Technical Appendix S2

Ichthys Gas Field Development Project: marine hydrocarbon spill modelling. Addendum report—supplemental spill risk modelling

ICHTHYS GAS FIELD DEVELOPMENT PROJECT

MARINE HYDROCARBON SPILL MODELLING. ADDENDUM REPORT—SUPPLEMENTAL SPILL RISK MODELLING

Revision 3 – 8 March 2011

Prepared for:
INPEX Browse, Ltd

INPEX Document No. C036-AH-REP-0107

Document control form

Document draft	*Originated by*	*Edit & review*	*Authorized for release by*	*Date*
Revision A Issued for internal review	*Sandy Ng* *Scott Langtry*			
Revision 0 Issued for client review		*Scott Langtry*	*Scott Langtry*	*14 December 2010*
Revision 1 issued after amendments			*Scott Langtry*	*23 December 2010*
Revision 2 issued after amendments			*Scott Langtry*	*19 January 2011*
Final with summary table			***Scott Langtry***	***8 March 2011***

Document name:

INPEX-Darwin-Addendum spill modelling Final Report.doc

APASA Project Number: J0095

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This report may be cited as follows:

Asia-Pacific Applied Science Associates. 2011. *Ichthys Gas Field Development Project: marine hydrocarbon spill modelling. Addendum report—supplemental spill risk modelling*. Report prepared by Asia-Pacific Applied Science Associates, Perth, for INPEX Browse, Ltd., Perth, Western Australia.

Contents

Figures

Tables

EXECUTIVE SUMMARY

A quantitative oil spill modeling study was undertaken to estimate the risk of contact to surrounding resources in the event of defined condensate spill scenarios associated with the development of the Ichthys reservoir, via a gas export pipeline (GEP) to Darwin Harbour. This study was an addendum to earlier studies documented in APASA 2009 and 2009b and involved the simulation of spill events using wind and current data that were considered representative of the variability and trends in the wind and circulation patterns over the Browse Basin.

The spill scenarios investigated in this study were:

Scenario 7b: A rupture of the GEP, releasing 50 m^3 of condensate, from seabed level, within 1 km of the shoreline crossing onto Wickham Point.

Scenario 7c: A rupture of the GEP, releasing 50 m^3 of condensate, from seabed level, on the approach to Darwin Harbour.

Scenario 12: A full-bore blowout of the Ichthys production well, from seabed level from a seabed production well (CPW) adjacent to the Central Processing Facility (CPF), discharging condensate for a period of 11 weeks at a constant rate of 4,000 bbl d^{-1} (26.5 m^3 hr^{1}).

Simulations for both the GEP rupture and the seabed blowout scenario indicate that the condensate is likely to be broken up into a cloud of droplets of a range of diameters, tending towards a relatively small size (< 200 µm) due to the turbulence created by the releasing gas. The condensate droplets will tend to be entrained with the gas and the larger droplets would surface rapidly, within minutes from the depth of water off the near shore crossing (< 10 m) and the approach to Darwin Harbour (< 40 m). Atmospheric weathering would then commence on surfacing, with > 80% of surfaced condensate likely to evaporate within a day of surfacing. However, some of the finer droplets that are displaced by the gas and mixed into the water column could stay entrained and drift for longer (multiple hours to days) in the water column. In the case of a deeper release from the depth adjacent to the CPF location, the generation of small droplet sizes is indicated to have a more significant effect both on the weathering rates of the condensate and the distribution of the condensate by water currents, with the potential for a large percentage (up to 40%) to remain entrained for long periods (days to 10s of days).

Assay data available for the oil indicate that a less volatile residual component (~10-20%) would be left after evaporation of the more volatile components and predictions for the total volume of hydrocarbons that would be on the surface indicate there would be a gradual rise over time under calm conditions, that do not produce breaking waves. Hence, the rate of surfacing would be marginally greater than the rate of weathering. Estimates for the peak volumes that could be generated on the surface were of the order of ~ 6% of the total spill volume – equating to ~ 1590 m^3. Re-entrainment of surfaced condensate would reduce this surfaced volume under wind conditions that subsequently produce breaking waves.

Stochastic modelling of the near shore GEP rupture scenario (Scenario 7b), involving repeated simulations under varying environmental conditions, indicated that surfaced condensate and entrained condensate is most likely to migrated over a reciprocating path with the strong local tidal flows, moving south-south-east between Channel Island and Wickham point on the flood tides and returning north along Wickham Point on the ebb tides, with weathering of the surface plume taking 2-3 tidal cycles. Surface plumes will tend to spread laterally from the tidal axis due to dispersion and the wind acting on the plume surface, hence contact with shorelines in this area by condensate films > 1 g m^{-2} is indicated to be highly likely (100% probability). Seasonal trends in the prevailing wind are indicated to increase the volume of condensate drifting inshore to strand on Wickham Point in the summer and onto Channel Island in the winter. The simulation indicated the potential for entrained condensate to remain entrained with the reciprocating tides, generating concentrations up to 400 ppb over the shallow margins.

Based on reverse-trajectory modelling, which involved tracking conservative particles backward in time using randomly selected samples of current and wind data in reverse to locate any intersection with the pipeline route, two locations along the GEP approaching Darwin Harbour were identified and investigated (Scenario 7c) specifically for the potential that Bare Sand Island, a recognised turtle nesting site, could be exposed to condensate. This latter investigation used forward simulations and accounted for seabed release and all weathering processes. The risk assessment for this scenario also indicated low potential (<1%) for condensate to reach Bare Sand Island from the pipeline during any season, either as surfaced or entrained condensate above the threshold concentrations. This result can be attributed to both the prevailing wind and current patterns, which would tend to divert condensate released at the pipeline away from the island, and the expected evaporation and dispersion rates of the condensate.

Simulation of the 11 week blowout scenarios indicated that condensate rising from the depth of the subsea production wells would be subject to a wide variety of wind and current patterns over this duration of release and, hence, portions of the slicks could follow quite different paths. This would tend to break up the slick and add to the area of coverage while reducing local concentrations. Due to the long duration of the release scenario relative to the duration of the seasons over the Browse Basin, blowouts commencing in one season could persist into the following one or two seasons, hence results of the seasonal analysis for the long-term blowout scenarios are best considered in terms of the season when the release commences.

Simulations of a seabed release commencing in summer indicated the highest likelihood that slicks will drift toward the north-eastern sector. These trajectories are also indicated to be the longest in a given direction, reflecting the persistence of wind from the south-west during summer. However, shorter trajectories in all other directions were also indicated as possible. The results indicated the potential for contact by surfaced condensate, at concentrations > 1 g m^{-2} at Browse Island (30%), North and South Scott Reef (10%), and Seringapatam Reef (20%) for this scenario, involving a worst case volume of ~ 150 m^3 of condensate, collectively among the locations, in any one simulation. The potential for entrained concentrations within the range 10-100 ppb were also indicated for each of these locations as well as shallow reef areas to the north-east. Rowley Shoals, located approximately 50 km to the south-west was indicated to be outside of the range of surface concentrations > 1 g m^{-2} but could potentially be contacted by lower concentration surface sheens or entrained condensate < 10 ppb.

For blowouts commencing in winter, simulations indicated that condensate slicks will most frequently drift toward the north-west to west, but could also drift for shorter distances in all other directions. The westerly trend indicated an increased risk (~20%) of contact with Seringapatam and North and South Scott Reef at > 1 g m^{-2} and a reduced risk for Browse Island (10%) compared to the summer commencement scenario. An increased risk of contact at these concentrations was indicated for Cartier Islet (10%), Ashmore Reef (1%) and Hibernia Reef (1%). The potential for entrained condensate concentrations ranging from 10-100 ppb was indicated for all of these islands and reefs. Rowley Shoals was indicated to have a low (1%) risk of contact by surface sheen > 1 g m^{-2} and entrained condensate < 10 ppb.

The blowout simulations commencing in the autumn and spring transitional seasons indicated risk profiles that were a composite of the winter and summer start outcomes, due to the high likelihood that 11 week releases would persist into winter (for an autumn commencement) or summer (for a spring commencement) but with a dominant trend towards the south-west. Browse Island was indicated to have > 30% risk of contact by surfaced condensate at > 1 g m^{-2}. South Scott Reef was predicted to have 20% risk of contact while Seringapatam Reef, Cartier Island, Ashmore Reef and Hibernia Reef have an estimated 1% risk of contact. Predictions for entrained condensate indicate that each of these locations could be contacted at > 10 ppb. Rowley Shoals was calculated to have >1% risk of contact by surfaced condensate > 1 g m^{-2} and > 10 ppb entrained condensate.

Risks of contact by condensate concentrations > 1 g m^{-2} are summarised as follows for individual islands and reefs, in the event of the blowout scenario first occurring in each season:

Season	**Location**								
	Browse Island	**North & South Scott Reef and Sandy**	**Seringapetam Reef**	**Ashmore Reef**	**Cartier Islet**	**Hibernia Reef**	**Adele Island**	**Rowley Shoals**	**Kimberley Coastline**
Summer	30%	10%	20%	1%	1%	1%	<1%	<1%	<1%
Transitional	45%	45%	15%	3%	10%	2%	<1%	1%	<1%
Winter	10%	85%	85%	<1%	10%	1%	<1%	1%	<1%

Note: <1% indicates that contact was not indicated during the simulations.

1 INTRODUCTION

An oil spill modelling study was carried out to quantify the risk of exposure by hydrocarbons to surrounding resources if identified spill scenarios were to occur at defined locations. This study is an addendum to earlier studies undertaken for INPEX Browse Ltd to assess risks associated with the construction and operation of gas and condensate production and processing facilities for the Ichthys Reservoir (APASA 2009: INPEX Document No. C036-AH-REP-0004 and APASA 2009b: INPEX Document No. C036-AH-REP-0060.

The proposed facilities include seabed production wells (CPW) feeding to a central processing facility (CPF), which would be located in the Browse Basin, and a gas export pipeline (GEP) that would conduct gas and partially processed condensate (downstream condensate) along the seabed between the CPF and a processing facility within Darwin Harbour. The GEP would come ashore at a location south of Wickham Point.

Figure 1 and Table 1 summarises the location of the hypothetical release sites for these scenarios.

Table 1: Locations of hypothetical spill sites used for the spill risk assessments in this study

Scenario No.	**Source**	**Longitude**	**Latitude**	**Water depth (m)**
Scenario 7b	GEP	130° 51′ 47.9″E	12° 32′ 8.3″S	9
Scenario 7c	GEP	130° 42′ 32.4″E	12° 22′ 1.2″S	21-38
Scenario 12	CPW	123° 13′ 53.0″E	12° 22′ 1.2″S	256

This document summarises the methods and findings of the quantitative modelling for the following scenarios, which have been numbered for consistency with the earlier documentation:

Scenario 7b: A rupture of the GEP, releasing 50 m^3 of downstream condensate, from seabed level, within 1 km of the shoreline crossing.

Scenario 7c: A rupture of the GEP, releasing 50 m^3 of downstream condensate, from seabed level, on the approach to Darwin Harbour. The actual rupture site for this scenario was determined using reverse trajectory modelling to determine the highest risk locations along the pipeline with respect to the potential for condensate to wash onto Bare Sand Island.

Scenario 12: A full-bore blowout of a seabed production well below, discharging reservoir condensate, from seabed level, for a period of 11 weeks at a constant rate of 4,000 bbl d^{-1} (26.5 $m^3\ hr^{1}$), resulting in the release of a total volume of 308,000 bbls (48,972 m^3). The location and depth for this scenario was identical to that used to assess risks from a 6 week discharge, documented in APASA (2009b).

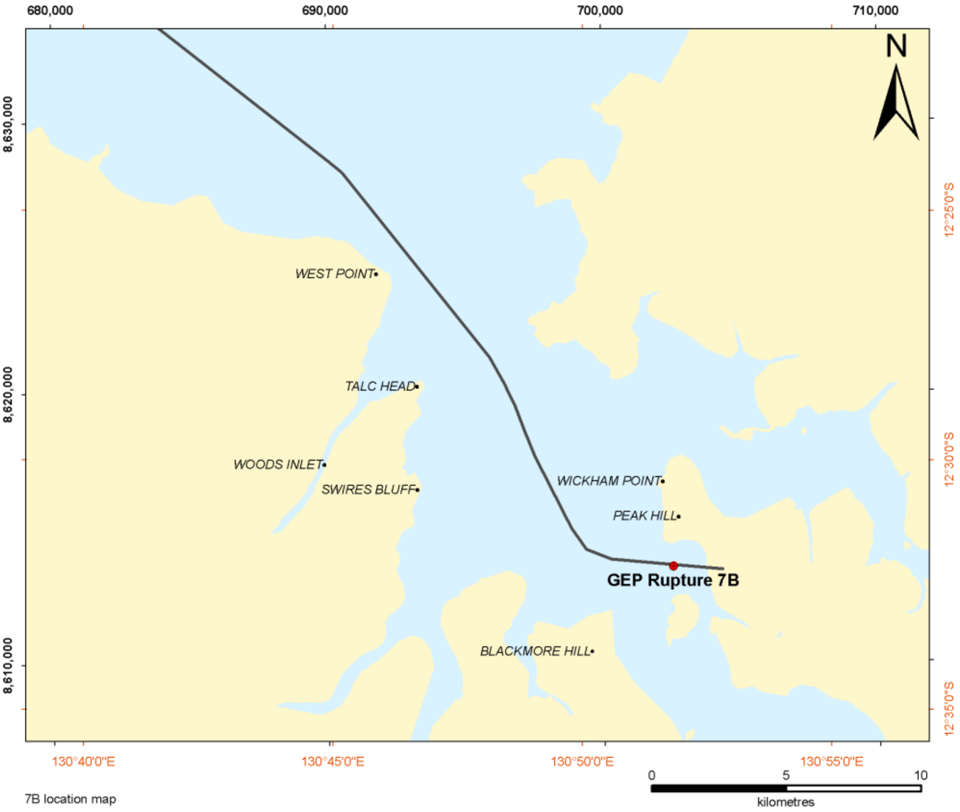


Figure 1-1: Location of the site specified for the GEP rupture adjacent to the shoreline crossing (GEP Rupture scenario 7B).

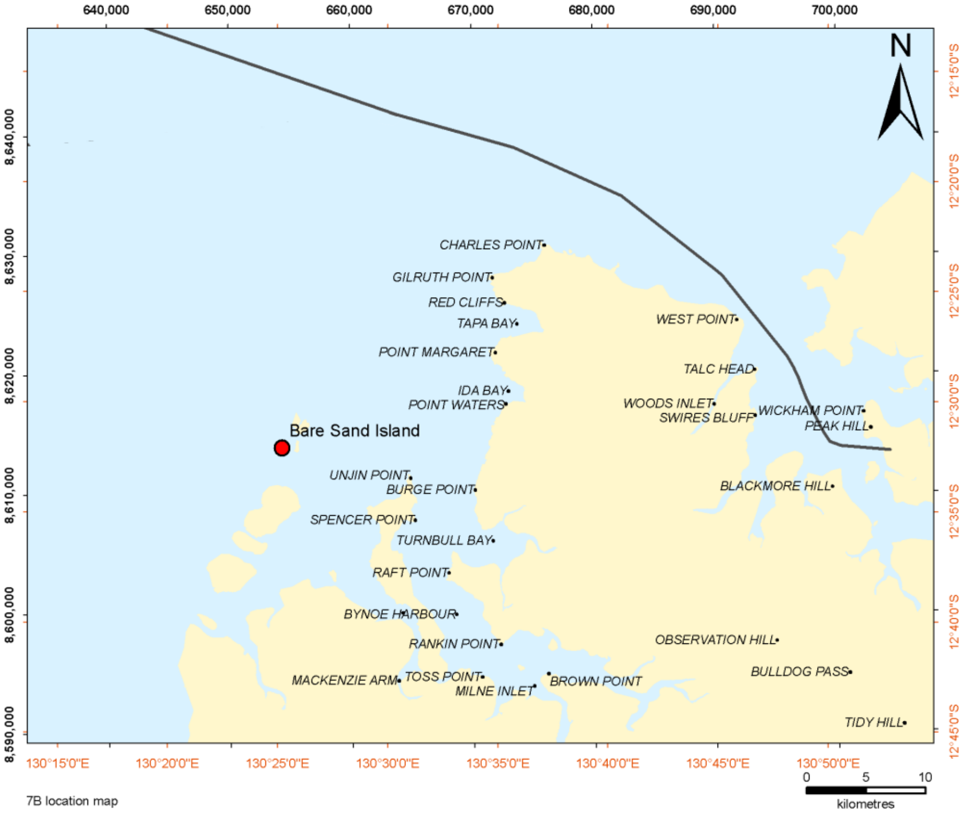


Figure 1-2: Route of the GEP approaching Darwin Harbour, used to define worst-case release sites for potential contact with Bare Sand Island (GEP rupture Scenario 7C).

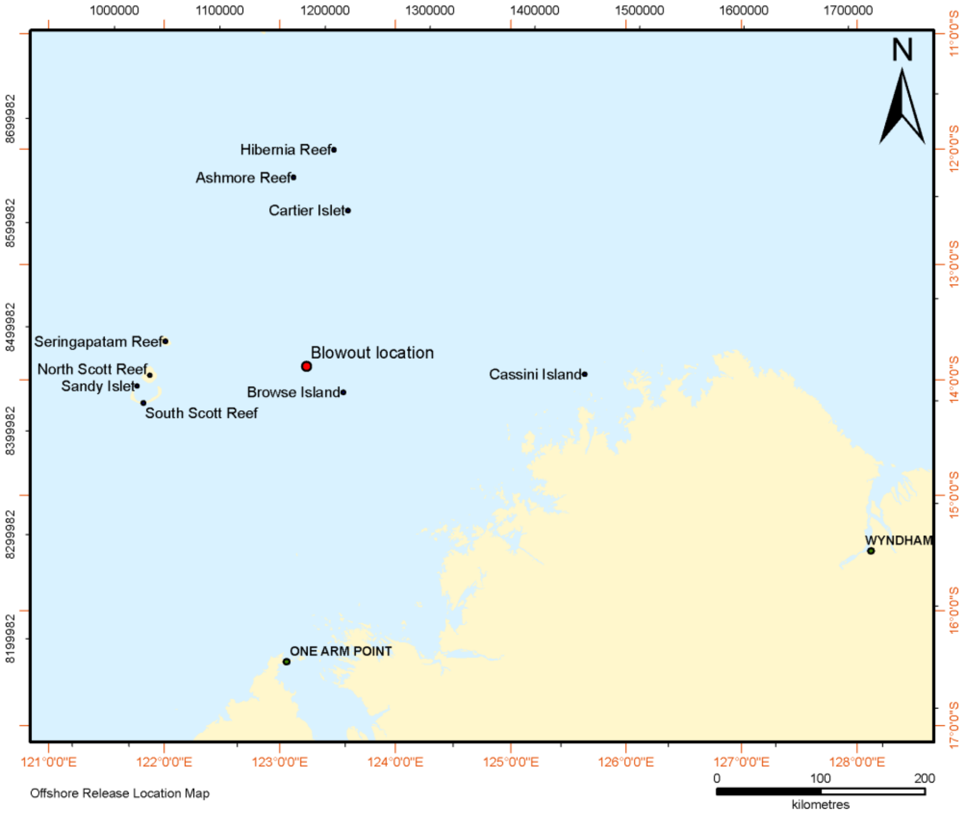


Figure 1-3: *Location of the site specified for the CPW Blowout Scenario*

2 METHODS

2.1 Spill Modelling

Spill modelling was carried out using the same three-dimensional oil spill trajectory and fates model, SIMAP (Spill Impact Mapping and Assessment Program) that was applied to the spill risk assessment documented in APASA (2009) and (2009b). 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 details of the SIMAP model are summarised in these earlier reports.

A stochastic modelling approach was applied to quantify estimates of risk to surrounding waters and shorelines in the event of defined spill scenarios occurring. This involved repeated simulations of the same scenario, defined by the oil type, spill volume, spill duration, and location of the release point, using different samples of metocean conditions each time, using a random selection scheme from a database of historic current and wind data for the study area. The random selection ensures that environmental conditions are selected objectively and proportional to their occurrence over the study area.

A dataset of historic wind and current data for the study region was prepared to represent spatial and temporal variations that could occur in future years. The data set was optimised to include spatial variation at scales of kilometres to hundreds of kilometres and temporal variation spanning scales from hours to interannual.

Based on an analysis of the wind patterns and temperatures affecting the study area, there are distinct seasons definable for the study area:

- Winter - May to August
- Summer - November to February
- Autumn transitional – March to April
- Spring transitional - September to October

To resolve the effect of these seasonal patterns, sets of simulations were run using samples of wind and current data that started within these months. In the case of the short discharge simulations, simulations would use environmental data entirely from within the same season as the commencement date. However, due to the long blowout duration that was simulated (85 day simulations) relative to the duration of the seasons, environmental data spanned over to subsequent seasons. For example, a spill commencing in late summer could continue across autumn and into winter. Hence, time series records spanning summer to winter were made available for random selection. This was a realistic approach to represent risks from long spills that commence in a defined seasons.

Outcomes of the independent simulations commencing in a given season were then compiled from each of the sample trajectories to provide a statistical weighting to the likelihood of contact for a given location. In these calculations, the model allowed for very low concentrations. Hence, threshold concentrations were applied to define when more meaningful contact was indicated in each simulation. Contact of oil on water or shoreline was registered when the predicted thickness of surface films exceeded a threshold of 1 g m^{-2} (0.001 mm or 1 μm). This is equivalent to the lowest thickness where the oil would tend to appear as a yellowish film and the upper limit at which it will appear as a dull coloured sheen (NOAA HAZMAT 1996). This threshold is expected to be conservative in terms of the potential for smothering or harm through contact toxicity and more indicative of the visual extent of coverage. Minimum thresholds for entrained and dissolved oil concentrations were set at a conservatively low threshold of 10 parts per billion (ppb), based on published reviews (e.g. French 2000).

