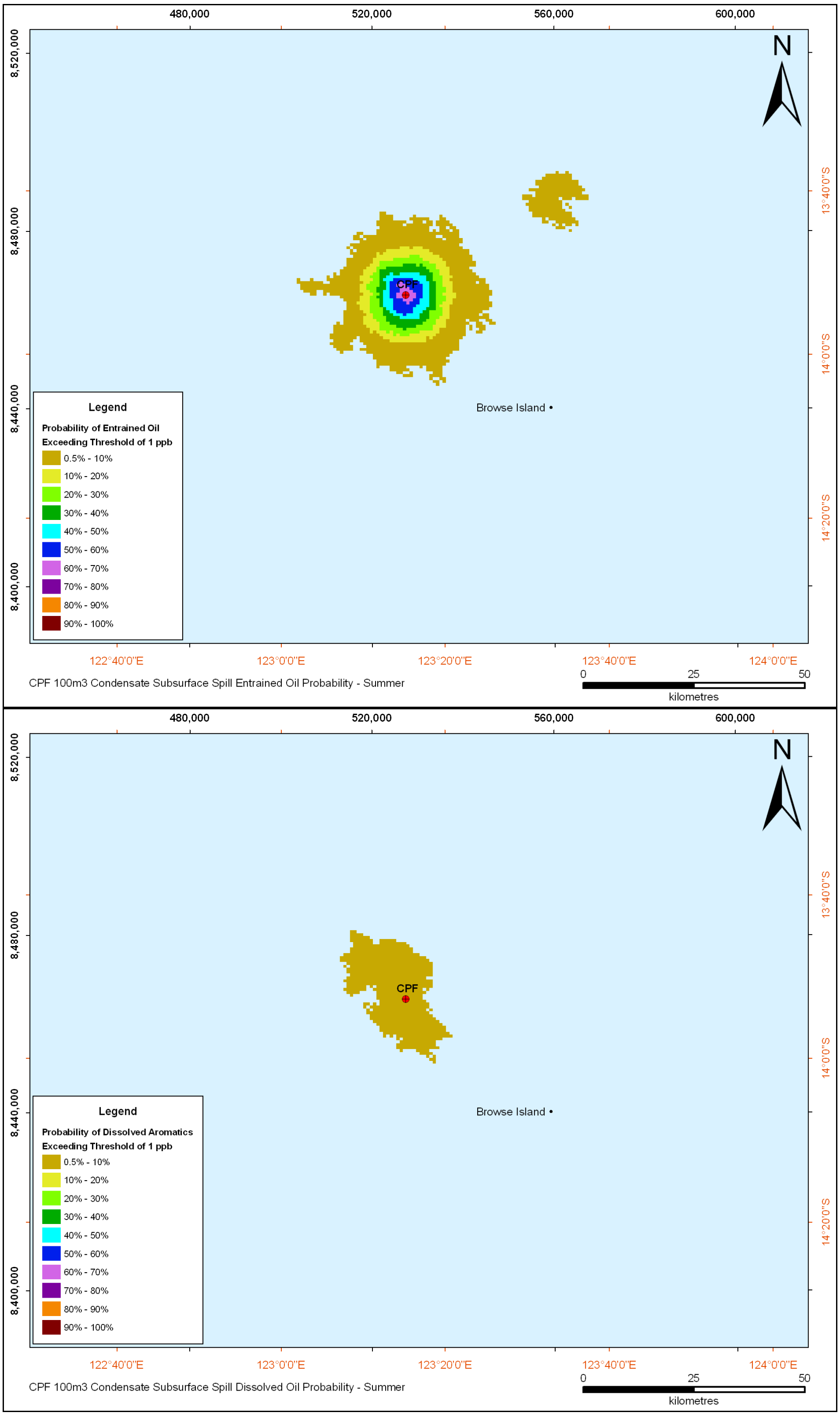


Figure 15. Scenario 1: predicted probability of exposure to entrained oil (top) and dissolved oil (bottom) concentrations exceeding 1 ppb as a result of a 100 m^3 release of condensate under summer conditions

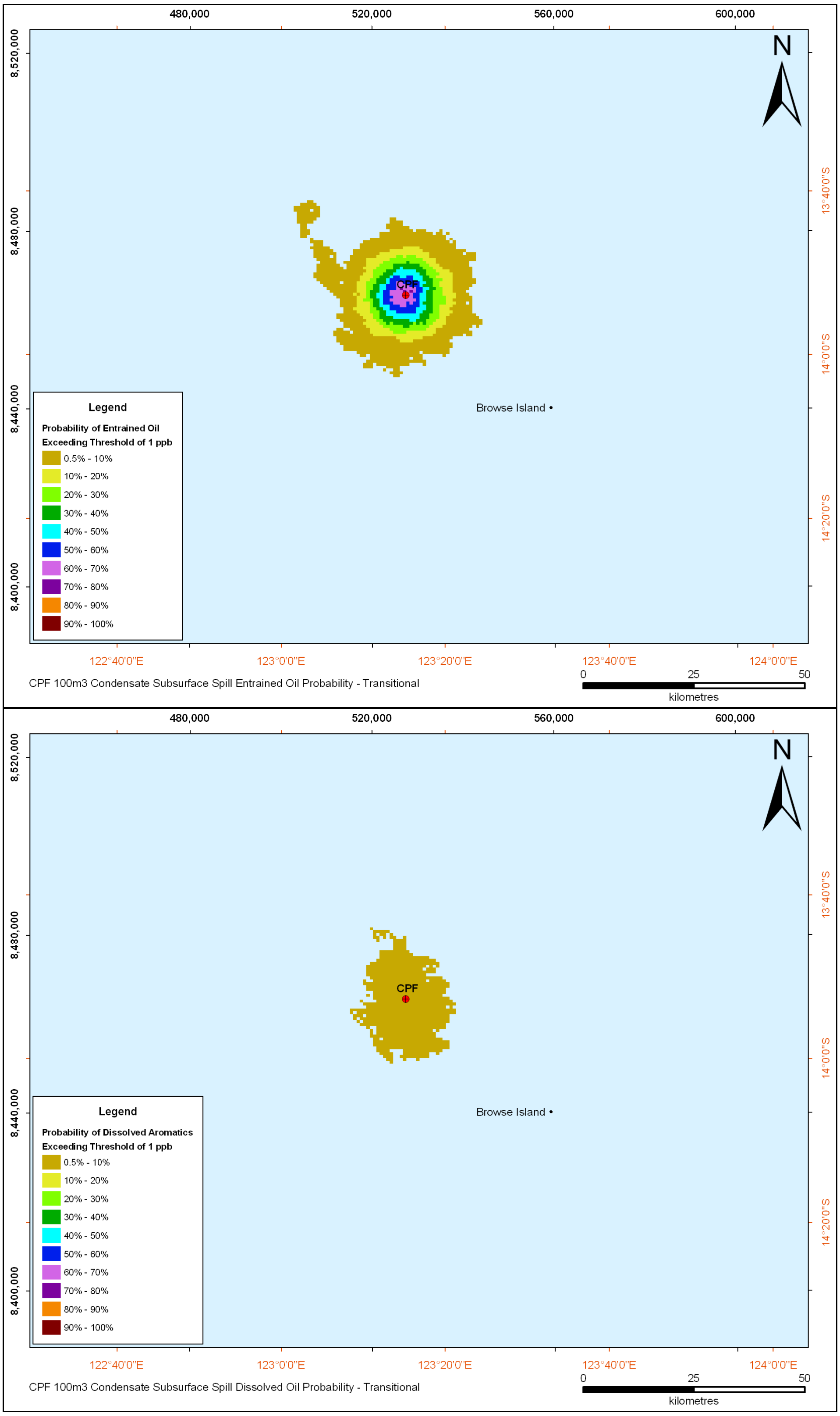
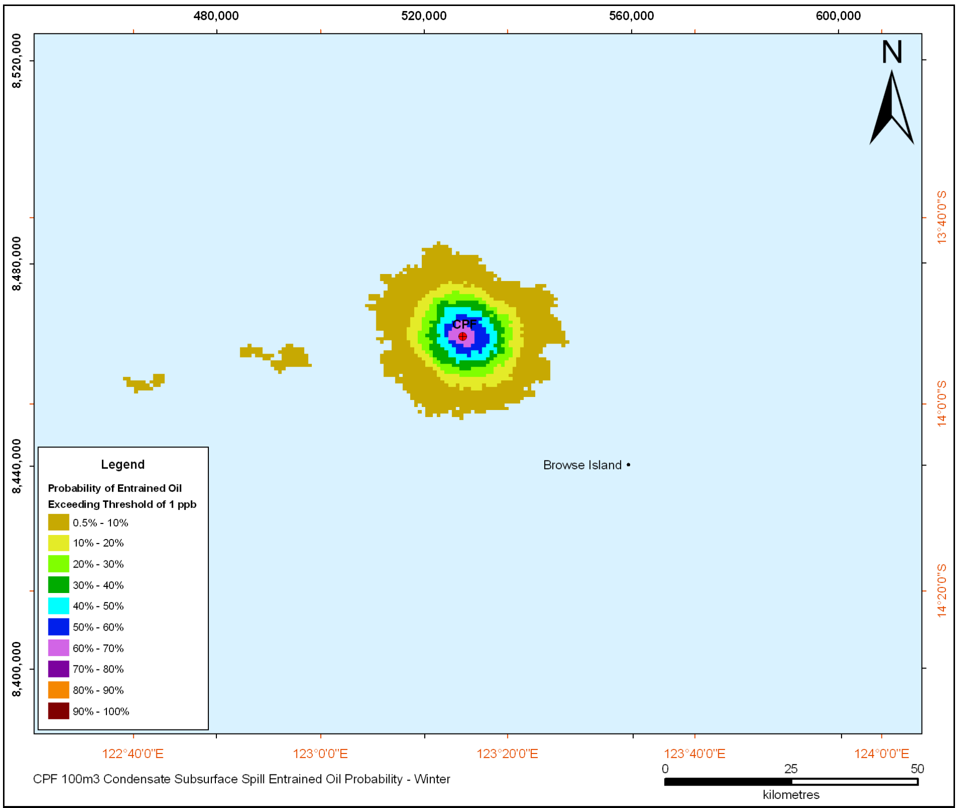


Figure 16. Scenario 1: predicted probability of exposure to entrained oil (top) and dissolved oil (bottom) concentrations exceeding 1 ppb as a result of a 100 m^3 release of condensate under transitional conditions



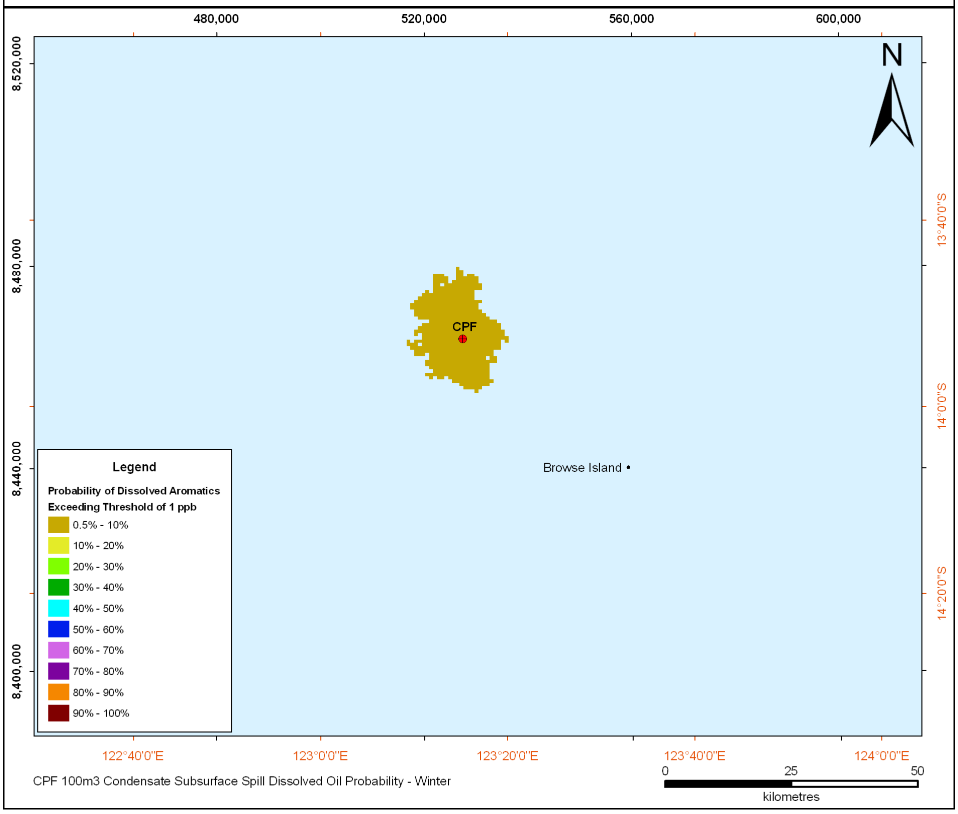


Figure 17. Scenario 1: predicted probability of exposure to entrained oil (top) and dissolved oil (bottom) concentrations exceeding 1 ppb as a result of a 100 m^3 release of condensate under winter conditions

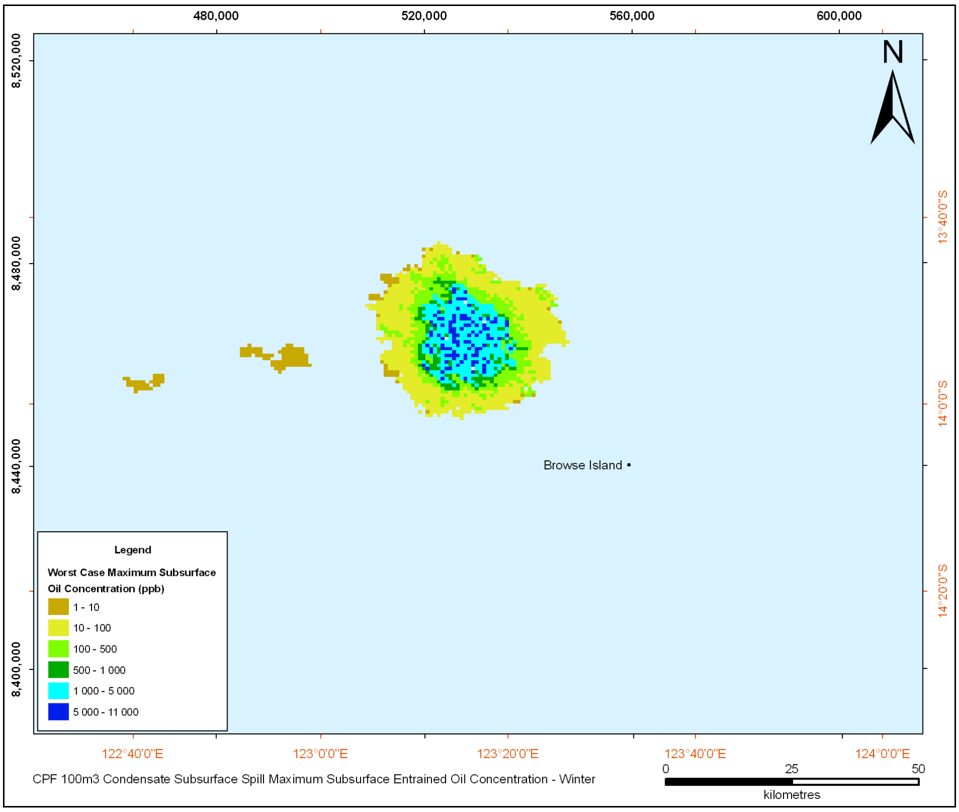


Figure 18. Scenario 1: predicted maximum entrained concentrations for each individual grid cell (above 1 ppb) calculated from 200 single trajectories as a result of a 100 m^3 release of condensate under winter conditions

Scenario 2: Storage tank rupture spill of diesel at the CPF

Diesel fuel will be delivered to and stored on the CPF for use in running machinery, with engineering safeguards such as fuel storage tank bunding and direction of deck-water to a water-oil separation system. This scenario considered the situation where the capacity of a deck-storage tank (50 m^3) was lost to the sea, or there was an unusually large spill from a refuelling operation at the CPF.

Figure 19 to Figure 21 show the predicted probability of surface oil exposure above 1 g/m^2 (1 µm) in the event of a 50 m^3 surface spill of diesel at the CPF for each of the three identified seasons. Results indicate there would low probability of contact with Browse Island during any season (< 1%).

There was a low probability (~0.5%) of exposure predicted for both entrained and dissolved aromatic hydrocarbons, exceeding the threshold of 1 ppb (Table 7). The maximum predicted concentration for entrained oil was 208 ppb, which occurred under winter wind conditions.

