WOODSIDE BROWSE TOROSA C QUANTITATIVE SPILL RISK ASSESSMENT

Preliminary Results - Scenario 9

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1 INTRODUCTION

RPS was commissioned by Woodside Pty Ltd (Woodside) to undertake a quantitative spill risk assessment of six hydrocarbon spill scenarios as part of the Browse Joint Venture (BJV). The Browse hydrocarbon resource is contained within the Brecknock, Calliance and Torosa reservoirs that are located approximately 425 km north of Broome and approximately 290 km off the Kimberley coastline. The BJV holds seven petroleum retention leases under the Offshore Petroleum and Greenhouse Gas Storage Act 2006 (OPGGS Act), the WA Petroleum (Submerged Lands) Act 1982 (PSL Act) and the Petroleum and Geothermal Energy Resources Act 1967 (WA). Five of the leases (WA-28-R, WA-29-R, WA-30-R, WA-31-R and WA-32-R) are in Commonwealth waters. Two leases (TR/5 and R2) are within the jurisdiction of the State of Western Australia.

The BJV propose to develop the Browse resource using two Floating Production Storage and Offloading (FPSO) facilities with up to 1,100 million standard cubic feet per day (MMscf/d) export capacity (annual daily average). The FPSOs will be supplied by a subsea production system and will export gas to existing North West Shelf (NWS) Project infrastructure via a ~ 85 km spur line and a ~ 900 km Browse Trunkline (BTL), which will tie in near the North Rankin Complex (NRC).

To support the assessment of environmental risks associated with any hydrocarbon releases during the operations, nine credible hydrocarbon spill scenarios have been determined by Woodside. The assessment is focused on the risk of exposure to hydrocarbons for surrounding resources and sensitive receptors if either of the defined spill scenarios were to occur.

The main objectives of the study are: (i) to quantify the movement and fate of spilled hydrocarbons that would result from accidental, uncontrolled releases; and (ii) to investigate the risk to sensitive receptors (emergent features, submerged features, and shorelines) posed by the release.

This technical memo presents results of the following scenario, with details summarised in Table 1.1.

- **Scenario 9:** 12-hour subsea release of Torosa Condensate due to well blowout at Torosa C well.

The regional context of the spill location for the assessed scenarios is shown in Figure 1.1

Nearfield modelling was undertaken to calculate the likely fate of condensate released from subsea, accounting for the rates of discharge of condensate and natural gas, the hole-size, and the water depth. This modelling yielded calculations for the depth-range that condensate should be lifted by the rising gas bubble plume as well as the size-distribution of the condensate droplets at that height range, which would affect rates of refloating and wave-entrainment as well as rates of dissolution of soluble components. These details were then applied as initiating conditions within stochastic simulations using the SIMAP oil spill model. One hundred replicate simulations of the same scenario were modelled, each using a unique time-series of current and wind data selected at random from a historic hindcast for the Timor Sea. Simulations were run for 15 days from initiation of the hypothetical releases to allow ample time for concentrations to decrease below conservative thresholds.

Table 1.1 Summary of the hydrocarbon spill scenario assessed in a stochastic manner in this study.

Scenario	Description	Oil Type	Spilled Quantity	Release Coordinates	Release Depth (BMSL)	Spill Duration (hours)	Simulation Duration (days)
9	Blowout at the Torosa C well	Torosa Condensate	887 m^3	13° 58’ 12.5” S 121° 58’ 37.7” E	425 m	12	15

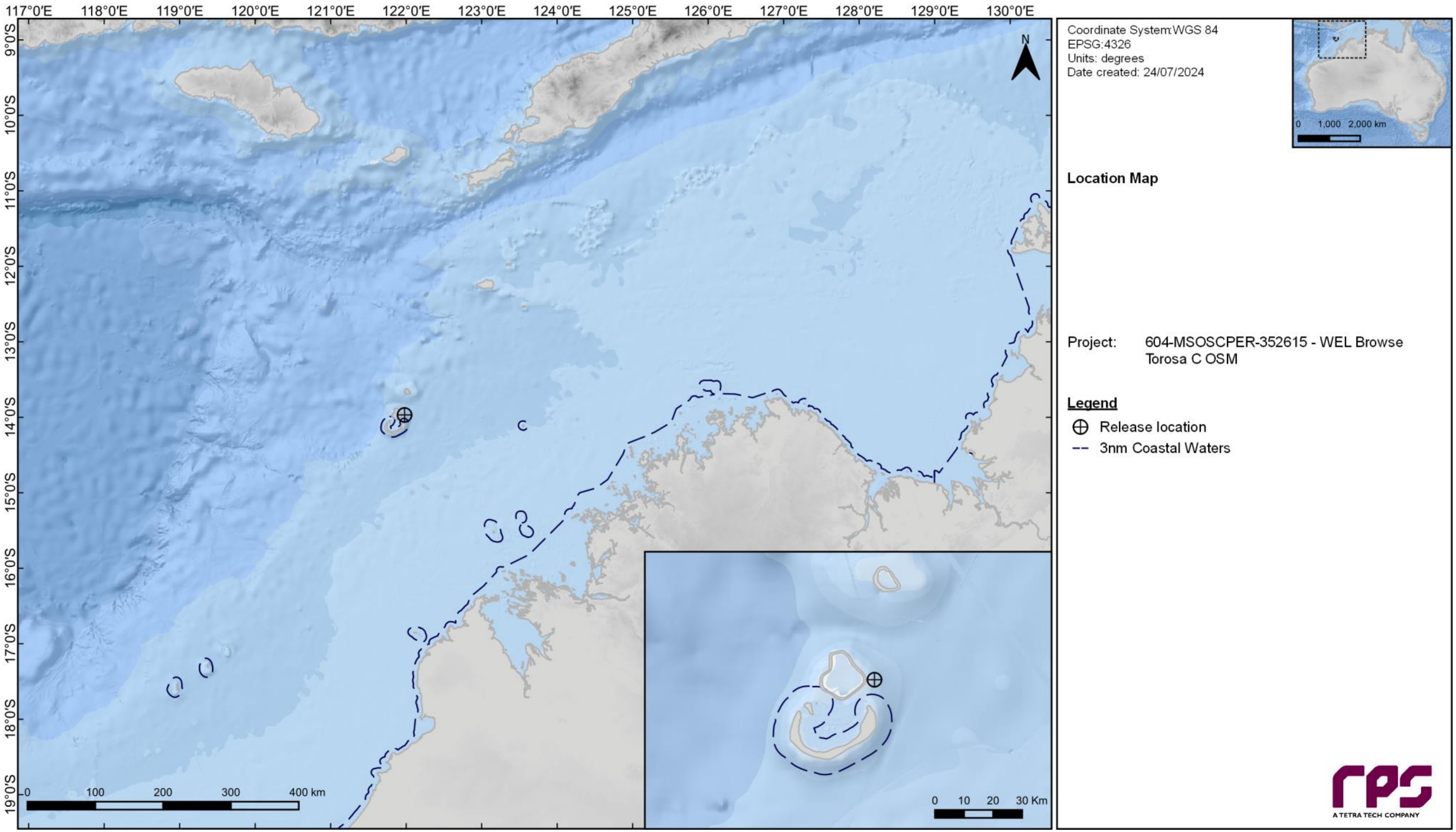


Figure 1.1 The release location for spill scenario 9.

2 OIL CHARACTERISTICS

2.1 Overview

The characteristics of Torosa Condensate were provided by Woodside and are summarised in Table 2.1.

Table 2.1 Characteristics of the oil mixtures used in the modelling.

Oil Type	Density (g/cm^3)	Viscosity (cP)	Component	Volatile (%)	Semi-volatile (%)	Low volatility (%)	Residual	Aromatics
			Boiling point (°C)	<180 C4 to C10	180-265 C11 to C20	265-380 C16 to C20	>380 >C20	Of whole oil <380 BP
Torosa Condensate	0.6866 at 6 °C	0.54 at 6 °C	% of total	61.4	20.2	7.4	11.0	15.4
			% aromatics	9.5	3.1	2.8	-	-

Atmospheric weathering will commence when oil droplets float to the water surface. Typical evaporation times once the hydrocarbons reach the surface and are exposed to the atmosphere are:

- Up to 12 hours for the C4 to C10 compounds (or less than 180 °C BP).
- Up to 24 hours for the C11 to C15 compounds (180-265 °C BP).
- Several days for the C16 to C20 compounds (265-380 °C BP).
- The residual compounds (BP > 380 °C) will resist evaporation and will require the slower process of degradation (photo and biological) to degrade.

The actual fate of released oil in the marine environment will depend greatly on the amount of oil that reaches the surface, either through the initial release or by rising after discharge in the water column. The droplet-size distribution of condensate that reaches surface will also have a large influence, through affecting the surface area presented to evaporation and dissolution and the susceptibility of the droplets to wave-induced entrainment.

2.2 Torosa Condensate

Torosa Condensate (API 75) contains a low proportion (~ 11% by mass) of hydrocarbon compounds that will not evaporate at atmospheric temperatures. These compounds will persist in the marine environment.

The unweathered mixture has a low dynamic viscosity (0.54 cP) so that the fluid condensate will flow easily to form thin sheens if the condensate is on the water surface. Low levels of wave energy would be required to break up and entrain any surface films that form at the sea surface. The pour point of the whole oil is 12 °C indicating that the fluid will remain in a liquid state over the annual temperature range observed on the Timor Sea.

The mixture is composed of hydrocarbons that have a wide range of boiling points and volatilities at atmospheric temperatures, and which will begin to evaporate at different rates on exposure to the atmosphere. Evaporation rates will increase with temperature, but in general about 61.4% of the oil mass should evaporate within the first 12 hours (BP < 180 °C); a further 20.2% should evaporate within the first 24 hours (180 °C < BP < 265 °C); and a further 67.4% should evaporate over several days (265 °C < BP < 380 °C).

Selective evaporation of the lower boiling-point components will lead to a shift in the physical properties of the remaining mixture, including an increase in the viscosity and pour point. No information has been made available to allow judgement as to whether the residual mixture, representing a small proportion (11% by mass) of the whole mixture, will solidify as it weathers.

The whole oil has low asphaltene content (< 0.5%), indicating a low propensity for the mixture to take up water to form water-in-oil emulsion over the weathering cycle.

Soluble aromatic hydrocarbons contribute approximately 15.4% by mass of the whole oil, with a large proportion (9.5%) in the highly volatile and soluble C4-C10 range of hydrocarbons. The fate of these compounds would vary depending upon the spill scenario. These compounds will evaporate rapidly from surface films as well as from droplets of condensate that are entrained in the highly mixed surface layer (upper few metres), reducing the potential for dissolution into the water if the condensate mixture is at the water surface or suspended in the upper metre of the water column. If the condensate droplets were trapped in deeper density layers, a high rate of dissolution would occur.

3 WEATHERING CHARACTERISTICS

3.1 Overview

A series of model weathering tests were conducted to illustrate the potential behaviour of the condensate, if released onto the water surface and exposed to idealised and representative environmental conditions.

- Instantaneous release onto the water surface of 50 m^3 under calm wind conditions (constant 5 knots), assuming low seasonal water temperature (27 °C) and average air temperature (25 °C). Slick also subject to ambient tidal and drift currents.
- Instantaneous release onto the water surface of 50 m^3 under variable wind conditions (4-19 knots, drawn from representative data files), assuming low seasonal water temperature (27 °C) and average air temperature (25 °C). Slick also subject to ambient tidal and drift currents.

The first case is indicative of cumulative weathering rates under calm conditions that would not generate entrainment, while the second case represents conditions that could cause degrees of entrainment. Both scenarios provide examples of potential behaviour during periods of a spill event for condensate that floats to the surface and forms a surface film.

3.2 Weathering calculations for release onto surface

The mass balance forecast for the low-wind case (Figure 3.1) indicates rapid evaporation of Torosa condensate over the first 6 hours and then progressively slower evaporation over the following days. Approximately 81% of the oil is predicted to evaporate within the first 12 hours. Under these calm conditions, most of the remaining oil will stay on the water surface and will evaporate at a slowing rate due to shift of the remaining mixture towards longer-chain compounds with higher boiling points. Weathering of the residual compounds will slow significantly, subject to more gradual decay through biological and photochemical processes.

Under the variable, and stronger, wind case (Figure 3.2), significant levels of entrainment into the water column are forecasted, with a resultant decrease in the mass of oil floating on the surface and a small decrease in the proportion that evaporates. Approximately 24 hours after the spill, around 19% of the oil mass is forecast to have entrained and a further 76% is forecast to have evaporated, leaving less than 0.3% of the oil floating on the water surface. The increased level of entrainment in the variable-wind case will result in a higher dissolution of the soluble compounds. However, the proportion of mass that is dissolved is forecasted to remain low (~ 3.3% of the original mass) after 12 hours, in comparison to < 0.03% in the low-wind case.

The proportion of the spill volume that entrains will vary with the timing of the release relative to sea conditions. Entrainment would occur more rapidly if the spill occurred when winds exceed more than a moderate breeze (> 9-10 m/s), generating breaking waves on the ocean surface. Higher rates of evaporation would occur under calmer conditions, reducing the mass available for entrainment.

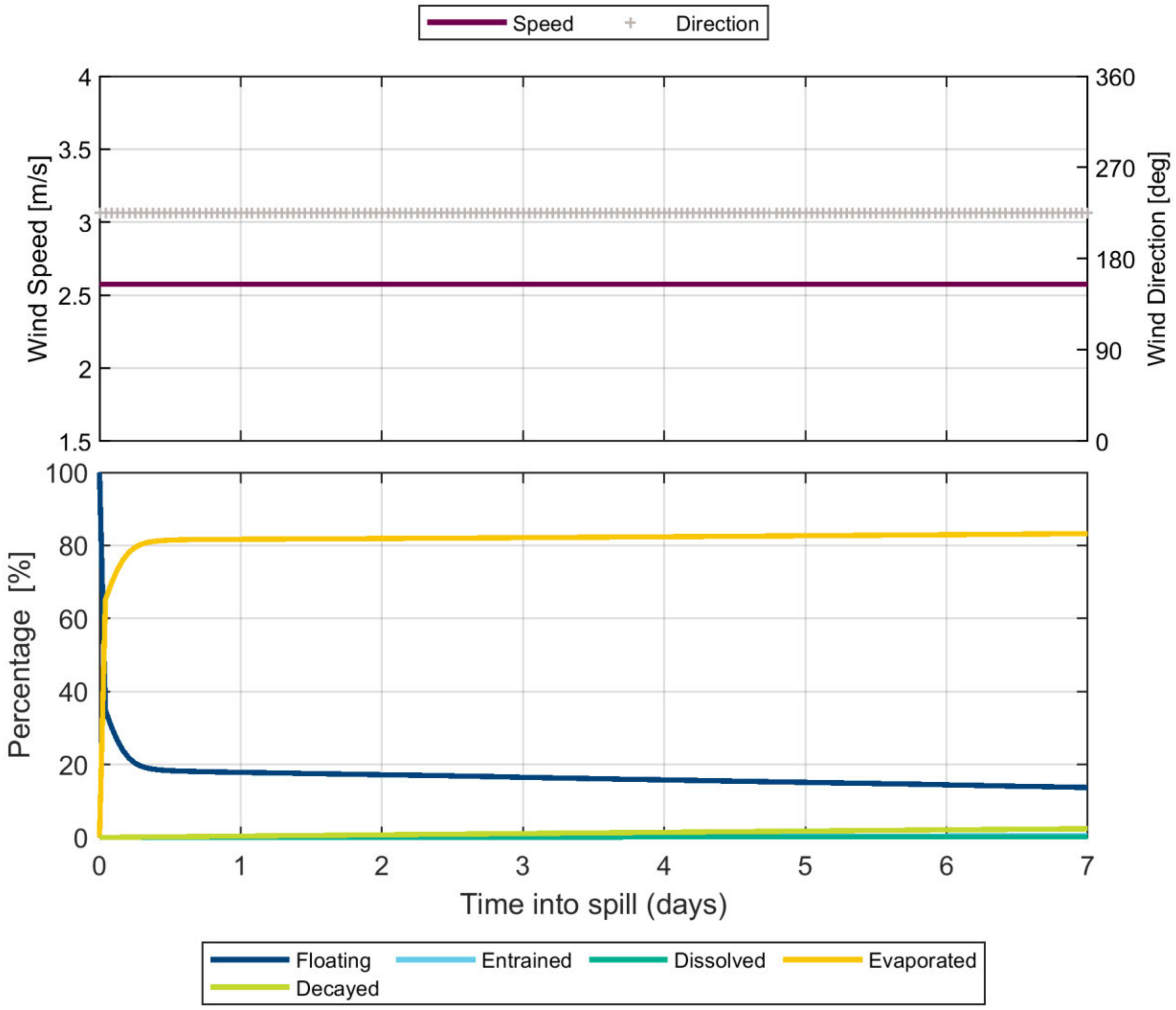


Figure 3.1 **Proportional mass balance plot representing the weathering of Torosa Condensate spilled onto the water surface as a one-off release (50 m^3) and subject to a constant 5 kn (2.6 m/s) wind at 27 °C water temperature and 25 °C air temperature.**

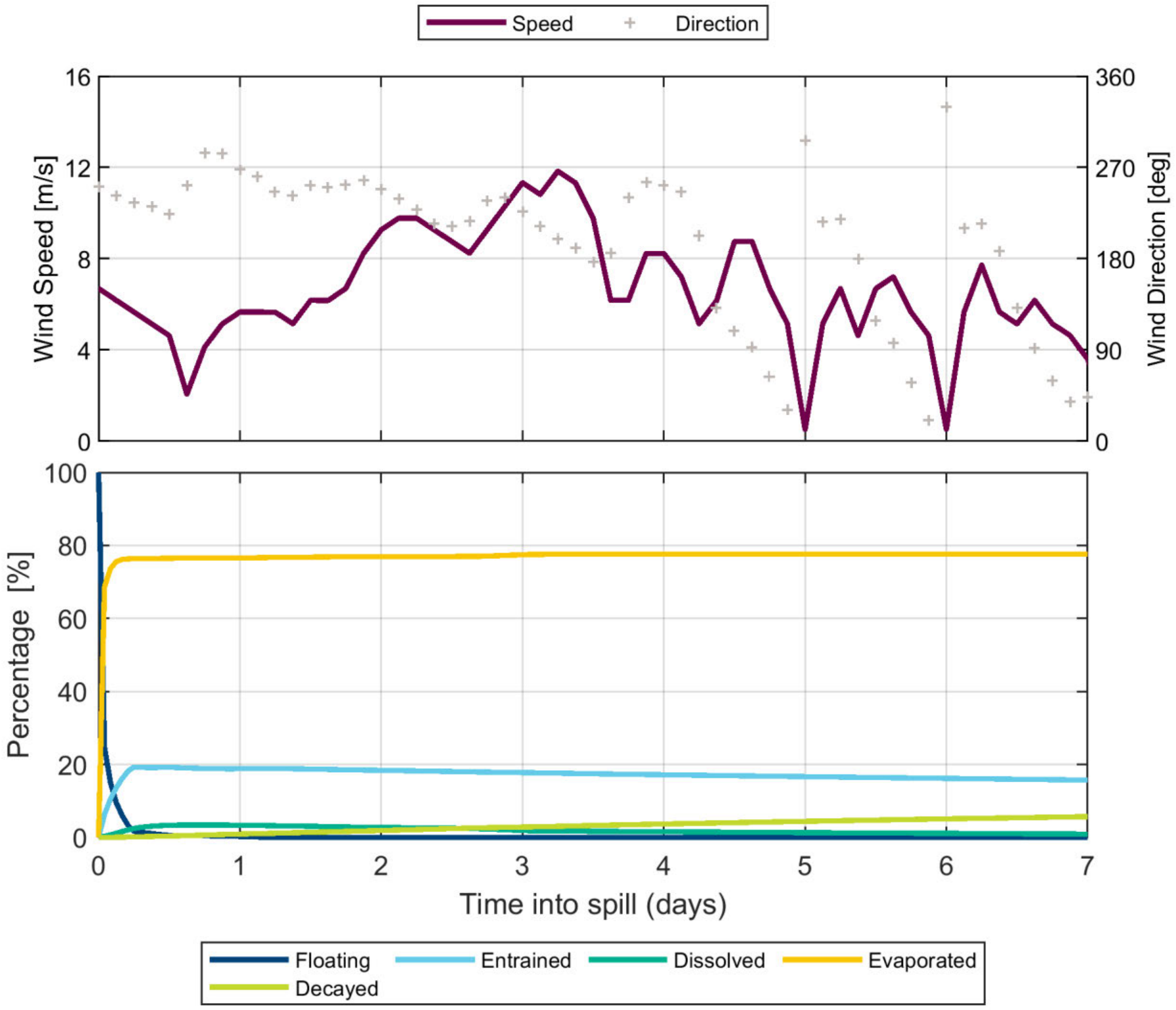


Figure 3.2 Proportional mass balance plot representing the weathering of Torosa Condensate spilled onto the water surface as a one-off release (50 m^3) and subject to variable wind at 27 °C water temperature and 25 °C air temperature.

4 SUBSURFACE DISCHARGE CHARACTERISTICS

4.1 Overview

When oil and gas are released from subsea, at pressure, through a restriction, a jet of oil droplets and gas bubbles will be generated. The momentum of the jet will quickly dissipate (within a few metres) and a two-phase buoyant plume will evolve. The high buoyancy of the gas bubbles will drive the entrainment of a plume of well fluids towards the surface. The displacement set up by the vertical movement will entrain water from the surrounding water column to set up an expanding fluid plume consisting of oil droplets entrained within seawater and any water contributed from the source. The gas bubbles will expand with reduction of pressure but will then fracture into smaller droplets as they rise, maintaining a relatively small size distribution (< 20 mm) that will result in relatively rapid dissolution of the natural gas into the surrounding water. The net buoyancy of the rising gas will initially accelerate the rising plume of well fluids and seawater towards the surface but will then slow due to reduction of the net gas volume to dissolution as well as the rising relative density of the liquid plume as the colder water from the seabed depth rises into the warmer water at shallower depths.

If the release initiates in relatively shallow water (100-200 m) with a high gas to oil ratio, the well fluid plume is likely to be lifted to the water surface at relatively high speed (> 5 m/s), generating an energetic geyser with high agitation due to gas passing through into the atmosphere around the geyser. The rising plume of oil droplets suspended in water will be displaced laterally setting up an energetic mixing zone around the geyser where entrained droplets will be suspended in the upper 2-3 m beneath the water surface. Once the energy of the displaced plume is spent, the fate of the droplets will be subject to the prevailing sea conditions, which will be subject to the local wind speeds, as well as the size-distribution of the droplets. The droplets will be positively buoyant, which will drive rise towards the surface, but the rise will be resisted by the viscosity of the water column so that smaller droplets with a higher surface area to volume ratio will rise slower than larger droplets with a lower surface area to volume ratio. Wave action will overcome the droplet buoyancy and will mix droplets downwards.

If the release occurs in deeper water, and/or the gas to oil ratio is low, the density of the rising plume of entrained seawater and entrained oil droplets may exceed the buoyancy lift generated by the gas bubble plume at a depth below the water surface and the fluid plume will separate from the gas phase. The rise of oil droplets from this lower depth will then be subject the lower relative buoyancy of the oil droplets, viscous resistance imposed by the water column and, in some situations, density stratification of the water column.

The SIMAP model requires information on the size-distribution of the oil droplets and the vertical distribution of the oil droplets after the evolution of the above processes, dependent upon the release scenario. The vertical rise of the gas bubbles and oil droplets was calculated using the OILMAP Deep blowout model (Spaulding *et al.* 2017). The size-distribution of the droplets was calculated using the SINTEF blow-out formulations (Johansen, 2003, Johansen *et al.* 2013a, 2013b), which have been shown to be more accurate for releases involving high gas to oil ratios.

4.2 Calculations for subsea release phase of Scenario 9

The input parameters for the OILMAP-Deep and the SINTEF models and the calculations of those models that were used as input to SIMAP are presented in Table 4.1. The model input into OILMAP-Deep also included temperature and salinity profiles representative of the release location to represent the density profile.

