SANTOS DARWIN PIPELINE DUPLICATION (DPD) PROJECT

Oil spill modelling study report

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TERMS AND ABBREVIATIONS

°	Degrees
‘	Minutes
“	Seconds
µm	Micrometre (unit of length; 1 µm = 0.001 mm)
Actionable oil	Oil which is thick enough for the effective use of mitigation strategies
AMP	Australian Marine Park
AMSA	Australian Maritime Safety Authority
API	American Petroleum Institute gravity. A measure of how heavy or light a petroleum liquid is compared to water.
ASTM	American Society for Testing and Materials
Biodegradation	Decomposition of organic material by microorganism
Bonn Agreement	An agreement for cooperation in dealing with pollution of the North Sea by oil and other harmful substances, 1983, includes: Governments of the Kingdom of Belgium, the Kingdom of Denmark, the French Republic, the Federal Republic of Germany, the Republic of Ireland, the Kingdom of the Netherlands, the Kingdom of Norway, the Kingdom of Sweden, the United Kingdom of Great Britain and Northern Ireland and the European Union.
BP	Boiling point
BTEX	Benzene, toluene, ethylbenzene, and xylenes
BU	Bayu-Undan
°C	degree Celsius (unit of temperature)
CFSR	Climate Forecast System Reanalysis
cP	Centipoise (unit of dynamic viscosity)
Decay	The process where oil components are changed either chemically or biologically (biodegradation) to another compound. It includes breakdown to simpler organic carbon compounds by bacteria and other organisms, photo-oxidation by solar energy, and other chemical reactions.
Dissolved hydrocarbons	Hydrocarbon droplets which are dissolved in water.
DPD	Darwin Pipeline Duplication
Dry Season	May to October
Dynamic viscosity	The dynamic viscosity of a fluid expresses its resistance to shearing flows, where adjacent layers move parallel to each other with different speeds.
EMBA	Environment that may be affected
Entrained hydrocarbons	Hydrocarbon droplets that are suspended into the water column, though not dissolved.
Evaporation	The process whereby components of the oil mixture are transferred from the sea-surface to the atmosphere as vapours.
g/m^2	Grams per square meter (unit of surface area density)
GDA	Geocentric Datum of Australia
GEBCO	General Bathymetric Chart of the Oceans
GEP	Gas Export Pipeline

GODAE	Global Ocean Data Assimilation Experiment
HYCOM	Hybrid Coordinate Ocean Model. A data-assimilative, three-dimensional ocean model.
ITOPF	International Tankers Owners Pollution Federation
KEF	Key Ecological Feature
km	Kilometre (unit of length)
km^2	Square Kilometres (unit of area)
Knots	unit of speed (1 knot = 0.514 m/s)
KP	Kilometre point. Refers to the surveyed distance along the main line or lateral line of a pipeline.
LC_{50}	Median lethal dose required for mortality of 50% of a tested population after a specified exposure duration.
m	Meter (unit of length)
m/s	Meter per Second (unit of speed)
m^3	Cubic meter (unit of volume)
MAHs	Monoaromatic hydrocarbons
MDO	Marine diesel oil
MGA	Map Grid of Australia
MNR	Marine Nature Reserve
MP	Marine Park
NASA	National Aeronautics and Space Administration
NCEP	National Centres for Environmental Prediction
nm	Nautical mile
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Ocean Partnership Program
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
NR	Nature Reserve
NRC	National Research Council
PAHs	Polynuclear aromatic hydrocarbons
ppb	parts per billion (concentration)
Pour point	The pour point of a liquid is the temperature below which the liquid loses its flow characteristics.
psu	Practical salinity units
Ramsar site	A site listed under the Ramsar Convention on wetlands which is an international intergovernmental treaty that provides the framework for the conservation and wise use of wetlands and their resources.
RFPA	Reef Fish Protected Areas
RSB	Reefs, shoals and banks
Sea surface exposure	Contact by floating oil on the sea surface at concentrations equal to or exceeding defined threshold concentrations. The consequence will vary depending on the threshold and the receptors.

Shoreline contact	Arrival of oil at or near shorelines at on-water concentrations equal to or exceeding defined threshold concentrations. Shoreline contact is judged for floating oil arriving within a 1 km buffer zone from any shoreline as a conservative measure
SIMAP	Spill Impact Model Application Package. SIMAP is designed to simulate the fate and effects of spilled hydrocarbons for surface or subsea releases
Single Oil spill modelling	Oil spill modelling involving a computer simulation of a single hypothetical oil spill event subject to a single sequence of wind, current and other sea conditions over time. Single oil spill modelling, also referred to as "deterministic modelling" provides a simulation of one possible outcome of a given spill scenario, subject to the metocean conditions that are imposed. Single oil spill modelling is commonly used to consider the fate and effects of 'worst-case' oil spill scenarios that are carefully selected in consideration of the nature and scale of the offshore petroleum activity and the local environment (NOPSEMA, 2018). Because the outcomes of a single oil spill simulation can only represent the outcome of that scenario under one sequence of metocean conditions, worst-case conditions are often identified from stochastic modelling. It is impossible to calculate the likelihood of any outcome from a single oil spill simulation. Single oil spill modelling is generally used for response planning, preparedness planning and for supporting oil spill response operations in the event of an actual spill.
Stochastic Oil spill modelling	Stochastic oil spill modelling is created by overlaying and statistically analysing the outcomes of many single oil-spill simulations of a defined spill scenario, where each simulation was subject to a different sequence of metocean conditions, selected objectively (typically by random selection) from a long sequence of historic conditions for the study area. Analysis of this larger set of simulations provides a more accurate indication of the area that maybe affected (EMBA) and also indicates which particular locations are more likely to be affected (as well as other statistics). Stochastic oil spill modelling avoids biases that affect single oil spill modelling (due to the reliance on only one possible sequence of conditions). However, when interpreting stochastic modelling, which is based on a wide range of potential conditions that might happen to occur, it is essential to understand that calculations for the Risk EMBA will enclose a much larger area than could be affected in any single spill event, where a more limited set of conditions will occur. Consequently, it is misleading to imply that the Risk EMBA contours derived from stochastic modelling indicate the outcomes expected from a single spill event (NOPSEMA, 2018). Stochastic modelling is generally used for risk assessment and preparedness planning by indicating locations that could be exposed and may require response or subsequent impact assessment.
TOPEX/Poseidon	A joint satellite mission between NASA and CNES to map ocean surface topography using an array of satellites equipped with detailed altimeters
USCG	United States Coast Guard
US EPA	United States Environmental Protection Agency
USA	United States of America
Weathered oil	Oil that no longer contains volatile or soluble components
Wet season	November to April
World Ocean Atlas	A collection of objectively analysed quality controlled physicochemical parameters (e.g., temperature, salinity, oxygen, phosphate, silicate, and nitrate) based on profile data from the World Ocean Database (NCEI, 2021) established by NOAA's National Centers for Environmental Information (NCEI)

EXECUTIVE SUMMARY

Background

Santos is assessing environmental impacts and risks associated with the Darwin Pipeline Duplication (DPD) Project. The DPD Project involves the installation of a gas export pipeline (GEP) from a point (kilometre point (KP) 0) in Commonwealth waters (25km from the Commonwealth/ NT waters boundary) to the Darwin LNG (DLNG) facility on Wickham Point in Darwin Harbour (KP122.2). The pipeline will transfer dry gas from the offshore Barossa field to the DLNG facility. The new pipeline (nearshore Barossa GEP) would run alongside the existing Bayu-Undan (BU) to Darwin GEP, typically within 50-100m, thereby effectively duplicating that pipeline.

To support the environmental risk assessment and approval requirements for the DPD Project, including the development of management plans, an oil spill modelling study was undertaken which considered the following four scenarios:

- **Scenario 1** – An offshore pipelay vessel fuel tank rupture at KP91.5 resulting in the release of 700 m^3 of marine diesel oil (MDO) on the surface over 6 hours;
- **Scenario 2** – A vessel fuel tank rupture at KP114 resulting in the release of 87.5 m^3 MDO on the surface over 6 hours;
- **Scenario 3** – An instantaneous surface spill of 10 m^3 of MDO due to a vessel to vessel refuelling incident within the harbour at KP114; and
- **Scenario 4** – A vessel fuel tank rupture at KP114 resulting in the release of 300 m^3 MDO on the surface over 6 hours.

The potential risk of exposure to the surrounding waters and contact to shorelines was assessed for wet (November to April) and dry (May to October) seasons.

The purpose of the modelling is to provide an understanding of the conservative 'outer envelope' of the potential area that may be affected in the unlikely event of a vessel-based spill. Since the modelling does not take into consideration any of the spill prevention, mitigation and response capabilities that would be implemented in response to the spill, the results presented herein are conservative.

Methodology

The modelling study was carried out in stages. Firstly, two-years (2019 – 2020) of wind and high-resolution current data covering Darwin Harbour and Beagle Gulf was generated. Secondly, the currents, winds and detailed hydrocarbon characteristics were used as inputs in the three-dimensional oil spill model (SIMAP) to simulate the drift, spread, weathering and fate of the spilled oil.

As spills can occur during any set of wind and current conditions, modelling was conducted using a stochastic (or statistical) approach, which involved running 100 spills modelled for each scenario, per season, with each simulation having the same information (i.e., spill volume, duration and MDO composition) and randomly selected start times. This ensured that each simulation was subjected to different wind and current conditions and, in turn, movement and weathering of the MDO. The results from the simulations were combined to determine the potential exposure to the surrounding waters, shorelines and sensitive receptors based on established exposure thresholds endorsed by NOPSEMA (NOPSEMA 2019).

The SIMAP system, methods and analysis presented herein, use modelling algorithms which have been anonymously peer reviewed and published in international journals. Further, RPS warrants that this work meets and exceeds the ASTM Standard F2067-13 "*Standard Practice for Development and Use of Oil Spill Models*".

Oil Properties

MDO has a density of 829.1 kg/m³ (API gravity of 37.6) and a dynamic viscosity of 4.0 cP at 25ºC, classifying it as a Group II light persistent oil according to the International Tankers Owners Pollution Federation (ITOPF, 2014) and USEPA/USCG classifications. MDO is characterised by a high percentage of volatile components (95%), which will evaporate when on the sea surface. It also contains 5% persistent hydrocarbons, which will not evaporate and decay slowly over time. It is important to note that some heavy components contained in MDO have a strong tendency to physically entrain into the upper water column in the presence of moderate winds (i.e., >12 knots) and breaking waves but can re-float to the surface when the winds ease.

Results

Scenario 1 – Offshore Pipelay Vessel Fuel Tank Rupture at KP91.5 (700 m³ of marine diesel oil)

- The KP91.5 stochastic modelling results showed that due to the location, the predominant movement of the oil would be in a northwest and south easterly direction. This was largely due to the sweep of the ebb and flood tide.
- The maximum distances of floating oil exposure zones to the release location at the low (≥1 g/m²), moderate (≥10 g/m²) and high (≥ 50 g/m²) thresholds were 26.4 km (southeast), 19.9 km (southeast) and 14 km (west northwest).
- Floating oil exposure was greatest (100% at the low threshold for both seasons) at Charles Point Wide Reef Fish Protected Area (RFPA and Outer Harbour Water Quality (WQ) Zone) due the proximity of the release location (1.11 km east and 0.65 km north, respectively). Otherwise, exposure at the low and moderate thresholds were predicted at Restricted Area 5 and Middle Harbour WQ Zone with all probabilities ≤10%.
- The probability of oil accumulating on any shoreline at, or above, the low threshold (≥10 g/m²) was highest for spills commencing during the wet season conditions (50%) and lower during the dry season months (25%) conditions. The quickest time for oil to accumulate on shorelines at, or above, the low threshold was 0.96 days during the wet. The greatest volume of oil ashore from a single spill during dry and wet conditions was 28.1 m³ and 59.7 m³, respectively. The wet season simulation resulting in the highest volume ashore took 2 days to initially reach the shorelines.
- The greatest probabilities of oil accumulation at, or above, the low threshold was predicted for the East Arm (16% dry and 33% wet conditions), Outer Harbour East (4% dry and 20% wet seasons) and Outer Harbour West (9% dry and 10% wet seasons). The greatest volume (peak) of oil accumulation during the dry and wet seasons was predicted occurred along Outer Harbour West (22.2 m³) and Outer Harbour East shorelines (43.8 m³), respectively. The minimum time for an oil spill simulation to reach a shoreline (at the low threshold) was 1.50 days (Outer Harbour West) during the dry season and 0.96 days (Cox-Finniss) during the wet season conditions.
- Dissolved hydrocarbon exposure at, or above, the low (10 ppb) and moderate (≥ 50 ppb) thresholds were 16.9 km (west) and 13.7 km (southeast), respectively, from the release location during both seasons. No exposure predicted for either season at the high threshold (≥ 400 ppb).
- Not including Charles Point Wide RFPA and Outer Harbour WQ Zone receptors due the proximity of the release location (1.11 km east and 0.65 km north, respectively) Booya shipwreck and Middle Harbour were predicted to be exposed to dissolved hydrocarbons at the low threshold in the 0 – 10 m depth during the dry and wet seasons with probabilities ranging from 1% to 7%. The maximum instantaneous concentrations were 23 ppb predicted at Middle Harbour WQ Zone during the dry season and 38 ppb at Booya shipwreck during the wet season.
- The maximum distances from the release location within the 0 – 10 m depth layer to the low (at the low (≥ 10 ppb) and moderate (≥ 100 ppb) thresholds, ranged between 182.3 km northeast (wet conditions) and 51.3 km east northeast (wet conditions) from the release location, respectively.

- Due to that the proximity of the release location to Charles Point Wide RFPA (1.11 km east) and Outer Harbour WQ Zone (0.65 km north), the probability of exposure was greatest for these receptors (100% at the low threshold for both seasons) and would take 1 hour for a spill to reach the boundaries of the receptors.

Scenario 2 – Vessel Fuel Tank Rupture at KP114 (87.5 m^3 of marine diesel oil)

- Results indicated that the predominant movement for the spilt diesel oil was in a north and south easterly direction, in line with the major tidal axis. Due to the high energy environment, the oil spills were predicted to spread rapidly across the water surface within various reaches of the port.
- The maximum distances to the low, moderate and high floating oil exposure zones were 29.3 km (west northwest), 14.9 km (southeast) and 0.1 km (west northwest), respectively.
- The probability of oil accumulation at, or above, the low threshold was 94% (dry season) and 83% (wet season). The quickest time for a spill to reach a shoreline and for oil accumulation to occur at, or above, the low threshold ranged between 0.21 days (dry season) and 0.17 days (wet season). The maximum volume ashore for a single spill ranged between 24.8 m^3 (dry season) and 24.7 m^3 (wet season). The maximum length of shoreline contacted at the low threshold was 29.6 km (dry season).
- The highest probability of oil accumulation at the low threshold was predicted along the West Arm (78% dry and 47% wet seasons) and East Arm (32% dry and 48% wet conditions) shorelines. The highest volume of oil accumulation during the dry and wet seasons occurred along the West Arm shoreline (24.2 m^3 (dry season) and 24.6 m^3 (wet season)). The minimum time for oil accumulation at the low threshold was 0.21 days (East Arm) for the dry season and 0.17 days (East Arm) during the wet season conditions.
- There was no exposure predicted for the moderate and high dissolved hydrocarbon thresholds. The maximum distances to the low threshold exposure zones during the dry and wet seasons were 3.9 km and 12.2 km north northwest, respectively. Exposure was limited to the 0 – 10 m depth layer.
- There was no exposure to any receptor during the dry season. Under wet season conditions, 3 receptors had recorded exposure at the low threshold (Ham Luong and Mauna Loa USAT shipwreck, and Outer Harbour WQ Zone) and the probabilities ranged between 1 and 6%. The maximum instantaneous dissolved concentrations were 9 ppb and 21 ppb predicted at the Mauna Loa USAT shipwreck during dry and wet seasons, respectively.
- The maximum distances travelled by entrained hydrocarbons within the 0 – 10 m depth layers at the low and moderate thresholds, which ranged between 36.1 km and 23.9 km northwest from the release location.
- For both seasons assessed, the Charles Point Wide RFPA and four Restricted Areas (1, 4, 5 and 6) were predicted to be exposed to entrained hydrocarbons at the low threshold with probabilities ranging from 45 – 97% and 5 – 69% during the dry and wet seasons, respectively. During both seasons Restricted Area 6 was predicted to have the greatest probability of low threshold exposure (97% and 69%). The maximum instantaneous concentrations were predicted at Outer Harbour during both the dry (436 ppb) and wet (677 ppb) seasons.

Scenario 3 – Vessel to Vessel Refuelling at KP 114 (10 m^3 of marine diesel oil)

- Floating oil exposure zones to the low and moderate thresholds were limited to 22.9 km (northwest) and 12.5 km (northwest), respectively during dry season conditions. There was no exposure predicted for the high threshold.
- During the dry and wet seasons the probability of oil accumulation at the low threshold was 58%, and the minimum time was 0.25 days and 0.29 days, respectively. The maximum volume ashore for a single spill ranged between 3.9 m^3 (dry season) and 4.3 m^3 (wet season). The maximum length of shoreline contacted at the low threshold was 9 km for the two seasons.
- The West Arm (49% dry and 28% wet conditions) and East Arm (8% dry and 26% wet seasons) shorelines recorded the highest probability of oil accumulation at the low threshold. The minimum time

before the accumulation was 0.29 days (Middle Arm and West Arm) during the dry season and 0.25 days (East Arm and Wickham Point) during the wet season conditions.

- There was no dissolved hydrocarbon exposure predicted for any spills during this scenario at or above the low threshold (≥ 10 ppb).
- Entrained hydrocarbons within the 0 – 10 m depth layers for the low (≥ 10 ppb) and moderate (≥ 100 ppb) thresholds, were predicted to range between 32 km and 19.6 km northwest.
- The highest probability of entrained hydrocarbon exposure was predicted at Ham Luong (61%) and Mauna Loa USAT (64%) shipwrecks during dry and wet seasons conditions. The maximum entrained concentrations were also predicted Ham Luong (745 ppb) and Mauna Loa USAT (639 ppb) shipwrecks for the two seasons. Also, there were four WQ Zones predicted to be exposed to entrained hydrocarbons at the low threshold during both seasons with probabilities ranging from 6% (East Arm) and 36% (Outer Harbour) during the dry season and 7% (Middle Arm) and 30% (Outer Harbour) during the wet season.

Scenario 4 – Vessel Fuel Tank Rupture at KP114 (300 m^3 of marine diesel oil)

- Floating oil exposure zones to the low, moderate and high thresholds were limited to 33.4 km (northwest; wet season), 19.6 km (northwest; dry season) and 10.2 km (north-northwest; dry season), respectively.
- The probability of shoreline accumulation at, or above, the low threshold (10 g/m^2) was 100% (dry season) and 91% (wet season). The minimum time before oil accumulation at, or above, the low threshold was 0.21 days during dry and wet seasons. The maximum volume ashore for a single spill during the dry and wet season was 114.8 m^3 and 115.5 m^3, respectively, and the maximum length of shoreline contacted at the low threshold was 57.7 km (dry season) and 54.2 km (wet season).
- The highest probability of oil accumulation at the low threshold was predicted along the West Arm (88% dry and 49% wet seasons) and East Arm (44% dry and 60% wet conditions) shorelines. The highest volume of oil accumulation during the dry and wet seasons occurred along the West Arm shoreline (103.5 m^3 (dry season) and 111.7 m^3 (wet season)).
- The maximum distances travelled by dissolved hydrocarbons from the release location to the low (≥ 10 ppb) exposure zone was 12.8 km (dry season) and 20.0 km (wet season), whilst distances were reduced to 0.6 km (dry season) and 7.3 km (wet season) for the moderate (≥ 50 ppb) exposure threshold. Exposure was limited to the 0 – 10 m depth layer. No exposure was predicted for the high (≥ 400 ppb) threshold.
- Dissolved hydrocarbon exposure at the low threshold was also predicted at shipwreck receptors during the dry (3) and wet seasons (5) with dry season probabilities ranging from 1 – 10% and wet season probabilities of exposure ranging between 2 – 17%. The greatest probability of low threshold exposure during the dry and wet season was predicted for Ham Luong and Mauna Loa USAT, respectively.
- The maximum distances travelled by entrained hydrocarbons from the release location to the low (≥ 10 ppb) exposure zone was 41.7 km (dry season) and 48.3 km (wet season), whilst distances were reduced to 30.3 km (dry season) and 32.4 km (wet season) for the moderate exposure threshold.
- During both seasons the Charles Point Wide RFPA and four Restricted Areas (1, 4, 5 and 6) were predicted to be exposed to entrained hydrocarbons at the low threshold with probabilities ranging from 14 – 99% and 50 – 94% during the dry and wet seasons, respectively. During both seasons, Restricted Area 6 was predicted to have the highest probability of exposure (99% and 94%).
- Exposure at the low threshold was predicted at 18 and 19 shipwreck receptors during the dry and wet season, respectively, with probabilities ranging from 5% (East Arm Vietnamese Refugee Boat 1) and 100% (Ham Luong, Mauna Loa USAT and Yu Han 22) during the dry season and 4% (Elizabeth River - unidentified wreck) and 95% (Ham Luong) during the wet season.

1 INTRODUCTION

1.1 Background

Santos is assessing environmental impacts and risks associated with the Darwin Pipeline Duplication (DPD) Project. The DPD Project involves the installation of a gas export pipeline (GEP) from a point (kilometre point (KP) 0) in Commonwealth waters (25km from the Commonwealth/ NT waters boundary) to the Darwin LNG (DLNG) facility on Wickham Point in Darwin Harbour (KP122.2). The pipeline will transfer dry gas from the offshore Barossa field to the DLNG facility. The new pipeline (nearshore Barossa GEP) would run alongside the existing Bayu-Undan (BU) to Darwin GEP, typically within 50-100m, thereby effectively duplicating that pipeline.

To support the environmental risk assessment and approval requirements for the DPD Project, including the development of management plans, an oil spill modelling study was undertaken which considered the following four scenarios:

- **Scenario 1** – An offshore pipelay vessel fuel tank rupture at KP91.5 resulting in the release of 700 m^3 of marine diesel oil (MDO) on the surface over 6 hours;
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- **Scenario 3** – An instantaneous surface spill of 10 m^3 of MDO due to a vessel to vessel refuelling incident within the harbour at KP114; and
- **Scenario 4** – A vessel fuel tank rupture at KP114 resulting in the release of 300 m^3 MDO on the surface over 6 hours.

Table 1.1 presents the coordinates of each location and Figure 1.1 is the location map.

The potential risk of exposure to the surrounding waters and contact to shorelines was assessed for wet (November to April) and dry (May to October) seasons.

The purpose of the modelling is to provide an understanding of the conservative ‘outer envelope’ of the potential area that may be affected in the unlikely event of a vessel-based spill. Since the modelling does not take into consideration any of the spill prevention, mitigation and response capabilities that would be implemented in response to the spill, the results presented herein are conservative.

The spill modelling was performed using an advanced three-dimensional trajectory and fates model; Spill Impact Mapping and Assessment Program (SIMAP). The SIMAP model calculates the transport, spreading, entrainment and evaporation of spilled hydrocarbons over time, based on the prevailing wind and current conditions and the physical and chemical properties.

Note that the oil spill model, method and analysis presented herein uses modelling algorithms which have been anonymously peer reviewed and published in international journals. Furthermore, RPS warrants that this work meets and exceeds the American Society for Testing and Materials (ASTM) Standard F2067-13 “*Standard Practice for Development and Use of Oil Spill Models*” (ASTM, 2013).

Table 1.1 Release locations for the Barossa DPD oil spill modelling study.

Scenario	Identifier	Easting (S)	Northing (E)	Water Depth (LAT m)
1	KP91.5	681,788.21	8,635,852.42	17.1
2, 3 & 4	KP114	696,972.89	8,619,537.48	19.44

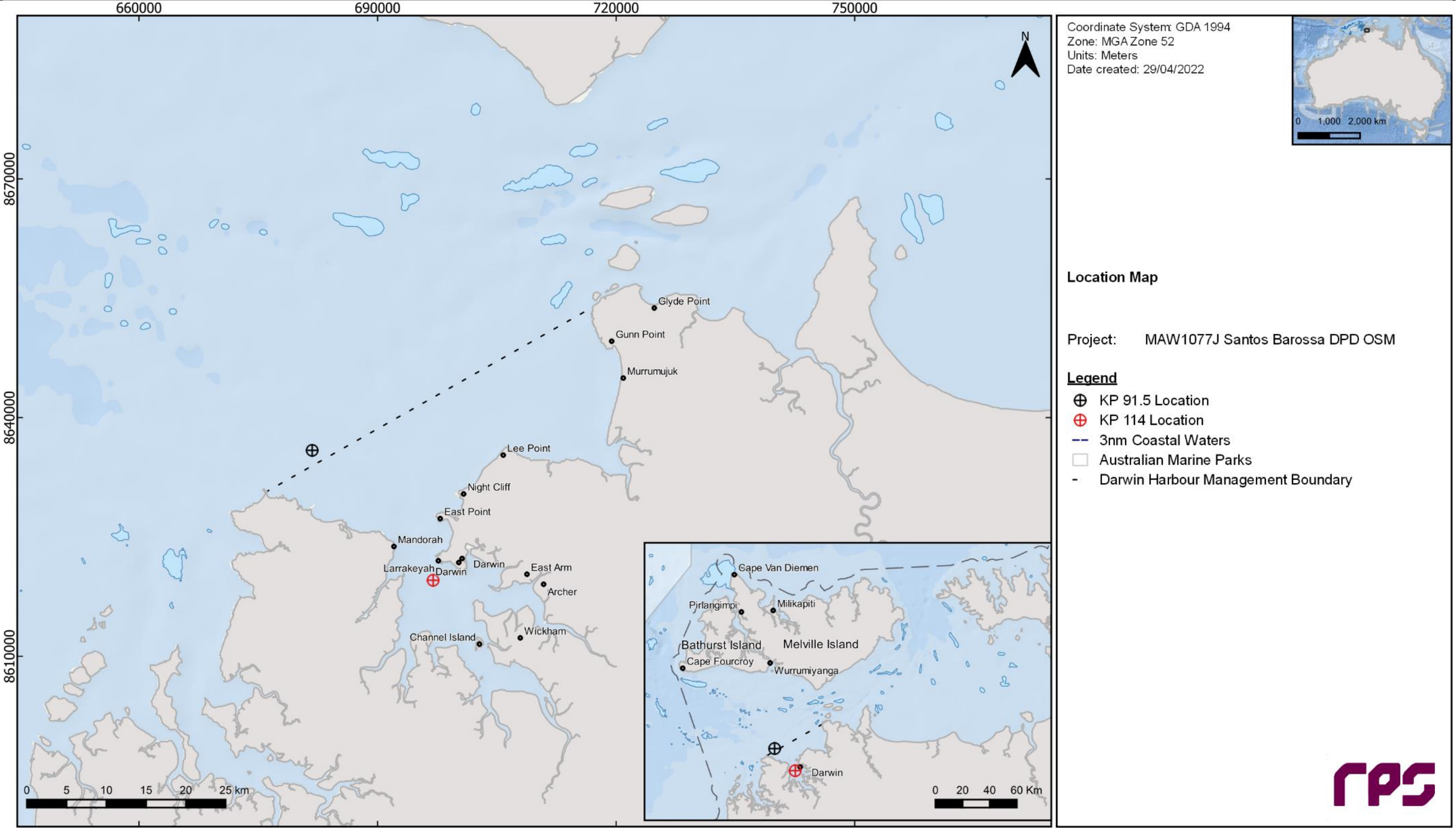

Figure 1.1 Release locations for the Barossa DPD oil spill modelling study.

1.2 What is Oil Spill Modelling?

Oil spill modelling is a valuable tool widely used for risk assessment, emergency response and contingency planning where it can be particularly helpful to proponents and decision makers. By modelling a series of the most likely oil spill scenarios, decisions concerning suitable response measures and strategic locations for deploying equipment and materials can be made, and the locations at most risk can be identified. The two types of oil spill modelling often used are stochastic (Section 1.2.1) and deterministic (Section 1.2.2) modelling.

1.2.1 Stochastic Modelling (Multiple Spill Simulations)

Stochastic oil spill modelling is created by overlaying a great number (often hundreds) of individual, computer-simulated hypothetical spills (NOPSEMA, 2018; Figure 1.2).

Stochastic modelling is a common means of assessing the potential risks from oil spills related to new projects and facilities. Stochastic modelling typically utilises hydrodynamic data for the location in combination with historic wind data. Typically, 100 iterations of the model will be run utilising the data that is most relevant to the season or timing of the project.

The outcomes are often presented as a probability of exposure and is primarily used for risk assessment purposes in view to understand the range of environments that may be affected or impacted by a spill. Elements of the stochastic modelling can also be used in oil spill preparedness and planning.

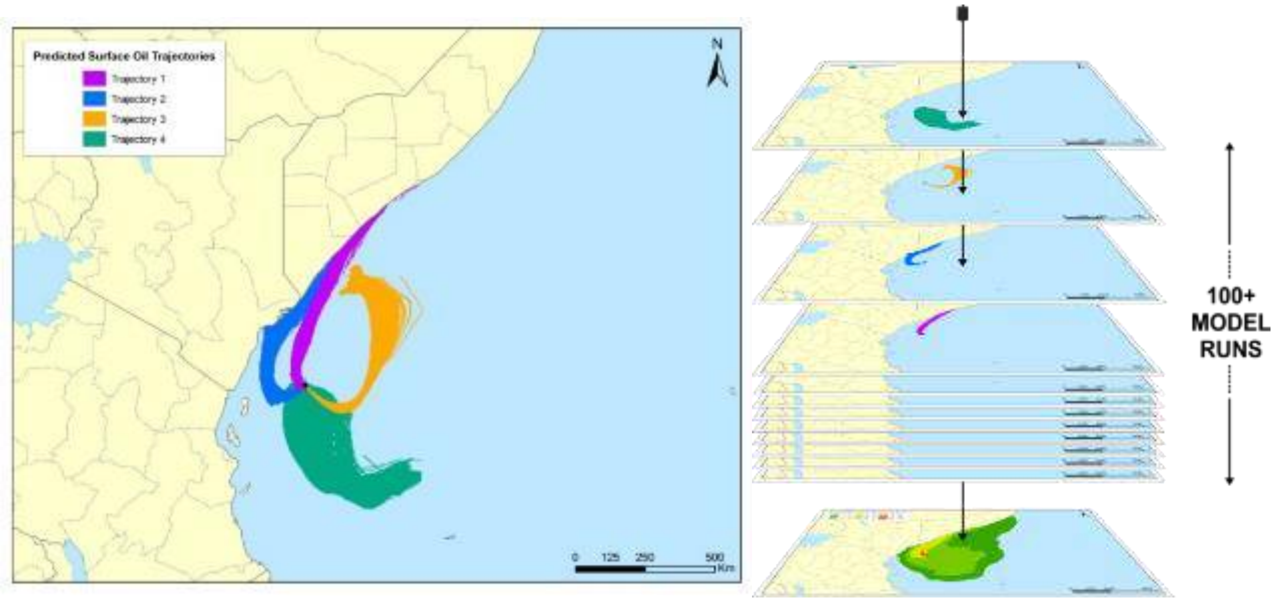

Figure 1.2 Examples of four individual spill trajectories (four replicate simulations) predicted by SIMAP for a spill scenario. The frequency of contact with given locations is used to calculate the probability of impacts during a spill. Essentially, all model runs are overlain (shown as the stacked runs on the right) and the number of times that trajectories contact a given location at a concentration is used to calculate the probability.

1.2.2 Deterministic Modelling (Single Spill Simulation)

Deterministic modelling is the predictive modelling of a single incident subject to a single sample of wind and weather conditions over time (NOPSEMA, 2018; Figure 1.3).

Deterministic modelling is often paired with stochastic modelling to place the large stochastic footprint into perspective. This deterministic analysis is generally a single run selected from the stochastic analysis and serves as the basis for developing the plans and equipment needs for a realistic spill response. Deterministic spills can be selected based on parameters such as minimum time to shoreline, largest swept area, maximum volume ashore and longest length of shoreline contacted by oil.

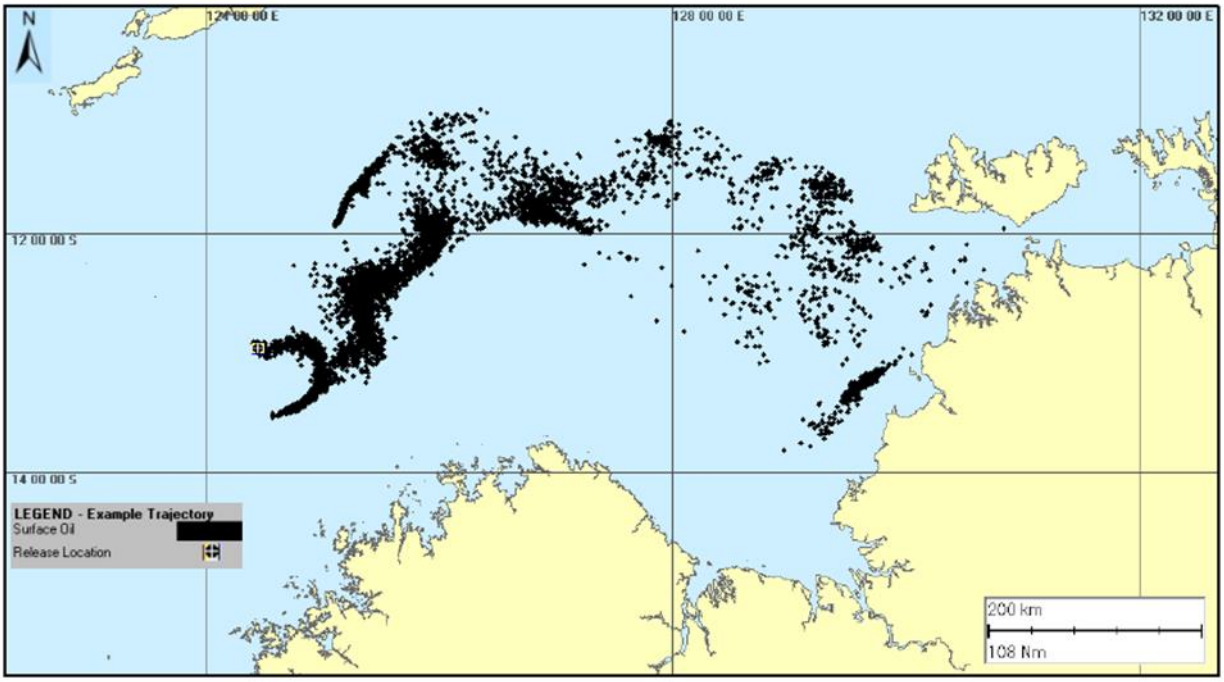

Figure 1.3 Example of an individual spill trajectory predicted by SIMAP for a spill scenario. Note, this image represents surface oil and does not take any thresholds into consideration.

2 SCOPE OF WORK

The scope of work included the following components:

1. Generate 2 years (2019 – 2020) of wind and high-resolution current data covering Darwin Harbour and the Beagle Gulf representing the complex tidal flows, in addition to the tidal wetting and drying of intertidal zones;
2. Include the wind and current data and the MDO characteristics as input into the three-dimensional oil spill model, SIMAP, to model the movement, spreading, weathering and shoreline accumulation by hydrocarbons over time;
3. For each scenario, run 100 oil spill simulations per season (200 total per scenario), with each simulation having the same spill information (spill volume, duration and composition of hydrocarbons) but varying start times. This ensured that each spill trajectory was subjected to a unique set of wind and current conditions;
4. Combine the results from the 100 spill trajectories (per season) to determine the probability and level of exposure to the waters and shorelines for defined thresholds;
5. Present the combined results from the 200 spill simulations, per scenario, to assess the low threshold environment that maybe affected (EMBA); and
6. From the 200 simulations modelled for each scenario, identify and present the “worst case” deterministic run resulting in the maximum volume of oil ashore.

3 CURRENTS

3.1 Development of Regional Current Data

To simulate the hydrodynamics within Darwin Harbour and Beagle Gulf, a three-dimensional model was setup which accounted for tidal and oceanic currents, bathymetry, bottom roughness and wind stress. The model framework was developed through the combination of a large-scale regional model with smaller refined regions, or sub-domains. The D-FLOW model is ideally suited to represent the hydrodynamics of complex coastal waters, including regions where the tidal range creates large intertidal zones.

The three-dimensional simulations were generated using a rectangular grid in the horizontal with a series of interconnected (two-way, dynamically-nested) grids of varying resolution; a technique referred to as “domain decomposition”. This allows for the generation of a series of grids with progressively increasing spatial resolution, down to an appropriate scale for accurate resolution of the hydrodynamics to resolve flows more accurately along the coastline, around islands and over regions with more complex bathymetry. The main advantage of domain decomposition over traditional one-way, or static, nesting systems is that the model domains interact seamlessly, allowing transport and feedback between the regions of different scales. The ability to dynamically couple multiple model domains offer a flexible framework for hydrodynamic model development. In the vertical, a sigma-coordinate approach was employed to divide the water column into a series of layers.

D-FLOW allows for the establishment of a:

- Detailed bathymetry of the study area with wetting and drying of the intertidal zones simulated in applicable areas;
- Boundary elevation forcing data in the form of water levels representing the tides was sourced from the TPXO8.0 database, which is derived from sea-surface topography measurement by the TOPEX/Poseidon satellite-borne radar altimeters; TOPEX). While elevation data representing the ocean currents sourced from Hybrid Coordinate Ocean Model (HYCOM); and
- Spatially-varying surface wind data.

3.2 Grid Setup

To optimise the computational effort required for a large, multi-layered model domain, and to achieve adequate horizontal and temporal resolution, a multiple-grid (domain-decomposition) strategy was applied using five sub-domains of varying horizontal grid cell size (Figure 3.1). The horizontal resolution within Darwin Harbour was 80 m (sub-grid 4), 240 m for the intermediate region (sub-grid 3), 720 m, 2.2 km and 6.5 km for the outer domains (sub-grids 2, 1 and 0, respectively).

A combination of datasets was used and merged to describe the shape of the seabed within Darwin Harbour and the intermediate area, including spot depths and contours which were digitised from nautical charts released by the hydrographic offices. For the outer domains, depths extracted from the General Bathymetric Chart of the Oceans (GEBCO) dataset on a 15 arc-second interval grid was used.

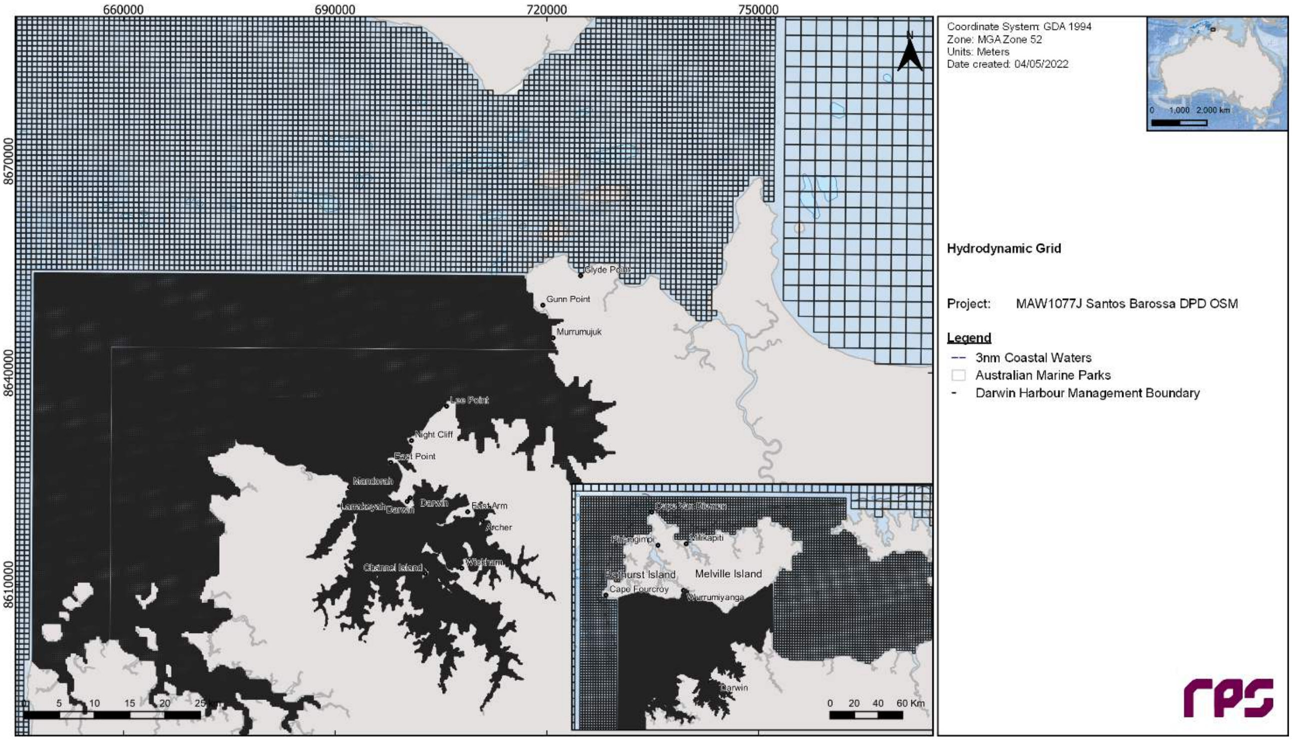

Figure 3.1 Detail of the hydrodynamic model grid.

3.3 Boundary Conditions

3.3.1 Overview

While the hydrodynamics in Darwin Harbour are controlled primarily by tidal flows, oceanic and wind forcing were explicitly included to account for the conditions beyond the port limits.

The model was forced on the open boundaries of the outer sub-domain with time series of water elevation obtained for the chosen simulation period. Spatial and temporal variation in wind forcing across the entire domain was accounted for by applying spatially-varying wind speed and wind direction data that varied over time.

3.3.1.1 Water Elevation

Water elevations at hourly intervals were obtained from the TPXO8.0 database, which is derived from measurements of sea-surface topography by the TOPEX/Poseidon satellite-borne radar altimeters. Tides are provided as complex amplitudes of earth-relative sea-surface elevation for eight primary harmonic constituents (M_2, S_2, N_2, K_2, K_1, O_1, P_1, Q_1), two long-period (M_f, M_m) and three non-linear (M_4, MS_4, MN_4) at a spatial resolution of 0.25°.

The tidal sea level data was augmented with non-tidal (or oceanic) sea level elevation data from the global Hybrid Coordinate Ocean Model (HYCOM; Bleck, 2002; Chassignet *et al.*, 2007, 2009; Halliwell, 2004), created by the USA's National Ocean Partnership Program (NOPP) as part of the Global Ocean Data Assimilation Experiment (GODAE). The HYCOM model is a three-dimensional model that assimilates observations of sea surface temperature, sea surface salinity and surface height, obtained by satellite instrumentation, along with atmospheric forcing conditions from atmospheric models to predict drift currents generated by such forces as wind shear, density, sea height variations and the rotation of the Earth. The model has a global coverage with a horizontal resolution of 1/12th of a degree (~7 km at mid-latitudes) and a temporal resolution of 24 hours.

3.3.1.2 Wind Forcing

Wind forcing was included in the hydrodynamic model as a boundary condition to capture its effect on water currents. For this model, wind data was sourced from the National Center for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR; see Saha *et al*., 2010). The CFSR wind model includes observations from many data sources: surface observations, upper-atmosphere air balloon observations, aircraft observations and satellite observations. The model is capable of accurately representing the interaction between the earth's oceans, land and atmosphere. The gridded wind data output is available at a horizontal resolution of 0.25° (~33 km) and a temporal resolution of 1 hour.

3.4 Surface Currents

Table 3.1 displays the predicted monthly average and maximum combined surface current speeds adjacent to the release locations. The surface modelled current speeds were relatively consistent ranging from 0.39 m/s to 0.42 m/s at KP91.5 and 0.33 m/s to 0.36 m/s (KP114). The dominant current directions at KP91.5 and KP114 were along the east-southeast to west-northwest axis and south-southeast to north-northwest axis, respectively. In addition, the maximum monthly current speeds ranged from 1.08 m/s to 1.23 m/s (KP91.5) and 1.07 m/s and 1.33 m/s (KP114).

Figure 3.2 and Figure 3.3 present the monthly and total surface current rose distributions from 2019 – 2020 (inclusive), respectively. Note the convention for defining current direction is the direction the current flows towards, which is used to reference current direction throughout this report. Each branch of the rose represents the currents flowing to that direction, with north to the top of the diagram. The rose branches are each divided into segments of different colour according to speed intervals of 0.1 m/s, which represent current speeds within the monthly or seasonal datasets, respectively. The length of each coloured segment (indicative of speeds) is relative to the proportion of time the currents flow in that direction.

Table 3.1 Summary of the predicted average and maximum surface current speeds adjacent to the KP91.5 and KP 114 release locations, derived from the modelled 2019 – 2020 dataset.

Season	Month	KP91.5 (Scenario 1) Average current speed (m/s)	KP91.5 (Scenario 1) Maximum current speed (m/s)	KP91.5 (Scenario 1) General direction(s) (towards)	KP114 (Scenario 2, 3 and 4) Average current speed (m/s)	KP114 (Scenario 2, 3 and 4) Maximum current speed (m/s)	KP114 (Scenario 2, 3 and 4) General direction(s) (towards)
Wet	January	0.39	1.17	East-southeast and west-northwest	0.33	1.18	South-southeast and north-northwest
	February	0.41	1.14		0.35	1.20	
	March	0.40	1.16		0.35	1.26	
	April	0.41	1.15		0.35	1.33	
Dry	May	0.39	1.19		0.33	1.27	
	June	0.39	1.13		0.33	1.16	
	July	0.39	1.08		0.33	1.07	
	August	0.40	1.12		0.34	1.15	
	September	0.41	1.15		0.36	1.29	
	October	0.42	1.19		0.36	1.30	
Wet	November	0.40	1.23		0.34	1.31	
	December	0.39	1.16		0.33	1.21	
	Minimum	**0.39**	**1.08**		**0.33**	**1.07**	
	Maximum	**0.42**	**1.23**		**0.36**	**1.33**	

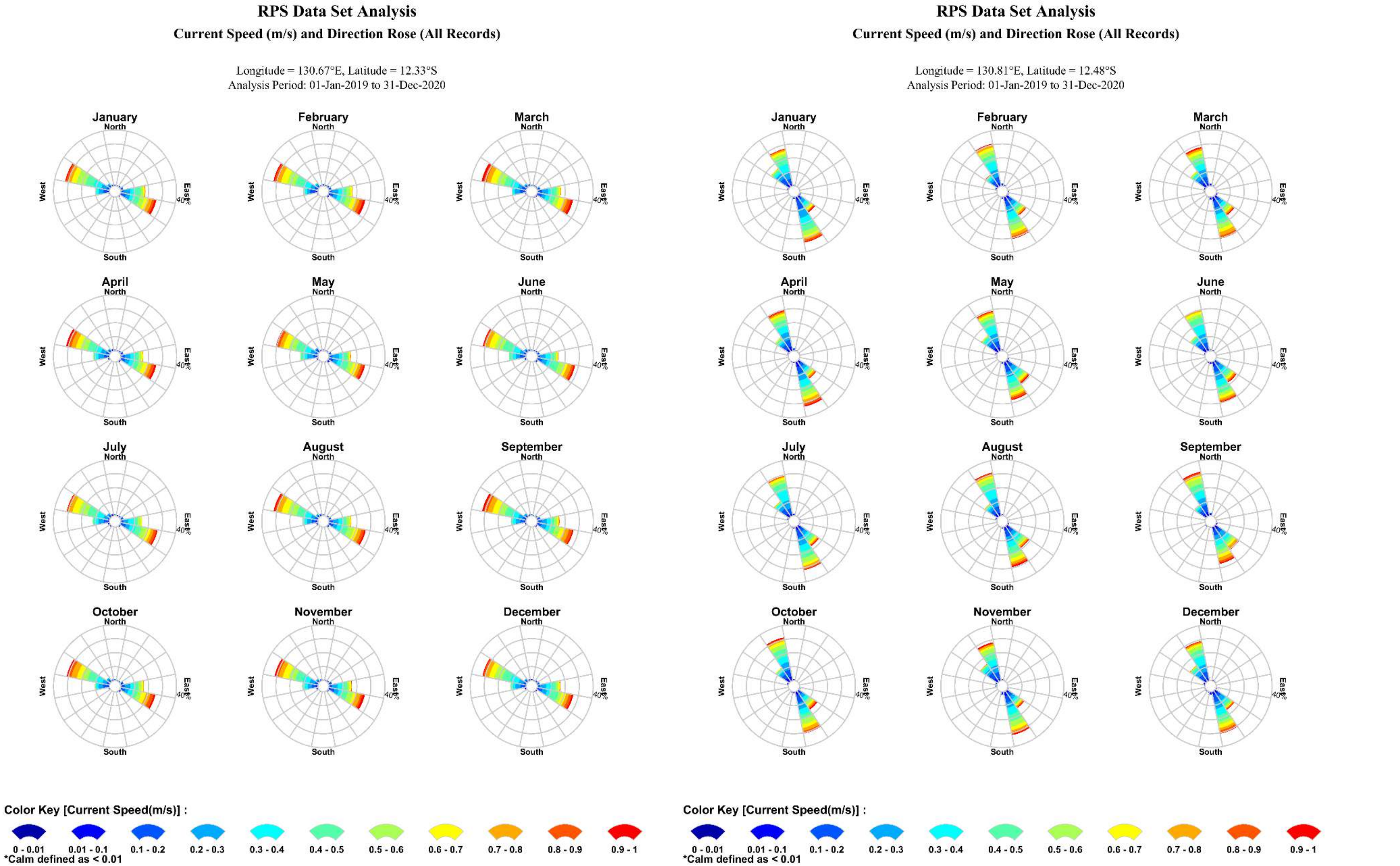

Figure 3.2 **Monthly surface current rose distributions from 2019 – 2020 (inclusive), for the closest current nodes to the KP91.5 (left) and KP 114 (right) release locations, derived from the modelled dataset.**

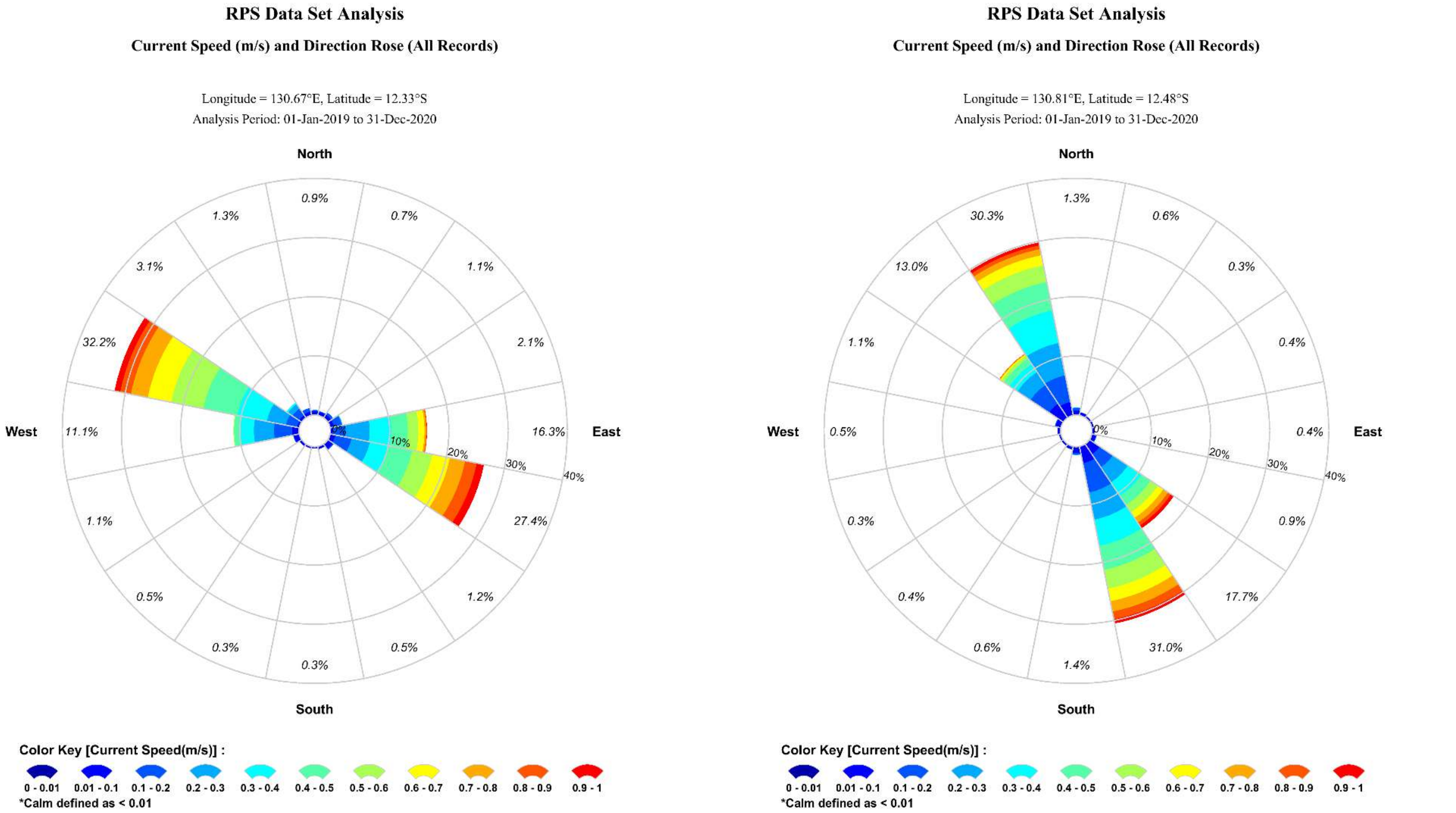

Figure 3.3 Total surface current rose distributions from 2019 – 2020 (inclusive), for the closest current nodes to the KP91.5 (left) and KP 114 (right) release locations, derived from the modelled dataset.