Table 7. Scenario 2: probability of sub-surface oil exposure by entrained or dissolved aromatic hydrocarbons

Season	Entrained Hydrocarbons		Aromatic Hydrocarbons	
	Probability (%)	Maximum concentration (ppb)	Probability (%)	Maximum concentration (ppb)
Summer	<1	110	<1	20
Transitional	<1	79	<1	3
Winter	<1	208	0	0

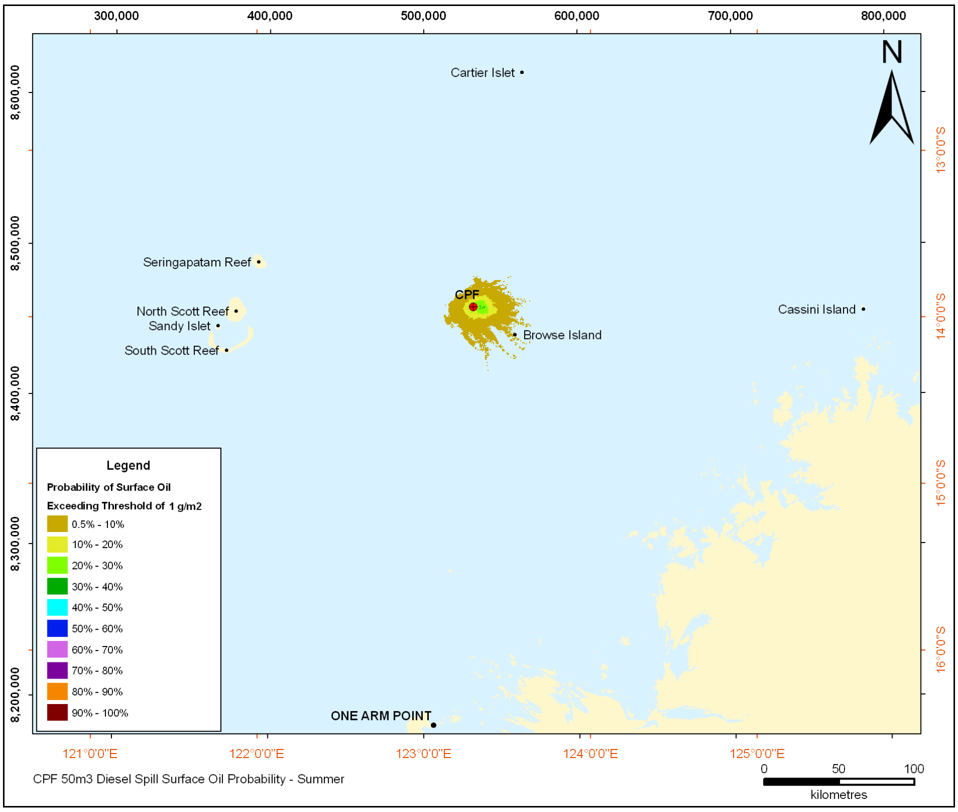


Figure 19. Scenario 2: predicted probability of oil exposure to the water surface above 1 g/m2 (1 μm) as a result of a 50 m^3 release of diesel under summer conditions

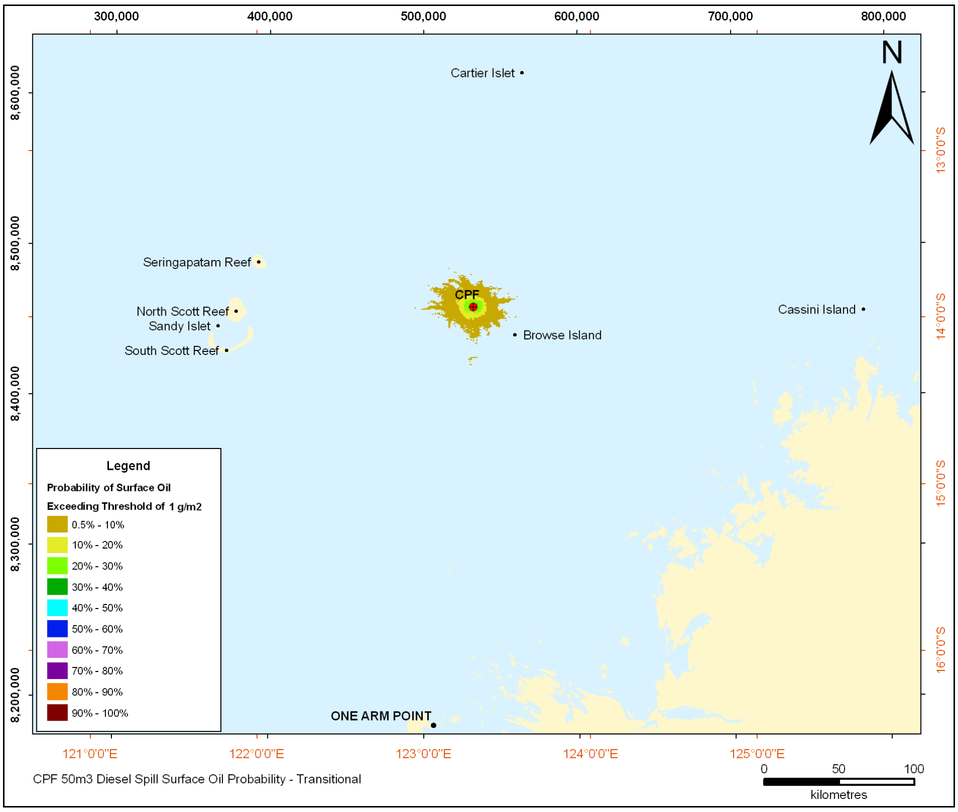


Figure 20. Scenario 2: predicted probability of oil exposure to the water surface above 1 g/m^2 (1 μm) as a result of a 50 m^3 release of diesel under transitional conditions

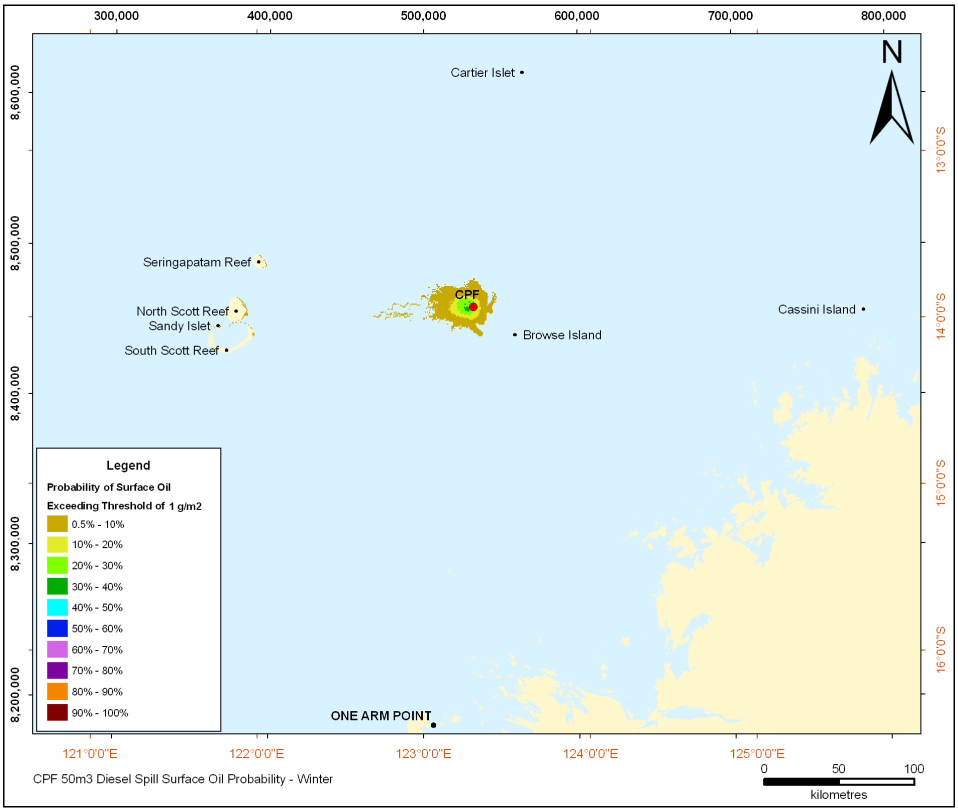


Figure 21. Scenario 2: predicted probability of oil exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 50 m^3 release of diesel under winter conditions

Scenario 3: Condensate line rupture midway between the CPF and the FPSO

This scenario involved the release of 730 m^3 of condensate over 12 hours assuming a constant flow rate of about 61 m^3/hr from 250 m below the sea surface, to represent a rupture of the seabed flowline. The assumed release site would be located midway between the CPF and the FPSO, approximately 35 km northwest of Browse Island.

Simulations of the surfacing of Ichthys condensate, assuming a pressurized release from the seabed, indicate that some condensate would surface rapidly (seconds to minutes), given the depth at the release site and entrainment by the rapidly rising gas bubbles. A larger proportion would form a subsurface plume of entrained droplets that would migrate with the prevailing currents while continuing to surface. Condensate would undergo rapid loss of the most volatile compounds over the first 3-4 hours of surfacing. Evaporation rates would then decrease over the next 20 hours as the condensate weathers to leave less volatile components. Delays in surfacing would extend the time required for complete evaporation.

Repeated simulations under summer conditions indicated that slicks are most likely to drift eastward, with the potential for low concentrations of weathered condensate to reach Browse Island or the mainland in 39% of cases (Table 8). The highest load of residual condensate predicted for the shoreline of Browse Island was 2.5% of the original spill volume (~18 m^3).

Table 8. Scenario 3: probability of shoreline hydrocarbon exposure

Season	Number of cases impacting shorelines (%)	Maximum probability of shoreline exposure at a single location (%)	Maximum oil on shore (% of volume)	Minimum time to shore (hours)	Maximum length of oiled shoreline (km)
Summer	39	34.5	2.5	70	53
Transitional	10	7.5	2.0	88	6
Winter	22	10.5	2.8	127	80

Stochastic modelling during transitional conditions indicated a relatively low probability of exposure to Browse Island and Seringapatam Reef (10% of cases, Table 8 and Figure 23) with no mainland shoreline oiling.

Browse Island is not predicted to be at risk (probability < 1%) during winter conditions, with slicks consistently predicted to drift toward to west due to the prevailing easterly winds (Figure 24). However, the Scott Reef group was predicted to be at risk of exposure (22%), with first exposure within 127 hours of the initial release. About 80 km of shoreline could receive weathered condensate at concentrations exceeding 1 g/m^2, with the highest expected load estimated as approximately 2.8% (~20 m^3) of the initial spill volume (Table 8).

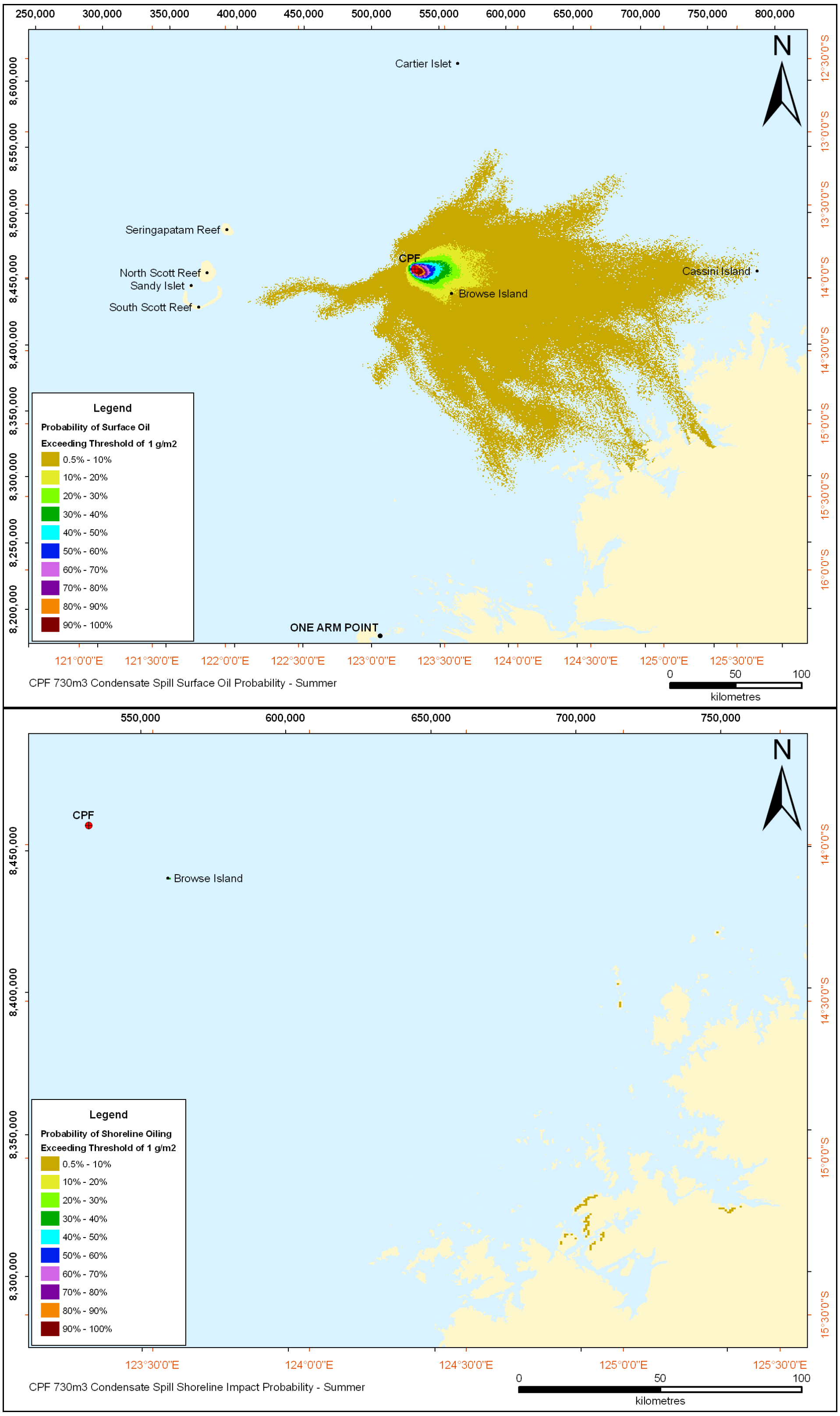


Figure 22. Scenario 3: predicted probability of oil exposure to the water surface (top) and shoreline oil exposure (bottom) above 1 g/m^2 (1 µm) as a result of a 730 m^3 release of condensate under summer conditions. Probability of shoreline exposure to Browse Island was indicated

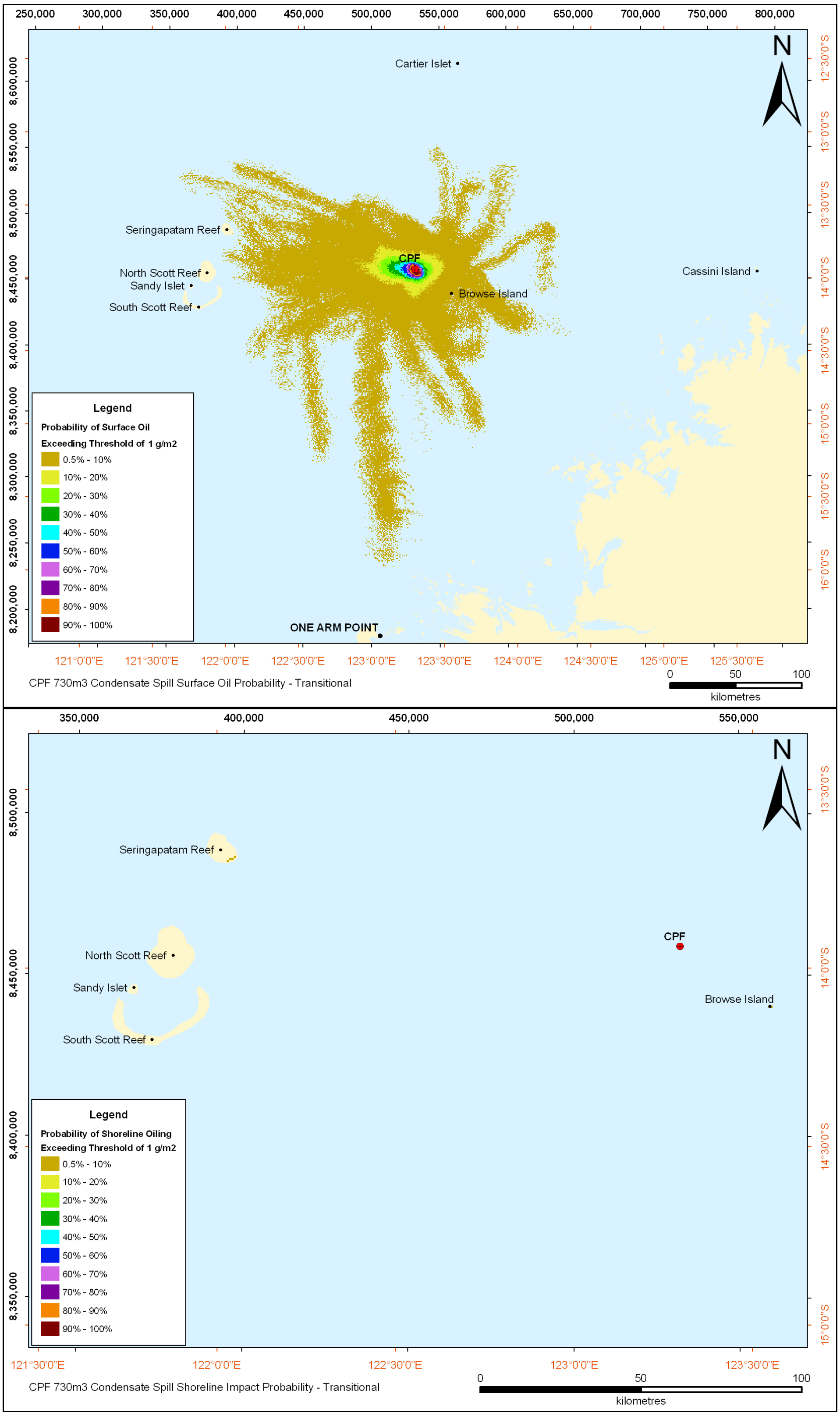


Figure 23. Scenario 3: predicted probability of oil exposure to the water surface (top) and shoreline oil exposure (bottom) above 1 g/m^2 (1 μm) as a result of a 730 m^3 release of condensate under transitional conditions. Probability of shoreline exposure to Browse Island was indicated

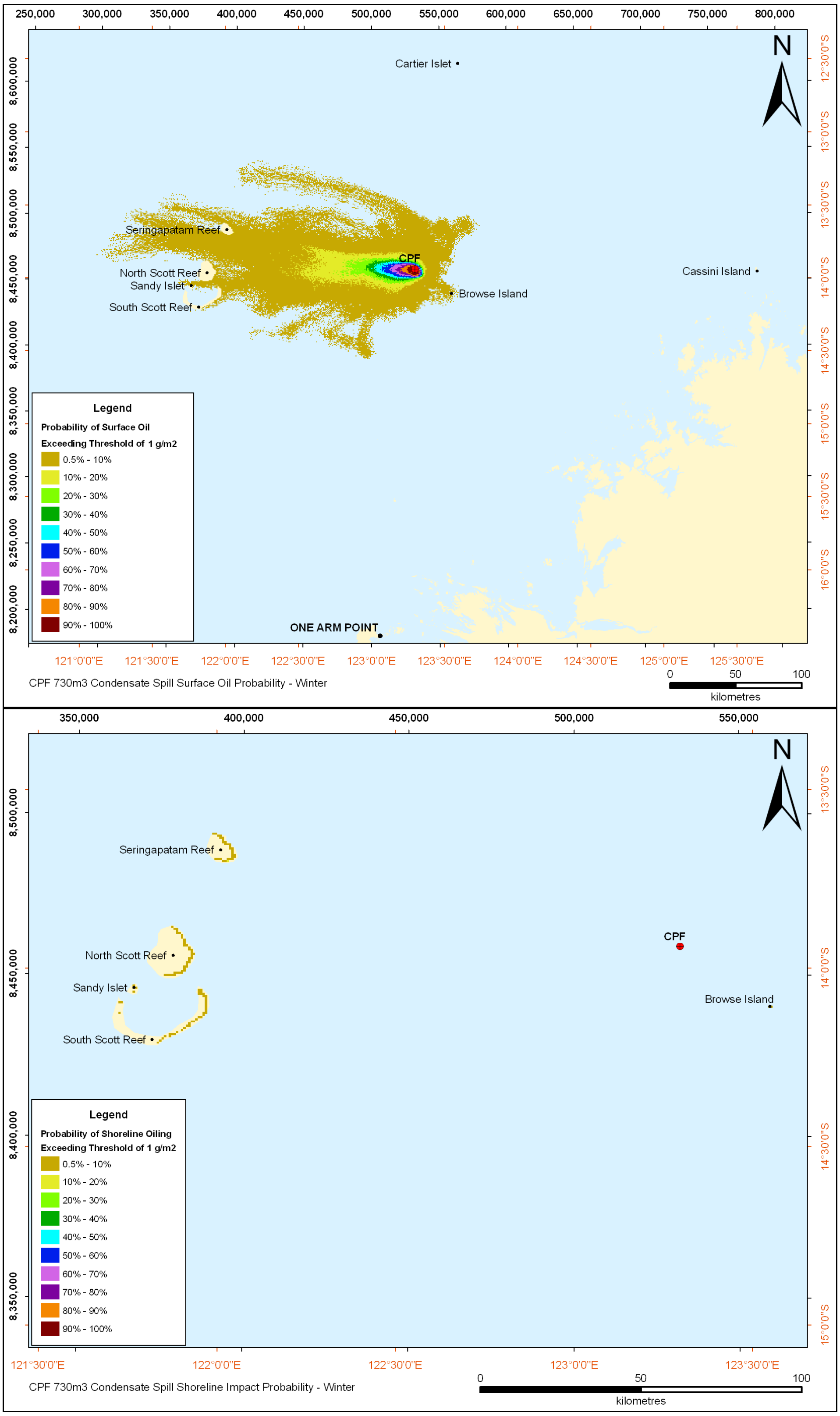


Figure 24. Scenario 3: predicted probability of oil exposure to the water surface(top) and shoreline oil exposure (bottom) above 1 g/m² (1 µm) as a result of a 730 m³ release of condensate under winter conditions. Probability of shoreline exposure to Browse Island was indicated

Due to the specified release depth, 100% of the condensate would initially be entrained within the water column, with concentrations expected to exceed 6000 ppb of entrained oil and 500 ppb of dissolved hydrocarbons in the water column above the release point. Concentrations would then decrease as the plumes rose and dispersed. Stochastic simulations indicated that the reduction in concentration to <1 ppb would occur within 10 km of the release point for either component (Figure 25 to Figure 27). Secondary entrainment, resulting from oil submerging from the surface slick, was indicated under some conditions at greater distances, but exposure risks to Browse Island from this process were indicated to be unlikely (< 1% probability).

