Environment plan
Appendix 7-1
Oil spill modelling study (RPS)

Stromlo-1 exploration drilling program

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November 2019

OIL SPILL MODELLING STUDY

Stromlo-1 exploration drilling program

MAQ0559M
Oil spill modelling study
Rev 2
25 November 2019

rpsgroup.com

Document status

Version	Purpose of document	Authored by	Reviewed by	Approved by	Review date
Rev0N	Final for issue	Dr Sasha Zigic		Dr Sasha Zigic	06/02/2019
Rev 1	Final for issue	Dr Sasha Zigic Dr Ryan Dunn		Dr Sasha Zigic	12/09/2019
Rev 2	Final for issue	Dr Sasha Zigic		Dr Sasha Zigic	22/11/2019

Approval for issue

Dr Sasha Zigic		25 November 2019

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Appendices

Appendix A: Results
Appendix B: Maximum weathered oil ashore during winter
Appendix C: WCD_{88} volume of oil ashore

TERMS AND ABBREVIATIONS

° – Degrees

‘– Minutes

“– Seconds

3D – Three-dimensional

Actionable oil – Oil which is thick enough for the effective use of mitigation strategies

ADCP – Acoustic Doppler Current Profiler – records current at multiple discrete depth levels

Aerial dispersant application (ADA) – Application of oil spill dispersants by spraying from fixed wing aircraft or helicopters

AMSA – Australian Maritime Safety Authority

API – American Petroleum Institute gravity. A measure of how heavy or light a petroleum liquid is compared to water.

AWS – Automatic weather station

AMP – Australian Marine Parks

Annulus – void between the pipe (or drill string) and casing

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.

BoM – Bureau of Meteorology

BOP – Blowout preventer. A safety device designed to prevent a blowout from occurring

°C – degree Celsius (unit of temperature)

Capping stack – A containment system kept in readiness at an onshore location. In the event of well blowout the capping stack is placed over the blown-out well as a “cap”, in an effort to contain the flow of hydrocarbons.

CFSR – Climate Forecast System Reanalysis

cm – Centimetre (unit of length)

CNES – Centre National D'études Spatiales (trans. National Centre for Space Studies)

Comparative Risk Analysis – comparison of the exposure calculations for different environmental components (water column, water surface, shorelines) with and without proposed spill mitigation measures, alternatively referred to as net benefit analysis

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 – oil components which are dissolved in water.

DOR – Dispersant to oil ratio

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.

EEZ – Exclusive economic zone

EMBA – Environment that may be affected

Risk EMBA - the geographical area encompassing the environment that may be affected by the unplanned events associated with the planned activities within the Petroleum Safety Zone. The maximum extent of an oil spill due to a blowout is the dimensioning factor for this area. The Risk EMBA has been used to inform the oil spill response planning and oil spill risk assessment.

ENSO - El Niño–Southern Oscillation is the periodic variation in wind patterns and sea surface temperatures over the Pacific Ocean that can affect the wider climate. Phases of ENSO are termed El Niño and La Nina.

Entrained hydrocarbons – oil droplets that are suspended into the water column, though not dissolved.

EP – Environmental plan

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 metre (unit of surface area density)

Fresh oil exposure – Refers to exposure to oil prior to emulsification, evaporation of all volatile components, and dissolution of soluble components

GAB – Great Australian Bight

GODAE – Global Ocean Data Assimilation Experiment

HYCOM – Hybrid Coordinate Ocean Model. A data-assimilative, three-dimensional ocean model

HYDROMAP – Advanced ocean/coastal tidal model used to predict tidal water levels, current speed and current direction.

IBRA – Interim Biogeographic Regionalisation for Australia

IOA – Index of Agreement. A measure that gives a non-dimensional measure of model accuracy or performance

IMCRA – Integrated Marine and Coastal Regionalisation of Australia

Isopycnal layers – Water column layers with corresponding water densities

ITOPF – The International Tanker Owners Pollution Federation

KEFs – Key ecological features

km – Kilometre (unit of length)

km^2 – Square kilometres (unit of area)

Knots – unit of speed (1 knot = 0.514 m/s

LC50 – Median lethal dose required for mortality of 50% of a tested population after a specified exposure duration

m – Metre (unit of length)

mm – Millimetre (unit of length)

µm – Micrometre (unit of length; 1 µm = 0.001 mm)

µg/l – Micrograms per litre (unit of concentration)

m/s – Metre per second (unit of speed)

m^3 – Cubic metre (unit of volume)

MAE – Mean Absolute Error

NASA – National Aeronautics and Space Administration

NCEP – National Centres for Environmental Prediction

NOAA – National Oceanic and Atmospheric Administration

NOEC – No observed effect concentration

nm – nautical mile

O – Observed variable

OCS – Offshore Constitutional Settlement

OILMAPDeep – Modelling software designed to calculate the near-field behaviour of multi-phase gas-hydrocarbon plumes during subsurface blowout releases.

OPEP – Oil pollution emergency plan

OSPAR Convention – Since 1972 the OSPAR Convention has worked to identify threats to the marine environment and has organised, across its maritime area, programmes and measures to ensure effective national action to combat them. In doing this, OSPAR has pioneered ways of monitoring and assessing the environmental status of the seas by setting internationally agreed goals and by agreeing commitments by participating Governments to deliver what is needed.

P – Model-predicted variable

PFW – Produced formation water. Water extracted from oil and gas reservoirs with these fluids

PNEC – Predicted no effect concentration

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

Relief well – A well drilled to intersect an oil (or gas) well that has experienced a blowout by diverting the pressurised fluids (oil and/or gas). Drilling muds and cements are typically pumped down the relief well in an effort to stop the flow from the reservoir in the damaged well.

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.

Sensitive receptor – a geographic area defined by certain characteristics (sections of shorelines, marine protected areas etc) that might be sensitive to oil exposure.

SIMAP – Spill Impact Mapping Analysis Program

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 2 km buffer zone from any shoreline as a conservative measure.

Sm^3 – Standard cubic metre (unit volume; temperature: 20 °C, pressure: 1.01325 barA)

SSDI – Subsurface dispersant injection

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, 2017). 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, 2017). 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.

Time averaged - ppb concentration over 96 hours

THC – Total hydrocarbons

TOPEX/Poseidon – A joint satellite mission between NASA and CNES to map ocean surface topography using an array of satellites equipped with detailed altimeters.

Weathered oil – oil that no longer contains volatile or soluble components.

WCCD – Worst credible case discharge

WCD – Worst case discharge

ZPE – Zones of potential exposure

1 INTRODUCTION

Equinor Australia B.V. (Equinor formerly Statoil) is the sole titleholder of exploration permit EPP39 which is in the Ceduna Sub-basin, off southern Australia and proposes to drill the Stromlo-1 exploration well in 2,239 m of water within the permit area (Figure 1). Table 1 shows the coordinates of the Stromlo-1 well.

To support the preparation of the Environment plan (EP) and associated Oil pollution emergency plan (OPEP) for the operation, RPS was commissioned to undertake an Oil spill modelling study to assess the potential outcomes of defined spill scenarios associated with exploration drilling operations at Stromlo-1. Four scenarios were assessed:

- Scenario 1: Worst Case Discharge (WCD).

This scenario was defined as the largest possible rate of oil discharge from the reservoir for the longest duration before successful completion of a relief well penetrating to this formation depth. The WCD would require that the drilling penetrated completely all the potential reservoir intervals which are expected to yield the highest potential flow of reservoir fluids and the drilling string had been removed so that the well was fully open.

The estimated average release rate of crude from the unrestricted flow from an open hole was 8,943 m^3/day over 129 days, from the seabed depth of 2239 m.

This scenario was modelled with no control measures in place and with no spill mitigation accounted for.

Stochastic modelling was carried out, meaning the results are based on 100 oil spills assumed to commence between October and May, with drilling to occur between November and April as no drilling will occur in the months of May to October.

The greatest extent defined by the 100 spill simulations was used to set the bounds of the Environment that May Be Affected, hereafter referred to as Risk EMBA. The risk EMBA set the geographic extent for identifying the environmental and socio- economic sensitivities, for stakeholder consultation and assist with spill response planning.

- Scenario 2: Worst Credible Case Discharge (WCCD).

This scenario was defined as the largest flow rate that could occur under a credible case, where there was a loss of well control and the drill string remains in place when the loss occurs. Hence, the flow of oil is via the annulus (i.e. void between the drill string and well casing).

The average release rate for the unrestricted annulus flow scenario was 6,720 m^3/day over the 102 days. This is based on a P90 time estimate for moving a rig from South-East Asia to the location then drilling a relief well and completing the killing of the well. There are currently capable rigs in Australia that would allow for a shorter time line, however the conservative assumption will allow for future changes in contracts and work plans in Australia for those rigs.

Stochastic modelling was also carried out, based on 100 oil spill simulations with starting times between October and May, without any mitigations included. This scenario was used to inform the OPEP and the oil spill response planning, as it is a more realistic case.

In addition, simulations that met selection criteria (fastest time before shoreline exposure and greatest volume of oil stranding on shorelines) were remodelled under identical conditions (i.e. the same start times and sequences of metocean conditions) with mitigation efforts represented. Aerial Dispersant Application (ADA) was represented from Day 2 with treatment continuing until no actionable oil concentrations remained on the water surface; and subsurface Dispersant Injection (SSDI) was represented from the end of Day 9 until discharge ceased at the end of Day 102. Side by side comparison of outcomes of the simulations, with and without mitigation, informed a comparative risk assessment (CRA) for dispersant treatment.

- Scenario 3: Installation of Capping Stack

This scenario was used to indicate the effectiveness when a capping stack (CS) is installed at day 15 following an unrestricted annulus flow. The average release rate of oil over the 15 days was 7,596 m^3/day after drilling the well to Total Depth (TD).

Additional mitigation efforts were also assessed for this scenario by including the application of ADA from Day 2 to Day 15 and SSDI from Day 9 to Day 15 into the simulation resulting in the fast time to shore. This permitted a CRA of the results with and without mitigation.

- Scenario 4: Blow Out Preventer closure.

This scenario was used to assess the effectiveness of the Blowout Preventer (BOP). After drilling the well to TD, there is a subsea release with an unrestricted annulus flow and the BOP is closed at the end of Day 1 and stopped the flow. The release rate was 7,749 m^3/day over one day. The application of ADA from Day 2 was also incorporated into the "fastest time to shore" simulation to compare the results with and without mitigation.

The spill modelling was performed using an advanced three-dimensional trajectory and fates model, SIMAP (Spill Impact Mapping Analysis Program). The SIMAP model calculates the transport, spreading, entrainment evaporation and decay of spilled hydrocarbons over time, based on the prevailing wind and current conditions, prevailing sea temperatures and the physical and chemical properties of the spilled oil. The model can represent spills occurring at any depth and calculates the fate of spilled oil, in three dimensions, as floating, entrained or dissolved components. If floating oil is calculated to drift to shorelines locations, the model calculates selective stranding and accumulation based on the shoreline type and oil properties. The SIMAP model supports the calculation of oil rising though the water column due to buoyancy and includes calculations for the influence of aerial and subsea dispersant treatment, which were incorporated in this study. Other response methods such as nearshore containment and recovery were not accounted for in the modelling but would further reduce potential impacts.

The SIMAP model system, the 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" (ASTM, 2013).

Table 1: Coordinates of Stromlo-1 exploration well used as the release location for the oil spill modelling study

Name	Latitude	Longitude	Water depth (m)
Stromlo-1	340 56' 21.47'' S	1300 39' 44.61'' E	2,239

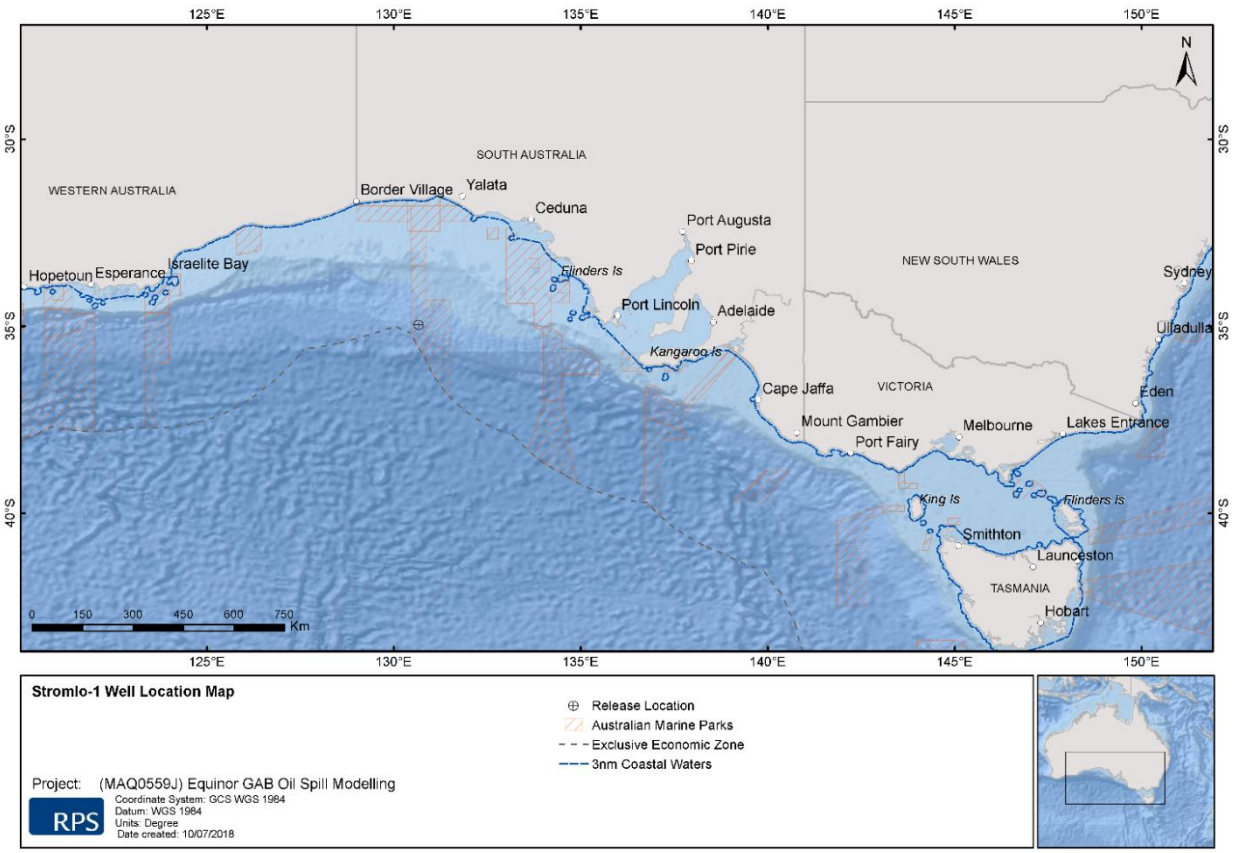


Figure 1: Stromlo-1 exploration well used as the release location for the oil spill modelling study

2 SCOPE OF WORK

The following workflow generally summarises the approach followed in this risk assessment:

1. A multi-year (2008–2012) database of historic wind and current data were compiled for the area to represent temporal and spatial variation over a wide area surrounding the Stomlo-1 well site. Data were compiled from data sources that covered the area that might receive any oil, optimised the resolution of wind and current forcing, included variation in current with depth, and spanned variations in large-scale oceanographic conditions. The best available data that met these criteria was available from hindcasts of meteorological and oceanographic models that spanned regional or global areas and integrated observations to optimise accuracy. This data was assessed for accuracy by comparison to observations available from fixed locations in the domain.

2. Near-field plume dynamics from the loss of well control were modelled for each scenario accounting for the depth of discharge, velocity of discharge, gas to oil ratio, oil and sea temperatures (at discharge depth) and variability in the vertical density structure of the ocean at the site. This stage calculated the dynamics of the two-phase (oil and associated gas) plume that is generated by subsea blowouts and delivered calculations for the size-distribution of oil droplets and the “trapping height”, which is where the oil droplets separate from the gas.

3. Setup the three-dimensional oil spill model (SIMAP) for each scenario, which included the input of wind, currents, oil characteristics, temperature and salinity data, time-varying release rate and outputs from near-field modelling (plume trapping height, plume diameter and droplet size distribution).

4. Stochastic modelling was carried out for Scenarios 1 and 2. The stochastic modelling involved running 100 single oil spills and each simulation had the same information (i.e. release location, volume, duration and oil properties) but with varied start dates and times during October to May from the multi-year dataset of historic dataset.

5. All 100 spill simulations for Scenario 1 were assessed to determine the greatest extent of surface oil, shoreline oil, dissolved oil and entrained oil (above the low exposure threshold) to define the Risk EMBA.

6. For Scenario 2, oil exposure at the water surface, at shorelines and in the water column were calculated from all 100 simulations to identify locations that might be exposed above defined concentrations thresholds and those that are more likely to be exposed, the potential concentrations that might be involved and the time that oil might take to drift to the locations (among other metrics).

7. Scenario 2 results were reviewed to identify the oil spill simulations that were deemed to represent the a) Fastest time before oil contact to shorelines; and b) Greatest volume of oil ashore. These simulations were repeated under identical conditions but applying the specified mitigation measures. Direct side-by-side comparisons of the outcomes of the mitigated and unmitigated cases were then made to quantify the effect.

8. For Scenarios 3 and 4, the fastest time to shore simulation was used to assess the effectiveness of the CS and BOP respectively and the results with and without mitigation.

3 REGIONAL CURRENTS

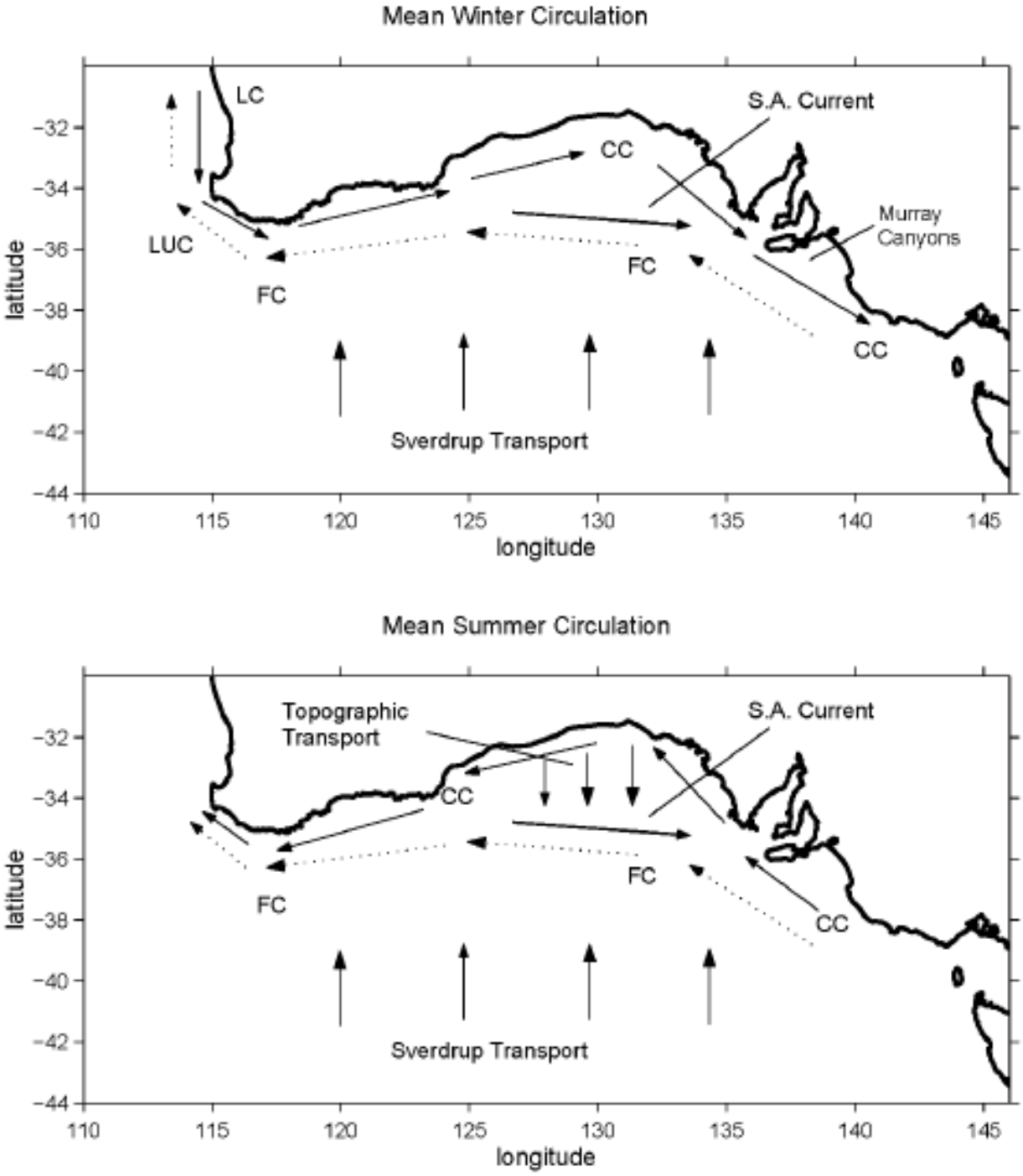
Ocean circulation over the wider domain in which oil might travel from the Stromlo-1 site is complex. Considered over seasons and at a regional scale, four distinct oceanic currents have been described within the Great Australian Bight (GAB): the Leeuwin Current (LC / LUC), the Flinders Current (FC), the South Australian Current (S.A. Current) and the Coastal Current (CC) (Figure 2; Middleton & Cirano, 2002; Middleton & Platov, 2003; Rogers et. al. 2013; Middleton & Bye, 2017). The LC is a seasonally varying current that flows from west to east, being strongest in March to November when current speeds typically reach around 0.5 m/s. The CC is a seasonally reversing current that typically flows close to the coast towards the east during the winter and westward during the summer. Two main water circulation mechanisms have been proposed to strongly affect circulation around the Stromlo-1 location – Sverdrup transport, which exerts movement of the upper water layers (down to around 100 m depth) towards the equator and is thought to contribute to the FC and to induce upwelling in deeper layers (Middleton & Cirano, 2002; Middleton & Bye, 2007). Topographic transport offshore from the shelf has been observed in the summer months and results in an anticyclonic gyre that is most intense off the Eyre Peninsula (Middleton & Platov 2003).

Figure 3 shows the current strengths and directions at various depths through the water column (34–1,420 m) as measured by current meters in the offshore Ceduna Basin in 2012 (Mathiesen, 2017). The current roses show the prevailing directions towards which the currents flow. The currents decrease with depth; e.g. at 34 m the mean currents are 20 cm/s, decreasing to around 6 cm/s at 1,420 m depth (Figure 4).

Whereas, the tidal currents are generally weaker in the deeper waters, it does become the more dominate force in shallower waters along coastlines. Therefore, it was critical to include the influence of both types of currents (ocean and tides) as part of the study (see Sections 3.1 and 3.3).

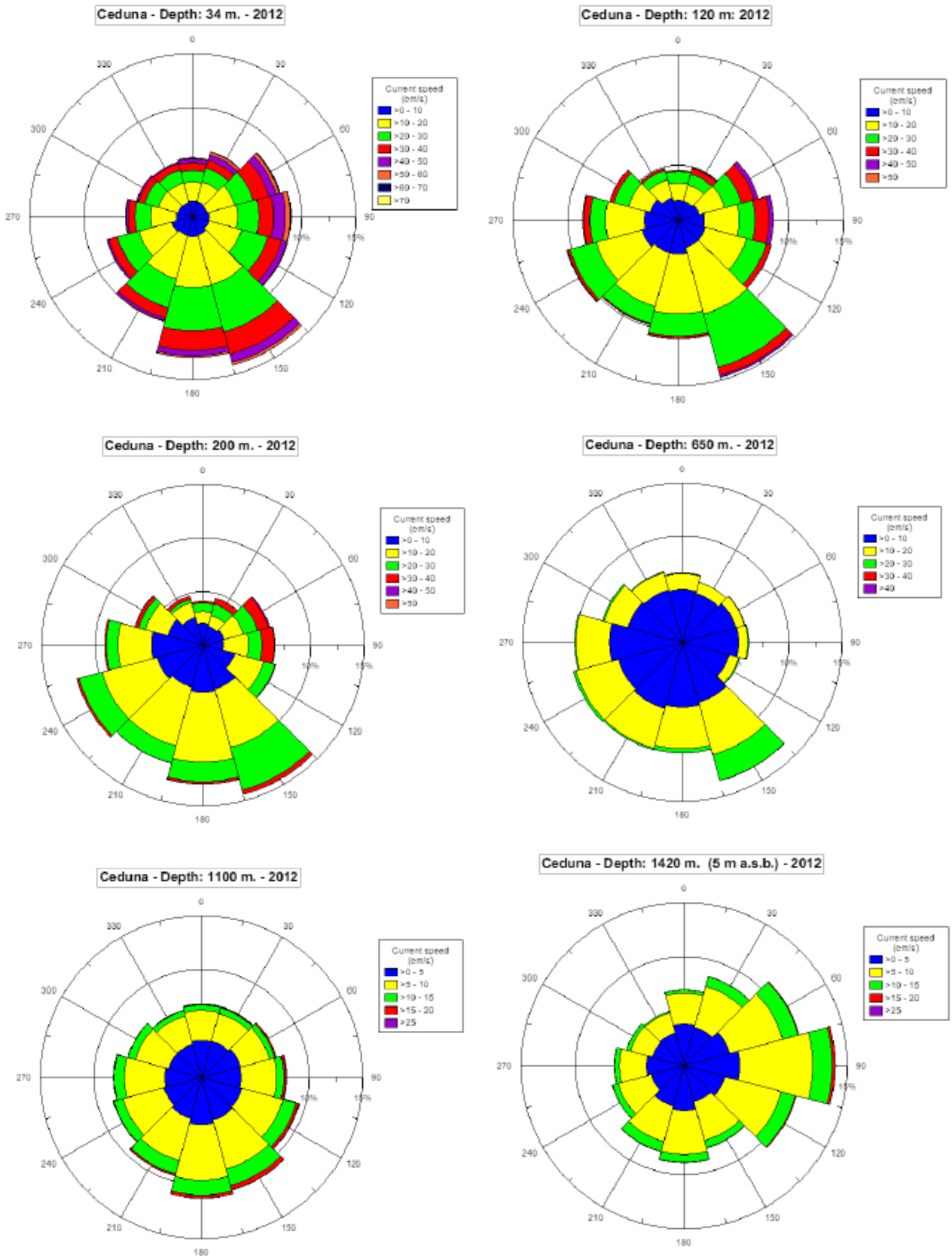
It is well known that oceanographic conditions fluctuate from one year to the next. Therefore, the five-year period of data spanning 2008 to 2012, inclusive, was selected because:

- The duration represented an average El Niño Southern Oscillation (ENSO) event.
- The period included at least one strong El Nino and one strong La Nina event to reflect the range of broader scale oceanographic forcing factors.
- A five-year period captured a large range of variability over local time and space-scales, considered sufficient to cover the range of expected metocean conditions for oil spill modelling.
- Overlapped with metocean measurements which were used to assess accuracy of the modelled currents.



Source: Rogers et al. (2013)

Figure 2: Schematic showing mean winter (top) and summer (bottom) circulation and the four major currents in the GAB



Source: Mathiesen (2017)

Figure 3: Currents through the water column in the Ceduna Basin in 2012

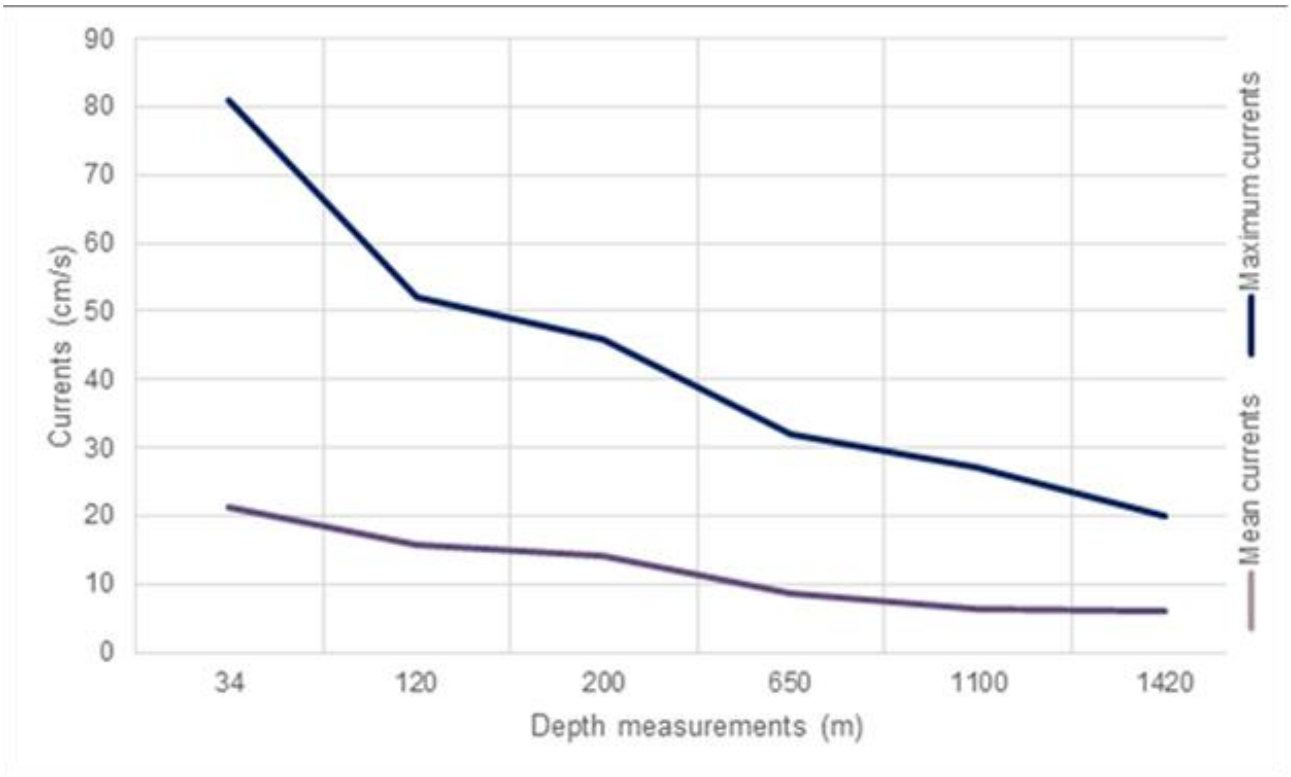


Figure 4: Current measurements versus depth for the Ceduna Basin

3.1 Tidal currents

Tidal currents describe orbital paths with short excursion lengths and will have low influence on the movement of oil in deeper waters. However, tidal oscillations add to the variability and dispersion of oil and may have a large influence on the movement of oil in shallower waters along coastlines. Therefore, it was critical to include the influence of tidal currents in the spill modelling.

Tides at the Stromlo-1 well location are semi-diurnal; characterised by two daily high tides of different heights. Tidal elevations at the well location, estimated using the NAO.99b tidal prediction system, indicate highest astronomical tides (HAT) of +75 cm and lowest astronomical tides (LAT; which equates to Chart Datum) of -47 cm (Mathiesen, 2017).

3.2 Tidal model

The tidal circulation was generated using RPS' advanced ocean/coastal model, HYDROMAP. The HYDROMAP model has been thoroughly tested and verified through field measurements throughout the world over 30 years (Isaji and Spaulding, 1984; Isaji et al. 2001; Zigic et al. 2003). HYDROMAP tidal current data has been used as input to forecast (in the future) and hindcast (in the past) oil spills in Australian waters and forms part of the Australian National Oil Spill Emergency Response System operated by AMSA (Australian Maritime Safety Authority).

HYDROMAP employs a nested sub-gridding strategy, which supports up to six levels of spatial resolution, halving the grid cell size as each level of resolution is employed. The sub-gridding allows for higher resolution of currents within areas of greater bathymetric and coastline complexity, and/or of interest to a study. Forcing of the model when used as a tide-only model is provided at the open boundaries of the model domain by spatially-varying data describing the amplitude and phase of the major tidal constituents. Tidal constituent data is extracted from the TOPEX/POSIEDON tidal database generated from satellite-borne altimeter observations.

The resolution of the tidal model grid was varied from 500 m in shallow and coastal regions up to 8 km for offshore, or deeper waters. The finer grid cells were used to resolve flows more accurately along the coastline, around islands and over regions with more complex bathymetry. Figure 5 shows the extent of the

tidal model grid that was applied for the region. The regional coverage of the tidal model was set to match the domain of the ocean model that was incorporated for the study, extending eastward and westward to encompass the south-east and south-west coasts of the Australian mainland and southward beyond Tasmania.

A bathymetric grid was developed for this region from multiple data sources, including 250 m resolution bathymetric data developed by Geoscience Australia and digitisation of navigational charts (Figure 6).

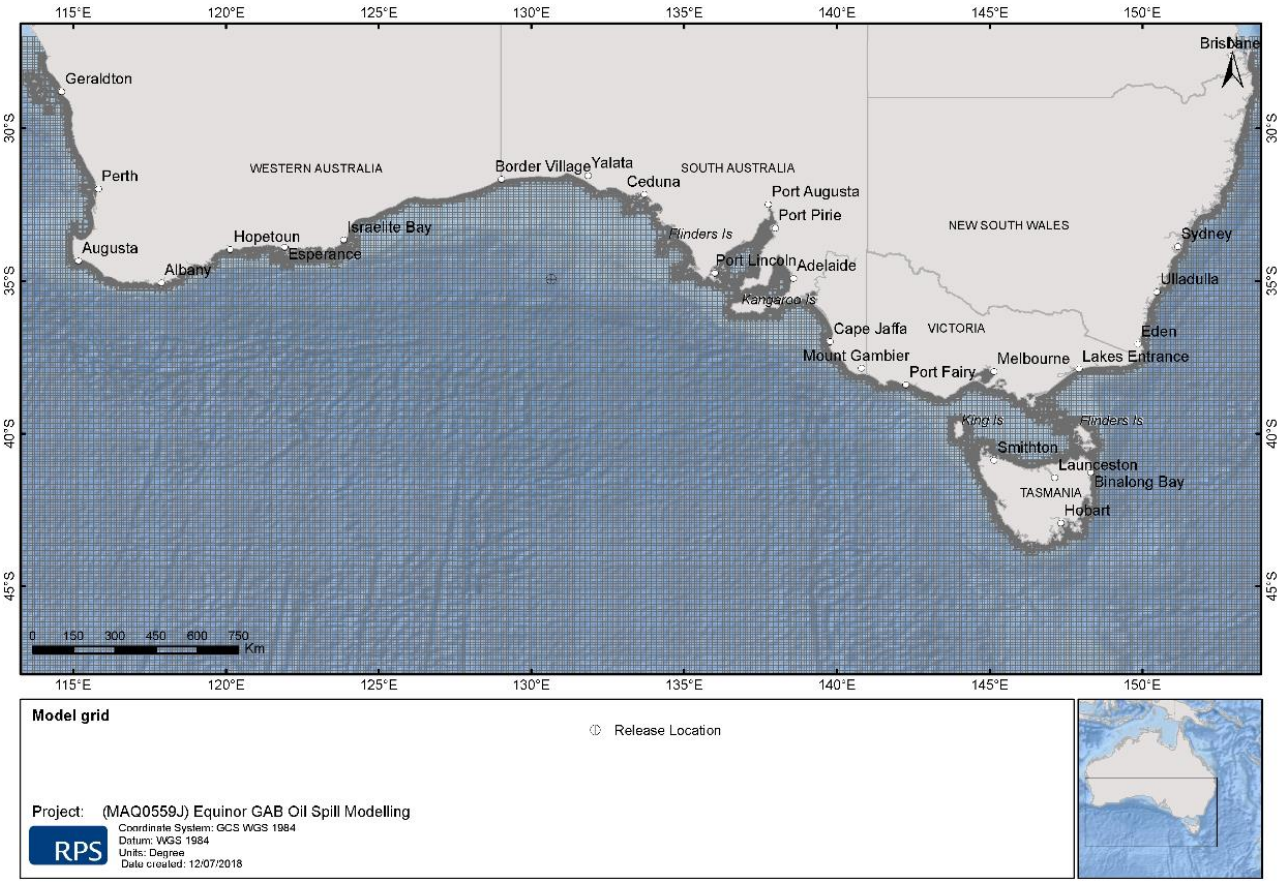


Figure 5: Extent of the model grid used to generate the tidal currents for the study region using the HYDROMAP model. Higher resolution areas are shown by the denser mesh

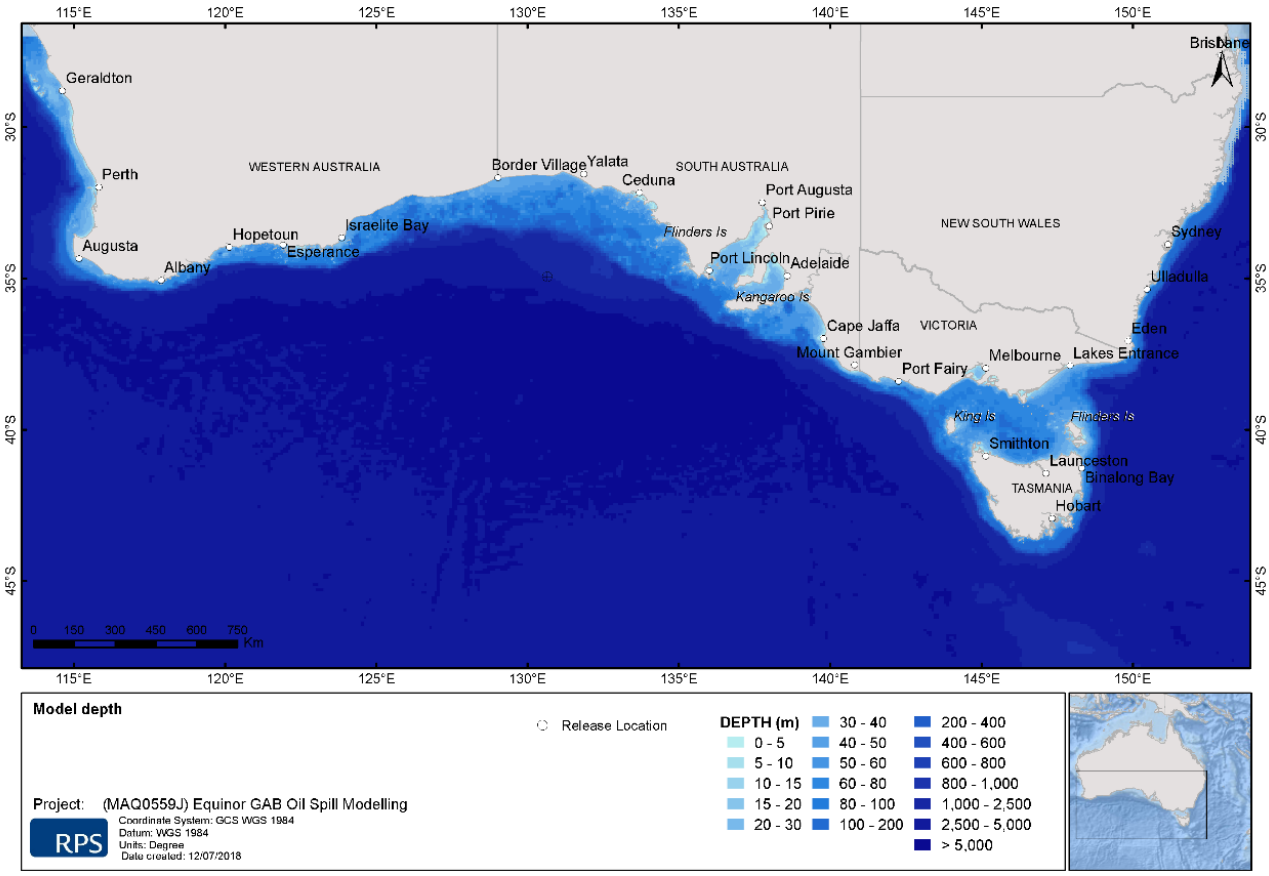


Figure 6: Bathymetry defined within the tidal model

3.2.1 Tidal forcing conditions

Tidal forcing along the boundary of the tidal model was obtained from satellite measured altimetry data (TOPEX/Poseidon 7.2). The altimeter derived data provided estimates of the eight dominant tidal constituents at a horizontal scale of approximately 0.25 degrees. The eight major tidal constituents used were K2, S2, m^2, N2, K1, P1, O1 and Q1. Local spatial variation in the tidal amplitude and phase of these eight constituents along the open boundaries was calculated by spatial interpolation from the grid scale of the TOPEX/Poseidon data to the grid scale of the open boundaries. Hydromap calculates local heights along the open boundaries, at each time step in the model to derive the slope in the water surface, which is applied to calculate the propagation of individual tidal waves. Net water levels are constituted at each time step from these tidal waves.

The Topex-Poseidon satellite data has a resolution of 0.25 degrees globally and is produced and quality controlled by NASA (National Aeronautics and Space Administration). The TOPEX and Poseidon satellites were equipped with two highly accurate altimeters, capable of taking sea level measurements at resolutions of ± 5 cm. Collectively, these satellites carried out 62,000 orbits of the planet (1992–2005). The Topex-Poseidon tidal data has been widely used and scrutinised by the oceanographic community (e.g. Andersen, 1995; Ludicone et al. 1998; Matsumoto et al. 2000; Kostianoy et al. 2003; Yaremchuk & Tangdong, 2004; Qiu & Chen 2010). As such the TOPEX/Poseidon tidal data is considered suitably accurate for calculation of tidal currents for this study.

3.2.2 Validation of the tidal model

To ensure that tidal predictions were accurate, predicted surface elevations were first compared graphically to observed data at six locations within the domain (Table 2 and Figure 7).

Figure 8 and Figure 9 show a comparison between the predicted and observed surface elevations for each of the six locations between 1–31 January 2014. They indicate that the HYDROMAP model accurately reproduced the phase and amplitudes of the sea surface elevation fluctuations attributable to astronomical tides throughout the spring and neap tidal cycles.

Measured and predicted tidal predictions for the six tide stations were also compared statistically applying the Mean Absolute Error (MAE) (Willmott, 1982; Willmott & Matsuura, 2005) and the Index of Agreement (IOA) (Willmott, 1981).

The MAE is simply the average discrepancy between each of the model-predicted (P) and observed (O) value, where the differences are expressed as absolute values. The MAE is a more natural measure of the average error (Willmott & Matsuura, 2005) and more readily understood.

$$MAE = N^{-1} \sum_{i=1}^{N} |P_i - O_i|$$

A low MAE indicates better fit between the predicted and observed data. One limitation of the MAE, for data that fluctuates (as per tidal levels) is that a small discrepancy in the phase of the data being compared will yield an apparently large error. Phase errors would not have any significance for the application of the predicted data in this study because spill times are randomised (i.e. not analysed for release at specific times).

The Index of Agreement (IOA) provides a standardised comparison that identifies additive and proportional differences in the means and variances between predicted and observed values:

$$IOA = 1 - \frac{\sum |X_{model} - X_{obs}|^2}{\sum (|X_{model} - \overline{X_{obs}}| + |X_{obs} - \overline{X_{obs}}|)^2}$$

Where: *X* represents the variable being compared and $\overline{X_{obs}}$ is the time mean of the observed values. A perfect agreement would exist between the predictions and observations if the index gives an agreement value of 1 and complete disagreement will produce an index measure of 0 (Wilmott, 1981). Willmott et al. (1985) also suggests that values meaningfully larger than 0.5 represent good model performance.

MAE values calculated for the nine stations were low and approaching 0 indicative of good fit of both the phase and amplitude of the predictions. MAE values indicated discrepancies of between 5 cm to 11 cm among the sites (Table 2). Given that observed water levels are subject to other phenomenon than astronomical tides, this comparison indicates robust calculation for tidal propagation over the region. The IOA values calculated from the comparison ranged between 0.95 to 0.99 across the six sites, approaching the ideal fit of 1, also indicative of robust model performance. No spatial trends in error indexes are presented, providing evidence that tidal predictions can be relied on away from the observation sites.

Table 2: Statistical comparison between the observed and HYDROMAP predicted surface elevation data from 1–31 January 2014

Tide Station	IOA	MAE (m)
Albany	0.98	0.07
Esperance	0.98	0.06
Eucla	0.96	0.08
Port Lincoln	0.95	0.11
Portland	0.97	0.07
Eden	0.99	0.05
Average	0.97	0.07

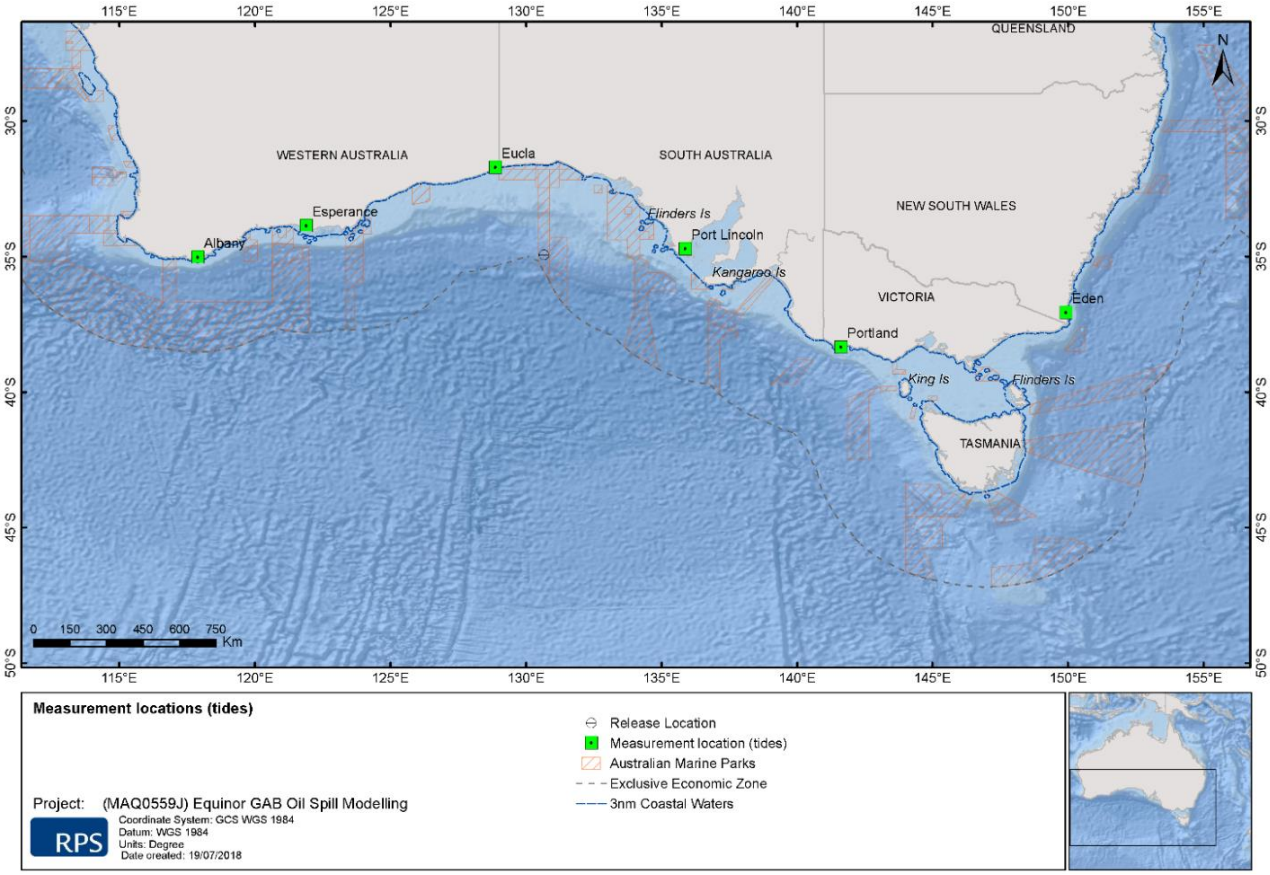


Figure 7: Tide stations used in the surface elevation comparison

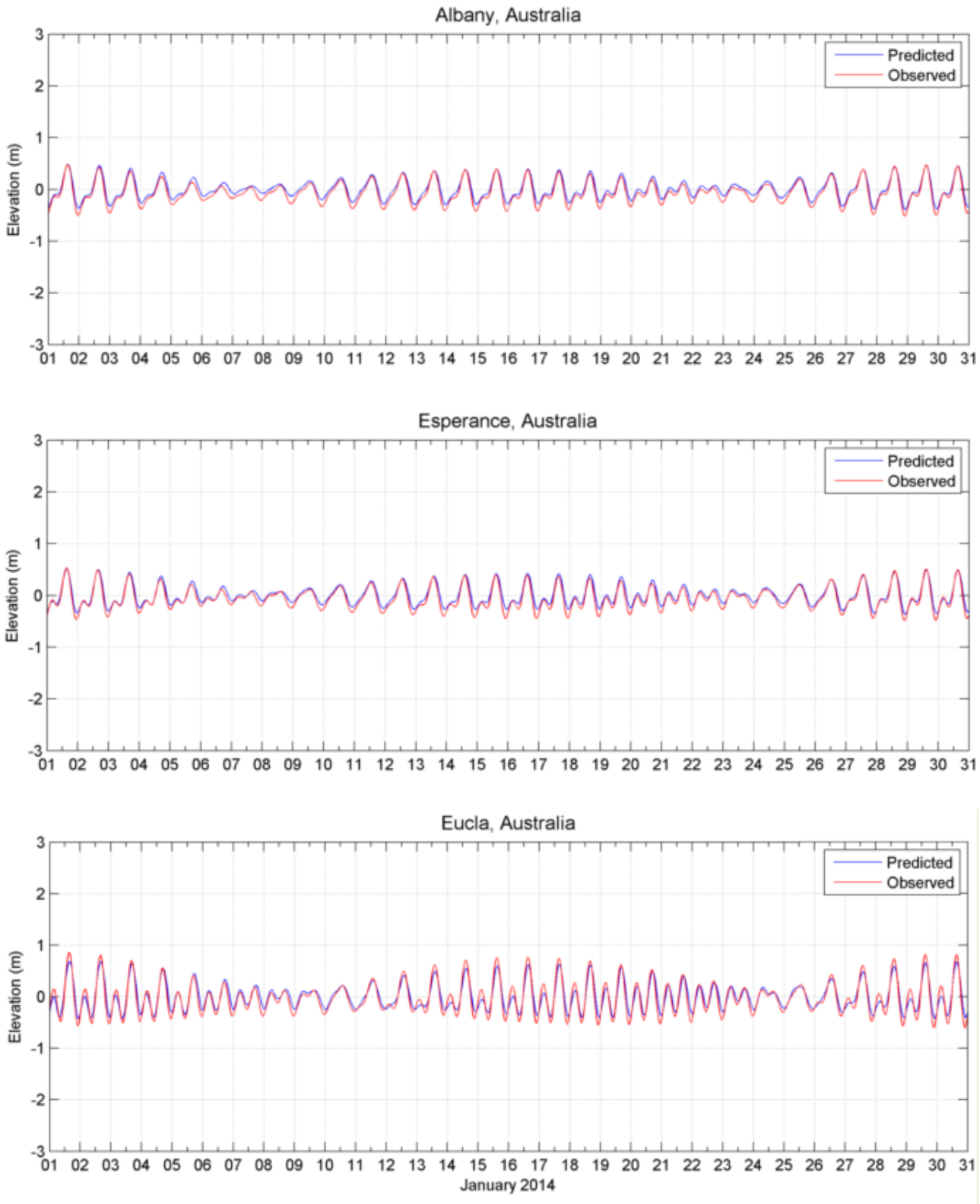


Figure 8: Comparison between predicted (blue line) and observed (red line) surface elevation variation at Albany (top), Esperance (middle) and Eucla (bottom), between 1–31 January 2014

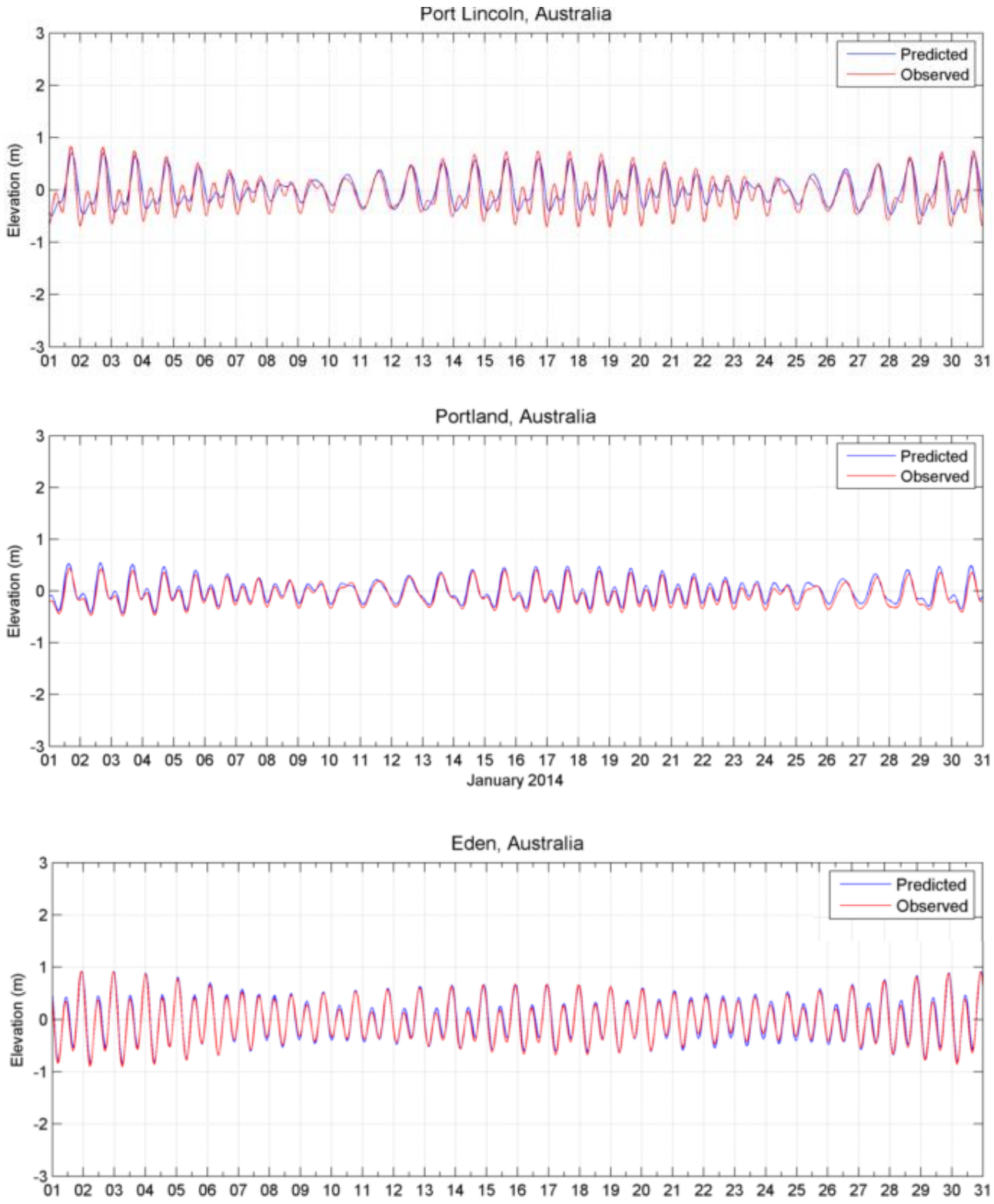


Figure 9: Comparison between predicted (blue line) and observed (red line) surface elevation variation at Port Lincoln (top), Portland (middle) and Eden (bottom), between 1–31 January 2014

3.3 Ocean currents within the Great Australian Bight

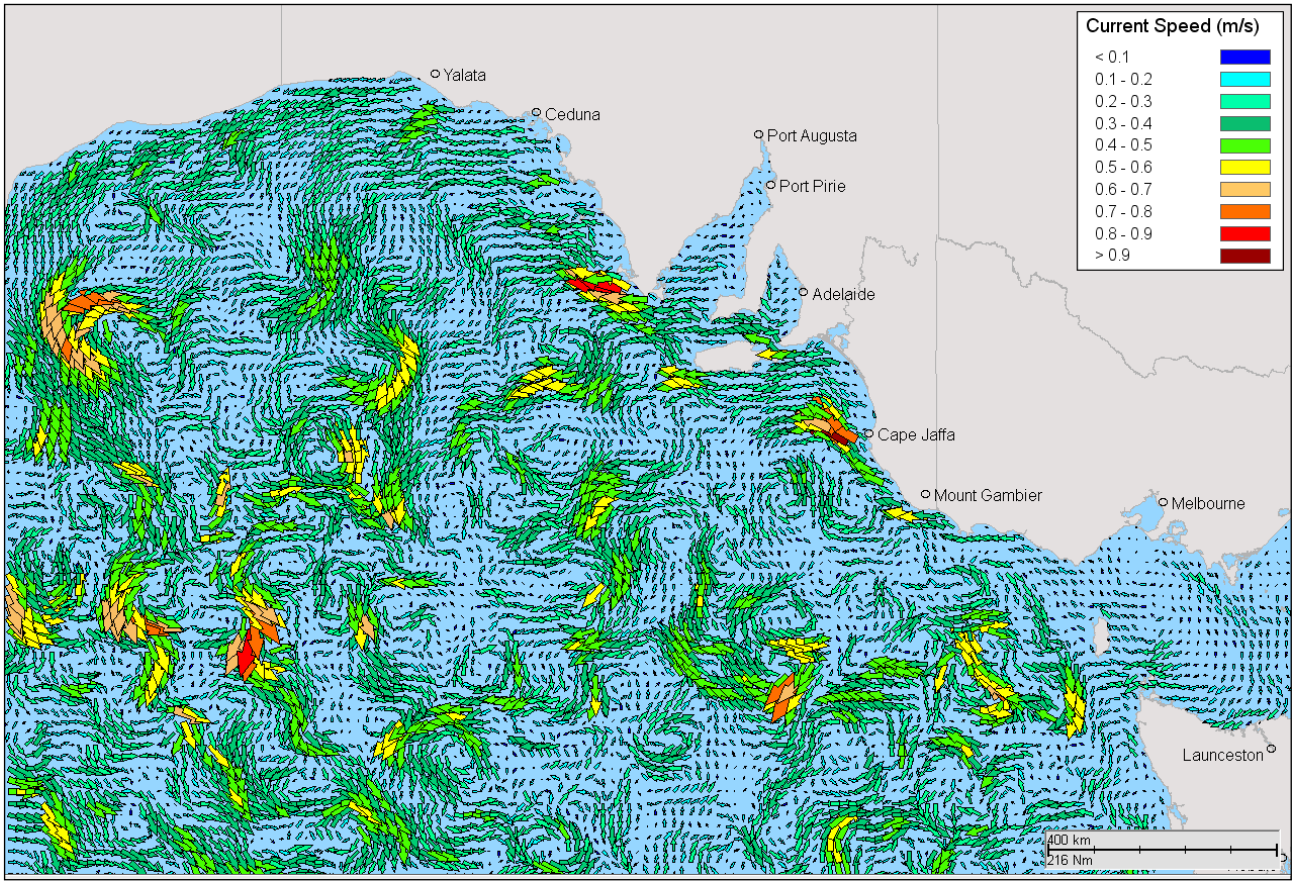
Predicting the transport and fate of any oil released at the Stromlo well site also required representation of non-tidal currents (or large scale ocean currents) spanning multiple years over a wide area. After reviewing the availability and quality of multiple sources, three-dimensional (3D) ocean current data from 2008 to 2012 (inclusive) from the Hybrid Coordinate Ocean Model (HYCOM; Chassignet et al. 2007) was selected to represent the non-tidal current flows.

The HYCOM model is operated by the HYCOM Consortium, sponsored by the Global Ocean Data Assimilation Experiment (GODAE). HYCOM is a three-dimensional ocean model with global coverage that assimilates observations of sea surface height, sea surface temperature and in-situ temperature and salinity measurements (Chassignet, et al. 2009). Reanalysis of past periods using the HYCOM model calculates for the exchange of heat flux and water mass and has been shown to realistically represent upwelling and downwelling events (George, 2014; Xu et. al. 2013).

The HYCOM predictions for drift currents are produced in three dimensions, from surface to seabed, at a horizontal spatial resolution of approximately 8.25 km (one twelth of a degree) over the region, at a frequency of once per day. The model is self-validated meaning that the model automatically self-calibrates and corrects with in-situ and satellite observations. The accuracy of calculations for heat-flux necessary to represent upwelling and downwelling events is assisted by assimilation of in-situ sea-surface temperature observations, from satellite, as well as in-situ vertical temperature and salinity profiles from floats and profile measurements. Calibration and quality control of the reanalysis (hind-cast) datasets produced using HYCOM results in more reliable representation of past oceanographic events than uncalibrated forecast data.

The complexity of the ocean current flows over the region that is calculated by the HYCOM model data is revealed by an example plot representing one single day (1 January 2012, see Figure 10). Arrows point in the direction of flow and the speed of the current is represented by the scale and colour of the arrows. Because these data are presented at daily steps, the HYCOM data does not represent tidal variations, which fluctuate over shorter time-scales.

Three-dimensional data representing horizontal movement at discrete depths was extracted from the HYCOM reanalysis data covering the historic period (2008 to 2012). While this data should represent effects of upwelling and downwelling processes on horizontal transport at a given depth, the data did not represent vertical currents between horizontal layers. This was considered reasonable because vertical currents associated with episodic upwelling and downwelling events are relatively small (3–30 cm/s; Kampf et. al 2004) compared to horizontal currents represented in the tidal and non-tidal current data (0.5–2 m/s), allowances for dispersion rates in the horizontal (0.1–50 m/s) and vertical (1–10 cm/s) as well as vertical movement of oil due to buoyancy.



The colours of the vectors indicate current speed in m/s

Figure 10: Predicted ocean surface currents on 1 January 2012. Derived from the HYCOM ocean hindcast model

3.4 Net water current comparison

A composite of the modelled ocean current data product was derived by combining predictions of ocean circulation data from the HYCOM model, with predictions of the tidal currents generated by the RPS HYDROMAP model.

To ensure that the combined current calculations were suitably accurate, the composite were visually compared to measured data available from a location approximately 50 km north of the Stromlo-1 well site (34° 28' 30'' S, 130° 42' 5'' E; Figure 11) that was previously measured by RPS MetOcean (now RPS) (2013). Rose plots that illustrate the distribution of the speed and direction of current flows were generated from the calculated net-current data and compared to those produced from the measured current data that were extracted directly from the RPS MetOcean (2013) report. Comparisons between the calculated and measured datasets were made at six different depths across two different periods (see Table 3).

The current roses show the frequency at which the current flows towards a given direction at a given speed. Each sector of the rose represents currents flowing toward that direction e.g. currents flowing towards the north are represented by the sector extending towards the top of the rose. Sixteen directions are used, representing the cardinal directions. Each sector is divided into segments that are colour-coded, representing intervals in current speed. The length of each segment within a sector indicates the frequency that currents flowed toward that direction at the given speed.

A comparison of the current roses (Figure 12 to Figure 17) indicate good agreement between the calculated net-currents and the measured currents at surface over time. The calculated current captures spatial trends in the distribution of current data that was represented in the measured data. Both data sets indicate reduction in current speed with increasing depth, speeds of up to 0.6 m/s are indicated for 30 m, reducing to 0.2 m/s in the deepest layer (1,000 m). Furthermore, both data sets indicate a shift in the current direction,

with flows more frequently towards the eastern and southern sectors in the upper water column and more frequently towards the southern and south-western sector in the deeper layers. The rose plots also reveal that current might flow toward any direction at each of the depth levels.

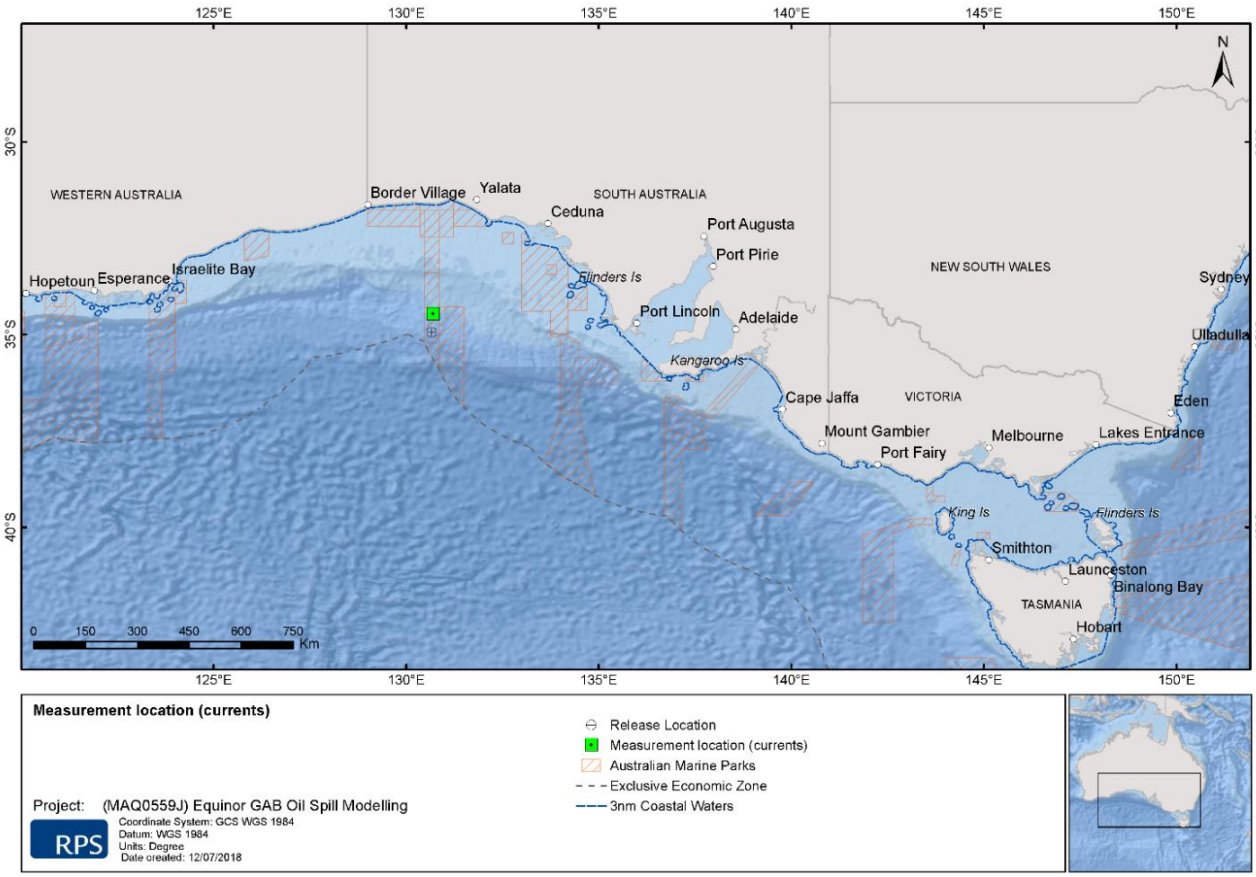
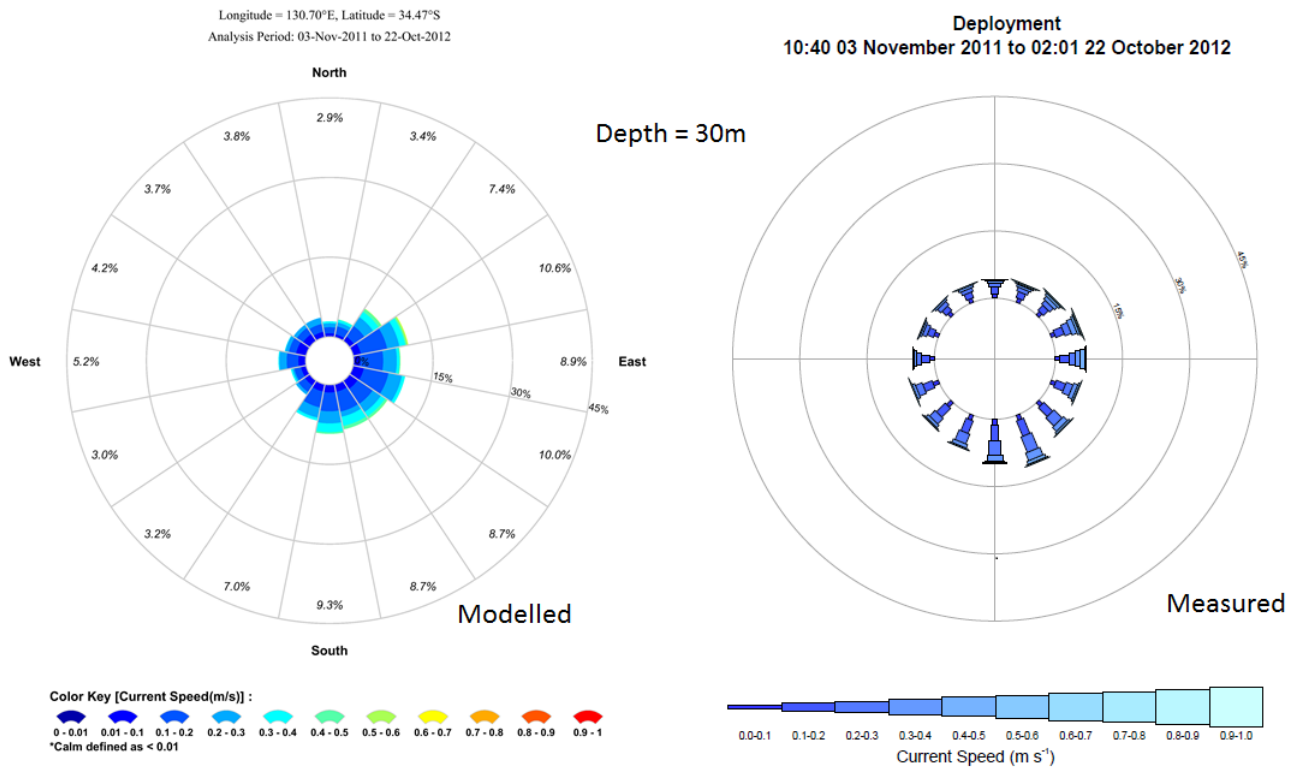


Figure 11: Current measurement location in relation to the Stromlo-1 well site

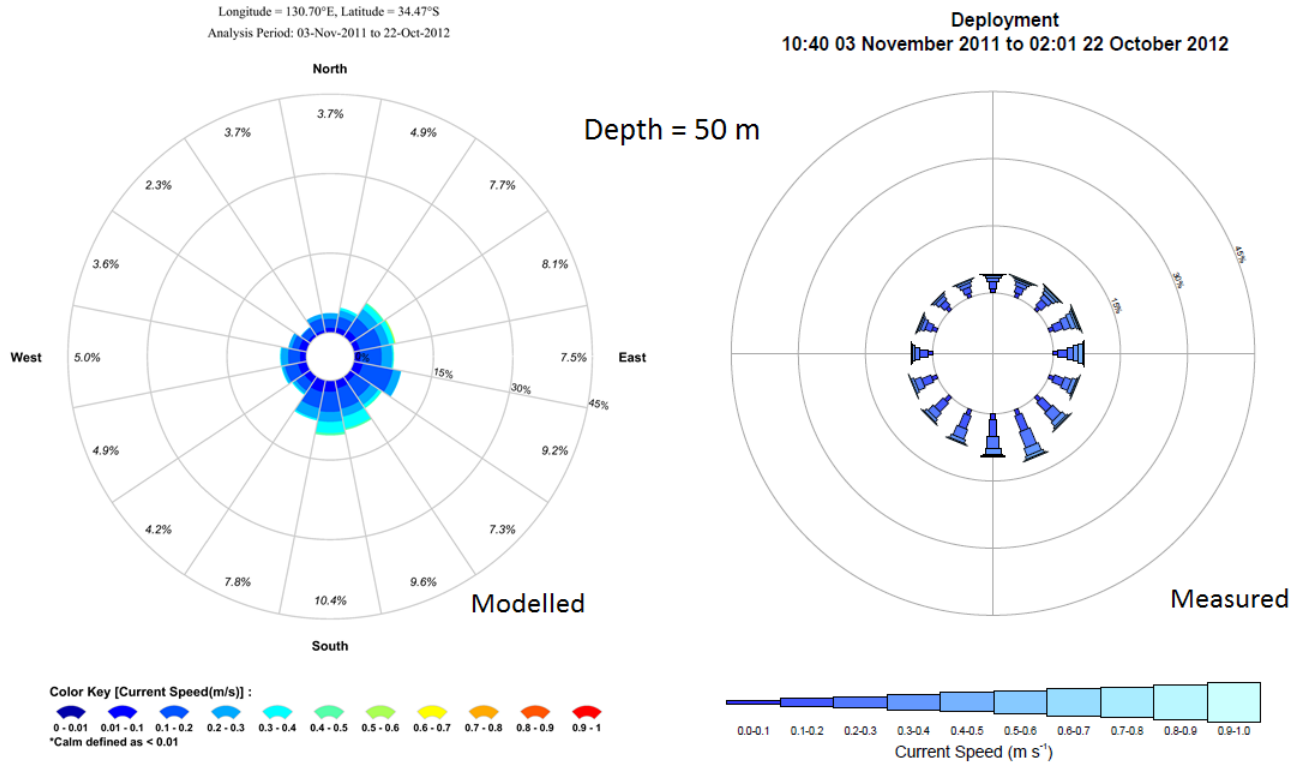
Table 3: Measured and calculated current data information

Depth (m)	Period	Measured data	Modelled data
30	03-11-2011 to 22-10-2012	ADCP	Tidal + ocean currents
50	03-11-2011 to 22-10-2012	ADCP	Tidal + ocean currents
70	03-11-2011 to 22-10-2012	ADCP	Tidal + ocean currents
200	03-11-2011 to 12-12-2012	CM04 - Current metre	Tidal + ocean currents
300	03-11-2011 to 12-12-2012	CM04 - Current metre	Tidal + ocean currents
1,000	03-11-2011 to 12-12-2012	CM04 - Current metre	Tidal + ocean currents



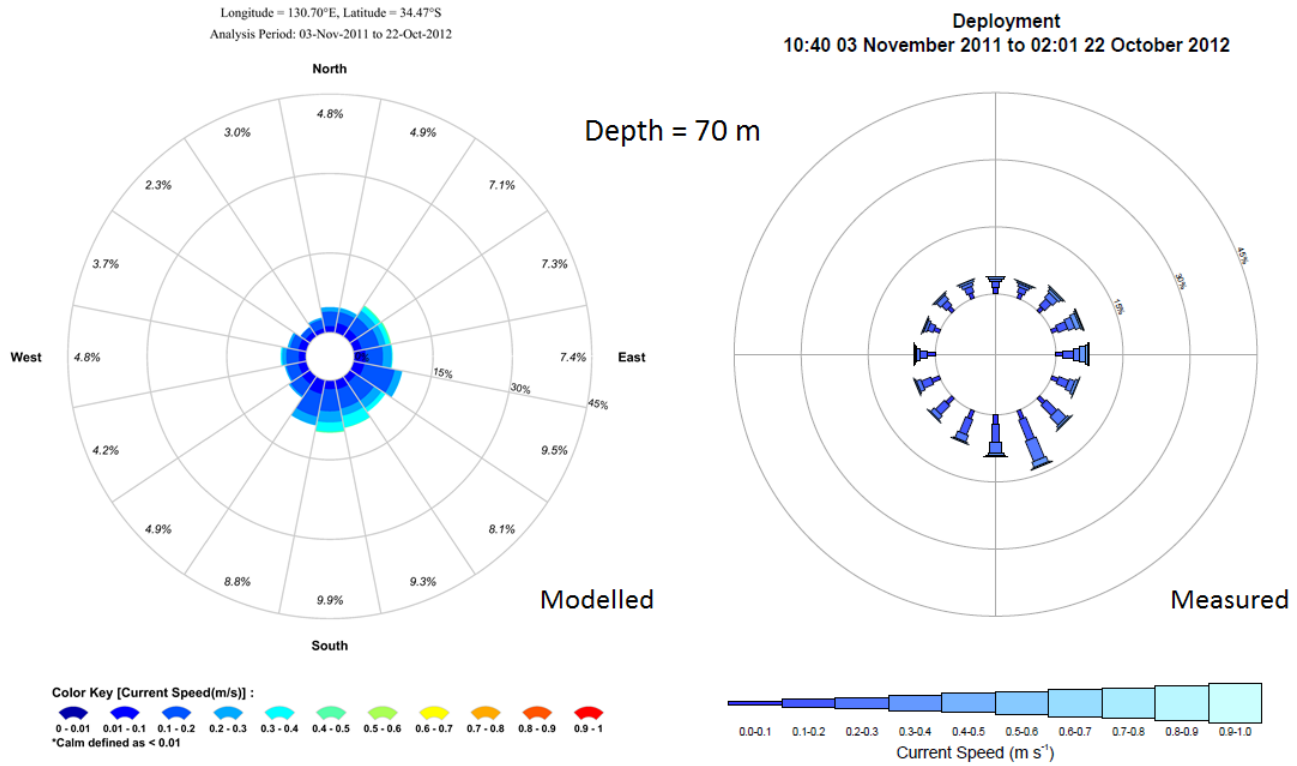
(source of measured data: RPS MetOcean 2013)

Figure 12: Modelled (left) and measured (right) current roses for depth layer of 30 m at 340 28' 30'' S, 1300 42' 5'' E



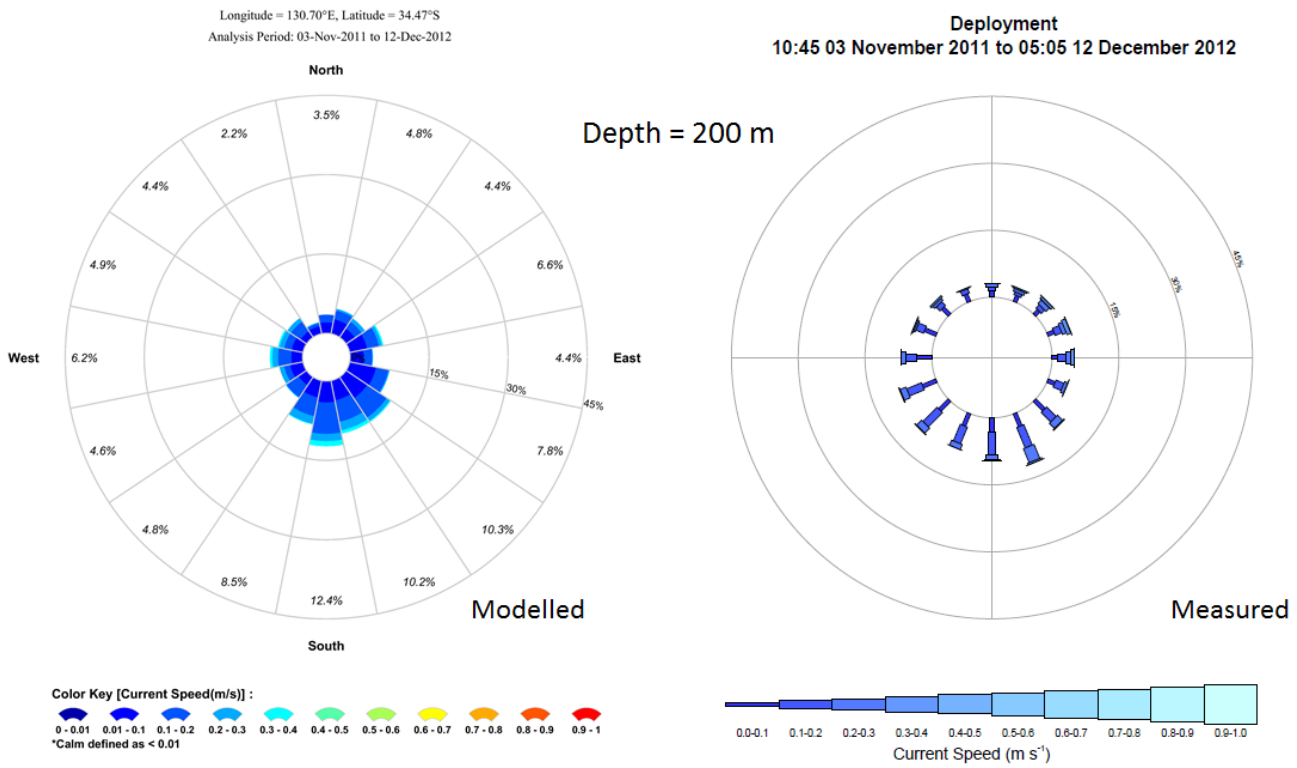
(source of measured data: RPS MetOcean 2013)

Figure 13: Modelled (left) and measured (right) current roses for depth layer of 50 m at 340 28' 30'' S, 1300 42' 5'' E



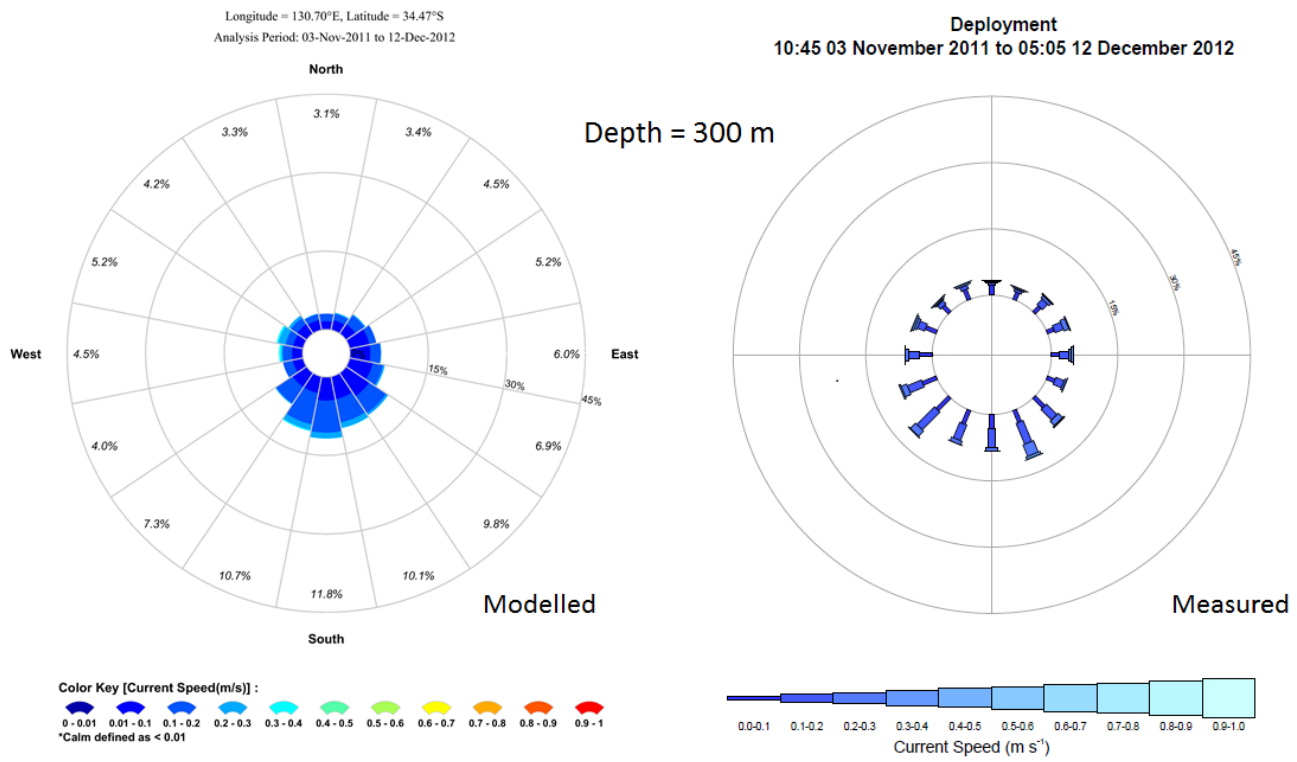
(source of measured data: RPS MetOcean 2013)

Figure 14: Modelled (left) and measured (right) current roses for depth layer of 70 m at 340 28' 30'' S, 1300 42' 5'' E



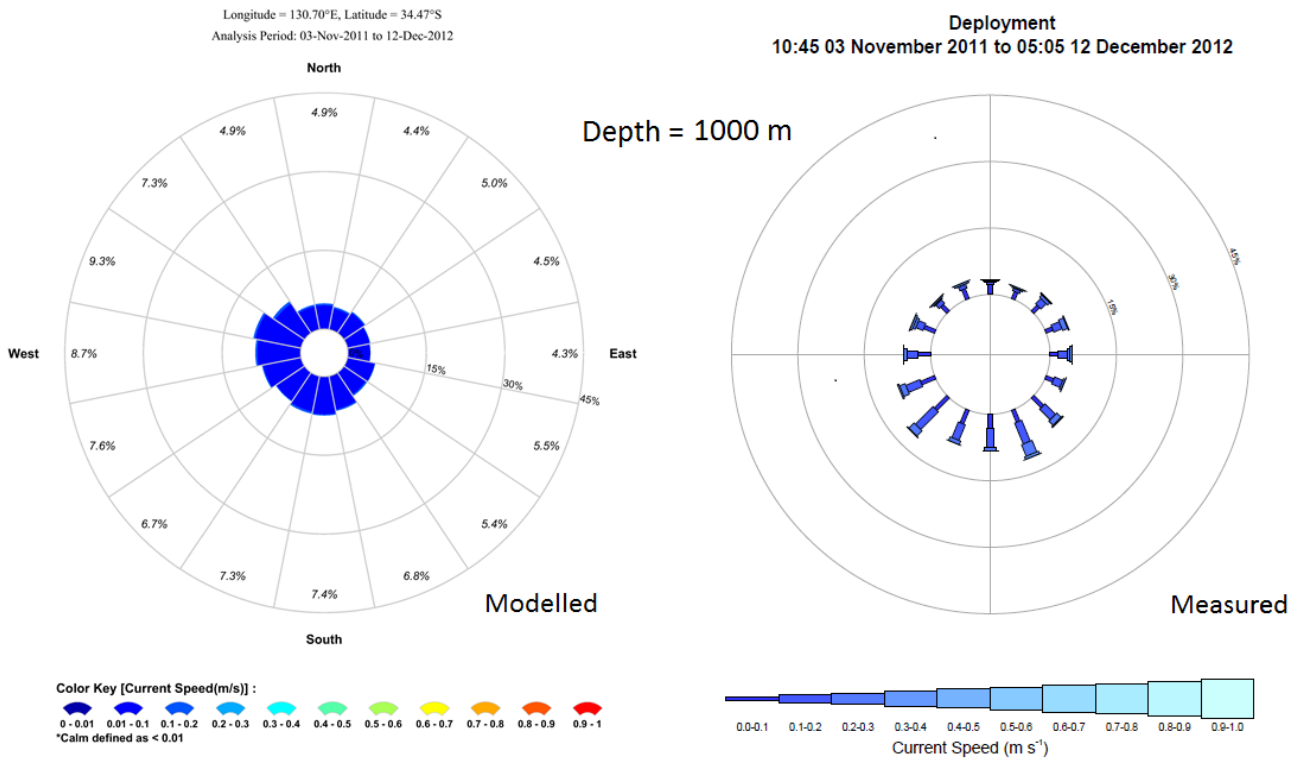
(source of measured data: RPS MetOcean 2013)

Figure 15: Modelled (left) and measured (right) current roses for depth layer of 200 m at 340 28' 30'' S, 1300 42' 5'' E



(source of measured data: RPS MetOcean 2013)

Figure 16: Modelled (left) and measured (right) current roses for depth layer of 300 m at 340 28' 30'' S, 1300 42' 5'' E



(source of measured data: RPS MetOcean 2013)

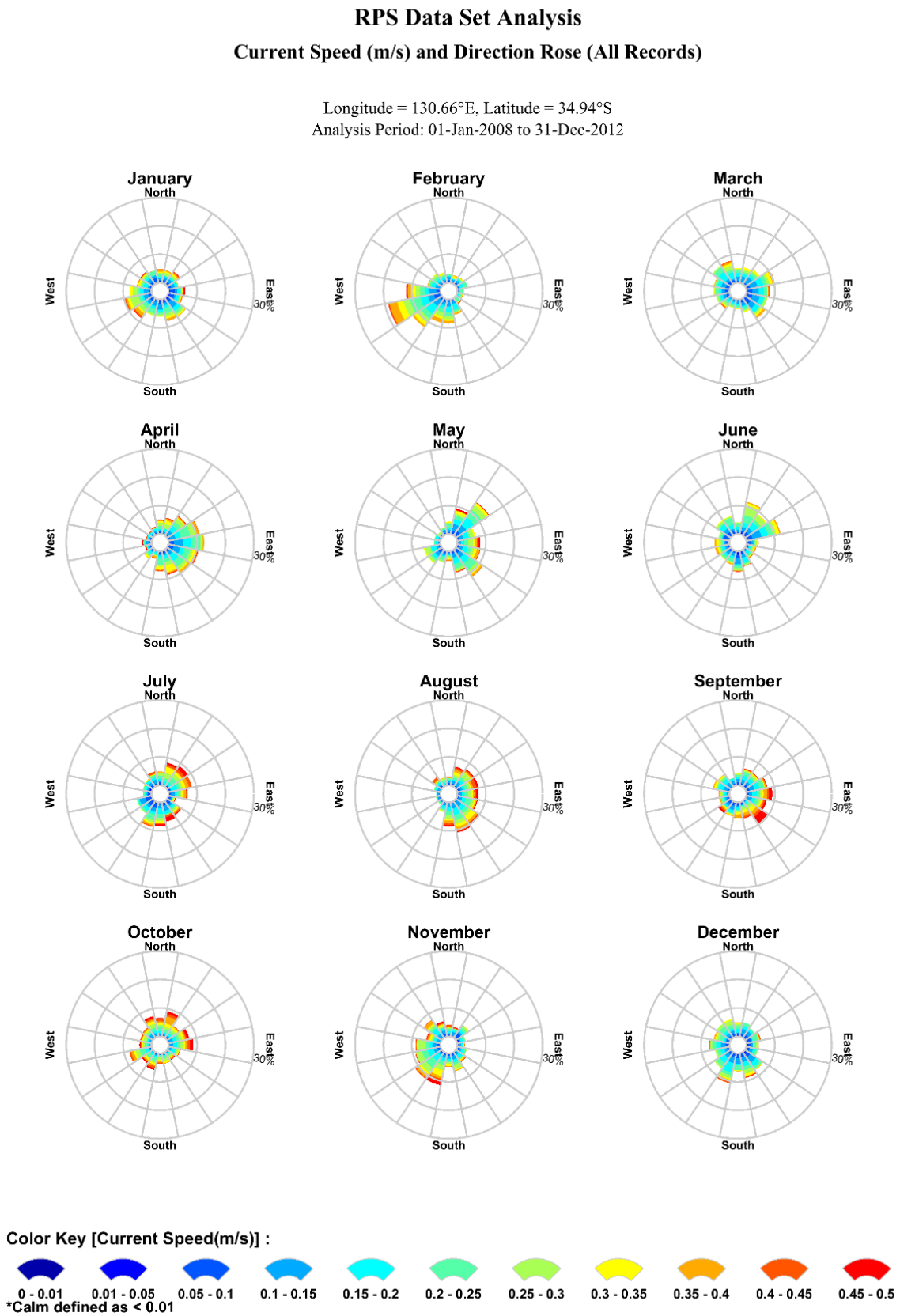
Figure 17: Modelled (left) and measured (right) current roses for depth layer of 1,000 m at 340 28' 30'' S, 1300 42' 5'' E

Analysis of the net current data derived by aggregating ocean current data from HYCOM with tidal current data from HYDROMAP for the period 2008–2012 (inclusive; Table 4) indicates a similar range of current speeds can occur year-round. Average monthly current speeds ranged from 0.17 m/s and 0.28 m/s. Maximum surface current speeds range between 0.44 m/s to 0.69 m/s. Predominant surface current directions varied between the months (Figure 18) indicating that the likelihood of spills moving, initially, in a given direction will vary over the drilling window (October to May).