4 WIND DATA

To account for the influence of the wind on the floating oil, the wind conditions between 2019 – 2020 (inclusive) was sourced from the CFSR model (see Section 3.3.1.2). Table 4.1 presents the monthly average and maximum winds derived from a CFSR wind node closest to the release locations. Monthly average wind speeds ranged from 7.1 to 13.5 knots at KP91.5 and 17.5 to 28.2 knots at KP114, while monthly maximums ranged from 17.3 to 29.2 knots at KP91.5 and 17.5 to 28.2 knots at KP114. The wind direction varied between the months, with the winds blowing generally from the west during the wet season and east-southeast during the dry season at both locations.

Figure 4.1 and Figure 4.2 show the monthly and total wind rose distributions derived from the nearest wind node to the KP91.5 release location. Plots for KP114 are not presented as they are identical to KP91.5. Note that the atmospheric convention for defining wind direction, that is, the direction the wind blows from, is used to reference wind direction throughout this report. Each branch of the rose represents wind coming from that direction, with north to the top of the diagram. Sixteen directions are used. The branches are divided into segments of different colour, which represent wind speed ranges from that direction. Speed ranges of 3 knots are predominantly used in these wind roses. The length of each segment within a branch is proportional to the frequency of winds blowing within the corresponding range of speeds from that direction.

Table 4.1 Summary of the predicted average and maximum winds for the nearest CFSR wind nodes to the KP91.5 and KP 114 release locations, derived from CFSR hindcast model from 2019 – 2020 (inclusive).

Season	Month	KP91.5 (Scenario 1)			KP114 (Scenario 2, 3 and 4)		
		Average wind speed (knots)	Maximum wind speed (knots)	General direction (from)	Average wind speed (knots)	Maximum wind speed (knots)	General direction (from)
Wet	January	11.9	29.2	West	11.3	28.2	West
	February	13.5	28.5	West	12.9	27.4	West
	March	8.3	22.9	West	7.9	22.0	West
	April	7.9	28.2	East	7.6	25.7	East
Dry	May	10.8	25.0	East-southeast	10.2	23.5	East-southeast
	June	9.9	23.2	East-southeast	9.4	21.7	East-southeast
	July	8.9	24.3	East-southeast	8.5	22.9	East-southeast
	August	7.9	22.2	Variable	7.6	21.1	Variable
	September	7.1	17.6	Variable	6.9	18.2	Variable
	October	7.2	17.3	West	6.8	17.5	West
Wet	November	7.9	18.5	West	7.4	19.4	West
	December	8.5	22.9	West	8.1	21.7	West
	Minimum	**7.1**	**17.3**		**6.8**	**17.5**	
	Maximum	**13.5**	**29.2**		**12.9**	**28.2**	

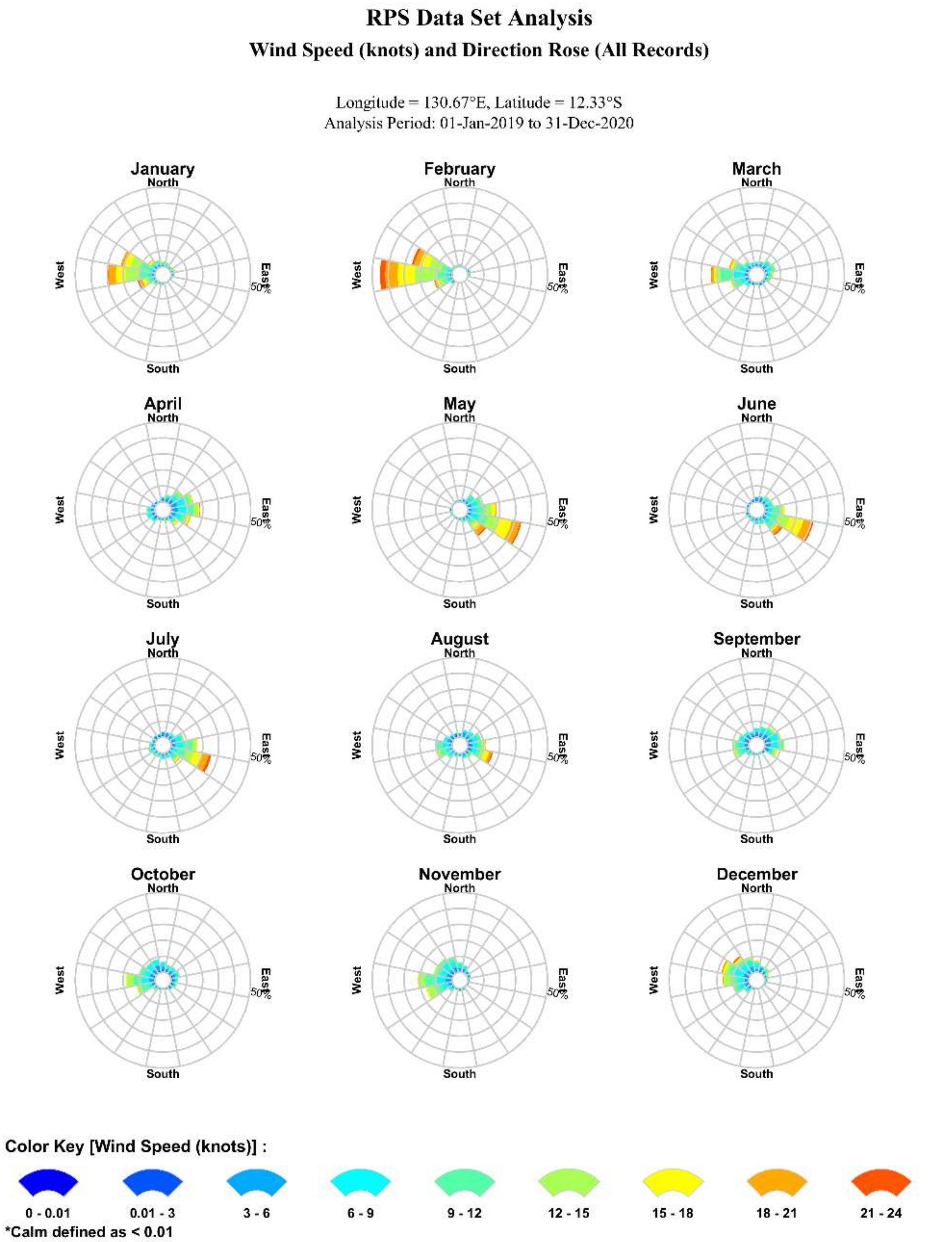

Figure 4.1 Monthly wind rose distributions from 2019 – 2020 (inclusive), for the closest wind node to KP91.5 release location, derived from CFSR hindcast model.

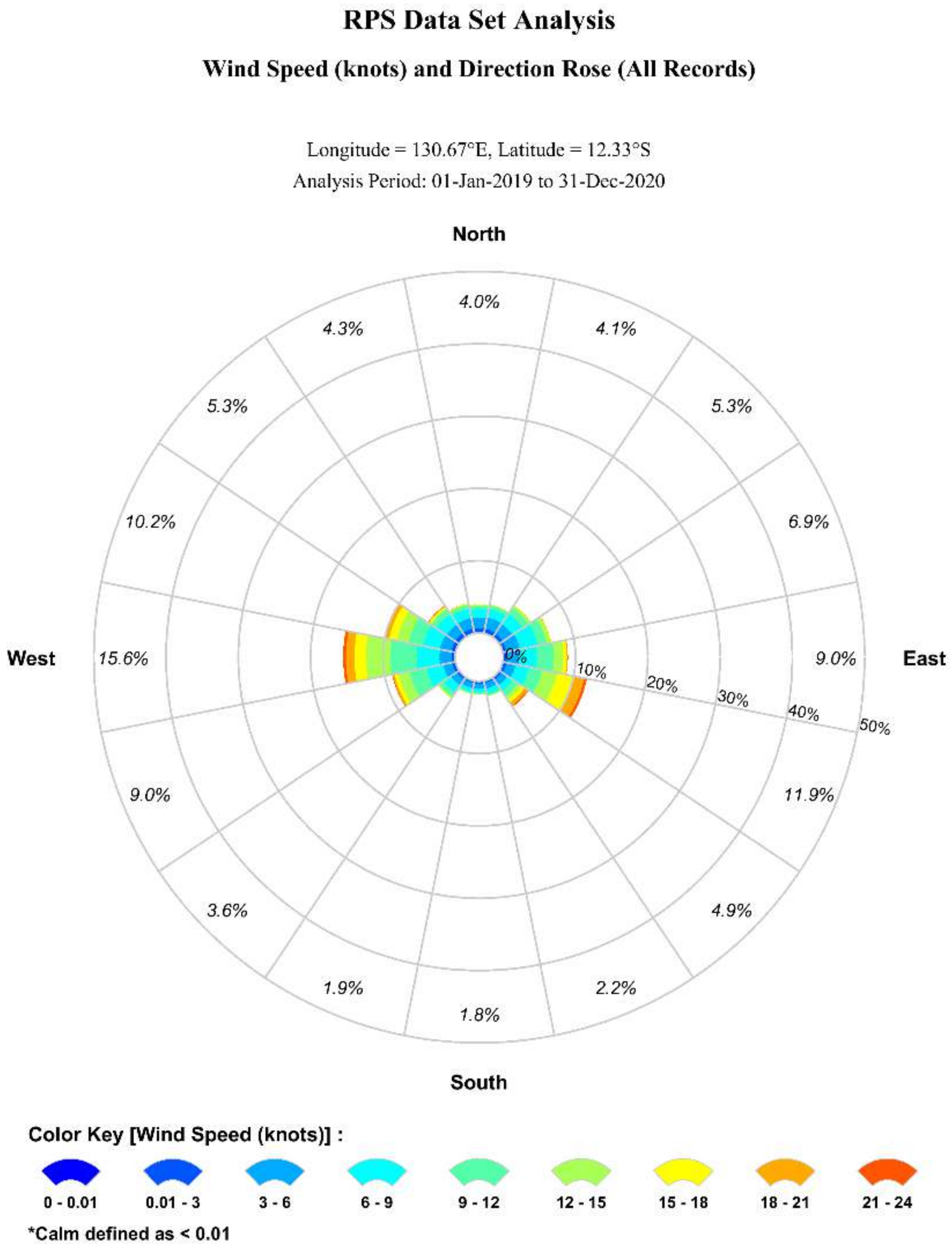

Figure 4.2 **Total wind rose distributions from 2019 – 2020 (inclusive), for the closest wind node to KP91.5 release location, derived from CFSR hindcast model.**

5 WATER TEMPERATURE AND SALINITY

Table 5.1. provides a summary of the monthly mean sea surface temperature and salinity values in the 0 – 5 m depth layer at the release locations. The temperature and salinity data throughout the water column was obtained from the World Ocean Atlas 2018 database produced by the National Oceanographic Data Centre (National Oceanic and Atmospheric Administration, NOAA) and its co-located World Data Centre for Oceanography (Levitus *et al.*, 2013). The data is used to inform the weathering, movement and evaporative loss of hydrocarbon spills in the surface and subsurface layers.

The monthly average sea surface temperatures ranged between 26.0°C (July) and 30.9°C (December) at KP91.5. While the sea surface temperatures at KP114 ranged between 24.4°C (June) and 31.0°C (December). The monthly average salinity values remain relatively consistent between the two locations (between 33.6 psu to 34.7 psu at KP91.5; and between 32.9 psu to 34.8 psu at KP114). The data align with the Darwin Harbour water quality monitoring program (https://depws.nt.gov.au/water/water-management/darwin-harbour/darwin-harbour-region-report-cards/2018-report-cards).

Table 5.1 Monthly average sea surface temperature and salinity adjacent to the KP91.5 and KP114 release locations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
KP91.5	Temperature (°C)	30.1	30.6	30.6	30.3	28.7	26.3	26.0	26.7	28.7	30.1	30.4	30.9
	Salinity (psu)	33.7	33.7	33.6	33.6	34.1	34.5	34.5	34.5	34.2	34.5	34.7	34.7
KP114	Temperature (°C)	29.9	30.6	30.5	30.1	28.2	24.4	25.2	26.2	28.8	30.2	30.6	31.0
	Salinity (psu)	33.1	33.0	32.9	33.5	34.2	34.5	34.5	34.6	34.2	34.5	34.8	34.6

6 OIL SPILL MODEL – SIMAP

The spill modelling was carried out using a purpose-developed oil spill trajectory and fates model, SIMAP. This model is designed to simulate the transport and weathering processes that affect the outcomes of hydrocarbon spills to the sea, accounting for the specific oil type, spill scenario, and prevailing wind and current circulation patterns.

SIMAP is the evolution of the United States Environmental Protection Agency (US EPA) Natural Resource Damage Assessment model (French & Rines, 1997; French *et al.*, 1999) and is designed to simulate the fate and effects of spilled oils and fuels for both the surface slick and the three-dimensional plume that is generated in the water column. SIMAP includes algorithms to account for both physical transport and weathering processes. The latter are important for accounting for the partitioning of the spilled mass over time between the water surface (surface slick), water column (entrained oil and dissolved compounds), atmosphere (evaporated compounds) and land (stranded oil). The model also accounts for the interaction between weathering and transport processes.

The physical algorithms calculate transport and spreading by physical forces, including surface tension, gravity and wind and current forces for both surface slicks and oil within the water column. The fates algorithms calculate all the weathering processes known to be important for oil spilled to marine waters. These include droplet and slick formation, entrainment by wave action, emulsification, dissolution of soluble components, sedimentation, evaporation, bacterial and photo-chemical decay and shoreline interactions. These algorithms account for the specific oil type being considered.

Entrainment is the physical process where globules of oil are transported from the sea surface into the water column by wind and wave-induced turbulence or be generated subsea by a pressurised discharge at depth. It has been observed that entrained oil is broken into droplets of varying sizes. Small droplets spread and diffuse into the water column, while larger ones rise rapidly back to the surface (Delvigne & Sweeney, 1988; Delvigne, 1991).

Dissolution is the process by which soluble hydrocarbons enter the water from a surface slick or from entrained droplets. The lower molecular weight hydrocarbons tend to be both more volatile and more soluble than those of higher molecular weight.

The formation of water-in-oil emulsions, or mousse, which is termed ‘emulsification’, depends on oil composition and sea state. Emulsified oil can contain as much as 80% water in the form of micrometre-sized droplets dispersed within a continuous phase of oil (Daling & Brandvik, 1991; Bobra, 1991; Daling *et al.*, 1997; Fingas, 1995, 1997).

Entrainment, dissolution and emulsification rates are correlated to wave energy, which is accounted for by estimating wave heights from the sustained wind speed, direction and fetch (i.e. distance downwind from land barriers) at different locations in the domain. Dissolution rates are dependent upon the proportion of soluble, short-chained hydrocarbon compounds, and the surface area at the oil/water interface of slicks. Dissolution rates are also strongly affected by the level of turbulence. For example, dissolution rates will be relatively high at the site of the release for a deep-sea discharge at high pressure.

Evaporation can result in the transfer of large proportions of spilled oil from the sea surface to the atmosphere, depending on the type of oil (Gundlach & Boehm, 1981). Evaporation rates vary over space and time dependent on the prevailing sea temperatures, wind and current speeds, the surface area of the slick and entrained droplets that are exposed to the atmosphere as well as the state of weathering of the oil. Evaporation rates will decrease over time, depending on the calculated rate of loss of the more volatile compounds. By this process, the model can differentiate between the fates of different oil types.

Decay (degradation) of hydrocarbons may occur as the result of photolysis, which is a chemical process energised by ultraviolet light from the sun, and by biological breakdown, termed biodegradation. Many types of marine organisms ingest, metabolise and utilise oil as a carbon source, producing carbon dioxide and water as by-products.

The SIMAP weathering algorithms include terms to represent these dynamic processes. Technical descriptions of the algorithms used in SIMAP and validations against real spill events are provided in French (1998), French *et al.*, (1999) and French-McCay (2004).

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

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

7 OIL PROPERTIES

Table 7.1 and Table 7.2 present the physical properties and boiling point ranges of the MDO used in this study. It has a density of 829.1 kg/m^3 (API of 37.6) and a low pour point of -14°C. The low viscosity (4 cP) indicates that this oil will spread quickly when released and will form a thin to low thickness film on the sea surface, increasing the rate of evaporation.

Generally, about 6.0% of the MDO mass should evaporate within the first 12 hours (Boiling point (BP) < 180°C); a further 34.6% should evaporate within the first 24 hours (180°C < BP < 265°C); and an additional 54.4% should evaporate over several days (265°C < BP < 380°C). Approximately 5% (by mass) of MDO will not evaporate though will decay slowly over time.

The oil is categorised as a group II oil (light-persistent) according to the International Tankers Owners Pollution Federation (ITOPF, 2014) and US EPA/USCG classifications. The classification is based on the specific gravity of hydrocarbons in combination with relevant boiling point ranges.

It is important to note that some heavy components contained in MDO have a strong tendency to physically entrain into the upper water column in the presence of moderate winds (i.e. >12 knots) and breaking waves but can re-float to the surface if these energies abate.

Table 7.1 Physical properties of the MDO

Characteristic	Marine Diesel Oil (MDO)
Density (kg/m^3)	829.1 (at 25 °C)
API	37.6
Dynamic viscosity (cP)	4.0 (at 25 °C)
Pour point (°C)	-14
Hydrocarbon property category	Group II
Hydrocarbon property classification	Light - Persistent

Table 7.2 Boiling point ranges of the MDO

Oil Type	Component	Volatile (%)	Semi-volatile (%)	Low-volatility (%)	Residual (%)
	Boiling point (°C)	<180 C_4 to C_{10}	180-160 C_{11} to C_{15}	160-380 C_{16} to C_{20}	>380 >C_{20}
Marine diesel oil (MDO)	% of total	6.0	34.6	54.4	5.0

8 FLOATING, SHORELINE AND IN-WATER THRESHOLDS

The thresholds and their relationship to exposure for the sea surface, shoreline, and water column (entrained and dissolved hydrocarbons) are presented in Sections 8.1 to 8.3. Supporting justifications of the adopted thresholds applied during the study and additional context relating to the area of influence are also provided. It is important to note that the thresholds herein are based on NOPSEMA (2019).

8.1 Floating Oil Exposure Thresholds

The modelling results can be presented to any levels; therefore, thresholds have been specified (based on scientific literature) to record floating oil exposure to the sea-surface at meaningful levels only, described in the following paragraphs.

The low threshold to assess the potential for floating oil exposure, was 1 g/m^2, which equates approximately to an average thickness of 1 µm, referred to as visible oil. Oil of this thickness is described as rainbow sheen in appearance, according to the Bonn Agreement Oil Appearance Code (Bonn Agreement, 2009; AMSA, 2014) (see Table 8.1). Table 8.1 provides a description of the appearance in relation to exposure zone thresholds used to classify the zones of floating oil exposure. Figure 8.1 shows photographs highlighting the difference in appearance between a silvery sheen, rainbow sheen and metallic sheen. The low threshold is considered below levels which would cause environmental harm and it is more indicative of the areas perceived to be affected due to its visibility on the sea surface and potential to trigger temporary closures of areas (i.e., fishing grounds) as a precautionary measure.

Ecological impact has been estimated to occur at 10 g/m^2 (a film thickness of approximately 10 µm or 0.01 mm) (French *et al.*,1996 and French-McCay 2009) as this level of fresh oiling has been observed to mortally impact some birds through adhesion of oil to their feathers, exposing them to secondary effects such as hypothermia. The appearance of oil at this average thickness has been described as a metallic sheen (Bonn Agreement, 2009). Concentrations above 10 g/m^2 is also considered the lower actionable threshold, where oil may be thick enough for containment and recovery as well as dispersant treatment (AMSA, 2015).

Oil concentrations on the sea surface of 25 g/m^2 (or greater) would be harmful for all birds that have landed in an oil film due to potential contamination of their feathers, with secondary effects such as loss of temperature regulation and ingestion of oil through preening (Scholten *et al.*, 1996 and Koops *et al.*, 2004). The appearance of oil at this thickness is also described as metallic sheen (Bonn Agreement, 2009). For this study the high exposure threshold was set to 50 g/m^2 and above based on NOPSEMA (2019). This threshold can also be used to inform response planning.

Table 8.2 defines the thresholds used to classify the zones of floating oil exposure reported herein.

Table 8.1 The Bonn Agreement Oil Appearance Code.

Code	Description Appearance	Layer Thickness Interval (g/m^2 or µm)	Litres per km^2
1	Sheen (silvery/grey)	0.04 – 0.30	40 – 300
2	Rainbow	0.30 – 5.0	300 – 5,000
3	Metallic	5.0 – 50	5,000 – 50,000
4	Discontinuous True Oil Colour	50 – 200	50,000 – 200,000
5	Continuous True Oil Colour	≥ 200	≥ 200,000

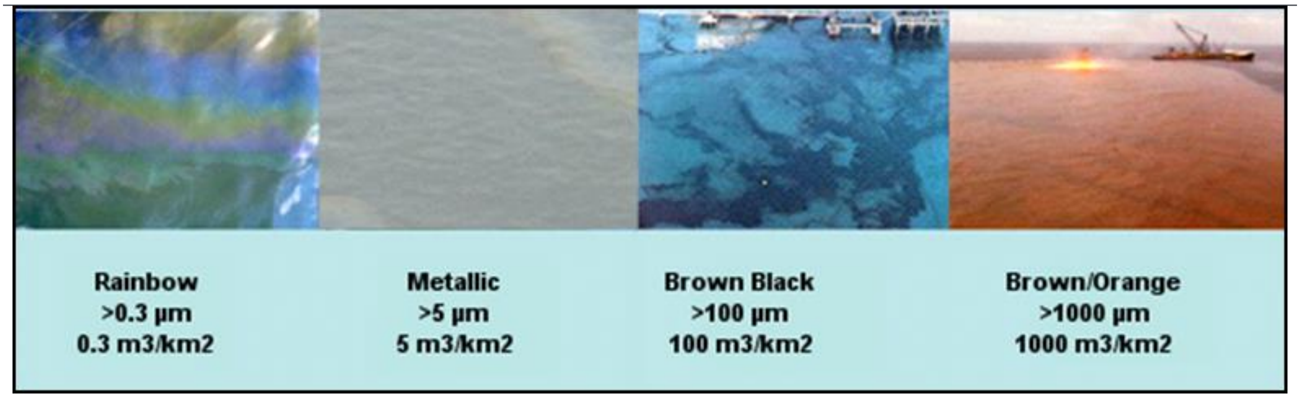

Figure 8.1 Photographs showing the difference between oil colour and thickness on the sea surface (source: adapted from Oil Spill Solutions, 2015).

Table 8.2 Floating oil exposure thresholds used in the Barossa DPD oil spill modelling study (in alignment with NOPSEMA, 2019).

Threshold level	Floating oil (g/m^2)	Description
Low	1	Approximates range of socio-economic effects and establishes planning area for scientific monitoring
Moderate	10	Approximates lower limit for harmful exposures to birds and marine mammals
High	50*	Approximates surface oil slick and informs response planning

* 50 g/m^2 also used to define the threshold for actionable floating oil.

8.2 Shoreline Accumulation Thresholds

There are many different types of shorelines, ranging from cliffs, rocky beaches, sandy beaches, mud flats and mangroves, and each of these influences the volume of oil that can remain stranded ashore and its thickness before the shoreline saturation point occurs. For instance, a sandy beach may allow oil to percolate through the sand, thus increasing its ability to hold more oil ashore over tidal cycles and various wave actions than an equivalent area of water; hence oil can increase in thickness onshore over time. A sandy beach shoreline was assumed as the default shoreline type for the modelling in this study, as it allows for the highest carrying capacity of oil (of the available open/exposed shoreline types). Hence the results are considered conservative (i.e., worst-case) given that a large part of the shoreline in the study area (especially the western part of the Joseph Bonaparte Gulf) is characterised by exposed rocky shorelines, with southern parts characterised by tidal mudflats and mangroves and eastern shorelines containing more sandy beaches.

Previous risk assessment studies used a threshold of 10 g/m^2 to assess the potential for shoreline accumulation (French-McCay *et al.*,2005a; 2005b). This is a conservative threshold used to define regions of socio-economic impact, such as triggering temporary closures of adjoining fisheries or the need for shore clean-up on beaches or man-made features/amenities (breakwaters, jetties, marinas, etc.). It would equate to approximately 2 teaspoons of hydrocarbon per square meter of shoreline accumulation. The appearance is described as a stain/film. On that basis, the 10 g/m^2 shoreline accumulation threshold has been selected to define the zone of potential “low shoreline accumulation”.

French *et al.* (1996) and French-McCay (2009) define a shoreline oil accumulation threshold of 100 g/m^2, or above, would potentially harm shorebirds and wildlife (fur-bearing aquatic mammals and marine reptiles on or along the shore) based on studies for sub-lethal and lethal impacts. This threshold has been used in previous environmental risk assessment studies (see French-McCay, 2003; French-McCay *et al.*, 2004, French-McCay *et al.*, 2011; 2012; NOAA, 2013). Additionally, a shoreline concentration of 100 g/m^2, or above, is the minimum concentration that the oil can be effectively cleaned according to AMSA (2015). This threshold equates to approximately ½ a cup of oil per square meter of shoreline accumulation. The appearance is described as a thin oil coat. Therefore, 100 g/m^2 has been selected to define the zone of potential "moderate shoreline accumulation".

Observations by Lin & Mendelssohn (1996) demonstrated that loadings of more than 1,000 g/m^2 of hydrocarbon during the growing season would be required to impact marsh plants significantly. Similar thresholds have been found in studies assessing hydrocarbon impacts on mangroves (Grant *et al.*, 1993; Suprayogi & Murray, 1999). This loading equates to approximately 1 litre of hydrocarbon per square meter of shoreline accumulation and the appearance is described as a hydrocarbon cover. A loading of 1,000 g/m^2 has been selected to define the zone of potential "high shoreline accumulation".

These shoreline accumulation thresholds derived from extensive literature review (outlined in Table 8.3) align with the threshold values for oil spill modelling specified in NOPSEMA (2019).

Table 8.3 Shoreline accumulation thresholds used in the Barossa DPD oil spill modelling study (in alignment with NOPSEMA, 2019).

Threshold level	Shoreline loading(g/m^2)	Description
Low (socioeconomic/sublethal)	10	Predicts potential for some socio-economic impact
Moderate	100*	Loading predicts area likely to require clean-up effort
High	1,000	Loading predicts area likely to require intensive clean-up effort

* 100 g/m^2 also used to define the threshold for actionable shoreline oil.

8.3 In-water Exposure Thresholds

Oil is a mixture of thousands of hydrocarbons of varying physical, chemical, and toxicological characteristics, and therefore, demonstrate varying fates and impacts on organisms. As such, for in-water exposure, the SIMAP model provides separate outputs for dissolved and entrained hydrocarbons from oil droplets. The consequences of exposure to dissolved and entrained components will differ because they have different modes and magnitudes of effect.

Entrained hydrocarbon concentrations were calculated based on oil droplets that are suspended in the water column, though not dissolved. The composition of this oil would vary with the state of weathering (oil age) and may contain soluble hydrocarbons when the oil is fresh. Calculations for dissolved hydrocarbons specifically calculates oil components which are dissolved in water, which are known to be the primary source of toxicity exerted by oil.

A complicating factor that should be considered when assessing the consequence of dissolved and entrained oil distributions is that there will be some areas where both physically entrained oil droplets and dissolved hydrocarbons co-exist. Higher concentrations of each will tend to occur close to the source where sea conditions can force mixing of relatively unweathered oil into the water column, resulting in more rapid dissolution of soluble compounds.

8.3.1 Dissolved Hydrocarbons

Laboratory studies have shown that dissolved hydrocarbons exert most of the toxic effects of oil on aquatic biota (Carls *et al.*, 2008; Nordtug *et al.*, 2011; Redman, 2015). The mode of action is a narcotic effect, which is positively related to the concentration of soluble hydrocarbons in the body tissues of organisms (French-McCay, 2002). Dissolved hydrocarbons are taken up by organisms directly from the water column by absorption through external surfaces and gills, as well as through the digestive tract. Thus, soluble hydrocarbons are termed "bioavailable".

Hydrocarbon compounds vary in water-solubility and the toxicity exerted by individual compounds is inversely related to solubility, however bioavailability will be modified by the volatility of individual compounds (Nirmalakhandan & Speece, 1988; Blum & Speece, 1990; McCarty, 1986; McCarty *et al.*, 1992a, 1992b; McCarty & Mackay, 1993; Verhaar *et al.*, 1992, 1999; Swartz *et al.*, 1995; French-McCay, 2002; McGrath & Di Toro, 2009). Of the soluble compounds, the greatest contributor to toxicity for water-column and benthic organisms are the lower-molecular-weight aromatic compounds, which are both volatile and soluble in water.

Although they are not the most water-soluble hydrocarbons within most oil types, the polynuclear aromatic hydrocarbons (PAHs) containing 2 – 3 aromatic ring structures typically exert the largest narcotic effects because they are semi-soluble and not highly volatile, so they persist in the environment long enough for significant accumulation to occur (Anderson *et al.*, 1974, 1987; Neff & Anderson, 1981; Malins & Hodgins, 1981; McAuliffe, 1987; NRC, 2003). The monoaromatic hydrocarbons (MAHs), including the BTEX compounds (benzene, toluene, ethylbenzene, and xylenes), and the soluble alkanes (straight chain hydrocarbons) also contribute to toxicity, but these compounds are highly volatile, so that their contribution will be low when oil is exposed to evaporation and higher when oil is discharged at depth where volatilisation does not occur (French-McCay, 2002).

French-McCay (2002) reviewed available toxicity data, where marine biota was exposed to dissolved hydrocarbons prepared from oil mixtures, finding that 95% of species and life stages exhibited 50% population mortality (LC_{50}) between 6 and 400 ppb (with an average of 50 ppb) total PAH concentration after 96 hrs exposure. Therefore, concentrations lower than 6 ppb total PAH value should be protective of 97.5% of species and life stages even with exposure periods of days (at least 96 hours). Early life-history stages of fish appear to be more sensitive than older fish stages and invertebrates.

Exceedances of 10, 50 or 400 ppb over a 1-hour timestep (see Table 8.4) were applied in this study to indicate the increasing potential for sub-lethal to lethal toxic effects (or low to high), based on NOPSEMA (2019).

8.3.2 Entrained Hydrocarbons

Entrained hydrocarbons consist of oil droplets that are suspended in the water column and insoluble. Insoluble compounds in oil cannot be absorbed from the water column by aquatic organisms, therefore they are not bioavailable through absorption of compounds from the water. Exposure to these compounds would require routes of uptake other than absorption of soluble compounds. The route of exposure of organisms to whole oil alone include direct contact with tissues of organisms and uptake of oil by direct consumption, with potential for biomagnification through the food chain (NRC, 2003).

Thresholds of 10 ppb and 100 ppb were applied over a 1-hour time exposure (Table 8.4) as per NOPSEMA (2019).

The 10-ppb threshold exposure zone is not considered to be of significant biological impact and is therefore outside the adverse exposure zone. This exposure zone represents the area contacted by the spill.

Table 8.4 Dissolved and entrained hydrocarbon exposure thresholds assessed over a 1-hour time step used in the Barossa DPD oil spill modelling study (in alignment NOPSEMA 2019).

	Exposure level	In-water threshold (ppb)	Description
Dissolved hydrocarbons	Low	10	Establishes planning area for scientific monitoring based on potential for exceedance of water quality triggers
	Moderate	50	Approximates potential toxic effects, particularly sublethal effects to sensitive species
	High	400	Approximates toxic effects including lethal effects to sensitive species
Entrained hydrocarbons	Low	10	Establishes planning area for scientific monitoring based on potential for exceedance of water quality triggers
	Moderate	100	As appropriate given oil characteristics for informing risk evaluation

9 RECEPTORS

A range of receptors and shorelines were assessed for floating oil exposure, shoreline contact and water column exposure (entrained and dissolved) as part of the study (Figure 9.1 to Figure 9.6). Receptor categories (see Table 9.1) include sections of shorelines and within the Harbour the shorelines have been sectorised to closely aligned with the nine water quality zones. Also included in the assessment were the nine water quality reporting zones in the Harbour. Risks of exposure were separately calculated for each receptor and have been tabulated in the respective sections. It should be noted, that given that the release location for Scenarios 2 and 3 resides within the Middle Harbour WQ Zone receptor, there is no tabulated results presented for the floating oil and water column.

Table 9.1 Summary of receptors used to assess floating oil, shoreline, and in-water exposure to hydrocarbons in the Barossa DPD oil spill modelling study.

Receptor Category	Acronym	Hydrocarbon Exposure Assessment		
		Water Column	Floating oil	Shoreline
Australian Marine Park	AMP	✓	✓	✗
Conservation Reserve	CR	✓	✓	✗
Key Ecological Feature	KEF	✓	✓	✗
Marine Park	MP	✓	✓	✗
National Park	NP	✓	✓	✗
Nature Reserves	NR	✓	✓	✗
Reefs, Shoals and Banks	RSB	✓	✓	✗
Reef Fish Protected Areas	RFPA	✓	✓	✗
Restricted areas	Restricted areas	✓	✓	✗
Shipwrecks	Shipwrecks	✓	✗	✗
Shorelines	Shore	✗	✓ (reported as nearshore waters)	✓
Water Quality Zones	WQ Zones	✓	✓	✗

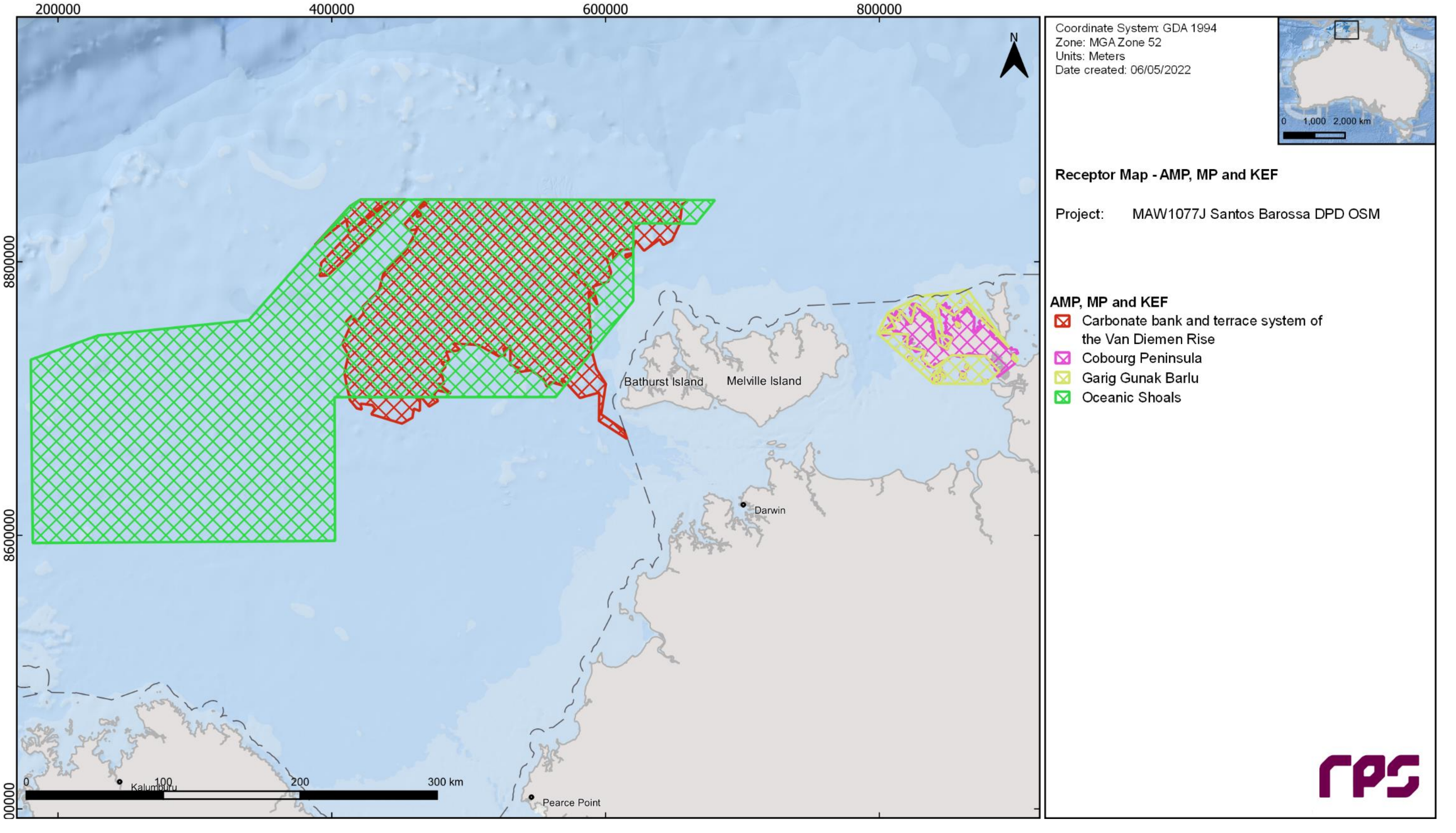

Figure 9.1 **Receptor map for Australian Marine Parks (AMP), Marine Parks (MP) and Key Ecological Features (KEFs).**

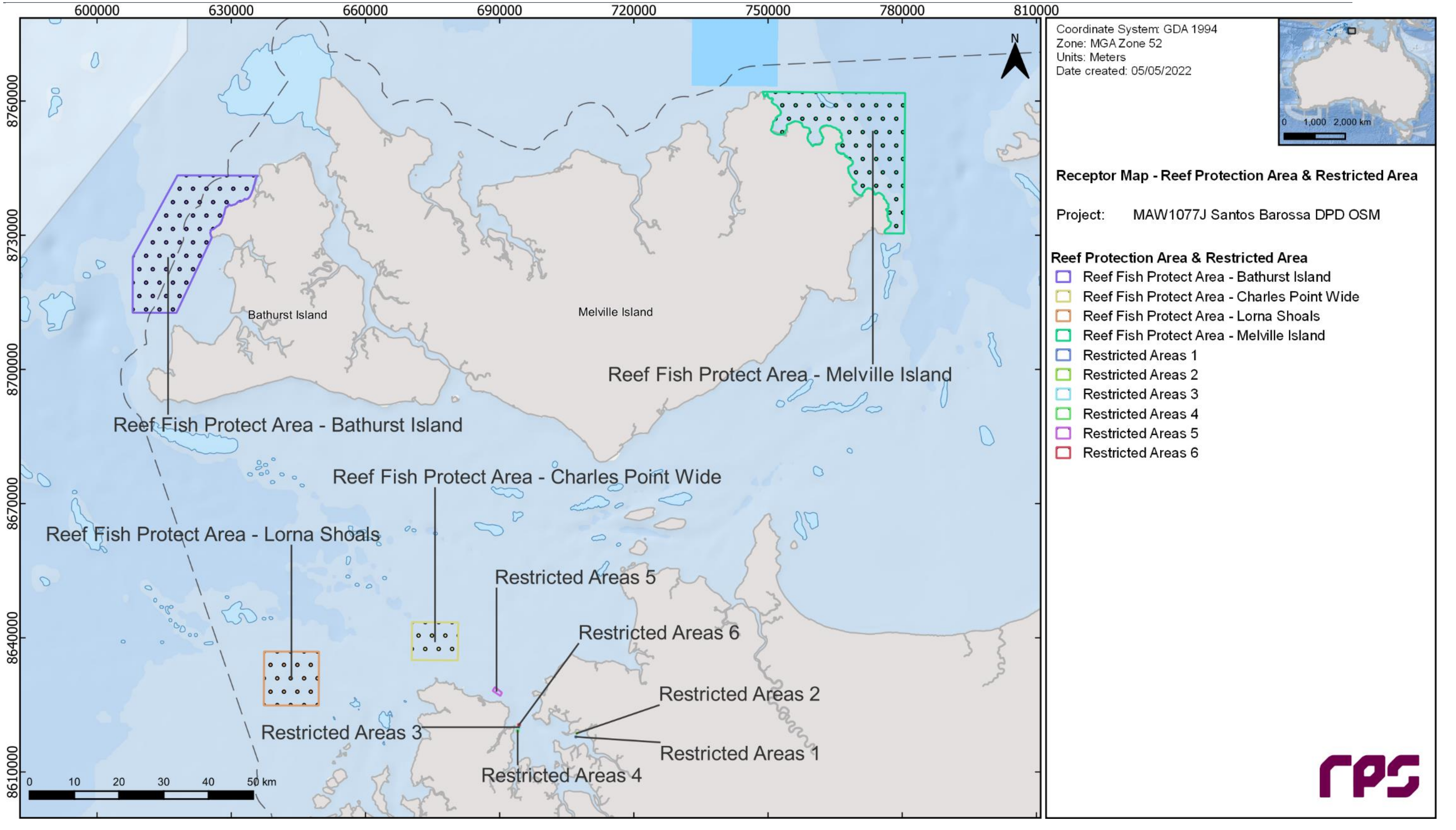

Figure 9.2 Receptor map for the reef fish protection areas (RFPA) and restricted areas.

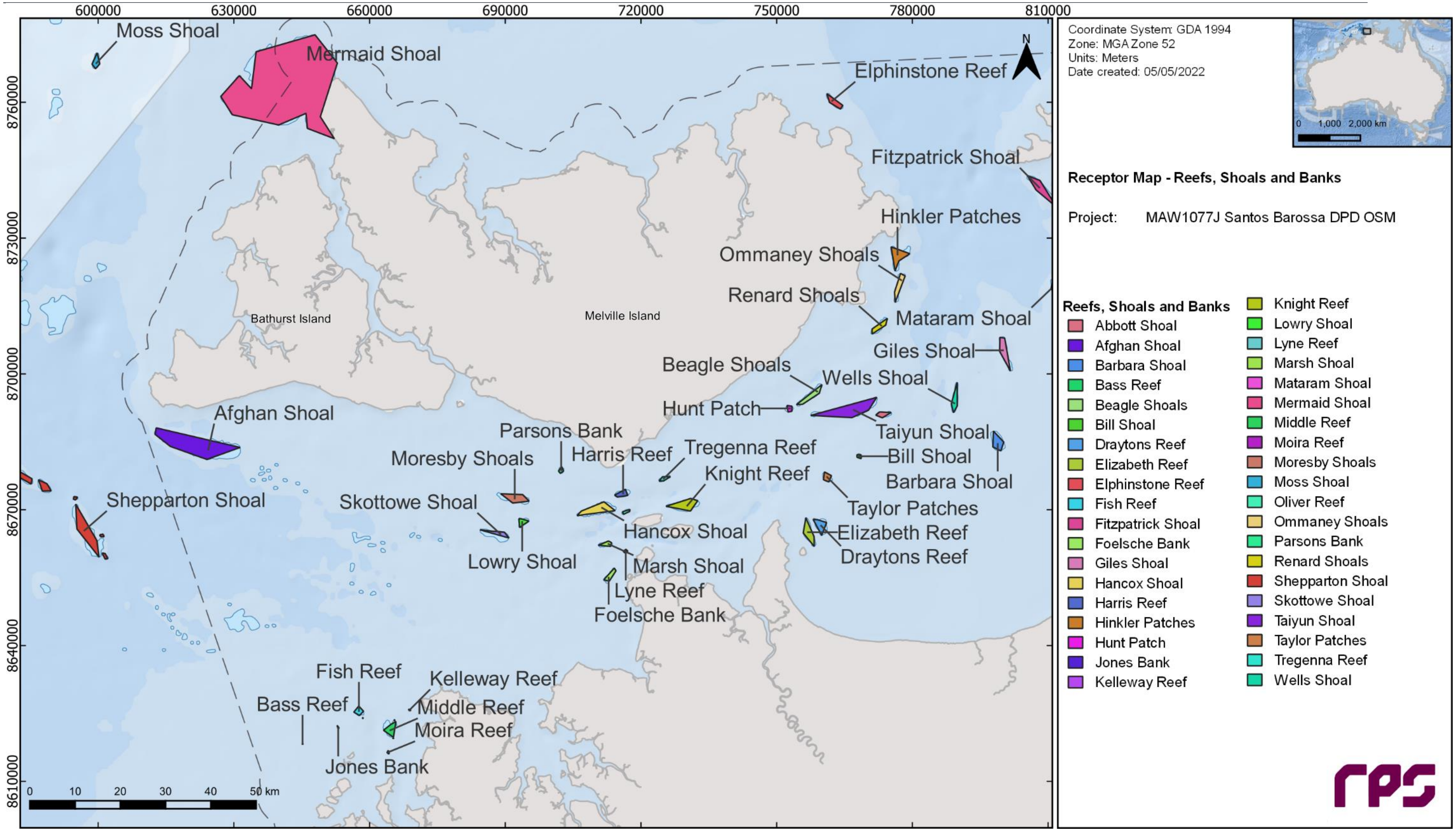

Figure 9.3 Receptor map for the reefs, shoals and banks (RSB).