Results of each season of commencement and scenario combination were summarised as:

1. Probability of contact above the defined threshold concentrations for surface-bound condensate
2. Potential volume of surface-bound condensate that could accumulate;
3. Potential concentrations of entrained condensate;
4. Minimum time before condensate is likely to arrive at any shoreline or reef, if affected; and
5. The maximum length of shoreline or reef that could be contacted above the threshold concentration.

Probability estimates for the water surface and shorelines were calculated from the frequency of exposure during all simulations within that season. The minimum time before exposure estimates were the shortest times during any simulation for that season and the potential volumes and shoreline lengths were the highest estimates obtained during any simulation within that season.

2.2 General inputs to the model simulations

The hypothesised spill scenarios involved releases into distinctly different environments, in terms of the current and wind conditions that could be expected and therefore the data required to provide representative forcing. The pipeline rupture scenario off Wickham Point (Scenario 7B), required wind and current data representative of the harbour, while the other scenarios (7C and 12) required wind and current data representative of the wider offshore waters, ranging from near shore zones to deeper open water settings. Appropriate data were applied in each case.

2.2.1 Wind and current data used for the near shore GEP rupture scenario (Scenario 7B)

Scenario 7B, which involved the release of condensate within Darwin Harbour, was simulated using wind and current data with coverage of the harbour and approaches. Historic wind data for Darwin Harbour were available from electronic measurements collected at Darwin Airport by the Bureau of Meteorology, at hourly intervals. Measurements at this point showed a close match to data collected by APASA over 4 months at East Arm Wharf, indicating the historic data was representative of the harbour.

Figure 2-1 shows the yearly and monthly wind roses summarising the distribution of wind speeds and directions (the wind blew from). The width of each segment indicates the frequency of occurrence. The wind roses indicate that predominant wind directions vary seasonally. 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, using a flexible mesh to maximise spatial resolution of the harbour. The set up and details of this model were summarized in APASA (2009). In summary, BFHYDRO produced three-dimensional current estimates, with changes in current speed and direction as a function of depth over a model grid where the shoreline changed due to tidal wetting and drying over the inter-tidal zone.

2.2.2 Wind and current data used for the offshore GEP rupture scenario (Scenario 7C) and blowout scenario (Scenario 12)

The longest set of uninterrupted wind data available for the offshore region was available from the NCEP/NCAR model re-analysis for the years 1998-2008, produced by the NOAA-CIRES Climate Diagnostics Center in the USA and made publicly available via their Web site (http://www.cdc.noaa.gov). This data is produced for a grid-work of nodes over the region, hence serves the critical requirement of providing spatial variation with distance offshore and alongshore. Comparisons to measurements at Browse Island indicate the NCEP/NCAR data correctly reflected observed seasonal trends in the study area (Figure 2-2 and Figure 2-3).

The area of interest for this study experiences strong tidal flows over the shallower regions, requiring accurate representation of tidal circulation. In contrast, tidal currents become less important over the deeper offshore regions (>100 - 200 m) and larger-scale drift currents become the dominant current force that would affect slick trajectories. These drift currents can be complex, represented as a series of eddies and connecting streams, and tend to persist longer (days to weeks) than tidal current flows (hours between reversals). Hence, drift currents can have a large influence on the net migration of released oil. Wind shear on the surface waters also generates local-scale drift currents that can persist for extended periods (multiple hours to days) and therefore also have greater influence on net movement than tidal currents over the deeper waters. Recognising that the drift of slicks could be variably affected by combinations of tidal, wind-induced and density-induced drift currents, each of these forces were represented.

Tidal current data for the offshore model region, and extending into Darwin Harbour, 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. The set up and validation of this model is described in Asia-Pacific ASA (2009).

Representation of the drift currents that affect the offshore model region were derived from the output of the Hybrid Coordinate Ocean Model (HYCOM), which is operated by the HYCOM Consortium, sponsored by the Global Ocean Data Assimilation Experiment (GODAE). HYCOM is a data-assimilative ocean model that is run in hind-cast, based on observations of satellite altimeter sea-surface height, sea surface temperature and in-situ temperature and salinity measurements. The HYCOM model data includes forcing due to ocean height, temperature and salinity gradients and wind forcing on the upper ocean, the rotation of the earth and momentum and has been shown to realistically reproduce the mesoscale circulation in the Timor Sea, including eddies and stream currents (Benfer et al. 2011). The HYCOM predictions for drift currents are produced at a spatial resolution of approximately 8.25 km over the region, at a frequency of once per day. An example of the drift currents indicated by the HYCOM data at one point in time (4/6/2008) is provided in Figure 2-4.

Net current (drift and tidal) at each location in the model, at each time step was represented by vector addition of the tidal and drift current estimates, with linear temporal interpolation to an hourly scale and distance-weighted spatial interpolation to the grid scale.

2.2.3 Water temperature and salinity settings

The water temperature would influence the viscosity and weathering rates of any condensate that is released. Following seasonal summaries published by the Department of Defence Directorate of Oceanography and Meteorology (DDDOM; www.metoc.gov.au), 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 parts per thousand [ppt] to 35.0 ppt) within Darwin Harbour throughout the year. Hence, a conservative low salinity within this range (34.0 ppt) was defined.

Offshore, sea surface temperatures vary seasonally within the limits 28°C (winter and spring) to 30°C (summer and autumn), while water salinity is almost constant and close to 35.0 ppt throughout the seasons (WNI 1997). These data were applied to the offshore spill simulations.

2.2.4 Allowances for random dispersion

Material on or within a body will tend to be spread by turbulent forces. To account for dispersive processes that occur below the scale of resolution of the current field, horizontal and vertical dispersion coefficients were applied in the simulations. Horizontal dispersion within Darwin Harbour was specified at 3 $m^2 s^{-1}$ for the surface and 1 $m^2 s^{-1}$ below this level, while vertical dispersion was specified at 1 $cm^2 s^{-1}$. These values are indicative of those reported for estuaries with large tidal exchange (Okubo 1971).

For the open ocean setting, a higher horizontal dispersion rate, 10 $m^2 s^{-1}$, was specified for the surface and with an allowance for 5 $m^2 s^{-1}$ in the upper 10 m and 1 $m^2 s^{-1}$ in deeper layers. Vertical dispersion was specified at 5 $cm^2 s^{-1}$ in the upper mixed layer and 1 $cm^2 s^{-1}$, below this layer. These settings are more typical of offshore locations (Okubo 1971).

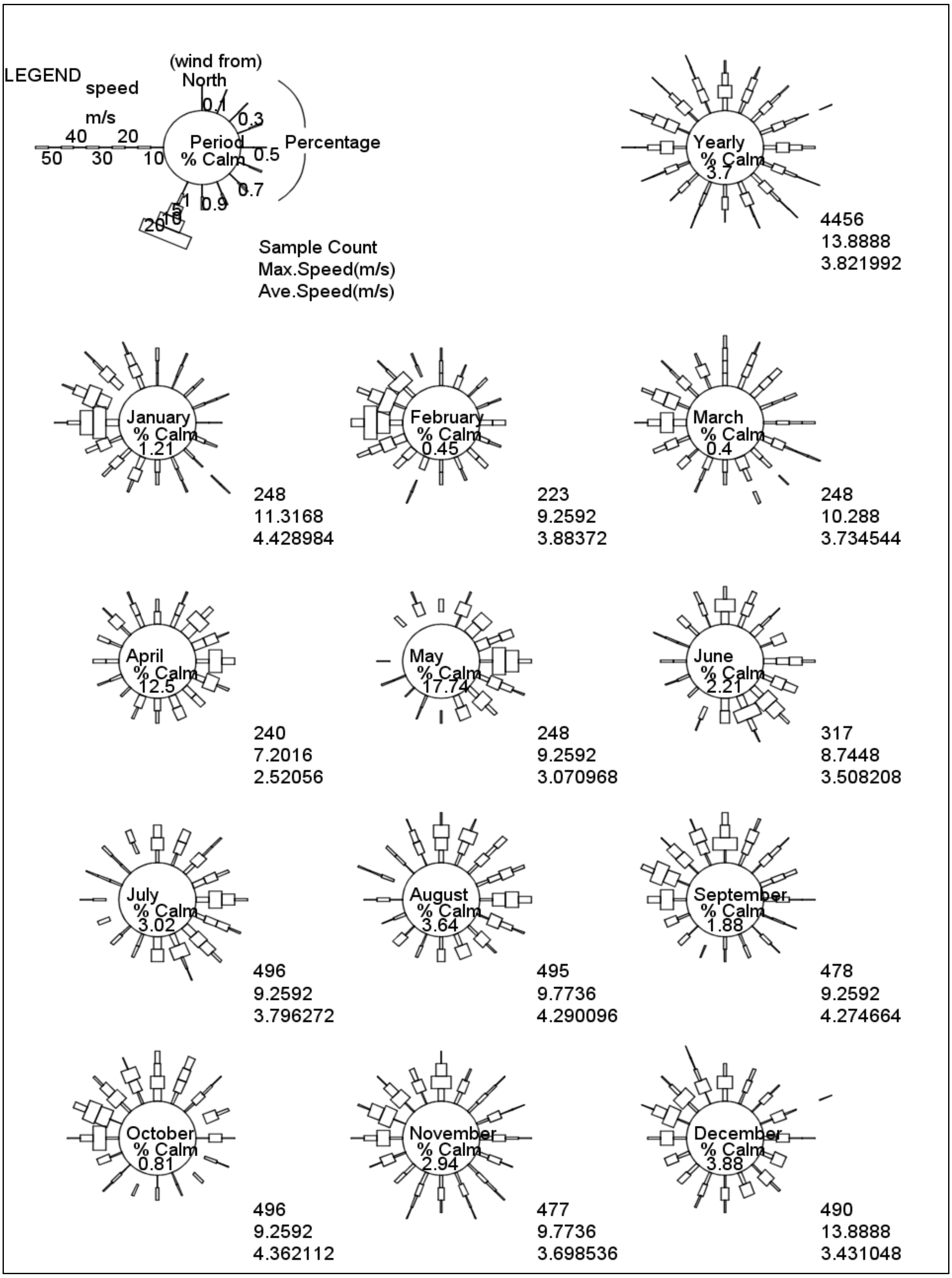


Figure 2-1. Monthly and yearly wind rose diagrams of the winds measured at Darwin Airport (sample data are January to December 2005)

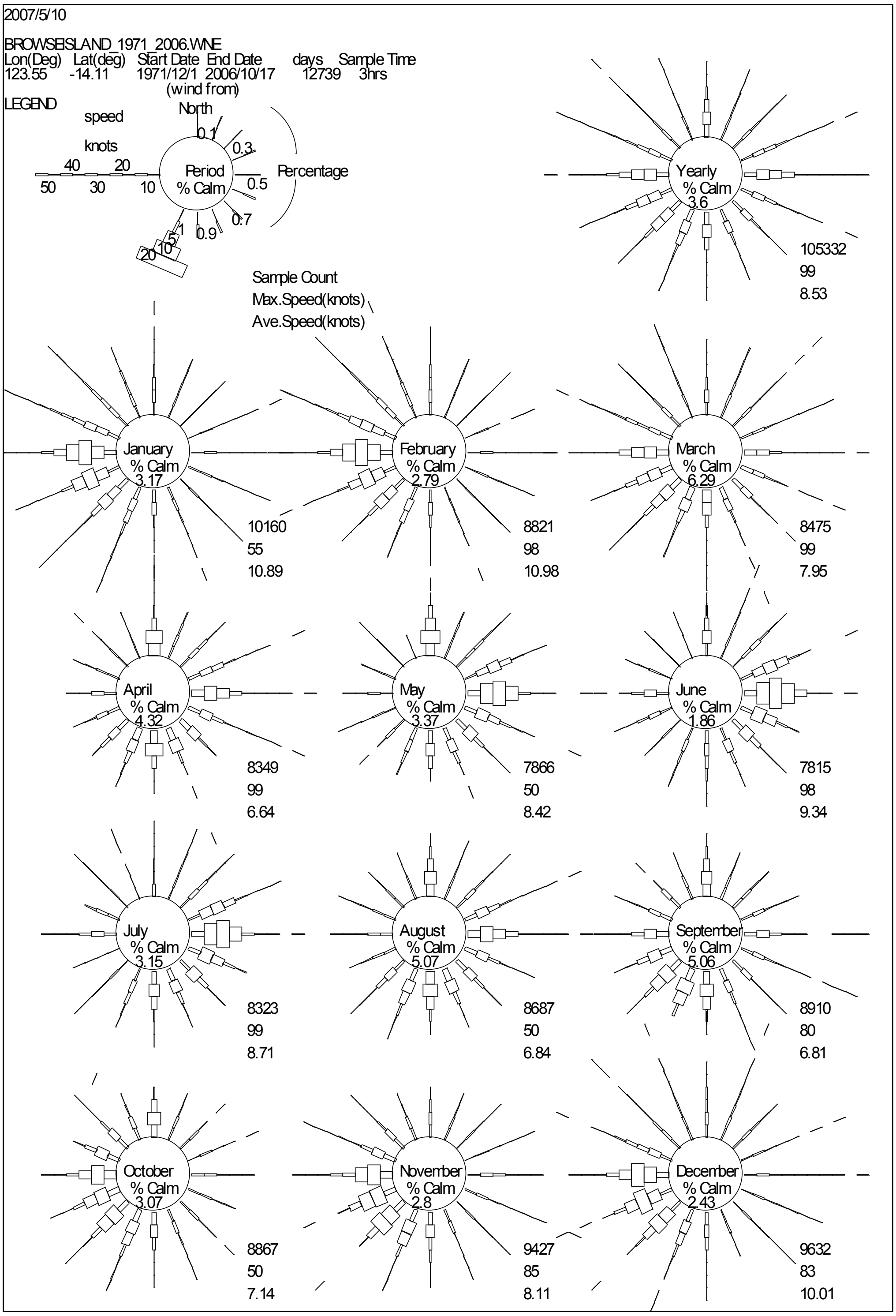


Figure 2-2. Monthly and yearly wind rose diagrams of the winds measured at Browse Island.

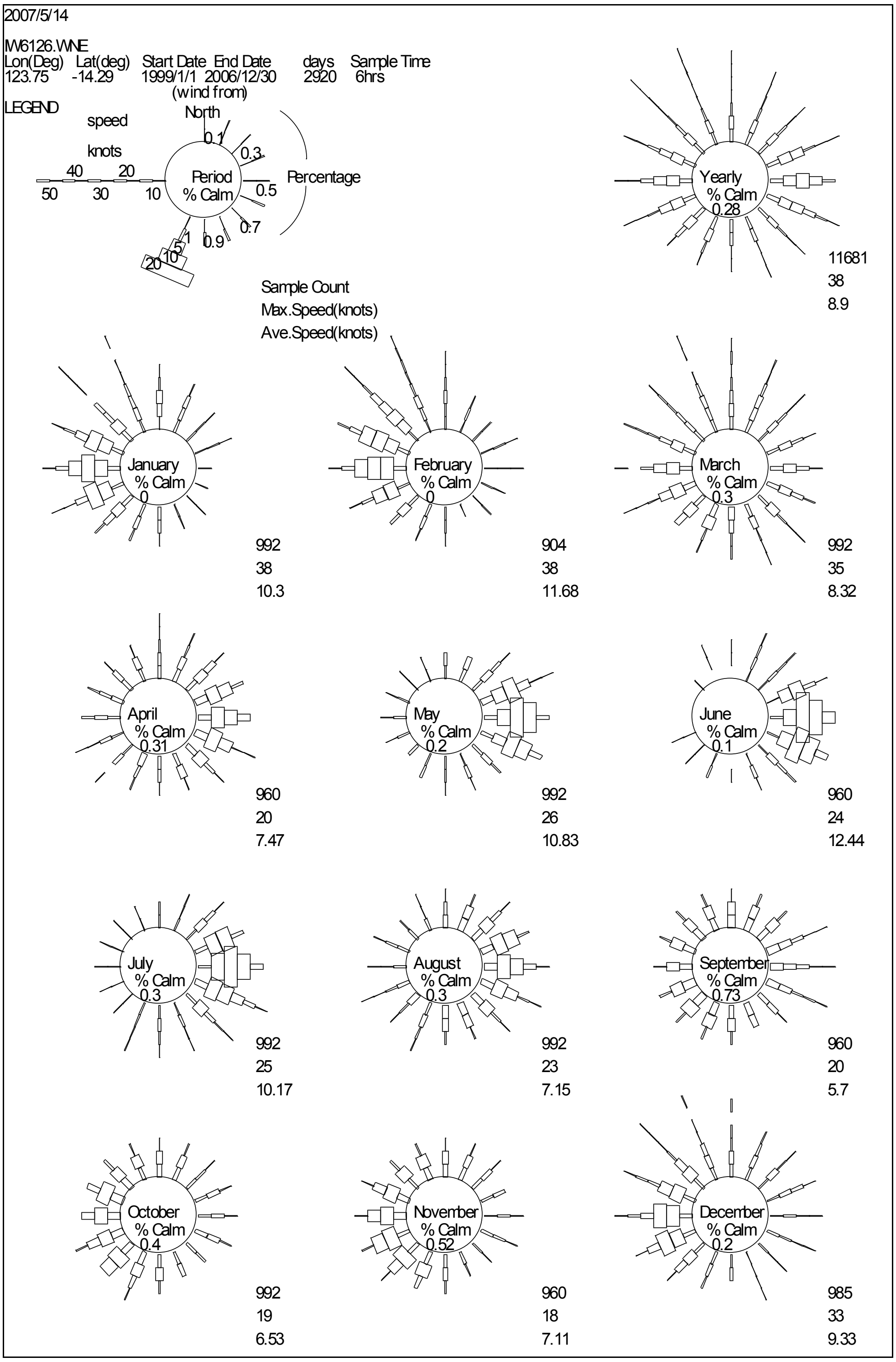


Figure 2-3. Monthly and yearly wind rose diagrams of the winds predicted at Browse Island by NCEP/NCAR model re-analysis.

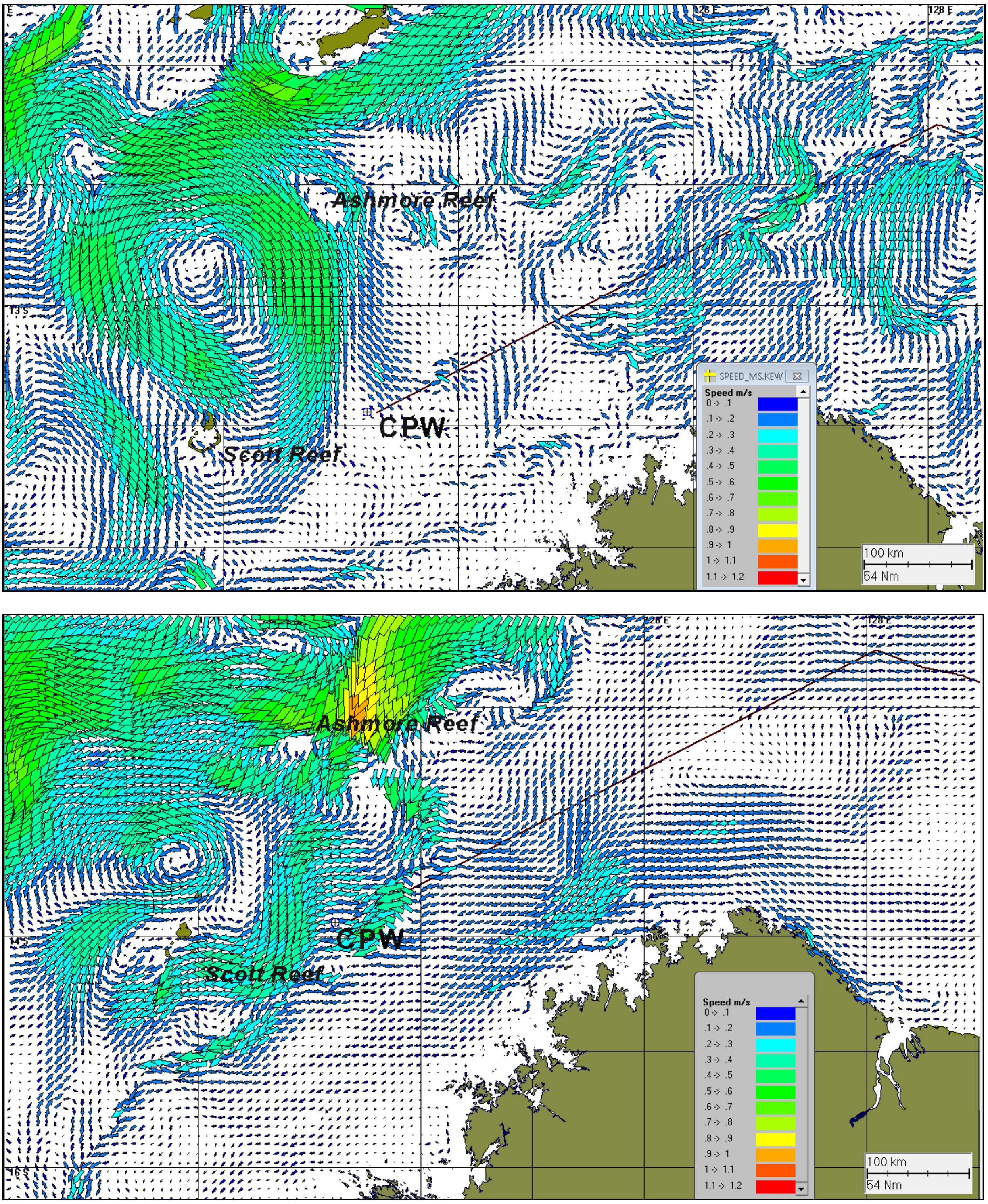


Figure 2-4: Examples of the complex drift currents operating over the offshore waters around the CPW, as indicated by the HYCOM model analysis for two points in time. Upper image is for 13/12/2006. Lower image is for 4/6/2008.

2.2.5 Oil properties and weathering characteristics

The chemical and physical properties of an oil type have a large influence upon the trajectory, spreading and weathering, if spilled into the sea. Characteristics of the condensate that would be released under each scenario were used within the SIMAP spill model to include these considerations. Inputs included the density, viscosity, pour-point, distillation curve (volume of oil distilled off versus temperature) as well as the aromatic/aliphatic component ratios within defined boiling point ranges. This compartmentalisation is used by SIMAP to define rates of evaporation, dissolution and weathering depending upon prevailing conditions, and the effect of these processes on the composition over time. Changes in composition will, in turn, affect rates of further weathering.