Table 4: Predicted average and maximum surface current speeds adjacent to the release location

Month	Average current speed (m/s	Maximum current speed (m/s	General direction (toward)
January	0.19	0.50	Variable
February	0.21	0.56	South-west
March	0.18	0.44	South-east–north–north-west
April	0.21	0.57	East
May	0.20	0.60	North-east–Southeast
June	0.18	0.65	North-east
July	0.22	0.66	North-east–South
August	0.28	0.88	East
September	0.24	0.82	Variable
October	0.28	0.65	Variable
November	0.22	0.69	South-west
December	0.17	0.50	South
Minimum	0.17	0.44	
Maximum	0.28	0.69	

Data derived by combining the HYCOM ocean data and HYDROMAP high resolution tidal data from 2008-2012 (inclusive). The study assessed oil spill simulations commencing in October to May only



Data was derived by combining the HYCOM ocean currents and HYDROMAP tidal currents for 2008– 2012 inclusive. The colour key shows the current magnitude (m/s, the compass direction provides the current direction flowing TOWARDS and the length of the wedge gives the percentage of the record for a particular speed and direction combination

Figure 18: Monthly modelled surface current rose plots near the release location

4 REGIONAL WINDS

Wind data from 2008–2012 (inclusive) was sourced from the National Centre for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) (see Saha et al. 2010). The CFSR wind data covers the same years and extents as the current data. 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.

Figure 19 shows the spatial resolution of the wind field used as input into the oil spill model. The wind nodes are spaced 33 km apart and contain datasets based on hourly intervals.

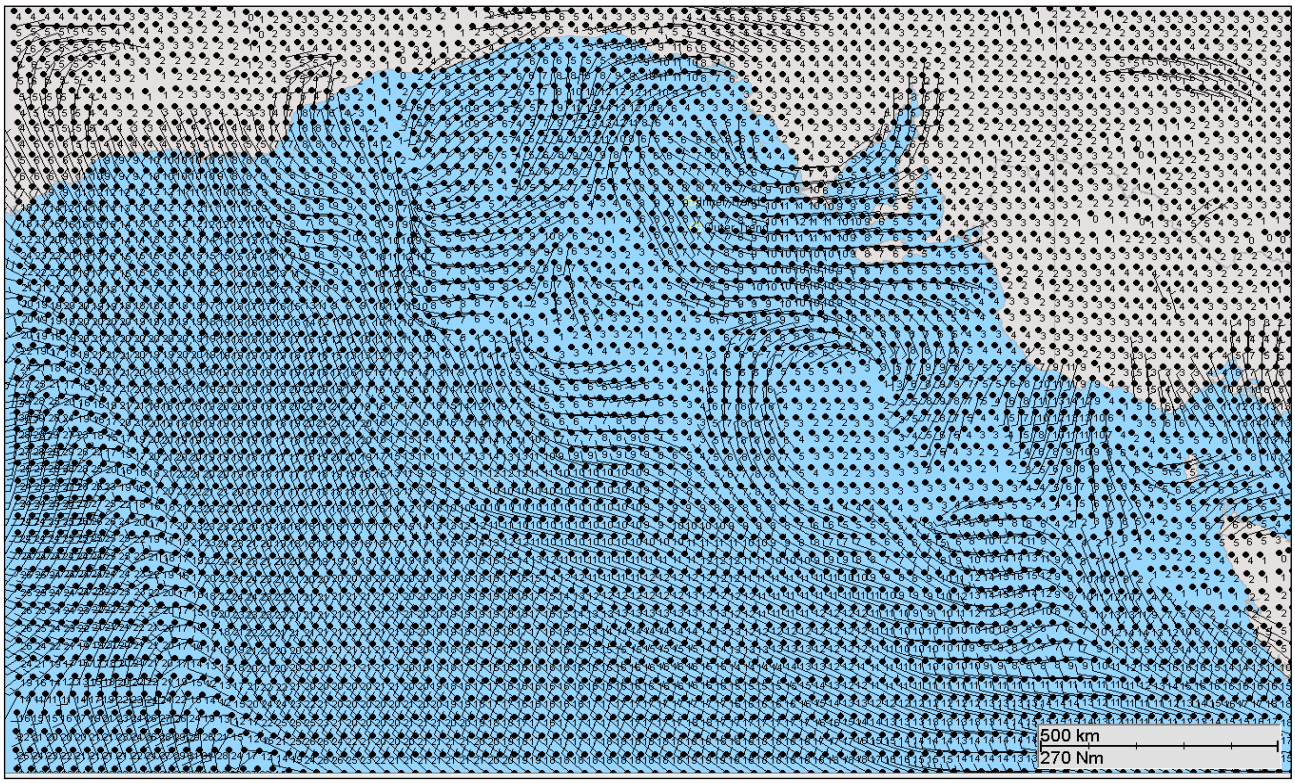


Figure 19: Spatial resolution of the wind data used as input into the oil spill model

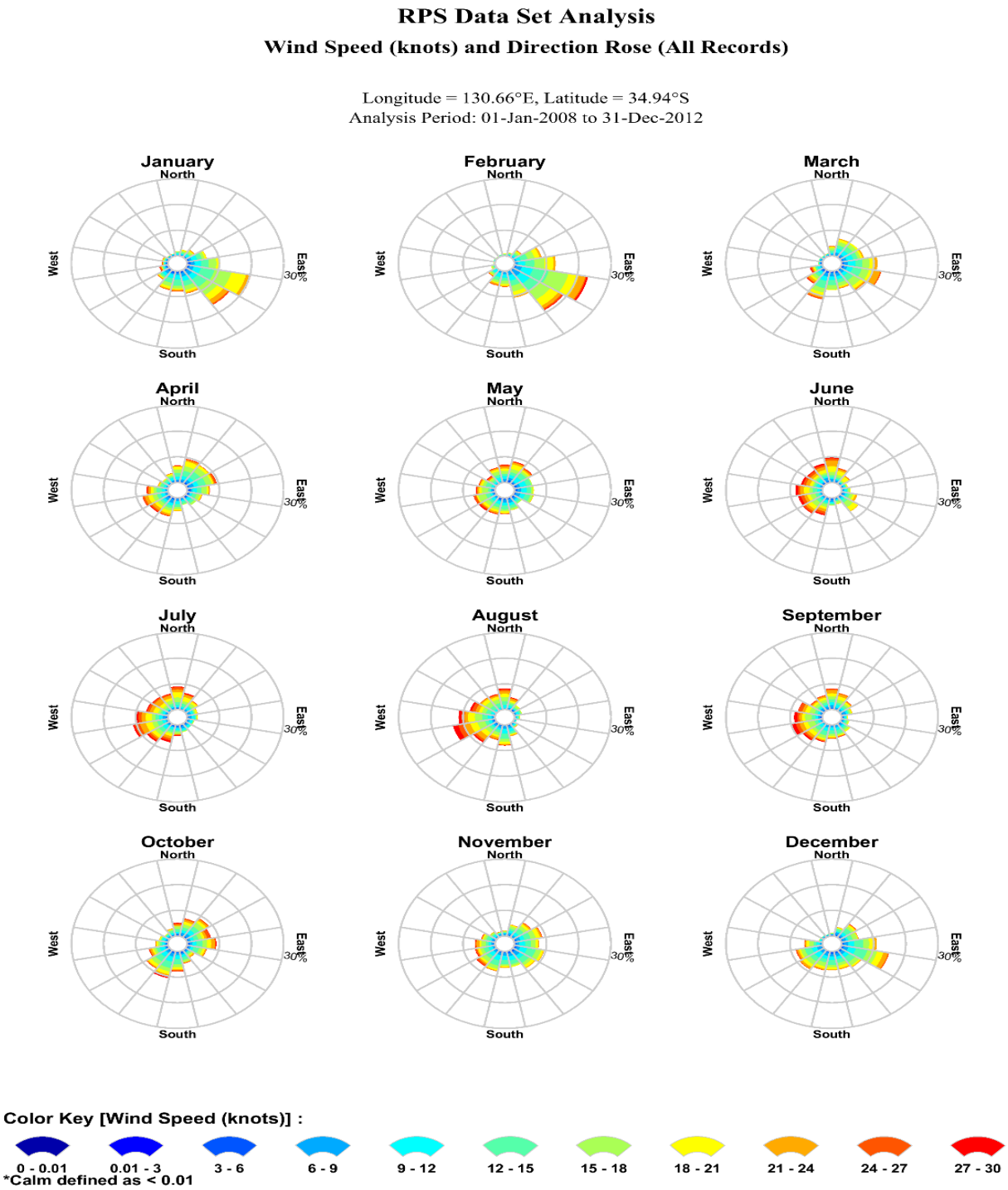
Table 5 present the monthly average and maximum winds speeds and directions derived from the CFSR station adjacent to the release location. Note that, in contrast to current data, wind directions by convention are stated with reference to the direction that they approach from. Average monthly wind speeds ranged from 13.2 knots and 14.5 knots. While maximum monthly wind speeds ranged between 31.1 knots to 45.6 knots. In the context of the effect of wind speeds on sea-states, moderate to strong breezes that will generate light to moderate white-capping (12 knots–18 knots) of the sea surface occur most frequently (Figure 20). Winds speeds exceeding 18 knots that will generate more energetic white-capping at the sea surface also occur relatively frequently in any month. This observation is significant because breaking waves at the sea surface will generate energy that forces physical entrainment of floating oil.

During the activity period (October to May) winds at Stromlo-1 predominately blow from the east and south-east and from the west and south-west in the non-activity period. The monthly wind roses in Figure 20 show that the strongest winds (>15 m/s) are generally restricted to westerlies and south-westerlies between May and October.

Table 5: Predicted average and maximum winds for the closest station to the release location

Month	Average wind speed (knots	Maximum wind speed (knots	General direction (from)
January	13.5	34.1	East
February	14.5	33.6	East
March	13.4	32.8	East–south–south-west
April	13.9	37.5	North-east–south-west
May	13.9	45.6	Variable
June	16.9	40.0	Variable
July	16.4	42.8	Variable
August	16.4	40.8	West
September	16.0	45.4	West
October	14.1	34.7	North-east–south-west
November	13.2	33.1	North-east–south-west
December	13.2	31.1	South
Minimum	**13.2**	**31.1**	
Maximum	**14.5**	**45.6**	

Data was derived from CFSR hindcast model from 2008-2012 (inclusive)



Data is derived from the CFSR model from 2008–2012 (inclusive). The colour key shows the wind magnitude, the compass direction provides the direction FROM and the length of the wedge gives the percentage of the record for a particular speed and direction combination

Figure 20: Monthly wind rose distributions for the closest wind node to the release location

4.1 Validation of wind data

The accuracy of the predicted wind data was assessed by comparison to measured data extracted from the Automated Weather Observing System from NOAA, for weather stations operated by the Australian Bureau of Meteorology (BoM). Five coastal wind stations along the GAB coastline were selected for the comparison (Figure 21 and Table 6).

IOA values calculated by comparison of data for corresponding times and locations (Table 6) ranged between 0.65 to 0.8 among the stations with an average of 0.74 across the five stations (Table 7). The average MAE across the five stations was calculated at 3.8 knots (range 2.89 to 5.39 knots). These calculations indicate a good model performance when replicating the wind conditions over the region.

Figure 22 to Figure 26 show comparison plots of the measured and predicted winds for each of the five stations and illustrates that the model represents the dynamic nature of the wind speeds and directions.

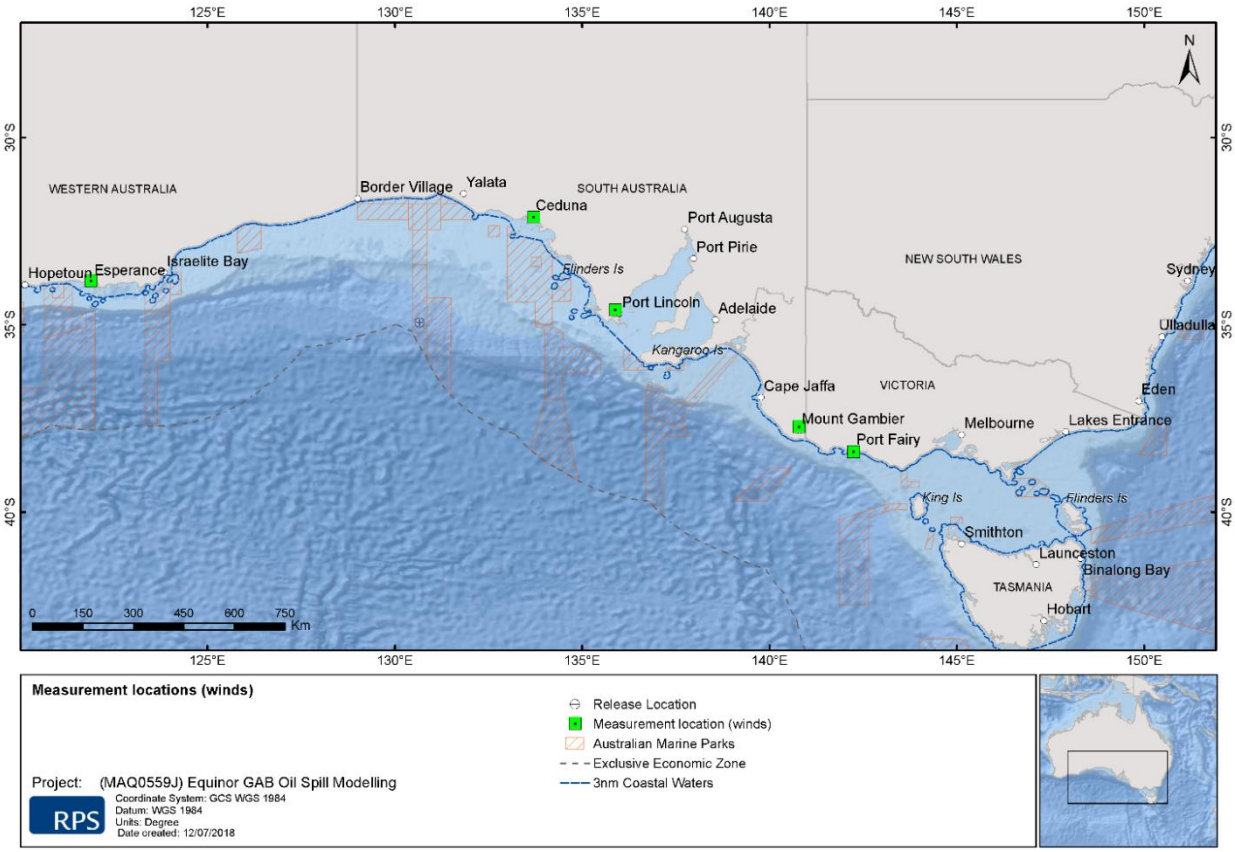


Figure 21: Wind measurement stations

Table 6: Wind stations location

Station	Latitude	Longitude
Ceduna	32° 7’ 58.8” S	133° 42’ 0.0” E
Esperance	33° 49’ 58.8” S	121° 53’ 34.8” E
Mount Gambier Aero	37° 43’ 58.8” S	140° 46’ 58.8” E
Port Fairy AWS	38° 24’ 0.0” S	142° 13’ 58.8” E
Port Lincoln	38° 36’ 18.0” S	135° 52’ 48.0” E

Table 7: Statistical evaluation between the measured and predicted winds at each location

Station	Index of agreement (IOA)	Mean average error (MAE – knots)
Ceduna	0.80	2.98
Esperance	0.65	5.39
Mount Gambier Aero	0.77	3.68
Port Fairy AWS	0.80	3.78
Port Lincoln	0.67	3.55

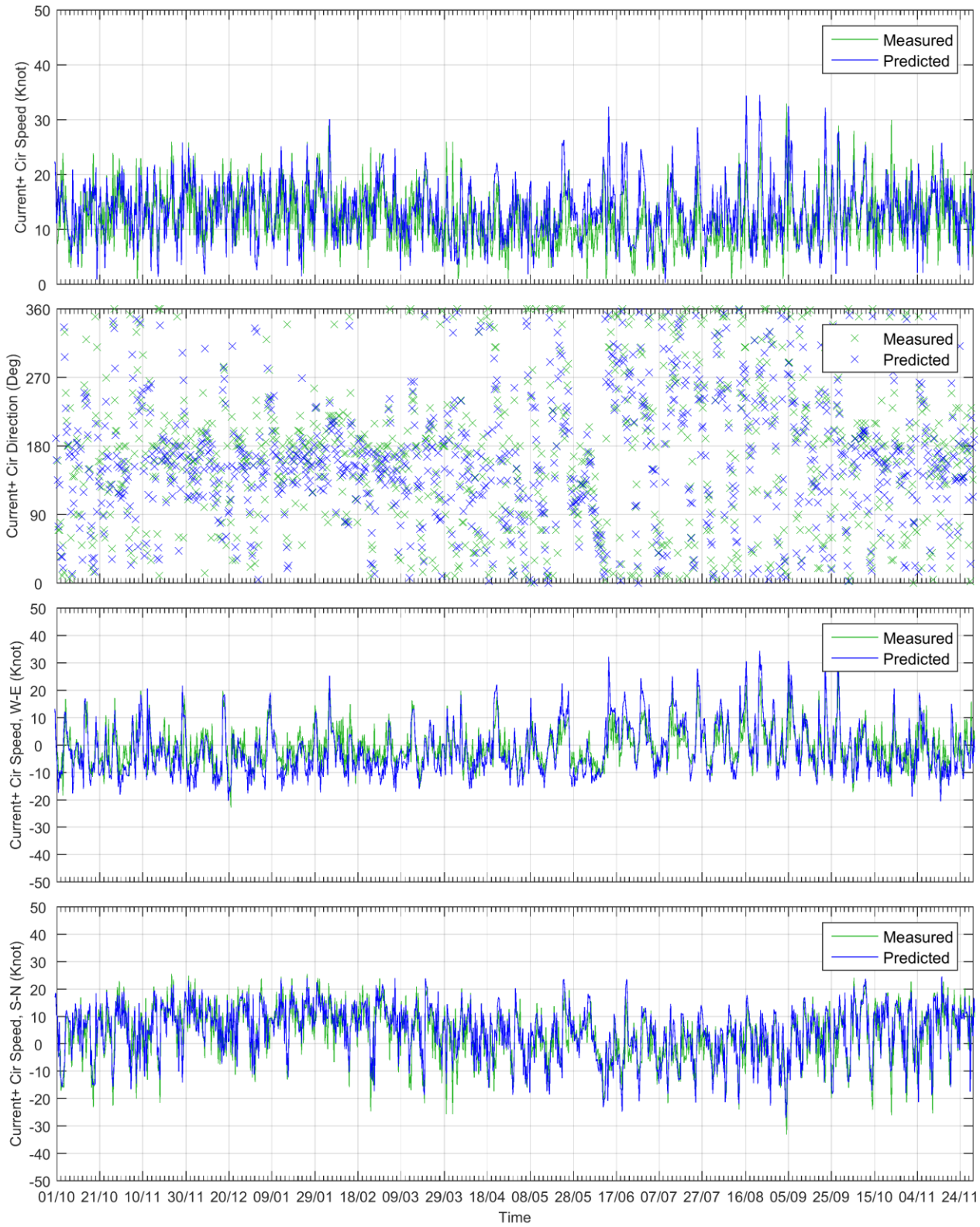


Figure 22: Comparison of measured and predicted current speeds (top image), east–west and north–south components (middle and bottom images, respectively), at Ceduna wind station

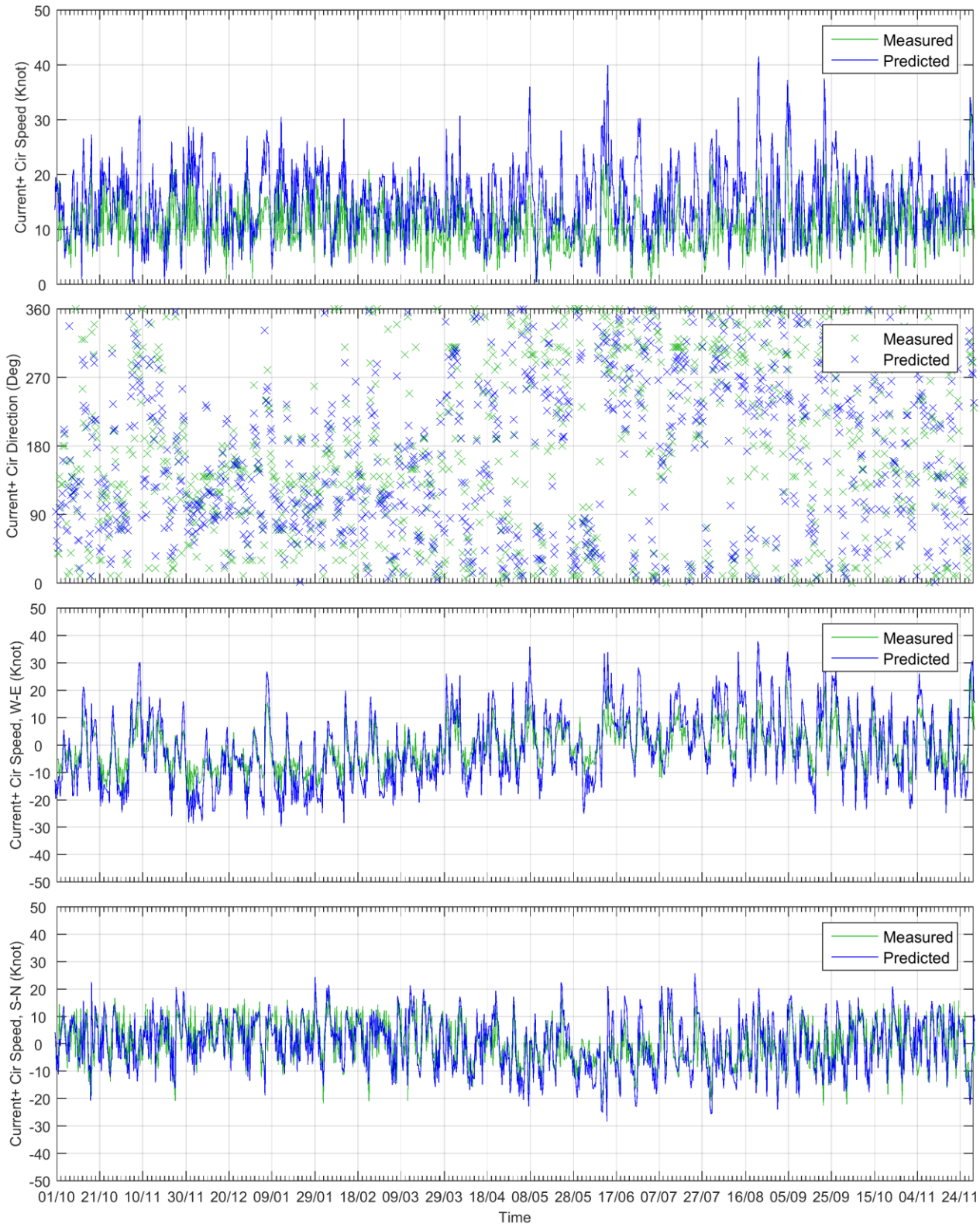


Figure 23: Comparison of measured and predicted current speeds (top image), east–west and north–south components (middle and bottom images, respectively), at Esperance wind station

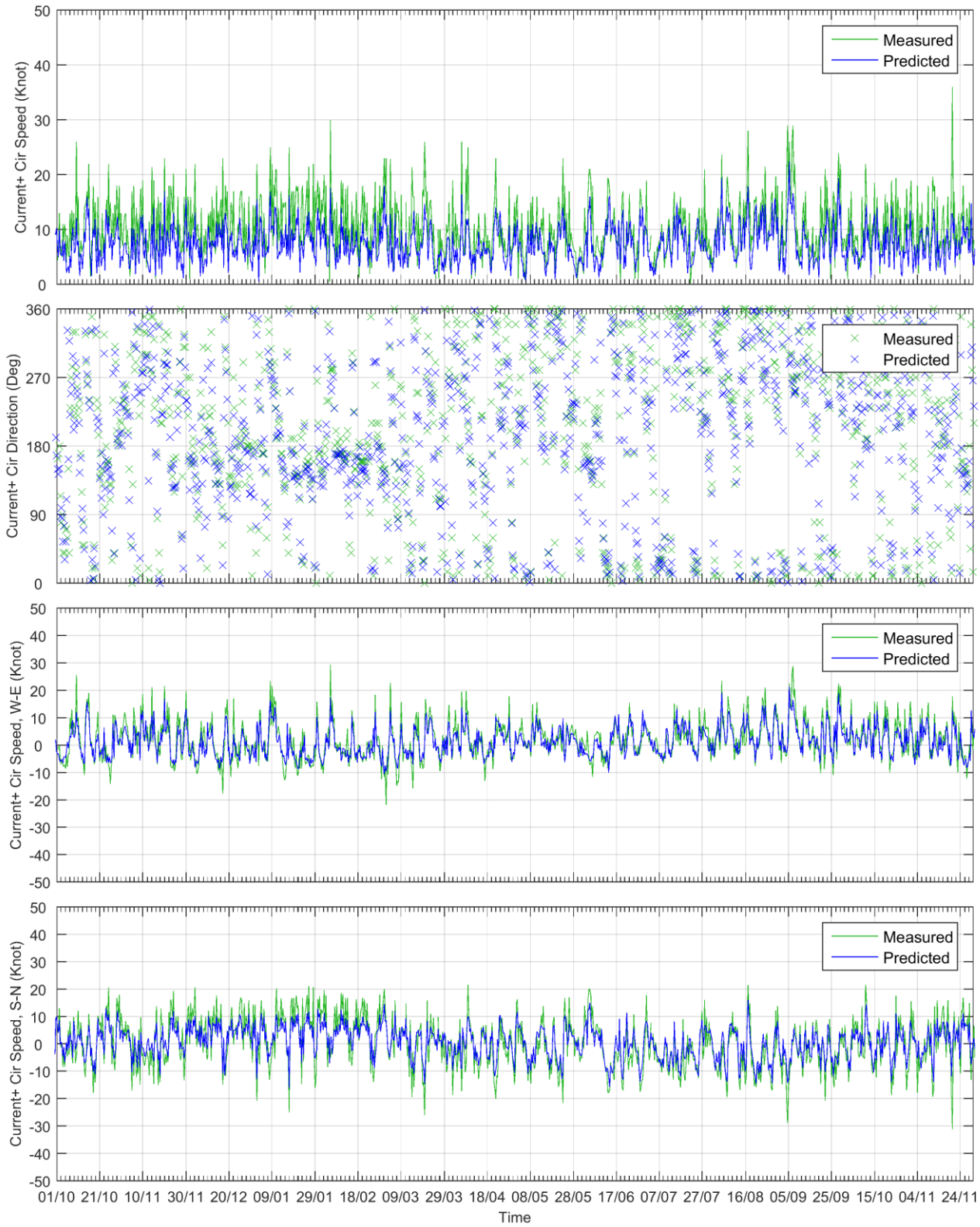


Figure 24: Comparison of measured and predicted current speeds (top image), east–west and north–south components (middle and bottom images, respectively), at Mount Gambier Aero wind station

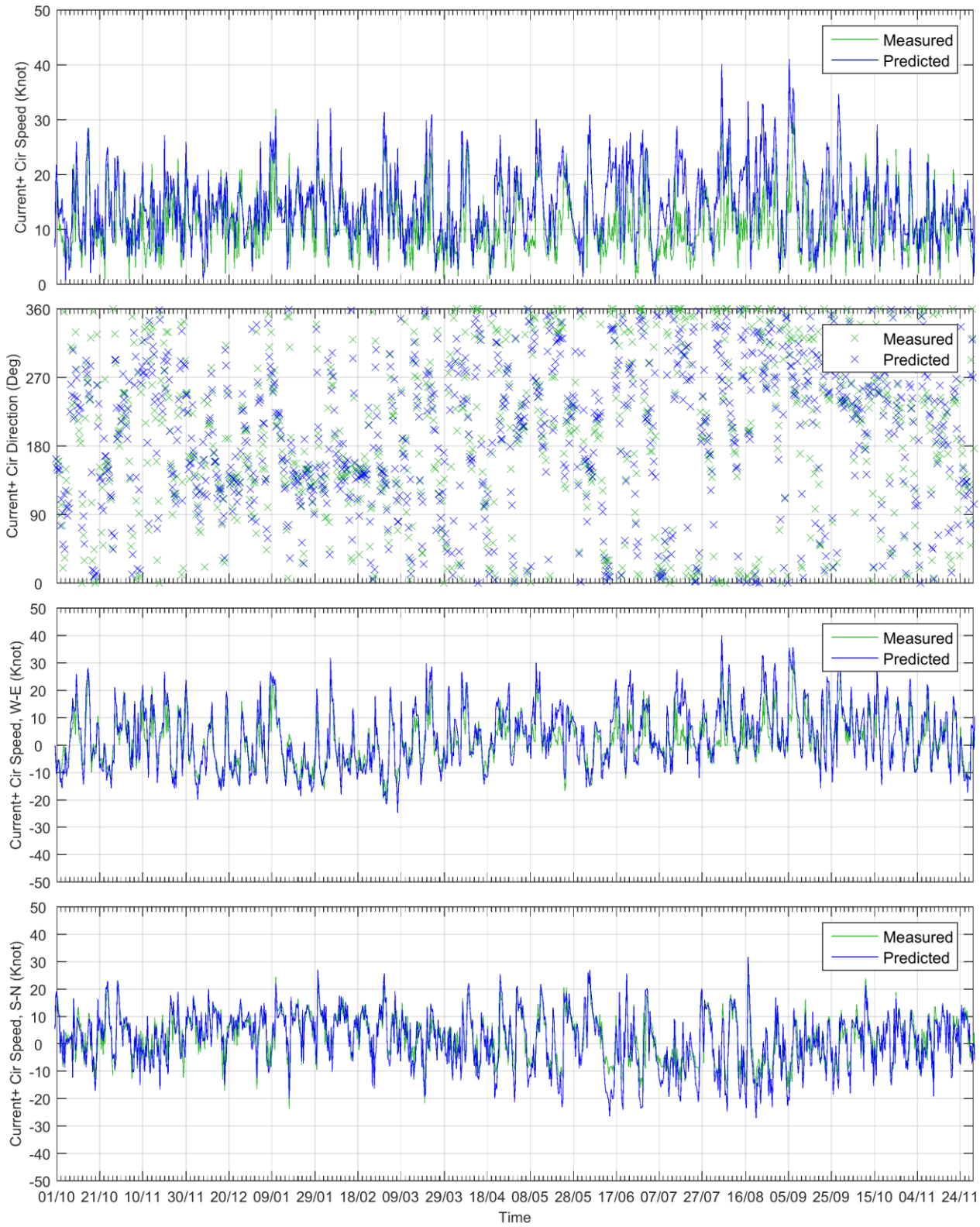


Figure 25: Comparison of measured and predicted current speeds (top image), east–west and north–south components (middle and bottom images, respectively), at Port Fairy AWS wind station

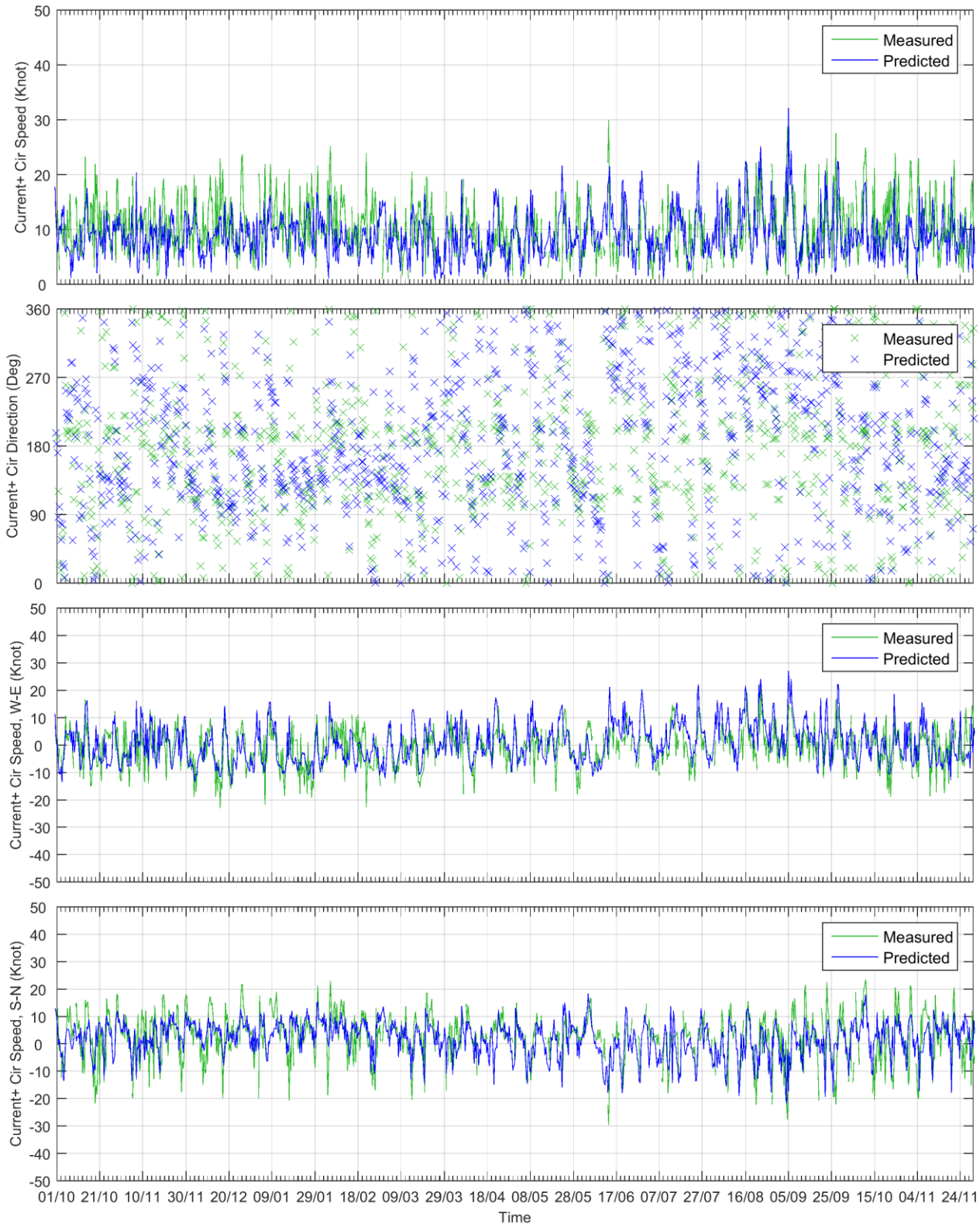


Figure 26: Comparison of measured and predicted current speeds (top image), east–west and north–south components (middle and bottom images, respectively), at Port Lincoln wind station

5 WATER TEMPERATURE AND SALINITY

The SIMAP model applies inputs that describe the vertical density-structure (temperature and salinity) of the ocean when calculating the rise of buoyant oil droplets. Monthly-averaged temperature and salinity values were obtained from the World Ocean Atlas 2013 database produced by the National Oceanographic Data Centre (National Oceanic and Atmospheric Administration; NOAA; see Levitus et al. 2013).

The World Ocean Atlas 2013 is a set of objectively analysed (1° grid) fields of in-situ parameters (e.g. temperature, salinity and dissolved oxygen) at standard depth levels for annual, seasonal, and monthly periods for the global oceans. The dataset represents the largest collection of restriction-free ocean profile data available internationally. Locarnini et al. (2013) and Zweng et al. (2013) provide discussion regarding the temperature and salinity data as part of the World Ocean Atlas 2013 database.

Table 8 presents the monthly average sea surface temperature and salinity adjacent the release location. Figure 27 shows the temperature and salinity profiles at 5 m intervals through the water column near exploration well. These figures illustrate the marked change in temperature that occurs between the sea bed and sea surface.

Sea surface temperatures are variable across the months, particularly in the upper 200 m of the water column, where they vary from a minimum of 14.8 °C in September to a maximum of 19.8 °C in February. At 1100 m below the sea surface, the temperature falls to less than 5 °C and at water depths of 1400 m water temperature is 2.8 °C (Mathiesen, 2017).

Salinity also varies vertically but over a smaller range (34.5 to 35.5) but is nearly constant year-round at the water surface.

Table 8: Monthly average sea surface temperature and salinity adjacent the release location. Data was derived from the World Ocean Atlas database

Season	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (˚C)	18.5	19.8	19.4	18.5	17.6	16.3	15.3	14.8	14.8	14.8	16.5	17.2
Salinity (PSU)	35.5	35.5	35.6	35.5	35.6	35.4	35.5	35.5	35.4	35.5	35.5	35.5

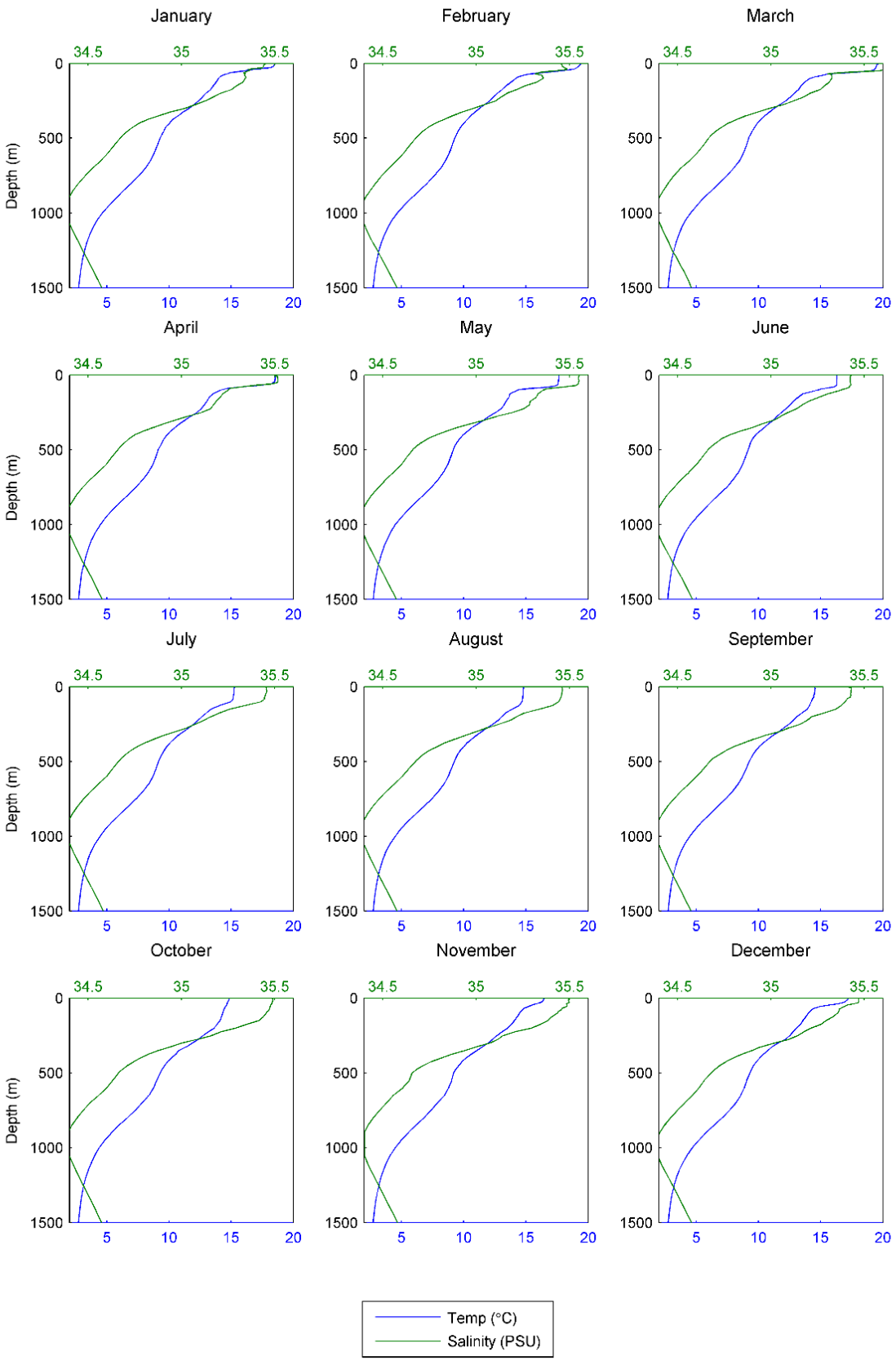


Figure 27: Monthly temperature and salinity profiles throughout the water column adjacent to the release location

6 SUBSEA PLUME MODEL – OILMAPDEEP

During a loss of well control, the oil and associated gas released from the seabed is driven upward into the water column due to the momentum of the high-pressure release. It will initially behave like a jet, which dissipates in the water column over a short distance (<10 m). The escaping oil shears into small droplets due to turbulence generated by passing through the exit hole and subsequent turbulence generated in the plume jet. The size-distribution of the oil droplets will vary with the exit velocity and viscosity of the oil. Following this phase, the density and buoyancy difference of the gas, water and oil mixture relative to the surrounding waters, forces the plume upward. As the plume rises, the volume of gas will increase due to reduction of water pressure, with gas bubbles dividing into an increasing number of bubbles due to the shearing effect exerted by the water column. This rising plume of gas bubbles will entrain the oil droplets along with cold seawater from the lower water column as a secondary plume. As the gas plume rises and entrains more ambient water from the water column, the density of the oil-water plume will increase relative to the warmer sea water higher in the water column. At the same time, the volume of gas will be reduced through dissolution into the warming water column, referred to as the trapping height and which is where oil droplets separate and are subsequently transported horizontally by currents and vertically by their individual buoyancies.

The rise velocity of the oil droplets alone (without gas-lift) will be decrease exponentially as the droplet size decreases. Oil droplets sizes may range from a few microns up to around 10–20 millimetres in diameter depending upon release conditions. Hence, the rise velocities over this size range might vary from hours to days and therefore, the location the oil surfaces. Figure 28 conceptually illustrates the various stages of a subsea release of oil and gas.

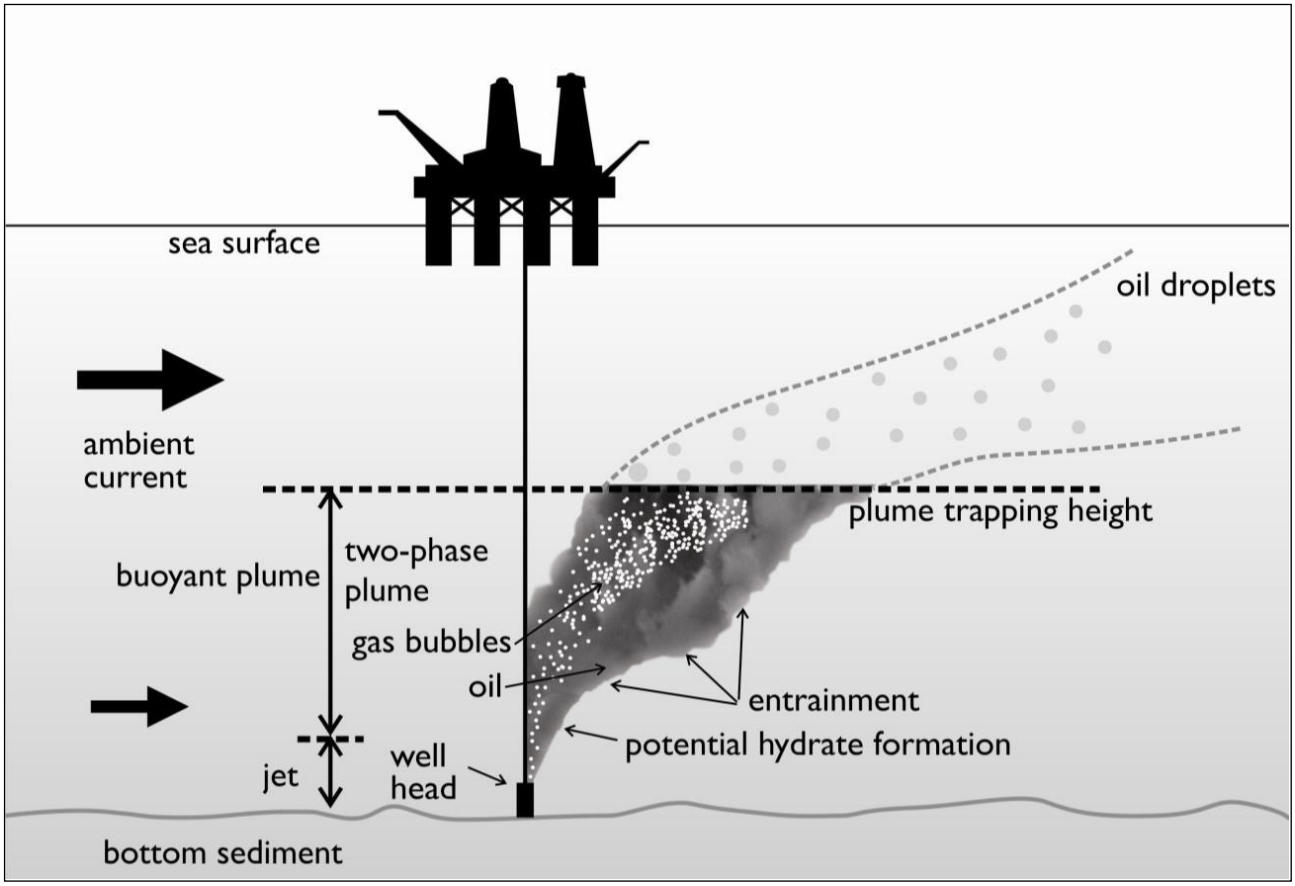
OILMAPDeep model (Spaulding et al. 2015) was used to simulate the near-field behaviour of the gas-oil subsea release in two phases – the initial jet phase and the buoyant plume phase. The initial jet phase is predominately driven by the exit velocity. During this phase, the oil droplet-size-distribution is calculated for a range of classes or bins. Next, the plume model predicts the rise dynamics of the oil and gas plumes to calculate at which point gas lift will be lost (i.e. the trapping height).

Outputs from OILMAPDeep (plume trapping height, plume diameter and droplet size distribution) are used as input to the SIMAP model to simulate the rise and dispersion of the oil droplets from this point onwards.

OILMAPDeep also supports calculation of the effects of SSDI through incorporation of a reduced interfacial tension (IFT) due to dispersant (Spaulding et al. 2015; Li et al. 2017a). Reduction of IFT has been found to result in smaller oil droplets released into the water column, which, in turn reduces the rise velocity of the oil. Smaller droplets also result in more rapid dissolution of soluble components from the oil and faster decay rates.

More detail on the OILMAPDeep model, can be found in Crowley et al. (2014), Spaulding et al. (2015) and French-McCay et al. (2017). The model has been validated against observations from the Macondo oil spill in the Gulf of Mexico in 2010 (Deepwater Horizon) as well as small and large-scale laboratory studies on subsurface releases of oil (Brandvik et al. 2013, 2014; Belore, 2014; Spaulding et al. 2015; Li et al. 2017a, 2017b).

Table 9 is a summary of the input data used for the subsea near-field plume modelling for the various scenarios modelled. Note that flow rates and gas to oil ratios deplete over time, therefore, to estimate the plume behaviour and oil droplet sizes more accurately, the near-field plume modelling was carried out at 5- to 10-day increments, over the entire release duration.



Source: Applied Science Associates, 2011)

Figure 28: Example of a blowout plume illustrating the various stages of the plume in the water column

Table 9: Summary of the parameters used for the subsea near-field plume modelling for the various cases modelled

Parameter	Scenario 1 – Liner design – 129-day well blowout		Scenario 2 – Relief well success at end Day 102		Scenario 3 – Capping stack success at end Day 15		Scenario 4 – BOP closure at the end of Day 1	
	Start	End	Start	End	Start	End	Start	Start
Oil flow rate (m^3/day)	12,303	6,223	7,749	5,764	7,749	7,446	7,749	7,749
Gas rate (1000Sm^3/day)	2,445	1,237	1,540	1,145	1,540	1,488	1,540	1,540
Gas to oil ratio (m^3/m^3)	129	119	129	122	129	128	129	129
Oil temperature (°C)	74		74		74		74	
Exit hole diameter (inch)	12.13		11.09		11.09		11.09	

Table 10 shows the predicted near-field plume dynamics at the start and end of the release for each scenario considering the depleting flow rates. The near-field modelling showed that in the event of a loss of well control at Stromlo-1, the fluid mixture would rise at least 358 m above the seabed with an average plume rise velocity of 0.4 m/s, until the oil in water plume lost momentum after about 17 minutes. The maximum plume diameter at this trapping height would vary between 134 to 202 m depending on the

scenario. Also presented in Table 10 are the range of oil droplet sizes calculated for the start and end of the simulations. Across all four scenarios, the oil droplet sizes are calculated to range from 679 µm (0.68 mm) up to 7,201 µm (7.2 mm). Oil droplet sizes are calculated to increase as the release rate declines over time.

Table 10: Predicted subsea near-field plume dynamics for each scenario (unmitigated case) at the start and end of the simulation

Variable		Scenario 1 - Liner design – 129 day well blowout		Scenario 2 - Relief well success at end Day 102		Scenario 3 - Capping stack success at end Day 15		Scenario 4 – BOP at the end of Day 1	
		Start	End	Start	End	Start	End	Start	End
Average plume rise velocity (m/s		0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Maximum plume rise velocity (m/s)		1.1	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Plume rise time in minutes until plume collapse		18.5	18.9	17.4	18.7	17.4	17.8	17.4	17.4
Maximum plume diameter upon collapse (m)		202	172	134	154	134	142	134	134
Plume trapping height below the sea surface (m)		1,824	1,869	1,869	1,881	1,869	1,869	1,869	1,869
Plume trapping height above the seabed (m)		414	369	369	358	369	369	369	369
Oil droplet size (µm) without SSDI	Minimum	679	1,440	922	1,257	922	962	922	922
	Median	2,037	4,321	2,766	3,773	2,766	2,887	2,766	2,766
	Maximum	3,396	7,201	4,610	6,389	4,610	4,812	4,610	4,610

The modelling results indicated no change to the plume diameter and trapping height above the seabed with SSDI treatment. However, the oil droplet diameters were found to decrease by up to order of magnitude (Table 11).

When SSDI is first applied after Day 9, the droplet size would range from 66 µm to 4,740 µm and a median value of 1,580 µm. If untreated, the range would be 948 µm to 4,740 µm and a median value of 2,844 µm. Fifty-nine per cent of the oil released was predicted to consist of droplet sizes below 70 µm, which is the critical size to remain permanently entrained in the water column allowing for a higher degree of biodegradation.

The smaller droplets as a result of the SSDI, will rise more slowly to the surface (more than 130 hours free rise time), therefore, allowing for additional time for dispersion and dilution of oil through the water column. There would be a reduced tendency for these smaller droplets to generate floating slicks. However, the tendency for the larger droplets to surface and form floating oil slicks would be unchanged. Since the SSDI is 90% effective (i.e. not all oil is treated), the larger (i.e. max) oil droplet sizes were unaffected (or untreated).

Table 11: Predicted unmitigated and with SSDI oil droplet sizes for Scenario 2 (Day 10 to 100) and Scenario 3 (Day 10 to 15)

Days	Unmitigated oil droplet sizes (µm)			Oil droplet size (µm) following SSDI		
	Min	Median	Max	Min	Median	Max
1	922.1	2,766.4	4,610.7	922.1	2,766.4	4,610.7
10	948	2,844.0	4,740.0	66	1,580.0	4,740.0
15	962.4	2,887.3	4,812.2	66.8	1,604.1	4,812.2
20	977.5	2,932.4	4,887.4	68.6	1,629.1	4,887.4
40	1,040.0	3,119.9	5,199.8	72.4	1,733.3	5,199.8
60	1,107.5	3,322.4	5,537.3	77.5	1,845.8	5,537.3
80	1,179.6	3,538.8	5,898.0	86.8	1,966.0	5,898.0
100	1,257.9	3,773.8	6,289.6	92.1	2,096.5	6,289.6

7 OIL SPILL MODEL – SIMAP

Modelling of the fate of oil beyond the initial discharge phase was performed using SIMAP. SIMAP is designed to simulate the fate and effects of spilled hydrocarbons for both the surface and subsurface releases (Spaulding et al. 1994; French et al. 1999; French-McCay, 2003; French-McCay, 2004; French-McCay et al. 2004).

SIMAP has been used to predict the weathering and fate of oil spills during and after major incidents including: Montara (Australia) well blowout August 2009 in the Timor Sea (Asia Pacific ASA, 2010); Macondo (USA) well blowout April 2010 in the Gulf of Mexico; Bohai Bay (China) oil spill August 2011; and the pipeline oil spill July 2013 in the Gulf of Thailand (SEER Associates, 2013).

The SIMAP model calculates the transport, spreading, entrainment, evaporation and decay of surface hydrocarbon slicks as well as the entrained and dissolved oil components in the water column, either from surface spills or from oil discharged subsea. The movement and weathering of the spilled oil is calculated for specific oil types. Input specifications for oil mixtures include the density, viscosity, pour point, distillation curve (volume lost versus temperature) and the aromatic/aliphatic component ratios within given boiling point ranges.

The SIMAP model separately calculates the movement of the material that: (i) is on the water surface (as surface slicks, (ii) in the water column (as either entrained whole oil droplets or dissolved hydrocarbon), (iii) has stranded on shorelines, or (iv) that has precipitated out of the water column onto the seabed. The model calculates the transport of surface slicks from the combined forces exerted by surface currents and wind acting on the oil. Transport of entrained oil (oil that is below the water surface) is calculated using the currents only.

SIMAP is a 3-dimensional model that allows for various response actions to be modelled including oil removal from skimming, burning, or collection booms, and surface and subsurface dispersant application.

Surface dispersant applications are simulated in SIMAP by specifying the applied dispersant volume, assumed effectiveness (per cent of the oil treated), DOR (i.e., volume of oil treated per volume of dispersant encountering the oil), time and spatial windows (when applied, and constraining weather and oil weathering characteristics (e.g. viscosity limit for dispersion via dispersant application). The SIMAP model's surface entrainment algorithm adjusts entrainment rate of a treated parcel of oil to reflect the DOR, level of turbulence (a function of wind speed), and oil characteristics (viscosity) at the time and location of dispersant application. This results in more floating oil dispersing into the water column and a change in entrained droplet size distribution to smaller droplet sizes (related to the DOR and level of turbulence), which in turn increases the dissolution rate of soluble components and thus their biodegradation rates due to this increased bioavailability. The influence of SSDI is accounted for by updating the oil droplet sizes, calculated using OILMAPDeep.

Biodegradation is included in the oil spill model. In the model, SIMAP, degradation is calculated for the surface slick, deposited oil on the shore, the entrained oil and dissolved constituents in the water column, and oil in the sediments. For surface oil, water column oil and sedimented oil a first order degradation rate is specified. Biodegradation rates are relatively high for hydrocarbons in dissolved state or in dispersed small droplets.

The SIMAP oil spill model includes advanced weathering algorithms, specifically focussed on unique oils that tend to form emulsions and/or tar balls. The weathering algorithms in oil behaviour are based on five years of extensive research conducted in response to the Macondo oil spill in the Gulf of Mexico. This advancement is particularly useful for long-term scenarios and allows the state of the oil within the Risk EMBA to be more clearly identified and can also assist in assessing the potential implications for proposed response planning.

The inputs into the model include:

- Spill duration and location
- Comprehensive tidal and ocean currents (see Section 3)

- Detailed wind data (see Section 4)
- Detailed monthly temperature and salinity data that spans the entire depth of the water column (see Section 5)
- Near field plume dimensions (plume trapping height and diameter) and varying droplet sizes and distributions (see Section 6)
- Detailed oil characteristics (see Section 7.4.4)
- Description of shoreline types (see Section 7.4.4)
- Variable flow rate for each day of the release period.

7.1 Stochastic modelling of 100 spills

Stochastic oil spill modelling is created by overlaying a great number (often 100) simulated hypothetical oil spills (NOPSEMA, 2018; e.g. Figure 29). Stochastic modelling involves running numerous individual oil spill simulations using a range of prevailing wind and current conditions that are historically representative of the season and location of where the spill event may occur.

Stochastic modelling was used for Scenarios 1 and 2 to provide insight into the potential area of effect from sea surface, shoreline or water column oiling.

For the stochastic modelling presented herein, **100 oil spills** were simulated for each scenario using the same spill information (release location, spill volume, duration and oil type) but with varied start dates and times during October to May from the years 2008–2012, corresponding to the period represented by the available wind and current data. During each simulation, the model records whether any grid cells are exposed to any oil concentrations, the concentrations involved and the elapsed time before exposure. The results of all 100 oil spill simulations were analysed to determine the following statistics for every grid cell:

- Exposure load (concentrations and volumes)
- Minimum time before exposure
- Probability of contact above defined concentrations
- Volume of oil that may strand on shorelines from any single simulation;
- Concentration that might occur on sections of individual shorelines
- Exposure (concentration × duration of exposure) to entrained and dissolved hydrocarbons in the water column.

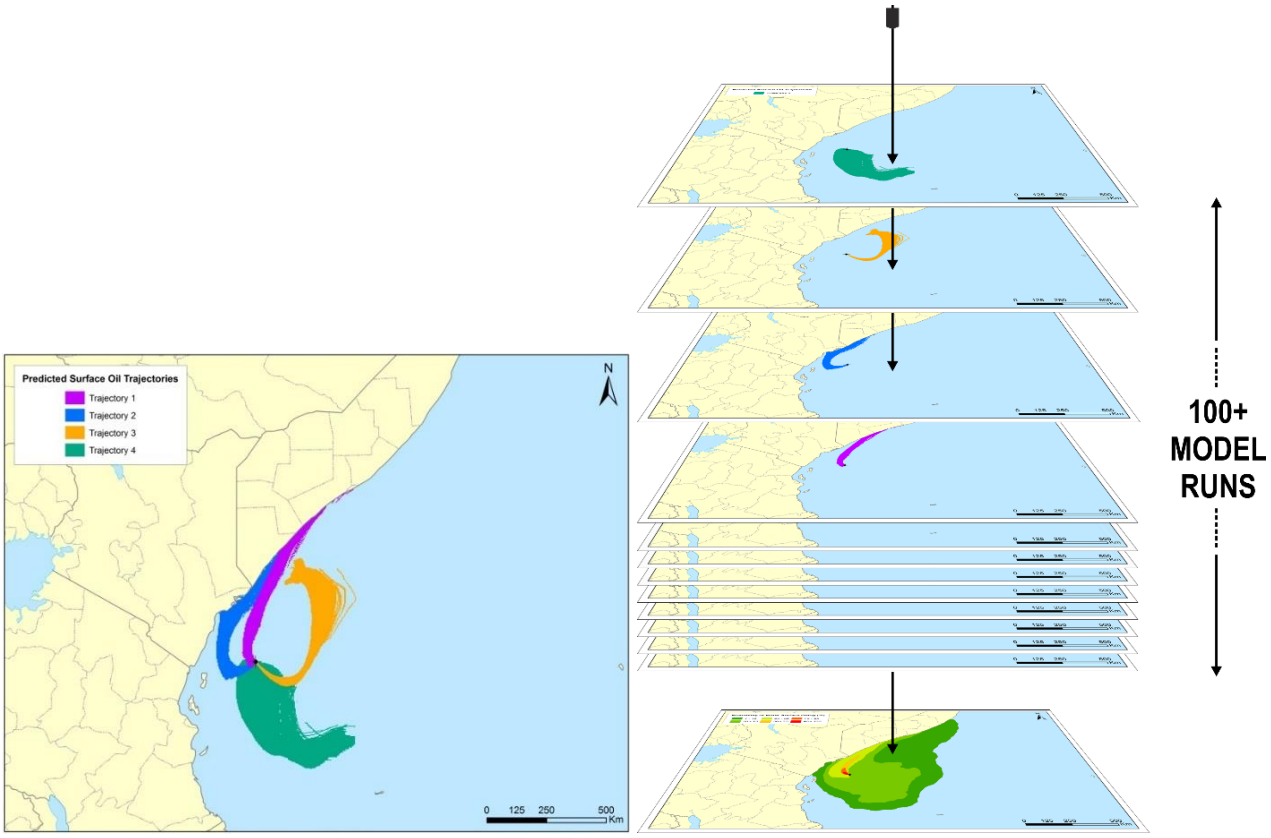


Figure 29: Predicted movement of four single oil spill simulations predicted by SIMAP for the same scenario (left image) All model runs are overlain (shown as the stacked runs on the right) and the number of times that trajectories contact a given location at a concentration is used to calculate the probability

7.2 Single oil spill modelling

While the stochastic modelling results provide an objective indication of all locations that maybe exposed or contacted by oil above the reporting thresholds, the approach describes a larger potential area of influence than can be expected from any one single spill event. To understand the potential area that might be affected during an isolated (single) spill event, it was helpful to analyse the outcomes of the single runs in more detail for Scenarios 2– 4, whilst also investigating the potential change to predicted outcomes based on proposed mitigation methods.

For Scenario 2 (relief well success at end Day 102), two unmitigated runs were selected from the set of stochastic results based on the following criteria:

a. Fastest (or minimum) time before oil contact to shorelines

b. Overall greatest volume of oil ashore.

The two spill simulations were repeated, varying only the inclusion of aerial and subsea dispersant, to illustrate the potential change (if any) between the unmitigated and mitigated cases. For Scenario 2, ADA was applied from Day 2 to day 102; SSDI was applied from Day 9 to Day 102.

The same approach was used to assess the potential change for the unmitigated simulations resulting in the greatest volume ashore for each state.

Due to the shorter release durations for Scenario 3 and 4, the comparisons were based on the unmitigated simulation resulting in the fastest time before oil contact to shorelines. Inputs for the Scenario 3 mitigated case involved, ADA from Day 2 to Day 15; and SSDI applied from Day 9 to the end of Day-15, due to the successful installation of a capping stack. While the plan for Scenario 4, comprises of ADA from Day 2 until no actionable oil concentrations of treatable oil remained on the water surface, due to the successful closure of a BOP at the end of Day 1.

Table 12 summarises the input data for the response countermeasures to mitigate the spill for each scenario. It should be noted, that the modelling setup did not include the entire response options available, particularly efforts around mechanical clean up and recovery for offshore and nearshore waters. It was not included, as it was difficult to quantify and in turn incorporate into the numerical simulations.

The aerial dispersant (or surface dispersant) effectiveness was set at 52% based on laboratory testing by Sintef (2001). It was assumed that that the dispersant will be effective on fresh, weathered and emulsified oil with a minimum thickness of 10 µm and a viscosity of up to 12,500 cP. Aerial dispersant application was assumed to occur on day 2 during daylight hours only, when the winds speeds were below 35 knots to ensure safe operating conditions for planes, but also to allow for sufficient mixing of the chemical dispersants and oil at the water surface (API et al. 2001; NOAA 2010). The dispersant to oil ratio (DOR) was set to 1:25 based on laboratory testing by Sintef (2001). Given that the SSDI is concentrated at the source it has a high encounter rate (IPIECA 2015), a 90% dispersant effectiveness was applied and 1 in 100 dispersant to oil ratio (DOR). For SSDI the dispersant effectiveness is a criteria based around the reduction of the droplet size. Therefore, as part of this study, it was assumed that 90% of oil that is treated will result in a reduction in droplet sizes, which in turn effectively slows the rise of oil to surface.

Table 12: Modelling input data to represent the spill response for each scenario

Response option	Parameters	Inputs
Subsea Dispersant Injection (SSDI) - Scenario 2 and 3	Period of application	Scenario 2: Relief well case; 9 to 102 days Scenario 3: Capping stack case; 9 to 15 day
	Subsea dispersant to oil ratio	1:100
	Subsea dispersant efficiency (%)	90%
Capping stack (CS) - Scenario 3	Successful deployment of capping stack	Day end 15
Aerial Dispersant Application (ADA) - Scenario 2, 3 and 4	Surface dispersant operation	Within 100 km around the well location. Note 1 km aerial dispersant exclusion zone around release location
	Maximum volume of dispersant applied per day	Day 2; 38 m^3 Day 3; 92 m^3 From Day 4; 110 m^3
	Surface dispersant commencement	See above – day 2
	Surface dispersant end	Until the end of the release
	Dispersant to oil ratio	1:25
	Dispersant effectiveness (%)	52%
	Maximum viscosity threshold (cP)	12,500
	Minimum and maximum operational wind speeds (knots)	0 and 35 knots
	Maximum operational wind speed (knots	35 knots (18 m/s
	Operational hours (day time only or day and night)	2 daylight sorties, instantaneous application: 08:45 14:30

7.3 Oil properties

Since the exact properties of the Ceduna sub-basin reservoir oil are unknown, Equinor had used geological analogues and modelling for the Stromlo-1 area to calculate the most likely oil type that may be encountered. Based on the analysis, Statfjord-C blend crude oil was selected as being an appropriate analogue for the assessment.

The crude has a density of 830 kg/m^3 (API of 38.8), a low pour point of (-24 °C) and a dynamic viscosity of 4.51 cP at 20 °C. This oil is composed of 67.1% volatiles and semi-to low volatiles compounds (low molecular weight hydrocarbons which would evaporate within hours to days once on the sea surface and 32.9% residuals (heavy hydrocarbons which is persistent and non-evaporative. These properties categorise

it as a Group 2 (or medium persistent) oil according to both oil classifications for AMSA (2015) and the International Tanker Owner Pollution Federation (ITOPF, 2012). Residual compounds will tend to remain in the environment for extended periods, subject to decay processes. Table 13 and Table 14 show the physical characteristics and boiling point ranges for Statfjord C blend oil, respectively.

Table 13: Physical characteristics of Statfjord C blend crude oil

Characteristic	Statfjord C blend
Density (kg/m^3)	830 @ 15 °C
API	38.8
Dynamic viscosity (cP)	4.51 @ 20 °C
Pour Point (ºC)	-24
Wax content (%)	4.6
Vanadium (ppm)	1.1
Nickel (ppm)	0.9
Asphaltenes (%)	0.1
Maximum water uptake (%)	70
ITOPF Oil Property Category	Group 2

Table 14: Boiling point ranges of Statfjord C blend crude oil

Characteristic	Volatiles (%)	Semi-volatiles (%)	Low volatiles (%)	Residual (%)
Boiling point (°C)	<180	180–265	265–380	>380
Statfjord C blend oil	30.6	15.3	21.3	32.9
	Not persistent			Persistent

The boiling points are dictated by the length of the carbon chains, with the longer and more complex compounds having a higher boiling point, and therefore lower volatility and evaporation rate.

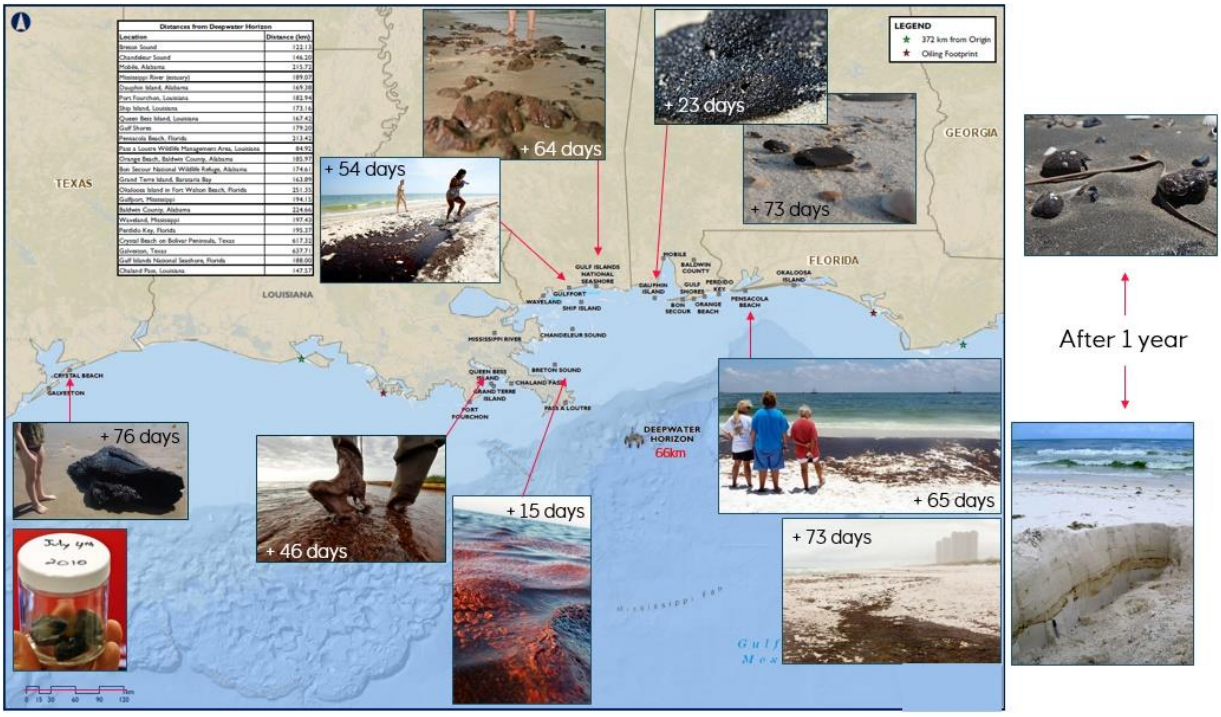
In the above table (see Table 14), the typical evaporation times once the hydrocarbons have reached the surface and are exposed to the atmosphere are approximately:

- Up to 12 hours for the C4 to C10 compounds (or <180 °C boiling point)
- Up to 24 hours for the C11 to C15 compounds (180–265 °C boiling point)
- Several days for the C16 to C20 compounds (265–380 °C boiling point)
- The residual compounds (>380 °C boiling point) will resist evaporation, persist in the marine environment for longer periods, and be subject to relatively slow degradation.

Laboratory testing by Sintef (2001) report that Statfjord C blend oil is a paraffinic oil that emulsifies very quickly with little water breaking out over a 24-hour assessment period in a tank. Statfjord C is characterised by a low asphaltene content (less than 0.1% by weight) and has a medium wax content of about 4.6%. The pour point is medium to high (approximately 15–21 °C) after one hour at sea. The laboratory testing demonstrated that during the three-day test, there was a 70% uptake of water before it started to decline. Based on very low asphaltene content, the emulsion should be classified as unstable.