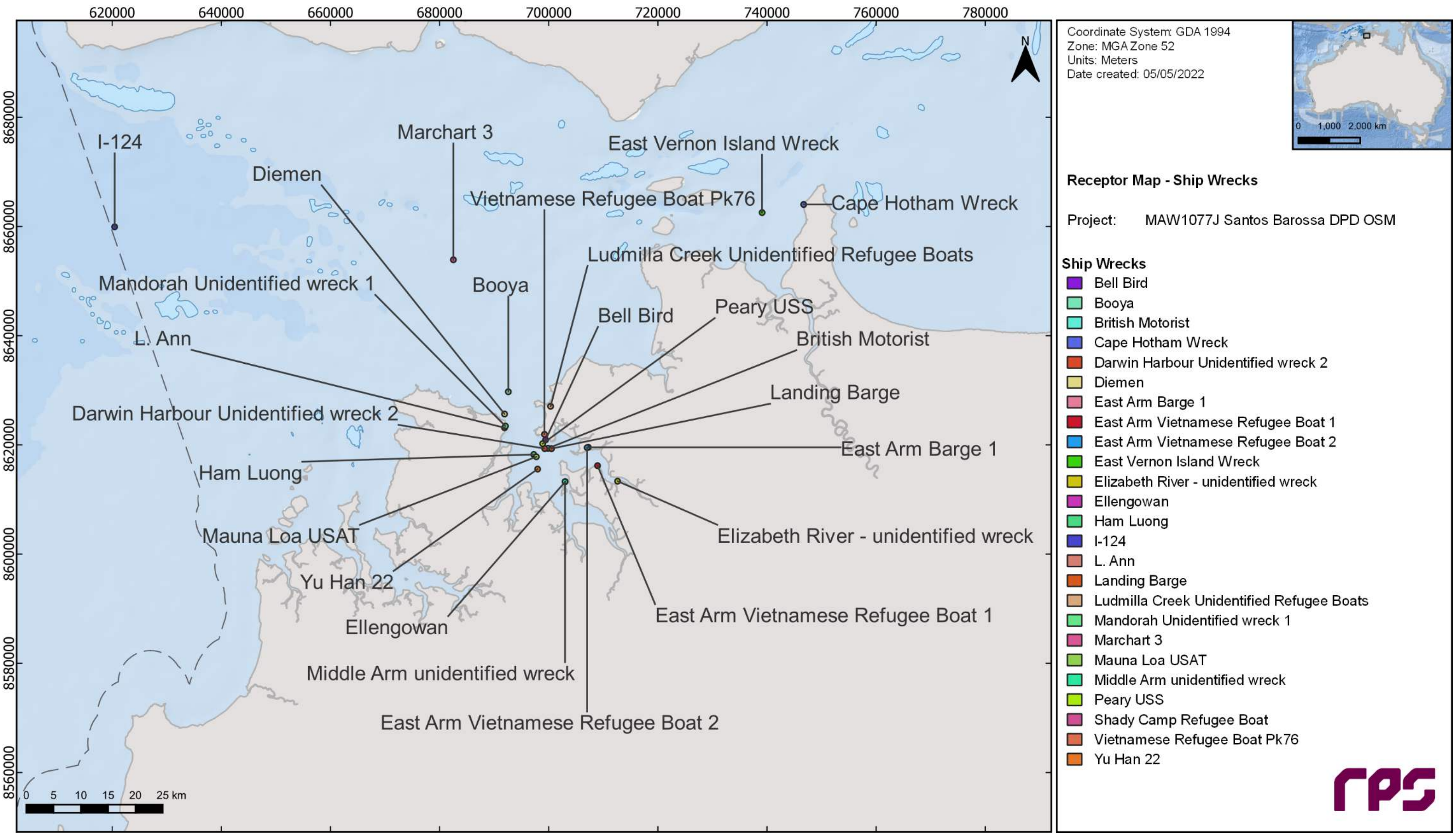

Figure 9.4 Receptor map for the shipwrecks.

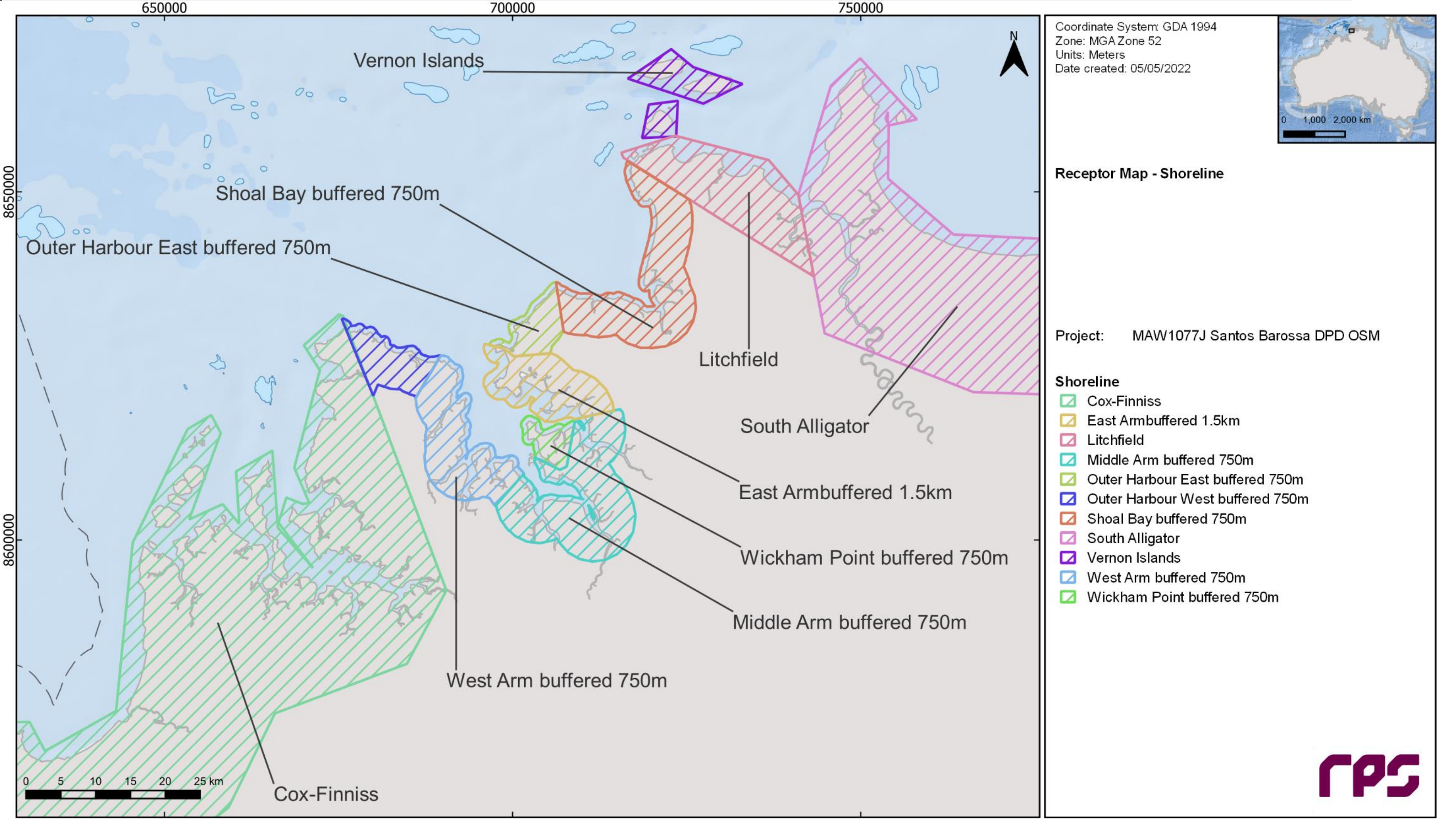

Figure 9.5 Receptor map for the shoreline sections.

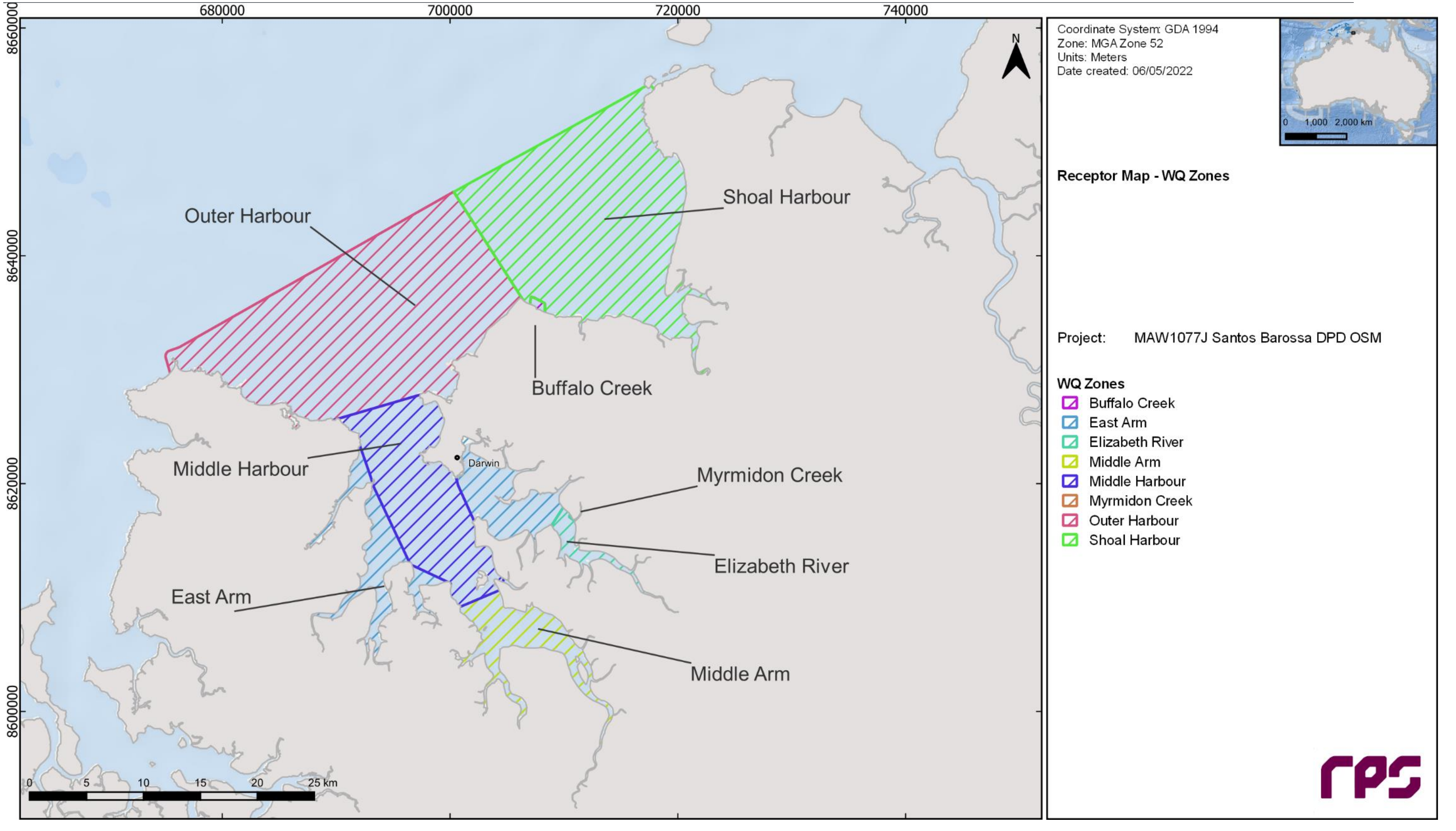

Figure 9.6 Receptor map for the water quality zones (WQ Zones).

10 MODEL SETTINGS

Table 10.1 provides a summary of the oil spill scenarios and model settings used in the assessment. The table also shows the thresholds that were used. The simulation lengths for each scenario were carefully selected based on extensive sensitivity testing. During the sensitivity testing process, sample spill simulations were run for longer than intended durations. Upon completion of the spill simulations, the results were carefully assessed to examine the persistence of the MDO (i.e., whether the maximum evaporative loss has been achieved for the period modelled; and whether a substantial volume of hydrocarbons remain in the water column (if any)) in conjunction with the extent of floating oil exposure based on reporting thresholds. Once there was agreement between the two factors (i.e., the final fate of hydrocarbon is accounted for, and the full exposure area is identified) the simulation length was deemed appropriate.

Table 10.1 Summary of the oil spill scenarios and model settings used in the Barossa DPD oil spill modelling study.

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Description	Offshore pipelay vessel fuel tank rupture	Vessel fuel tank rupture	Vessel to vessel refuelling	Vessel fuel tank rupture
Location Name	KP91.5	KP114	KP114	KP114
Spill volume (m^3)	700	87.5	10	300
Release duration (hours)	6	6	Instantaneous	6
Simulation length (days)	50	20	10	30
Number of randomly selected spill start times per season	100			
Model period	Wet season (November to April) and dry season (May to October).			
Oil type	MDO			
Release type	Surface			
Floating oil exposure thresholds (g/m^2)	1 (low exposure) 10 (moderate exposure) 50 (high exposure)			
Shoreline accumulation thresholds (g/m^2)	10 (low potential exposure) 100 (moderate potential exposure) 1,000 (high potential exposure)			
Dissolved hydrocarbon exposure thresholds (ppb)	10 (10 ppb x 1 hr, potential low exposure) 50 (50 ppb x 1 hr, potential moderate exposure) 400 (400 ppb x 1 hr, potential high exposure)			
Entrained hydrocarbon exposure thresholds (ppb)	10 (10 ppb x 1 hr, potential low exposure) 100 (100 ppb x 1 hr, potential moderate exposure)			

11 CALCULATION OF EXPOSURE RISK

The stochastic sampling approach provides an objective measure of the possible outcomes of a spill because randomly selected environmental conditions with more simulations will tend to use the most commonly occurring conditions, while more unusual conditions will be represented less frequently.

During each simulation, the SIMAP model records the location (by latitude, longitude and depth) of each of the particles (representing a given mass of oil) on or in the water column, at regular time steps. For any particles that contact a shoreline, the model records the accumulation of oil mass that arrives on each section of shoreline over time, less any mass that is lost to evaporation and/or subsequent removal by current and wind forces.

The collective records from all simulations are then analysed by dividing the study region into a three-dimensional grid. For oil particles that are classified as being at the water surface (floating oil), the sum of the mass in all oil particles (including accounting for spreading and dispersion effects) located within a grid cell, divided by the area of the cell provides estimates of the concentration of oil in that grid cell, at each time step. For entrained and dissolved hydrocarbons particles, concentrations are calculated at each time step by summing the mass of particles within a grid cell and dividing by the volume of the grid cell.

The concentrations of oil calculated for each grid cell, at each time step, are then analysed to determine whether concentration estimates exceed defined threshold concentrations over time.

Risks are then summarised as follows:

- The probability of exposure to a location is calculated by dividing the number of spill simulations where any contact occurred above a specified threshold at that location by the total number of replicate spill simulations. For example, if contact occurred at a location (above a specified threshold) during 21 out of 100 simulations, a probability of exposure of 21% is indicated;
- The minimum potential time to a shoreline location is calculated by the shortest time over which oil at a concentration above a threshold was calculated to travel from the source to the location in any of the replicate simulations;
- The maximum potential concentration of oil predicted for each shoreline section is the greatest mass per m^2 of shoreline calculated to strand at any location within that section during any of the replicate simulations; and
- Similar treatments were undertaken for entrained and dissolved hydrocarbon exposures.

Thus, the minimum time to shoreline and the maximum potential concentration estimates indicate the worst potential outcome of the modelled spill scenario for each section of shoreline. However, the average over the replicates presents an average of the potential outcomes, in terms of oil that could strand.

Note also that results quoted for sections of shoreline are derived for any individual location within that section, as a conservative estimate. Locations will represent shoreline lengths of the order of ~1 km for Scenario 1 and 0.5 km for Scenario 2 & 3, while sections or regions will represent shorelines spanning tens to hundreds of kilometres. The maximum potential concentrations quoted will not necessarily occur over the full extent of each section, therefore multiplying the maximum concentration estimates by the full area of the section is not recommended as this will greatly overestimate the total volume expected on that section.

12 SCENARIO 1 RESULTS – OFFSHORE PIPELAY VESSEL FUEL TANK RUPTURE AT KP91.5

This scenario examined the potential exposure following a 700 m^3 surface release of MDO over 6 hours in the event of an offshore pipelay vessel fuel tank rupture at KP91.5. A total of 200 spill trajectories were simulated (i.e., 100 spills per season) and tracked for 50 days.

Section 12.1 presents the low threshold environment that may be affected (EMBA), resulting from the 200 spill simulations. Section 12.2 shows the seasonal (or stochastic) analysis, while Section 12.3 presents in more detail the results for the simulation resulting in the largest volume of oil ashore.

12.1 EMBA

Figure 12.1 shows the full geographic EMBA derived by overlaying the results from all 200 spill simulations at the low (≥1 g/m^2) exposure thresholds.

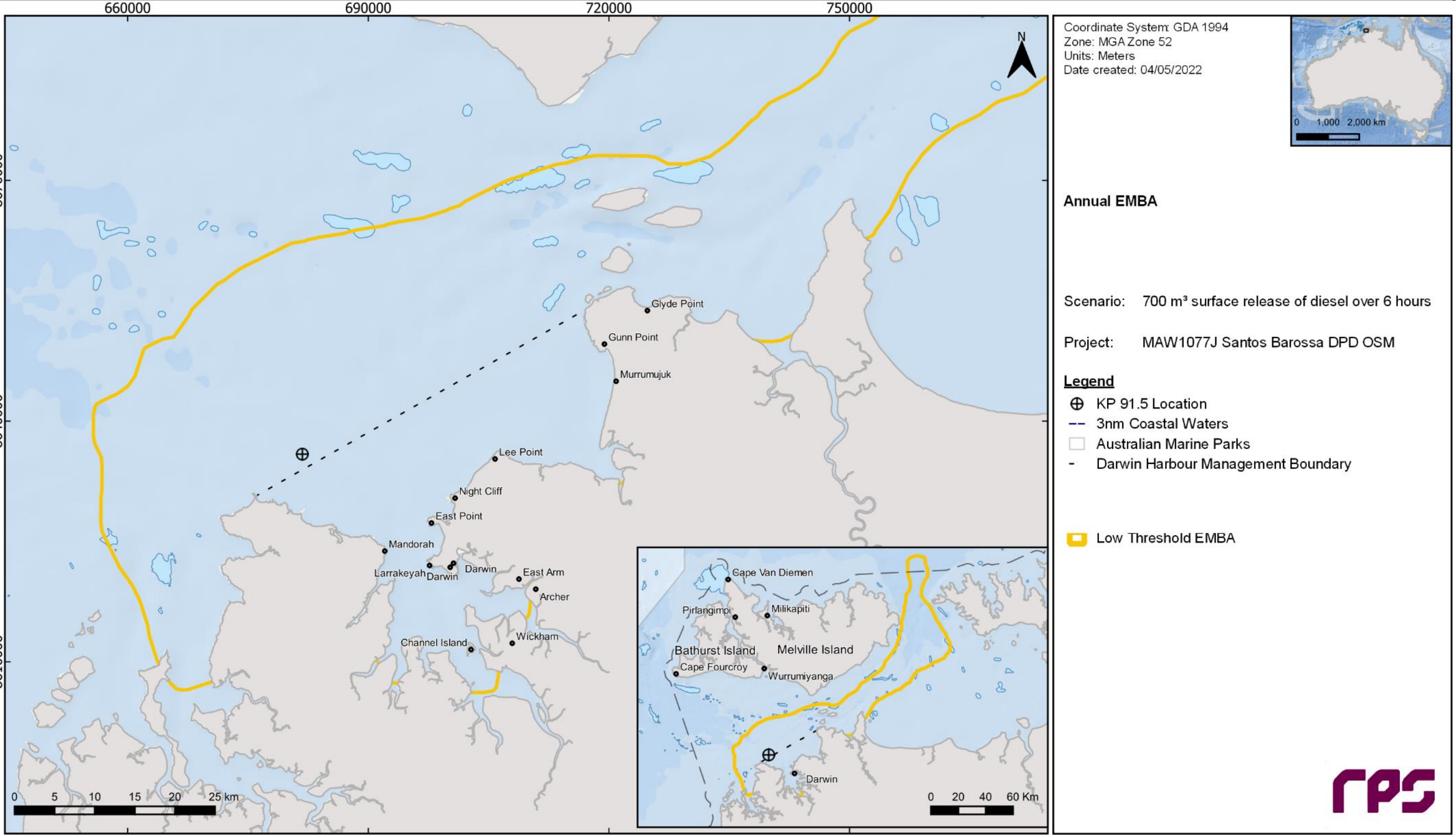

Figure 12.1 **Predicted low threshold risk EMBA from an offshore pipelay vessel fuel tank rupture at KP91.5. The annualised results were calculated from 200 spill simulations.**

12.2 Stochastic Analysis

12.2.1 Floating Oil Exposure

Table 12.1 summarises the maximum distances and directions travelled by the floating oil from the release location at each threshold for each season. The maximum distances to the low (≥1 g/m^2), moderate (≥10 g/m^2) and high (≥ 50 g/m^2) exposure zones were 26.4 km (southeast), 19.9 km (southeast) and 14 km (west northwest), occurring during dry season conditions. Table 12.2 summarises the potential floating oil exposure to individual receptors for each season and Figure 12.2 to Figure 12.3 illustrate the extent of floating oil exposure for each season.

Given that the release location was 1.11 km east of Charles Point Wide RFPA and 0.65 km north of the Outer Harbour WQ Zone, the probability of oil exposure was greatest for these receptors (100% at the low threshold for both seasons) and would take 1 hour for a spill to reach the boundaries of the receptors.

Otherwise, floating oil exposure at the low and moderate thresholds were predicted at Restricted Area 5 and Middle Harbour WQ Zone with all probabilities ≤10% (see Table 12.2).

Table 12.1 Maximum distances and directions travelled by floating oil from an offshore pipelay vessel fuel tank rupture at KP91.5 for each season. Results were calculated from 100 spill simulations per season.

Season	Distance and direction travelled	Zones of potential floating oil exposure		
		Low	Moderate	High
Dry	Maximum distance (km) from release location	26.4	19.9	14.0
	Maximum distance (km) from the release location (99th percentile)	23.5	17.5	13.8
	Direction	SE	SE	WNW
Wet	Maximum distance (km) from release location	24.9	19.3	12.4
	Maximum distance (km) from release location (99th percentile)	20.6	18.0	12.2
	Direction	SE	WNW	SE

Table 12.2 Summary of the potential exposure by floating oil to individual receptors from an offshore pipelay vessel fuel tank rupture at KP91.5 for each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry						Wet					
		Probability of floating oil exposure (%)			Minimum time before floating oil exposure (days)			Probability of floating oil exposure (%)			Minimum time before floating oil exposure (days)		
		Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
RFPA	Charles Point Wide	100	90	38	0.04	0.04	0.13	97	82	27	0.04	0.04	0.08
Restricted Area	5	3	1	-	0.54	1.50	-	2	-	-	0.67	-	-
WQ Zones	East Arm	-	-	-	-	-	-	1	-	-	1.38	-	-
	Middle Harbour	6	2	-	0.29	0.29	-	10	1	-	0.17	0.29	-
	Outer Harbour	100	92	35	0.04	0.04	0.08	100	92	31	0.04	0.04	0.13

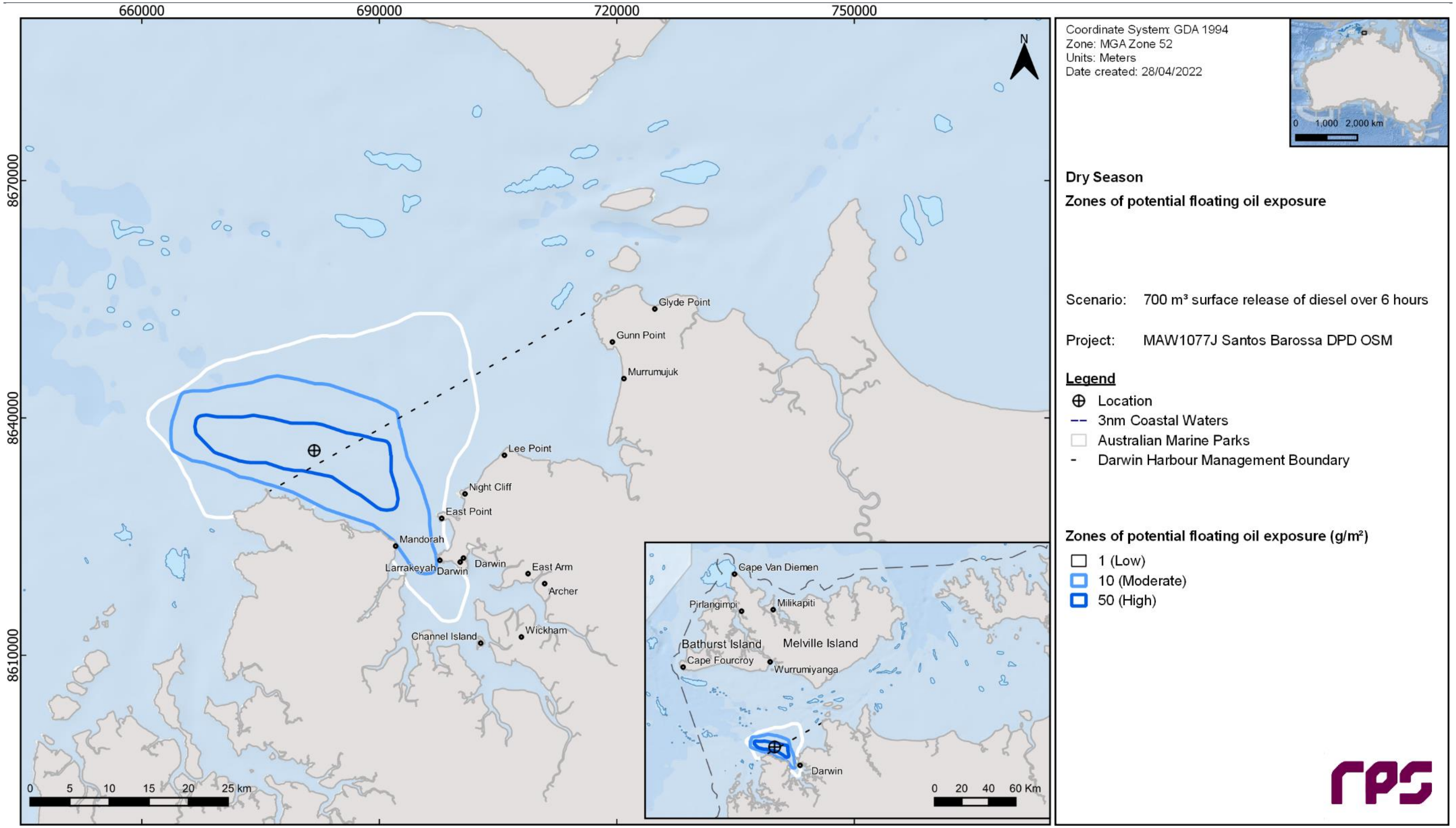

Figure 12.2 Zones of potential floating oil exposure from an offshore pipelay vessel fuel tank rupture at KP91.5 during dry season conditions. The results were calculated from 100 spill simulations.

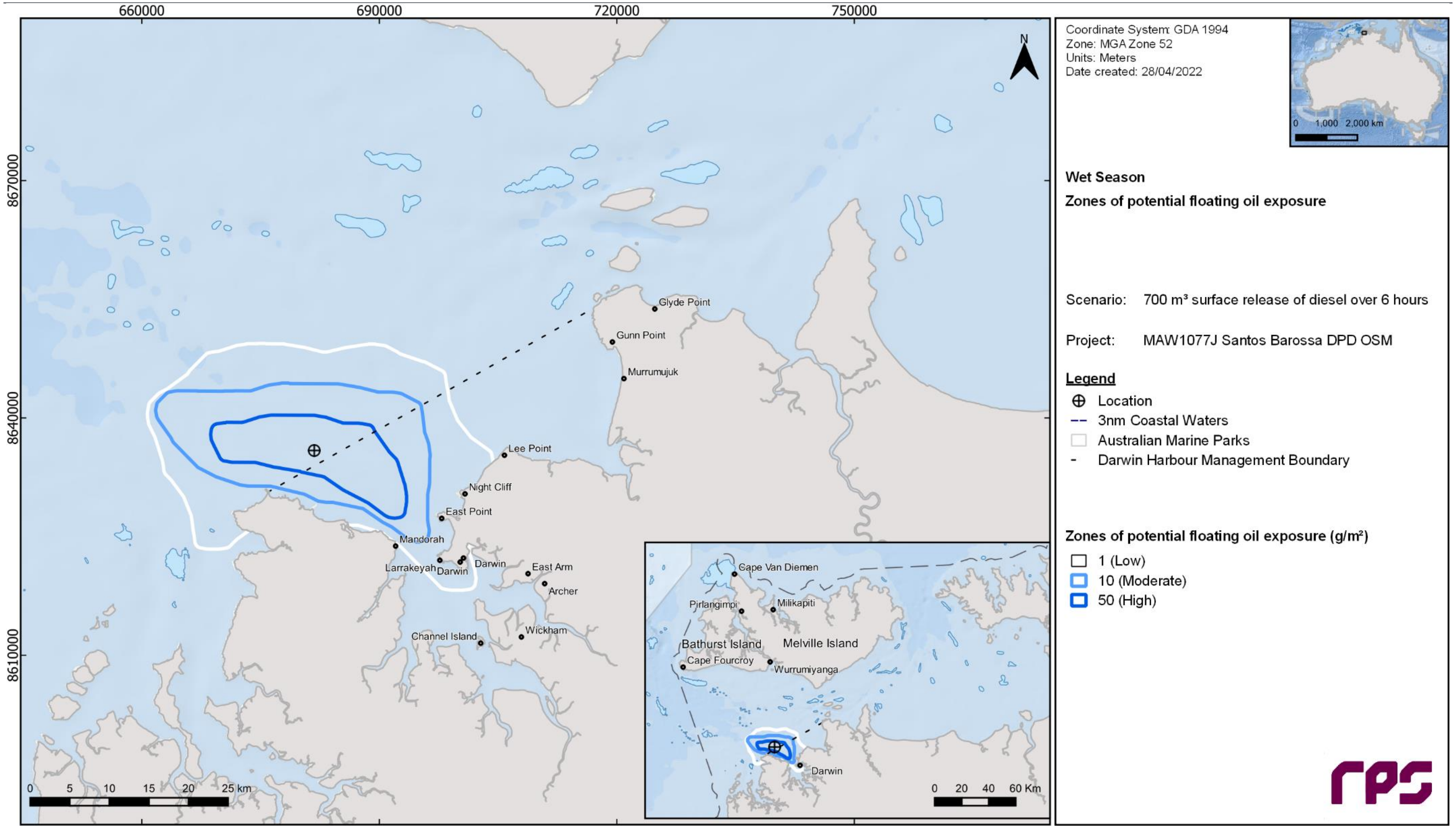

Figure 12.3 Zones of potential floating oil exposure from an offshore pipelay vessel fuel tank rupture at KP91.5 during wet season conditions. The results were calculated from 100 spill simulations.

12.2.2 Shoreline Accumulation

Table 12.3 summarises the predicted oil accumulation on any shoreline during each season. The probability of oil accumulation at, or above, the low threshold (10 g/m^2) was 25% (dry season) and 50% (wet season). The minimum time before oil accumulation at, or above, the low threshold ranged between 1.5 days (dry season) and 0.96 days (wet season). The maximum volume ashore for a single spill ranged between 28.1 m^3 (dry season) and 59.7 m^3 (wet season) and the maximum length of shoreline contacted at the low threshold was 23.1 km (dry season) and 22.1 km wet season). The maximum lengths of oil accumulation on shorelines at, or above, the moderate (100 – 1,000 g/m^2) and high (≥1,000 g/m^2) thresholds was 12 km and 2 km, respectively, during the wet season.

Table 12.4 and Table 12.5 summarise the oil accumulation on individual shoreline receptors for each season. The maximum potential shoreline loading for the specified thresholds for each season are presented in Figure 12.4 and Figure 12.5.

The greatest probabilities of oil accumulation at, or above, the low threshold was predicted for the East Arm (16% dry and 33% wet conditions), Outer Harbour East (4% dry and 20% wet seasons) and Outer Harbour West (9% dry and 10% wet seasons). The greatest volume (peak) of oil accumulation during the dry and wet seasons was predicted occurred along Outer Harbour West (22.2 m^3) and Outer Harbour East shorelines (43.8 m^3), respectively. The minimum time before oil accumulation at the low threshold was 1.50 days (Outer Harbour West) during the dry season and 0.96 days (Cox-Finniss) during the wet season conditions.

Table 12.3 Summary of oil accumulation on any shoreline from an offshore pipelay vessel fuel tank rupture at KP91.5 during each season. Results were calculated from 100 spill simulations per season.

Shoreline Statistics	Dry			Wet		
	Low	**Moderate**	**High**	**Low**	**Moderate**	**High**
Probability of accumulation on any shoreline (%)	25	3	-	50	12	1
Absolute minimum time before oil ashore (days)	1.50	1.96	-	0.96	1.29	3.54
Maximum length of shoreline contacted (km)	23.1	7.0	-	22.1	12.0	2.0
Average length of shoreline contacted (km)	6.6	3.0	-	6.8	4.9	2.0
		Dry			**Wet**	
Maximum volume of hydrocarbons ashore (m^3)		28.1			59.7	
Average volume of hydrocarbons ashore (m^3)		1.3			3.2	

Table 12.4 Summary of oil accumulation on individual shoreline sectors from an offshore pipelay vessel fuel tank rupture at KP91.5 for the dry season. Results were calculated from 100 spill simulations per season.

Shoreline sector	Maximum probability of shoreline loading (%)			Minimum time before shoreline accumulation (days)			Load on shoreline (g/m^2)		Volume on shoreline (m^3)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Low	Moderate	High	Low	Moderate	High	Mean	Peak	Mean	Peak	Low	Moderate	High	Low	Moderate	High
Cox-Finniss	4	1	-	1.92	2.50	-	1	194	0.1	6.3	6.0	2.0	-	8.0	2.0	-
East Arm	16	-	-	1.79	-	-	3	89	0.2	3	2.8	-	-	6.0	-	-
Middle Arm	2	-	-	4.50	-	-	<1	15	<0.1	0.3	1.0	-	-	1.0	-	-
Outer Harbour East	4	-	-	7.29	-	-	2	36	0.1	2.5	5.2	-	-	9.0	-	-
Outer Harbour West	9	2	-	1.50	1.96	-	5	680	0.3	22.2	3.2	3.0	-	10.0	5.0	-
Shoal Bay	2	-	-	13.13	-	-	<1	18	<0.1	1.8	3.0	-	-	5.0	-	-
Vernon Islands	8	-	-	7.71	-	-	1	27	<0.1	0.8	1.5	-	-	2.0	-	-
West Arm	6	1	-	2.58	3.58	-	1	113	0.2	7	4.2	1.0	-	12.0	1.0	-

Table 12.5 Summary of oil accumulation on individual shoreline sectors from an offshore pipelay vessel fuel tank rupture at KP91.5 for the wet season. Results were calculated from 100 spill simulations per season.

Shoreline sector	Maximum probability of shoreline loading (%)			Minimum time before shoreline accumulation (days)			Load on shoreline (g/m^2)		Volume on shoreline (m^3)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Low	Moderate	High	Low	Moderate	High	Mean	Peak	Mean	Peak	Low	Moderate	High	Low	Moderate	High
Cox-Finniss	5	1	-	0.96	1.83	-	2	298	0.2	8.1	8.2	1.0	-	18.0	1.0	-
East Arm	33	9	1	1.25	1.46	3.63	8	1,050	0.9	16	3.3	2.1	1	8.0	5.0	1.0
Middle Arm	-	-	-	-	-	-	<1	6	<0.1	0.3	-	-	-	-	-	-
Outer Harbour East	20	6	1	1.71	2.25	3.54	10	1,116	1.3	43.8	5.4	4.5	1	12.0	8.0	1.0
Outer Harbour West	10	3	-	1	1.29	-	6	399	0.4	16.9	4.7	4.0	-	11.0	5.0	-
Shoal Bay	2	-	-	9.46	-	-	<1	22	<0.1	1.6	2.5	-	-	3.0	-	-
Vernon Islands	9	-	-	9.13	-	-	2	76	<0.1	1.8	1.8	-	-	3.0	-	-
West Arm	5	-	-	3.46	-	-	1	50	<0.1	1.8	2.6	-	-	7.0	-	-

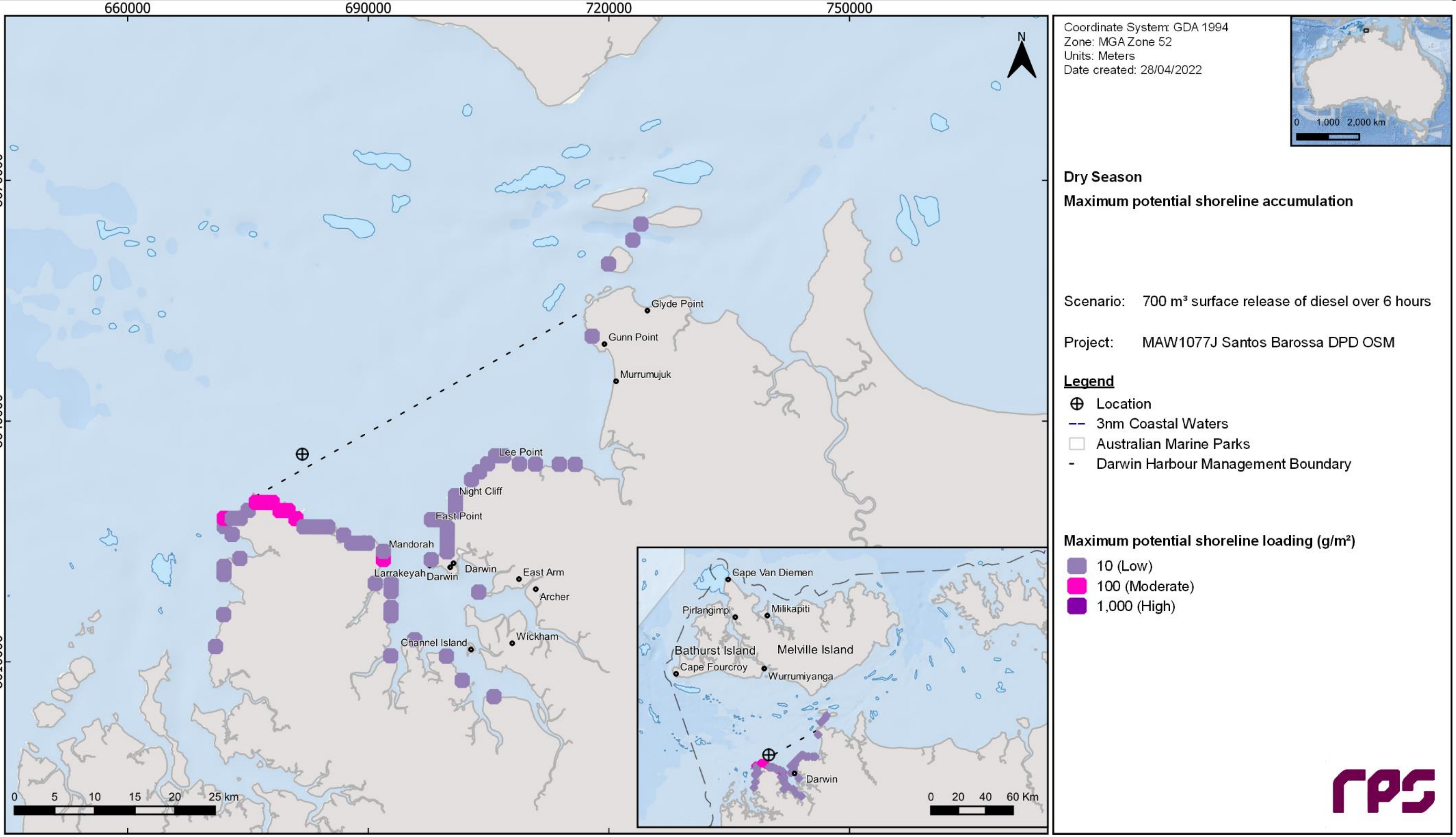

Figure 12.4 Maximum potential shoreline loading from an offshore pipelay vessel fuel tank rupture at KP91.5 during dry season conditions. The results were calculated from 100 spill simulations.

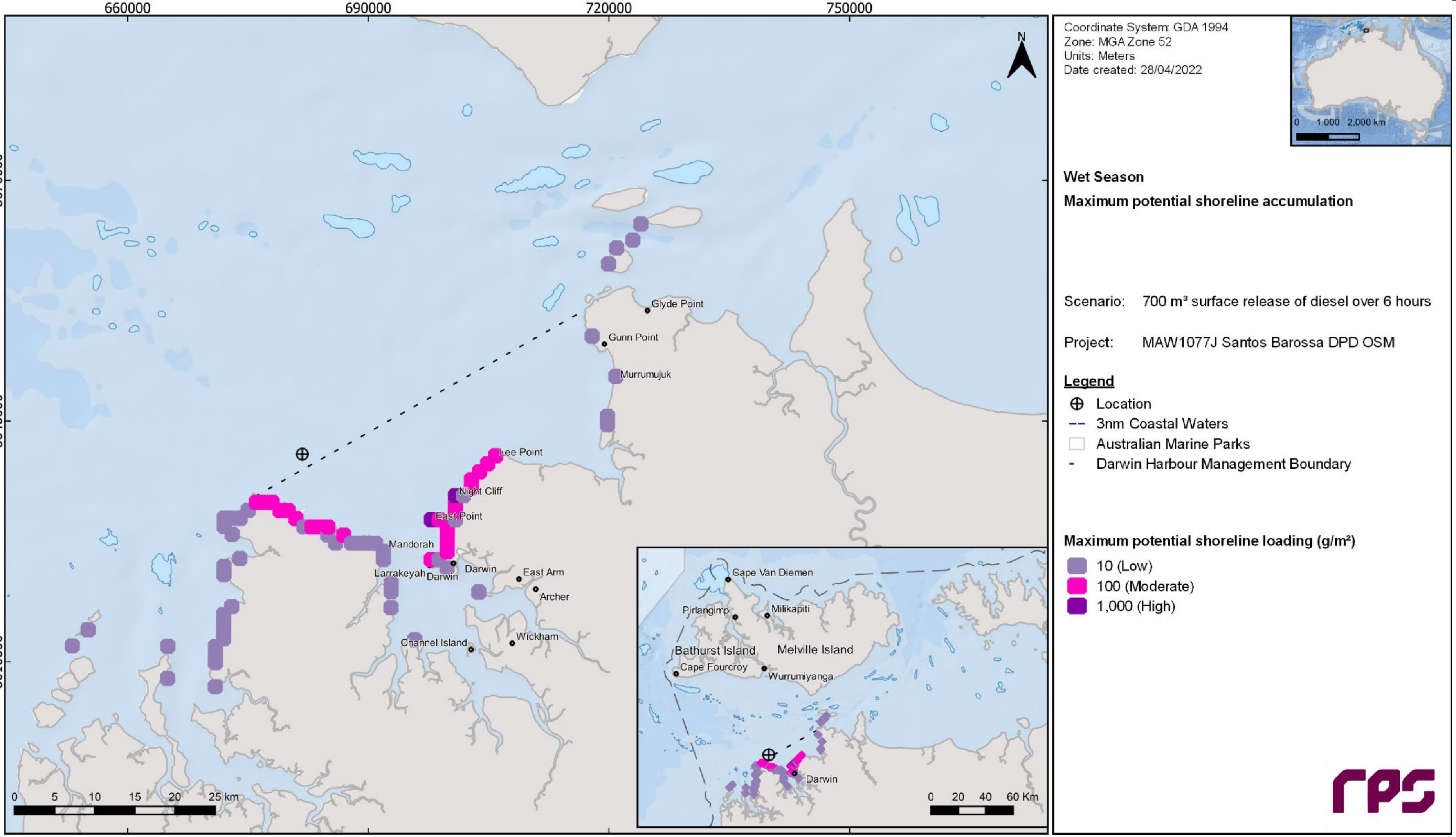

Figure 12.5 Maximum potential shoreline loading from an offshore pipelay vessel fuel tank rupture at KP91.5 during wet season conditions. The results were calculated from 100 spill simulations.

12.2.3 In-water exposure

12.2.3.1 Dissolved Hydrocarbons

Table 12.6 summarises the maximum distances and directions travelled by dissolved hydrocarbons from the release location to each threshold in the 0 – 10 m depth layer. The maximum distances to the low (≥ 10 ppb) and moderate (≥ 50 ppb) exposure zones were 16.9 km (west) and 13.7 km (southeast), respectively. There was no exposure predicted for either season at the high threshold (≥ 400 ppb).

Table 12.7 and Table 12.8 summarise the potential exposure to receptors from dissolved hydrocarbons in the 0 – 10 m and 10 – 20 m depth layers, respectively, for each threshold and season. Figure 12.6 to Figure 12.9 illustrate the extents of dissolved hydrocarbon exposure for each season in the 0 – 10 m and 10 – 20 m depth layers.

Four receptors (Charles Point Wide RFPA, Booya shipwreck, Middle Harbour and Outer Harbour WQ Zones) were predicted to be exposed to dissolved hydrocarbons at the low threshold in the 0 – 10 m depth during the dry and wet seasons with probabilities ranging from 1% to 40%. The maximum instantaneous concentrations were 97 ppb predicted at Charles Point Wide RFPA during the dry season and 91 ppb within the Outer Harbour WQ Zone during the wet season.

In comparison, within the 10 – 20 m depth layer only two receptors were predicted to be exposed to dissolved hydrocarbons at the low threshold (Charles Point Wide RFPA (dry and wet seasons) and the Outer Harbour WQ Zone (wet season)) and probabilities of 1% (meaning 1 simulation out of 100 had triggered the exposure).

Table 12.6 Maximum distances and directions travelled by dissolved hydrocarbons (0 – 10 m depth layer) from an offshore pipelay vessel fuel tank rupture at KP91.5 during each season. Results were calculated from 100 spill simulations per season.

Season	Distance and direction travelled	Zones of potential dissolved hydrocarbon exposure		
		Low 10 ppb	Moderate 50 ppb	High 400 ppb
Dry	Maximum distance (km) from the release location	16.9	10.0	-
	Maximum distance (km) from the release location (99th percentile)	16.5	9.6	-
	Direction	W	ESE	-
Wet	Maximum distance (km) from the release location	15.8	13.7	-
	Maximum distance (km) from the release location (99th percentile)	15.2	13.5	-
	Direction	W	SE	-

Table 12.7 Summary of dissolved hydrocarbon exposure for each receptor in the 0 – 10 m depth layer for an offshore pipelay vessel fuel tank rupture at KP91.5 during each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry							Wet						
		Maximum instantaneous concentration (ppb)	Probability of instantaneous dissolved hydrocarbon exposure			Minimum time (days) before instantaneous dissolved hydrocarbon exposure			Maximum instantaneous concentration (ppb)	Probability of instantaneous dissolved hydrocarbon exposure			Minimum time (days) before instantaneous dissolved hydrocarbon exposure		
			Low	Moderate	High	Low	Moderate	High		Low	Moderate	High	Low	Moderate	High
RFPA	Charles Point Wide	97	33	4	-	0.08	0.13	-	75	33	2	-	0.04	0.13	-
Shipwrecks	Booya	10	1	-	-	0.38	-	-	38	7	-	-	0.29	-	-
WQ Zones	Middle Harbour	23	2	-	-	0.33	-	-	25	1	-	-	0.42	-	-
	Outer Harbour	94	28	6	-	0.04	0.13	-	91	40	4	-	0.04	0.13	-

Table 12.8 Summary of dissolved hydrocarbon exposure for each receptor in the 10 – 20 m depth layer for an offshore pipelay vessel fuel tank rupture at KP91.5 during each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry							Wet						
		Maximum instantaneous concentration (ppb)	Probability of instantaneous dissolved hydrocarbon exposure			Minimum time (days) before instantaneous dissolved hydrocarbon exposure			Maximum instantaneous concentration (ppb)	Probability of instantaneous dissolved hydrocarbon exposure			Minimum time (days) before instantaneous dissolved hydrocarbon exposure		
			Low	Moderate	High	Low	Moderate	High		Low	Moderate	High	Low	Moderate	High
RFPA	Charles Point Wide	10	1	-	-	0.08	0.13	-	25	1	-	-	0.04	0.13	-
WQ Zones	Outer Harbour	7	-	-	-	0.04	0.13	-	38	1	-	-	0.04	0.13	-

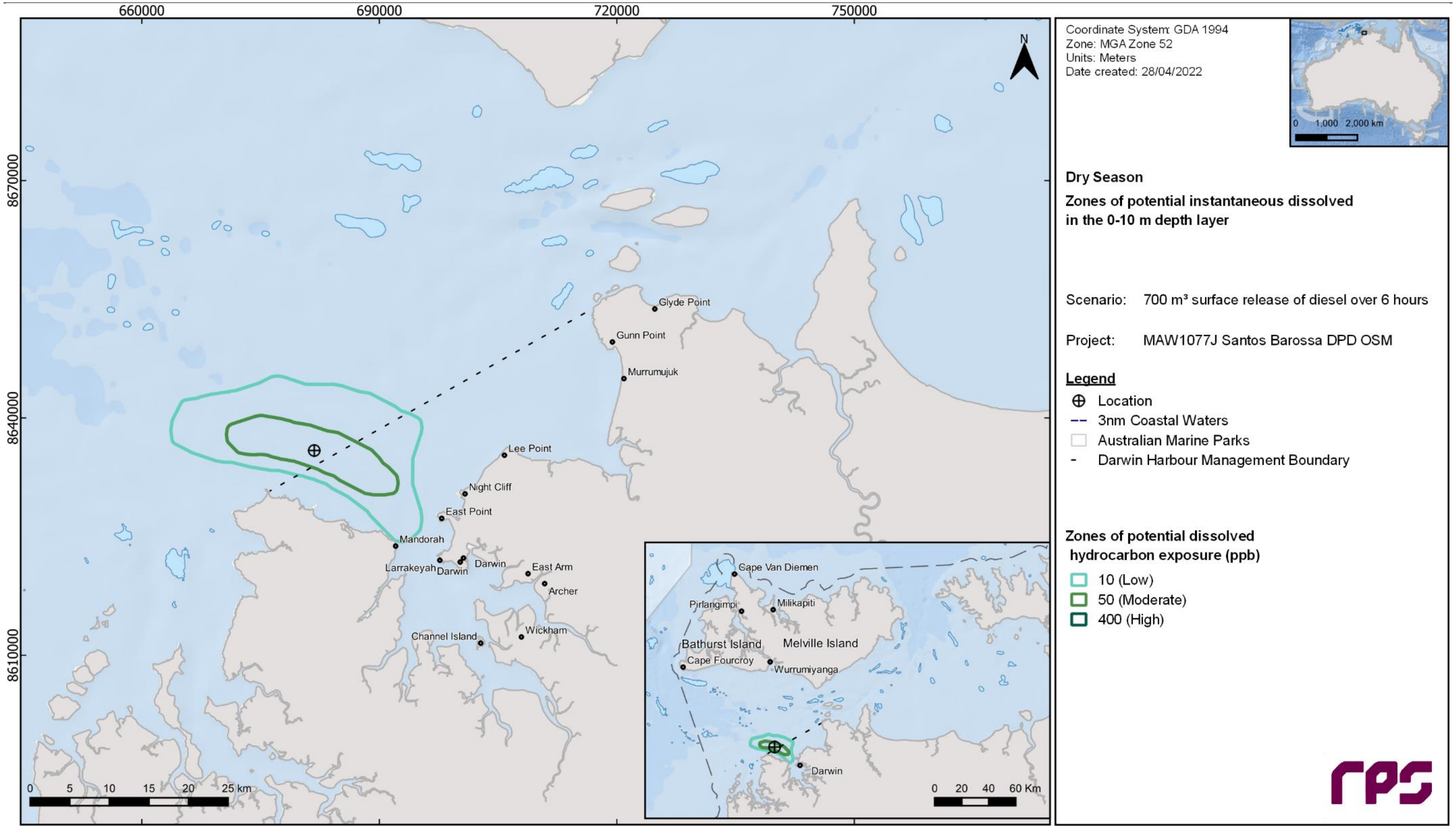

Figure 12.6 Zones of potential dissolved hydrocarbon exposure at 0 – 10 m below the sea surface from an offshore pipelay vessel fuel tank rupture at KP91.5 during dry season conditions. The results were calculated from 100 spill simulations.