The calculations indicate that the release scenario will generate a cone of rising gas bubbles that will entrain the oil droplets and ambient sea water to a depth of approximately 234 m below the surface before the gas would likely separate. The mixed plume was initially forecast to rise towards the water surface with a vertical velocity of around 7.5 m/s, gradually slowing with an increasing plume diameter as more ambient water is entrained. The terminal velocity of rising water and condensate at the point of surfacing was calculated at approximately 2.2 m/s, setting up a circular displacement plume surrounding a central plume diameter of approximately 54 m.

The average droplet size-distribution of the entrained oil in the displacement plume was calculated to be relatively large (range from 2,660 µm [median of the smallest 20%] to 9,582 µm [median of the largest 20%]) due to the relatively low rate of release relative to the hole-size.

These droplets will be subject to dissolution at the surface layer and the lateral displacement of the rising plume. The relatively large size of the droplets indicates that droplets would tend to rise to the surface beyond the energetic mixing zone under calm sea conditions, forming sheens and slicks. More energetic sea conditions would result in a high proportion remaining entrained in the wave mixed zone.

The ongoing nature of the release combined with the potential for the plume to breach the water surface may present other hazards, including conditions that may lead to high local concentrations of natural gas and volatile organic compounds evaporating from the liquid phase. These issues are not addressed by this study but should be considered when evaluating the practicality of response operations near the surfacing area and slicks that are set up

Table 4.1 Near-field subsurface discharge model parameters for Scenario 9.

OILMAP	Parameter	Value
Inputs	Release depth (m BMSL)	425
	Oil density (g/cm^3) (at 6 °C)	0.6866
	Oil viscosity (cP) (at 6 °C)	0.54
	Oil temperature (°C)	139
	Hole diameter (m) [in]	0.48 [18.75]
	Period	**12 hours**
	Oil flow rate (m^3/hr) [bbl/hr]	74 [465]
	Gas:oil ratio (m^3/m^3) [scf/bbl]	17,638 [99,031]
Outputs	Plume diameter (m)	54
	Plume height (m ASB)	425
	Plume initial rise velocity (m/s)	7.5
	Plume terminal rise velocity (m/s)	2.2
Predicted Oil Droplet Size Distribution	20% droplets of size (µm)	2,660
	20% droplets of size (µm)	3,884
	20% droplets of size (µm)	5,049
	20% droplets of size (µm)	6,562
	20% droplets of size (µm)	9,582

5 RESULTS

5.1 Overview

The following results present the analysis of stochastic modelling of the longer-term outcomes of the spill scenario, with results annualised (i.e., analysed for release times within all seasons). Results are presented for oil that is floating, entrained as droplets in the water column, dissolved into the water column and stranded on shorelines.

The model results have been analysed for instantaneous concentrations (1 hr time-steps) compared to thresholds defined by Woodside for floating, entrained, and dissolved components.

Risks of shoreline exposure (probability and minimum times) were calculated in two ways:

1. For floating oil arriving at shorelines as floating film concentrations exceeding thresholds.
2. For oil accumulating over time on shorelines. For this assessment, the model calculated the arrival of oil at any concentrations with allowances for subsequent weathering and degradation. The highest concentrations and volume calculated to accumulate at any time during any simulation was calculated for each grid cell representing part of a shoreline. Calculations were also made for the accumulated volume for each shoreline.

5.2 Scenario 9: 12-hour Subsea release of Torosa Condensate due to a Well Blowout

5.2.1 Overview

The scenario investigated the probability of oil exposure to surrounding regions due to a 12-hour subsea release of 887 m^3 of Torosa Condensate due to a well blowout at the Torosa C well. Results have been separately calculated for four components:

- Floating oil;
- Floating oil that strands on shorelines;
- Oil entrained in the water column as droplets; and
- Soluble, aromatic, hydrocarbons dissolved in the water column.

5.2.1.1 Floating and Shoreline Oil

Floating oil concentrations of 1 g/m^2 threshold could potentially be found up to 170 km from the release location. At the 10 g/m^2 and 50 g/m^2 thresholds, the furthest distance for floating oil are predicted to be 33 km and 2 km, respectively (Table 5.1, Figure 5.1, Figure 5.2 and Figure 5.3).

Table 5.1 Maximum distances from the release location to zones of floating oil exposure.

Distance and direction travelled	Zones of potential sea surface exposure		
	1 g/m^2	10 g/m^2	50 g/m^2
Maximum distance travelled (km) by a spill trajectory	170	33	2
Direction of maximum travel	North	Northwest	Northeast

The highest probability of contact for floating oil concentrations above 1 g/m^2 is forecast for Scott Reef South (6.5%). For the submerged receptor Scott Reef North, the probability of contact at this threshold is calculated to be 100% (see Table 5.4). The worst-case for maximum local oil accumulation on any surrounding shoreline was calculated at 539 g/m^2 on Sandy Islet (included in Scott Reef South and Scott Reef NR).

Figure 5.4 to Figure 5.12 illustrate the minimum times for floating oil to contact surrounding locations, contours showing the extent of the environment (EMBA), and the smoothed EMBA for floating oil at the 1 g/m² threshold.

The predicted probabilities of shoreline oil arriving at receptors are shown in Figure 5.13 to Figure 5.15. There is an 10.5% probability that shoreline oil concentrations above 10 g/m² will contact Sandy Islet (Scott Reef NR and Scott Reef South). The probability of contact at concentrations exceeding 100 g/m² is 2.5%, while the probability for concentrations above 250 g/m² is 0.5%.

The worst-case maximum accumulated volume along a shoreline is 7 m^3 Sandy Islet (Scott Reef NR and Scott Reef South).

5.2.1.2 Entrained Oil

Entrained oil concentrations exceeding 10 ppb are predicted to drift up to 423 km from the release location. At a threshold of 100 ppb and 1,000 ppb, the furthest distance for entrained oil is predicted to be 76 km and 7 km, respectively (see Table 5.2, Figure 5.16 to Figure 5.18).

Table 5.2 Maximum distances from the release location to zones of entrained oil exposure.

Distance and direction travelled	Zones of potential entrained oil exposure		
	10 ppb	100 ppb	1,000 ppb
Maximum distance travelled (km) by a spill trajectory	423	76	7
Direction of maximum travel	Northeast	Northeast	Northwest

Contour plots (Figure 5.16 to Figure 5.18) show the probability of entrained oil reaching locations with concentrations exceeding the 10 ppb, 100 ppb and 1,000 ppb thresholds. These plots indicate that entrained oil could drift over a broad area around the hypothetical spill site, with the longest trajectories of concentration extending northeast due to prevailing ocean currents.

The highest probability of contact for entrained oil above 10 ppb is forecast to be 64% for Scott Reef North, while there is an 37% probability of contact at concentrations greater than 100 ppb and a 5% probability of contact at concentrations greater than 1,000 ppb (see Table 5.5).

The worst-case entrained oil concentration for any receptor is 3,783 ppb at Scott Reef North (see Table 5.5).

The forecast annualised minimum times to contact by entrained oil, as well as the EMBA and smoothed EMBA for entrained oil at the 10 ppb 100 ppb and 1,000 ppb thresholds, are depicted in Figure 5.19 to Figure 5.27

Cross-sectional transects of maximum entrained oil concentrations at surrounding locations, compiled from the multiple replicate simulations, indicate that concentrations above 100 ppb could extend down to approximately 30 m in depth (see Figure 5.28 and Figure 5.29).

5.2.1.3 Dissolved Aromatic Hydrocarbons

Dissolved aromatic hydrocarbon concentrations above the 10 ppb and 50 ppb thresholds are calculated to potentially occur up to 303 km and 137 km from the release location, respectively (see Table 5.3, Figure 5.30 and Figure 5.31).

Table 5.3 **Maximum distances from the release location to zones of dissolved aromatic hydrocarbon exposure.**

Distance and direction travelled	Zones of potential dissolved aromatic hydrocarbon exposure		
	10 ppb	50 ppb	400 ppb
Maximum distance travelled (km) by a spill trajectory	303	137	-
Direction of maximum travel	North	North	-

The highest probability of contact by dissolved aromatic hydrocarbons is predicted at Scott Reef North, with concentrations above 10 ppb and 50 ppb having probabilities of 35% and 10.5%, respectively. No receptors are predicted to be in contact with concentrations at or above the 400 ppb threshold (see Table 5.6).

The maximum dissolved aromatic hydrocarbon concentration predicted at any receptor was 247 ppb at Scott Reef North.

The annualised minimum times to contact by dissolved aromatic hydrocarbons, as well as the EMBA and smoothed EMBA for concentrations at or above the 10 ppb and 50 ppb thresholds, are depicted in Figure 5.32 to Figure 5.37.

Cross-sectional transects of the maximum dissolved aromatic hydrocarbon concentrations through the release site indicate that concentrations above 50 ppb could reach depths of approximately 35 m (see Figure 5.38 and Figure 5.39).

5.2.1.4 Results – Tables and Figures

5.2.1.5 Floating Oil and Shoreline Oil

Table 5.4 **Expected annualised floating and shoreline oil outcomes at sensitive receptors for a 12-hour subsea release of 887 m^3 of Torosa Condensate.**

	Receptors	Probability (%) of films arriving at receptors at			Minimum time to receptor (hours) for films at			Probability (%) of shoreline accumulation on receptors at			Minimum time to receptor (hours) for shoreline accumulation at			Maximum local accumulated concentration (g/m^2)		Maximum accumulated volume (m^3) along this shoreline	
		≥ 1 g/m^2	≥ 10 g/m^2	≥ 50 g/m^2	≥ 1 g/m^2	≥ 10 g/m^2	≥ 50 g/m^2	≥ 10 g/m^2	≥ 100 g/m^2	≥ 250 g/m^2	≥ 10 g/m^2	≥ 100 g/m^2	≥ 250 g/m^2	averaged over all replicate spills	in the worst replicate spill	averaged over all replicate simulations	in the worst replicate simulation
Australian Marine Parks	Argo-Rowley Terrace MP*	<0.5	<0.5	<0.5	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Ashmore Reef MP	<0.5	<0.5	<0.5	NC	NC	NC	1	<0.5	<0.5	194	NC	NC	0.3	34	<1	2
	Cartier Island MP	<0.5	<0.5	<0.5	NC	NC	NC	0.5	<0.5	<0.5	292	NC	NC	0.2	21	<1	<1
	Kimberley MP*	<0.5	<0.5	<0.5	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Islands	Cartier Island	<0.5	<0.5	<0.5	NC	NC	NC	0.5	<0.5	<0.5	292	NC	NC	0.2	21	<1	<1
Nature Reserve	Scott Reef NR	4	1	<0.5	17	17	NC	10.5	2.5	0.5	29	47	89	8.3	539	<1	7
Reefs, Shoals and Banks	Ashmore Reef	<0.5	<0.5	<0.5	NC	NC	NC	1	<0.5	<0.5	194	NC	NC	0.3	34	<1	2
	Hibernia Reef*	<0.5	<0.5	<0.5	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Johnson Bank*	<0.5	<0.5	<0.5	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sahul Bank*	<0.5	<0.5	<0.5	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sandy Islet	2.5	<0.5	<0.5	40	NC	NC	10.5	2.5	0.5	29	47	89	8.3	539	<1	7
	Scott Reef North*	100	98.5	3.5	1	1	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Scott Reef South	6.5	1.5	<0.5	4	15	NC	10.5	2.5	0.5	29	47	89	8.3	539	<1	7
	Seringapatam Reef*	5.5	<0.5	<0.5	26	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Vee Shoal*	<0.5	<0.5	<0.5	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Woodbine Bank*	<0.5	<0.5	<0.5	NC	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NC: No contact to receptor predicted for specified threshold.

* Floating oil will not accumulate on submerged features and at open ocean locations. NA

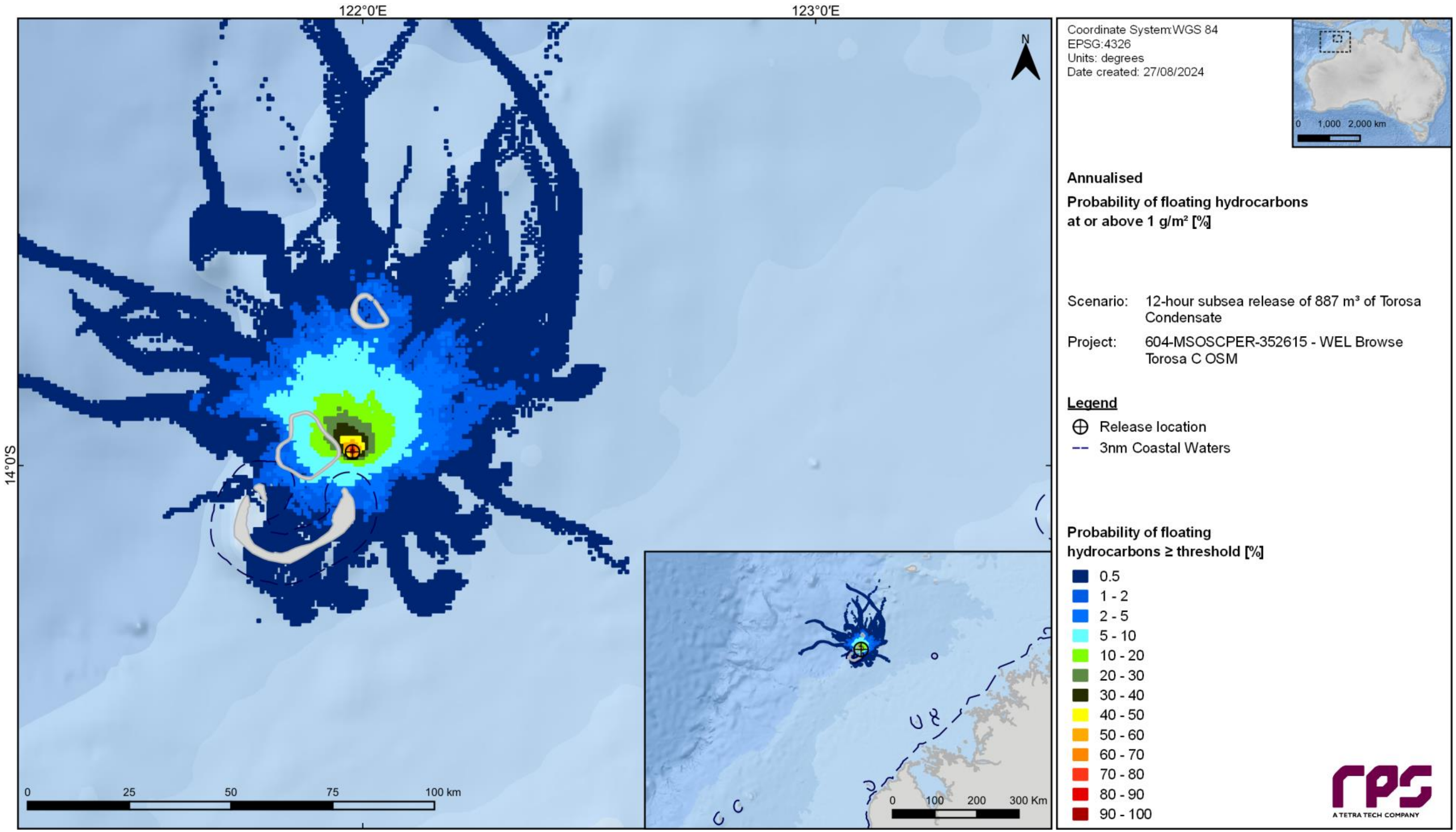


Figure 5.1: Predicted annualised probability of floating oil concentrations at or above 1 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

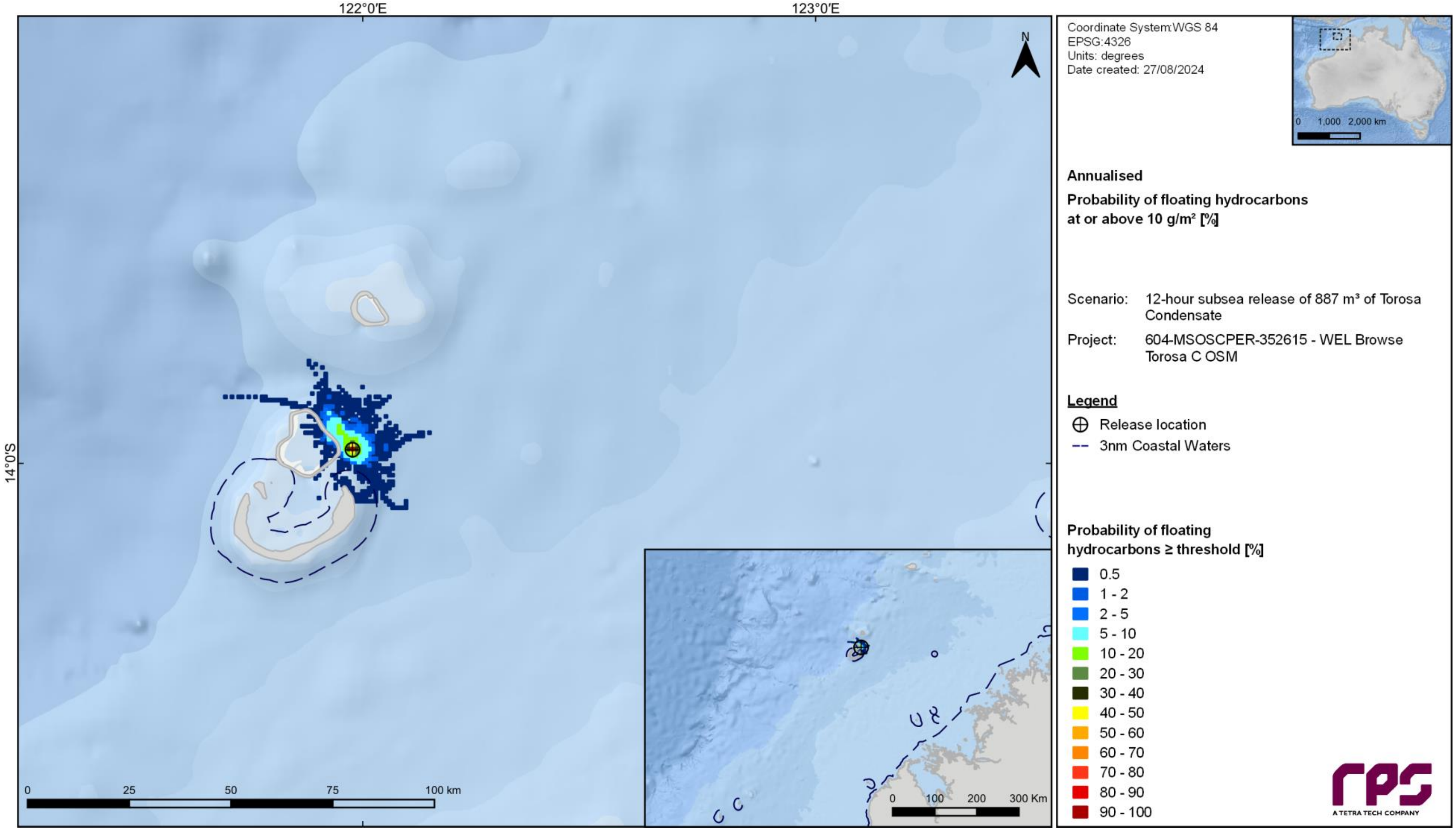


Figure 5.2: Predicted annualised probability of floating oil concentrations at or above 10 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

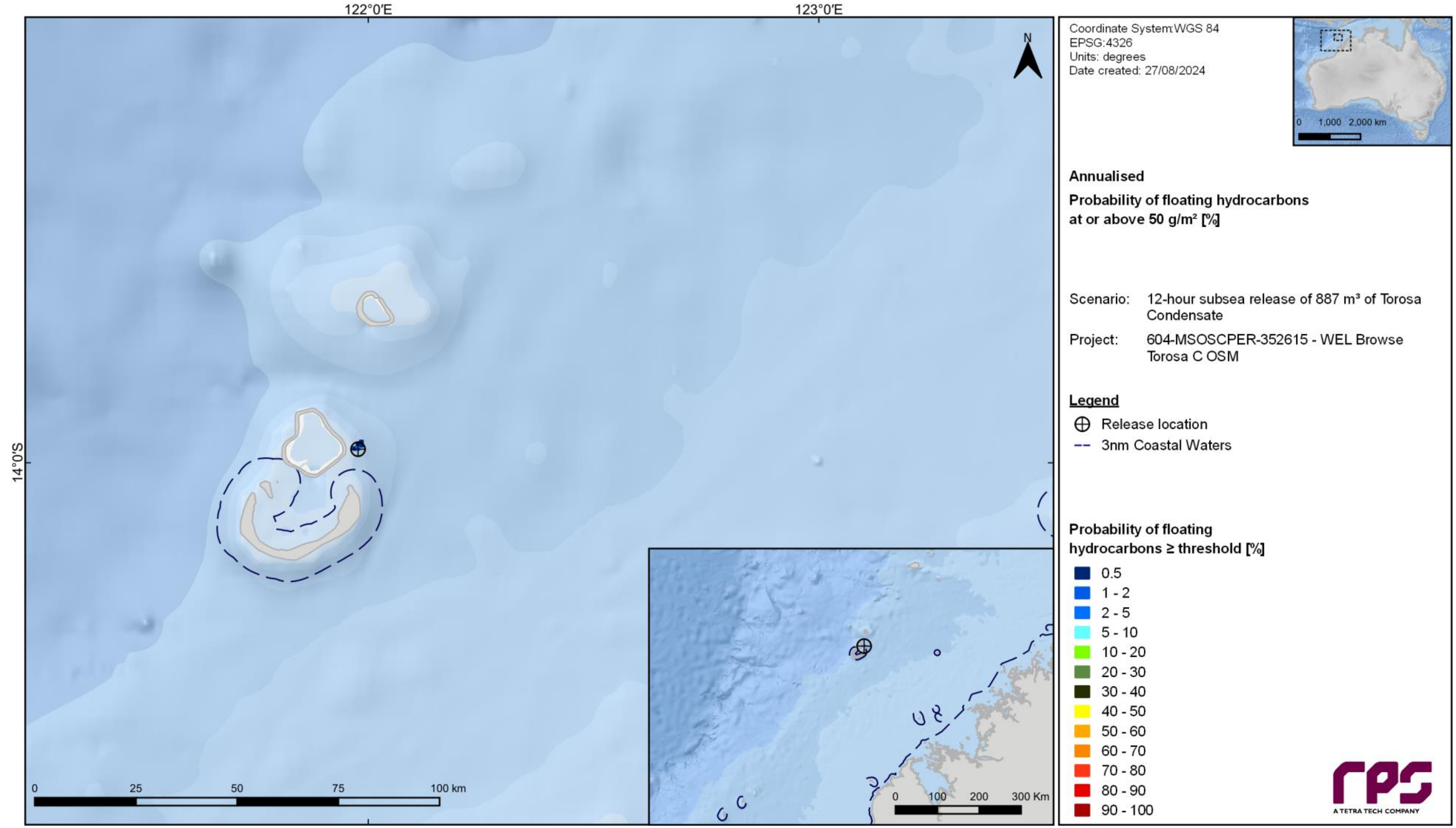


Figure 5.3: Predicted annualised probability of floating oil concentrations at or above 50 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