As described in APASA (2009, 2009B), INPEX provided independent test specifications for two condensate types for use in the assessment (Corelab 2005, Aspentech 2008). These data indicate that the reservoir will produce a light olive-brown condensate at room temperature, with a low pour point (-10 ºC) relative to sea temperatures that occur in the study area. Hence, the unweathered oil mixture would not be expected to solidify but to flow as a liquid. The condensate would have a relatively low density (744 kg m^{-3} ; API of 58.7) and viscosity (0.75 Centipoise) and a high saturated hydrocarbon content (86.9%), while the aromatic hydrocarbon content would represent 9.6% of the liquid phase (Corelab 2005, Aspentech 2008). Analysis of the aqueous phase within the reservoir indicates low dissolved aromatic hydrocarbons (Aspentech 2008).

Weathering predictions for this reservoir condensate, if spilled at the sea surface, indicates that a high proportion (70-80%) of the condensate is likely to evaporate within the first day of release, leaving a less-volatile residue that will evaporate more slowly and may be subject to entrainment under energetic wave conditions (APASA 2009).

Following preliminary processing at the CPF, the condensate that would be transported with gas in the GEP (downstream condensate) would have marginally lower density (API of 75.7, density of 682.9 kg/m^3) and viscosity (0.296 cP) than the offshore condensate. Specifications for this hydrocarbon type indicate the downstream condensate would be more volatile, with complete evaporation occurring within 12 hours, if spilled at the sea surface.

In the case of a discharge below sea level, condensate would initially be entrained within the water column as a plume of whole oil droplets, which must then rise to the surface for a surface slick to be generated. Atmospheric weathering will not commence until the condensate surfaces. Dissolution of soluble hydrocarbon components into the water column and the much slower process of biological degradation will be the sole weathering processes affecting entrained droplets.

Due to the high gas pressure that would be present in the GEP and the well, it was calculated, using a blowout simulation, that condensate would be released as a range of droplet sizes of a relatively small size (< 200 µm) and that, following an initial phase of rapid rise due to entrainment with the rising gas, the smaller droplets will rise slower than the larger droplets, due to greater effect of turbulent mixing on the smaller droplets. Release of this condensate from the depth of the seabed at the GEP pipeline approaching the near-shore crossing (< 10 m) is likely to result in relatively rapid surfacing (seconds to minutes) for the larger droplets so that there would be only a minor delay in weathering of this component. However, the smallest droplets may be displaced to rise more slowly (multiple hours; Figure 2-5).

In contrast, release at the depth of the CPW location (~260 m below MSL) with a relatively small droplet size is likely to result in a marked extension of the weathering time because the smaller droplets would rise over periods of 10s of hours to days, delaying atmospheric weathering of this component and increasing the spread of the condensate due to prevailing water currents. A significant proportion of the volume (~ 40%) could also be trapped in the water column for an extended time (weeks) as small entrained droplets due to turbulence and density layers in the water column and these droplets would drift and disperse widely with prevailing water currents.

Simulations of ongoing releases, at a constant rate, from the CPW depth indicates that evaporation rates for the Ichthys condensate will be marginally slower than the supply rate of new condensate at the sea surface but will fluctuate with prevailing conditions – evaporation being highest under hot conditions with a light breeze that provides some agitation of the slick and entrainment being highest under wind conditions that generate breaking waves. Predicted outcomes under two example sets of varying wind and current conditions (both at 25 ºC) are illustrated in Figure 2-6.

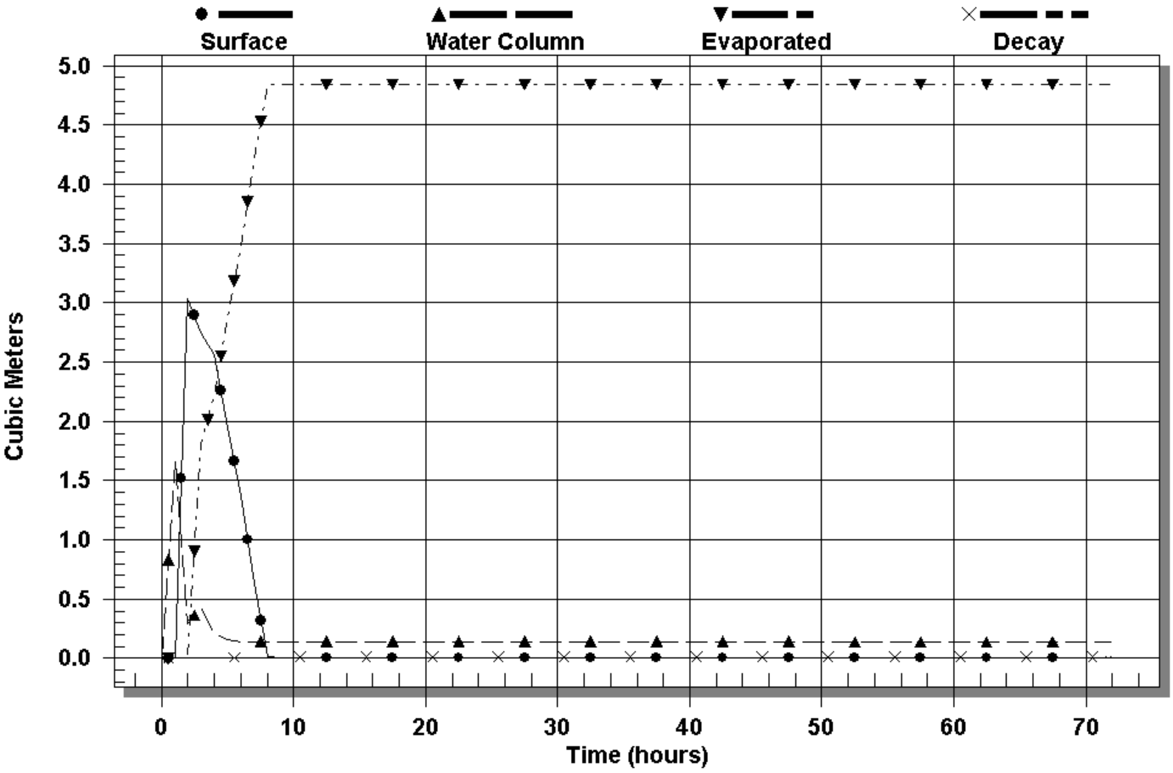


Figure 2-5: Weathering and fates graphs (by volume) for the downstream condensate, given a short-term (3 hours) sub-surface release at the depth of the GEP approaching the near-shore crossing (9 m).

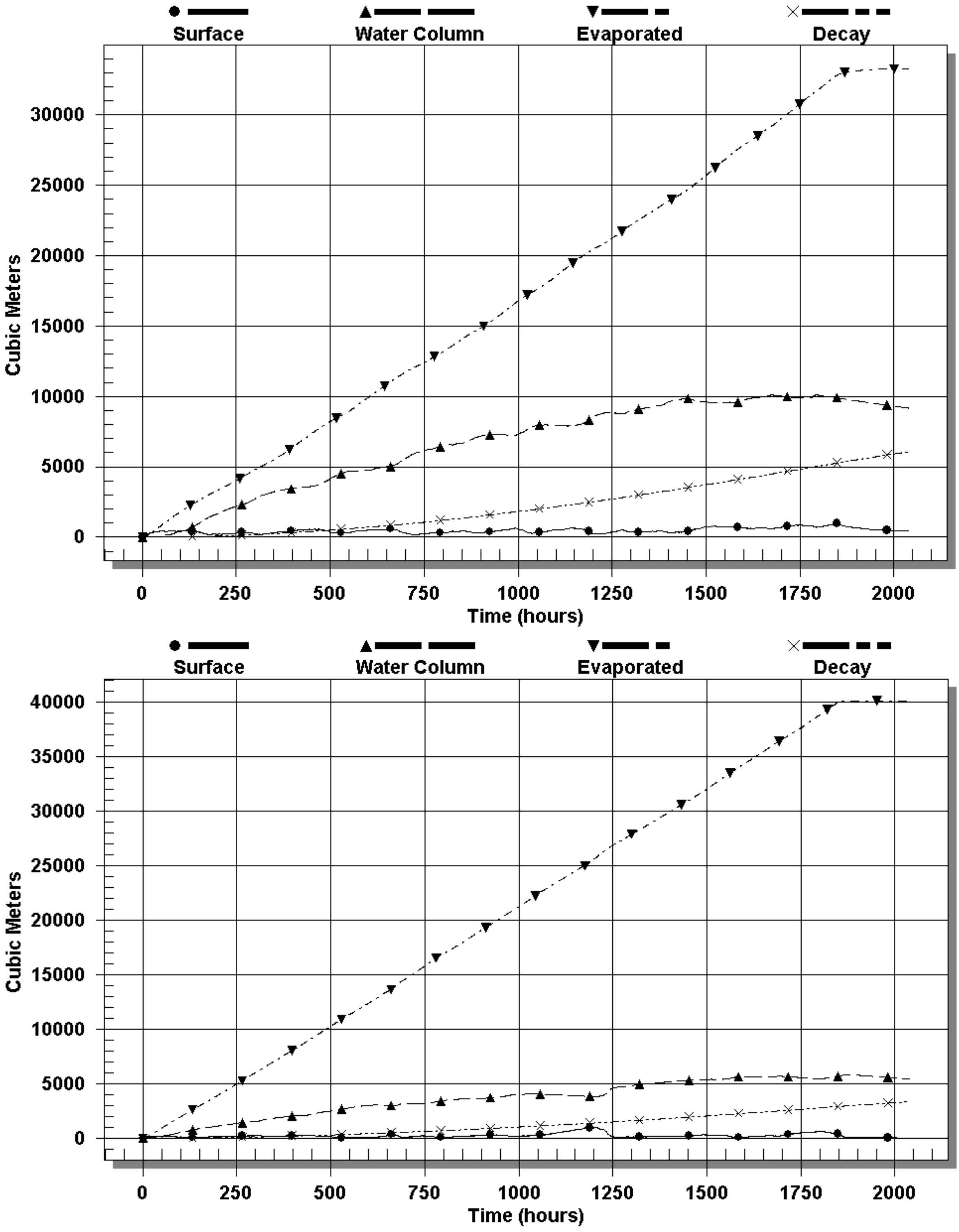


Figure 2-6: Weathering and fates graphs (by volume) for the reservoir condensate, given a continuous (77-day) sub-surface release at the depth of the WEL (256 m) under two different samples of wind and current data (both at 25 ºC surface water temperature). The upper panel is from a simulation with windier conditions.

2.3 Scenario settings

2.3.1 Scenario 7B – Rupture of the GEP within 1 km from the near-shore crossing

Simulations were set to represent the constant release of downstream condensate at a rate of 16.6 m^3 hr^{-1} for 3 hours (50 m^3 total) from seabed level (9 m below MSL). Because the condensate would be released with gas, it was assumed that the release would be highly turbulent and the condensate would be atomised into droplets of small size. Following suggestions by Delvigne and Sweeney (1988) for a turbulent release, the size distribution was capped at 200 µm. A total of 100 simulations were run for each season for this scenario, with each simulation run for 7 days.

2.3.2 Scenario 7C – Rupture of the GEP approaching Darwin Harbour

This scenario used settings that were identical to Scenario 7B, with the exception of the release location and depth.

This scenario principally focussed upon risks of oil contact to Great Sand Island, which lies approximately 30 km to the south-west of the proposed GEP route approaching Darwin Harbour, and because risks to this Island would vary with the release point along the GEP route, the first step for this scenario was to identify release locations along the GEP route that would present the highest risk for Bare Sand Island. Locations were identified by undertaking a reverse trajectory analysis. This involved repeated simulation of particle transport from Bare Sand Island in reverse (i.e. by applying randomly selected samples of current and wind data in reverse order) to identify locations where floating material, such as oil slicks, that arrive at this site are most likely to arrive from. The overlap of the model predictions with the GEP route was used to define the highest risk locations along this route.

Having identified candidate sites, forward stochastic simulations were undertaken for a release at the depth of this site, following the scenario specifications for Scenario 7B, and applying full weathering allowances.

2.3.3 Scenario 12 – Long term (11 week) Blowout at the CPW location.

Simulations were set to represent the constant release of reservoir condensate at a rate of 4,000 bbl d^{-1} (26.5 m^3 hr^{-1}) over 77 days, totalling 308,000 bbl (48,972 m^3) over the release duration. The release was specified to occur from the seabed depth (~256 m) as droplets with a range of sizes. Because the condensate would be released with gas, the size distribution was limited to 200 µm, following published measurements for releases under turbulent conditions (Delvigne & Sweeney, 1988). Each simulation was tracked for an additional 8 days after discharge ceased (85 days of simulation in total) to account for the fate of condensate remaining at the end of the release. Horizontal dispersion rates were specified at 10 m^2 s^{-1} to account for dispersive processes acting below the scale of resolution of the input current field, based on typical values for open waters (Okubo 1971). Due to much longer simulations, which will each sample a larger range of conditions, 20 replicate simulations were completed for each season for this scenario.

Table 2: Summary of the scenario settings

No.	Scenario	Depth (m)	Spilled Fluid	Total Volume (m3)	Release Duration	Simulation Period
7B	Near-shore GEP rupture	9	Downsteam Condensate**	50	3 hours	7 days
7C	GEP rupture approaching Darwin Harbour	21-38	Downstream Condensate**	50	3 hours	7 days
12	11 week Blowout at the CPW location	256	Reservoir* Condensate*	48,972	77 days	85 days

Notes:

** Condensate characteristics assumed for reservoir samples, prior to processing.*

*** Condensate characteristics assumed for condensate after partial processing at the CPF.*

2.4 Thresholds of contact

SIMAP will track oil concentrations to lower than those likely to be ecologically significant. Hence, threshold concentrations are specified to define instances of contact with a particular location.

Following APASA (2009, 2009B), surface contact was registered for contact by slicks at a conservatively low minimum concentration of 1 g m^{-2}, equivalent to a thickness of approximately 0.001 mm (1 μm). An oil film of this concentration is likely to appear as a dull rainbow sheen or yellowish film (NOAA HAZMAT 1996). The threshold for shoreline exposure was also similarly set to a concentration of 1 g m^{-2}, with the model allowing for these concentrations to accumulate from surface concentrations <1 g m^{-2}. This thickness of oil on shorelines is considered conservative as it is below the concentration where physical collection would normally be practical and, at ~1 μm thickness, is unlikely to cause smothering. The analysis also estimated the potential concentrations of entrained condensate and dissolved (aromatic) hydrocarbon compounds that could be generated over shallow near-shore habitats.

3 RESULTS

3.1 Scenario 7B: Near-shore rupture of the gas export pipeline

This scenario considered the potential impacts from a rupture of the GEP at a subtidal location within 1 km of the shore crossing onto Wickham Point. Condensate surfacing from the release depth to form a surface slick is predicted to most likely to drift over a reciprocating path over time with the strong local tidal flow, which flows north-west on the ebb and south east on the flood. Therefore, the resulting slick with concentration > 1 g m^{-2} is likely to mostly affect waters between Channel Island and Wickham Point, with most of the surfaced condensate evaporating over 1-2 tidal cycles, but adjacent shorelines could be affected by condensate that spreads away from the tidal axis over this time due to dispersion and wind-induced drift. Consequently, risks to shorelines were predicted to vary seasonally.

The simulations indicated that condensate could accumulate on shorelines or fringing mangroves throughout East Arm and Main Arm at > 1 g m^{-2}. It should be noted that this distribution exceeds the distribution for surface slicks at > 1 g m^{-2} due to the prediction that thinner sheens could accumulate on these more distant shorelines to > 1 g m^{-2}. The probability of contact by some part of the shoreline by surface-bound condensate at concentrations > 1 g m^{-2} was quantified at 100% during all seasons, with shoreline exposure likely to occur in under 2 hours in any season. The highest proportion of the total release that was predicted to strand on shoreline habitats in any simulation was relatively low (1.2% or 0.6 m^3).

The shoreline south of the shoreline crossing and the northern end of Channel Island were indicated to have the highest probability of contact at > 1 g m^{-2}. For a rupture in Autumn or summer, when the wind is most frequently from the western sector, the risk of accumulation on this section of shorelines > 1 g m^{-2} was calculated at 87% and 44%, respectively. Due to entrained condensate generated during the release and subsequent mixing of condensate by near-shore waves, estimates of entrained condensate at up to 400 ppb where indicated along shorelines in the simulations.

Table 3: Scenario 7B: Probability of shoreline oil exposure

Season	Number of cases impacting shorelines (%)	Maximum probability of shoreline exposure at a single location (%)	Highest % of release on shore (%)	Minimum time to shore (hours)	Maximum length of oiled shoreline (km)
Summer	100	44	1.2	2.0	12.6
Autumn	100	37	0.6	2.0	18.5
Winter	100	37	0.5	2.0	1.9
Spring	100	87	0.3	2.0	28.7

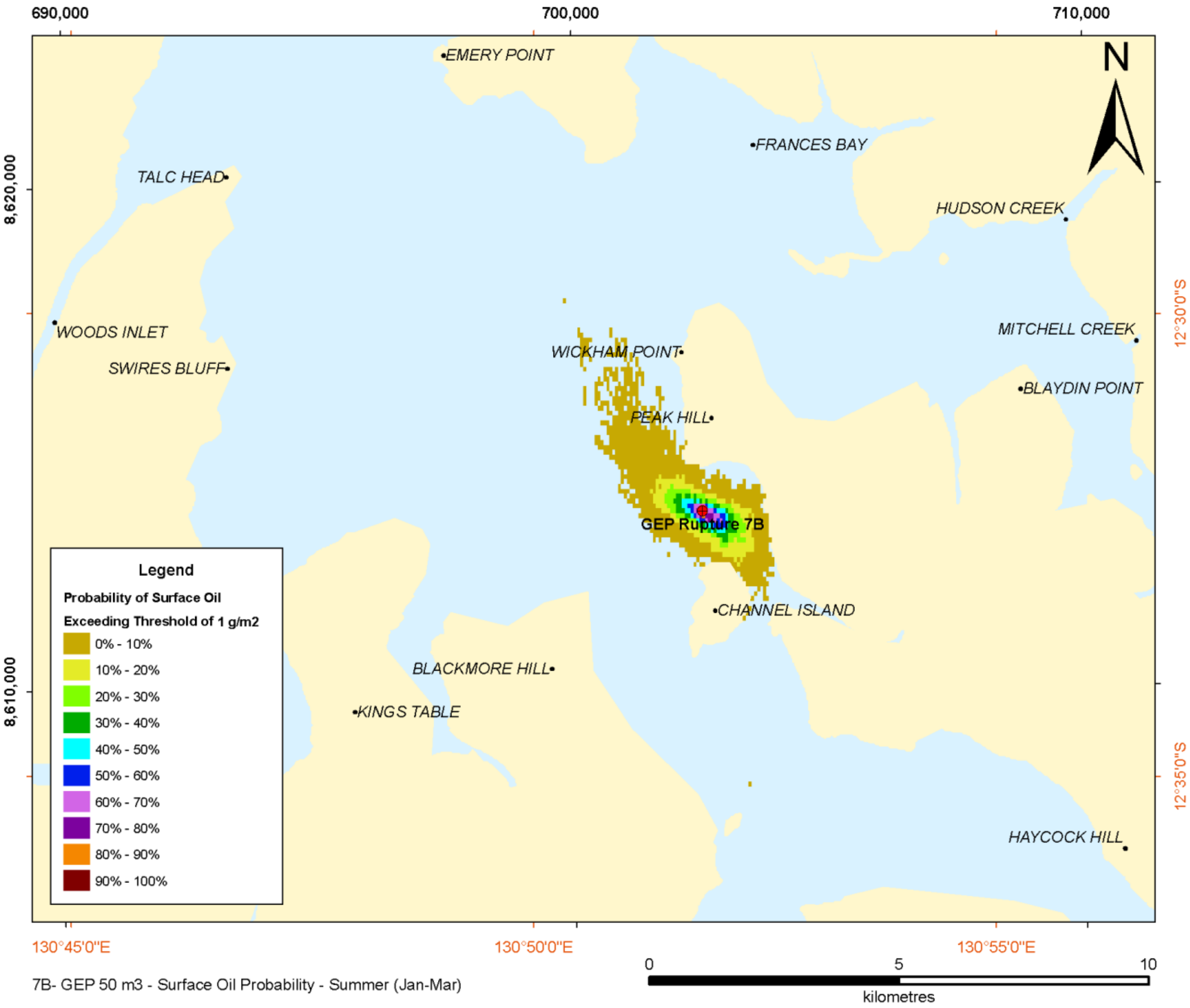


Figure 3-1. Scenario 7B: Predicted probability of oil exposure to the water surface > 1 g m^{-2} (1 µm) under summer conditions (Jan-Mar).

