

## 3 Oil spill modelling

### 3.1 The oil-spill modelling system

Oil spill modelling was carried out using the three-dimensional oil spill model, SIMAP (Spill Impact Mapping and Assessment Program). SIMAP is designed to simulate the fate of spilled hydrocarbons for both the surface slick and the three-dimensional plume that is generated in the water column (French *et al.* 1994, 1999, French 2000a). SIMAP is a development of the Natural Resource Damage and Assessment (NRDA) model, which was developed for the U.S. Dept. of Interior (French *et al.* 1996) and has been extensively applied and validated against a large number of real spill events (e.g. French & Rhines 1997, French 1998).

The SIMAP physical fates model calculates the transport, spreading, entrainment, evaporation and decay of spilled oil over time, based on the physical properties of a defined oil type and the prevailing weather conditions. Input specifications for oil-types include the density, viscosity, pour point, distillation curve (volume lost versus temperature) and the aromatic/aliphatic component ratios within given boiling point ranges. These algorithms are used to proportion the distribution of the oil (as mass and concentrations) over time into six components:

- Surface bound oil;
- Entrained oil;
- Dissolved hydrocarbons,
- Evaporated oil;
- Sedimented oil; and
- Decayed hydrocarbons.

The SIMAP trajectory model separately calculates the transport of the material that is on the water surface (as surface slicks), in the water column (as either entrained whole oil droplets or dissolved hydrocarbon), has stranded on shorelines or has sedimented out of the water column onto the seabed. For subsea releases, a blow-out module is used, which calculates the loss of soluble components to the water column based on the depth and general pressure of the release accounting for the size of oil parcels that are produced. Higher rates of dissolution are produced for high pressure releases (e.g. where a high gas pressure is forcing the release) as these produce smaller oil droplets with a larger surface area/volume ratio. Release rates, oil parcel sizes and other parameters are based on empirical measurements from real blow-out events (Spaulding *et al.* 2000).

SIMAP was used to predict the fate of multiple spills commencing at randomly selected times under prevailing conditions (known as stochastic modelling). The stochastic model performed 100 simulations for a given scenario and season combination. A threshold thickness of 0.001 mm ( $\sim 0.001 \text{ L/m}^2$  or  $0.8 \text{ g/m}^2$ ), which would be visible as a dull rainbow film, was defined as a threshold for recording episodes of contact with surface

cells by surface-bound hydrocarbons. A minimum concentration of 10 ppb was defined for entrained oil and dissolved (aromatic) hydrocarbons.

Results of the multiple simulations were analysed to provide a statistical weighting to potential spill outcomes. Statistics included the probability of contact (estimated from the rate of contact from the sample simulations) and the concentrations that could be involved in contact (estimated from the maximum concentrations predicted during any one simulation).

### **3.2 Data input to the oil spill model**

Input data for this study included the same spatially-varying wind data supplied to the hydrodynamic model (Section 2.1.1), the corresponding three-dimensional circulation data produced by the HYDROMAP model, specifications for seasonal environmental conditions, including seasonal water temperatures, and specifications for spill scenarios, including details of the oil type and specifications for the discharge.

Analysis of the wind data from each location indicated some differences in the prevailing directions of winds, as well as slight differences in the timing of seasonal changes, along and across the shelf within the study area. (Figures 26 - 28). However, in general, the seasons can be summarised as:

- Summer: October to March - winds are predominantly from the southwest and west at Barrow Island and locations further west. Winds shift to southerly towards the eastern margin of the domain during March.
- Winter: May to August - winds are predominantly from the eastern sector (northeast to southeast) over the offshore waters. Winds tend to be more variable over Barrow Island early in May.
- Transitional months: April and August - winds are more variable in direction than the major seasons and tend to persist for shorter durations from a given direction.

These monthly groupings were therefore applied to seasonally stratify the assessment of risk from given spill scenarios.

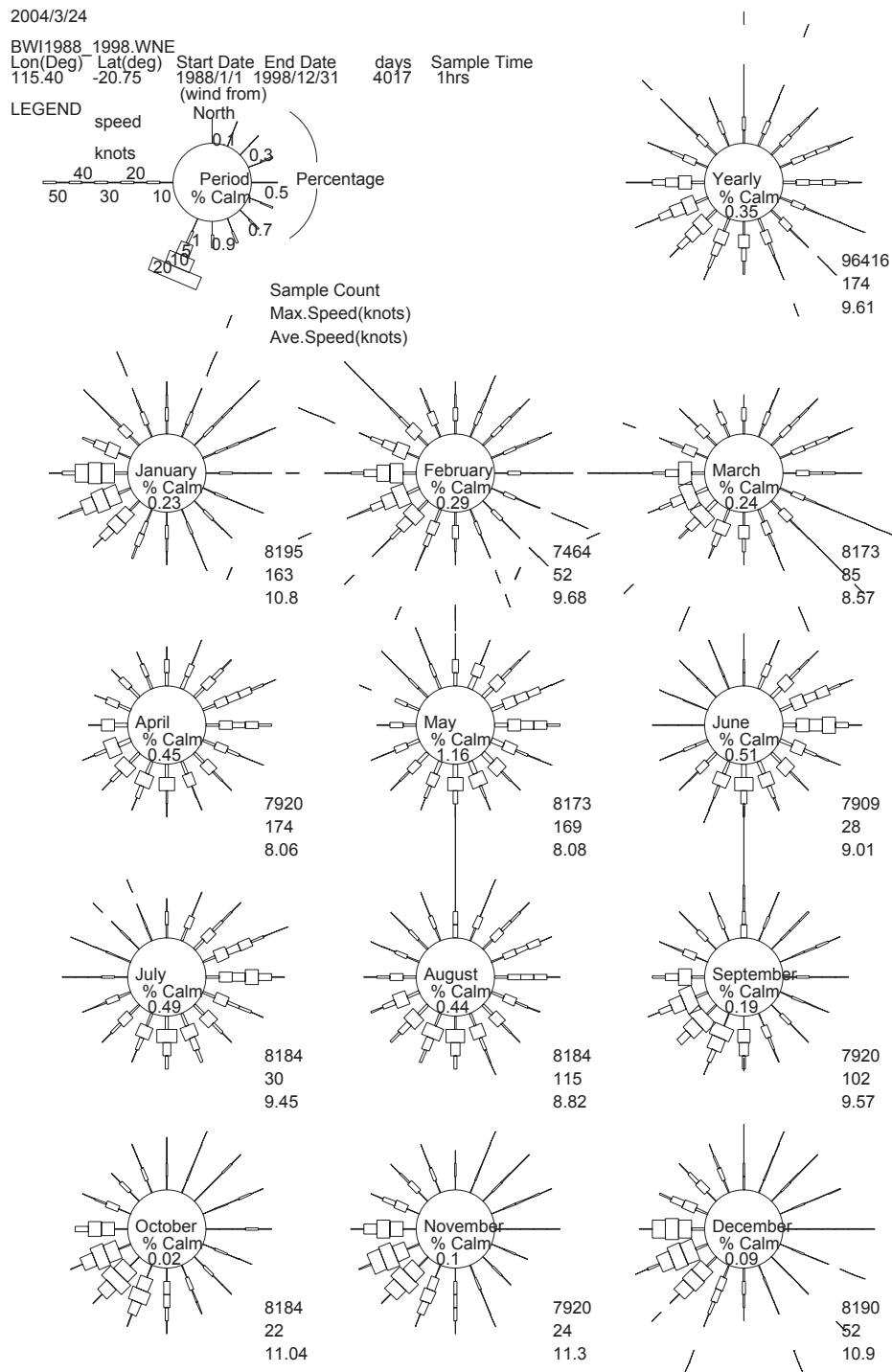
Spill scenario information supplied to the model included specification of the oil type, the volume and duration of the spill, the horizontal and vertical location of the spill source, and the pressure of the release (Table 5). Scenarios covered spills of the following oil types:

- Gorgon condensate
- Marine diesel (North West Shelf formulation);
- Light crude oil;
- Bunker fuel (Fuel oil No. 6)

ChevronTexaco made data for the chemical and physical nature of the condensate and aqueous phase liquids from the Gorgon production field available from samples

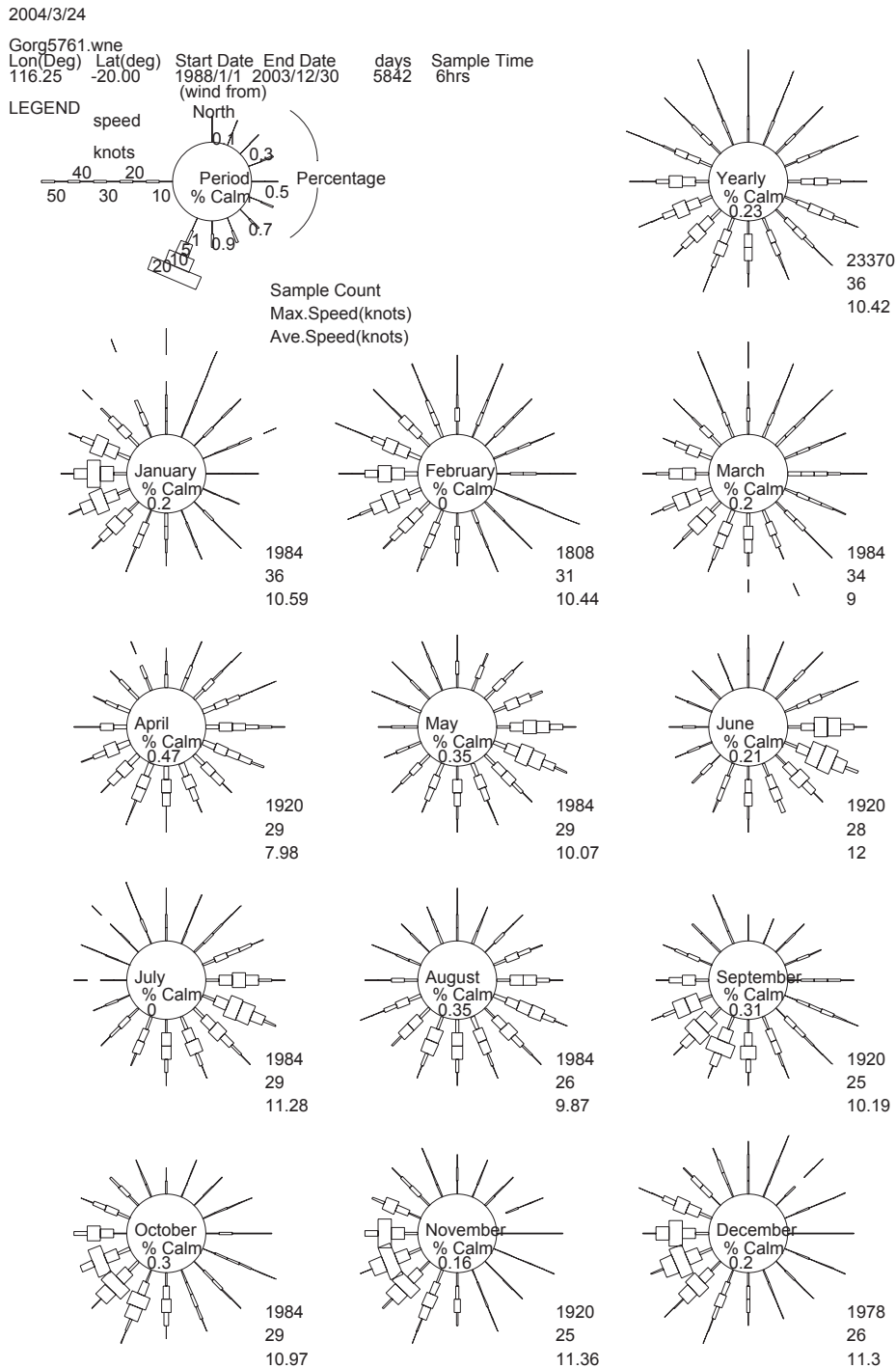
collected during exploration and appraisal drilling operations. The data indicated unweathered Gorgon condensate would have a low pour point (-54 C) and viscosity (< 1 cSt) and a density marginally lower than light crude oil (API 47.7). Grouping the components of the oil into pseudo-components, the data indicated the oil would contain approximately 6% by mass that was highly volatile and highly soluble (B.P. < 180 °C); and 44% by mass that was moderately volatile and moderately soluble (B.P.180-264 °C). Approximately 38% by mass of the oil can be classified as low volatility/solubility (B.P. 264 – 380 °C). The remaining components (~ 12%) can be classified as non-volatile at local ambient temperatures. About 9% by volume of the total oil volume is contributed by mono aromatic or polycyclic aromatic compounds.

Predictions for the weathering of this condensate using the SIMAP model under prevailing conditions of winds, tides and winter (worst-case) sea-water temperatures indicated that condensate spilled onto the water surface would undergo a relatively steady rate of loss to evaporation over a number of days, but that evaporation would then slow and cease with approximately 12% of the oil mass remaining as a residual. Under light winds (5 knots), total loss of all volatiles was expected to take about 48 hours. In contrast, evaporation was predicted to account for the loss of only 60-70% of the mass of a Diesel spill, 70-80% of the mass of a typical light crude oil spill and only 10-20 % of the mass of a heavy fuel oil. Factors such as the water temperature, wind speed, wave energy (a function of the wind speed and fetch), and depth of the release would affect the evaporation rates achieved under particular circumstances. Thus these evaporation rates should be treated as a guide only.



**Figure 26: Wind roses showing the monthly distribution of wind speed and direction at Barrow Island (1988-1998).**





**Figure 28: Wind roses showing the monthly distribution of wind speed and direction at NCEP station 5761 (1988-1998; See Figure 25).**

**Table 5: Assumptions in specifying the hydrocarbon spill scenarios.**

Spill source	Spill Location	Depth (m)	Spilled fluid	Volume (m <sup>3</sup> )	Duration (hours)	Other
Rupture at Central manifold	Central manifold of Gorgon production area	200	Condensate & water	2172	3	Release volume estimated from fluids held up in flow-lines during expected year 12 production rates: 1553 m <sup>3</sup> water; 632 m <sup>3</sup> condensate. Gas release at sonic rate (154 bar operating pressure), atomising all fluids.
Rupture of Feed pipeline	14km from Barrow Island along proposed Feed pipeline route 1	50	Condensate & water	1621	4.5	Release volume estimated from fluids held up in flow-lines during expected year 12 production rates: 1028 m <sup>3</sup> water; 593 m <sup>3</sup> condensate. Gas release at sonic rate (154 bar operating pressure), atomising all fluids.
Rupture of Feed pipeline	14km from Barrow Island along proposed Feed pipeline route 2	50	Condensate & water	1621	4.5	Release volume estimated from fluids held up in flow-lines during expected year 12 production rates: 1028 m <sup>3</sup> water; 593 m <sup>3</sup> condensate. Gas release at sonic rate (154 bar operating pressure), atomising all fluids.
Rupture of Feed pipeline	200 m from Barrow Island along proposed Feed pipeline route 1	12	Condensate & water	1621	4.5	Release volume estimated from fluids held up in flow-lines during expected year 12 production rates: 1028 m <sup>3</sup> water; 593 m <sup>3</sup> condensate. Gas release at sonic rate (154 bar operating pressure), atomising all fluids.
Rupture of export pipeline	2.2 km from Barrow Island along export pipeline	2	Condensate	1565	3	Release occurs while pipeline is pressurised during delivery to a tanker. Volume and duration assume time for shut-down and suck-back of flow to depressurise the line.
Refuelling accident during the supply gas pipe-laying	10 km, 5 km or 2.5 km west of Barrow Island.	Surface	Diesel fuel	2.5	< 1	Minor spill that is immediately shut-off
Refuelling incident or spill of fuel from the port facilities	Adjacent to the MOF Jetty	Surface	Diesel fuel	0.1-10 *	< 1	Minor spill that is immediately shut-off

**Table 5: Continued.**

Spill source	Spill Location	Depth (m)	Spilled fluid	Volume (m <sup>3</sup> )	Duration (hours)	Other
Grounded export tanker	Randomised within 2,000 m radius of most likely grounding site for a tanker along the 12 m depth contour (based on typical depth of export tankers) adjacent to the tanker terminal. Most likely grounding site during each major wind season predicted using stochastic modelling, assuming windage appropriate to tankers of the proposed size (source: US coast guard).	Surface	Processed condensate, light crude oil or bunker fuel oil	10-100*	1-24*	Spill from cracked tank that is brought under control within 1 day. Hydrocarbon types modelled separately (not as a mixed-oil release).