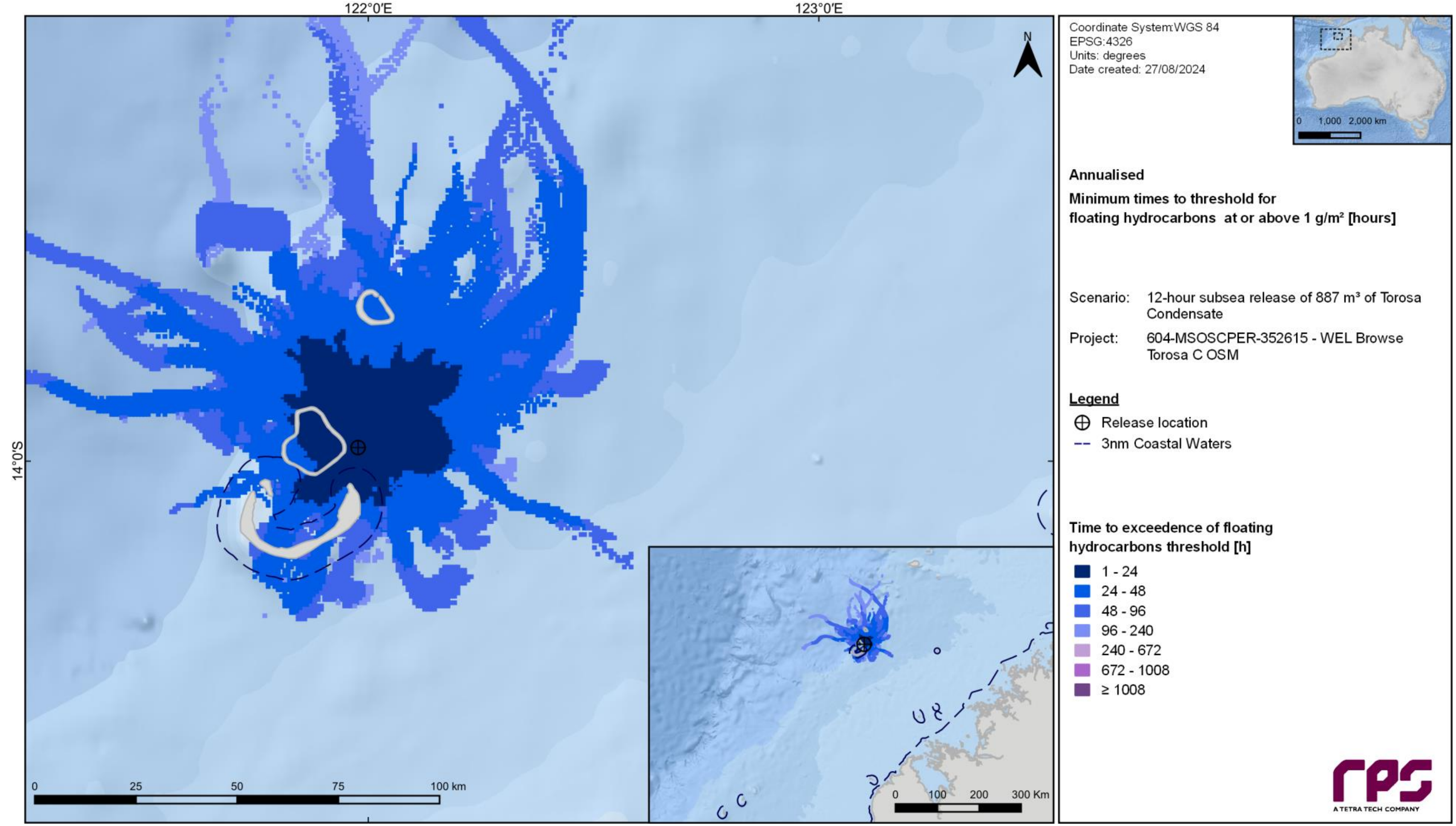


Figure 5.4: Predicted annualised minimum times to contact by floating oil concentrations at or above 1 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

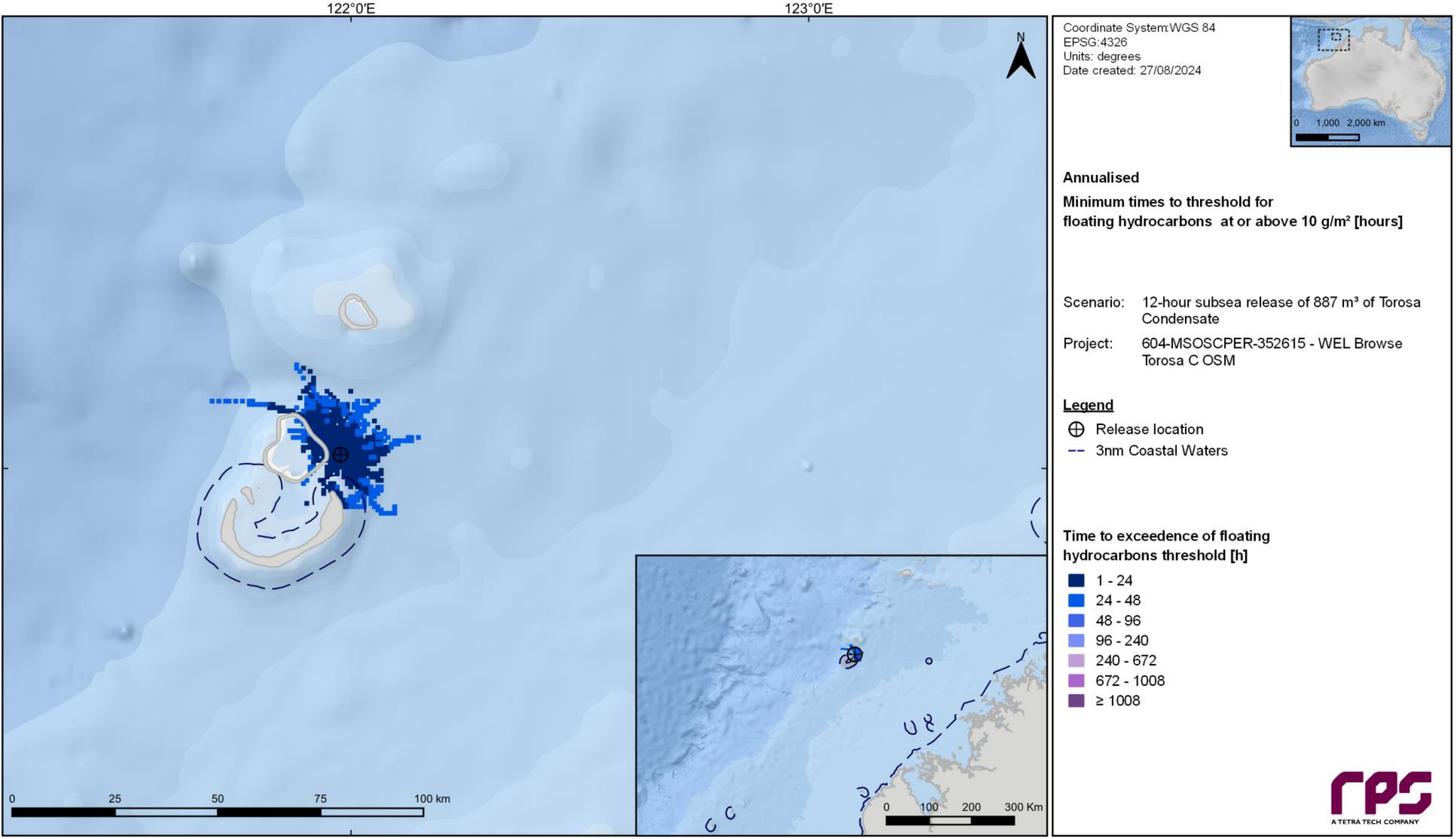


Figure 5.5: Predicted annualised minimum times to contact by floating oil concentrations at or above 10 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

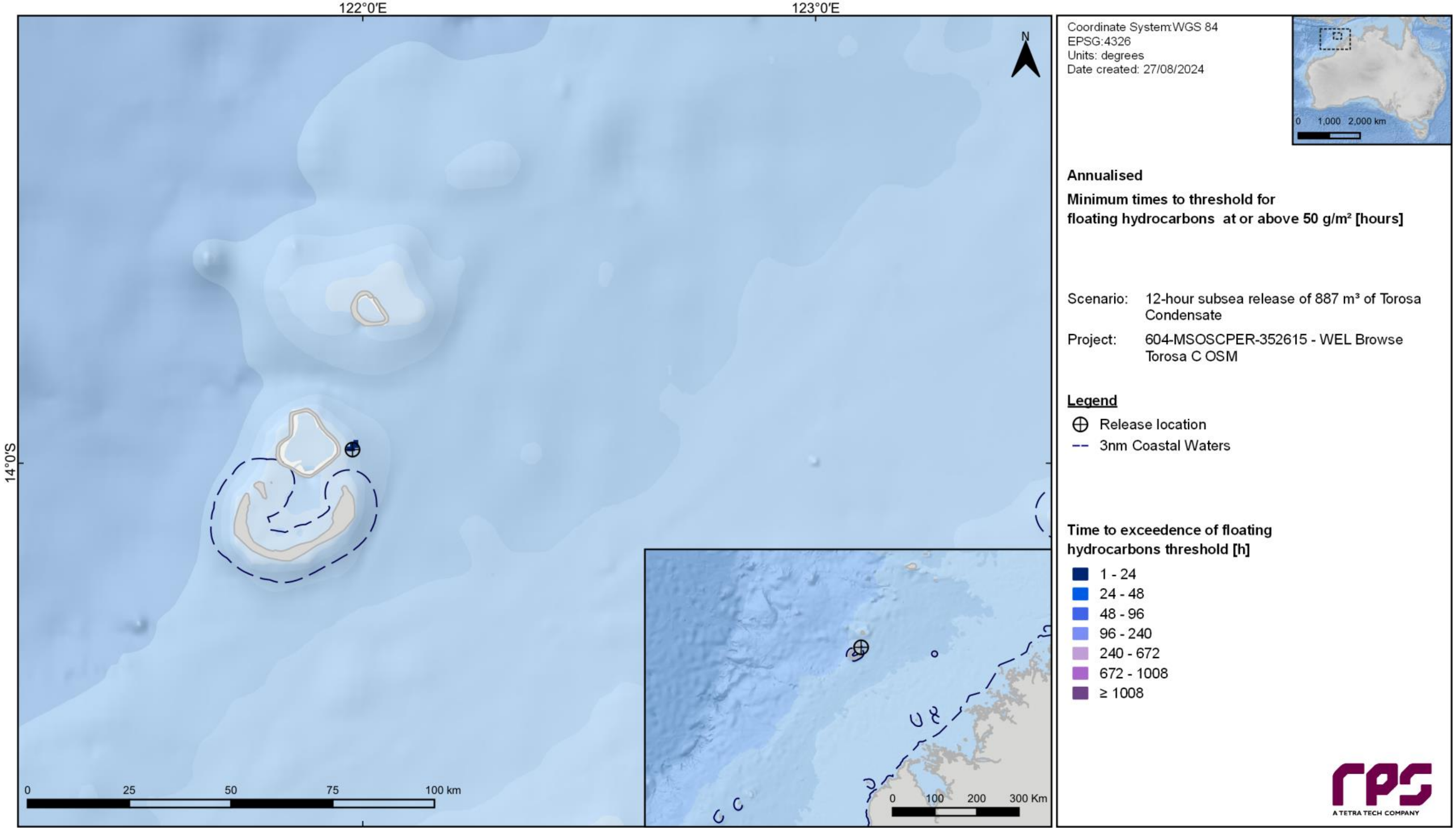


Figure 5.6: Predicted annualised minimum times to contact by floating oil concentrations at or above 50 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

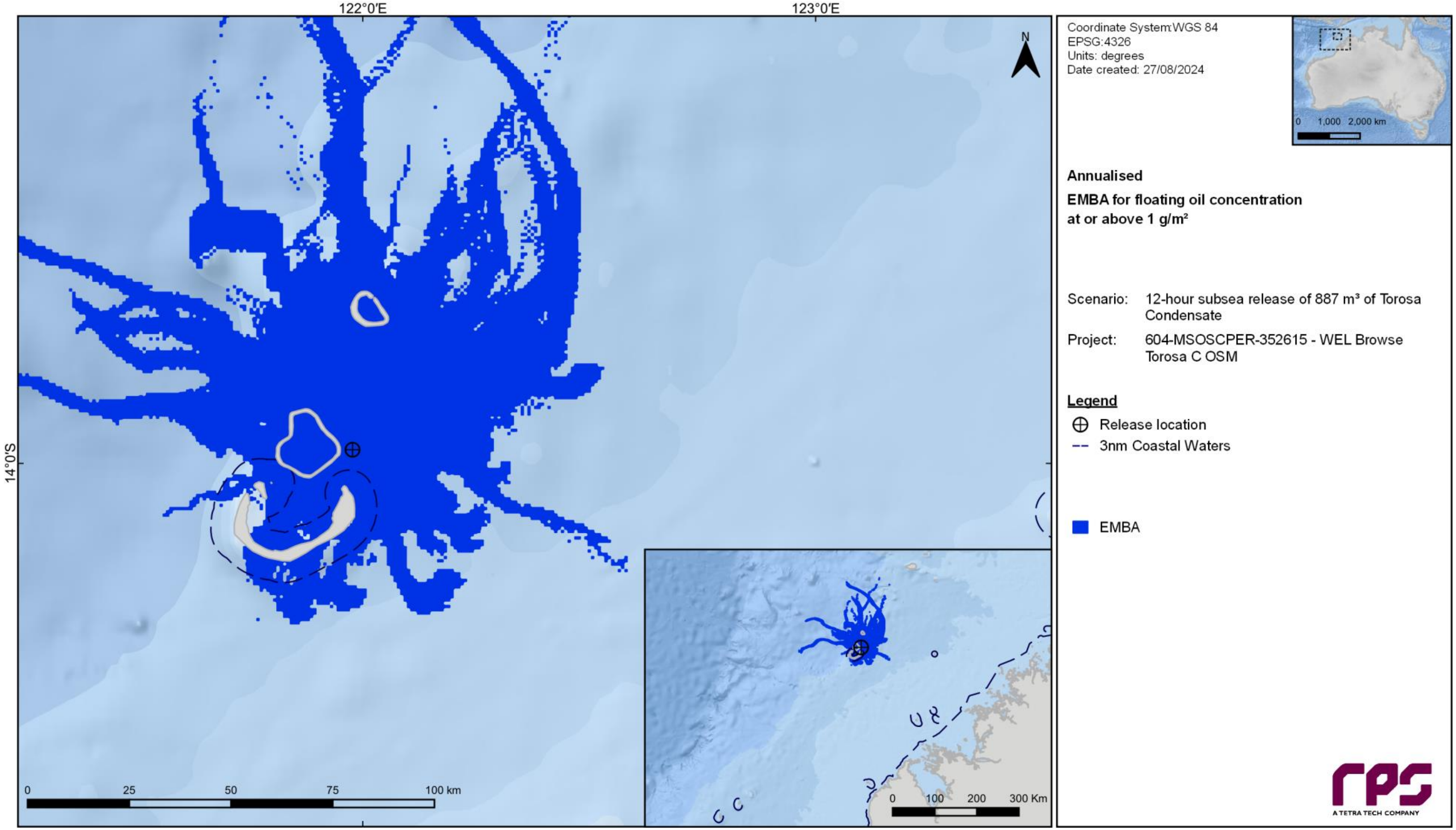


Figure 5.7: Predicted annualised EMBA of floating oil concentrations at or above 1 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

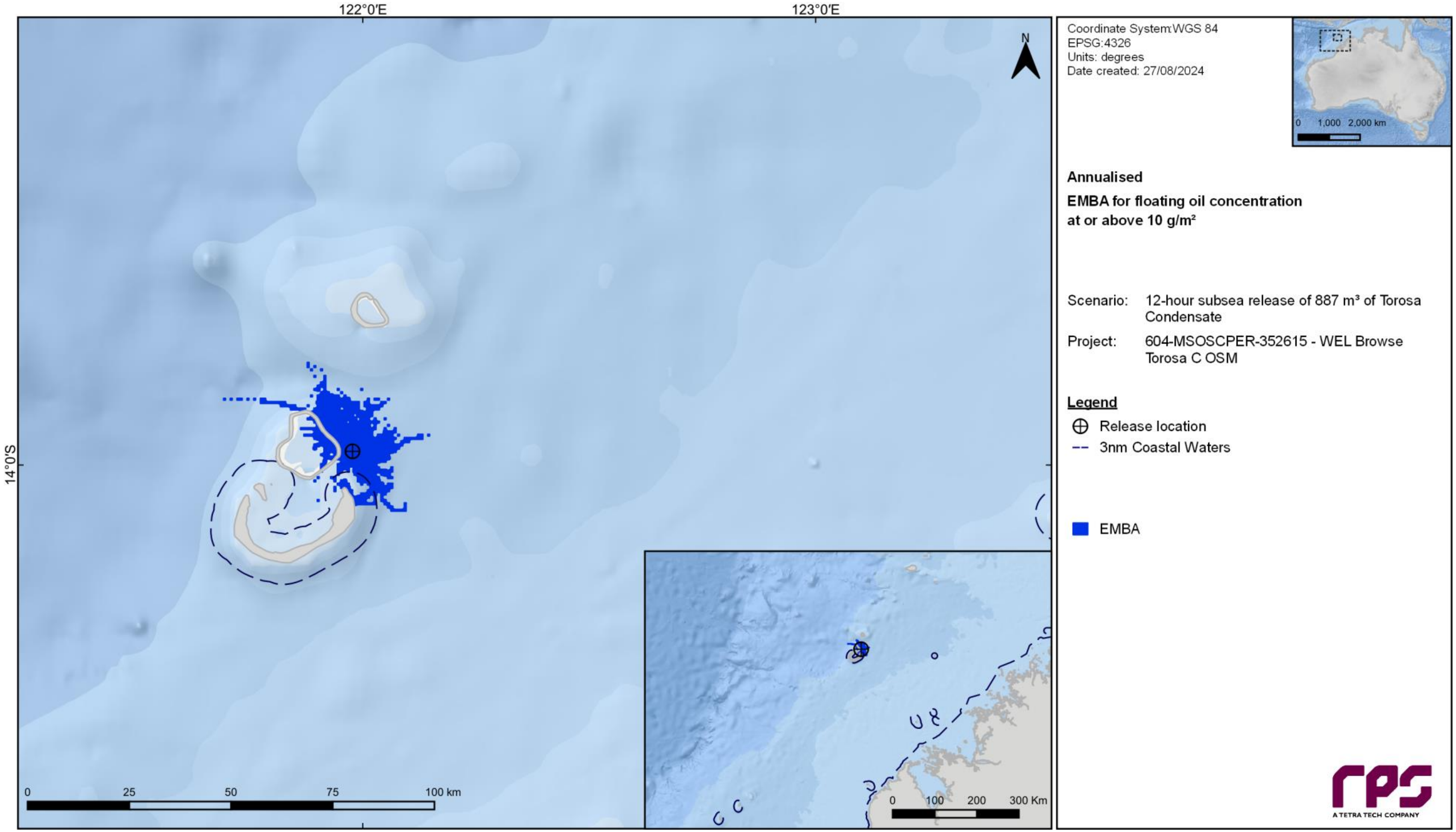


Figure 5.8: Predicted annualised EMBA of floating oil concentrations at or above 10 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

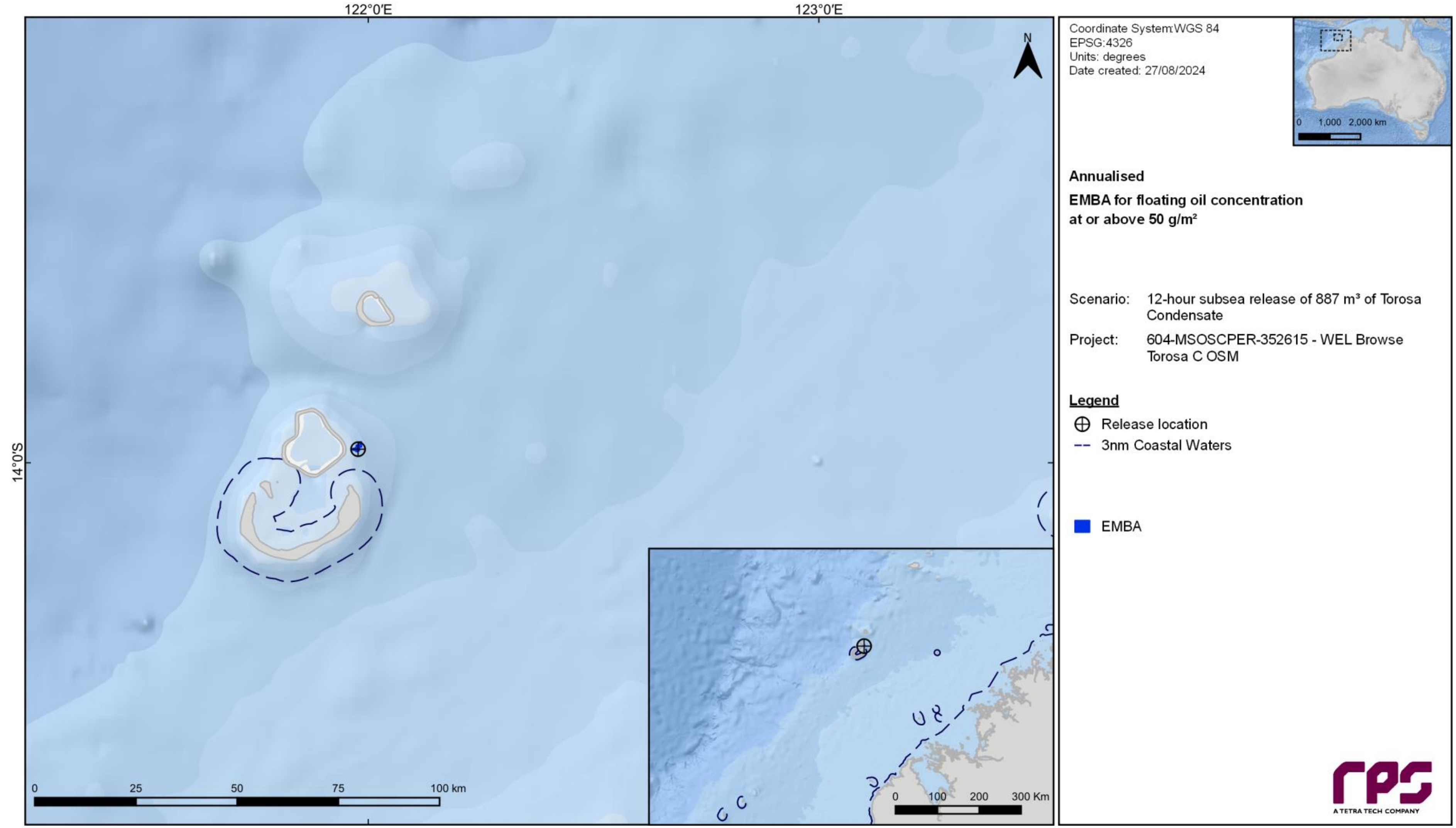


Figure 5.9: Predicted annualised EMBA of floating oil concentrations at or above 50 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