The Deepwater Horizon crude (MC252) which has very similar physical properties to Statfjord C blend was found to form an unstable and low-viscosity water-in-oil during the first few days at sea. Allowing for a high degree of natural dispersion when exposed to breaking wave conditions. Under calm sea conditions, a more stable and light-brown/orange coloured water-in-oil emulsion started to form after several days, and viscosities of 10,000–15,000 mPa s were achieved after 1–2 weeks (Daling et al. 2014).

Figure 30 provides example photographs illustrating the varying age-based states of MC252 on the sea surface and following shoreline contact.



(Source: Equinor State Control Agency stakeholder consultation presentation 23 August 2018)

Figure 30: In the absence of long-term laboratory tests for the proxy oil (Statfjord C blend), above photos illustrate the varying age-based states of MC252 on the sea surface and following shoreline contact associated with the Macondo oil spill in 2010

7.4 Sea surface, shoreline and in-water thresholds

The thresholds described below for surface, shoreline, and in-water (entrained and dissolved) oil have been adopted according to low, moderate and high, based on increasing concentrations of oiling:

Low thresholds are unlikely to affect species but would be visible and detectable by instrumentation and may trigger socioeconomic impacts, such as temporary closures of areas such as fishing grounds as a precautionary measure.

Moderate thresholds represent moderate concentrations of oil exposure/contact which are anticipated to result in behavioural changes and sub-lethal effects to biota (effects that may result in changes in reproduction or growth) and are unlikely to result in lethal effects (representing potential death of individuals) although lethality may occur if ingestion occurs.

High thresholds represent high concentrations of oil that are expected to result in sub-lethal and lethal effects to at least some species (representing potential death of individuals).

Reporting threshold values (based on the scientific literature) represent potential effects ranging from possible social and economic effects, degradation of water quality as well as possible effects on the behaviour, survival and recruitment success on biota. The changes in the state of the oil over time, in addition to a wide range of sensitivities and in turn potential effects on marine life, does not make it possible to strictly assign single specific effect thresholds. Instead, the analysis presented herein is presented for ranges of low, moderate and high threshold levels, with separate analysis for oil floating at the sea surface, stranded on shoreline, dissolved in the water column and suspended in the water column.

Moderate levels were defined based on available evidence that indicated the potential for low-level sub-lethal effects on some biota, or else evidence of reduced survival rates of sensitive species. This level can be considered a lower ecological threshold. The higher threshold was defined on the assumption that there would be more potential for reduced survivorship of less sensitive species.

This report contains additional stochastic and deterministic analysis for WCD scenario (Scenario 1, see Section 10), which was not presented in the previous version (i.e. Rev0N, 06/02/2019). Furthermore, results can be found in Appendix A for the WCD scenario based on the "commonly used sea surface and in-water exposure values for oil spill modelling" as reported within the NOPSEMA Bulletin #1 (NOPSEMA, 2019), which were not established at the time that the initial report was submitted.

7.4.1 Exposure thresholds for oil on the sea surface

As a conservative approach, the same reporting thresholds for fresh and weathered oil exposure on the sea surface was applied in this study, which were 1–10 g/m^2 (low), 10-25 g/m^2 (moderate) and above 25 g/m^2 (high) (Table 15). As the effects of fresh oil are better understood than for weathered oil, appropriate effects thresholds for fresh oil are more readily identifiable. Exposure pathways of species to weathered oil (i.e. smothering and potential ingestion for some species) are less likely to result in adverse effects.

The lowest threshold (1 g/m^2) equates to a volume of approximately 1 ml of oil spread over 1 m^2 of water surface, which would result in an oil film with an average thickness of approximately 1 µm (or 0.001 mm). Oil of this thickness is described as a rainbow sheen, according to the Bonn Agreement Oil Appearance Code (Bonn Agreement, 2009, Table 16) and is close to the practical limit of observing oil in the marine environment (AMSA, 2015).

Ecological impact has been estimated to occur at 10 g/m^2 (a film thickness of approximately 10 µm or 0.01 mm) according to 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).

Scholten et al. (1996) and Koops et al. (2004) indicated that at 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. The appearance of oil at this thickness is also described as metallic sheen (Bonn Agreement, 2009).

Note that the higher threshold applied in this study falls below the thickness that would begin to present as patches of true oil colour (Table 16).

Figure 31 shows examples of the differences between oil colour and corresponding thickness on the sea surface. Hydrocarbons in the marine environment may appear differently due the ambient environmental conditions (wind and wave action).

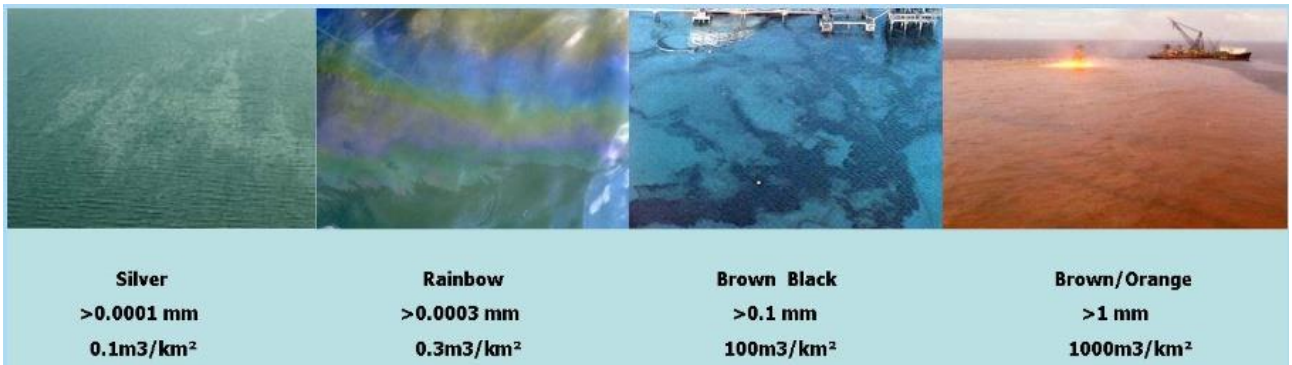
Table 15: Oil exposure thresholds on the sea surface

Scenario (analysis)	Thresholds (g/m^2)	Potential level of exposure	Appearance	Fresh oil presence	Weathered oil presence
1–4	1–10	Low	Rainbow to metallic sheen	¼ teaspoon to 2 teaspoons of oil every 1m^2	15 to 148 oil patches (1-inch tarballs) per 10 m × 10 m region
1 – 4 (stochastic and deterministic)	10*–25	Moderate	Metallic sheen	2 teaspoons to under 2 tablespoons of oil every 1 m^2	148 to 370 oil patches (1-inch tarballs) per 10 m × 10 m region
	>25	High	Metallic sheen to continuous true oil colour	>2 tablespoon of oil every 1 m^2	>370 oil patches (1-inch tarballs) per 10 m × 10 m region
1 (see Appendix A stochastic results only)	10*–50	Moderate†	Approximates lower limit for harmful exposures to birds and marine mammals (NOPSEMA, 2019)		
	>50	High**	Approximates surface oil slick and informs response planning (NOPSEMA, 2019)		

* 10 g/m^2 also used to define the threshold for actionable sea surface oil
† Based on commonly used exposure values for oil spill modelling" as reported by NOPSEMA Bulletin #1 (NOPSEMA, 2019)
Weathered oil thresholds are conservatively assumed to be the same as for fresh oil, for lack of quantitative data documenting specific concentrations where reduced toxicity would occur

Table 16: Bonn Agreement Oil Appearance Code

Code	Description appearance	Layer thickness Interval	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–>



(source: OilSpillSolutions.org, 2015)

Figure 31: Difference between oil appearance on the sea surface

The generic oil colour categories used in this report are meant as a guide only. For more accurate description of oil appearance on the sea surface a detailed analysis of an oil should be undertaken.

The specific oil type will determine appearance (i.e. colour) and behaviour on the sea surface. Lighter oils such as marine diesel and condensate, have true oil colours that are pale or transparent. As such, these oil types may not increase beyond a rainbow or metallic sheen, despite their thickness increasing beyond 25 g/m^2 (~25 um). Moreover, the physical properties and appearance of oil types will change due to weathering on the sea surface. For example, oils with high paraffinic wax content will form waxy sheets that break up into flakes or nodules after the more volatile components have evaporated. Take up of water by the oil (emulsification) will also significantly change the appearance and thickness of floating oil. Stable water-in-oil emulsions will have a higher combined mass and thickness and will present as thick, semi-solid, aerated layers that tend to be coloured strongly red/brown, orange or yellow, rather than the true oil colour.

It should be noted that in the case of solidified or emulsified oils, mass per area estimates cannot be directly referenced to the Bonn Agreement visibility scale that refers only to oil present as films or slicks of oil alone.

7.4.2 Thresholds for shoreline contact

The oil spill modelling results for shoreline accumulation were separated into fresh and weathered oil components but were linked to the same environmental thresholds of 10-100 g/m^2 (low), 100-1,000 g/m^2 (moderate) and above 1000 g/m^2 (high). Table 17 shows the number of weathered oil patches per square metre on the shoreline for corresponding thresholds, assuming that each patch was a sphere that was 1 inch in diameter.

The lower threshold (10 g/m^2) was applied as the visible limit for oil on shore. This threshold may trigger socio-economic impact, such as triggering temporary closures of beaches to recreation or fishing, or closure of commercial fisheries and might trigger attempts for shore clean-up on beaches or man-made features/amenities (breakwaters, jetties, marinas, etc.). In previous risk assessment studies, French-McCay et al. (2005a; 2005b) used a threshold of 10 g/m^2, equating to approximately two teaspoons of oil per square metre of shoreline, as a low impact threshold when assessing the potential for shoreline contact.

French et al. (1996) and French-McCay (2009) define a shoreline oil threshold of 100 g/m^2, or above, would potentially harm shorebirds and wildlife (furbearing 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 limit that the oil can be effectively cleaned according the AMSA (2015) guideline. This threshold equates to approximately half a cup of oil per square metre of shoreline contacted. The appearance is described as a thin oil coat.

The higher threshold of 1,000 g/m^2, and above, was adopted to inform locations that might receive oil accumulation levels that could have a higher potential for ecological effect. Observations by Lin and Mendelssohn (1996), demonstrated that loadings of more than 1,000 g/m^2 of oil during the growing season would be required to impact marsh plants significantly. Similar thresholds have been found in studies assessing oil impacts on mangroves (Grant et al. 1993; Suprayogi and Murray, 1999). This concentration equates to approximately 1 litre or 4¼ cups of fresh oil per square metre of shoreline contacted. The appearance is described as an oil cover.

Table 17: Thresholds for oil accumulation on shorelines

Oil thresholds on the shoreline (g/m^2)	Potential level of exposure	Appearance	Fresh oil presence	Weathered oil presence
10–100	Low	Stain/Film	2 tsp to ½ cup of oil every 1 m^2	2–12 oil patches (1-inch tarballs) per m^2
100*–1,000	Moderate	Coat	~ ½ cup to >4 ¼ cups of oil every 1 m^2	12–120 oil patches (1-inch tarballs) per m^2
>1,000	High	Cover	>4 ¼ cups of oil every 1 m^2	>120 oil patches (1-inch tarballs) per m^2

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

Weathered oil thresholds are conservatively assumed to be the same as for fresh oil, for lack of quantitative data documenting specific concentrations where reduced toxicity would occur

7.4.3 Dissolved and entrained hydrocarbon 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.

7.4.3.1 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; Mackay et al. 1992; McCarty & Mackay, 1993; Verhaar et al. 1992, 1999; Swartz et al. 1995; French-McCay, 2002; McGrath et al. 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 (LC50) between 6 and 400 ppb total PAH concentration after 96 hrs exposure, with an average of 50 ppb. Hence, 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.

The application of a 6 ppb over 1 hour for the Scenario 1 Risk EMBA calculation, should be considered conservative for any effects, commencing at behavioural and other sublethal effects. The ANZECC (2000) guidelines recommend 7 ppb for PAH (only calculated for Napthalene) as a trigger value for investigation of possible effects, based on a review of a select studies, but depending largely on the analysis by Tsvetnenko (1998). Tsvetnenko (1998) followed US EPA methods (Stephan et al. 1985; US EPA, 1994) to apply correction factors from lethal concentrations. The trigger value of 6 ppb applied for the Risk EMBA, which was derived by linear back-calculation from toxicity testing over 48-96 hrs, is slightly conservative but otherwise consistent with respect to the ANZECC (2000) recommendation.

Exceedances of 6, 50 or 400 ppb (Table 18) over 96 hours was applied to indicate increasing potential for sub-lethal to lethal toxic effects (or low to high). A 96 hour time frame was used when considering chronic exposure of receptors as a means of comparing similar durations encountered in laboratory studies. During the analysis, this meant that for each simulation, the concentrations in each grid cell were calculated as a moving average, stepping by an hour each calculation. The derived value is then divided by the 96 hour time frame, to determine the averaged value in ppb. Hence, in the report the results are presented as time averaged exposure.

Additionally, Appendix A includes WCD Scenario 1 stochastic modelling results for instantaneous dissolved hydrocarbon exposures (concentrations) of 10, 50 and 400 ppb, to represent low, moderate and high thresholds, respectively, as reported within the NOPSEMA Bulletin #1 (NOPSEMA, 2019). The instantaneous concentrations are determined by the model time step of one hour.

Table 18: Dissolved hydrocarbon exposure thresholds

Scenario	Threshold (ppb)	Duration of exposure (hours)	Description	Potential level of exposure
1–4	6–50	96	Very sensitive species	Low
	50–400	96	Average sensitive species	Moderate
	>400	96	Tolerant sensitive species	High
1 (see Appendix A stochastic results only)	10–50*	1	Establishes planning area for scientific monitoring based on potential for exceedance of water quality triggers	Low
	50–400*	1	Approximates potential toxic effects, particularly sublethal effects to sensitive species	Moderate
	>400*	1	Approximates toxic effects including lethal effects to sensitive species	High

* Based on commonly used exposure values for oil spill modelling" as reported by NOPSEMA Bulletin #1 (NOPSEMA, 2019)

7.4.3.2 Entrained hydrocarbons

Entrained hydrocarbons consist of oil droplets that are suspended in the water column and insoluble. As such, insoluble compounds in oil cannot be absorbed from the water column by aquatic organisms, hence 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, 2005).

The 10 ppb threshold represents the very lowest concentration and corresponds generally with the lowest trigger levels for chronic exposure for entrained hydrocarbons in the ANZECC (2000) water quality guidelines. Due to the requirement for relatively long exposure times (> 24 hours) for these concentrations to be significant, they are likely to be more meaningful for juvenile fish, larvae and planktonic organisms that might be entrained (or otherwise moving) within the entrained plumes, or when entrained hydrocarbons adhere to organisms or trapped against a shoreline for periods of several days or more.

This 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. This area does not define the area of influence as it is considered that the environment will not be affected by the entrained hydrocarbon at this level. The application of a 6 ppb over 1 hour was used for the Risk EMBA calculation in Scenario 1 (see Table 19).

Exceedances of 10 ppb, 70 ppb, 100 ppb and 500 ppb (Table 19) over 96 hours was applied to indicate increasing potential for sub-lethal to lethal toxic effects (or low to high). for Scenarios 1–4, to cover the range of thresholds outlined in the ANZECC/ ARMCANZ (2000) water quality guidelines and the incremental change for greater potential effect. Similar to the dissolved oil, the entrained oil thresholds were assessed over 96 hours timeframe to consider chronic exposure of receptors as a means of comparing similar durations encountered in laboratory studies. Thereby, for each simulation, the concentrations in each grid cell were calculated as a moving average, stepping by an hour each calculation. The derived value is then divided by the 96 hour time frame, to determine the averaged value in ppb. Hence, in the report the results are presented as time averaged exposure.

Additionally, Appendix A includes WCD Scenario 1 stochastic modelling results for instantaneous entrained hydrocarbon exposures (concentrations) of 10 and 100 ppb, to represent low and high thresholds, respectively, as reported within the NOPSEMA Bulletin #1 (NOPSEMA, 2019). The instantaneous concentrations are determined by the model time step of one hour.

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.

Table 19: Entrained hydrocarbon exposure thresholds

Scenario	Trigger value (ppb)	Duration of exposure (hours)	Description	Potential level of exposure
1 - 4	10–70	96	Highly sensitive species	Very low
	70–100	96	Very sensitive species	Low
	100–500	96	Average sensitive species	Moderate
	>500	96	Tolerant sensitive species	High
1 (see Appendix A stochastic results only)	10–100*	1	Establishes planning area for scientific monitoring based on potential for exceedance of water quality triggers	Low
	>100*	1	As appropriate given oil characteristics for informing risk evaluation	High

* Based on commonly used exposure values for oil spill modelling" as reported by NOPSEMA Bulletin #1 (NOPSEMA, 2019)

7.4.4 Shoreline Interaction

The fate of spilled oil once it reaches shorelines depends on the characteristics of the oil, the type and width of the shoreline, and the energy environment (Reed et al. 1986, 1988, 1989; Gundlach, 1987; Reed & Gundlach, 1989; Harper & Harvey-Kelly, 1994; Humphrey, 1994). Even when beached, oil will continue to weather. However, several additional processes become important: refloatation, penetration into the substrate, and retention/transport in the shore-groundwater system.

The movement of oil on and off, into and out of the shoreline is a very dynamic process, changing as wind and wave conditions change. In SIMAP, each shoreline cell has an oil holding capacity based on oil viscosity, shoreline type, slope, width and shoreline grid cell length. Volatiles are assumed to evaporate off the shoreline immediately. Oil is eroded from the shoreline over time at a rate specific to the shore type. Deposition ceases when the holding capacity for the shore surface is reached. Subsequent oil deposited is not allowed to remain on the shore surface and is refloated (or resuspended) as slicks that continue to move along shore. After stranding permanently, the shoreline oil is removed exponentially with time. The shore holding capacities defined for the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME) completed by French et al. 1996, for the federal government were used for the spill simulations performed for the spill risk assessment. These oil holding capacities were based on observations from the Amoco Cadiz spill in France and the Exxon Valdez spill in Alaska (based on Gundlach 1987) and later work summarized in French et al. 1996.

There are several different types of shorelines found along Australia's southern coast. The type of shoreline will influence the volume of hydrocarbon that could be stranded ashore and its thickness before the shoreline saturation point occurs. For instance, a sandy beach may allow hydrocarbon to percolate through the sand, thus increasing its ability to hold more hydrocarbon ashore over tidal cycles and various wave actions in comparison to a rocky shore; hence hydrocarbon can increase in thickness onshore over time.

Shoreline data between Albany (WA) and Beachport (SA) was supplied as part of this study which was obtained from the OzCoasts Smartline dataset sourced from Geoscience Australia (2018). The Environmental Sensitivity Index (ESI) shoreline data used to define the habitat types in the model, were reclassified to a simpler classification; rocky, sand, mud flat, gravel and artificial. High resolution satellite imagery was used for the remainder of the study area between Cervantes and Albany (WA); and Beachport (SA) and Coffs Harbour (NSW).

Table 20 lists the shore widths and holding capacities for common shore types used in the spill model for three different oil viscosity ranges.

Table 20: Modelled shore widths and oil holding capacities for each shore type

Type of shore	Width (m)	Oil holding capacity (mm)		
		Oil viscosity 30 CSt	Oil viscosity 30–2,000 cSt	Oil viscosity >2,000 cSt
Rocky Shore	1	1	2	2
Gravel Beach	2	2	9	15
Sand Beach	10	4	17	25
Mud Flat (Seaward)	10	3	6	10
Wetland (Salt marsh)	1	1	2	2
Human-altered Shore	1	1	2	2

8 MODEL SETTINGS AND ASSUMPTIONS

The modelling study assessed the following four scenarios:

- Scenario 1: Unrestricted flow open hole over 129 days, no control measures and unmitigated. An average 8,943 m^3/day subsea release of crude oil over 129 days (total ~1,153,634 m^3) tracked for 189 days.
- Scenario 2: Unrestricted annulus flow during the loss of well control and relief well success at day 102 day, with an average 6,720 m^3/day subsea release of crude oil over 102 days (total ~685,440 m^3) tracked for 162 days.
- Scenario 3: Capping stack success at end Day 15. A 7,749 m^3/day subsea release of crude oil over 15 days (total ~116,235 m^3) tracked for 55 days.
- Scenario 4: BOP closure success at end Day 1. A total of 12,303 m^3 of crude oil released subsea over 1 day and tracked for 45 days.

The modelling was based on spills commencing October to May conditions, during the 'activity period' as no drilling will occur in the months of June to September.

Table 21 provides a summary of the oil spill model settings used and assumptions for the four scenarios.

The simulation lengths were carefully selected for each scenario based on extensive sensitivity testing. During the sensitivity testing process, sample oil spill simulations were run for longer than intended durations for each scenario. Upon completion of the spill simulations, the results were carefully assessed to examine the persistence of the crude (i.e. whether the maximum evaporative loss has been achieved for the period of time modelled; and whether a substantial volume of hydrocarbons remain in the water column (if any)) in conjunction with the extent of sea surface 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 21: Summary of the oil spill model settings used for Scenarios 1–4

Parameter	Scenario 1 - Liner design – 129 day well blowout	Scenario 2 - Relief well success at end Day 102	Scenario 3 - Capping stack success at end Day 15	Scenario 4 - BOP closure success at end Day 1
Total volume released (m^3)	1,153,634	685,440	113,940	7,749
Average oil flow rate (m^3/day). Flow rate depletes over time	8,943	6,720	7,596	7,749
Exit hole (inches)	12.13	11.09	11.09	11.09
Release duration (days)	129	102	15	1
Simulation length (days)	189	162	55	45
Release height	Seabed level			
Oil Proxy	Statfjord C blend crude oil			
Activity period	October to May			
Surface oil exposure thresholds (g/m^2)	Low: 1 – 10 Moderate: 1 – 25 High: >25			
Thresholds for shoreline contact/accumulation (g/m^2)	Low: 10 – 100 Moderate: 100 – 1,000 High: >1,000			

Parameter	Scenario 1 - Liner design – 129 day well blowout	Scenario 2 - Relief well success at end Day 102	Scenario 3 - Capping stack success at end Day 15	Scenario 4 - BOP closure success at end Day 1
Dissolved hydrocarbon exposure thresholds(ppb) averaged over 96 hours. The application of a 6 ppb over 1 hour was used to calculate the Risk EMBA for Scenario 1	Low: 6 – 50 Moderate: 50 – 400 High: >400			
Entrained hydrocarbon exposure thresholds(ppb) averaged over 96 hours. The application of a 6 ppb over 1 hour was used to calculate the Risk EMBA for Scenario 1	Very low: 10 – 70 Low: 70 – 100 Moderate: 100 – 500 High: >500			

9 PRESENTATION AND INTERPRETATION OF MODEL RESULTS

The results from the modelling study are presented in several tables and figures, which aim to provide an understanding of the predicted sea surface exposure, shoreline contact and in-water exposure. Fresh oil refers to oil that contains volatile or soluble components and is not emulsified, while 'weathered oil' refers oil that no longer contains volatile or soluble components.

If readers are not fully familiar with how to interpret stochastic modelling outputs, please refer to the following NOPSEMA factsheet before reading this report section:
https://www.nopsema.gov.au/assets/Publications/A626200.pdf

9.1 Stochastic analysis

The stochastic results provide a summary based on the collective behaviour of all 100 spill trajectories, for Scenario 1 and 2. The results for Scenario 1 are presented as maps to set the bounds of the Risk EMBA and the geographic range of response capability. Scenario 2, the results are presented in both tabulated format in addition to contoured plots.

The stochastic results are calculated as follows:

- The **zones of potential oil exposure on the sea surface** – the highest concentration at each grid cell to occur during at least one time-step (1 hr) across all 100 simulations and classified relative to the threshold (i.e. low exposure: 1–10 g/m^2; moderate exposure: 10–25 g/m^2 and high exposure: >25 g/m^2).

- The **probability of oil exposure on the sea surface, in-water or shoreline** – is calculated by dividing the number of spill simulations passing over a given grid cell at a given reporting threshold, divided by the total number of simulations.

- The **minimum time before oil exposure on the sea surface or shorelines** – is determined by ranking the elapsed time before sea surface exposure or shoreline accumulation (at a given reporting threshold) to a given location/grid cell for each of the 100 spill simulations.

- The **average volume of oil ashore** – is determined by averaging the volume of oil ashore across all simulations predicted to make shoreline contact.

- The **maximum volume of oil ashore from a single spill simulation** – is determined by identifying the simulation that recorded the maximum volume of oil to come ashore and presenting that maximum volume value.

- The **length of shoreline oiled from a single spill simulation** – is determined by calculating the number of shoreline grid cells contracted by each simulation (at a given reporting threshold).

- The **maximum potential hydrocarbon loading on shorelines** – is determined by identifying the maximum loading for grid cell for each of the 100 spill simulations.

- The **zones of entrained and dissolved hydrocarbon exposure** – are calculated from the results of the 100 spill trajectories, for each given grid cell by applying 96-hour equivalent time-based averaging in the model to calculate the potential exposure

- The **zones of dissolved hydrocarbon exposure** – highest concentration at each grid cell to occur during at least one time-step (1 hr) across all 100 simulations and classified relative to the threshold by applying 96-hour equivalent time-based averaging in each grid cell to calculate the potential exposure.

9.2 Receptors assessed for sea surface and in-water exposure

At total of 80 individual receptors were assessed for potential sea surface and in-water exposure, founded on the following four key receptor types (see Figure 32):

- state waters
- Australian Network Marine Park (AMPs)
- Marine Key Ecological Features (KEFs)
- Integrated Marine and Coastal Regionalisation of Australia (IMCRA) meso-scale bioregions.

Coastal waters is a belt of water between the limits of the Australian States and the Northern Territory and a line 3 nm seaward of the territorial sea baseline. Figure 33 depicts the state coastal waters, which were assessed separately for sea surface and in-water (0–10 m depth) exposure.

Thirty-four Australian Marine Parks (AMPs), which are part of the Temperate East, South-east and South-west networks, were assessed for sea surface and in-water (0–10 m) exposure (see Figure 34).

Key ecological features (FEFs) are elements of the Commonwealth marine environment that are considered to be of regional importance for either a region's biodiversity or its ecosystem function and integrity (Department of the Environment and Energy). A total of 16 KEFs were evaluated for sea surface and in-water (0–10m and 90–100 m), which are shown in Figure 35.

The Integrated Marine and Coastal Regionalisation of Australia (IMCRA) is a classification developed by the Department of Environment and Energy which divides the marine environment into bioregions, or areas that behave as a unit from an ecological and regional planning perspective (Department of Environment and Energy). The current version (Version 4.0) includes waters from the coast to the edge of the Exclusive Economic Zone excluding Antarctica and Heard and Macdonald Islands. Twenty-three meso-scale bioregions were assessed as part of the study for sea surface and in-water (0–10 m) exposure (see Figure 36).

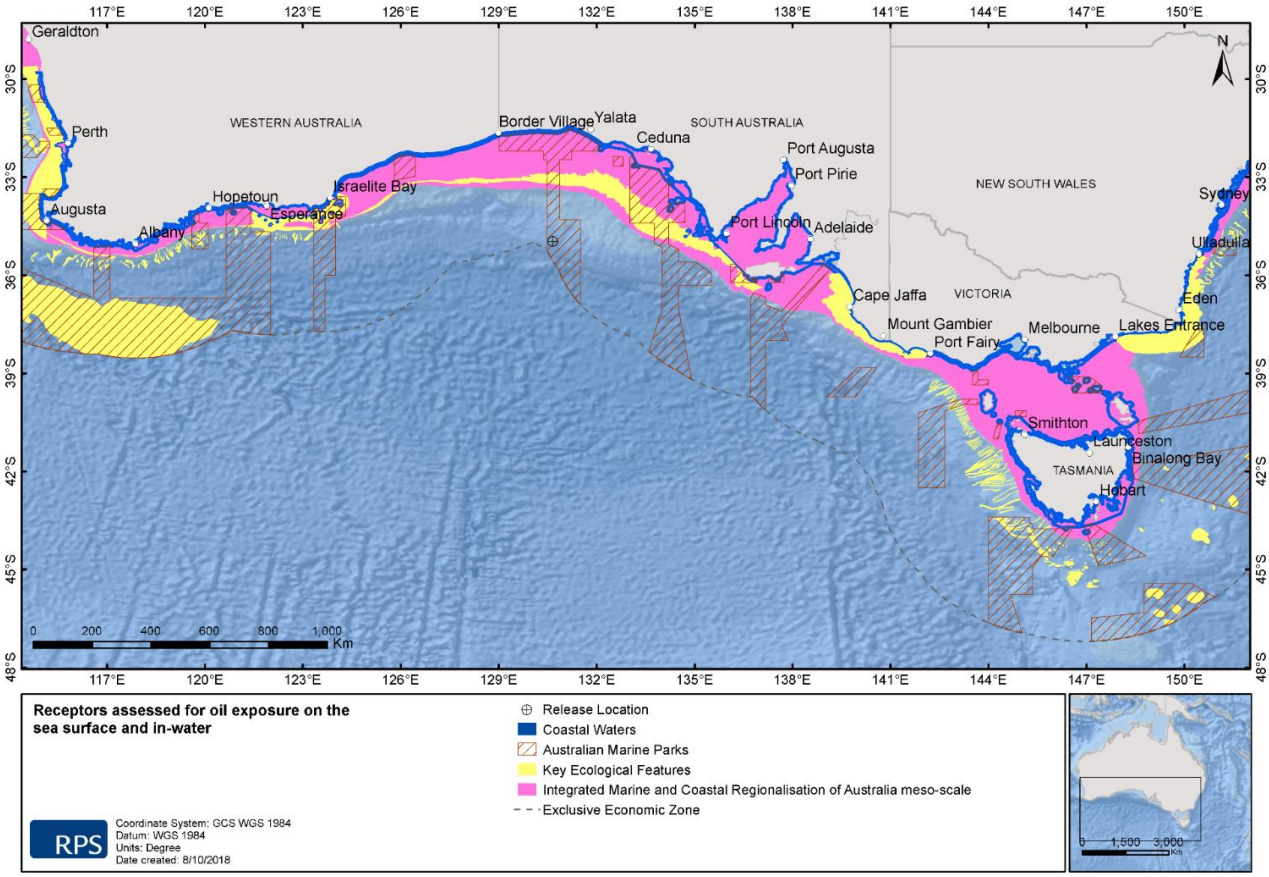


Figure 32: Four key receptor types assessed for sea surface and in-water from hydrocarbons

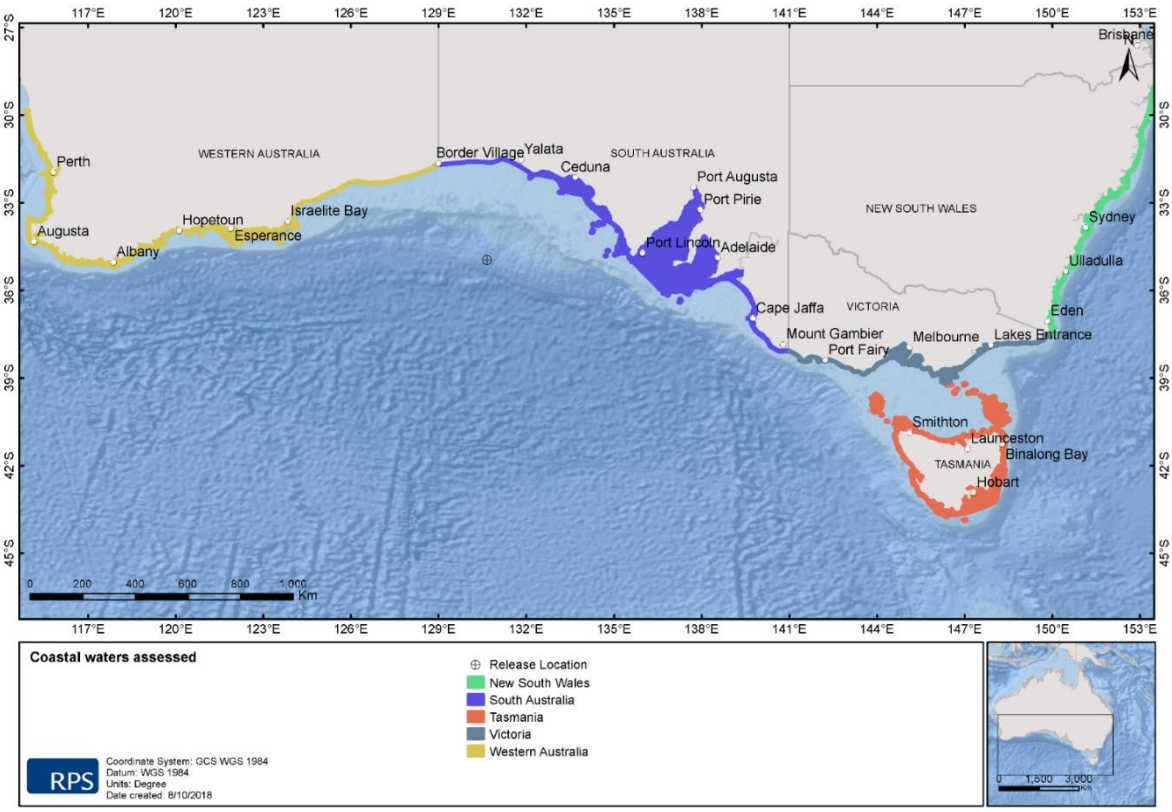


Figure 33: State coastal waters assessed for sea surface and in-water exposure (0-10 m depth) from hydrocarbons

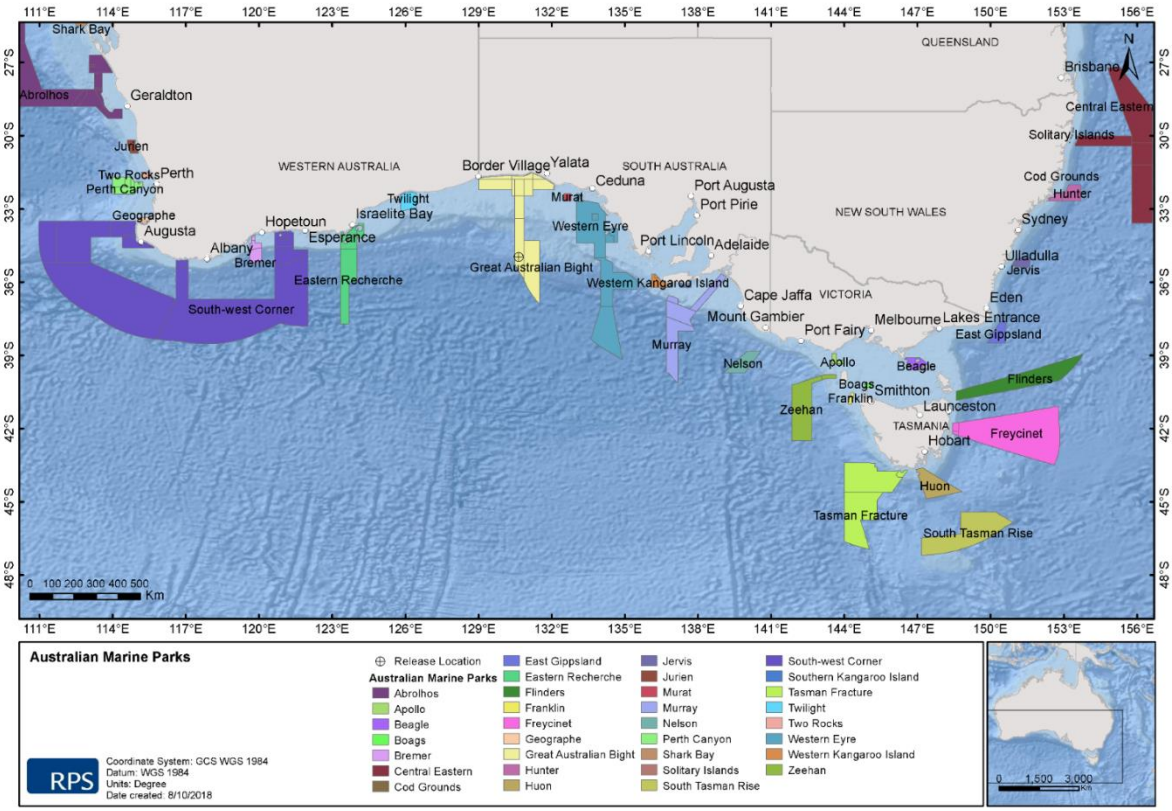


Figure 34: Australian Marine Parks assessed for sea surface and in-water (0- 10 m depth) exposure from hydrocarbons

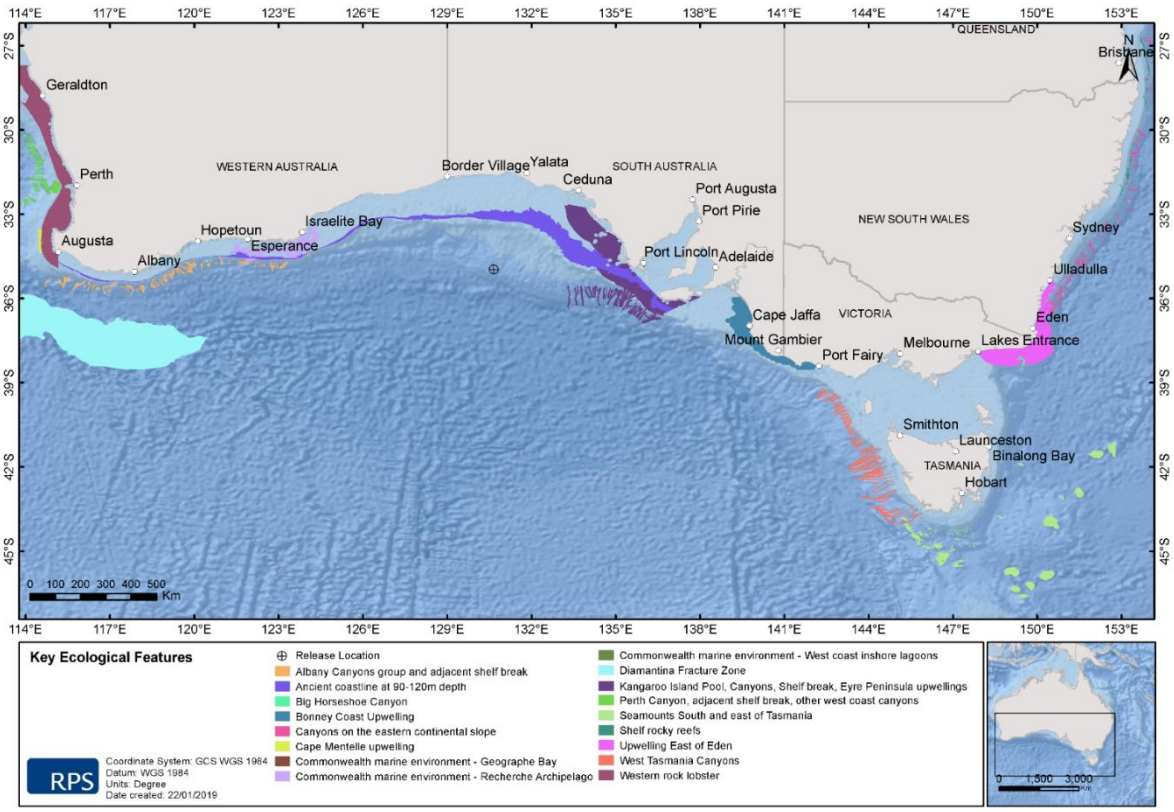


Figure 35: Key ecological features (KEFs) assessed for sea surface and in-water exposure (0-10 m and 90 – 100 m depth) from hydrocarbons

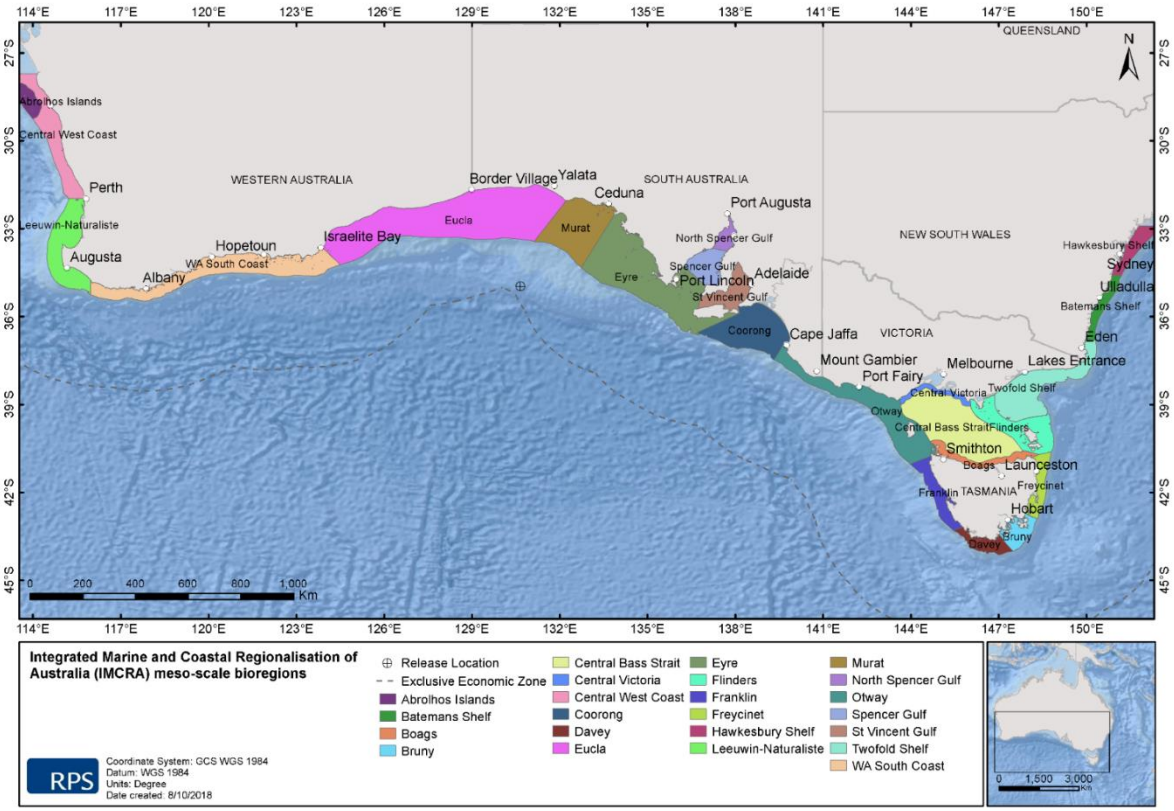


Figure 36: Integrated Marine and Coastal Regionalisation of Australia (IMCRA) meso-scale bioregions assessed for shoreline contact from hydrocarbons

9.3 Shoreline receptors assessed for oil accumulation

A total of 112 individual shoreline receptors were assessed based around:

- state shorelines
- local government areas
- Interim Biogeographic Regionalisation for Australia (IBRA) subregions.

Figure 37 shows a map of the state shorelines.

Figure 38 and Figure 39 depicts the local government areas (LGAs) east and west of Stromlo-1, respectively, and a total of 52 LGAs were evaluated.

The Interim Biogeographic Regionalisation for Australia (IBRA) is a classification developed by the Department of Environment and Energy which divides the Australian territory into 89 bioregions, according to their climate, geology, landform, native vegetation and species information (Department of the Environment and Energy). The bioregions are further refined into 419 subregions. This study considers the 55 subregions as shown in Figure 40.

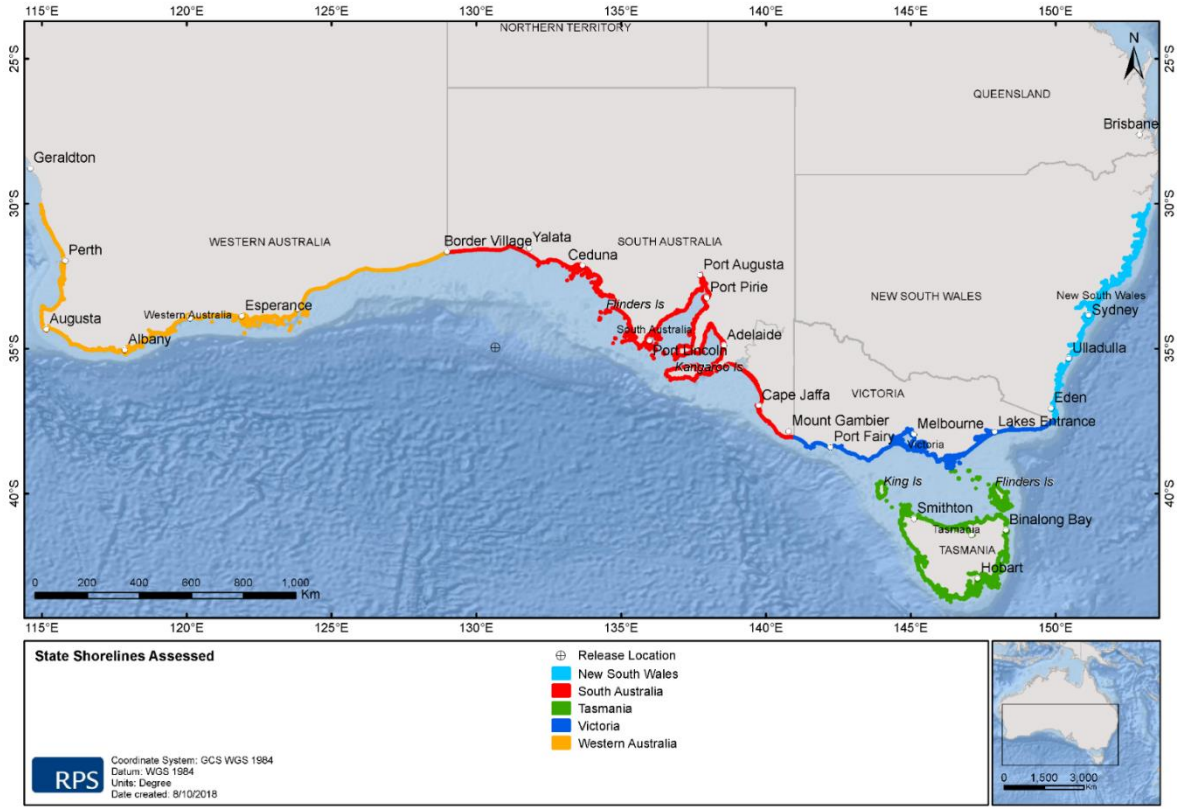


Figure 37: State shorelines assessed for oil contact

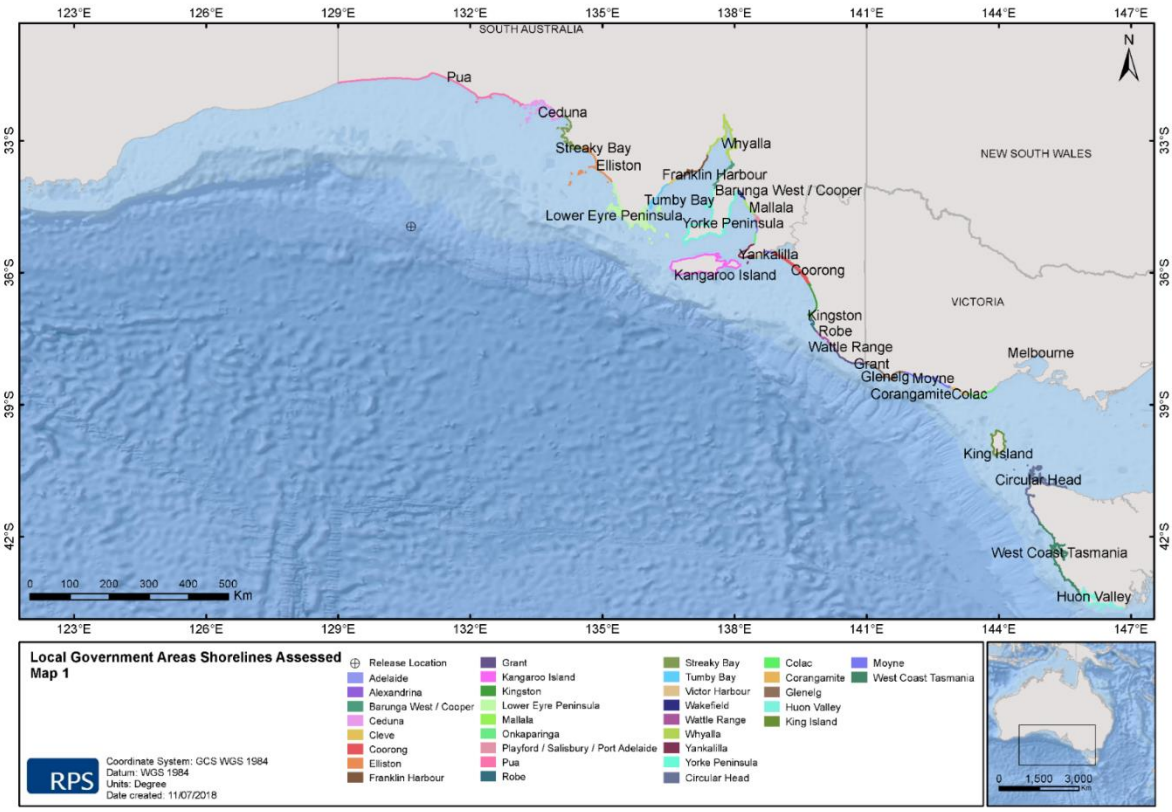


Figure 38: Local government areas (LGAs) east of Stromlo-1 assessed for shoreline contact from hydrocarbons

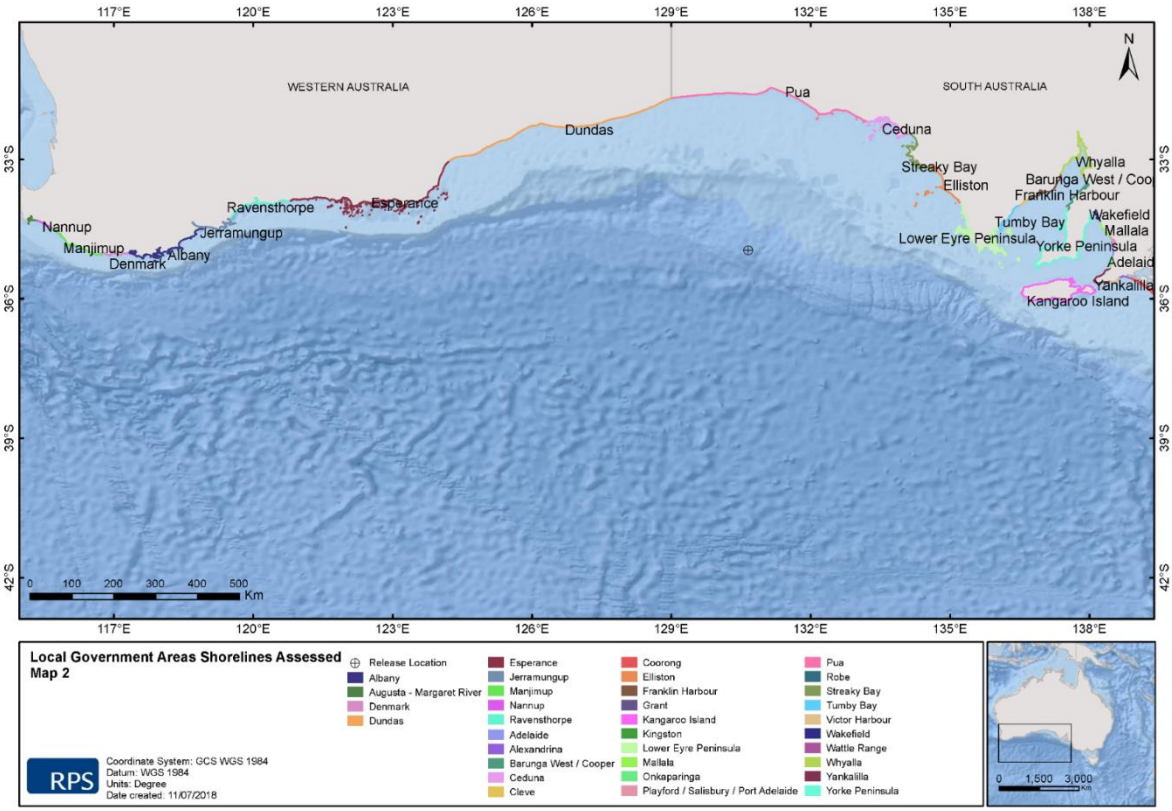


Figure 39: Local government areas (LGAs) west of Stromlo-1 assessed for shoreline contact from hydrocarbons

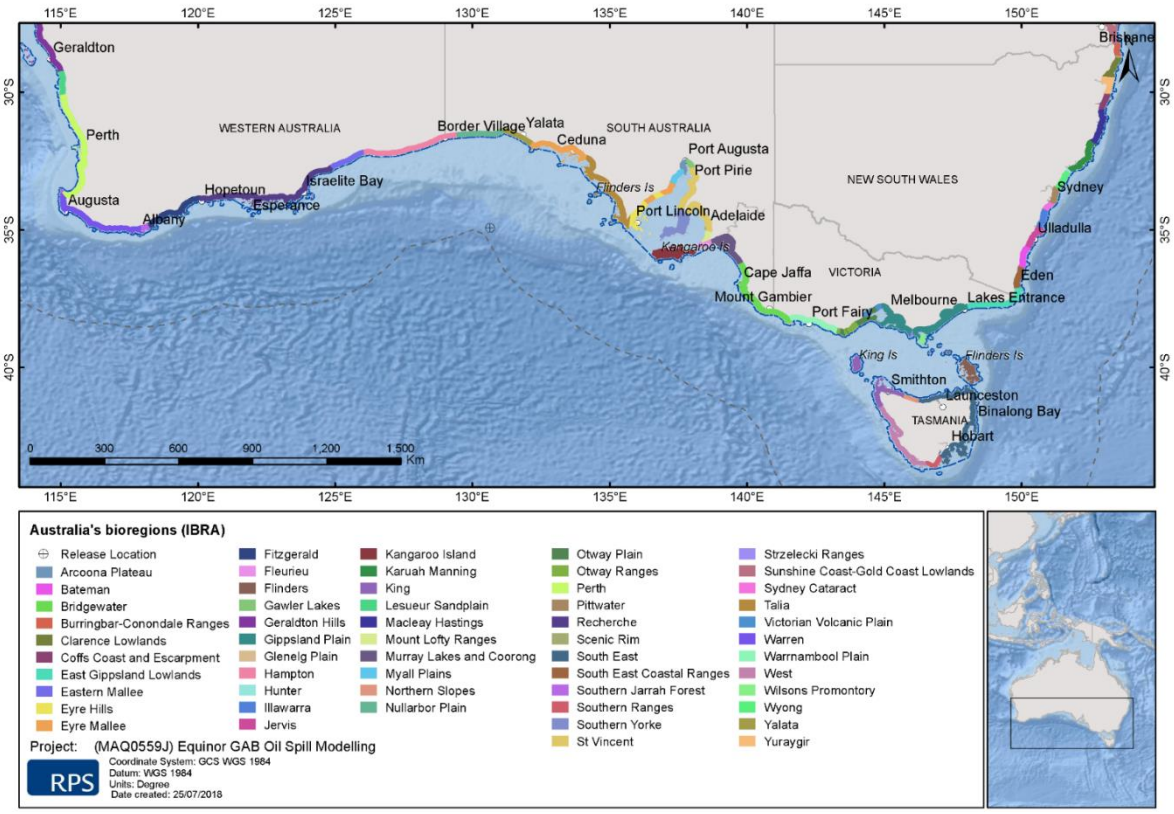


Figure 40: Interim Biogeographic Regionalisation for Australia (IBRA) subregions assessed for shoreline contact from hydrocarbons

10 SCENARIO 1 OUTCOMES – UNRESTRICTED FLOW OPEN HOLE (WCD)

This scenario examined the potential exposure following an unrestricted flow from an open hole during a blowout over 129 days, with no control measures in place and no spill mitigation accounted for. As previously mentioned, while this scenario is considered overly conservative, it has been used to set the bounds of the Risk EMBA and determine the geographic range of response capability. One hundred oil spills were simulated which commenced between October and May conditions and tracked for a period of 189 days. The stochastic results are presented in Section 10.1. Results for single oil spill simulations are presented Section 10.2.

10.1 Seasonal analysis

10.1.1 Environment may be affected

Figure 41 shows a map of greatest extent of oil exposure on the surface (fresh and weathered), in-water (entrained and dissolved) and shoreline contact, which was produced by overlaying the results from the 100 oil spill simulations. The following low reporting thresholds have been applied:

- Fresh and weathered sea surface oil – 1 g/m^2
- Shoreline oil contact – 10 g/m^2
- Dissolved hydrocarbon – 6 ppb (instantaneous)
- Entrained hydrocarbons – 10 ppb (instantaneous).

Figure 42 is a map of the Risk EMBA, which encompasses the full geographic area that could be affected and was derived from the stochastic modelling results (i.e. results from 100 spill trajectories). Both maps (Figure 41 and Figure 42) are based on an average 8,943 m^3/day subsea release of crude oil over 129 days. One hundred oil spills were simulated which commenced between October and May conditions and tracked for a period of 189 days.

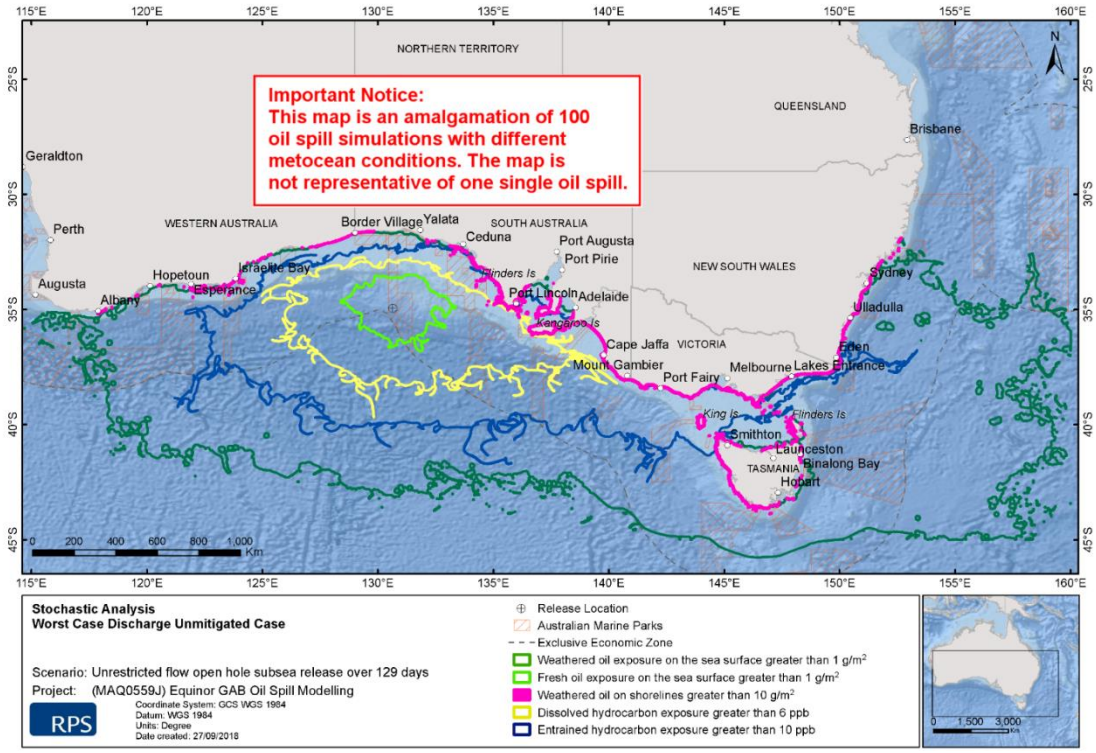


Figure 41: Greatest extent of oil exposure on the surface, in-water and shoreline contact, produced from the results of 100 unmitigated simulations commencing between October and May conditions. Each simulation represents an average 8,943 m³/day subsea release of crude oil over 129 days and tracked for 189 days

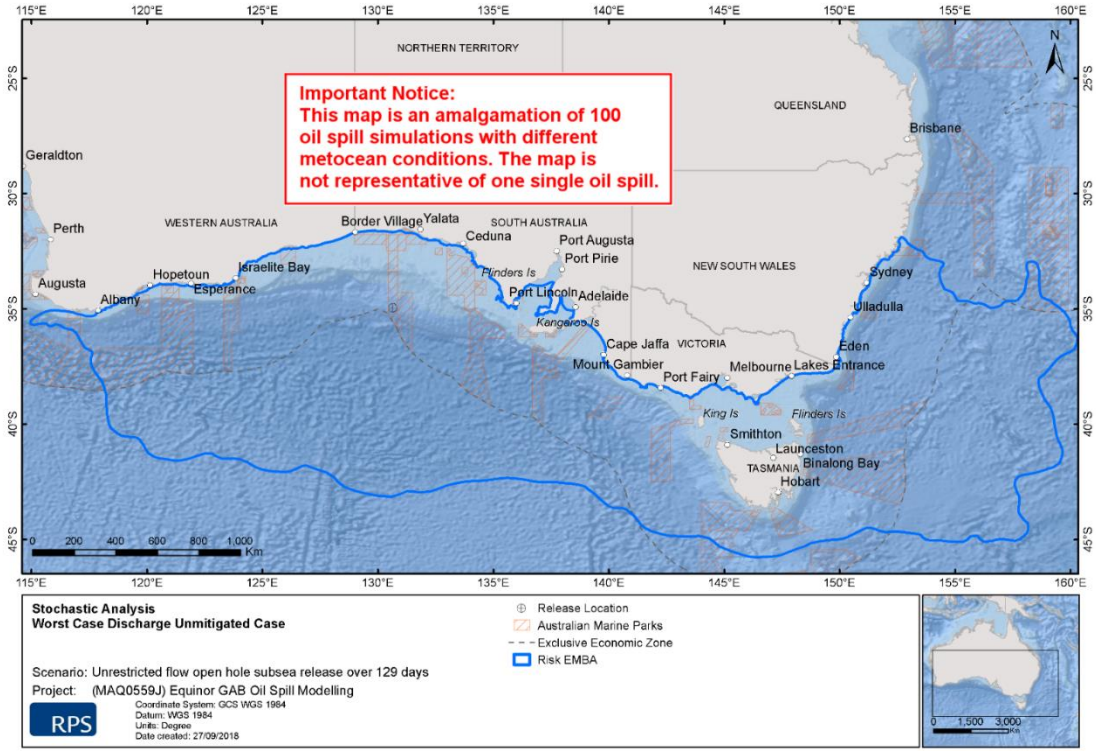


Figure 42: Risk EMBA (Environment May Be Affected), produced from the results of 100 unmitigated simulations commencing between October and May conditions. Each simulation represents an average 8,943 m³/day subsea release of crude oil over 129 days and tracked for 189 days

10.1.2 Oil exposure on the sea surface

Table 22 summarises the maximum distances travelled by spills from Stromlo-1 above each. The results are derived from 100 oil spill simulations commencing during summer conditions (October to May). When tracked to the low exposure threshold (1–10 g/m^2), the maximum distance travelled by a spill from Stromlo-1 was 2,721 km (east). The maximum distance travelled by a spill simulation at the moderate and high exposure threshold was 1,913 km (east) and 1,319 km (east-southeast), respectively.

Table 23 to presents the probability and minimum time before oil exposure on the sea surface within coastal waters, Australian Marine Parks, key ecological features and biologically important areas, respectively. The results are derived from 100 oil spill simulations commencing during summer conditions (October to May).

Tasmanian, South Australian and Victorian coastal waters were all predicted to experience sea surface oil exposure at the low to high thresholds. Oil exposure was predicted for New South Wales coastal waters at the low and moderate thresholds and for Western Australian coastal waters low only. South Australian coastal waters were predicted to experience the greatest probability of oil exposure at the moderate threshold (98%). The predicted minimum time before moderate exposure to the state based coastal waters ranged from 22.6 days (South Australia) to 145.3 days (New South Wales, see

Table 23).

South-east and South-west Network AMPs were predicted to experience sea surface oil exposure at the moderate threshold. No Temperate East Network AMPs were predicted to experience sea surface oil exposure at the moderate threshold (Table 24). The probability of moderate sea surface exposure was greatest for the following AMPs; Western Eyre (100%), Western Kangaroo Island (93%) and Murray (92%). The minimum time before moderate sea surface oil exposure to MPAs range between 14.4 days (Western Eyre) to 176.2 days (East Gippsland, see Table 24).

The KEF with the greatest probability of sea surface exposure at the moderate threshold was the surface waters immediately above the Ancient coastline at 90-120 m depth (100%, see Table 25). Additional KEFs with high probabilities of moderate sea surface contact included Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings (99%) and Bonney coast upwelling (87%). The corresponding minimum times before moderate sea surface exposure at the Ancient coastline, Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings and Bonney coast upwelling was 14.2 days, 20.3 days and 35.2 days, respectively. Minimum times before moderate sea surface exposure for KEFs experiencing moderate exposure ranged between 14.2 days and 117.3 days (Commonwealth marine environment - Recherche Archipelago KEF).

Table 22 Summary of the greatest distance (direction) from Stromlo-1 location to varying thresholds of sea surface exposure and corresponding areas of coverage, derived from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days.

Statistics	Summer		
	Low (1–10 g/m^2)	Moderate (10–25 g/m^2)	High (>25 g/m^2)
Greatest distance travelled (km) by a spill trajectory	2,721	1,913	1,319
99th percentile greatest distance travelled (km) by a spill trajectory	2,494	1,295	981
95th percentile greatest distance travelled (km) by a spill trajectory	2,285	1,069	576
90th percentile greatest distance travelled (km) by a spill trajectory	2,133	817	484
Direction (greatest distance travelled)	East	East	East-Southeast
Maximum area of coverage (km^2) by a spill trajectory	1,340,890	368,330	161,680

Table 23 Probability and minimum time before oil exposure on the sea surface for coastal waters, derived from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents an 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days.

Coastal waters	Summer					
	Maximum probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
	Low (1–10 g/m²)	Moderate (10–25 g/m²)	High (>25 g/m²)	Low (1–10 g/m²)	Moderate (10–25 g/m²)	High (>25 g/m²)
Tasmania	85	23	20	54.5	64.5	65.2
South Australia	100	98	93	21.2	22.6	34.4
Western Australia	21	0	0	58.5	-	-
Victoria	92	78	45	43.5	52.1	81.2
New South Wales	74	1	0	66.0	145.3	-

Table 24 Probability and minimum time before oil exposure on the sea surface for Australian Marine Parks, derived from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days.

Australian Marine Park Network	Australian Marine Parks (AMPs)	Summer					
		Maximum probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
		Low (1–10 g/m²)	Moderate (10–25 g/m²)	High (>25 g/m²)	Low (1–10 g/m²)	Moderate (10–25 g/m²)	High (>25 g/m²)
South-east	Apollo	90	35	8	58.8	60.3	73.7
	Beagle	77	9	0	65.8	107.2	0.0
	Boags	72	0	0	59.8	-	-
	East Gippsland	42	1	0	91.0	176.2	-
	Flinders	44	0	0	82.1	-	-
	Franklin	79	12	0	56.5	91.0	-
	Freycinet	26	0	0	86.5	-	-
	Huon	30	0	0	97.9	-	-
	Murray	99	92	44	31.4	32.7	33.4
	Nelson	92	25	0	44.3	81.6	
	South Tasman Rise	0	0	0	-	-	-
	Tasman Fracture	49	0	0	91.5	-	-
	Zeehan	90	30	0	50.8	62.8	
South-west	Abrolhos	0	0	0	-	-	-
	Bremer	17	0	0	81.3	-	-
	Eastern Recherche	42	19	7	46.1	63.3	82.4
	Geographe	0	0	0	-	-	-
	Jurien	0	0	0	0.0	-	-
	Murat	39	2	1	34.5	34.8	56.1
	Perth Canyon	0	0	0	-	-	-
	South-west Corner	33	2	0	54.6	107.2	-

Australian Marine Park Network	Australian Marine Parks (AMPs)	Summer					
		Maximum probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
		Low (1–10 g/m²)	Moderate (10–25 g/m²)	High (>25 g/m²)	Low (1–10 g/m²)	Moderate (10–25 g/m²)	High (>25 g/m²)
	Southern Kangaroo Island	94	85	19	33.6	33.9	64.0
	Twilight	36	5	0	34.8	65.7	-
	Two Rocks	0	0	0	-	-	-
	Western Eyre	100	100	95	14.3	14.4	14.5
	Western Kangaroo Island	99	93	63	23.8	31.5	31.9
Temperate East	Central Eastern	5	0	0	147.0	-	-
	Cods Grounds	0	0	0	-	-	-
	Gifford	0	0	0	-	-	-
	Hunter	5	0	0	145.2	-	-
	Jervis	23	0	0	136.3	-	-
	Lord Howe	10	0	0	135.5	-	-
	Solitary Islands	0	0	0	-	-	-

Table 25 Probability and minimum time before oil exposure on the sea surface for key ecological features, derived from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days.

Key Ecological Features (KEFs)	Summer					
	Maximum probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
	Low (1–10 g/m²)	Moderate (10–25 g/m²)	High (>25 g/m²)	Low (1–10 g/m²)	Moderate (10–25 g/m²)	High (>25 g/m²)
Seamounts South and east of Tasmania	36	0	0	96.25	-	-
West Tasmania Canyons	91	32	4	48.88	56.7	149.71
Bonney Coast Upwelling	95	87	74	34.96	35.2	44.46
Upwelling East of Eden	68	16	0	81.96	116.7	-
Big Horseshoe Canyon	36	0	0	87.88	-	-
Commonwealth marine environment - Geographe Bay	0	0	0	-	-	-
Cape Mentelle upwelling	0	0	0	-	-	-
Naturaliste Plateau	0	0	0	-	-	-
Diamantina Fracture Zone	19	0	0	76.38	-	-
Albany Canyons group and adjacent shelf break	31	9	0	57.67	101.8	-
Commonwealth marine environment - Recherche Archipelago	26	5	0	57.67	117.3	-
Ancient coastline at 90-120m depth	100	100	99	13.17	14.2	14.25
Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings	100	99	95	13.04	20.3	23.08
Western rock lobster	0	0	0	-	-	-
Canyons on the eastern continental slope	34	0	0	117.17	-	-

Key Ecological Features (KEFs)	Summer					
	Maximum probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
	Low (1–10 g/m²)	Moderate (10–25 g/m²)	High (>25 g/m²)	Low (1–10 g/m²)	Moderate (10–25 g/m²)	High (>25 g/m²)
Shelf rocky reefs	23	0	0	150.46	-	-
Western demersal slope and associated fish communities	0	0	0	-	-	-
Perth Canyon, adjacent shelf break, other west coast canyons	0	0	0	-	-	-
Commonwealth marine environment - West coast inshore lagoons	0	0	0	-	-	-

Figure 43 is a map illustrating the oil exposure on the sea surface (inclusive of fresh and weathered oil), produced by overlaying the results from 100 oil spill simulations commencing during summer conditions. Figure 44 shows the probability map of oil exposure on the sea surface at or above the moderate threshold.

Each simulation was based on a 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days.

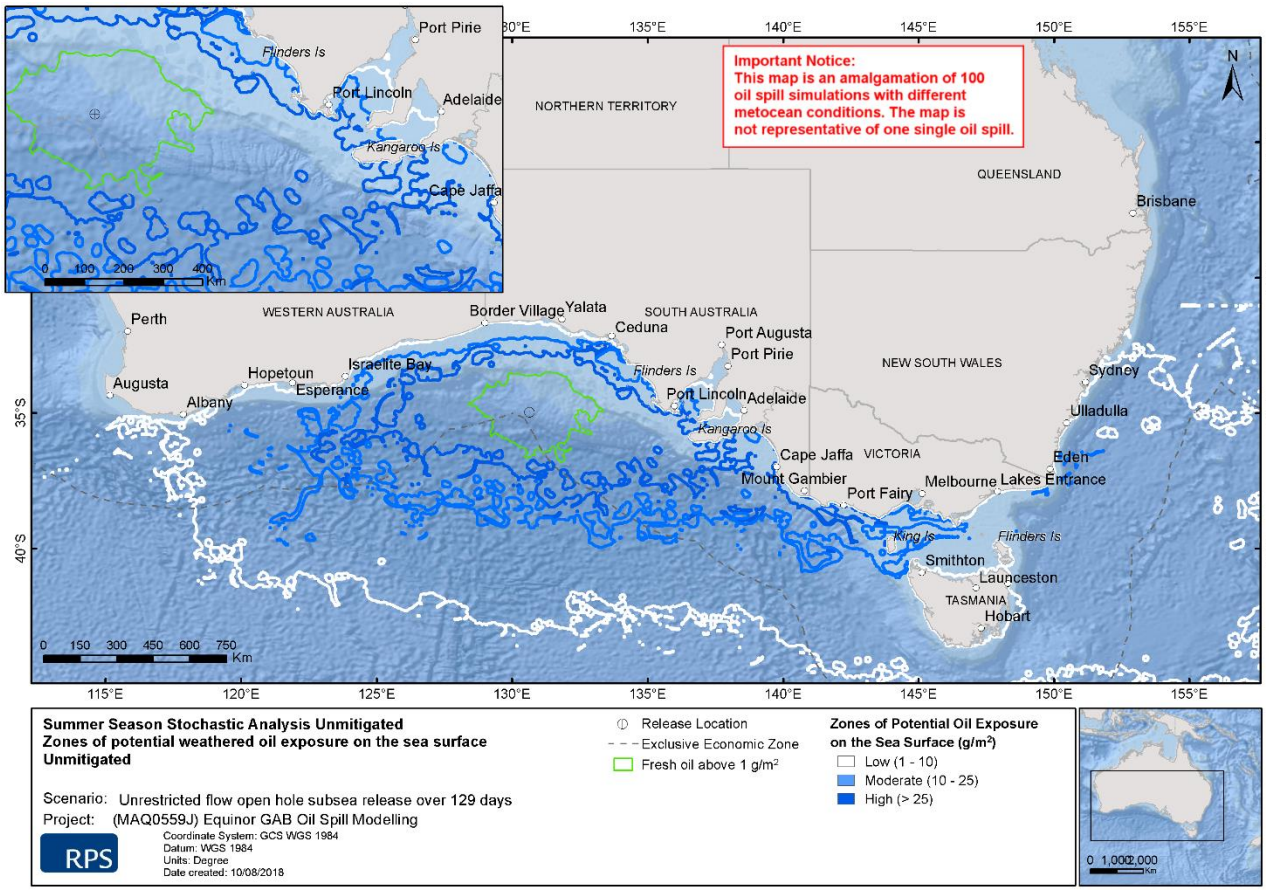


Figure 43 Zones of potential oil exposure on the sea surface, produced from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days

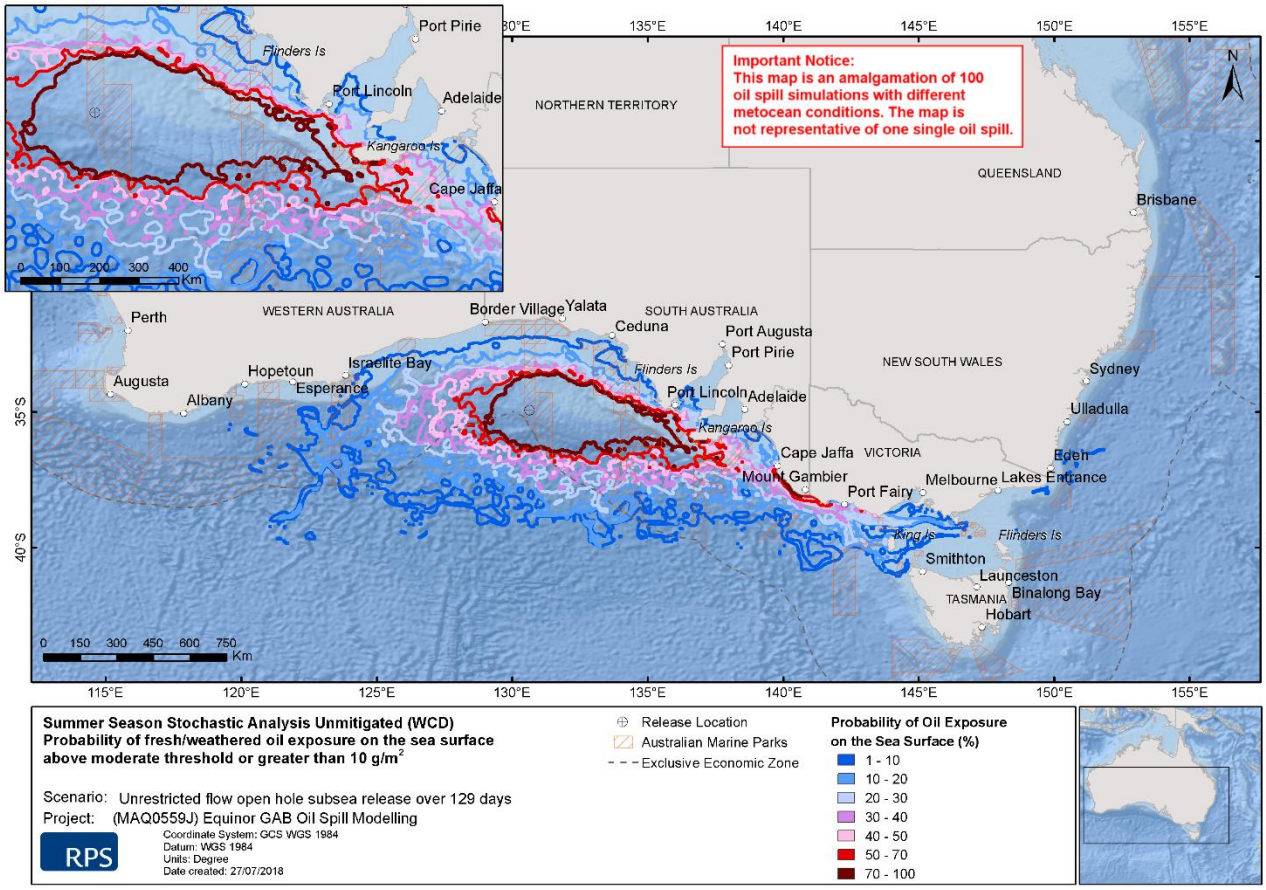


Figure 44 Probability of oil exposure on the sea surface at or above the moderate threshold, produced from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days

10.1.3 Oil contact to shorelines

Figure 45 is a bar plot of the minimum times before weathered oil contact to shorelines at or above the low threshold (>10 g/m²) for each simulation. The results have been sorted and are presented from minimum to maximum values to highlight the range or differences in results, which is due to the prevailing current and wind conditions for each simulation. Note: P100, P95 and P50 represents the 100th, 95th and 50th percentiles, respectively.

The minimum time or fastest time to shore was 21.4 days. Fifty per cent of simulations took at least 52 days to reach a shoreline at or above the low threshold.

Figure 46 is a bar plot (sorted) of the maximum volume of weathered oil ashore for the 100 simulations. The greatest volume ashore was 244,466 m³. The maximum volume ashore for 50 out of 100 simulations was 165,012 m³.

Figure 47 presents the sorted bar plot of the maximum length of shoreline oiled at or above the low threshold for each simulation. Half of the 100 simulations contacted shorelines lengths below 2,434 km based on at or above the low threshold.