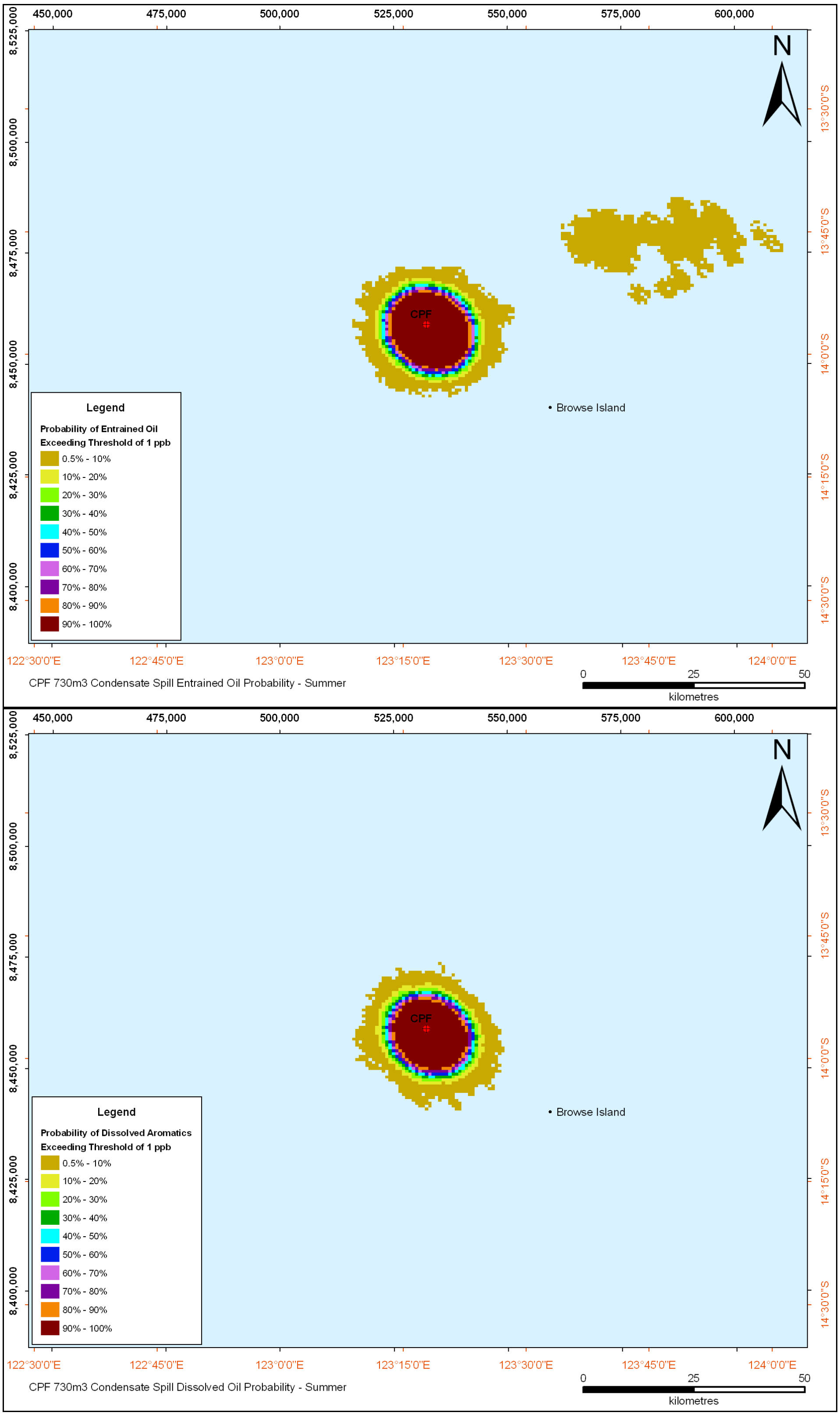


Figure 25. Scenario 3: predicted probability of exposure to entrained (top) and dissolved (bottom) hydrocarbons concentrations exceeding 1 ppb as a result of a 730 m^3 release of condensate under summer conditions

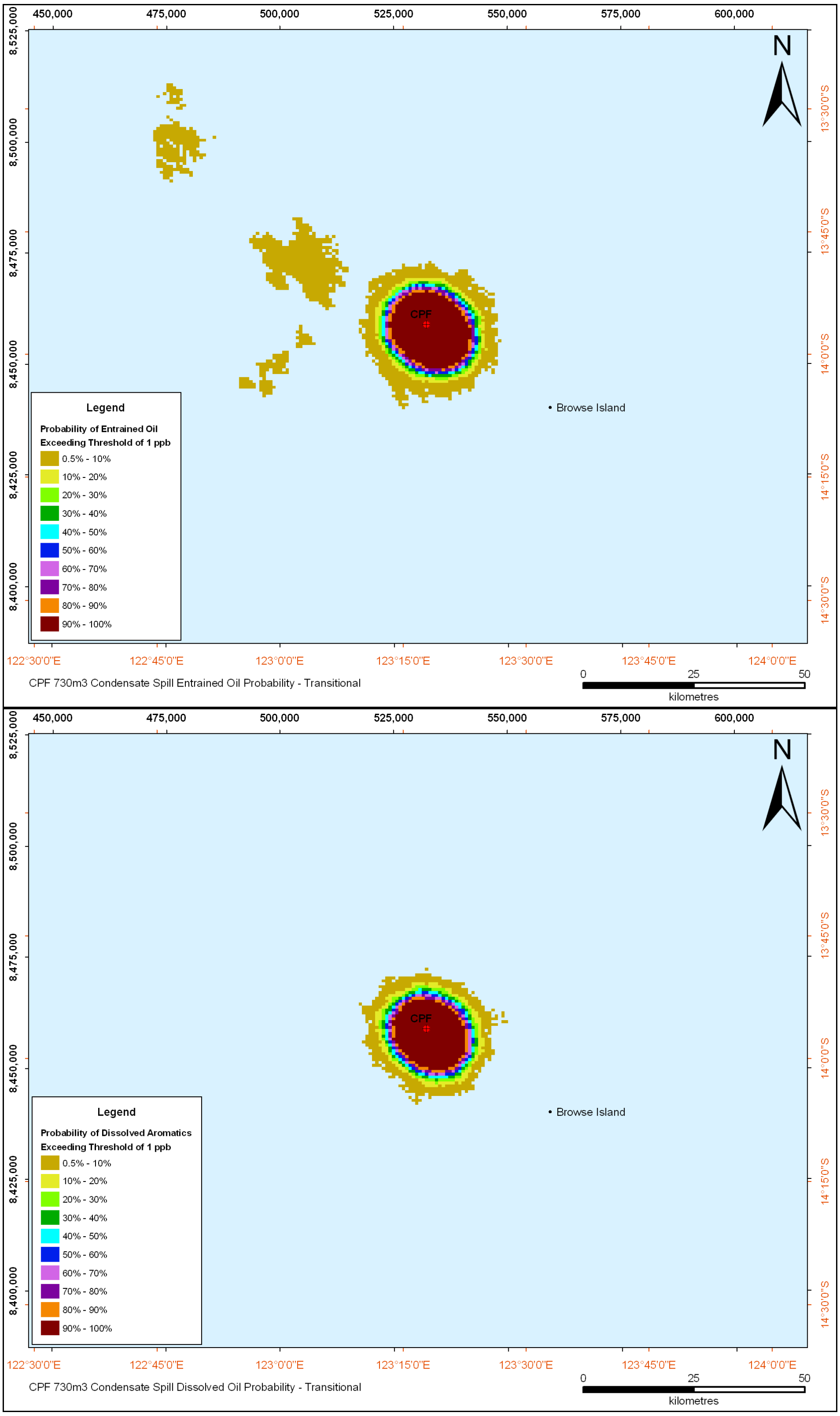


Figure 26. Scenario 3: predicted probability of exposure to entrained oil (top) and dissolved oil (bottom) concentrations exceeding 1 ppb as a result of a 730 m^3 release of condensate under transitional conditions

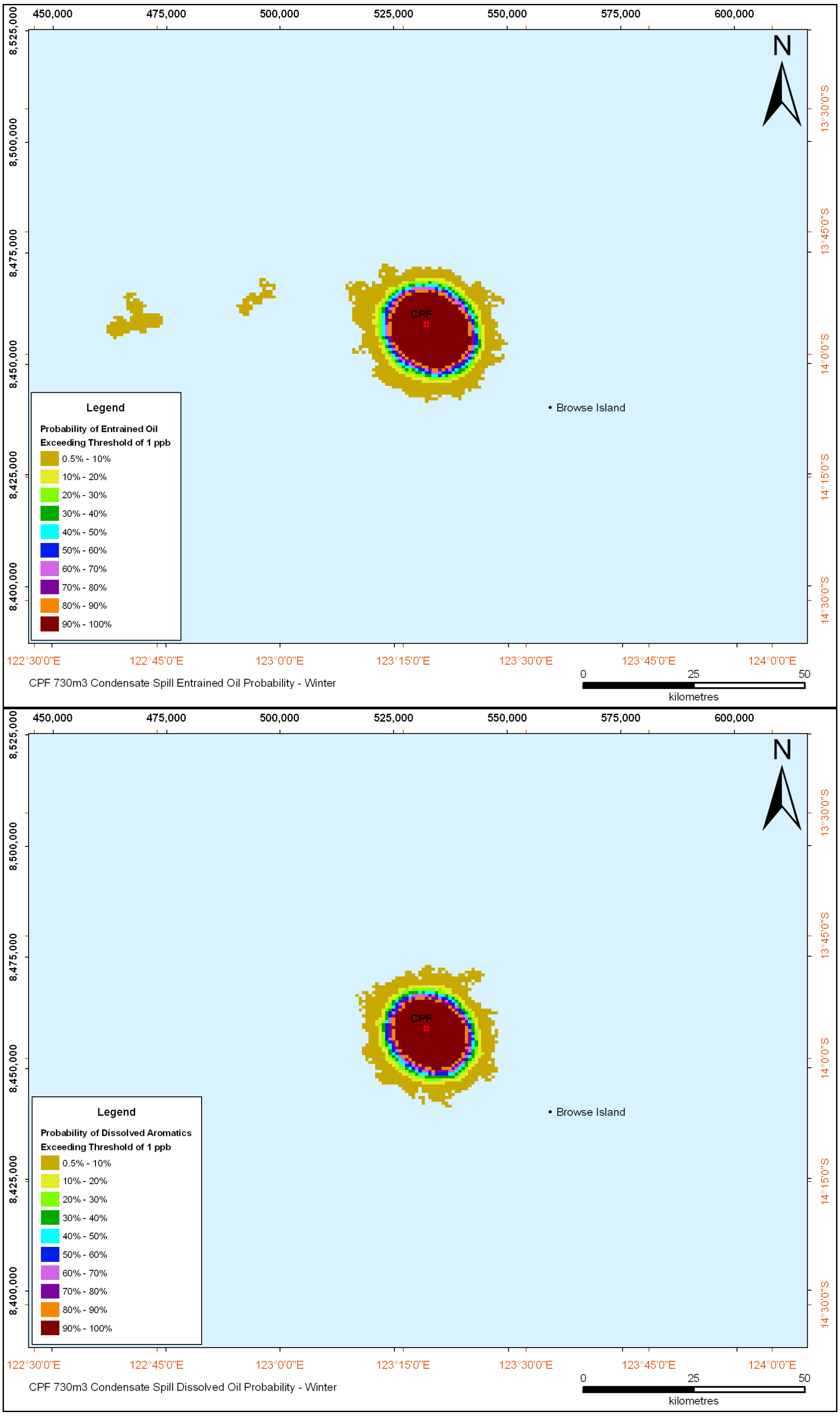


Figure 27. Scenario 3: predicted probability of exposure to entrained oil (top) and dissolved oil (bottom) concentrations exceeding 1 ppb as a result of a 730 m^3 release of condensate under winter conditions

Scenario 4: Ship collision at the FPSO

This scenario involved the release of 1000 m^3 of condensate onto the sea-surface over a period of 12 hours and served to represent an accidental release from an export ship. To accommodate variations in the placement of the ship-leak, the source of the release was varied randomly within a 10 km radius from the FPSO.

Because the release is onto the water surface, the condensate will initially form a surface slick that will spread due to gravity and surface tension as well as the influence of prevailing currents and wind. Evaporation of volatile components would be the primary weathering process in this scenario due to the large surface area exposed to the atmosphere. Consequently, there would be greater loss of volatile compounds to the atmosphere than to the water column compared to a sub-sea release. Where the wind is sufficiently strong to generate breaking wind-waves, an increasing proportion of the condensate will tend to physically entrain over time. Conversely, entrained oil will resurface when weather conditions and seas return to a calm state. The spill model accounted for these processes in calculating the fate of slicks under varying conditions.

Figure 28 to Figure 30 show the probability of oil exposing the water surface at concentrations >1 g/m^2 for the three seasons. Figure 31 to Figure 33 show the corresponding probability of shoreline exposure.

The percent of cases in which oil reached any shoreline varied from 20% for transitional period to 38% during winter. With the prevailing winds blowing from the westerly sector during summer, a high percentage of spills were predicted to drift toward the eastern sector, with an estimated 31.5% probability of condensate accumulating at any one location on Browse Island at concentrations >1 g/m^2 (Figure 31). The first exposure estimated to take approximately 16 hours. There was also a low potential risk (2%) indicated for slicks to reach the mainland or inshore islands. Maximum estimated volumes that could make landfall in each season were in the range of 8% of the initial spill volume (80 m^3; Table 9).

Table 9. Scenario 4: probability of shoreline oil exposure

Season	Number of cases impacting shorelines (%)	Maximum probability of shoreline exposure at a single location (%)	Maximum oil on shore (% of volume)	Minimum time to shore (hours)	Maximum length of oiled shoreline (km)
Summer	36	31.5	5.7	16	312
Transitional	20	12.0	4.7	25	50
Winter	38	13.5	8.0	112	133

Table 10. Scenario 4: probability of sub-surface oil exposure by entrained or dissolved aromatic hydrocarbons

Season	Entrained Hydrocarbons		Aromatic Hydrocarbons	
	Probability (%)	Maximum concentration (ppb)	Probability (%)	Maximum concentration (ppb)
Summer	<1	1460	1	13
Transitional	<1	2241	1	10
Winter	<1	1800	1	21

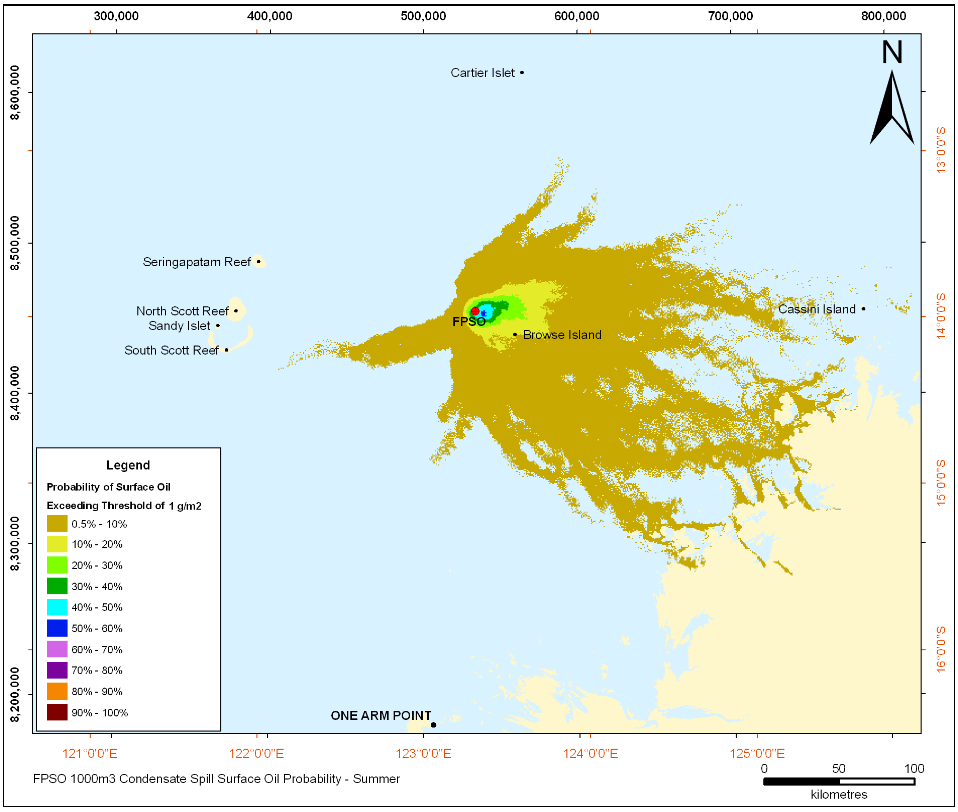


Figure 28. Scenario 4: predicted probability of oil exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 1000 m^3 release of condensate under summer conditions

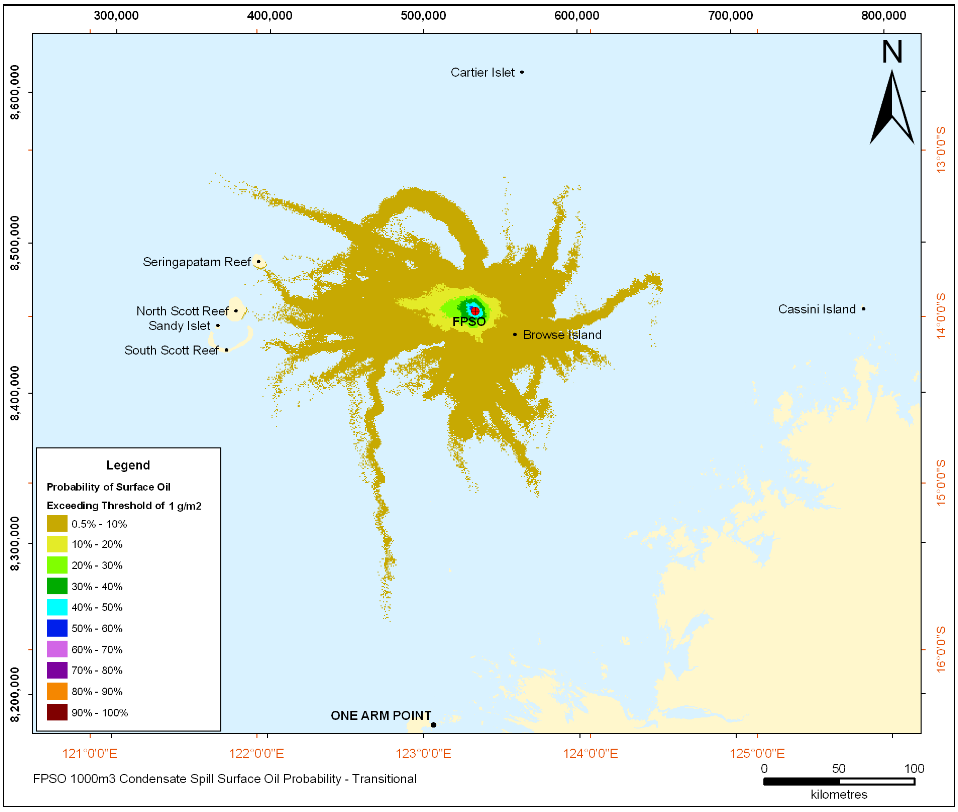


Figure 29. Scenario 4: predicted probability of oil exposure to the water surface above 1 g/m² (1 µm) as a result of a 1000 m³ release of condensate under transitional conditions