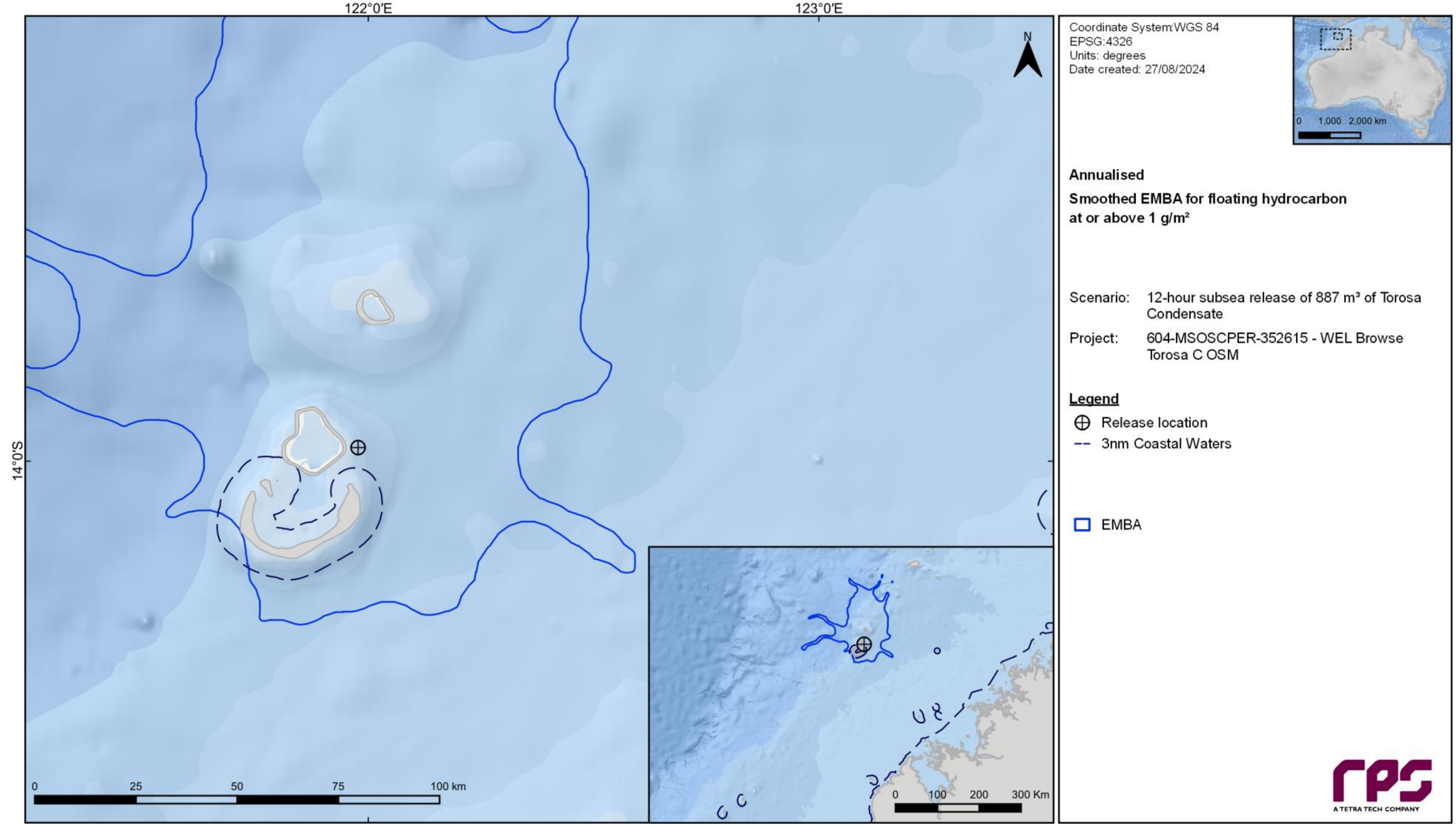


Figure 5.10: Predicted annualised smoothed EMBA of floating oil concentrations at or above 1 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

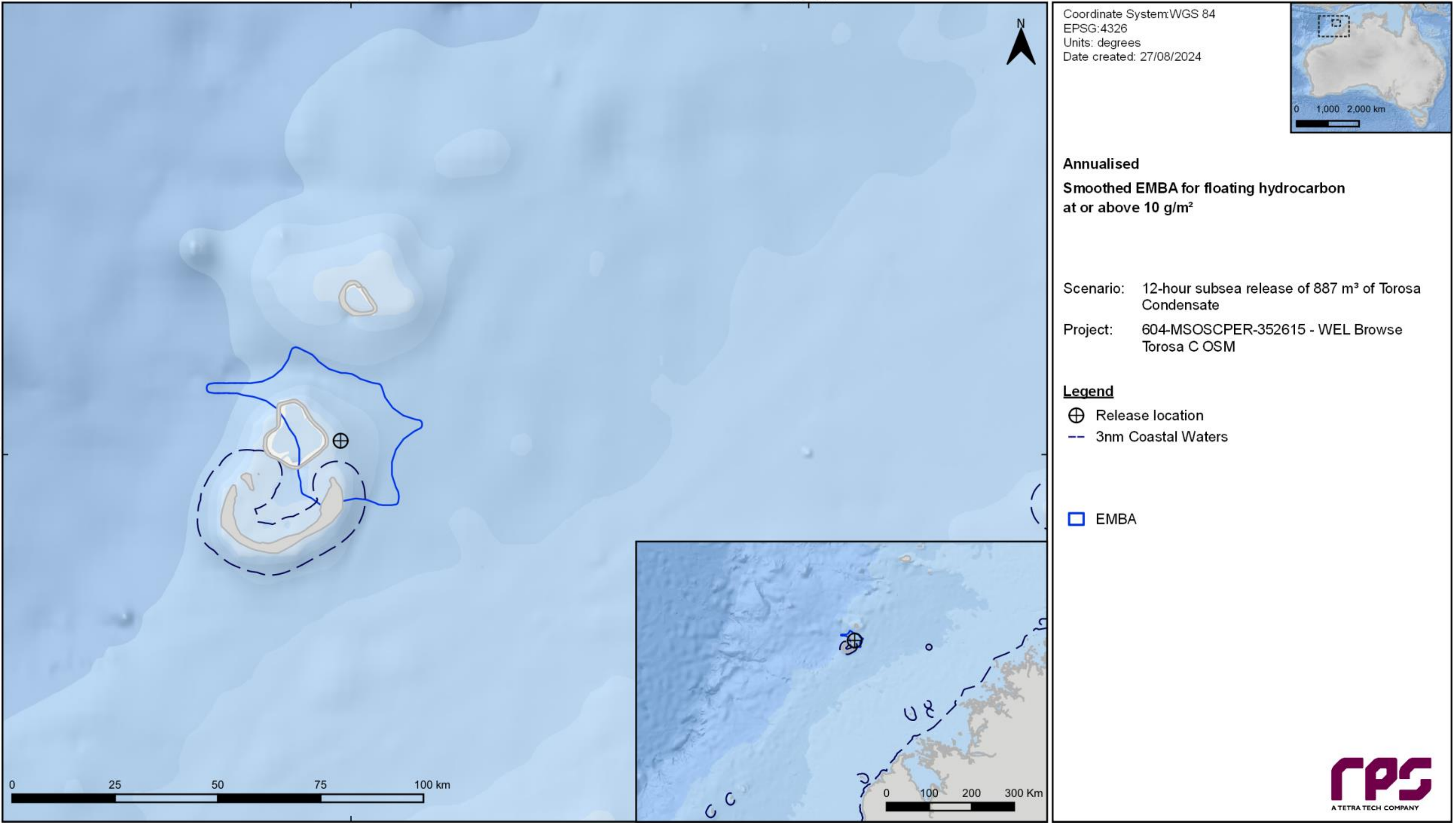


Figure 5.11: **Predicted annualised smoothed EMBA of floating oil concentrations at or above 10 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.**

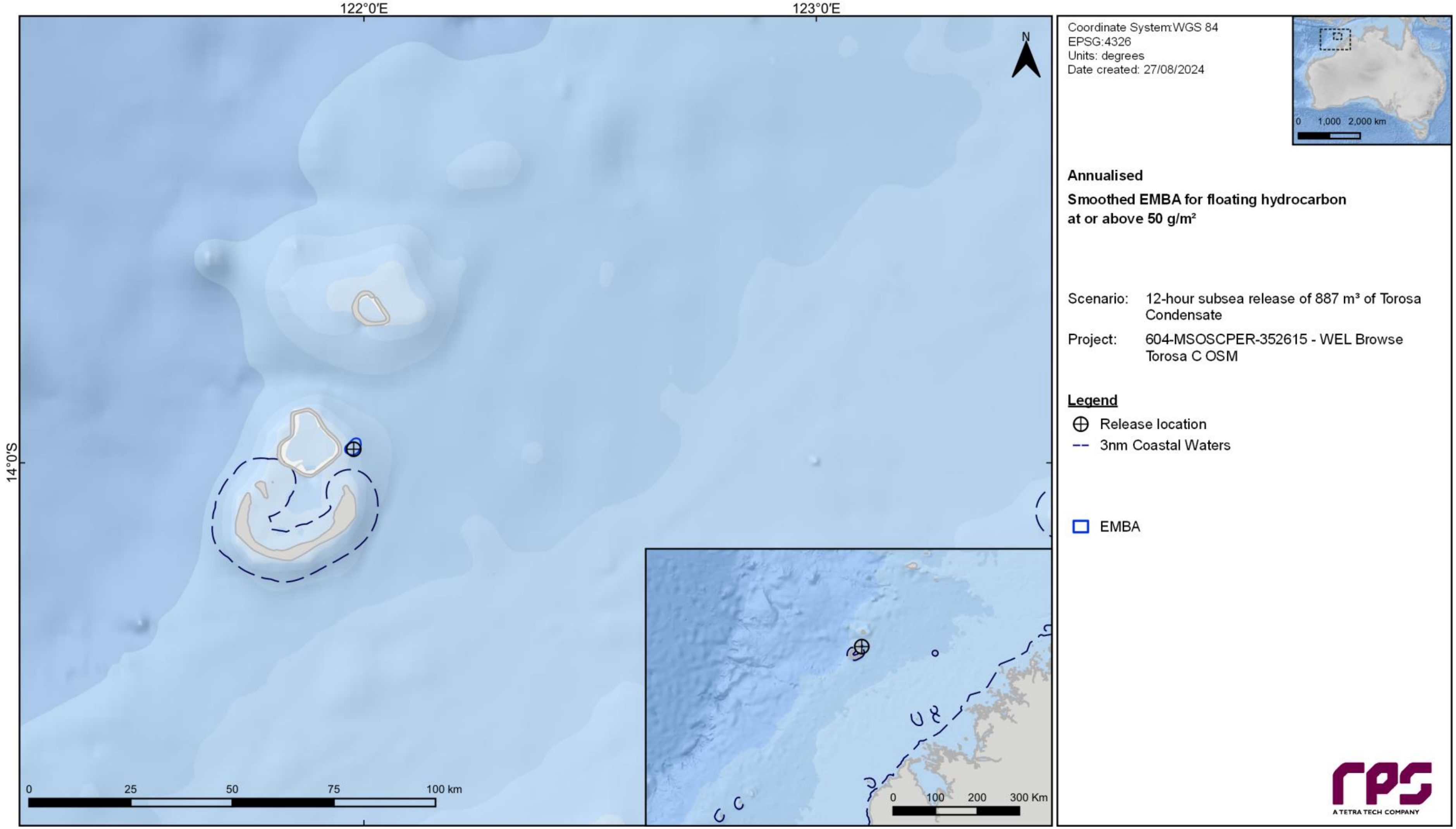


Figure 5.12: Predicted annualised smoothed EMBA of floating oil concentrations at or above 50 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

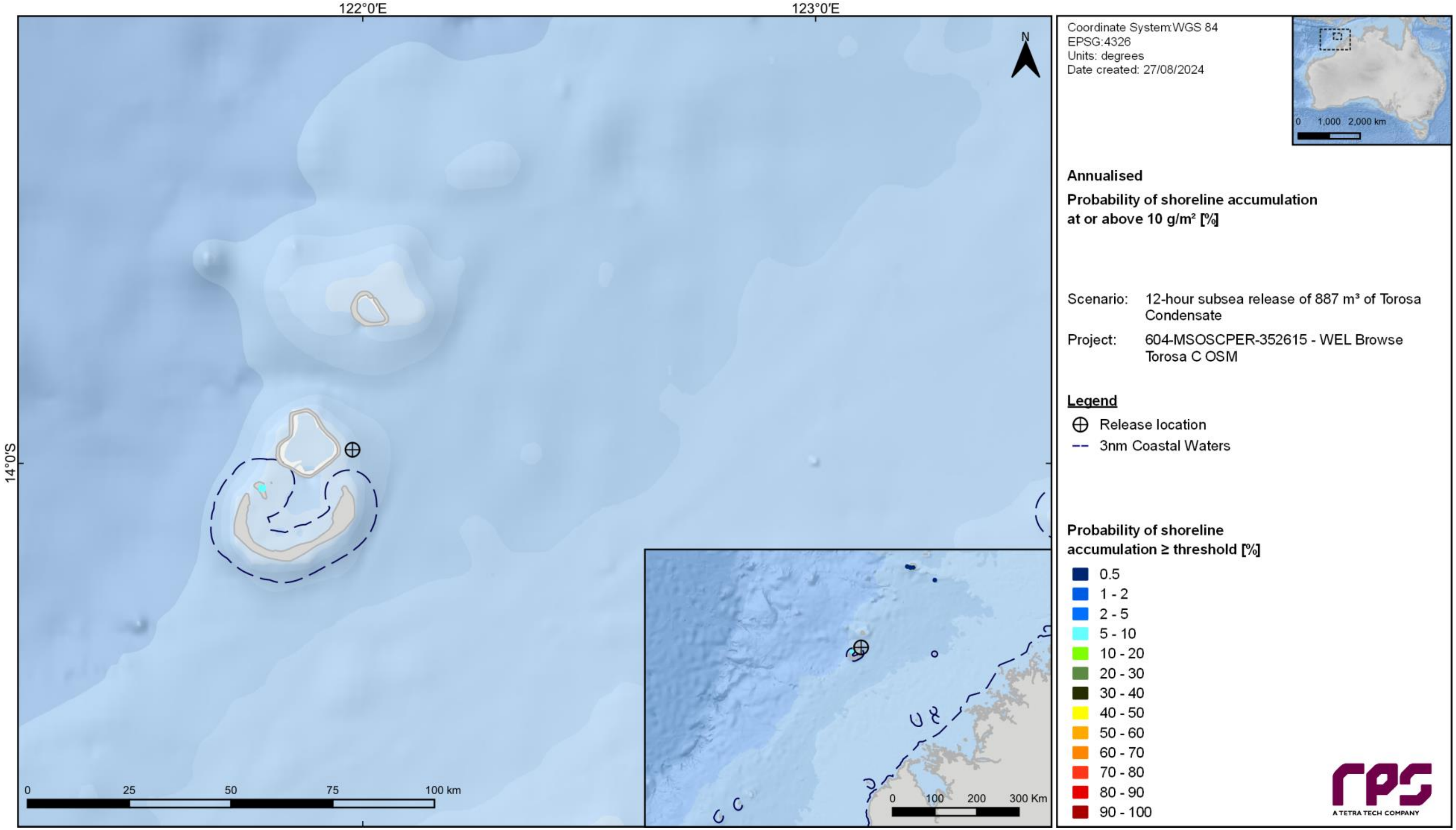


Figure 5.13: Predicted annualised probability of shoreline oil concentrations at or above 10 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

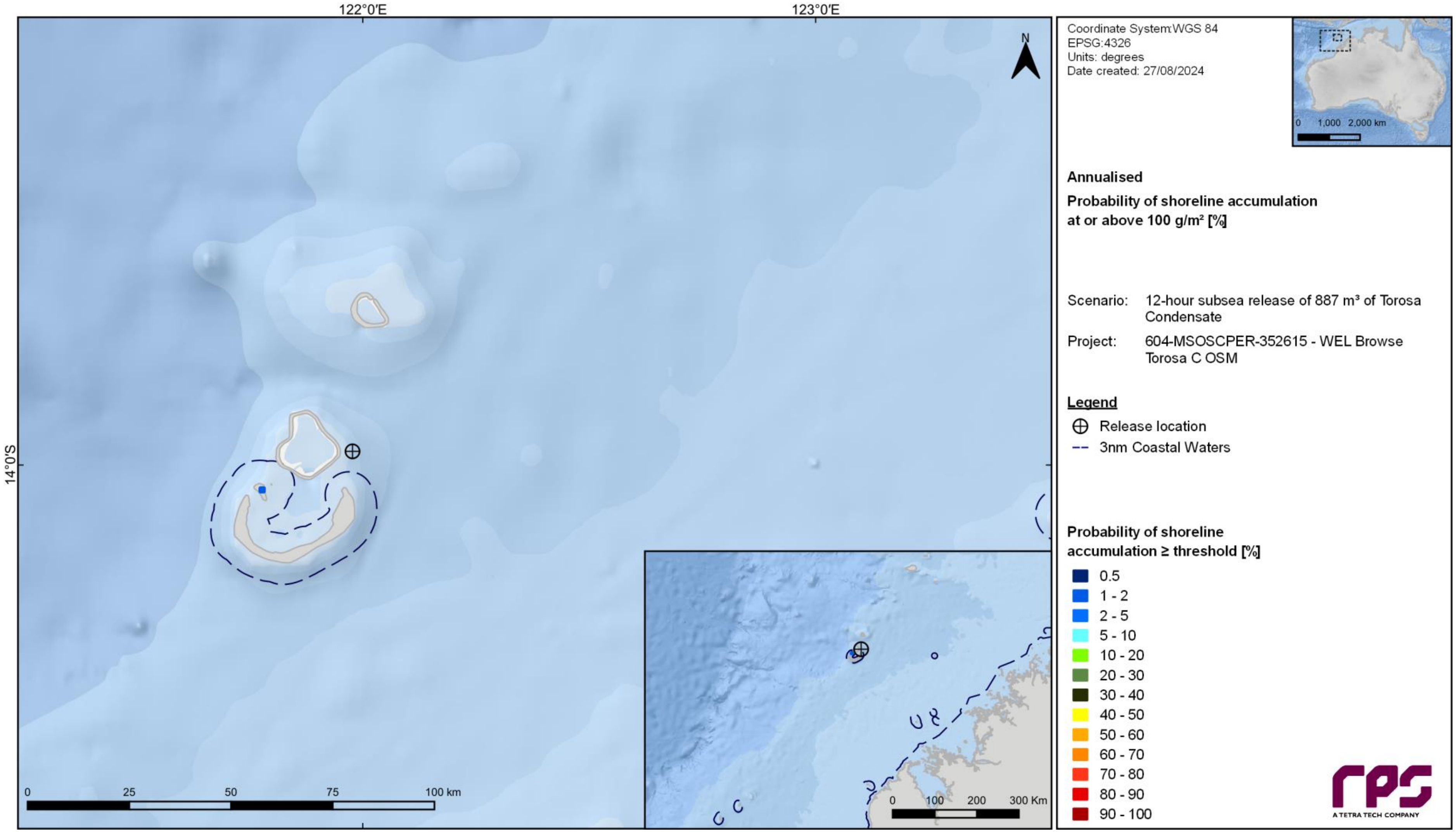


Figure 5.14: Predicted annualised probability of shoreline oil concentrations at or above 100 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

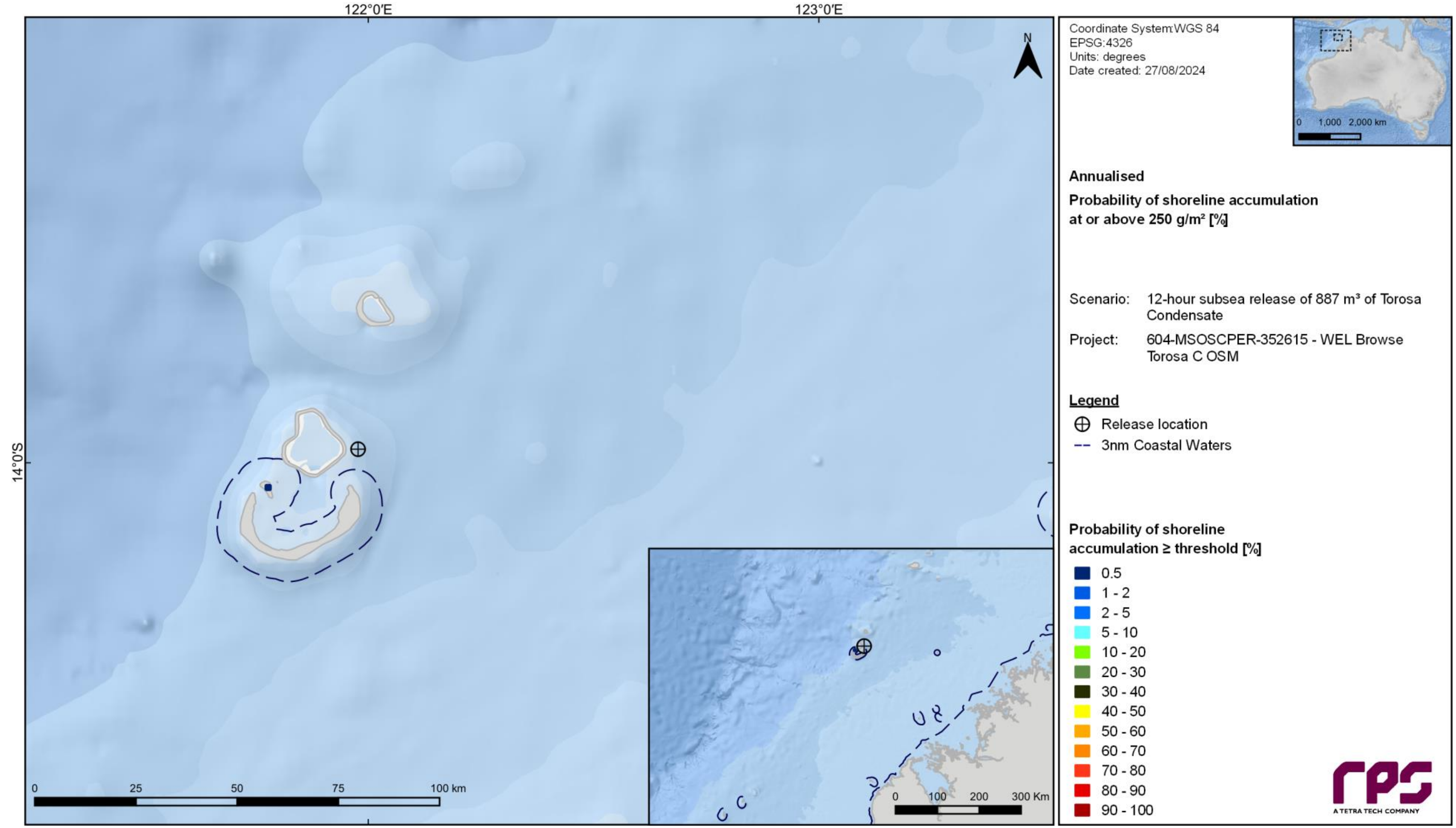


Figure 5.15: Predicted annualised probability of shoreline oil concentrations at or above 250 g/m² resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

5.2.1.6 Entrained Oil

Table 5.5 **Expected annualised entrained oil outcomes at sensitive receptors for a 12-hour subsea release of 887 m³ of Torosa Condensate.**

Receptors		Probability (%) of entrained hydrocarbon concentration contact			Minimum time to receptor waters (hours) at			Maximum entrained hydrocarbon concentration (ppb)	
		≥ 10 ppb	≥ 100 ppb	≥ 1,000 ppb	≥ 10 ppb	≥ 100 ppb	≥ 1,000 ppb	averaged over all replicate spills	in the worst replicate
Australian Marine Parks	Argo-Rowley Terrace MP	1	<0.5	<0.5	308	NC	NC	<1	18
	Ashmore Reef MP	2	<0.5	<0.5	160	NC	NC	<1	55
	Cartier Island MP	0.5	<0.5	<0.5	267	NC	NC	<1	11
	Kimberley MP	1	<0.5	<0.5	177	NC	NC	<1	31
Islands	Cartier Island	<0.5	<0.5	<0.5	NC	NC	NC	<1	10
Nature Reserve	Scott Reef NR	23.5	5.5	<0.5	10	11	NC	22	996
Reefs, Shoals and Banks	Ashmore Reef	1.5	<0.5	<0.5	170	NC	NC	<1	55
	Hibernia Reef	<0.5	<0.5	<0.5	NC	NC	NC	<1	10
	Johnson Bank	1	<0.5	<0.5	265	NC	NC	<1	30
	Sahul Bank §	1	<0.5	<0.5	215	NC	NC	<1	19
	Sandy Islet	20	4.5	<0.5	18	27	NC	15	393
	Scott Reef North	64	37	5	1	1	3	196	3,783
	Scott Reef South	30.5	9.5	<0.5	4	5	NC	33	996
	Seringapatam Reef	26	4	<0.5	20	30	NC	13	197
	Vee Shoal	0.5	<0.5	<0.5	298	NC	NC	<1	12
	Woodbine Bank	0.5	<0.5	<0.5	293	NC	NC	<1	11

NC: No contact to receptor predicted for specified threshold.