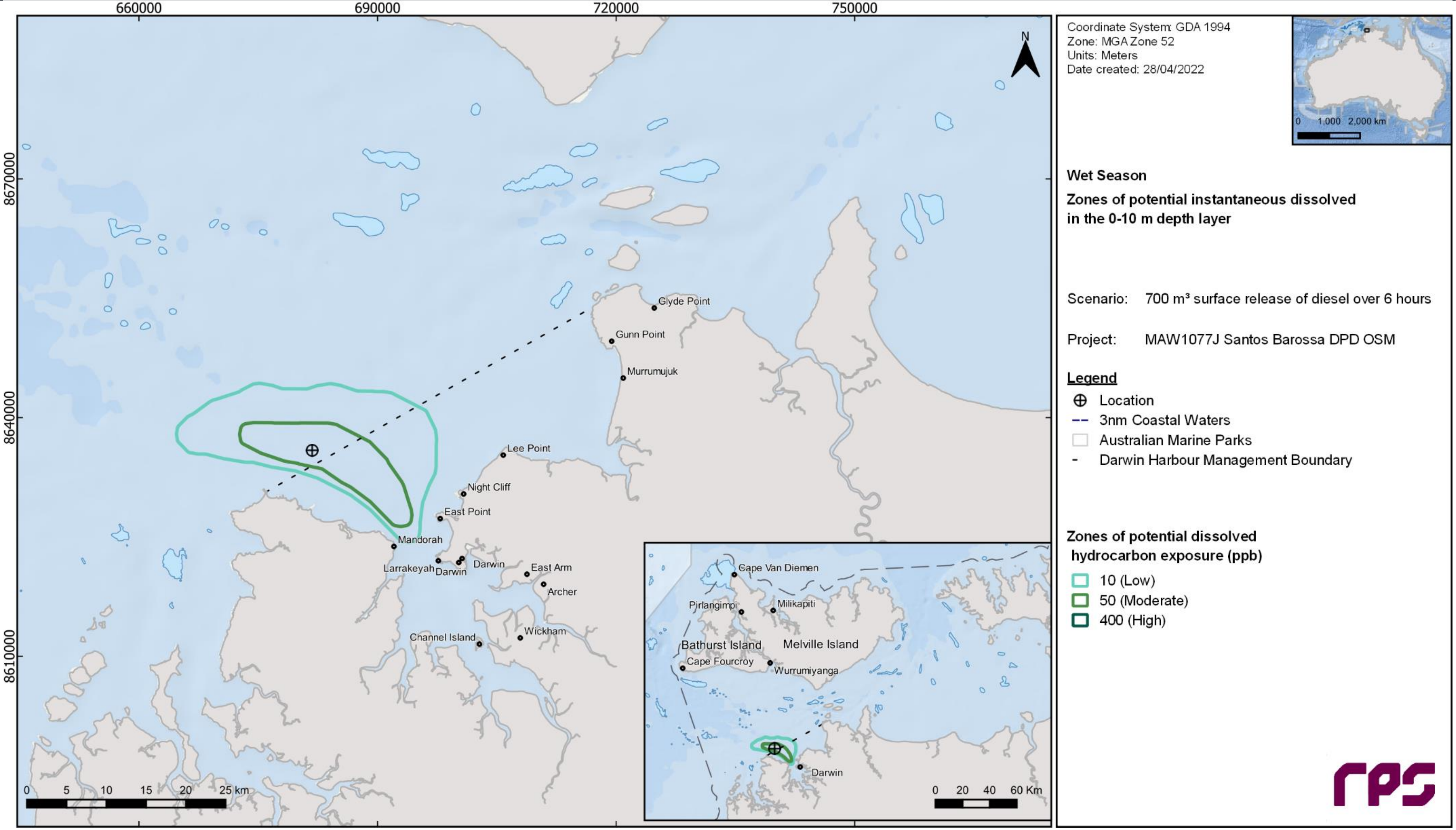

Figure 12.7 Zones of potential dissolved hydrocarbon exposure at 0 – 10 m below the sea surface from an offshore pipelay vessel fuel tank rupture at KP91.5 during wet season conditions. The results were calculated from 100 spill simulations.

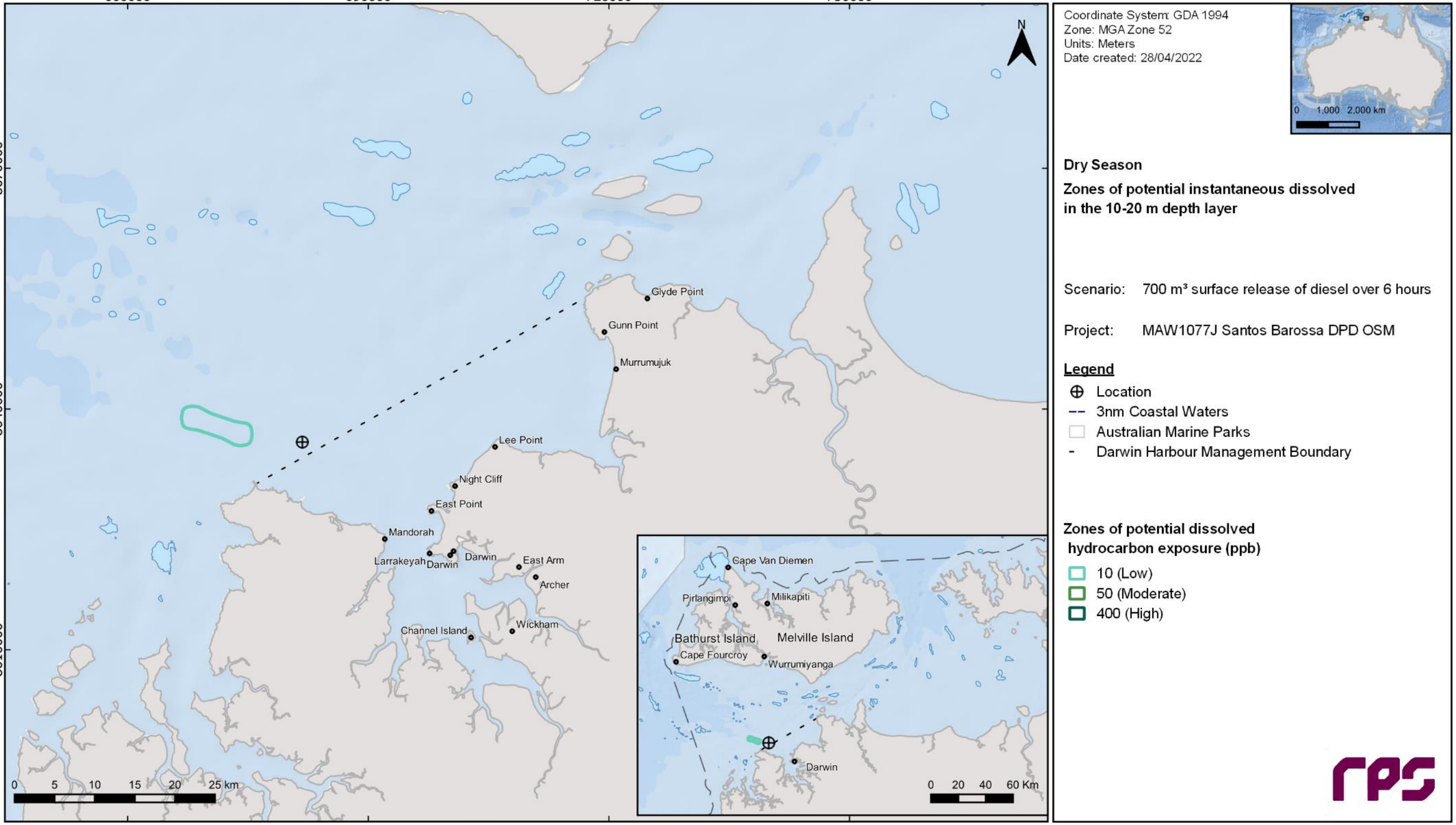

Figure 12.8 Zones of potential dissolved hydrocarbon exposure at 10 – 20 m below the sea surface from an offshore pipelay vessel fuel tank rupture at KP91.5 during dry season conditions. The results were calculated from 100 spill simulations.

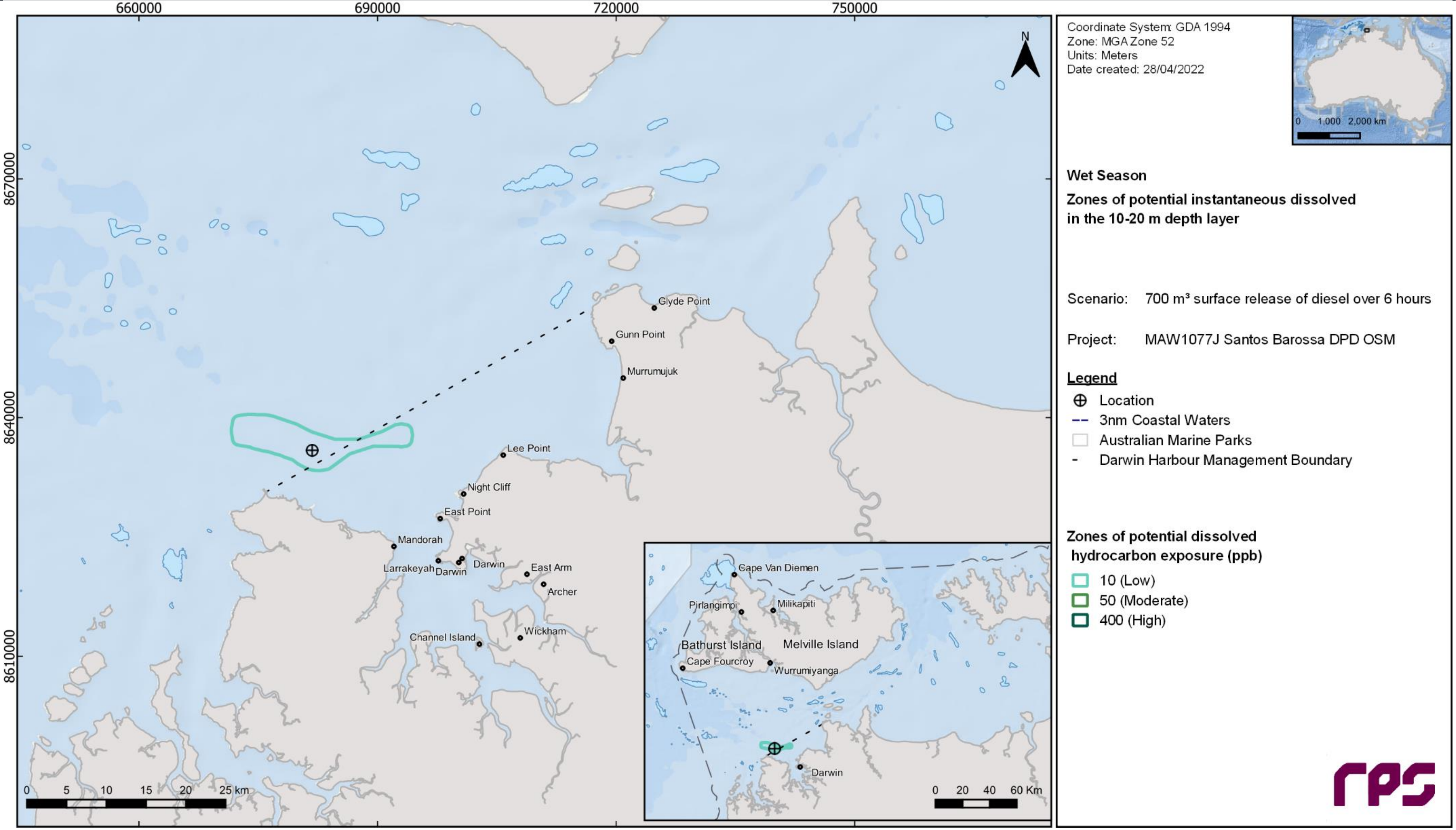

Figure 12.9 Zones of potential dissolved hydrocarbon exposure at 10 – 20 m below the sea surface from an offshore pipelay vessel fuel tank rupture at KP91.5 during wet season conditions. The results were calculated from 100 spill simulations.

12.2.3.2 Entrained Hydrocarbons

Table 12.9 summarises the maximum distances and directions travelled by entrained hydrocarbons within the 0 – 10 m depth layer at the low (≥ 10 ppb) and moderate (≥ 100 ppb) thresholds, which ranged between 182.3 km northeast (wet conditions) and 51.3 km east northeast (wet conditions) from the release location, respectively.

Table 12.10 and Table 12.11 summarise the potential exposure to receptors from entrained hydrocarbons in the 0 – 10 m and 10 – 20 m depth layers, respectively, for each season. Figure 12.10 to Figure 12.13 illustrate extent of entrained hydrocarbon exposure for each season in the 0 – 10m and 10 – 20 m depth layers.

Given that the proximity of the release location to Charles Point Wide RFPA (1.11 km east) and Outer Harbour WQ Zone (0.65 km north), the probability of exposure was greatest for these receptors (100% at the low threshold for both seasons) and would take 1 hour for a spill to reach the boundaries of the receptors.

During the dry and wet seasons 5 and 10 RSBs, respectively, were predicted to be exposed to entrained hydrocarbons at the low threshold with probabilities ranging from 1 – 28% during the two seasons. During both seasons the Foelsche Bank was predicted to have the greatest probability of low exposure threshold (28% dry season wet season). It was also the only RSB to be exposed at the moderate threshold, with a 1% probability and took up to 6.46 days before exposure.

In addition, low entrained hydrocarbon exposure was predicted at 9 and 11 shipwreck receptors during the dry and wet season, respectively, with probabilities ranging from 23% (Marchart 3) and 100% (Booya) during the dry season, and 2% (Marchart 3) and 98% (Booya) during the wet season.

Furthermore, 6 and 7 WQ Zones for the dry and wet season conditions were predicted to be exposed to entrained hydrocarbons at the low threshold. The probabilities ranged from 42% (Buffalo Creek) and 100% (Middle Harbour) during the dry season and 25% (Middle Arm) and 98% (Middle Harbour) during the wet season. The maximum entrained hydrocarbon concentrations were also predicted at Outer Harbour during both the dry (8,733 ppb) and wet (8,974 ppb) seasons.

In comparison, in the 10 – 20 m depth layer only Charles Point Wide RFPA and the Outer Harbour WQ Zone were predicted to be exposed to hydrocarbons at the low threshold during the two seasons. Exposure at the high threshold was predicted within Charles Point Wide RFPA and the probability was 6%.

Table 12.9 Maximum distances and directions travelled by entrained hydrocarbons (0 – 10 m depth layer) from an offshore pipelay vessel fuel tank rupture at KP91.5 during each season. Results were calculated from 100 spill simulations per season.

Season	Distance and direction travelled	Zones of potential entrained hydrocarbon exposure	
		Low 10 ppb	Moderate 100 ppb
Dry	Maximum distance (km) from release location	147.7	36.9
	Maximum distance (km) from release location (99th percentile)	142.1	34.5
	Direction	NE	ENE
Wet	Maximum distance (km) from release location	182.3	51.3
	Maximum distance (km) from release location (99th percentile)	174.7	48.7
	Direction	NE	ENE

Table 12.10 Probability of entrained hydrocarbons exposure to receptors in the 0 – 10 m depth layer for an offshore pipelay vessel fuel tank rupture at KP91.5 during each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry					Wet				
		Maximum concentration (ppb)	Probability (%) of instantaneous entrained hydrocarbon exposure		Minimum time (days) before instantaneous entrained hydrocarbon exposure		Maximum concentration (ppb)	Probability (%) of instantaneous entrained hydrocarbon exposure		Minimum time (days) before instantaneous entrained hydrocarbon exposure	
			Low	Mod	Low	Mod		Low	Mod	Low	Mod
RSB	Abbott Shoal	6	-	-	-	-	15	4	-	12.08	-
	Foelsche Bank	109	28	1	4.79	6.46	214	28	1	4.71	7.42
	Giles Shoal	3	-	-	-	-	15	1	-	19.25	-
	Hancox Shoal	12	1	-	10.50	-	9	-	-	-	-
	Knight Reef	11	1	-	11.71	-	11	1	-	9.96	-
	Marsh Shoal	36	8	-	5.88	-	94	7	-	4.75	-
	Mataram Shoal	4	-	-	-	-	12	1	-	23.50	-
	Middle Reef	5	-	-	-	-	19	1	-	3.67	-
	Oliver Reef	17	1	-	9.96	-	19	4	-	9.04	-
	Taiyun Shoal	8	-	-	-	-	15	3	-	11.67	-
	Taylor Patches	4	-	-	-	-	11	2	-	12.04	-
NP	Djukbinj	12	1	-	14.71	-	28	6	-	9.46	-
RFPA	Charles Point Wide	7,051	100	100	0.04	0.04	6,886	100	93	0.04	0.04
	Melville Island	6	-	-	-	-	10	1	0	22.13	-
Restricted Area	5	212	100	33	0.21	0.79	308	97	59	0.29	0.88
Shipwrecks	Bell Bird	93	97	-	1.42	-	227	94	27	1.29	2.42
	Booya	1,156	100	59	0.21	0.21	2,468	98	72	0.17	0.17
	British Motorist	97	97	-	1.42	-	230	94	26	1.29	2.42
	Cape Hotham Wreck	6	-	-	-	-	20	2	-	10.46	-
	Diemen	193	99	31	0.29	1.29	293	97	55	0.21	2.33
	East Vernon Island Wreck	9	-	-	-	-	26	4	-	9.46	-
	Landing Barge	80	97	-	2.33	-	182	94	12	1.29	2.46
	Marchart 3	45	23	-	2.96	-	78	2	-	2.33	-

	Mauna Loa USAT	94	96	-	1.38	-	213	94	20	1.29	2.83
	Vietnamese Refugee Boat Pk76	108	97	2	1.42	3.42	256	95	38	1.25	2.38
	Yu Han 22	55	89	-	2.50	-	131	93	5	2.38	3.50
Near shore waters	Tiwi Islands	7	-	-	-	-	12	1	-	15.83	-
CR	Vernon Islands	69	16	-	4.88	-	162	19	1	4.79	7.92
WQ Zones	East Arm	80	97	-	2.33	-	182	94	13	1.29	2.46
	Middle Arm	8	-	-	-	-	19	25	-	6.63	-
	West Arm	88	97	-	1.38	-	134	95	16	1.79	3.92
	Middle Harbour	2,643	100	48	0.25	0.29	2,465	98	71	0.17	0.17
	Outer Harbour	8,733	100	100	0.04	0.04	8,974	100	95	0.04	0.04
	Shoal Bay	375	100	34	2.17	2.71	467	94	24	2.17	2.67
	Buffalo Creek	34	42	-	6.83	-	49	35	-	4.21	-

Table 12.11 Probability of entrained hydrocarbons exposure to receptors in the 10 – 10 m depth layer for an offshore pipelay vessel fuel tank rupture at KP91.5 during each season. Results were calculated from 100 spill simulations 2er season.

Receptor		Dry					Wet				
		Maximum concentration (ppb)	Probability of instantaneous entrained hydrocarbon exposure		Minimum time (days) before instantaneous entrained hydrocarbon exposure		Maximum concentration (ppb)	Probability of instantaneous entrained hydrocarbon exposure		Minimum time (days) before instantaneous entrained hydrocarbon exposure	
			Low	High				Low	High		
RFPA	Charles Point Wide	16	12	-	0.04	0.04	15	15	6	0.04	0.04
WQ Zones	Outer Harbour	17	9	-	0.04	0.04	17	10	-	0.04	0.04

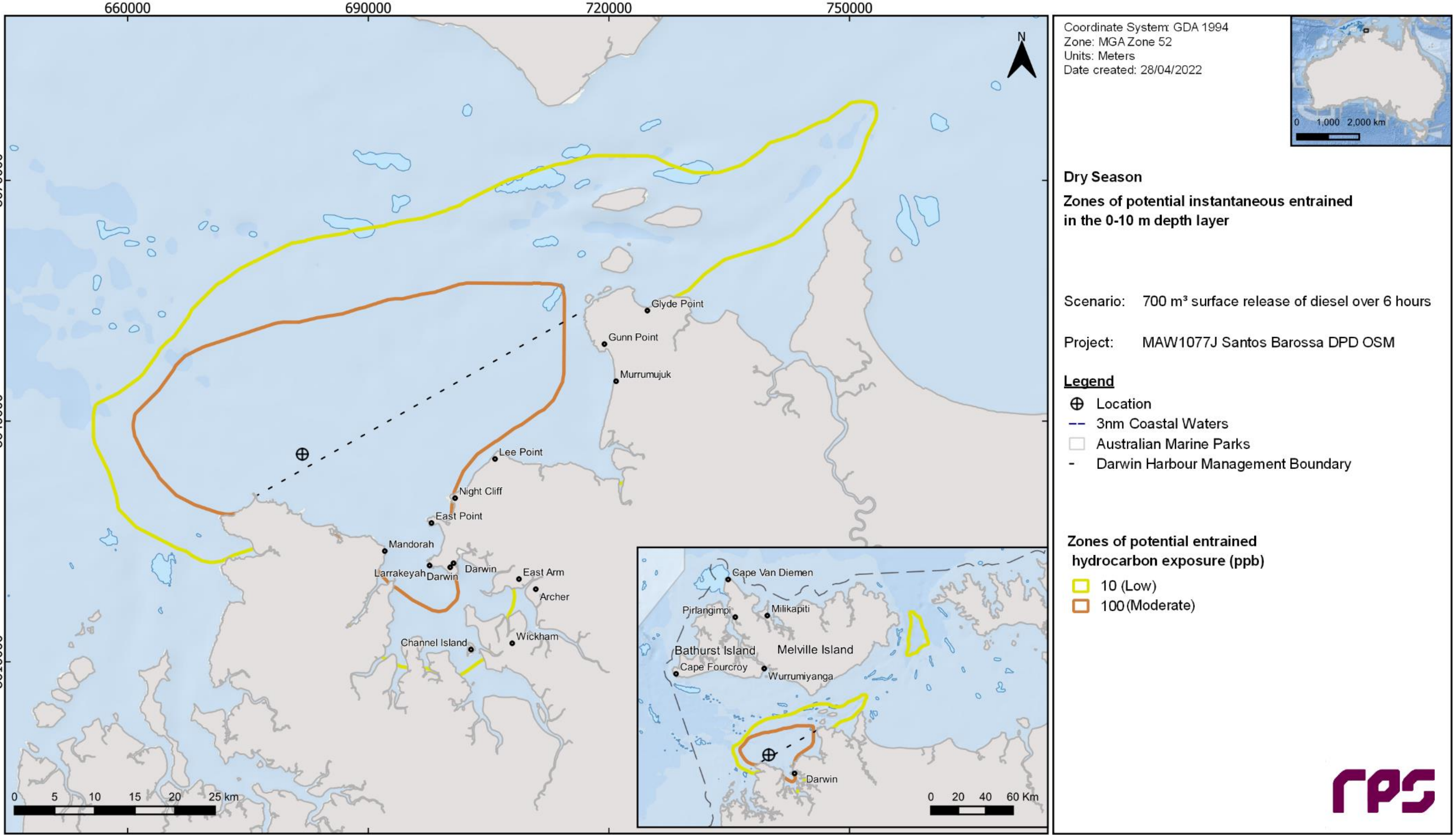

Figure 12.10 Zones of potential entrained hydrocarbon exposure at 0 – 10 m below the sea surface from an offshore pipelay vessel fuel tank rupture at KP91.5 during dry season conditions. The results were calculated from 100 spill simulations.

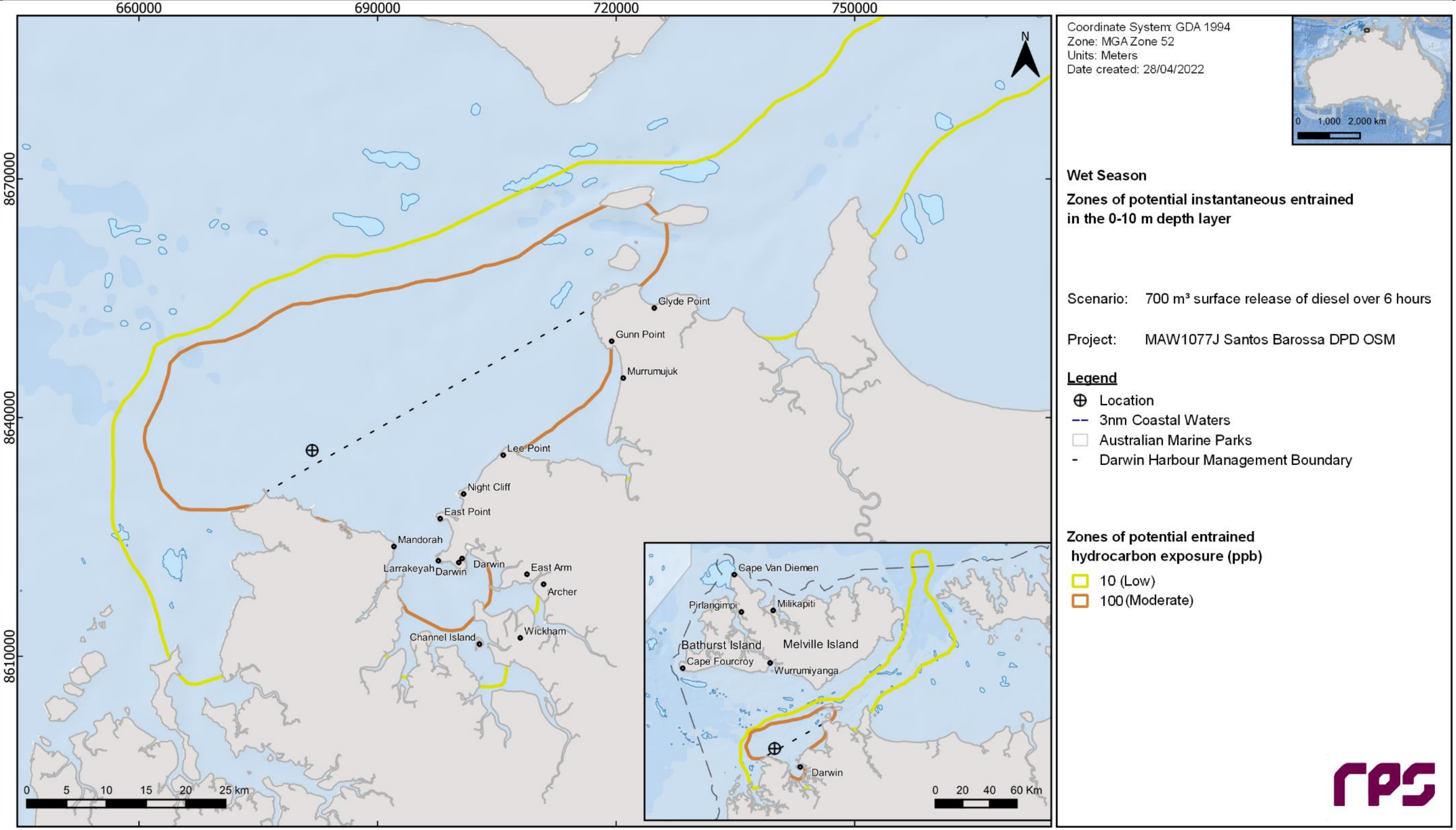

Figure 12.11 Zones of potential entrained hydrocarbon exposure at 0 – 10 m below the sea surface from an offshore pipelay vessel fuel tank rupture at KP91.5 during wet season conditions. The results were calculated from 100 spill simulations.

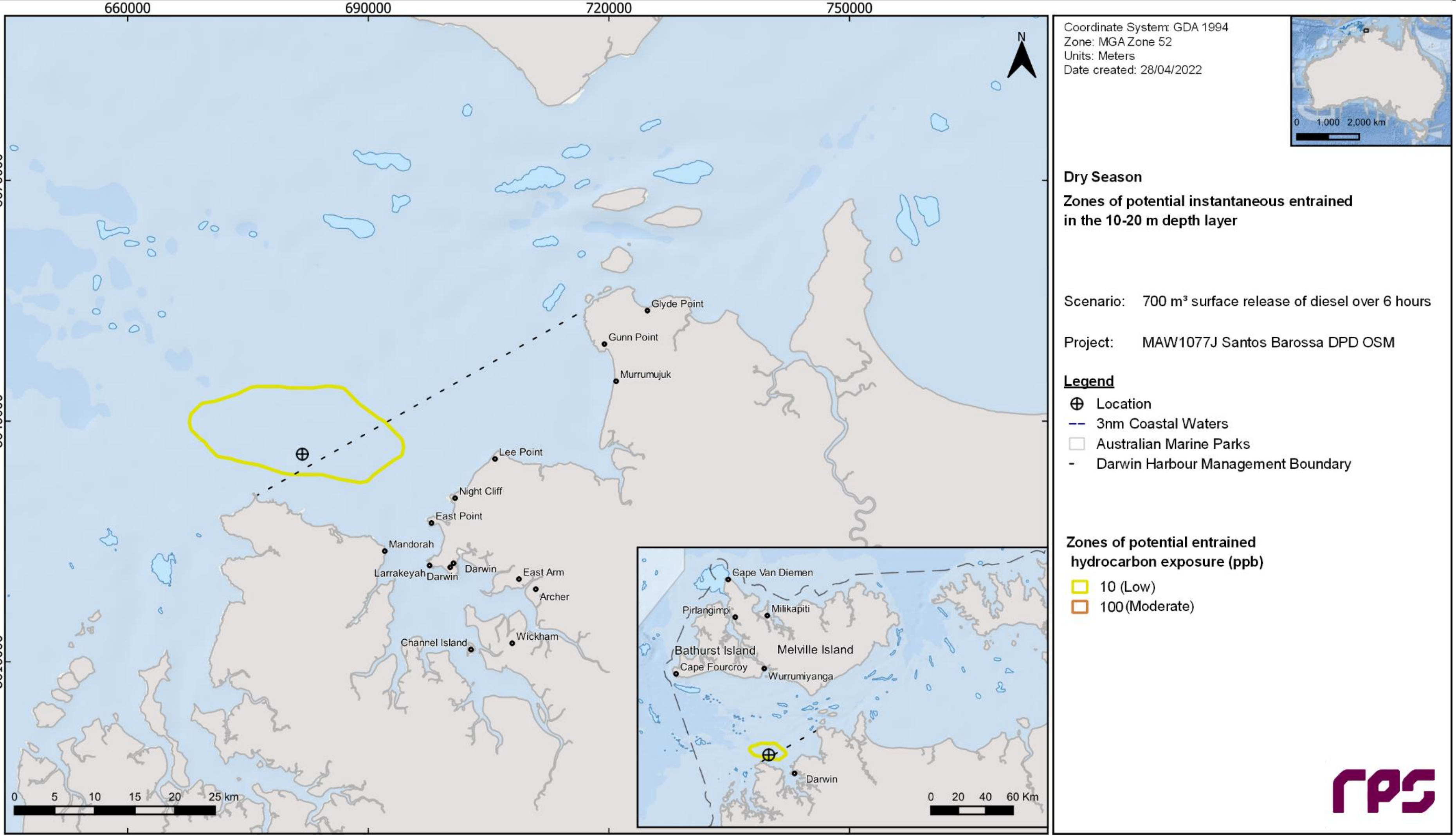

Figure 12.12 Zones of potential entrained hydrocarbon exposure at 10 – 20 m below the sea surface from an offshore pipelay vessel fuel tank rupture at KP91.5 during dry season conditions. The results were calculated from 100 spill simulations.

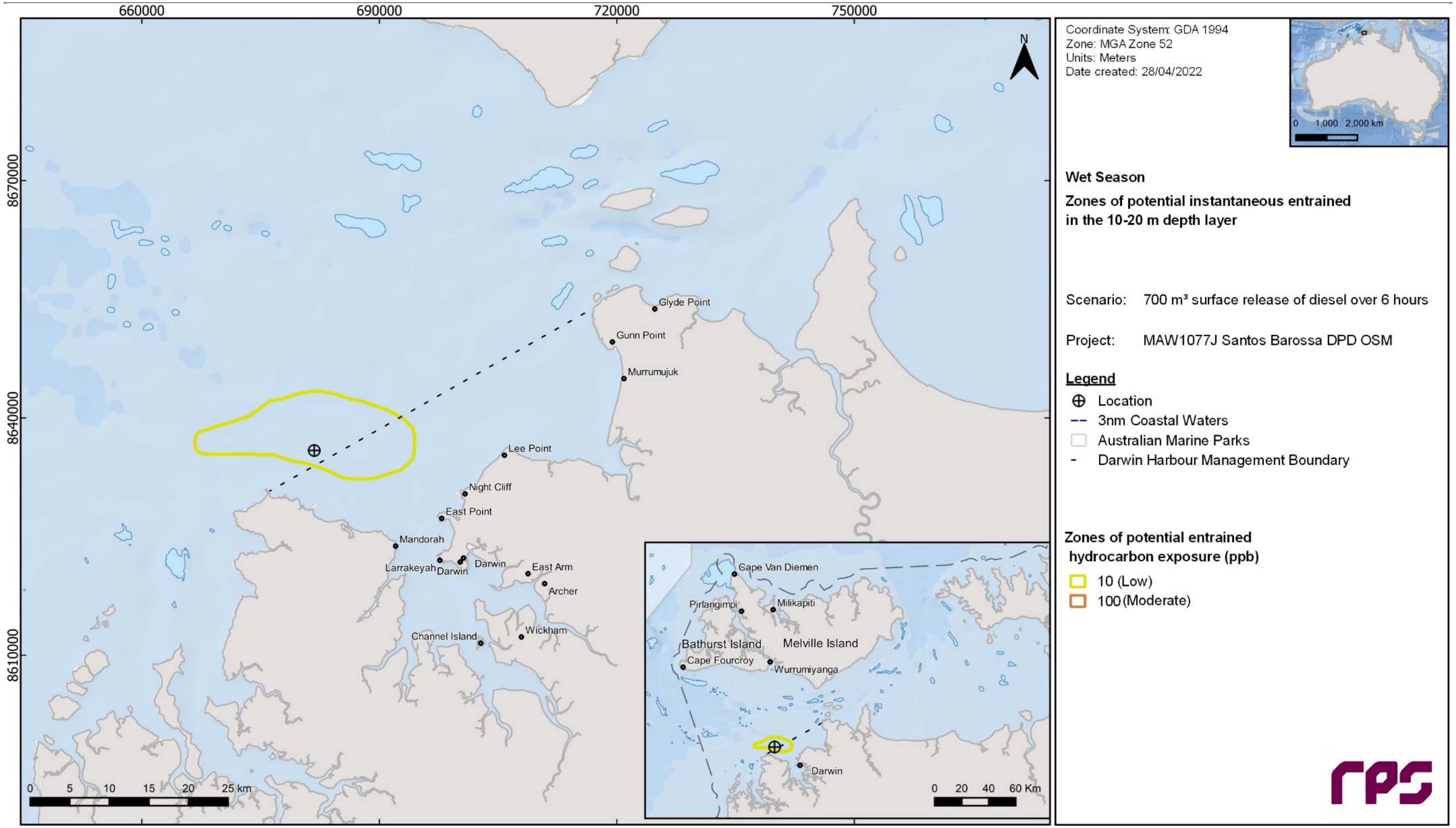

Figure 12.13 Zones of potential entrained hydrocarbon exposure at 10 – 20 m below the sea surface from an offshore pipelay vessel fuel tank rupture at KP91.5 during wet season conditions. The results were calculated from 100 spill simulations.

12.3 Deterministic Analysis

The stochastic modelling results were assessed and the deterministic simulation resulting in the largest volume ashore (59.7 m^3) was identified as run 97, which commenced at 4 pm 14 March 2019, during the wet season.

Zones of floating oil exposure on the sea surface (swept area) and shoreline accumulation over the entire 50-day simulation are presented in Figure 12.14. The spill drifted predominantly east-southeast from the release location and the oil was predicted to initially accumulate on the shoreline between Lee Point and Larrakeyah.

Zones of entrained hydrocarbon exposure within the 0 – 10 m depth layer (surface layer) are presented in Figure 12.15.

No zones of dissolved hydrocarbon exposure above the minimum reporting threshold were predicted for the simulation.

Figure 12.16 and Figure 12.17 displays timeseries of the area of floating oil exposure and volume of oil ashore for each threshold during the 50-day simulation.

Figure 12.18 presents the fates and weathering for the corresponding single spill trajectory. At the conclusion of the simulation, approximately 590 m^3 (85%) of the spilled oil had evaporated and 33 m^3 (5%) remained on the shoreline. In addition, 54 m^3 (8%) was predicted to have decayed by the end of the simulation, while there was no oil predicted to remain on the surface.

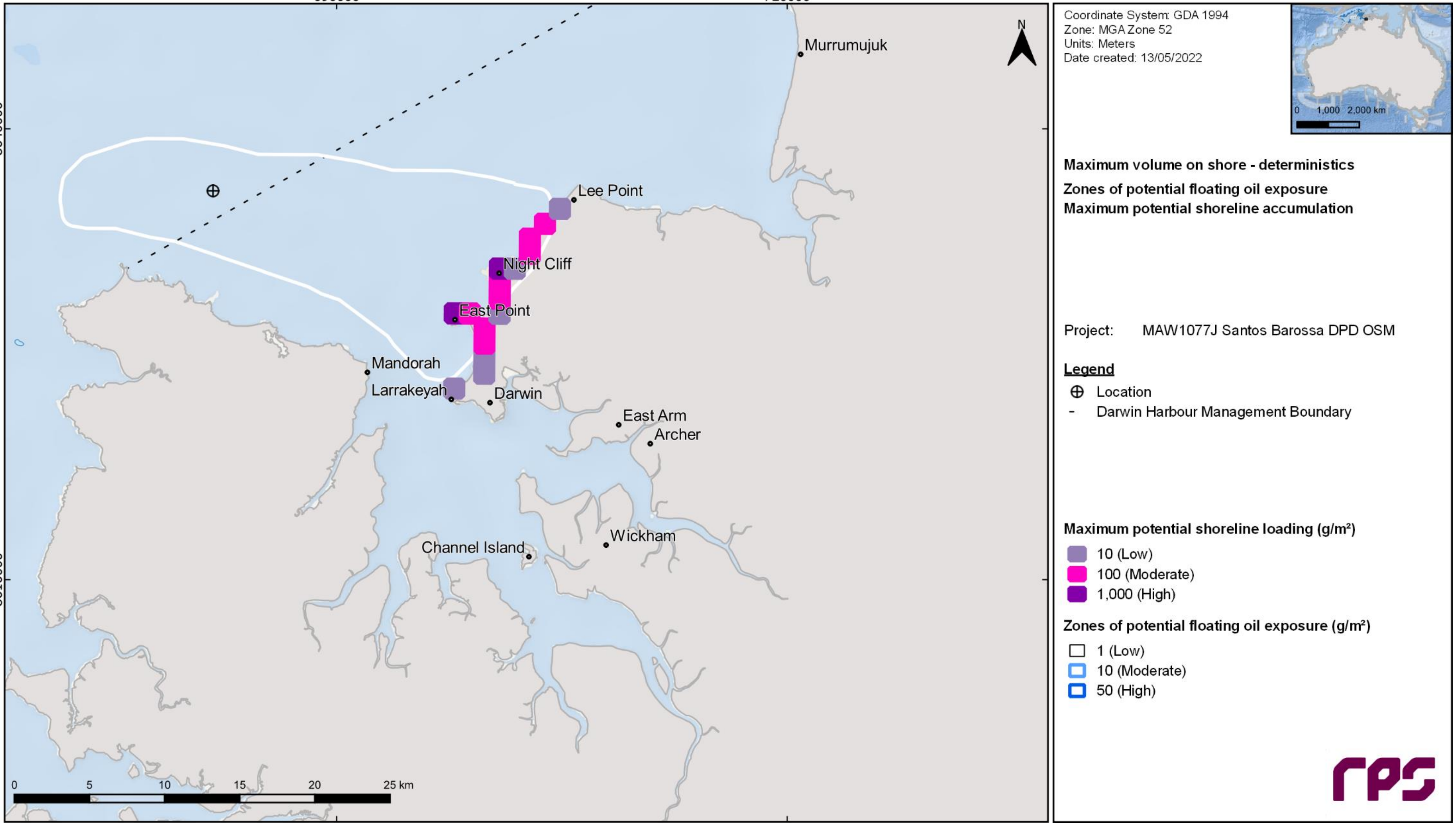

Figure 12.14 Zones of potential exposure on the sea surface and shoreline accumulation (over the 50 days) for the simulation resulting in the maximum volume of oil ashore starting at 4 pm 14 March 2019, during the wet season.

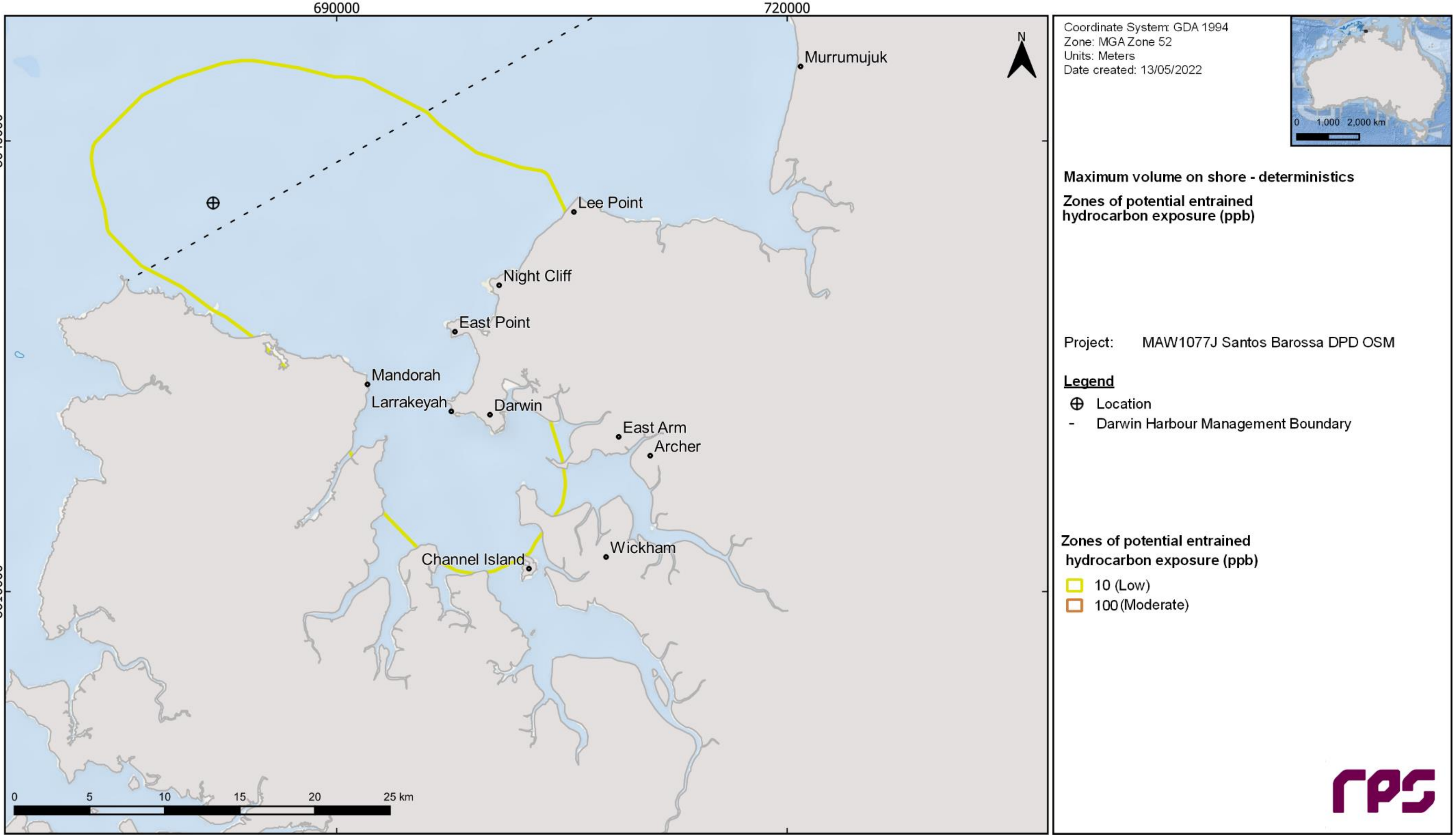

Figure 12.15 Zones of potential entrained hydrocarbon exposure 0 – 10 m below the sea (over the 50-days) for the simulation resulting in the maximum volume of oil ashore starting at 4 pm 14 March 2019, during the wet season.

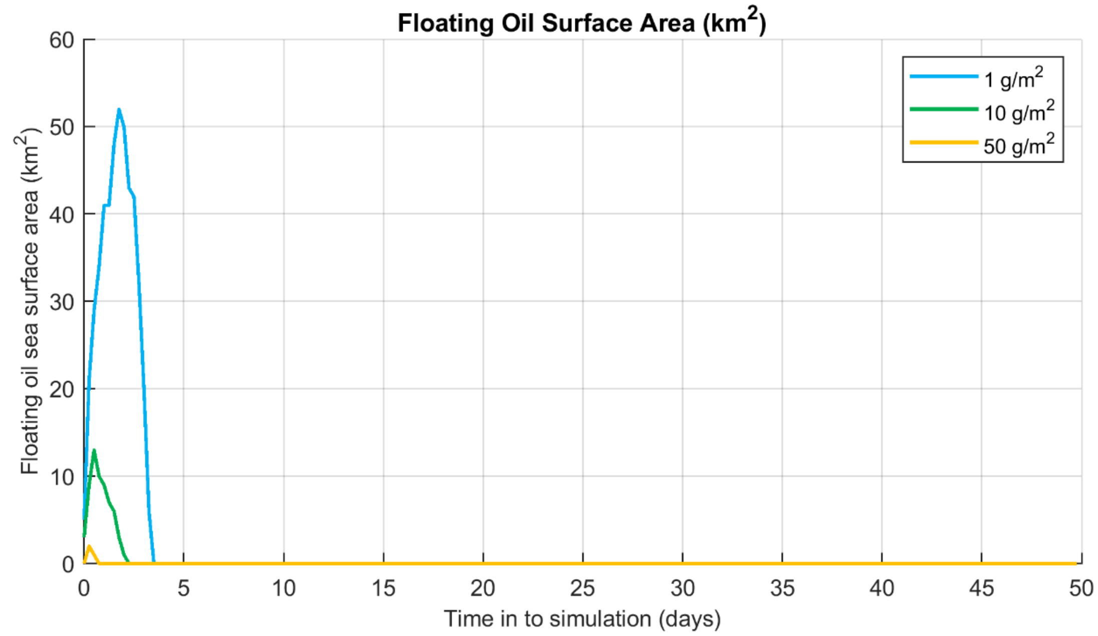

Figure 12.16 Time series of the area of floating oil exposure for each threshold for the simulation resulting in the maximum volume of oil ashore starting at 4 pm 14 March 2019, during the wet season.