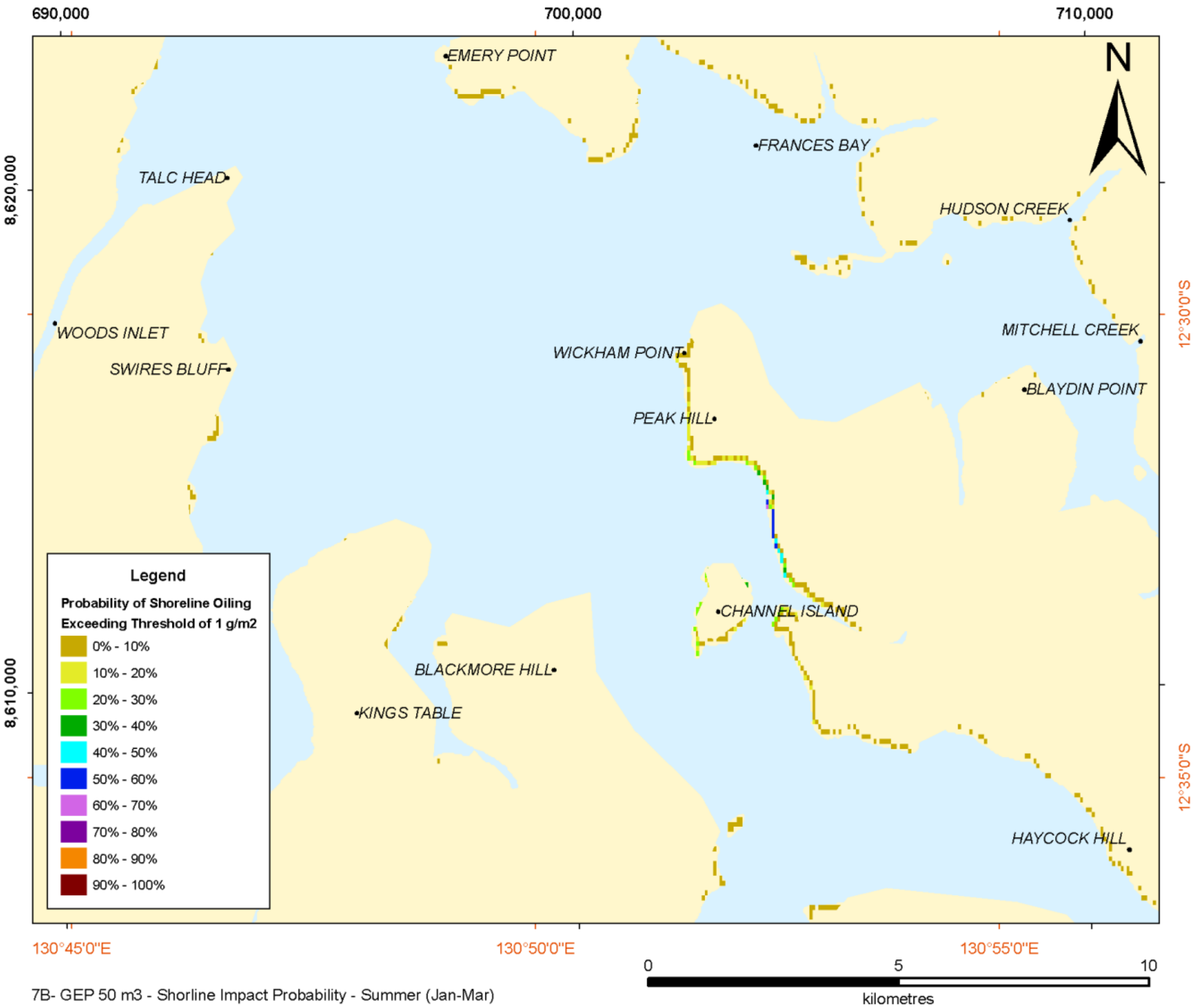


Figure 3-2. Scenario 7B: Predicted probability of shoreline exposure > 1 g m^{-2} (1 µm) under summer conditions (Jan-Mar).

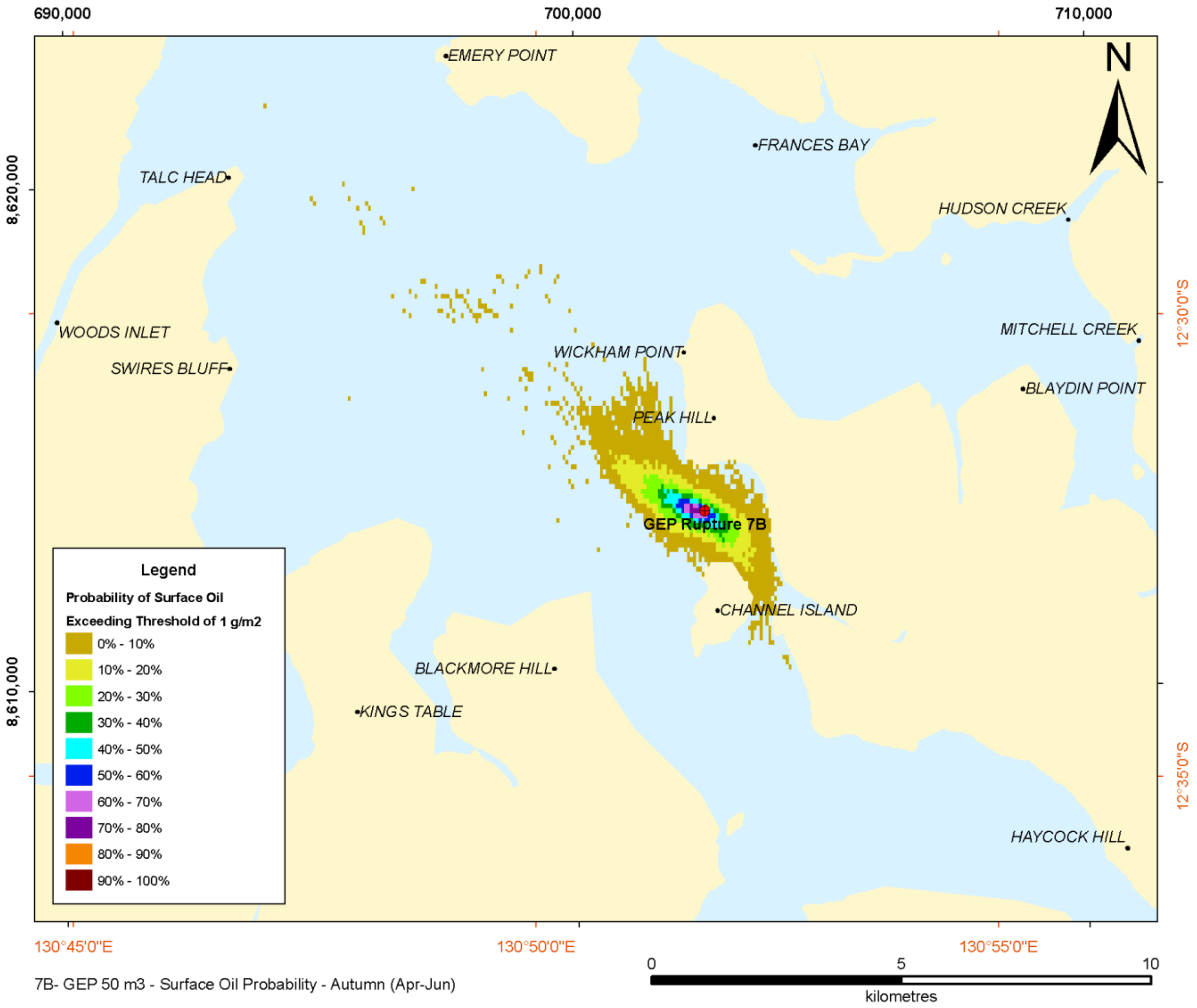
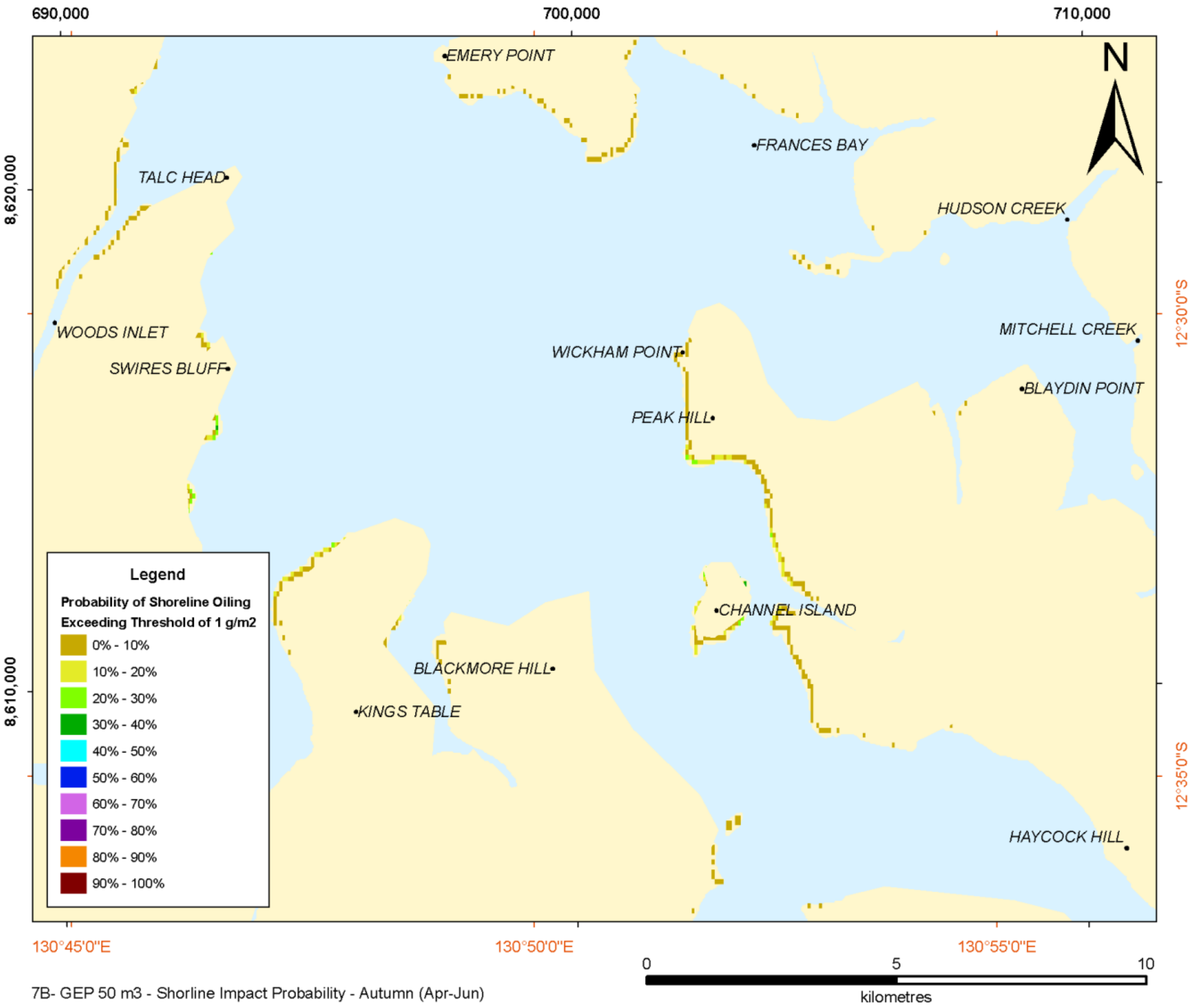


Figure 3-3. Scenario 7B: Predicted probability of oil exposure to the water surface > 1 g m^{-2} (1 µm) under autumn conditions (Apr-Jun).



7B- GEP 50 m3 - Shorline Impact Probability - Autumn (Apr-Jun)

Figure 3-4. Scenario 7B: Predicted probability of shoreline exposure > 1 g m^{-2} (1 µm) under autumn conditions (Apr-Jun).

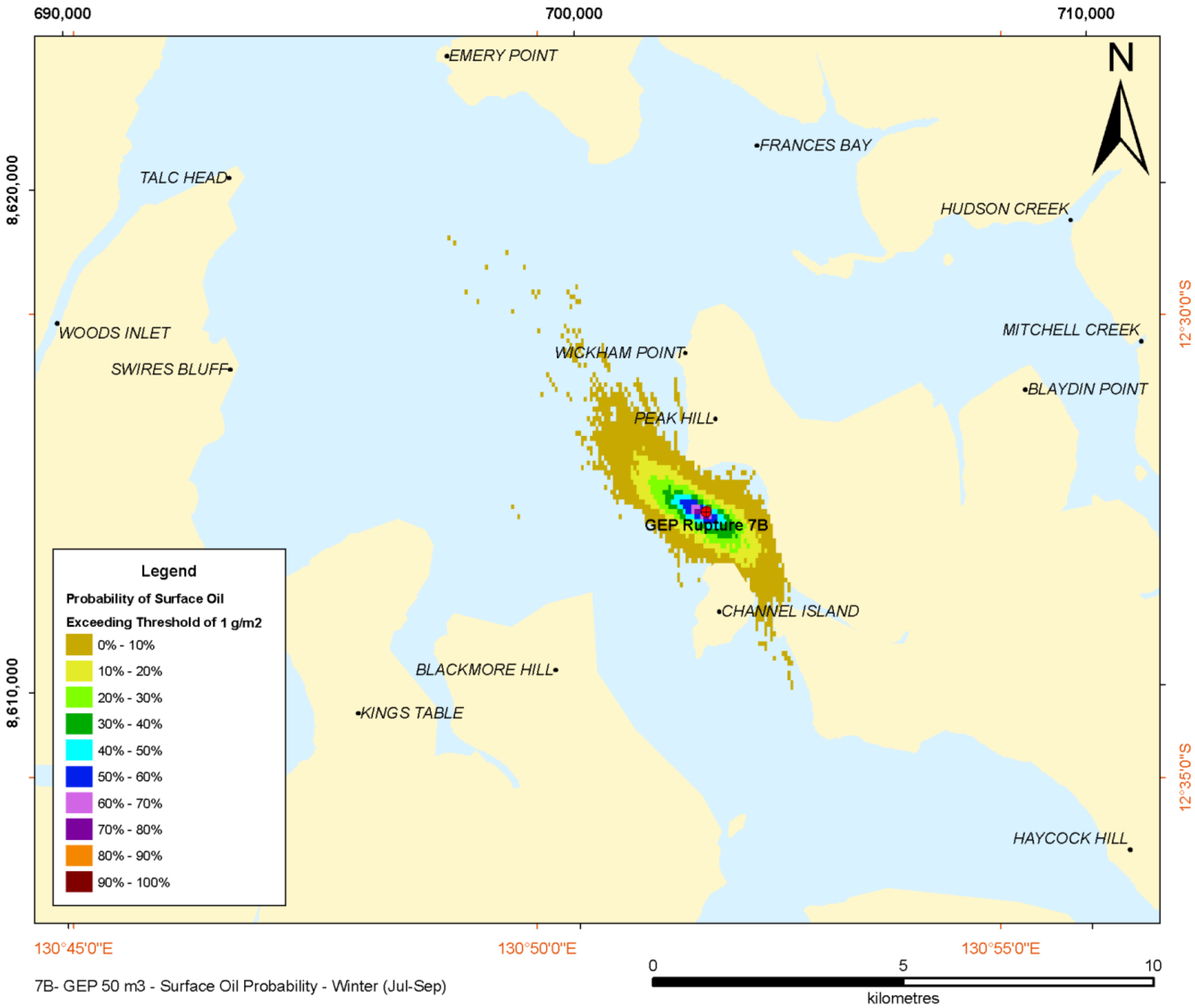


Figure 3-5. Scenario 7B: Predicted probability of oil exposure to the water surface > 1 g m^{-2} (1 μm) under winter conditions (Jul-Sep).

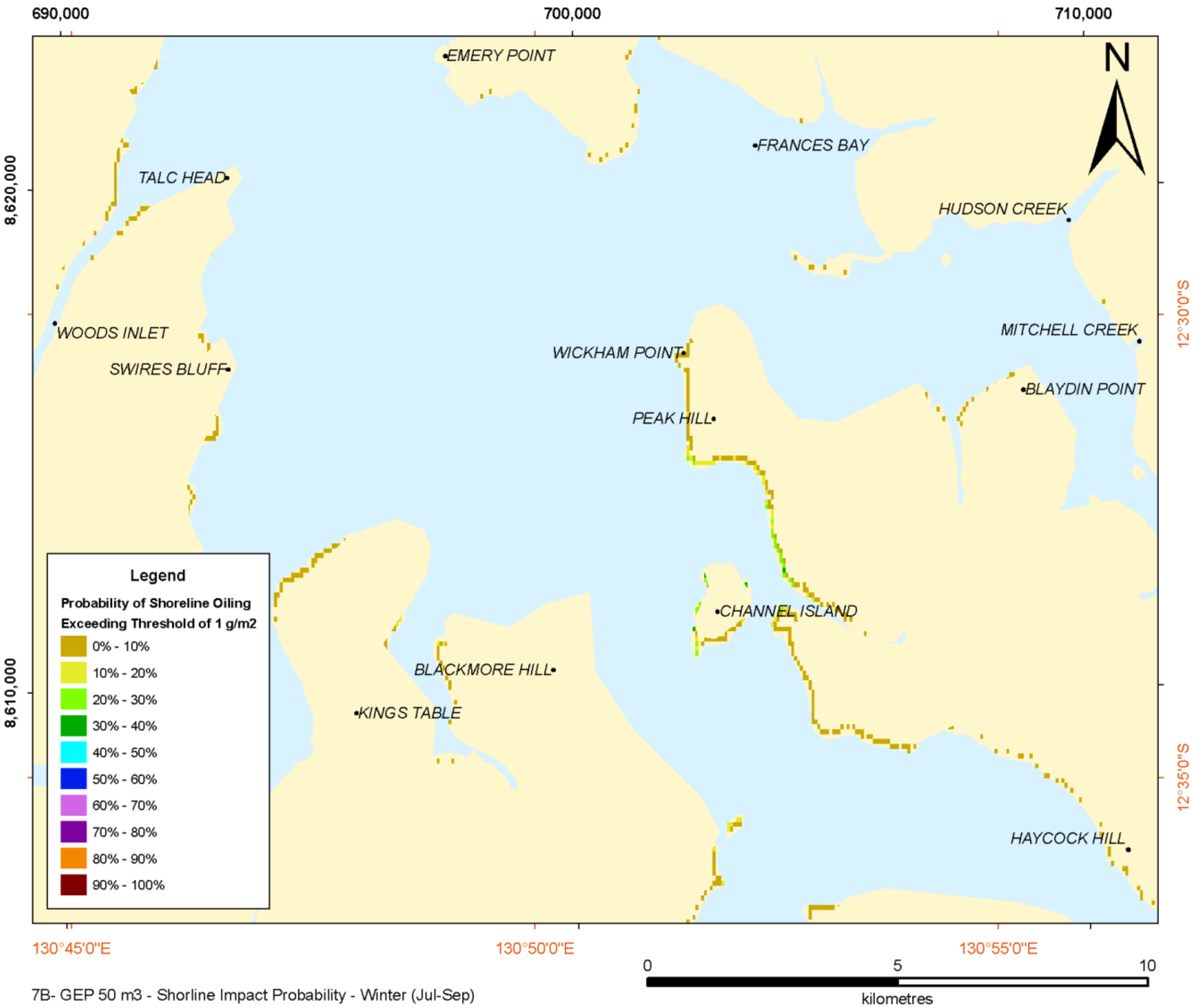


Figure 3-6. Scenario 7B: Predicted probability of shoreline exposure > 1 g m^{-2} (1 µm) under winter conditions (Jul-Sep).

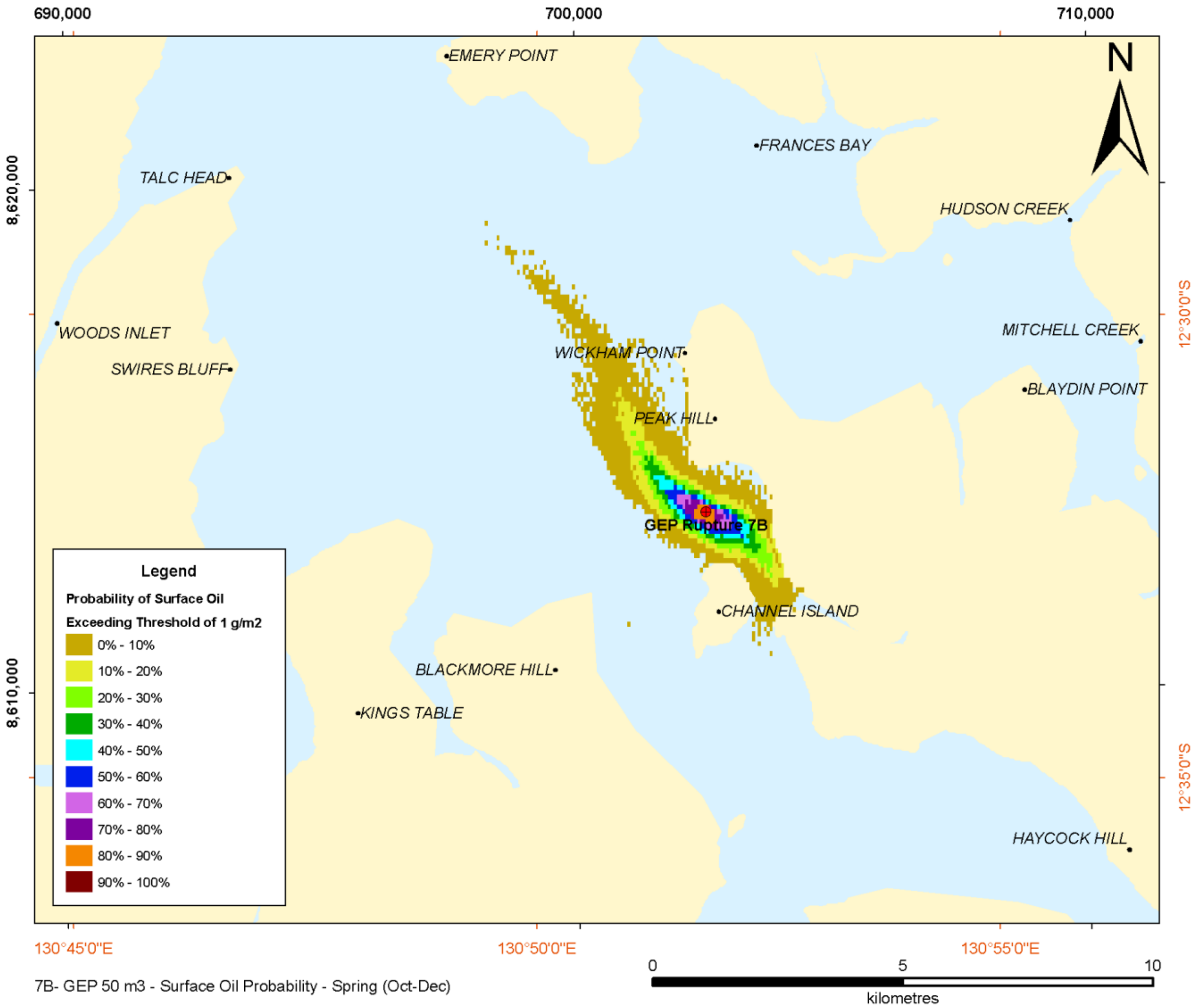


Figure 3-7. Scenario 7B: Predicted probability of oil exposure to the water surface > 1 g m^{-2} (1 µm) under spring conditions (Oct-Dec).