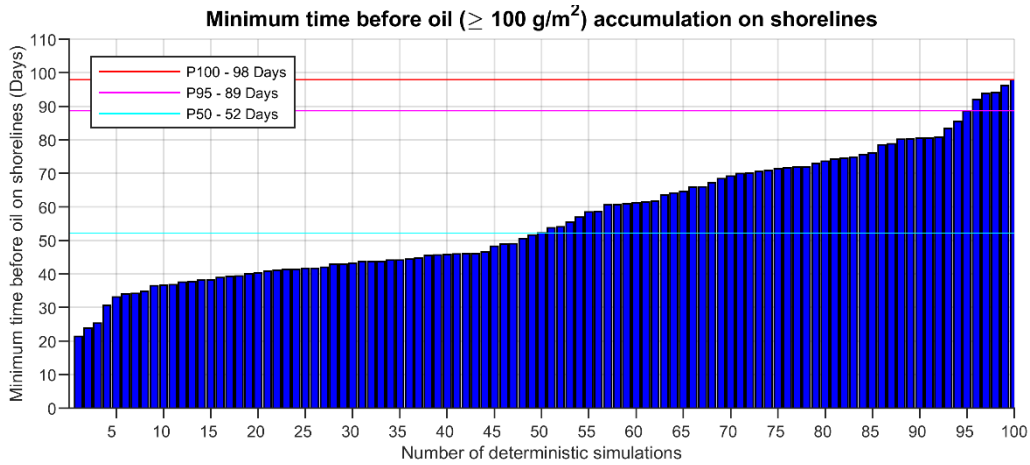


Figure 45: Sorted bar plots of the minimum time before weathered oil contact to shorelines at or above the low threshold for simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

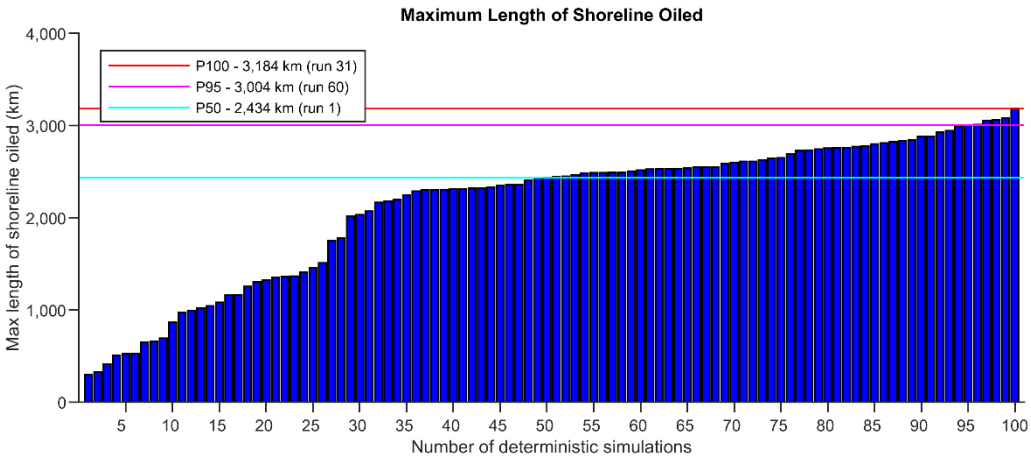


Figure 46: Sorted bar plots of the maximum volume of weathered oil ashore for simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

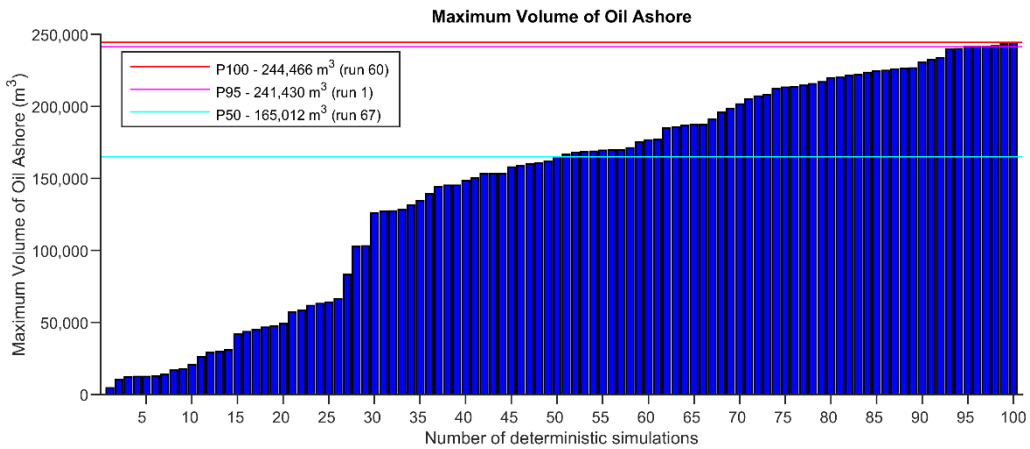


Figure 47: Sorted bar plots of the maximum length of shoreline contacted by weathered oil at or above the low threshold for simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Table 26 provides a summary of the fresh and weathered oil contact to any shoreline. The results were derived from 100 oil spill simulations commencing between October and May conditions. There were no shorelines contacted by fresh oil. For the weathered oil, all 100 simulations recorded contact at the moderate threshold. It took a minimum of 21.4 days for weathered oil to reach the shorelines. The maximum oil volume ashore for a single simulation was 244,466 m^3. The maximum length of shoreline contact by weathered oil above the low and moderate thresholds was 3,184 km and 3,080 km, respectively.

Table 27 provides a summary of probability, minimum time and loading of weathered oil contact to shorelines for each state, at varying thresholds. The probability of shoreline contact at the moderate threshold range from 30% (Western Australia) to 100% (South Australia). The corresponding minimum times before moderate shoreline contact for Western Australia and South Australia were 56 days and 21 days, respectively. The South Australian shoreline demonstrated the greatest predicted peak load (1,521,305 g/m^2) and peak volume ashore (208,4237 m^3). The mean length of shoreline contacted at the moderate threshold ranged between 39 km (New South Wales) and 1,302 km (South Australia).

Table 28 and Table 29 provide a summary of the weathered oil contact to shorelines for each of the IBRA subregions and LGAs, at varying thresholds, respectively.

Table 26: Summary of fresh and weathered oil contact to any shorelines. Results were derived from 100 oil spill simulations per case commencing between October and May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Statistics	Fresh oil	Weathered oil
Probability of oil contact to any shoreline at or above the moderate threshold (%)	0	100
Minimum time before oil accumulation on shorelines at or above the moderate threshold (days)	-	21.4
Maximum volume of oil ashore (m^3)	0	244,466
Average volume of oil ashore (m^3) across all simulations	0	146,298
Maximum length of shoreline contacted by oil at or above the low threshold (km) for a single simulation	0	3,184
Average length of shoreline contacted by oil at or above the low threshold (km)	0	2,206
Maximum length of shoreline contacted by oil at or above the moderate threshold (km)	0	3,080
Average length of shoreline contacted by oil at or above the moderate threshold (km)	0	2,059
Maximum length of shoreline contacted by oil at or above the high threshold	0	2,130
Average shoreline length contacted by oil at or above the high threshold (km)	0	1,394

Table 27: Probability, minimum time and loading of weathered oil contact to shorelines for each state, at varying thresholds. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

States	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)			Load on shoreline (g/m^2)	Volume on shoreline (m^3)		Mean length of shoreline contacted			Maximum length of shoreline contacted (km)		
	Low	Mod.	High	Low	Mod.	High	Mean	Mean	Peak	Low	Mod.	High	Low	Mod.	High
Tasmania	85	85	85	55	55	55	7,933	14,764	67,742	537	505	307	1,027	987	717
South Australia	100	100	100	21	21	21	27,005	108,373	208,427	1,380	1,302	941	1,905	1,808	1,347
Western Australia	30	30	27	56	56	58	5,144	1,864	11,679	84	81	60	342	318	188
Victoria	96	96	92	44	44	44	13,490	25,954	62,553	571	512	328	905	828	592
New South Wales	51	51	45	105	105	110	1,389	101	532	43	39	15	209	181	68

Mod. represents Moderate

Table 28: Probability, minimum time and loading of weathered oil contact to shorelines for each Interim Biogeographic Regionalisation for Australia (IBRA) subregion. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Interim Biogeographic Regionalisation for Australia (IBRA) subregion	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)		Load on shoreline (g/m^2)		Volume on shoreline (m^3)		Mean length of shoreline contacted			Maximum length of shoreline contacted (km)		
	Low	Mod.	High	Low	Mod.	High	Mean	Mean	Peak	Low	Mod.	High	Low	Mod.	High
West	79	79	76	62.5	62.5	62.8	3,330	2,388	11,271	200	189	116	361	349	259
Southern Jarrah Forest	4	4	1	114.7	114.7	169.6	635	10	26	7	7	7	14	14	7
King	85	85	85	54.6	54.6	54.8	14,211	11,449	50,955	264	246	159	397	383	304
Flinders	80	80	78	66.6	66.6	67.0	10,146	3,859	17,519	121	119	87	318	302	225
Kangaroo Island	99	99	99	31.5	31.5	32.1	32,743	31,730	62,267	389	377	317	492	481	417
Hunter	5	5	2	150.4	150.4	151.5	520	8	13	4	3	2	7	5	2
Fitzgerald	3	3	1	127.8	127.8	169.6	738	13	26	8	8	7	11	11	7
Recherche	30	30	27	56.3	56.3	58.3	5,880	1,835	11,283	74	73	58	249	243	181
Eastern Mallee	3	3	1	110.3	110.3	130.0	548	8	16	8	8	2	14	14	2
Warren	1	1	1	146.5	146.5	147.1	903	28	28	16	16	5	16	16	5
Hampton	5	5	4	110.8	110.8	113.3	729	181	587	56	39	12	111	86	29

Interim Biogeographic Regionalisation for Australia (IBRA) subregion	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)		Load on shoreline (g/m^2)		Volume on shoreline (m^3)		Mean length of shoreline contacted			Maximum length of shoreline contacted (km)		
	Low	Mod.	High	Low	Mod.	High	Mean	Mean	Peak	Low	Mod.	High	Low	Mod.	High
Nullarbor Plain	4	4	4	112.1	112.1	114.3	1,061	32	73	15	15	5	27	27	11
Eyre Mallee	57	57	53	38.1	38.1	38.2	3,423	287	5,976	21	21	14	104	104	88
Talia	100	100	100	21.4	21.4	21.4	38,811	22,457	65,785	280	266	192	458	435	340
Eyre Hills	99	99	97	25.3	25.3	25.9	38,692	15,037	36,857	177	170	136	320	304	229
St Vincent	1	1	0	165.5	165.5	-	567	2	2	2	2	0	2	2	0
Southern Yorke	94	94	93	36.5	36.5	36.7	11,874	3,034	9,863	119	105	62	234	209	113
Mount Lofty Ranges	19	18	9	83.9	83.9	92.7	840	19	142	10	8	4	34	32	7
Fleurieu	85	85	82	44.5	44.5	55.7	3,022	350	1,226	48	45	23	98	91	52
Murray Lakes and Coorong	71	70	46	43.8	43.8	84.0	1,144	1,402	6,843	85	69	45	168	147	93
Glenelg Plain	93	93	92	43.8	43.8	44.0	35,254	1,855	5,242	24	24	19	32	32	27
Bridgewater	96	96	93	40.2	42.3	42.3	19,795	48,359	96,410	423	398	277	517	501	386
Warrnambool Plain	93	93	92	44.7	44.8	45.3	10,807	5,881	16,342	163	148	93	231	225	163
Otway Ranges	89	89	85	61.9	61.9	72.2	2,654	365	2,040	41	37	20	73	70	50
Otway Plain	89	89	85	61.9	61.9	62.4	5,793	1,392	3,909	41	34	19	98	84	43
Gippsland Plain	75	75	65	84.4	84.4	89.0	2,287	1,510	7,021	124	102	55	225	202	141
Strzelecki Ranges	60	60	44	87.7	87.7	104.8	1,689	22	103	6	6	4	14	9	7
Wilsons Promontory	80	80	75	66.5	66.5	66.6	21,916	2,730	9,531	56	56	45	93	93	86
East Gippsland Lowlands	59	59	54	98.8	98.8	126.8	957	149	617	52	38	11	141	107	34
South East Coastal Ranges	26	26	18	116.9	116.9	138.8	684	19	49	12	11	4	29	29	14
Bateman	28	28	26	109.2	109.2	110.0	1,486	77	324	25	22	11	86	68	34
Jervis	20	20	12	115.1	115.1	136.6	672	19	50	13	13	6	29	29	11
Illawarra	12	12	11	134.0	134.0	134.6	812	32	67	20	18	7	32	27	14
Sydney Cataract	6	6	3	135.3	135.3	162.6	658	9	21	7	7	3	16	16	5
Pittwater	11	10	5	151.2	151.2	166.8	574	10	21	8	8	3	16	14	5
Wyong	6	6	2	150.5	150.5	152.0	483	19	41	14	12	9	25	23	14
Karuah Manning	6	5	2	148.9	148.9	150.0	348	17	31	12	11	3	25	18	5
South East	48	47	20	93.2	93.2	118.2	485	29	116	19	17	5	57	52	9
Southern Ranges	38	38	24	100.7	100.7	104.3	724	21	63	13	12	6	29	27	11

Mod. represents Moderate

Table 29: Probability, minimum time and loading of weathered oil contact to shorelines for Local Government Areas (LGAs). Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Local government areas (LGAs)	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)			Load on shoreline (g/m^2)	Volume on shoreline (m^3)		Mean length of shoreline contacted			Maximum length of shoreline contacted (km)		
	Low	Mod.	High	Low	Mod.	High	Mean	Mean	Peak	Low	Mod.	High	Low	Mod.	High
King Island	85	85	84	55	55	55	23,828	8,695	38,097	127	118	85	188	179	134
Lower Eyre Peninsula	100	100	100	24	24	25	46,160	35,196	94,632	350	333	252	476	465	372
Esperance	30	30	27	56	56	58	5,946	1,847	11,365	74	73	59	247	243	188
Elliston	100	100	99	21	21	21	10,421	2,073	7,149	90	88	67	193	184	132
Ceduna	27	27	25	38	38	38	3,757	487	5,967	32	31	22	100	100	86
Albany	4	4	1	115	115	147	640	20	65	12	12	14	34	34	14
Jerramungup	3	3	1	134	134	170	700	9	14	7	7	5	11	11	5
Ravensthorpe	7	7	4	73	73	91	473	10	16	6	6	2	11	9	2
Dundas	7	7	3	110	110	115	390	53	221	28	19	5	82	59	7
Pua	39	39	37	57	57	66	3,688	58	515	11	10	6	82	79	43
Streaky Bay	46	46	32	52	52	52	1,586	201	3,235	24	23	15	95	88	64
Tumby Bay	29	29	25	78	78	84	993	114	415	24	22	9	59	52	18
Cleve	6	4	0	144	147	-	194	2	2	2	2	0	2	2	0
Franklin Harbour	0	0	0	-	-	-	0	0	0	0	0	0	0	0	0
Whyalla	0	0	0	-	-	-	0	0	0	0	0	0	0	0	0
Barunga West/Cooper	1	1	0	165	165	-	567	2	2	2	2	0	2	2	0
Yorke Peninsula	94	94	93	36	36	37	11,874	3,034	9,863	119	105	62	234	209	113
Mallala	0	0	0	-	-	-	0	0	0	0	0	0	0	0	0
Adelaide	0	0	0	-	-	-	0	0	0	0	0	0	0	0	0
Onkaparinga	13	11	4	90	90	93	1,343	15	93	7	6	2	20	18	2
Yankalilla	89	89	87	41	41	41	8,554	728	1,840	40	37	21	84	79	45
Victor Harbour	82	81	71	45	45	56	1,755	62	292	12	11	7	27	27	16
Kangaroo Island	99	99	99	32	32	32	32,601	31,328	61,149	385	373	313	488	476	413

Local government areas (LGAs)	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)			Load on shoreline (g/m^2)	Volume on shoreline (m^3)		Mean length of shoreline contacted			Maximum length of shoreline contacted (km)		
	Low	Mod.	High	Low	Mod.	High	Mean	Mean	Peak	Low	Mod.	High	Low	Mod.	High
Alexandrina	37	37	15	87	87	89	434	84	371	16	12	6	27	25	11
Coorong	71	70	46	44	44	84	1,195	1,287	6,479	75	62	41	147	127	84
Kingston	88	88	84	40	44	54	3,946	4,869	17,651	104	97	68	143	143	129
Robe	94	94	90	43	43	43	19,518	7,317	15,489	51	49	35	59	59	43
Wattle Range	96	96	92	42	43	43	20,671	10,820	20,095	83	78	51	95	95	66
Grant	96	96	92	42	42	42	26,688	14,647	31,746	96	91	68	109	109	88
Glenelg	95	95	92	44	44	44	29,376	13,437	32,865	132	123	87	175	163	120
Moyne	92	92	92	45	45	45	6,926	3,248	9,302	111	99	57	154	152	104
Corangamite	93	93	90	52	52	61	19,706	2,651	8,037	51	48	38	61	61	57
Colac	89	89	87	62	62	62	5,236	1,640	5,062	60	53	31	88	82	64
Circular Head	84	84	81	59	59	59	5,629	3,089	14,533	160	149	90	277	252	195
West Coast Tasmania	80	80	76	63	63	63	3,409	1,822	8,672	151	143	90	274	263	197
Huon Valley	64	64	49	68	68	81	2,641	375	1,484	40	38	28	111	109	54

Mod. represents Moderate

Figure 48 shows an overlay of shoreline loading of weathered oil (from the 100 simulations). The map shows weathered oil at varying thresholds from Albany in Western Australia to approximately Coffs Harbour in New South Wales and includes Tasmania. Along the Western Australian coastline, the areas with potentially higher loadings generally occurred between Esperance and Israelite Bay. High shoreline loadings in South Australia were generally concentrated Flinders Island to Kangaroo Island. Smaller isolated areas occurred near Border Village, Fowlers Bay, Ceduna, Cape Jaffa and Mount Gambier. In Victoria, shoreline loadings appeared highest from the western state border to the Cape Otway region, and then at Mornington Peninsula, Wilsons Promontory. Flinders Island, King Island and north west of Smithton for Tasmania. Potentially high shoreline loadings in New South Wales occur near Eden, Bateman's Bay and Newcastle north of Sydney.

Additionally, Figure 49 and Figure 50 presents the maximum potential shoreline loading from weathered oil based on clean-up methods and the probability of weathered oil contact to shorelines based on the moderate thresholds, respectively.

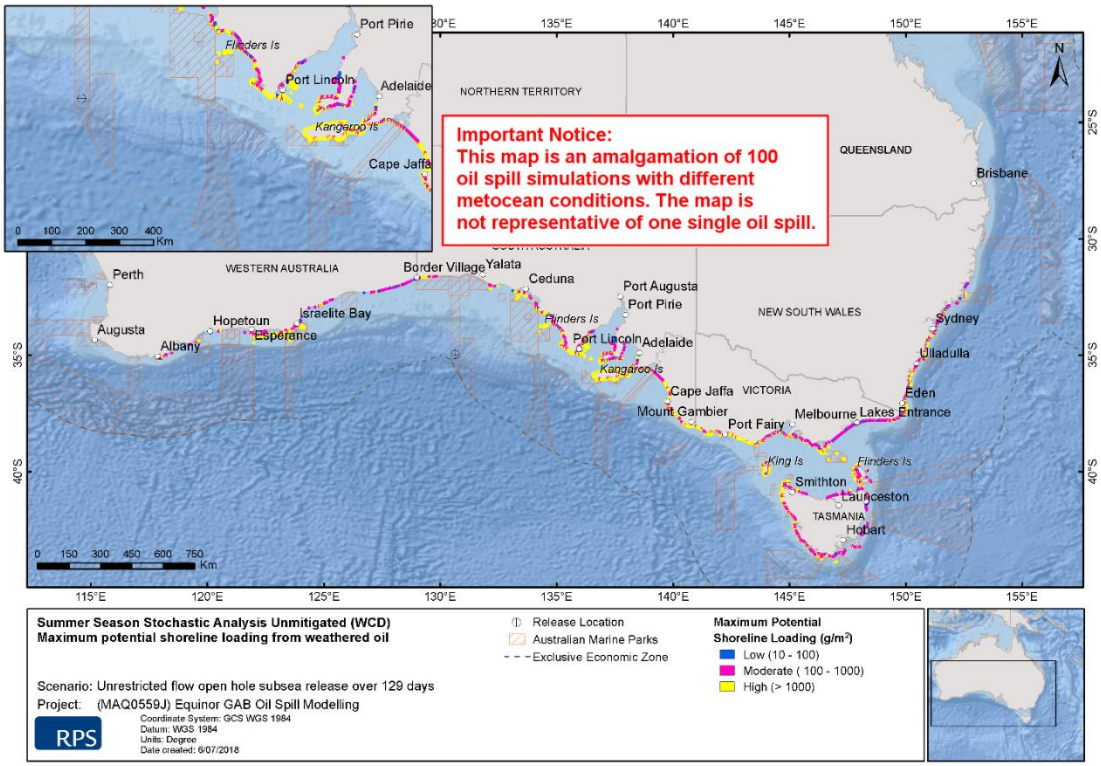


Figure 48: Maximum potential shoreline loading from weathered oil. Results were produced from 100 oil spill simulations per case commencing between October and May conditions. Each simulation was based on an average 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days

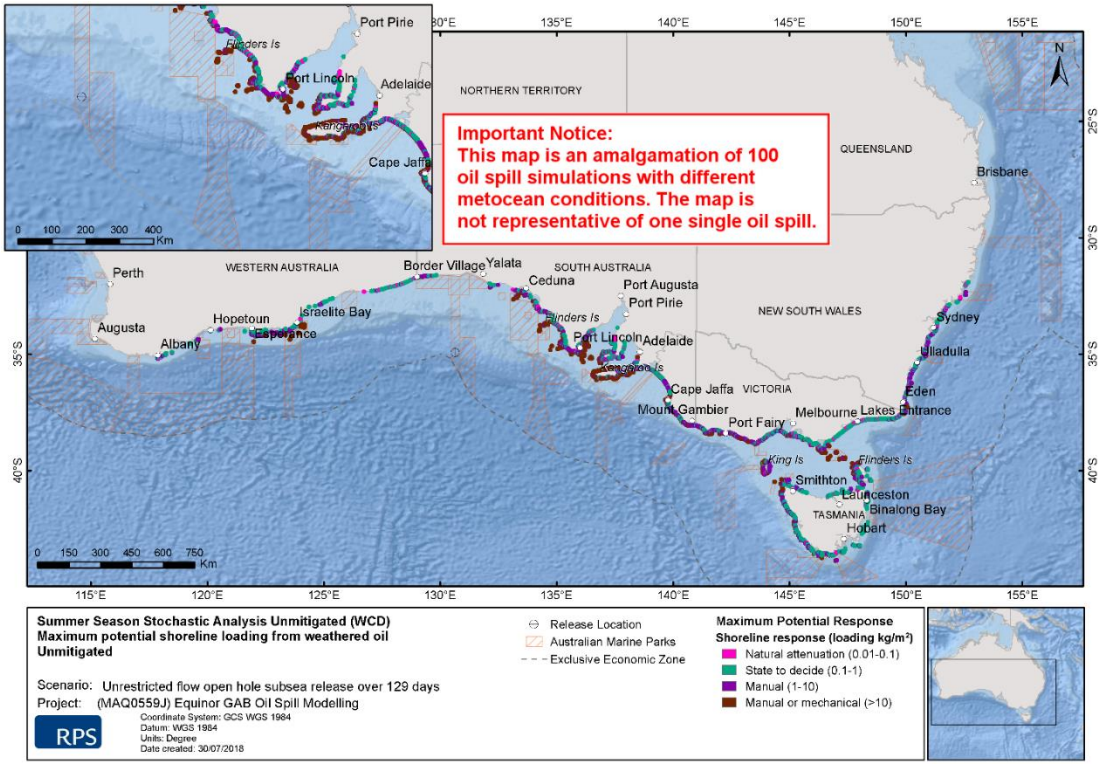


Figure 49: Maximum potential shoreline loading (based on clean-up methods) from weathered oil. Results were produced from 100 oil spill simulations per case commencing between October and May conditions. Each simulation was based on an average 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days

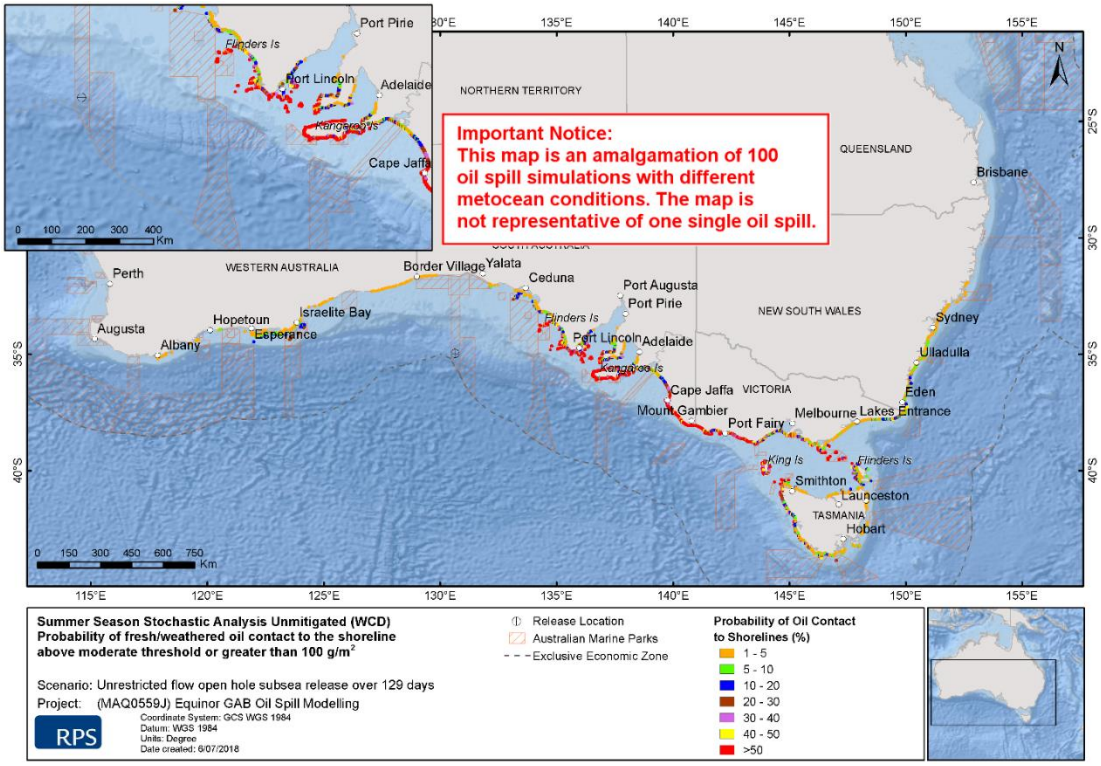
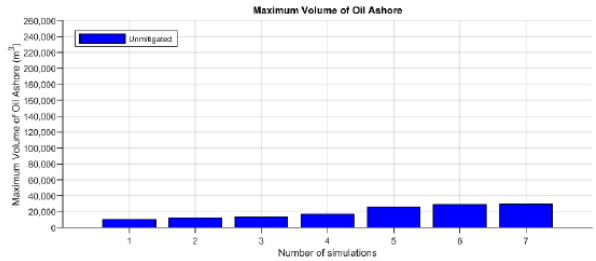


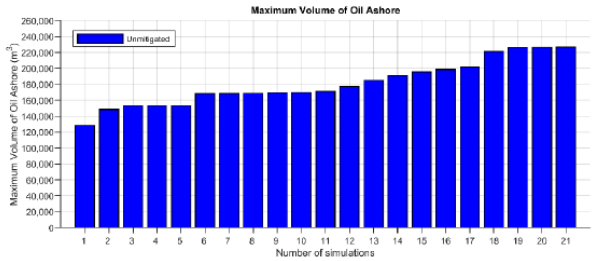
Figure 50: Probability of weathered oil contact to shorelines at or above the moderate threshold. Results were produced from 100 oil spill simulations per case commencing between October and May conditions. Each simulation was based on an average 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days

Figure 51 presents sorted bar plots of the maximum weathered oil ashore at or above the low threshold for each month for simulations commencing between October and May conditions. Additionally, sorted bar plots for simulations commencing between June and September conditions are presented in Appendix A (Figure 145).

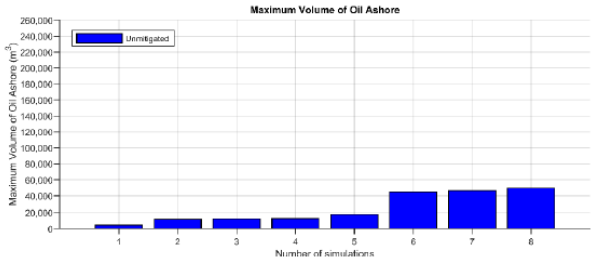
October



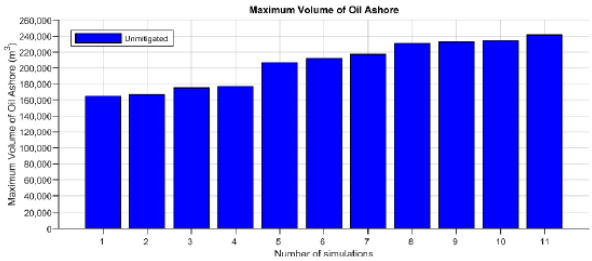
February



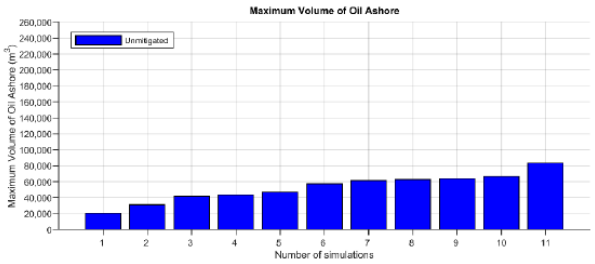
November



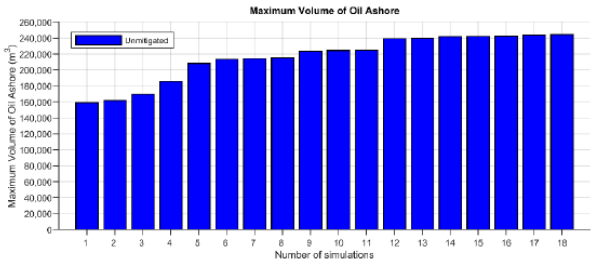
March



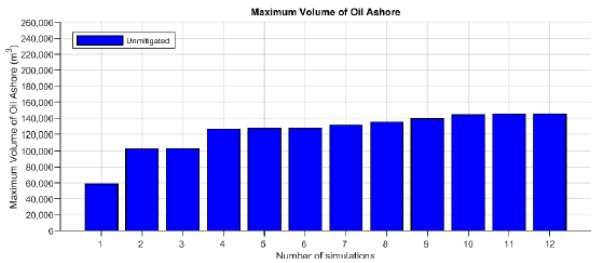
December



April



January



May

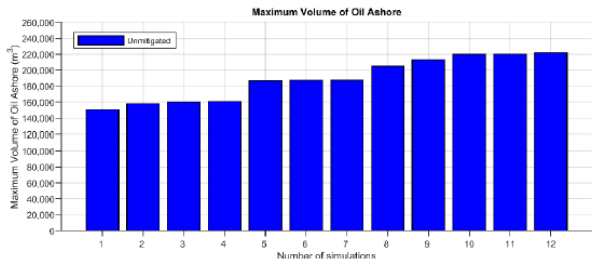


Figure 51: Sorted bar plots of the maximum oil ashore weathered oil at or above the low threshold for each month for simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days

10.1.4 In-water oil exposure

10.1.4.1 Entrained hydrocarbon exposure

Table 30 shows the probability of entrained hydrocarbon exposure (0-10 m water depth) within coastal waters (3 nm offshore) for each threshold. Also presented is the maximum exposure. The results are derived from 100 oil spill simulations commencing during summer conditions (October to May). Only the state waters of Victoria were predicted to experience exposure to entrained hydrocarbons at the moderate threshold (31%).

Table 31 presents the time averaged (over 96 hours) maximum entrained hydrocarbon exposure and probability of exposure (0-10 m water depth) within Australian Marine Parks. No AMPs were predicted to experience exposure to entrained hydrocarbons at the moderate threshold.

Table 32 displays the maximum predicted exposure (over time) and probability of entrained hydrocarbon exposure (90-100 m water depth) for key ecological features. No KEFs were predicted to experience entrained hydrocarbon exposure (90-100 m water depth). Figure 53 shows the moderate and high entrained hydrocarbon (96-hour time averaged) exposures zones in the 0 – 200m layer for the WCD scenario and overlaid are the KEFS.

Table 30 Maximum entrained hydrocarbon (time averaged) exposure and probability for each threshold (0-10 m water depth) within coastal waters. Derived from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days

Coastal waters	Maximum time averaged exposure (ppb)	Probability of exposure to entrained hydrocarbons (%) at each threshold			
		Very low	Low	Moderate	High
Tasmania	23	12	0	0	0
South Australia	79	69	2	0	0
Western Australia	0	0	0	0	0
Victoria	222	72	39	31	0
New South Wales	16	4	0	0	0

Table 31 Maximum entrained hydrocarbon (time averaged) exposure and probability for each threshold (0-10 m water depth) within Australian Marine Parks. Derived from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days

Australian Marine Park Network	Australian Marine Parks (AMPs)	Maximum time averaged exposure (ppb)	Probability of exposure to entrained hydrocarbons (%) at each threshold			
			Very low	Low	Moderate	High
South-east	Apollo	0	0	0	0	0
	Beagle	0	0	0	0	0
	Boags	0	0	0	0	0
	East Gippsland	0	0	0	0	0
	Flinders	0	0	0	0	0
	Franklin	0	0	0	0	0
	Freycinet	0	0	0	0	0
	Huon	0	0	0	0	0

Australian Marine Park Network	Australian Marine Parks (AMPs)	Maximum time averaged exposure (ppb)	Probability of exposure to entrained hydrocarbons (%) at each threshold			
			Very low	Low	Moderate	High
	Murray	0	0	0	0	0
	Nelson	0	0	0	0	0
	South Tasman Rise	0	0	0	0	0
	Tasman Fracture	0	0	0	0	0
	Zeehan	0	0	0	0	0
South-west	Abrolhos	0	0	0	0	0
	Bremer	0	0	0	0	0
	Eastern Recherche	0	0	0	0	0
	Geographe	0	0	0	0	0
	Jurien	0	0	0	0	0
	Murat	0	0	0	0	0
	Perth Canyon	0	0	0	0	0
	South-west Corner	0	0	0	0	0
	Southern Kangaroo Island	0	0	0	0	0
	Twilight	0	0	0	0	0
	Two Rocks	0	0	0	0	0
	Western Eyre	0	0	0	0	0
	Western Kangaroo Island	1,316	0	0	0	0
	Central Eastern	0	0	0	0	0
	Cods Grounds	0	0	0	0	0
	Gifford	0	0	0	0	0
Temperate East	Hunter	0	0	0	0	0
	Jervis	0	0	0	0	0
	Lord Howe	0	0	0	0	0
	Solitary Islands	0	0	0	0	0

Table 32 Maximum entrained hydrocarbon (time averaged) exposure and probability for each threshold (90-100 m water depth) for Key Ecological Features. Derived from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days

Key Ecological Features (KEFs)	Maximum time averaged exposure (ppb)	Probability of exposure to entrained hydrocarbons (%) at each threshold			
		Very low	Low	Moderate	High
Seamounts South and east of Tasmania	0	0	0	0	0
West Tasmania Canyons	0	0	0	0	0
Bonney Coast Upwelling	0	0	0	0	0
Upwelling East of Eden	0	0	0	0	0
Big Horseshoe Canyon	0	0	0	0	0
Commonwealth marine environment - Geographe Bay	0	0	0	0	0
Cape Mentelle upwelling	0	0	0	0	0
Naturaliste Plateau	0	0	0	0	0
Diamantina Fracture Zone	0	0	0	0	0
Albany Canyons group and adjacent shelf break	0	0	0	0	0

Key Ecological Features (KEFs)	Maximum time averaged exposure (ppb)	Probability of exposure to entrained hydrocarbons (%) at each threshold			
		Very low	Low	Moderate	High
Commonwealth marine environment - Recherche Archipelago	0	0	0	0	0
Ancient coastline at 90-120m depth	0	0	0	0	0
Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings	0	0	0	0	0
Western rock lobster	0	0	0	0	0
Canyons on the eastern continental slope	0	0	0	0	0
Shelf rocky reefs	0	0	0	0	0
Western demersal slope and associated fish communities	0	0	0	0	0
Perth Canyon, adjacent shelf break, other west coast canyons	0	0	0	0	0
Commonwealth marine environment - West coast inshore lagoons	0	0	0	0	0

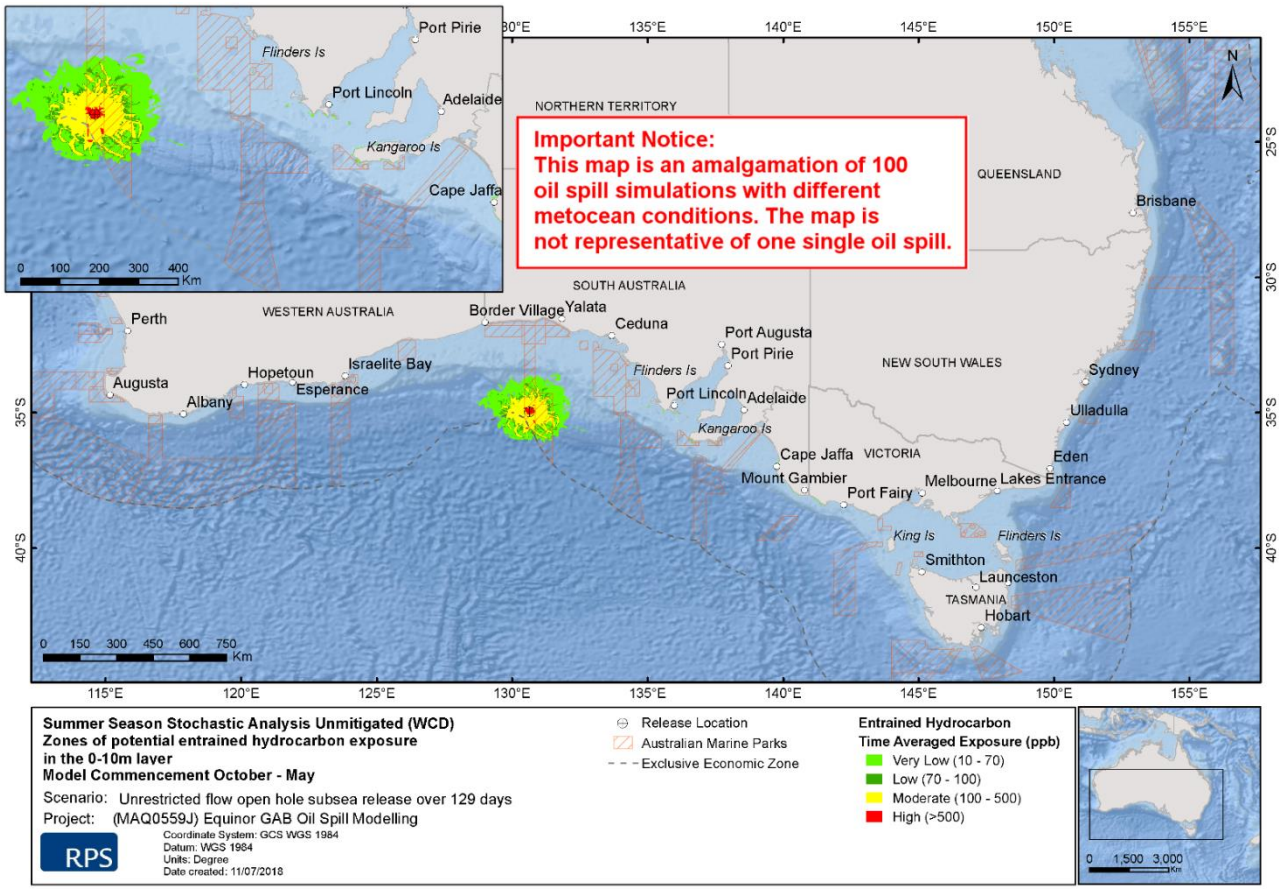


Figure 52 show zones of potential entrained hydrocarbon exposure (96-hour time averaged) exposure in the surface layer (0-10 m). The image was produced by overlaying the results from the 100 oil spill simulations commencing during summer conditions.

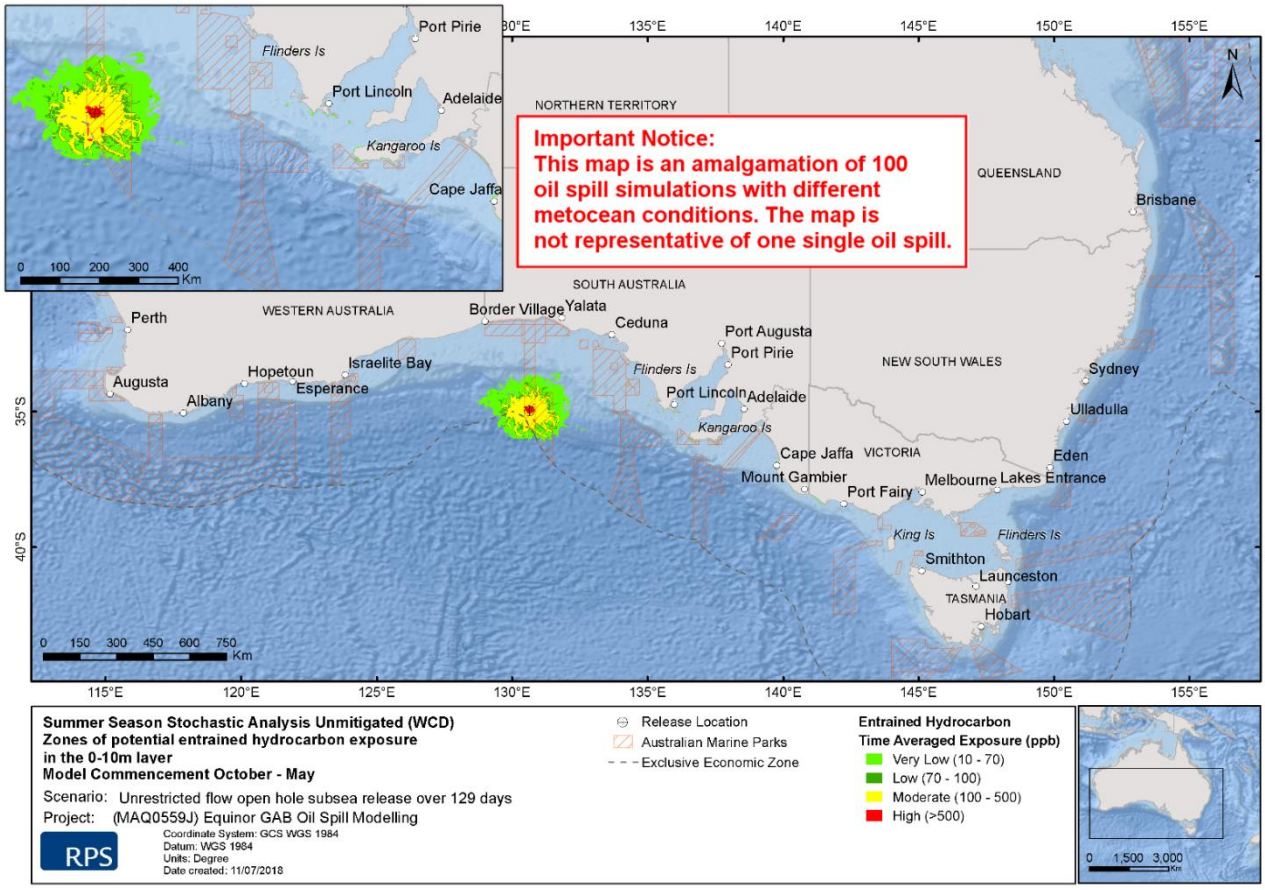


Figure 52 **Zones of potential entrained hydrocarbon time averaged exposure in the 0-10 m layer below the sea surface. Image is produced from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days**

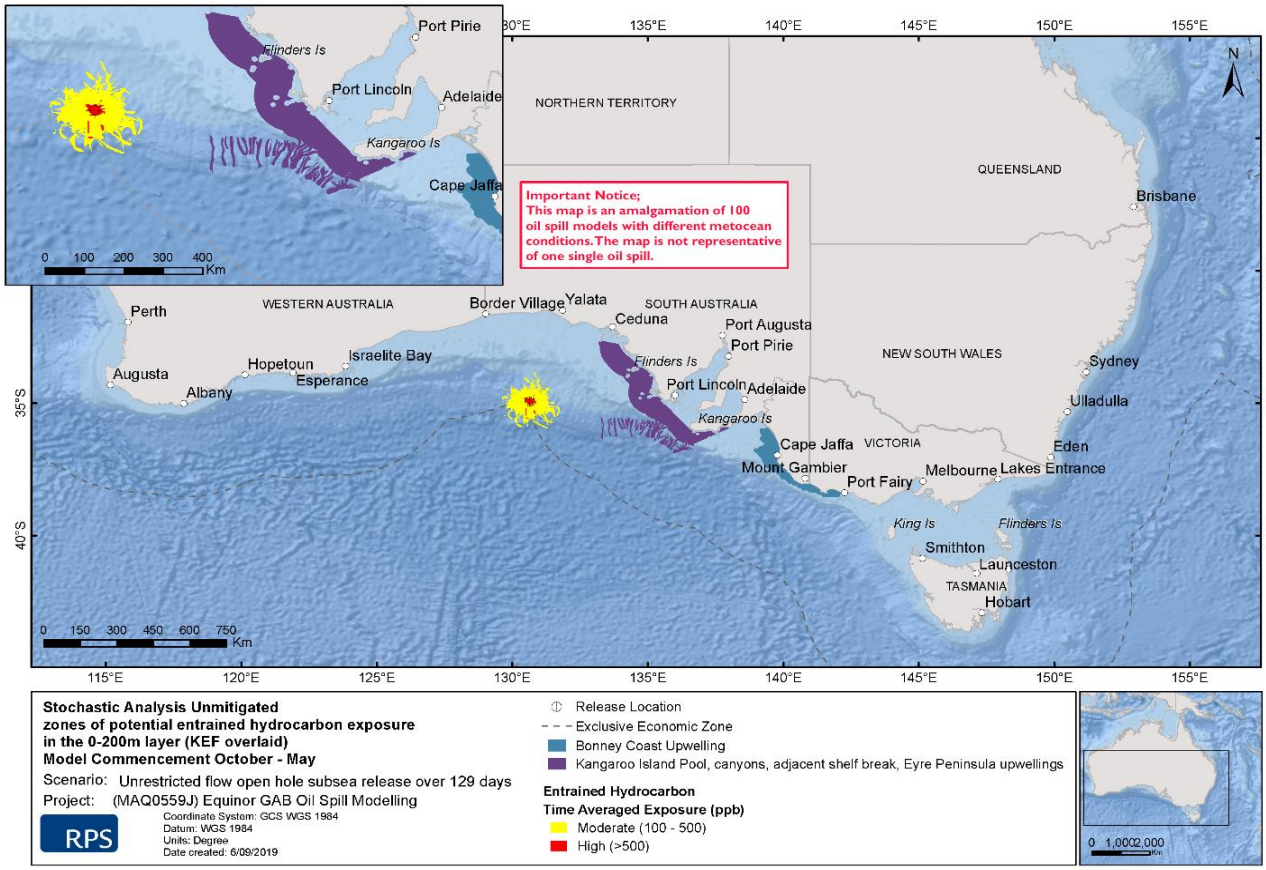


Figure 53 Moderate and high entrained hydrocarbon (96-hour time averaged) exposures zones in the 0–200 m layer for the WCD scenario and overlaid are the KEFs. Image is produced from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days

10.1.4.2 Dissolved aromatic oil exposure

Table 33 shows the probability of dissolved hydrocarbon 96-hour time averaged exposure (0-10 m water depth) within coastal waters (3 nm offshore) for each threshold. Also presented is the maximum exposure. The results are derived from 100 oil spill simulations commencing during summer conditions (October to May). No dissolved aromatic exposure was predicted for any state waters.

Table 34 presents the maximum dissolved hydrocarbon exposure and probability of exposure 0-10 m water depth) within AMPs. No predicted dissolved aromatic exposure at the moderate threshold was predicted for any AMPs.

Table 35 displays the maximum predicted exposure and probability of dissolved hydrocarbon exposure (90-100 m water depth) for KEFs. No predicted dissolved aromatic exposure at the moderate threshold was predicted for any KEFs.

Table 33 Maximum dissolved hydrocarbon exposure (time averaged) and probability for each threshold (0-10 m water depth) within state waters. Derived from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days

Coastal waters	Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbons (%) at each threshold		
		Low	Moderate	High
Tasmania	0	0	0	0
South Australia	0	0	0	0
Western Australia	0	0	0	0
Victoria	0	0	0	0
New South Wales	0	0	0	0

Table 34 Maximum dissolved hydrocarbon exposure (time averaged) and probability for each threshold (0-10 m water depth) within Australian Marine Parks. Derived from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days

Australian Marine Park Network	Australian Marine Parks (AMPs)	Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbons (%) at each threshold		
			Low	Moderate	High
South-east	Apollo	0	0	0	0
	Beagle	0	0	0	0
	Boags	0	0	0	0
	East Gippsland	0	0	0	0
	Flinders	0	0	0	0
	Franklin	0	0	0	0
	Freycinet	0	0	0	0
	Huon	0	0	0	0
	Murray	0	0	0	0
	Nelson	0	0	0	0
	South Tasman Rise	0	0	0	0
	Tasman Fracture	0	0	0	0
	Zeehan	0	0	0	0
South-west	Abrolhos	0	0	0	0
	Bremer	0	0	0	0
	Eastern Recherche	0	0	0	0
	Geographe	0	0	0	0
	Jurien	0	0	0	0
	Murat	0	0	0	0
	Perth Canyon	0	0	0	0
	South-west Corner	0	0	0	0
	Southern Kangaroo Island	0	0	0	0
	Twilight	0	0	0	0
	Two Rocks	0	0	0	0

Australian Marine Park Network	Australian Marine Parks (AMPs)	Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbons (%) at each threshold		
			Low	Moderate	High
	Western Eyre	1,959	1	0	0
	Western Kangaroo Island	0	0	0	0
	Central Eastern	0	0	0	0
	Cods Grounds	0	0	0	0
	Gifford	0	0	0	0
Temperate East	Hunter	0	0	0	0
	Jervis	0	0	0	0
	Lord Howe	0	0	0	0
	Solitary Islands	0	0	0	0

Table 35 Maximum dissolved hydrocarbon exposure (time averaged) and probability for each threshold (90-100 m water depth) for Key Ecological Features. Derived from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days.

Key Ecological Features (KEFs)	Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbons (%) at each threshold		
		Low	Moderate	High
Seamounts South and east of Tasmania	0	0	0	0
West Tasmania Canyons	0	0	0	0
Bonney Coast Upwelling	0	0	0	0
Upwelling East of Eden	0	0	0	0
Big Horseshoe Canyon	0	0	0	0
Commonwealth marine environment - Geographe Bay	0	0	0	0
Cape Mentelle upwelling	0	0	0	0
Naturaliste Plateau	0	0	0	0
Diamantina Fracture Zone	0	0	0	0
Albany Canyons group and adjacent shelf break	0	0	0	0
Commonwealth marine environment - Recherche Archipelago	0	0	0	0
Ancient coastline at 90-120m depth	0	0	0	0
Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings	0	0	0	0
Western rock lobster	0	0	0	0
Canyons on the eastern continental slope	0	0	0	0
Shelf rocky reefs	0	0	0	0
Western demersal slope and associated fish communities	0	0	0	0
Perth Canyon, adjacent shelf break, other west coast canyons	0	0	0	0
Commonwealth marine environment - West coast inshore lagoons	0	0	0	0

Figure 54 show zones of potential dissolved hydrocarbon time averaged exposure in the surface layer (0-10 m) during summer conditions. The image was produced by overlaying the results from the 100 oil spill simulations commencing during summer conditions.

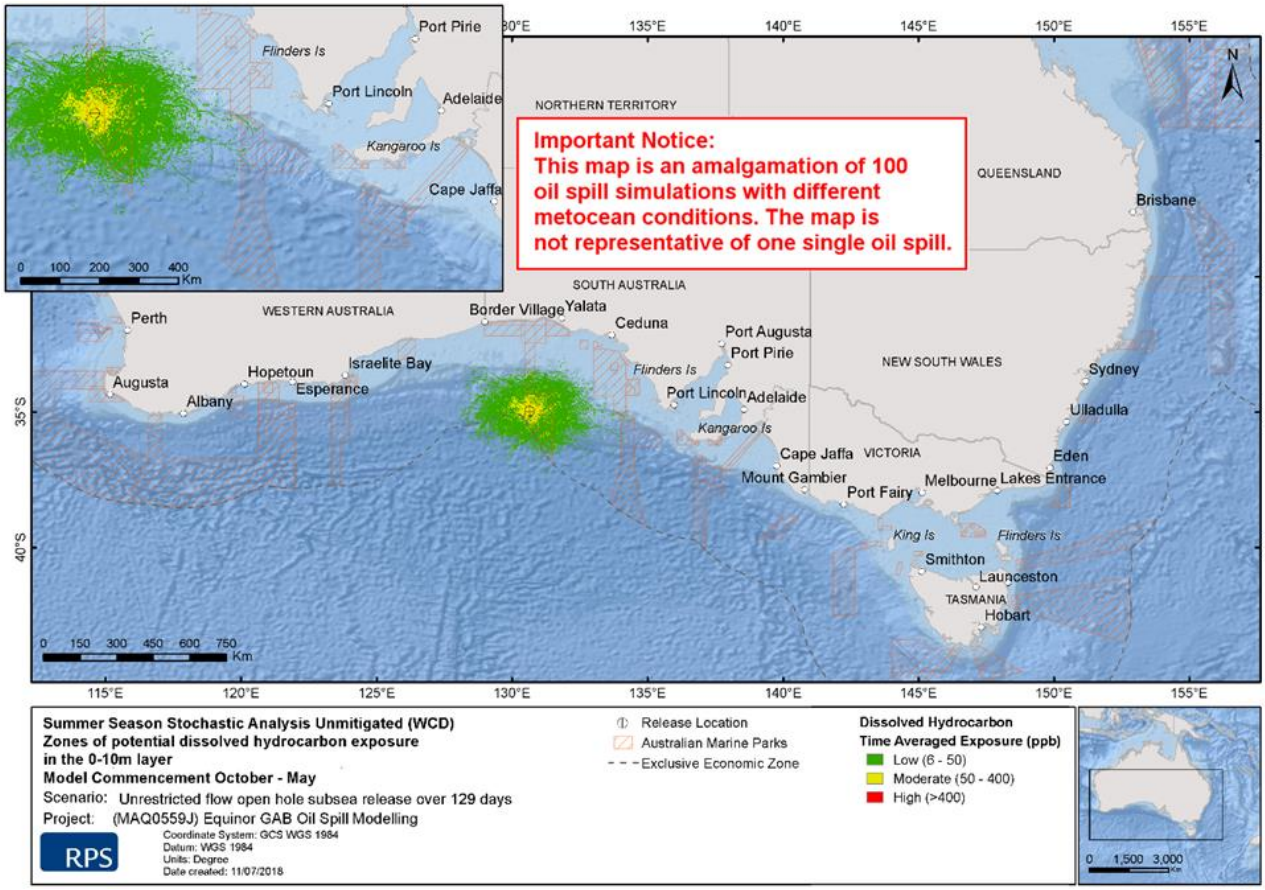


Figure 54 Zones of potential dissolved hydrocarbon time averaged exposure in the surface layer (0-10 m). Image is produced from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days

10.2 Single oil spill simulations

All 100 modelling results were reviewed, and the following oil spill simulations were identified and are presented below:

a. Fastest time before oil contact to shorelines (see Section 10.2.1)

b. Greatest volume of oil ashore (see Section 10.2.2)

10.2.1 Fastest time before oil contact to shorelines

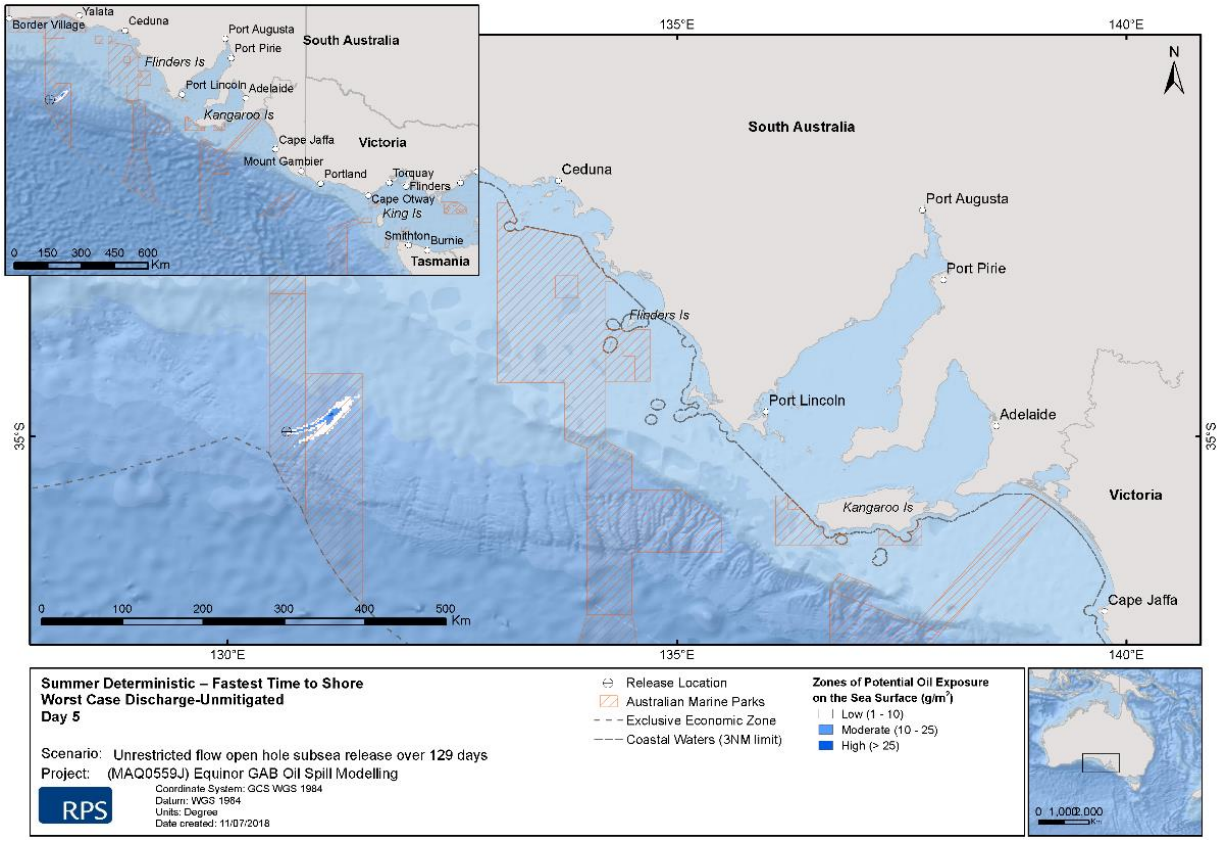
From the 100 simulations, the spill commencing 30 May 2011 at 20:00 hrs (run 81) was identified to result in the fastest (i.e. minimum) time before oil contact to shorelines at or above the low threshold (10 g/m²).

Figure 55 and Figure 56 show maps of the oil exposure on the sea surface at days 5, 10 and 20 and 40, respectively. Note that the potential sea surface exposure in these figures are reported with a 25 g/m² threshold.

Figure 57 shows the shoreline loading over the entire 189-day period based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs.

Figure 58 show maps of potential entrained hydrocarbon exposure (96-hour time averaged) and dissolved hydrocarbon oil exposure in the 0-10 m depth. Additionally, Figure 59 show maps of potential dissolved hydrocarbon exposure (96-hour time averaged) and dissolved hydrocarbon oil exposure in the 0-10 m depth.

Figure 60 shows the predicted weathering and fates graphs. By the end of the simulation (day 189), 701,565 m^3 had evaporated and 131,397 m^3 had decayed. Shoreline contact was predicted to occur 21.4 days following the initial spill event. By day 189, the volume of weathered crude oil remaining ashore was 160,892 m^3. Furthermore, 156,597 m^3 of weathered crude remained on the sea surface, while 252 m^3 was predicted to remain entrained in the water column.



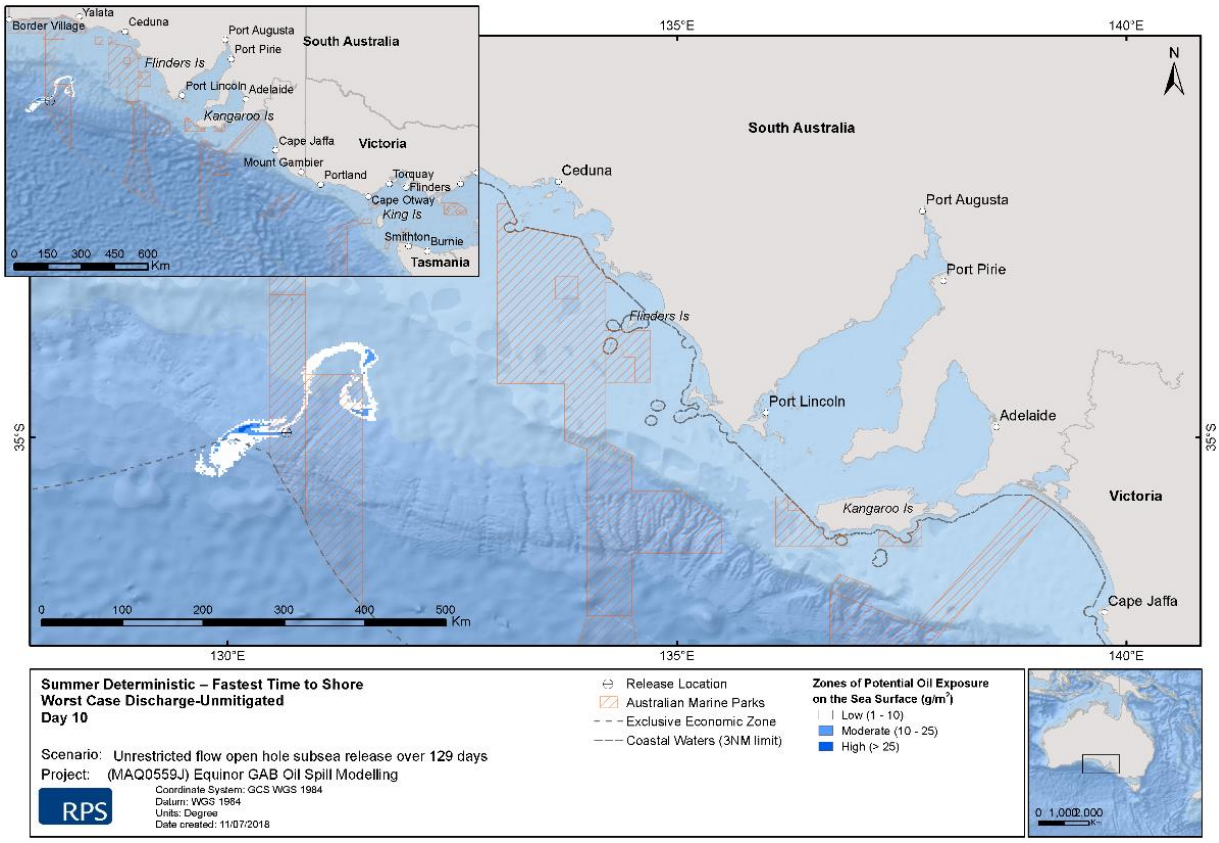


Figure 55: Oil exposure on the sea surface (swept area) at day 5 and 10 for the oil spill simulation resulting in the fastest time before oil contact to shorelines at or above low threshold. Based on an 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days. The simulation commences 30 May 2011 at 20:00 hrs

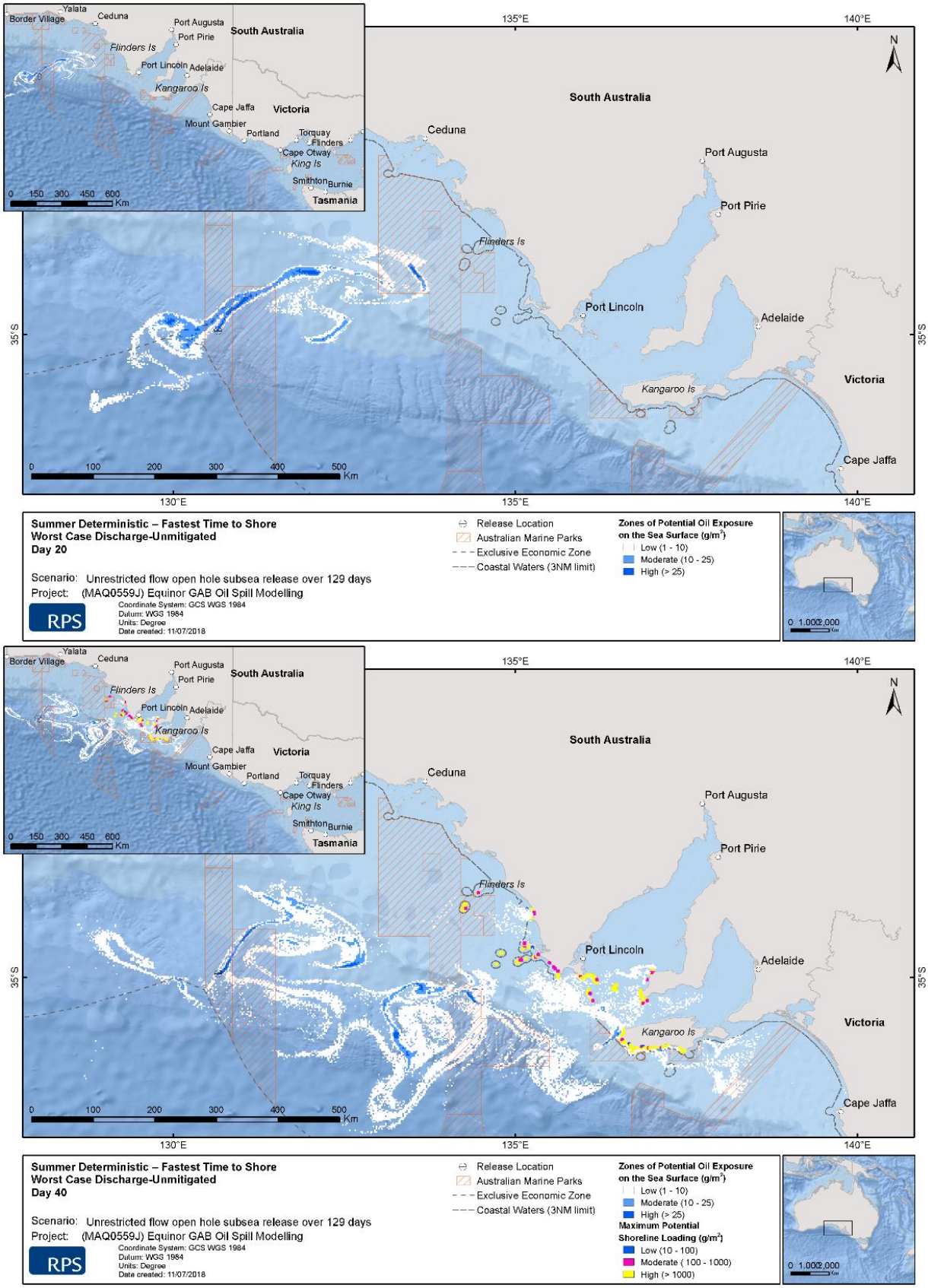


Figure 56: Oil exposure on the sea surface (swept area) at day 20 and 40 for the oil spill simulation resulting in the fastest time before oil contact to shorelines at or above low threshold. Based on an 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days. The simulation commences 30 May 2011 at 20:00 hrs

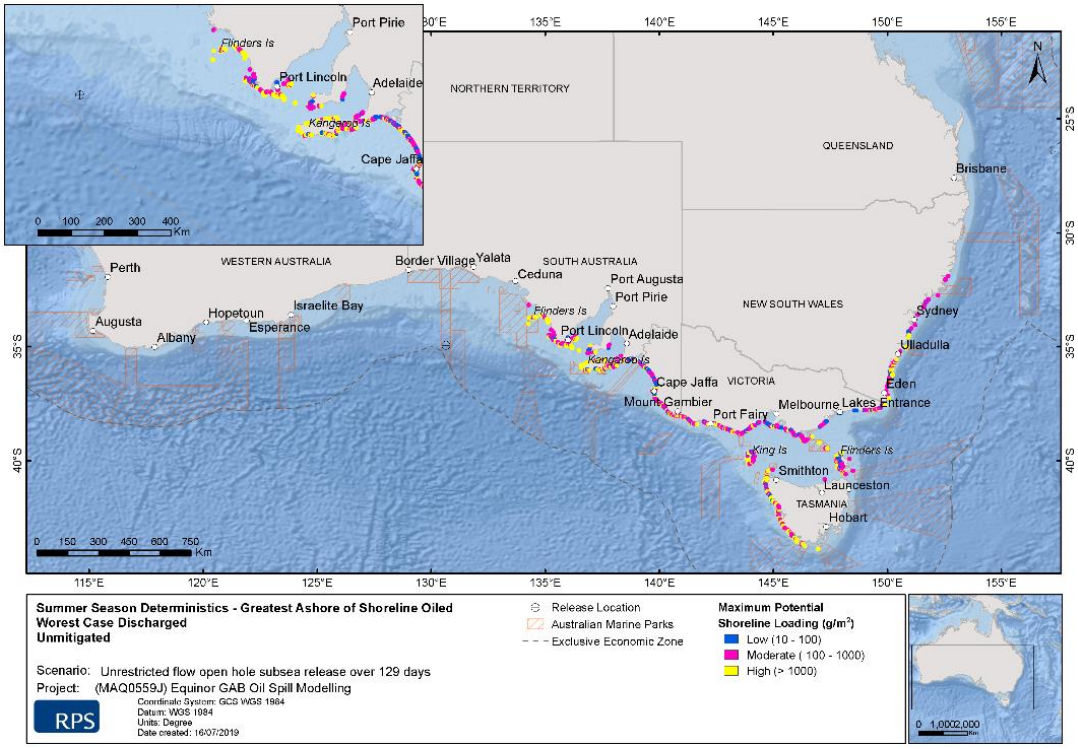


Figure 57: Shoreline loading over the entire 189 day period. Results are based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days

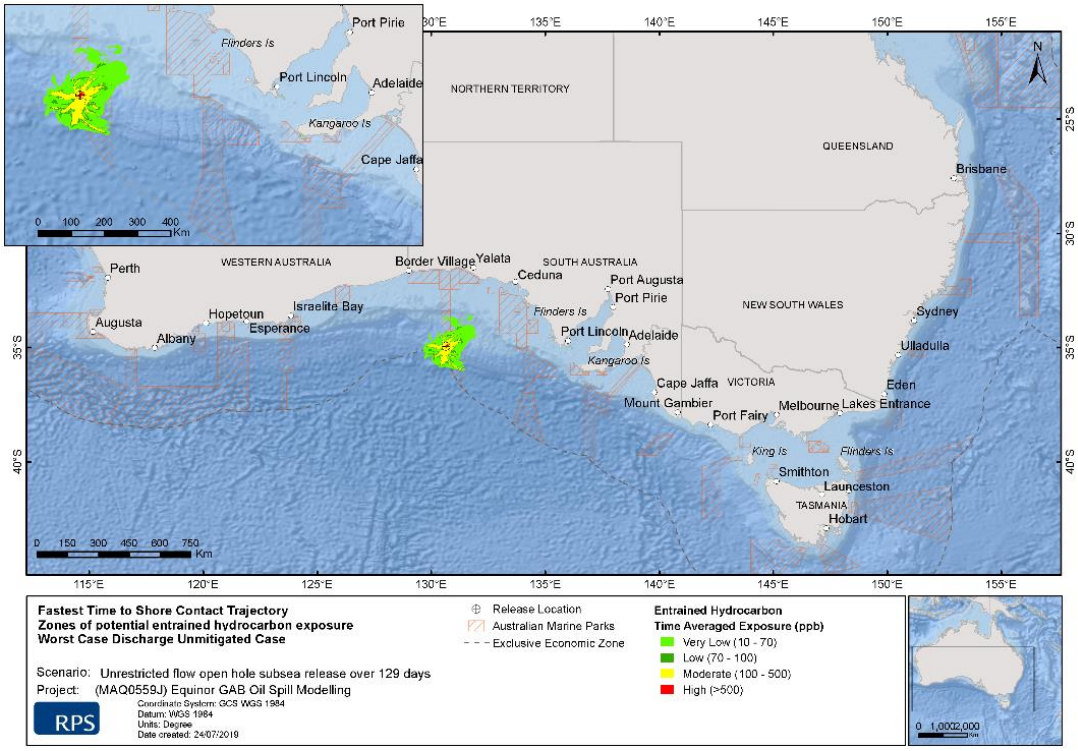


Figure 58: Potential entrained hydrocarbon exposure (96-hour time averaged) in the 0-10 m layer over the entire 189-day period. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days

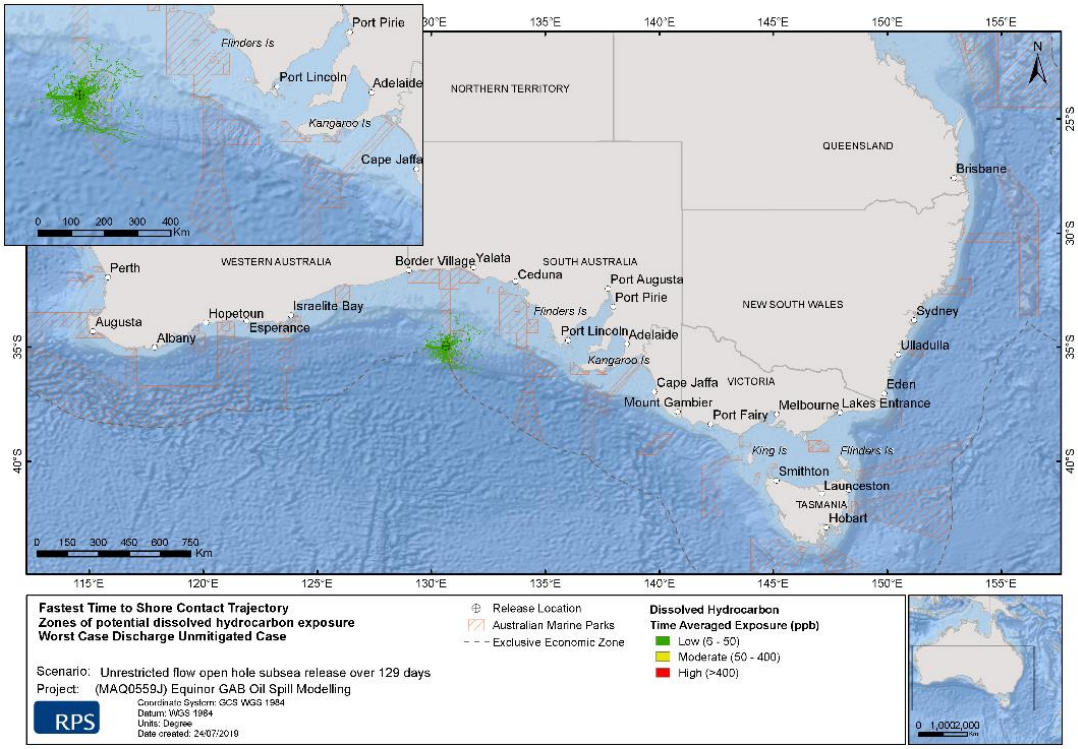


Figure 59: Potential dissolved hydrocarbon exposure (96-hour time averaged) in the 0-10 m layer over the entire 189-day period. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days

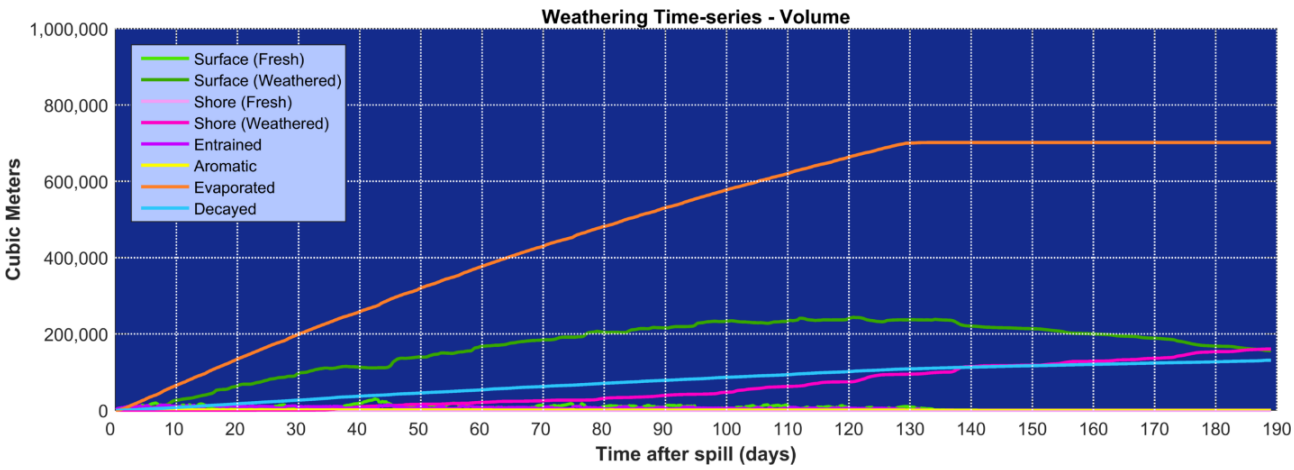


Figure 60: Predicted weathering and fates graphs over the 189-day period. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days

10.2.2 Greatest volume of oil ashore

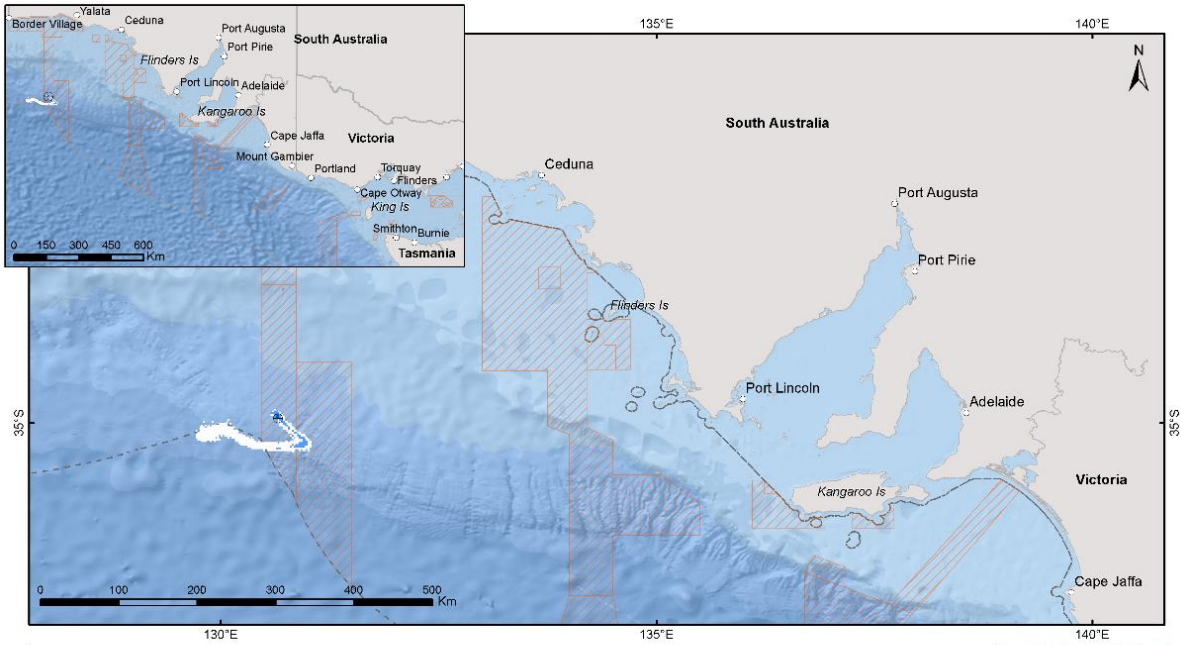
From the 100 simulations, the spill commencing 26 April 2009 at 06:00 hrs (run 60) was identified to result in the greatest volume of weathered oil ashore.

Figure 61 and Figure 62 show maps of the oil exposure on the sea surface at days 5, 10 and 20 and 40, respectively. Note that the potential sea surface exposure in these figures are reported with a 25 g/m^2 threshold.

Figure 63 shows the shoreline loading over the entire 189-day period based on the simulation resulting in the greatest volume of oil ashore commencing 30 May 2011 at 20:00 hrs.

Figure 64 show maps of potential entrained hydrocarbon exposure (96-hour time averaged) and dissolved hydrocarbon oil exposure in the 0-10 m depth. Additionally, Figure 65 show maps of potential dissolved hydrocarbon exposure (96-hour time averaged) and dissolved hydrocarbon oil exposure in the 0-10 m depth.

Figure 66 shows the predicted weathering and fates graphs. By the end of the simulation (day 189), 701,259 m^3 had evaporated and 135,763 m^3 had decayed. The maximum volume of weathered crude oil ashore was 244,466 m^3. Furthermore, 44,844 m^3 of weathered crude remained on the sea surface, while 237 m^3 was predicted to remain entrained in the water column.