§ Probabilities and maximum concentrations calculated at depth of submerged feature

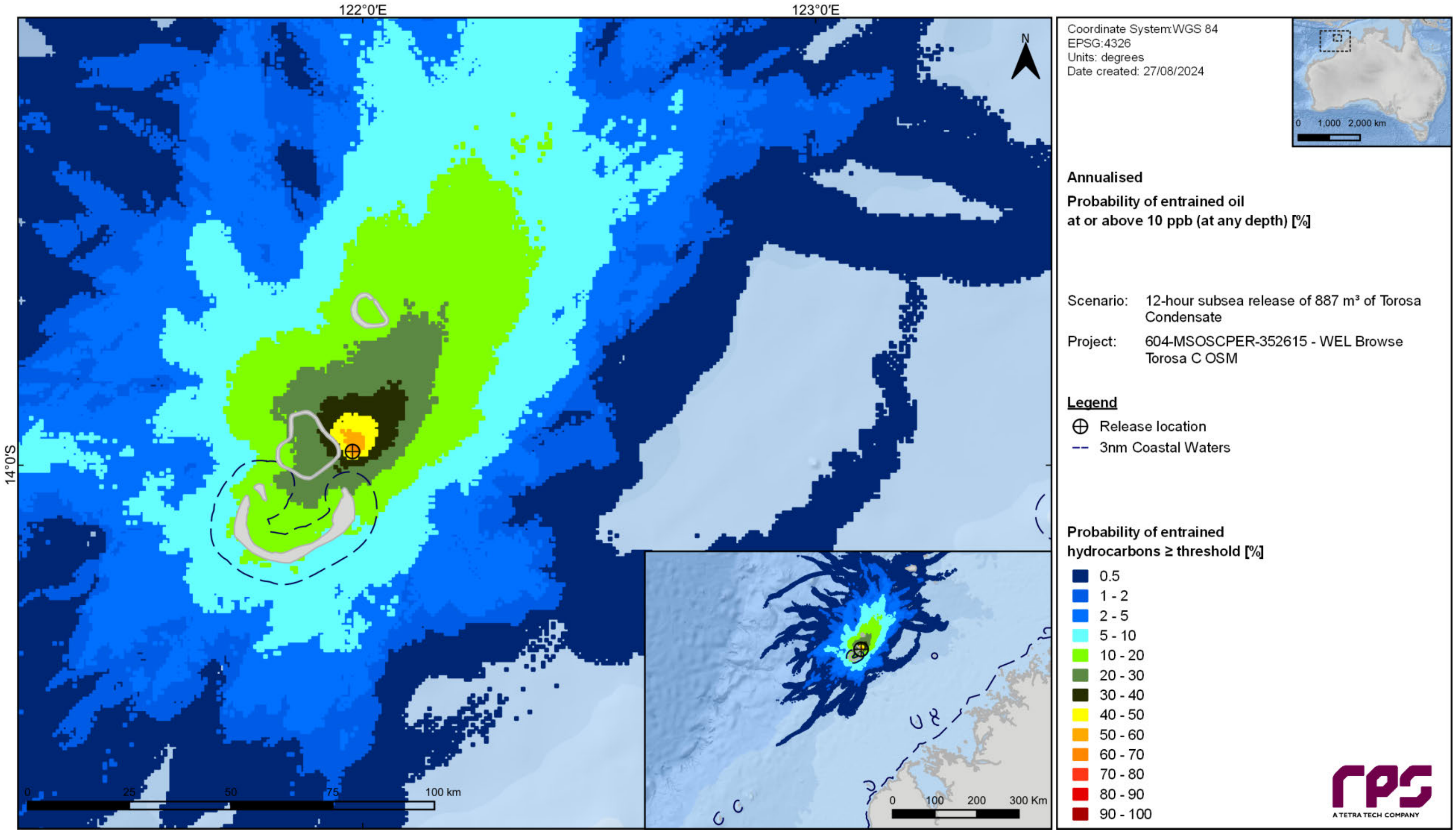


Figure 5.16: Predicted annualised probability of entrained oil concentrations at or above 10 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

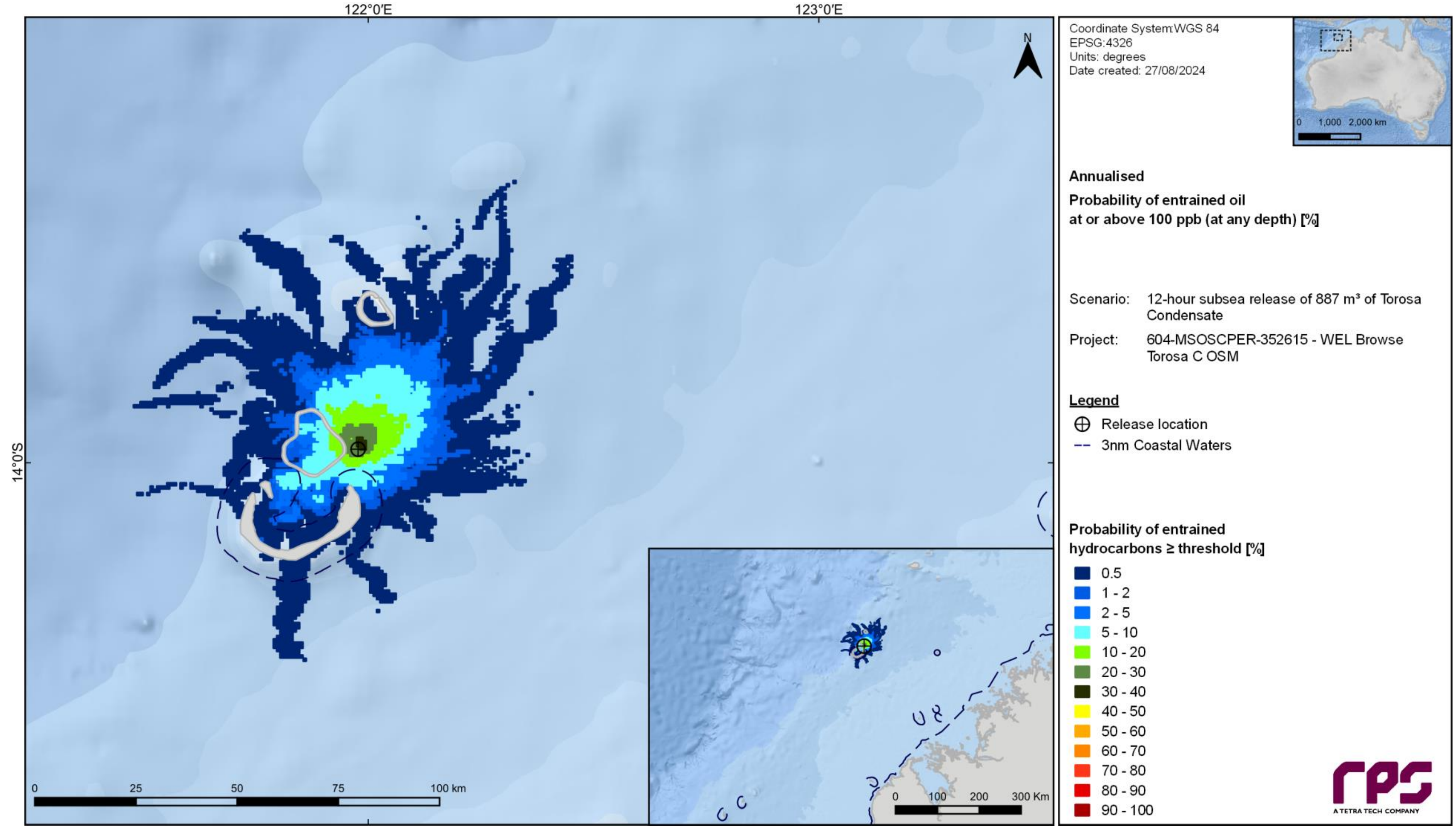


Figure 5.17: Predicted annualised probability of entrained oil concentrations at or above 100 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

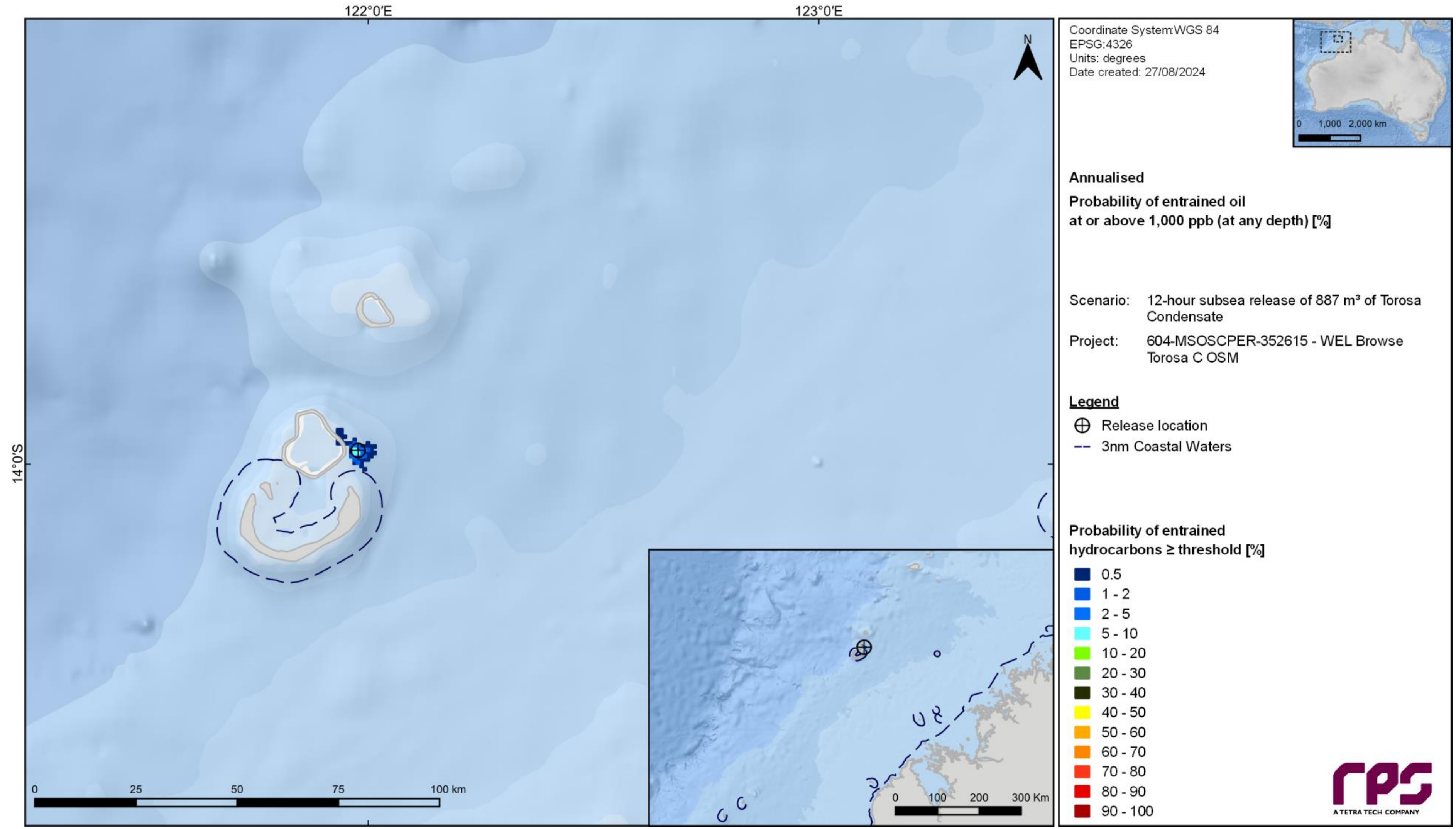


Figure 5.18: Predicted annualised probability of entrained oil concentrations at or above 1,000 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

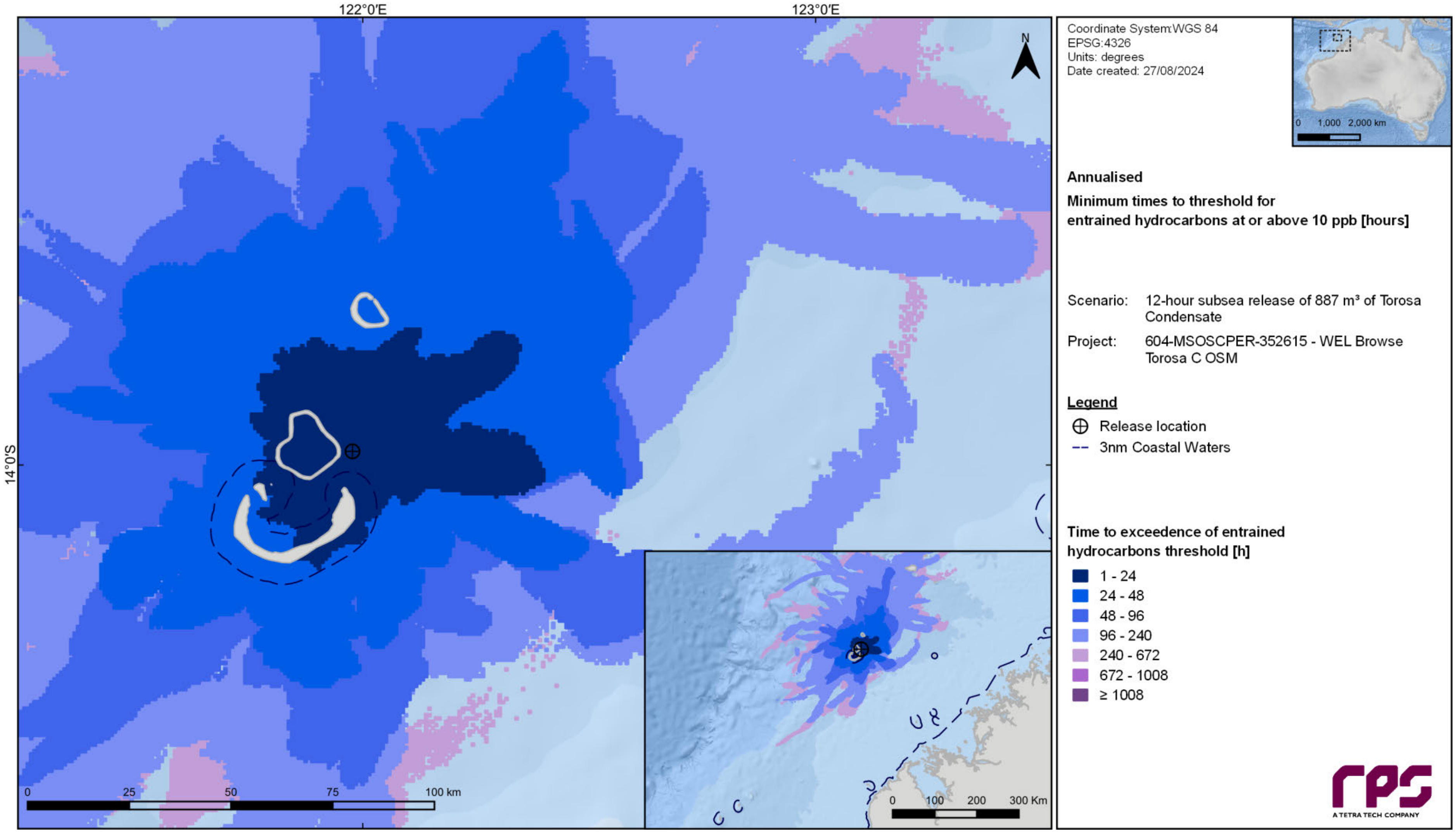


Figure 5.19: Predicted annualised minimum times to contact by entrained oil concentrations at or above 10 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

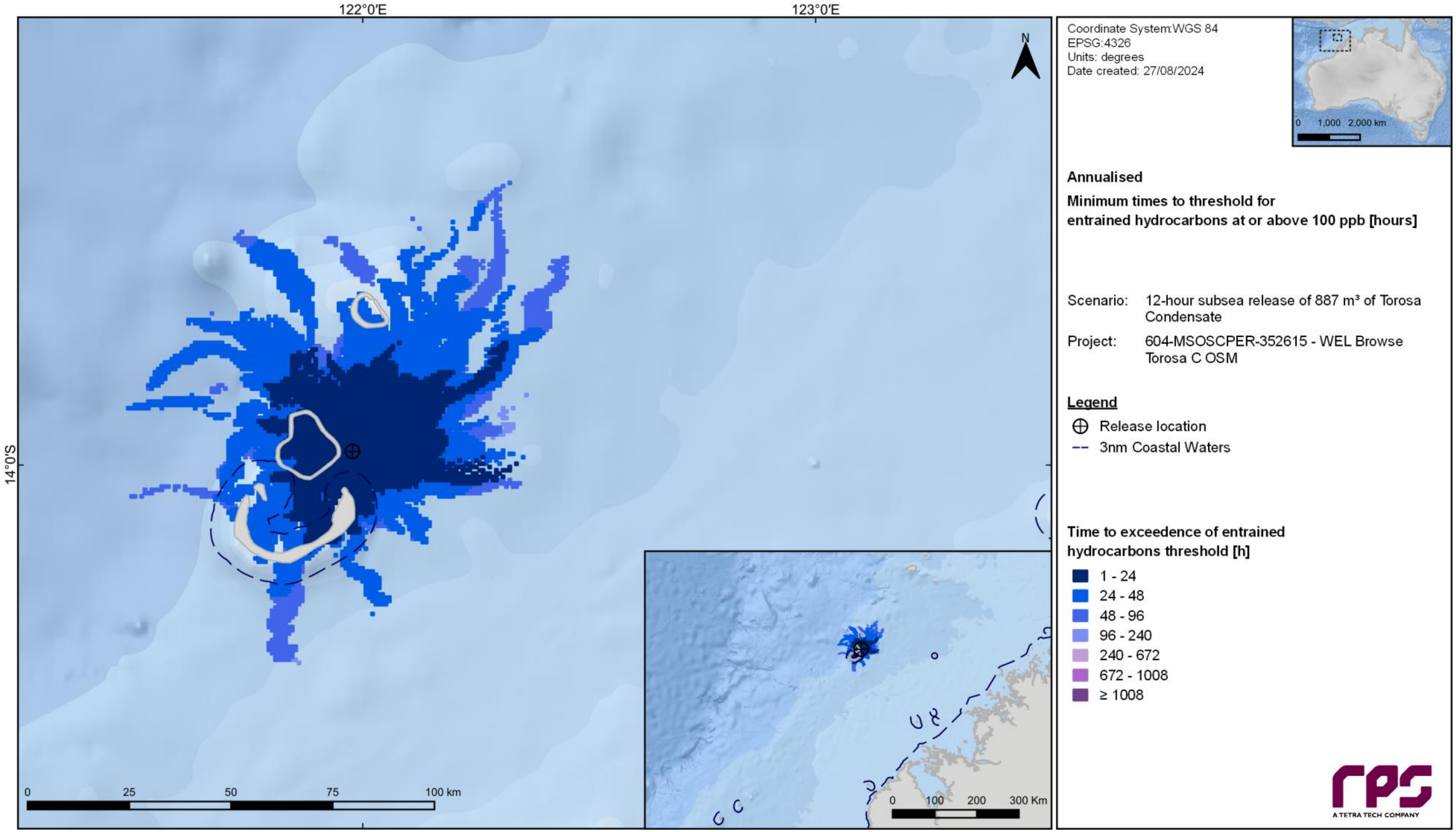


Figure 5.20: Predicted annualised minimum times to contact by entrained oil concentrations at or above 100 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

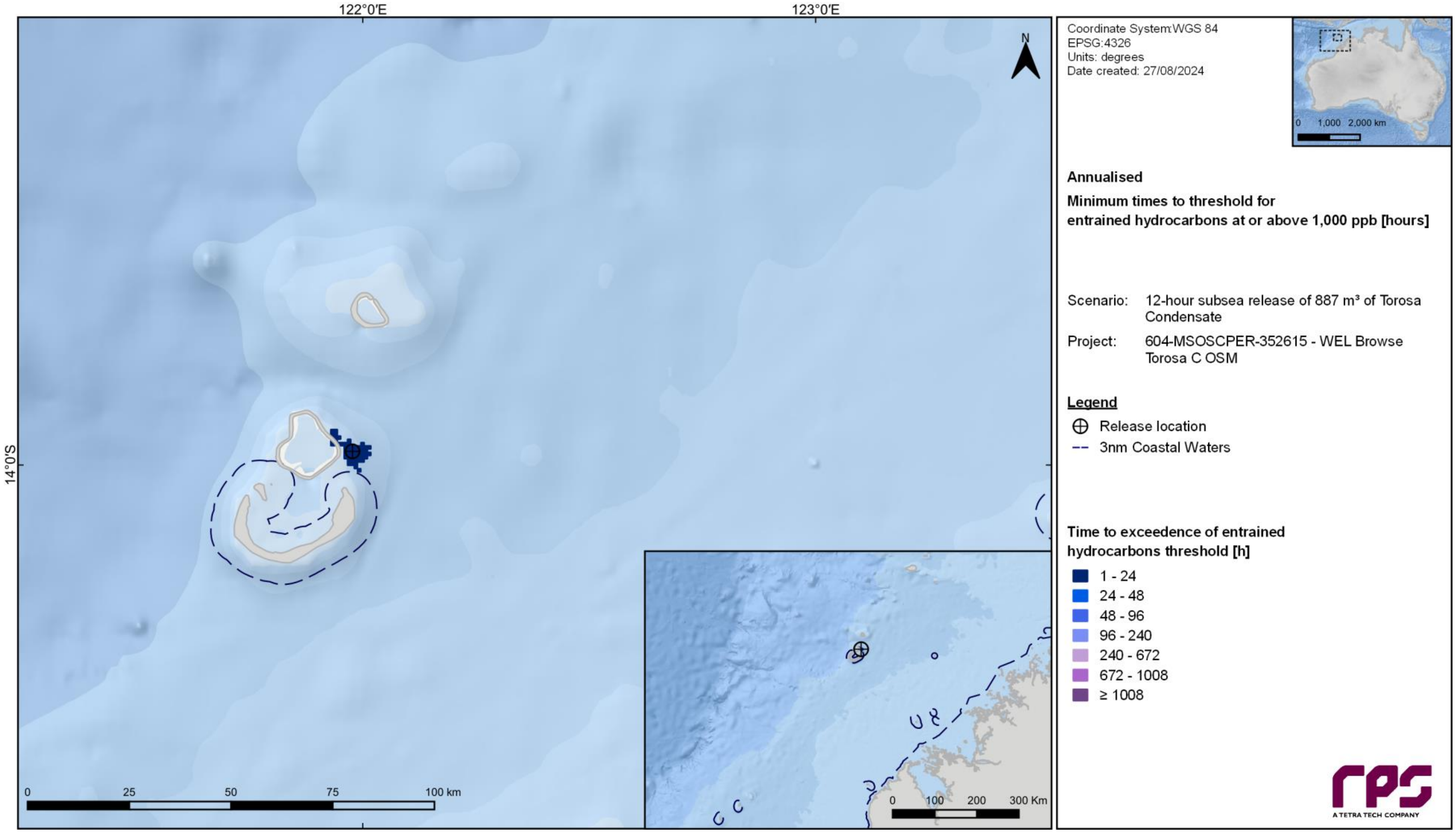


Figure 5.21: Predicted annualised minimum times to contact by entrained oil concentrations at or above 1,000 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