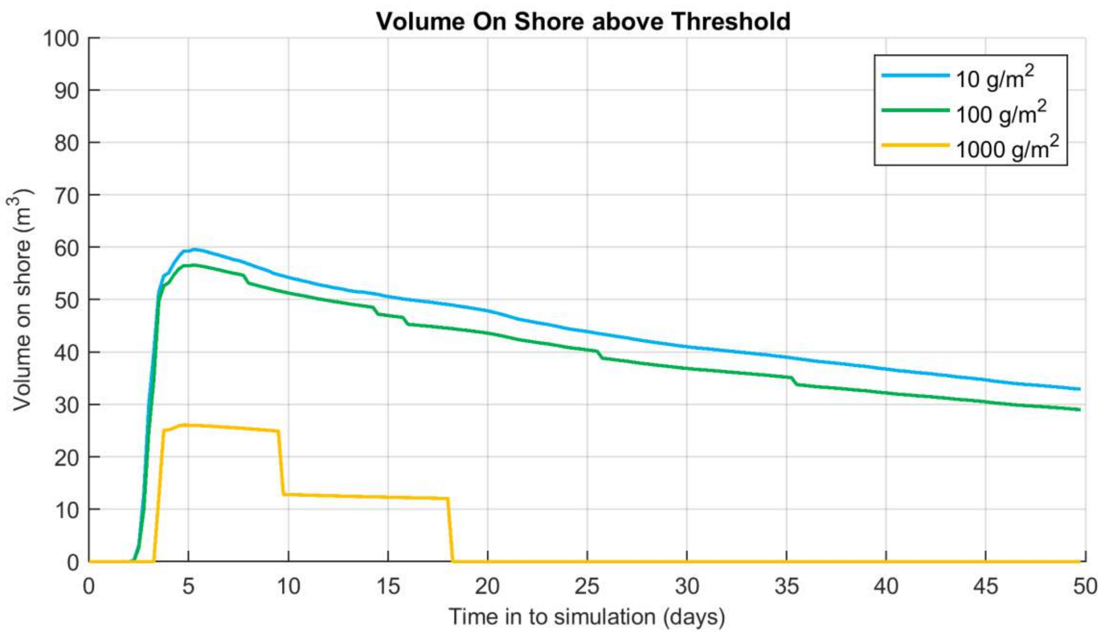

Figure 12.17 Time series of the volume of oil ashore for each threshold for the simulation resulting in the maximum volume of oil ashore starting at 4 pm 14 March 2019, during the wet season.

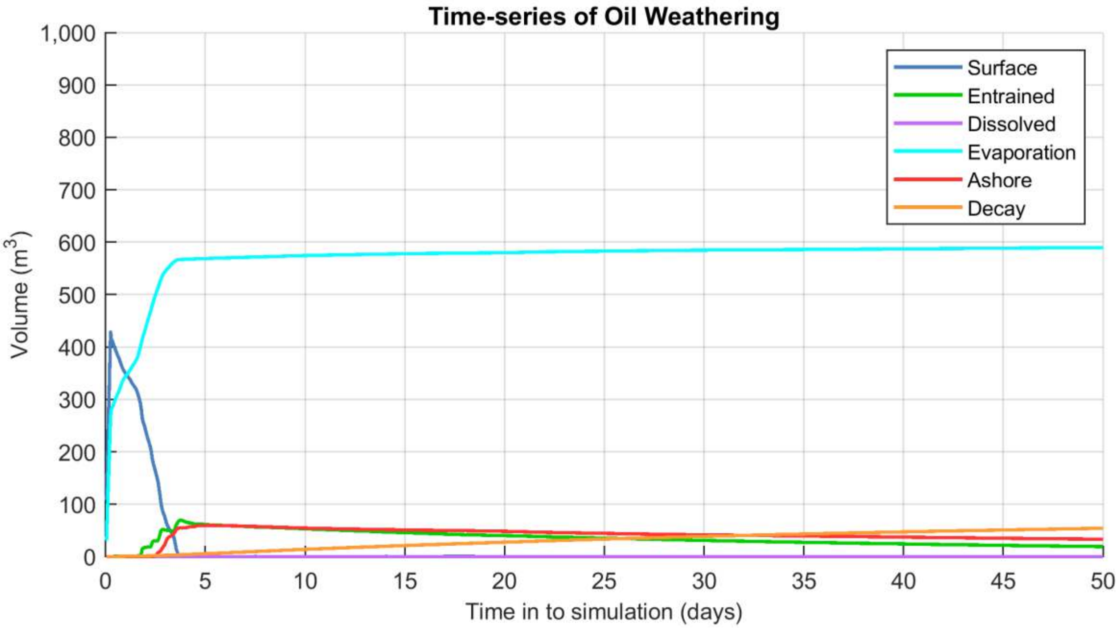

Figure 12.18 Predicted weathering and fates for the simulation resulting in the maximum volume of oil ashore starting at 4 pm 14 March 2019, during the wet season.

13 SCENARIO 2 RESULTS – VESSEL FUEL TANK RUPTURE AT KP114

This scenario examined the potential exposure following an 87.5 m^3 surface release of MDO over 6 hours in the event of a vessel fuel tank rupture at KP114. A total of 200 spill trajectories were simulated (i.e., 100 spills per season) and tracked for 20 days.

Section 13.1 presents the low threshold environment that may be affected (EMBA), resulting from the 200 spill simulations. Section 13.2 shows the seasonal (or stochastic) analysis, while Section 13.3 presents in more detail the results for the simulation resulting in the largest volume of oil ashore.

13.1 EMBA

Figure 13.1 shows the full geographic EMBA derived by overlaying the results from all 200 spill simulations at the low (≥1 g/m^2) exposure thresholds.

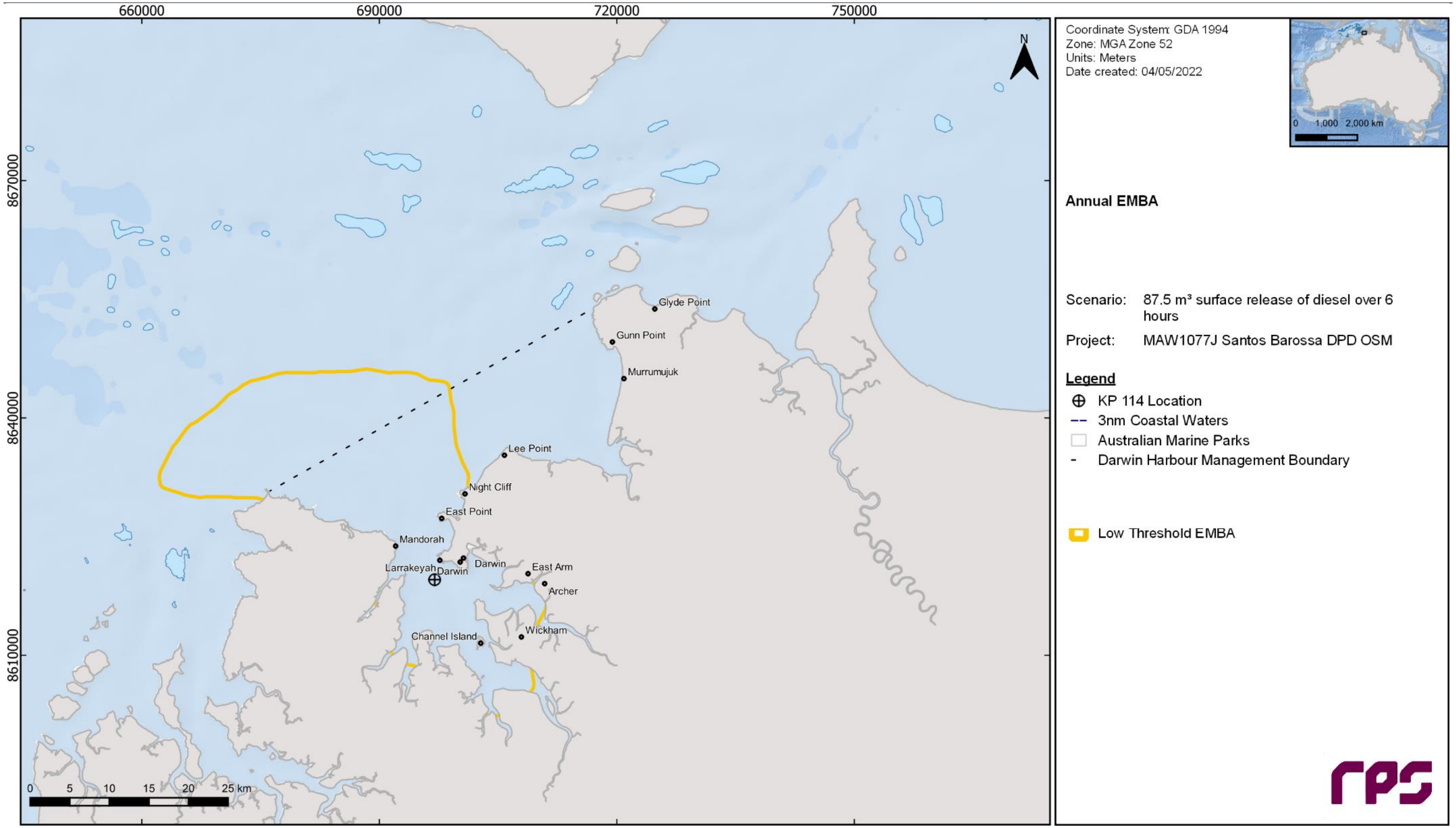

Figure 13.1 Predicted low threshold risk EMBA from a vessel fuel tank rupture at KP114. The annualised results were calculated from 200 spill simulations.

13.2 Stochastic Analysis

13.2.1 Floating Oil Exposure

Table 13.1 summarises the maximum distances and directions travelled by the floating oil from the release location at each threshold for each season. The maximum distances to the low (≥1 g/m^2), moderate (≥10 g/m^2) and high (≥ 50 g/m^2) exposure zones were 29.3 km (west northwest), 14.9 km (southeast) and 0.1 km (west northwest), respectively, during dry season conditions and 29.3 km (west northwest), 11.0 km (southeast) and 0.1 km (west northwest), respectively during wet season conditions. Table 13.2 summarises the potential floating oil exposure to individual receptors for each season and Figure 13.2 and Figure 13.3 illustrate the extent of floating oil exposure for each season.

During both the dry and wet seasons, floating oil exposure at the low threshold was predicted at Restricted Areas 4, 5 and 6 with probabilities ranging between 11 – 35% and 2 – 27%, respectively. No moderate or high exposure was predicted for any Restricted Area.

Only the one simulation during wet season conditions (1% probability) had triggered the low threshold exposure within Charles Point Wide RFPA and it took 0.67 days.

Additionally, four WQ Zones had recorded floating oil exposure at the low threshold with probabilities ranging between 7 – 60% and 11 – 35% during the dry and wet seasons, respectively, (see Table 13.2). Due to the influence of the tides forcing the oil out of the harbour during the ebb tide, the Outer Harbour WQ Zone had also recorded exposure at the moderate threshold during dry (8%) and wet (3%) season conditions, which took as a minimum 0.21 days.

Table 13.1 Maximum distances and directions travelled by floating oil from vessel fuel tank rupture at KP114 at each threshold for each season. Results were calculated from 100 spill simulations per season.

Season	Distance and direction travelled	Zones of potential floating oil exposure		
		Low	Moderate	High
Dry	Maximum distance (km) from release location	20.3	14.9	0.1
	Maximum distance (km) from the release location (99th percentile)	19.6	12.8	0.1
	Direction	NW	NW	SE
Wet	Maximum distance (km) from release location	29.3	11.0	0.1
	Maximum distance (km) from release location (99th percentile)	24.0	9.6	0.1
	Direction	WNW	NW	SE

Table 13.2 Summary of the potential exposure by floating oil to individual receptors from a vessel fuel tank rupture at KP114 for each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry						Wet					
		Probability of floating oil exposure (%)			Minimum time before floating oil exposure (days)			Probability of floating oil exposure (%)			Minimum time before floating oil exposure (days)		
		Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
RFPA	Charles Point Wide	-	-	-	-	-	-	1	-	-	0.67	0.67	-
Restricted Areas	4	35	-	-	0.29	-	-	27	-	-	0.33	-	-
	5	11	-	-	0.21	-	-	2	-	-	0.29	-	-
	6	31	-	-	0.33	-	-	20	-	-	0.33	-	-
WQ Zones	East Arm	9	-	-	0.29	-		21	-	-	0.29	-	
	Middle Arm	7	-	-	0.21	-		11	-	-	0.21	-	
	West Arm	38	-	-	0.25	-		30	-	-	0.25	-	
	Outer Harbour	60	8	-	0.08	0.21		35	3	-	0.08	0.21	

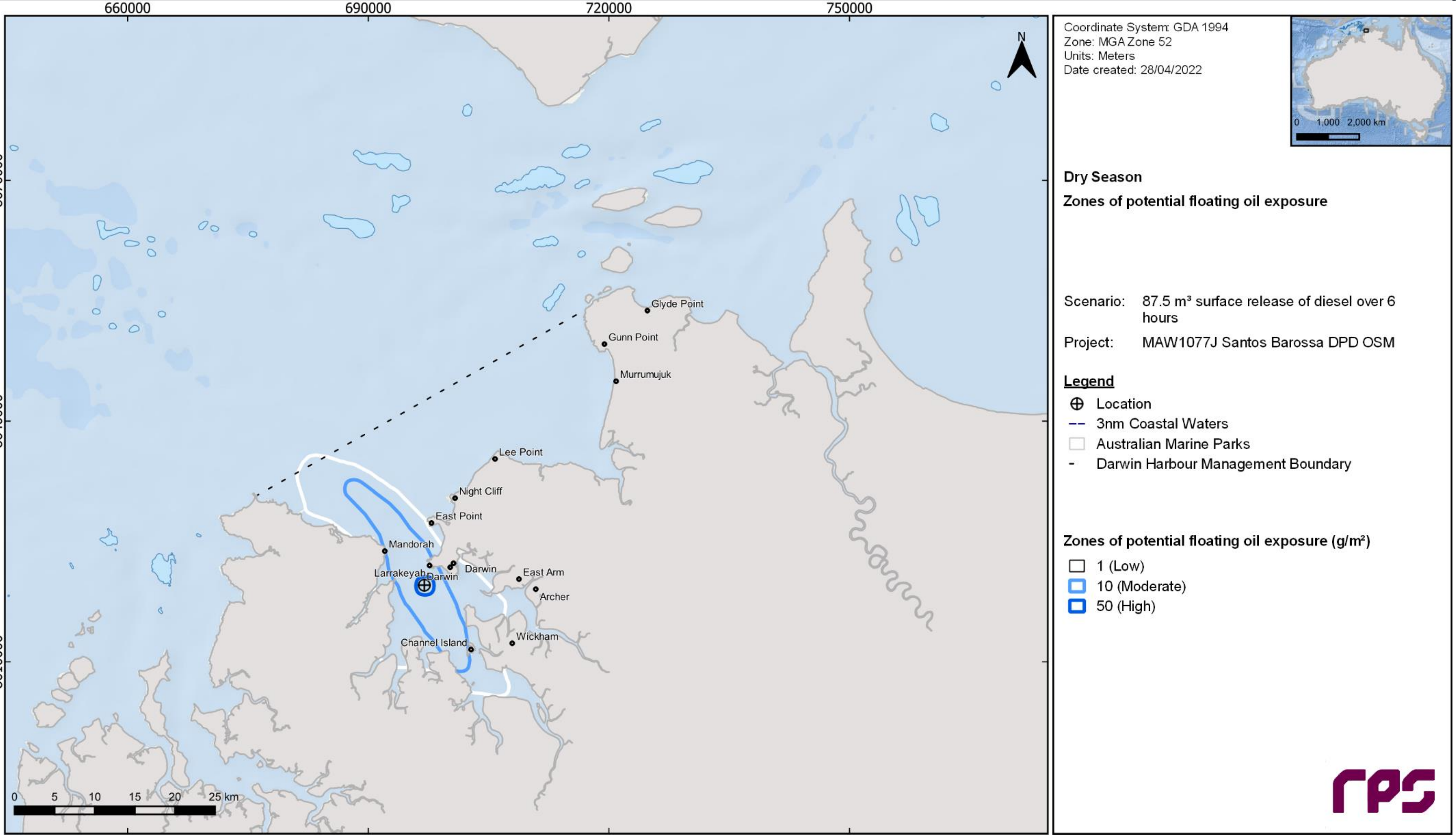

Figure 13.2 Zones of potential floating oil exposure from a vessel fuel tank rupture at KP114 during dry season conditions. The results were calculated from 100 spill simulations.

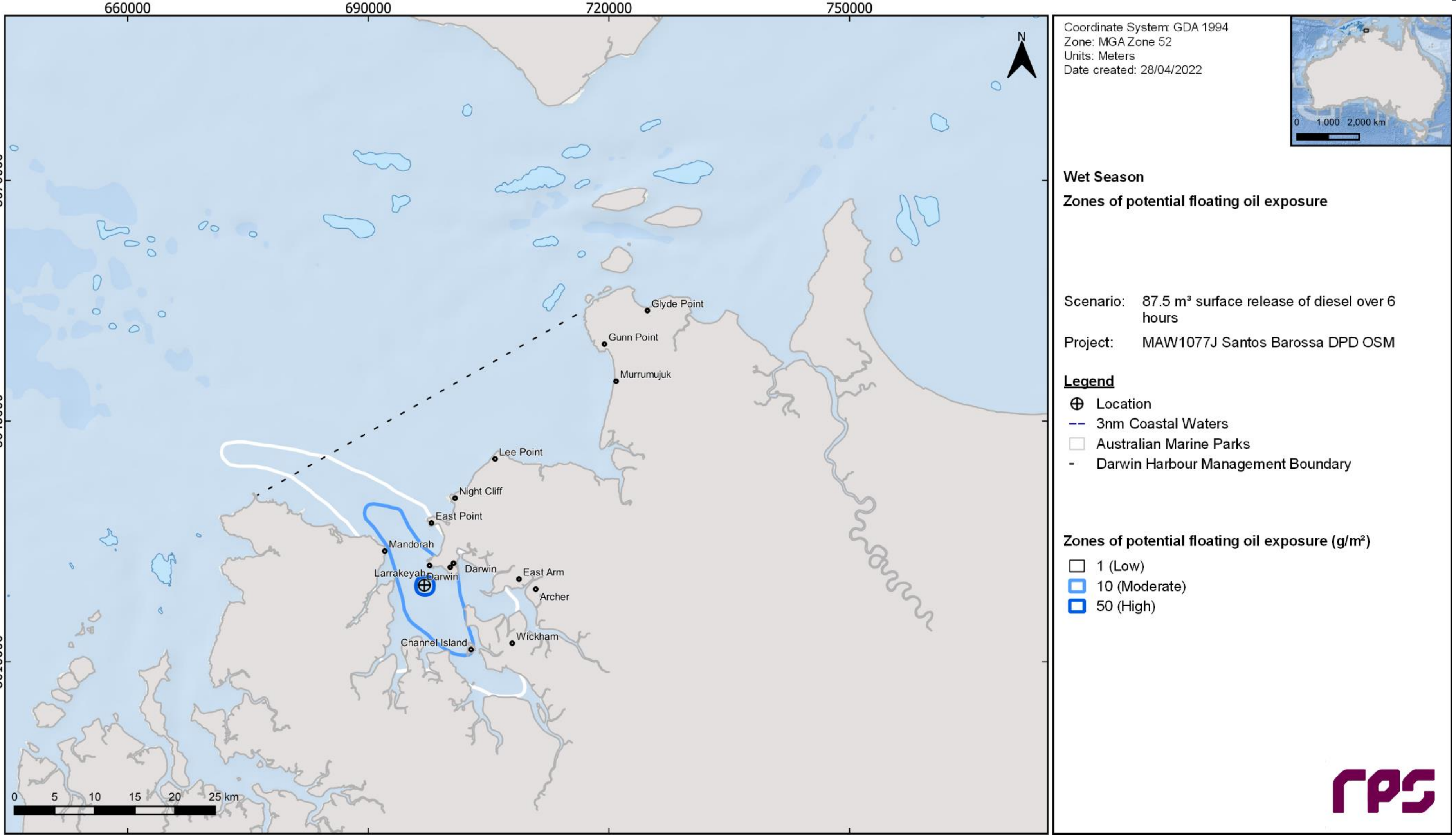

Figure 13.3 Zones of potential floating oil exposure from a vessel fuel tank rupture at KP114 during wet season conditions. The results were calculated from 100 spill simulations.

13.2.2 Shoreline Accumulation

Table 13.3 summarises the predicted oil accumulation on any shoreline during each season. The probability of oil accumulation at, or above, the low threshold (10 g/m^2) was 94% (dry season) and 83% (wet season). The minimum time before oil accumulation at, or above, the low threshold ranged between 0.21 days (dry season) and 0.17 days (wet season). The maximum volume ashore for a single spill ranged between 24.8 m^3 (dry season) and 24.7 m^3 (wet season) and the maximum length of shoreline contacted at the low threshold was 29.6 km (dry season) and 28.1 km (wet season). The maximum lengths of oil accumulation on shorelines at, or above, the moderate (100 – 1,000 g/m^2) and high (≥1,000 g/m^2) thresholds was 5.5 km (dry season) and 6.5 km (wet season), and 0.5 km (dry season), respectively there was no shoreline contact at the high (≥1,000 g/m^2) threshold during wet season conditions.

Table 13.4 and Table 13.5and summarise the oil accumulation on individual shoreline receptors for each season. The maximum potential shoreline loading for the specified thresholds for each season are presented in Figure 13.4 and Figure 13.5.

The highest probability of oil accumulation at the low threshold was predicted along the West Arm (78% dry and 47% wet seasons) and East Arm (32% dry and 48% wet conditions) shorelines. The greatest volume (peak) of oil accumulation during the dry and wet seasons occurred along the West Arm shoreline (24.2 m^3 (dry season) and 24.6 m^3 (wet season)). The minimum time before oil accumulation at the low threshold was 0.21 days (East Arm) for the dry season and 0.17 days (East Arm) during the wet season conditions.

Table 13.3 Summary of oil accumulation on any shoreline from a vessel fuel tank rupture at KP114 during each season. Results were calculated from 100 spill simulations per season.

Shoreline Statistics	Dry			Wet		
	Low	Moderate	High	Low	Moderate	High
Probability of accumulation on any shoreline (%)	94	45	1	83	52	-
Absolute minimum time before oil ashore (days)	0.21	0.38	1.25	0.17	0.21	-
Maximum length of shoreline contacted	29.6	5.5	0.5	28.1	6.5	-
Average length of shoreline contacted (km)	7.3	1.8	0.5	9.8	2.2	-
		Dry			Wet	
Maximum volume of hydrocarbons ashore (m^3)		24.8			24.7	
Average volume of hydrocarbons ashore (m^3)		4.5			5.8	

Table 13.4 Summary of oil accumulation on individual shoreline sectors from a vessel fuel tank rupture at KP114 for the dry season. Results were calculated from 100 spill simulations per season.

Shoreline sector	Maximum probability of shoreline loading (%)			Minimum time before shoreline accumulation (days)			Load on shoreline (g/m²)		Volume on shoreline (m³)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Low	Moderate	High	Low	Moderate	High	Mean	Peak	Mean	Peak	Low	Moderate	High	Low	Moderate	High
Cox-Finniss	2	-	-	1.42	-	-	<1	21	<0.1	0.2	0.5	-	-	0.5	-	-
East Arm	32	8	-	0.21	0.42	-	6	642	0.5	8.4	2.4	1.0	-	13.0	2.0	-
Middle Arm	9	2	-	0.33	0.63	-	2	197	0.2	4.5	3.0	1.7	-	6.5	2.0	-
Outer Harbour East	-	-	-	-	-	-	<1	4	<0.1	<0.1	-	-	-	-	-	-
Outer Harbour West	4	-	-	0.79	-	-	<1	41	<0.1	1.3	2.7	-	-	4.5	-	-
West Arm	78	38	1	0.29	0.38	1.25	10	1,189	3.6	24.2	6.6	1.8	0.5	23	4	0.5
Wickham Point	15	1	-	0.58	0.83	-	2	102	0.1	2.7	1.9	0.5	-	4.5	0.5	-

Table 13.5 Summary of oil accumulation on individual shoreline sectors from a vessel fuel tank rupture at KP114 for the wet season. Results were calculated from 100 spill simulations per season.

Shoreline sector	Maximum probability of shoreline loading (%)			Minimum time before shoreline accumulation (days)			Load on shoreline (g/m²)		Volume on shoreline (m³)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Low	Moderate	High	Low	Moderate	High	Mean	Peak	Mean	Peak	Low	Moderate	High	Low	Moderate	High
Cox-Finniss	-	-	-	-	-	-	<1	5	<0.1	< 0.1	-	-	-	-	-	-
East Arm	48	16	-	0.17	0.21	-	5	776	1.1	14.6	3.2	1.2	-	15.0	3.0	-
Middle Arm	21	2	-	0.29	0.83	-	1	154	0.2	2.8	1.8	0.7	-	4.0	1.0	-
Outer Harbour East	2	-	-	1.25	-	-	<1	28	<0.1	0.2	0.5	-	-	0.5	-	-
Outer Harbour West	3	-	-	1.08	-	-	<1	35	<0.1	1.4	2	-	-	3.5	-	-
West Arm	47	31	-	0.21	0.46	-	10	852	3.5	24.6	9.2	2.5	-	25.0	6.5	-
Wickham Point	45	7	-	0.21	0.58	-	6	364	0.8	7.6	3	1.1	-	6.5	2.0	-

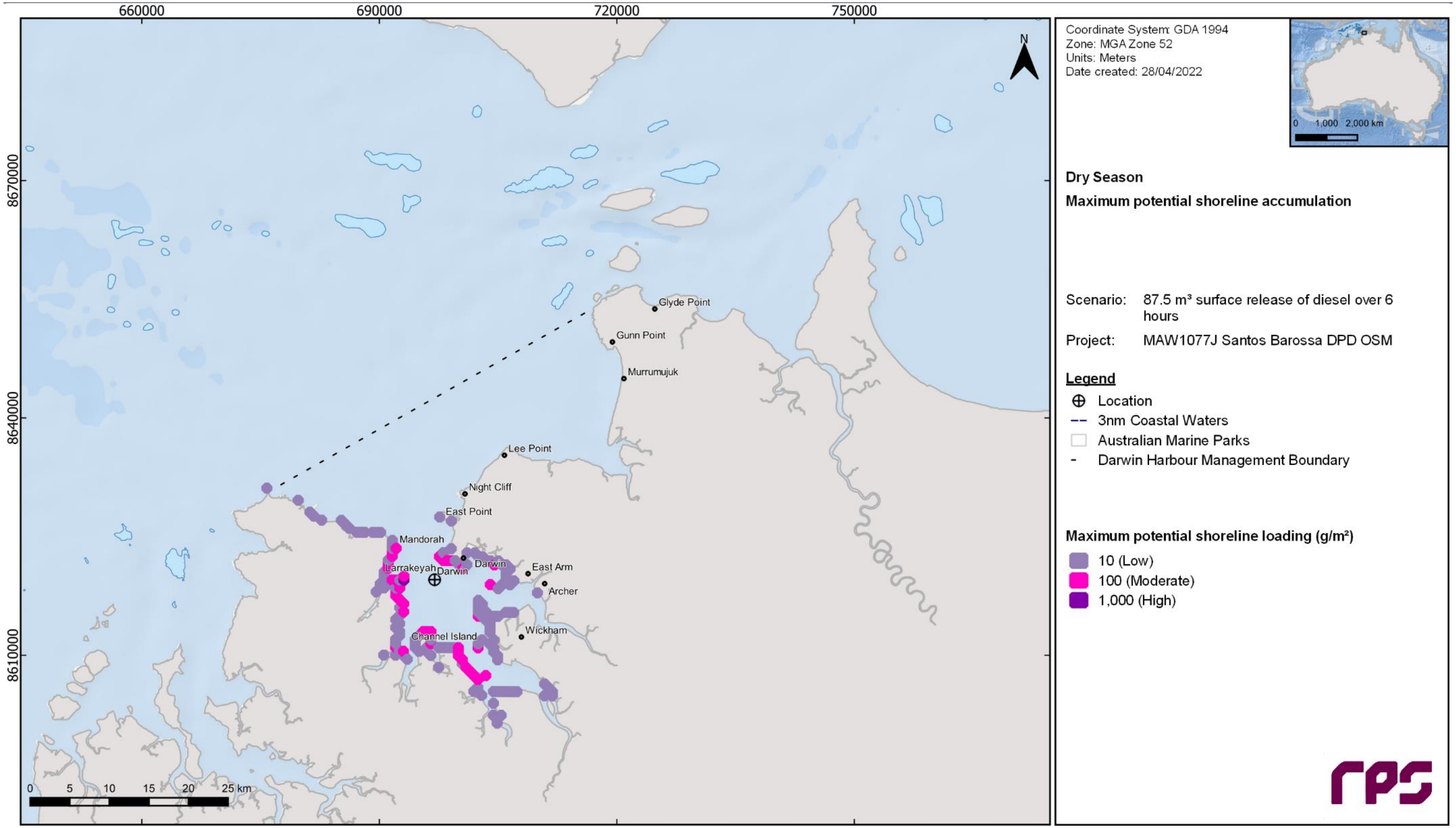

Figure 13.4 Maximum potential shoreline loading from a vessel fuel tank rupture at KP114 during dry season conditions. The results were calculated from 100 spill simulations.

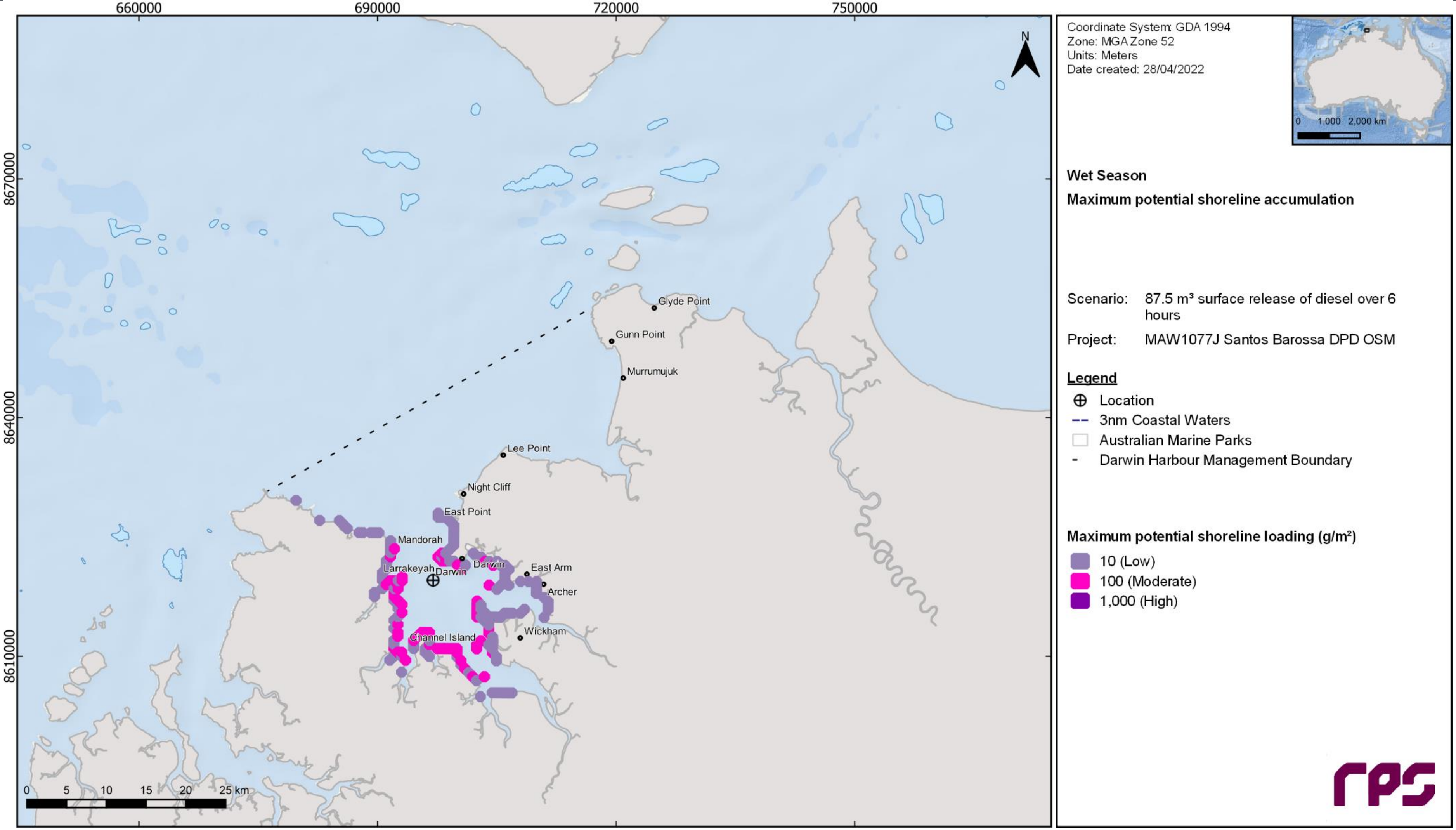

Figure 13.5 Maximum potential shoreline loading from a vessel fuel tank rupture at KP114 during wet season conditions. The results were calculated from 100 spill simulations.

13.2.3 In-water exposure

13.2.3.1 Dissolved Hydrocarbons

Table 13.6 summarises the maximum distances and directions travelled by dissolved hydrocarbons from the release location to the low threshold (≥ 10 ppb), in the 0 – 10 m depth layer as there was no exposure predicted for the moderate and high thresholds. The maximum distances during the dry and wet seasons were 3.9 km and 12.2 km north northwest, respectively. Exposure was limited to the 0 – 10 m depth layer.

Table 13.7 summarises the potential exposure to receptors from dissolved hydrocarbons in the 0 – 10 m depth layer for each threshold and season. Figure 13.6 and Figure 13.7 illustrate the extent of dissolved hydrocarbon exposure for each season in the 0 – 10 m depth layers.

There was no exposure to any receptor during the dry season. Under wet season conditions, 3 receptors had recorded exposure at the low threshold (Ham Luong and Mauna Loa USAT shipwreck, and Outer Harbour WQ Zone) and the probabilities ranged between 1 and 6%. There was no exposure at the moderate threshold to any receptor. The maximum instantaneous dissolved concentrations were 9 ppb and 21 ppb predicted at the Mauna Loa USAT shipwreck during dry and wet seasons, respectively.

Table 13.6 Maximum distances and directions travelled by dissolved hydrocarbons (0 – 10 m depth layer) from a vessel fuel tank rupture at KP114 during each season. Results were calculated from 100 spill simulations per season.

Season	Distance and direction travelled	Zones of potential dissolved hydrocarbon exposure		
		Low 10 ppb	Moderate 50 ppb	High 400 ppb
Dry	Maximum distance (km) from the release location	3.9	-	-
	Maximum distance (km) from the release location (99th percentile)	3.9	-	-
	Direction	NNW	-	-
Wet	Maximum distance (km) from the release location	12.2	-	-
	Maximum distance (km) from the release location (99th percentile)	12.2	-	-
	Direction	NNW	-	-

Table 13.7 Summary of dissolved hydrocarbon exposure for each receptor in the 0 – 10 m depth layer from a vessel fuel tank rupture at KP114 during each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry							Wet						
		Maximum instantaneous concentration (ppb)	Probability of instantaneous dissolved hydrocarbon exposure			Minimum time (days) before instantaneous dissolved hydrocarbon exposure			Maximum instantaneous concentration (ppb)	Probability of instantaneous dissolved hydrocarbon exposure			Minimum time (days) before instantaneous dissolved hydrocarbon exposure		
			Low	Moderate	High	Low	Moderate	High		Low	Moderate	High	Low	Moderate	High
Shipwrecks	Ham Luong	6	-	-	-	-	-	-	21	6	-	-	0.13	-	-
	Mauna Loa USAT	9	-	-	-	-	-	-	21	4	-	-	0.17	-	-
	Outer Harbour	3	-	-	-	-	-	-	10	1	-	-	0.33	-	-

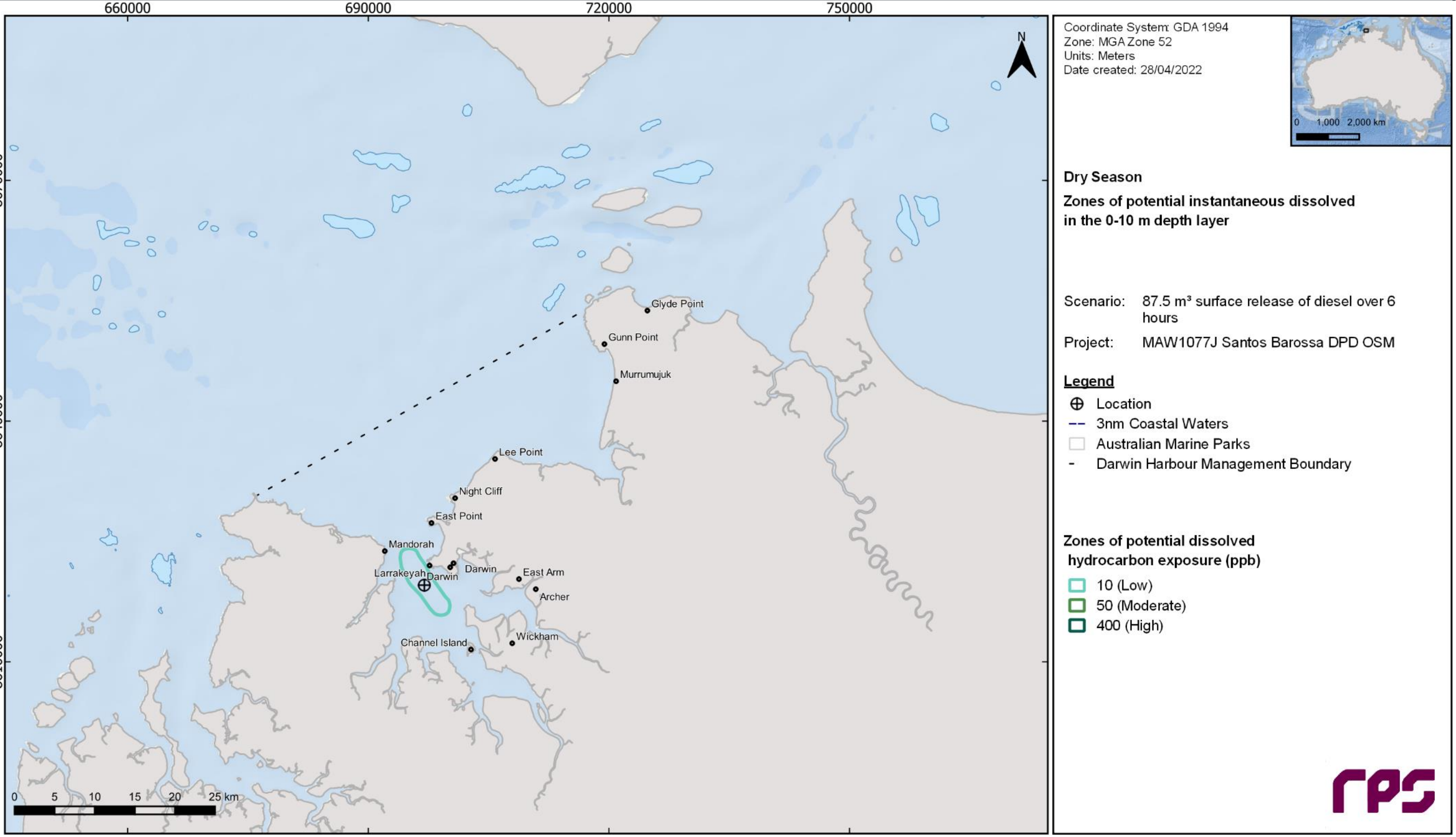

Figure 13.6 Zones of potential dissolved hydrocarbon exposure at 0 – 10 m below the sea surface from a vessel fuel tank rupture at KP114 during dry season conditions. The results were calculated from 100 spill simulations.

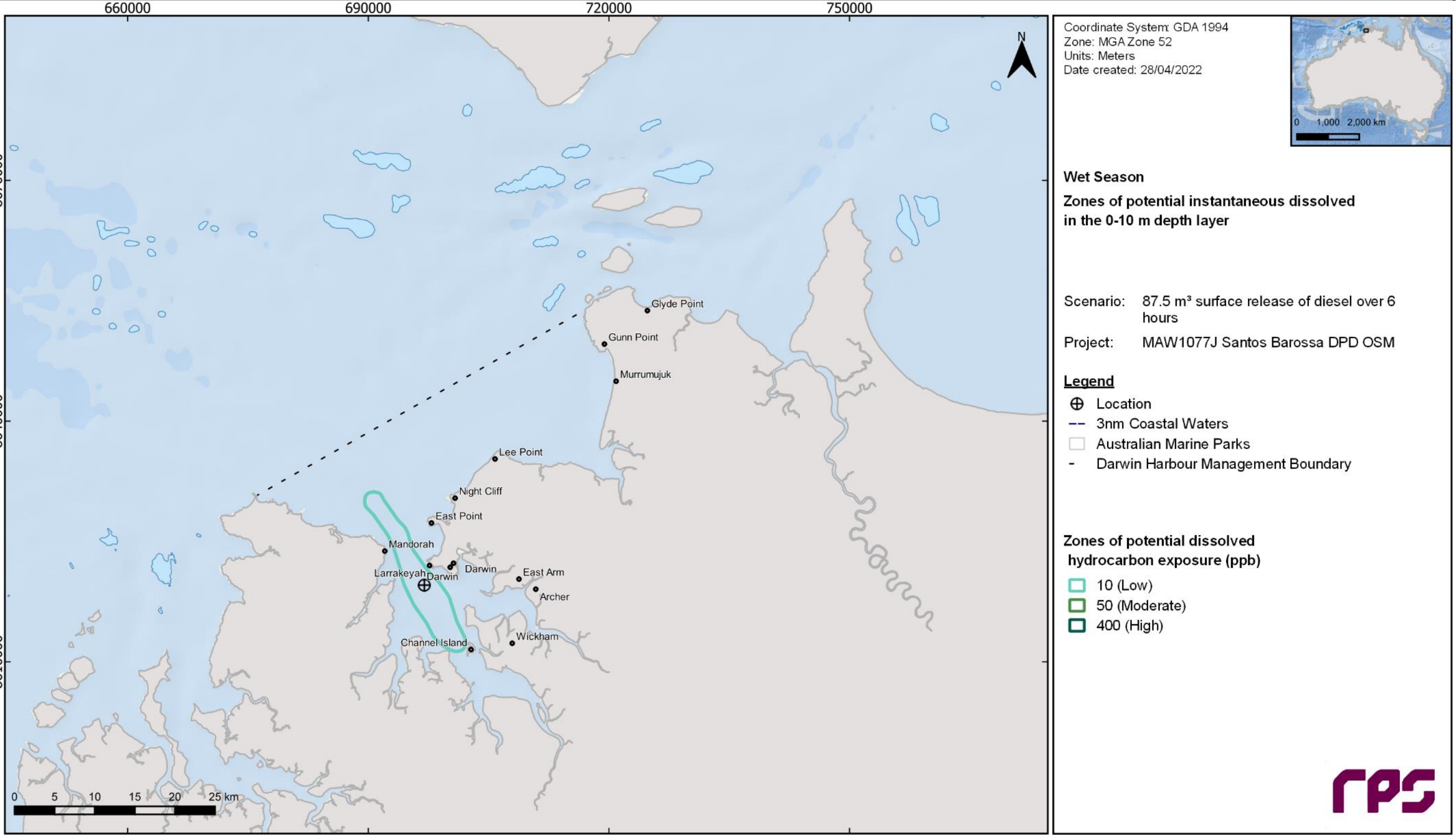

Figure 13.7 Zones of potential dissolved hydrocarbon exposure at 0 – 10 m below the sea surface from a vessel fuel tank rupture at KP114 during wet season conditions. The results were calculated from 100 spill simulations.

13.2.3.2 Entrained Hydrocarbons

Table 13.8 summarises the maximum distances and directions travelled by entrained hydrocarbons within the 0 – 10 m depth layers at the low (≥ 10 ppb) and moderate (≥ 100 ppb) thresholds, which ranged between 36.1 km and 20.3 km west northwest from the release location, during the dry season conditions and 33.8 km and 23.9 km northwest from the release location, during the wet season conditions.

Table 13.9 summarises the potential exposure to receptors from entrained hydrocarbons in the 0 – 10 m depth layer for each season. Figure 13.8 and Figure 13.9 illustrate the extent of entrained hydrocarbon exposure for each season in the 0 – 10 m depth layer.

During both seasons the Charles Point Wide RFPA and four Restricted Areas (1, 4, 5 and 6) were predicted to be exposed to entrained hydrocarbons at the low threshold with probabilities ranging from 45 – 97% and 5 – 69% during the dry and wet seasons, respectively. During both seasons Restricted Area 6 was predicted to have the greatest probability of low threshold exposure (97% and 69%).

Exposure at the low threshold was predicted at 15 and 16 shipwreck receptors during the dry and wet season, respectively with probabilities ranging from 28% (Ellengowan) and 97% (Mauna Loa USAT) during the dry season and 2% (East Arm Vietnamese Refugee Boat 1) and 78% (Mauna Loa USAT) during the wet season.

Furthermore, 4 WQ Zones were predicted to be exposed at the low threshold with probabilities ranging from 31% (Middle Arm) and 93% (Outer Harbour) during the dry season. While under wet season conditions there were 5 receptors and probabilities ranging from 2% (Elizabeth River) and 70% (Outer Harbour) during the wet season. The maximum instantaneous concentrations were predicted at Outer Harbour during both the dry (436 ppb) and wet (677 ppb) seasons.

Table 13.8 Maximum distances and directions travelled by entrained hydrocarbons (0 – 10 m depth layer) from the release location vessel fuel tank rupture at KP114 during each season. Results were calculated from 100 spill simulations per season.

Season	Distance and direction travelled	Zones of potential entrained hydrocarbon exposure	
		Low 10 ppb	Moderate 100 ppb
Dry	Maximum distance (km) from release location	36.1	20.3
	Maximum distance (km) from release location (99th percentile)	34.8	19.4
	Direction	WNW	NW
Wet	Maximum distance (km) from release location	33.8	23.9
	Maximum distance (km) from release location (99th percentile)	32.8	23.0
	Direction	NW	NW

Table 13.9 Probability of entrained hydrocarbons exposure to receptors in the 0 – 10 m depth layer from a vessel fuel tank rupture at KP114 during each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry					Wet				
		Maximum concentration (ppb)	Probability of instantaneous entrained hydrocarbon exposure		Minimum time (days) before instantaneous entrained hydrocarbon exposure		Maximum concentration (ppb)	Probability of instantaneous entrained hydrocarbon exposure		Minimum time (days) before instantaneous entrained hydrocarbon exposure	
			Low	Mod	Low	Mod		Low	Mod	Low	Mod
RFPA	Charles Point Wide	71	45	-	0.71	-	117	36	1	0.71	0.96
Restricted Area	1	9	-	-	-	-	18	5	-	0.42	-
	4	130	94	7	0.21	0.58	253	67	1	0.17	0.38
	5	114	88	2	0.17	0.46	99	58	-	0.29	-
	6	181	97	22	0.17	0.42	350	69	2	0.13	0.33
Shipwrecks	Bell Bird	199	62	2	0.21	0.63	126	65	4	0.21	0.54
	Booya	122	83	3	0.17	0.33	282	60	2	0.13	0.21
	British Motorist	218	71	3	0.21	0.50	182	69	13	0.17	0.33
	Darwin Harbour Unidentified wreck 2	248	83	10	0.13	0.29	460	72	31	0.08	0.17
	Diemen	129	94	7	0.21	0.42	98	64	-	0.21	-
	East Arm Vietnamese Refugee Boat 1	6	-	-	-	-	14	2	-	0.88	-
	Ellengowan	75	28	-	0.46	-	84	41	-	0.17	-
	Ham Luong	1,073	96	45	0.04	0.04	1,588	78	50	0.04	0.04
	L. Ann	70	84	-	0.33	-	41	58	-	0.63	-
	Landing Barge	179	61	2	0.29	0.67	109	66	2	0.21	0.71
	Mandorah Unidentified wreck 1	70	84	-	0.33	-	41	58	-	0.63	-
	Mauna Loa USAT	1,197	97	46	0.04	0.04	1,992	78	49	0.04	0.04
	Middle Arm unidentified wreck	75	28	-	0.46	-	84	41	-	0.17	-
	Peary USS	262	82	12	0.17	0.25	310	72	30	0.13	0.21
	Vietnamese Refugee Boat Pk76	118	55	1	0.33	0.63	85	59	-	0.21	-

	Yu Han 22	500	95	27	0.08	0.13	521	75	20	0.08	0.17
WQ Zones	Elizabeth River	6	-	-	-	-	14	2	-	0.88	-
	East Arm	145	45	1	0.29	0.67	94	62	-	0.21	-
	Middle Arm	282	31	4	0.25	0.38	389	34	9	0.17	0.25
	West Arm	132	92	3	0.21	0.42	208	67	2	0.17	0.29
	Outer Harbour	436	93	22	0.13	0.13	677	70	21	0.08	0.13

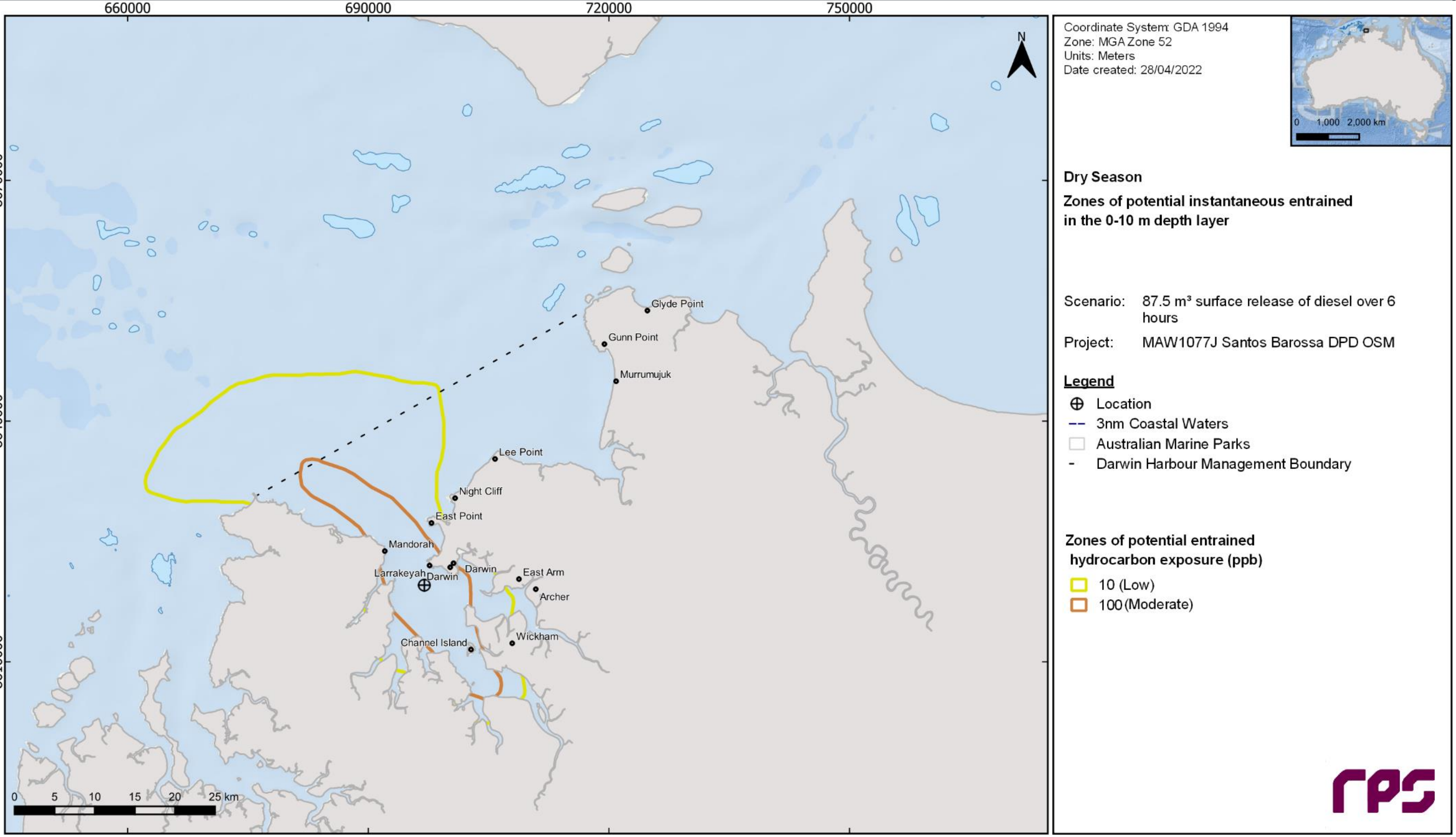

Figure 13.8 Zones of potential entrained hydrocarbon exposure at 0 – 10 m below the sea surface from a vessel fuel tank rupture at KP114 during dry season conditions. The results were calculated from 100 spill simulations.