\* Spill duration and volume randomised within this range

## 4 Chemical spill and discharge modelling

### 4.1 The chemical spill modelling system

Simulations of spills of Monoethylene glycol (MEG), and of discharges of hydrotest water, were carried out using the CHEMMAP model (Chemical Spill modelling and analysis program). CHEMMAP is a variant of the SIMAP model that predicts the trajectory and fate of a wide variety of chemical products, including floating, sinking, soluble and insoluble chemicals and product mixtures (French McCay & Payne 2001, French McCay & Isaji 2004). CHEMMAP model algorithms include components for:

- Simulation of the initial release and plume dynamics of a product lighter, denser or neutrally buoyant relative to water,
- Slick spreading and transport of floating materials,
- Transport of dissolved and particulate materials in three dimensions,
- Evaporation and volatilization, with atmospheric dispersion of evaporated components,
- Dissolution and adsorption,
- Sedimentation and resuspension, and
- Degradation.

The model uses circulation data to predict the transport of plumes and/or slicks and physical-chemical properties to predict the fate of a chemical spill into water. These properties include the chemicals density, vapour pressure, water solubility, environmental degradation rates, adsorbed/dissolved partitioning coefficient ( $K_{OC}$ ), viscosity, and surface tension.

### 4.2 Data input to the chemical spill model

CHEMMAP was applied in stochastic mode to investigate risks associated with MEG spills. One hundred independent spills were simulated from randomly selected start-times within each season. This modelling used the same inputs of wind and circulation data that were applied to stochastic modelling of oil spill using SIMAP (Section 2.1.2) and specifications for the expected discharge rate and duration given a rupture of the MEG line (Table 6).

Materials safety data for MEG ([www.msds.com.au](http://www.msds.com.au)) indicate that it has a slightly lower density than ambient seawater (1.14 kg/L), is readily miscible and does not react to form a precipitate. Thus, the primary dispersive process would be mixing due to the initial discharge and subsequent transport by local currents.

Simulations of hydrotest water discharge were carried out in single discharge mode at times corresponding to neap tides and weak winds at the discharge sites, to estimate the worst-case outcome of the discharge, in terms of current mixing. The hydrotest water

was assumed to have the same density as the receiving waters and the chemical treatment agents were assumed to be soluble. Other assumptions of the hydrotest spill simulations are listed in Table 6.

**Table 6: Assumptions in specifying the non-hydrocarbon spill and discharge scenarios.**

Spill source	Spill Location	Depth (m)	Spilled fluid	Volume (m <sup>3</sup> )	Duration (hours)	Other
Rupture of coolant pipeline	14 km from Barrow Island along proposed Feed pipeline route 1	50	Mono ethylene glycol (MEG)	11	< 1	Rapid depressurisation occurs, releasing 0.9 m <sup>3</sup> in first 2 minutes. Remaining 10 m <sup>3</sup> seeps out within 10's of minutes.
Discharge of hydrotest water from the feed pipeline	Production manifold (M2)	200	Chemically-treated hydrotest water	32,075	23.3	Water treated with "Bactron" at 150 mg/l and "OS2" at 100 mg/l. Water is discharged through a pipe with an internal diameter of 697 mm.
Discharge of hydrotest water from the domestic gas pipeline	1 km east of Barrow Island adjacent to the MOF Jetty	2	Chemically-treated hydrotest water	13,555	24.7	Water treated with "Bactron" at 150 mg/l and "OS2" at 100 mg/l. Water is discharged through a pipe with an internal diameter of 440 mm.

## 5 Outcomes of spill risk modelling

### 5.1 Releases of condensate and reservoir water from the upstream supply

Fluids within the production well, production flow lines and supply gas pipeline to Barrow Island are expected to include water and hydrocarbon condensate. Assays of the condensate indicate it will contain approximately 6% highly volatile and highly soluble components (B.P. < 180 C), 44% that would be moderately volatile and moderately soluble (B.P. 180-265 C), 38% that has low volatility and solubility (B.P. 265-380) and a residual component (~12%) that would be both insoluble and non-volatile. The assay indicated the water would not contain significant concentrations of hydrocarbons. A rupture of one of the offshore manifolds, or the feed-gas pipeline to Barrow Island during production at normal operating pressures was identified as the worst-case scenario for these facilities. The risk of a rupture of an offshore manifold, either from an anchor or other physical impact, corrosion or material defect has been estimated as  $1.50 \times 10^{-5}$  per year based on historic failure data (Appendix B4). The risk of a rupture of the feed-gas pipeline from similar causes was estimated to be  $2.81 \times 10^{-5}$  per year per km of pipeline, based on historic submarine pipeline failure data (Appendix B4).

A rupture from either source is expected to result in a release of gas and all held-up liquids within the manifold, infield flow lines and feed-gas pipeline. Gas would be released at sonic velocity, generating an atomised plume of small globules (< 200  $\mu\text{m}$  diameter: Spaulding *et al.* 2000) of condensate and turbulent mixing of released reservoir water. Modelling of this scenario from the manifold and three locations along the proposed pipeline routes indicated that the atomised plume of condensate would tend to rise towards the surface, where it would pool to form a thin slick. The large surface area to volume of the atomised condensate was predicted to result in rapid dissolution of all soluble hydrocarbons close to the depth of the discharge. Dissolved hydrocarbon plumes generated in this process were also predicted to rise, due to entrainment by the rising plume of condensate. Dilution by seawater of both the entrained condensate and dissolved hydrocarbons was predicted as the plumes rose. A higher dilution effect (approximately 6-fold) was indicated for the scenarios where a discharge was from the manifold and minimal (approximately 2-fold) for a discharge near the shore crossing due to differences in the depths of these sites and therefore the time for entrainment to occur as the plume rises.. The entrained condensate was predicted to surface and generate slicks from all of the locations examined. Differences in the depths of the sites affected the concentrations of oil that were expected at the surface. Peak concentrations of condensate in the surface slick were predicted to be lowest for a central manifold rupture (~50 g/m<sup>2</sup>) and highest for a rupture near the shore crossing onto Barrow Island (~ 2,120 g/m<sup>2</sup>). The risk of surface slicks formed in this way washing onto adjacent coastlines was predicted to vary among the source locations.

Risks of shoreline contact resulting from a rupture at the manifold were estimated by modelling for the summer conditions, as winds and surface currents are most likely to be towards the adjacent islands at this time of year. Stochastic modelling indicated that slicks of floating condensate generated by a rupture at the manifold under summer conditions would most commonly drift towards the northeast, passing to seaward of the Montebello

Islands (Figure 29). Further, these slicks were predicted to thin to a rainbow sheen within 40 km, horizontally from the manifold and, therefore, before landfall was possible (the nearest shoreline is 64 km distance). Peak concentrations of aromatic hydrocarbons in the surface layer were predicted to decrease to < 10 ppb within 30 km (Figure 30). Consequently, the probability of exposure to shallow water habitats by potentially harmful concentrations of floating oil or aromatic hydrocarbons, given that the incident occurred in the first place, was estimated to be <  $1 \times 10^{-2}$ . Taking account of the chance of such an incident occurring in summer ( $7.5 \times 10^{-5}$ ), the overall risk to shallow habitats from such an incident is estimated to be <  $7.5 \times 10^{-7}$  during this season. Risks of exposure during other seasons are not expected to be larger due to the lower frequency of winds towards land.

Slicks generated from a rupture 14 km off Barrow Island along either of the proposed routes were predicted to potentially reach landfall before thinning to rainbow sheen (Figures 31 & 34). The risk of exposure to any shoreline (up to  $6.3 \times 10^{-1}$ , given that the spill occurred in the first place, or  $8.8 \times 10^{-6}$  overall), the potential shoreline area that could be affected (up to 23 km) and the potential volume of condensate on shore (up to  $27 \text{ m}^3$ ) were predicted to be highest in summer from either source (Table 7), due to the higher frequency of south-westerly winds in this season. Shoreline locations that were predicted to be at >  $1 \times 10^{-2}$  risk of exposure from floating condensate (at >  $0.3 \text{ g/m}^2$ ) if a spill occurred during summer included the west coast of Barrow Island, most Islands in the Lowendal group and Islands along the south-western side of the Montebello Islands. The probability of exposure to shorelines by surface-bound condensate was predicted to be higher for a rupture along route 2 than route 1 during the major part of the year (Table 7) due to the greater potential to involve the Montebello and Lowendal Islands.

A feed-gas pipeline rupture at 14 km offshore was predicted to potentially generate concentrations of aromatic hydrocarbons exceeding 10 ppb within shallow water habitats along the west and south coast of the Montebello Islands, and over the shallow pavement reefs between Barrow Island and the Montebello Islands (Figures 32, 33, 35 and 36). Shallow areas off the south-west coast of Barrow Island were also predicted to be at risk of experiencing aromatic hydrocarbons (> 10 ppb) during autumn. Concentrations up to 1.8 ppm (Table 8), coupled with extended periods of exposure (> 12 hours) were predicted for some of the west-facing shorelines, indicating a potential for acute toxicity to biota resident in these areas if the feed-gas pipeline ruptured at the tested locations..

A rupture of the feed gas pipeline near the shore crossing onto Barrow Island was predicted to have a high probability, year-round of delivering condensate onto shorelines ( $9.6 \times 10^{-1} - 1.0 \times 10^0$  per incident; Table 7; Figure 37), due to the close proximity to Barrow Island's shoreline. Taking account of the probability of a rupture occurring at this site in the first place ( $2.81 \times 10^{-5} \text{ yr}^{-1}$ ), the overall risk of shoreline exposure from this scenario was estimated to be  $2.76 \times 10^{-5} \text{ yr}^{-1}$ . The potential length of shoreline that could be affected (~43 km) and the worst-case volume (~  $159 \text{ m}^3$ ) were predicted to be highest during summer (Table 7). A rupture of the feed-gas pipeline near the shore crossing was also predicted to potentially affect shallow water habitats along the east coast of Barrow Island, the Montebello Islands and the Lowendal Islands. Simulations indicated that elevated concentrations of aromatic hydrocarbons (up to 4.5 ppm) could be trapped against shorelines from this scenario (Figures 38 & 39). These episodes spanned sufficiently long periods during some conditions to potentially expose resident biota to acutely toxic dosages of aromatic hydrocarbons.

## 5.2 Releases of processed condensate from the export pipeline

Following separation from water and gas, condensate would be exported via the existing subsea pipeline to the tanker terminal. Rupture of the export pipeline when the pipeline was pressurised and delivering condensate to a tanker was identified as the worst-case incident for this pipeline. The probability of a rupture of this export pipeline was estimated to be  $1.48 \times 10^{-4}$  per year per km of pipeline (Appendix B4). A location along this pipeline about 2 km from the western shore of Barrow Island was identified as the worst-case location for such as rupture, due to the proximity of shallow reef habit and the location of this point close to the strong currents migrating between Barrow Island and the Lowendal Islands. Simulation of this spill scenario from the worst-case location indicated that slicks of floating condensate would most commonly drift backwards and forwards along a generally north-south axis with subsequent tidal changes, while undergoing net-drift with the prevailing winds. Slicks were predicted to have between  $7.2 \times 10^{-1}$  and  $1.0 \times 10^0$  chance, per incident, of washing onto some parts of the shorelines throughout the adjacent islands depending upon the season (Figure 40, Table 7). Taking account of the probability of such an incident occurring, the overall probability of shoreline exposure was estimated to be  $1.26 \times 10^{-4}$  per year (Table 7).

The highest probability of shoreline exposure ( $1.0 \times 10^0$  per incident), the largest potential shoreline area (81 km), and the highest potential volumes of condensate on shore ( $606 \text{ m}^3$ ) were predicted for winter when prevailing easterly winds would tend to force slicks onto Barrow Island. Shorelines of the Lowendal Islands and Montebello Islands were also predicted to potentially receive condensate during winter. The lighter and more variable winds during the transitional months (April and September) were predicted to increase the risk of exposure to the Lowendal Islands but reduce the risk of exposure to the west coast of Barrow Island. Slicks were still predicted to most commonly drift along a north-south axis with the prevailing tidal currents under summer wind conditions. However, the high frequency of winds from the southeast were expected to increase the probability that slicks would drift to the east and pass south of the Lowendal Islands, with the effect that the probability of exposure to shorelines, the average length of affected shoreline and the average volume of stranding condensate were predicted to be lower (Table 7).

A pressurised release of condensate from the export pipeline was predicted to generate relatively high concentrations of dissolved aromatic hydrocarbons within the channel between Barrow Island and the Lowendal Islands, particularly within the intertidal and shallow-subtidal areas along the east coast of Barrow Island (Figures 41 and 42). Peak concentrations predicted for these habitats were of the order of 10-30 ppm, while the average predicted concentrations among simulations were 1-3 ppm. Highest expected concentrations in each case were during winter, when near-surface currents set up by easterly winds tended to result in accumulation along the eastern shore of Barrow Island. The average peak dosage (concentration accumulated over time, averaged among simulations) of aromatic hydrocarbons within the shallow intertidal areas inshore of the discharge were predicted to be approximately 33 ppm-hrs (maximum = 60 ppm-hrs), indicating a potential for toxicity to resident biota.

### 5.3 Releases from a grounded tanker

Export tankers that are arriving or leaving the Barrow Island tanker terminal could potentially be carrying bulk quantities of condensate, crude oil from other sources and bunker oil, as fuel for the ships' engines. Modelling considered risks from each of these oil types, assuming a non-pressurised release of oil at or near the water surface following grounding of a tanker upon adjacent reefs. The risk of such an incident occurring was estimated to be  $1.97 \times 10^{-4}$  per year. Simulations indicated that the assumed spill conditions would result in higher losses of the volatile components to the atmosphere, including volatile aromatic compounds, than would occur from a subsea release. Dissolution of remaining soluble components into the water column would also tend to occur more slowly, except where entrainment rates were high due to high wave energy. The persistence of surface-bound oil was predicted to vary with the oil type. Surface spills of Gorgon condensate were predicted to persist for less than three days while a proportion of a crude oil or bunker oil would persist indefinitely without evaporating.

Stochastic modelling indicated that spills of hydrocarbon from a grounded and holed tanker in the vicinity of the tanker terminal would have between  $2.5 \times 10^{-1}$  and  $9.9 \times 10^{-1}$  chance, per incident, of contacting surrounding shorelines depending upon the oil type and the season (Tables 7 and 8; Figures 43 to 51). Taking account of the risk of such an incident occurring in the first place, the risk of shoreline oiling from a grounded tanker is estimated to range between  $1.06 \times 10^{-4}$  and  $1.45 \times 10^{-4}$  per annum.

Shorelines and shallow habitats throughout the Barrow Island, Lowendal Islands and Montebello Islands chain are expected to be in range of spills of the three hydrocarbon types from adjacent to the tanker terminal. Shorelines along parts of the mainland and the islands inshore of these islands were also predicted to be at some risk ( $> 1 \times 10^{-2}$  per incident) of receiving floating oil that was thicker than rainbow sheen. These risks were predicted to vary depending upon the oil type that was lost and the prevailing season. Factors associated with the oil type that affected these risks included the spreading rate of the oils (a function of the viscosity) and the rates of evaporation (a function of the volatility of the oil components). The condensate spills were predicted to spread faster, increasing the areas that were potentially affected by some oil, but reducing the loads that were involved. In contrast, a heavy bunker fuel was predicted to spread and evaporate more slowly so that higher loads could potentially come ashore from a given spill.

During summer and the transitional months, the most likely grounding site predicted for a tanker that drifts from the tanker terminal without power was on the north-east side of the tanker terminal. Slicks of floating oil from this area were expected to most commonly drift to the northeast, passing to the south of the Lowendal Islands. However, shorelines of the Lowendal group were predicted to have up to  $2.0 \times 10^{-1}$  chance per incident of exposure depending upon the oil type. Exposure of shorelines along the eastern coast of Barrow was predicted at up to  $1.0 \times 10^{-1}$  probability. Potential loads on shorelines predicted for bunker fuel, crude oil and condensate spills were estimated to be up to 39%, 18% and 6% of the spill volume, respectively. Aromatic hydrocarbons shed from the slicks were predicted to most commonly expose the shallow pavement areas and bommie fields to the south and south east of the Lowendal Islands during these seasons, at concentrations up to 500 ppb.