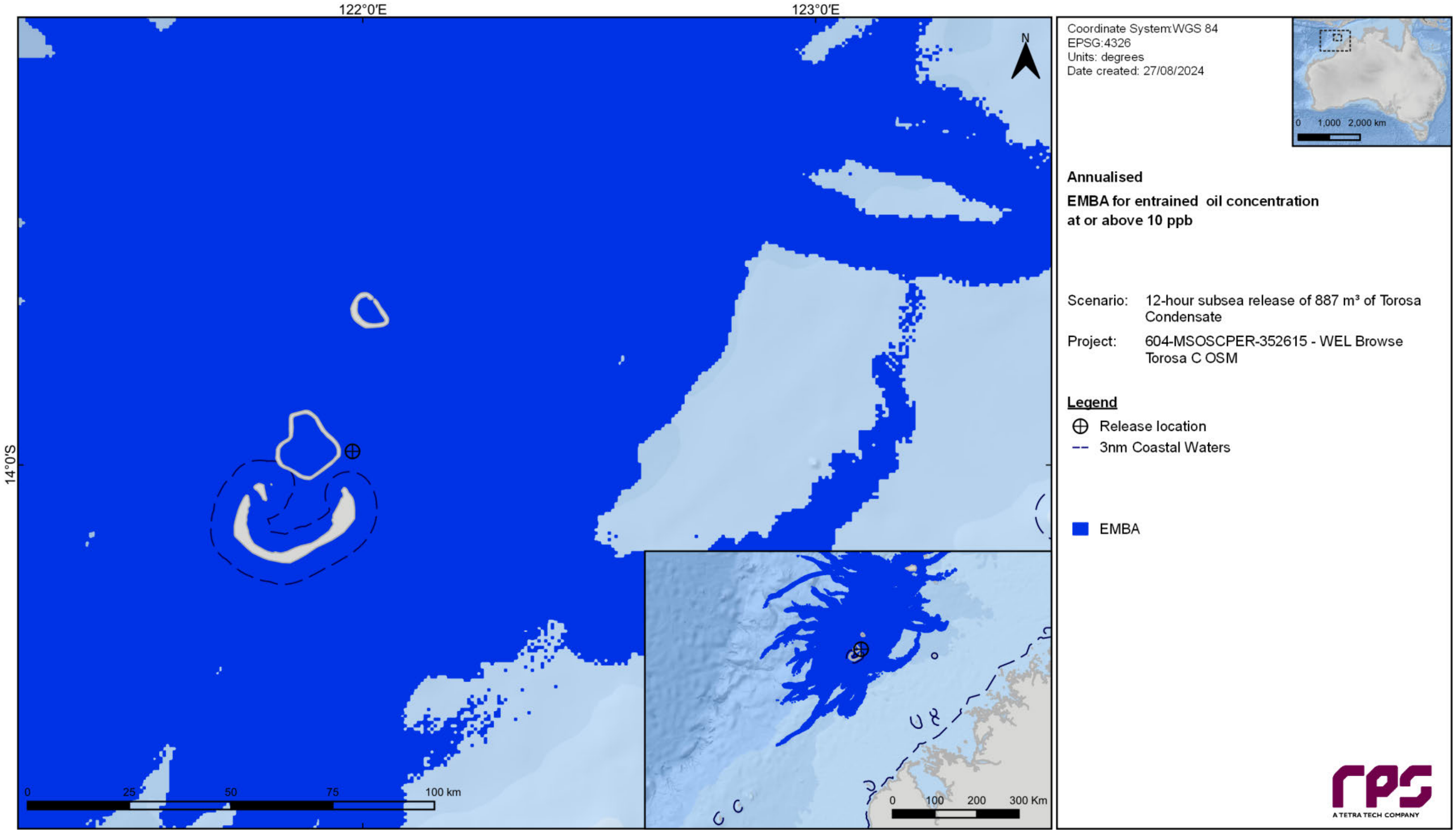


Figure 5.22: Predicted annualised EMBA of entrained oil concentrations at or above 10 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

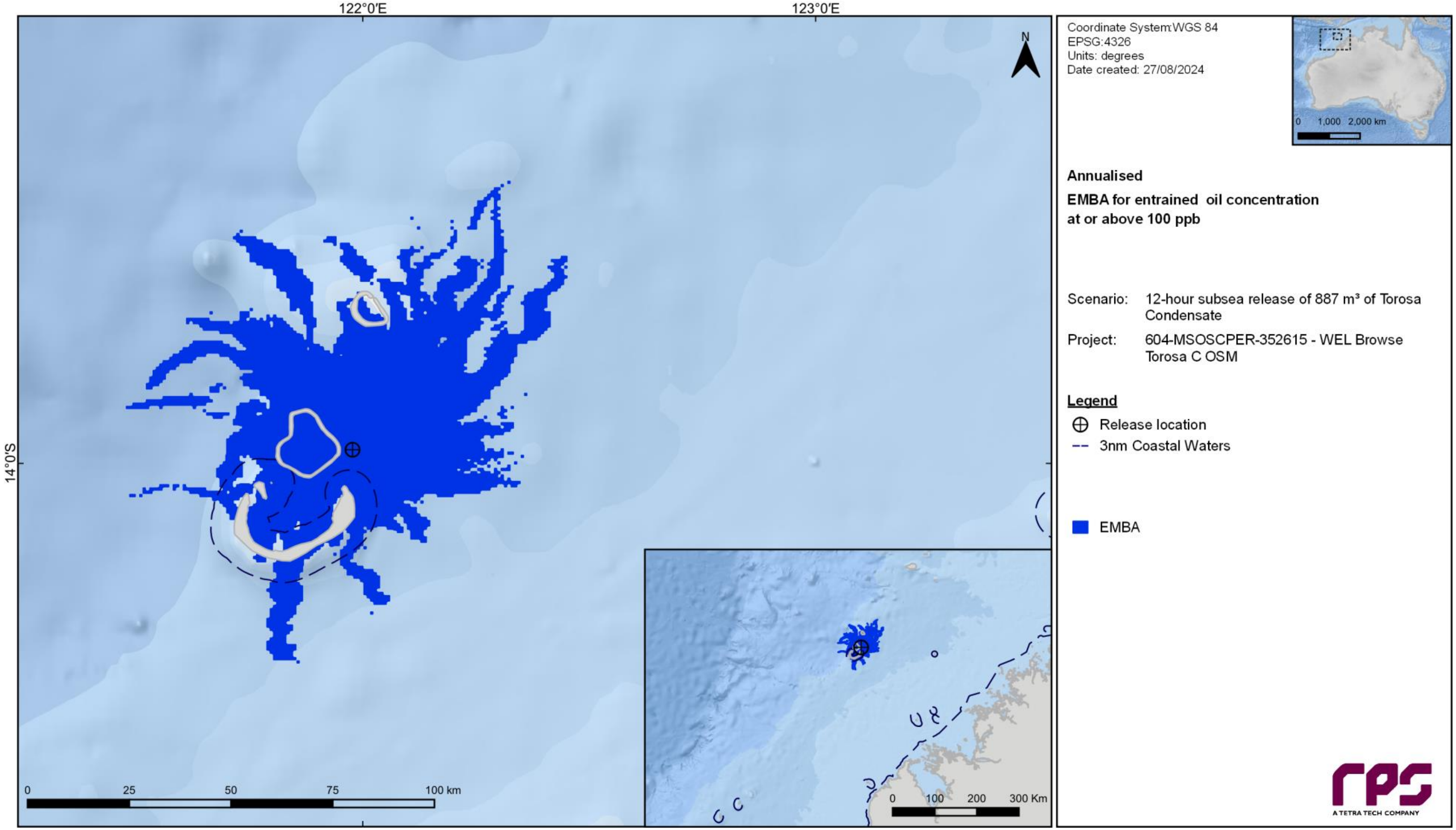


Figure 5.23: Predicted annualised EMBA of entrained oil concentrations at or above 100 ppb resulting from a 12-hour subsea release of 887 m^3 of Torosa Condensate.

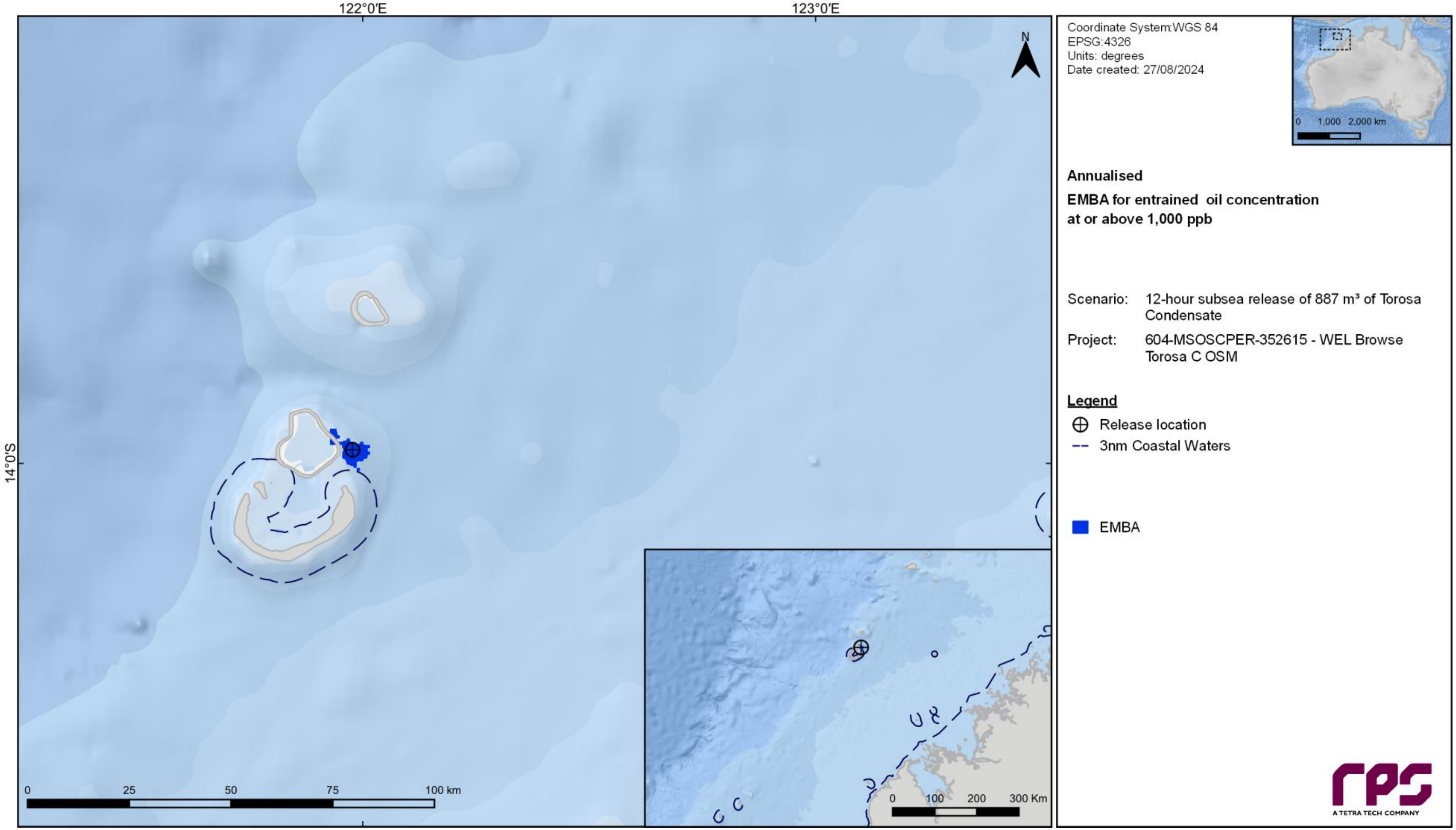
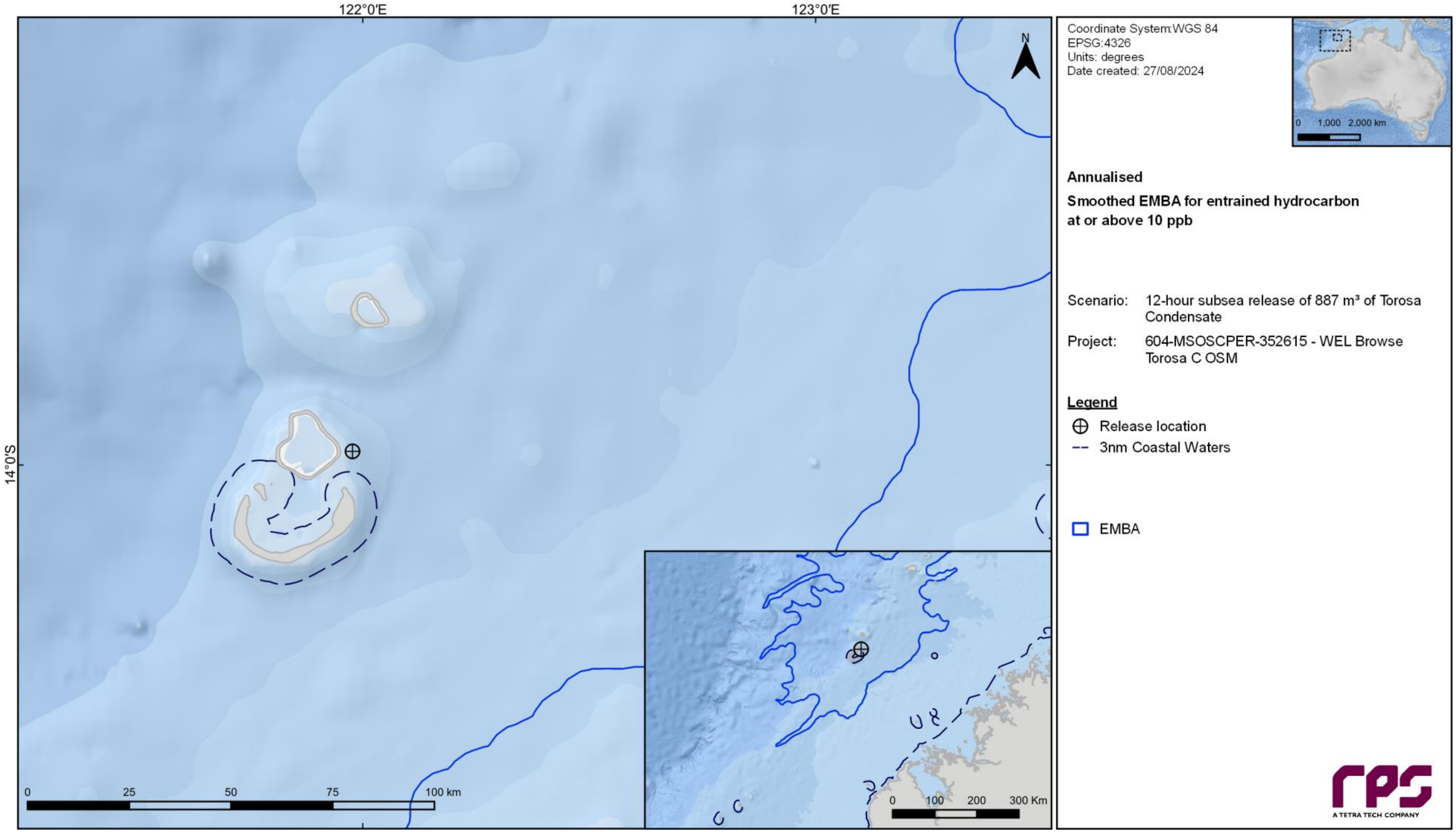


Figure 5.24: Predicted annualised EMBA of entrained oil concentrations at or above 1,000 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.



Coordinate System:WGS 84
EPSG:4326
Units: degrees
Date created: 27/08/2024

Annualised

Smoothed EMBA for entrained hydrocarbon at or above 10 ppb

Scenario:	12-hour subsea release of 887 m³ of Torosa Condensate
Project:	604-MSOSCPER-352615 - WEL Browse Torosa C OSM

Legend

⊕ Release location

-- 3nm Coastal Waters

☐ EMBA

Figure 5.25: Predicted annualised smoothed EMBA of entrained oil concentrations at or above 10 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

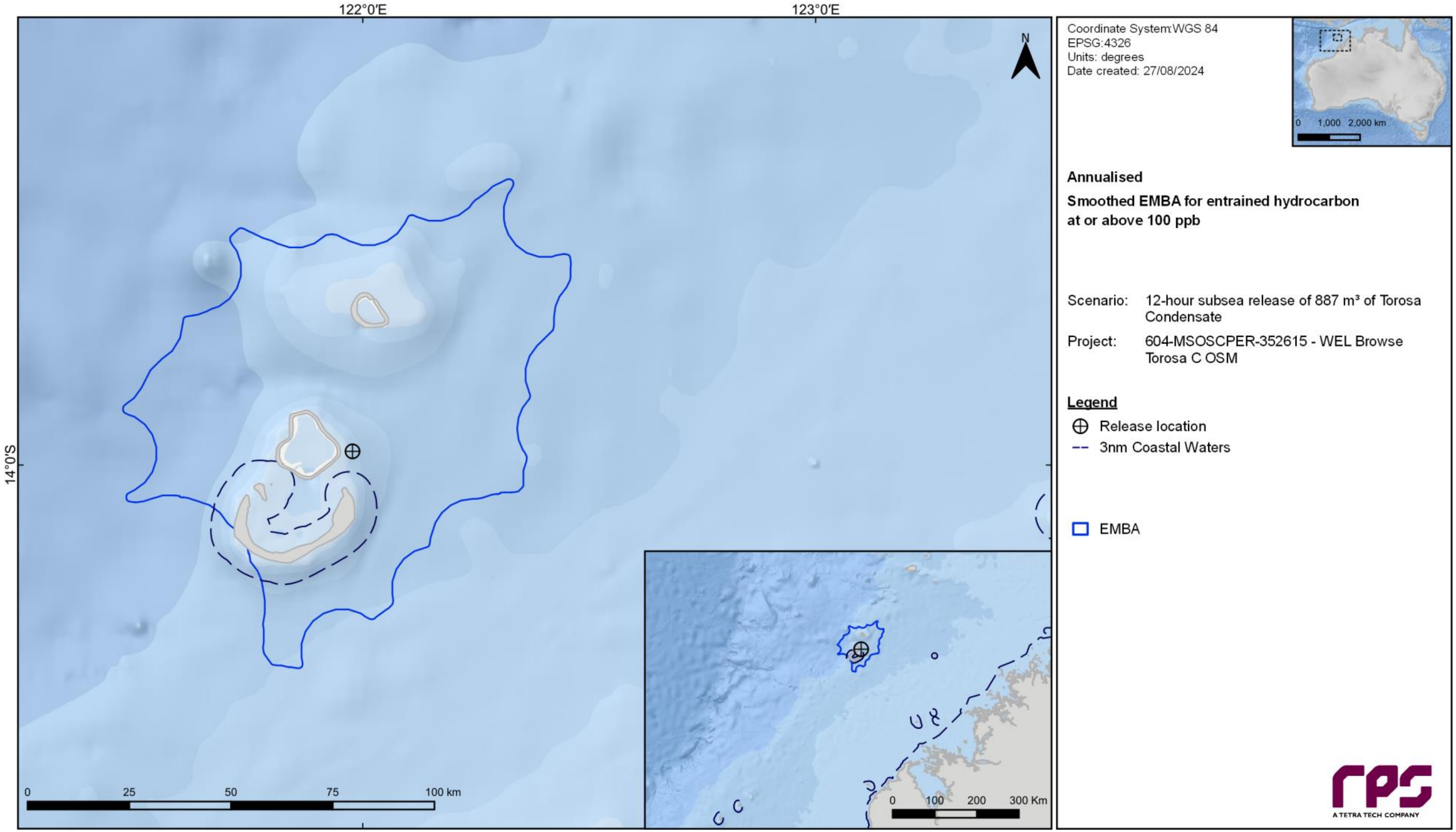


Figure 5.26: Predicted annualised smoothed EMBA of entrained oil concentrations at or above 100 ppb resulting from a 12-hour subsea release of 887 m^3 of Torosa Condensate.

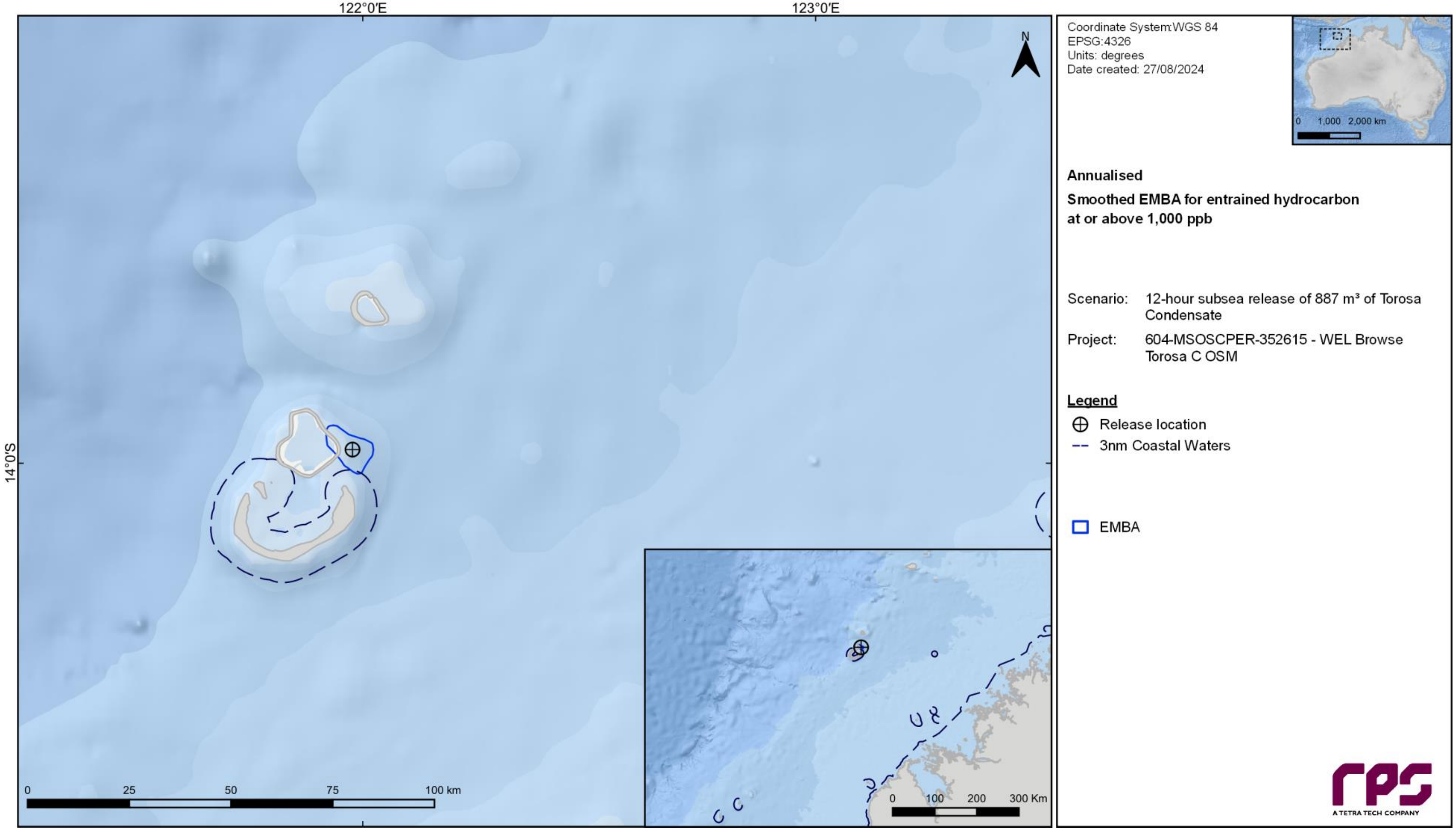


Figure 5.27: Predicted annualised smoothed EMBA of entrained oil concentrations at or above 1,000 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

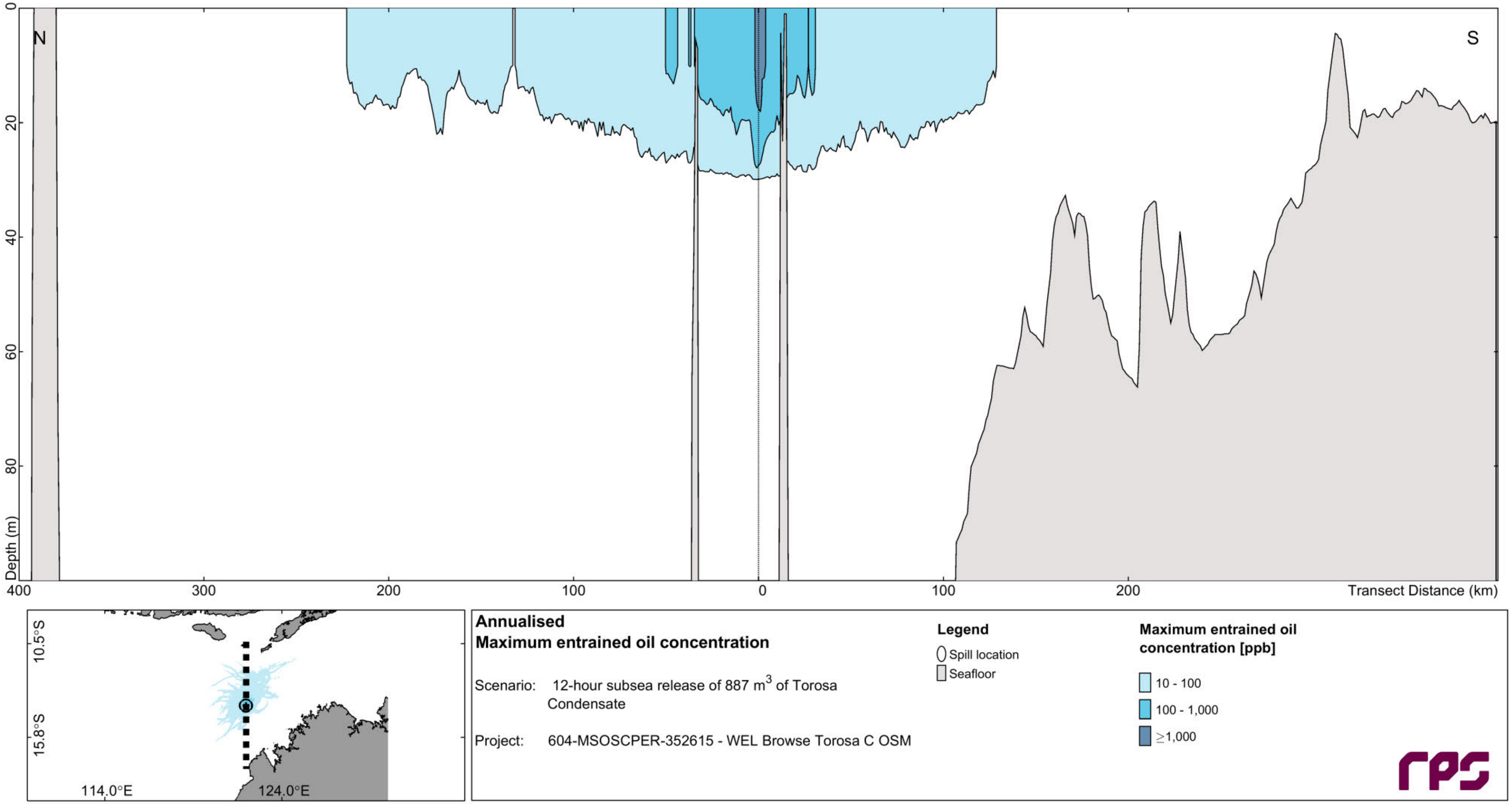


Figure 5.28 North-to-south cross section transect of predicted annualised maximum entrained oil concentration from a 12-hour subsea release of 887 m³ of Torosa Condensate.