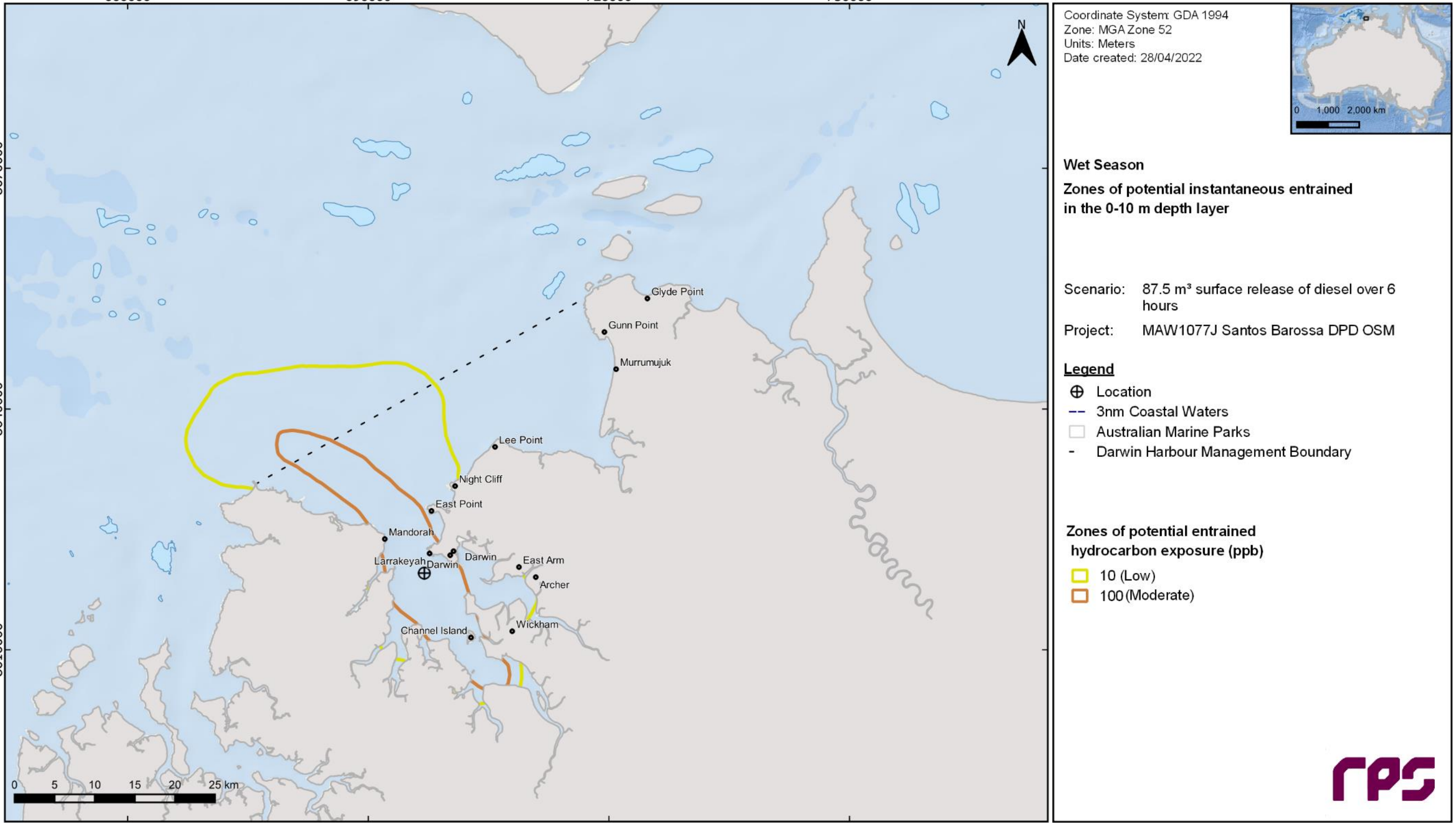

Figure 13.9 Zones of potential entrained hydrocarbon exposure at 0 – 10 m below the sea surface from a vessel fuel tank rupture at KP114 during wet season conditions. The results were calculated from 100 spill simulations.

13.3 Deterministic Analysis

The stochastic modelling results were assessed and the deterministic simulation resulting in the largest volume ashore (24.8 m^3) was identified as run 38, which commenced at 2 am 2 September 2019 during the dry season.

Zones of exposure on the sea surface (swept area) and shoreline accumulation over the entire 20-day simulation are presented in Figure 13.10. The spill had drifted predominately south and west from the release from the release location and the oil was predicted to accumulate on the western shoreline up to Mandorah.

Zones of entrained hydrocarbon exposure within the 0 – 10 m depth layer (surface layer) over the 20-day simulation are presented in Figure 13.11.

No zones of dissolved hydrocarbon exposure above the reporting threshold were predicted for the simulation.

Figure 13.12 and Figure 13.13 show time series of the area of floating oil and the volume of oil ashore exposure for each threshold during the 20-day simulation.

Figure 13.14 presents the fates and weathering for the corresponding single spill trajectory. At the conclusion of the simulation, approximately 74 m^3 (85%) of the spilled oil was lost to the atmosphere through evaporation and 10 m^3 (12%) remained on the shoreline. In addition, 2 m^3 (2%) was predicted to have decayed by the end of the simulation, while there was no oil predicted to remain on the surface.

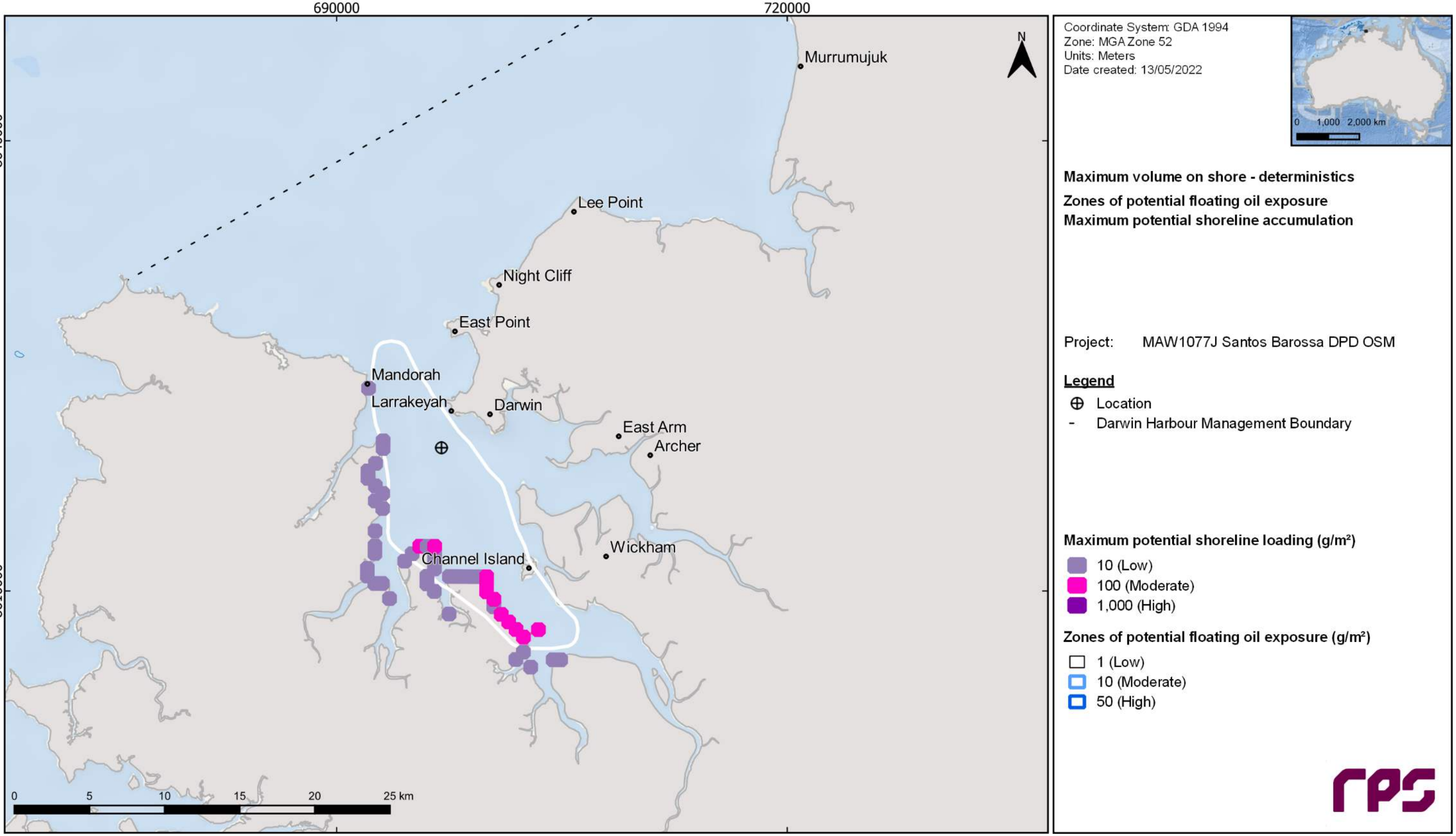

Figure 13.10 Zones of potential exposure on the sea surface and shoreline accumulation (over the 20-days) for the simulation resulting in the maximum volume of oil ashore starting at 2 am 2 September 2019 during the dry season.

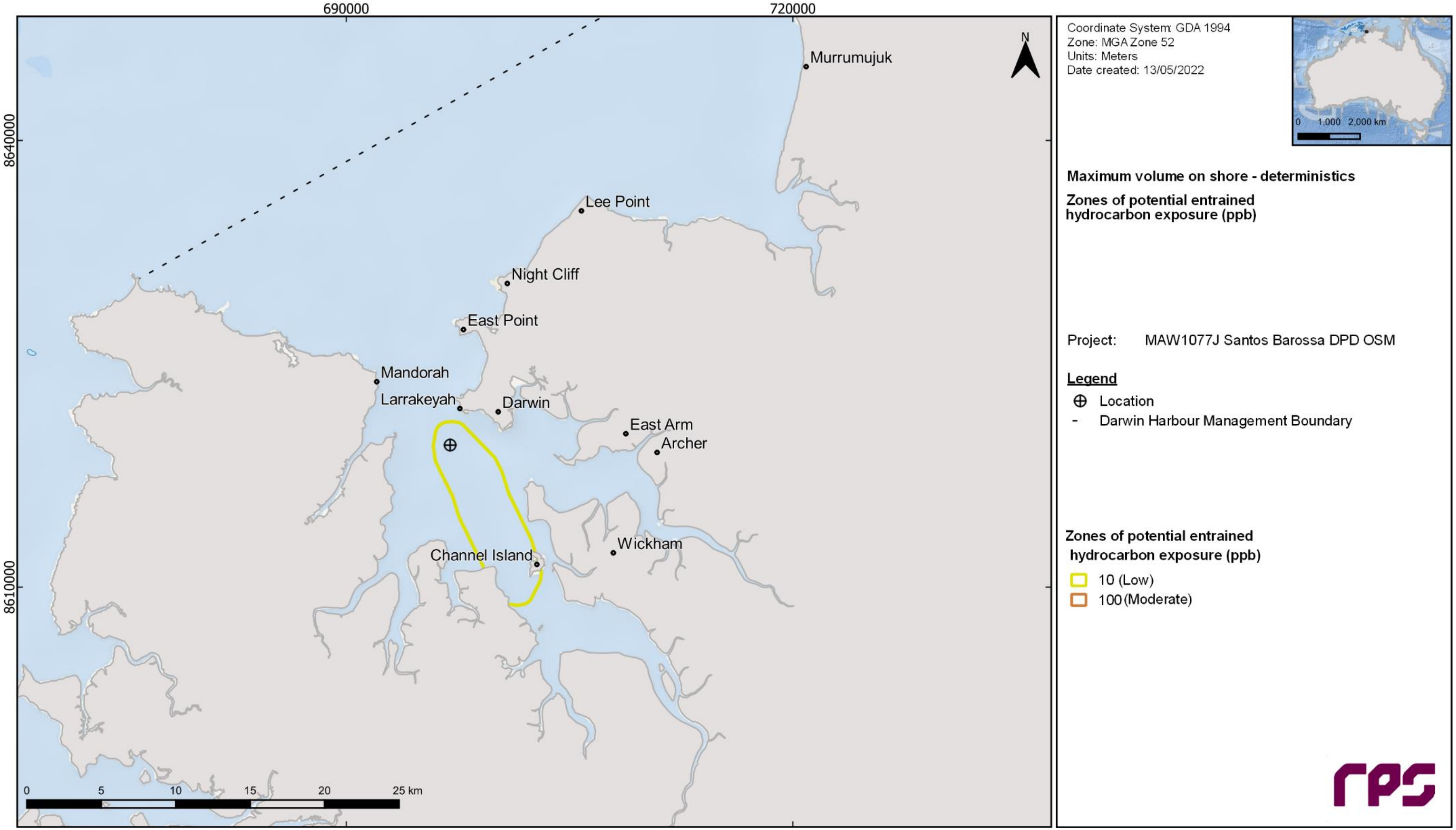

Figure 13.11 Zones of potential entrained hydrocarbon exposure 0 – 10 m below the sea (over the 20-days) for the simulation resulting in the maximum volume of oil ashore starting at 2 am 2 September 2019 during the dry season.

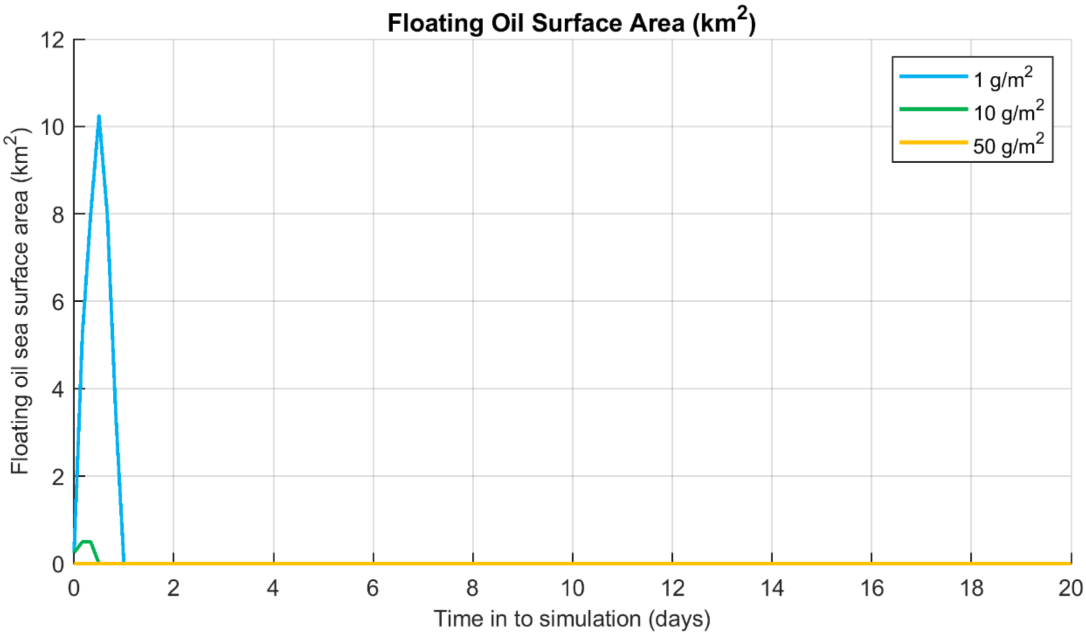

Figure 13.12 Time series of the floating oil surface area exposure for each threshold for the simulation resulting in the maximum volume of oil ashore starting at 2 am 2 September 2019 during the dry season.

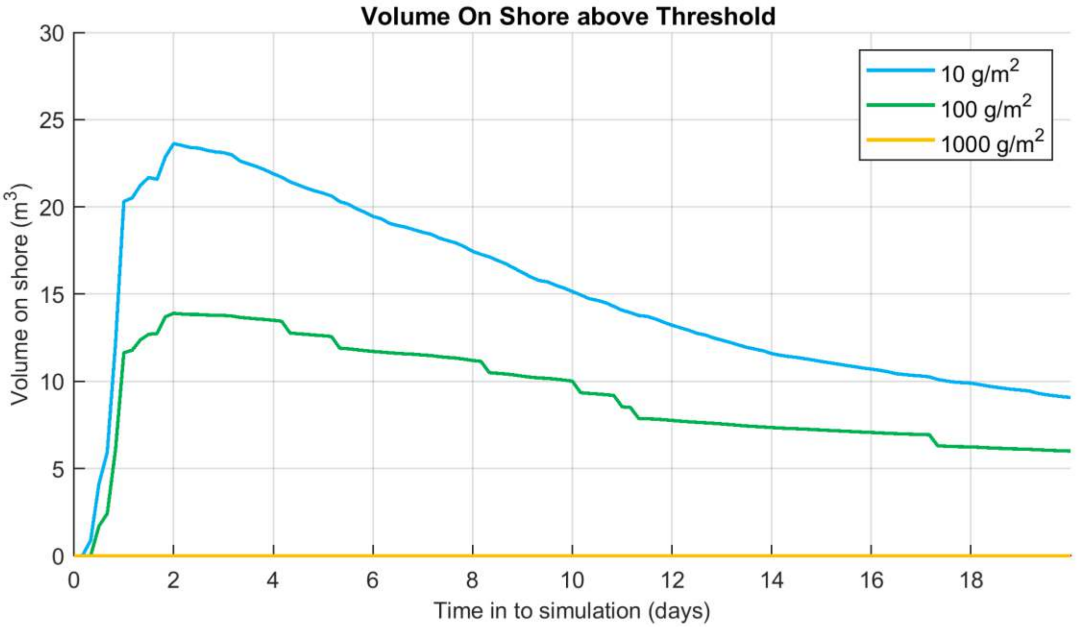

Figure 13.13 Time series of the volume of oil ashore for each threshold for the simulation resulting in the maximum volume of oil ashore starting at 2 am 2 September 2019 during the dry season.

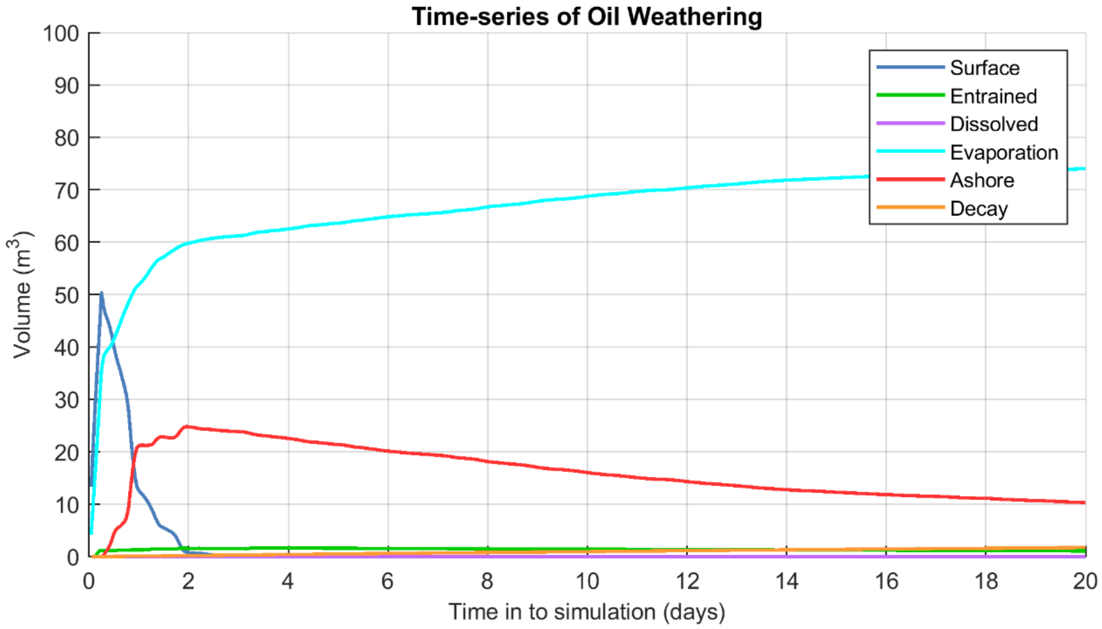

Figure 13.14 Predicted weathering and fates graph for the simulation resulting in the maximum volume of oil ashore starting at 2 am 2 September 2019 during the dry season.

14 SCENARIO 3 RESULTS – VESSEL TO VESSEL REFUELLING AT KP114

This scenario examined the potential exposure following an instantaneous 10 m^3 surface release of MDO vessel to vessel refuelling incident at KP114. A total of 200 spill trajectories were simulated (i.e., 100 spills per season) and tracked for 10 days.

Section 14.1 presents the low threshold environment that may be affected (EMBA) resulting from the 200 spill simulations. Section 14.2 shows the seasonal (or stochastic) analysis, while Section 14.3 presents in more detail the results for the simulation resulting in the largest volume of oil ashore.

14.1 EMBA

Figure 14.1 shows the full geographic EMBA derived by overlaying the results from all 200 spill simulations at the low (≥1 g/m^2) exposure thresholds.

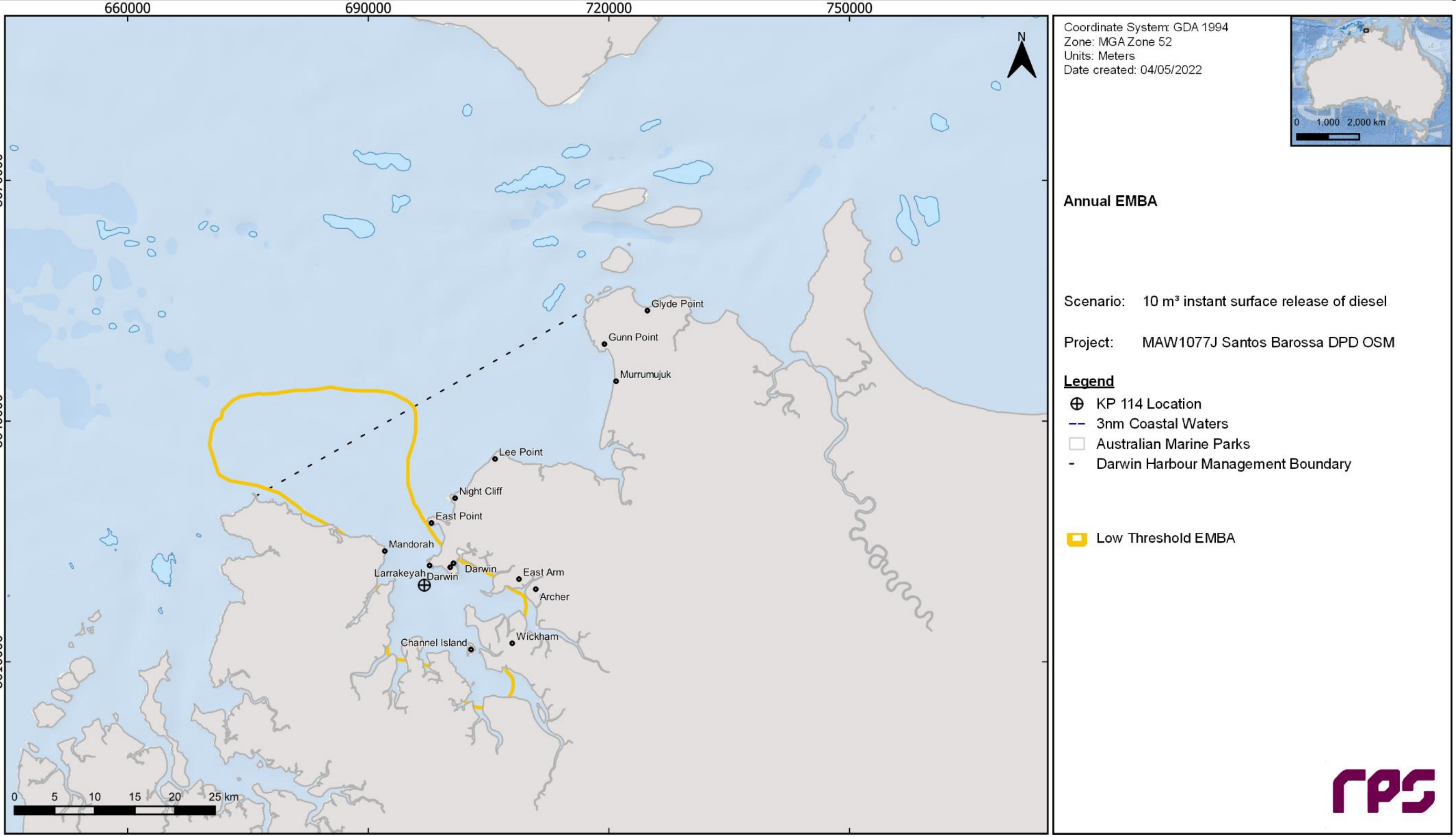

Figure 14.1 Predicted low threshold risk EMBA from a vessel to vessel refuelling incident at KP114. The annualised results were calculated from 200 spill simulations.

14.2 Stochastic Analysis

14.2.1 Floating Oil Exposure

Table 14.1 summarises the maximum distances and directions travelled by the floating oil from the release location at each threshold for each season. The maximum distances to the low (≥1 g/m^2) and moderate (≥10 g/m^2) exposure zones were 22.9 km (northwest) and 12.5 km (northwest), respectively during dry season conditions. There was no exposure predicted for the high threshold (≥ 50 g/m^2).

Table 14.2 summarises the potential floating oil exposure to individual receptors for each season. Figure 14.2 and Figure 14.3 illustrate the extent of floating oil exposure for each season.

During the dry season, exposure at the low threshold was predicted at Restricted Areas 4, 5 and 6 with probabilities ranging between 2 – 7%, while during the wet season exposure was predicted at Restricted Areas 4 (2%) and 5 (1%). No moderate or high threshold exposure was predicted for any Restricted Area.

Additionally, five WQ Zones were predicted to experience floating oil exposure at the low threshold with probabilities ranging between 2 – 21% and 2 – 19% during the dry and wet seasons, respectively (see Table 14.2).

Table 14.1 Maximum distances and directions travelled by floating oil from a vessel to vessel refuelling incident at KP114 at each threshold for each season. Results were calculated from 100 spill simulations per season.

Season	Distance and direction travelled	Zones of potential floating oil exposure		
		Low	Moderate	High
Dry	Maximum distance (km) from release location	22.9	12.5	-
	Maximum distance (km) from the release location (99th percentile)	21.5	12.5	-
	Direction	NW	NW	-
Wet	Maximum distance (km) from release location	19.6	5.5	-
	Maximum distance (km) from release location (99th percentile)	15.2	5.5	-
	Direction	NW	NNW	-

Table 14.2 Summary of the potential exposure by floating oil to individual receptors from a vessel to vessel refuelling incident at KP114 for each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry						Wet					
		Probability of floating oil exposure (%)			Minimum time before floating oil exposure (days)			Probability of floating oil exposure (%)			Minimum time before floating oil exposure (days)		
		Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Restricted Areas	4	7	-	-	0.42	-	-	2	-	-	0.33	-	-
	5	2	-	-	0.21	-	-	1	-	-	0.29	-	-
	6	4	-	-	0.29	-	-	-	-	-	-	-	-
WQ Zones	East Arm	2	-	-	0.54	-	-	4	-	-	0.38	-	-
	Middle Arm	3	-	-	0.21	-	-	2	-	-	0.29	-	-
	West Arm	10	-	-	0.21	-	-	4	-	-	0.29	-	-
	Outer Harbour	21	2	-	0.08	0.13	-	19	-	-	0.08	-	-

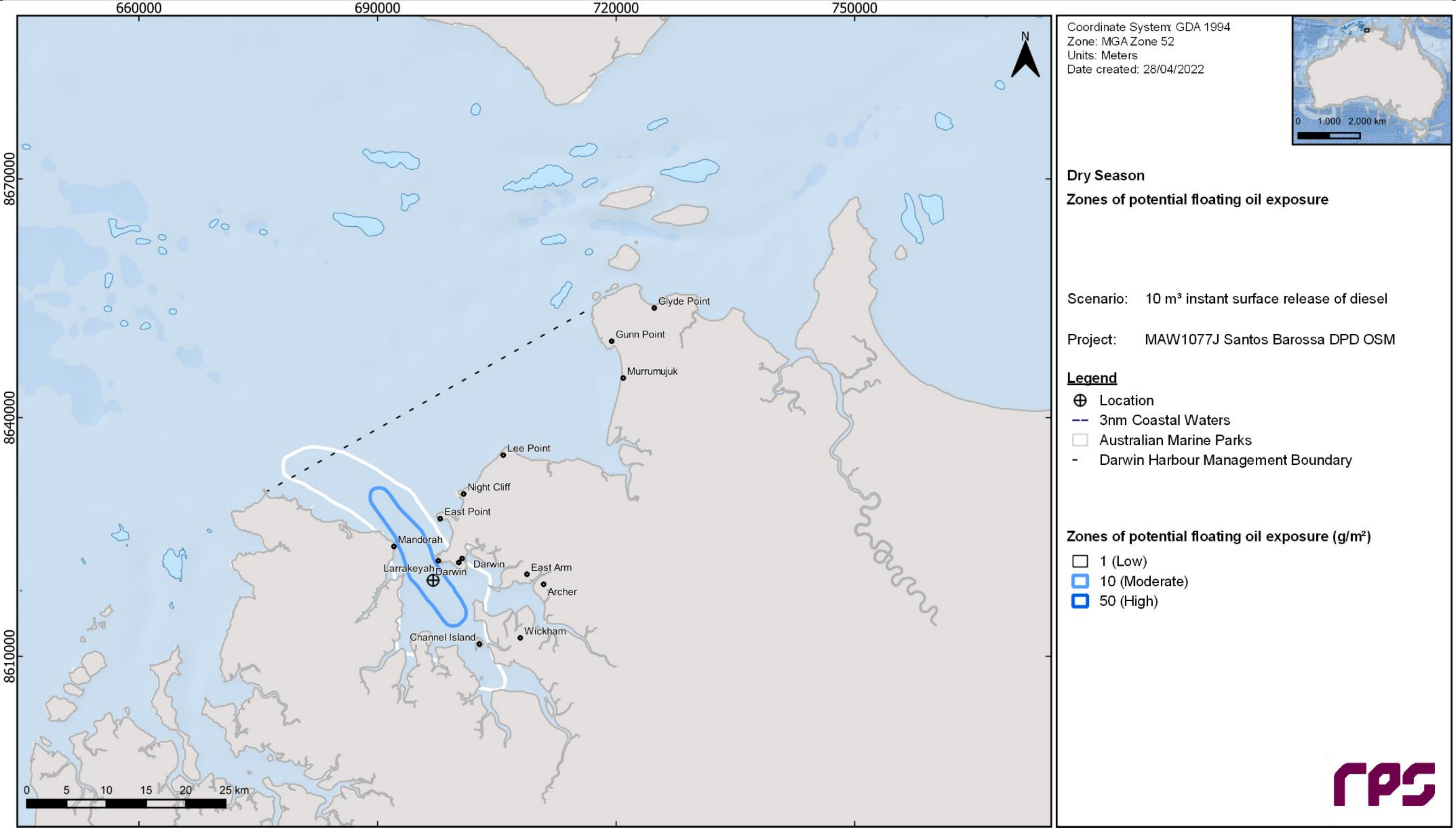

Figure 14.2 Zones of potential floating oil exposure from a vessel to vessel refuelling incident at KP114 during dry season conditions. The results were calculated from 100 spill simulations.

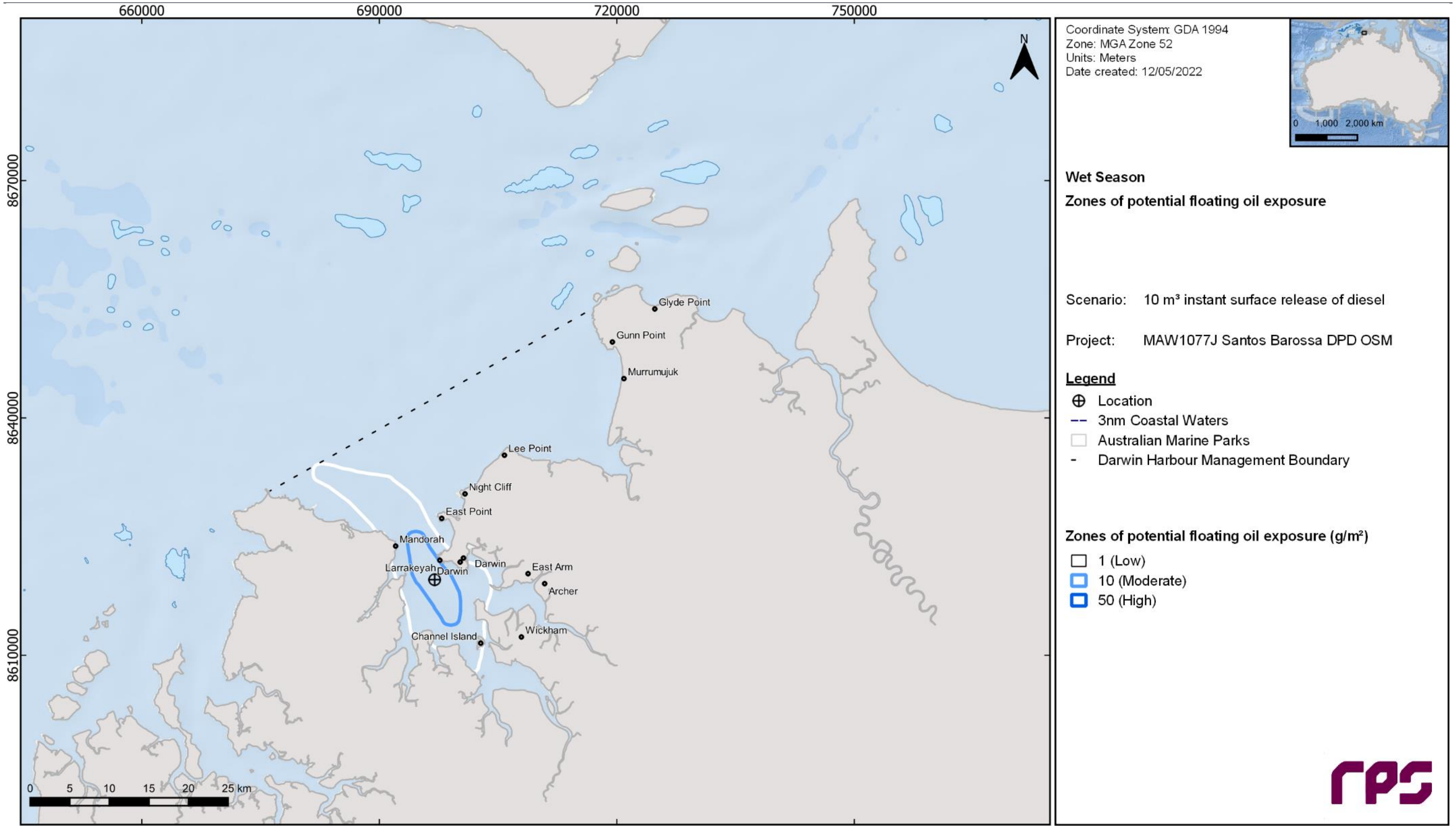

Figure 14.3 Zones of potential floating oil exposure from a vessel to vessel refuelling incident at KP114 during wet season conditions. The results were calculated from 100 spill simulations.

14.2.2 Shoreline Accumulation

Table 14.3 summarises the predicted oil accumulation on any shoreline during each season. The probability of oil accumulation at, or above, the low threshold (10 g/m^2) was 58% during the dry and wet season. The minimum time before oil accumulation at, or above, the low threshold was 0.25 days and 0.29 days for the dry and wet seasons, respectively. The maximum volume ashore for a single spill ranged between 3.9 m^3 (dry season) and 4.3 m^3 (wet season). The maximum length of shoreline contacted at the low threshold was 9 km for the two seasons. The maximum lengths of oil accumulation on shorelines at, or above, the moderate (100 – 1,000 g/m^2) threshold was 2 km during wet season conditions. There was no oil accumulation predicted for the high threshold (≥1,000 g/m^2).

Table 14.4 and Table 14.5 summarise the oil accumulation on individual shoreline receptors for each season. The maximum potential shoreline loading for the specified thresholds for each season are presented in Figure 14.4 and Figure 14.5.

The greatest probabilities of oil accumulation at, or above, the low threshold was predicted for the West Arm (49% dry and 28% wet conditions) and East Arm (8% dry and 26% wet seasons) shorelines. The minimum time before the accumulation was 0.29 days (Middle Arm and West Arm) during the dry season and 0.25 days (East Arm and Wickham Point) during the wet season conditions.

The greatest volume (peak) of oil accumulation during the dry and wet seasons occurred along the West Arm (3.9 m^3) and Wickham Point (4.1 m^3) shorelines, respectively.

Table 14.3 Summary of oil accumulation on any shoreline from a vessel to vessel refuelling incident at KP114 during each season. Results were calculated from 100 spill simulations per season.

Shoreline Statistics	Dry			Wet		
	Low	Moderate	High	Low	Moderate	High
Probability of accumulation on any shoreline (%)	58	14	-	58	16	-
Absolute minimum time before oil ashore (days)	0.29	0.38	-	0.25	0.29	-
Maximum length of shoreline contacted	9	0.5	-	9	2	-
Average length of shoreline contacted (km)	2.6	0.4	-	3	0.7	-
		Dry			Wet	
Maximum volume of hydrocarbons ashore (m^3)		3.9			4.3	
Average volume of hydrocarbons ashore (m^3)		0.7			0.8	

Table 14.4 Summary of oil accumulation on individual shoreline sectors from a vessel to vessel refuelling incident at KP114 for the dry season. Results were calculated from 100 spill simulations per season.

Shoreline sector	Maximum probability of shoreline loading (%)			Minimum time before shoreline accumulation (days)			Load on shoreline (g/m²)		Volume on shoreline (m³)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Low	Moderate	High	Low	Moderate	High	Mean	Peak	Mean	Peak	Low	Moderate	High	Low	Moderate	High
East Arm	8	4	-	0.33	0.42	-	3	130	0.1	2.2	1.7	0.5	-	3.5	0.5	-
Middle Arm	4	-	-	0.29	-	-	<1	27	<0.1	0.3	1.4	-	-	1.5	-	-
Outer Harbour West	2	-	-	0.88	-	-	<1	61	<0.1	1.2	1.7	-	-	2	-	-
West Arm	49	6	-	0.29	0.38	-	3	137	0.5	3.9	2.4	0.5	-	8.5	0.5	-
Wickham Point	3	-	-	0.42	-	-	<1	27	<0.1	0.5	1.3	-	-	2	-	-

Table 14.5 Summary of oil accumulation on individual shoreline sectors from a vessel to vessel refuelling incident at KP114 for the wet season. Results were calculated from 100 spill simulations per season.

Shoreline sector	Maximum probability of shoreline loading (%)			Minimum time before shoreline accumulation (days)			Load on shoreline (g/m²)		Volume on shoreline (m³)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Low	Moderate	High	Low	Moderate	High	Mean	Peak	Mean	Peak	Low	Moderate	High	Low	Moderate	High
East Arm	26	6	-	0.25	0.29	-	2	208	0.2	2.6	1.9	0.6	-	9	1	-
Middle Arm	1	-	-	0.33	-	-	55	55	0.4	0.4	1	-	-	1	-	-
Outer Harbour West	1	-	-	2.75	-	-	14	14	0.3	0.3	0.5	-	-	0.5	-	-
West Arm	28	8	-	0.29	0.29	-	5	199	0.4	3	2.8	0.6	-	8	1	-
Wickham Point	19	2	-	0.25	0.58	-	3	133	0.2	4.1	1.9	1.2	-	6	2	-

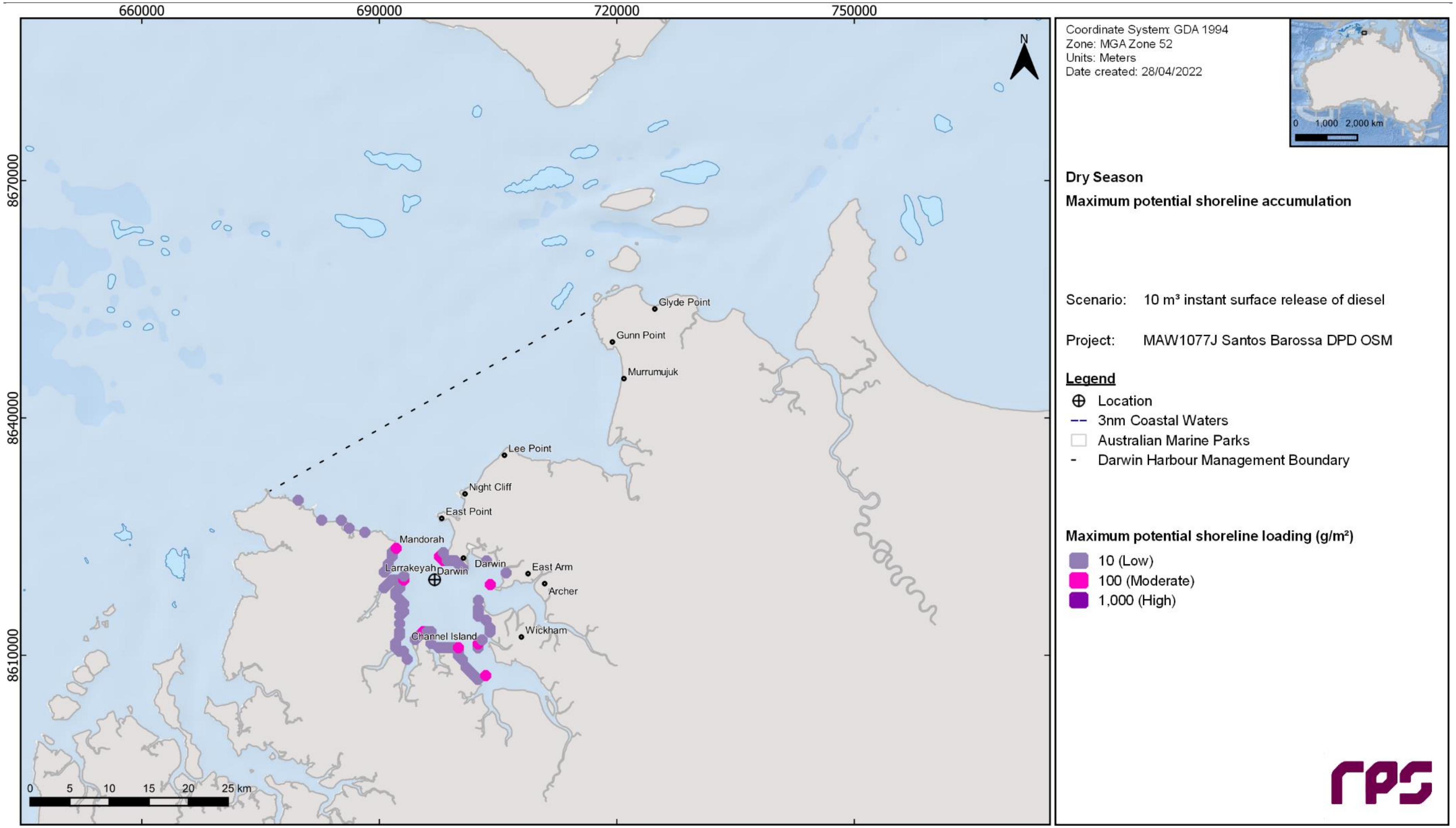

Figure 14.4 Maximum potential shoreline loading from a vessel to vessel refuelling incident at KP114 during dry season conditions. The results were calculated from 100 spill simulations.

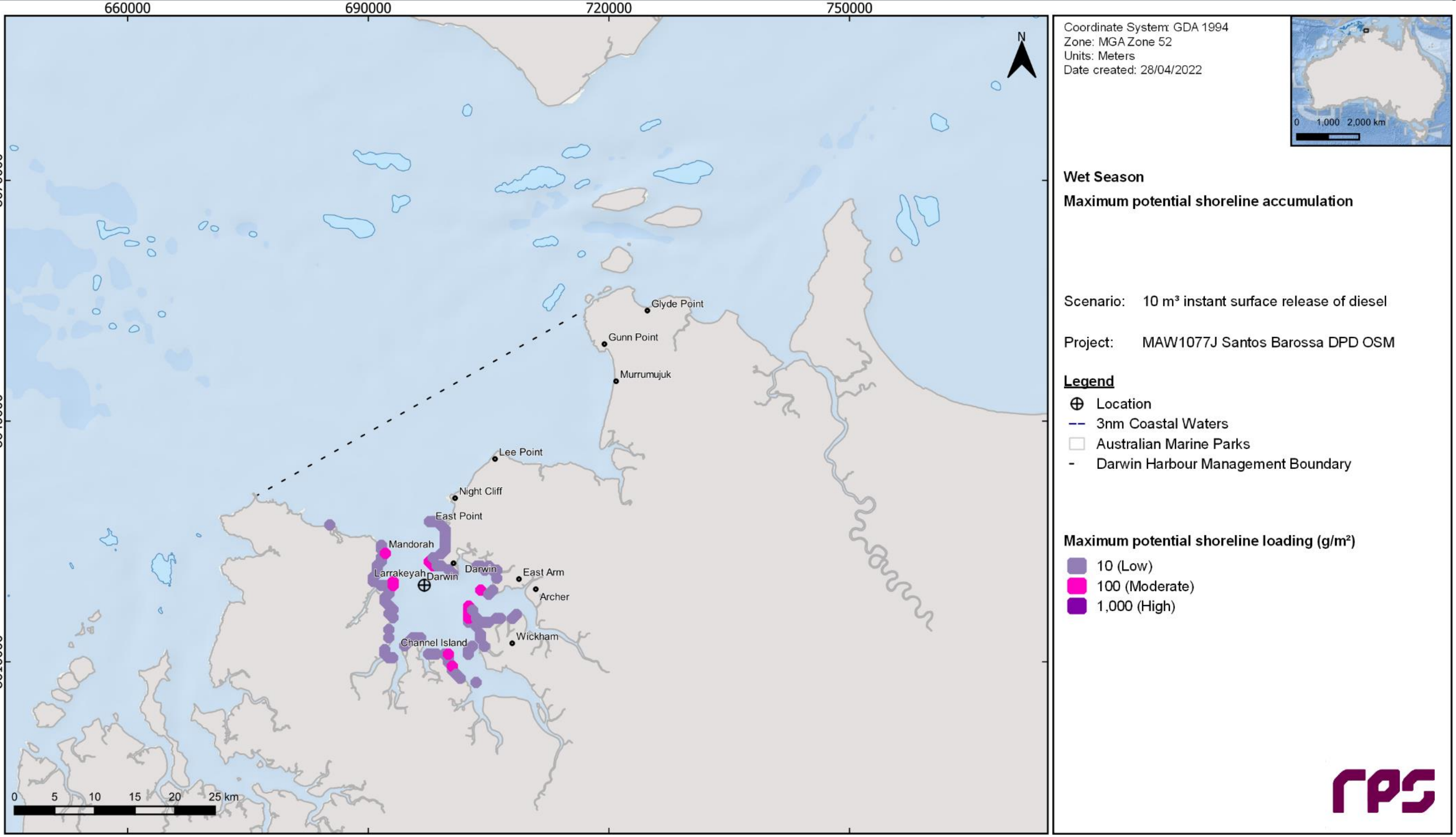

Figure 14.5 Maximum potential shoreline loading from a vessel to vessel refuelling incident at KP114 during wet season conditions. The results were calculated from 100 spill simulations.