Under winter winds, the shallow ground west of the tanker terminal was predicted to be the most likely grounding site and slicks are most likely to drift with the strong current operating within the Barrow Island channel, before traversing west around the north or

south ends of Barrow Island. Consequently, Barrow Island was predicted to have the highest risk of exposure ( $5.0 \times 10^{-1}$  -  $7.0 \times 10^{-1}$  per event). However, other shorelines throughout the adjacent islands were also predicted to be at some risk. Potential shore loads were predicted to be up to 50% of the spill volume for a bunker fuel spill and 12% for a condensate spill (Table 7). Subsurface plumes of aromatic hydrocarbons were predicted to most commonly affect the east coast of Barrow Island (at up to 260 ppb), and potentially reach Barrow Island shoals (at  $> 10$  ppb).

## 5.4 Diesel spills from operational vessels

Diesel spills onto water tend to spread rapidly and to entrain readily. Diesel fuel is also unusual in that the toxicity of the oil is not directly related to the aromatic content, but is thought to relate to other less volatile components within the entrained oil (French 2000). Thus, concentrations of entrained diesel are more indicative of the potential for toxicity to submerged habitats than are concentrations of aromatic compounds. Modelling considered spills of diesel from various sources off the east and west coasts of Barrow Island.

The risk of a diesel spill occurring during refuelling of the pipe-laying barge from a support vessel has been estimated as  $4.1 \times 10^{-2}$  per year, assuming 10 refuelling operations occur within an 8-month period. Risks of exposure to shoreline habitats from either surface oil or entrained oil due to a refuelling spill off the west coast were predicted to decrease with distance offshore (Figures 52 to 54), especially during summer (Table 7). The rate of contact with shorelines during summer at concentrations exceeding a silver sheen ( $0.1 \text{ g/m}^2$ ) was predicted to be  $8.4 \times 10^{-1}$  per incident at 2.5 km offshore,  $6.0 \times 10^{-1}$  per incident at 5 km offshore and  $1.6 \times 10^{-1}$  per incident at 10 km offshore, indicating that there is a reduction of risks to shorelines with increasing distance from shore and that distances of 10 km or more would be appropriate to achieve a significant reduction of risk. The overall risk of exposure to shorelines from a refuelling incident from 10 km offshore was predicted to be  $6.29 \times 10^{-3}$  (assuming pipe laying operations do not extend beyond 1 year). The longer time required for diesel to drift onto shore from 10 km offshore was predicted to increase the potential for effective dispersal of entrained and floating diesel before exposing shallow waters off Barrow Island or the adjacent islands.

It is anticipated that diesel fuel will be transferred from supply vessels to the MOF Jetty twice per year and the probability of a spill occurring during these operations has been estimated at the rate of  $9.0 \times 10^{-3}$  per year (Appendix B4). Stochastic modelling indicated that a small diesel spill from the MOF Jetty should not travel more than about 12 km before entraining and dispersing to a rainbow sheen, but could potentially affect a larger area either as a silver sheen or as surface entrained diesel (Figure 55). Diesel was predicted to most commonly drift along a north-south axis with the strong currents acting along the Barrow Island channel. Wind driven currents during winter and the transitional months are expected to force plumes of entrained diesel against the shore resulting in highest concentrations (up to 2.4 ppm) within the shallow waters along the east coast of Barrow Island. Accounting for the probability of a spill occurring in the first place, the probability of exposure to shorelines from refuelling operations at the MOF are estimated to be  $5.3 \times 10^{-5}$  per annum. A higher risk of exposure to the shallow pavement areas west of the Lowendal Islands was predicted for summer.

**Table 7: Estimated risk of shoreline contact for defined spill scenarios. Results are for oil concentrations exceeding 0.3 g/m<sup>2</sup>, equivalent of a coloured sheen. Primary risks use annual rates from Appendix B4 and expressed as seasonal rates based on the number of months in summer (6), Winter (4) and transitional (2) seasons. Secondary risk is per event. The Joint risk is calculated as the product of the primary and secondary risk and is per year of operation for the nominated location.**

Spill Scenario			Risk estimates			Shoreline exposed (km)			Volume on shore (m <sup>3</sup> )			
Spill source	Season	Spilled fluid	Volume	Primary	Secondary	Joint	Maximum	Mean	St. dev.	Maximum	Mean	St. dev.
Rupture at Central manifold	Summer	Condensate	2172	7.50 x 10 <sup>-5</sup> y <sup>-1</sup>	<1 x 10 <sup>-2</sup>	<7.50 x 10 <sup>-7</sup>	NC	NC	NC	NC	NC	NC
	Annual	Condensate	2172	1.50 x 10 <sup>-4</sup> y <sup>-1</sup>	NT	NT	NT	NT	NT	NT	NT	NT
Rupture of supply gas pipeline 14km from Barrow Island on route 1	Summer	Condensate	1621	1.41 x 10 <sup>-5</sup> km <sup>-1</sup> y <sup>-1</sup>	3.4 x 10 <sup>-1</sup>	4.78 x 10 <sup>-6</sup>	23.4	2.8 ± 6.0	1.0 ± 0.2	26.2	1.0 ± 0.2	
	Transitional	Condensate	1621	4.68 x 10 <sup>-6</sup> km <sup>-1</sup> y <sup>-1</sup>	1.8 x 10 <sup>-1</sup>	8.43 x 10 <sup>-7</sup>	31.2	1.7 ± 5.4	0.4 ± 0.1	24.2	0.4 ± 0.1	
	Winter	Condensate	1621	9.37 x 10 <sup>-6</sup> km <sup>-1</sup> y <sup>-1</sup>	<1 x 10 <sup>-2</sup>	9.37 x 10 <sup>-8</sup>	NC	NC	NC	NC	NC	
Rupture of supply gas pipeline 14km from Barrow Island on route 2	Annual	Condensate	1621	2.81 x 10 <sup>-5</sup> km <sup>-1</sup> y <sup>-1</sup>	2.0 x 10 <sup>-1</sup>	5.71 x 10 <sup>-6</sup>						
	Summer	Condensate	1621	1.41 x 10 <sup>-5</sup> km <sup>-1</sup> y <sup>-1</sup>	6.3 x 10 <sup>-1</sup>	8.80 x 10 <sup>-6</sup>	21.2	4.5 ± 5.9	0.7 ± 0.1	27.5	0.7 ± 0.1	
	Transitional	Condensate	1621	4.68 x 10 <sup>-6</sup> km <sup>-1</sup> y <sup>-1</sup>	1.2 x 10 <sup>-1</sup>	5.62 x 10 <sup>-7</sup>	9.5	0.7 ± 2.4	0.2 ± 0.05	12.5	0.2 ± 0.05	
Rupture of supply gas pipeline 200 m from Barrow Island on route 1	Winter	Condensate	1621	9.37 x 10 <sup>-6</sup> km <sup>-1</sup> y <sup>-1</sup>	4.0 x 10 <sup>-2</sup>	3.75 x 10 <sup>-7</sup>	6.7	0.3 ± 1.3	< 0.001	< 0.05	< 0.001	
	Annual	Condensate	1621	2.81 x 10 <sup>-5</sup> km <sup>-1</sup> y <sup>-1</sup>	3.5 x 10 <sup>-1</sup>	9.79 x 10 <sup>-6</sup>						
	Summer	Condensate	1621	1.41 x 10 <sup>-5</sup> km <sup>-1</sup> y <sup>-1</sup>	9.9 x 10 <sup>-1</sup>	1.39 x 10 <sup>-5</sup>	43.4	14.4 ± 6.3	129.4 ± 25.9	158.6	129.4 ± 25.9	
Rupture of export pipeline 2.2 km from Barrow Island	Transitional	Condensate	1621	4.68 x 10 <sup>-6</sup> km <sup>-1</sup> y <sup>-1</sup>	1.0 x 10 <sup>-0</sup>	4.68 x 10 <sup>-6</sup>	37.9	15.6 ± 6.9	75.9 ± 10.4	116.6	75.9 ± 10.4	
	Winter	Condensate	1621	9.37 x 10 <sup>-6</sup> km <sup>-1</sup> y <sup>-1</sup>	9.6 x 10 <sup>-1</sup>	8.99 x 10 <sup>-6</sup>	20.6	9.3 ± 5.3	12.8 ± 3.6	39.1	12.8 ± 3.6	
	Annual	Condensate	1621	2.81 x 10 <sup>-5</sup> km <sup>-1</sup> y <sup>-1</sup>	9.8 x 10 <sup>-1</sup>	2.76 x 10 <sup>-5</sup>						
Rupture of export pipeline 2.2 km from Barrow Island	Summer	Condensate	1565	7.40 x 10 <sup>-5</sup> km <sup>-1</sup> y <sup>-1</sup>	7.2 x 10 <sup>-1</sup>	5.33 x 10 <sup>-5</sup>	57.9	10.2 ± 15.0	3.8 ± 1.1	22.4	3.8 ± 1.1	
	Transitional	Condensate	1565	2.47 x 10 <sup>-5</sup> km <sup>-1</sup> y <sup>-1</sup>	9.6 x 10 <sup>-1</sup>	2.37 x 10 <sup>-5</sup>	49.6	24.5 ± 13.5	33.8 ± 8.6	47.8	33.8 ± 8.6	
	Winter	Condensate	1565	4.93 x 10 <sup>-5</sup> km <sup>-1</sup> y <sup>-1</sup>	1.0 x 10 <sup>-0</sup>	4.93 x 10 <sup>-5</sup>	81.3	32.4 ± 17.9	295 ± 137	605.8	295 ± 137	
Refuelling accident 10 km west of Barrow Island	Annual	Condensate	1565	1.48 x 10 <sup>-4</sup> km <sup>-1</sup> y <sup>-1</sup>	8.5 x 10 <sup>-1</sup>	1.26 x 10 <sup>-4</sup>						
	Summer	Diesel	2.5	2.05 x 10 <sup>-2</sup> y <sup>-1</sup>	1.6 x 10 <sup>-1</sup>	3.28 x 10 <sup>-3</sup>	5.5	0.5 ± 1.3	0.006 ± 0.02	0.09	0.006 ± 0.02	
	Transitional	Diesel	2.5	6.83 x 10 <sup>-3</sup> y <sup>-1</sup>	1.2 x 10 <sup>-1</sup>	8.20 x 10 <sup>-4</sup>	7.1	0.6 ± 1.8	0.005 ± 0.01	0.06	0.005 ± 0.01	
Refuelling accident 10 km west of Barrow Island	Winter	Diesel	2.5	1.37 x 10 <sup>-2</sup> y <sup>-1</sup>	1.6 x 10 <sup>-1</sup>	2.19 x 10 <sup>-3</sup>	5.8	0.7 ± 1.8	0.012 ± 0.03	0.10	0.012 ± 0.03	
	Annual	Diesel	2.5	4.1 x 10 <sup>-2</sup> y <sup>-1</sup>	1.5 x 10 <sup>-1</sup>	6.29 x 10 <sup>-3</sup>						

**Table 7: Continued**

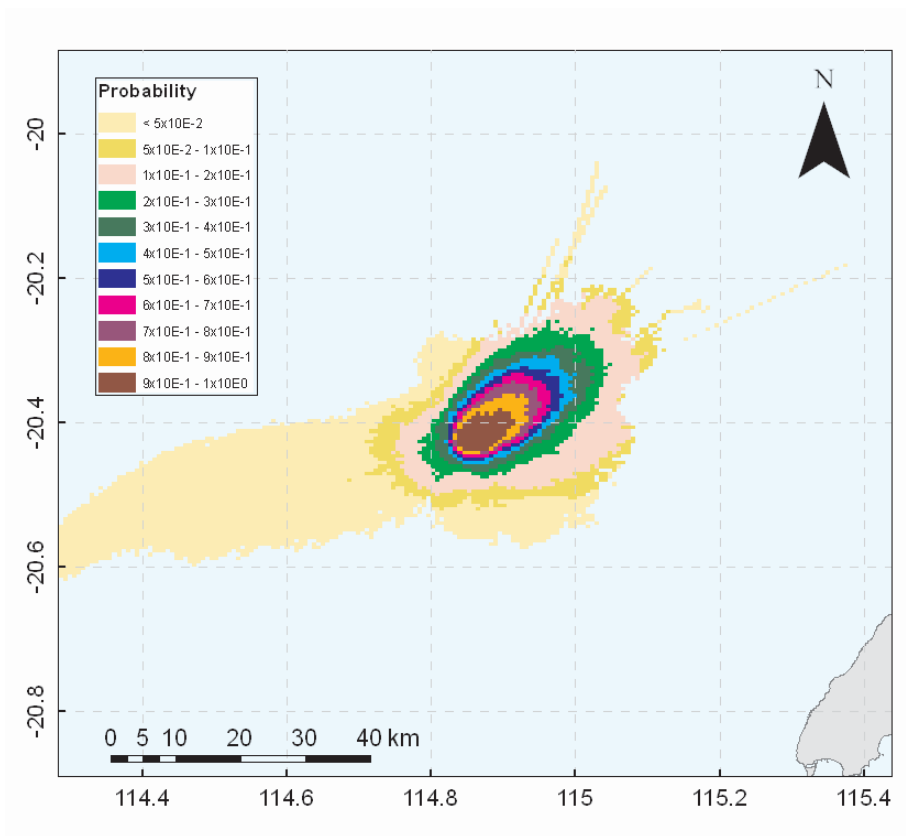
Spill Scenario			Risk estimates			Shoreline exposed (km)		Volume on shore (m <sup>3</sup> )		
Spill source	Season	Spilled fluid	Volume	Primary	Secondary	Joint (pa)	Maximum	Mean $\pm$ St. dev.	Maximum	Mean $\pm$ St. dev.
Refuelling accident 5 km west of Barrow. Island	Summer	Diesel	2.5	$2.05 \times 10^{-2} \text{ y}^{-1}$	$6.0 \times 10^{-1}$	$1.23 \times 10^{-2}$	6.8	$3.0 \pm 1.6$	0.1	$0.04 \pm 0.05$
	Transitional	Diesel	2.5	$6.83 \times 10^{-3} \text{ y}^{-1}$	$1.6 \times 10^{-1}$	$1.09 \times 10^{-3}$	4.8	$0.4 \pm 1.2$	0.05	$0.004 \pm 0.01$
	Winter	Diesel	2.5	$1.37 \times 10^{-2} \text{ y}^{-1}$	$8.0 \times 10^{-2}$	$1.09 \times 10^{-3}$	5.5	$0.3 \pm 1.2$	0.1	$0.006 \pm 0.02$
	Annual	Diesel	2.5	$4.10 \times 10^{-2} \text{ y}^{-1}$	$3.5 \times 10^{-1}$	$1.45 \times 10^{-2}$				
Refuelling accident 2.5 km west Barrow Island	Summer	Diesel	2.5	$2.05 \times 10^{-2} \text{ y}^{-1}$	$8.4 \times 10^{-1}$	$1.72 \times 10^{-2}$	6.8	$2.1 \pm 2.4$	0.1	$0.08 \pm 0.06$
	Transitional	Diesel	2.5	$6.83 \times 10^{-3} \text{ y}^{-1}$	$7.2 \times 10^{-1}$	$4.92 \times 10^{-3}$	6.1	$2.6 \pm 2.1$	0.1	$0.06 \pm 0.05$
	Winter	Diesel	2.5	$1.37 \times 10^{-2} \text{ y}^{-1}$	$1.6 \times 10^{-1}$	$2.19 \times 10^{-3}$	5.0	$0.6 \pm 1.5$	0.1	$0.01 \pm 0.04$
	Annual	Diesel	2.5	$4.10 \times 10^{-2} \text{ y}^{-1}$	$5.9 \times 10^{-1}$	$2.43 \times 10^{-2}$				
Spill alongside MOF Jetty	Summer	Diesel	0.1-10*	$4.50 \times 10^{-3} \text{ y}^{-1}$	$8.4 \times 10^{-1}$	$3.78 \times 10^{-3}$	17.8	$3.6 \pm 3.8$	0.5	$0.2 \pm 0.2$
	Transitional	Diesel	0.1-10*	$1.50 \times 10^{-3} \text{ y}^{-1}$	$7.2 \times 10^{-1}$	$1.08 \times 10^{-3}$	21.7	$4.8 \pm 4.2$	0.5	$0.4 \pm 0.1$
	Winter	Diesel	0.1-10*	$3.00 \times 10^{-3} \text{ y}^{-1}$	$1.6 \times 10^{-1}$	$4.80 \times 10^{-4}$	30.6	$6.6 \pm 5.0$	0.5	$0.4 \pm 0.1$
	Annual	Diesel	0.1-10*	$9.0 \times 10^{-3} \text{ y}^{-1}$	$5.9 \times 10^{-1}$	$5.34 \times 10^{-3}$				
Spill from grounded tanker adjacent tanker terminal	Summer	Bunker Fuel oil	10-100*	$1.17 \times 10^{-5} \text{ y}^{-1}$	$3.2 \times 10^{-1}$	$3.74 \times 10^{-6}$	31.8	$3.5 \pm 7.2$	39.0	$3.6 \pm 2.8$
	Transitional	Bunker Fuel oil	10-100*	$3.90 \times 10^{-6} \text{ y}^{-1}$	$6.8 \times 10^{-1}$	$2.65 \times 10^{-6}$	47.3	$9.9 \pm 12.6$	34.9	$9.1 \pm 7.9$
	Winter	Bunker Fuel oil	10-100*	$7.80 \times 10^{-6} \text{ y}^{-1}$	$9.5 \times 10^{-1}$	$7.41 \times 10^{-6}$	50.7	$20.2 \pm 9.8$	46.9	$27.4 \pm 12.5$
	Annual	Bunker Fuel oil	10-100*	$2.34 \times 10^{-5} \text{ y}^{-1}$	$5.9 \times 10^{-1}$	$1.38 \times 10^{-5}$				
Spill from grounded tanker adjacent tanker terminal	Summer	Condensate	10-100*	$1.17 \times 10^{-5} \text{ y}^{-1}$	$2.5 \times 10^{-1}$	$2.93 \times 10^{-6}$	37.3	$2.0 \pm 6.0$	5.9	$0.3 \pm 1.0$
	Transitional	Condensate	10-100*	$3.90 \times 10^{-6} \text{ y}^{-1}$	$5.7 \times 10^{-1}$	$2.22 \times 10^{-6}$	40.6	$6.7 \pm 10.1$	8.8	$1.4 \pm 2.2$
	Winter	Condensate	10-100*	$7.80 \times 10^{-6} \text{ y}^{-1}$	$9.5 \times 10^{-1}$	$7.41 \times 10^{-6}$	60.7	$17.4 \pm 11.2$	11.6	$6.5 \pm 3.5$
	Annual	Condensate	10-100*	$2.34 \times 10^{-5} \text{ y}^{-1}$	$5.4 \times 10^{-1}$	$1.26 \times 10^{-5}$				
Spill from grounded tanker adjacent tanker terminal	Summer	Light crude oil	10-100*	$1.17 \times 10^{-5} \text{ y}^{-1}$	$5.1 \times 10^{-1}$	$5.97 \times 10^{-6}$	56.2	$7.7 \pm 13.2$	18.2	$2.0 \pm 4.7$
	Transitional	Light crude oil	10-100*	$3.90 \times 10^{-6} \text{ y}^{-1}$	$9.1 \times 10^{-1}$	$3.55 \times 10^{-6}$	70.2	$18.1 \pm 19.1$	18.4	$5.8 \pm 6.6$
	Winter	Light crude oil	10-100*	$7.80 \times 10^{-6} \text{ y}^{-1}$	$9.9 \times 10^{-1}$	$7.72 \times 10^{-6}$	69.6	$24.5 \pm 11.6$	19.8	$15.2 \pm 5.3$
	Annual	Light crude oil	10-100*	$2.34 \times 10^{-5} \text{ y}^{-1}$	$7.4 \times 10^{-1}$	$1.72 \times 10^{-5}$				