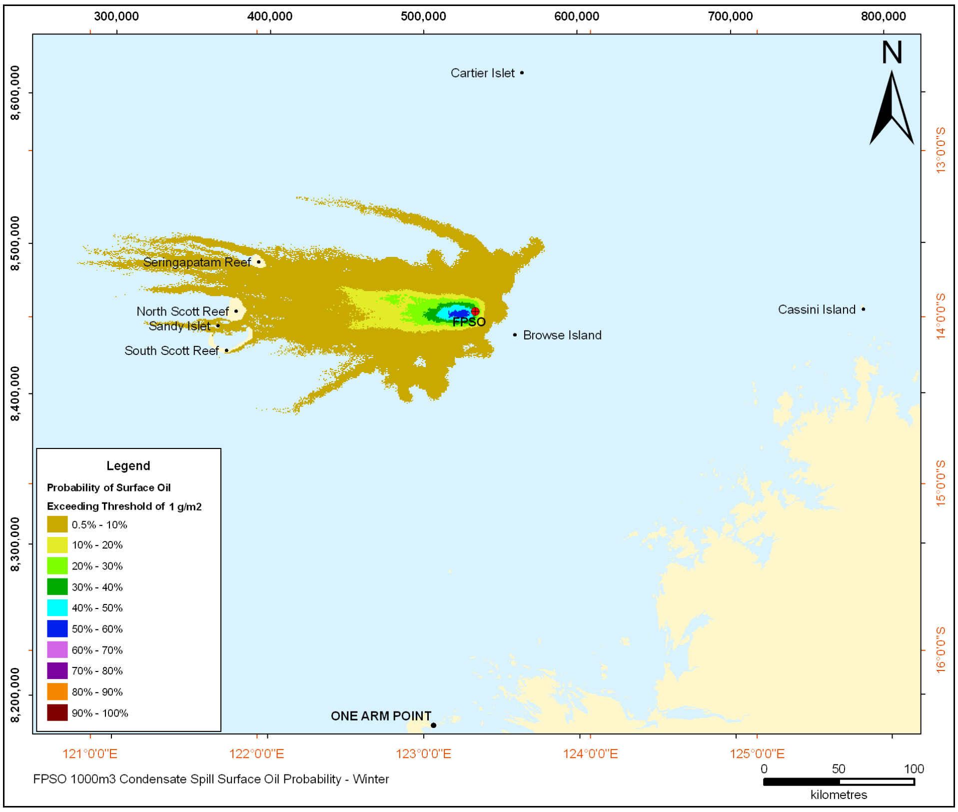


Figure 30. Scenario 4: predicted probability of oil exposure to the water surface above 1 g/m² (1 µm) as a result of a 1000 m³ release of condensate under winter conditions

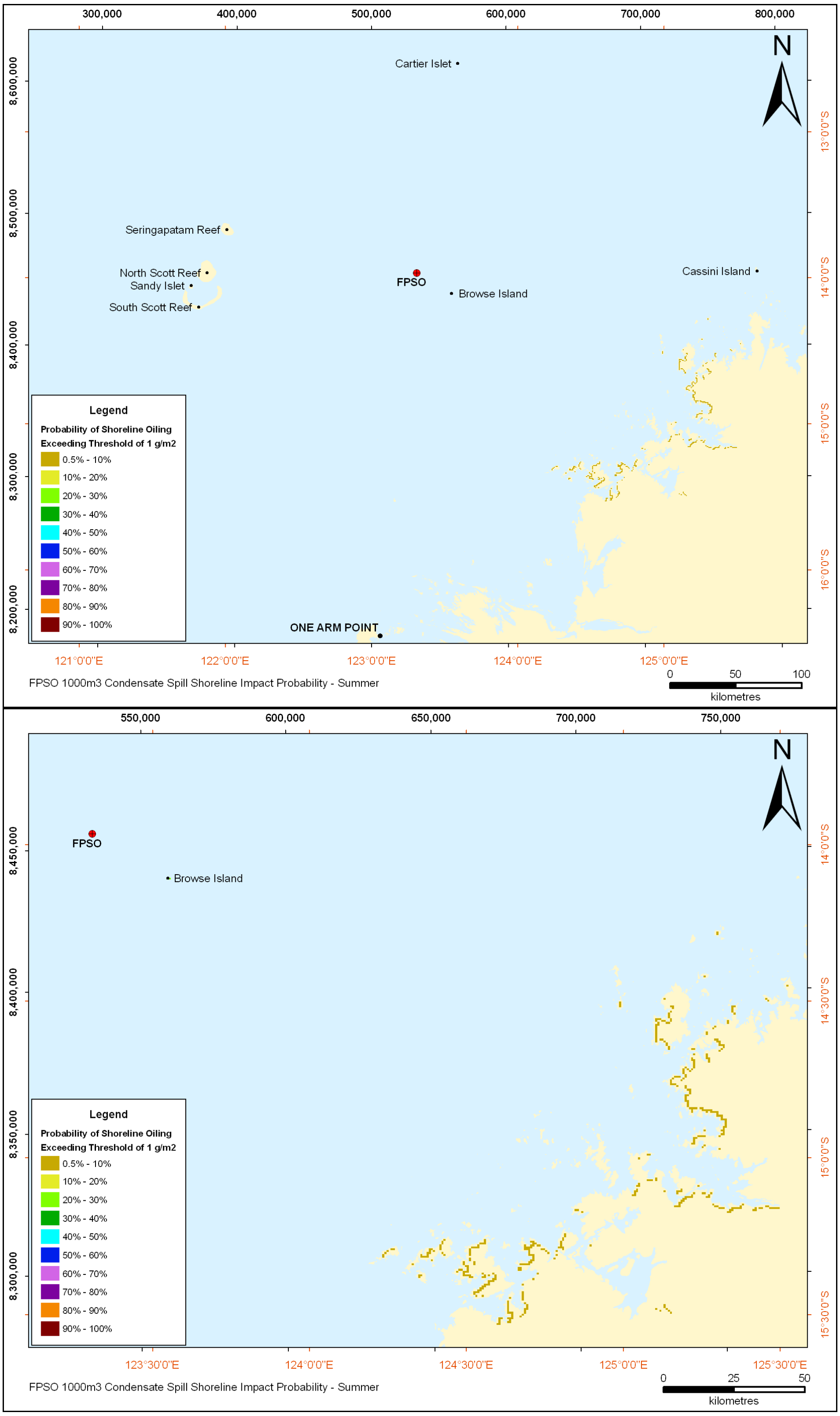


Figure 31. Scenario 4: large scale view (top) and zoomed in view (bottom) of the predicted probability of shoreline exposure above 1 g/m^2 (1 μm) as a result of a 1000 m^3 release of condensate under summer conditions. Probability of shoreline exposure to Browse Island was indicated

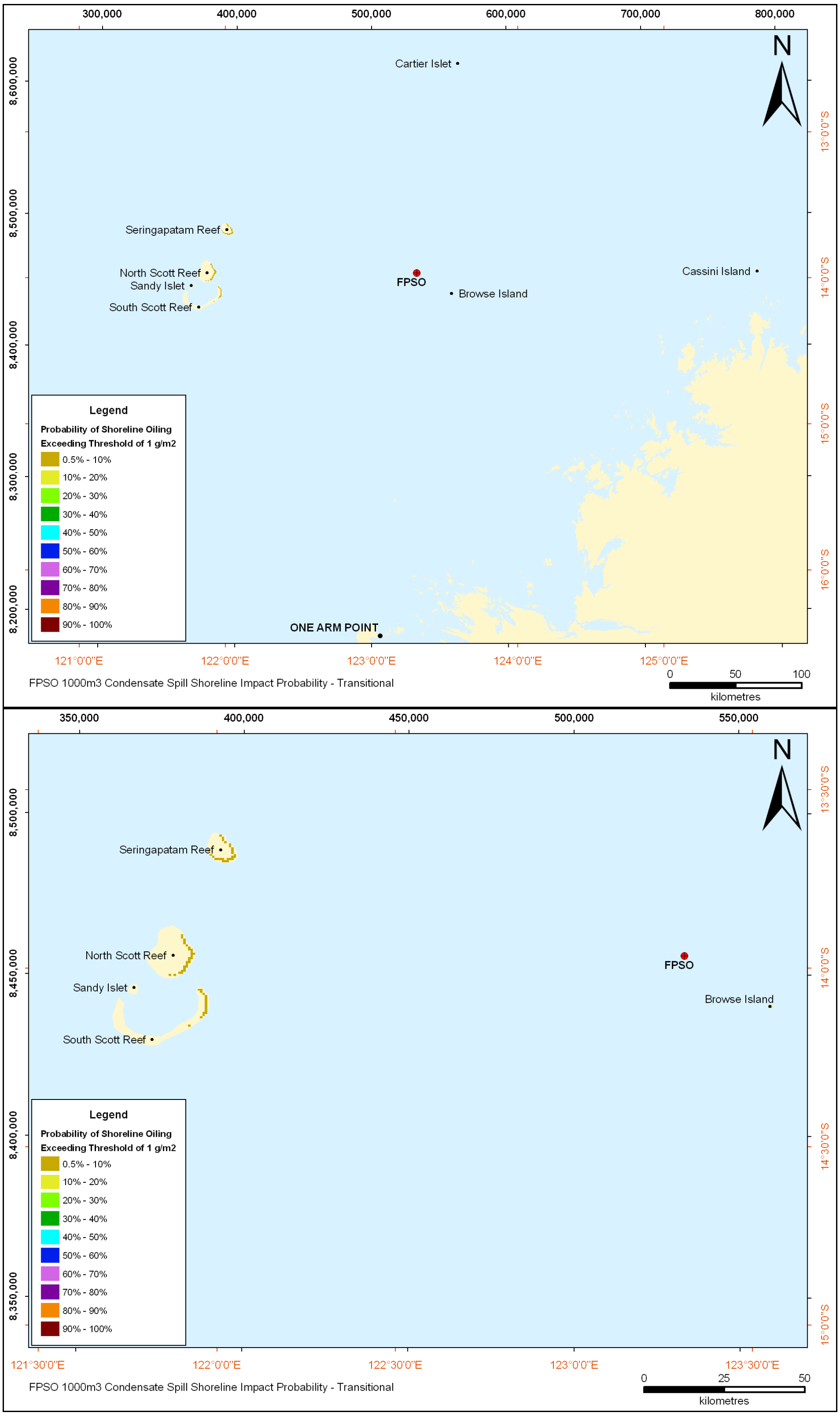


Figure 32. Scenario 4: large scale view (top) and zoomed in view (bottom) of the predicted probability of shoreline exposure above 1 g/m^2 (1 μm) as a result of a 1000 m^3 release of condensate under transitional conditions. No risk of shoreline exposure to Browse Island was indicated

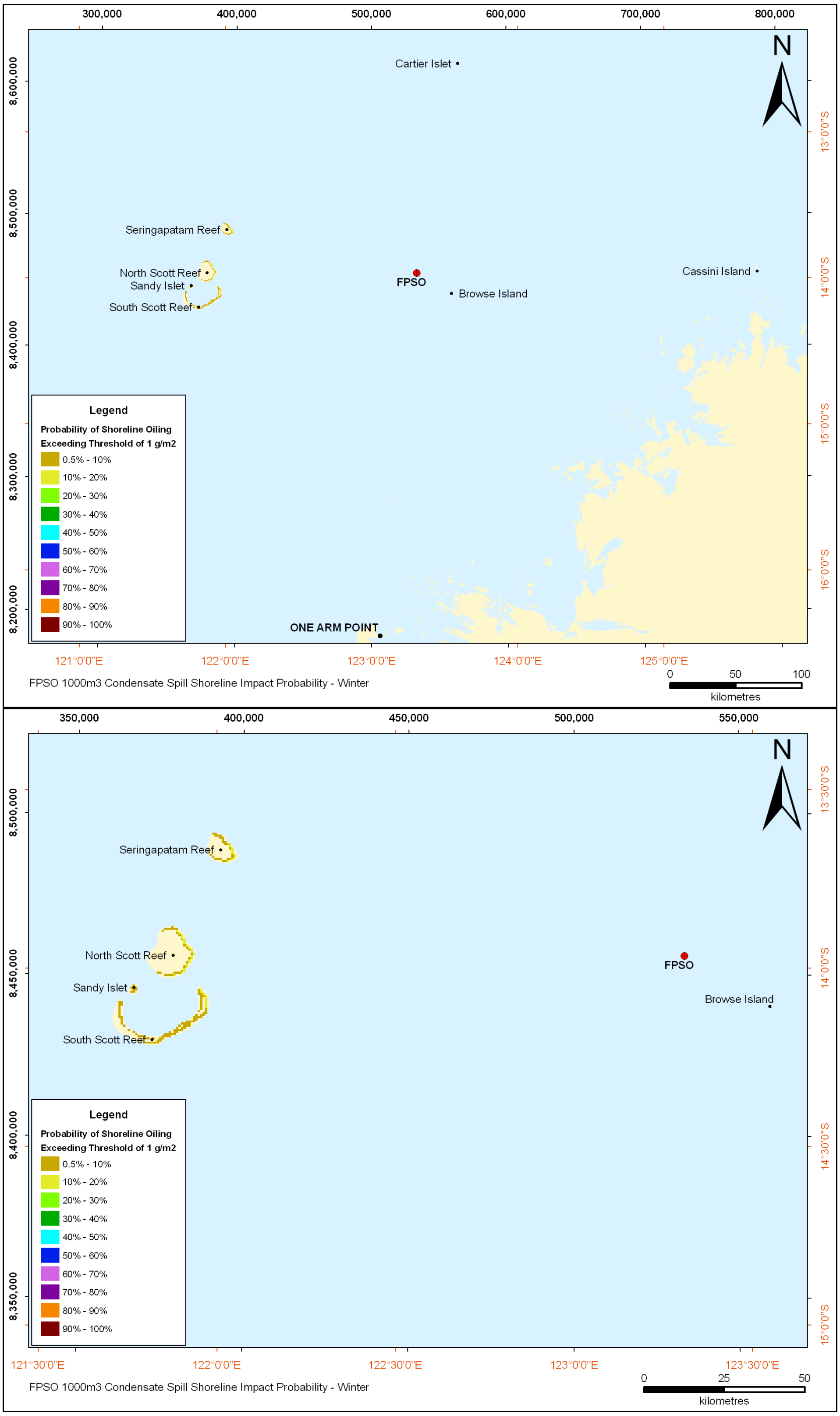


Figure 33. Scenario 4: large scale view (top) and zoomed in view (bottom) of the predicted probability of shoreline exposure above 1 g/m^2 (1 μm) as a result of a 1000 m^3 release of condensate under winter conditions. No risk of shoreline exposure to Browse Island was indicated

Scenario 5: Loading hose failure adjacent to the FPSO.

This scenario was to examine the potential probabilities of exposure from the loss of 30 m^3 of condensate, at the water surface, from a failed loading hose leading from the FPSO.

Simulations indicated that surface slicks would decrease to below the threshold concentration of 1 g/m^2 within 30 km from the FPSO release site (Figure 34 to Figure 36) due to a combination of spreading, evaporation and entrainment. Hence, surface slicks are unlikely (< 1%) to reach any of the significant reefs and islands surround the FPSO from this scenario. The likelihood of entrained condensate subsequently reaching the island was also predicted to be low (~1%) during all three seasons.