14.2.3 In-water exposure

14.2.3.1 Dissolved Hydrocarbons

There was no dissolved hydrocarbon exposure predicted for any spills during this scenario at or above the low threshold ((≥ 10 ppb).

14.2.3.2 Entrained Hydrocarbons

Table 14.6 summarises the maximum distances and directions travelled by entrained hydrocarbons within the 0 – 10 m depth layers for the low (≥ 10 ppb) and moderate (≥ 100 ppb) thresholds, which ranged between 32 km and 18.9 km northwest from the release location during dry season conditions and 31.9 km and 19.6 km northwest from the release location during wet season conditions.

Table 14.7 summarises the potential exposure to receptors from entrained hydrocarbons in the 0-10 m depth layer for each season. Figure 14.6 to Figure 14.7 illustrate extent of entrained hydrocarbon exposure for each season in the 0 – 10 m depth layer.

During both seasons the Charles Point Wide RFPA and three Restricted Areas (4, 5 and 6) were predicted to be exposed at the low threshold with probabilities ranging from 8 – 50% and 4 – 29% during the dry and wet seasons, respectively. During both seasons Restricted Area 6 was predicted to have the greatest probability of low threshold exposure (50% dry season and 29% wet season).

Exposure for the low threshold was predicted at 15 shipwreck receptors during both seasons, with probabilities ranging from 2% (Ellengowan and Middle Arm unidentified wreck) and 61% (Ham Luong) during the dry season and 2% (Ellengowan, Mandorah Unidentified wreck 1 and Middle Arm unidentified wreck) and 64% (Mauna Loa USAT) during the wet season. The maximum entrained concentrations were also predicted Ham Luong (745 ppb) and Mauna Loa USAT (639 ppb) shipwrecks for the two seasons.

Four WQ Zones were predicted to be exposed to entrained hydrocarbons at the low threshold during both seasons with probabilities ranging from 6% (East Arm) and 36% (Outer Harbour) during the dry season and 7% (Middle Arm) and 30% (Outer Harbour) during the wet season. The maximum entrained concentrations were predicted at Outer Harbour during both the dry (265 ppb) and wet (301 ppb) seasons.

Table 14.6 Maximum distances and directions travelled by entrained hydrocarbons (0 – 10 m depth layer) from the release location for a vessel to vessel refuelling incident at KP114 during each season during each season. Results were calculated from 100 spill simulations per season.

Season	Distance and direction travelled	Zones of potential entrained hydrocarbon exposure	
		Low 10 ppb	Moderate 100 ppb
Dry	Maximum distance (km) from release location	32.0	18.9
	Maximum distance (km) from release location (99th percentile)	30.9	18.7
	Direction	NW	NW
Wet	Maximum distance (km) from release location	31.9	19.6
	Maximum distance (km) from release location (99th percentile)	30.5	19.0
	Direction	NW	NW

Table 14.7 Probability of entrained hydrocarbons exposure to receptors in the 0 – 10 m depth layer from a vessel to vessel refuelling incident at KP114 during each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry					Wet				
		Maximum concentration (ppb)	Probability of instantaneous entrained hydrocarbon exposure		Minimum time (days) before instantaneous entrained hydrocarbon exposure		Maximum concentration (ppb)	Probability of instantaneous entrained hydrocarbon exposure		Minimum time (days) before instantaneous entrained hydrocarbon exposure	
			Low	Mod	Low	Mod		Low	Mod	Low	Mod
RFPA	Charles Point Wide	44	8	-	0.67	-	42	4	-	0.63	-
Restricted Area	4	34	36	-	0.21	-	36	14	-	0.29	-
	5	40	14	-	0.13	-	75	11	-	0.17	-
	6	44	50	-	0.17	-	66	29	-	0.29	-
Shipwrecks	Bell Bird	36	10	-	0.25	-	36	24	-	0.21	-
	Booya	48	12	-	0.13	-	54	15	-	0.13	-
	British Motorist	49	16	-	0.17	-	50	39	-	0.13	-
	Darwin Harbour Unidentified wreck 2	102	34	1	0.08	0.21	82	51	-	0.08	-
	Diemen	43	30	-	0.17	-	60	16	-	0.29	-
	Ellengowan	14	2	-	0.46	-	33	2	-	0.17	-
	Ham Luong	745	61	13	0.04	0.04	297	62	13	0.04	0.04
	L. Ann	15	6	-	0.42	-	15	2	-	0.54	-
	Landing Barge	25	10	-	0.29	-	36	29	-	0.25	-
	Mandorah Unidentified wreck 1	15	6	-	0.42	-	15	2	-	0.54	-
	Mauna Loa USAT	687	56	13	0.04	0.04	639	64	13	0.04	0.04
	Middle Arm unidentified wreck	14	2	-	0.46	-	33	2	-	0.17	-
	Peary USS	84	33	-	0.13	-	82	46	-	0.08	-
	Vietnamese Refugee Boat Pk76	24	4	-	0.33	-	20	7	-	0.29	-
	Yu Han 22	218	40	2	0.08	0.13	209	44	2	0.08	0.13
WQ Zones	East Arm	21	6	-	0.29	-	35	18	-	0.25	-

	Middle Arm	134	8	2	0.17	0.21	94	7	0	0.21	-
	West Arm	35	26	-	0.17	-	36	11	-	0.17	-
	Outer Harbour	265	36	5	0.08	0.13	301	30	6	0.08	0.08

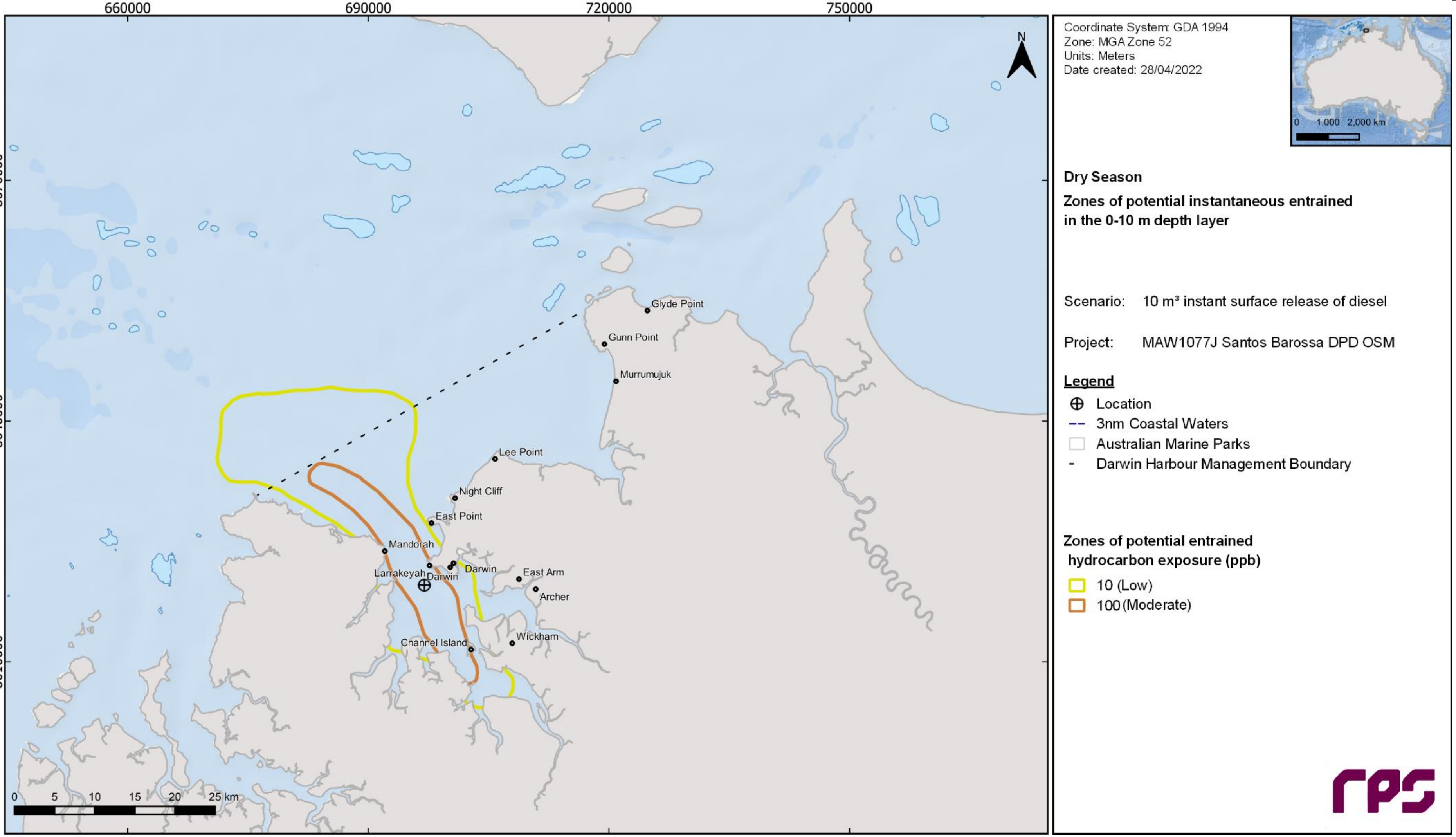

Figure 14.6 Zones of potential entrained hydrocarbon exposure at 0 – 10 m below the sea surface from a vessel to vessel refuelling incident at KP114 during dry season conditions. The results were calculated from 100 spill simulations.

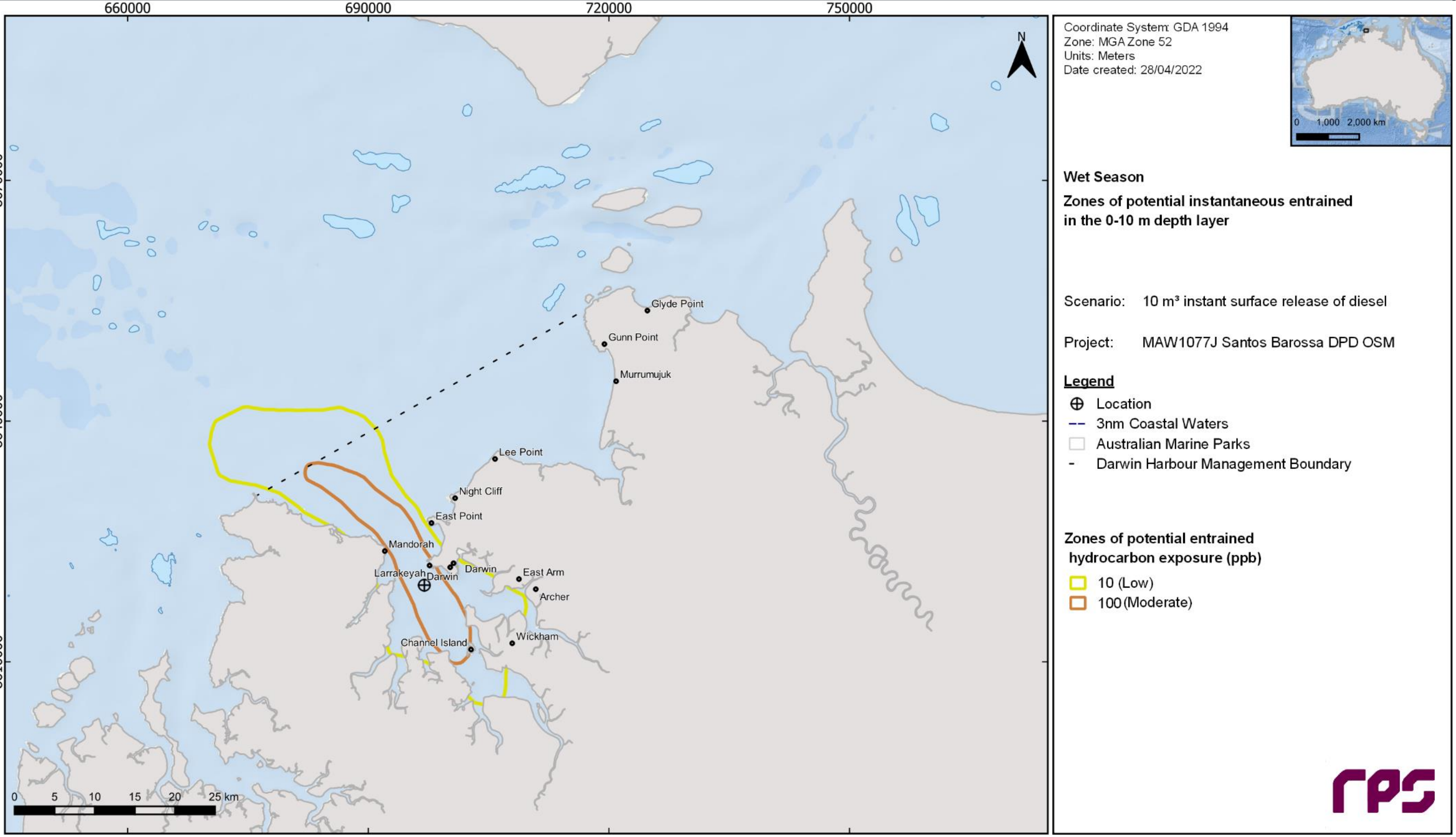

Figure 14.7 Zones of potential entrained hydrocarbon exposure at 0 – 10 m below the sea surface from a vessel to vessel refuelling incident at KP114 during wet season conditions. The results were calculated from 100 spill simulations.

14.3 Deterministic Analysis

The stochastic modelling results were assessed and the deterministic simulation resulting in the largest volume ashore (4.3 m^3) was identified as run 69, which commenced at 6 pm 25 November 2019 during the wet season.

Zones of exposure on the sea surface (swept area) and shoreline accumulation over the entire 10-day simulation are presented in Figure 14.8. The spill had drifted south-southeast from the release from the release location and the oil was predicted to accumulate on the shoreline at Wickham.

No zones of entrained and dissolved hydrocarbon exposure were predicted above the minimum reporting thresholds or the simulation.

Figure 14.9 and Figure 14.10 show time series of the area of floating oil exposure and the volume of oil ashore for each threshold during the 10-day simulation.

Figure 14.11 presents the fates and weathering for the corresponding single spill trajectory. At the conclusion of the simulation, approximately 8 m^3 (80%) of oil had evaporated and 2 m^3 (20%) had accumulated on the shoreline.

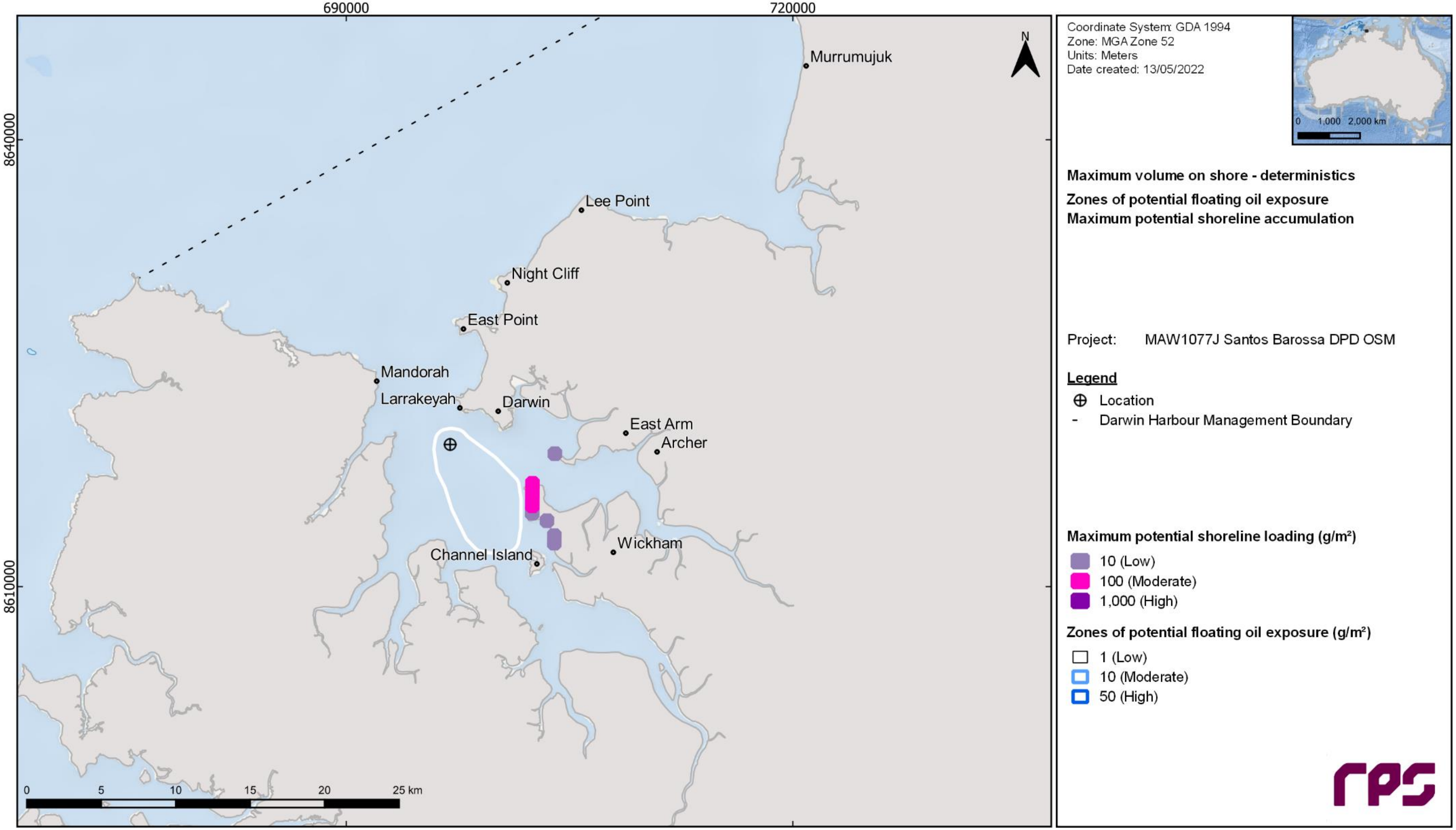

Figure 14.8 Zones of potential exposure on the sea surface and shoreline accumulation (over the 10 days) for the simulation resulting in the maximum volume of oil ashore starting at 6 pm 25 November 2019 during the wet season.

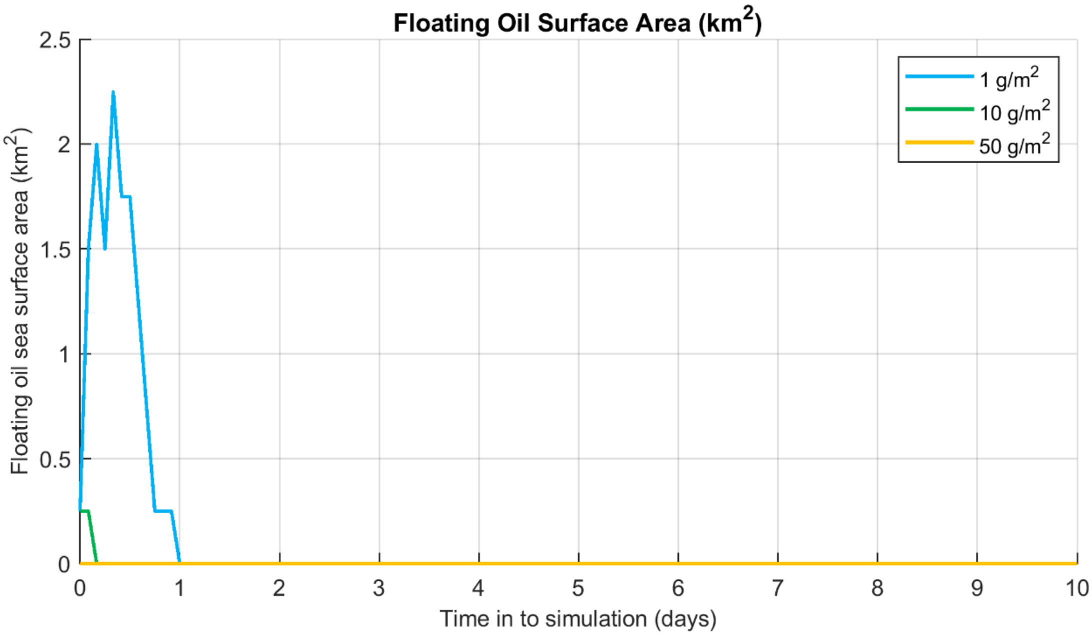

Figure 14.9 Time series of the area of floating oil exposure for each threshold for the simulation resulting in the maximum volume of oil ashore starting at 6 pm 25 November 2019 during the wet season.

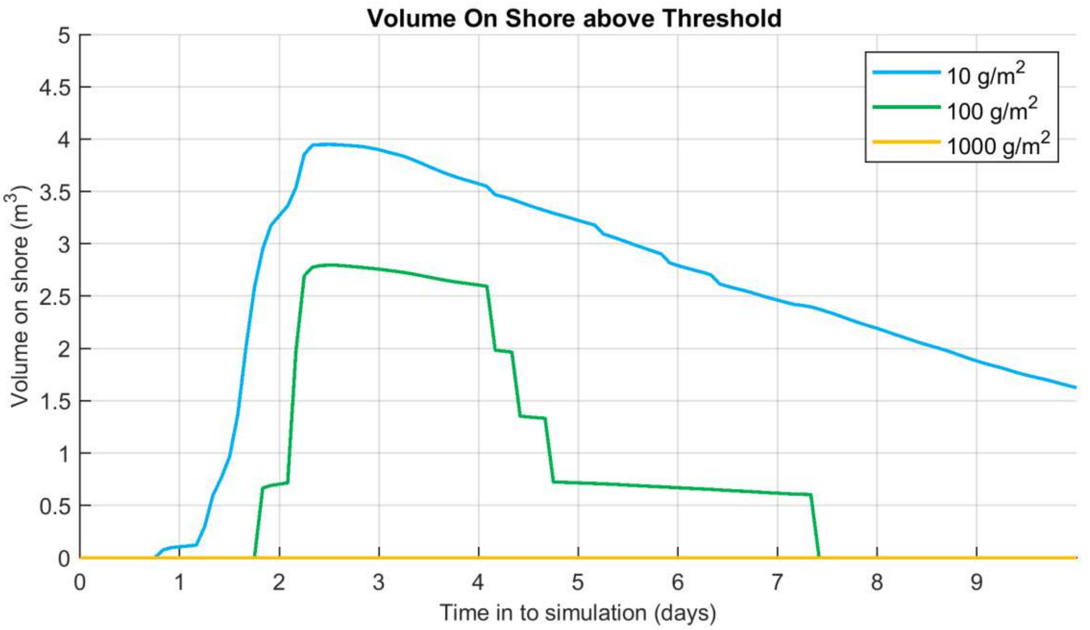

Figure 14.10 Time series of the volume of oil ashore for each threshold for the simulation resulting in the maximum volume of oil ashore starting at 6 pm 25 November 2019 during the wet season.

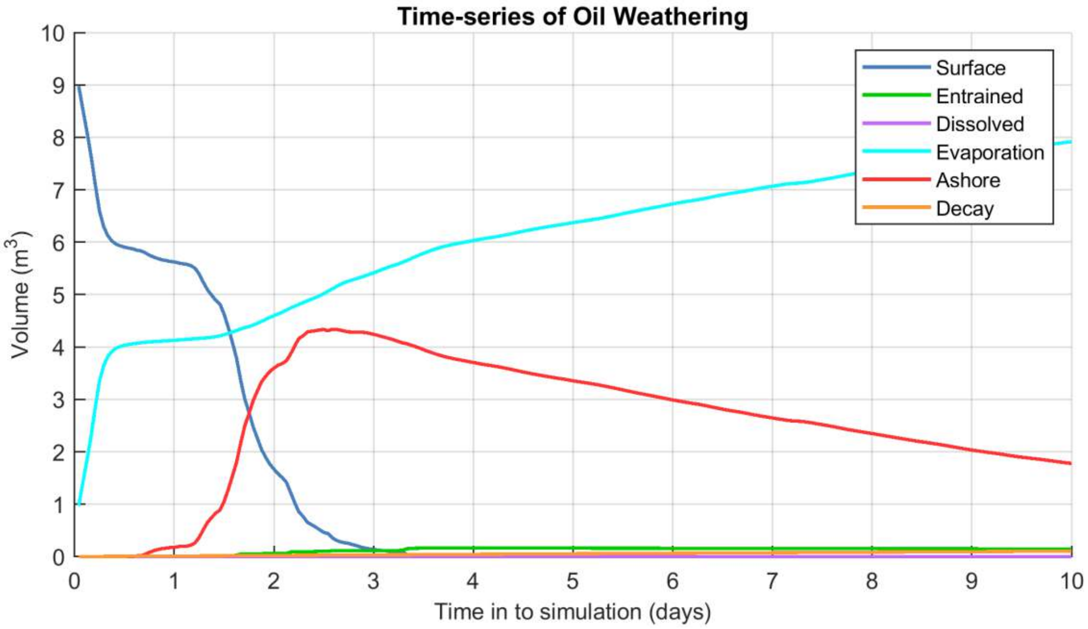

Figure 14.11 Predicted weathering and fates graph for the simulation resulting in the maximum volume of oil ashore starting at 6 pm 25 November 2019 during the wet season.

15 SCENARIO 4 RESULTS – VESSEL FUEL TANK RUPTURE AT KP114

This scenario examined the potential exposure following a 300 m^3 surface release of MDO over 6 hours in the event of a vessel fuel tank rupture at KP114. A total of 200 spill trajectories were simulated (i.e., 100 spills per season) and tracked for 30 days.

Section 15.1 presents the low threshold environment that may be affected (EMBA), resulting from the 200 spill simulations. Section 15.2 shows the seasonal (or stochastic) analysis, while Section 15.3 presents in more detail the results for the simulation resulting in the largest volume of oil ashore.

15.1 EMBA

Figure 15.1 shows the full geographic EMBA derived by overlaying the results from all 200 spill simulations at the low (≥1 g/m^2) exposure thresholds.

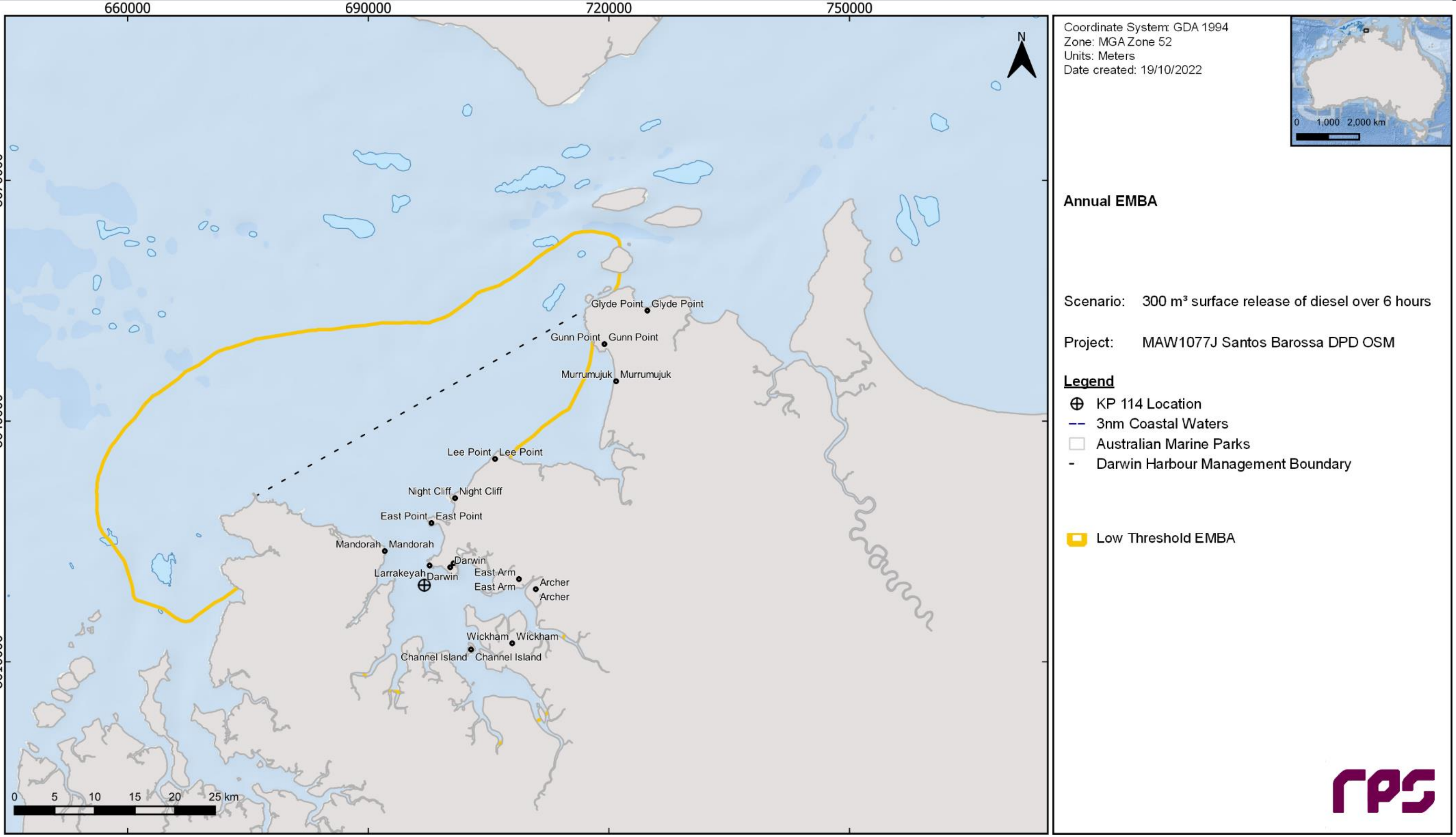

Figure 15.1 Predicted low threshold risk EMBA from a vessel fuel tank rupture at KP114. The annualised results were calculated from 200 spill simulations.

15.2 Stochastic Analysis

15.2.1 Floating Oil Exposure

Table 15.1 summarises the maximum distances and directions travelled by the floating oil from the release location at each threshold for each season. The maximum distances to the low (≥1 g/m^2), moderate (≥10 g/m^2) and high (≥ 50 g/m^2) exposure zones were 24.2 km (northwest), 19.6 km (northwest) and 10.2 km (north-northwest), respectively, during dry season conditions and 33.4 km (northwest), 18.9 km (northwest) and 8.4 km (north-northwest), respectively during wet season conditions. Table 15.2 summarises the potential floating oil exposure to individual receptors for each season and Figure 15.2 and Figure 15.3 illustrate the extent of floating oil exposure for each season.

During both the dry and wet seasons, floating oil exposure at the low threshold was predicted at Restricted Areas 1, 4, 5 and 6 with probabilities ranging between 1 – 60% and 1 – 30%, during the dry and wet season, respectively. Additionally, floating oil exposure at the moderate threshold was predicted at Restricted Areas 4 and 6 with probabilities of 10% and 4%, respectively during the dry season and 8% and 5%, respectively during the wet season. No high exposure was predicted for any Restricted Area.

Only the two simulations during wet season conditions (2% probability) triggered the low threshold exposure within Charles Point Wide RFPA, with a minimum time of exposure of 0.96 days.

During the dry season five WQ Zones recorded floating oil exposure at the low threshold with probabilities ranging between 13% (Middle Arm) and 100% (Middle Harbour). In comparison, during the wet season six WQ Zones recorded floating oil exposure at the low threshold with probabilities ranging between 1% (Elizabeth River) and 100% (Middle Harbour, see Table 15.2).

Table 15.1 Maximum distances and directions travelled by floating oil from vessel fuel tank rupture at KP114 at each threshold for each season. Results were calculated from 100 spill simulations per season.

Season	Distance and direction travelled	Zones of potential floating oil exposure		
		Low	Moderate	High
Dry	Maximum distance (km) from release location	24.2	19.6	10.2
	Maximum distance (km) from the release location (99th percentile)	21.2	18.7	9.9
	Direction	NW	NW	NNW
Wet	Maximum distance (km) from release location	33.4	18.9	8.4
	Maximum distance (km) from release location (99th percentile)	31.7	17.5	8.3
	Direction	NW	NW	NNW

Table 15.2 Summary of the potential exposure by floating oil to individual receptors from a vessel fuel tank rupture at KP114 for each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry						Wet					
		Probability of floating oil exposure (%)			Minimum time before floating oil exposure (days)			Probability of floating oil exposure (%)			Minimum time before floating oil exposure (days)		
		Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
IMCRA	Beagle Gulf-Darwin Coast	100	100	99	0.04	0.04	0.04	100	100	97	0.04	0.04	0.04
IMCRA	Anson Beagle	100	100	99	0.04	0.04	0.04	100	100	97	0.04	0.04	0.04
RFPA	Charles Point Wide	-	-	-	-	-	-	2	-	-	0.96	-	-
Restricted Areas	1	1	-	-	1	-	-	1	-	-	1.92	-	-
Restricted Areas	4	60	10	-	0.17	0.42	-	30	8	-	0.29	0.5	-
Restricted Areas	5	25	2	-	0.21	0.33	-	17	-	-	0.17	-	-
Restricted Areas	6	55	4	-	0.21	0.46	-	30	5	-	0.25	0.46	-
WQ Zones	Elizabeth River	-	-	-	-	-	-	1	-	-	1.29	-	-
WQ Zones	East Arm	29	5	-	0.29	0.33	-	43	5	-	0.21	0.58	-
WQ Zones	Middle Arm	13	5	-	0.21	0.25	-	19	5	-	0.17	0.17	-
WQ Zones	West Arm	60	10	-	0.21	0.33	-	35	10	-	0.21	0.5	-
WQ Zones	Middle Harbour	100	100	99	0.04	0.04	0.04	100	100	97	0.04	0.04	0.04
WQ Zones	Outer Harbour	82	49	2	0.08	0.08	0.21	67	30	3	0.08	0.08	0.17

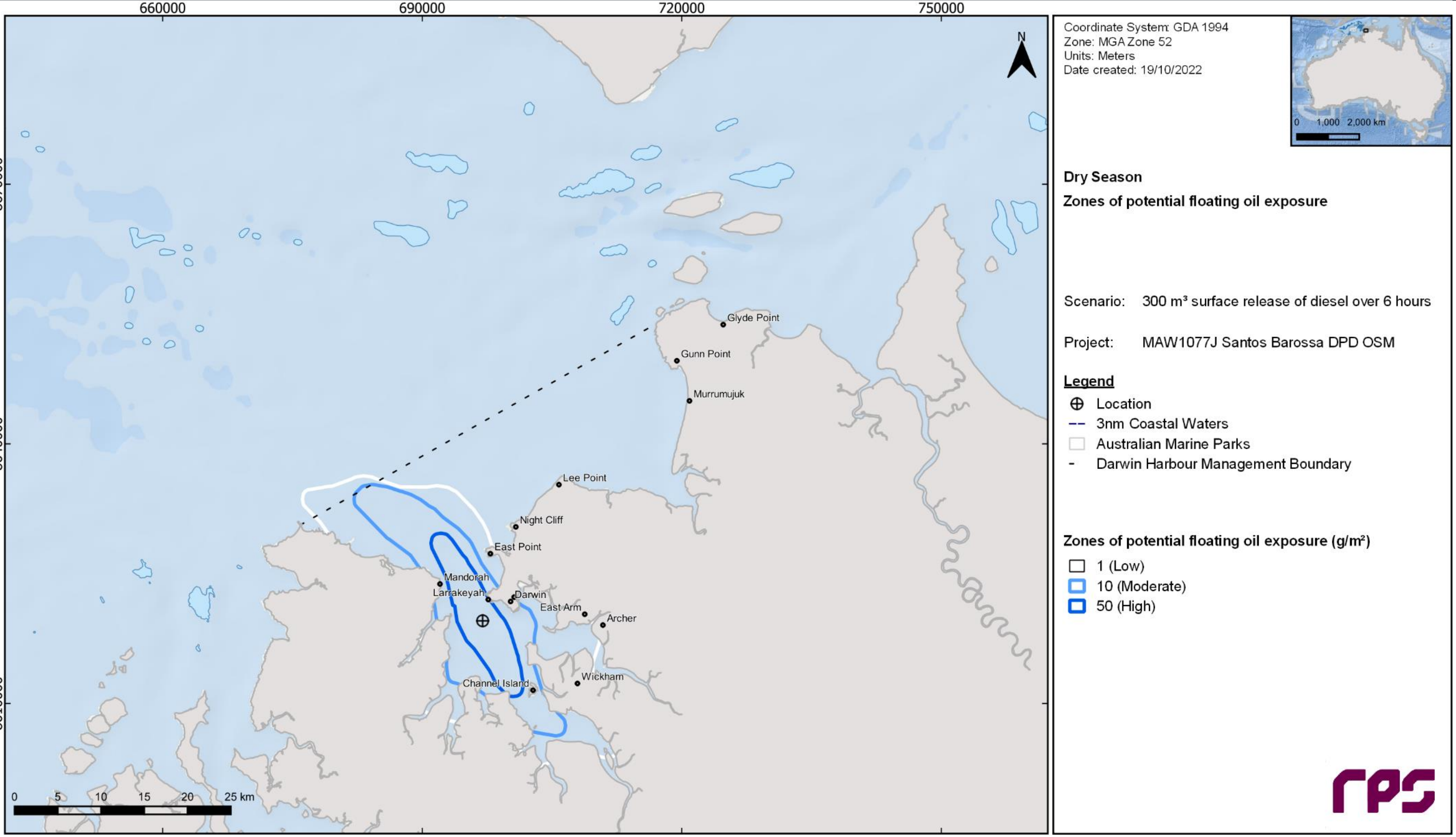

Figure 15.2 Zones of potential floating oil exposure from a vessel fuel tank rupture at KP114 during dry season conditions. The results were calculated from 100 spill simulations.

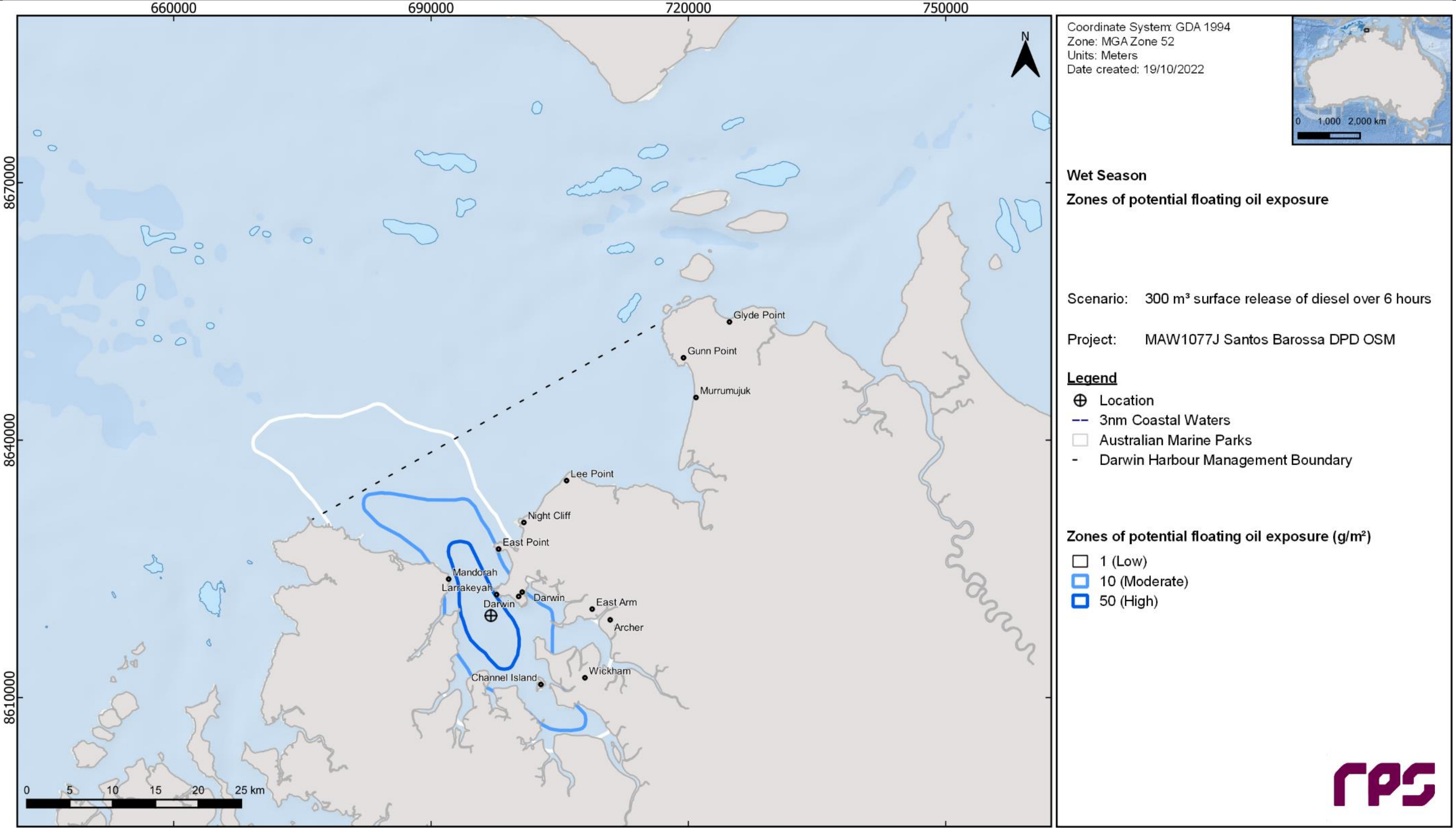

Figure 15.3 Zones of potential floating oil exposure from a vessel fuel tank rupture at KP114 during wet season conditions. The results were calculated from 100 spill simulations.

15.2.2 Shoreline Accumulation

Table 15.3 summarises the predicted oil accumulation on any shoreline during each season. The probability of shoreline accumulation at, or above, the low threshold (10 g/m^2) was 100% (dry season) and 91% (wet season). The minimum time before oil accumulation at, or above, the low threshold was 0.21 days during the dry and wet seasons. The maximum volume ashore for a single spill during the dry and wet season was 114.8 m^3 and 115.5 m^3, respectively, and the maximum length of shoreline contacted at the low threshold was 57.7 km (dry season) and 54.2 km (wet season). The maximum lengths of oil accumulation on shorelines at, or above, the moderate (100 – 1,000 g/m^2) and high (≥1,000 g/m^2) thresholds was 21.1 km (dry season) and 19.1 km (wet season), and 2.0 km (dry season) and 2.5 km (wet season), respectively.

Table 15.4 and Table 15.5 summarise the oil accumulation on individual shoreline receptors for each season. The maximum potential shoreline loading for the specified thresholds for each season are presented in Figure 15.4 and Figure 15.5.

The highest probability of oil accumulation at the low threshold was predicted along the West Arm (88% dry and 49% wet seasons) and East Arm (44% dry and 60% wet conditions) shorelines. The highest volume of oil accumulation during the dry and wet seasons occurred along the West Arm shoreline (103.5 m^3 (dry season) and 111.7 m^3 (wet season)). The minimum time before oil accumulation at the low threshold was 0.21 days (East Arm) for the dry season and 0.21 days (Wickham Point) during the wet season conditions.

Table 15.3 Summary of oil accumulation on any shoreline from a vessel fuel tank rupture at KP114 during each season. Results were calculated from 100 spill simulations per season.

Shoreline Statistics	Dry			Wet		
	Low	Moderate	High	Low	Moderate	High
Probability of accumulation on any shoreline (%)	100	85	23	91	75	29
Absolute minimum time before oil ashore (days)	0.21	0.29	0.46	0.21	0.21	0.29
Maximum length of shoreline contacted	57.7	21.1	2.0	54.2	19.1	2.5
Average length of shoreline contacted (km)	15.5	4.4	0.9	16.1	5.2	1.0
		Dry			Wet	
Maximum volume of hydrocarbons ashore (m^3)		114.8			115.5	
Average volume of hydrocarbons ashore (m^3)		20.2			21.0	

Table 15.4 Summary of oil accumulation on individual shoreline sectors from a vessel fuel tank rupture at KP114 for the dry season. Results were calculated from 100 spill simulations per season.

Shoreline sector	Maximum probability of shoreline loading (%)			Minimum time before shoreline accumulation (days)			Load on shoreline (g/m²)		Volume on shoreline (m³)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Low	Moderate	High	Low	Moderate	High	Mean	Peak	Mean	Peak	Low	Moderate	High	Low	Moderate	High
Cox-Finniss	5	-	-	1.25	-	-	27	76	< 0.1	0.9	0.7	-	-	1	-	-
Vernon Islands	-	-	-	-	-	-	-	-	< 0.1	< 0.1	-	-	-	-	-	-
East Arm	44	22	3	0.21	0.33	0.63	79	2,587	2.2	41.4	3.5	1.9	0.5	23	7.5	0.5
Outer Harbour East	-	-	-	-	-	-	-	-	< 0.1	< 0.1	-	-	-	-	-	-
Wickham Point	30	11	-	0.25	0.58	-	35	411	0.6	8.6	3.7	1	-	10.5	2.5	-
Outer Harbour West	16	3	-	0.67	0.96	-	23	116	0.2	5.3	2.5	0.8	-	8	1	-
West Arm	88	71	20	0.25	0.33	0.46	89	4,779	16	103.5	12.4	4.1	0.8	37	17	2
Middle Arm	33	6	-	0.33	0.38	-	36	845	0.9	22.4	3.1	2.6	-	20.5	5	-

Table 15.5 Summary of oil accumulation on individual shoreline sectors from a vessel fuel tank rupture at KP114 for the wet season. Results were calculated from 100 spill simulations per season.

Shoreline sector	Maximum probability of shoreline loading (%)			Minimum time before shoreline accumulation (days)			Load on shoreline (g/m²)		Volume on shoreline (m³)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Low	Moderate	High	Low	Moderate	High	Mean	Peak	Mean	Peak	Low	Moderate	High	Low	Moderate	High
Cox-Finniss	5	-	-	2	-	-	21	41	< 0.1	0.4	0.7	-	-	1	-	-
Vernon Islands	1	-	-	13.17	-	-	20	23	< 0.1	0.5	1	-	-	1	-	-
East Arm	60	38	6	0.25	0.33	0.5	74	1,899	3.9	54.8	5.3	1.6	0.7	18	8.5	1.5
Outer Harbour East	4	1	-	0.71	0.79	-	66	132	< 0.1	0.9	0.5	0.5	-	0.5	0.5	-
Wickham Point	50	31	2	0.21	0.29	1.67	78	1,103	3.1	31.7	5.3	2.4	0.5	12	7.5	0.5
Outer Harbour West	7	4	-	1.13	1.38	-	41	305	0.3	9.8	6.3	1.9	-	11	3.5	-
West Arm	49	36	16	0.25	0.33	0.5	112	4,870	11.5	111.7	12.8	5.4	1.2	37.5	16	2.5
Middle Arm	42	8	-	0.25	0.29	-	37	746	0.9	17.6	3	1.5	-	20	3	-

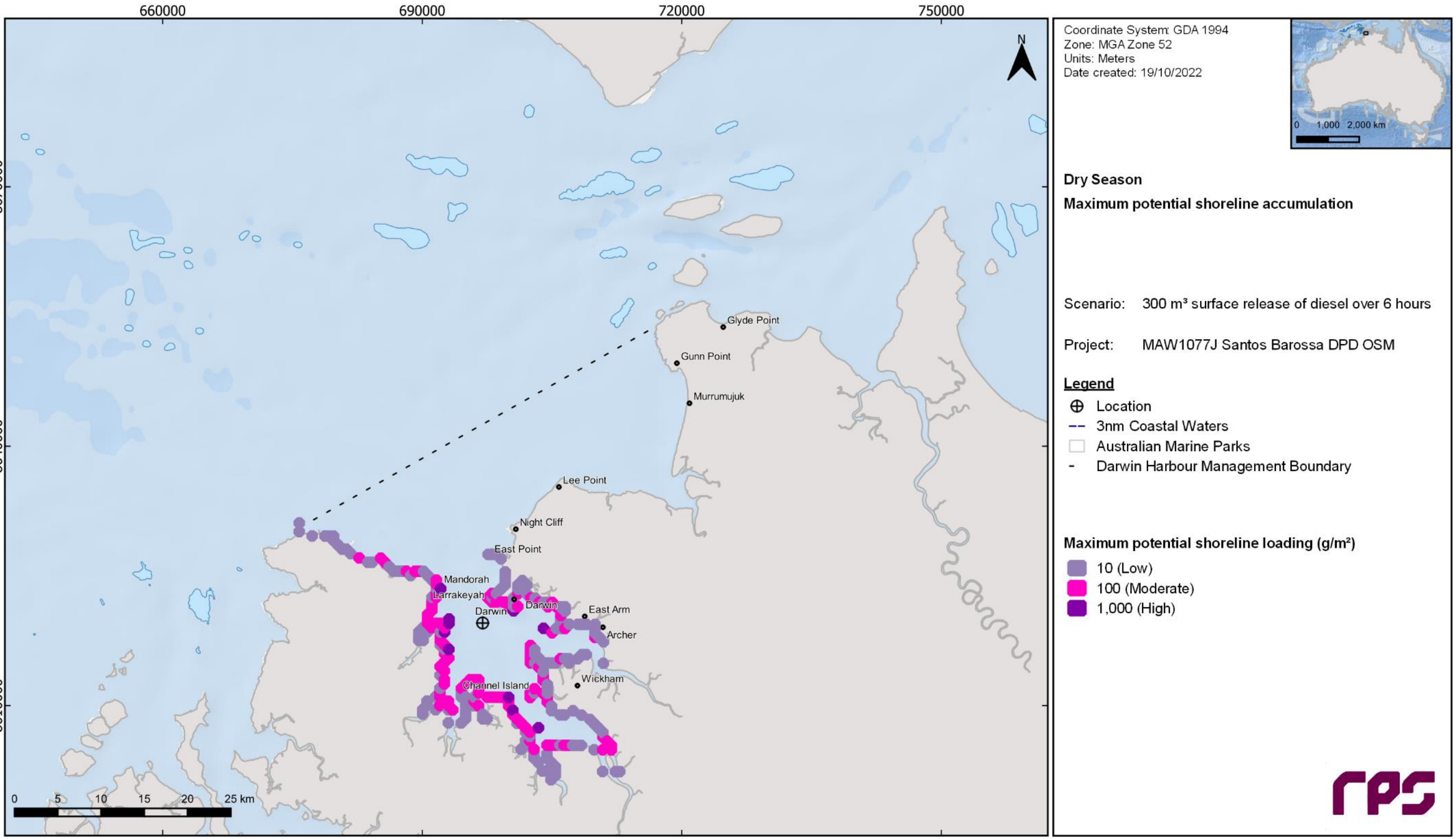

Figure 15.4 Maximum potential shoreline loading from a vessel fuel tank rupture at KP114 during dry season conditions. The results were calculated from 100 spill simulations.