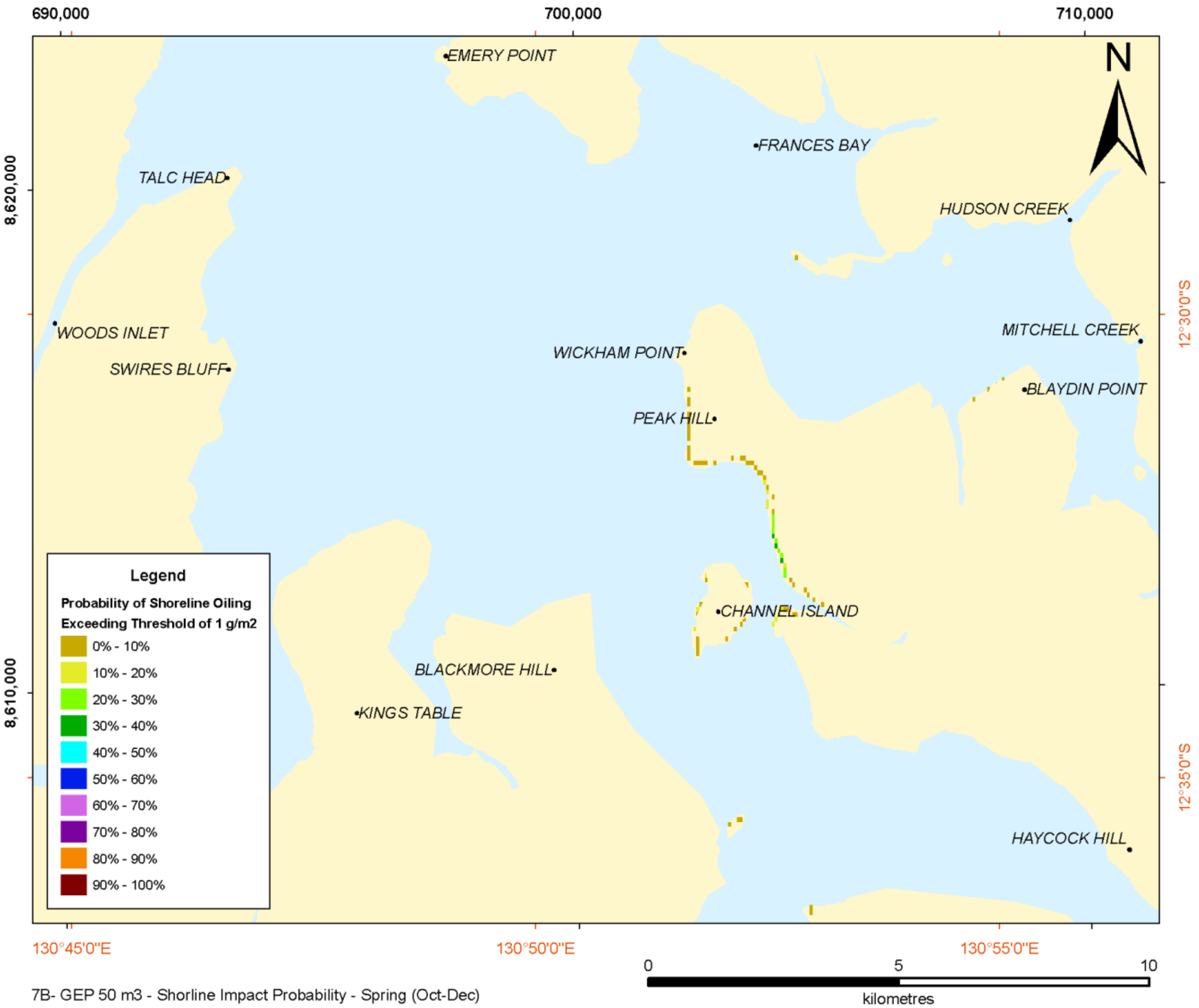


Figure 3-8. Scenario 7B: Predicted probability of shoreline exposure > 1 g m^{-2} (1 µm) under spring conditions (Oct-Dec).

3.2 Scenario 7C: Rupture of the GEP approaching Darwin Harbour

This scenario considered the potential outcome of a rupture of the GEP, releasing condensate from the seabed at locations northwest of Darwin Harbour. Consistent with Scenario 7B, a total volume of 50 m^3 is expected to release over a 3-hour period from the depth of the pipeline at the release point.

The initial analysis involved reverse trajectory modelling to determine the highest risk locations along the pipeline for a release of condensate, with respect to the potential for condensate to contact Bare Sand Island due to the significance of this island as a turtle nursery. The reverse trajectory modelling used floating particles only (representing surface-bound condensate) and particles were treated as non-weathering – hence were conserved for the duration of the simulation. Trajectories were traced backwards for 14 days, on the basis that this would be a conservative overestimate of the persistence of surfaced condensate.

Results of the reverse trajectory modelling are summarised as contour plots indicating the probability that a given location could be the source of floating material that contacts Bare Sand Island (Figure 3-9 -Figure 3-12). The contour plots indicate a relatively low risk (< 10%) that the GEP pipeline route would be a source location for conservative (i.e. non-weathering) floating material arriving at Bare Sand Island during any season, with the most likely source location being to the west or south-west during summer and transitional seasons and to the north-east during winter. Accounting for the weathering rate of the surfaced condensate, which would require a site within a few days drift time from Bare Sand Island, the analysis indicated that a section approximately 50 km north-west of Bare Sand Island was likely to present the highest risk to this island during summer and the transitional months but a higher risk site during winter would be toward the north-east of Bare Sand Island, and east of Cox Peninsula, if slicks rounded Cox Peninsula and track south-west. Locations chosen to investigate with forward trajectory and weathering analysis from the reverse trajectory modelling are listed in Table 4.

Table 4: Locations of sites chosen by reverse trajectory modelling to assess risks to Bare Sand Island from a 50 m3 release from the GEP pipeline.

Season	Longitude	Latitude	Water depth (m)
Summer	128°42′ 10″E	12°25′ 0.6″S	38
Transitional	128°42′ 10″E	12°25′ 0.6″S	38
Winter	130°42′ 32.4″E	12°22′ 1.2″S	21

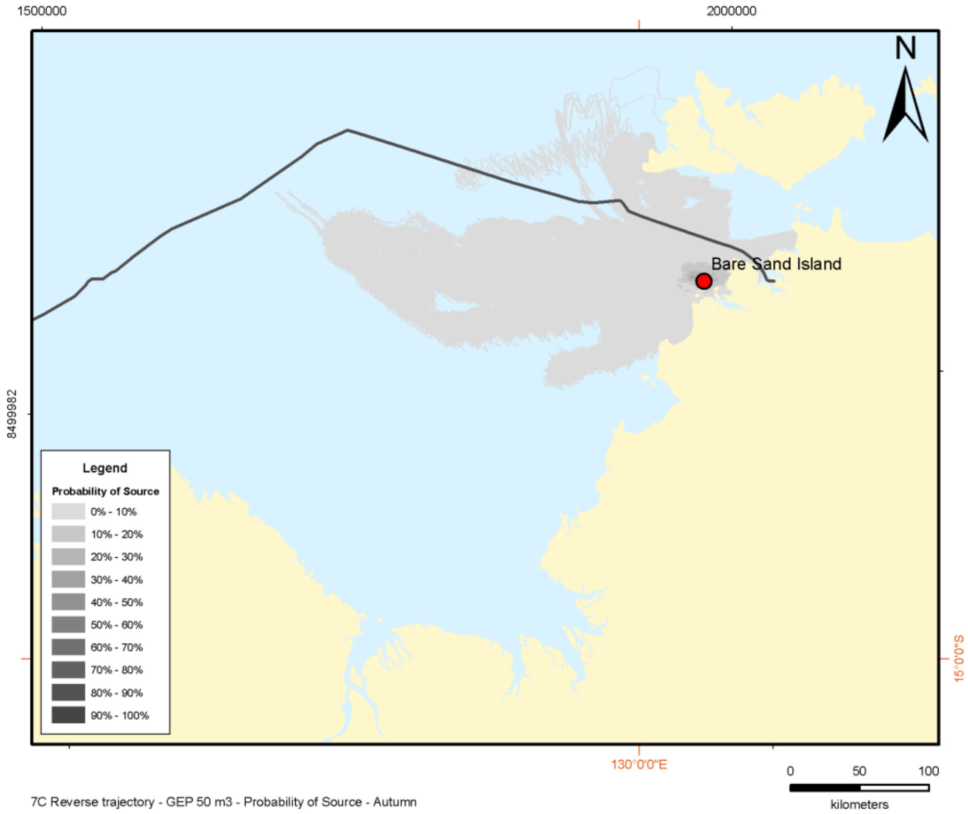
The forward stochastic modelling was undertaken from these identified sites to assess the likely trajectory and weathering for a seabed release, accounting for release as small droplets and all subsequent weathering processes.

Results of the forward stochastic modelling for a summer release indicated a very low risk that condensate would migrate onto Bare Sand Island from Site 1 at > 1 g m^{-2} (Figure 3-13) or even as barely visible sheen >0.015 g m^{-2}, because slicks are highly likely to migrate toward the east or east-north-east during this season, and not migrate southward toward this island, or else disperse to below these thresholds before reaching the island. Similar findings were indicated for the transitional seasons, where slicks are more likely to drift toward the north-east (Figure 3-14).

Results for the winter simulation also indicated a very low risk that condensate would wash onto Bare Sand Island, or other shorelines, from the site identified as the highest risk along the GEP route in this season (Site 2; Figure 3-15), before evaporating and dispersing. The trajectories of slicks were predicted to be mostly westward and, due to the high evaporation rate of the condensate, slicks were not indicated to persist at concentrations > 1 g m^{-2} before rounding Cox Peninsula. Considering barely visible sheens, risks are also indicated to be low because the migration path after rounding Cox Peninsula will tend to continue westerly.

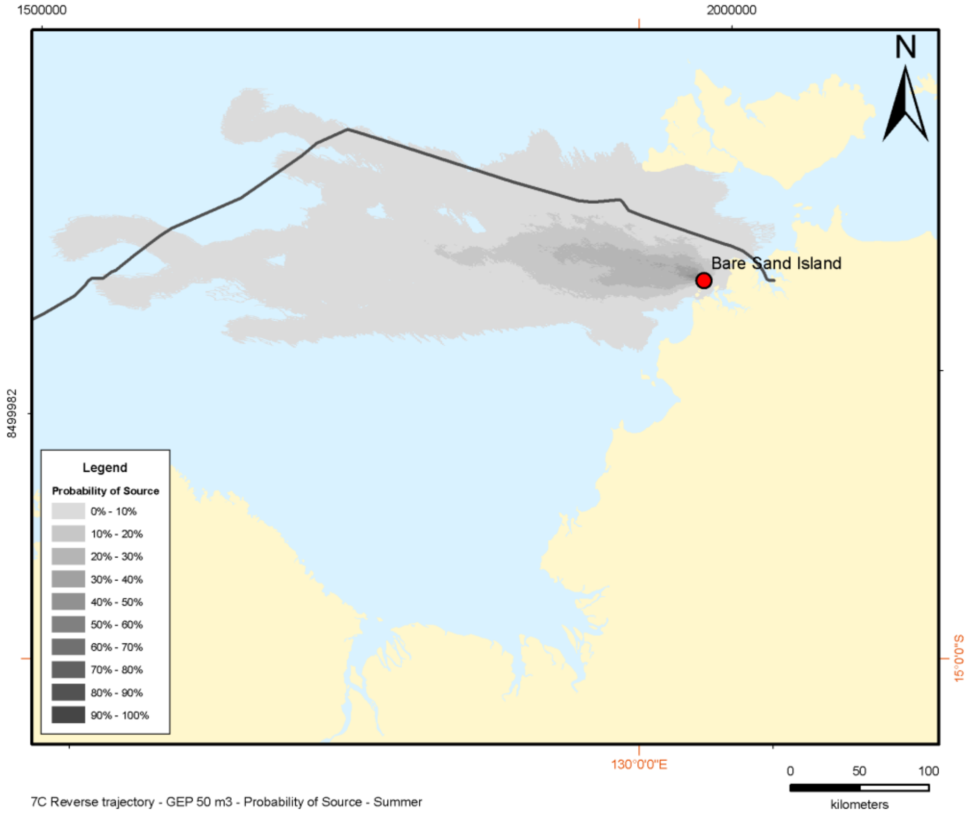
Assessment of the fate of entrained condensate indicated low risk (<1%) that entrained condensate > 1 ppb would reach Bare Sand Island from the two identified locations, during any season. This result is attributed to the current patterns in the area, which would tend to divert entrained material away from this location, and the distance separating the Island from the pipeline, allowing for dispersal to occur in the case that rarer current patterns occurred.

The combined results indicate low risk to Bare Sand Island from the two hypothesised release points. However, a low probability (< 10%) of shoreline contact > 1 g m^{-2}, and of entrained condensate > 10 ppb, was indicated for the eastern and western headlands of Darwin Harbour for a rupture at Site 2 (Figure 3-16).



7C Reverse trajectory - GEP 50 m3 - Probability of Source - Autumn

Figure 3-9. Scenario 7C Reverse Trajectory: Predicted likelihood of locations being a source of oil arriving at Bare Sand Island under spring or autumn transitional conditions.



7C Reverse trajectory - GEP 50 m3 - Probability of Source - Summer

Figure 3-10. Scenario 7C Reverse Trajectory: Predicted likelihood of locations being a source of oil arriving at Bare Sand Island under summer conditions.

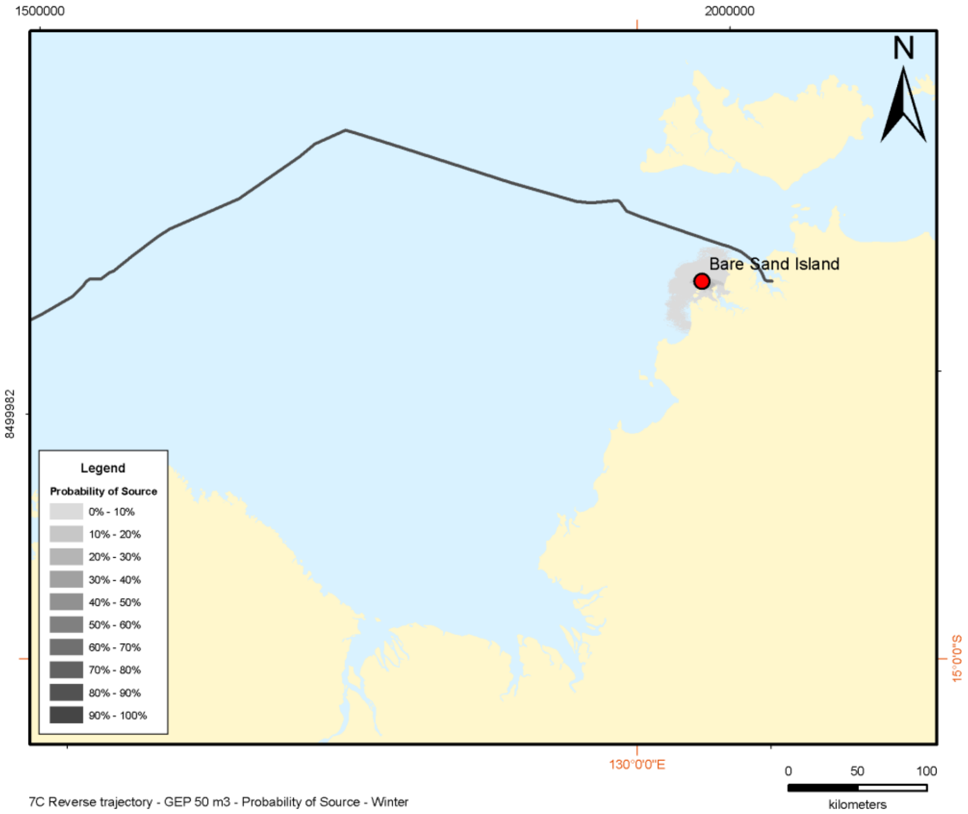


Figure 3-11. Scenario 7C Reverse Trajectory: Predicted likelihood of locations being a source of oil arriving at Bare Sand Island under winter conditions.

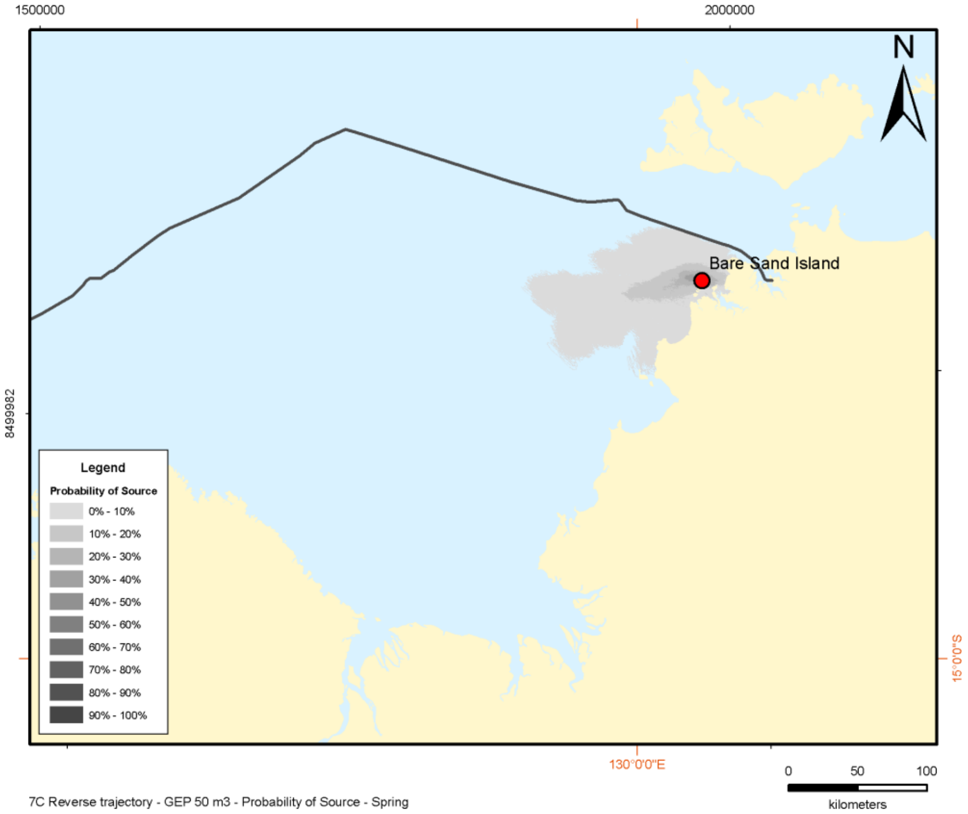


Figure 3-12. Scenario 7C Reverse Trajectory: Predicted likelihood of locations being a source of oil arriving at Bare Sand Island under spring conditions.

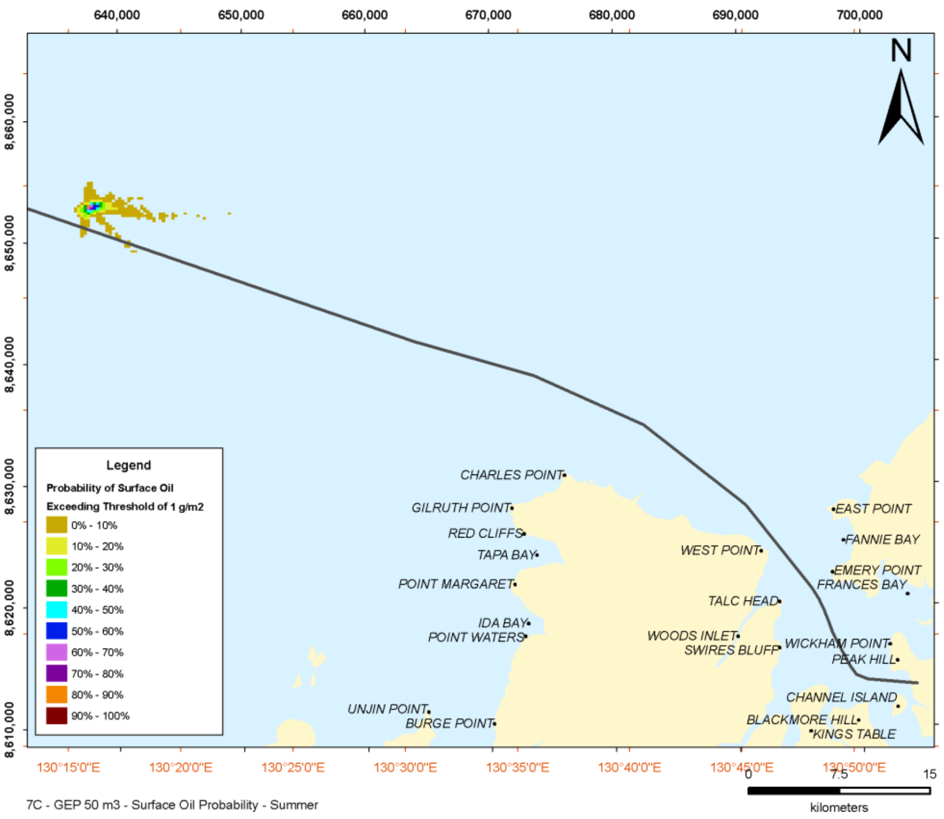


Figure 3-13. Scenario 7C: Predicted probability of oil exposure to the water surface > 1 g m^{-2} (1 µm) under summer conditions for a GEP rupture.