Table 11. Scenario 5: probability of sub-surface hydrocarbon exposure by entrained or dissolved aromatic hydrocarbons

Season	Entrained Hydrocarbons		Aromatic Hydrocarbons	
	Probability (%)	Maximum concentration (ppb)	Probability (%)	Maximum concentration (ppb)
Summer	<1	44	1	10
Transitional	<1	17	1	7
Winter	0	0	1	7

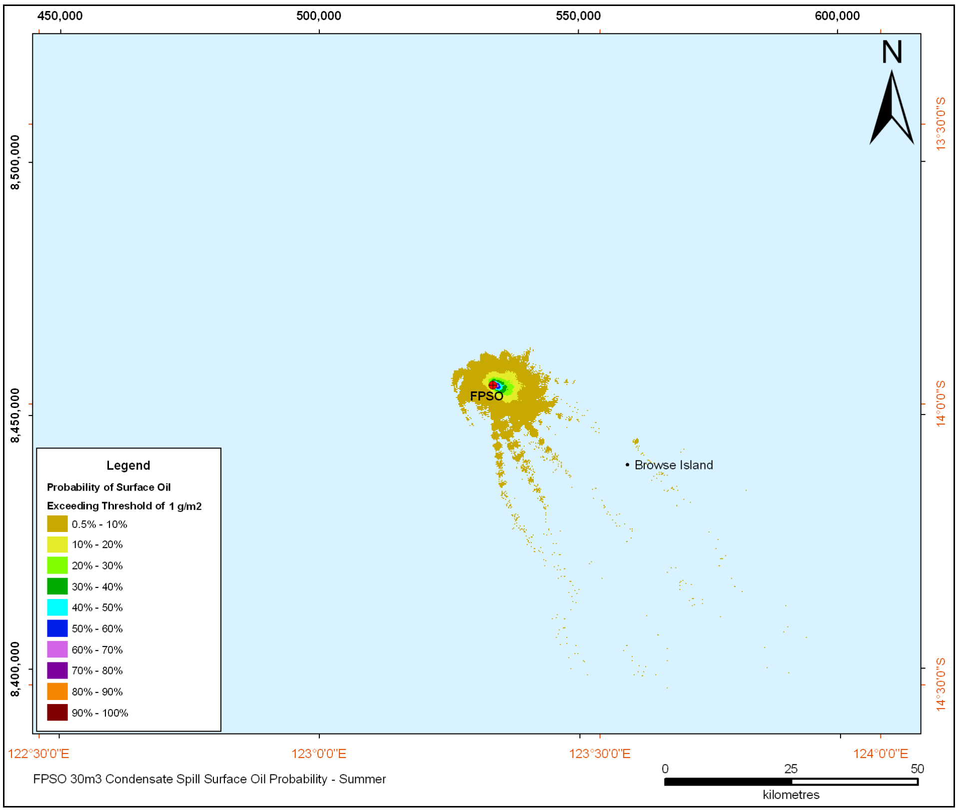


Figure 34. Scenario 5: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 30 m^3 release of condensate under summer conditions

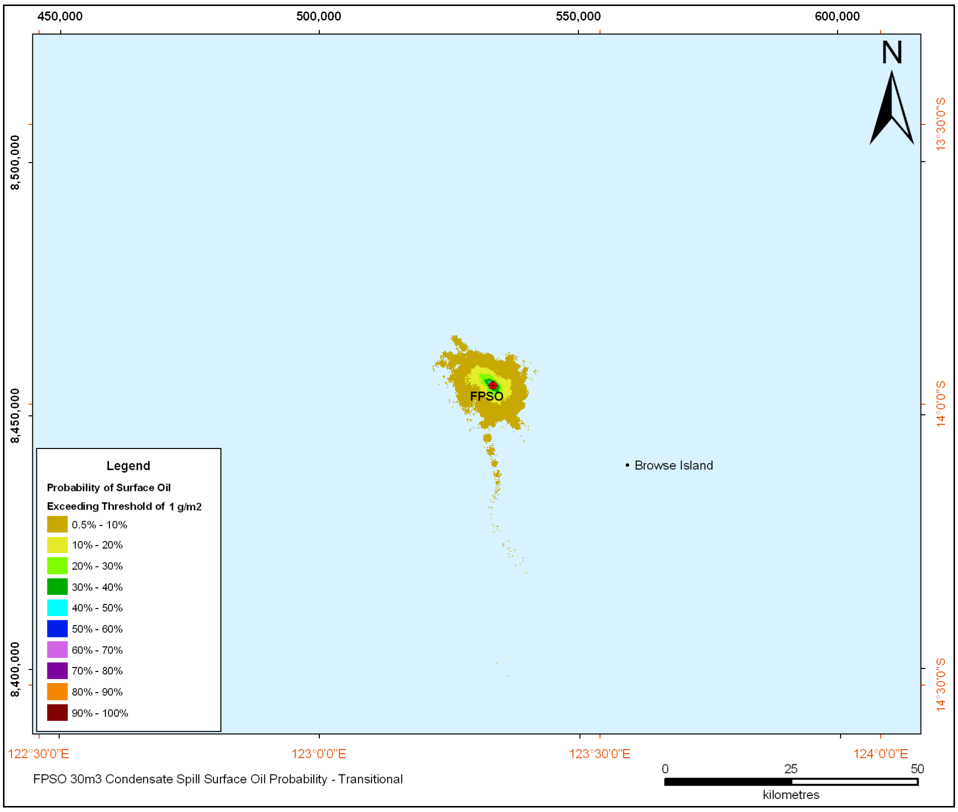


Figure 35. Scenario 5: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 30 m^3 release of condensate under transitional conditions

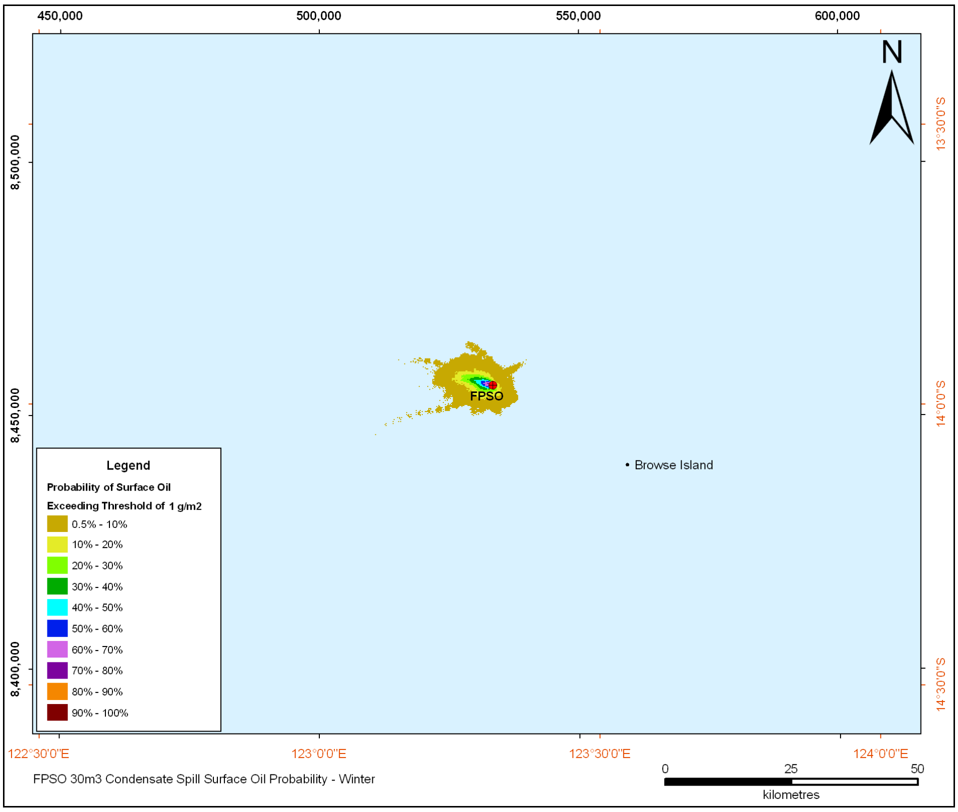


Figure 36. Scenario 5: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 30 m^3 release of condensate under winter conditions

Scenario 6A: Spill during refuelling of construction barge offshore

This scenario investigated the release of a relatively small volume (2500 L or 2.5 m^3) of diesel fuel during refuelling of a construction barge adjacent to the FPSO. The spill volume was chosen to represent a relatively large release from this type of incident, given the safety procedures and equipment that would be in place during refuelling operations. A low threshold for contact (1 g/m^2) was used to define exposure at surface level, at which concentration a diesel film would be dull coloured.

Figure 37 to Figure 39 show the probability of water exposure for each of the seasons. There would likely be patches of diesel visible at the surface within 15 km from the release site. The inconsistent patches of diesel would result from a combination of the relatively high evaporation and spreading rates for diesel oil and the wind and current conditions, which are predicted to help disperse the spill to silvery sheen within a day or two.

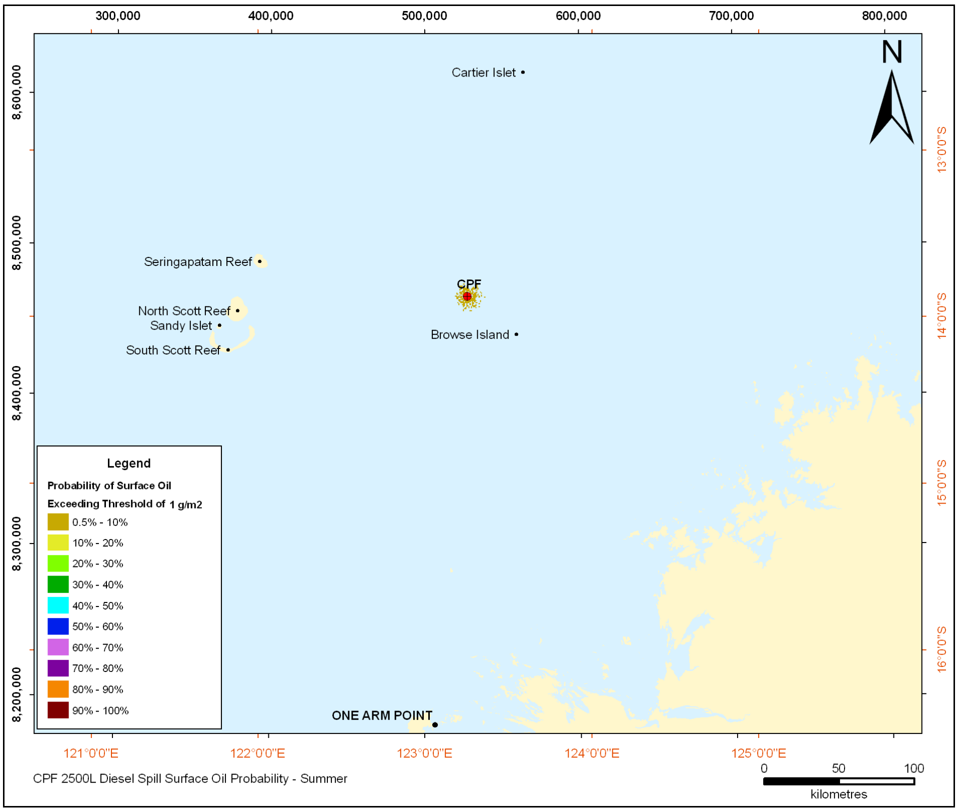


Figure 37. Scenario 6A: probability of oil exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 2.5 m^3 release of diesel under summer conditions. No risk of shoreline exposure to Browse Island was indicated

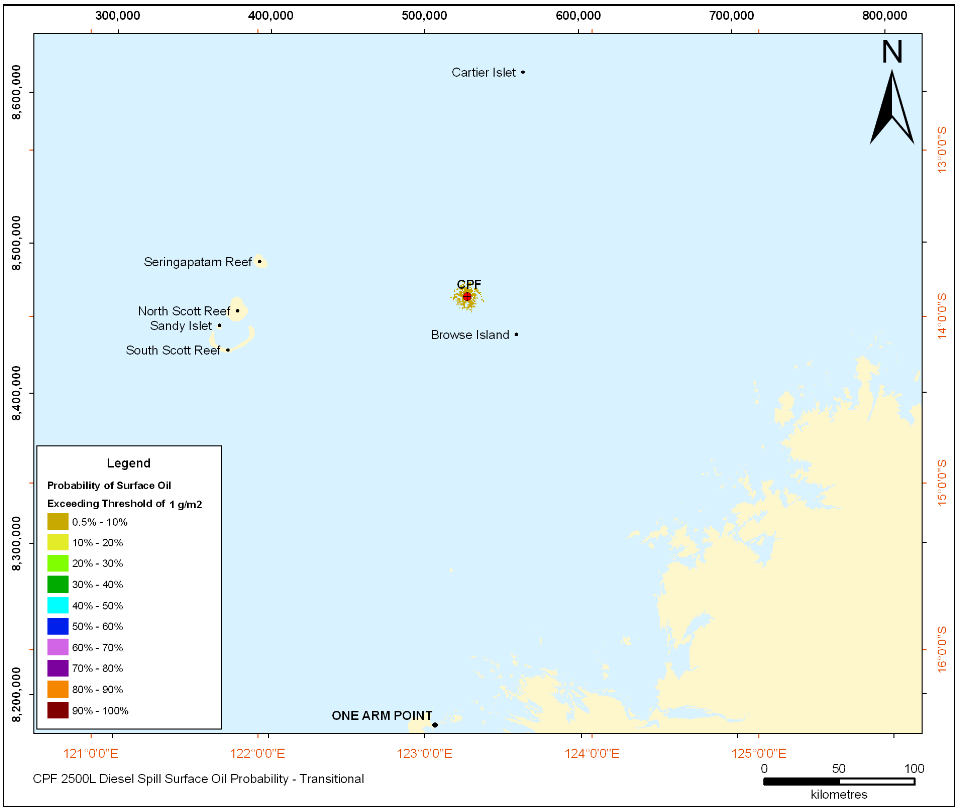


Figure 38. Scenario 6A: probability of oil exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 2.5 m^3 release of diesel under transitional conditions. No risk of shoreline exposure to Browse Island was indicated

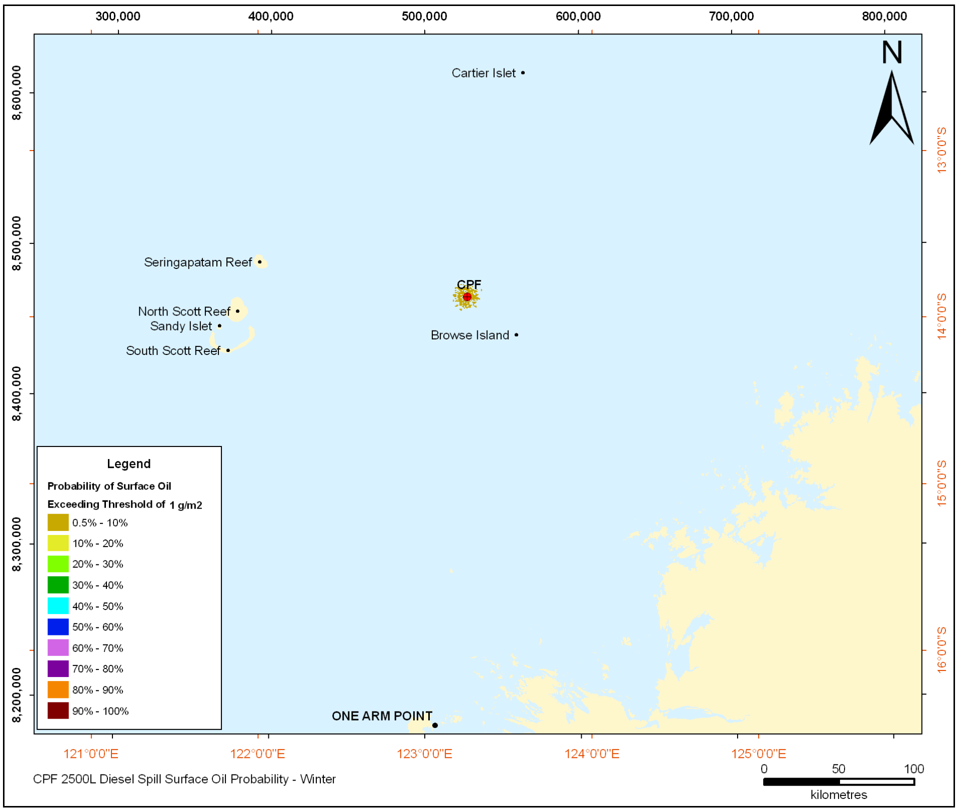


Figure 39. Scenario 6A: probability of oil exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 2.5 m^3 release of diesel under winter conditions. No risk of shoreline exposure to Browse Island was indicated

Scenario 6B: Spill during refuelling of construction barge near the military boundary along the pipeline route

The SIMAP stochastic model was also used to simulate a 2.5 m^3 release of diesel at a location adjacent to the military exercise area. The site represents the point of intersection of the Military Boundary with the pipeline route.

Figure 40 to Figure 42 show the probability of oil exposure to the water for the release site. Because this scenario involves a surface release, slicks of condensate are predicted to spread and evaporate very quickly upon release, and will rapidly decrease below the thickness threshold. Consequently, no slicks would be expected outside a 5 km radius of the release site. Hence, there should be no impact to nearby shorelines or submerged reefs by surface slicks from this scenario.

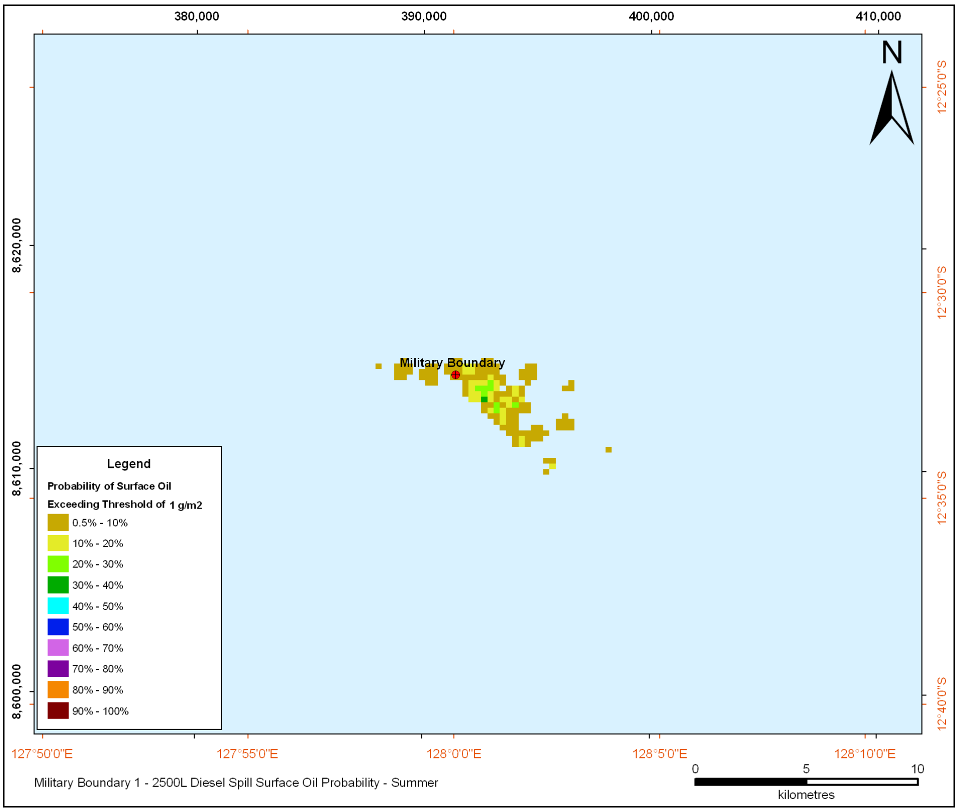


Figure 40. Scenario 6B: zoomed in view of the predicted probability of oil exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 2.5 m^3 release of diesel under summer conditions

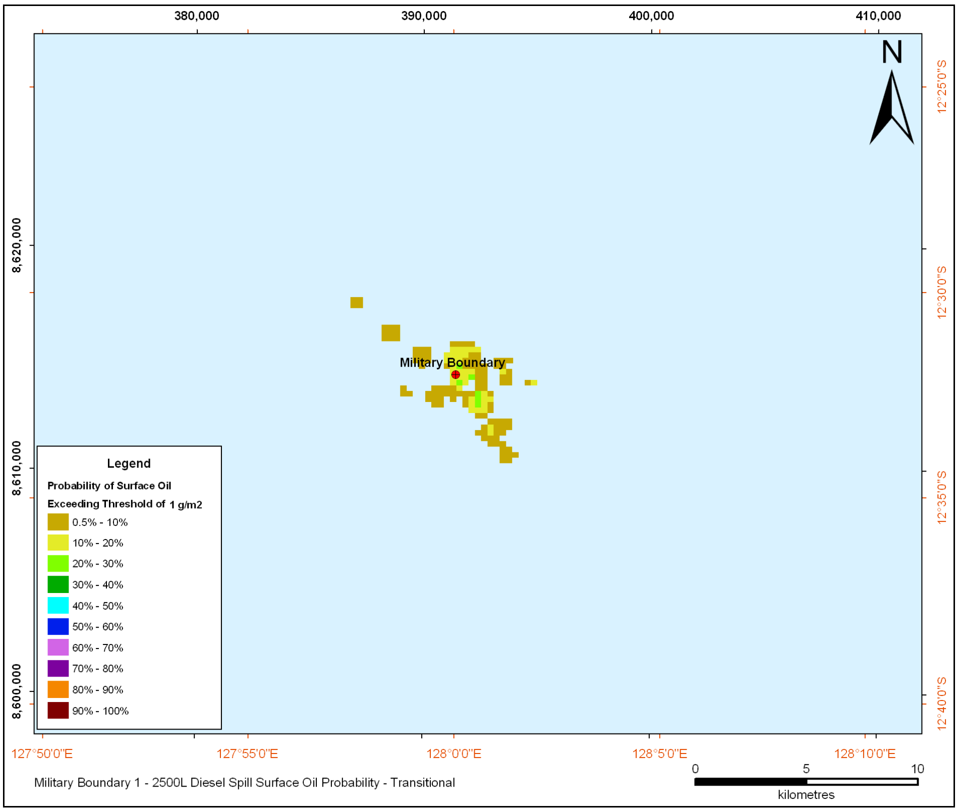


Figure 41. Scenario 6B: zoomed in view of the predicted probability of oil exposure to the water surface above 1 g/m^2 (1 μm) as a result of a 2.5 m^3 release of diesel under transitional conditions