**Table 8 : Estimates for the maximum and mean concentrations of aromatic hydrocarbons and total hydrocarbons (for diesel spills) that could occur within inshore waters. Values in italics are for total hydrocarbons.**

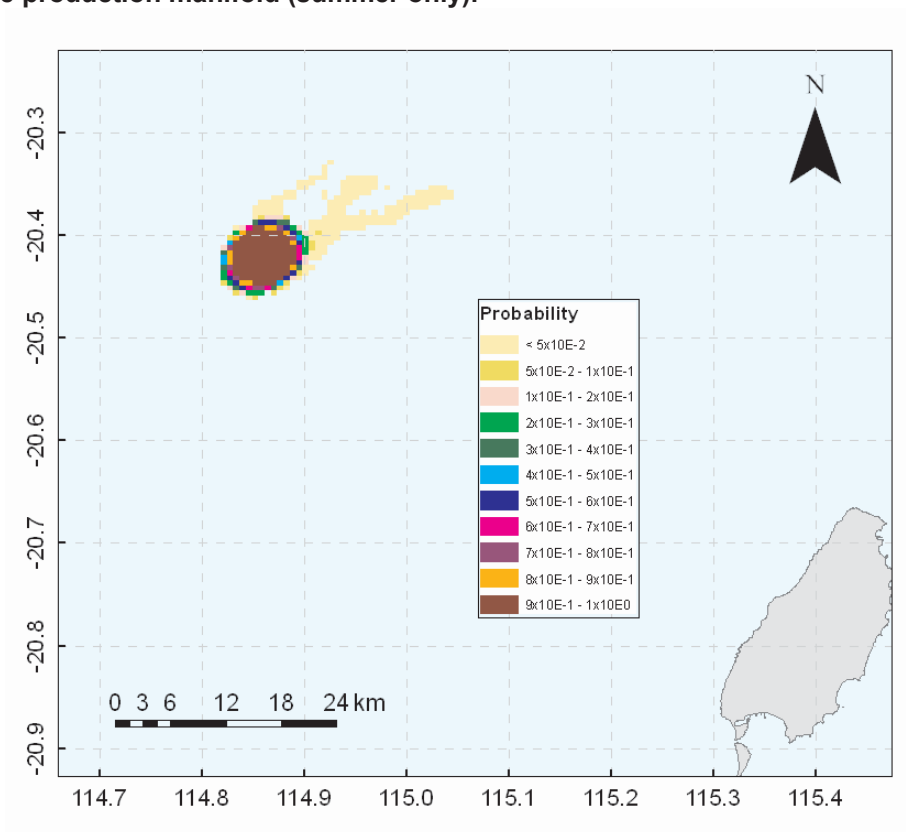
Spill Scenario	Spill			Concentration within inshore waters (ppb)		
	Season	Spilled fluid	Volume (m <sup>3</sup> )	Maximum	Mean	
Rupture at Central manifold	Summer	Condensate	2172	NC	NC	
Rupture of supply gas pipeline	Summer	Condensate	1621	1,754 (Montes)	29 (Montes)	
14km from B.I. on route 1	Transitional	Condensate	1621	280 (Montes)	6 (Montes)	
	Winter	Condensate	1621	NC	NC	
Rupture of supply gas pipeline	Summer	Condensate	1621	866 (Montes)	27 (Montes)	
14km from B.I. on route 2	Transitional	Condensate	1621	NC	NC	
	Winter	Condensate	1621	NC	NC	
Rupture of supply gas pipeline	Summer	Condensate	1621	4,524 (Barrow, west)	2,534 (Barrow, west)	
200 m from B.I. on route 1	Transitional	Condensate	1621	3,677 (Barrow, west)	2,024 (Barrow, west)	
	Winter	Condensate	1621	2,820 (Barrow, west)	1,978 (Barrow, west)	
Rupture of export pipeline 2.2 km from B.I.	Summer	Condensate	1565	10,239 (Barrow, east)	965 (Barrow, east)	
	Transitional	Condensate	1565	31,808 (Barrow, east)	1,604 (Barrow, east)	
	Winter	Condensate	1565	15,130 (Barrow, east)	3,075 (Barrow, east)	
Refuelling accident 10 km west of B.I.	Summer	Diesel	2.5	92 (Montes)	6 (Montes)	
	Transitional	Diesel	2.5	103 (Barrow, west)	5 (Barrow, west)	
	Winter	Diesel	2.5	NC	NC	

**Table 8: Continued**

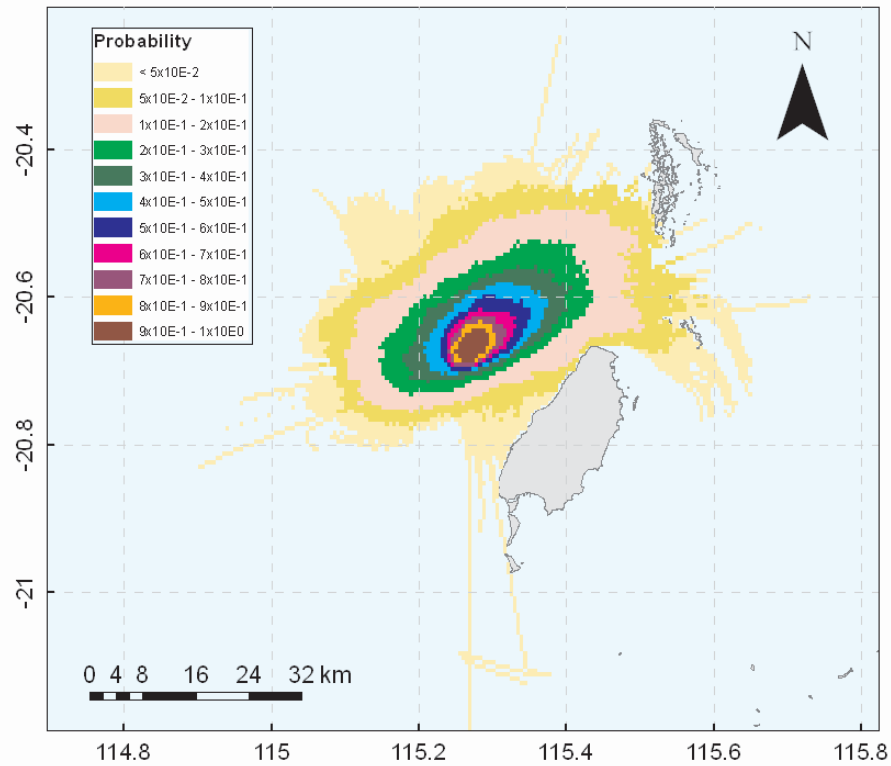
Spill Scenario	Spill			Concentration within inshore waters (ppb)		
	Season	Spilled fluid	Volume (m <sup>3</sup> )	Maximum	Mean	
Refuelling accident 5 km west of B. I.	Summer	Diesel	2.5	56 (Barrow, west)	4 (Barrow, west)	
	Transitional	Diesel	2.5	NC	NC	
	Winter	Diesel	2.5	NC	NC	
Refuelling accident 2.5 km west of B. I.	Summer	Diesel	2.5	440 (Montes)	11 (Barrow, west)	
	Transitional	Diesel	2.5	59 (Montes)	3 (Barrow, west)	
	Winter	Diesel	2.5	NC	NC	
Spill alongside MOF Jetty	Summer	Diesel	0.1-10*	1,888 (Barrow, east)	73 (Barrow, east)	
	Transitional	Diesel	0.1-10*	2,356 (Barrow, east)	140 (Barrow, east)	
	Winter	Diesel	0.1-10*	2,372 (Barrow, east)	160 (Barrow, east)	
Spill from vessel collision on approach to port	Summer	Diesel	2-20*	2,771 (Barrow, east)	32 (Barrow, east)	
	Transitional	Diesel	2-20*	8,055 (Barrow, east)	81 (Barrow, east)	
	Winter	Diesel	2-20*	3,808 (Barrow, east)	43 (Barrow, east)	
Spill from grounded tanker adjacent tanker terminal	Summer	Bunker Fuel oil	10-100*	16 (Barrow, east)	NC	
	Transitional	Bunker Fuel oil	10-100*	150 (Lowendal)	2 (Lowendal)	
	Winter	Bunker Fuel oil	10-100*	110 (Barrow, east)	4 (Lowendal)	
Spill from grounded tanker adjacent tanker terminal	Summer	Condensate	10-100*	26 (Lowendal)	NC	
	Transitional	Condensate	10-100*	43 (Double)	NC	
	Winter	Condensate	10-100*	117 (Barrow, east)	4 (barrow, east)	
Spill from grounded tanker adjacent tanker terminal	Summer	Light crude oil	10-100*	222 (Lowendal)	5 (Lowendal)	
	Transitional	Light crude oil	10-100*	79 (Barrow, east)	4 (Lowendal)	
	Winter	Light crude oil	10-100*	264 (Barrow, east)	8 (Barrow, east)	



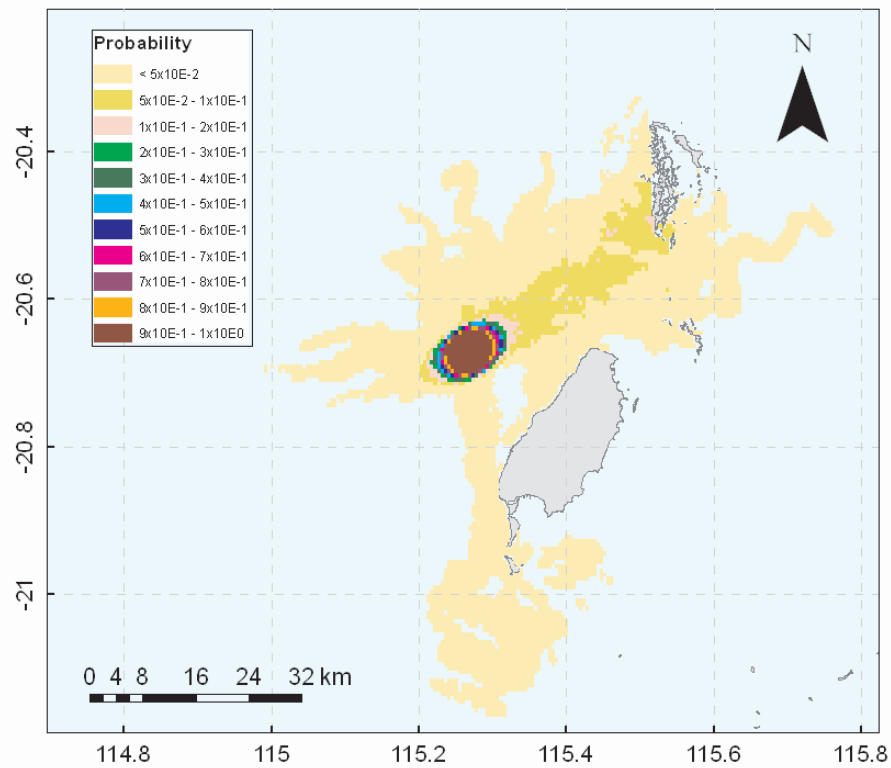
**Figure 29** Probability of contact by condensate (at >0.3 g/m<sup>2</sup>) given a rupture at the offshore production manifold (summer only).