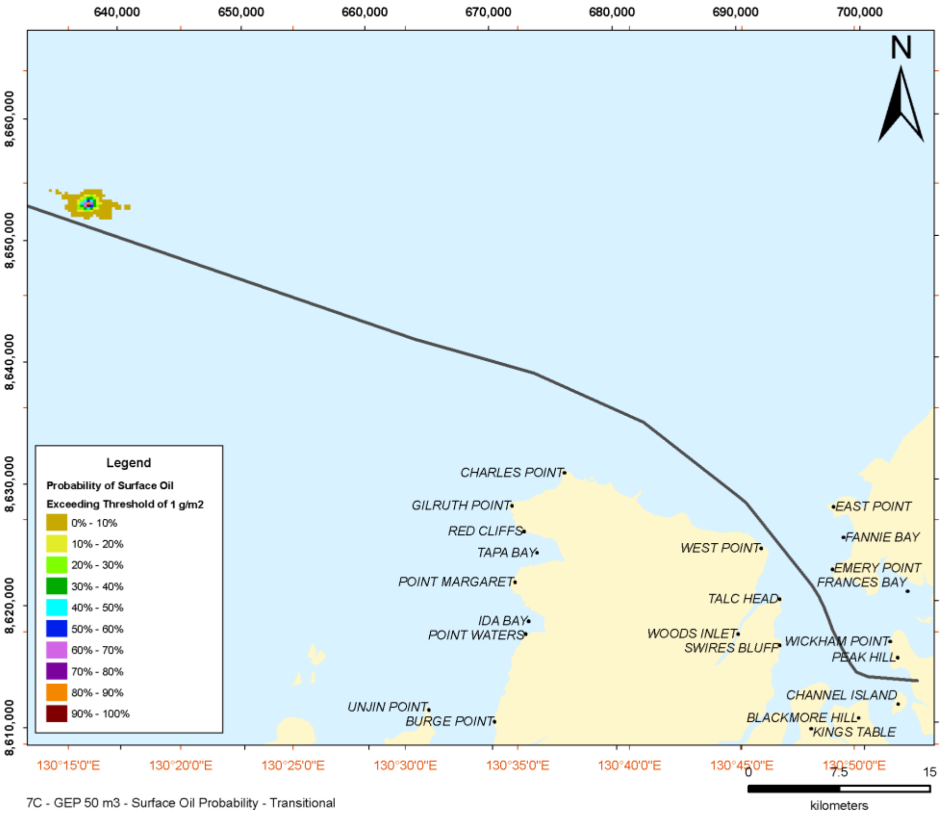


Figure 3-14. Scenario 7C: Predicted probability of oil exposure to the water surface > 1 g m^{-2} (1 µm) under transitional conditions for a GEP rupture.

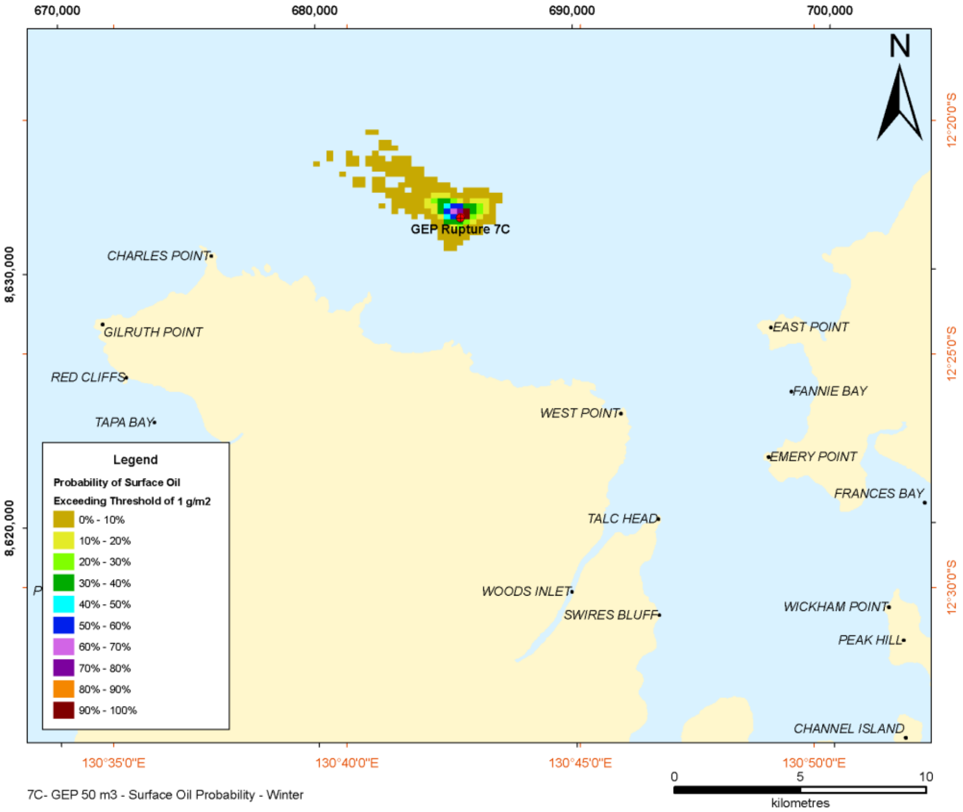


Figure 3-15. Scenario 7C: Predicted probability of oil exposure to the water surface > 1 g m^{-2} (1 µm) under winter conditions for a GEP rupture .

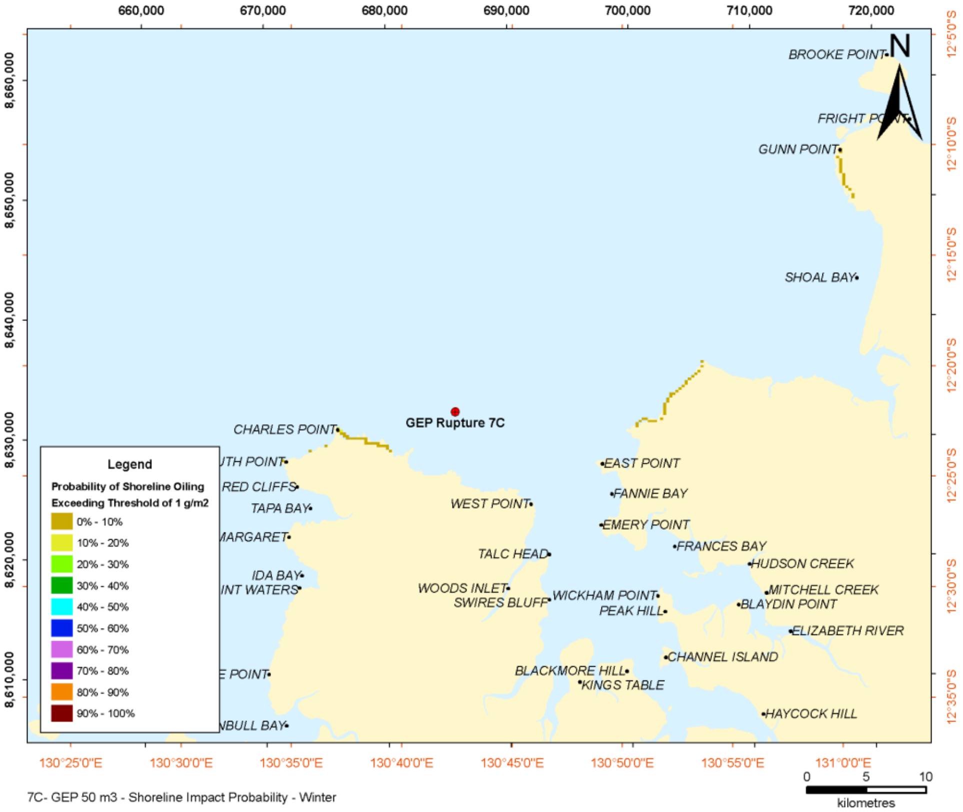


Figure 3-16. Scenario 7C: Predicted probability of shoreline exposure > 1 g m^{-2} (1 µm) under winter conditions for a GEP rupture.

3.3 Scenario 12: Ichthys production blowout

This scenario considered risks of condensate contacting surrounding resources in the event of a blowout at the Ichthys production well that persists for 11 weeks (77 days), with the release occurring at seabed level. This scenario allowed for a release of the condensate expected from the reservoir at the rate of 4,000 barrels (bbls) per day, resulting in a total released volume of 308,000 bbls or 48,972 m^3. Simulations were run from randomised start dates within the major seasons over the Browse Basin. However, due to the duration of the simulations, approaching 3 months, a blowout commencing in one season could persist into the following one or possibly two seasons. Hence, the results presented in this seasonal risk analysis should be considered in terms of risks from spills that commence in a given season.

Simulations allowed for a range of droplet sizes, of a relatively small size (< 200µm), due to the atomisation of the fluid due to the turbulence generated by released gas, which would expand rapidly on escape from the pressurised well. Simulations of this release scenario indicated that a range of droplet sizes would be generated and that condensate would rise towards the surface over time at a rate that will vary with droplet size. The larger droplets would surface relatively quickly (10s of minutes), and begin to generate thin slicks and sheens close to the release location, while the smallest droplets may be trapped and rise to the surface more slowly (10s of days) while drifting with the prevailing currents. This process will increase the spread of surfacing condensate, hence the area of the surface slick at a given point during the release, while reducing the concentration at a given location. Additional variation in the distribution of slicks will be generated by the wide range of wind and current conditions that could occur from place to place throughout an 11-week scenario. In contrast to a shorter release, where slicks will be subject to a similar time-history of conditions over time, hence migrate over a similar path, condensate releasing continuously over 11 weeks is likely to follow quite different environmental forcing conditions over time, with latter discharges more likely to be under different seasonal conditions. Trajectories of drifting condensate will respond to seasonal changes involving a reversal of the direction of the prevailing wind, or alteration of drift current patterns and, thus, risk contours from the long duration releases will exhibit a blend of the seasonal trends.

Figure 3-17 shows the predicted probability of surface oil exposure > 1 g m^{-2} to locations around the CPW location for an 11 week blowout commencing in summer, based on the specified wind and current archives. As previously described, these figures summarise the areas that were indicated to have some potential for contact (> 1%) during all simulations, with each simulation occurring under different conditions, both between and during the release. Thus, allowing for a wide range of environmental conditions that could affect the movement of condensate surfacing from the release depth. Therefore, the full extent that is indicated will be larger than the area that would be contacted during any single event. The extent should be interpreted as showing those locations that have some potential (> 1%) of contact, with higher probability ratings indicating those locations that are more likely to be contacted due to trends in the environmental conditions.

The modelling showed that the most likely direction of migration for a release that starts in the summer months would be toward the north-east sector, but with the potential to also migrate in all other directions. It is noted that the risks indicated for the Kimberly coastline, immediately to the east, in this analysis is lower than that suggested in APASA (2009b) for a summer spill, with the current analysis indicating lower potential for eastward drift onto this coastline over the longer term. This difference is attributed to the inclusion of the more complex drift currents in the present analysis, with these currents tending to oppose the effect of the predominantly westerly winds (i.e. flowing towards the eastern sector). With the adition of these relatively strong currents, there was a greater drift towards the south-west and west forecasted when the wind speeds were low, and a damping of the drift movement towards the east when the wind speeds were higher from the west . Differences to the risk contours presented in APASA (2009b) are also partially attributed to the mixing of seasonal conditions produced by the longer simulations. Contour plots generated for these longer simulations reflect a greater contribution of combination of autumn and winter trends contributed by trajectories that were forecasted for the latter parts of the simulations which extend into these seasons.

Trajectories to north-eastern sector were generated when south-westerly or westerly winds were the dominant forcing relative to prevailing drift currents and are indicated to be the longest in a given direction. The longest trajectories in directions other than north-east are expected toward the south-west, mostly for condensate released late in the simulations, resulting in overlap with the transitional (autumn) season, when drift currents were more frequently flowing south-west along the shelf edge, parallel with the coastline, and the wind was either calm or towards the same sector. Risks of contact with Browse Island at > 1 g m^{-2} was indicated at 30% for a spill commencing in summer (Figure 3-18), with the earliest time for contact calculated to be > 80 hours, indicating that this contact would be from entrained condensate that has remained submerged or from highly weathered residue. Given this long duration, condensate would be expected to have lost the more soluble components. Seringapatam Reef is predicted to have up to 20% risk of contact and North and South Scott Reefs were calculated to have up to 10% risk of contact, with the minimum travel time also indicated to be relatively long (> 90 hours). Cartier Islet, Ashmore Reef and Hibernia Reef towards the north-east are indicated to have a low (1%) risk of contact at > 1 g m^{-2} (Table 5).. Contact with reefs by surfaced condensate would be dependent on the depth of the reef and state of the tide at the time if slicks did pass over these features. The risk of contact with Rowley Shoals, to the south-east, was forecasted to be lower (<1%) at the defined threshold concentration (1 g m^{-2}) due to the distance from the well site.

Predictions for the locations that could receive entrained condensate concentrations > 10 ppb due to a blowout commencing in summer are presented in Figure 3-19. Because these locations may only have been passed through once during one of the multiple simulations, results are also presented for the highest concentration reached at each cell during each simulation, averaged among replicate simulations (Figure 3-20) to indicate locations where condensate would be more likely to occur.

The simulations indicated that condensate would tend to concentrate towards the surface but could mix to depths exceeding 20-30 m in deeper water but then concentrate on entry into shallower water. Hence, exceedance of threshold concentrations tended to reflect the intersection with shoals and reefs. The results indicate some risk of entrained condensate > 10 ppb reaching the shallow waters around Browse Island, Scott Reef, Cartier Islet, Ashmore Reef, Hibernia Reef, as well as the shoal areas to the north-east of the CPW location. Maximum instantaneous concentrations at Browse Island and Scott Reef were indicated to reach 100-500 ppb under worst case conditions, while instantaneous concentrations up to 100 ppb were indicated for Ashmore Reef. Rowley Shoals was indicated to be immediately outside of the area forecasted to potentially receive entrained condensate at > 10 ppb.

Table 5: Scenario 12: Summary of risk calculations for a blowout commencing in each season.

Season	Probability of contacting any shoreline or reef (%)	Maximum oil arriving on shorelines or reefs (%)	Maximum oil arriving on shorelines or reefs (m^3)	Minimum time to shoreline or reef (hours)	Maximum length of contacted shoreline or reef (km)
Summer	45	0.301	147	89	24.2
Transitional	80	1.434	702	65	40.7
Winter	85	0.484	237	123	34.4

For a blowout that commences in winter, the initial trajectory of surfaced condensate is predicted to most frequently trend toward the north-west and west, but more localised trajectories are indicated in all directions (Figure 3-21). The westerly trend in trajectories indicates an increased risk of contact by surfaced condensate to Seringapatam Reef and to North and South Scott Reef, with the probability of contact at > 1 g m^{-2} indicated at 85%, at some time during a release (Figure 3-22). Browse Island is indicated to have 10% risk of contact from a release commencing in winter. The potential for sheen to be observed as far north as the Indonesian waters approaching the Lesser Sunda Islands of Indonesia and as far southwest as Rowley Shoals was also indicated. The total volume of oil predicted to arrive on any reefs or islands, collectively, during any release was calculated at approximately 240 m^3, or 0.5% of the released volume. However, due to the relatively long minimum drift time that is indicated (123 hours), relatively low concentrations of surfaced condensate are expected to occur at any one location on these reefs and islands (<10 g m^{-2}).

Some risk of contact by surfaced condensate is indicated for Cartier Islet (10%), Ashmore Reef (1%) and Hibernia reef (1%) at > 1 g m^{-2} for a blowout commencing in winter (Figure 3-23). Rowley Shoals were calculated to have 1% risk of contact at this threshold. The highest potential concentration of surfaced condensate on Cartier Islet was calculated at <10 g m^{-2} while concentrations at Ashmore and Hibernia Reefs were calculated at < 2 g m^{-2}. For Rowley Shoal, low concentration sheens ($\leq$1 g m^{-2}) were indicated to be the worst case concentrations.

The stochastic simulations indicated that entrained condensate would tend to migrate to the north-west through to southwest, with the dominant influence of the drift currents in these directions, and was predicted to potentially reach the shallow waters around Ashmore Reef, Cartier Islet, Seringapatam Reef and North and South Scott reef at concentrations > 10 ppb as an average among the simulations (Figure 3-24). Concentrations at Ashmore Reef and South Scott Reef were indicated to potentially exceed 100 ppb, as an average, while the shallow reef areas to the north-east of the CPW that were indicated to be in range for a blowout commencing during the summer months are indicated to be too far east of the likely transport for the winter-start case. However, entrained condensate concentrations > 10 ppb, are indicated, as an average, over the shallow reef areas to the south-east of the CPW. Entrained condensate was indicated to potentially exceed concentrations > 10 ppb at Browse Island for a blowout commencing in winter, but only as the worst case of all of the replicates, indicating that the migration of entrained condensate plumes to this location would be less likely for this season than indicated for the summer commencement. Rowley Shoals were indicated to be potentially within range of entrained condensate plumes > 10 ppb that drift towards the sout-west.

Due to the short duration of the autumn and spring transitional seasons (~ 4 weeks), blowouts persisting for 11 weeks that commence in these seasons would continue well into winter, or into summer, respectively. Hence, the stochastic modelling results for the blowouts commencing in the transitional months were strongly influenced by both winter and summer current and wind patterns. The contours indicate an increased tendency for slicks to migrate toward the south-west along the outer shelf and inshore of South Scott Reef than for the other cases, and this was due to the trajectories predicted for condensate released in Autumn (Figure 3-25). With the change to winter, trajectories are most likely to shift toward the north-west to south-west. Wind and current conditions during the spring are similar to those in summer. Hence, condensate released in the spring and following summer all tended to migrate toward the north-eastern sector.

The risk contours for the transitional blowout scenario indicate the potential (>1%) for contact by surfaced condensate at > 1 g m^{-2} for Browse Island, Seringapatam Reef, North and South Scott Reef (Figure 3-26). Cartier Islet, Ashmore Reef and Hibernia Reef are also indicated to have some risk, based on the surface water contours (Figure 3-25). The probability of contact with at least one of these islands or reefs at > 1 g m^{-2} was calculated at 80% for this scenario, with a worst case estimate of ~ 700 m^3 of condensate (~1.4% of the released volume) passing over or stranding. Of these locations, the shortest time before contact was calculated as 65 hours for Browse Island. Some potential for sheen < 1 g m^{-2} to enter Indonesian waters approaching the Lesser Sunda Islands is also indicated after an elapsed time of > 132 hours.

Predictions for the migration and dispersion of entrained condensate indicates that plumes are most likely to migrate to the south-west towards Rowley Shoals, which were indicated to be potentially within range of entrained condensate plumes > 10 ppb. The results alos indicate that plumes could migrate to the west toward Seringapatam Reef, and North and South Scott Reef and to the north and north-east, to Ashmore Reef (Figure 3-27). Averaged among replicates, the estimated maximum concentration of entrained condensate was < 100 ppb at each of these locations (Figure 3-28). Maximum potential concentrations of entrained condensate were also calculated at < 100 ppb.

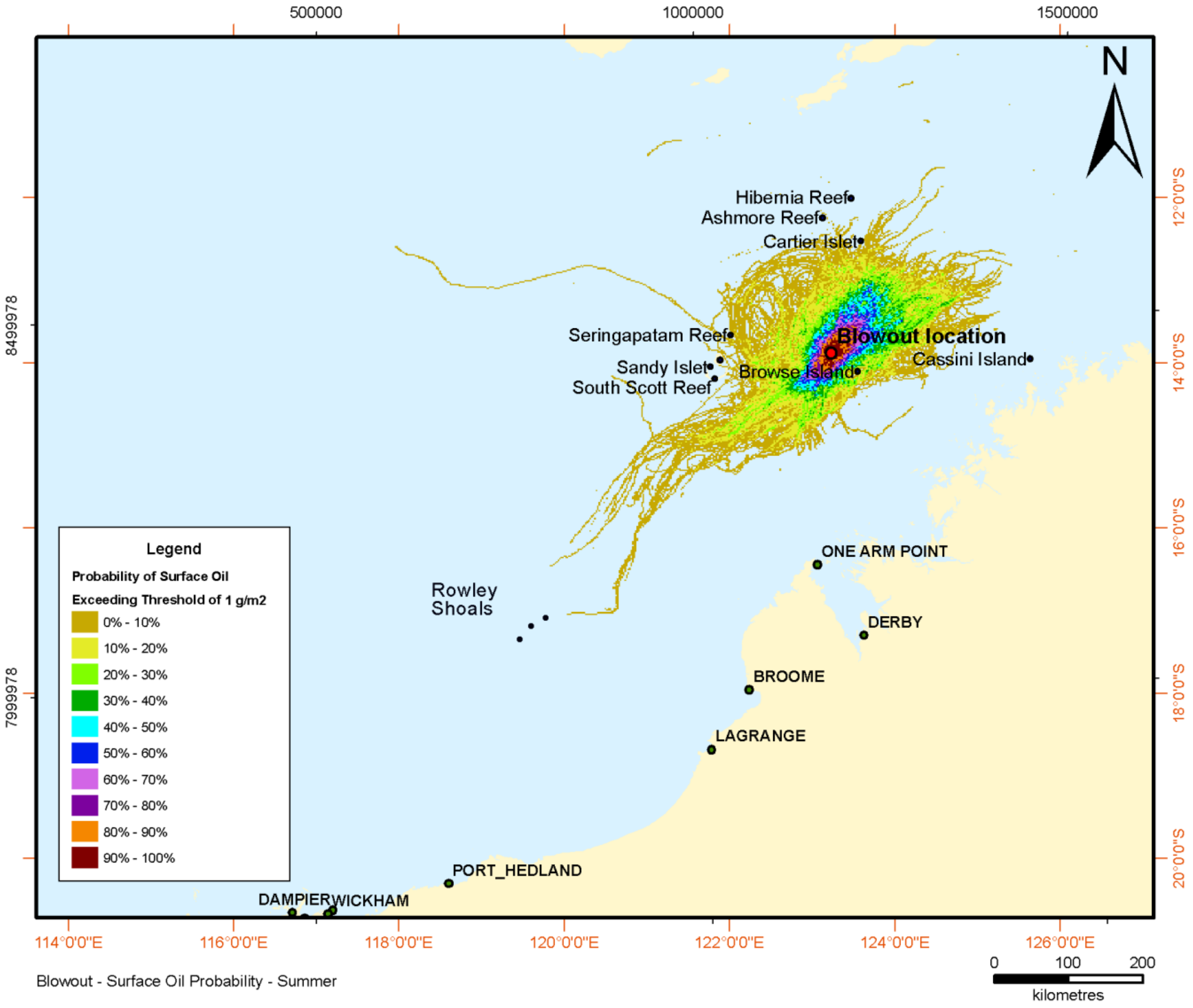


Figure 3-17. Scenario 12: Predicted probability of condensate concentrations > 1 g m^{-2} (1 µm) occurring at locations due to an 11 week blowout commencing in summer.