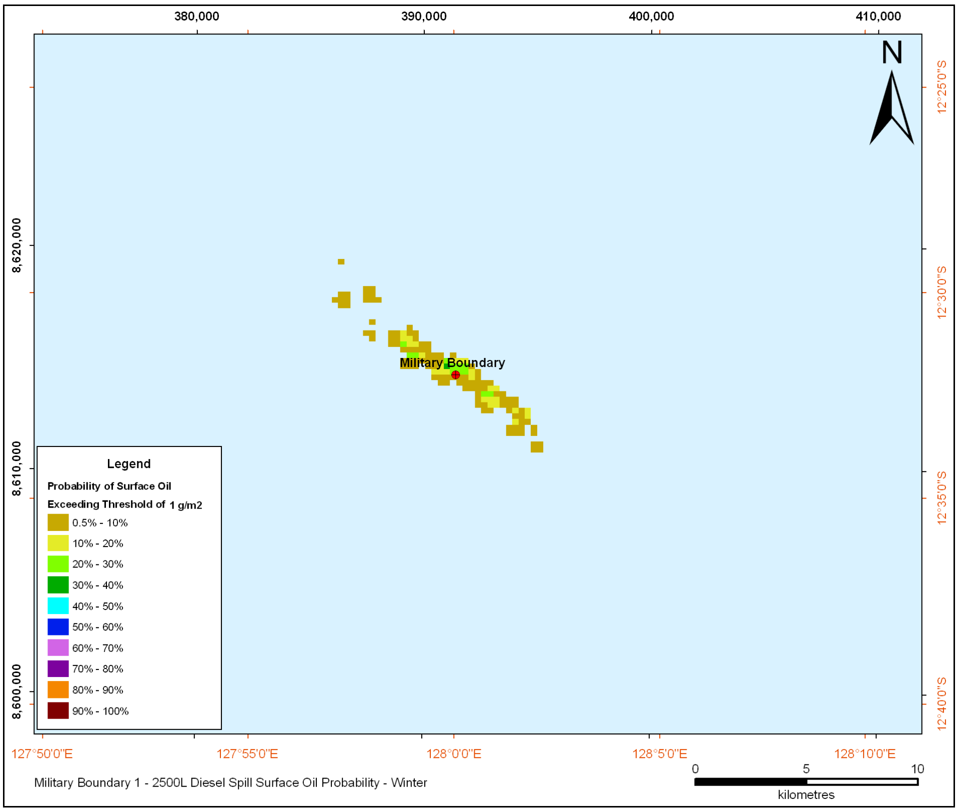


Figure 42. Scenario 6B: zoomed in view of the predicted probability of oil exposure to the water surface above 1 g/m^2 (1 μm) as a result of a 2.5 m^3 release of diesel under winter conditions

Results for inshore spill scenarios

Slicks generated within Darwin Harbour would mainly be transported by the prevailing tidal current, due to the strength of the tidal currents within the harbour. However, simulations indicate that wind forcing would add to the net-drift of slicks over longer durations than a tidal period. Hence, seasonal wind patterns were expressed as a tendency for slicks to drift westward during winter and eastward during summer. Figure 43 and Figure 44 show the interaction between tidal and wind forces for the expected movement of an example slick released off East Arm Wharf under a given set of tidal and wind conditions. In this example, the release occurred at the end of the flooding tide and drifted only a small distance eastward before the tide reversed. The slick was predicted to elongate as the ebbing tide increased in speed, with a large proportion leaving East Arm before the tide reversed again. Under the influence of the wind drift, the slick was predicted to drift eastward toward Darwin City on the ebbing tide. Due to the 12 hour return period for tides in the harbour, a slick would undertake multiple flood and ebb migrations over the days following a spill, increasing the chances of grounding onto a given shoreline within the harbour.

Estimates for the probability of shoreline exposure are presented for each scenario in the following sections.

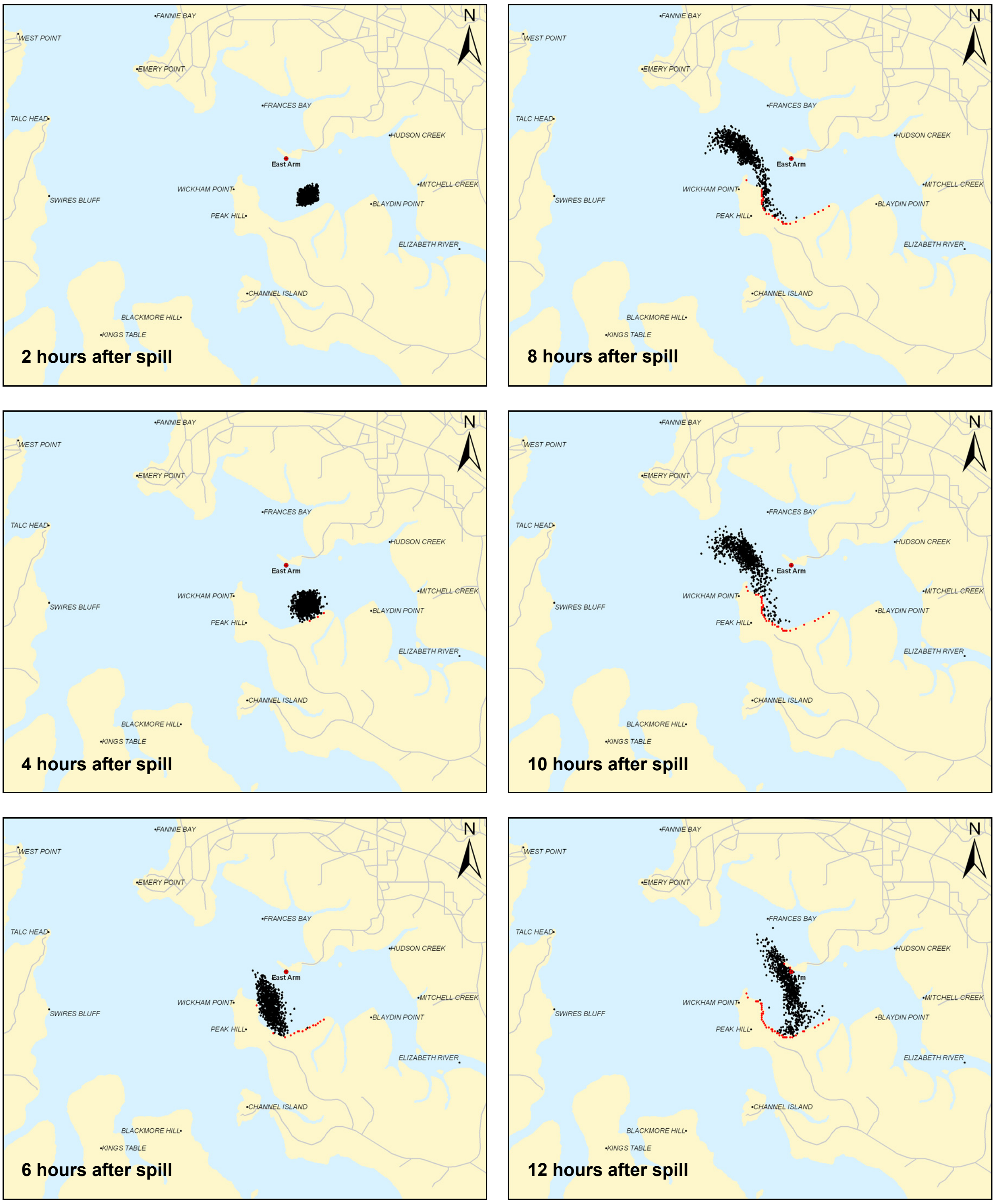


Figure 43. Movement of a hypothetical hydrocarbon spill (black spillets on water and red spillets stranded on land) from the East Arm Wharf locations 2, 4, 6, 8, 10 and 12 hours after the spill

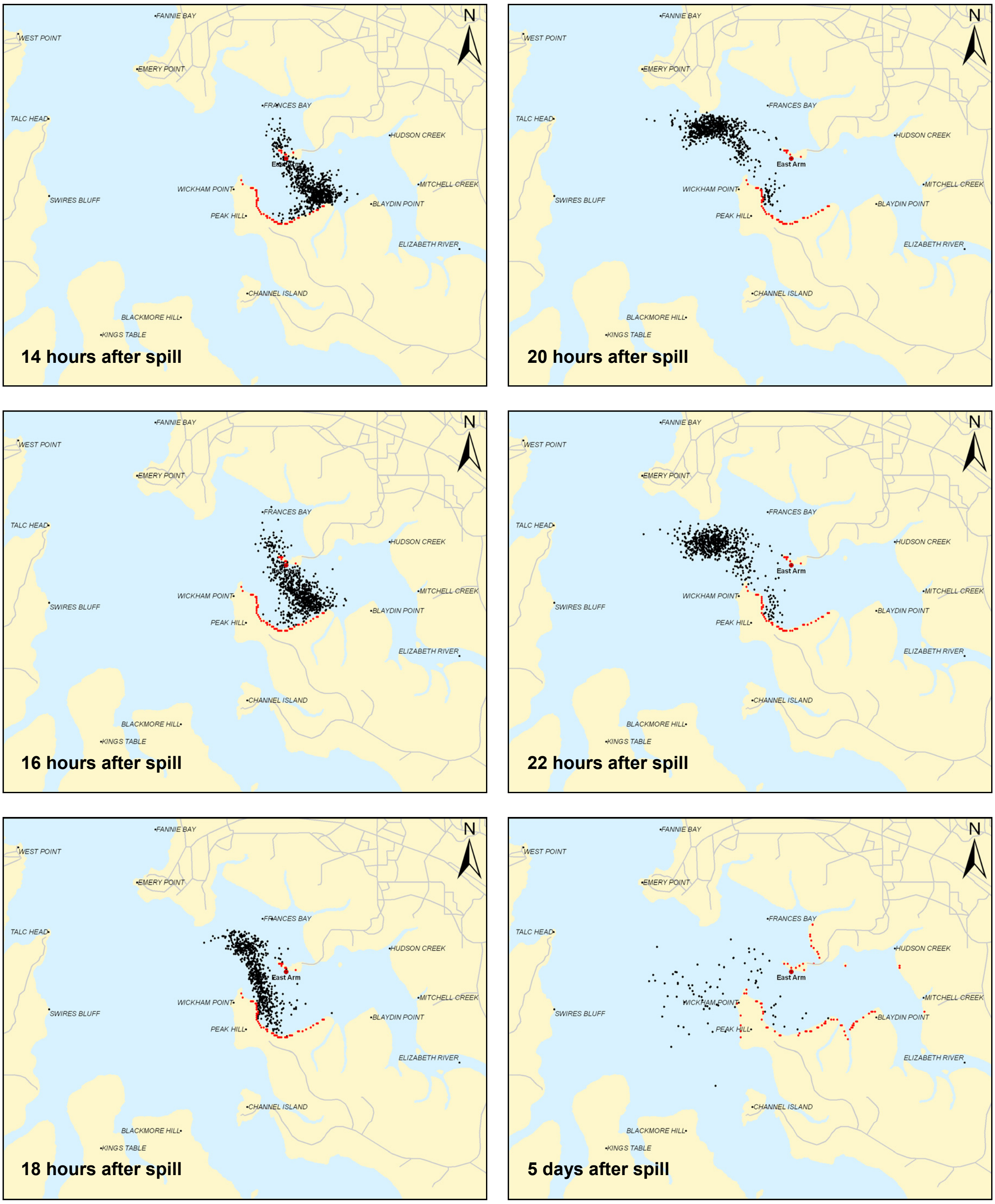


Figure 44. Movement of a hypothetical hydrocarbon spill (black spillets on water and red spillets stranded on land) from the East Arm Wharf locations 2, 4, 6, 8, 10 and 12 hours after the spill

Scenario 7: Gas export pipeline rupture

This scenario considered the potential impacts from a full bore rupture of the gas export pipeline (GEP) in Darwin Harbour. The vast majority of the hydrocarbons lost would be very light and would evaporate without staying in the water column. INPEX estimated that up to 50 m^3 of unprocessed condensate could be released over 3 hours. Due to the gas being highly pressurised the entire contents of the pipeline would escape within 3 hours.

Modelling indicated, for all seasons, the movement of the surface slick was tidally dominated. Probability envelopes remained in the central corridor of the harbour reaching upstream as far as Channel Island and down stream to the entrance to the harbour between East Point and West Point (Figure 45 to Figure 47).

Shoreline exposure was not predicted to occur above the threshold values stated earlier in this report.

Entrained oil was only expected within close proximity (< 1 km) of the release site due to the initial subsurface release. Once surfaced, condensate is unlikely to entrain again due to the relatively calm conditions inside the harbour.

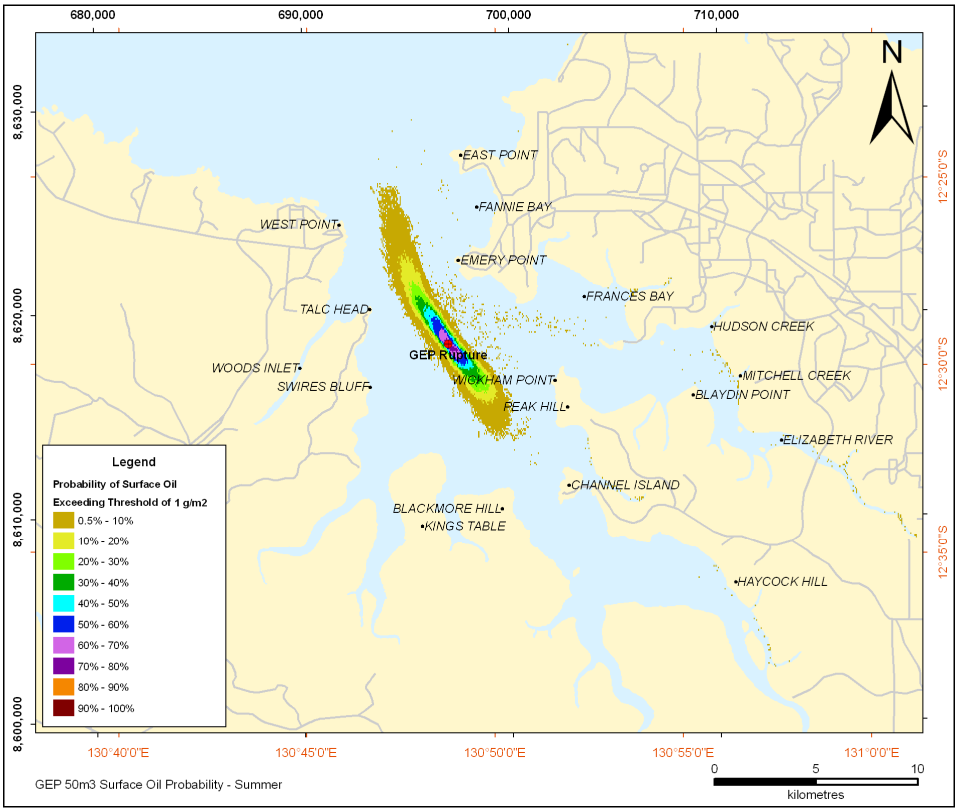


Figure 45. Scenario 7: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 50 m^3 release of unprocessed condensate under summer conditions

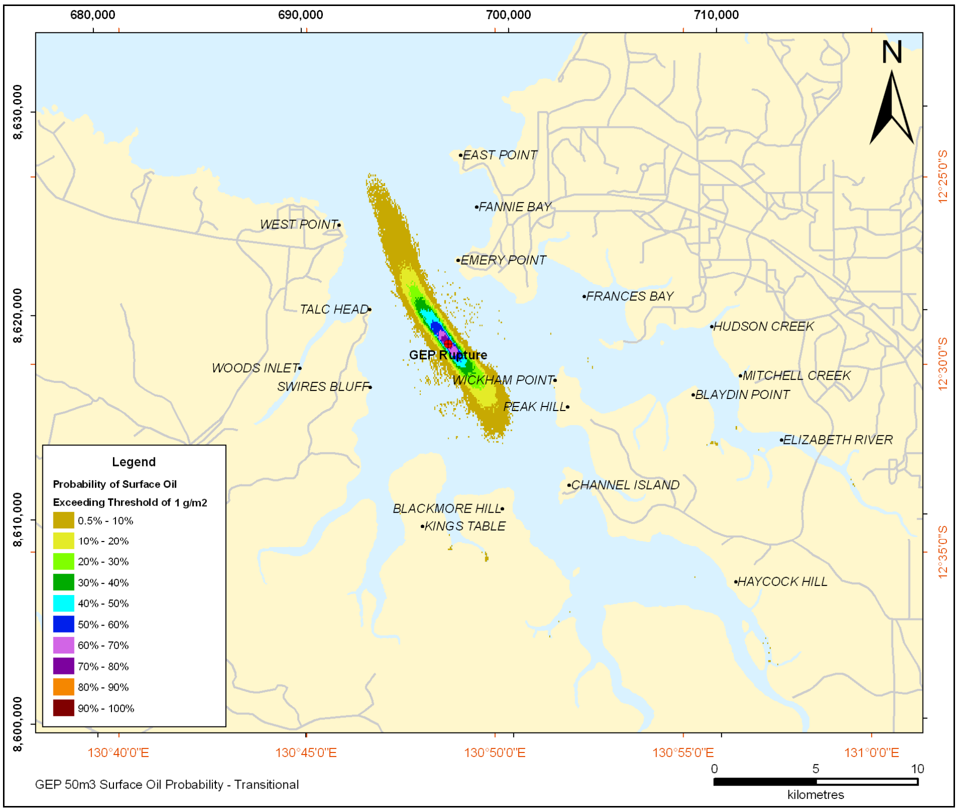


Figure 46. Scenario 7: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 50 m^3 release of unprocessed condensate under transitional conditions

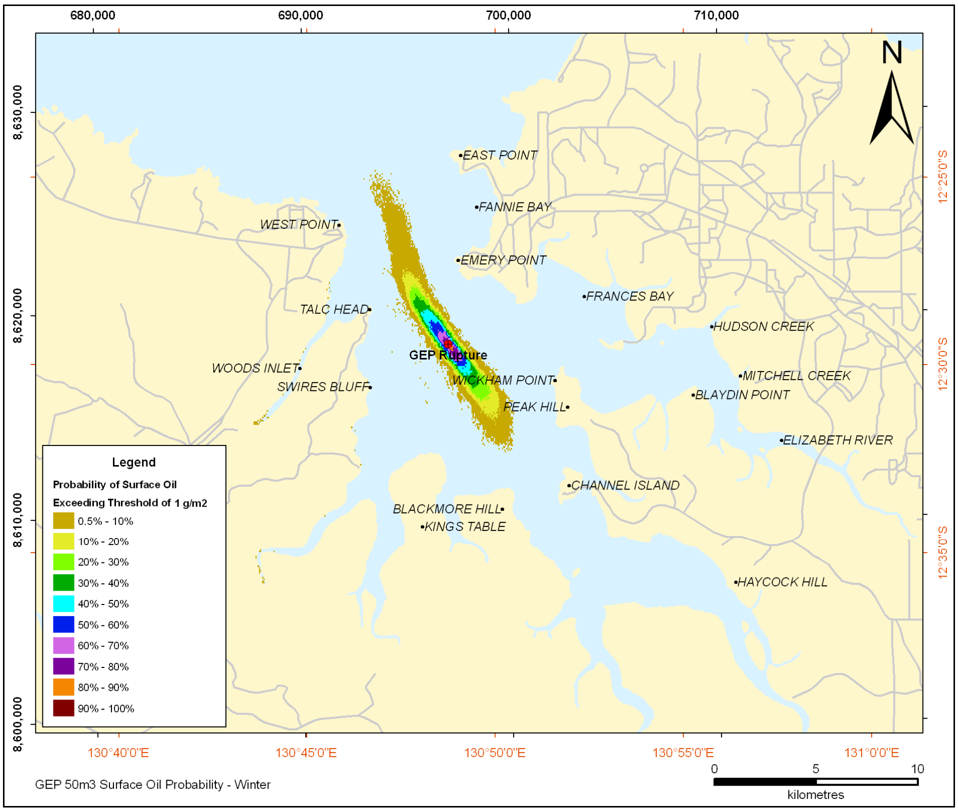


Figure 47. Scenario 7: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 50 m^3 release of unprocessed condensate under winter conditions

Scenario 8: Gas export pipeline leak

This scenario considers the potential impacts from a slow leak from a 25 mm hole in the gas export pipeline in Darwin Harbour, resulting in a total volume of 1 m^3 of unprocessed condensate releasing from seabed level over 24 hours.