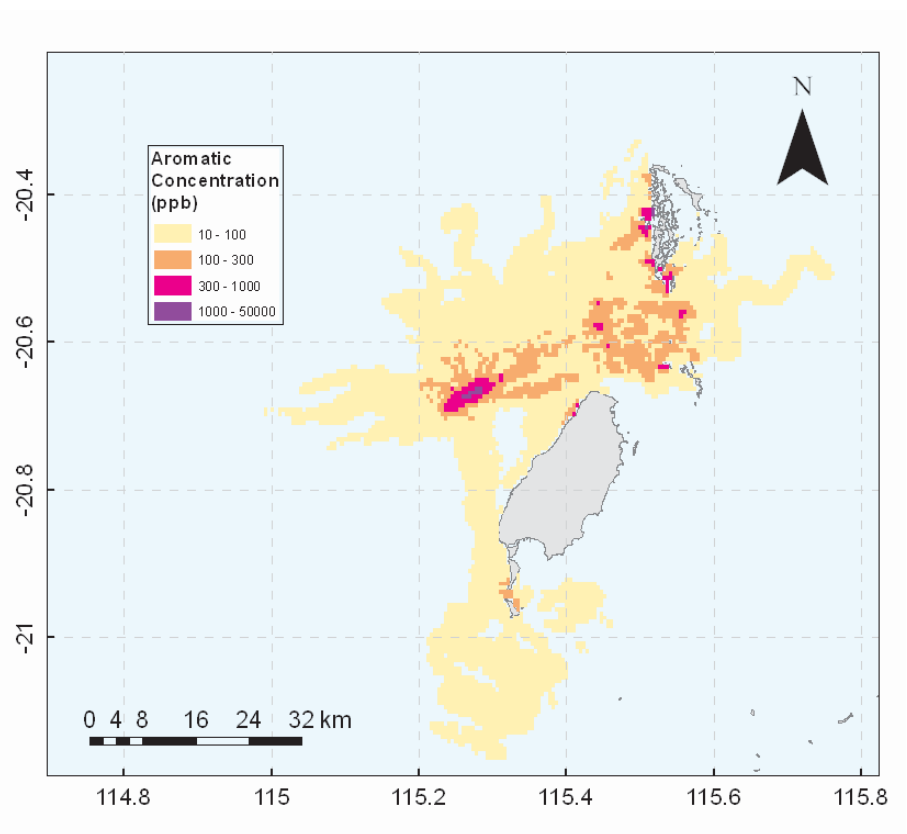
**Figure 30** Probability of contact by dissolved aromatic hydrocarbons (at >10 ppb) given a rupture at the offshore production manifold (summer only).



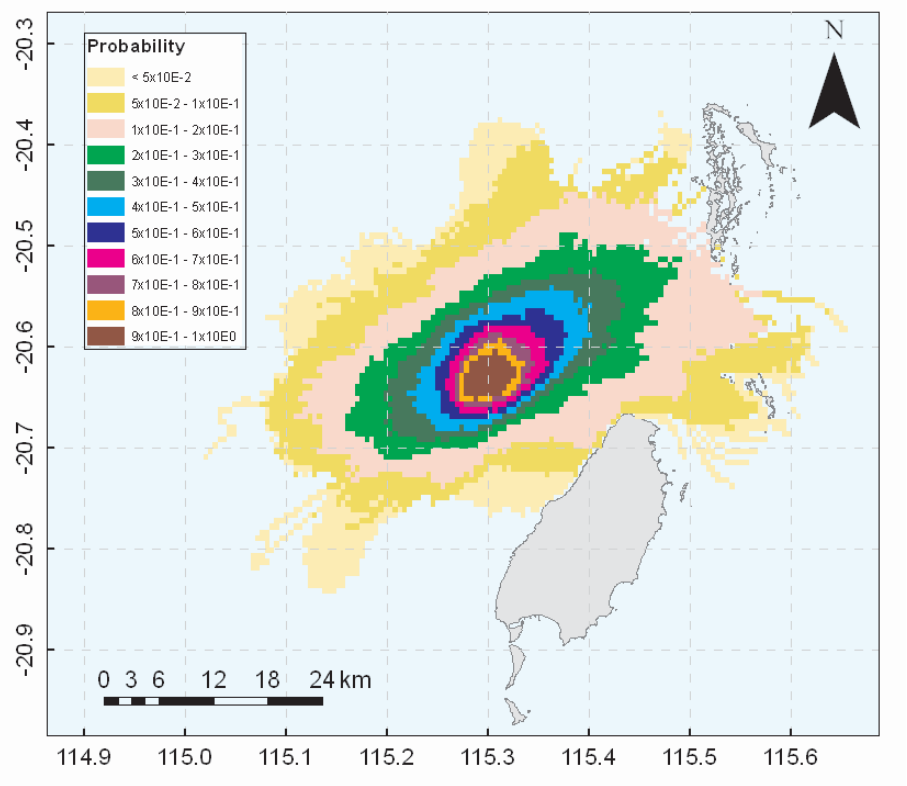
**Figure 31 Probability of contact by condensate (at >0.3 g/m<sup>2</sup>) given a rupture of the supply gas pipeline 14km off Barrow Island along route 1.**



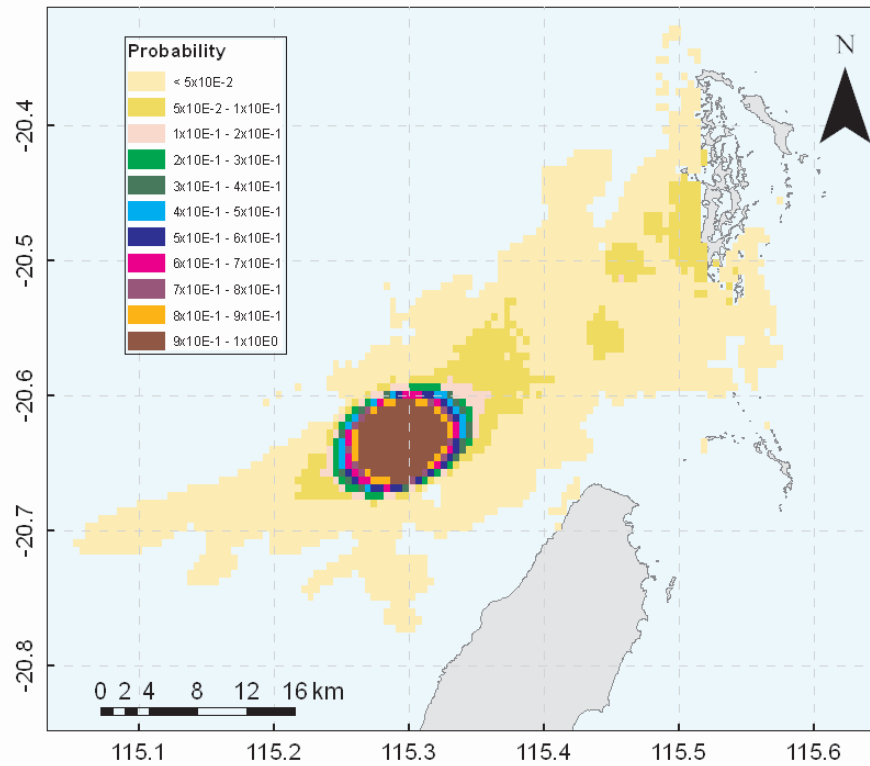
**Figure 32 Probability of contact by dissolved aromatic hydrocarbons (at >10 ppb) given a rupture of the supply gas pipeline 14km off Barrow Island along route 1.**



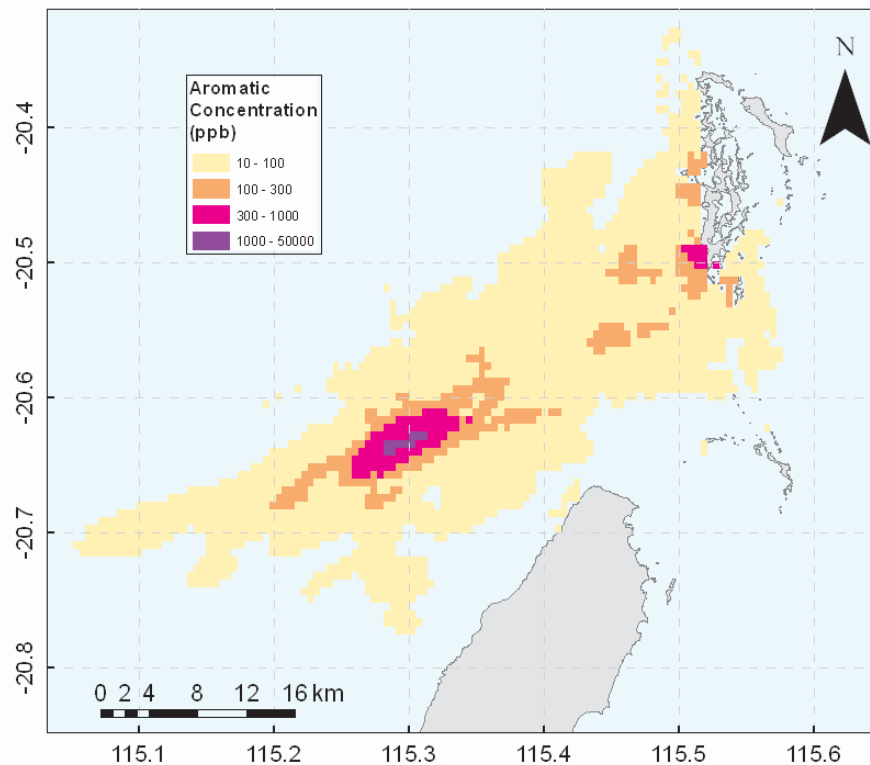
**Figure 33** Maximum potential concentrations of dissolved aromatic hydrocarbons given a rupture of the supply gas pipeline 14km off Barrow Island along route 1.



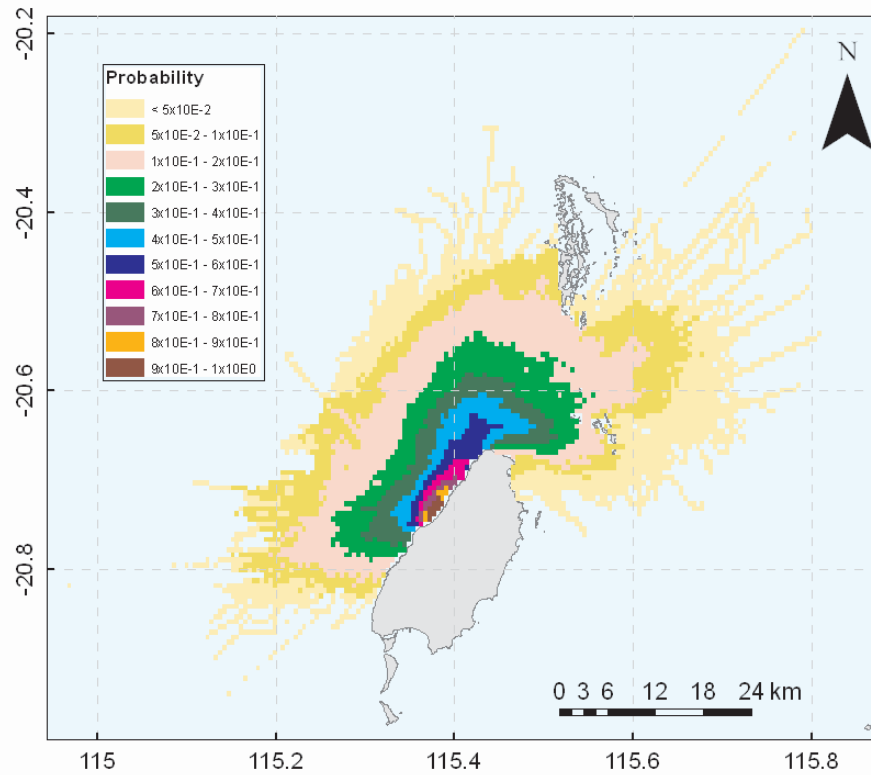
**Figure 34** Probability of contact by condensate (at >0.3 g/m<sup>2</sup>) given a rupture of the supply gas pipeline 14km off Barrow Island along route 2.



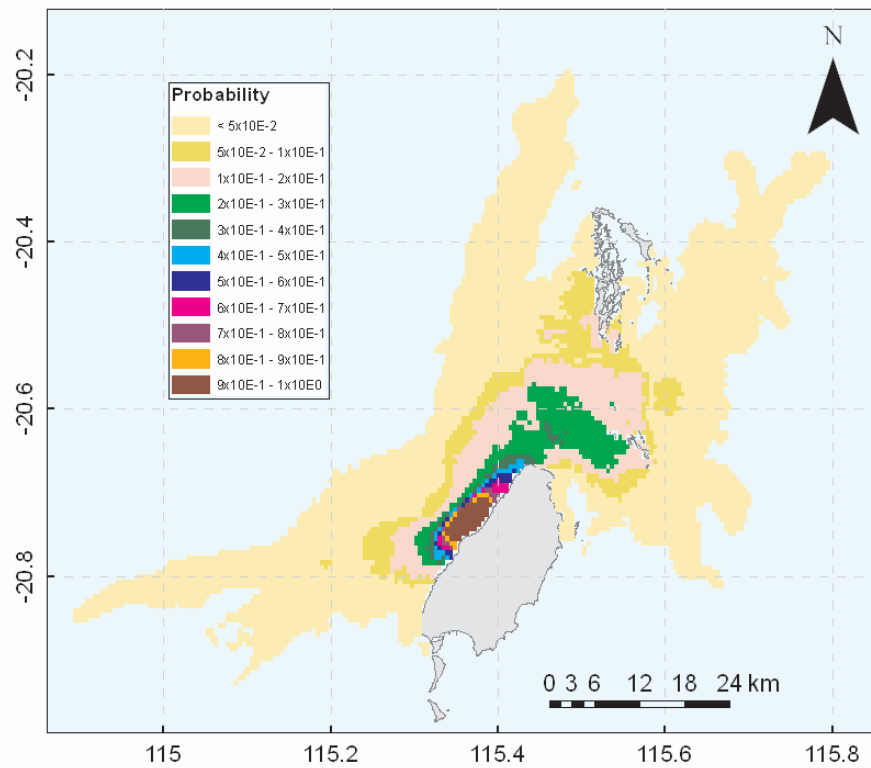
**Figure 35 Probability of contact by dissolved aromatic hydrocarbons (at >10 ppb) given a rupture of the supply gas pipeline 14km off Barrow Island along route 2.**



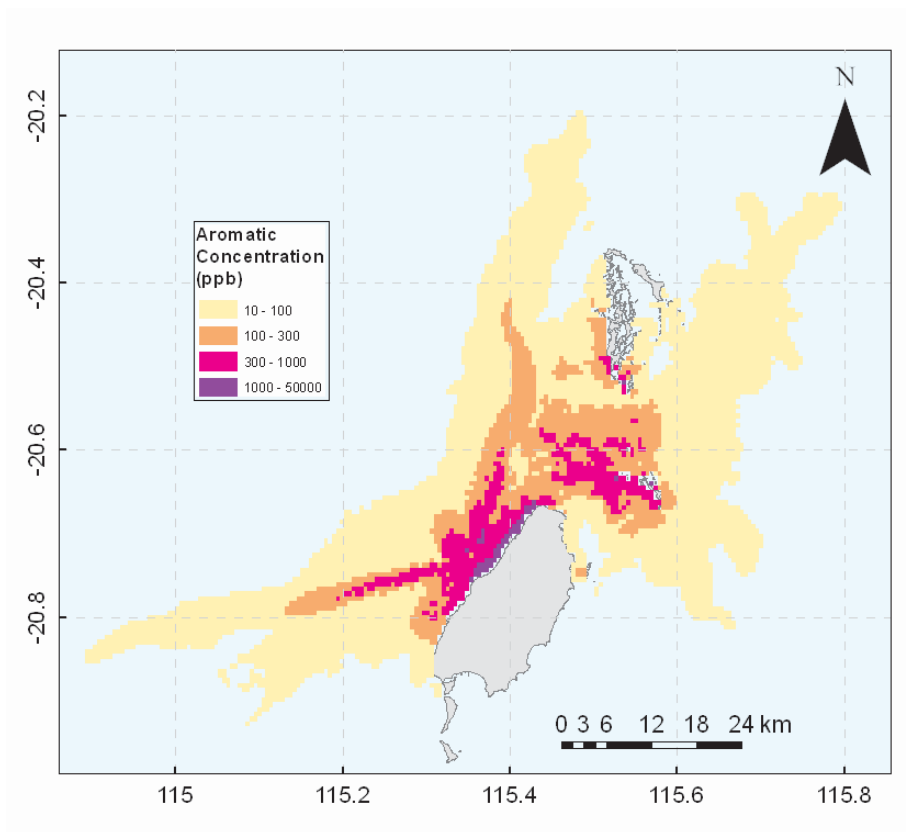
**Figure 36 Maximum potential concentrations of dissolved aromatic hydrocarbons given a rupture of the supply gas pipeline 14km off Barrow Island along route 1.**



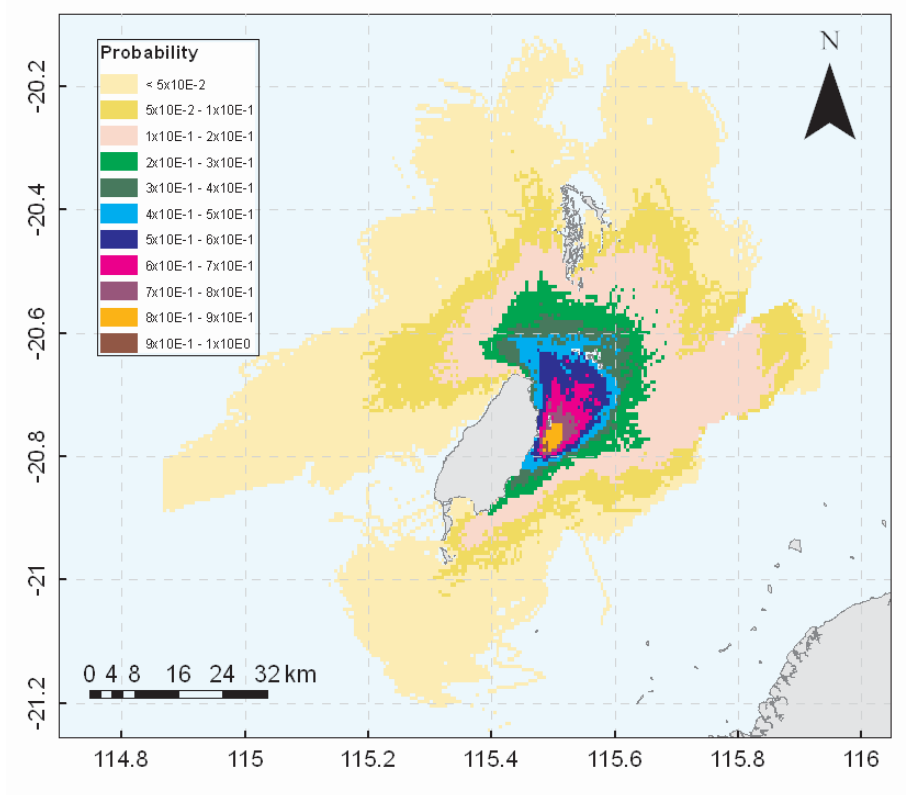
**Figure 37** Probability of contact by condensate (at >0.3 g/m<sup>2</sup>) given a rupture of the supply gas pipeline 200m off Barrow Island along route 1.