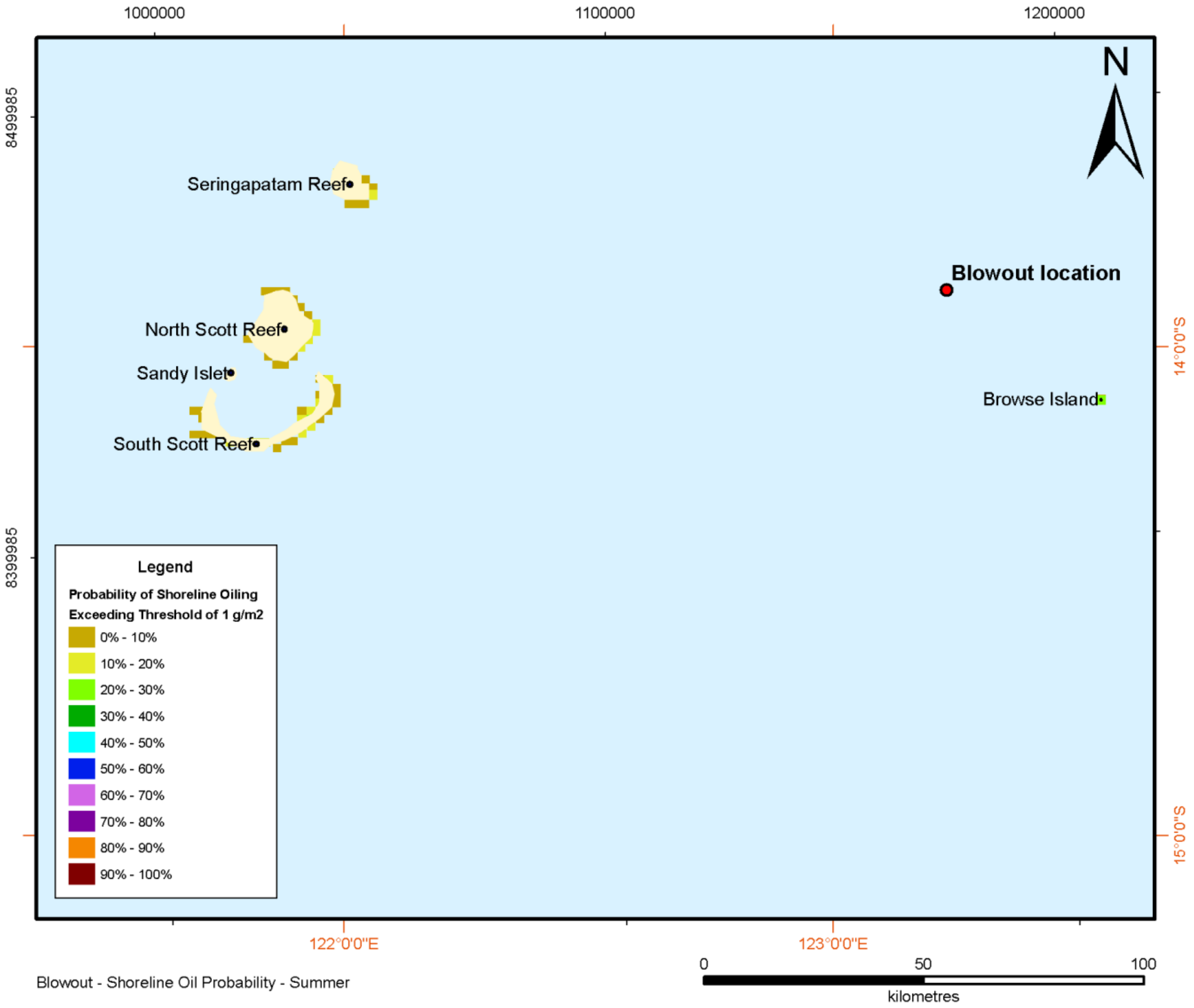


Figure 3-18: Scenario 12: Predicted probability of condensate concentrations > 1 g m-2 (1 µm) occurring at shoreline locations due to an 11 week blowout commencing in summer.

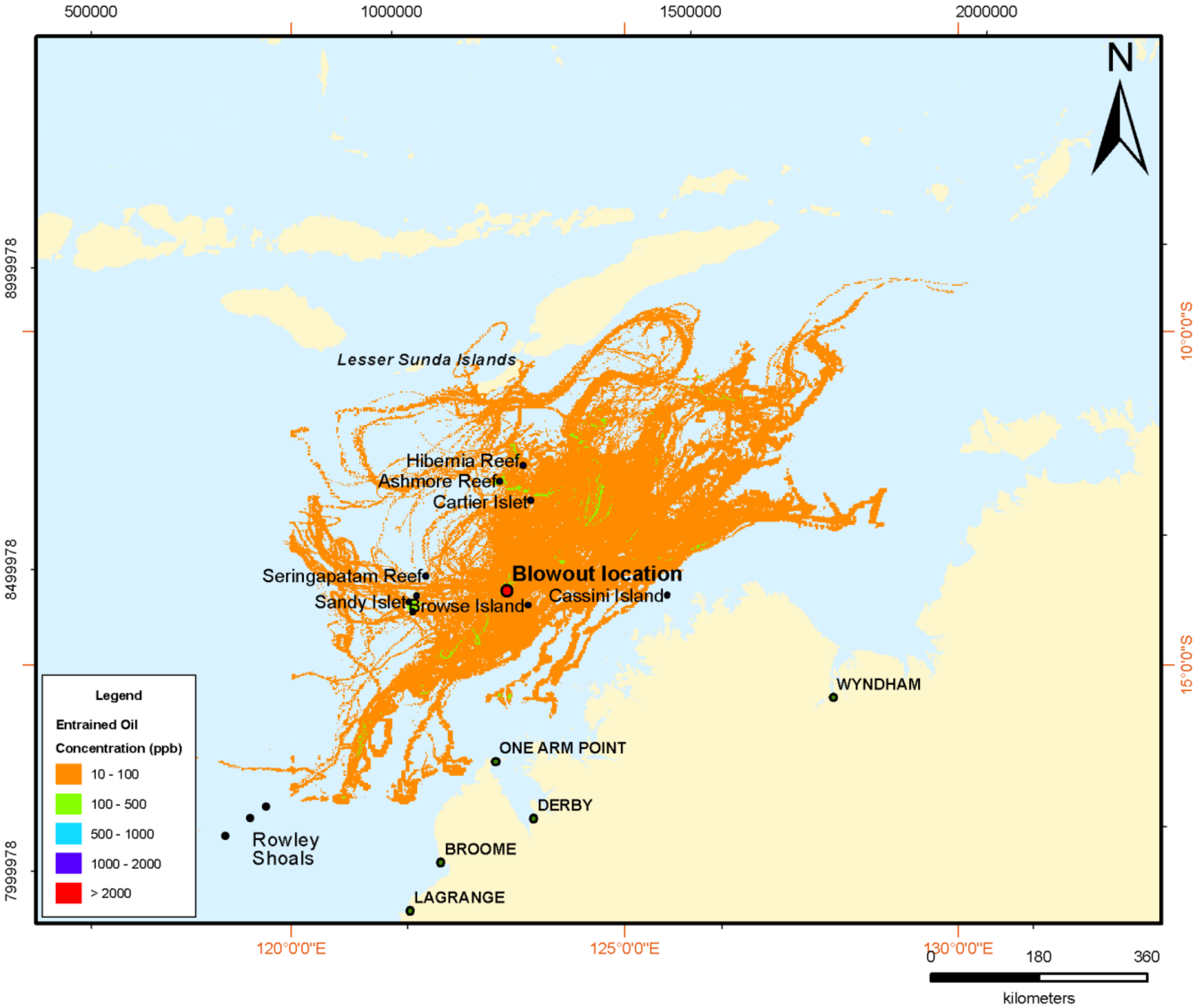


Figure 3-19: Scenario 12: Locations where concentrations of entrained condensate (> 10 ppb) could occur at one point in time due to a blowout commencing in summer. Results show the highest predicted short-term (1 hour) concentration among simulations.

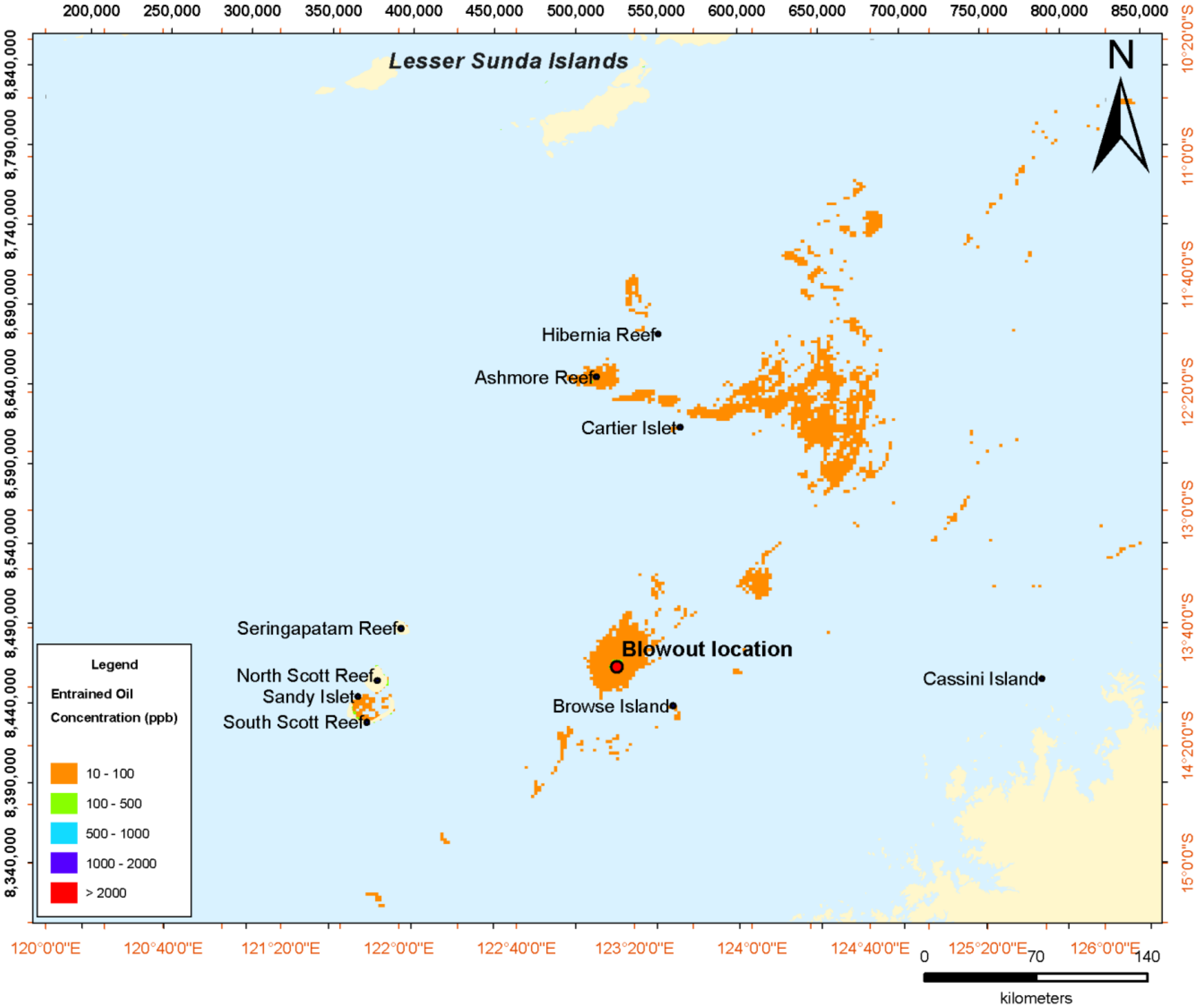


Figure 3-20: Scenario 12: Average potential concentrations of entrained condensate at surrounding locations for an 11 week blowout at the CPW commencing in summer. Results show the highest predicted short-term concentrations in each cell, averaged among simulations.

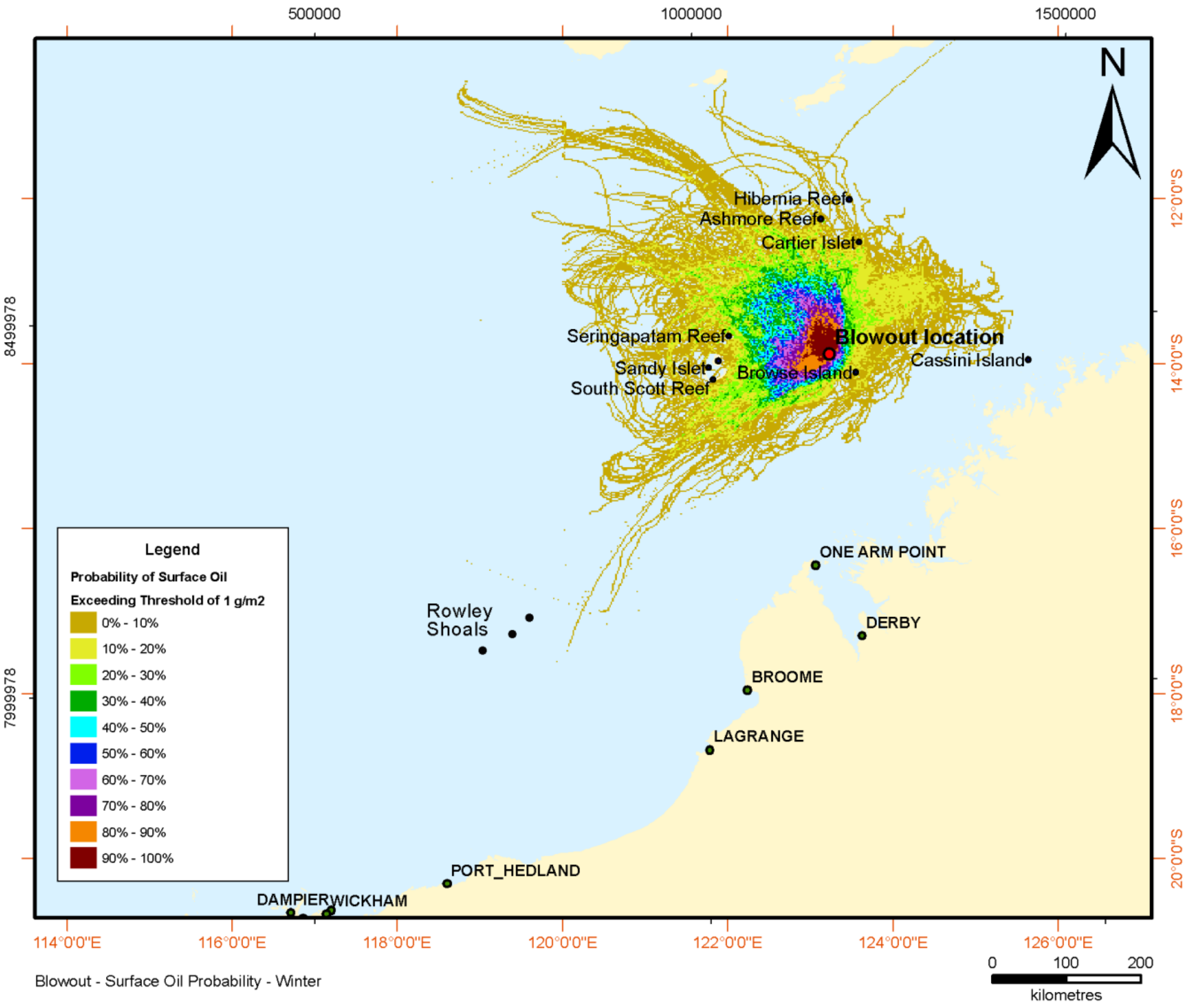


Figure 3-21: Scenario 12: Predicted probability of condensate concentrations > 1 g m^{-2} (1 µm) occurring at locations due to an 11 week blowout commencing in winter.

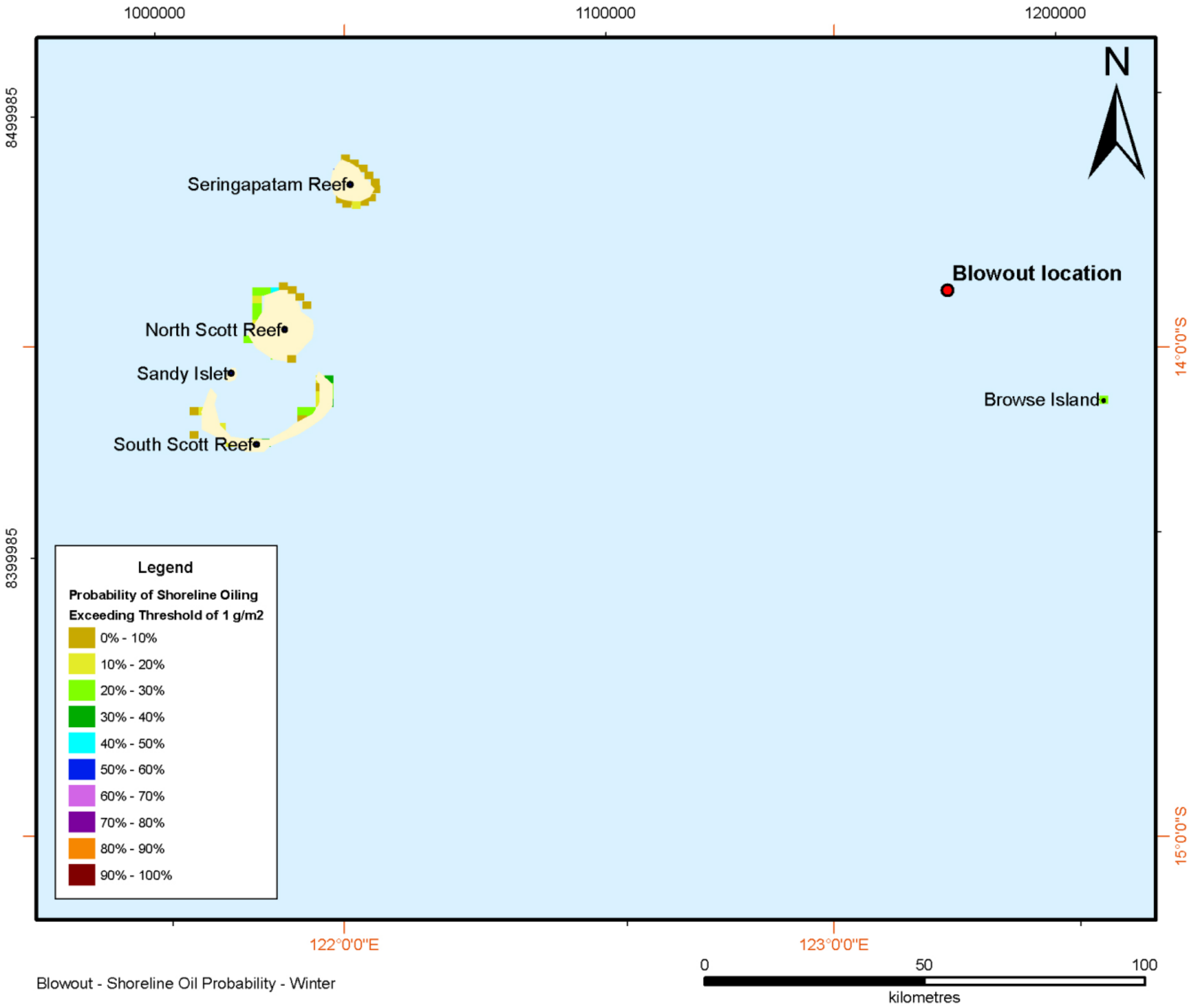


Figure 3-22: Scenario 12: Predicted probability of condensate concentrations > 1 g m-2 (1 µm) occurring at shoreline locations due to an 11 week blowout commencing in winter.