Modelling indicated the movement of the slick would be minimal and due to the small volume very low exposure probabilities were predicted (Figure 48 to Figure 50).

Due to the slow release rate and high volatility of the condensate, the risk of exposure to any shores within Darwin Harbour, above the threshold of 1 μm, was estimated at <1% in any season.

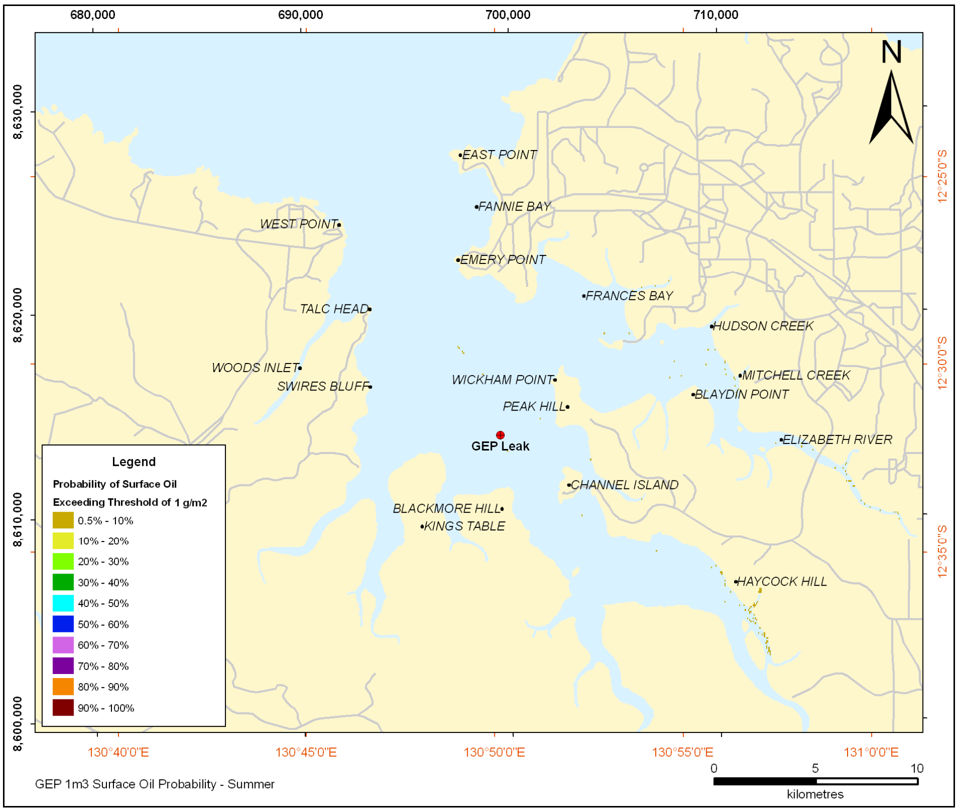


Figure 48. Scenario 8: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 μm) as a result of a 1 m^3 release of condensate under summer conditions

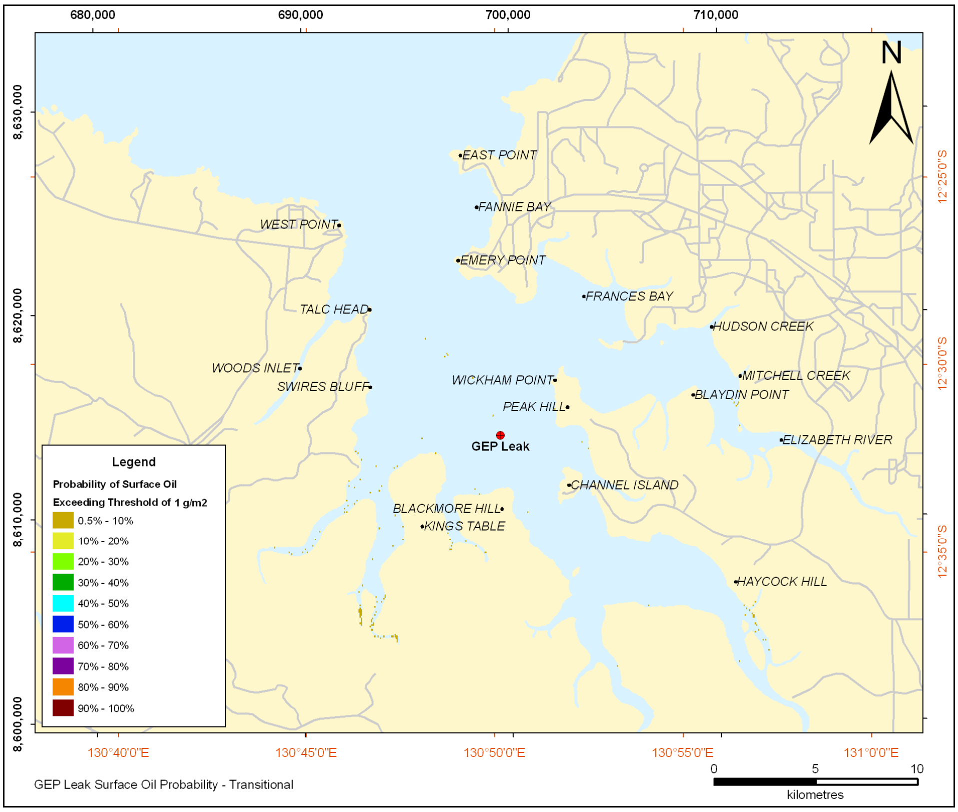


Figure 49. Scenario 8: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 1 m^3 release of condensate under transitional conditions

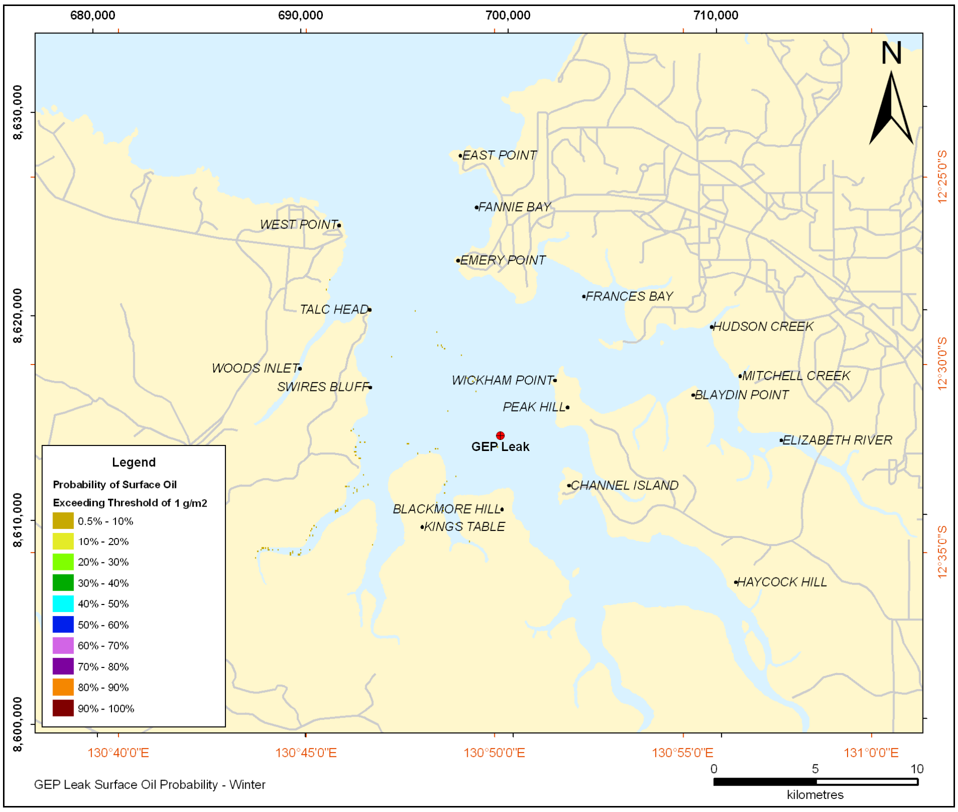


Figure 50. Scenario 8: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) as a result of a 1 m^3 release of condensate under winter conditions

Scenario 9: Condensate loading line coupling spill at the Jetty

This scenario considers the risk posed from the rupture of a condensate loading line at the proposed Jetty location, resulting in the spill of 25 m^3 of processed condensate.

Processed condensate is predicted to evaporate rapidly. Slicks were likely to be contained within East Arm during all seasons. The highest exposure probability for shorelines was predicted for Blaydin Point and the western headland of Lightning Creek. Shorelines around Blaydin Point were predicted to have up to 19% probability of receiving slicks > 1 g/m^2 in summer, 13% in the transitional period and 23% during winter (Table 12). Under worst-case conditions, up to 23% of the spill volume (or ~6 m^3) was predicted to reach the shoreline.

Given the release of the condensate onto the surface, and the high volatility of this product, probabilities of exposure from entrained condensate of dissolved aromatic hydrocarbons were predicted to be relatively low during all seasons. The probability of concentrations >1 ppb occurring within the inter-tidal margin were predicted to be low (1 and 2% for entrained and dissolved components respectively) and the maximum concentrations remained low (Table 13).

Table 12. Scenario 9: probability of shoreline hydrocarbon exposure

Season	Number of cases impacting shorelines (%)	Maximum probability of shoreline exposure at a single location (%)	Maximum oil on shore (% of volume)	Minimum time to shore (hours)	Maximum length of oiled shoreline (km)
Summer	47	19	16.9	1	2.7
Transitional	49	13	23.1	1	2.4
Winter	46	23	19.4	1	2.6

Table 13. Scenario 9: probability of sub-surface hydrocarbon exposure by entrained or dissolved aromatic hydrocarbons

Season	Entrained Hydrocarbons		Aromatic Hydrocarbons	
	Probability (%)	Maximum concentration (ppb)	Probability (%)	Maximum concentration (ppb)
Summer	1	3.7	2	9.5
Transitional	1	6.3	2	12.1
Winter	1	2.3	2	18.0

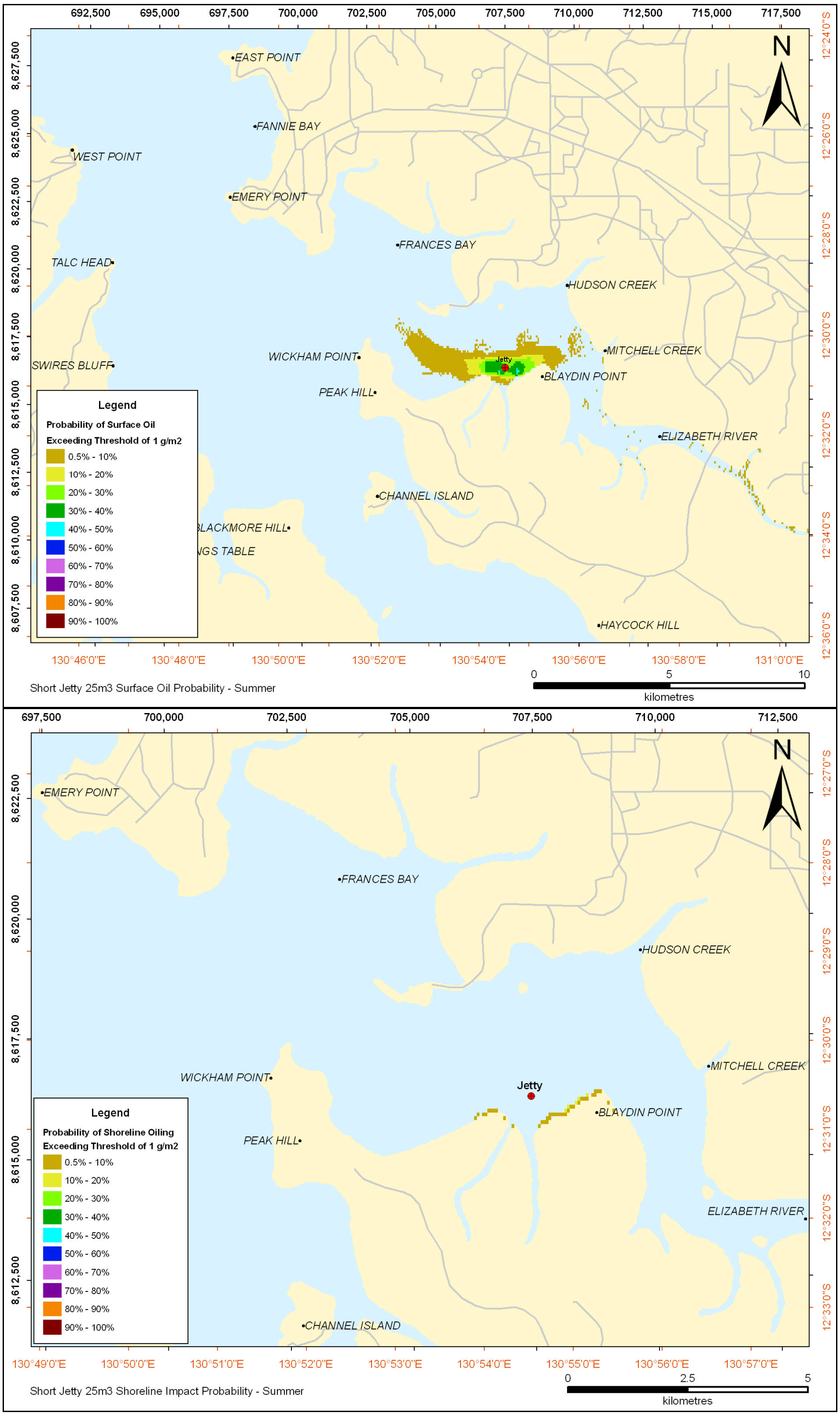


Figure 51. Scenario 9: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) (top) and probability of shoreline exposure above 1 g/m^2 (1 µm) (bottom) as a result of a25 m^3 release of condensate under summer conditions

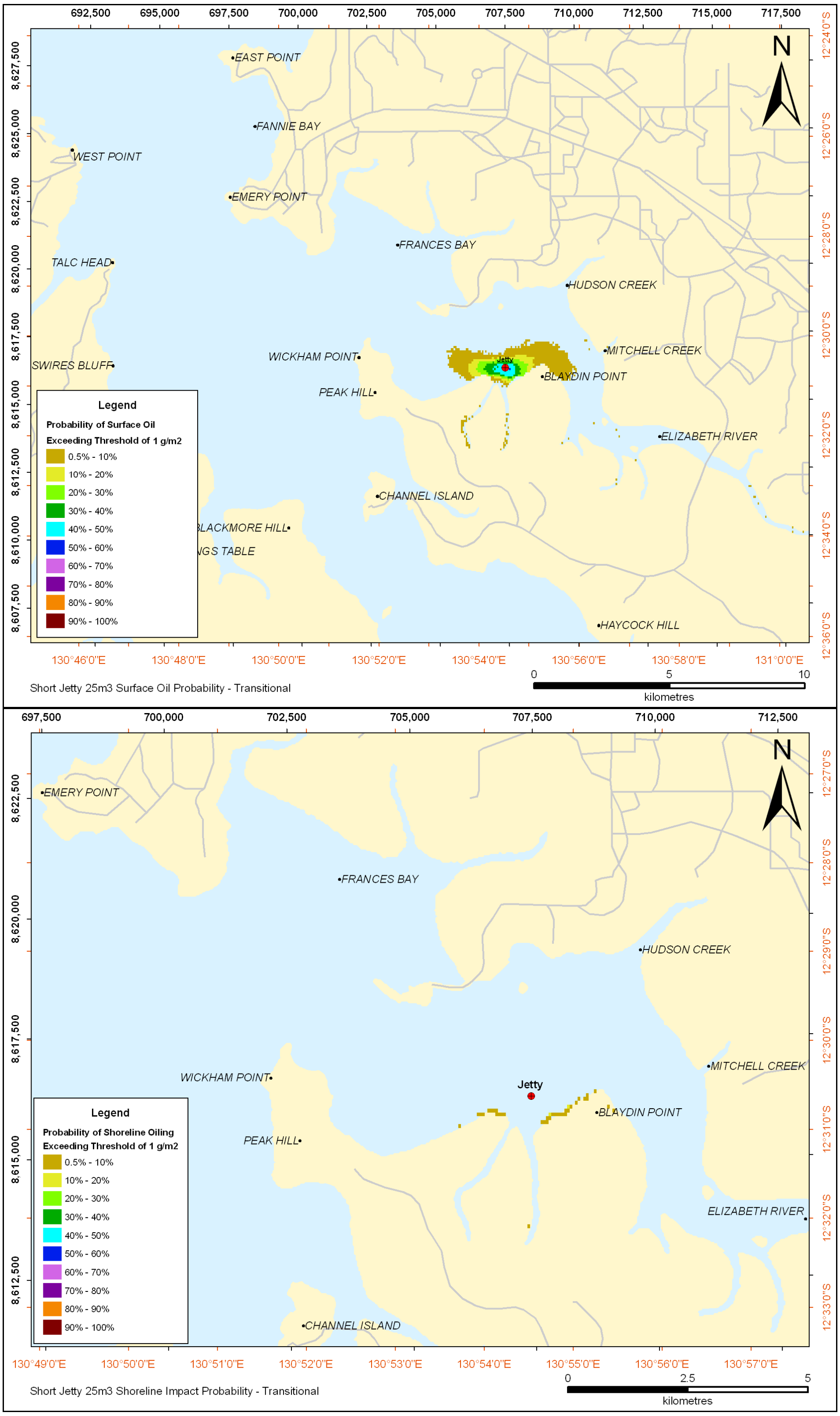
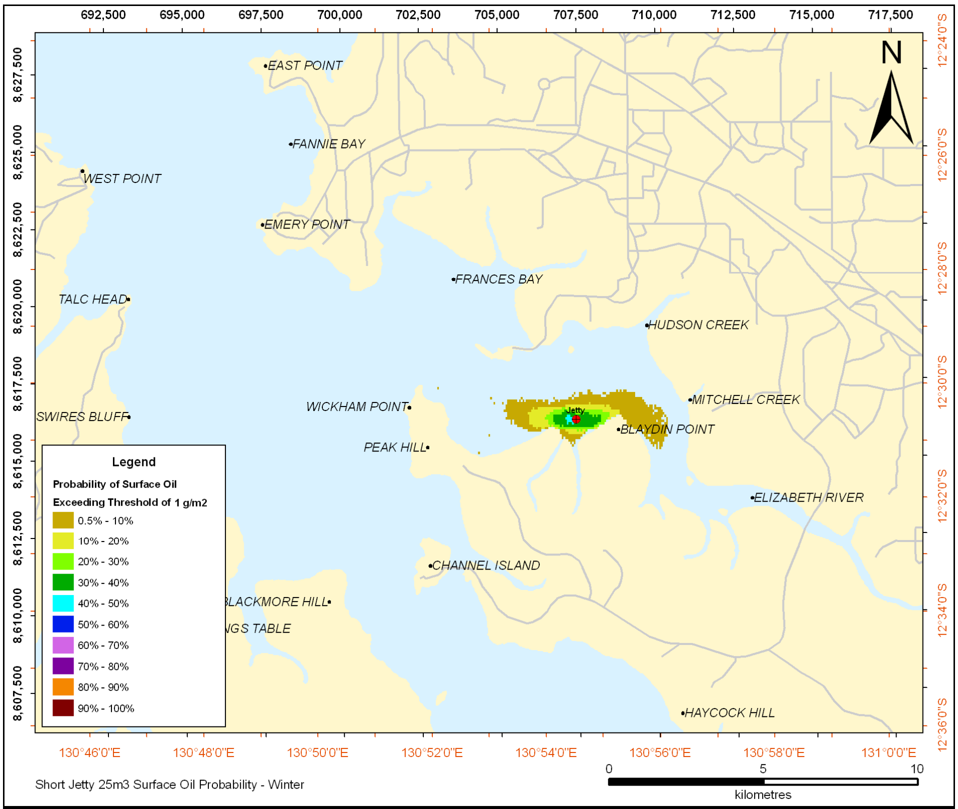