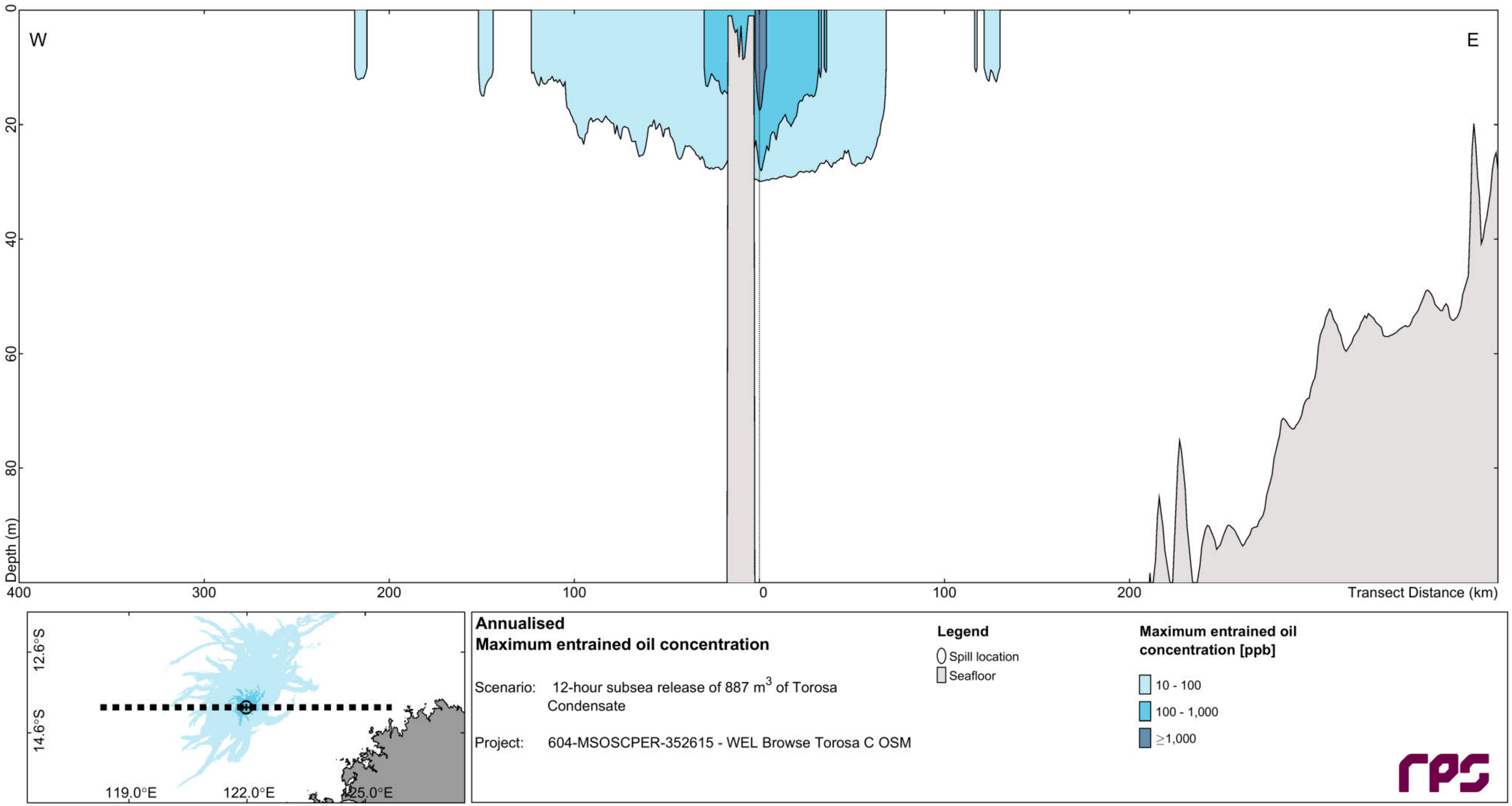


Figure 5.29 West-to-east cross section transect of predicted annualised maximum entrained oil concentration from a 12-hour subsea release of 887 m³ of Torosa Condensate.

5.2.1.7 Dissolved Aromatic Hydrocarbons

Table 5.6 Expected annualised dissolved aromatic outcomes at sensitive receptors for a 12-hour subsea release of 887 m³ of Torosa Condensate.

Receptors		Probability (%) of dissolved aromatic concentrations			Maximum dissolved aromatic hydrocarbon concentration (ppb)	
		≥ 10 ppb	≥ 50 ppb	≥ 400 ppb	averaged over all replicate spills	in the worst replicate
Australian Marine Parks	Argo-Rowley Terrace MP	<0.5	<0.5	<0.5	<1	<1
	Ashmore Reef MP	0.5	<0.5	<0.5	<1	19
	Cartier Island MP	<0.5	<0.5	<0.5	<1	<1
	Kimberley MP	0.5	<0.5	<0.5	<1	12
Islands	Cartier Island	<0.5	<0.5	<0.5	<1	<1
Nature Reserve	Scott Reef NR	10	2.5	<0.5	4	123
Reefs, Shoals and Banks	Ashmore Reef	0.5	<0.5	<0.5	<1	19
	Hibernia Reef	<0.5	<0.5	<0.5	<1	5
	Johnson Bank	<0.5	<0.5	<0.5	<1	2
	Sahul Bank §	<0.5	<0.5	<0.5	<1	<1
	Sandy Islet	4	0.5	<0.5	2	58
	Scott Reef North	35	10.5	<0.5	15	247
	Scott Reef South	14	2.5	<0.5	5	124
	Seringapatam Reef	6	0.5	<0.5	3	94
	Vee Shoal	<0.5	<0.5	<0.5	<1	<1
	Woodbine Bank	<0.5	<0.5	<0.5	<1	<1

NC: No contact to receptor predicted for specified threshold.

§ Probabilities and maximum concentrations calculated at depth of submerged feature

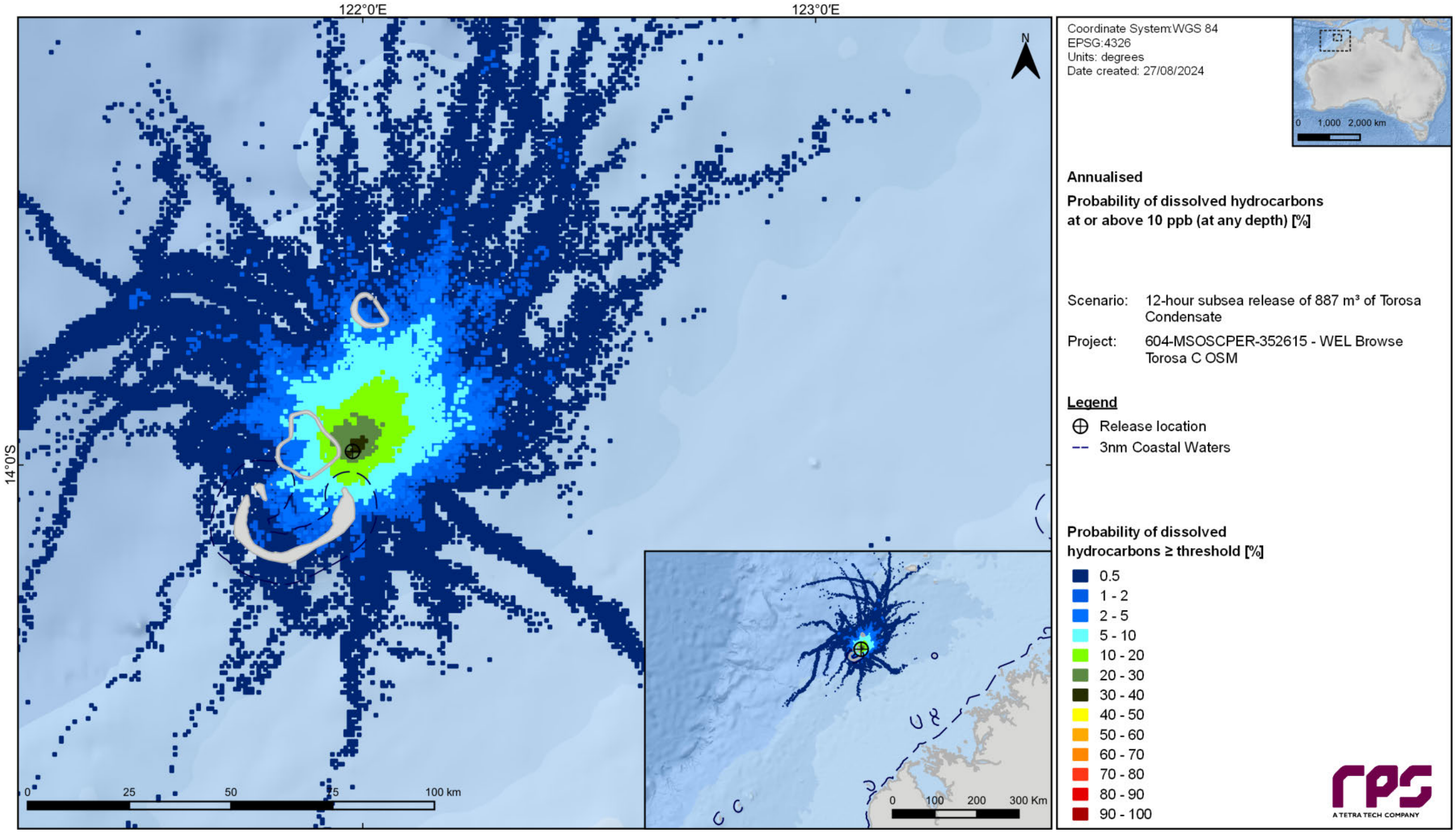


Figure 5.30: Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 10 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

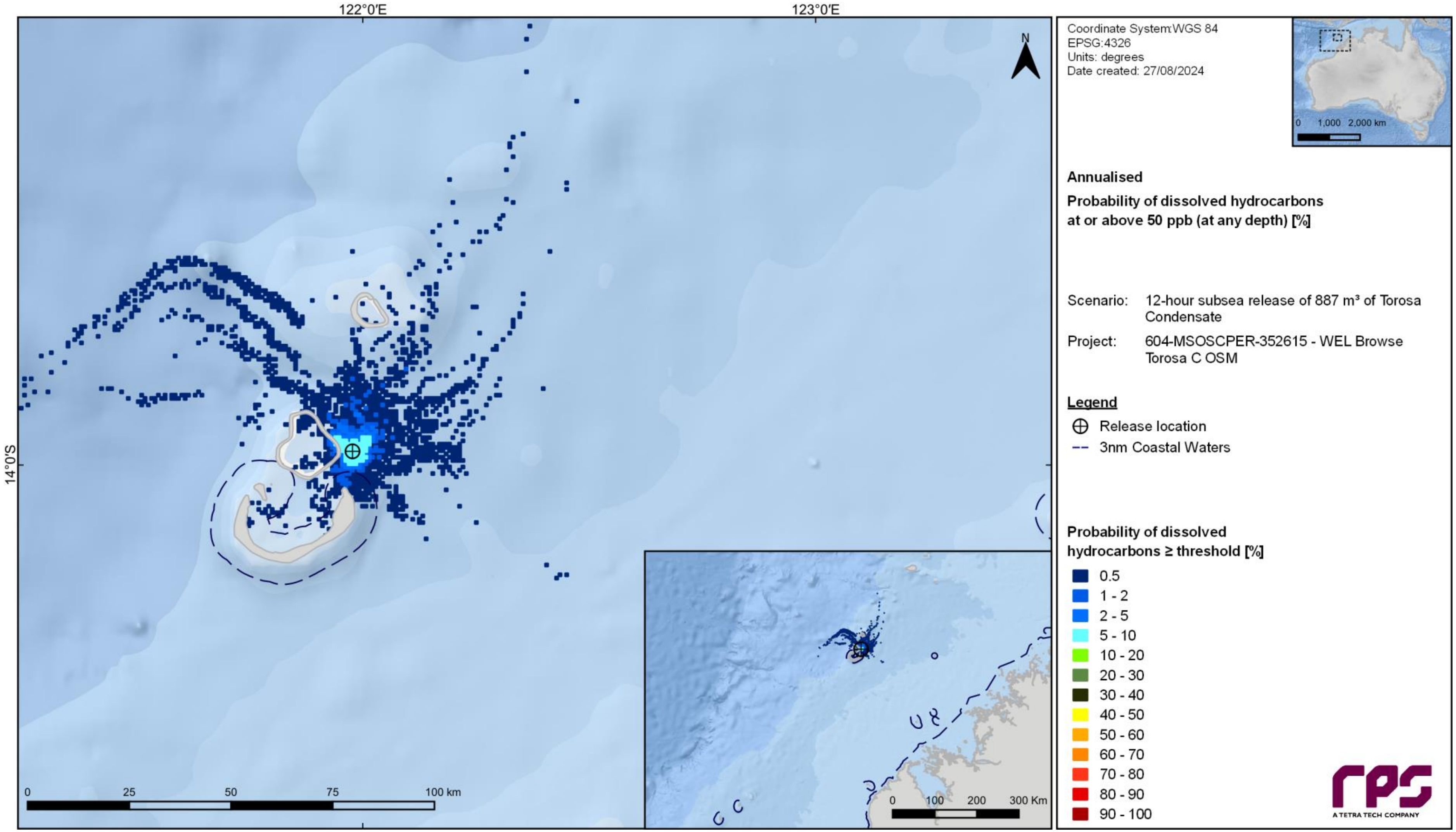


Figure 5.31: Predicted annualised probability of dissolved aromatic hydrocarbon concentrations at or above 50 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

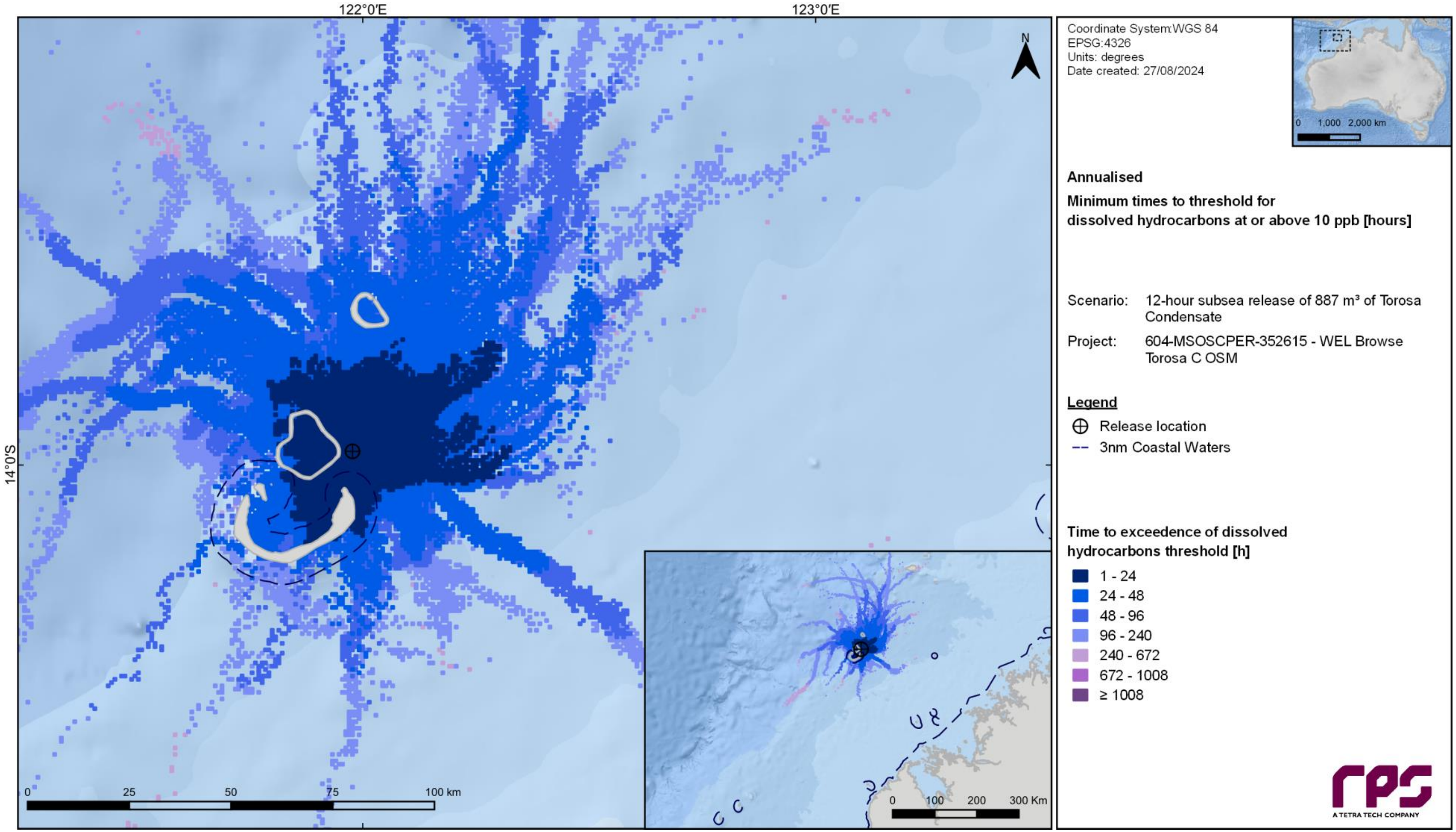


Figure 5.32: Predicted annualised minimum times to contact by dissolved aromatic hydrocarbon concentrations at or above 10 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

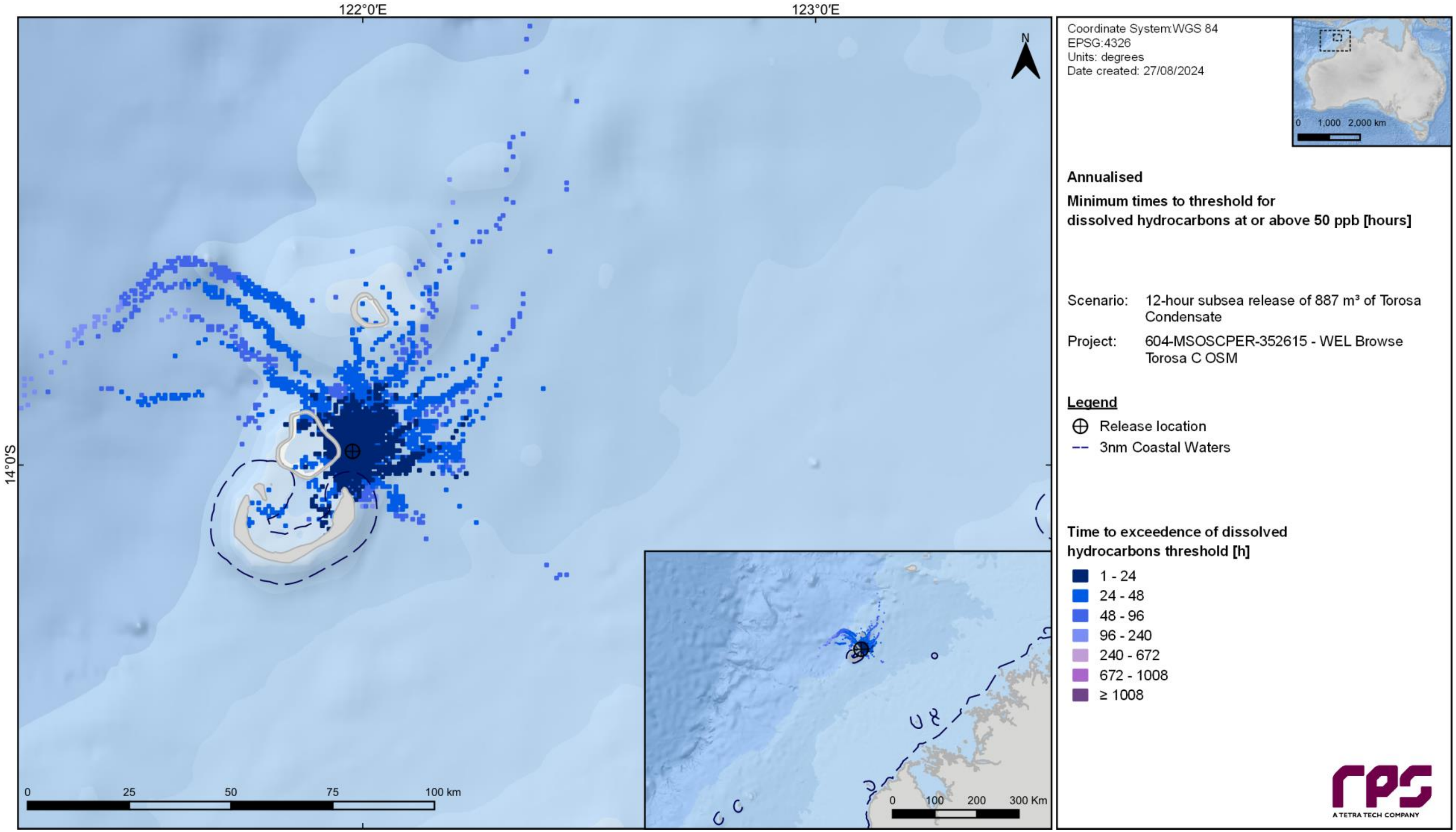


Figure 5.33: Predicted annualised minimum times to contact by dissolved aromatic hydrocarbon concentrations at or above 50 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