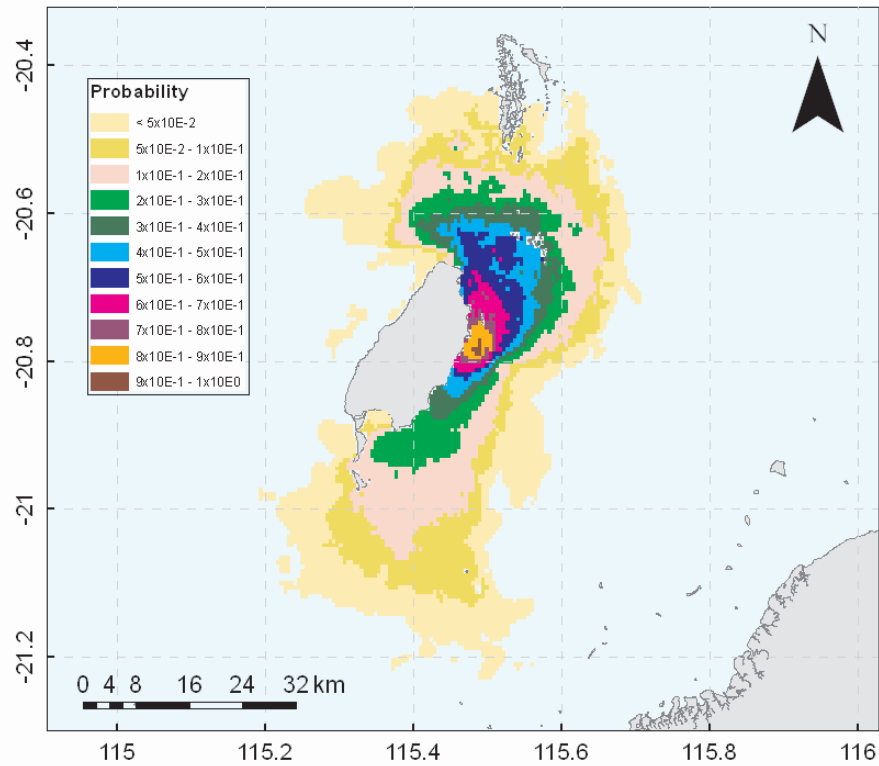
**Figure 38** Probability of contact by dissolved aromatic hydrocarbons (at >10 ppb) given a rupture of the supply gas pipeline 200m off Barrow Island along route 1.



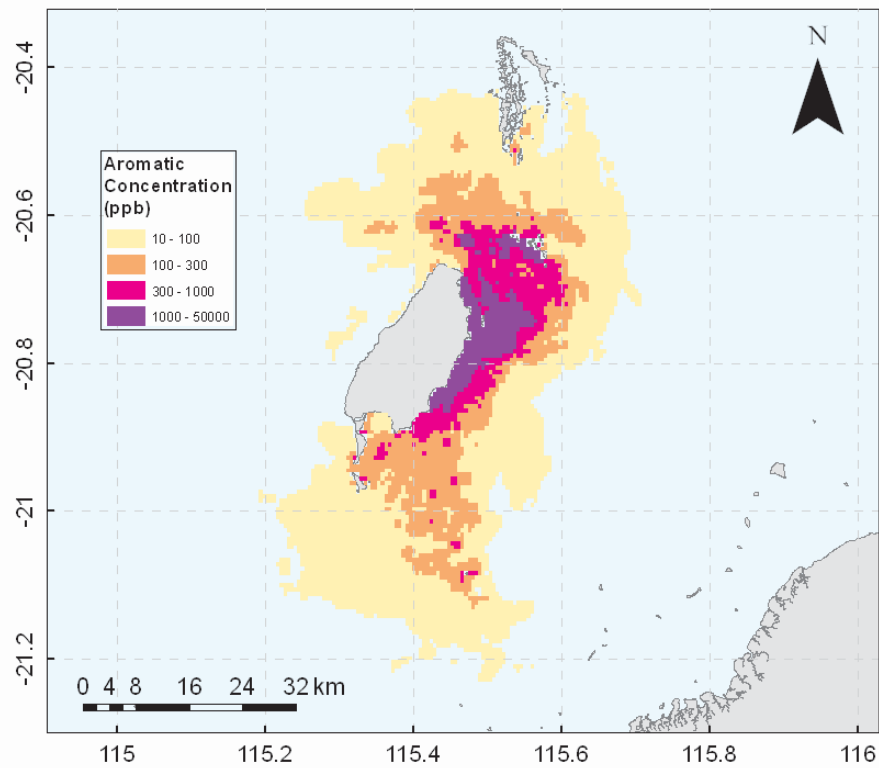
**Figure 39** Maximum potential concentrations of dissolved aromatic hydrocarbons given a rupture of the supply gas pipeline 200m off Barrow Island along route 1.



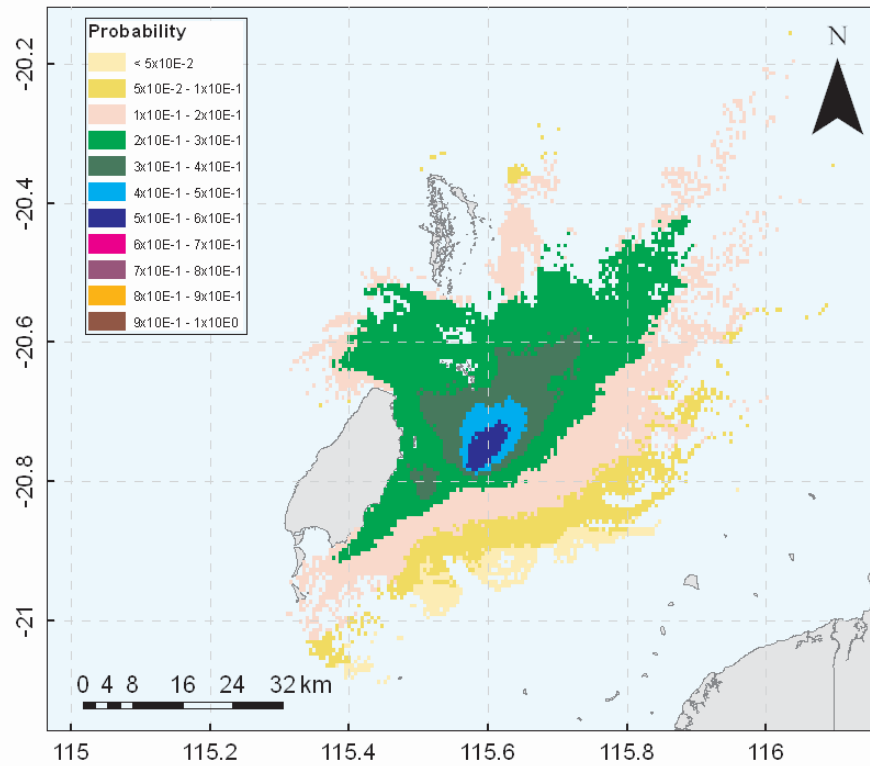
**Figure 40** Probability of contact by condensate (at  $>0.3 \text{ g/m}^2$ ) given a rupture of the condensate export pipeline.



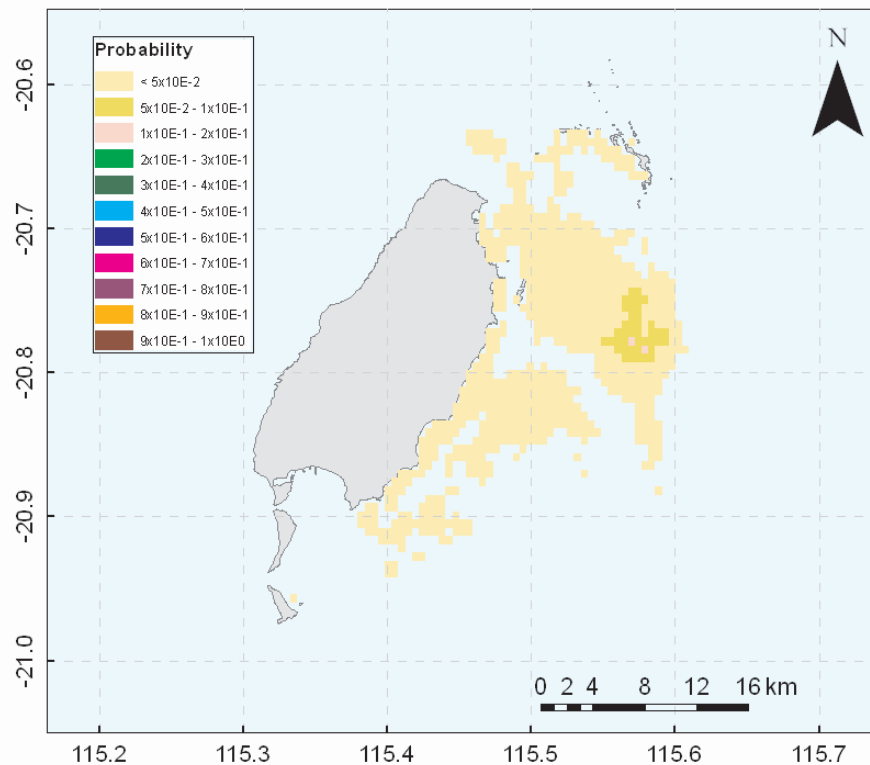
**Figure 41** Probability of contact by dissolved aromatic hydrocarbons (at >10 ppb) given a rupture of the condensate export pipeline.



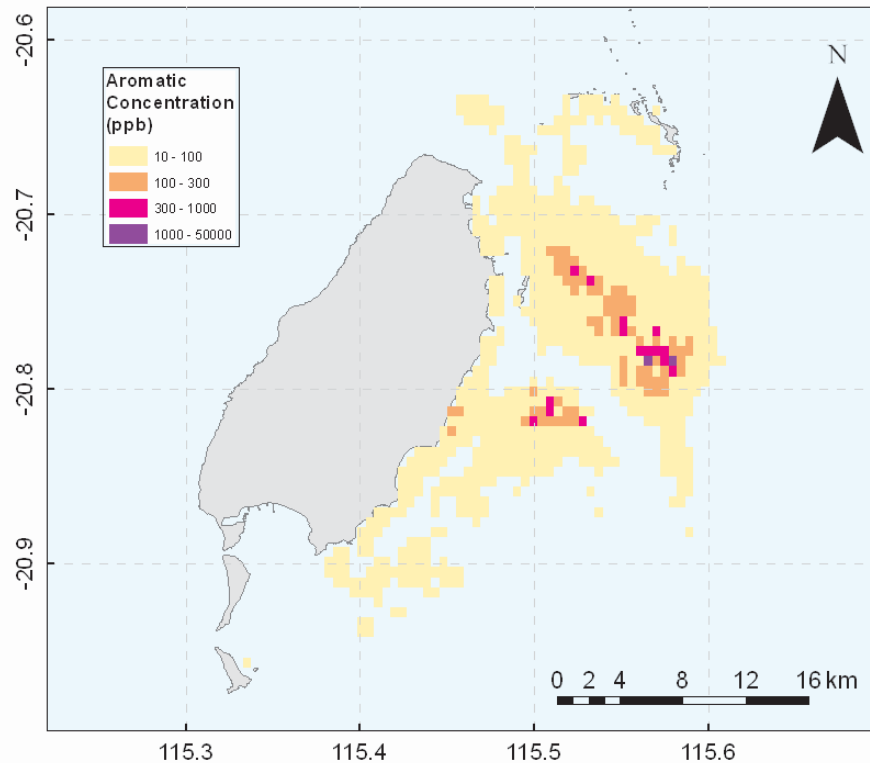
**Figure 42** Maximum potential concentrations of dissolved aromatic hydrocarbons given a rupture of the condensate export pipeline.



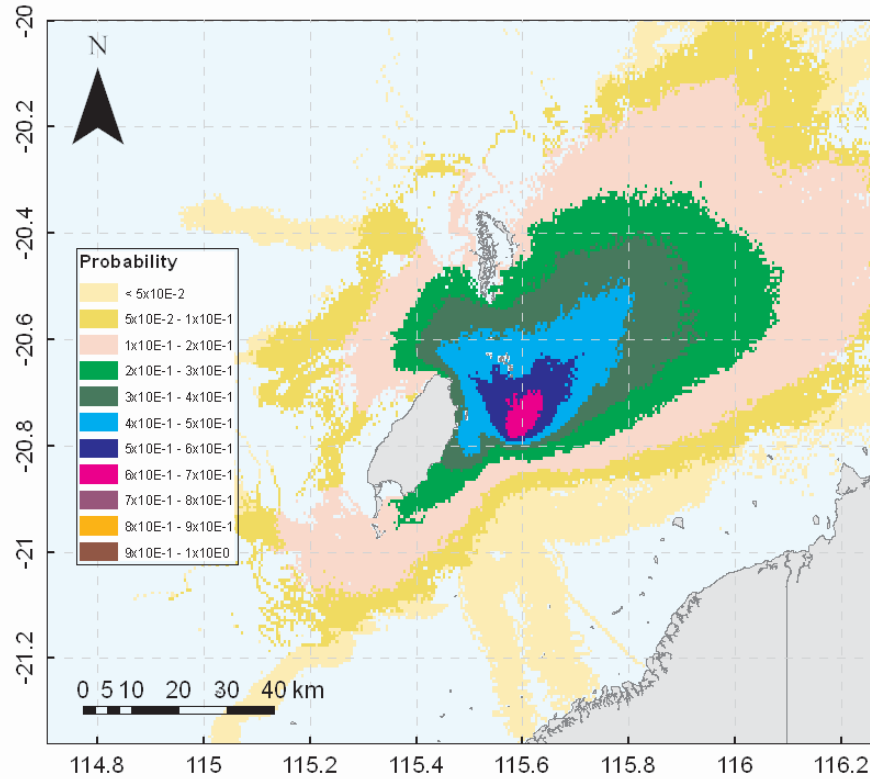
**Figure 43** Probability of contact by condensate (at  $>0.3 \text{ g/m}^2$ ) given condensate release from a tanker grounded adjacent the tanker terminal.