Figure 52. Scenario 9: predicted probability of hydrocarbon exposure to the water surface above 1 g/m² (1 µm) (top) and probability of shoreline exposure above 1 g/m² (1 µm) (bottom) as a result of a25 m³ release of condensate under transitional conditions



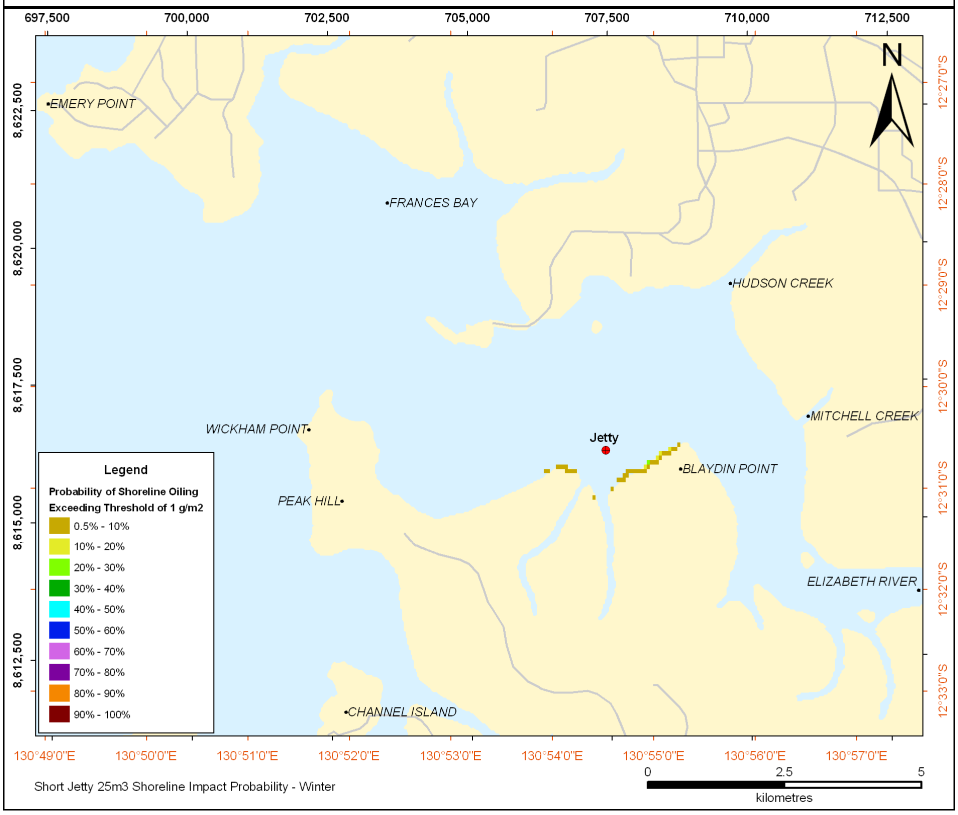


Figure 53. Scenario 9: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) (top) and probability of shoreline exposure above 1 g/m^2 (1 µm) (bottom) as a result of a25 m^3 release of condensate under winter conditions

Scenario 10: Refuelling incident at the East Arm Wharf

This scenario considered a 200 L spill of diesel from a source at the East Arm Wharf for summer, winter and the transitional periods. Figure 54 to Figure 56 show the predicted probability of oil exposure to the water surface (above 1 μm) for each of the three seasons. Table 14 summarises the probability estimates for this scenario.

Table 14. Scenario 10: Probability of shoreline hydrocarbon exposure

Season	Number of cases impacting shorelines (%)	Maximum probability of shoreline exposure at a single location (%)	Maximum oil on shore (% of volume)	Minimum time to shore (hours)	Maximum length of oiled shoreline (km)
Summer	99	79	82	<1	9.355
Transitional	95	78	76	<1	7.643
Winter	91	67	70	<1	9.808

Simulations indicate that the initial movement of slicks, during all seasons, would be predominantly along an east–west axis due to the sweep of the ebbing and flooding tides passing along the East Arm Wharf. Spills occurring in summer were mostly contained within East Arm due to the predominantly westerly winds during this period. Spills during the transitional and winter periods occasionally entered Middle Arm.

Exposure to the shore was predicted to occur almost immediately due to the location of the spill, next to the East Arm Wharf. For all seasons, shoreline exposure probability was greater than 90% and the maximum amount of oil on shore was 82% (or 164 L) of the initial spill volume. Across all seasons the maximum length of oiled coastline was < 10 km. The majority of oil on shore was on the eastern shore between East Arm Wharf and Mitchell Creek and on the western shore between Wickham Point and Blaydin Point.

Irrespective of the season neither entrained nor dissolve hydrocarbons were predicted to reach the surrounding inter-tidal zones at concentrations exceeding 1 ppb from this scenario. This result can be attributed to the low influence of the wind on transport of the water column, and hence any plumes of hydrocarbons that are dissolved or entrained below the surface. Plumes are predicted to migrate along the main tidal axis, with effective dilution occurring over a series of ebbing and flooding tides.

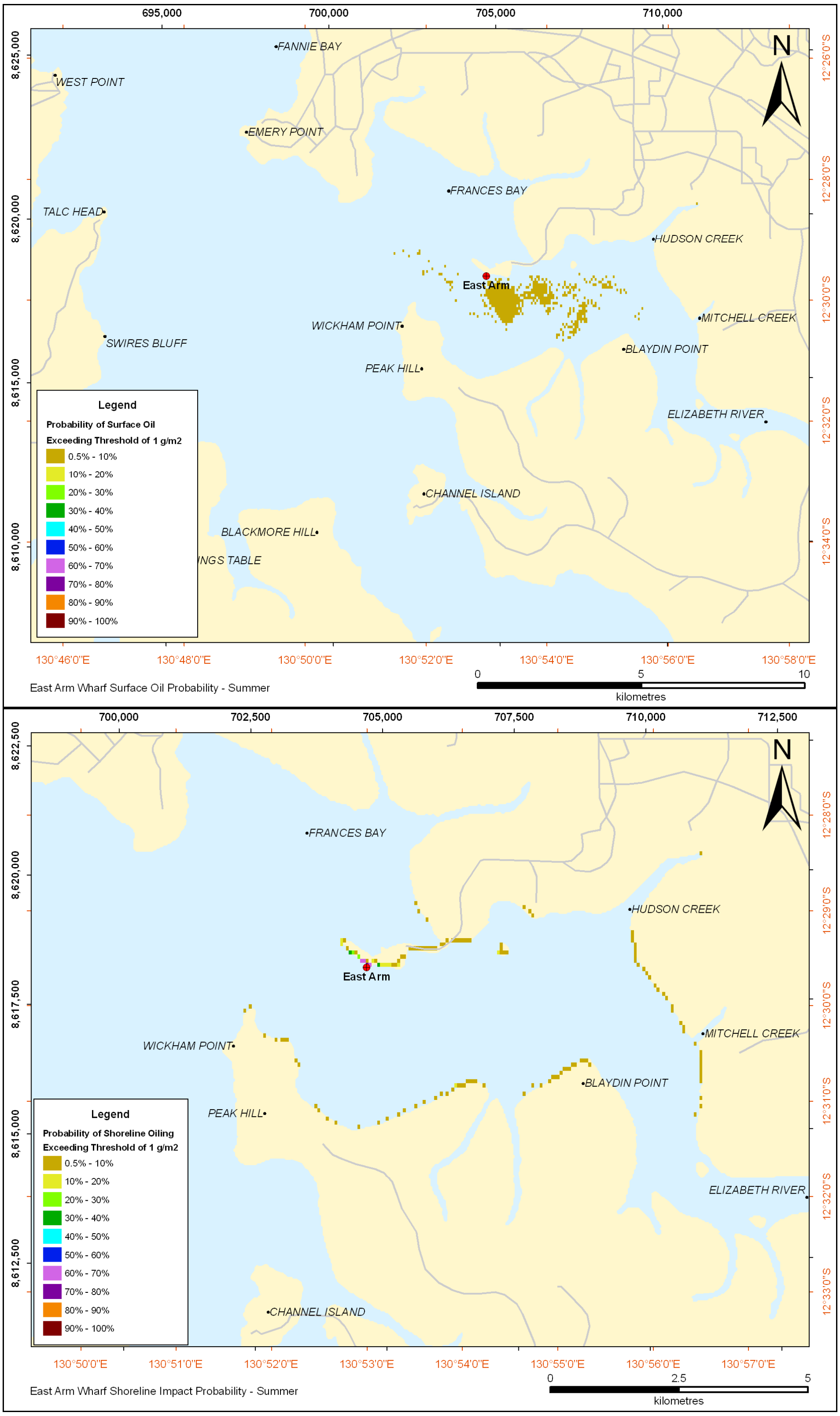


Figure 54. Scenario 10: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) (top) and shoreline oiling above 1 g/m^2 (1 µm) (bottom) as a result of a 200 L release of diesel under summer conditions

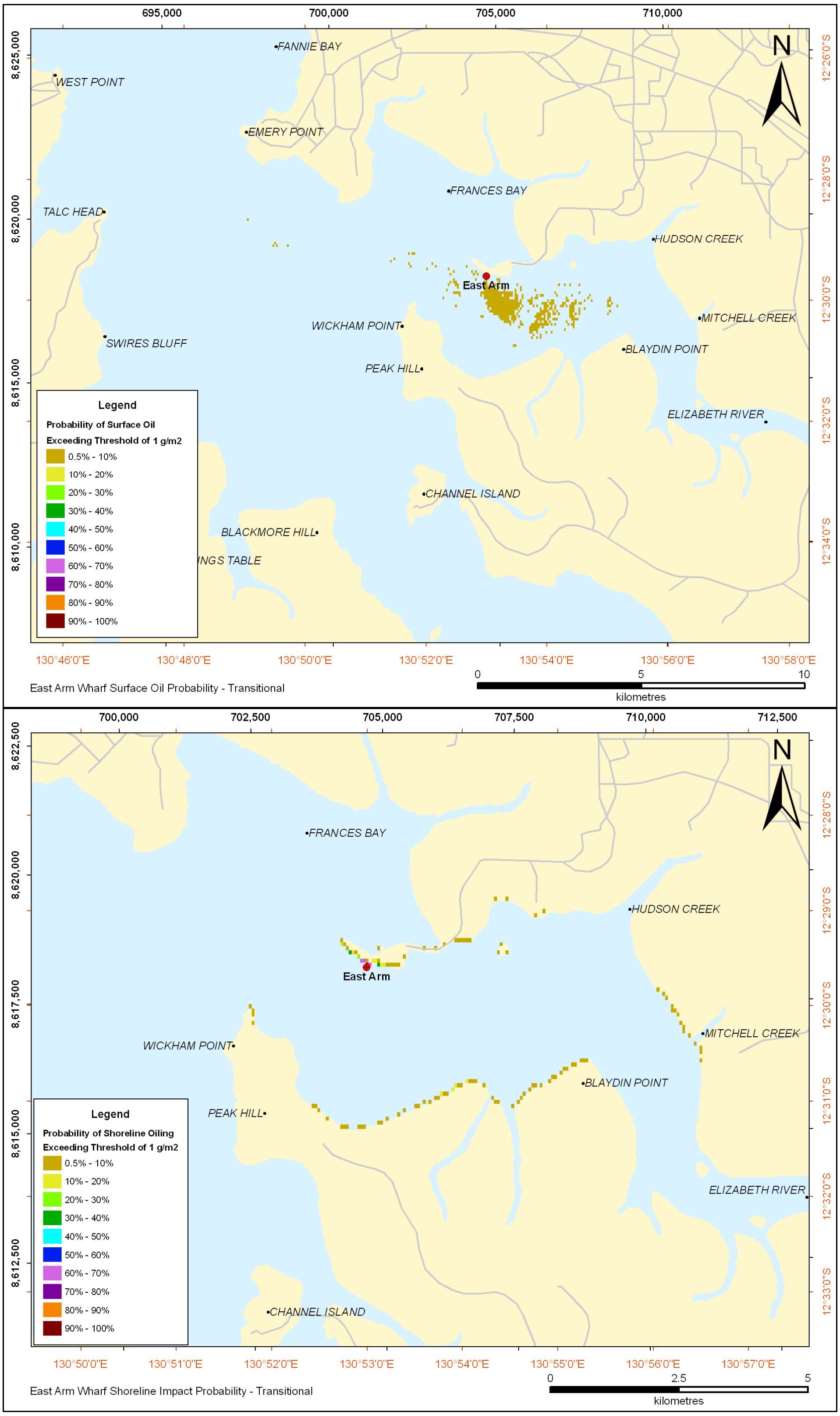


Figure 55. Scenario 10: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 µm) (top) and shoreline oiling above 1 g/m^2 (1 µm) (bottom) as a result of a 200 L release of diesel under transitional conditions

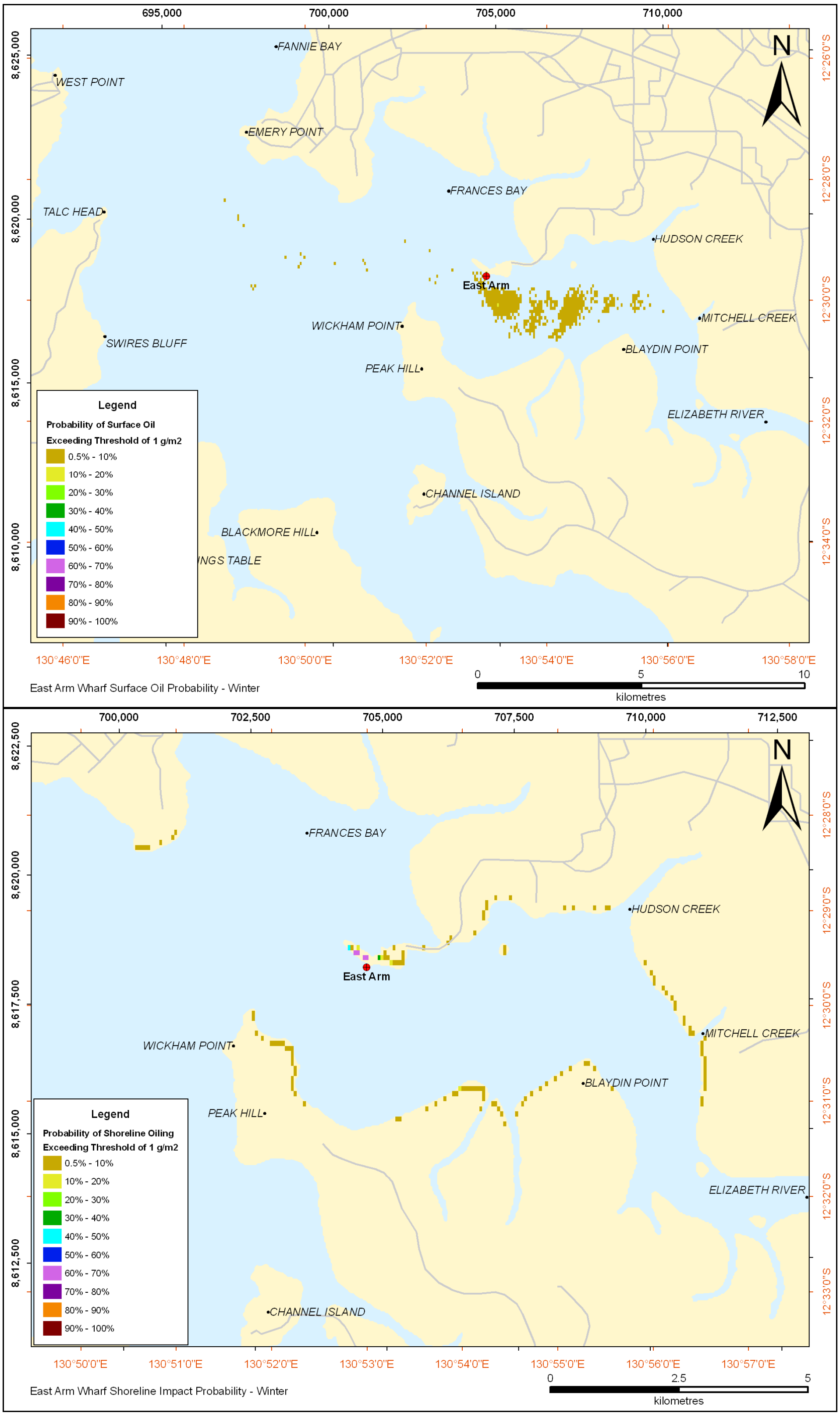


Figure 56. Scenario 10: predicted probability of hydrocarbon exposure to the water surface above 1 g/m^2 (1 μm) (top) and shoreline oiling above 1 g/m^2 (1 μm) (bottom) as a result of a 200 L release of diesel under winter conditions

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