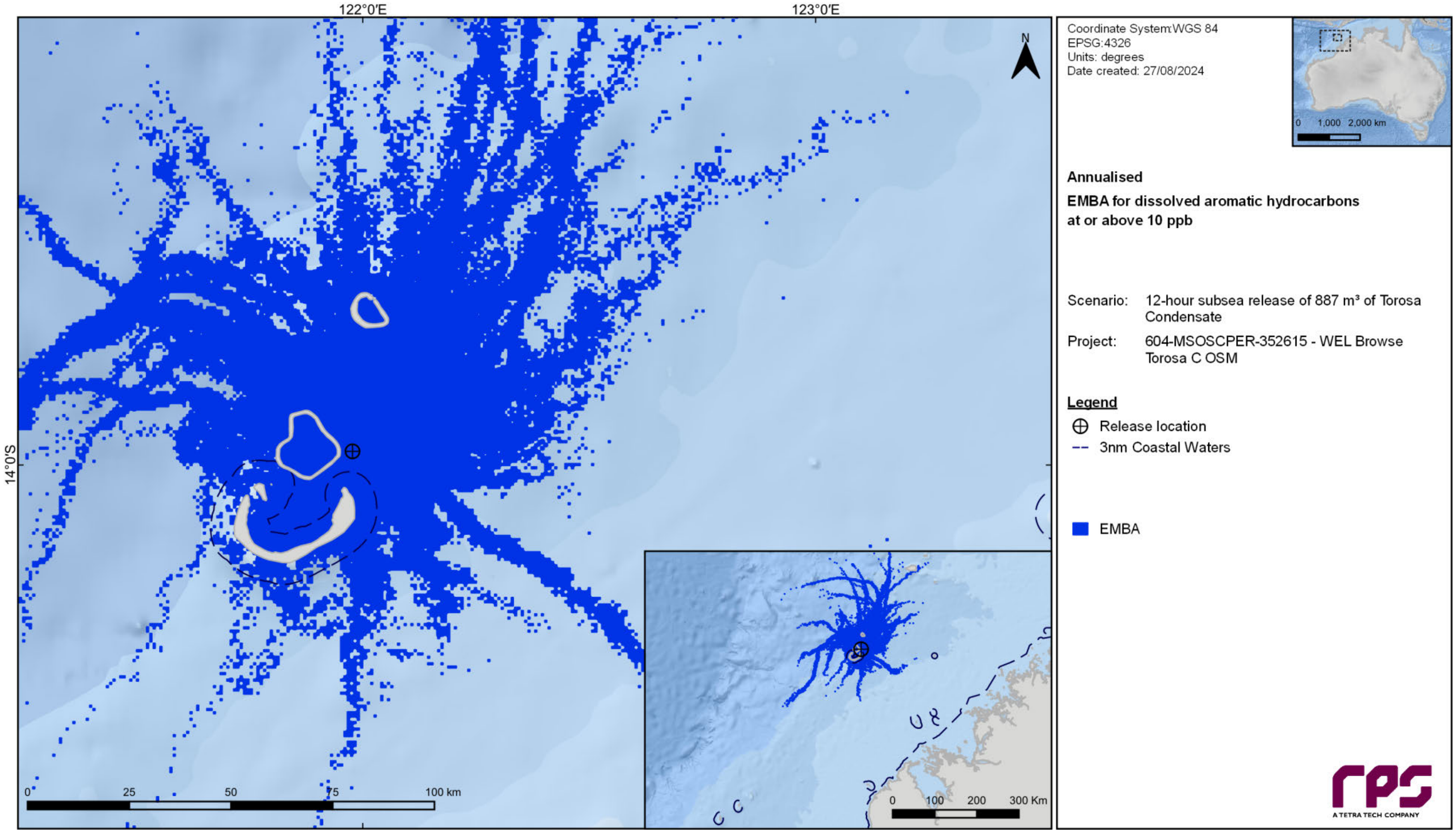


Figure 5.34: Predicted annualised EMBA of dissolved aromatic hydrocarbon concentrations at or above 10 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

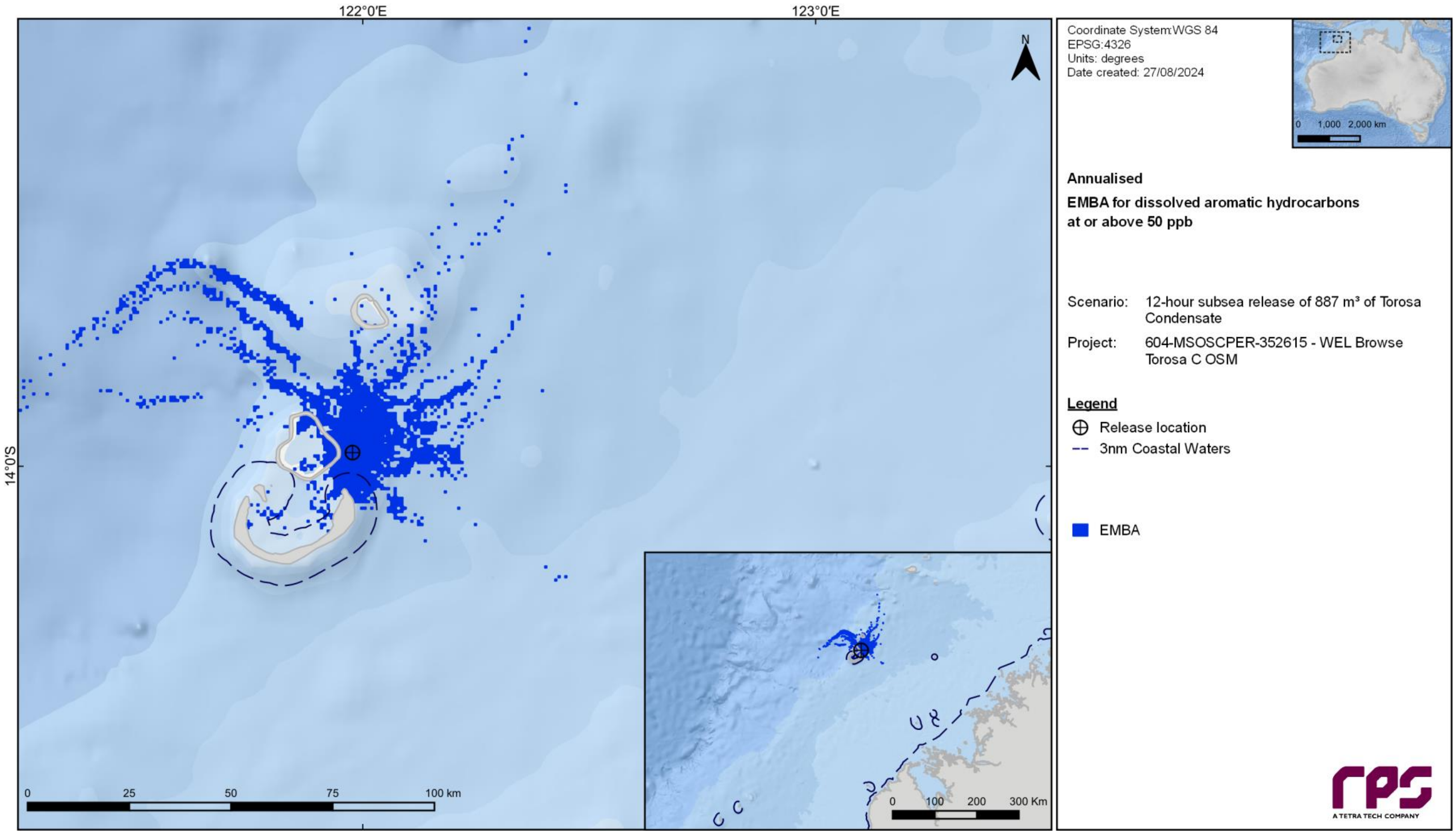


Figure 5.35: Predicted annualised EMBA of dissolved aromatic hydrocarbon concentrations at or above 50 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

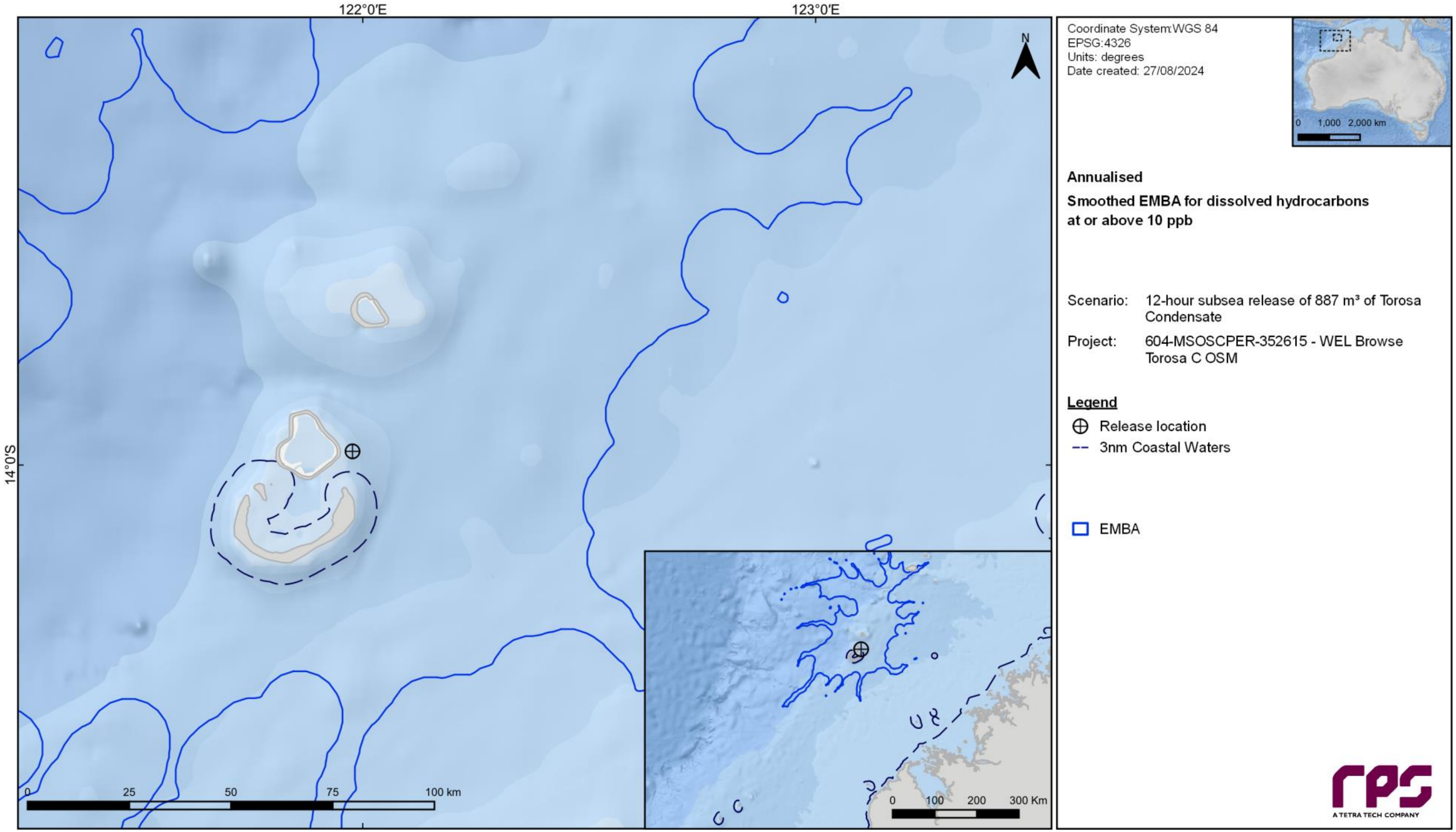


Figure 5.36: Predicted annualised smoothed EMBA of dissolved aromatic hydrocarbon concentrations at or above 10 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

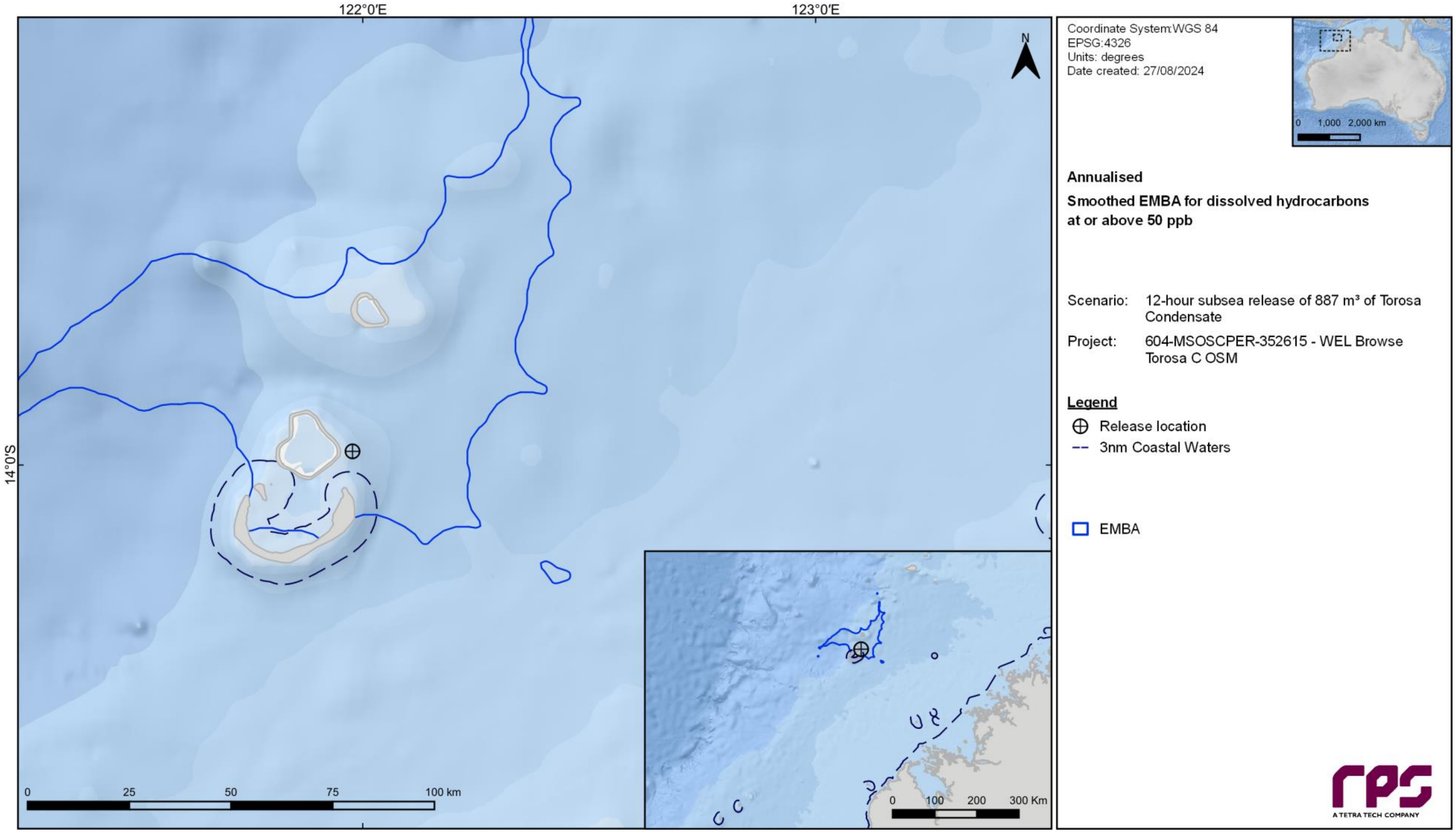


Figure 5.37: Predicted annualised smoothed EMBA of dissolved aromatic hydrocarbon concentrations at or above 50 ppb resulting from a 12-hour subsea release of 887 m³ of Torosa Condensate.

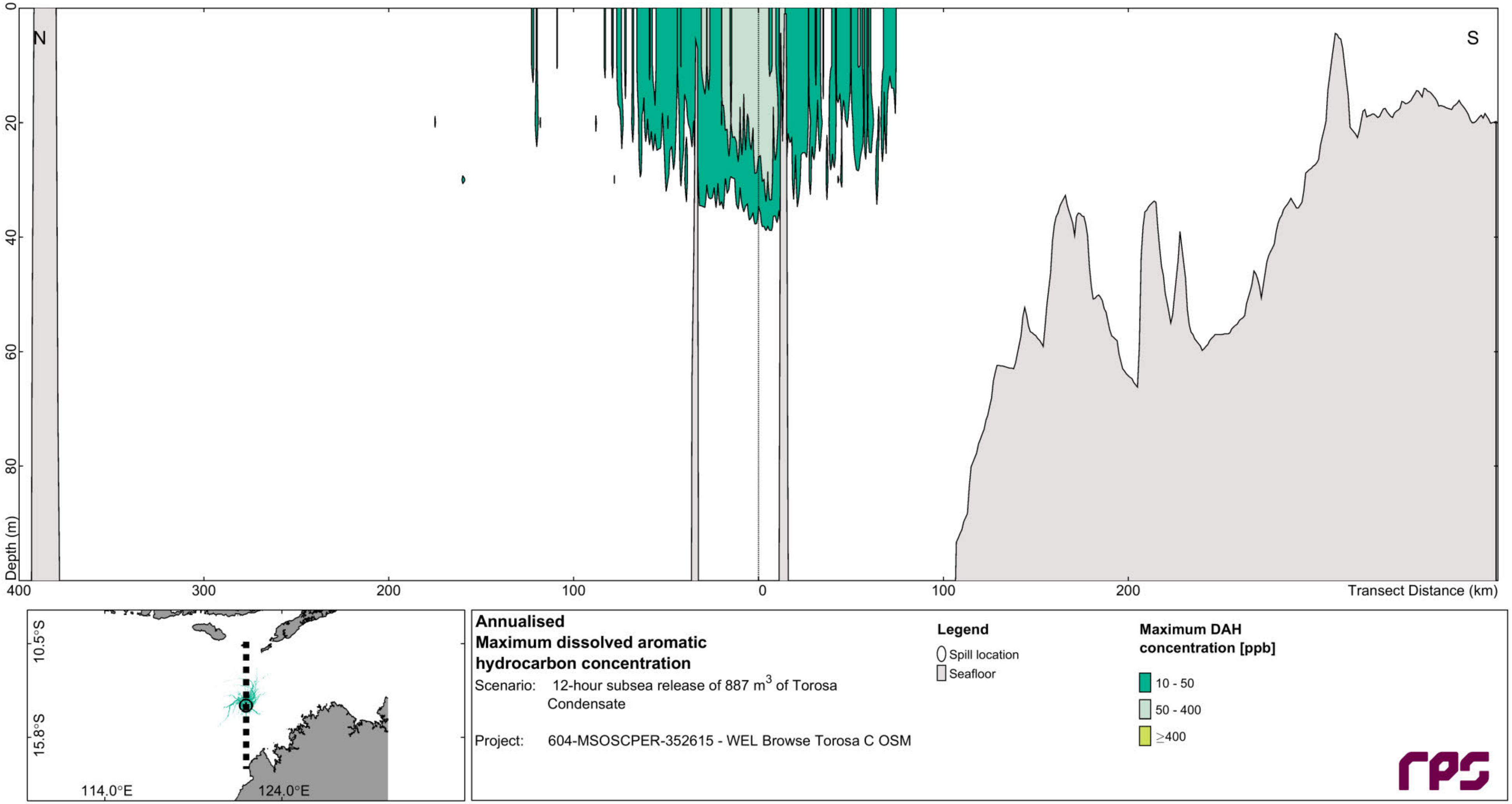


Figure 5.38 North-to-south cross section transect of predicted annualised maximum dissolved hydrocarbon concentration from a 12-hour subsea release of 887 m³ of Torosa Condensate.

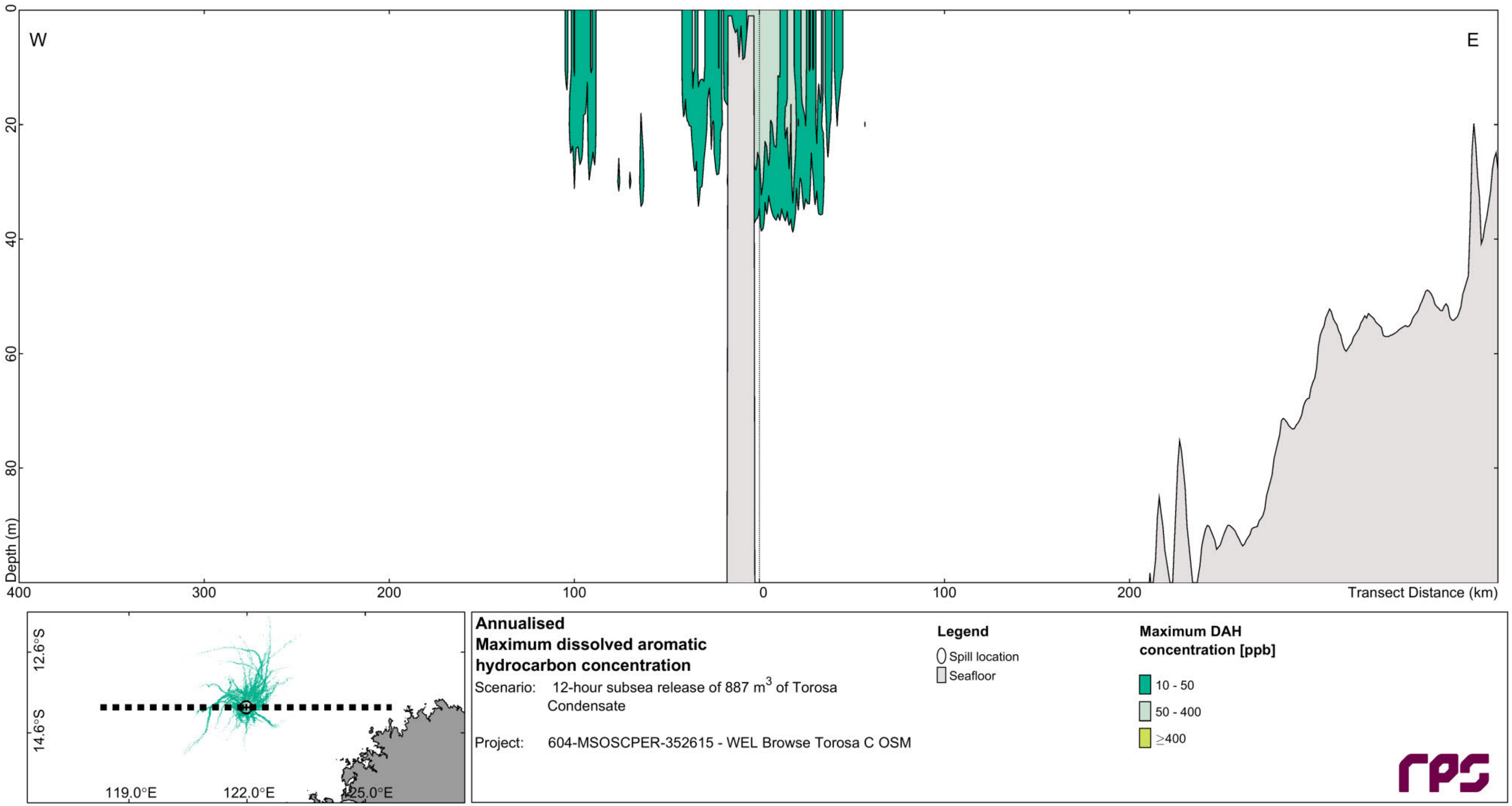


Figure 5.39 West-to-east cross section transect of predicted annualised maximum dissolved hydrocarbon concentration from a 12-hour subsea release of 887 m³ of Torosa Condensate.

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