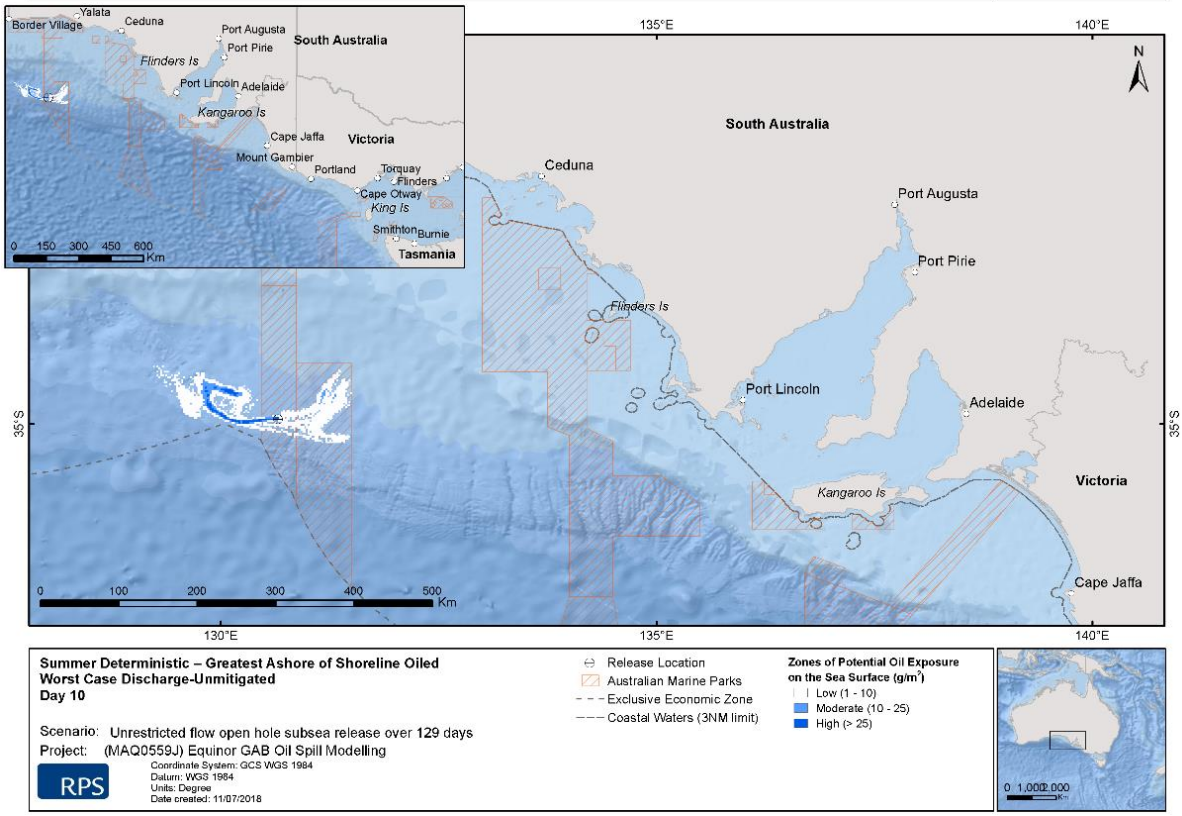
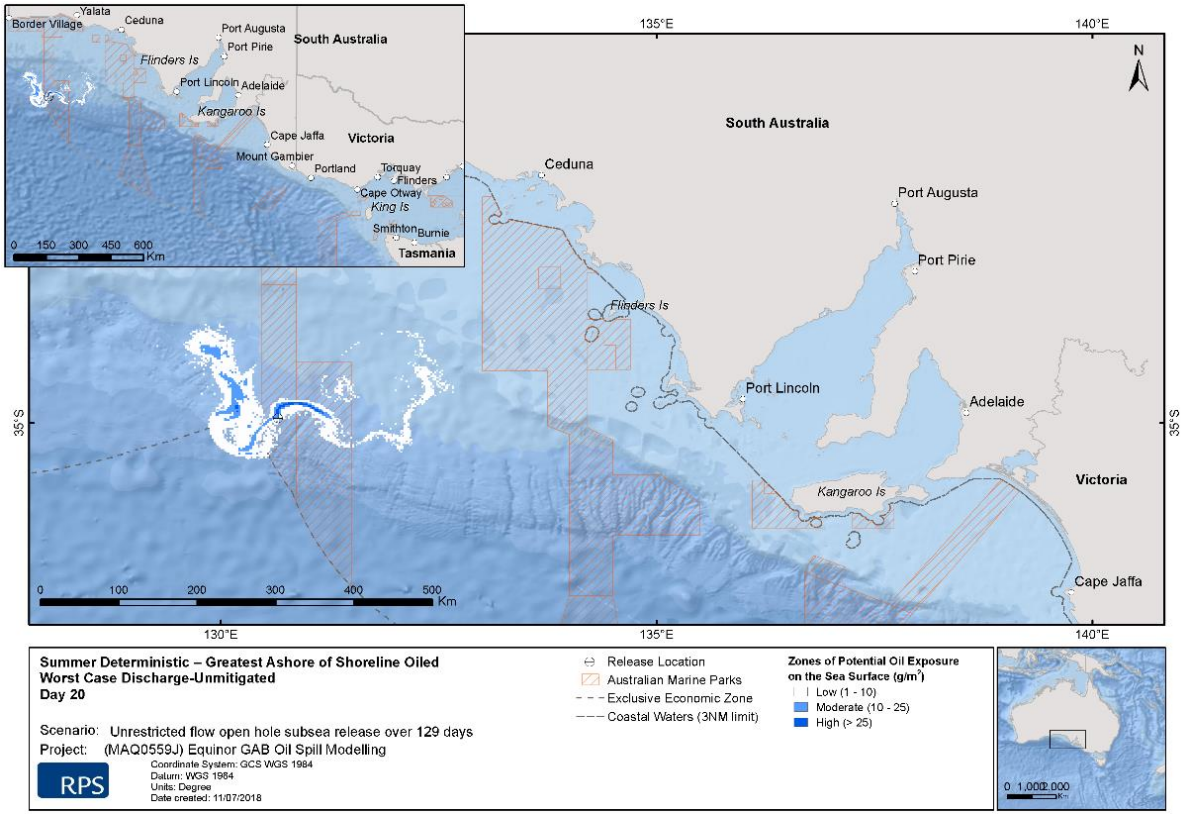


Figure 61: Oil exposure on the sea surface (swept area) at day 5 and 10 for the oil spill simulation resulting in the greatest volume of oil ashore at or above low threshold. Based on an 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days. The simulation commences 30 May 2011 at 20:00 hrs



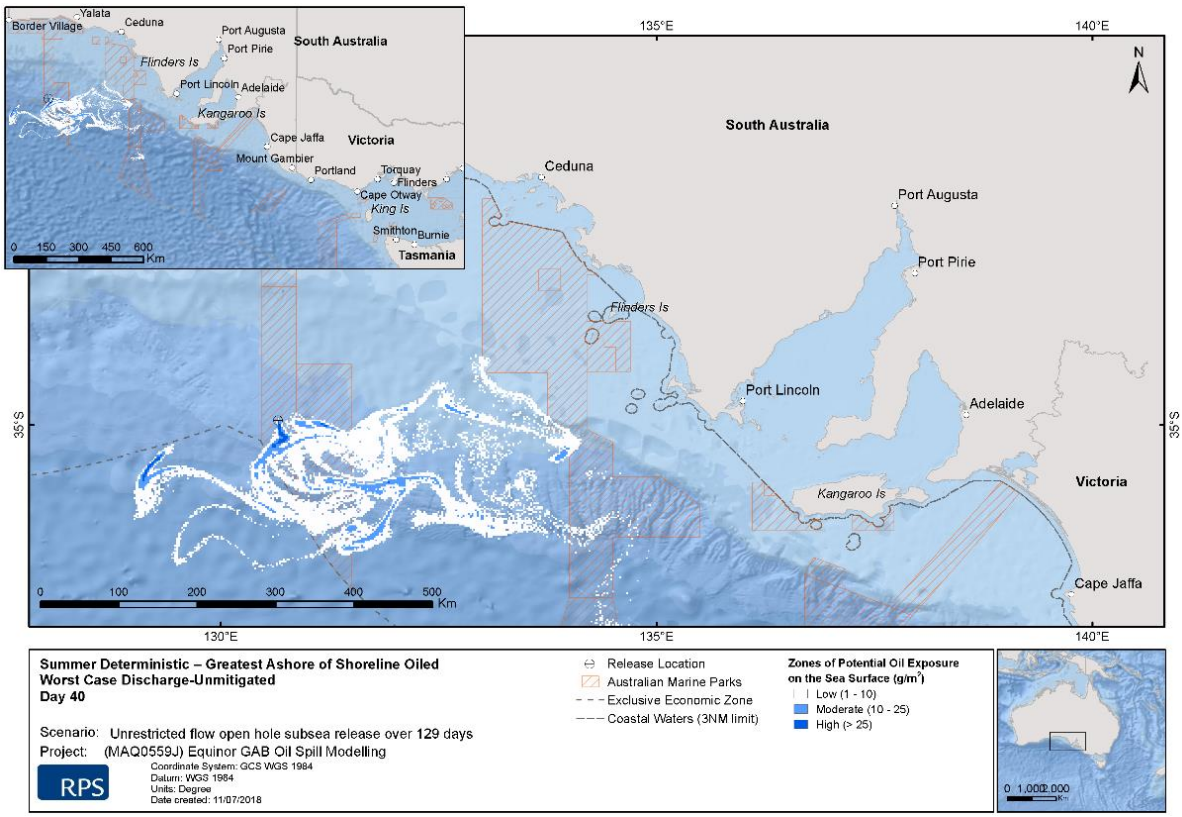


Figure 62: Oil exposure on the sea surface (swept area) at day 10 and 20 for the oil spill simulation resulting in the greatest volume of oil ashore at or above low threshold. Based on an 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days. The simulation commences 26 April 2009 at 06:00 hrs

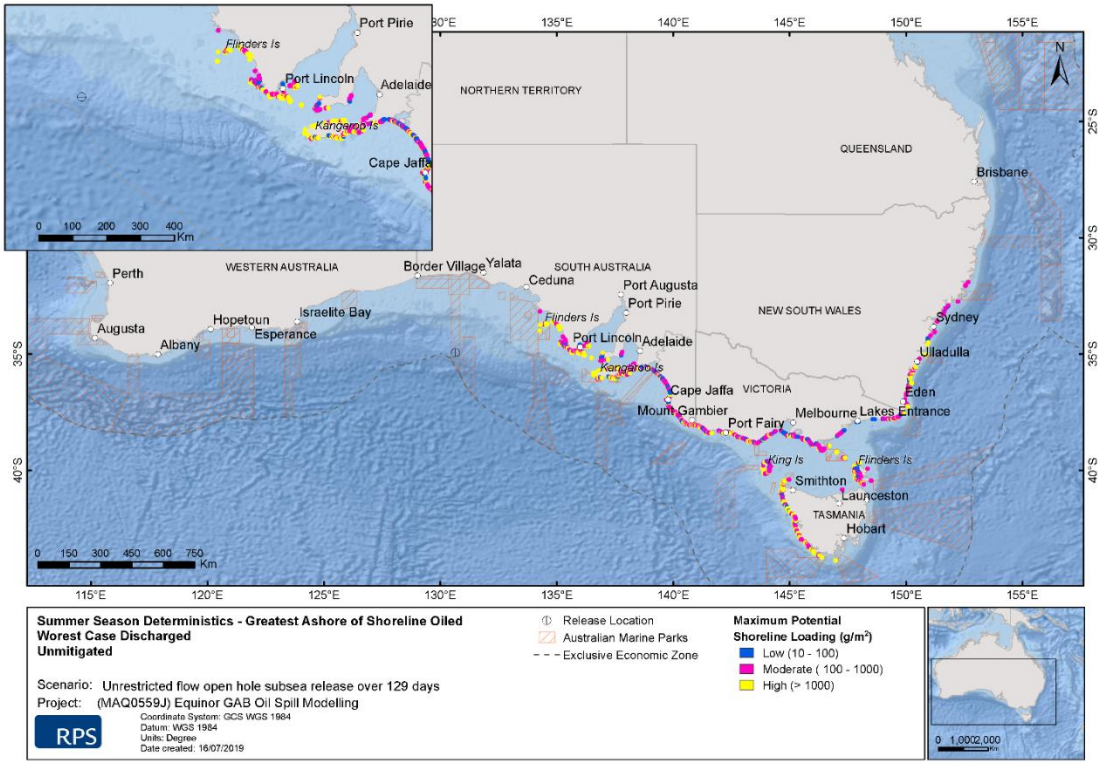


Figure 63: Shoreline loading over the entire 189 day period. Results are based on the simulation resulting in the greatest volume of oil ashore commencing 26 April 2009 at 06:00 hrs. Modelling examined an average 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days

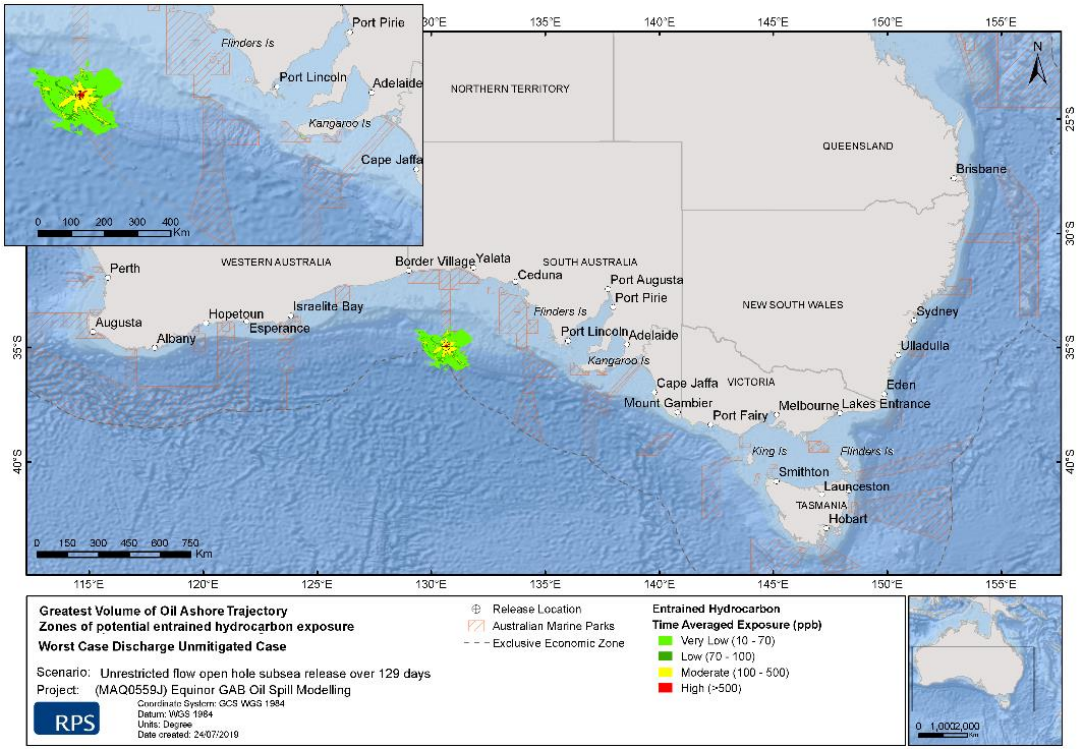


Figure 64: Potential entrained hydrocarbon exposure (96-hour time averaged) in the 0-10 m layer over the entire 189-day period. Based on the simulation resulting in the greatest volume of oil ashore commencing 26 April 2009 at 06:00 hrs. Modelling examined an average 8,943 m³/day subsea release of crude oil over 129 days tracked for 189 days

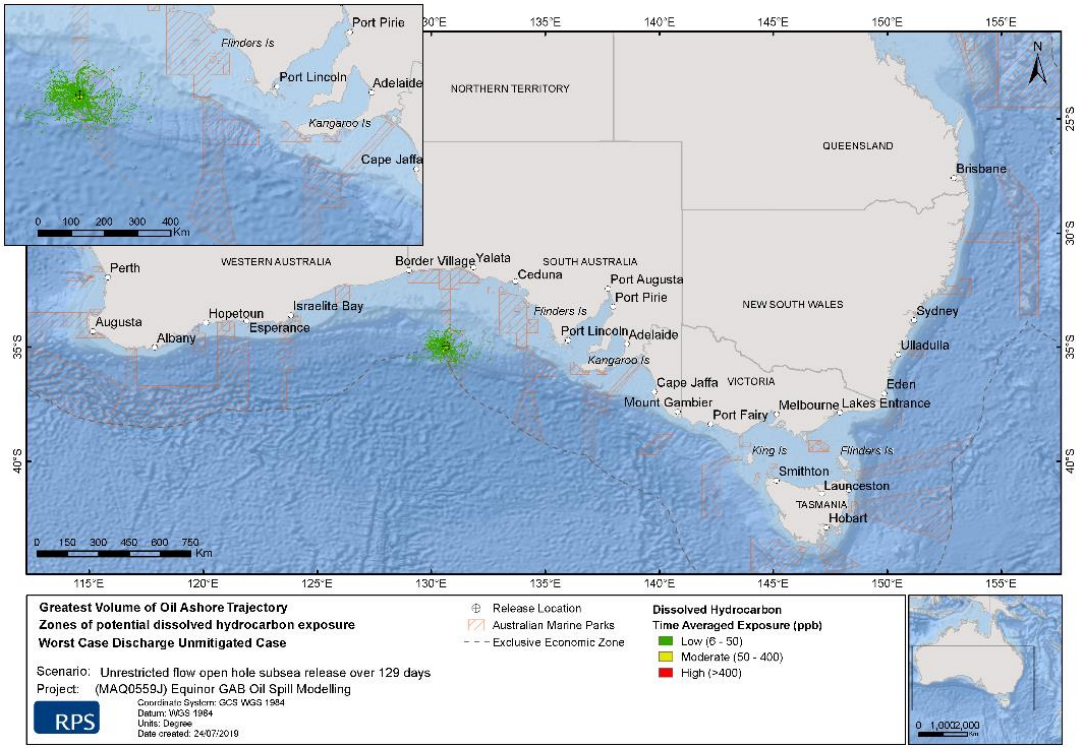


Figure 65: Potential dissolved hydrocarbon exposure (96-hour time averaged) in the 0-10 m layer over the entire 189-day period. Based on the simulation resulting in the greatest volume of oil ashore commencing 26 April 2009 at 06:00 hrs. Modelling examined an average 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days

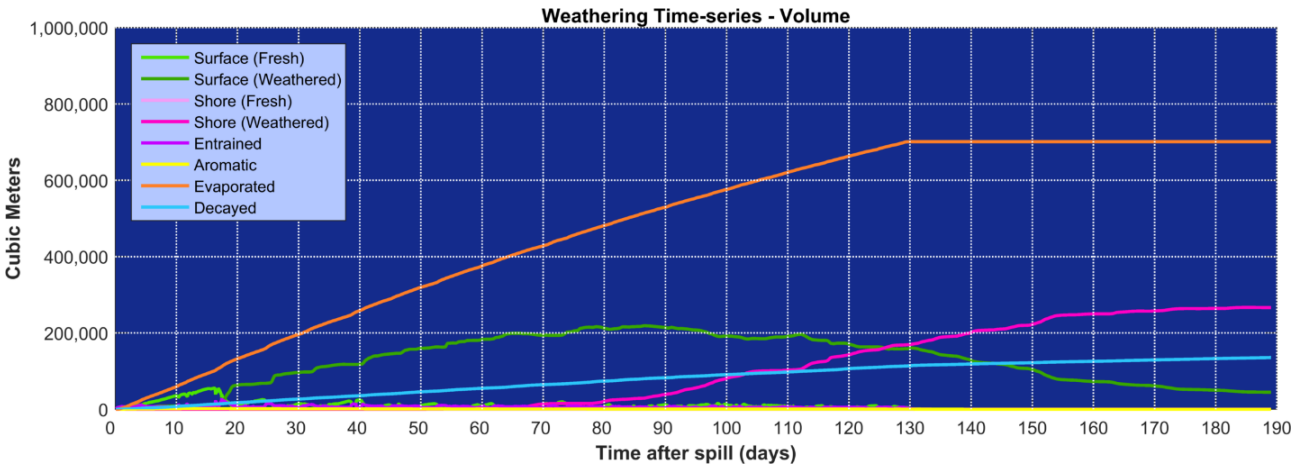


Figure 66: Predicted weathering and fates graphs over the 189-day period. Based on the simulation resulting in the greatest volume of oil ashore commencing 26 April 2009 at 06:00 hrs. Modelling examined an average 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days

11 SCENARIO 2 OUTCOMES – UNRESTRICTED ANNULUS FLOW

This scenario examined the potential exposure following an unrestricted annulus flow during the blowout over the 102 days, when the well is killed by drilling a relief well. The average subsea crude release rate was 6,720 m^3/day over the 102 days and the oil was tracked for an additional 60 days upon cessation. One hundred oil spills were simulated for both unmitigated and mitigated cases, which commenced between October and May conditions and tracked for a period of 162 days. The stochastic results are presented in Section 11.1. Results for single oil spill simulations are presented Section 11.2.

11.1 Seasonal analysis

11.1.1 Oil exposure on the sea surface

Table 36 summarises the distances travelled by spill simulations on the sea surface (as weathered oil) for each threshold, for the unmitigated and mitigated cases. Weathered oil was presented as it travelled further than the fresh oil.

The maximum distance travelled by an unmitigated spill simulation at the moderate exposure threshold (10–25 g/m^2) was 1,455 km east-southeast from Stromlo-1, compared to 1,224 km east-southeast for the mitigated case. Whilst an unmitigated simulation had travelled a maximum distance of 1,284 km east-southeast at the high exposure threshold (>25 g/m^2), compared to a 1,039 km east-southeast for the mitigated case. The 90th percentile ranked unmitigated and mitigated simulations had travelled a maximum distance of 704 km and 405 km, respectively, when tracked to the moderate threshold.

Table 36: Summary of the distances travelled by spill simulations on the sea surface (as weathered oil) for each threshold, for the unmitigated and mitigated cases. Each simulation represents an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Statistics	Unmitigated			Mitigated		
	Low	Moderate	High	Low	Moderate	High
Greatest distance travelled (km) and direction by a spill simulation	2,645 east	1,455 east-south-east	1,284 east-south-east	2,513 east	1,224 east-south-east	1,039 east-south-east
East-Southeast	2,242	1,182	556	1,857	728	468
East-Southeast	1,966	857	439	1,471	491	317
East	1,790	704	369	1,251	405	286

Table 37 to Table 40 presents the probability and minimum time before oil exposure on the sea surface within state waters, AMPs, KEFs and IMCRAs, respectively, for unmitigated and mitigated cases. The results were derived from 100 oil spill simulations (per case) with varied start dates and times between October and May conditions.

Tasmanian (18%), South Australian (89%) and Victorian (54%) coastal waters were all predicted to experience sea surface oil exposure at the moderate threshold for the unmitigated case. South Australian coastal waters were predicted to record the minimum time before oil exposure at 21.3 days. For the mitigated case, only South Australia (47%) and Victoria (8%) had recorded weathered oil exposure at the moderate threshold. For South Australian coastal waters, the minimum time before exposure was very similar to the unmitigated case, however, for Victorian coastal waters, there was a delay from 52.2 days to 81.3 days.

Murray, Murat, Western Eyre and Southern Kangaroo Island were the only AMPs predicted to experience sea surface oil exposure at the moderate threshold for both unmitigated and mitigated cases (Table 38). The probability was greatest for Western Eyre AMP (100% unmitigated and 80% mitigated). The minimum time before oil exposure was the same for the unmitigated and mitigated cases for Murray, Western Eyre and Murat, though increased for Southern Kangaroo Island from 33.7 days to 60.7 days, respectively.

The Bonney Coast Upwelling recorded the greatest probability of oil exposure at the moderate threshold of all KEFs for unmitigated (72%) and mitigated (35%) cases. West Tasmania Canyons was the only other KEF predicted to be exposed at the moderate threshold and only for the unmitigated case. Minimum times before exposure above Bonney Coast Upwelling for the unmitigated and mitigated cases was 35.3 days and 44.5 days, respectively.

For the unmitigated case, the IMCRA meso-scale bioregions of Eyre (100%), Murat (96%) and Coorong (80%) recorded the greatest probability of sea surface exposure at the moderate threshold. Following the implementation of mitigation, the probabilities for Eyre, Murat and Coorong reduced to 86%, 69% and 4%, respectively. The minimum time before moderate oil exposure within Eyre, Murat and Coorong remained the same for unmitigated and mitigated cases (14 days, 12 days and 33 days, respectively).

Table 37: Probability and minimum time before weathered oil exposure on the sea surface for each threshold within state waters, for the unmitigated and mitigated cases. Results were derived from 100 oil spill simulations per case commencing during October to May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Coastal waters	Unmitigated						Mitigated					
	Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)			Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Tasmania	67	18	2	54.5	64.6	132.2	27	0	0	67.0	-	-
South Australia	100	89	72	21.3	22.9	41.0	100	47	1	21.4	23.0	49.2
Western Australia	20	0	0	58.9	-	-	50	0	0	54.5	-	-
Victoria	82	54	15	43.5	52.2	81.4	75	8	0	43.7	81.3	-
New South Wales	51	0	0	67.0	-	-	12	0	0	66.7	-	-

Table 38: Probability and minimum time before weathered oil exposure on the sea surface for each threshold within Australian Marine Parks (AMPs), for the unmitigated and mitigated cases. Results were derived from 100 oil spill simulations per case commencing during October to May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Australian Marine Park Network	Australian Marine Parks (AMPs)	Unmitigated						Mitigated					
		Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)			Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
		Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
South-east	Apollo	74	20	0	60.3	60.3	-	57	0	0	60.0	-	-
	Beagle	57	0	0	66.9	-	-	28	0	0	67.3	-	-
	Boags	34	0	0	69.1	-	-	18	0	0	61.2	-	-
	East Gippsland	17	0	0	91.6	-	-	13	0	0	91.8	-	-
	Flinders	15	0	0	82.3	-	-	14	0	0	83.3	-	-
	Franklin	48	0	0	58.0	-	-	22	0	0	57.3	-	-
	Freycinet	18	0	0	91.0	-	-	13	0	0	90.3	-	-
	Huon	15	0	0	98.2	-	-	8	0	0	101.5	-	-

Australian Marine Park Network	Australian Marine Parks (AMPs)	Unmitigated						Mitigated					
		Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)			Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
		Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
	Murray	93	78	2	32.4	32.7	111.5	92	10	1	32.5	32.8	92.2
	Nelson	83	3	0	44.3	96.8	0.0	77	0	0	44.3	-	-
	South Tasman Rise	0	0	0	-	-	-	-	0	0	-	-	-
	Tasman Fracture	16	0	0	95.0	-	-	12	0	0	92.4	-	-
	Zeehan	79	15	0	51.0	99.5		53	0	0	51.0	-	-
South-west	Abrolhos	0	0	0	-	-	-	-	0	0	-	-	-
	Bremer	12	0	0	85.4	-	-	8	0	0	92.1	-	-
	Eastern Recherche	39	16	1	47.0	77.9	112.8	37	0	0	46.5	-	-
	Geographe	0	0	0	-	-	-	0	0	0	-	-	-
	Jurien	0	0	0	-	-	-	0	0	0	-	-	-
	Murat	23	2	0	34.5	39.8	-	10	1	0	34.5	39.8	-
	Perth Canyon	0	0	0	-	-	-	0	0	0	-	-	-
	South-west Corner	24	1	0	56.8	128.3	0.0	14	0	0	70.5	-	-
	Southern Kangaroo Island	91	58	2	33.7	38.7	150.1	88	3	0	33.7	60.7	-
	Twilight	30	4	0	51.5	90.8	0.0	19	0	0	53.9	-	-
	Two Rocks	0	0	0	-	-	-	0	0	0	-	-	-
	Western Eyre	100	100	90	14.3	14.4	14.5	100	80	22	14.3	14.5	14.5
	Western Kangaroo Island	96	85	15	30.4	31.6	60.3	92	9	0	24.0	31.9	-
Temperate East	Central Eastern	0	0	0	0.0	-	-	0	0	0	-	-	-
	Cods Grounds	0	0	0	0.0	-	-	0	0	0	-	-	-
	Gifford	0	0	0	0.0	-	-	0	0	0	-	-	-
	Hunter	0	0	0	0.0	-	-	0	0	0	-	-	-
	Jervis	8	0	0	140.5	-	-	0	0	0	-	-	-
	Lord Howe	3	0	0	139.7	-	-	0	0	0	-	-	-
	Solitary Islands	0	0	0	-	-	-	0	0	0	-	-	-

Table 39: Probability and minimum time before weathered oil exposure on the sea surface above key ecological features, for the unmitigated and mitigated cases. Results were derived from 100 oil spill simulations per case commencing during October to May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Key Ecological Features (KEFs)	Unmitigated						Mitigated					
	Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)			Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Seamounts South and east of Tasmania	17	0	0	100.3	-	-	9	0	0	92.88	-	-
West Tasmania Canyons	83	17	0	49.1	70.5	-	67	0	0	48.92	-	-
Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings	100	94	82	14.8	22.4	24.1	100	79	13	14.8	20.6	24.1
Bonney Coast Upwelling	87	72	51	35.0	35.3	46.2	84	35	0	35.04	44.5	-
Upwelling East of Eden	46	0	0	82.1	-	-	29	0	0	82.54	-	-
Commonwealth marine environment - Recherche Archipelago	21	0	0	57.8	-	-	19	0	0	58.38	-	-

Table 40: Probability and minimum time before weathered oil exposure on the sea surface within Integrated Marine and Coastal Regionalisation of Australia (IMCRA) meso-scale bioregions, for unmitigated and mitigated cases. Results were derived from 100 oil spill simulations per case commencing during October to May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Integrated Marine and Coastal Regionalisation of Australia (IMCRA)	Unmitigated						Mitigated					
	Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)			Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Central West Coast	0	0	0	0	0	0	0	0	0	0	0	0
Abrolhos Islands	0	0	0	0	0	0	0	0	0	0	0	0
Eucla	84	42	22	12	13	23	87	22	3	12	13	23
Murat	100	96	73	11	12	13	100	69	21	11	12	13
Leeuwin-Naturaliste	0	0	0	0	0	0	0	0	0	0	0	0

Integrated Marine and Coastal Regionalisation of Australia (IMCRA)	Unmitigated						Mitigated					
	Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)			Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Eyre	100	100	93	13	14	14	100	86	23	13	14	14
North Spencer Gulf	0	0	0	0	0	0	0	0	0	0	0	0
Hawkesbury Shelf	1	0	0	149	0	0	0	0	0	0	0	0
WA South Coast	25	0	0	58	0	0	23	0	0	61	0	0
Spencer Gulf	57	4	0	38	137	0	45	0	0	38	0	0
St Vincent Gulf	89	27	1	33	68	115	89	2	0	33	86	0
Batemans Shelf	16	0	0	129	0	0	5	0	0	129	0	0
Coorong	92	80	10	32	33	86	91	4	0	32	33	0
Twofold Shelf	54	0	0	70	0	0	33	0	0	70	0	0
Otway	88	72	51	41	44	46	89	35	0	41	45	0
Central Victoria	72	22	0	61	90	0	55	0	0	61	0	0
Central Bass Strait	75	23	0	55	61	0	62	0	0	59	0	0
Flinders	61	4	0	67	102	0	46	0	0	67	0	0
Boags	38	0	0	61	0	0	17	0	0	60	0	0
Freycinet	12	0	0	90	0	0	9	0	0	92	0	0
Franklin	59	0	0	60	0	0	31	0	0	63	0	0
Bruny	11	0	0	104	0	0	4	0	0	105	0	0
Davey	26	0	0	87	0	0	8	0	0	95	0	0

Figure 67 is a map illustrating the oil exposure on the sea surface (inclusive of fresh and weathered oil) for the unmitigated and mitigated cases, produced by overlaying the results from 100 oil spill simulations.

The results for the unmitigated case revealed that fresh oil exposure on the sea surface above the low threshold (>1 g/m^2; prior to emulsification or evaporation of all volatile components) remained offshore and was more than 155 km from the nearest shorelines for all 100 simulations. Beyond this zone, would be a large area potentially affected by weathered oil, increasingly degraded with increasing distance from the well. The drift of the slick generally extends to the east of the well, indicating potentially high concentrations (>25 g/m^2) of surface oil near Ceduna, Port Lincoln, Kangaroo Island and Mount Gambier in SA and southeast of Port Fairy in Victoria. The zone of potential moderate oil concentrations on the sea surface (10 - 25 g/m^2) occurred closest to shore near Ceduna and Port Adelaide and extends partway into Spencer Gulf. It also extended close to the coast from Kangaroo Island to Mount Gambier, and then from Mount Gambier to Wilsons Promontory in Victoria. Potential low concentrations (1 - 10 g/m^2) of weathered surface oil generally extended along the coastline from west of Hopetoun in WA to north of Eden in NSW and includes Tasmania.

As part of the mitigated case, aerial and subsea dispersant was included in all 100 simulations. The subsea dispersant reduced the oil droplet sizes, causing a greater volume of oil to remain entrained in the water-column and biodegrade faster than surface oil. This significantly reduced area affected by weathered oil at moderate concentrations to low. Except for areas along the shorelines from Port Fairy to Ceduna. Regions of high concentrations were also smaller and the closest areas to shore with oil concentrations above 25 g/m^2 were offshore of Ceduna.

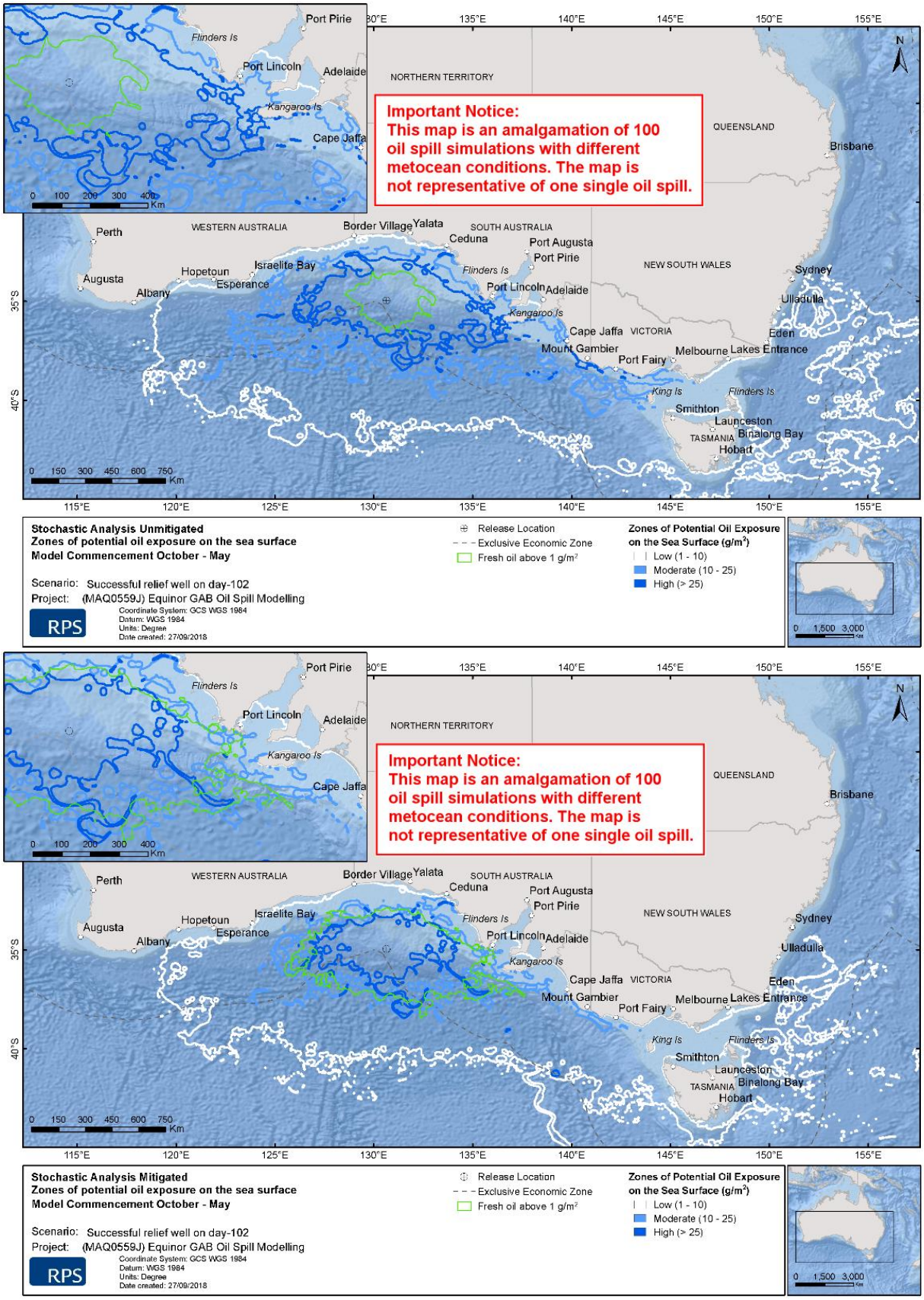


Figure 67: Zones of potential oil exposure on the sea surface, for the unmitigated (upper image) and mitigated (lower image) cases. Results were produced from 100 oil spill simulations per case commencing during October to May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

11.1.2 Oil contact to shorelines

Figure 68 is a bar plot of the minimum times before weathered oil contact to shorelines at or above the low threshold (>10 g/m^2) for each unmitigated and mitigated simulation. The results have been sorted and are presented from minimum to maximum values to highlight the range or differences in results, which is due to the prevailing current and wind conditions for each simulation. Overall, the minimum time before exposure only marginally decreased for the mitigated simulations. The minimum time or fastest time to shore was 21.4 days. Fifty percent of the unmitigated simulations took at least 52 days to reach a shoreline. While the longest time for an unmitigated simulation to reach a shoreline was 96 days.

Figure 69 is a bar plot (sorted) of the maximum volume of weathered oil ashore for the unmitigated and mitigated simulations. By applying aerial and subsea dispersant, all mitigated simulations showed a reduction in volume of oil ashore. The greatest volume ashore for an unmitigated simulation was 147,338 m^3 compared to 48,256 m^3 for a mitigated simulation. While the lowest volume ashore from an unmitigated and mitigated simulation was 473 m^3 and 61 m^3, respectively. The maximum volume ashore for 50 out of 100 unmitigated and mitigated simulations was below 82,405 m^3 and 25,863 m^3, respectively.

Figure 70 presents the sorted bar plot of the maximum length of shoreline oiled at or above the low threshold for each unmitigated and mitigated simulation. Similarly, the length of shoreline oiled reduced for each of the mitigated simulations. The shortest length of shoreline oiled by an unmitigated and mitigated simulation 135 km and 40 km, respectively. Half of the unmitigated and mitigated simulations had contacted shorelines lengths below 1,863 km and 1,378 km, respectively.

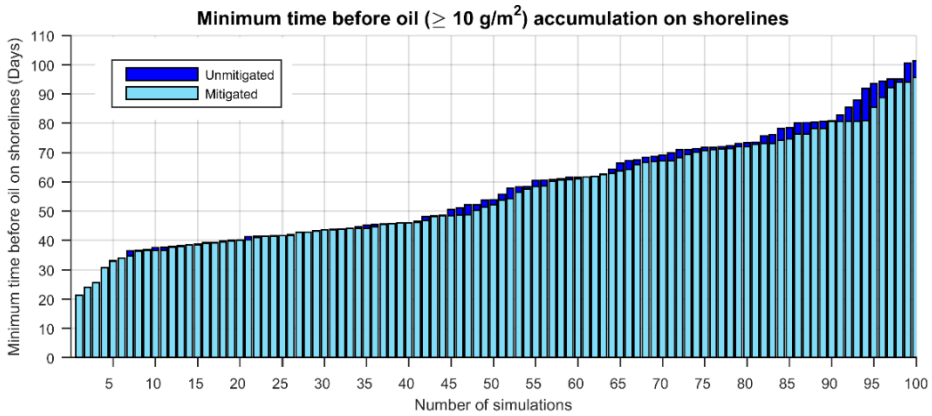


Figure 68: Sorted bar plots of the minimum time before weathered oil contact to shorelines at or above the low threshold, for each unmitigated and mitigated simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

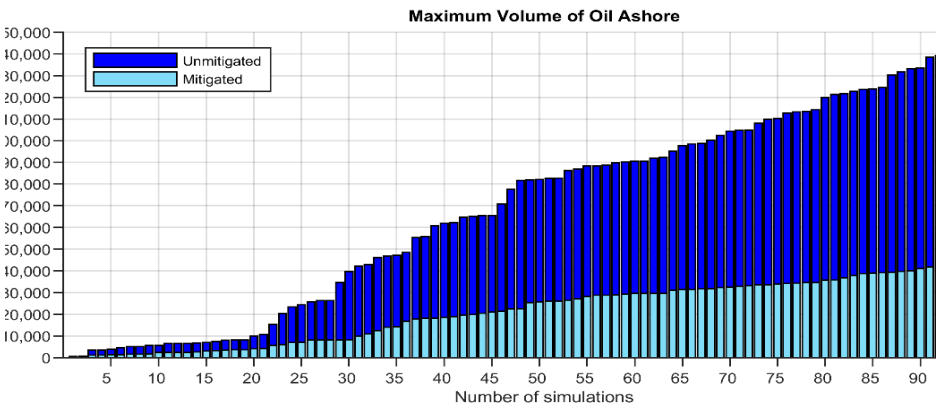


Figure 69: Sorted bar plots of the maximum volume of weathered oil ashore unmitigated and mitigated simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

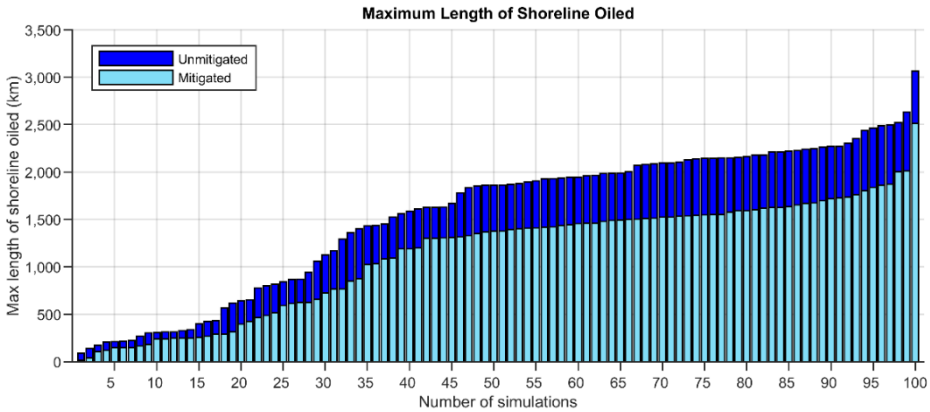


Figure 70: Sorted bar plots of the maximum length of shoreline contacted by weathered oil at or above the low threshold for unmitigated and mitigated simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Table 41 provides a summary of fresh and weathered oil contact to any shoreline for the unmitigated and mitigated cases. The results were derived from 100 oil spill simulations commencing between October and May conditions. There were no shorelines contacted by fresh oil for the unmitigated case, though 27 mitigated simulations out of 100 did. For both cases, all 100 simulations recorded weathered oil contact at the moderate threshold. It took a minimum of 58.6 days and 21 days for fresh and weathered oil, respectively to reach the shorelines. The maximum fresh oil volume ashore for a single mitigated simulation was 41 m^3, which was significantly lower than the volume of weathered oil (48,256 m^3). The maximum length of shoreline contact by weathered oil above the moderate threshold for an unmitigated and mitigated simulation was 2,838 km and 2,148 km, respectively.

Table 42 provides a summary of probability, minimum time and loading of weathered oil contact to shorelines for each state, at varying thresholds, for the unmitigated and mitigated cases. While Table 43 presents the predicted volume of weathered oil and lengths of shorelines contacted for each state, at varying thresholds, for the unmitigated and mitigated cases. The probability of oil contact along the South Australian shoreline at the moderate threshold was 100% for the unmitigated and mitigated cases. The most significant reduction in probability between the unmitigated and mitigated results was recorded for the New South Wales shoreline (30% and 11%, respectively). The South Australian shoreline recorded the quickest oil contact at 21 days, while it took around 110 days to reach New South Wales. South Australia recorded a peak volume ashore for an unmitigated and mitigated simulation of 124,815 m^3 and 38,021 m^3, respectively. The maximum length of Victorian shorelines contacted by oil (above the moderate threshold) for an unmitigated and mitigated simulation was 739 km and 583 km, respectively.

Table 44 and Table 45 provide a summary of the weathered oil contact to shorelines for each of the IBRA subregions, at varying thresholds, for the unmitigated and mitigated cases.

Table 46 and Table 47 provide a summary of the weathered oil contact to shorelines for the LGAs, at varying thresholds, for the unmitigated and mitigated cases.

Table 41: Summary of fresh and weathered oil contact to any shorelines, for the unmitigated and mitigated cases. Results were derived from 100 oil spill simulations per case commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Statistics	Unmitigated		Mitigated	
	Fresh oil	Weathered oil	Fresh oil	Weathered oil
Probability of oil contact to any shoreline at or above the moderate threshold (%)	0	100	27	100
Minimum time before oil accumulation on shorelines at or above the moderate threshold (days)	-	21.4	58.6	21.0
Maximum volume of oil ashore (m^3)	0	147,338	41	48,256
Average volume of oil ashore (m^3) across all simulations	0	72,376	2	22,535
Maximum length of shoreline contacted by oil at or above the low threshold (km) for a single simulation	0	3,062	64	2,511
Average length of shoreline contacted by oil at or above the low threshold (km)	0	1,778	14	1,303
Maximum length of shoreline contacted by oil at or above the moderate threshold (km)	0	2,828	50	2,148
Average length of shoreline contacted by oil at or above the moderate threshold (km)	0	1,624	14	1,124
Maximum length of shoreline contacted by oil at or above the high threshold	0	1,896	0	1,318
Average shoreline length contacted by oil at or above the high threshold (km)	0	1,080	0	708

Table 42: Probability, minimum time and loading of weathered oil contact to shorelines for each state, at varying thresholds, for the unmitigated and mitigated cases. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

States	Unmitigated							Mitigated						
	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)			Load on shoreline (g/m²)	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)			Load on shoreline (g/m²)
	Low	Mod.	High	Low	Mod.	High	Mean	Low	Mod.	High	Low	Mod.	High	Mean
Tasmania	72	72	68	54.7	54.7	54.9	5,558	66	66	62	54.6	54.6	55	2,793
South Australia	100	100	100	21.4	21.4	21.5	16,400	100	100	100	21	21	21.5	7,131
Western Australia	24	24	24	55.8	55.8	61.4	4,776	22	22	21	56.1	57.9	58.5	2,610
Victoria	84	84	82	43.7	43.7	43.8	8,610	81	80	80	43.7	43.7	43.8	3,291
New South Wales	31	30	22	110.1	110.1	129.2	1,200	12	11	6	109.1	109.1	110.1	922

Mod. represents Moderate

Table 43: Predicted volume of weathered oil and lengths of shorelines contacted for each state, at varying thresholds, for the unmitigated and mitigated cases. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

States	Unmitigated								Mitigated							
	Volume on shoreline (m³)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)			Volume on shoreline (m³)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Mean	Peak	Low	Mod.	High	Low	Mod.	High	Mean	Peak	Low	Mod.	High	Low	Mod.	High
Tasmania	7,916	38,480	357	329	217	887	832	617	2,154	9,575	190	173	114	687	628	451
South Australia	54,856	124,815	1097	1015	706	1812	1683	1163	17,748	38,021	878	766	505	1,610	1,395	898
Western Australia	1,370	7,054	74	70	50	240	220	150	340	1,458	37	35	28	118	113	91
Victoria	13,612	34,690	448	388	233	830	739	517	4,052	10,627	336	271	138	733	583	331
New South Wales	19	87	12	11	4	75	68	11	8	31	5	4	3	18	11	5

Mod. represents Moderate

Table 44: Probability, minimum time and loading of weathered oil contact to shorelines for each Interim Biogeographic Regionalisation for Australia (IBRA) subregion, for the unmitigated and mitigated cases. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Interim Biogeographic Regionalisation for Australia (IBRA) subregion	Unmitigated							Mitigated						
	Probability of shoreline contact (%)		Minimum time before shoreline contact (days)			Load on shoreline (g/m^2)		Probability of shoreline contact (%)		Minimum time before shoreline contact (days)			Load on shoreline (g/m^2)	
	Low	Mod.	High	Low	Mod.	High	Mean	Low	Mod.	High	Low	Mod.	High	Mean
West	61	61	59	63	63	68	2,072	46	45	33	63	63	68	1,103
Southern Jarrah Forest	1	1	0	149	149	-	302	0	0	0	-	-	-	0
King	72	72	68	55	55	55	9,221	65	65	61	55	55	55	3,817
Flinders	61	61	60	67	67	67	7,146	47	47	43	67	67	67	4,197
Kangaroo Island	94	94	94	31	31	32	19,320	93	93	92	31	32	32	7,084
Hunter	0	0	0	-	-	-	0	0	0	0	-	-	-	0
Fitzgerald	0	0	0	-	-	-	0	0	0	0	-	-	-	0
Recherche	24	24	24	56	56	61	5,224	21	21	20	58	58	59	2,758
Eastern Mallee	2	2	0	124	124	-	325	0	0	0	-	-	-	0
Warren	1	1	0	147	147	-	574	0	0	0	-	-	-	0
Hampton	4	4	3	112	112	117	774	4	4	4	56	59	62	4,941
Nullarbor Plain	4	4	2	112	112	120	610	4	4	2	61	62	66	1,792
Eyre Mallee	45	45	37	38	38	38	2,624	29	29	16	38	38	38	1,539
Talia	100	100	100	21	21	22	26,611	100	100	100	21	21	22	12,622
Eyre Hills	91	91	91	26	26	26	24,880	92	92	92	26	26	26	10,280
St Vincent	0	0	0	-	-	-	0	0	0	0	-	-	-	0
Southern Yorke	87	87	86	37	37	37	7,453	88	88	85	37	37	37	3,356
Mount Lofty Ranges	8	8	5	92	92	92	755	2	2	0	135	135	-	624
Fleurieu	71	71	68	45	45	65	2,030	64	60	46	65	65	71	936
Murray Lakes and Coorong	57	55	29	54	54	87	779	41	40	15	54	66	89	357
Glenelg Plain	82	82	80	44	44	44	19,993	74	74	73	44	44	44	6,653

Interim Biogeographic Regionalisation for Australia (IBRA) subregion	Unmitigated							Mitigated						
	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)			Load on shoreline (g/m^2)	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)			Load on shoreline (g/m^2)
	Low	Mod.	High	Low	Mod.	High	Mean	Low	Mod.	High	Low	Mod.	High	Mean
Bridgewater	88	86	83	42	42	42	10,915	86	86	79	42	42	42	3,750
Warrnambool Plain	82	81	80	45	45	46	6,097	80	80	76	45	45	46	2,094
Otway Ranges	73	73	64	62	62	64	1,403	68	64	43	62	62	85	578
Otway Plain	75	75	63	62	62	63	3,559	73	72	53	62	62	63	1,221
Gippsland Plain	54	51	47	84	84	90	1,545	48	45	39	88	88	89	771
Strzelecki Ranges	36	35	22	88	97	108	999	15	13	5	92	92	108	502
Wilsons Promontory	59	59	59	67	67	67	15,257	57	57	54	66	66	67	5,777
East Gippsland Lowlands	29	28	21	99	101	129	705	13	12	6	126	129	129	685
South East Coastal Ranges	10	10	3	132	132	135	429	1	1	0	132	132	-	279
Bateman	13	12	12	110	110	132	1,070	1	1	1	109	109	110	953
Jervis	5	5	2	136	136	150	686	0	0	0	-	-	-	0
Illawarra	2	2	0	143	143	-	268	2	1	0	148	148	-	127
Sydney Cataract	1	1	0	151	151	-	528	0	0	0	-	-	-	0
Pittwater	1	1	0	151	151	-	357	0	0	0	-	-	-	0
Wyong	2	2	1	159	159	162	961	1	1	0	151	151	-	190
Karuah Manning	2	2	0	152	152	-	209	0	0	0	-	-	-	0
South East	14	13	6	114	114	114	603	5	3	0	93	93	-	200
Southern Ranges	12	12	8	104	104	105	720	7	7	3	104	104	104	476

Mod. represents Moderate

Table 45: Predicted volume of weathered oil and lengths of shorelines contacted for each Interim Biogeographic Regionalisation for Australia (IBRA) subregion, for the unmitigated and mitigated cases. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Interim Biogeographic Regionalisation for Australia (IBRA) subregion	Unmitigated								Mitigated							
	Volume on shoreline (m³)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km))			Volume on shoreline (m³)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Mean	Peak	Low	Mod.	High	Low	Mod.	High	Mean	Peak	Mod.	High	Low	Mod.	High	Mod.
West	1192	5690	143	131	78	331	308	234	411	2,399	83	77	58	268	252	184
Southern Jarrah Forest	4	4	7	7	0	7	7	0	0	0	0	0	0	0	0	0
King	6486	30279	196	181	125	376	352	261	1,783	7,263	115	105	74	302	272	191
Flinders	1957	9659	78	75	58	268	259	188	675	2,473	50	48	40	161	150	125
Kangaroo Island	17254	43353	350	337	269	483	463	386	5,384	10,646	307	284	203	454	417	311
Hunter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fitzgerald	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Recherche	1350	6946	68	65	49	193	188	141	322	1,440	35	34	28	111	109	86
Eastern Mallee	7	14	9	8	0	16	14	0	0	0	0	0	0	0	0	0
Warren	10	10	9	9	0	9	9	0	0	0	0	0	0	0	0	0
Hampton	135	355	50	38	15	77	66	27	1,380	5,414	44	34	19	86	79	64
Nullarbor Plain	21	60	14	14	8	32	32	14	103	404	11	10	14	34	32	25
Eyre Mallee	214	3980	17	16	12	104	100	75	165	3,036	15	13	11	98	95	66
Talia	11359	36105	202	190	137	435	422	318	4,128	13,778	148	136	99	411	390	272
Eyre Hills	8617	22757	159	150	115	295	279	209	2,872	6,747	128	118	86	254	234	172
St Vincent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Southern Yorke	1622	5965	96	83	48	200	168	84	440	1,693	59	50	33	141	111	59
Mount Lofty Ranges	10	22	9	6	3	25	14	5	5	7	5	5	0	5	5	0
Fleurieu	189	921	38	34	15	95	88	48	43	174	19	16	9	50	43	23
Murray Lakes and Coorong	881	5011	65	52	39	163	134	88	292	1,188	50	36	31	150	100	54
Glenelg Plain	994	2936	23	22	17	29	29	25	306	835	21	20	12	29	29	23
Bridgewater	25758	64611	389	356	226	510	481	352	8,091	23,562	354	276	164	494	406	256

Interim Biogeographic Regionalisation for Australia (IBRA) subregion	Unmitigated								Mitigated							
	Volume on shoreline (m^3)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km))			Volume on shoreline (m^3)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Mean	Peak	Low	Mod.	High	Low	Mod.	High	Mean	Peak	Mod.	High	Low	Mod.	High	Mod.
Warrnambool Plain	3101	9882	145	126	72	229	215	156	890	2,574	121	93	45	204	179	84
Otway Ranges	165	1127	32	27	13	73	66	43	46	301	21	17	7	66	57	25
Otway Plain	730	1838	35	27	16	91	70	29	201	564	25	19	11	68	48	18
Gippsland Plain	856	4286	99	84	39	211	179	111	250	1,232	62	48	19	186	150	70
Strzelecki Ranges	10	52	5	4	3	9	7	7	5	24	4	4	2	7	7	2
Wilsons Promontory	1477	4778	47	46	35	84	82	66	402	1,591	29	28	22	73	66	52
East Gippsland Lowlands	48	188	23	16	6	64	41	14	21	64	12	7	5	32	14	7
South East Coastal Ranges	9	14	8	7	2	14	14	2	2	2	5	5	0	5	5	0
Bateman	20	58	12	11	5	39	34	9	29	29	14	9	5	14	9	5
Jervis	4	6	3	3	2	5	5	2	0	0	0	0	0	0	0	0
Illawarra	5	6	9	7	0	9	9	0	2	4	5	2	0	7	2	0
Sydney Cataract	7	7	7	7	0	7	7	0	0	0	0	0	0	0	0	0
Pittwater	6	6	9	9	0	9	9	0	0	0	0	0	0	0	0	0
Wyong	4	5	2	2	2	2	2	2	2	2	5	2	0	5	2	0
Karuah Manning	4	7	6	3	0	9	5	0	0	0	0	0	0	0	0	0
South East	10	23	7	6	3	16	16	5	2	3	4	2	0	5	2	0
Southern Ranges	19	30	14	13	5	25	23	9	6	14	7	6	2	11	9	2

Mod. represents Moderate

Table 46: Probability, minimum time and loading of weathered oil contact to shorelines for Local Government Areas (LGAs), for the unmitigated and mitigated cases. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Local Government Areas (LGAs)	Unmitigated							Mitigated						
	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)			Load on shoreline (g/m²)	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)			Load on shoreline (g/m²)
	Low	Mod.	High	Low	Mod.	High	Mean	Low	Mod.	High	Low	Mod.	High	Mean
King Island	85	85	84	55	55	55	23,828	64	64	60	55	55	55	5703
Lower Eyre Peninsula	100	100	100	24	24	25	46,160	97	97	97	21	21	26	12417
Esperance	30	30	27	56	56	58	5,946	21	21	20	58	58	59	2719
Elliston	100	100	99	21	21	21	10,421	80	80	77	21	21	21	3914
Ceduna	27	27	25	38	38	38	3,757	16	15	10	38	38	38	2347
Albany	4	4	1	115	115	147	640	0	0	0	-	-	-	0
Jerramungup	3	3	1	134	134	170	700	0	0	0	-	-	-	0
Ravensthorpe	7	7	4	73	73	91	473	0	0	0	-	-	-	0
Dundas	7	7	3	110	110	115	390	5	4	1	56	59	73	522
Pua	39	39	37	57	57	66	3,688	14	14	10	53	53	62	2392
Streaky Bay	46	46	32	52	52	52	1,586	16	16	8	52	52	52	1350
Tumby Bay	29	29	25	78	78	84	993	19	18	8	79	79	97	297
Cleve	6	4	0	144	147	-	194	0	0	0	-	-	-	0
Franklin Harbour	0	0	0	-	-	-	0	0	0	0	-	-	-	0
Whyalla	0	0	0	-	-	-	0	0	0	0	-	-	-	0
Barunga West / Cooper	1	1	0	165	165	-	567	0	0	0	-	-	-	0
Yorke Peninsula	94	94	93	36	36	37	11,874	88	88	85	36	36	37	3356
Mallala	0	0	0	-	-	-	0	0	0	0	-	-	-	0
Adelaide	0	0	0	-	-	-	0	0	0	0	-	-	-	0
Onkaparinga	13	11	4	90	90	93	1,343	0	0	0	-	-	-	0
Yankalilla	89	89	87	41	41	41	8,554	69	69	66	41	41	41	2951
Victor Harbour	82	81	71	45	45	56	1,755	29	29	16	70	70	87	640
Kangaroo Island	99	99	99	32	32	32	32,601	93	93	92	31	32	32	7079

Local Government Areas (LGAs)	Unmitigated							Mitigated						
	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)			Load on shoreline (g/m^2)	Probability of shoreline contact (%)			Minimum time before shoreline contact (days)			Load on shoreline (g/m^2)
	Low	Mod.	High	Low	Mod.	High	Mean	Low	Mod.	High	Low	Mod.	High	Mean
Alexandrina	37	37	15	87	87	89	434	12	11	0	89	89	-	175
Coorong	71	70	46	44	44	84	1,195	38	38	15	54	66	89	384
Kingston	88	88	84	40	44	54	3,946	71	70	62	44	44	63	787
Robe	94	94	90	43	43	43	19,518	79	78	76	43	43	43	3564
Wattle Range	96	96	92	42	43	43	20,671	85	84	73	42	42	43	3770
Grant	96	96	92	42	42	42	26,688	83	82	78	42	42	42	5294
Glenelg	95	95	92	44	44	44	29,376	81	80	78	44	44	44	5506
Moyne	92	92	92	45	45	45	6,926	77	77	74	45	45	46	1519
Corangamite	93	93	90	52	52	61	19,706	77	76	73	61	61	61	3423
Colac	89	89	87	62	62	62	5,236	73	72	58	62	62	63	1046
Circular Head	84	84	81	59	59	59	5,629	50	50	40	59	59	60	1973
West Coast Tasmania	80	80	76	63	63	63	3,409	42	41	33	63	63	68	1171
Huon Valley	64	64	49	68	68	81	2,641	23	23	18	89	89	97	1661

Mod. represents Moderate

Table 47: Predicted volume of weathered oil and lengths of shorelines contacted for Local Government Areas (LGAs), for the unmitigated and mitigated cases. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Local Government Areas (LGAs)	Unmitigated								Mitigated							
	Volume on shoreline (m^3)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)			Volume on shoreline (m^3)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Mean	Peak	Low	Mod.	High	Low	Mod.	High	Mean	Peak	Low	Mod.	High	Low	Mod.	High
King Island	8,695	38,097	127	118	85	188	179	134	1437	5848	72	66	51	143	120	93
Lower Eyre Peninsula	35,196	94,632	350	333	252	476	465	372	6633	18349	237	218	159	411	388	261
Esperance	1,847	11,365	74	73	59	247	243	188	325	1458	36	35	29	118	113	91
Elliston	2,073	7,149	90	88	67	193	184	132	392	2009	40	38	30	138	138	113
Ceduna	487	5,967	32	31	22	100	100	86	275	3036	17	17	15	95	93	66
Albany	20	65	12	12	14	34	34	14	0	0	0	0	0	0	0	0
Jerramungup	9	14	7	7	5	11	11	5	0	0	0	0	0	0	0	0
Ravensthorpe	10	16	6	6	2	11	9	2	0	0	0	0	0	0	0	0
Dundas	53	221	28	19	5	82	59	7	135	656	14	11	20	41	34	20
Pua	58	515	11	10	6	82	79	43	383	5162	15	13	10	79	77	68
Streaky Bay	201	3,235	24	23	15	95	88	64	167	1865	21	18	16	86	79	52
Tumby Bay	114	415	24	22	9	59	52	18	25	64	16	11	3	34	23	5
Cleve	2	2	2	2	0	2	2	0	0	0	0	0	0	0	0	0
Franklin Harbour	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Whyalla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barunga West/Cooper	2	2	2	2	0	2	2	0	0	0	0	0	0	0	0	0
Yorke Peninsula	3,034	9,863	119	105	62	234	209	113	440	1693	59	50	33	141	111	59
Mallala	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Adelaide	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Onkaparinga	15	93	7	6	2	20	18	2	0	0	0	0	0	0	0	0
Yankalilla	728	1,840	40	37	21	84	79	45	106	323	18	15	9	45	36	23
Victor Harbour	62	292	12	11	7	27	27	16	15	45	9	8	4	16	14	7

Local Government Areas (LGAs)	Unmitigated								Mitigated							
	Volume on shoreline (m^3)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)			Volume on shoreline (m^3)		Mean length of shoreline contacted (km)			Maximum length of shoreline contacted (km)		
	Mean	Peak	Low	Mod.	High	Low	Mod.	High	Mean	Peak	Low	Mod.	High	Low	Mod.	High
Kangaroo Island	31,328	61,149	385	373	313	488	476	413	5331	10479	304	281	200	449	413	306
Alexandrina	84	371	16	12	6	27	25	11	18	42	10	6	0	25	14	0
Coorong	1,287	6,479	75	62	41	147	127	84	292	1130	49	35	30	125	88	52
Kingston	4,869	17,651	104	97	68	143	143	129	792	3466	90	73	31	143	134	91
Robe	7,317	15,489	51	49	35	59	59	43	1219	3215	47	38	24	59	52	36
Wattle Range	10,820	20,095	83	78	51	95	95	66	1838	5816	74	53	44	95	75	52
Grant	14,647	31,746	96	91	68	109	109	88	2740	8014	88	71	39	109	95	52
Glenelg	13,437	32,865	132	123	87	175	163	120	2281	5682	109	89	50	156	132	84
Moyne	3,248	9,302	111	99	57	154	152	104	518	1601	82	61	25	134	113	50
Corangamite	2,651	8,037	51	48	38	61	61	57	403	1125	42	36	22	61	59	43
Colac	1,640	5,062	60	53	31	88	82	64	231	770	36	29	14	82	70	34
Circular Head	3,089	14,533	160	149	90	277	252	195	530	2184	67	61	41	188	177	116
West Coast Tasmania	1,822	8,672	151	143	90	274	263	197	355	1872	72	68	45	206	193	145
Huon Valley	375	1,484	40	38	28	111	109	54	90	352	18	16	14	54	48	32

Mod. represents Moderate

Figure 71 shows an overlay of shoreline loading of weathered oil (from the 100 simulations) for unmitigated and mitigated cases. The map for the unmitigated case shows weathered oil at varying thresholds from Albany in Western Australia to approximately Coffs Harbour in New South Wales and includes Tasmania. Along the Western Australian coastline, the areas with potentially higher loadings generally occurred between Esperance and Israelite Bay. High shoreline loadings in South Australia were generally concentrated from Flinders Island east to Kangaroo Island. Smaller isolated areas occurred near Border Village, Fowlers Bay, Ceduna, Cape Jaffa and Mount Gambier. In Victoria, shoreline loadings appeared highest from the western state border to the Cape Otway region, and then at Mornington Peninsula, Wilsons Promontory. Flinders Island, King Island and north west of Smithton for Tasmania. Potentially high shoreline loadings in New South Wales occur near Eden, Bateman's Bay and Newcastle north of Sydney.

The results for the mitigated case showed a similar extent, however, there was an obvious reduction in the level of shoreline loading or removal in certain areas. Particularly from Border Village to Albany, west of the well; and Wilsons Promontory to Sydney, east of the well. There were also less eastern Tasmanian shorelines contacted by weathered oil.

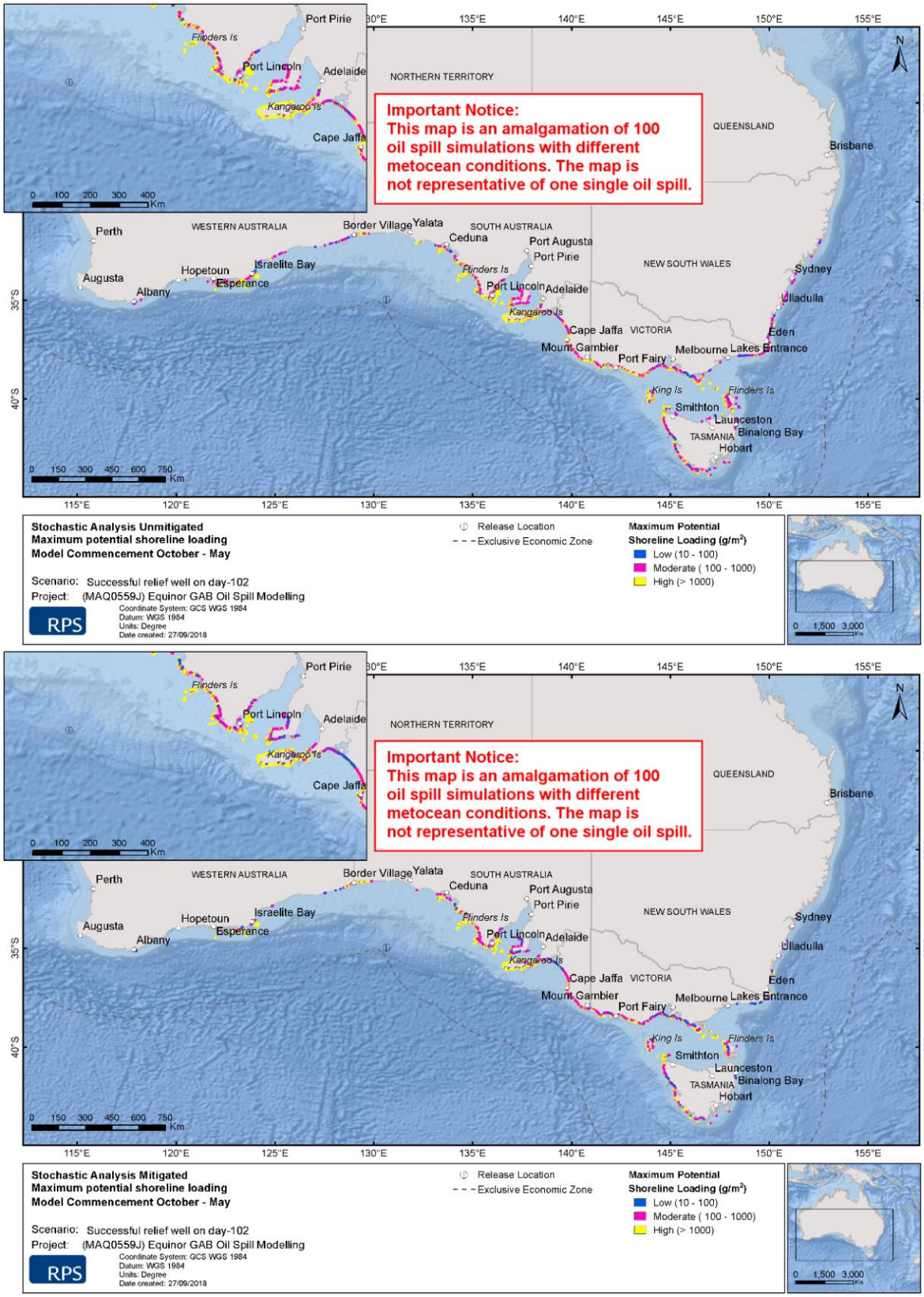


Figure 71: Maximum potential shoreline loading from weathered oil, for the unmitigated (upper image) and mitigated (lower image) cases. Results were produced from 100 oil spill simulations per case commencing between October and May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

11.1.3 In-water oil exposure

11.1.3.1 Entrained hydrocarbon exposure

Table 48 shows the probability of entrained hydrocarbon exposure (0-10 m water depth) within state coastal waters (3 nm offshore) for each threshold and the unmitigated and mitigated cases. Also presented is the maximum 96-hour time averaged concentrations. The results are based on the stochastic modelling (i.e. the outcomes from 100 oil spill simulations with varied start dates and times between October and May conditions). No moderate exposure was predicted within any state waters.

Table 48: Maximum entrained hydrocarbon (time averaged) exposure and probability for each threshold (0-10 m depth) within state waters, for mitigated and unmitigated cases. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Coastal waters	Unmitigated	Mitigated				Mitigated				
	Maximum time averaged exposure (ppb)	Probability of exposure to entrained hydrocarbons (%) for each threshold				Maximum time averaged exposure (ppb)	Probability of exposure to entrained hydrocarbons (%) for each threshold			
		Very low	Low	Moderate	High		Very low	Low	Moderate	High
Tasmania	12	2	0	0	0	0	0	0	0	0
South Australia	44	53	0	0	0	129	15	2	1	0
Western Australia	0	0	0	0	0	0	0	0	0	0
Victoria	121	59	13	5	0	44	27	0	0	0
New South Wales	0	0	0	0	0	0	0	0	0	0

Table 49 presents the maximum entrained hydrocarbon exposure and probability of exposure (0-10 m water depth) within AMPs. No AMPs were predicted to experience exposure at or above the moderate threshold.

Table 50 and Table 51 present the maximum entrained hydrocarbon exposure concentrations and probability for the 0–10 m and 90–100 m water depth for KEFs, respectively. No predicted entrained hydrocarbon exposure at the moderate threshold was predicted for any KEFs.

The maximum entrained hydrocarbon exposure concentrations and probabilities for IMCRA meso-scale bioregions are presented

Table 52. For the unmitigated case, only Otway had recorded entrained hydrocarbon exposure at the moderate threshold at 5%. Following the implementation of mitigation, low probability of moderate exposure was predicted at Eucla (3%) and Eyre (2%).

Table 48: Maximum entrained hydrocarbon (time averaged) exposure and probability for each threshold (0-10 m depth) within state waters, for mitigated and unmitigated cases. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Coastal waters	Unmitigated Mitigated					Mitigated				
	Maximum time averaged exposure (ppb)	Probability of exposure to entrained hydrocarbons (%) for each threshold				Maximum time averaged exposure (ppb)	Probability of exposure to entrained hydrocarbons (%) for each threshold			
		Very low	Low	Moderate	High		Very low	Low	Moderate	High
Tasmania	12	2	0	0	0	0	0	0	0	0
South Australia	44	53	0	0	0	129	15	2	1	0
Western Australia	0	0	0	0	0	0	0	0	0	0
Victoria	121	59	13	5	0	44	27	0	0	0
New South Wales	0	0	0	0	0	0	0	0	0	0

Table 49: Maximum entrained hydrocarbon (time averaged) exposure and probability for each threshold (0-10 m depth) within Australian Marine Parks (AMPs), derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Australian Marine Park Network	Australian Marine Parks (AMPs)	Unmitigated					Mitigated				
		Maximum time averaged exposure (ppb)	Probability of entrained hydrocarbon exposure (%) for each threshold				Maximum time averaged exposure (ppb)	Probability of entrained hydrocarbon exposure (%) for each threshold			
			Very low	Low	Moderate	High		Very low	Low	Moderate	High
South-east	Apollo	0	0	0	0	0	0	0	0	0	0
	Beagle	0	0	0	0	0	0	0	0	0	0
	Boags	0	0	0	0	0	0	0	0	0	0
	East Gippsland	0	0	0	0	0	0	0	0	0	0
	Flinders	0	0	0	0	0	0	0	0	0	0
	Franklin	0	0	0	0	0	0	0	0	0	0
	Freycinet	0	0	0	0	0	0	0	0	0	0
	Huon	0	0	0	0	0	0	0	0	0	0
	Murray	0	0	0	0	0	35	2	0	0	0

Australian Marine Park Network	Australian Marine Parks (AMPs)	Unmitigated					Mitigated				
		Maximum time averaged exposure (ppb)	Probability of entrained hydrocarbon exposure (%) for each threshold				Maximum time averaged exposure (ppb)	Probability of entrained hydrocarbon exposure (%) for each threshold			
			Very low	Low	Moderate	High		Very low	Low	Moderate	High
	Nelson	0	0	0	0	0	0	0	0	0	0
	South Tasman Rise	0	0	0	0	0	0	0	0	0	0
	Tasman Fracture	0	0	0	0	0	0	0	0	0	0
	Zeehan	0	0	0	0	0	0	0	0	0	0
South-west	Abrolhos	0	0	0	0	0	0	0	0	0	0
	Bremer	0	0	0	0	0	0	0	0	0	0
	Eastern Recherche	0	0	0	0	0	0	0	0	0	0
	Geographe	0	0	0	0	0	0	0	0	0	0
	Jurien	0	0	0	0	0	0	0	0	0	0
	Murat	0	0	0	0	0	0	0	0	0	0
	Perth Canyon	0	0	0	0	0	0	0	0	0	0
	South-west Corner	0	0	0	0	0	0	0	0	0	0
	Southern Kangaroo Island	0	0	0	0	0	0	0	0	0	0
	Twilight	0	0	0	0	0	0	0	0	0	0
	Two Rocks	0	0	0	0	0	0	0	0	0	0
	Western Eyre	0	0	0	0	0	95	2	0	0	0
	Western Kangaroo Island	12	1	0	0	0	0	0	0	0	0
	Central Eastern	0	0	0	0	0	0	0	0	0	0
	Cods Grounds	0	0	0	0	0	0	0	0	0	0
	Gifford	0	0	0	0	0	0	0	0	0	0
Temperate East	Hunter	0	0	0	0	0	0	0	0	0	0
	Jervis	0	0	0	0	0	0	0	0	0	0
	Lord Howe	0	0	0	0	0	0	0	0	0	0
	Solitary Islands	0	0	0	0	0	0	0	0	0	0

Table 50: Maximum entrained hydrocarbon (time averaged) exposure and probability for each threshold (0-10 m depth) for Key Ecological Features (KEFs). Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Key Ecological Features (KEFs)	Unmitigated					Mitigated				
	Maximum time averaged exposure (ppb)	Probability of exposure to entrained hydrocarbons (%) for each threshold				Maximum time averaged exposure (ppb)	Probability of exposure to entrained hydrocarbons (%) for each threshold			
		Very low	Low	Moderate	High		Very low	Low	Moderate	High
Seamounts South and east of Tasmania	0	0	0	0	0	0	0	0	0	0
West Tasmania Canyons	0	0	0	0	0	0	0	0	0	0
Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings	0	0	0	0	0	93	17	2	0	0
Bonney Coast Upwelling	0	0	0	0	0	44	27	0	0	0
Upwelling East of Eden	0	0	0	0	0	0	0	0	0	0
Commonwealth marine environment - Recherche Archipelago	0	0	0	0	0	0	0	0	0	0

Table 51: Maximum entrained hydrocarbon (time averaged) exposure and probability for each threshold (90-100 m depth) for Key Ecological Features (KEFs). Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Key Ecological Features (KEFs)	Unmitigated					Mitigated				
	Maximum time averaged exposure (ppb)	Probability of entrained hydrocarbon exposure (%) for each threshold				Maximum time averaged exposure (ppb)	Probability of entrained hydrocarbon exposure (%) for each threshold			
		Very low	Low	Moderate	High		Very low	Low	Moderate	High
Seamounts South and east of Tasmania	0	0	0	0	0	0	0	0	0	0
West Tasmania Canyons	0	0	0	0	0	0	0	0	0	0
Big Horseshoe Canyon	0	0	0	0	0	0	0	0	0	0
Diamantina Fracture Zone	0	0	0	0	0	0	0	0	0	0
Albany Canyons group and adjacent shelf break	0	0	0	0	0	0	0	0	0	0
Ancient coastline at 90-120 m depth	0	0	0	0	0	0	0	0	0	0
Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings	0	0	0	0	0	35	5	0	0	0
Western rock lobster	0	0	0	0	0	0	0	0	0	0
Canyons on the eastern continental slope	0	0	0	0	0	0	0	0	0	0
Shelf rocky reefs	0	0	0	0	0	0	0	0	0	0
Western demersal slope and associated fish communities	0	0	0	0	0	0	0	0	0	0
Perth Canyon, adjacent shelf break, other west coast canyons	0	0	0	0	0	0	0	0	0	0
Commonwealth marine environment - West coast inshore lagoons	0	0	0	0	0	0	0	0	0	0

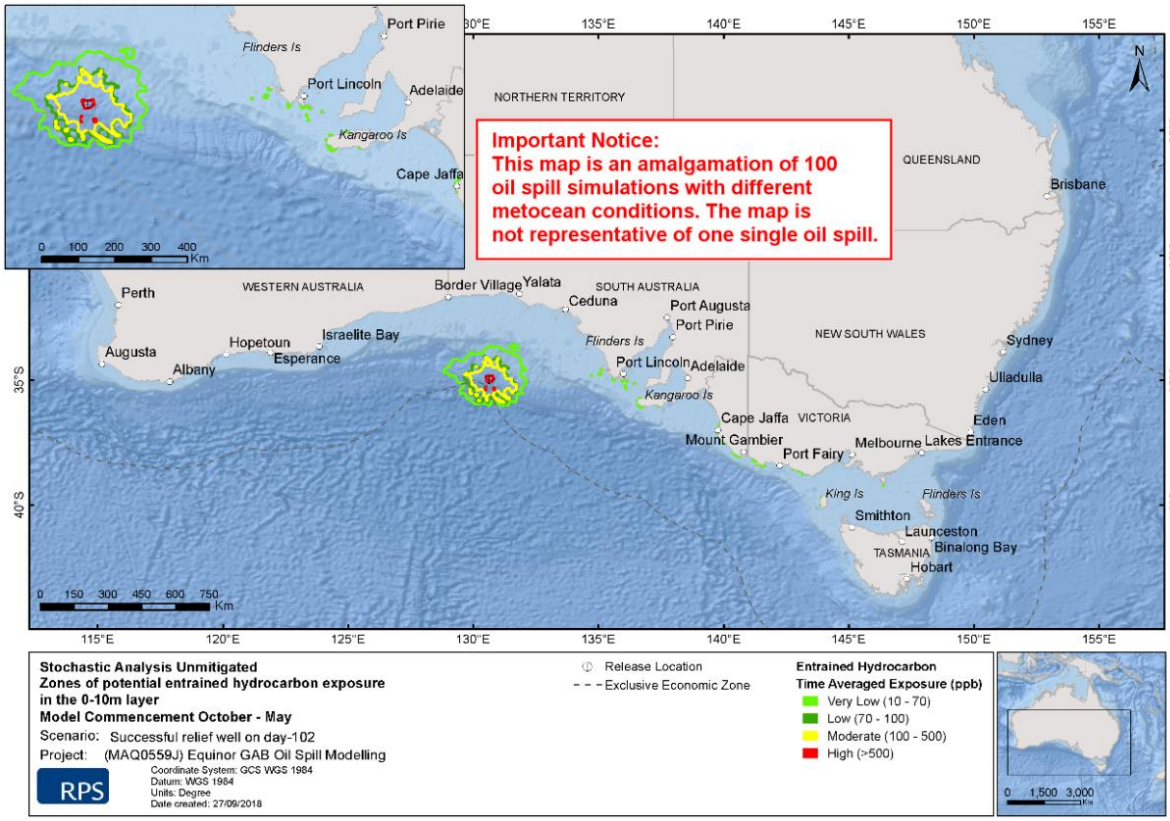
Table 52: Maximum entrained hydrocarbon (time averaged) exposure and probability for each threshold (0-10 m depth) for Integrated Marine and Coastal Regionalisation of Australia (IMCRA) meso-scale bioregions. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Integrated Marine and Coastal Regionalisation of Australia (IMCRA)	Unmitigated					Mitigated				
	Maximum time averaged exposure (ppb)	Probability of entrained hydrocarbon exposure (%) for each threshold				Maximum time averaged exposure (ppb)	Probability of entrained hydrocarbon exposure (%) for each threshold			
		Very low	Low	Moderate	High		Very low	Low	Moderate	High
Central West Coast	0	0	0	0	0	0	0	0	0	0
Abrolhos Islands	0	0	0	0	0	0	0	0	0	0
Eucla	0	0	0	0	0	161	13	5	3	0
Murat	0	0	0	0	0	80	29	2	0	0
Leeuwin-Naturaliste	0	0	0	0	0	0	0	0	0	0
Eyre	54	53	0	0	0	130	25	5	2	0
North Spencer Gulf	0	0	0	0	0	0	0	0	0	0
Hawkesbury Shelf	0	0	0	0	0	0	0	0	0	0
WA South Coast	0	0	0	0	0	0	0	0	0	0
Spencer Gulf	0	0	0	0	0	0	0	0	0	0
St Vincent Gulf	25	27	0	0	0	0	0	0	0	0
Batemans Shelf	0	0	0	0	0	0	0	0	0	0
Coorong	22	10	0	0	0	11	1	0	0	0
Twofold Shelf	0	0	0	0	0	0	0	0	0	0
Otway	121	59	13	5	0	44	27	0	0	0
Central Victoria	0	0	0	0	0	0	0	0	0	0
Central Bass Strait	0	0	0	0	0	0	0	0	0	0
Flinders	14	1	0	0	0	0	0	0	0	0
Boags	0	0	0	0	0	0	0	0	0	0
Freycinet	0	0	0	0	0	0	0	0	0	0
Franklin	0	0	0	0	0	0	0	0	0	0
Bruny	0	0	0	0	0	0	0	0	0	0
Davey	0	0	0	0	0	0	0	0	0	0

Figure 72 to Figure 74 show zones of potential entrained hydrocarbon (96-hour time averaged) exposure in the surface layer (0-10 m), 80-100 m depth layer and 0-200 m water depth for the unmitigated and mitigated cases. The images are based on the results from 100 oil spill simulations for each case.