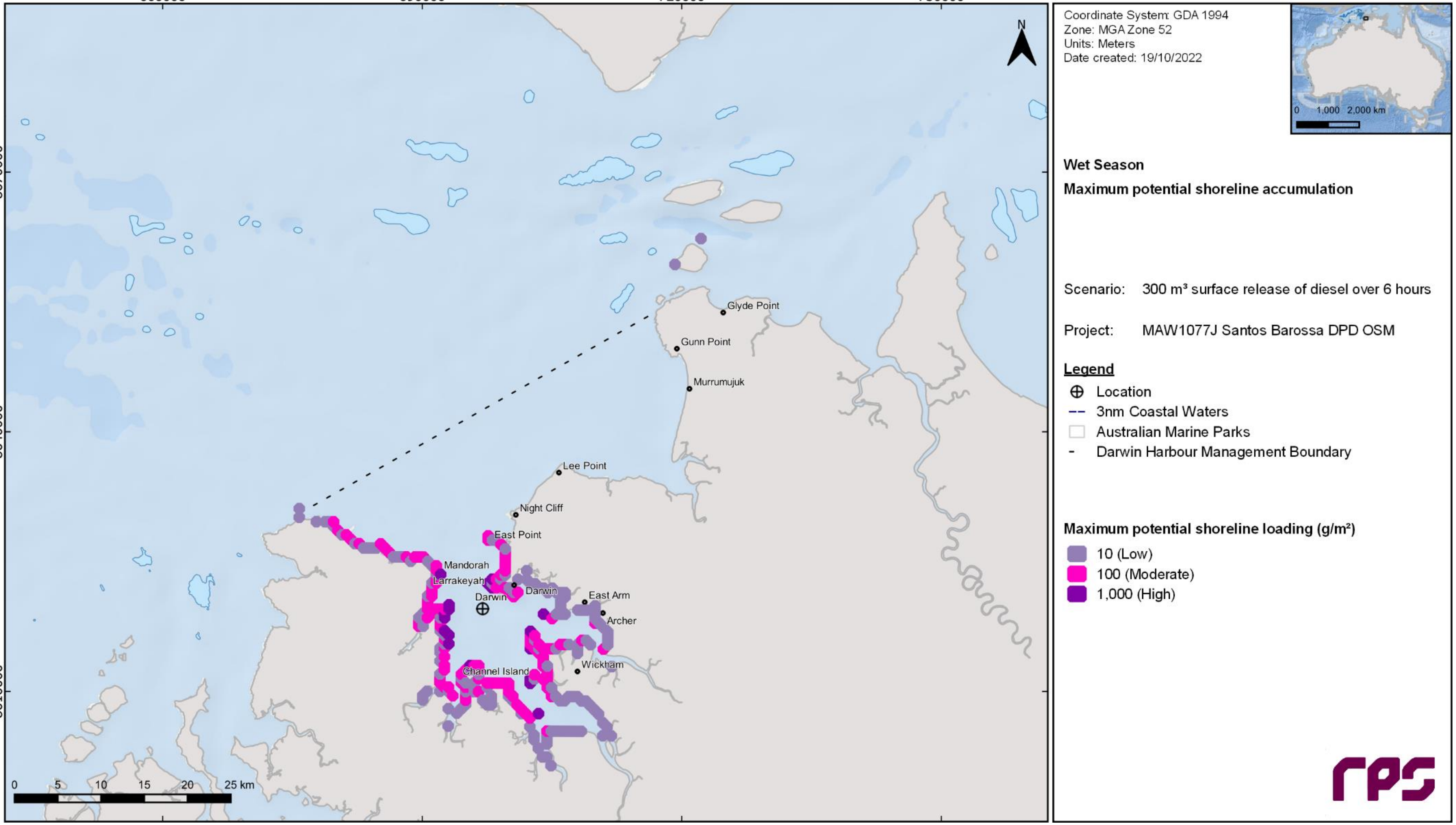

Figure 15.5 Maximum potential shoreline loading from a vessel fuel tank rupture at KP114 during wet season conditions. The results were calculated from 100 spill simulations.

15.2.3 In-water exposure

15.2.3.1 Dissolved Hydrocarbons

Table 15.6 summarises the maximum distances and directions travelled by dissolved hydrocarbons from the release location to the low (≥ 10 ppb) and moderate (≥ 50 ppb) thresholds in the 0 – 10 m depth layer. No exposure was predicted for the high (≥ 400 ppb) threshold. The maximum distances from the release location to the low exposure zone was 12.8 km (dry season) and 20.0 km (wet season), whilst distances were reduced to 0.6 km (dry season) and 7.3 km (wet season) for the moderate exposure threshold.

Table 15.7 summarises the potential exposure to receptors from dissolved hydrocarbons in the 0 – 10 m depth layer for each threshold and season. Figure 15.6 and Figure 15.7 illustrate the extent of dissolved hydrocarbon exposure for each season in the 0 – 10 m depth layers.

During both the dry and wet seasons, exposure at the low threshold was predicted at the Anson Beagle IMCRA during the dry and wet seasons with probabilities of 11% and 19%, respectively.

Dissolved hydrocarbon exposure at the low threshold was also predicted at shipwreck receptors during the dry (3) and wet seasons (5), with probabilities ranging from 1 – 10% and between 2 – 17%, respectively. The greatest probability of low threshold exposure during the dry and wet season was predicted for Ham Luong and Mauna Loa USAT, respectively.

Only a single simulation during dry season conditions (1% probability) triggered the low threshold exposure within Restricted Area 6 with a minimum time of exposure of 0.67 days.

During the dry season, 2 WQ Zones recorded exposure at the low threshold with probabilities of 2% (Outer Harbour) and 11% (Middle Harbour), whilst during the wet season, 3 WQ Zones recorded exposure with probabilities ranging between 1% (Middle Arm) and 19% (Middle Harbour, see Table 15.7).

The highest dissolved hydrocarbon concentration was 93 ppb during the wet seasons predicted for Beagle Gulf-Darwin Coast, Anson Beagle IMCRA and Middle Harbour WQO Zone.

Table 15.6 Maximum distances and directions travelled by dissolved hydrocarbons (0 – 10 m depth layer) from a vessel fuel tank rupture at KP114 during each season. Results were calculated from 100 spill simulations per season.

Season	Distance and direction travelled	Zones of potential dissolved hydrocarbon exposure		
		Low 10 ppb	Moderate 50 ppb	High 400 ppb
Dry	Maximum distance (km) from the release location	12.8	0.6	-
	Maximum distance (km) from the release location (99th percentile)	12.3	0.6	-
	Direction	NW	NW	-
Wet	Maximum distance (km) from the release location	20.0	7.3	-
	Maximum distance (km) from the release location (99th percentile)	18.2	7.3	-
	Direction	NW	NNW	-

Table 15.7 Summary of dissolved hydrocarbon exposure for each receptor in the 0 – 10 m depth layer from a vessel fuel tank rupture at KP114 during each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry							Wet						
		Maximum instantaneous concentration (ppb)	Probability of instantaneous dissolved hydrocarbon exposure			Minimum time (days) before instantaneous dissolved hydrocarbon exposure			Maximum instantaneous concentration (ppb)	Probability of instantaneous dissolved hydrocarbon exposure			Minimum time (days) before instantaneous dissolved hydrocarbon exposure		
			Low	Moderate	High	Low	Moderate	High		Low	Moderate	High	Low	Moderate	High
	Beagle Gulf-Darwin Coast	68	11	1	-	0.04	0.25	-	93	19	3	-	0.04	0.08	-
IMCRA	Anson Beagle	68	11	1	-	0.04	0.25	-	93	19	3	-	0.04	0.08	-
Restricted Areas	6	13	1	-	-	0.67	-	-	8	-	-	-	-	-	-
Shipwrecks	Darwin Harbour Unidentified wreck 2	4	-	-	-	-	-	-	13	3	-	-	0.38	-	-
	Ham Luong	26	10	-	-	0.13	-	-	51	15	2	-	0.04	0.17	-
	Mauna Loa USAT	41	8	-	-	0.13	-	-	55	17	1	-	0.08	0.13	-
	Peary USS	6	-	-	-	-	-	-	12	2	-	-	0.58	-	-
	Shipwrecks - Yu Han 22 (SURF	11	1	-	-	0.38	-	-	21	7	-	-	0.21	-	-
WQ Zones	Middle Arm	6	-	-	-	-	-	-	15	1	-	-	0.38	-	-
	Middle Harbour	68	11	1	-	0.04	0.25	-	93	19	3	-	0.04	0.08	-
	Outer Harbour	16	2	-	-	0.46	-	-	32	8	-	-	0.21	-	-

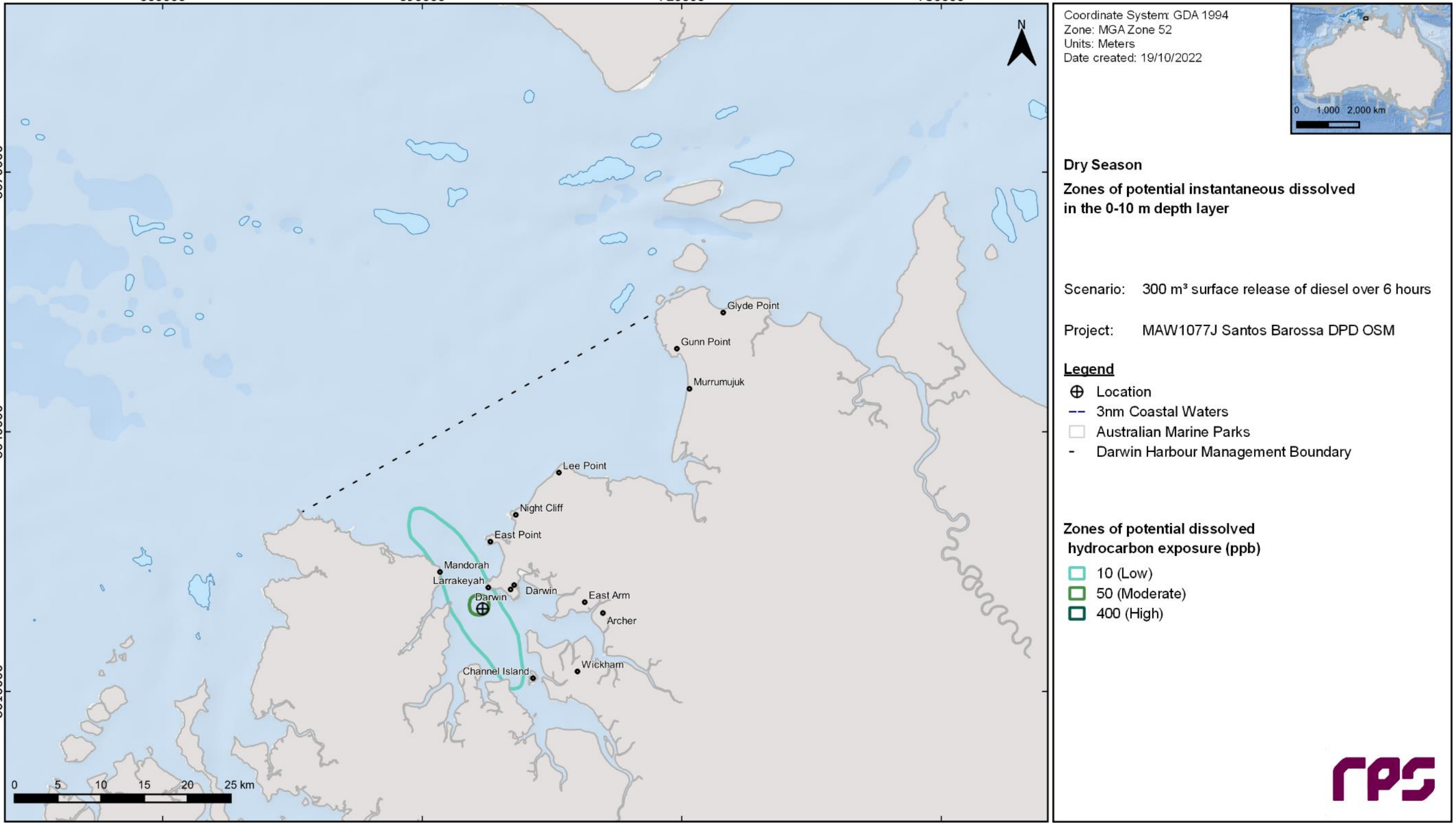

Figure 15.6 Zones of potential dissolved hydrocarbon exposure at 0 – 10 m below the sea surface from a vessel fuel tank rupture at KP114 during dry season conditions. The results were calculated from 100 spill simulations.

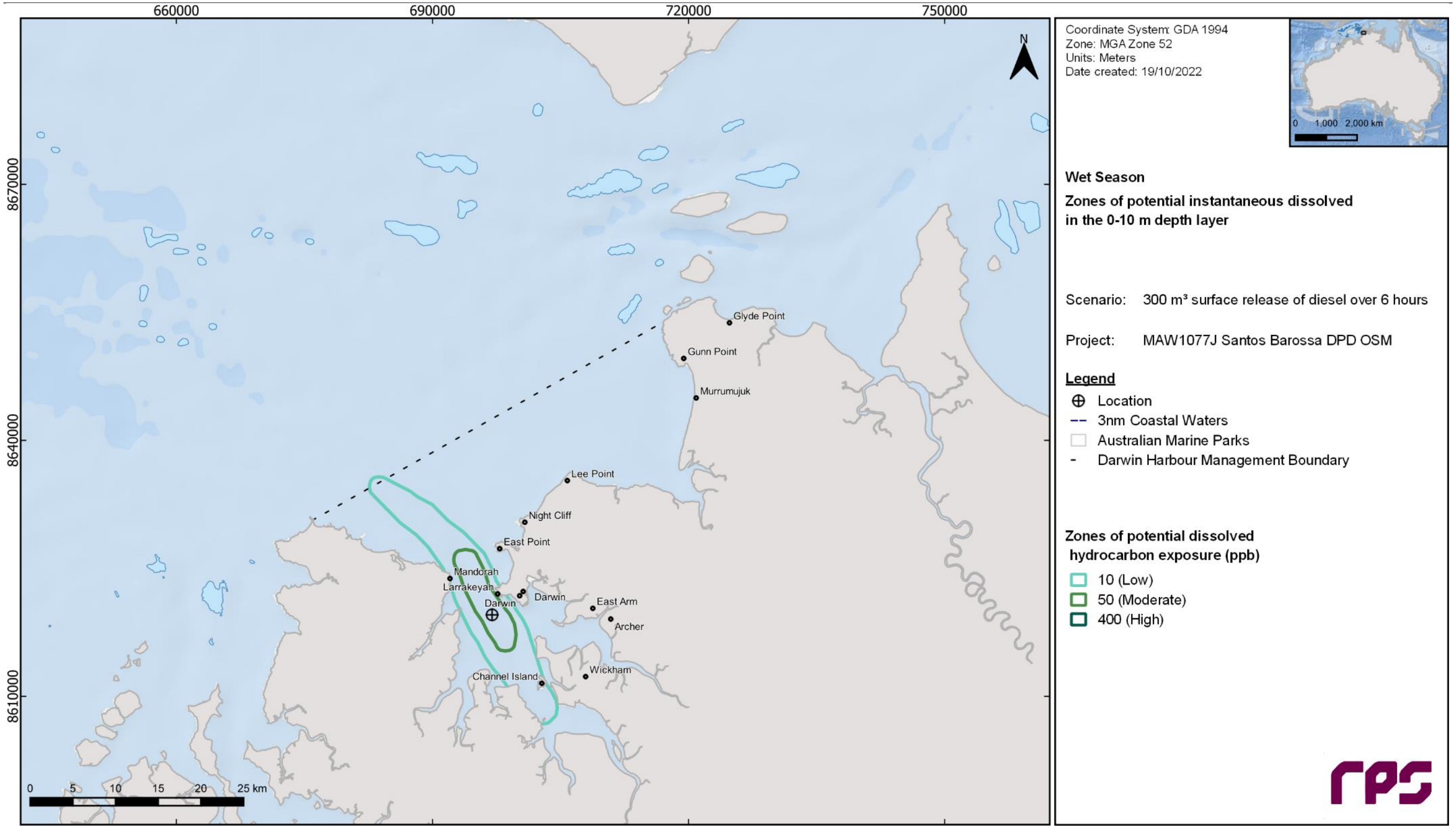

Figure 15.7 Zones of potential dissolved hydrocarbon exposure at 0 – 10 m below the sea surface from a vessel fuel tank rupture at KP114 during wet season conditions. The results were calculated from 100 spill simulations.

15.2.3.2 Entrained Hydrocarbons

Table 15.8 summarises the maximum distances and directions travelled by entrained hydrocarbons within the 0 – 10 m depth layers at the low (≥ 10 ppb) and moderate (≥ 100 ppb) thresholds. The maximum distances from the release location to the low exposure zone was 41.7 km (dry season) and 48.3 km (wet season), whilst distances were reduced to 30.3 km (dry season) and 32.4 km (wet season) for the moderate exposure threshold. Exposure was limited to the 0 – 10 m depth layer.

Table 15.9 summarises the potential exposure to receptors from entrained hydrocarbons in the 0 – 10 m depth layer for each season. Figure 15.8 and Figure 15.9 illustrate the extent of entrained hydrocarbon exposure for each season in the 0 – 10 m depth layer.

During both seasons the Charles Point Wide RFPA and four Restricted Areas (1, 4, 5 and 6) were predicted to be exposed at the low threshold with probabilities ranging from 14 – 99% and 50 – 94% during the dry and wet seasons, respectively. During both seasons Restricted Area 6 was predicted to have the greatest probability of exposure (99% and 94%, respectively).

Anson Beagle IMCRA was also predicted to experience exposure at the low threshold with probabilities of 100% during the dry season and 96% during the wet season.

Only a single simulation during dry season conditions (1% probability) triggered the low threshold exposure within the Middle Reef and Kelleway Reef RSB receptors. Additionally, only a single simulation (1% probability) was also predicted to trigger the low threshold exposure at Vernon Islands Conservation Reserve during the wet season with a corresponding time of exposure of 12.21 days.

Exposure at the low threshold was predicted at 18 and 19 shipwreck receptors during the dry and wet season, respectively with probabilities ranging from 5% (East Arm Vietnamese Refugee Boat 1) and 100% (Ham Luong, Mauna Loa USAT and Yu Han 22) during the dry season and 4% (Elizabeth River - unidentified wreck) and 95% (Ham Luong) during the wet season.

Furthermore, 8 WQ Zones were predicted to be exposed at the low threshold during the dry and wet season with probabilities ranging from 2% (Myrmidon Creek) and 100% (Middle Harbour) during the dry season. Whilst, under wet season conditions probabilities throughout the 8 WQ Zones ranged from 14% (Myrmidon Creek) and 96% (Middle Harbour, see Table 15.9).

The highest entrained hydrocarbon concentration was 6,826 ppb predicted for Beagle Gulf-Darwin Coast, Anson Beagle IMCRA and Middle Harbour WQO Zone during the wet season.

Table 15.8 Maximum distances and directions travelled by entrained hydrocarbons (0 – 10 m depth layer) from the release location vessel fuel tank rupture at KP114 during each season. Results were calculated from 100 spill simulations per season.

Season	Distance and direction travelled	Zones of potential entrained hydrocarbon exposure	
		Low 10 ppb	Moderate 100 ppb
Dry	Maximum distance (km) from release location	41.7	30.3
	Maximum distance (km) from release location (99th percentile)	40.3	29.3
	Direction	WNW	NW
Wet	Maximum distance (km) from release location	48.3	32.4
	Maximum distance (km) from release location (99th percentile)	43.7	31.2
	Direction	NW	NW

Table 15.9 Probability of entrained hydrocarbons exposure to receptors in the 0 – 10 m depth layer from a vessel fuel tank rupture at KP114 during each season. Results were calculated from 100 spill simulations per season.

Receptor		Dry					Wet				
		Maximum concentration (ppb)	Probability of instantaneous entrained hydrocarbon exposure		Minimum time (days) before instantaneous entrained hydrocarbon exposure		Maximum concentration (ppb)	Probability of instantaneous entrained hydrocarbon exposure		Minimum time (days) before instantaneous entrained hydrocarbon exposure	
			Low	Mod	Low	Mod		Low	Mod	Low	Mod
	Beagle Gulf-Darwin Coast	5,932	100	91	0.04	0.04	6,826	96	82	0.04	0.04
Conservation Reserve	Vernon Islands	4	-	-	-	-	13	1	-	12.21	-
IMCRA	Anson Beagle	5,932	100	91	0.04	0.04	6,826	96	82	0.04	0.04
RFPA	Charles Point Wide	239	96	10	0.67	0.71	393	90	14	0.67	0.71
Restricted Area	1	28	14	-	0.75	-	87	50	-	0.46	-
	4	495	99	68	0.17	0.29	679	94	42	0.21	0.29
	5	414	98	43	0.17	0.25	354	93	36	0.17	0.21
	6	616	99	77	0.13	0.17	665	94	62	0.21	0.25
RSB	Middle Reef	13	1	-	9.75	-	4	-	-	-	-
	Kelleway Reef	15	1	-	8.34	-	5	-	-	-	-
Shipwrecks	Bell Bird	732	96	22	0.21	0.25	552	90	40	0.21	0.33
	Booya	450	98	32	0.13	0.17	963	89	51	0.13	0.13
	British Motorist	853	97	40	0.17	0.29	850	92	67	0.13	0.21
	Darwin Harbour Unidentified wreck 2	895	98	62	0.13	0.17	1,010	92	74	0.08	0.13
	East Arm Barge 1	13	7	-	1.33	-	34	27	-	0.79	-
	East Arm Vietnamese Refugee Boat 1	23	5	-	1.25	-	103	36	1	0.33	0.83
	East Arm Vietnamese Refugee Boat 2	13	7	-	1.33	-	34	27	-	0.79	-
	Elizabeth River - unidentified wreck	8	-	-	-	-	14	4	-	1.38	-
	Ellengowan	302	92	3	0.21	0.46	344	84	21	0.17	0.25

	Ham Luong	3,673	100	89	0.04	0.04	3,915	95	81	0.04	0.04
	L. Ann	248	97	40	0.29	0.46	240	92	13	0.25	0.58
	Landing Barge	675	95	25	0.29	0.29	607	90	48	0.21	0.21
	Mandorah Unidentified wreck 1	248	97	40	0.29	0.46	240	92	13	0.25	0.58
	Mauna Loa USAT	4,201	100	89	0.04	0.04	6,002	93	81	0.04	0.04
	Middle Arm unidentified wreck	302	92	3	0.21	0.46	344	84	21	0.17	0.25
	Diemen	500	99	67	0.13	0.21	499	92	48	0.13	0.25
	Peary USS	1,055	98	58	0.13	0.21	1,070	93	75	0.08	0.17
	Vietnamese Refugee Boat Pk76	448	95	13	0.21	0.54	320	87	22	0.25	0.50
	Yu Han 22	1,674	100	81	0.08	0.13	1,581	94	73	0.08	0.08
WQ Zones	Elizabeth River	23	5	-	1.25	-	107	36	1	0.33	0.83
	East Arm	604	94	15	0.29	0.33	476	87	34	0.21	0.29
	Middle Arm	1,002	94	11	0.21	0.25	1,090	80	29	0.17	0.17
	West Arm	479	99	58	0.21	0.25	603	95	32	0.17	0.21
	Middle Harbour	5,932	100	91	0.04	0.04	6,826	96	82	0.04	0.04
	Outer Harbour	1,480	99	78	0.08	0.13	2,135	93	68	0.08	0.08
	Shoal Bay	17	24	-	6.21	-	29	22	-	4.25	-
	Myrmidon Creek	14	2	-	2.33	-	68	14	-	0.38	-

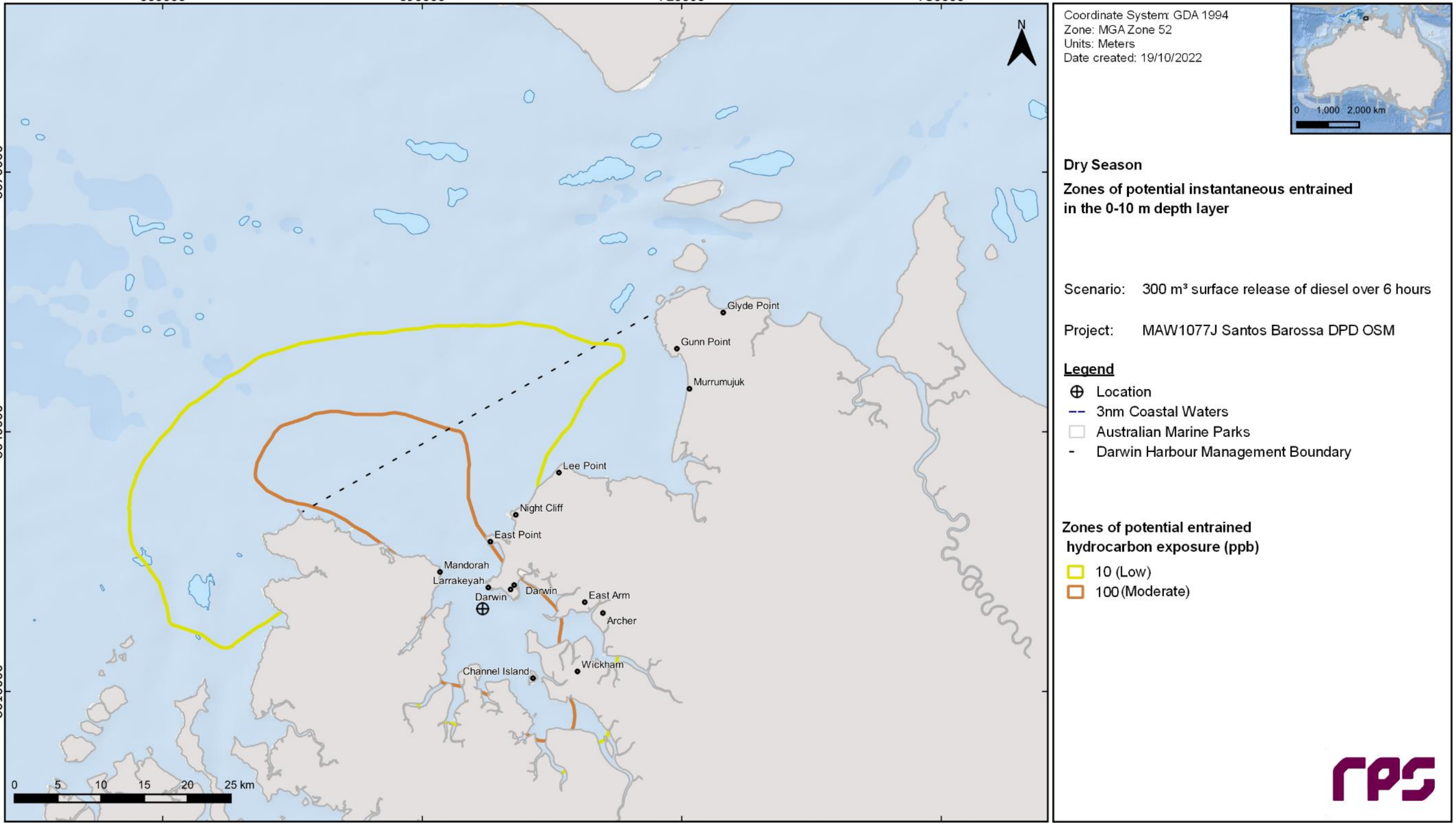

Figure 15.8 Zones of potential entrained hydrocarbon exposure at 0 – 10 m below the sea surface from a vessel fuel tank rupture at KP114 during dry season conditions. The results were calculated from 100 spill simulations.

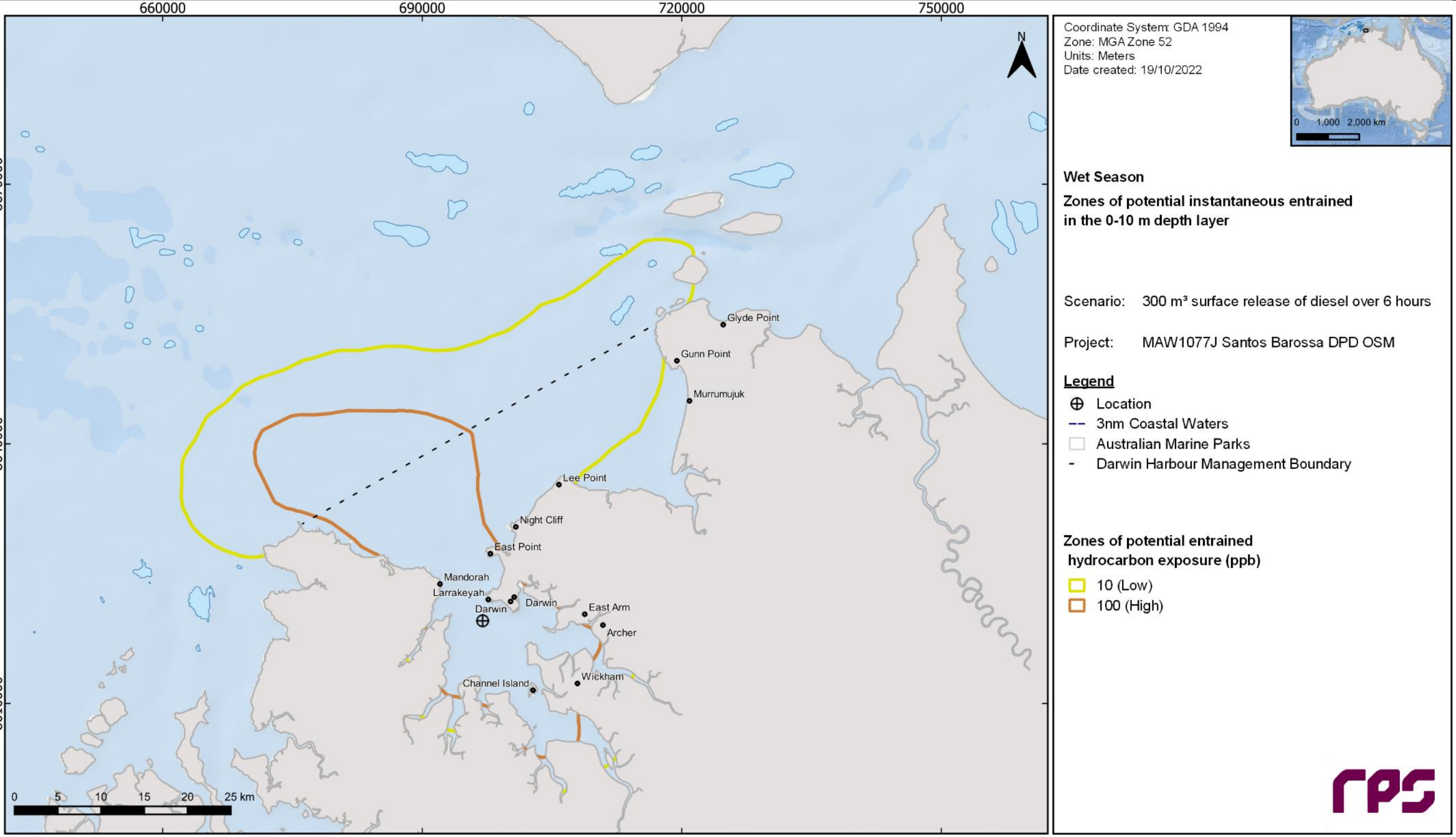

Figure 15.9 Zones of potential entrained hydrocarbon exposure at 0 – 10 m below the sea surface from a vessel fuel tank rupture at KP114 during wet season conditions. The results were calculated from 100 spill simulations.

15.3 Deterministic Analysis

The stochastic modelling results were assessed and the deterministic simulation resulting in the largest volume ashore (115.5 m^3) was identified as run 55, which commenced at 9 am 20 April 2020 during the wet season.

Zones of exposure on the sea surface (swept area) and shoreline accumulation over the entire 30-day simulation are presented in Figure 15.10. The spill drifted predominately south and west from the release location and the oil was predicted to accumulate on the western shoreline up to Mandorah.

Zones of entrained hydrocarbon exposure within the 0 – 10 m depth layer (surface layer) over the 30-day simulation are presented in Figure 15.11.

Figure 15.12 and Figure 15.13 show time series of the area of floating oil and the volume of oil ashore exposure for each threshold during the 30-day simulation.

Figure 15.14 presents the fates and weathering for the corresponding single spill trajectory. At the conclusion of the simulation, approximately 214 m^3 (71%) of the spilled oil was lost to the atmosphere through evaporation and ~75 m^3 (25%) remained on the shoreline. In addition, ~8 m^3 (3%) was predicted to have decayed by the end of the simulation, while there was no oil predicted to remain on the surface.

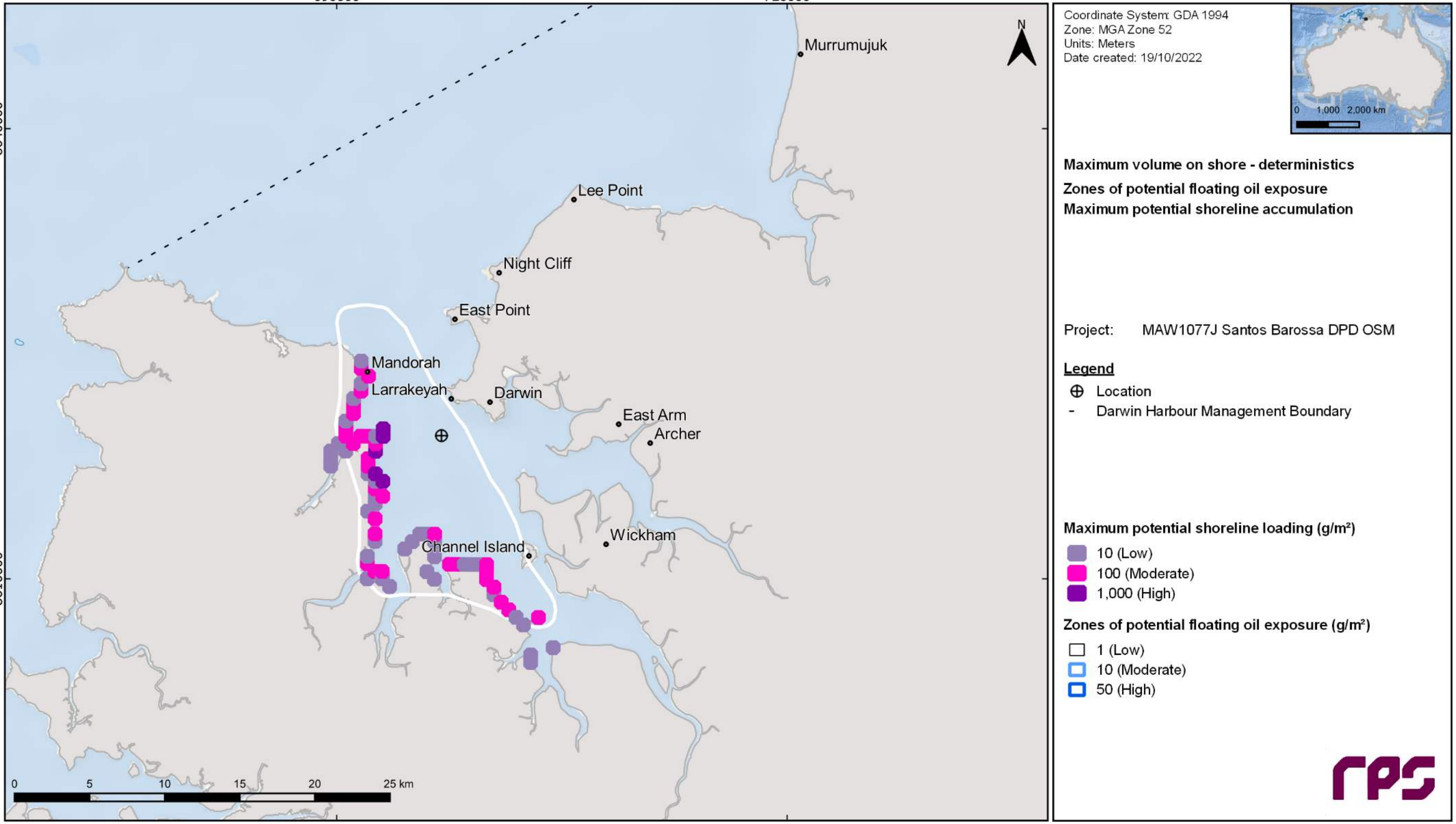

Figure 15.10 Zones of potential exposure on the sea surface and shoreline accumulation (over the 30-days) for the simulation resulting in the maximum volume of oil ashore starting at 9 am 20 April 2020 during the wet season.

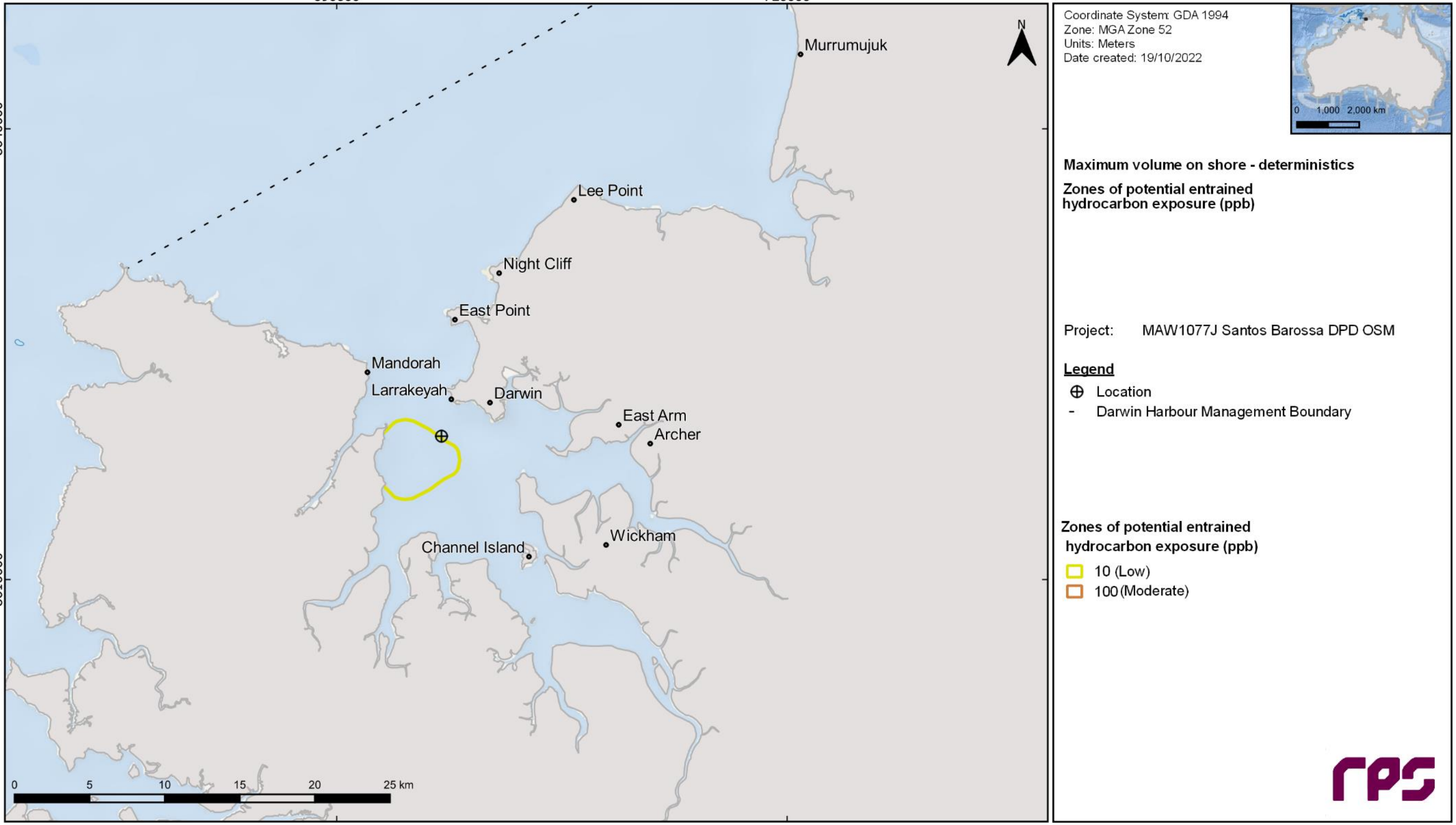

Figure 15.11 Zones of potential entrained hydrocarbon exposure 0 – 10 m below the sea (over the 30-days) for the simulation resulting in the maximum volume of oil ashore starting at 9 am 20 April 2020 during the wet season.

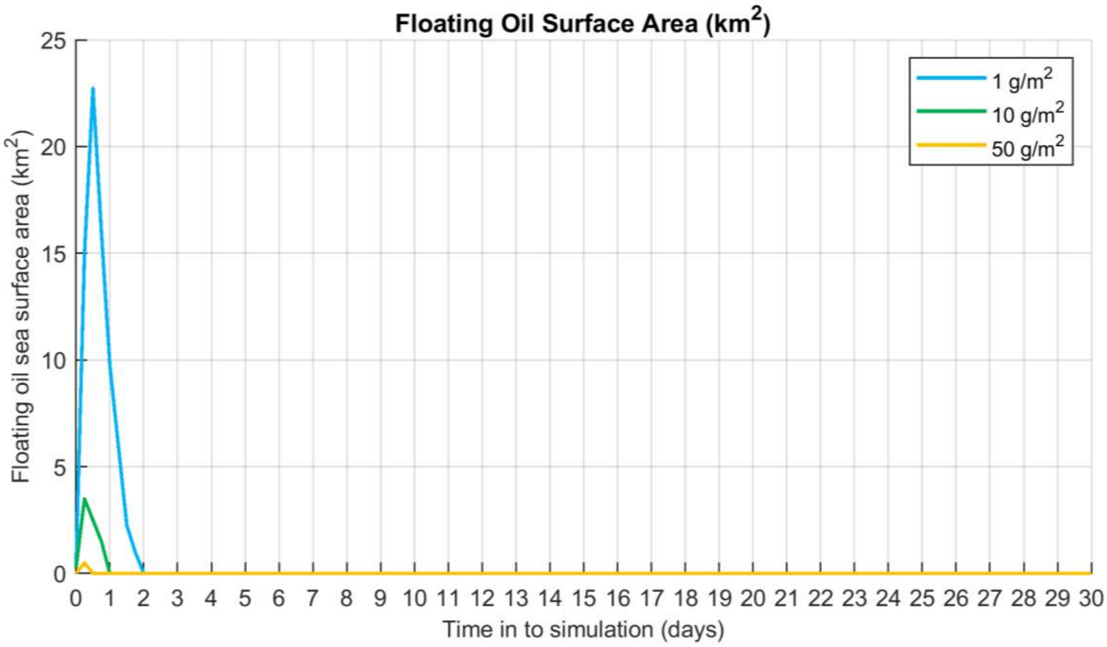

Figure 15.12 Time series of the floating oil surface area exposure for each threshold for the simulation resulting in the maximum volume of oil ashore starting at 9 am 20 April 2020 during the wet season.

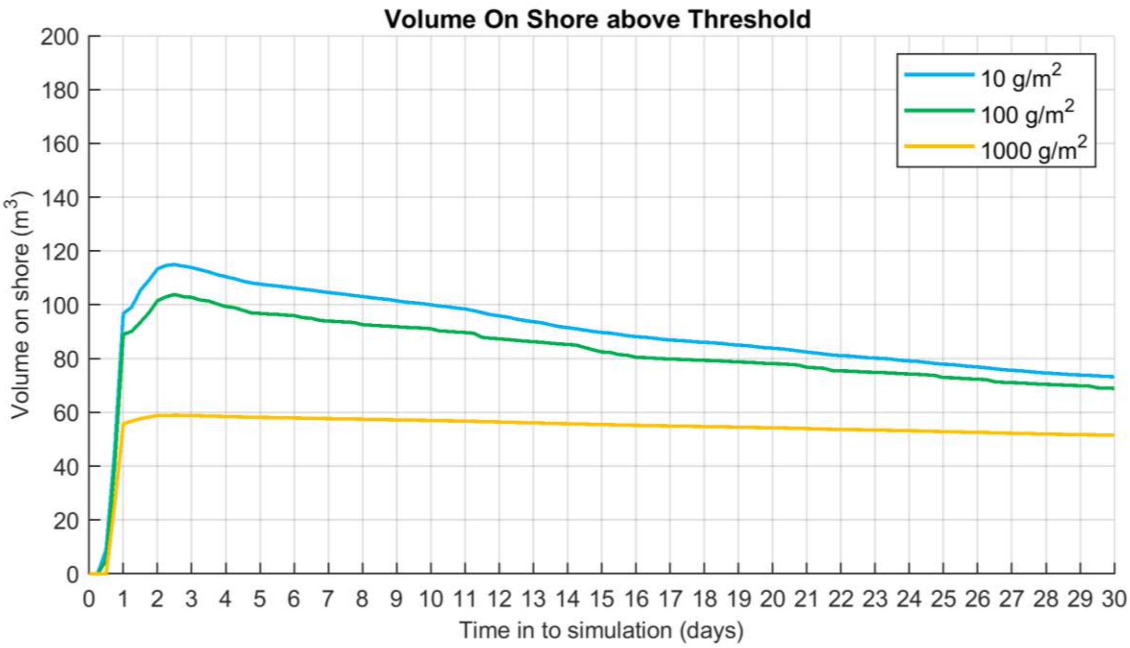

Figure 15.13 Time series of the volume of oil ashore for each threshold for the simulation resulting in the maximum volume of oil ashore starting at 9 am 20 April 2020 during the wet season.

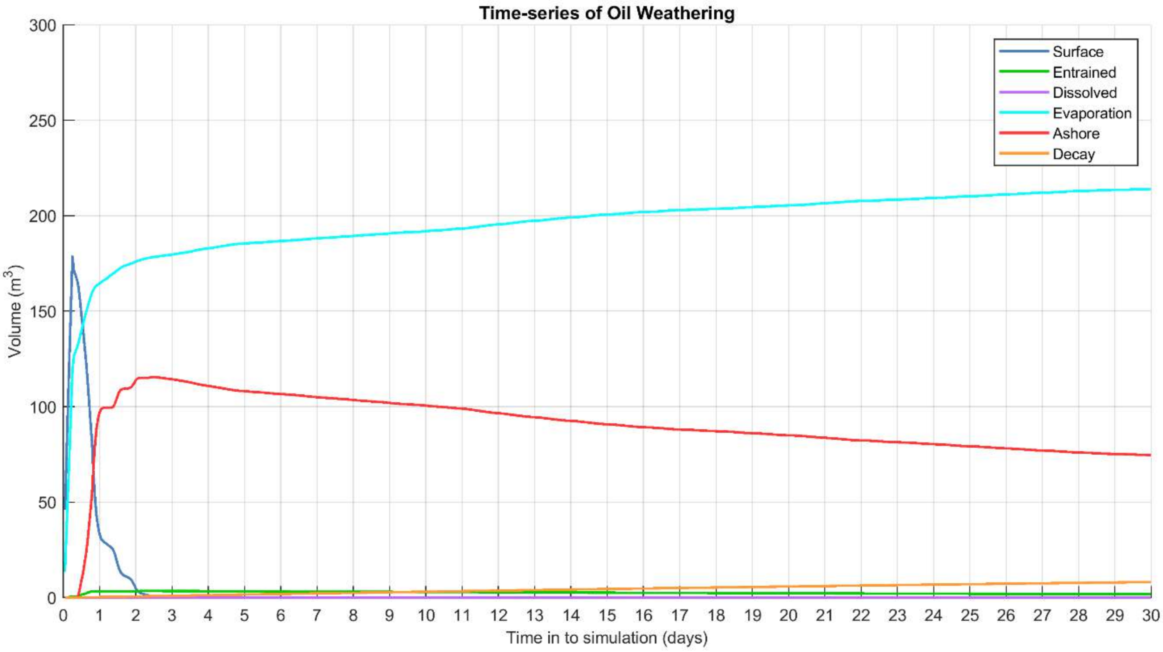

Figure 15.14 Predicted weathering and fates graph for the simulation resulting in the maximum volume of oil ashore starting at 9 am 20 April 2020 during the wet season.

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