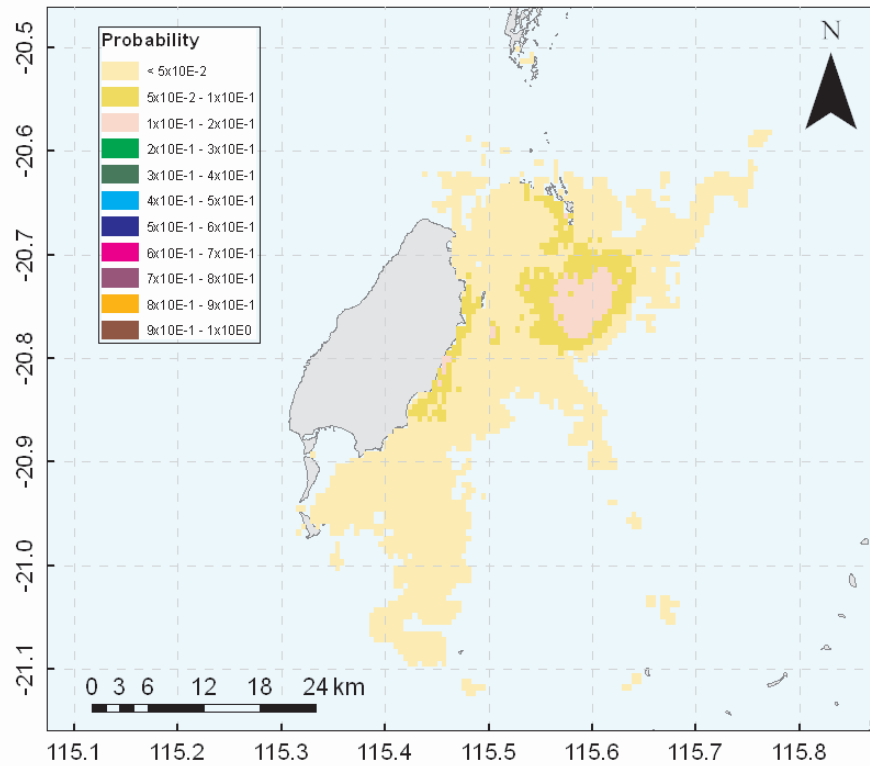
**Figure 44** Probability of contact by dissolved aromatic hydrocarbons (at  $>10 \text{ ppb}$ ) given condensate release from a tanker grounded adjacent the tanker terminal.



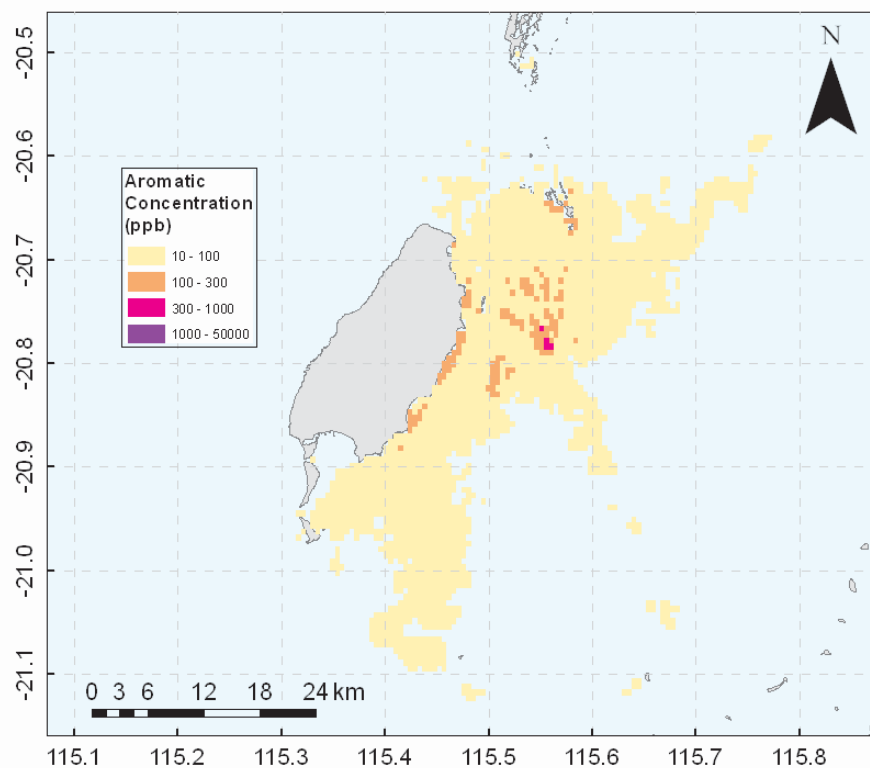
**Figure 45** Maximum potential concentrations of dissolved aromatic hydrocarbons given condensate release from a tanker grounded adjacent the tanker terminal.



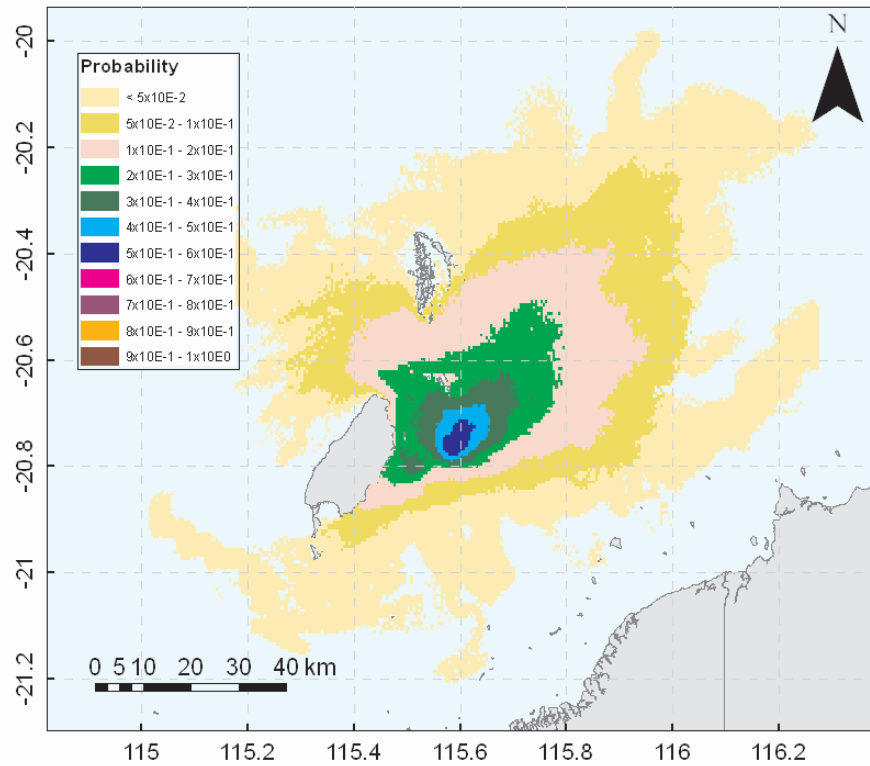
**Figure 46** Probability of contact by crude oil (at  $>0.3 \text{ g/m}^2$ ) given release from a tanker grounded adjacent the tanker terminal.



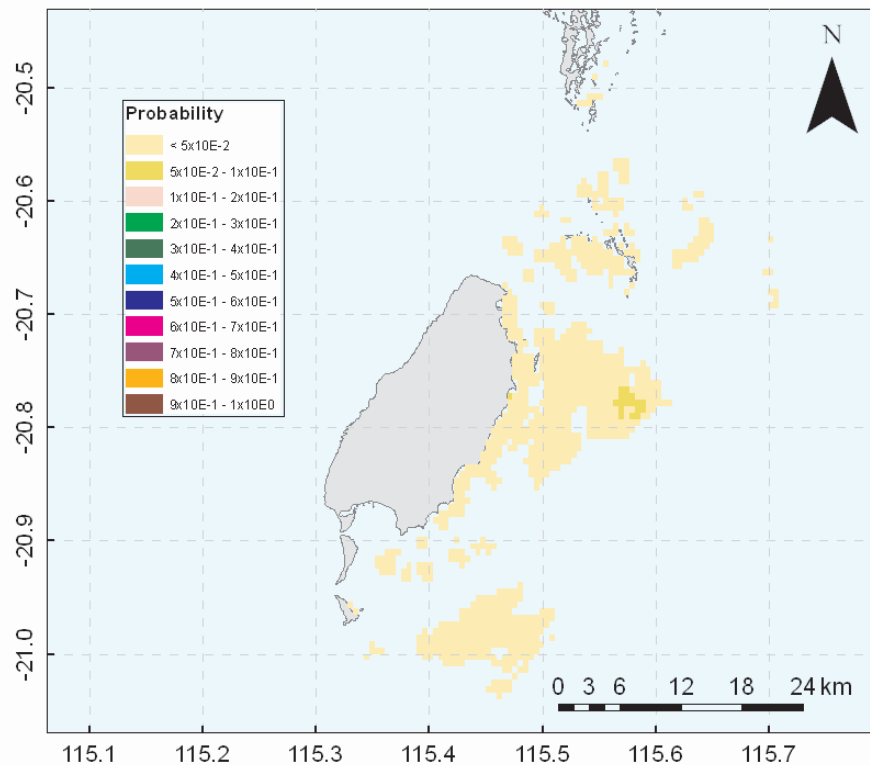
**Figure 47** Probability of contact by dissolved aromatic hydrocarbons (at >10 ppb) given release of crude oil from a tanker grounded adjacent the tanker terminal.



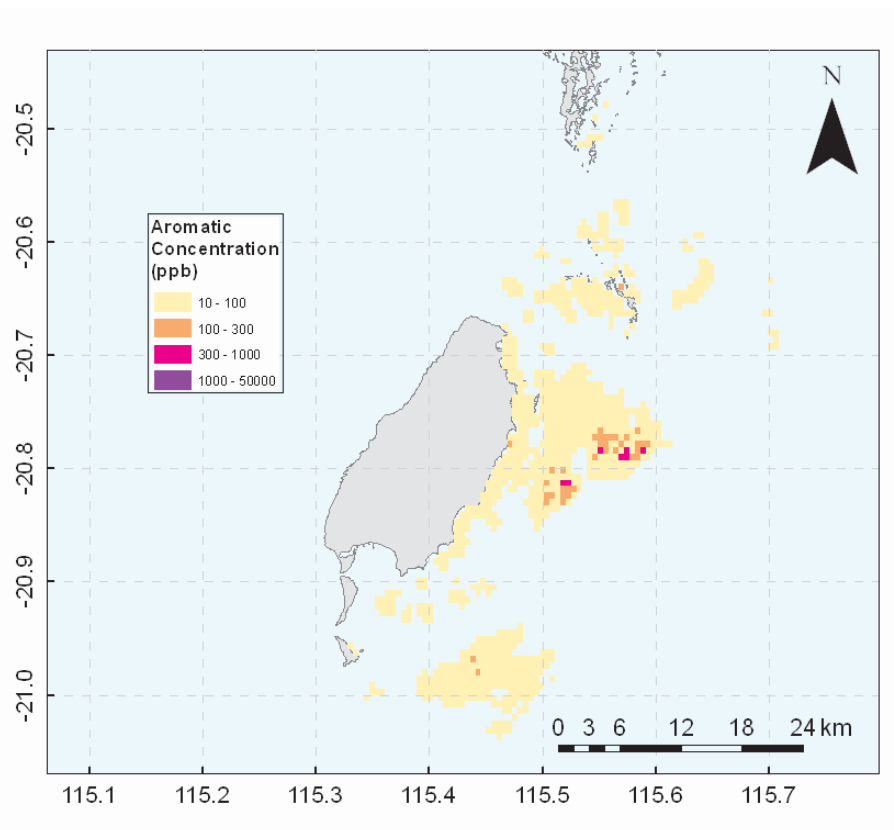
**Figure 48** Maximum potential concentrations of dissolved aromatic hydrocarbons given crude oil release from a tanker grounded adjacent the tanker terminal.



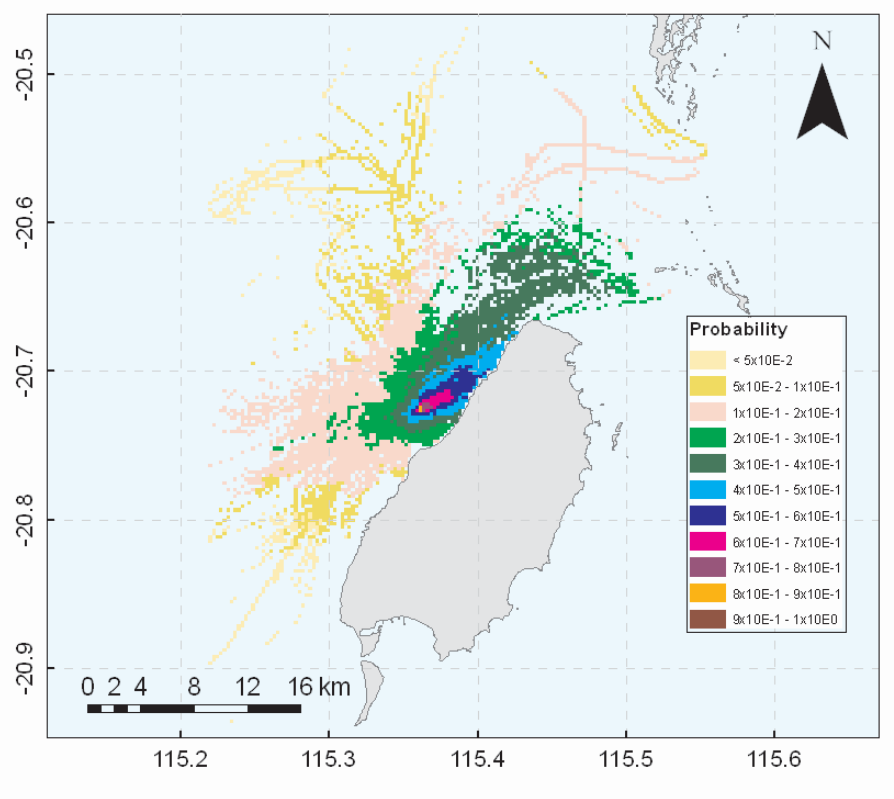
**Figure 49** Probability of contact by bunker oil (at  $>0.3 \text{ g/m}^2$ ) given release from a tanker grounded adjacent the tanker terminal.



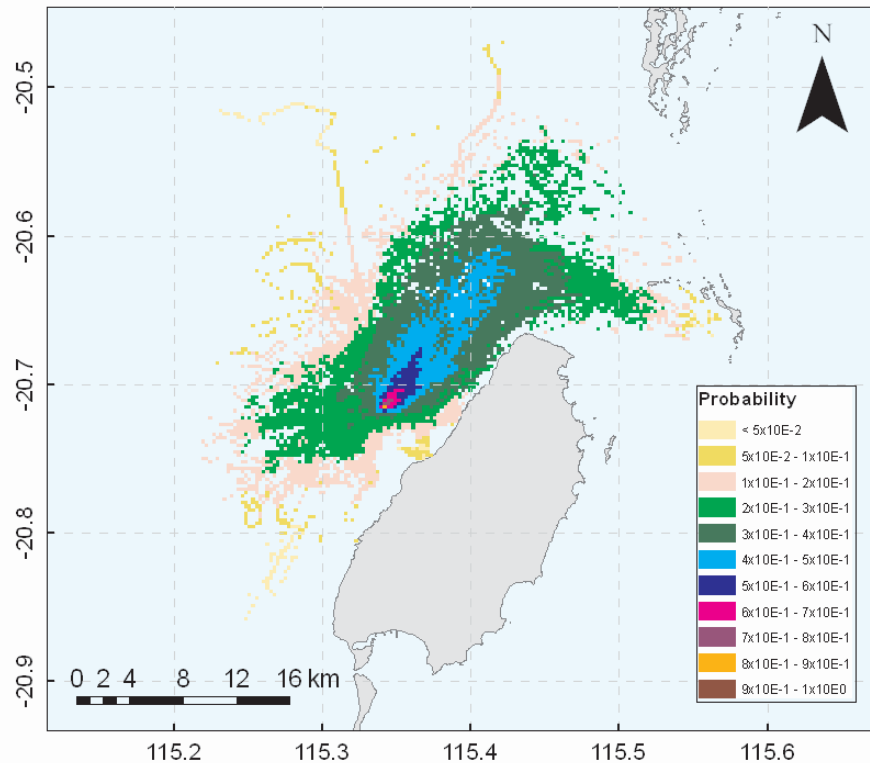
**Figure 50** Probability of contact by dissolved aromatic hydrocarbons (at  $>10 \text{ ppb}$ ) given release of bunker oil from a tanker grounded adjacent the tanker terminal.