As a result of the SSDI causing a greater volume of oil to remain entrained, the mitigated maps show much larger zones of exposure at all depths assessed. Figure 75 shows the moderate and high entrained hydrocarbon (96-hour time averaged) exposures zones in the 0–200 m layer for the WCCD scenario for the unmitigated and mitigated cases and overlaid are the KEFs. No predicted entrained hydrocarbon exposure at the moderate threshold was predicted for any KEFs.

Figure 76 presents a comparison of the entrained hydrocarbon exposure zones zones (at and above the moderate threshold) in the 0–10 m layer for the unmitigated WCCD and WCD scenarios. While the exposure and shoreline loadings were visibly different between the scenarios, the areas exposed to entrained hydrocarbons at or above the moderate thresholds were similar in size. This would be attributed to the carrying capacity of the ambient waters, oil rising quickly to the surface and evaporating, as well as ongoing biodegradation and an increasing volume exposed to low thresholds. Over time, the in-water oil is likely to continue to biodegrade and dilute beyond the modelling thresholds as new oil is added daily. Therefore, in the absence of further modelling, the WCCD plots of in-water oil after dispersant application (mitigated) are a good representation of the extent of entrained hydrocarbon exposure zones (at and above the moderate threshold) for the mitigated WCD scenario.



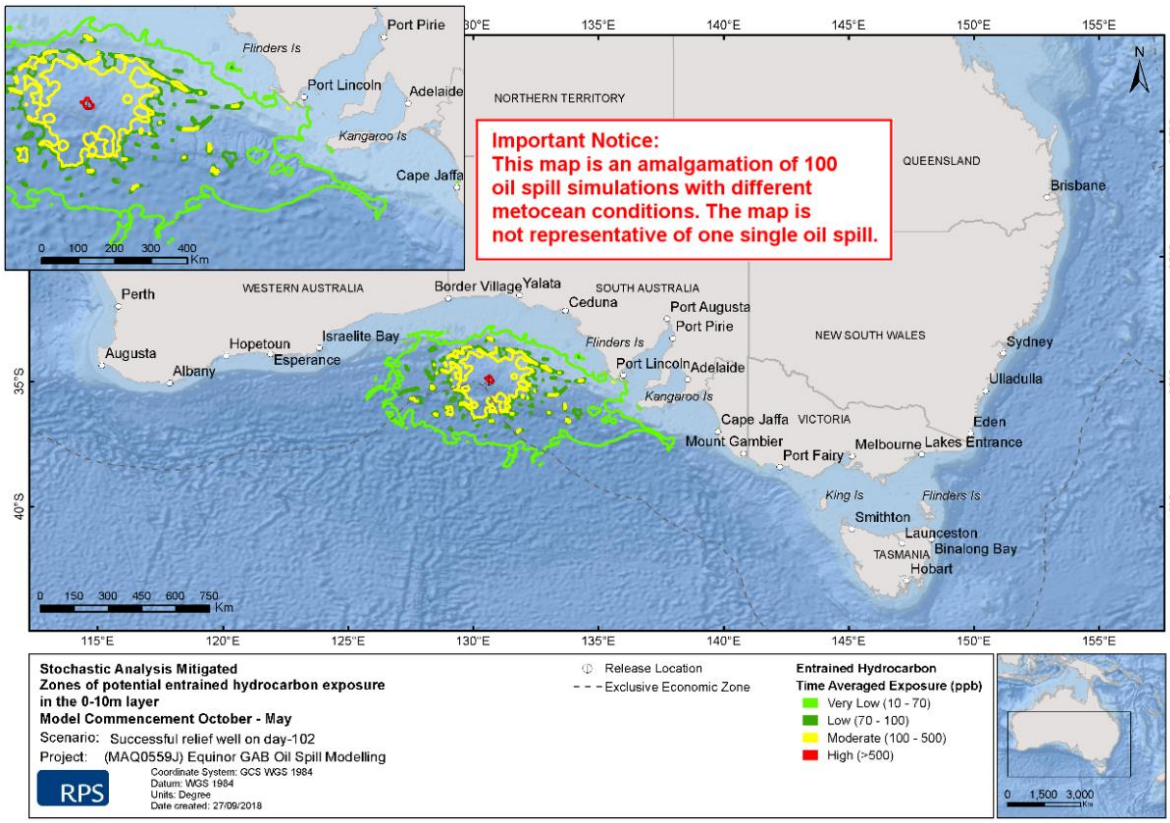


Figure 72: Zones of potential entrained hydrocarbon time averaged exposure in the surface layer (0-10 m) for the unmitigated (upper image) and mitigated (lower image) cases. Images were produced from the results of 100 oil spill simulations per case commencing between October and May conditions. Each simulation represents an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

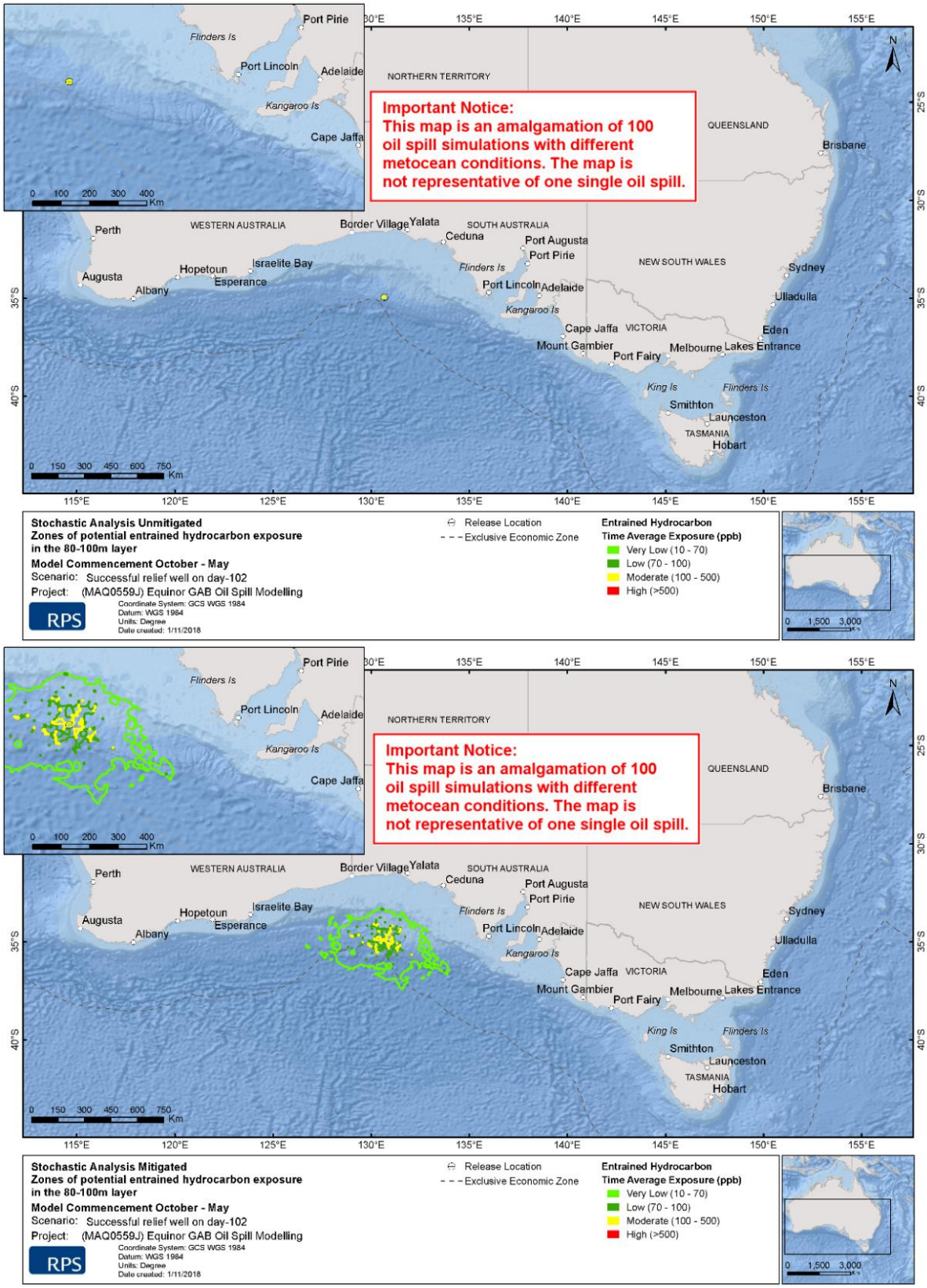


Figure 73: Zones of potential entrained hydrocarbon time averaged exposure in the 80-100 m depth layer for the unmitigated (upper image) and mitigated (lower image) cases. Images were produced from the results of 100 oil spill simulations per case commencing between October and May conditions. Each simulation represents an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

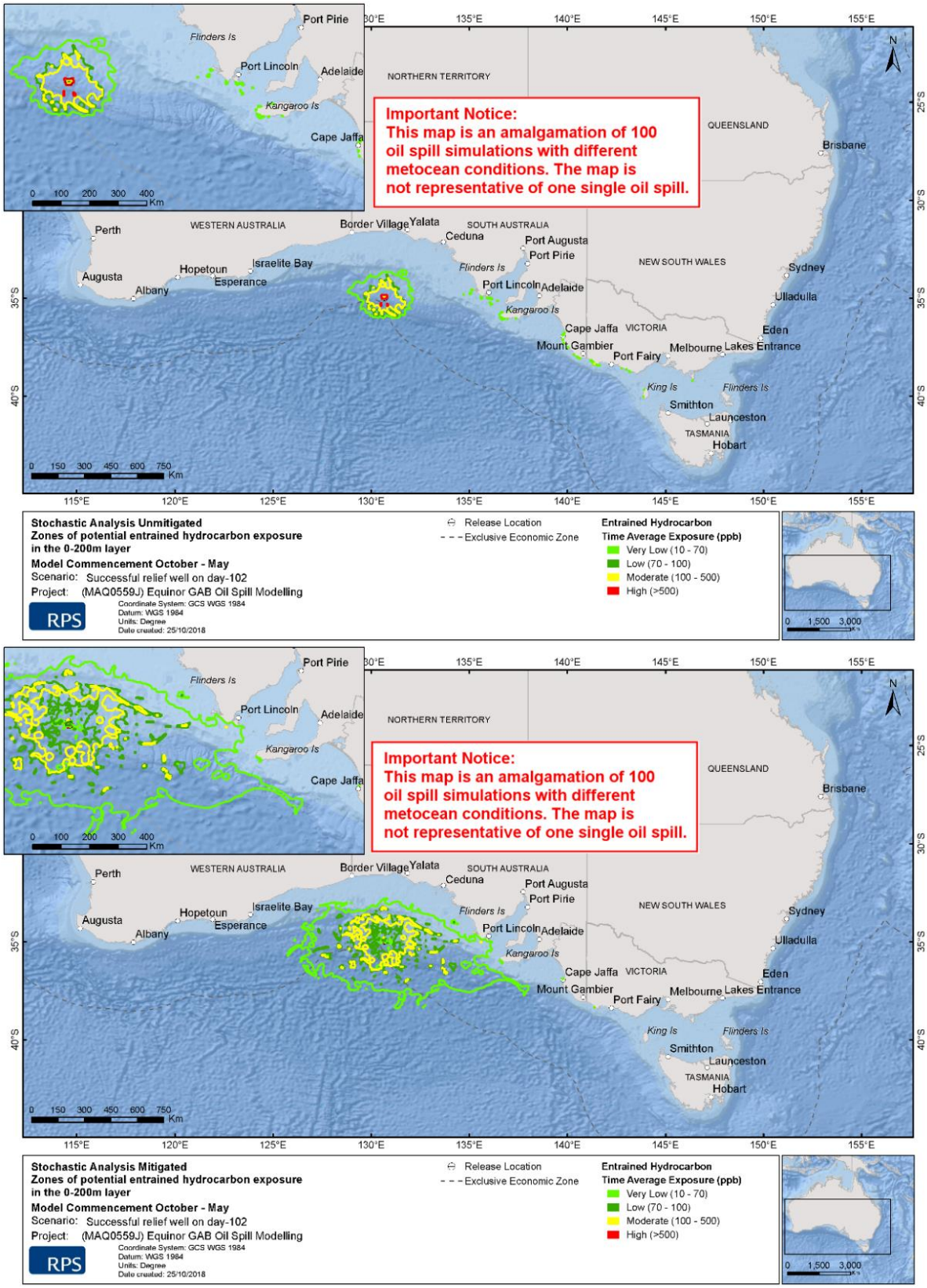


Figure 74: Zones of potential entrained hydrocarbon time averaged exposure in the 0-200 m depth layer for the unmitigated (upper image) and mitigated (lower image) cases. Images were produced from the results of 100 oil spill simulations per case commencing between October and May conditions. Each simulation represents an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

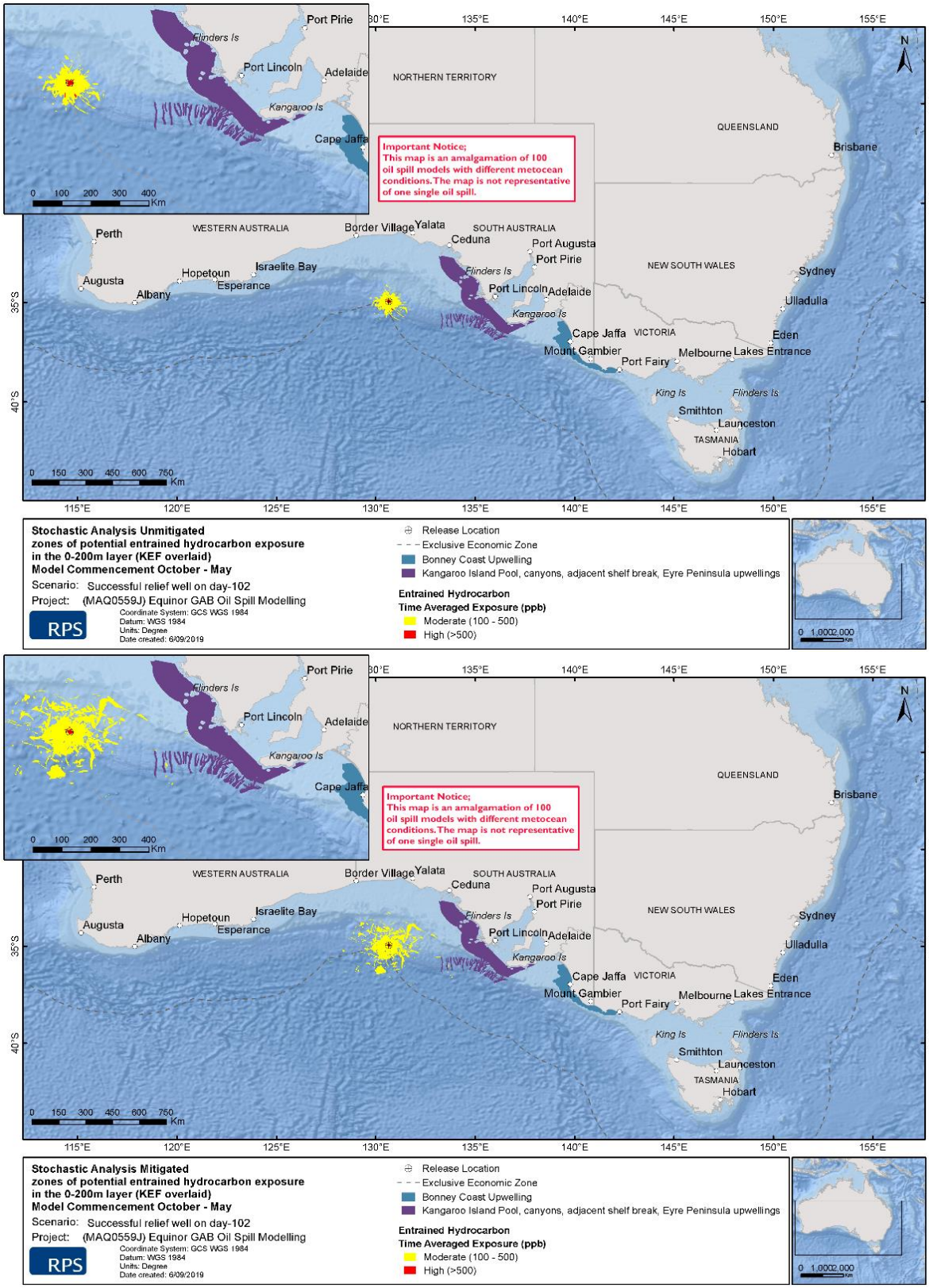


Figure 75 Moderate and high entrained hydrocarbon (96-hour time averaged) exposures zones in the 0–200 m layer for the WCCD scenario for the unmitigated (upper image) and mitigated (lower image) cases and overlaid are the KEFS. Image is produced from the results of 100 oil spill simulations commencing during summer conditions (October to May). Each simulation represents a 8,943 m^3/day subsea release of crude oil over 129 days tracked for 189 days.

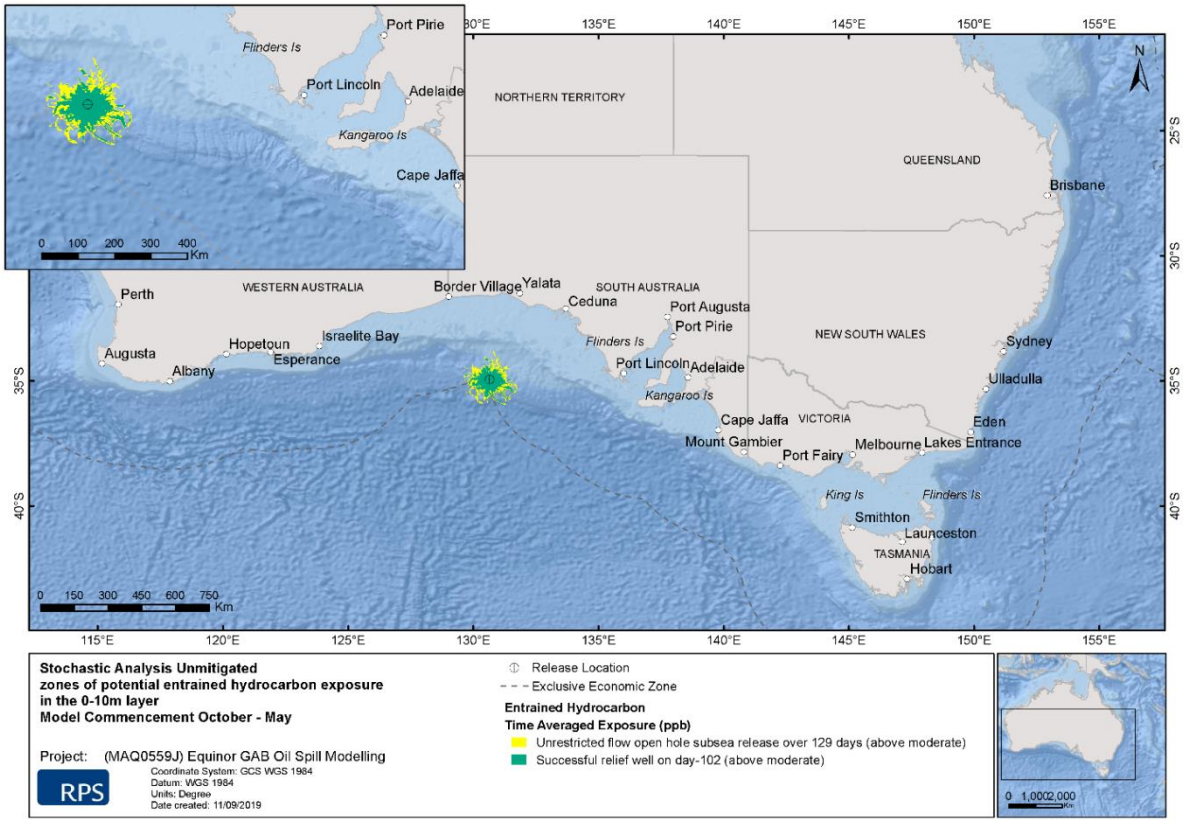


Figure 76 Comparison of the entrained hydrocarbon exposure zones (at and above the moderate threshold) in the 0–10 m layer for the unmitigated WCCD and WCD scenarios. Image is produced from the results of 100 oil spill simulations commencing during summer conditions (October to May).

11.1.3.2 Dissolved hydrocarbon exposure

Table 53 shows the probability of dissolved hydrocarbon 96-hour time averaged exposure (0-10 m depth) within coastal waters (3 nm offshore) for each threshold. Also presented is the maximum exposure. The results are based on the stochastic modelling (i.e. the overlay of results from 100 oil spill simulations commenced in October to May conditions. No dissolved hydrocarbon exposure at the moderate threshold was predicted for any of the state waters.

Table 54 presents the maximum dissolved hydrocarbon exposure and probability of exposure 0-10 m water depth) within AMPs. No predicted exposure at the moderate threshold for any of the AMPs.

Table 55 and Table 56 present the maximum dissolved hydrocarbon exposure and probability for the 0-10 m and 90-100 m water depth for KEFs, respectively. No predicted exposure at the moderate threshold for any of the KEFs.

The maximum dissolved hydrocarbon exposure and probabilities for IMCRA meso-scale bioregions are presented in Table 57. No moderate exposure predicted for the IMCRA meso-scale bioregions.

Table 53: Maximum dissolved hydrocarbon exposure (time averaged) and probability for each threshold (0-10 m water depth) within state waters, derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

State waters	Unmitigated				Mitigated			
	Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbon (%) for each threshold			Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbon (%) for each threshold		
		Low	Moderate	High		Low	Moderate	High
Tasmania	0	0	0	0	0			
South Australia	0	0	0	0	0			
Western Australia	0	0	0	0	0			
Victoria	0	0	0	0	0			
New South Wales	0	0	0	0	0			

Table 54: Maximum dissolved hydrocarbon exposure (time averaged) and probability for each threshold (0-10 m water depth) within Australian Marine Parks (AMPs), derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Australian Marine Park Network	Australian Marine Parks (AMPs)	Unmitigated				Mitigated			
		Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbon (%) for each threshold			Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbon (%) for each threshold		
			Low	Moderate	High		Low	Moderate	High
South-east	Apollo	0	0	0	0	0	0	0	0
	Beagle	0	0	0	0	0	0	0	0
	Boags	0	0	0	0	0	0	0	0
	East Gippsland	0	0	0	0	0	0	0	0
	Flinders	0	0	0	0	0	0	0	0
	Franklin	0	0	0	0	0	0	0	0
	Freycinet	0	0	0	0	0	0	0	0
	Huon	0	0	0	0	0	0	0	0
	Murray	0	0	0	0	0	0	0	0
	Nelson	0	0	0	0	0	0	0	0
	South Tasman Rise	0	0	0	0	0	0	0	0
	Tasman Fracture	0	0	0	0	0	0	0	0
	Zeehan	0	0	0	0	0	0	0	0
South-west	Abrolhos	0	0	0	0	0	0	0	0
	Bremer	0	0	0	0	0	0	0	0
	Eastern Recherche	0	0	0	0	0	0	0	0
	Geographe	0	0	0	0	0	0	0	0
	Jurien	0	0	0	0	0	0	0	0
	Murat	0	0	0	0	0	0	0	0
	Perth Canyon	0	0	0	0	0	0	0	0
	South-west Corner	0	0	0	0	0	0	0	0
	Southern Kangaroo Island	0	0	0	0	0	0	0	0
	Twilight	0	0	0	0	0	0	0	0
	Two Rocks	0	0	0	0	0	0	0	0

Australian Marine Park Network	Australian Marine Parks (AMPs)	Unmitigated				Mitigated			
		Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbon (%) for each threshold			Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbon (%) for each threshold		
			Low	Moderate	High		Low	Moderate	High
	Western Eyre	13	1	0	0	11	1	0	0
	Western Kangaroo Island	0	0	0	0	0	0	0	0
	Central Eastern	0	0	0	0	0	0	0	0
	Cods Grounds	0	0	0	0	0	0	0	0
	Gifford	0	0	0	0	0	0	0	0
Temperate East	Hunter	0	0	0	0	0	0	0	0
	Jervis	0	0	0	0	0	0	0	0
	Lord Howe	0	0	0	0	0	0	0	0
	Solitary Islands	0	0	0	0	0	0	0	0

Table 55: Maximum dissolved hydrocarbon exposure (time averaged) and probability for each threshold (0-10 m water depth) for Key Ecological Features (KEFs). Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Key Ecological Features (KEFs)	Unmitigated				Mitigated			
	Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbon (%) for each threshold			Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbon (%) for each threshold		
		Low	Moderate	High		Low	Moderate	High
Seamounts South and east of Tasmania	0	0	0	0	0	0	0	0
West Tasmania Canyons	0	0	0	0	0	0	0	0
Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings	0	0	0	8	8	1	0	0
Bonney Coast Upwelling	0	0	0	0	0	0	0	0
Upwelling East of Eden	0	0	0	0	0	0	0	0
Commonwealth marine environment - Recherche Archipelago	0	0	0	0	0	0	0	0

Table 56: Maximum dissolved hydrocarbon exposure (time averaged) and probability for each threshold (90-100 m water depth) for Key Ecological Features (KEFs), derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

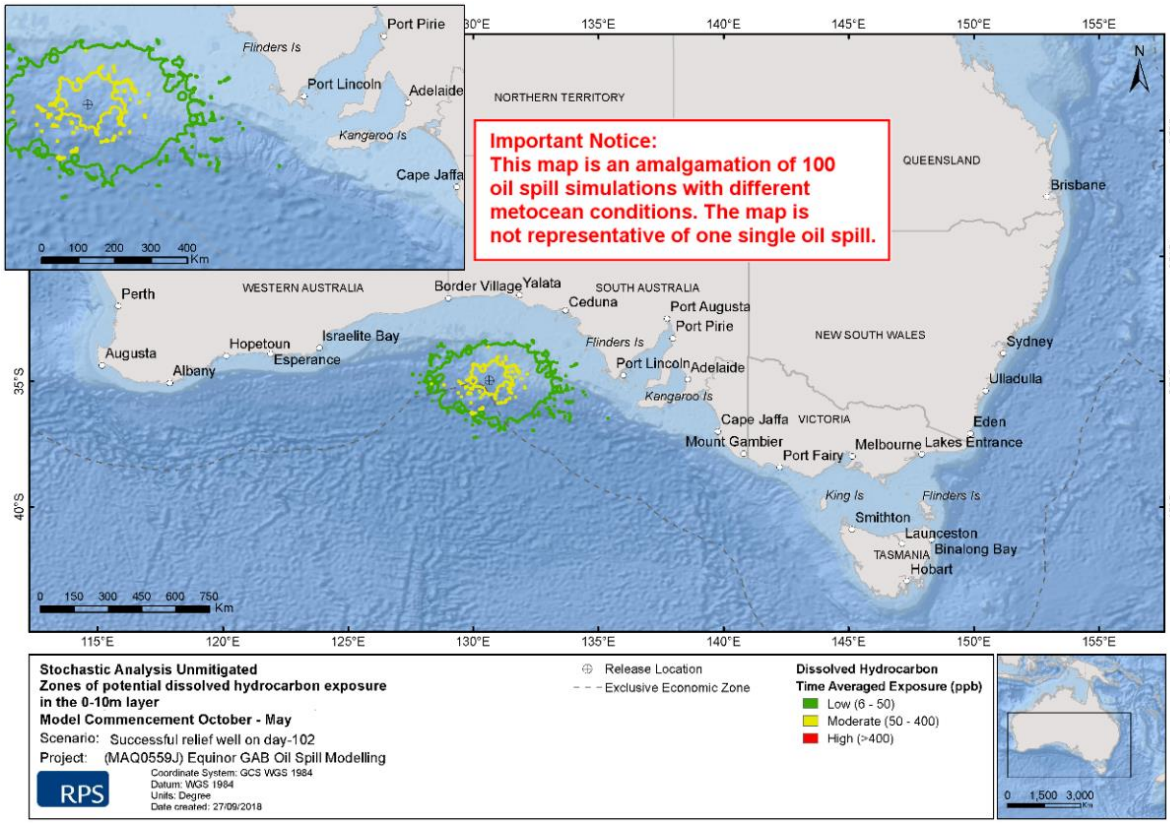
Key Ecological Features (KEFs)	Unmitigated				Mitigated			
	Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbon (%) for each threshold			Maximum time averaged exposure (ppb)	Probability of exposure to dissolved hydrocarbon (%) for each threshold		
		Low	Moderate	High		Low	Moderate	High
Seamounts South and east of Tasmania	0	0	0	0	0	0	0	0
West Tasmania Canyons	0	0	0	0	0	0	0	0
Big Horseshoe Canyon	0	0	0	0	0	0	0	0
Diamantina Fracture Zone	0	0	0	0	0	0	0	0
Albany Canyons group and adjacent shelf break	0	0	0	0	0	0	0	0
Ancient coastline at 90-120m depth	0	0	0	0	0	0	0	0
Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings	0	0	0	0	0	0	0	0
Western rock lobster	0	0	0	0	0	0	0	0
Canyons on the eastern continental slope	0	0	0	0	0	0	0	0
Shelf rocky reefs	0	0	0	0	0	0	0	0
Western demersal slope and associated fish communities	0	0	0	0	0	0	0	0
Perth Canyon, adjacent shelf break, other west coast canyons	0	0	0	0	0	0	0	0
Commonwealth marine environment - West coast inshore lagoons	0	0	0	0	0	0	0	0

Table 57: Maximum dissolved hydrocarbon exposure (time averaged) and probability for each threshold (0-10 m depth) for Integrated Marine and Coastal Regionalisation of Australia (IMCRA) meso-scale bioregions, derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Integrated Marine and Coastal Regionalisation of Australia (IMCRA) meso-scale bioregions	Unmitigated				Mitigated			
	Maximum time averaged exposure (ppb)	Probability of dissolved hydrocarbon exposure (%) for each threshold			Maximum time averaged exposure (ppb)	Probability of dissolved hydrocarbon exposure (%) for each threshold		
		Low	Moderate	High		Low	Moderate	High
Central West Coast	0	0	0	0	0	0	0	0
Abrolhos Islands	0	0	0	0	0	0	0	0
Eucla	9	1	0	0	8	1	0	0
Murat	25	2	0	0	10	1	0	0
Leeuwin-Naturaliste	0	0	0	0	0	0	0	0
Eyre	21	2	0	0	13	1	0	0
North Spencer Gulf	0	0	0	0	0	0	0	0
Hawkesbury Shelf	0	0	0	0	0	0	0	0
WA South Coast	0	0	0	0	0	0	0	0
Spencer Gulf	0	0	0	0	0	0	0	0
St Vincent Gulf	0	0	0	0	0	0	0	0
Batemans Shelf	0	0	0	0	0	0	0	0
Coorong	0	0	0	0	0	0	0	0
Twofold Shelf	0	0	0	0	0	0	0	0
Otway	0	0	0	0	0	0	0	0
Central Victoria	0	0	0	0	0	0	0	0
Central Bass Strait	0	0	0	0	0	0	0	0
Flinders	0	0	0	0	0	0	0	0
Boags	0	0	0	0	0	0	0	0
Freycinet	0	0	0	0	0	0	0	0
Franklin	0	0	0	0	0	0	0	0
Bruny	0	0	0	0	0	0	0	0
Davey	0	0	0	0	0	0	0	0

Figure 77 to Figure 79 show zones of potential dissolved hydrocarbon time averaged exposure in the surface layer (0-10 m), 80-100 m depth layer and 0-200 m depth layer for the unmitigated and mitigated cases. The images are derived from the stochastic modelling results (i.e. the overlay of results from 100 oil spill simulations commencing between October and May conditions. The results in general were similar, particularly when comparing the 0-200 m depth layer maps.

Figure 80 presents a comparison of the dissolved hydrocarbon exposure zones (at and above the moderate threshold) in the 0 – 10m layer for the unmitigated WCCD and WCD scenarios. Similar to the entrained hydrocarbon results, the dissolved hydrocarbon extent at and above the moderate thresholds were similar in size. This would be attributed to the carrying capacity of the ambient waters, oil rising quickly to the surface and evaporating, as well as ongoing biodegradation and an increasing volume exposed to low thresholds. Over time, the in-water oil is likely to continue to biodegrade and dilute beyond the modelling thresholds as new oil is added daily. Therefore, in the absence of further modelling, the WCCD plots of in-water oil after dispersant application (mitigated) are a good representation of the extent of dissolved hydrocarbon exposure zones (at and above the moderate threshold) for the mitigated WCD scenario.



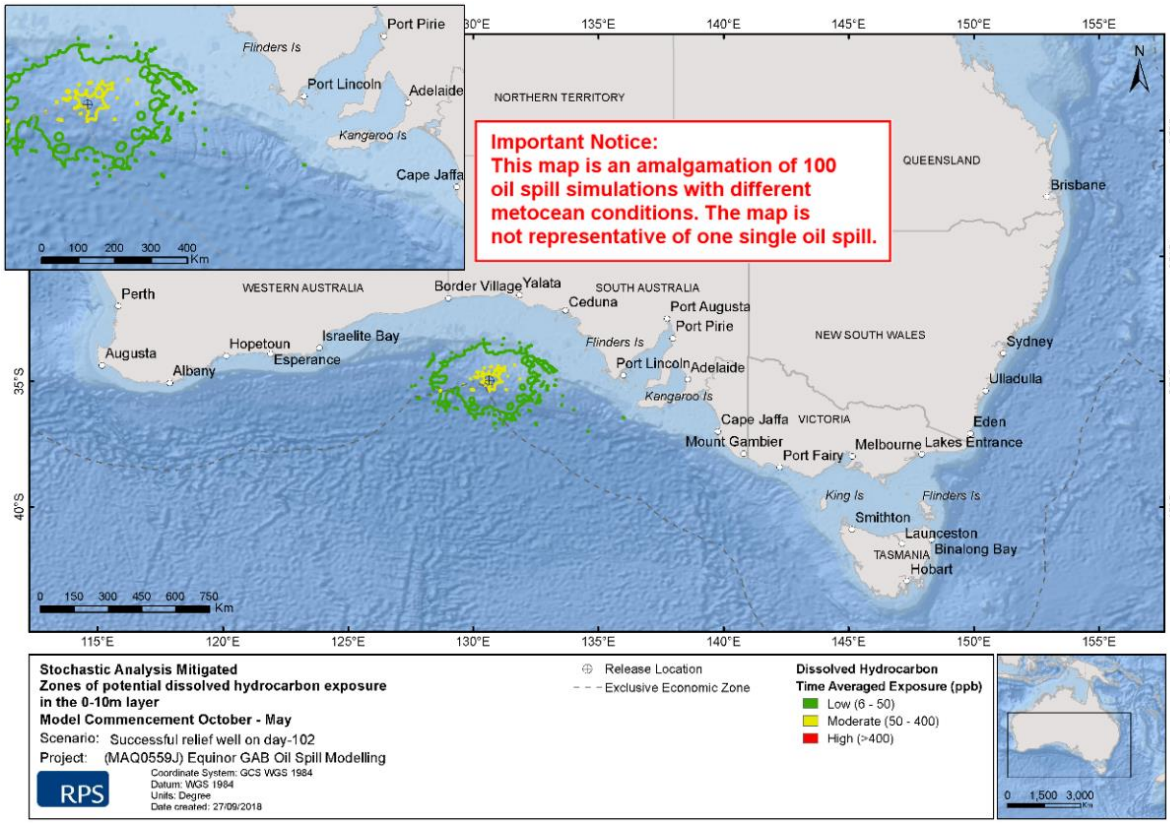
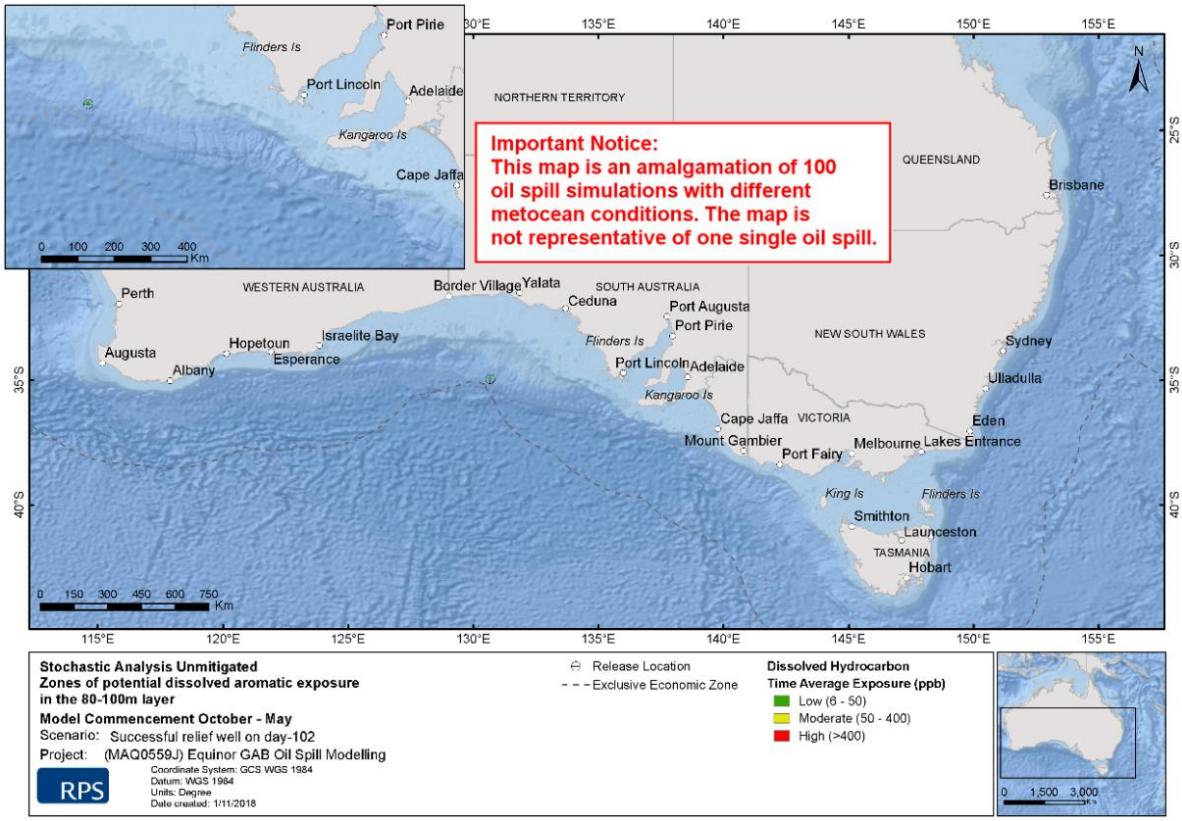


Figure 77: Zones of potential dissolved hydrocarbon time averaged exposure in the surface layer (0-10 m for the unmitigated (upper image) and mitigated (lower image) cases. Images were produced from the results of 100 oil spill simulations per case commencing between October and May conditions. Each simulation represents an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days



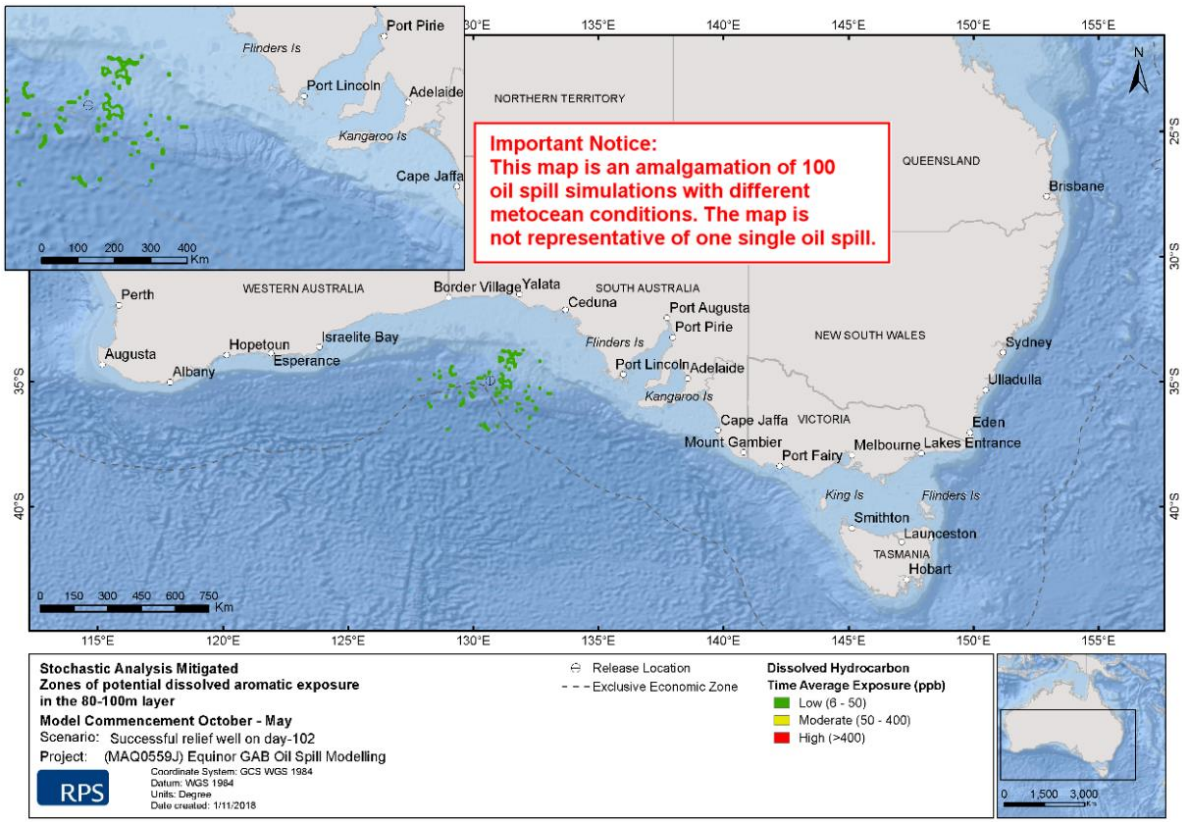


Figure 78: Zones of potential dissolved hydrocarbon time averaged exposure in the 80-100 m depth layer for the unmitigated (upper image) and mitigated (lower image) cases. Images were produced from the results of 100 oil spill simulations per case commencing between October and May conditions. Each simulation represents an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

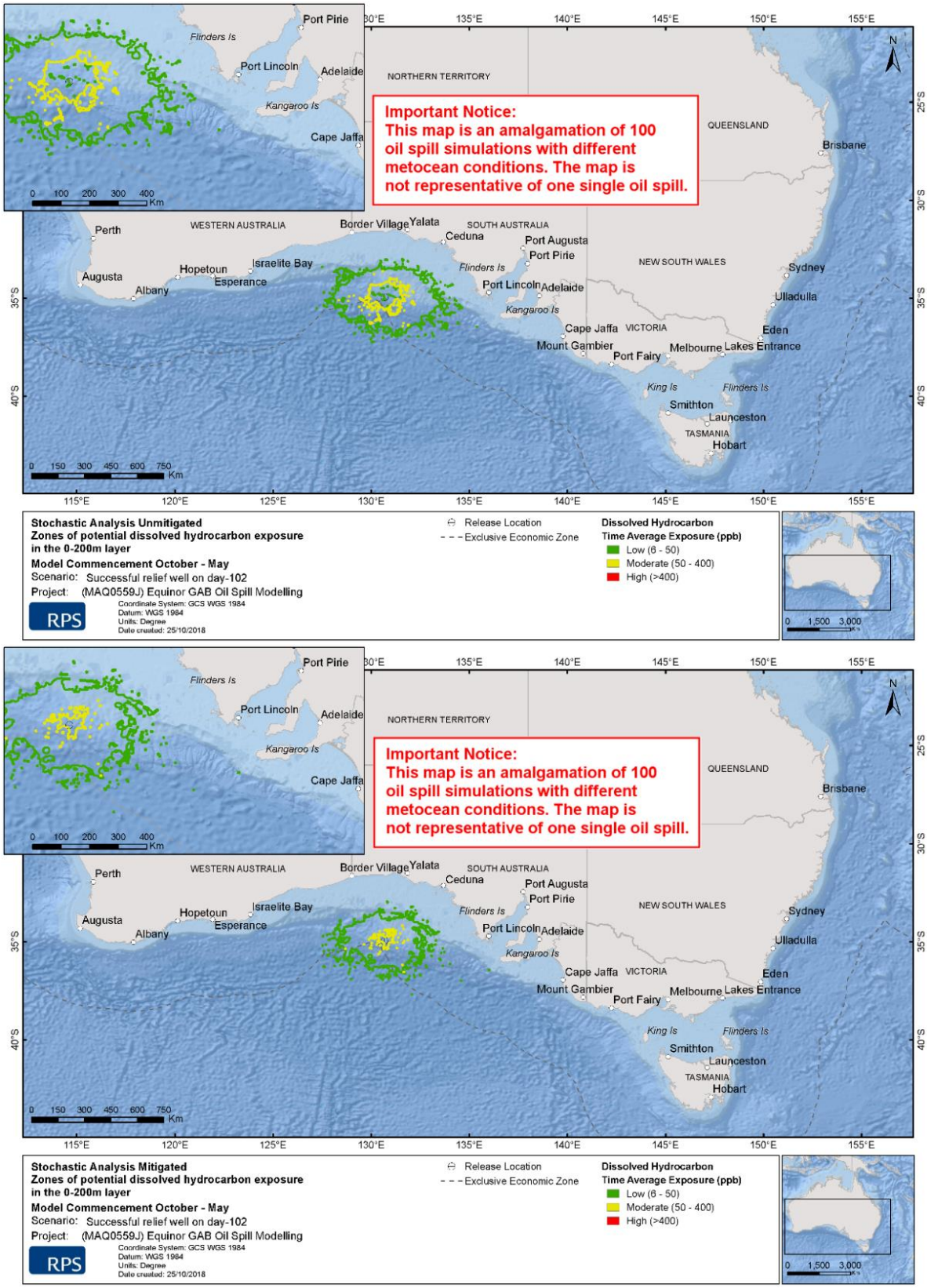


Figure 79: Zones of potential dissolved hydrocarbon time averaged exposure in the 0-200 m depth layer for the unmitigated (upper image) and mitigated (lower image) cases. Images were produced from the results of 100 oil spill simulations per case commencing between October and May conditions. Each simulation represents an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

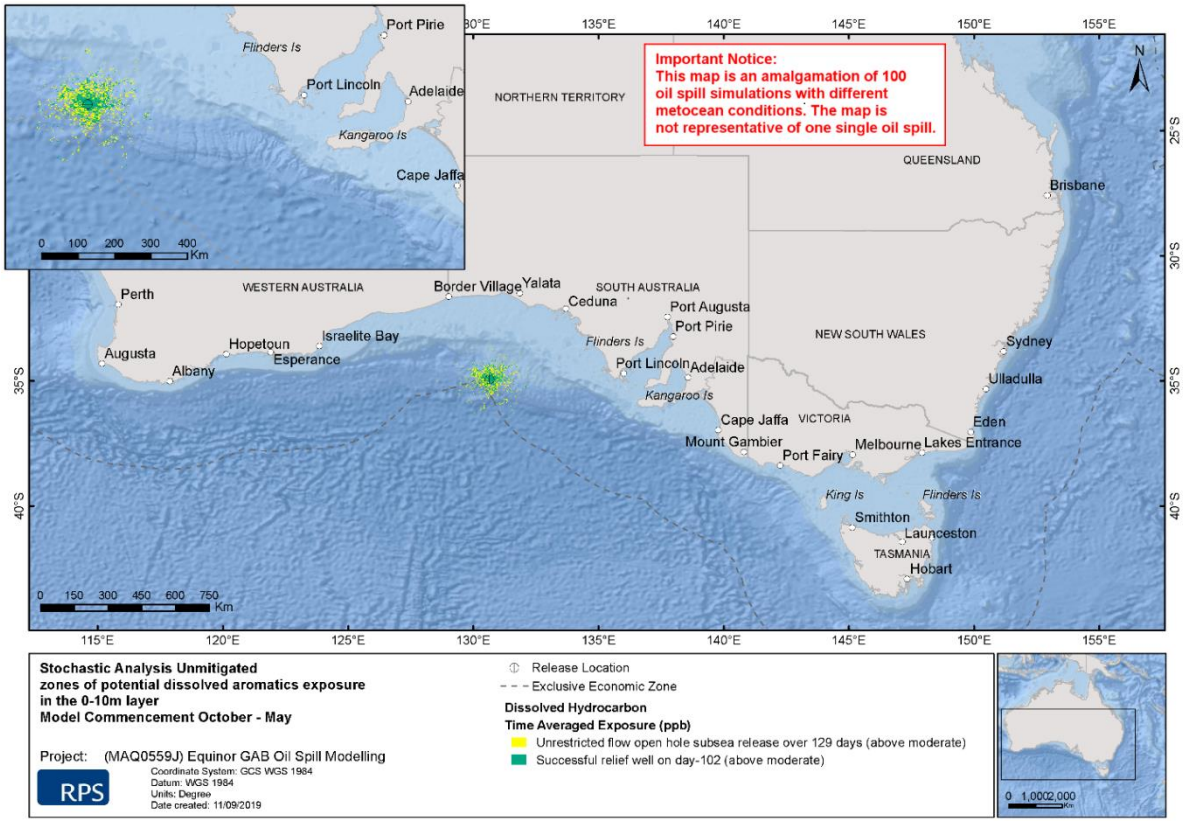


Figure 80 Comparison of the dissolved hydrocarbon exposure zones (at and above the moderate threshold) in the 0–10 m layer for the unmitigated WCCD and WCD scenarios. Image is produced from the results of 100 oil spill simulations commencing during summer conditions (October to May).

11.2 Single oil spill simulations

All 100 unmitigated modelling results for the unrestricted annulus flow over 102 days were reviewed and the following oil spill simulations were identified and are presented below:

a. Fastest time before oil contact to shorelines (see Section 11.2.1)

b. Greatest volume of oil ashore (see Section 11.2.2)

c. Greatest volume of oil ashore based on a state specific basis (see Sections 11.2.2.1 to 11.2.2.5).

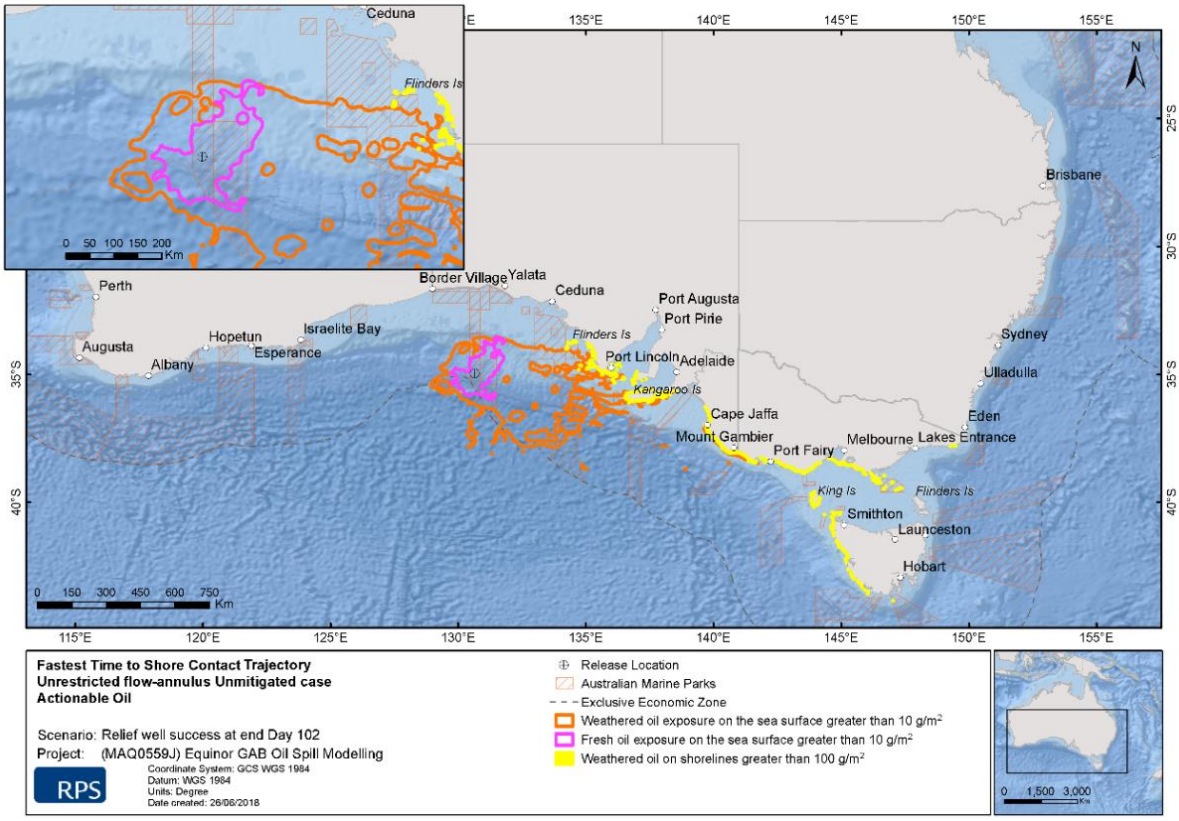
To assess the potential change (if any) for the proposed mitigation measures, the same start times were used as per the identified unmitigated oil spill simulations, although the surface and subsea dispersant were included. Aerial surface dispersant was applied from Day 2 until there was no fresh surface oil amenable to dispersant application; and SSDI was applied from Day 9 to Day 102.

11.2.1 Fastest time before oil contact to shorelines

From the 100 unmitigated simulations, the spill commencing 30 May 2011 at 20:00 hrs (run 81) was identified to result in the fastest (i.e. minimum) time before oil contact to shorelines.

To assess the potential change (if any) for the proposed mitigation methods, the same start time was used (30 May 2011 at 20:00 hrs), although the model inputs were revised to include aerial dispersant from Day 2 until Day 103; and SSDI from Day 9 to Day 102.

Figure 81 shows the extent of oil at actionable thresholds for the unmitigated and mitigated modelling results over the entire 162-day simulation period.



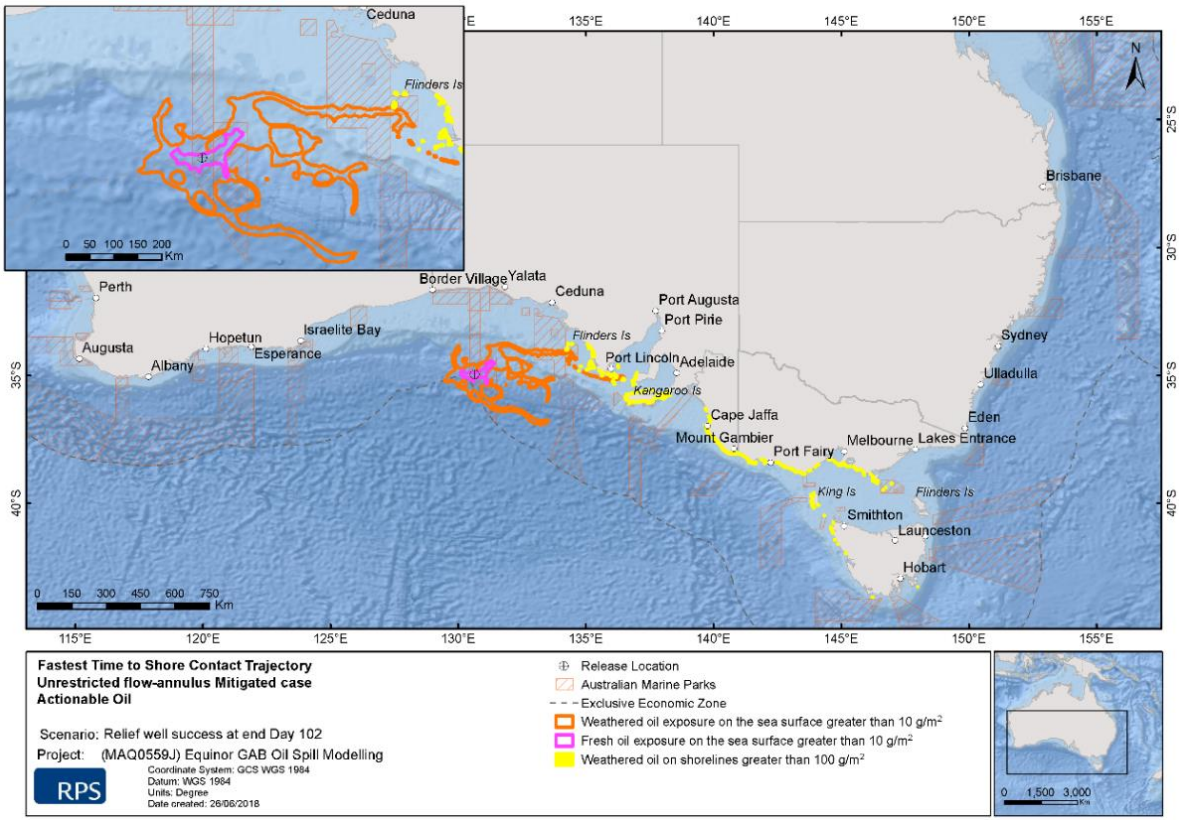


Figure 81: Actionable oil for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Figure 82 shows maps of sea surface exposure for the unmitigated and mitigated modelling cases. Figure 83 illustrates the shoreline loading for the two cases.

Figure 84 and Figure 85 show maps of potential entrained hydrocarbon exposure (time averaged) and dissolved hydrocarbon oil exposure in the 0-10 m depth, respectively, for the unmitigated and mitigated modelling results.

Figure 86 presents the three-dimensional profile of the maximum potential entrained hydrocarbon exposure (time averaged) for the unmitigated and mitigated modelling results.

Figure 87 shows graphs of the mass of oil ashore above each threshold (low, moderate and high) for the unmitigated and mitigated modelling results. Initial shoreline contact was predicted to occur during day 22 for both the unmitigated and mitigated cases and in both instances at high concentrations (i.e. >1,000 g/m^2). For both cases, the concentrations were at or above 100 g/m^2. At day 50, 100 and 162 the volume ashore greater than 100 g/m^2 for the unmitigated case was 9,789 m^3, 30,739 m^3 and 88,483 m^3. While the volume ashore greater than 100 g/m^2 at day 50, 100 and 162 for the mitigated case was almost half at 5,940 m^3, 13,100 m^3 and 27,904 m^3, respectively.

Figure 88 is a graph displaying the area of sea surface exposure and length of shoreline oiled for the unmitigated and mitigated modelling results. Under the unmitigated case, the area of visible oil on the surface steadily increased before peaking at day 98 at 76,506 km^2 and declining thereafter to 50,060 km^2 by day 162. Alternatively, for the mitigated case the maximum area coverage of visible sea surface oil occurred at day 110 (19,873 km^2) and by day 162 the coverage of visible sea surface oil was predicted to be 11,263 km^2. The unmitigated and mitigated results showed that the oil on the shorelines was at actionable levels at day 22. By the end of the simulation at day 162, the length of actionable shoreline oil was 2,012 km and 1,469 km for the unmitigated and mitigated cases, respectively. The maximum sea surface area of actionable oil for unmitigated and mitigated cases was 132 km^2 and 495 km^2, respectively, which occurred at day 32 and day 16, respectively.

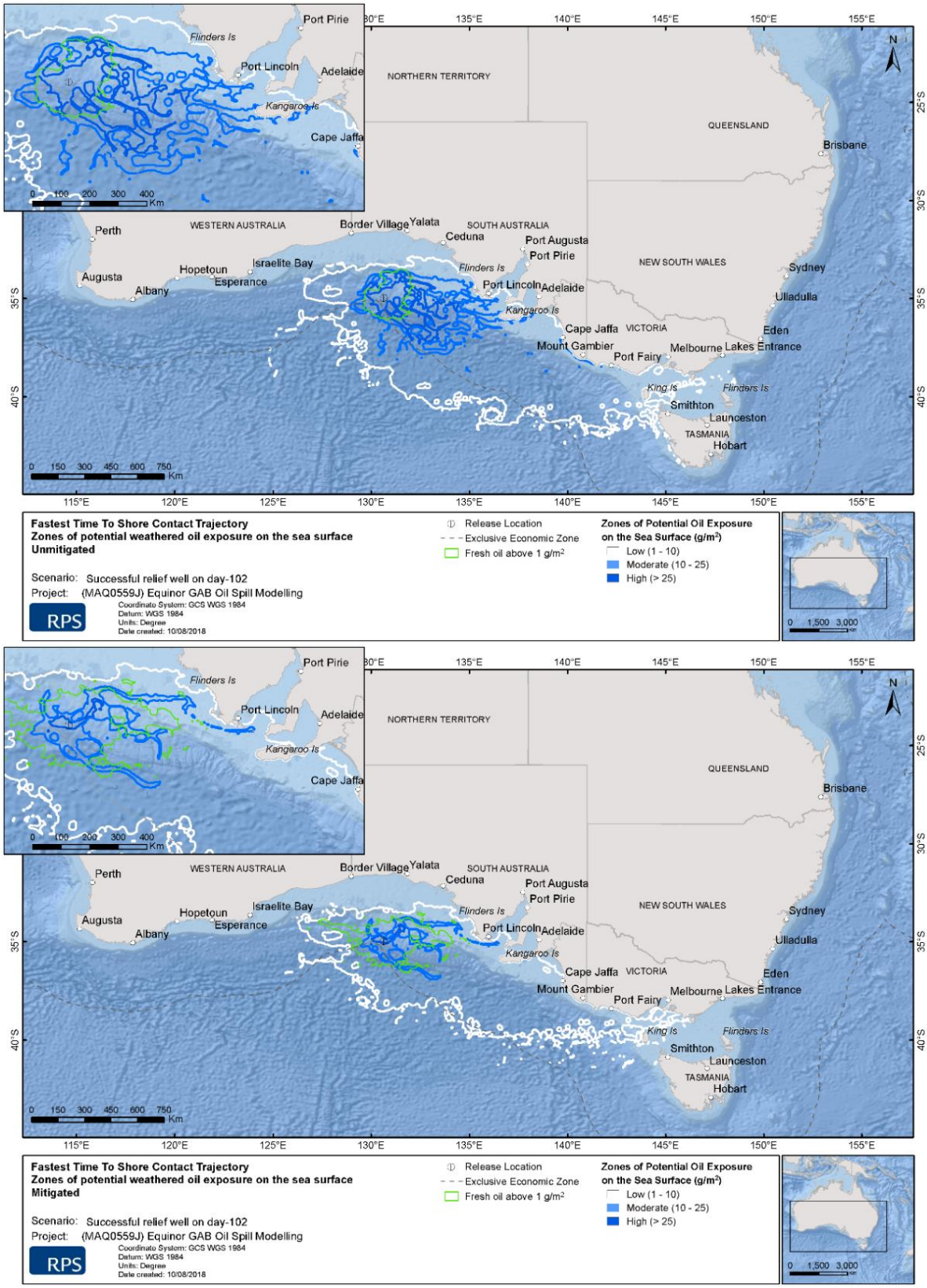


Figure 82: Oil exposure on the sea surface for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

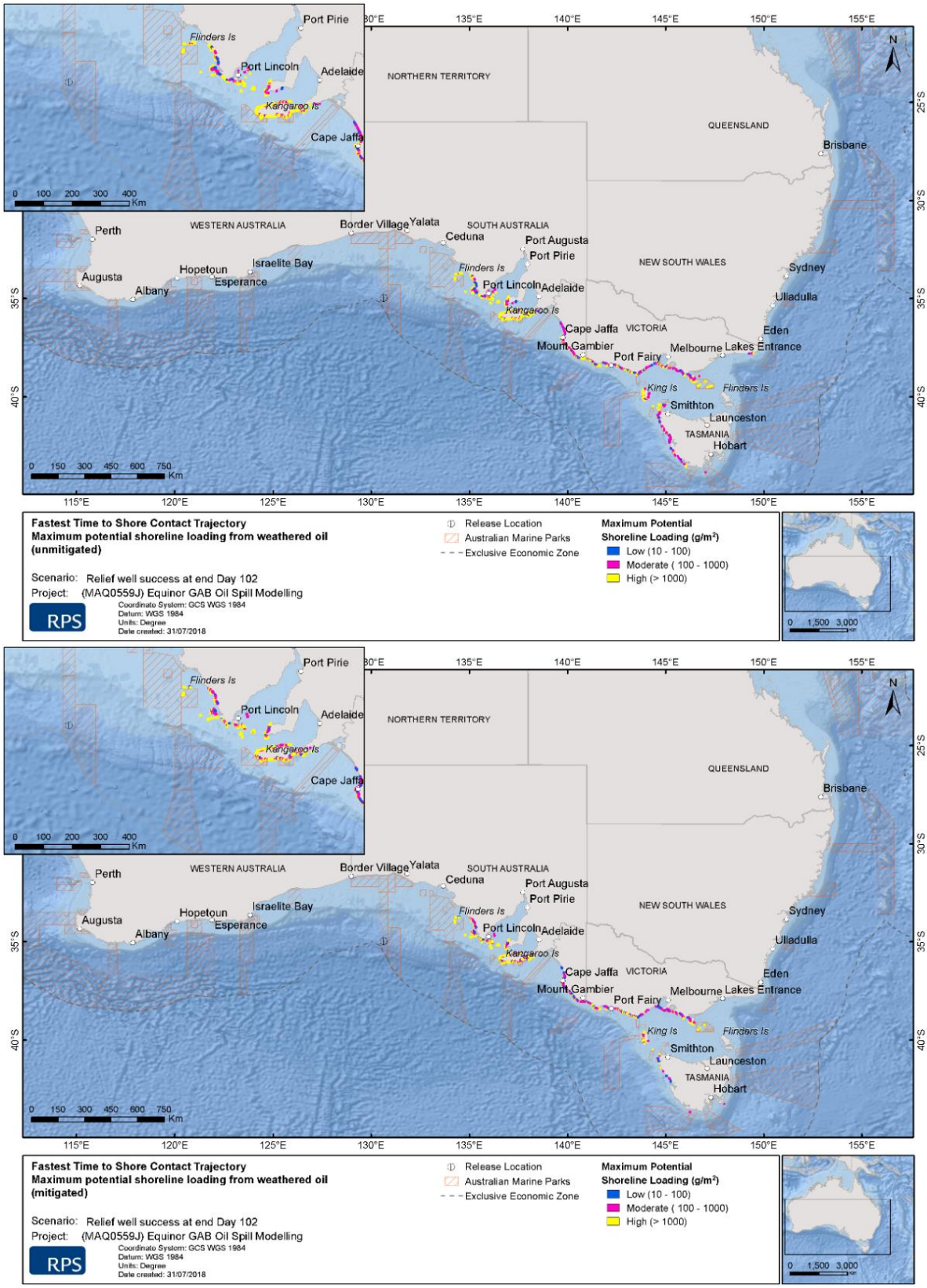


Figure 83: Shoreline loading for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Results are based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

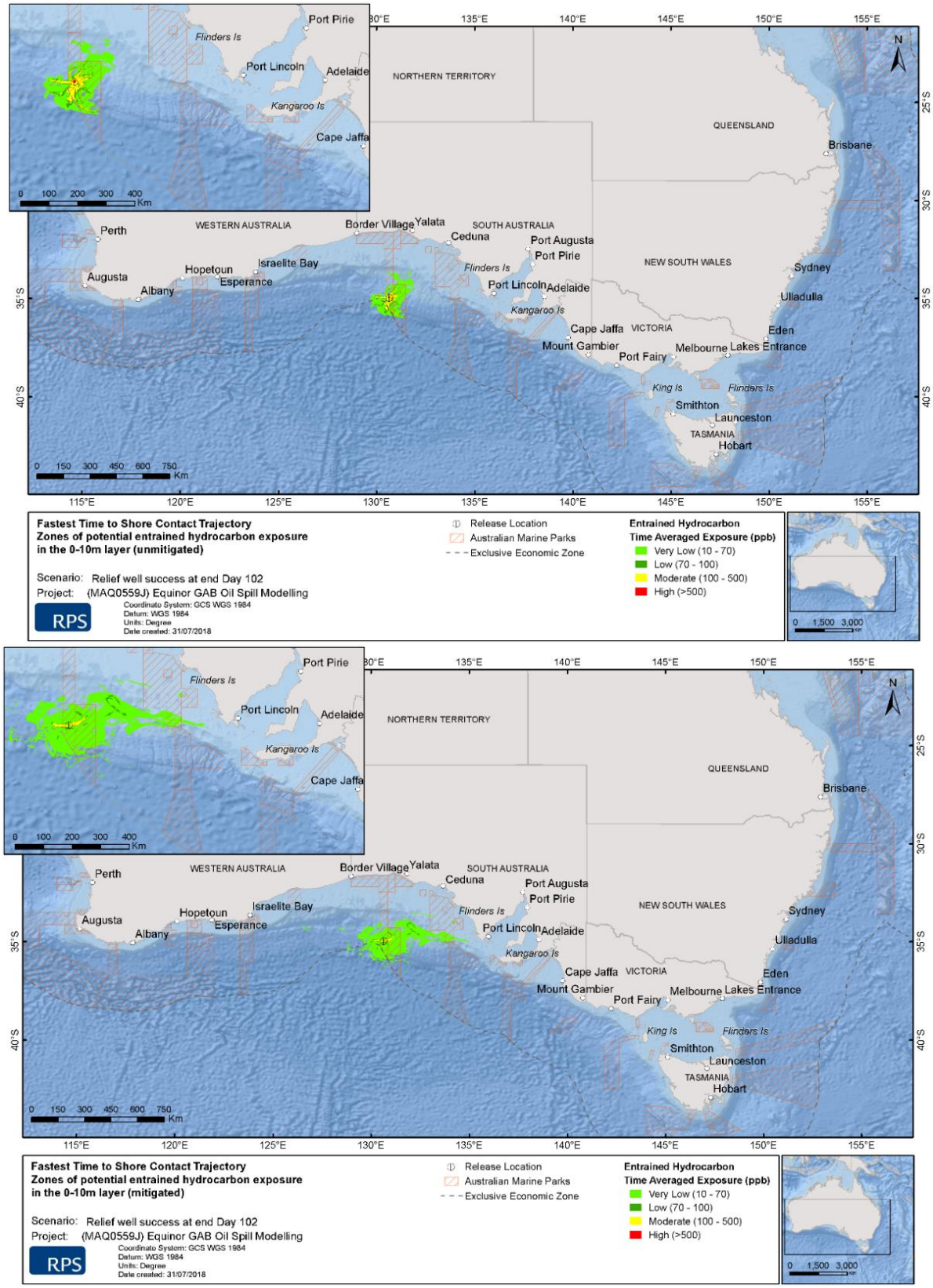


Figure 84: Potential entrained hydrocarbon exposure (time averaged) in the 0-10 m layer for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

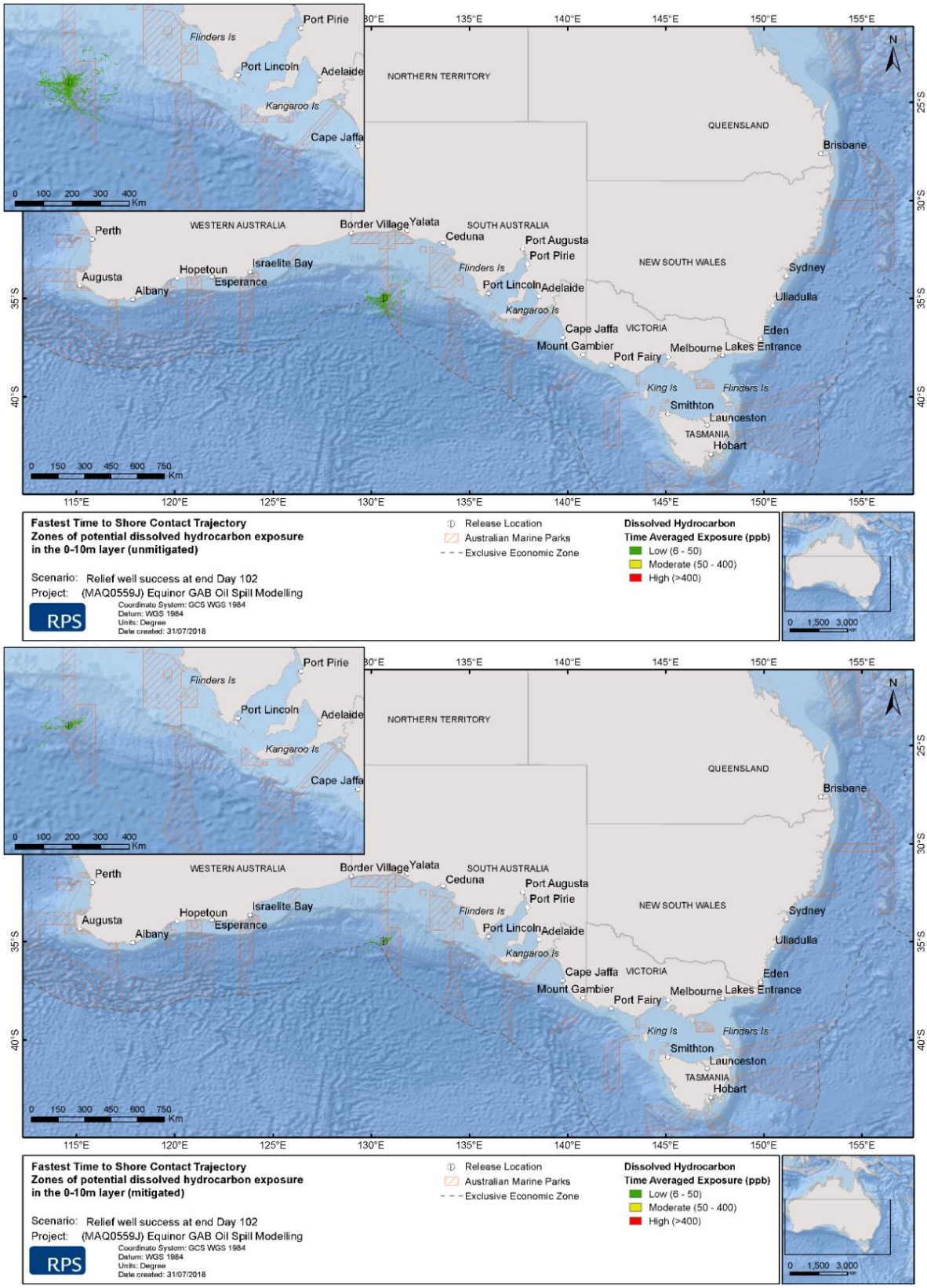
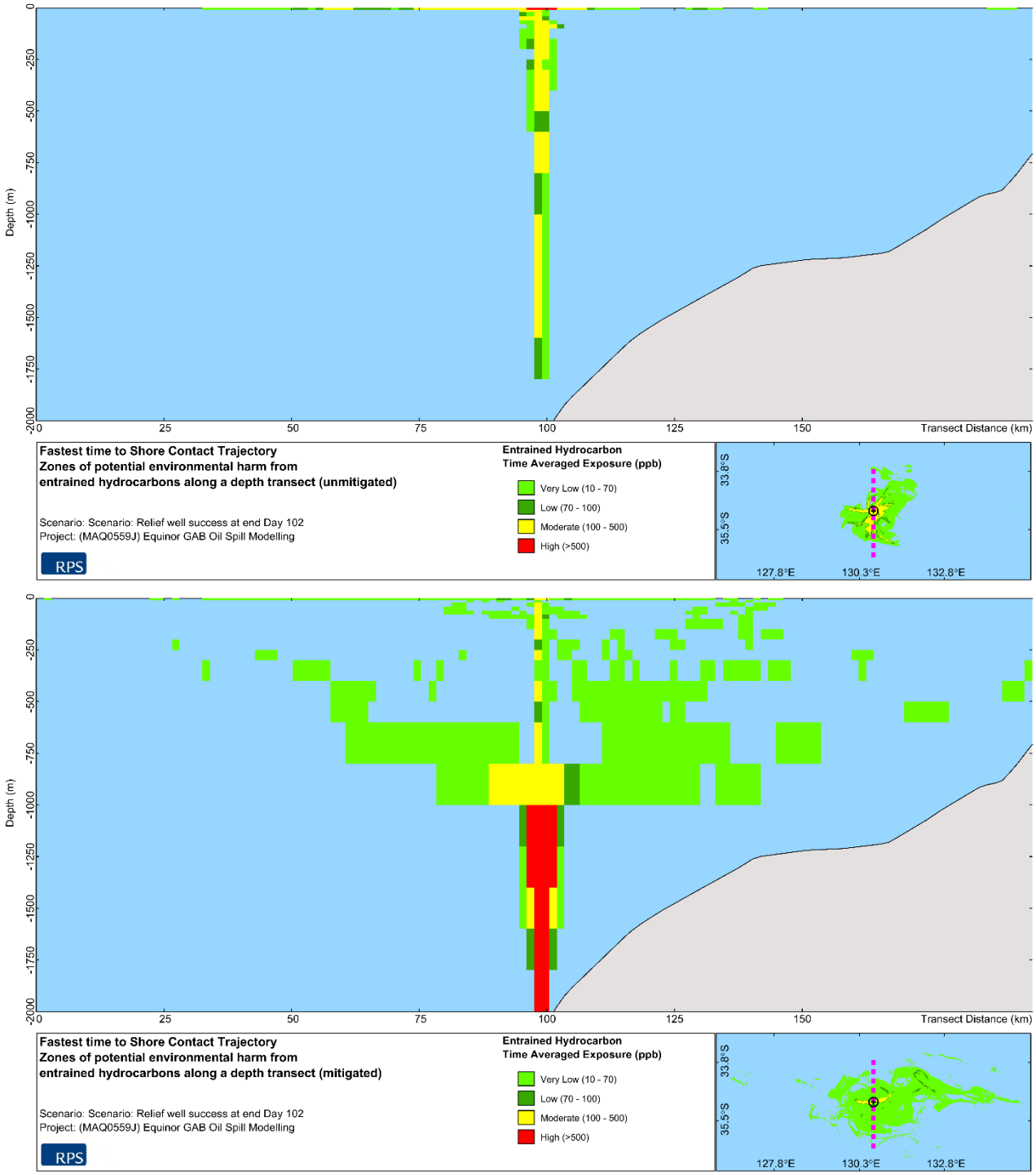
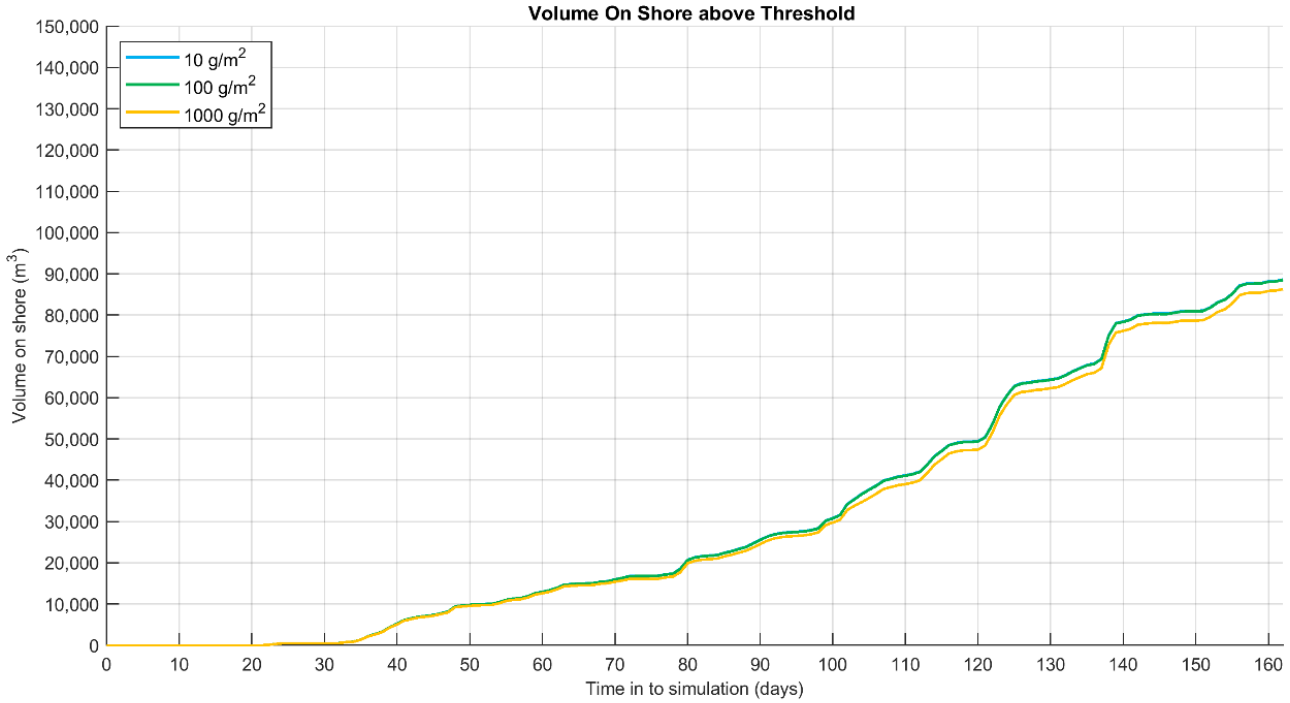


Figure 85: Potential dissolved hydrocarbon exposure (time averaged) in the 0-10 m layer for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days



Note the distance scales are slightly different

Figure 86: Three-dimensional profiles of the maximum potential entrained hydrocarbon exposure (time averaged) for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days



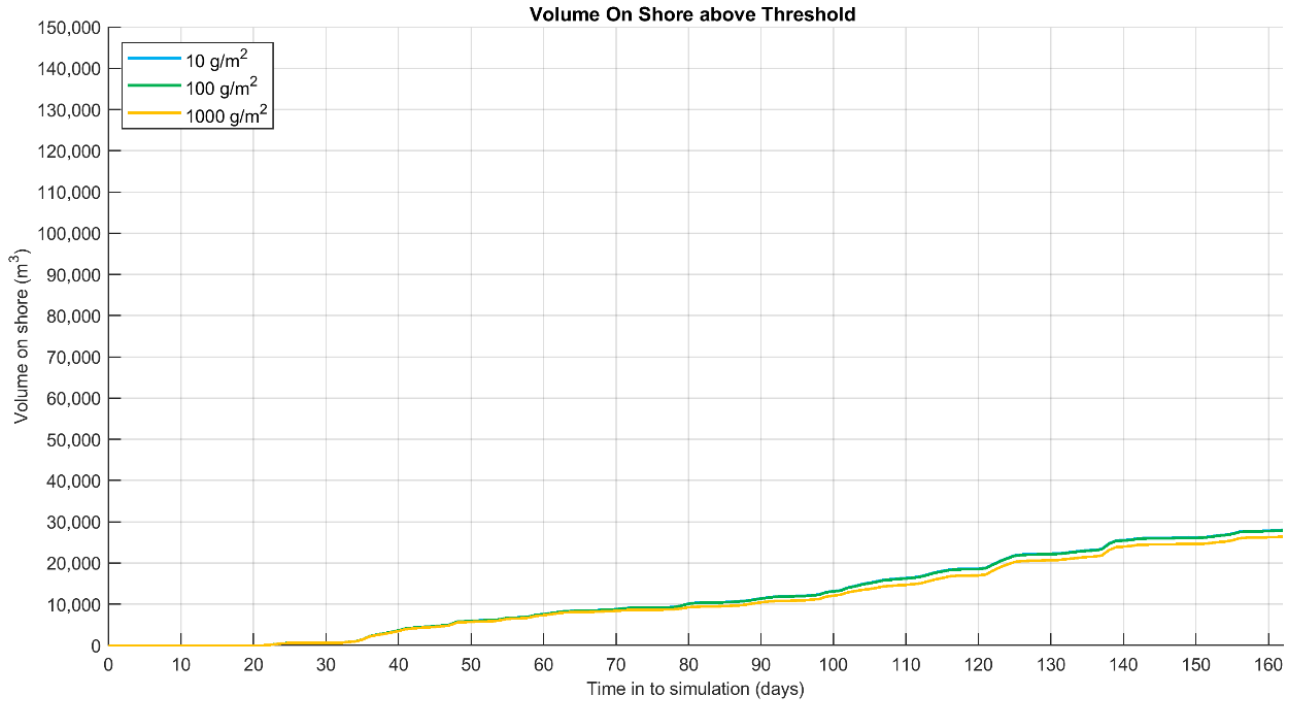


Figure 87: Mass of oil ashore over time, above each threshold, for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

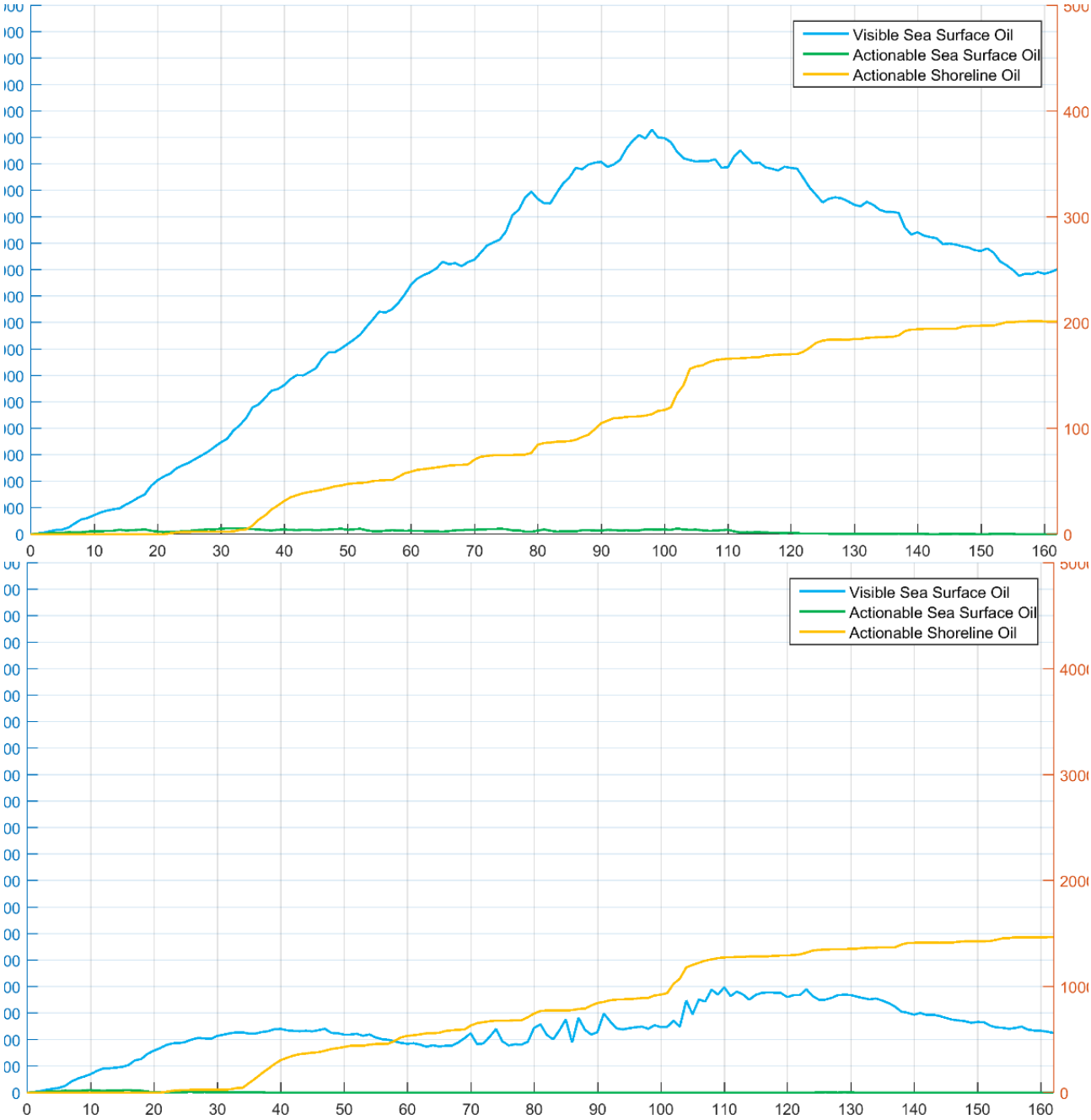


Figure 88: Area of sea surface exposure and length of shoreline oiled for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Figure 89 shows the predicted weathering and fates graphs for the unmitigated and mitigated modelling results. By the end of the unmitigated simulation (day 162), 422,633 m³ had evaporated and 68,692 m³ had decayed. In comparison, for the mitigated simulation, 93,063 m³ and 463,168 m³ had evaporated and decayed, respectively. By day 162, the volume of weathered crude oil remaining ashore was 89,038 m³ and 28,712 m³ for the unmitigated and mitigated modelling, respectively. Furthermore, 104,118 m³ and 40,838 m³ of weathered crude remained on the sea surface for the unmitigated and mitigated simulations, respectively, while 182 m³ and 56,788 m³ was predicted to remain entrained in the water column, respectively.