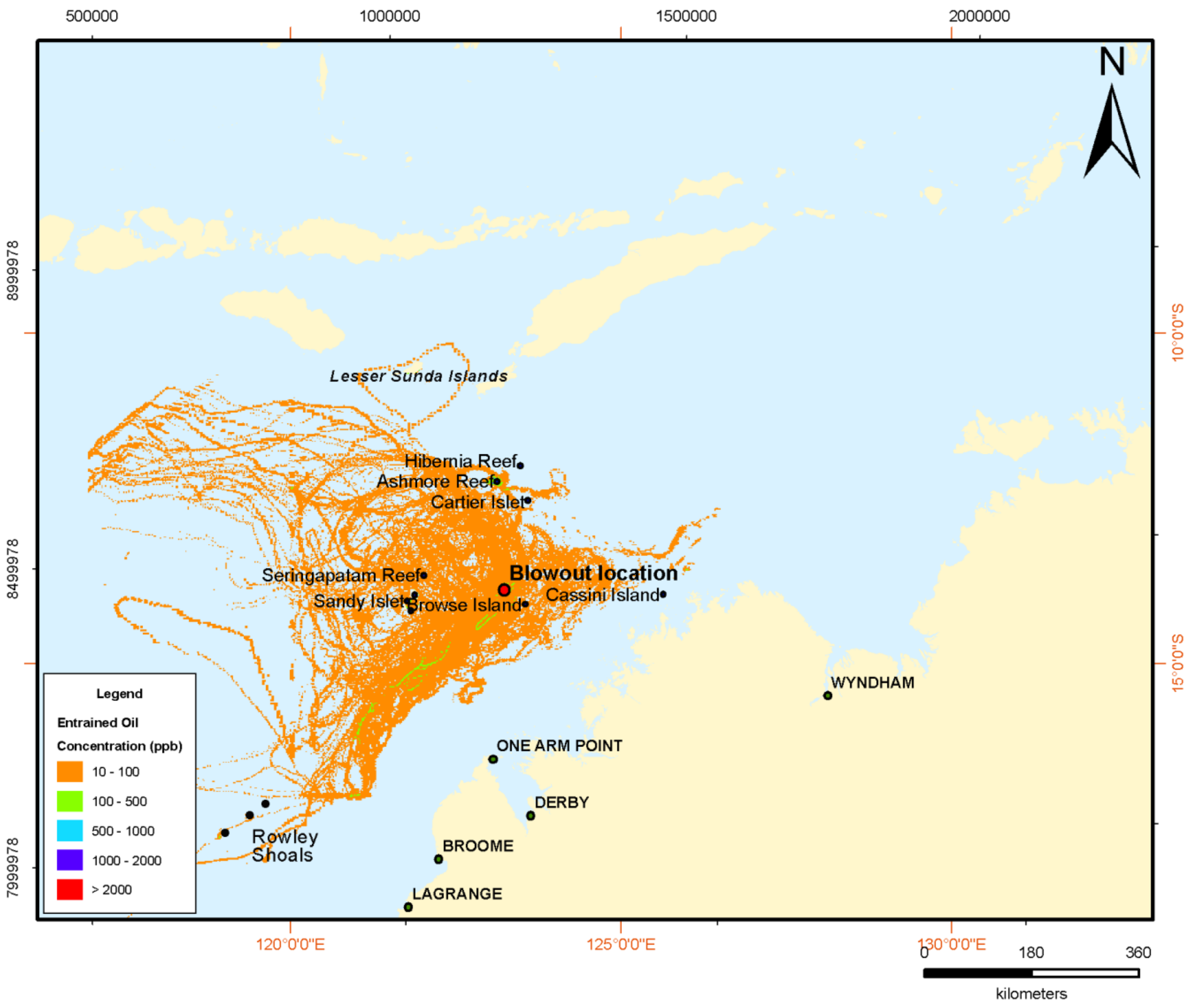


Figure 3-23: Scenario 12: Locations where concentrations of entrained condensate (> 10 ppb) could occur at one point in time (hourly time step) due to a blowout commencing in winter. Results show the highest predicted short-term (1 hour) concentration among simulations.

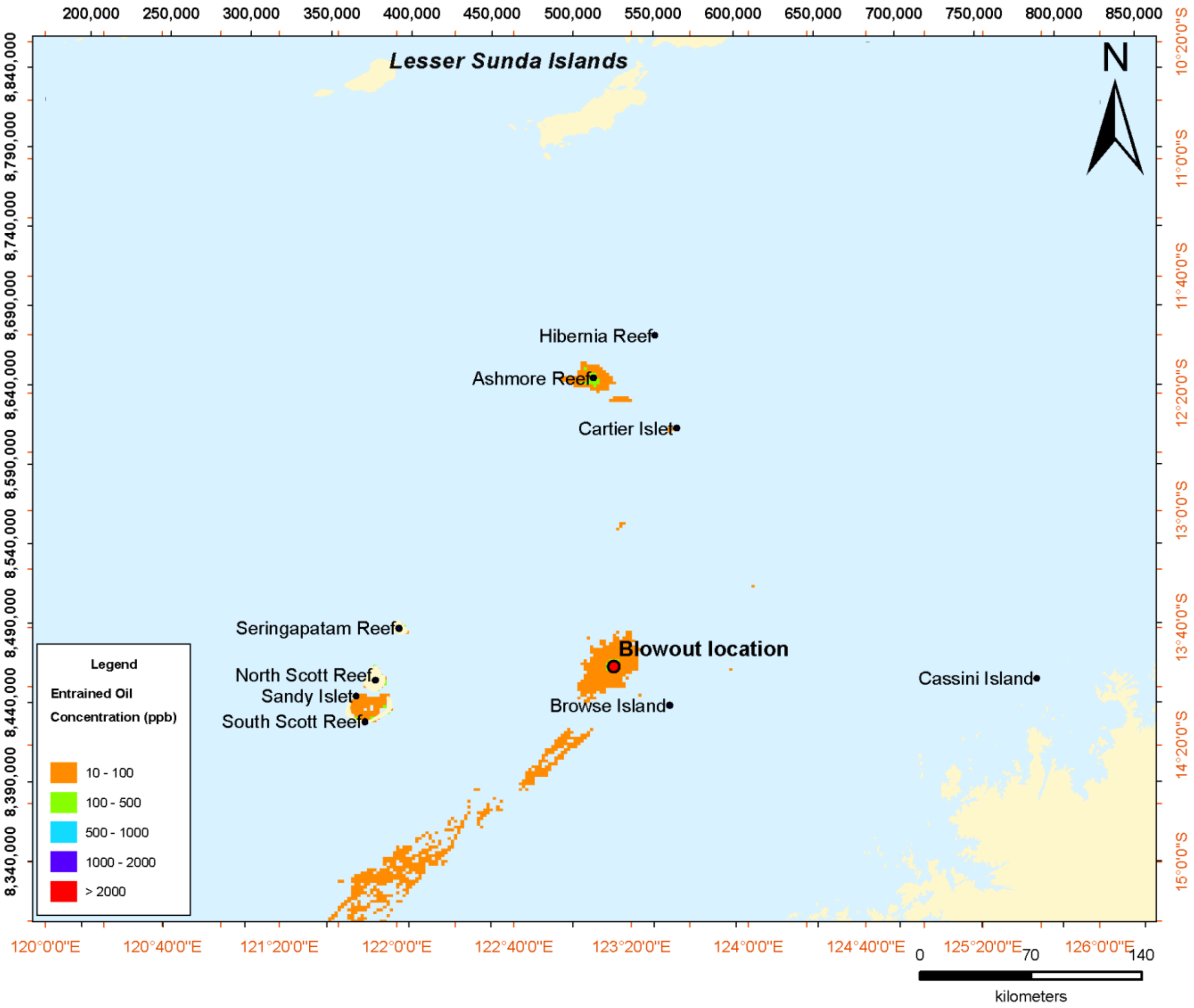
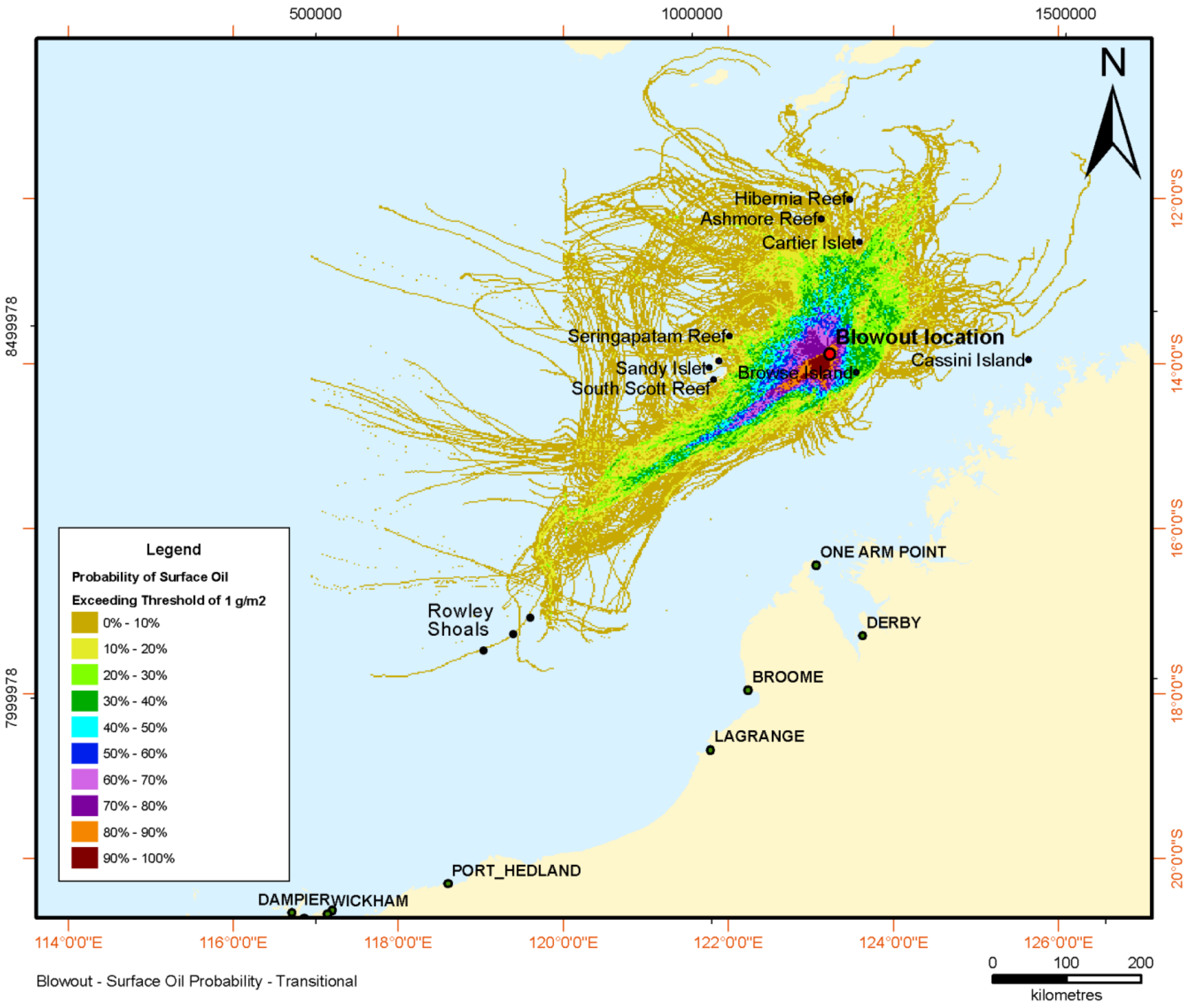


Figure 3-24: Scenario 12: Average potential concentrations of entrained condensate at surrounding locations for an 11 week blowout at the CPW commencing in winter. Results show the highest predicted short-term concentrations averaged among simulations



Blowout - Surface Oil Probability - Transitional

Figure 3-25. Scenario 12: Predicted probability of condensate concentrations > 1 g m^{-2} (1 µm) occurring at locations due to an 11 week blowout commencing in the transitional seasons.

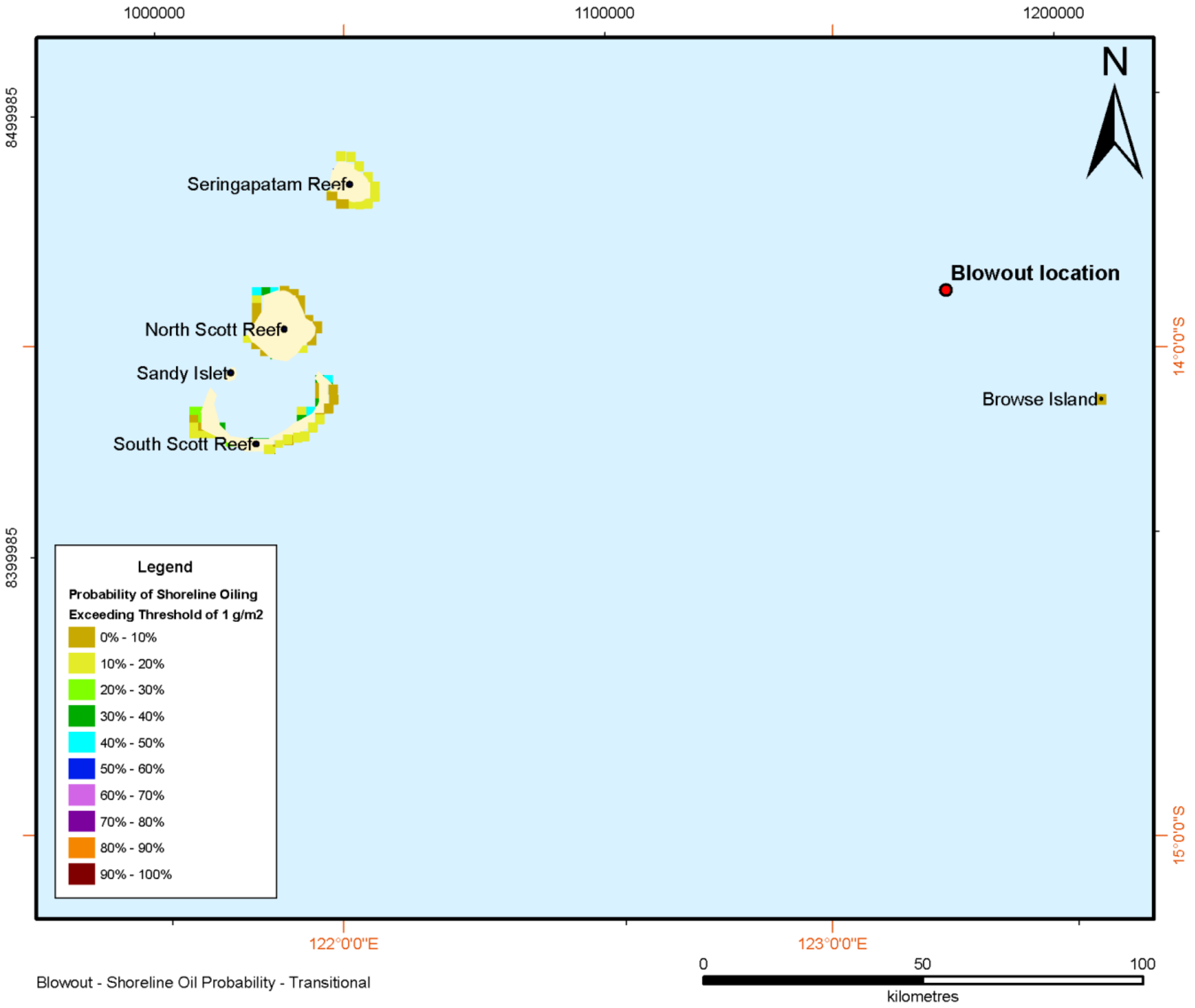


Figure 3-26: Scenario 12: Predicted probability of condensate concentrations > 1 g m-2 (1 µm) occurring at shoreline locations due to an 11 week blowout commencing in the transitional seasons.

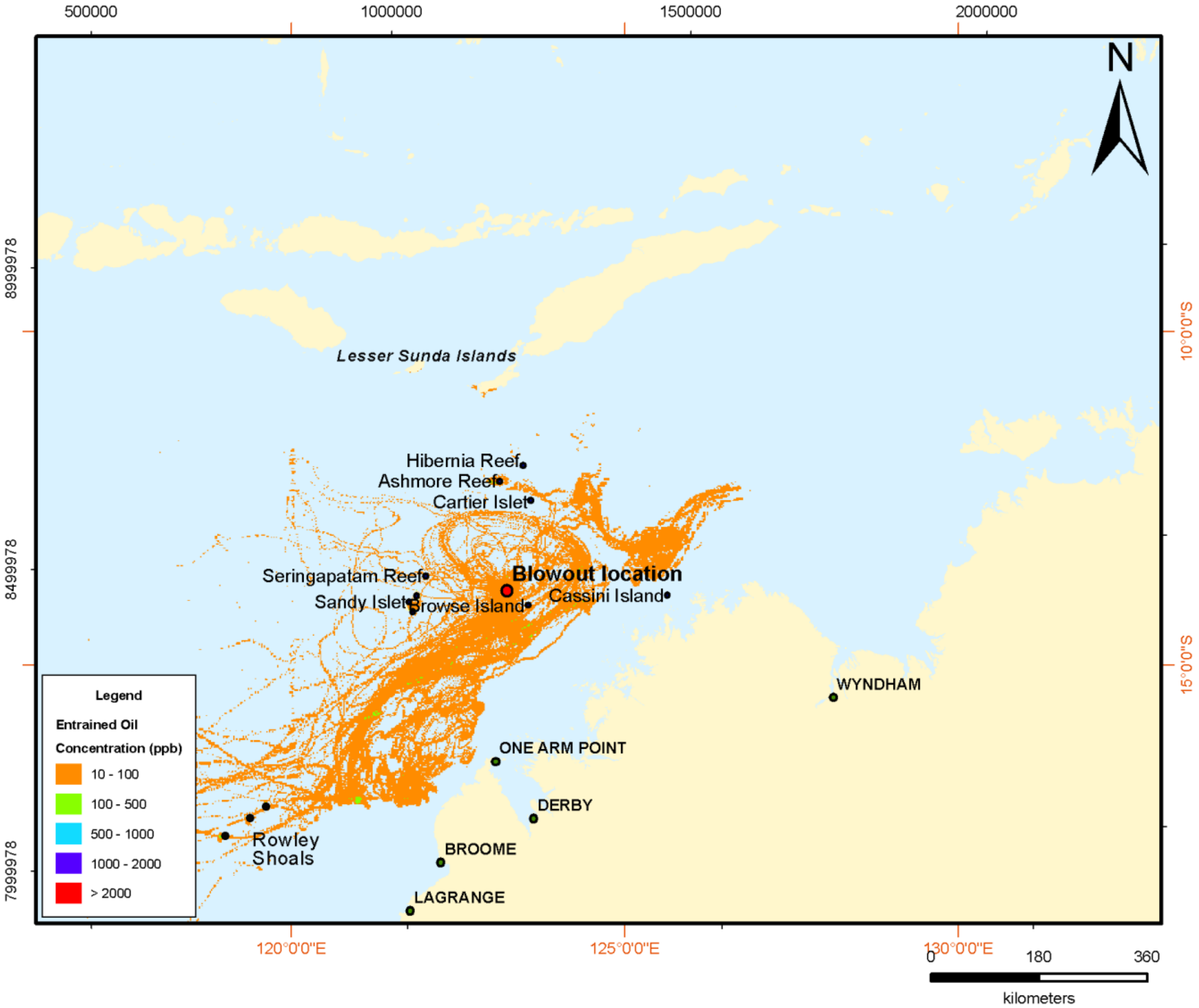


Figure 3-27: Scenario 12: Locations where concentrations of entrained condensate (> 10 ppb) could occur at one point in time (hourly time step) due to a blowout commencing in the transitional seasons. Results show the highest predicted short-term (1 hour) concentration among simulations.

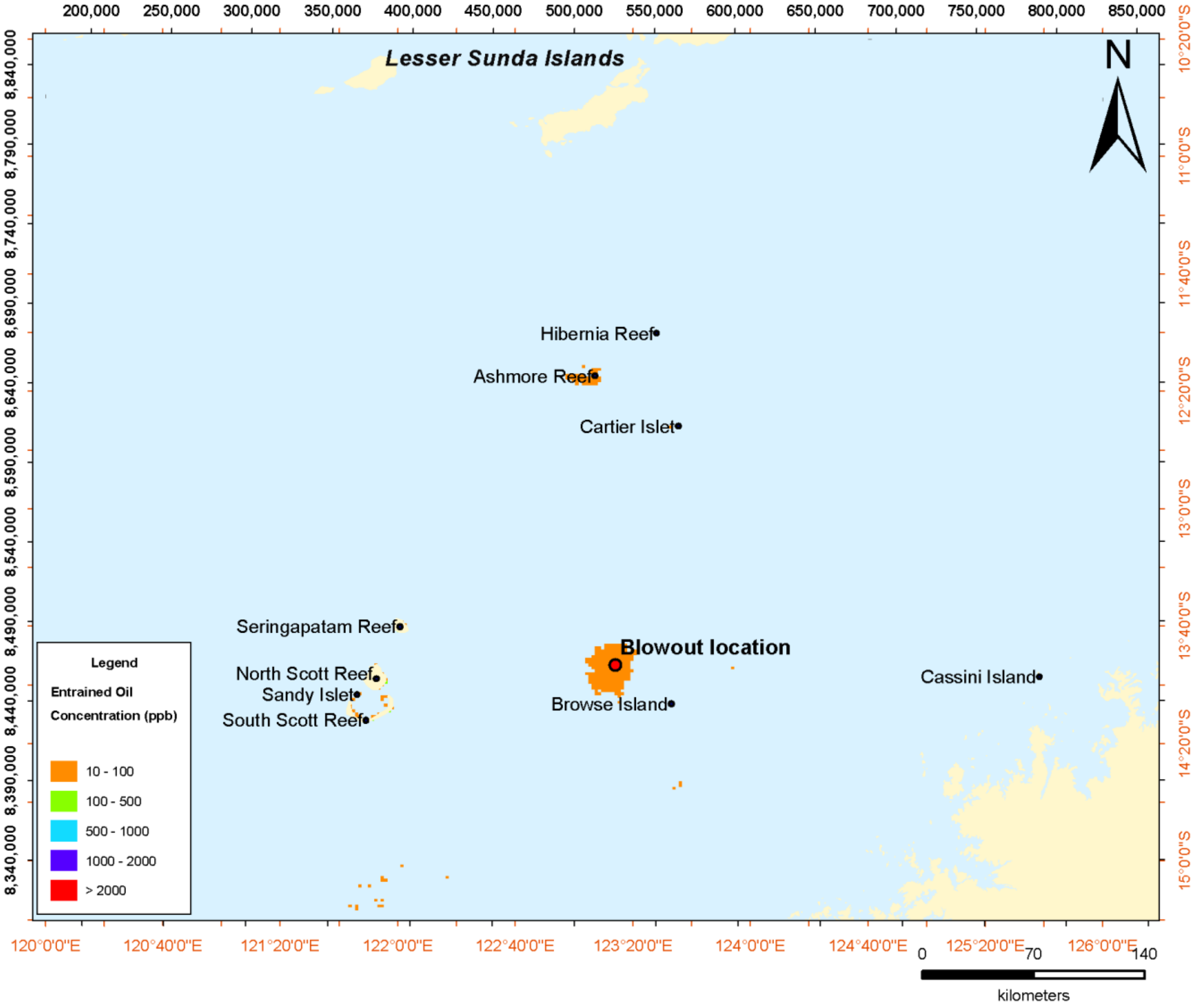


Figure 3-28: Scenario 12: Average potential concentrations of entrained condensate at surrounding locations for an 11 week blowout at the CPW commencing in the transitional seasons. Results show the highest predicted short-term concentrations averaged among simulations

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