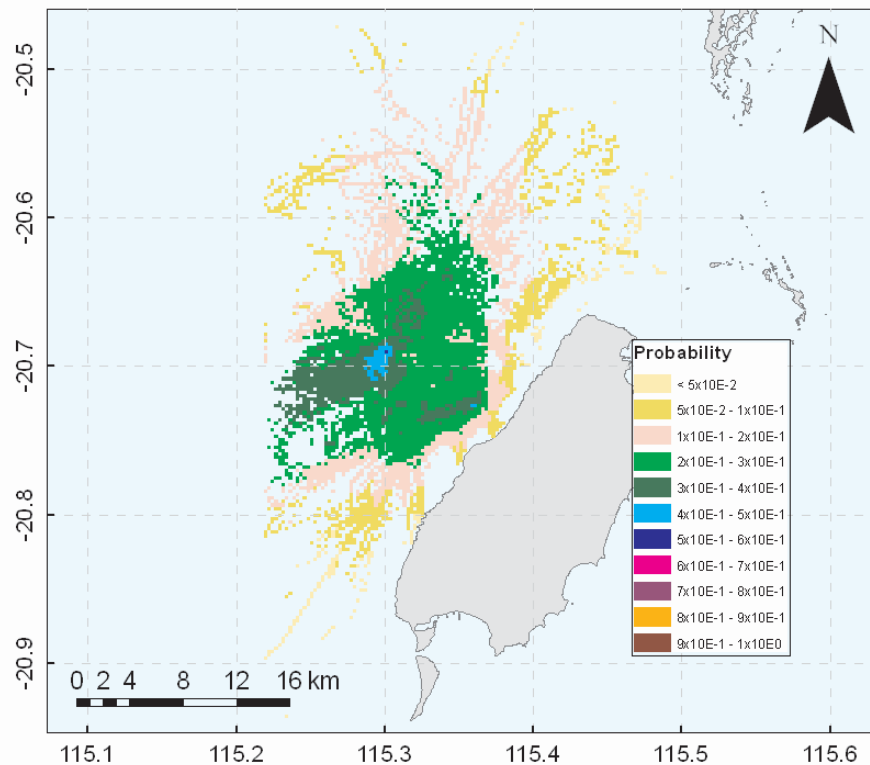
**Figure 51** Maximum potential concentrations of dissolved aromatic hydrocarbons given bunker oil release from a tanker grounded adjacent the tanker terminal.



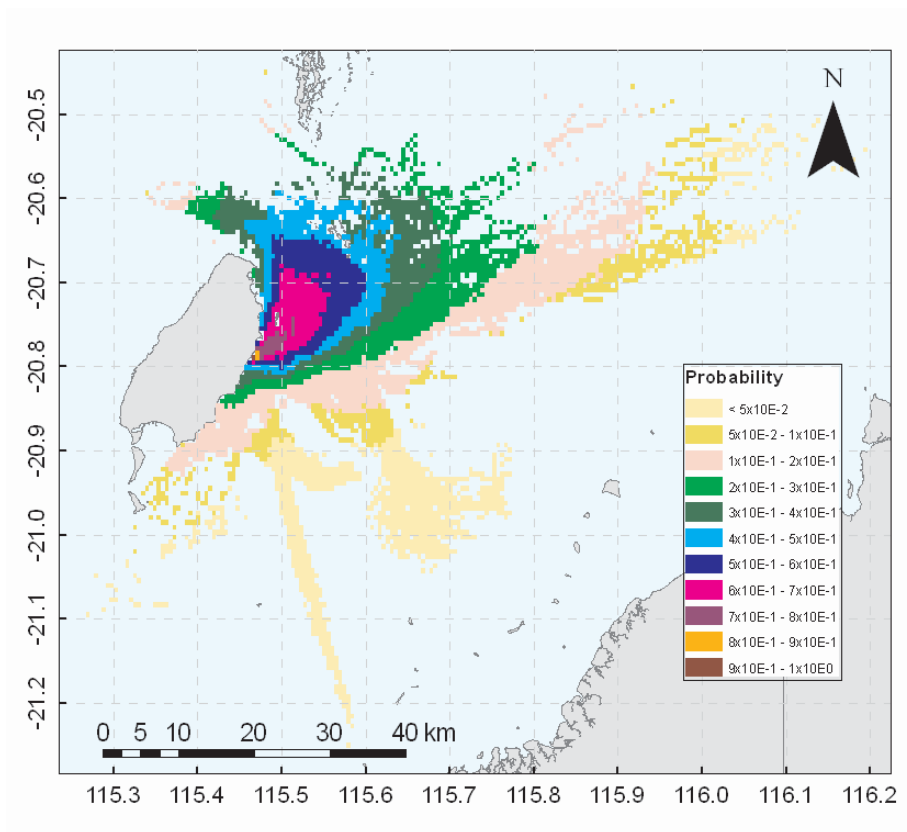
**Figure 52** Probability of contact by diesel (at  $>0.1 \text{ g/m}^2$ ) given a refuelling accident 2.5km offshore along route 1. Note the lower concentration threshold specified for diesel.



**Figure 53** Probability of contact by diesel (at  $>0.1 \text{ g/m}^2$ ) given a refuelling accident 5km offshore along route 1. Note the lower concentration threshold specified for diesel.



**Figure 54** Probability of contact by diesel (at  $>0.1 \text{ g/m}^2$ ) given a refuelling accident 10 km offshore along route 1. Note the lower concentration threshold specified for diesel.



**Figure 55 Probability of contact by diesel (at  $>0.1 \text{ g/m}^2$ ) given a refuelling accident at the MOF Jetty. Note the lower concentration threshold specified for diesel.**

## 5.5 Spills of Mono-ethylene glycol (MEG)

Mono-ethylene glycol (MEG) would be pumped from Barrow Island to the production wells via a separate pipeline running parallel with the supply gas pipeline. Rupture of the MEG line is expected to result in rapid (within 2 minutes) depressurisation of the pipeline, releasing about 11 m<sup>3</sup> of MEG before the supply is isolated automatically in response to the pressure drop. The risk of a rupture of the MEG line from a physical impact, corrosion or mechanical failure has been estimated as 4.32 x 10<sup>-5</sup> per km per year (Appendix B4).

Simulation of this release scenario at 50 m depth along pipeline route 1, indicated that the MEG will be initially mixed into the receiving seawater by the velocity of the release, resulting in peak concentrations of around 6,000 mg/m<sup>3</sup> of MEG adjacent to the discharge, which would disperse to < 50 mg/m<sup>3</sup> within about 3 hours. Stochastic modelling of this scenario under randomly selected currents indicated that the plume would tend to drift along the axis of the local tidal currents and dilute to < 10 mg/m<sup>3</sup> within 3 km of the discharge. Shallow subtidal and intertidal habitats in the region all occur outside this range. Consequently, the overall risk of exposure for these habitats from a mid-pipe release site is expected to be low (< 4.32 x 10<sup>-7</sup>).

## 5.6 Discharge of hydrotest water

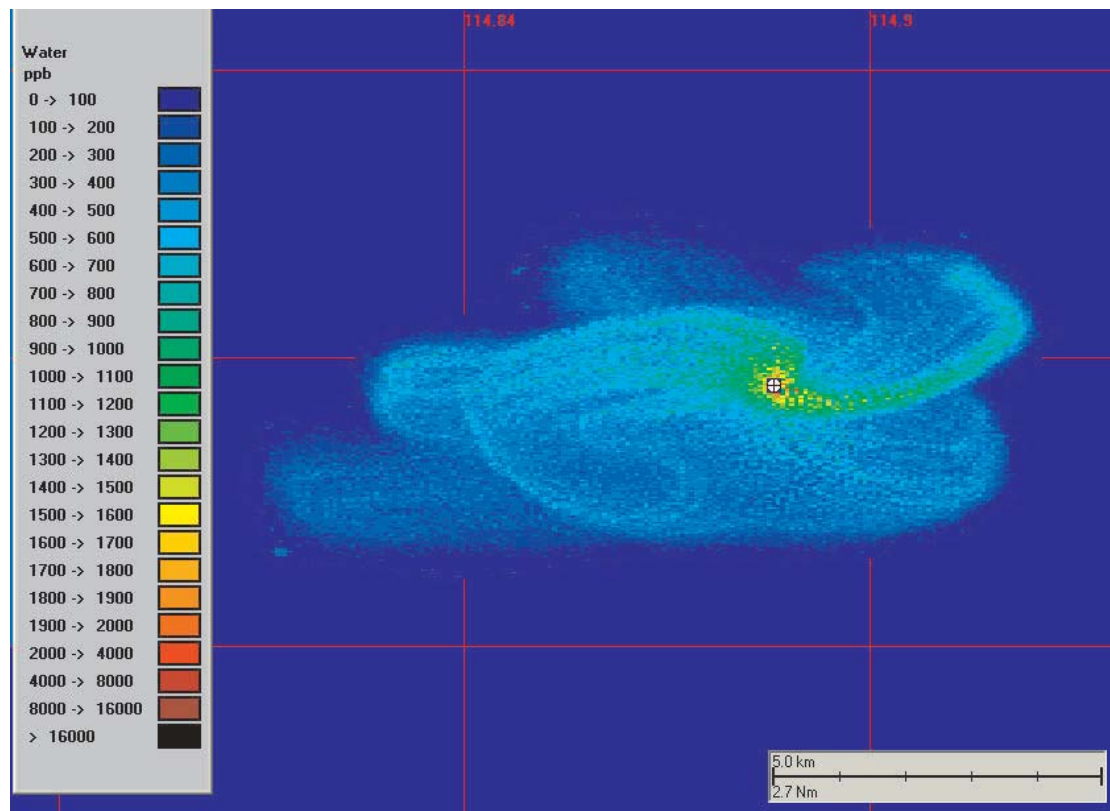
The supply gas pipeline and domestic gas pipelines would be filled with chemically-treated hydrotest water that would need to be emptied prior to commissioning of the pipelines. Added chemicals would include an oxygen scavenger (Ammonium bisulphite) and a biocide (Phosphonium sulphate). Ammonium bisulphite would react with the oxygen within the hydrotest water to form Ammonium sulphate, consuming all oxygen in the water. Ammonium sulphate is non toxic and the treatment dosage (~100 mg/l) would leave no excess Ammonium bisulphite. Phosphonium sulphate would also be applied at ~ 95 mg/l, which has a reported toxicity at > 19 mg/l (48 hr EC<sub>50</sub> *Daphnia magna*) and in addition would react on discharge with oxygen in the water column at the rate of ~ 7.3 mg/l per litre of undiluted discharge. Consequently, the principal environmental consideration of this discharge would be the anoxic state of the hydrotest water, potential toxicity presented by the Phosphonium sulphate and the scavenging of oxygen from the ambient seawater. Modelling was applied to quantify whether dilution of the hydrotest water due to the discharge and dispersion by ambient currents would be sufficient to ensure that oxygen concentrations in the receiving waters are not significantly reduced and that concentrations of Phosphonium sulphate would be lower than the low reliability no-effect concentration (nominally < 0.19 mg/l applying a dilution factor of 100 to the above EC<sub>50</sub> value).

If discharged in-situ, hydrotest water within the supply gas line would most likely be discharged at one of the production field manifolds (M2). One option for the discharge of hydrotest water from the domestic gas line would be a location off the east coast of Barrow Island. Discharge of hydrotest waters would be achieved by forcing a pig through the pipeline at a defined rate. A pig velocity of about 1 m/s was judged in each case as the minimum velocity that would ensure effective removal of the hydrotest water.

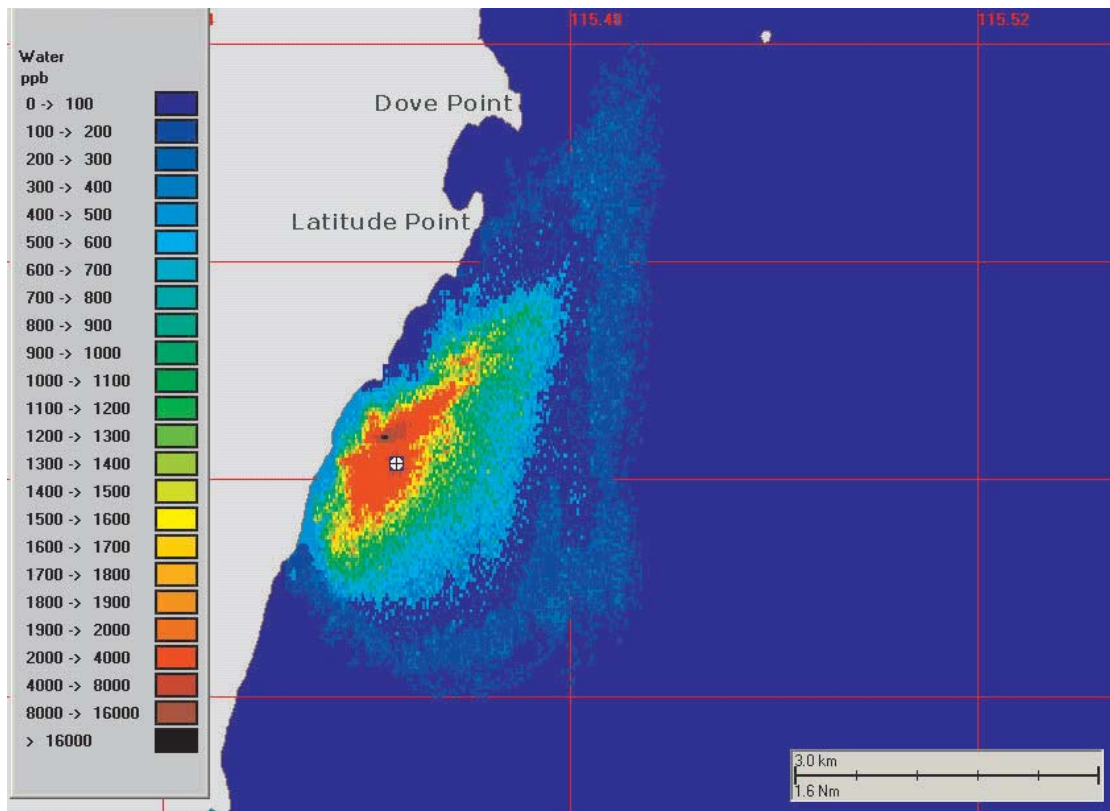
Discharge of hydrotest water at the offshore production area was predicted to generate maximum 10-minute average concentrations near the discharge of 1,750 ppb of hydrotest water in seawater, indicating a minimum dilution rate of 57,000 times (Figure

61). This indicates that the concentration of Phosphonium sulphate near the discharge should be maintained below 0.0016 mg/l and that oxygen concentrations should be maintained at above 99% of ambient concentrations.

Discharge of hydrotest water into the tidal channel off the eastern shore of Barrow Island was predicted to generate maximum 10-minute average concentrations near the discharge of 19,566 ppb of hydrotest water in seawater, indicating a minimum dilution rate of 51,000 times (Figure 62). Thus, the maximum concentration of Phosphonium sulphate near the discharge should be maintained below 0.0018 mg/l and oxygen concentrations should similarly be maintained above 99% of ambient concentrations. Concentrations during periods of peak tidal flow were predicted to be generally lower than 5,000 ppb of hydrotest water in seawater within the immediate area of the discharge. Thus, concentrations of Phosphonium sulphate should normally be lower than the maximums quoted above.



**Figure 56 Predictions for the maximum instantaneous concentration of Phosphonium sulphate at locations surrounding the offshore site proposed for discharge of Hydrotest water. Results are shown for the highest concentration at any depth within each location.**



**Figure 57 Predictions for the maximum instantaneous concentration of Phosphonium sulphate at locations surrounding the inshore site proposed for discharge of Hydrottest water, which is on the western side of Barrow Island adjacent to the existing oil export line. Results are shown for the highest concentration at any depth within each location.**

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