Table 58 provides a comparison of the mass balance at day 102 (end of the release) and 162 (end of the simulation), for the unmitigated and mitigated cases. The volume of surface fresh oil at day 102 for the unmitigated and mitigated cases were 6,157 m^3 and 3,501 m^3, respectively. While, no fresh oil was predicted to remain on the sea surface under either at the end of the simulations (day 162). At day 102, 166,395 m^3 and 40,052 m^3 of weathered oil was predicted to occur on the sea surface for the unmitigated and mitigated cases, respectively. There was no fresh oil predicted to accumulate on the shorelines on day 102 or 162 for either simulation. Alternatively, volumes of weathered oil ashore at day 102 was 2 ½ times greater for the unmitigated simulation (34,421 m^3) compared to the mitigated simulation (14,279 m^3). Alternatively, the volume of entrained oil for the mitigated case was significantly higher at 157,633 m^3 at day 102 compared to the unmitigated case at 3,143 m^3.

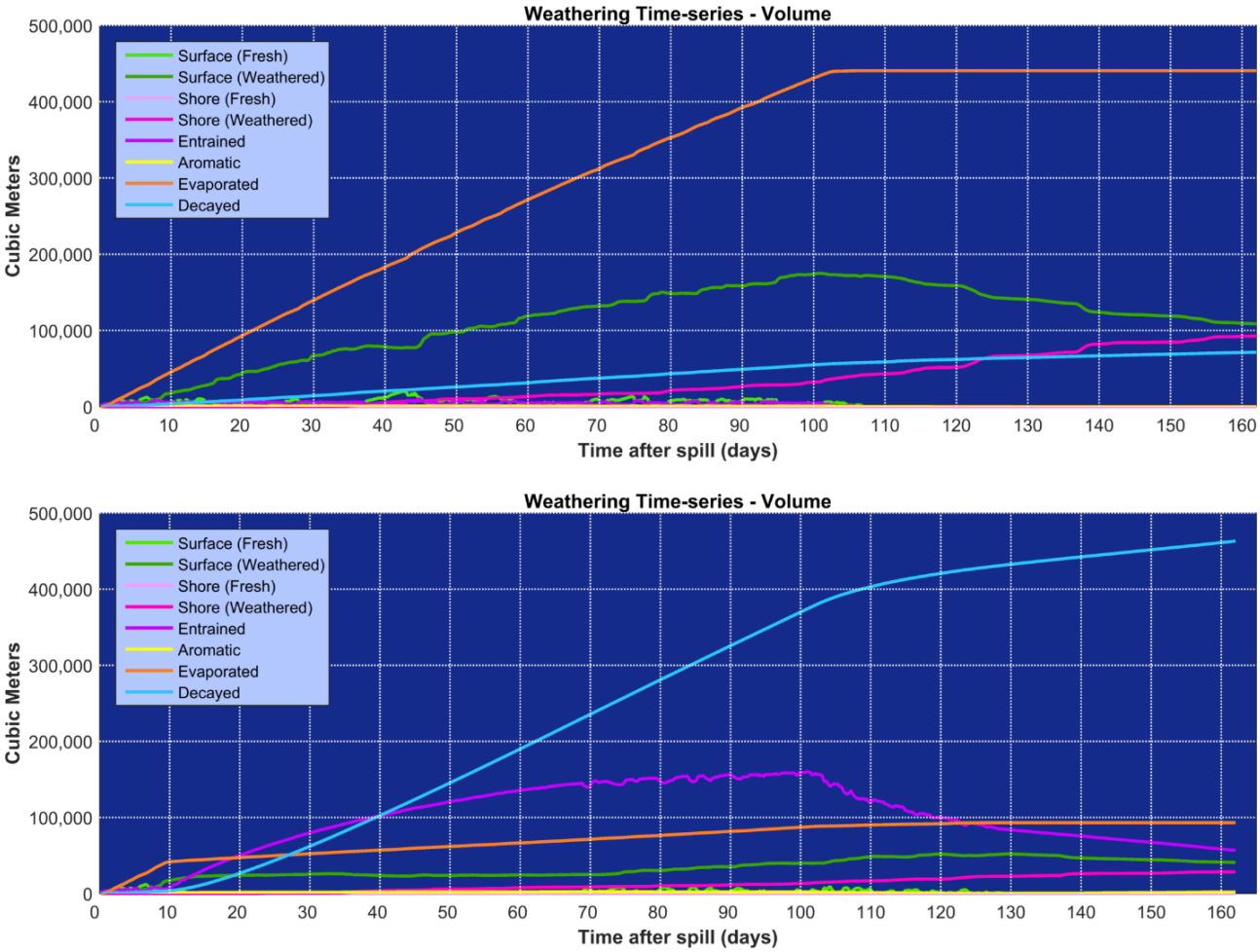


Figure 89: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases over the 162-day period. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Table 58: Summary of the mass balance at day 102 and 162, for the unmitigated and mitigated cases. Based on the simulation resulting in the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Exposure metrics	At Day-102 the end of the release		At Day-162 end of the simulation	
	Unmitigated	Mitigated	Unmitigated	Mitigated
Surface Fresh (m^3)	6,157	3,501	0	0
Surface Weathered (m^3)	166,395	40,052	104,118	40,838
Ashore Fresh (m^3)	0	0	0	0
Ashore weathered (m^3)	34,421	14,279	89,038	28,712
Entrained (m^3)	3,143	157,633	182	56,788
Aromatic (m^3)	583	2,191	0	2,084
Evaporated (m^3)	420,107	88,234	422,633	93,062
Decay (m^3)	53,868	378,767	68,692	463,160

11.2.2 Greatest volume of oil ashore

From the 100 unmitigated simulations, the spill commencing 20th May 2009 at 04:00 hrs (run 18, see Figure 45) was identified to result in the greatest volume of weathered oil ashore.

To assess the potential change (if any) for the proposed mitigation methods, the same start time was used (20th May 2009 at 04:00 hrs), although the model inputs were revised to include aerial dispersant from Day 2 until until Day 103; and SSDI from the end of Day 9 to Day 102.

Figure 90 the extent of oiling at actionable oil thresholds for the unmitigated and mitigated modelling results over the entire 162-day simulation period.

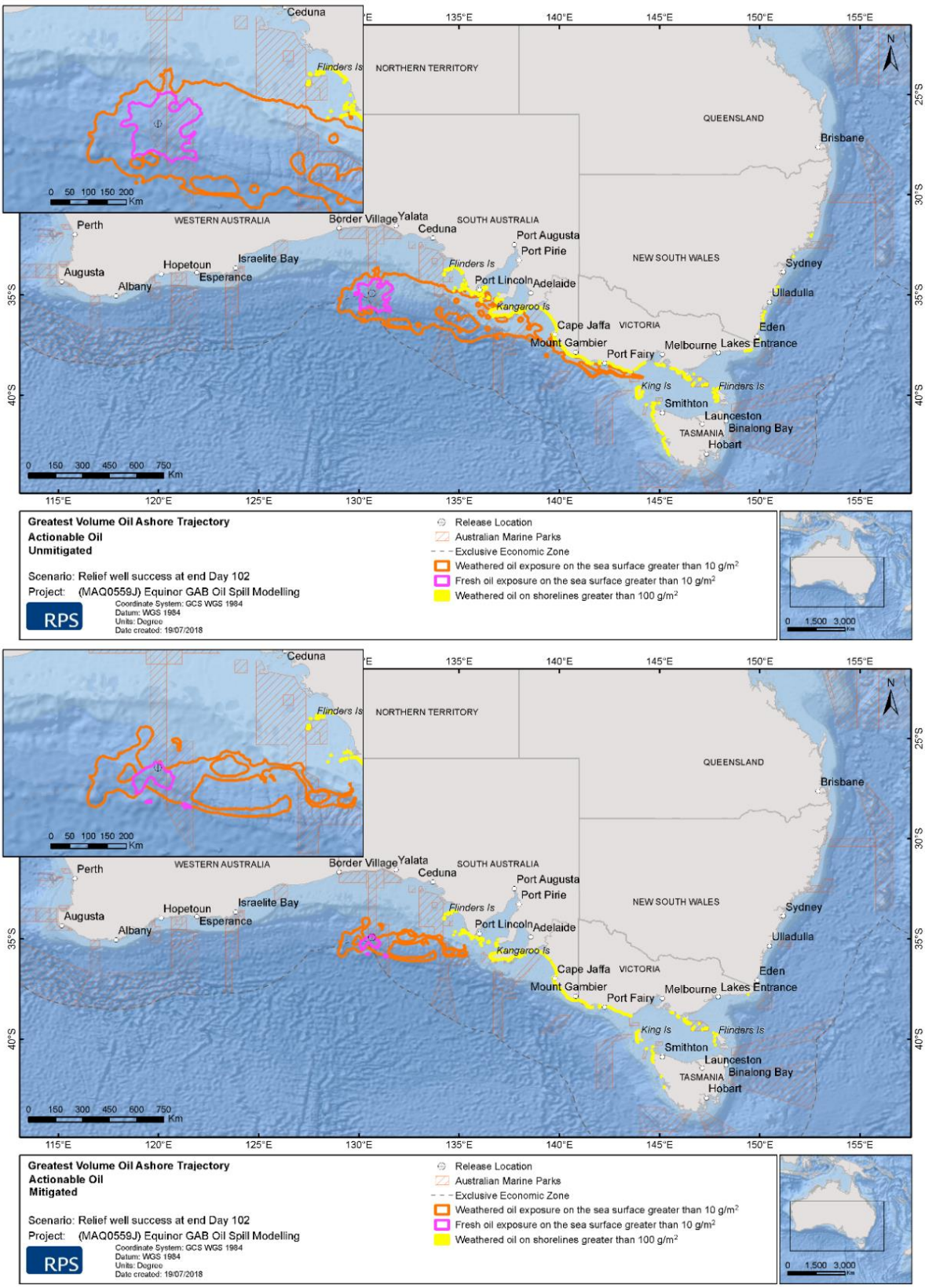


Figure 90: Actionable oil for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil ashore commencing 20 May 2009 at 04:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

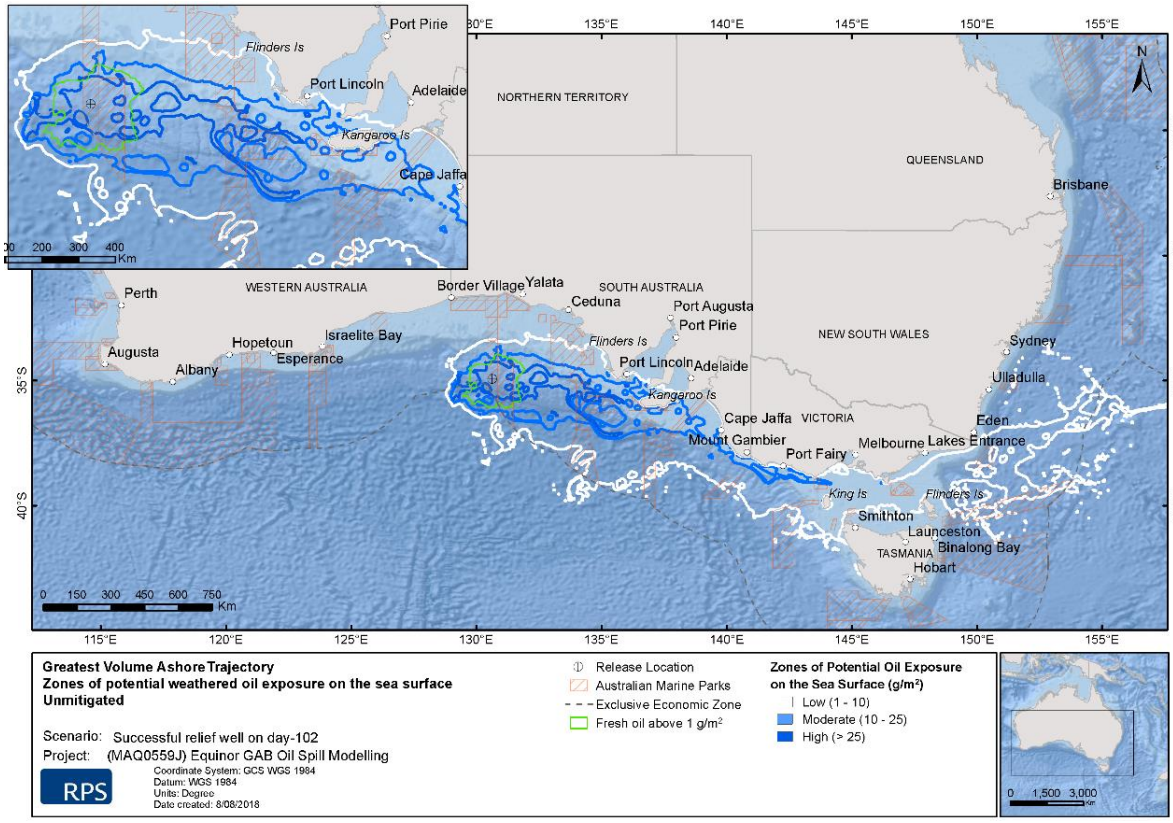
Figure 91 shows maps of sea surface exposure for the unmitigated and mitigated modelling cases.Figure 92 illustrates the shoreline loading for the two cases.

Figure 93 and Figure 94 show maps of potential entrained and dissolved hydrocarbon exposure (time averaged) in the surface waters (0-10 m depth), respectively, for the unmitigated and mitigated modelling results.

Figure 95 presents three-dimensional profile of the maximum potential entrained hydrocarbon exposure (time averaged) for the unmitigated and mitigated modelling results.

Figure 96 shows graphs of the mass of oil ashore above each threshold (low, moderate and high) for the unmitigated and mitigated modelling results. Initial shoreline contact was predicted to occur during day 26 for the unmitigated case and day 21 for the mitigated case and in both instances, high concentrations (i.e. >1,000 g/m^2). For both cases, the concentrations were equal to or above 100 g/m^2. At day 50, 100 and 162 the volume ashore greater than 100 g/m^2 for the unmitigated case was 2,831 m^3, 71,208 m^3 and 147,338 m^3, respectively. While the volume ashore above 100 g/m^2 at day 50, 100 and 162 for the mitigated case was 2,473 m^3, 20,845 m^3 and 44,205 m^3, respectively. The day 162 mass ashore was 3 ½ times less for the mitigated case in comparison to the unmitigated case.

Figure 97 is a graph displaying the area of sea surface exposure and length of shoreline oiled for the unmitigated and mitigated modelling results. Under the unmitigated case the area of visible oil on the surface steadily increased during the release period before peaking at day 88 at 57,254 km^2 and declining thereafter to 10,971 km^2 by day 162. Alternatively, the maximum coverage of visible oil on the sea surface oil for the mitigated simulation occurred at day 100 (19,216 km^2) and by day 162 reduced to 5,729 km^2. The unmitigated and mitigated modelling results showed that oil on the shorelines was at actionable levels at day 26 and day 21, respectively. By the end of the simulation at day 162, the length of actionable shoreline oil was 2,163 km and 1,371 km for the unmitigated and mitigated cases, respectively. The area of actionable oil on the sea surface oil for the unmitigated and mitigated results occurred at day 35 and day 9, respectively. The corresponding areas of coverage on these days were 1,355 km^2 and 406 km^2 for the unmitigated and mitigated cases, respectively.



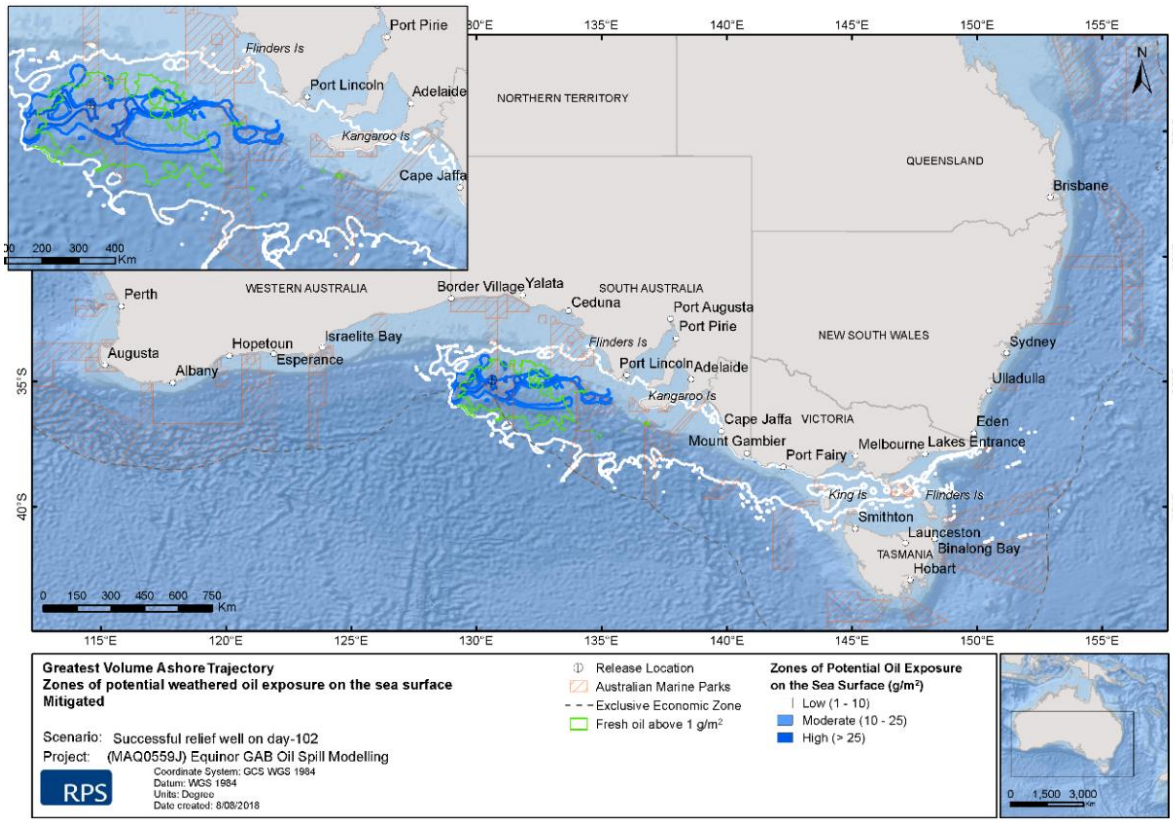


Figure 91: Sea surface exposure for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil ashore commencing 20 May 2009 at 04:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

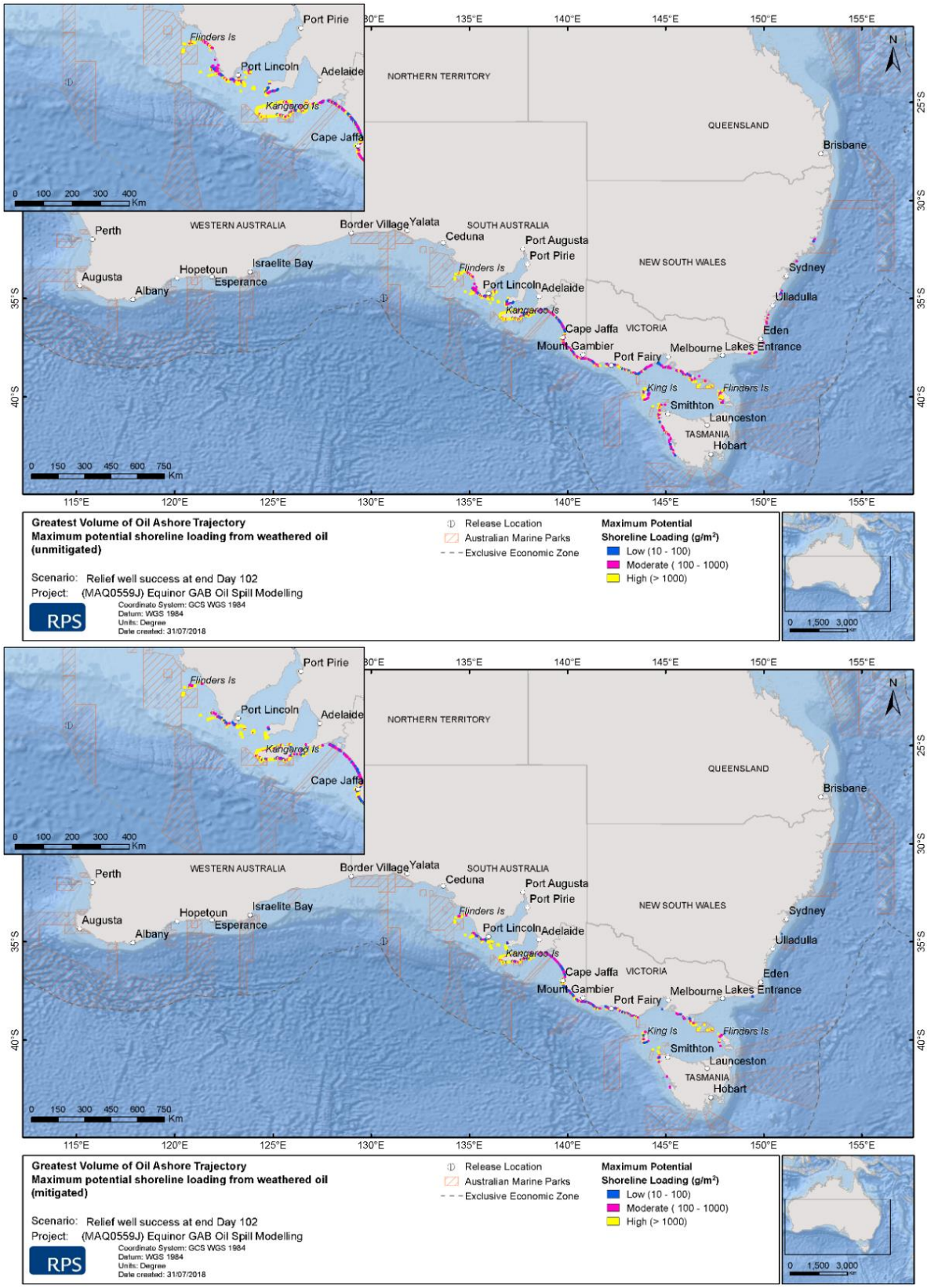


Figure 92: Shoreline loading for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Results are based on the simulation resulting in the greatest volume of weathered oil ashore commencing 20 May 2009 at 04:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

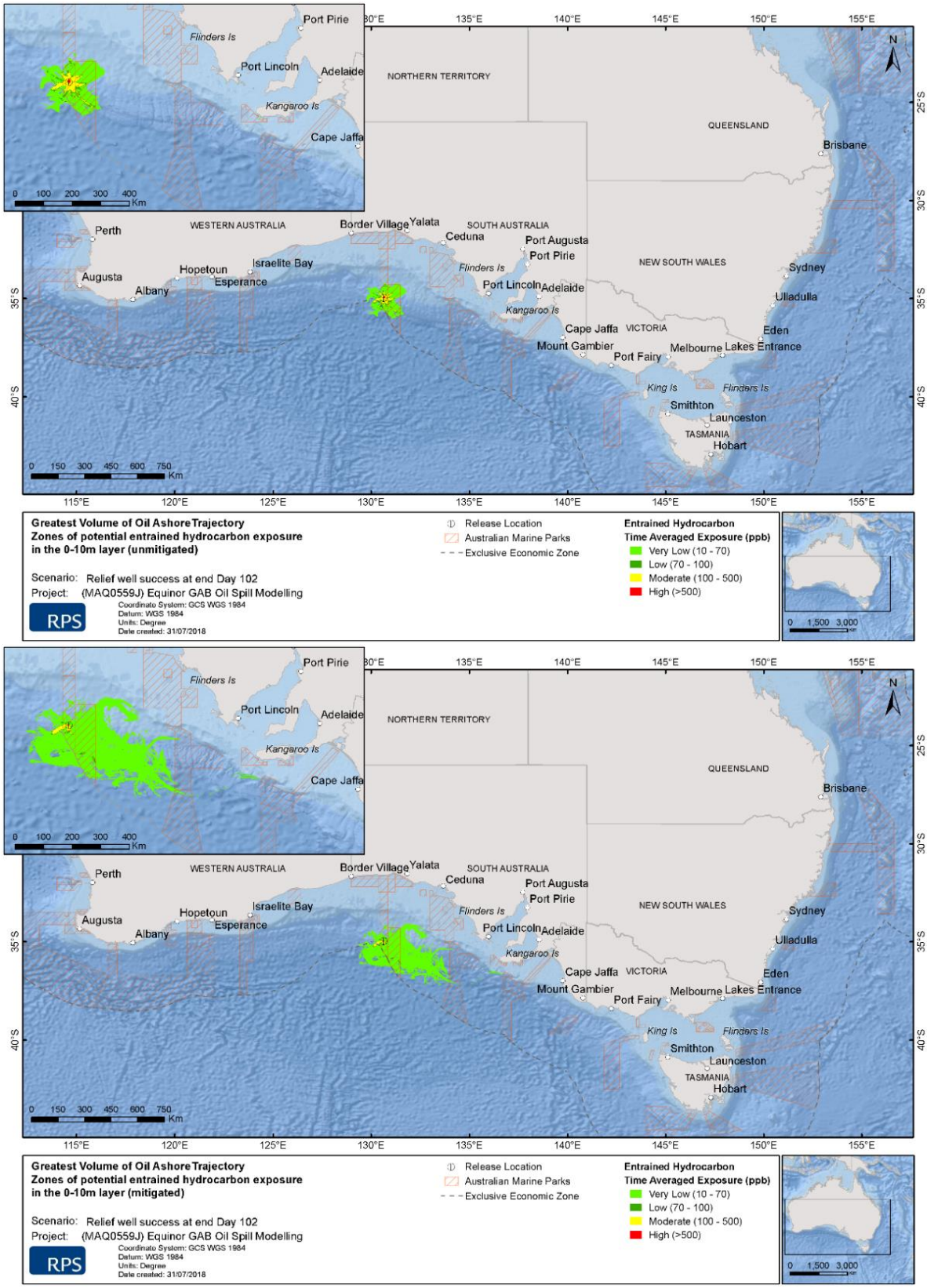


Figure 93: Potential entrained hydrocarbon exposure (time averaged) in the 0-10 m layer for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil ashore commencing 20 May 2009 at 04:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

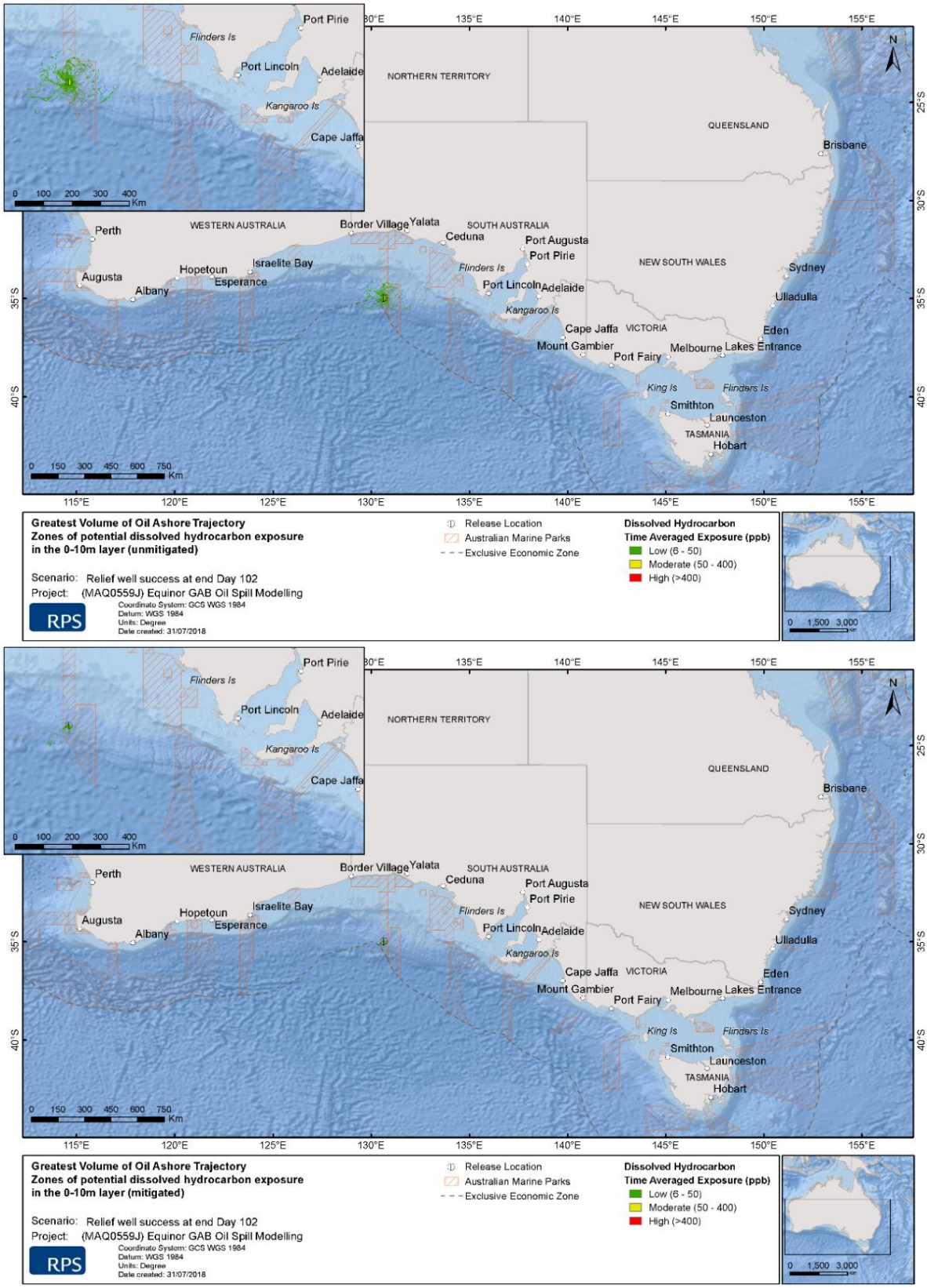
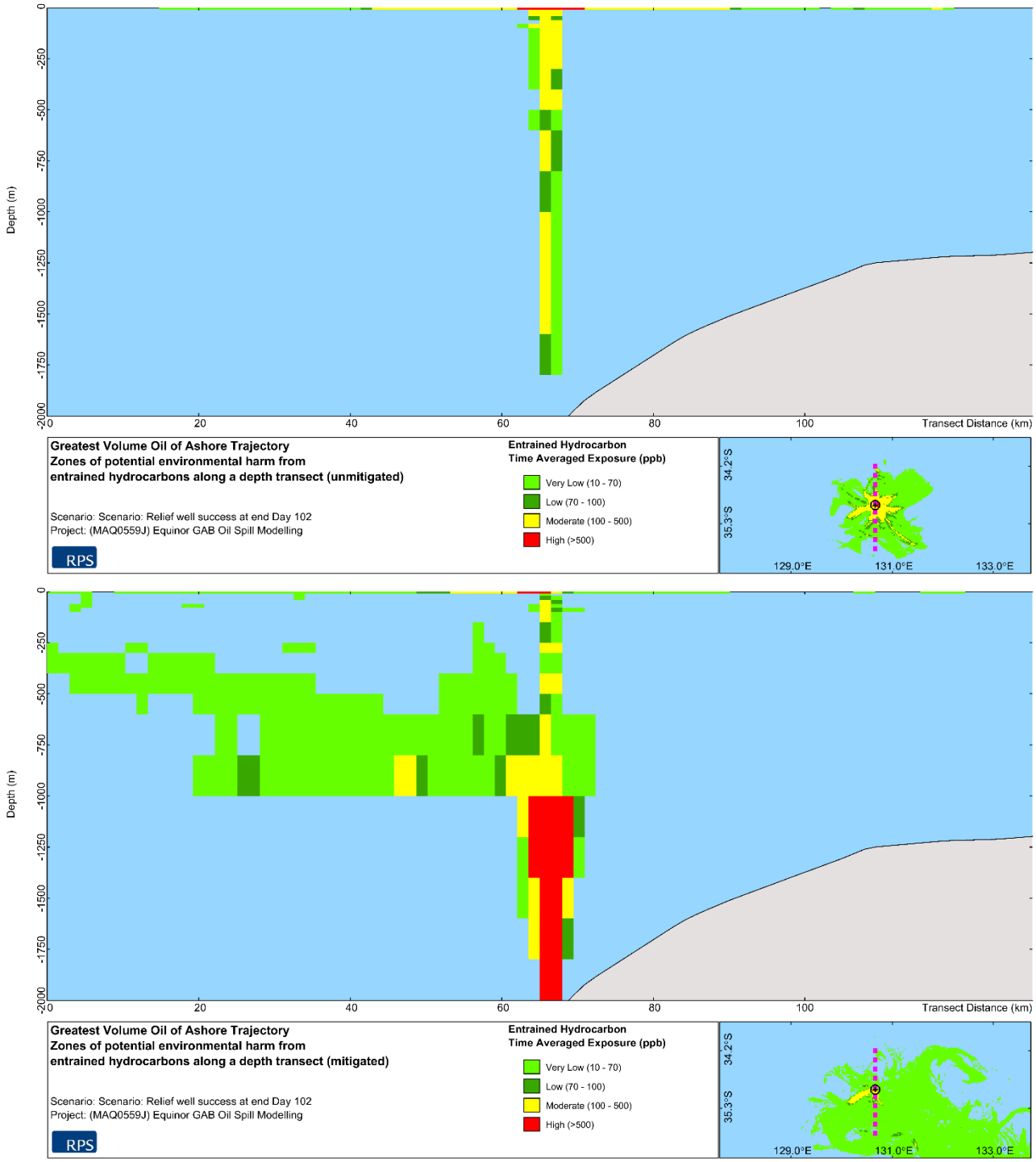
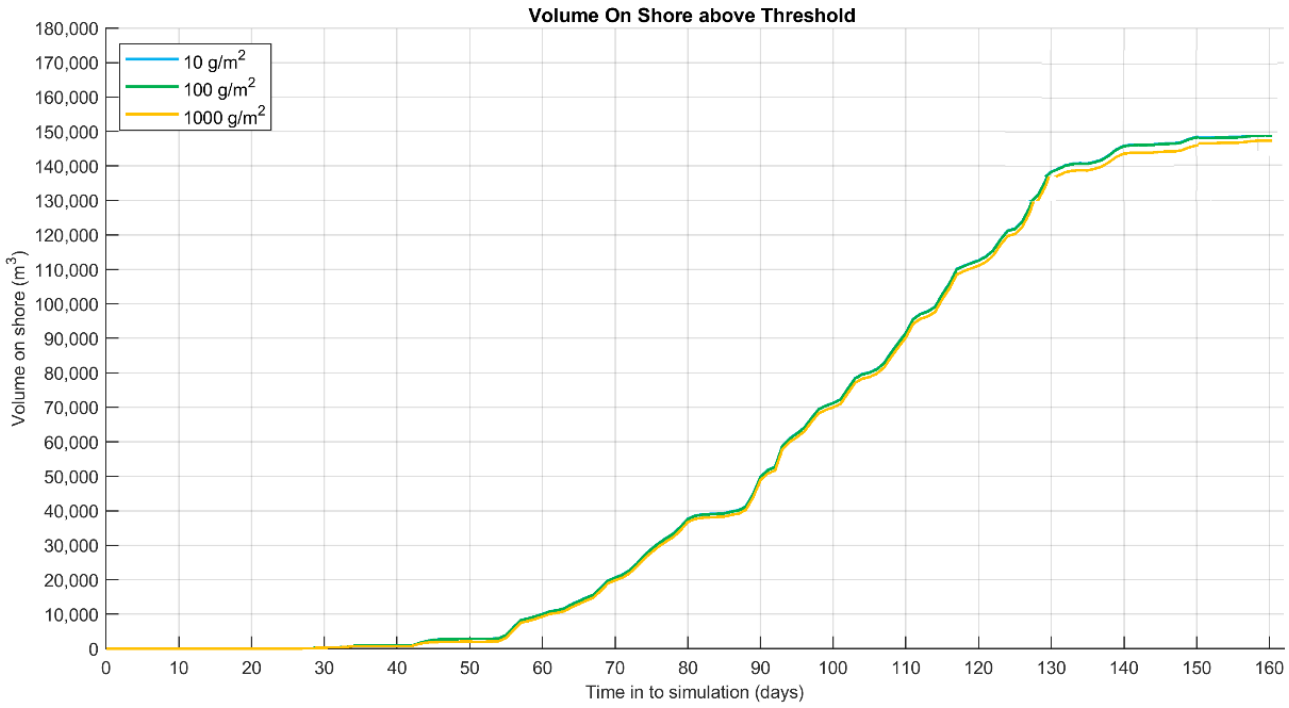


Figure 94: Potential dissolved hydrocarbon exposure (time averaged) in the 0-10 m layer for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil ashore commencing 20 May 2009 at 04:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days and tracked for 162 days



Note the distance scales are different

Figure 95: Three-dimensional profiles of the maximum potential entrained hydrocarbon exposure (time averaged) for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil ashore commencing 20 May 2009 at 04:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days



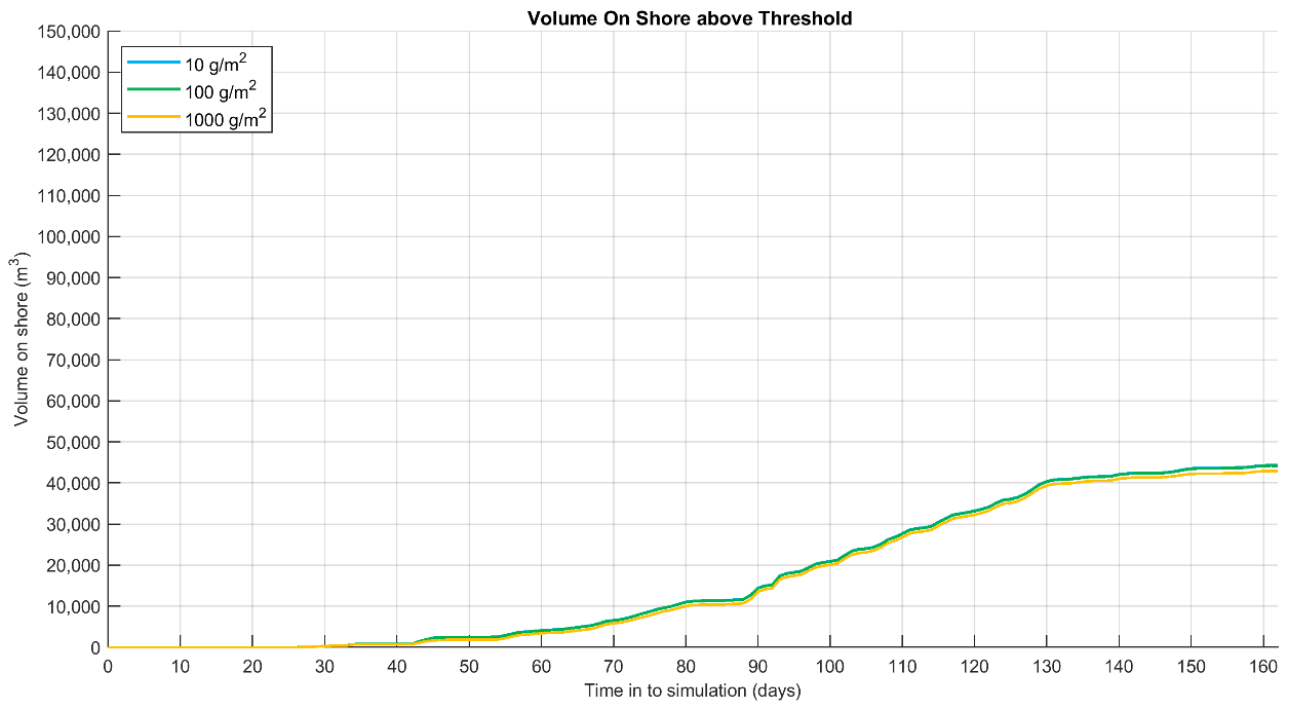


Figure 96: Mass on shore above each threshold for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the greatest volume of weathered oil ashore commencing 20 May 2009 at 04:00 hrs. Modelling examined 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

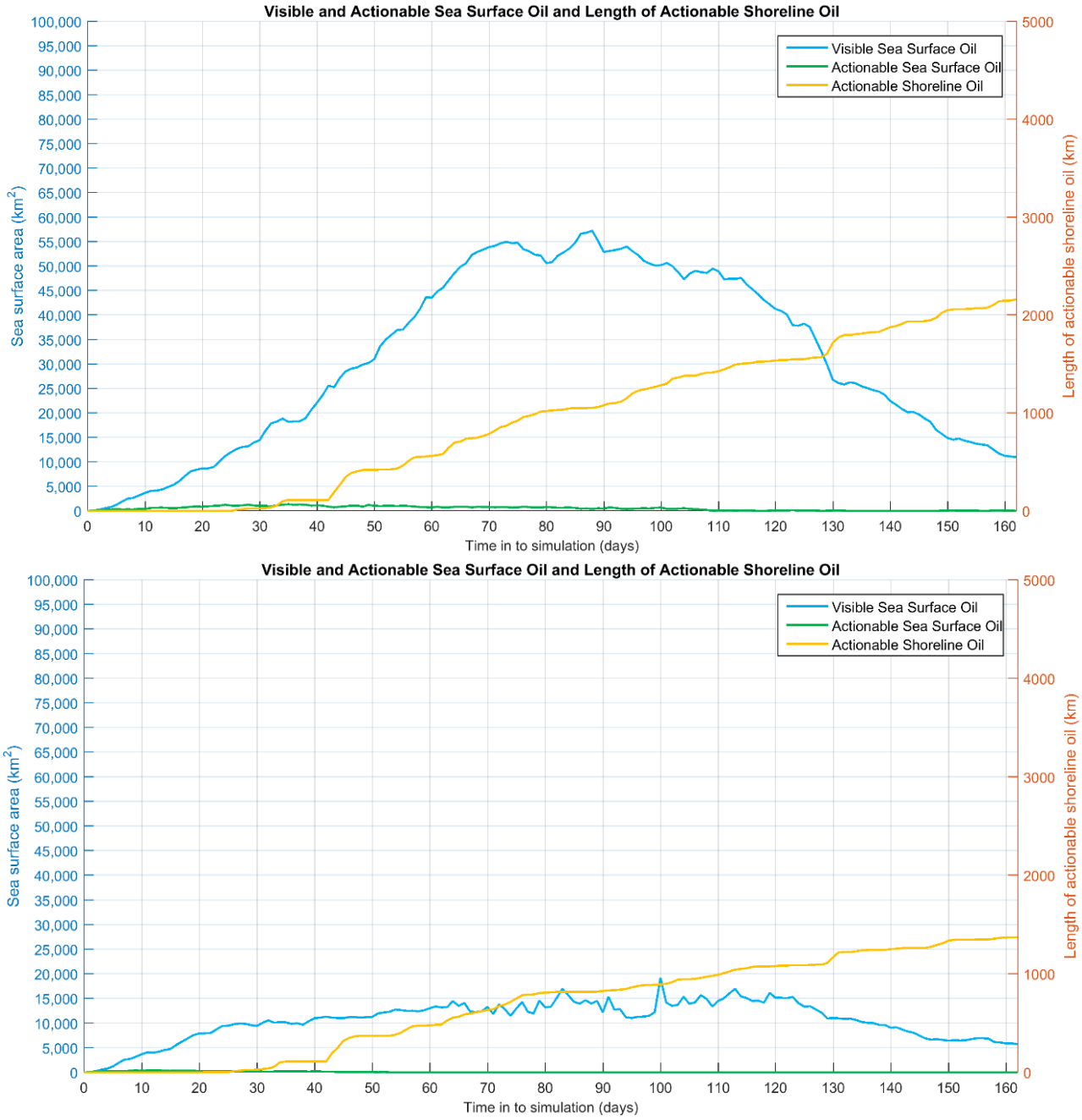


Figure 97: Area of sea surface exposure and length of shoreline oiled for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the greatest volume of weathered oil ashore commencing 20 May 2009 at 04:00 hrs. Modelling examined 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Figure 98 shows the predicted weathering and fates graphs for the unmitigated and mitigated modelling results. By the end of the simulation (day 162), 436,631 m³ and 69,995 m³ had evaporated and decayed, respectively, for the unmitigated model simulation. In comparison, 93,310 m³ and 462,393 m³ had evaporated and decayed, respectively, under the mitigated model conditions. The volume of weathered crude remaining ashore was predicted to be 147,338 m³ and 48,256 m³ for the unmitigated and mitigated modelling, respectively. Furthermore, 31,305 m³ and 23,954 m³ of weathered crude remained on the sea surface for the unmitigated and mitigated modelling, respectively. Entrained oil was higher for the mitigated simulation at 55,525 m³ compared to 181 m³ for the unmitigated simulation.

Table 59 provides a comparison of the mass balance at day 102 and 162, for the unmitigated and mitigated cases. Sea surface exposure to fresh oil at day 102 based on unmitigated and mitigated cases were 5,423 m^3 and 1,120 m^3, respectively. While, no fresh oil was predicted to remain on the sea surface under either unmitigated or mitigated case conditions at the end of the simulations (day 162), 31,305 m^3 and 23,954 m^3 of weathered oil was predicted to occur on the sea surface at day 162 under unmitigated or mitigated case conditions, respectively. At day 102, 121,664 m^3 and 31,501 m^3 of weathered oil was on the sea surface for the unmitigated and mitigated cases, respectively. Shoreline contact by fresh oil was not predicted to occur on day 102 or 162 under unmitigated or mitigated case conditions. Alternatively, volumes of weathered oil ashore for the unmitigated case was 3 ½ times higher than the mitigated cases at day 102 (75,537 m^3 and 22,714 m^3, respectively). At day 102, the mitigated simulation had a higher volume of entrained oil at 159,771 m^3 compared to the unmitigated case at 5,219 m^3.

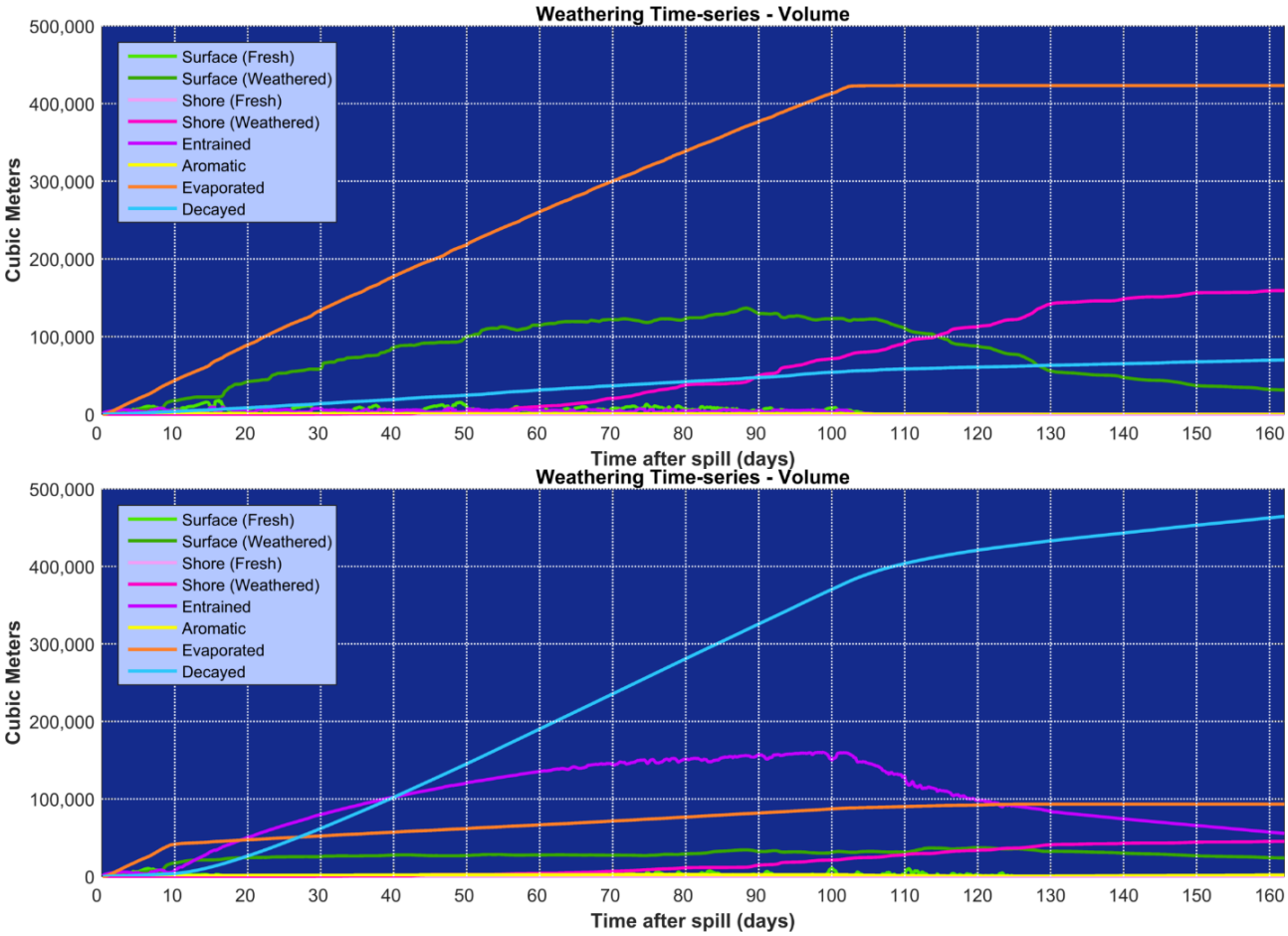


Figure 98: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the greatest volume of weathered oil ashore commencing 20 May 2009 at 04:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Table 59: Summary of the mass balance at day 102 and 162, for the unmitigated and mitigated cases. Based on the simulation resulting in the greatest volume of weathered oil ashore commencing 20 May 2009 at 04:00 hrs, with an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Exposure metrics	At Day-102 the end of the release		At Day-162 end of the simulation	
	Unmitigated	Mitigated (aerial dispersant and SSDI)	Unmitigated	Mitigated
Surface Fresh (m^3)	5,423	1,120	0	0
Surface Weathered (m^3)	121,664	31,501	31,305	23,954
Ashore Fresh (m^3)	0	0	0	0
Ashore weathered (m^3)	75,537	22,714	147,338	48,256
Entrained (m^3)	5,219	159,771	181	55,562
Aromatic (m^3)	577	2,113	0	1,965
Evaporated (m^3)	421,824	88,242	436,631	93,310
Decay (m^3)	55,196	379,979	69,985	462,393

11.2.2.1 Victoria

From the 100 unmitigated simulations, the spill commencing 21st April 2009 at 14:00 hrs (run 75) was identified to result in the greatest volume of weathered oil on the Victorian shoreline.

Figure 99 and Figure 100 show maps of sea surface exposure and shoreline loading, respectively, for the unmitigated and mitigated modelling results. The mitigated case includes aerial dispersant from Day 2 until Day 103; and SSDI from the end of Day 9 to Day 102.

Figure 101 shows the predicted weathering and fates graphs for the unmitigated and mitigated cases. By the end of the simulation (day 162), 422,443 m^3 (~62% of the total release volume) and 72,274 m^3 (~11%) had evaporated and decayed, respectively under unmitigated model conditions. In comparison, 93,503 m^3 (~14%) and 463,989 m^3 (~68%) had evaporated and decayed, respectively, under the mitigated model conditions. The maximum fresh volume ashore during the simulation for the unmitigated and mitigated modelling was 2.4 m^3 and 7.1 m^3, respectively. By day 162, the volume of weathered crude remaining ashore was predicted to be 159,439 m^3 (~23%) and 52,950 m^3 (~8%) for the unmitigated and mitigated modelling, respectively. Furthermore, 30,042 m^3 (~4%) and 16,254 m^3 (~2%) of weathered crude remained on the sea surface for the unmitigated and mitigate simulations, respectively while 168 m^3 (0.02%) and 55,772 m^3 (~8%) was predicted to remain entrained in the water column.

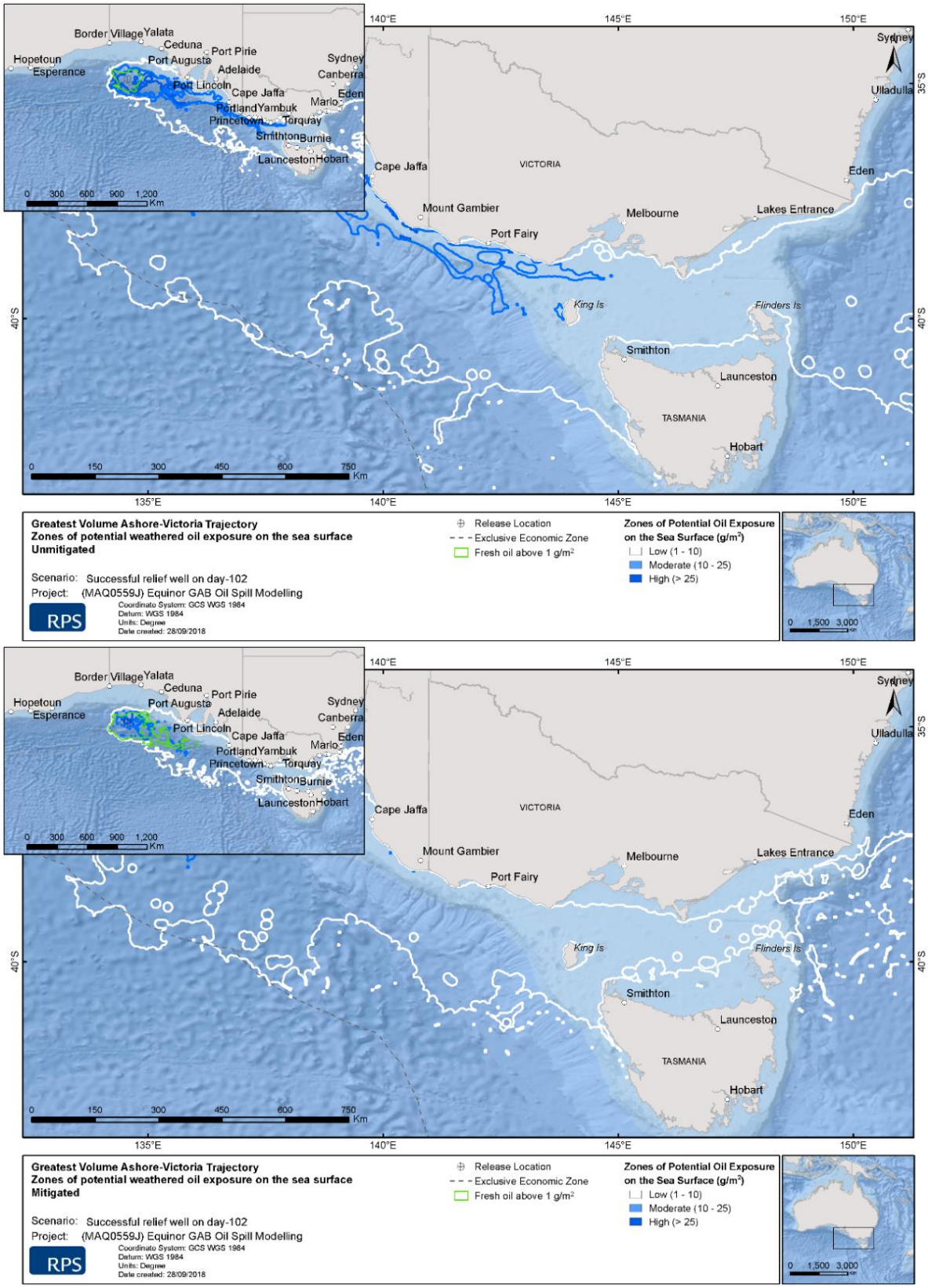


Figure 99: Sea surface exposure for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil on the Victorian shoreline, commencing 21 April 2009 at 14:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days and tracked for 162 days

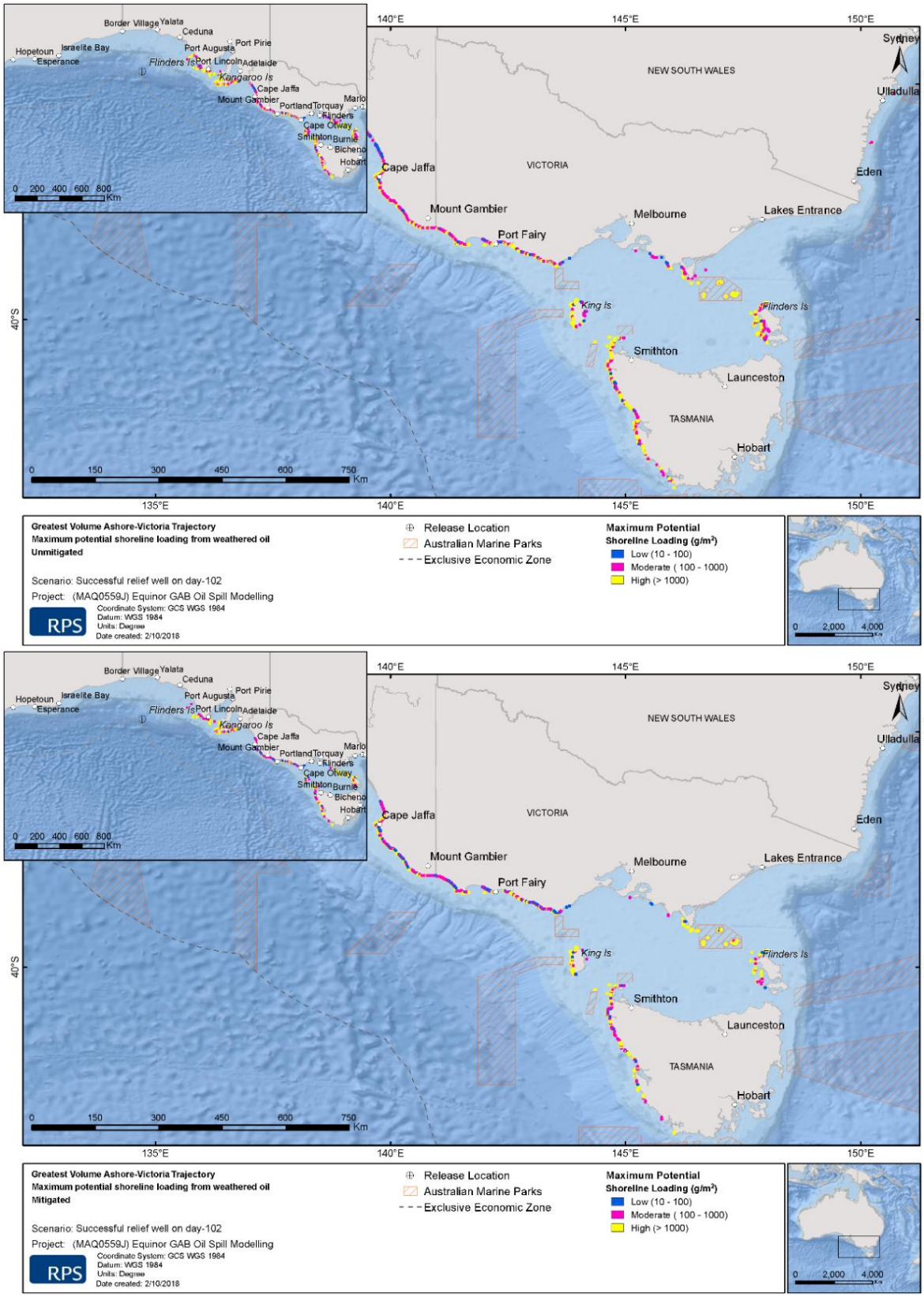


Figure 100: Shoreline loading for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil on the Victorian shoreline, commencing 21 April 2009 at 14:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days and tracked for 162 days

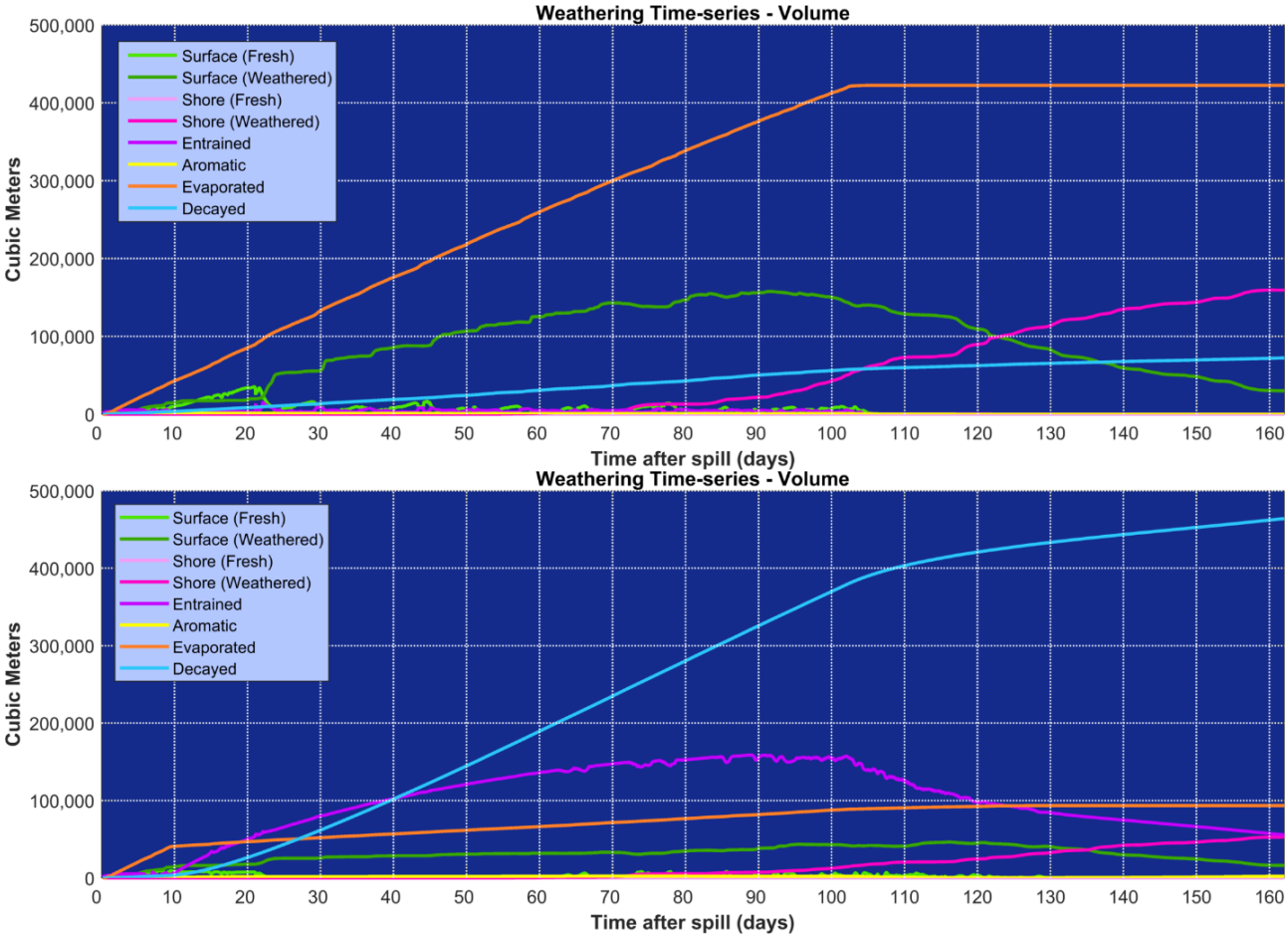


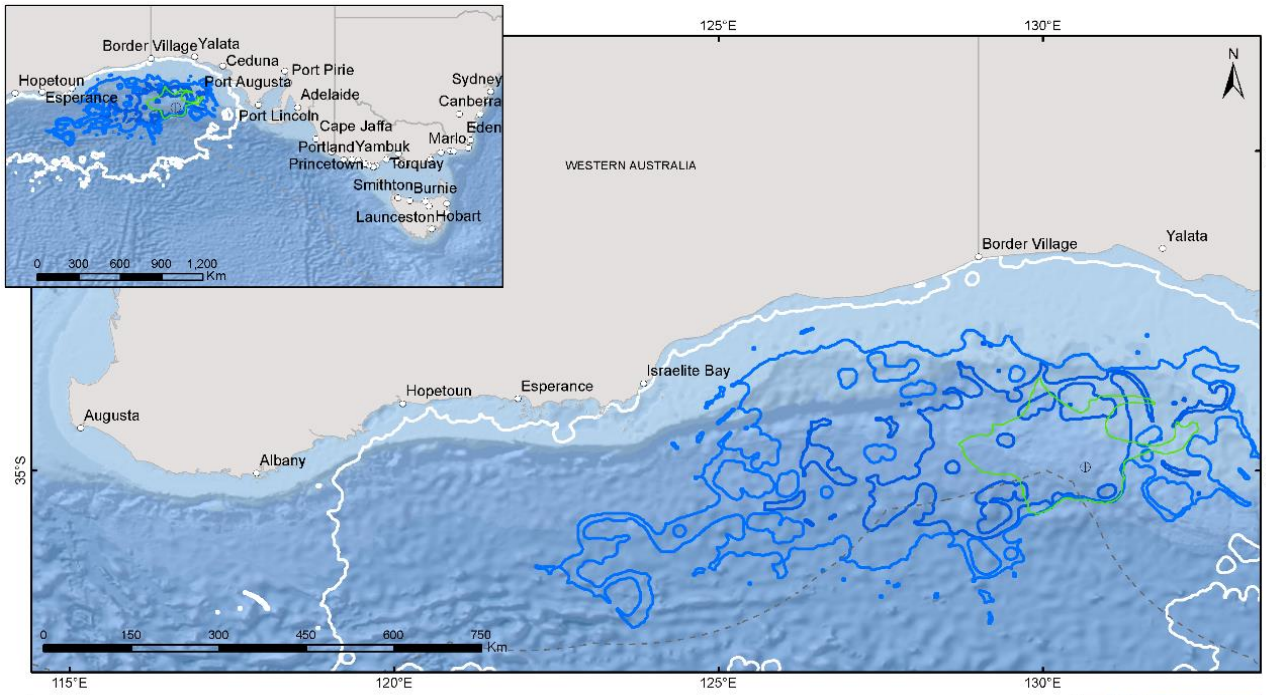
Figure 101: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the greatest volume of weathered oil on the Victorian shoreline, commencing 21 April 2009 at 14:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days and tracked for 162 days

11.2.2.2 Western Australia

From the 100 unmitigated simulations, the spill commencing 3rd November 2009 at 00:00 hrs (run 83) was identified to result in the greatest volume of weathered oil on the Western Australian shoreline.

Figure 102 andFigure 103 show maps of sea surface exposure and shoreline loading, respectively, for the unmitigated and mitigated modelling results. The mitigated case includes aerial dispersant from Day 2 until Day 103; and SSDI from the end of Day 9 to Day 102.

Figure 104 shows the predicted weathering and fates graphs for the unmitigated and mitigated cases. By the end of the simulation (day 162), 421,834 m^3 (~62% of the total release volume) and 70,977 m^3 (~10%) had evaporated and decayed, respectively under unmitigated model conditions. In comparison, 94,152 m^3 (~14%) and 462,286 m^3 (~67%) had evaporated and decayed, respectively, under the mitigated model conditions. By day 162, the volume of weathered crude remaining ashore was predicted to be 8,058 m^3 (~1%) and 1,531 m^3 (~0.2%) for the unmitigated and mitigated modelling, respectively. Furthermore, 183,674 m^3 (~27%) and 67,517 m^3 (~10%) of weathered crude remained on the sea surface for the unmitigated and mitigated simulations, respectively, while 141 m^3 (0.02%) and 57,380 m^3 (~8%) was predicted to remain entrained in the water column.



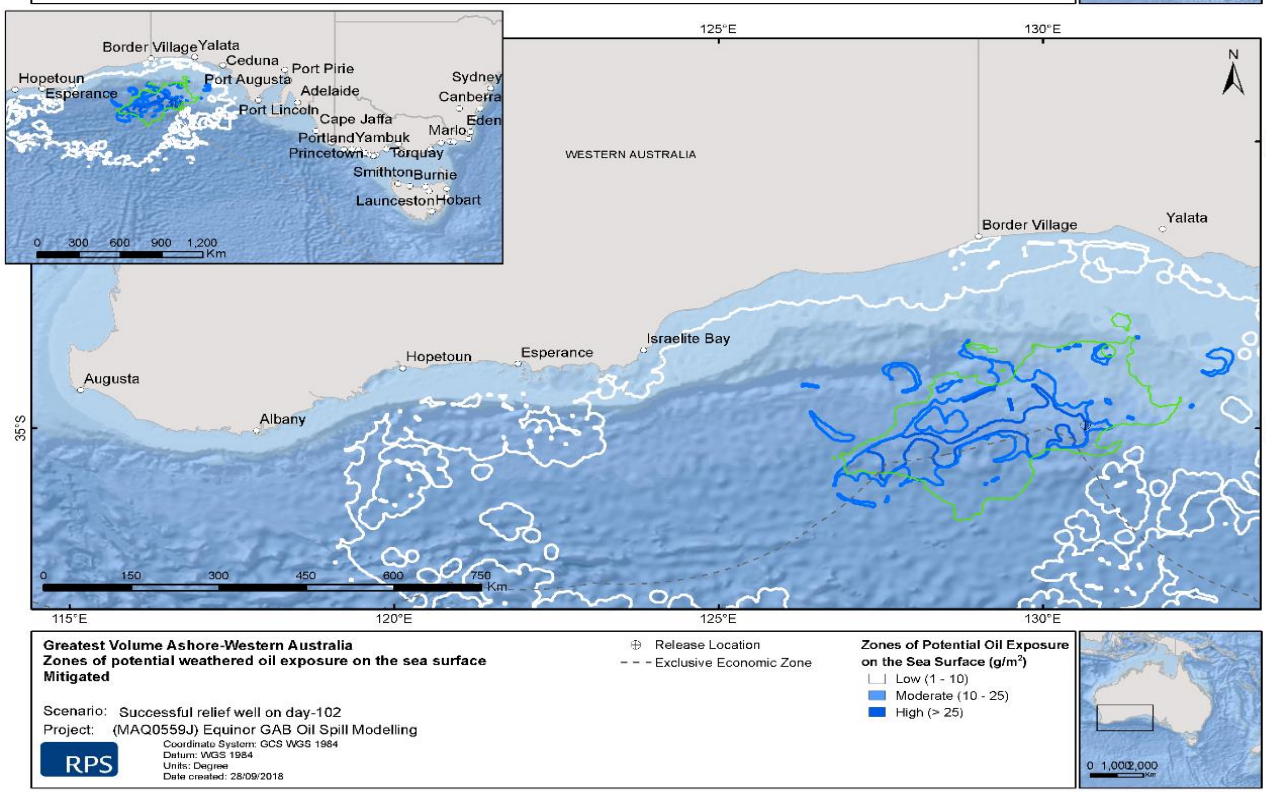


Figure 102: Sea surface exposure for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil on the Western Australian shoreline, commencing 3 November 2009 at 00:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days and tracked for 162 days

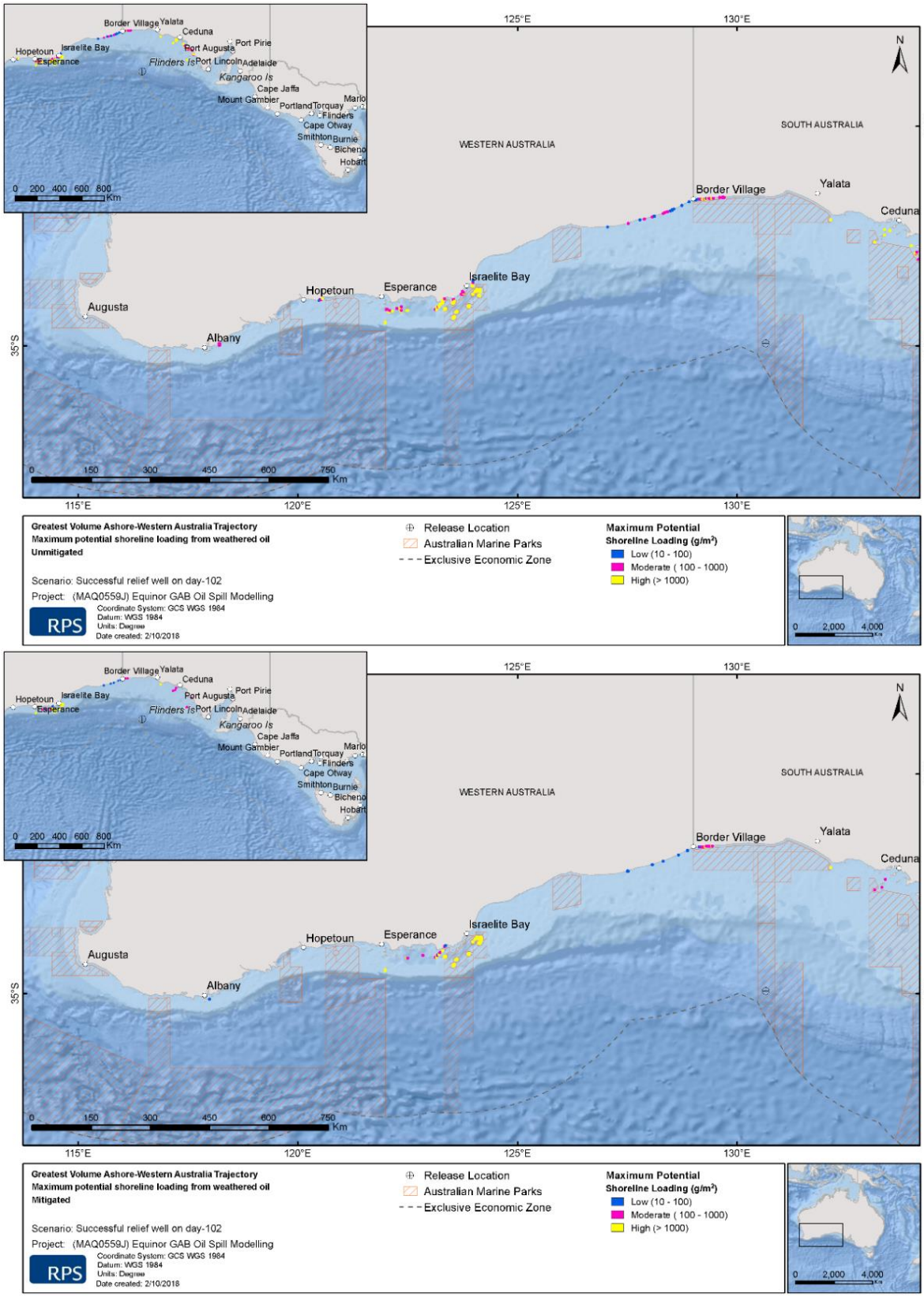


Figure 103: Shoreline loading for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil on the Western Australian shoreline, commencing 3 November 2009 at 00:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days and tracked for 162 days

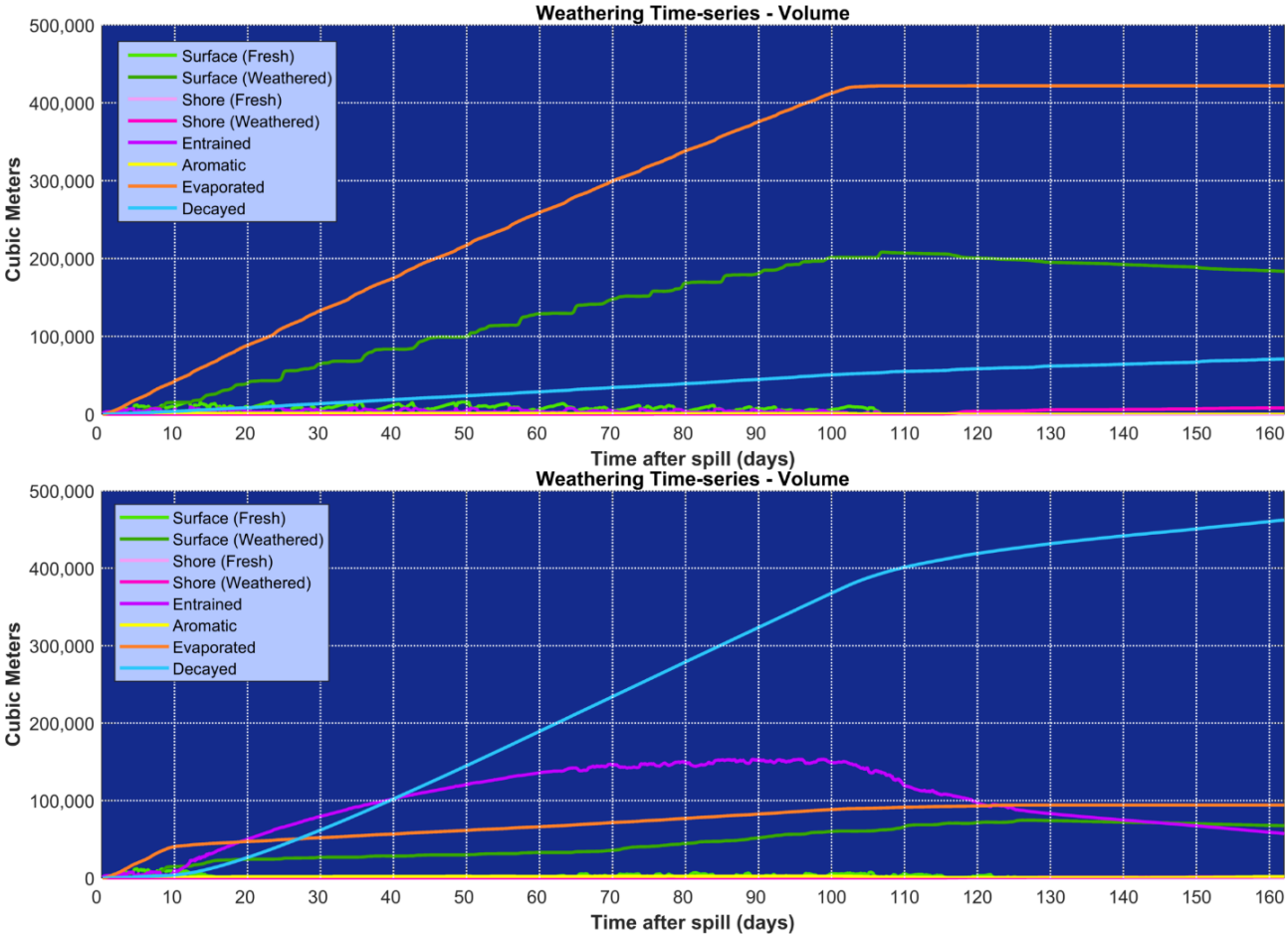


Figure 104: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the greatest volume of weathered oil on the Western Australian shoreline, commencing 3 November 2009 at 00:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days and tracked for 162 days

11.2.2.3 Tasmania

From the 100 unmitigated simulations, the spill commencing 22nd March 2009 at 23:00 hrs (run 1) was identified to result in the greatest volume of weathered oil on the Tasmanian shoreline.

Figure 105 and Figure 106show maps of sea surface exposure and shoreline loading, respectively, for the unmitigated and mitigated modelling results. The mitigated case includes aerial dispersant from Day 2 until Day 103; and SSDI from the end of Day 9 to Day 102.

Figure 107 shows the predicted weathering and fates graphs for the unmitigated and mitigated cases. By the end of the simulation (day 162), 422,424 m^3 (~62% of the total release volume) and 72,814 m^3 (~11%) had evaporated and decayed, respectively for the unmitigated simulation. In comparison, 93,895 m^3 (~14%) and 464,770 m^3 (~68%) had evaporated and decayed, respectively, under the mitigated model conditions. By day 162, the volume of weathered crude remaining ashore was predicted to be 3 times higher at 152,496 m^3 (~22%) and 48,845 m^3 (~7%) for the unmitigated and mitigated modelling, respectively. Furthermore, 36,353 m^3 (~5%) and 19,411 m^3 (~3%) of weathered crude remained on the sea surface for the unmitigated and mitigated results, respectively. While 155 m^3 (0.02%) and 55,924 m^3 (~8%) was predicted to remain entrained in the water column under unmitigated and mitigated modelling conditions, respectively.

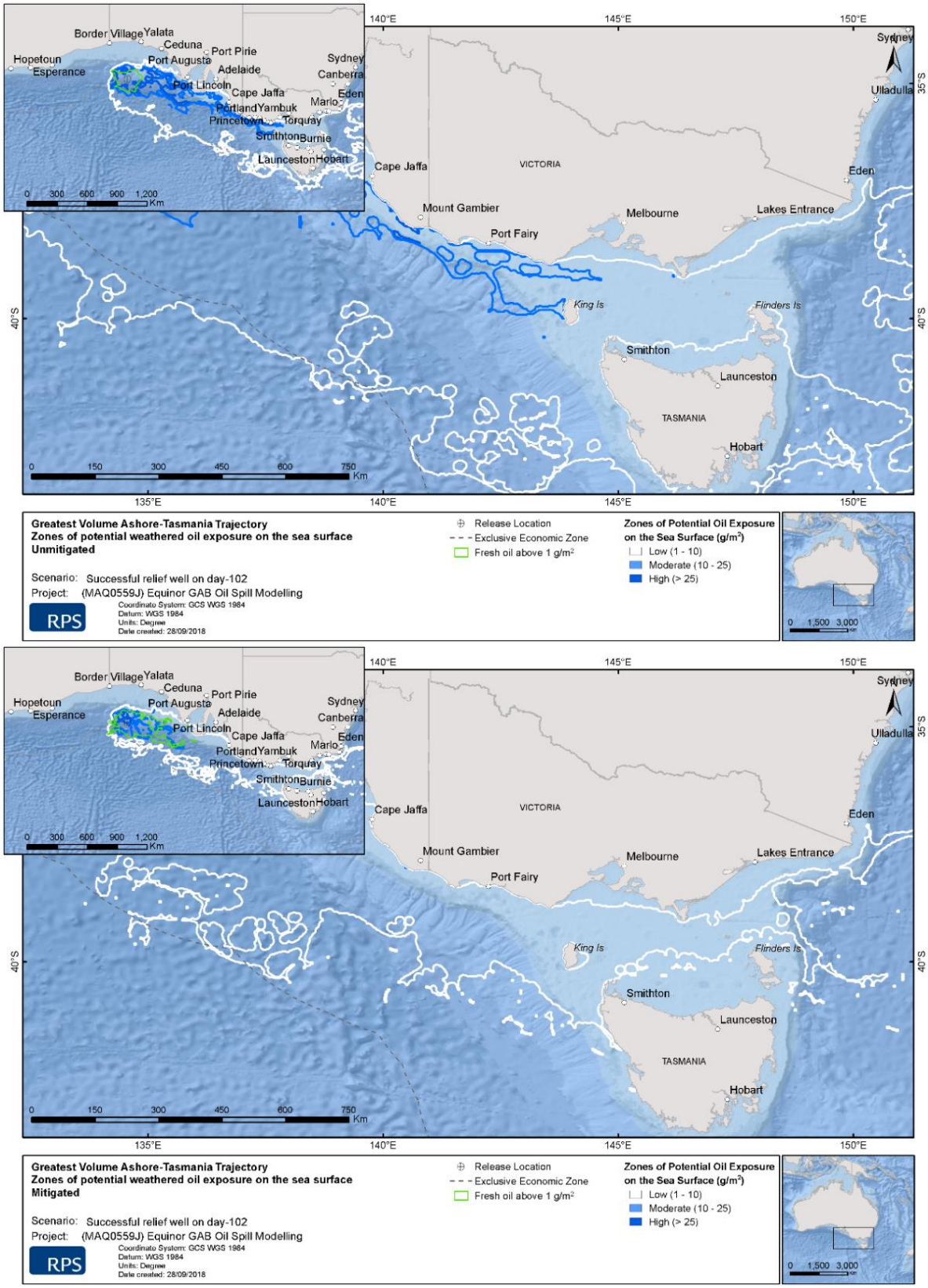
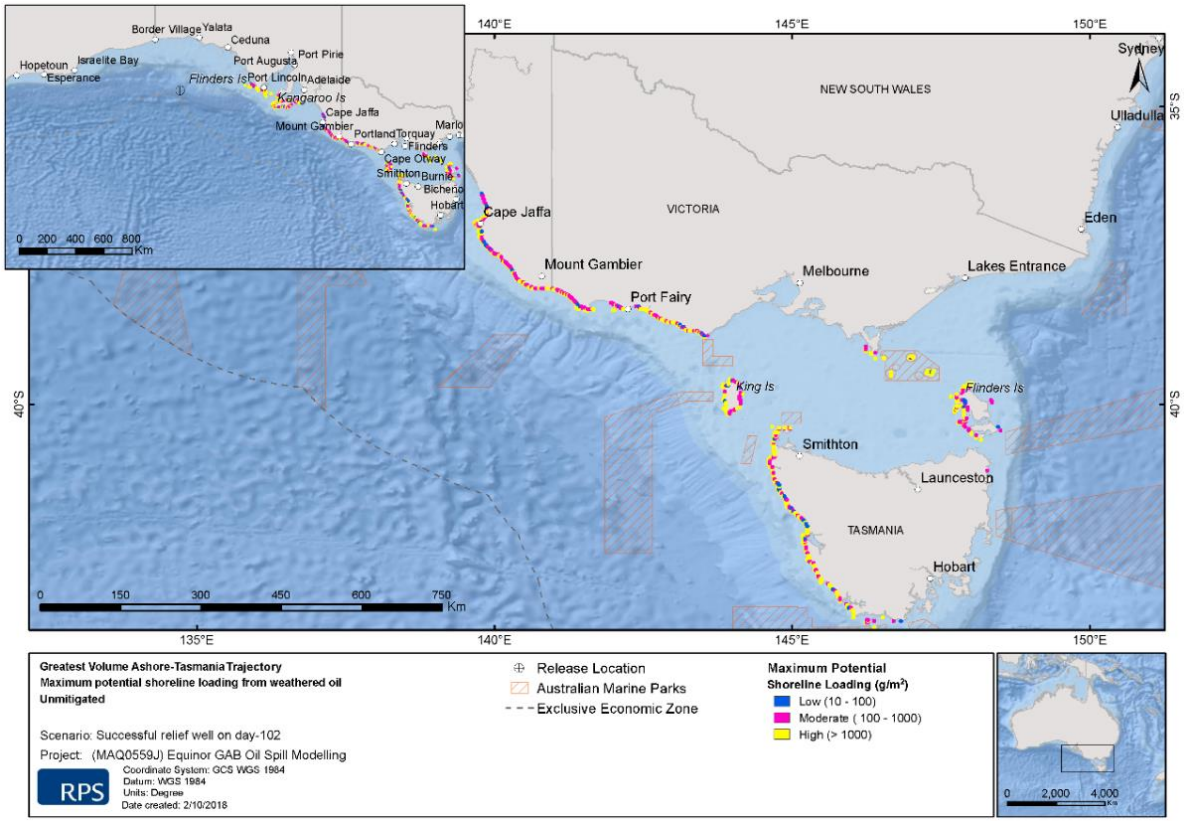


Figure 105: Sea surface exposure for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil on the Tasmanian shoreline, commencing 22 March 2009 at 23:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days and tracked for 162 days



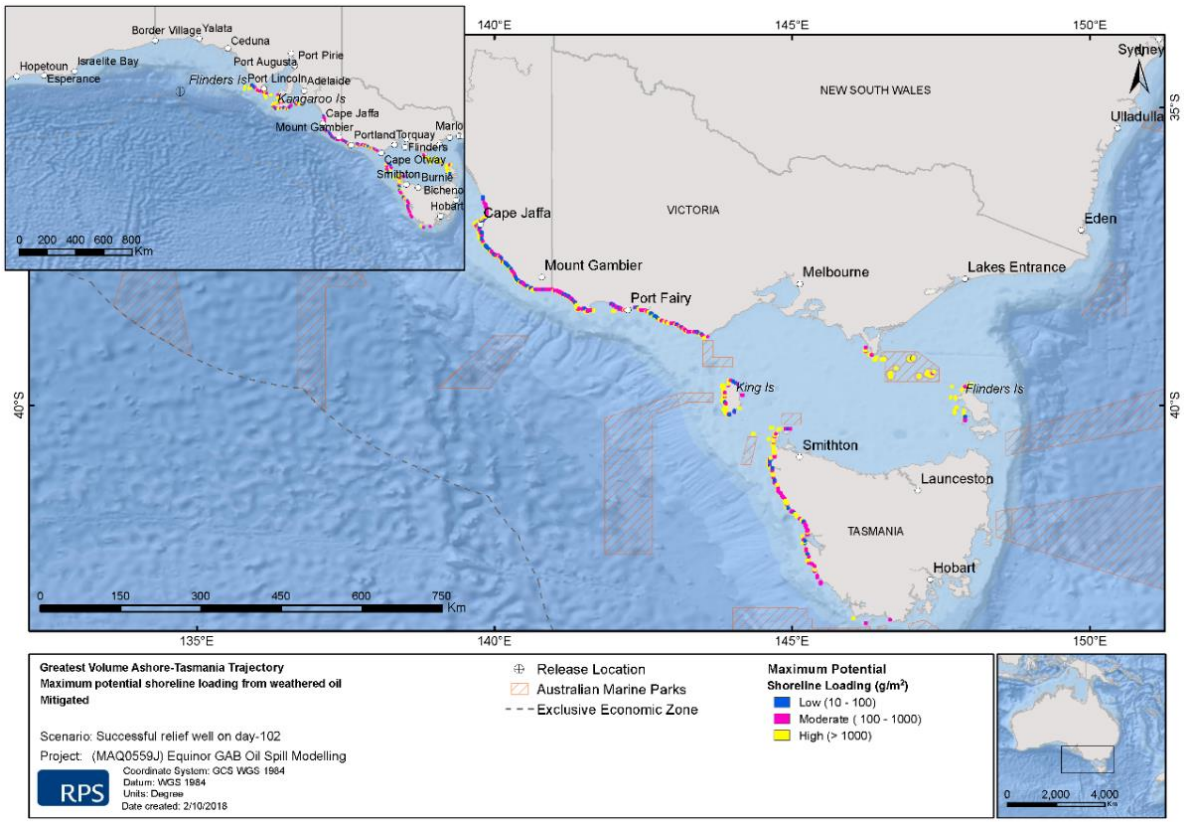


Figure 106: Shoreline loading for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil on the Tasmanian shoreline, commencing 22 March 2009 at 23:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days and tracked for 162 days

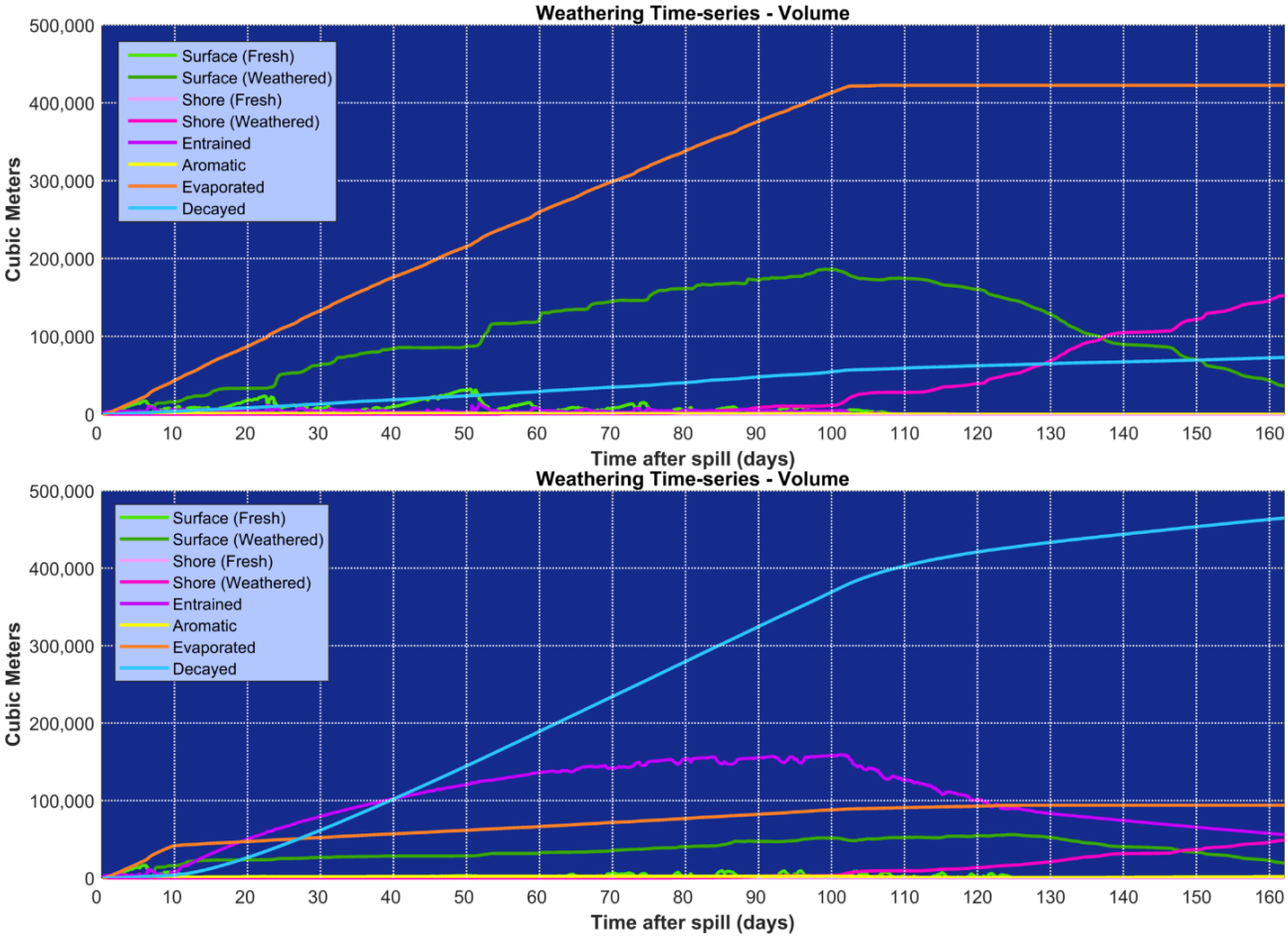


Figure 107: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the greatest volume of weathered oil on the Tasmanian shoreline, commencing 22 March 2009 at 23:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days and tracked for 162 days

11.2.2.4 New South Wales

From the 100 unmitigated simulations, the spill commencing 28th May 2009 at 10:00 hrs (run 90) was identified to result in the greatest volume of weathered oil on the New South Wales shoreline.

Figure 108 and Figure 109 show maps of sea surface exposure and shoreline loading, respectively, for the unmitigated and mitigated modelling results. The mitigated case includes aerial dispersant from Day 2 until Day 103; and SSDI from the end of Day 9 to Day 102.

Figure 110 shows the predicted weathering and fates graphs for the unmitigated and mitigated cases. By the end of the unmitigated simulation (day 162) 423,055 m^3 (~62% of the total release volume) and 69,166 m^3 (~10%) had evaporated and decayed, respectively. In comparison, 93,296 m^3 (~14%) and 464,049 m^3 (~68%) had evaporated and decayed, respectively, for the mitigated model results. By day 162, the volume of weathered crude remaining ashore was predicted to be 3 ½ times higher at 151,748 m^3 (~22%) and 39,534 m^3 (~6%) for the unmitigated and mitigated modelling, respectively. Furthermore, 39,864 m^3 (~6%) and 29,292 m^3 (~4%) of weathered crude remained on the sea surface for the unmitigated and mitigated modelling. While only 180 m^3 (0.03%) was predicted to remain entrained in the water column for the unmitigated simulation and 56,275 m^3 (~8%) for the mitigated modelling conditions.

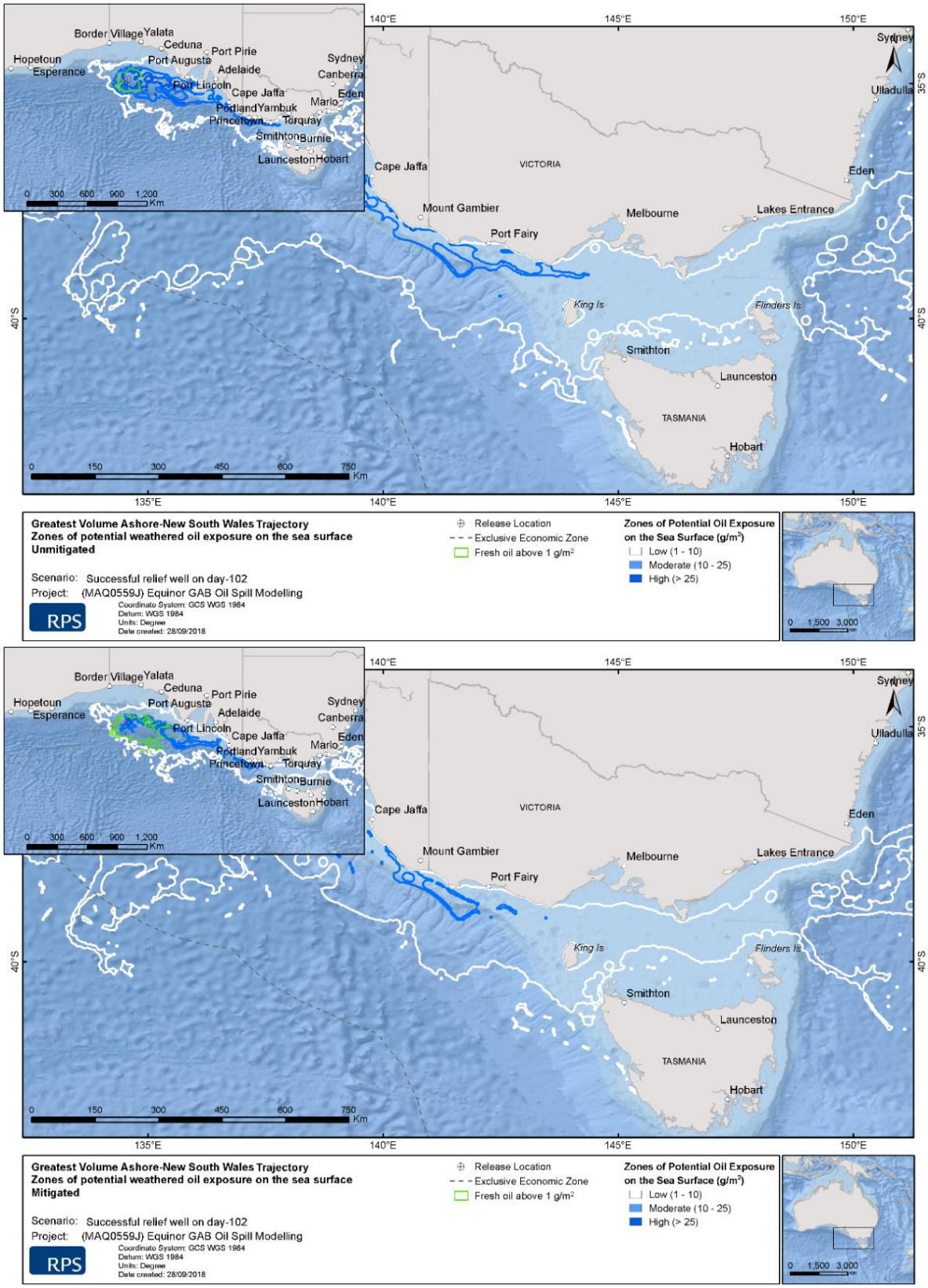


Figure 108: Sea surface exposure for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil ashore on the New South Wales shoreline, commencing 28 May 2009 at 10:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days and tracked for 162 days

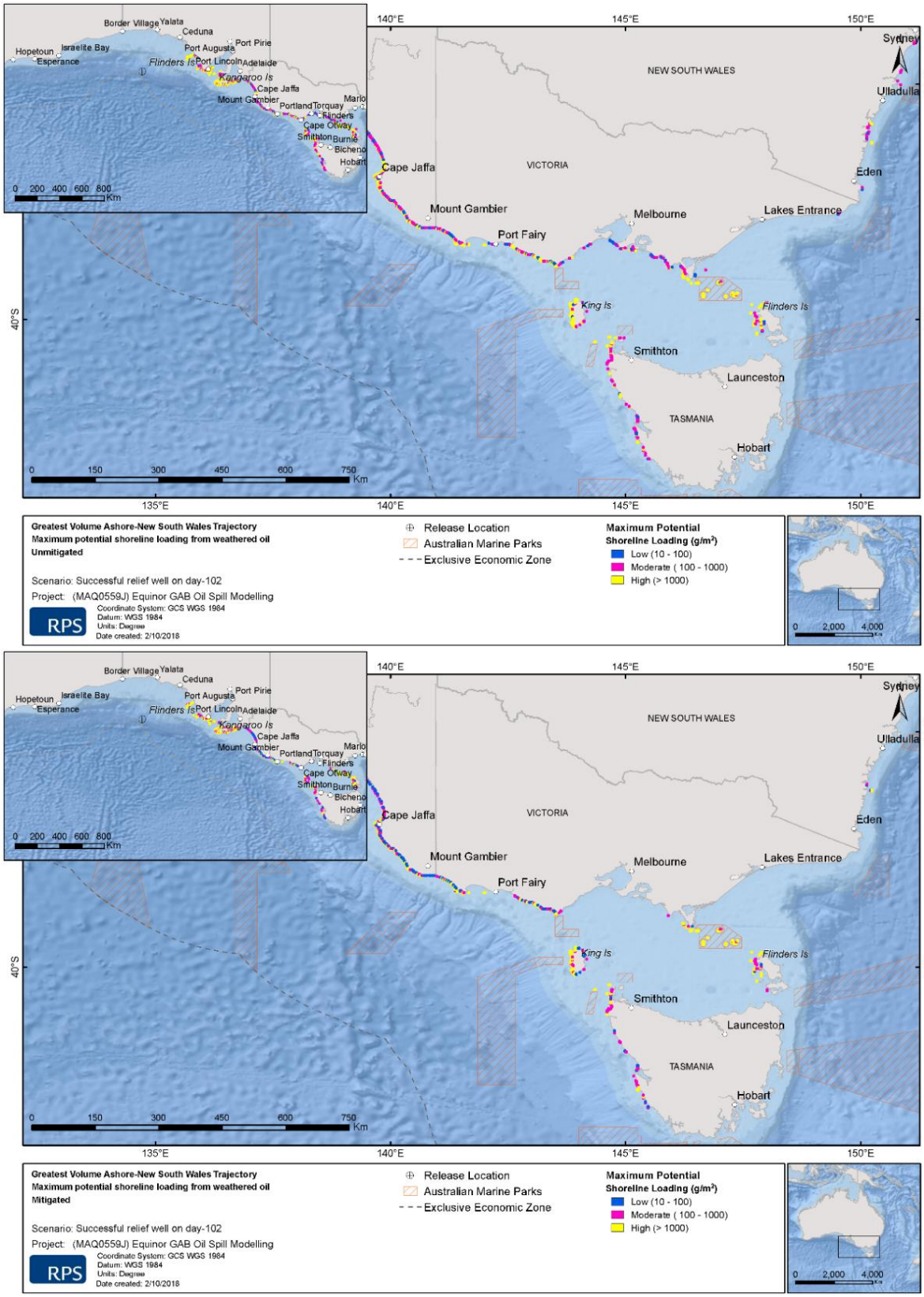


Figure 109: Shoreline loading for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Results are based on the deterministic simulation resulting in the greatest volume of weathered oil ashore on New South Wales state, commencing 28 May 2009 at 10:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days and tracked for 162 days

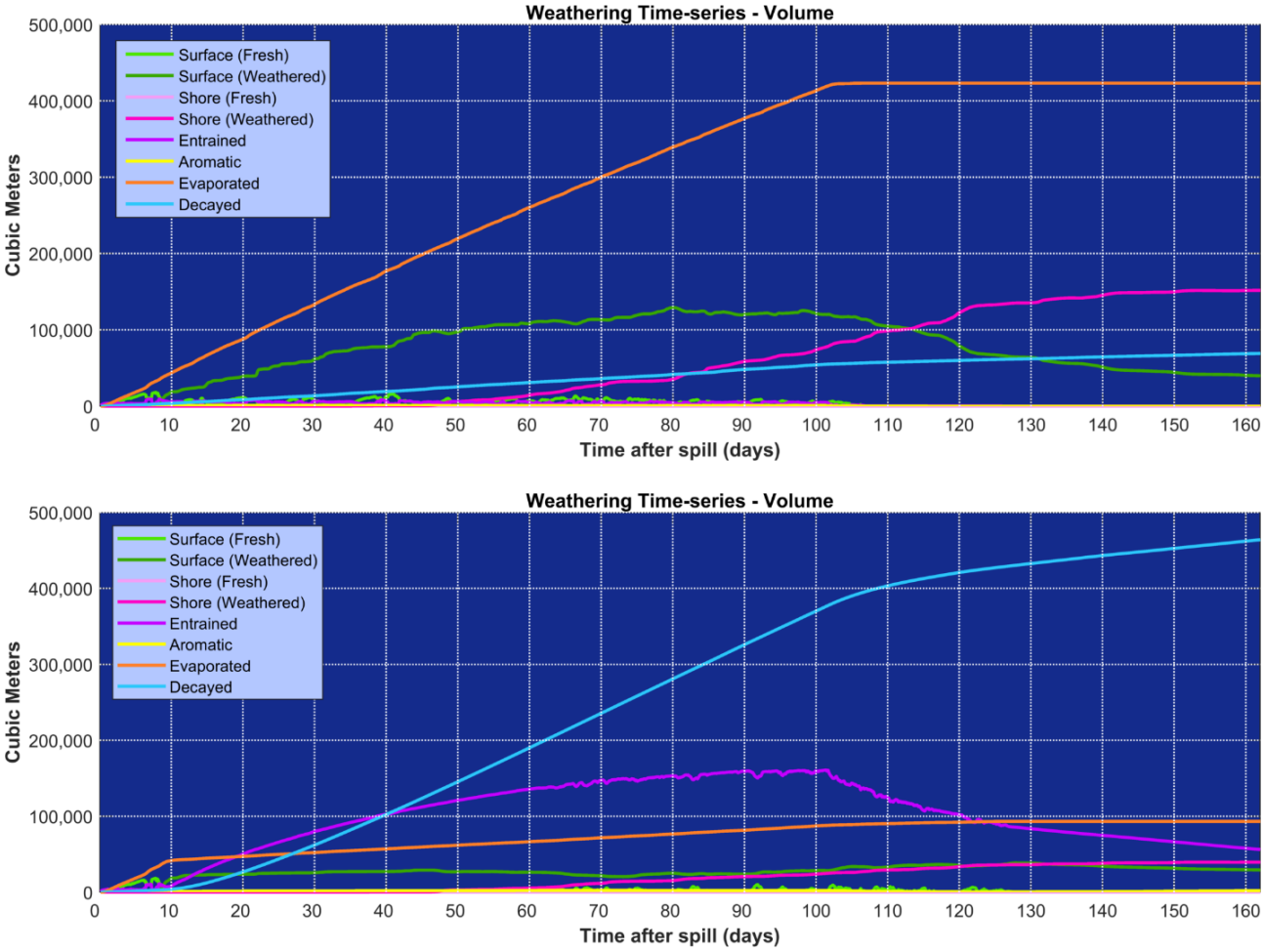


Figure 110: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the greatest volume of weathered oil on the New South Wales shoreline, commencing 28 May 2009 at 10:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days and tracked for 162 days

11.2.2.5 South Australia

The results of all 100 unmitigated simulations were reviewed and the spill commencing 3 May 2012 at 23:00 hrs (run 59) was identified to result in the greatest volume of weathered oil on the South Australian shoreline.

Figure 111 and Figure 112 show maps of sea surface exposure and shoreline loading, respectively, for the unmitigated and mitigated modelling results. The mitigated case includes aerial dispersant from Day 2 until Day 103; and SSDI from the end of Day 9 to Day 102.

Figure 113 shows the predicted weathering and fates graphs for the unmitigated and mitigated cases. At the end of the simulation (day 162), 422,930 m^3 (~62% of the total release volume) and 71,035 m^3 (~10%) had evaporated and decayed, respectively under unmitigated model conditions. In comparison, 93,735 m^3 (~14%) and 462,476 m^3 (~67%) had evaporated and decayed, respectively, under the mitigated model conditions. The maximum fresh volume ashore during the simulation for the two cases was 4.3 m^3 and 6.5 m^3, respectively. By day 162, the volume of weathered crude remaining ashore was predicted to be 144,158 m^3 (~21%) and 42,941 m^3 (~6%) for the unmitigated and mitigated modelling, respectively. Furthermore, 46,369 m^3 (~7%) and 25,871 m^3 (~4%) of weathered crude remained on the sea surface for the unmitigated and mitigated modelling. While 189 m^3 (0.03%) and 57,703 m^3 (~8%) was predicted to remain entrained in the water column for the unmitigated and mitigated modelling conditions, respectively.

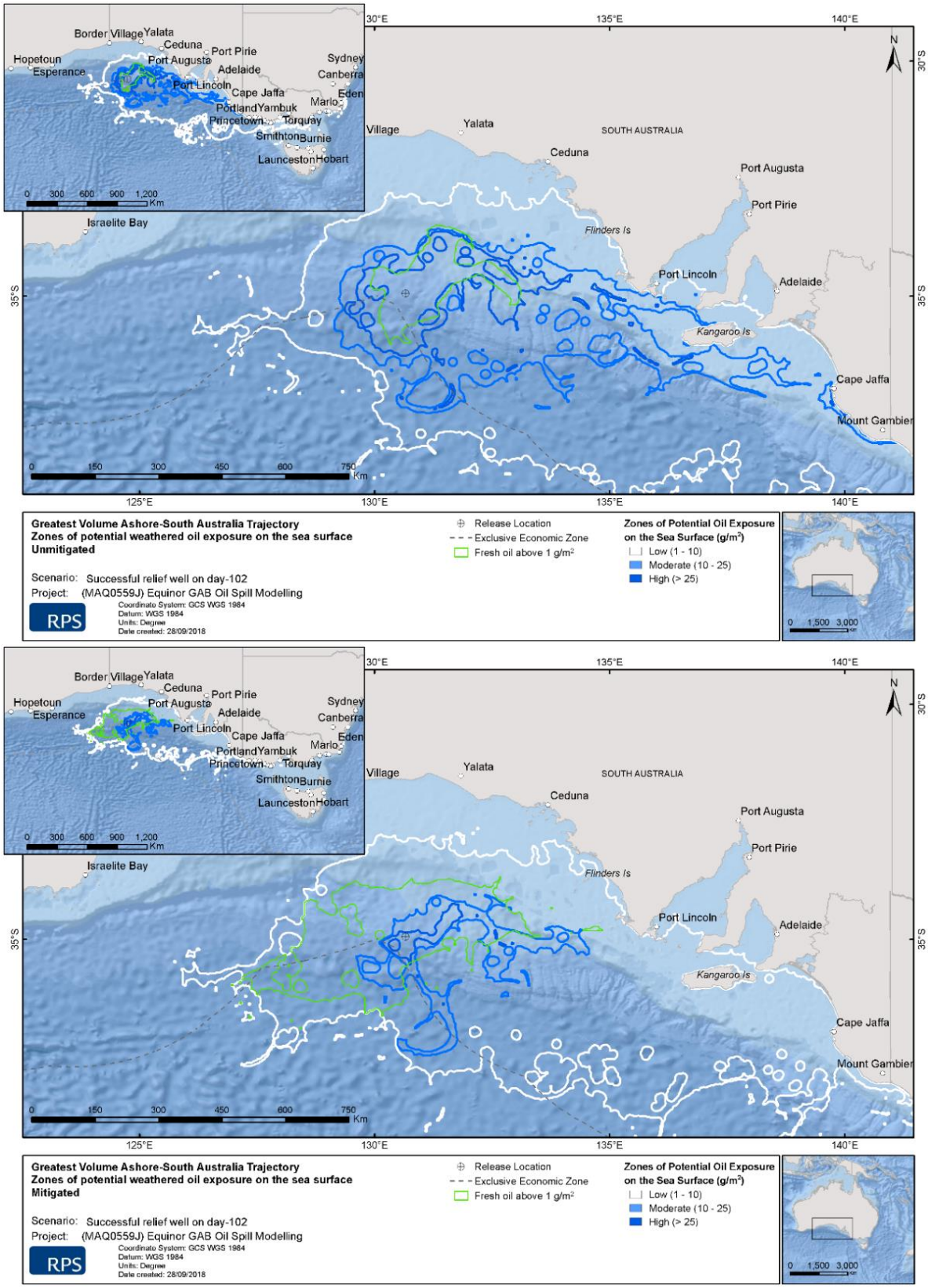


Figure 111: Sea surface exposure for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil ashore on the South Australia shoreline, commencing 3 May 2012 at 23:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days and tracked for 162 days

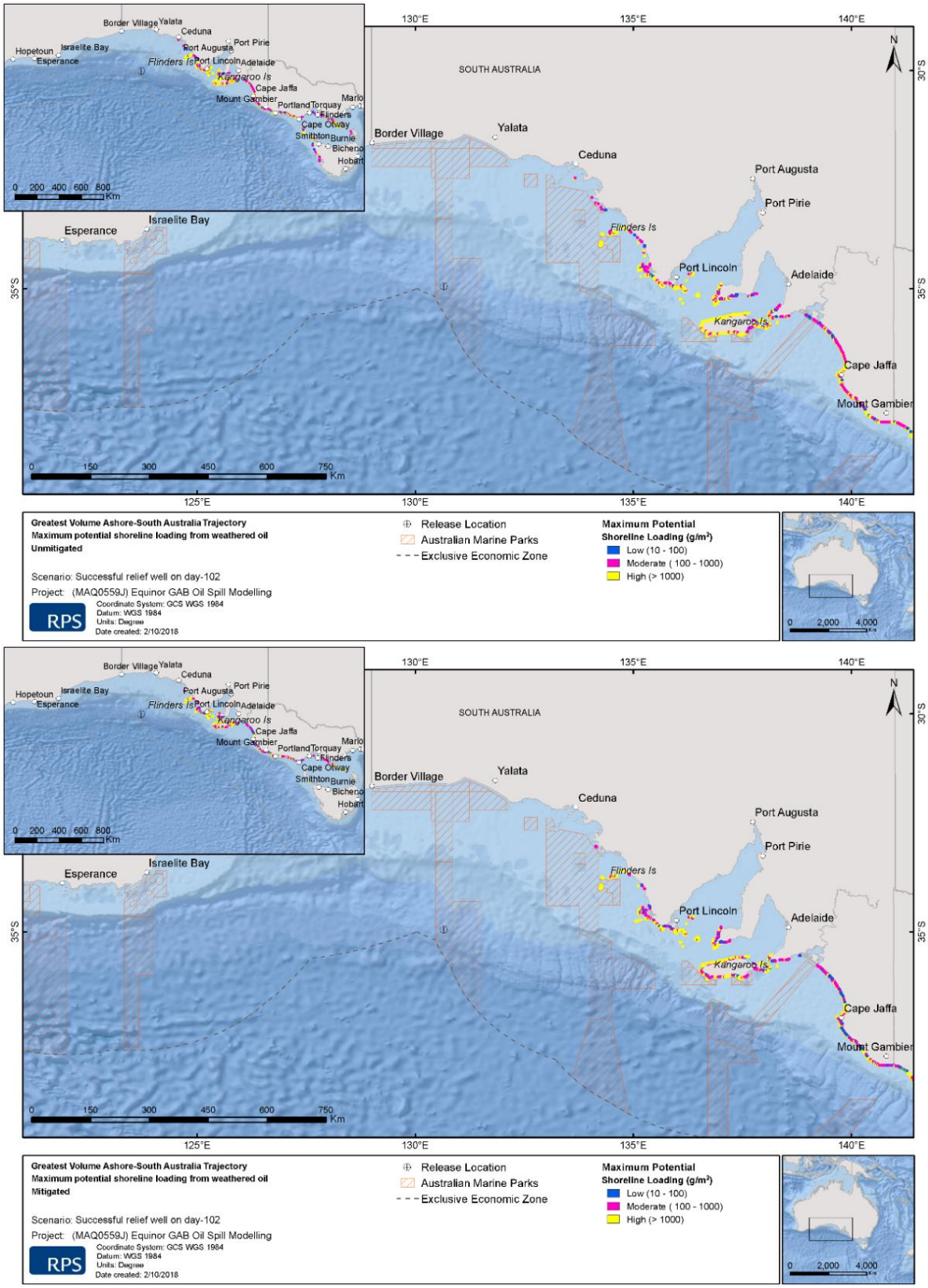


Figure 112: Shoreline loading for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the greatest volume of weathered oil ashore on the South Australia shoreline, commencing 3 May 2012 at 23:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days and tracked for 162 days

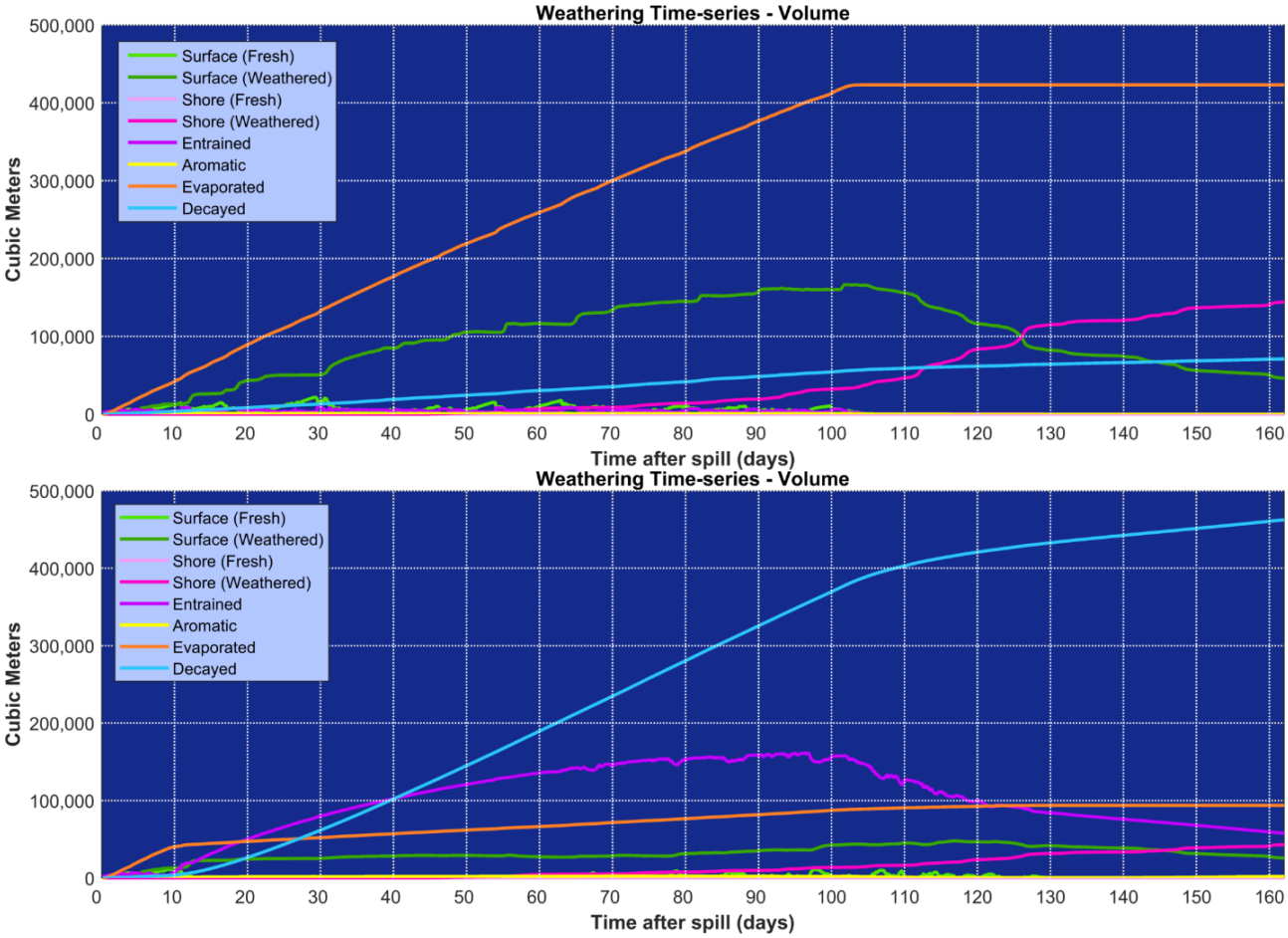


Figure 113: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the greatest volume of weathered oil on the South Australian shoreline, commencing 28 April 2012 at 14:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days and tracked for 162 days

11.2.3 P50 reference case

From the unmitigated simulations occurring between November to February ("target window" or most likely operational window), the spill commencing 7th February 2009 at 02:00 hrs (run 56) was identified as the simulation which resulted in the P50 (50th percentile) volume of weathered oil ashore.

To assess the potential change (if any) for the proposed mitigation methods, the same start time was used (7th February 2009 at 02:00 hrs), although the model inputs were revised to include aerial dispersant from Day 2 Day 103; and SSDI from Day 9 to Day 102.

Figure 114 illustrates the extent of oil at actionable oil thresholds for the unmitigated and mitigated modelling results over the entire 162-day simulation period.

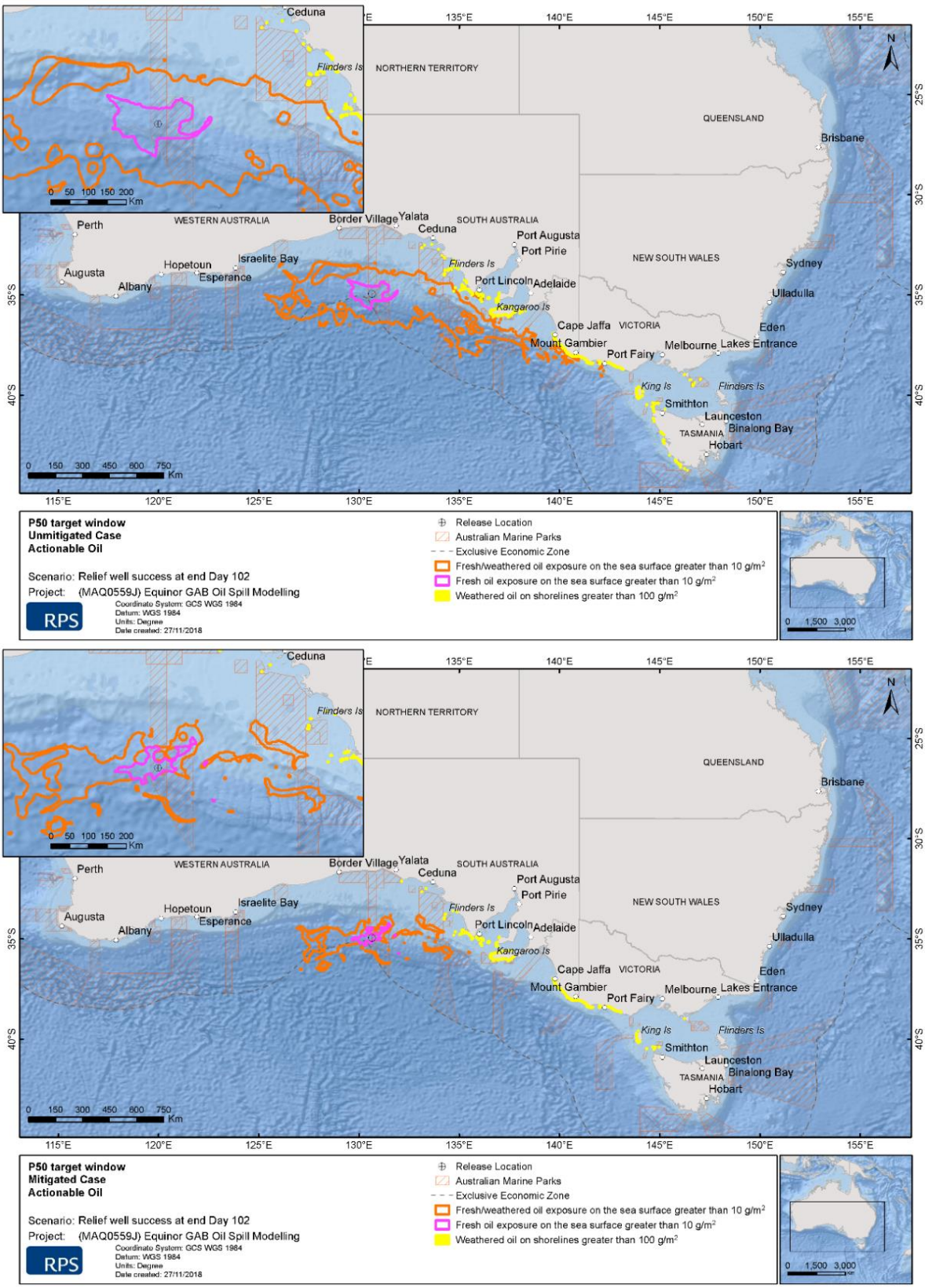


Figure 114: Actionable oil for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

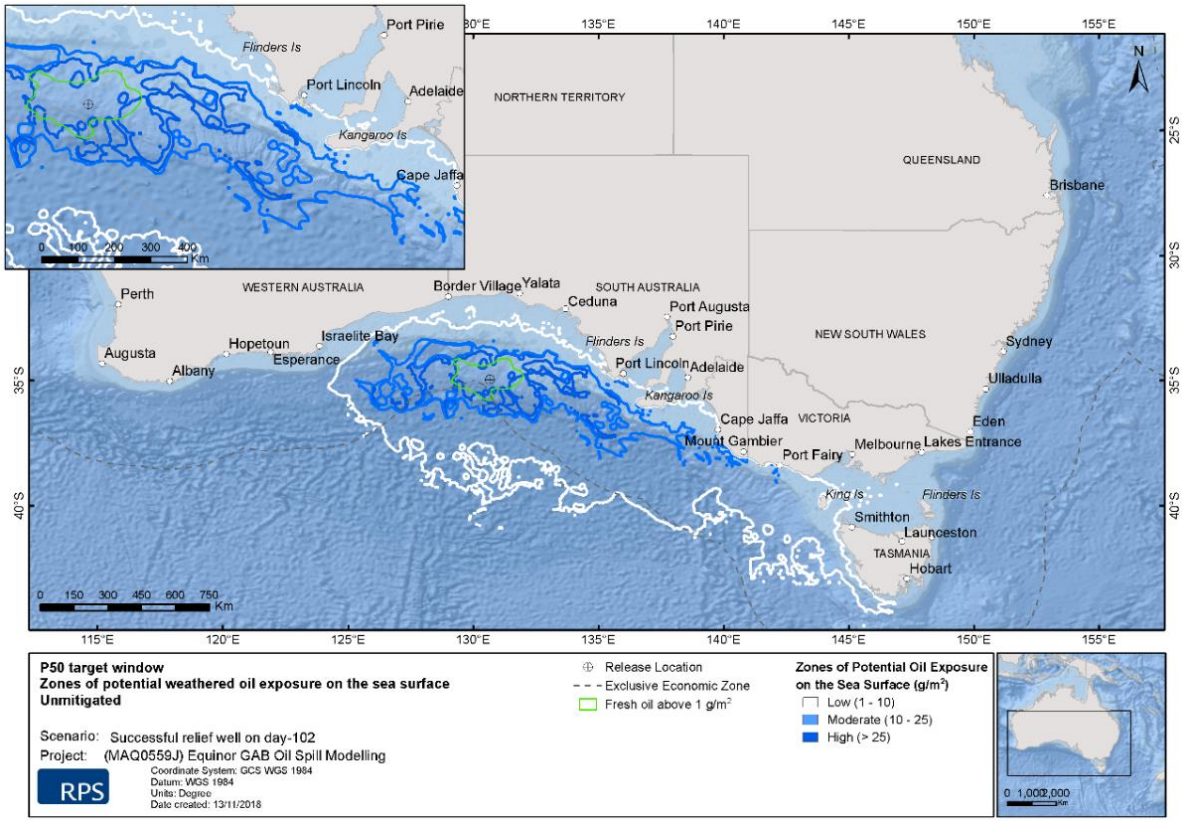
Figure 115 shows maps of sea surface exposure for the unmitigated and mitigated modelling cases. Figure 116 illustrates the shoreline loading for the two cases.

Figure 117 and Figure 118 show maps of potential entrained and dissolved hydrocarbon exposure (time averaged) in the surface waters (0-10 m depth), respectively, for the unmitigated and mitigated modelling results.

Figure 119 presents three-dimensional profile of the maximum potential entrained hydrocarbon exposure (time averaged) for the unmitigated and mitigated modelling results.

Figure 120 shows graphs of the mass of oil ashore above each threshold (low, moderate and high) for the unmitigated and mitigated modelling results. Initial shoreline contact at or above 10 g/m^2 was predicted to occur during day 71 for the unmitigated case and day 70 for the mitigated case. At day 100 and 162 the volume ashore greater than 100 g/m^2 for the unmitigated case was 2,097 m^3 and 50,195 m^3, respectively, while the volume ashore above 100 g/m^2 at day 100 and 162 for the mitigated case was 1,122 m^3 and 18,729 m^3, respectively.

Figure 121 is a graph displaying the area of sea surface exposure and length of shoreline oiled for the unmitigated and mitigated modelling results. Under the unmitigated case the area of visible oil on the surface steadily increased during the release period and peaked at day 143 at 83,524 km^2 and declined to 68,907 km^2 by day 162. Alternatively, the maximum coverage of visible oil on the sea surface oil for the mitigated simulation occurred at day 123 (30,807 km^2) and by day 162 was 15,848 km^2. The unmitigated and mitigated modelling results showed that oil on the shorelines was at actionable levels at day 71 and day 70, respectively. By the end of the simulation at day 162, the length of actionable shoreline oil was 1,394 km and 912 km for the unmitigated and mitigated cases, respectively.



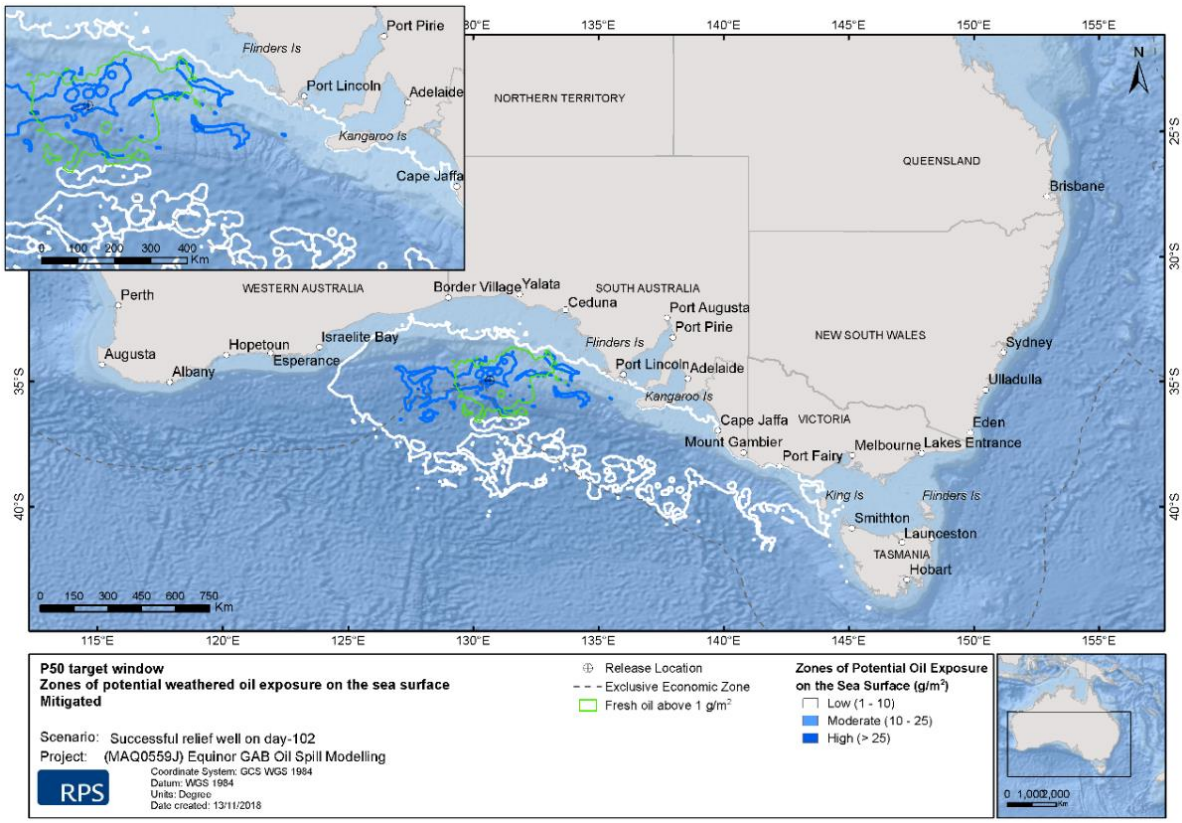
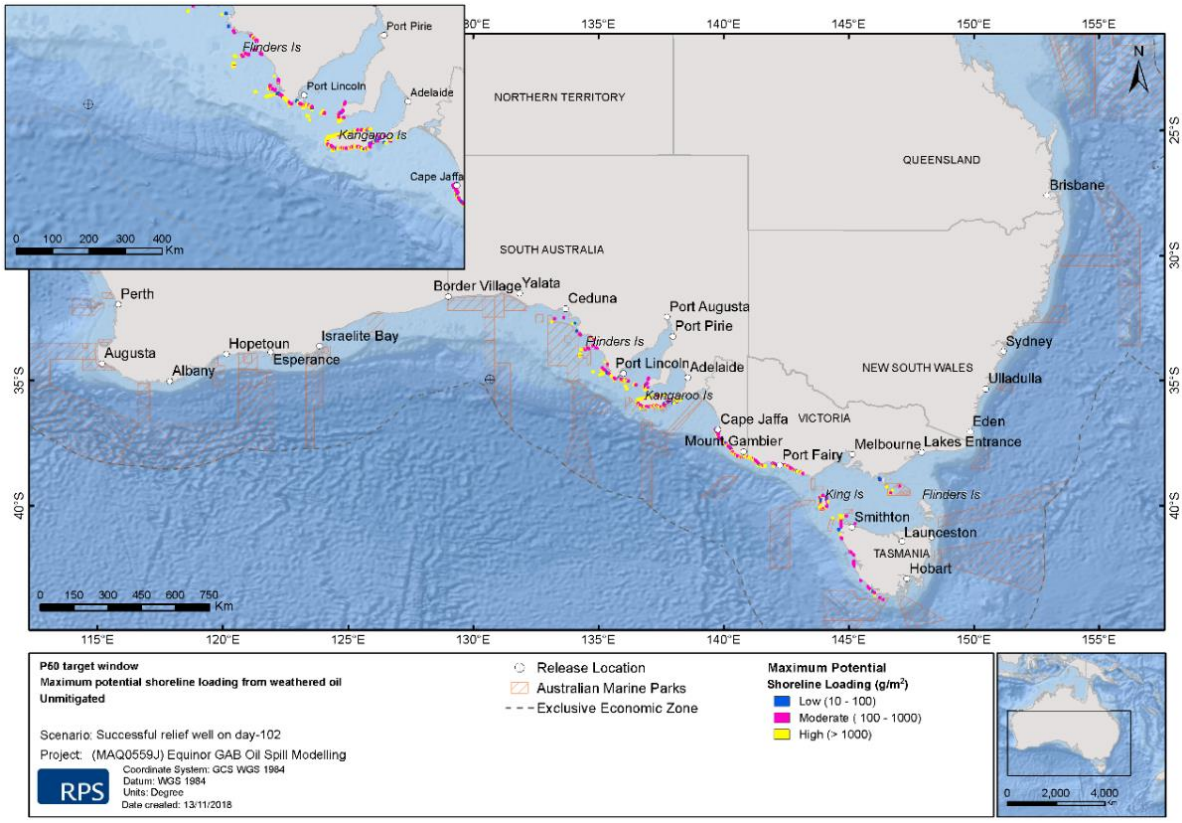


Figure 115: Sea surface exposure for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days



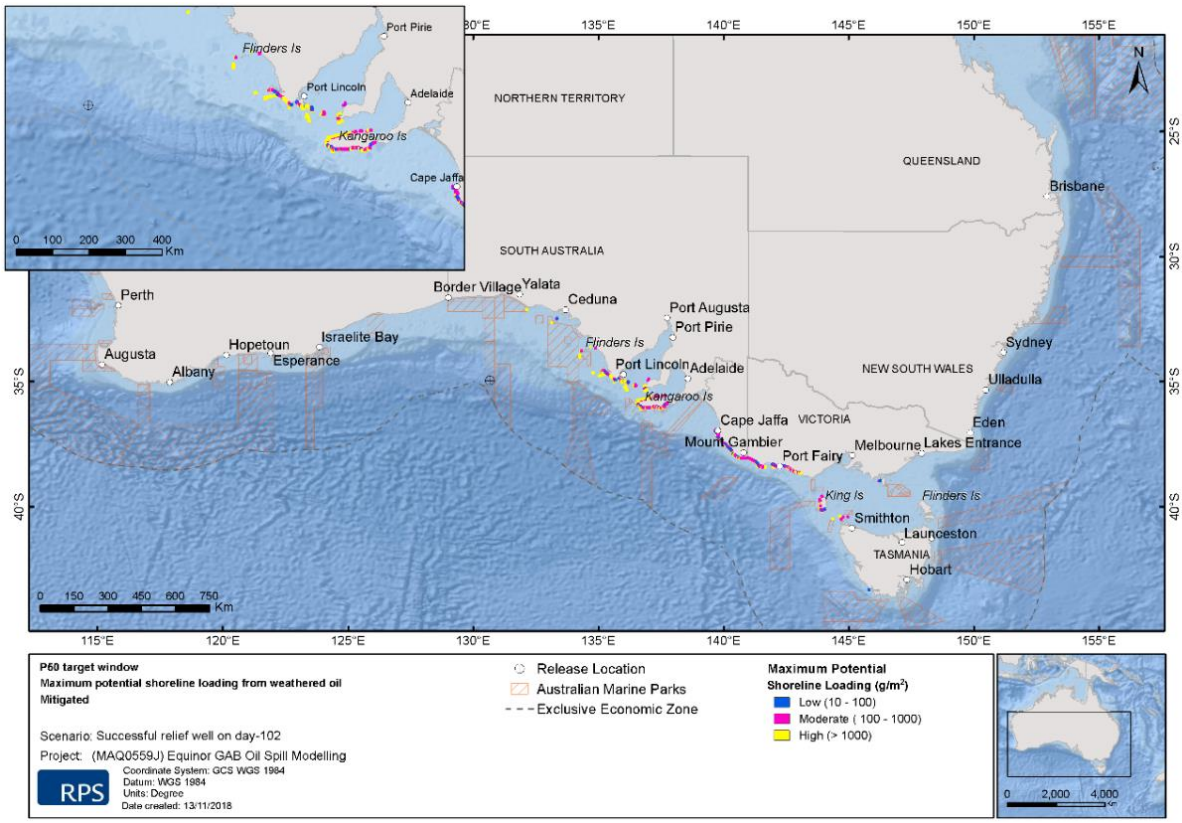


Figure 116: Shoreline loading for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Results are based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

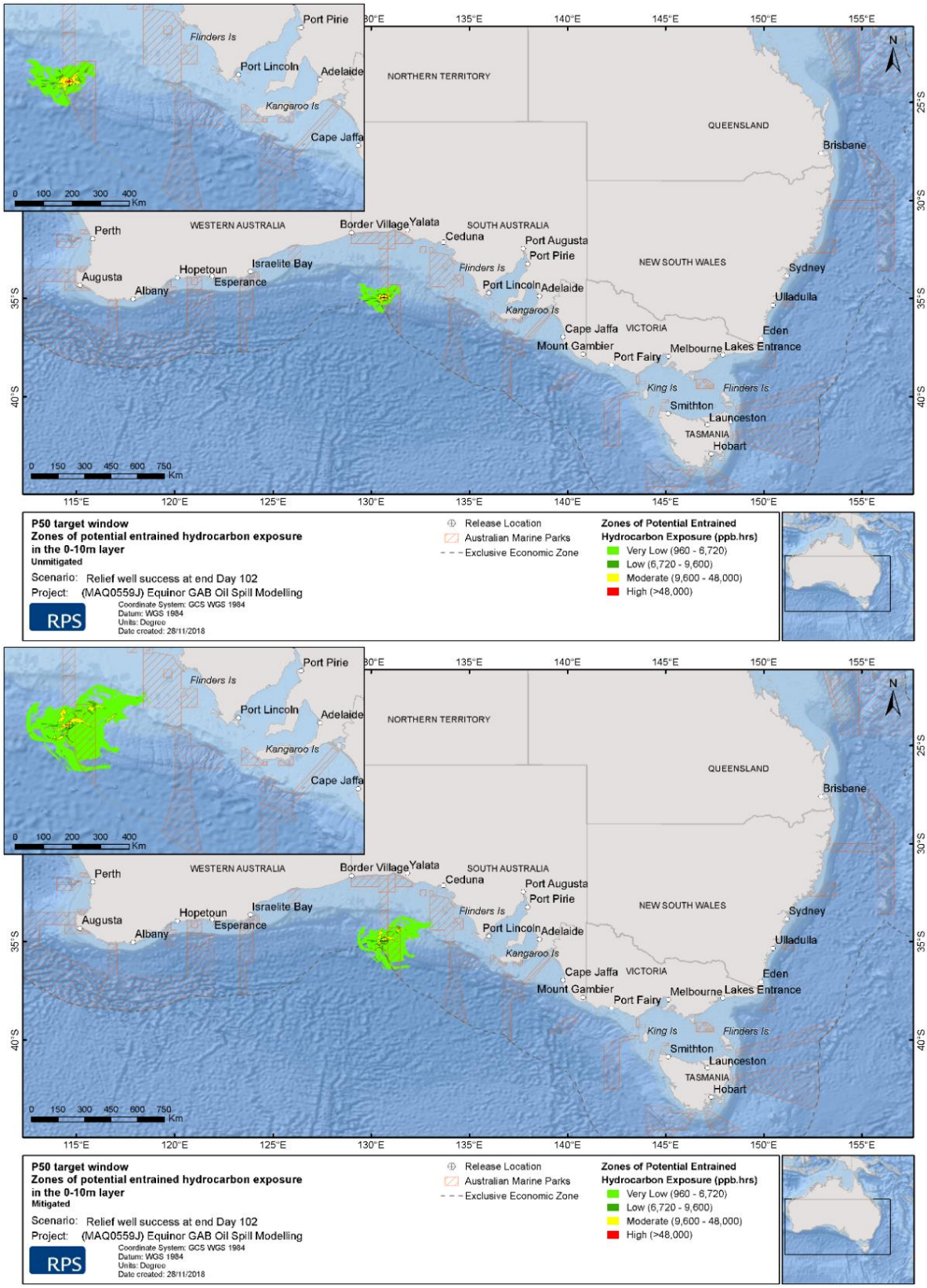
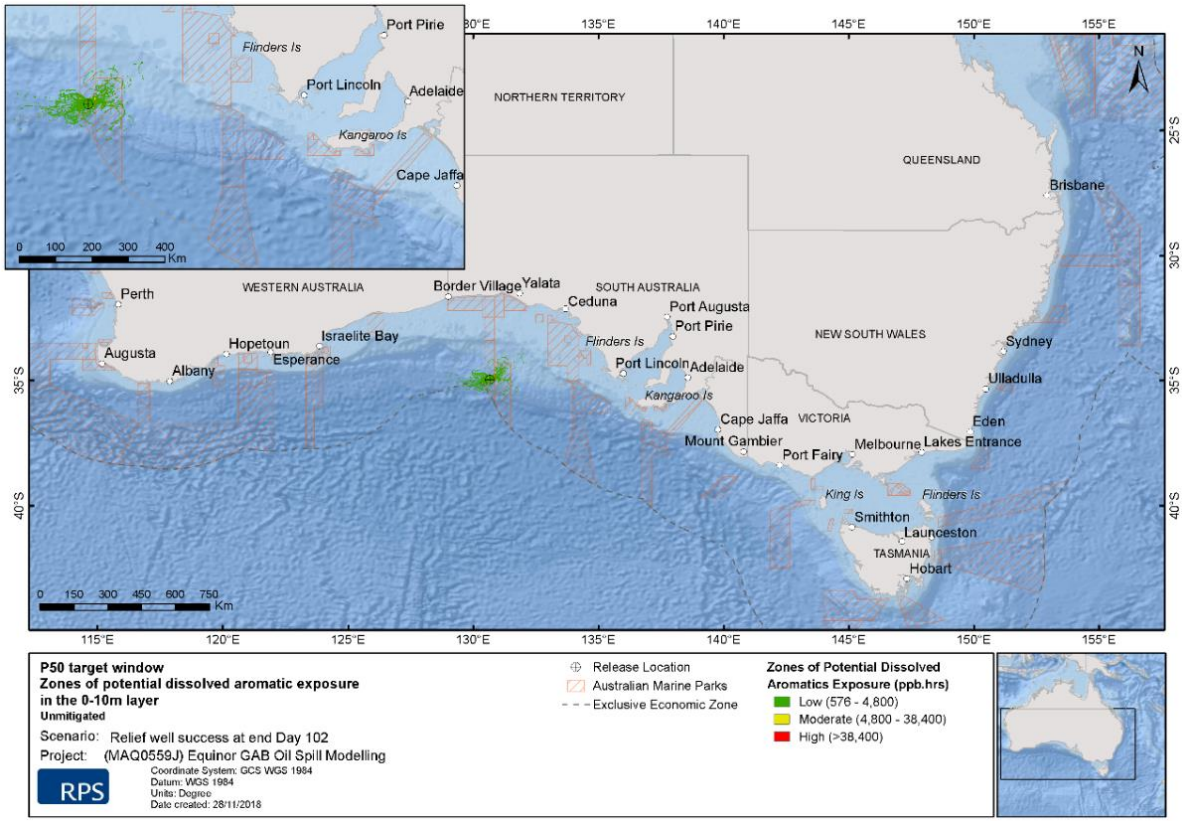


Figure 117: Potential entrained hydrocarbon exposure (time averaged) in the 0-10 m layer for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days



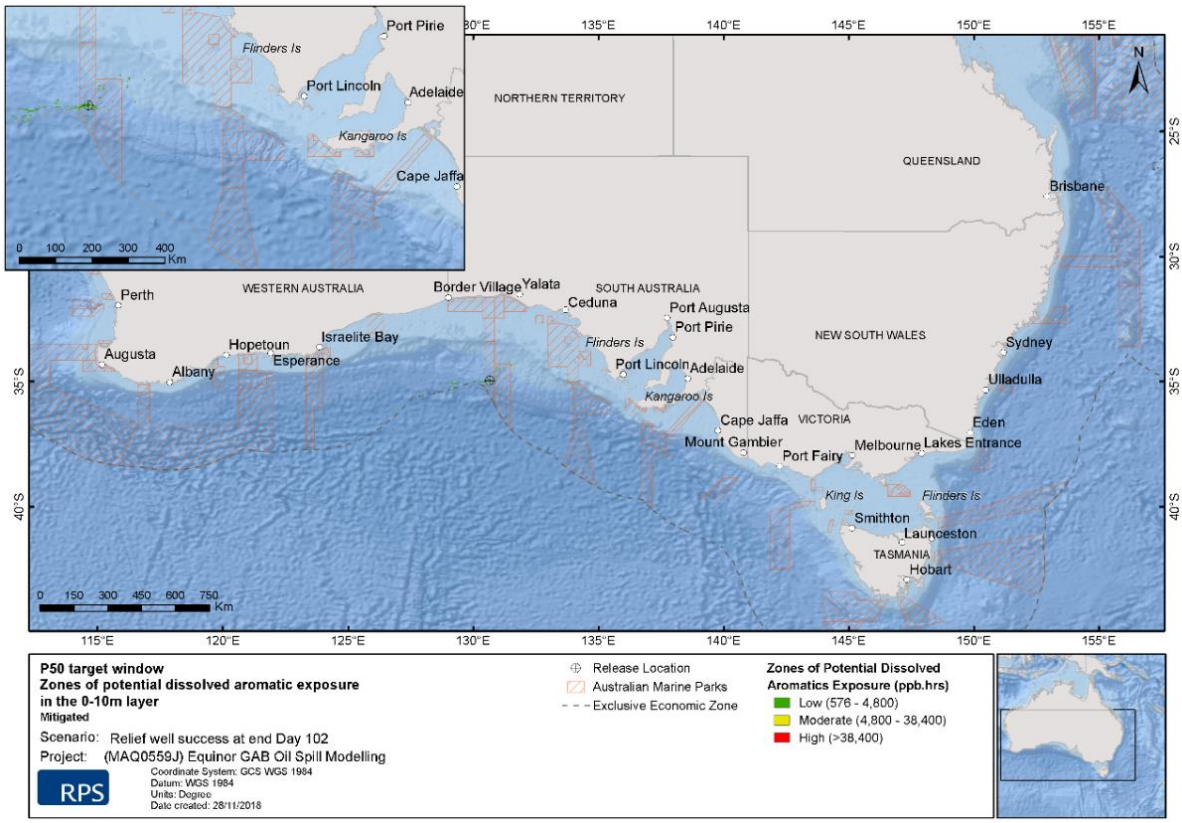


Figure 118: Potential dissolved hydrocarbon exposure (time averaged) in the 0-10 m layer for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

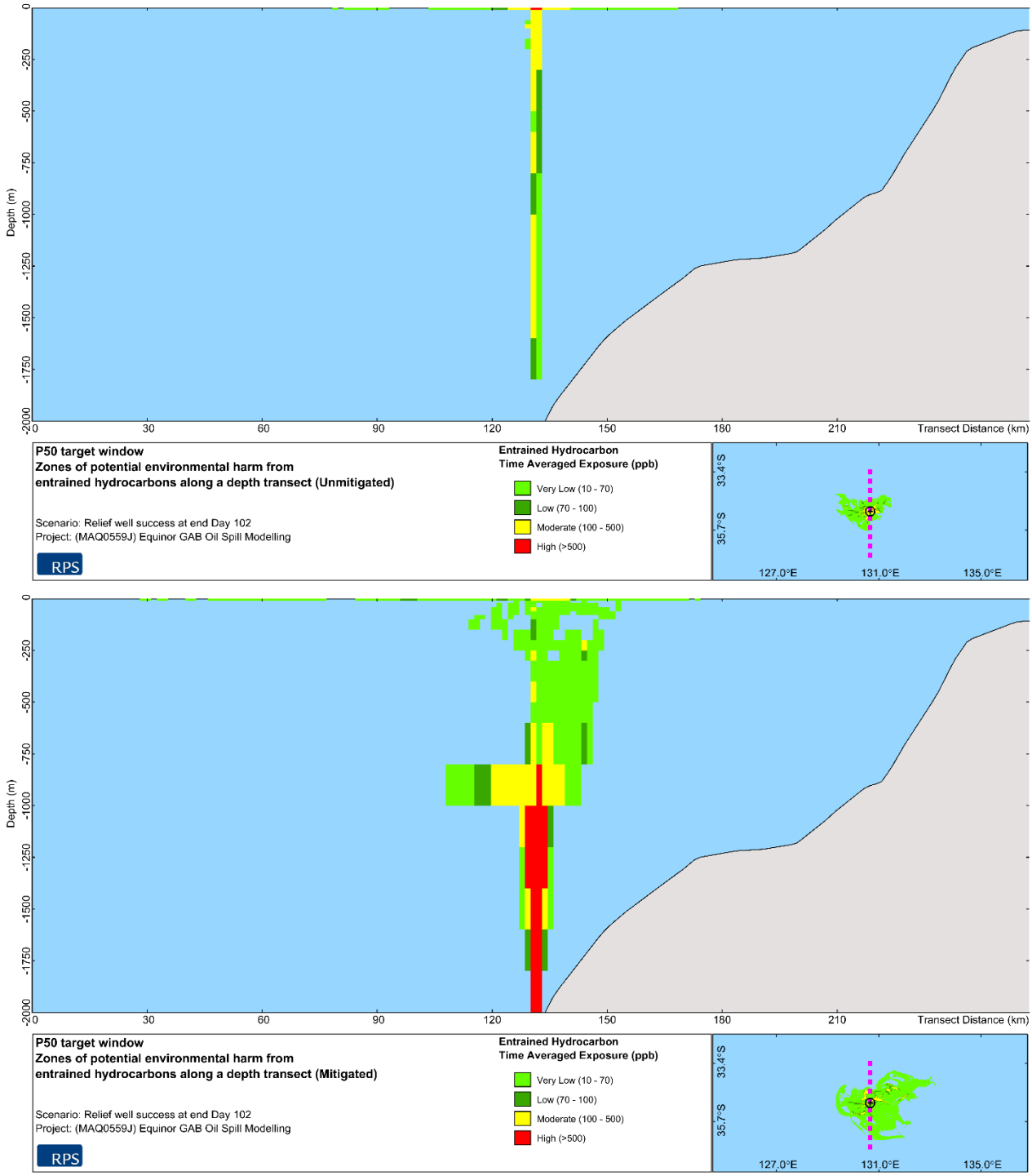
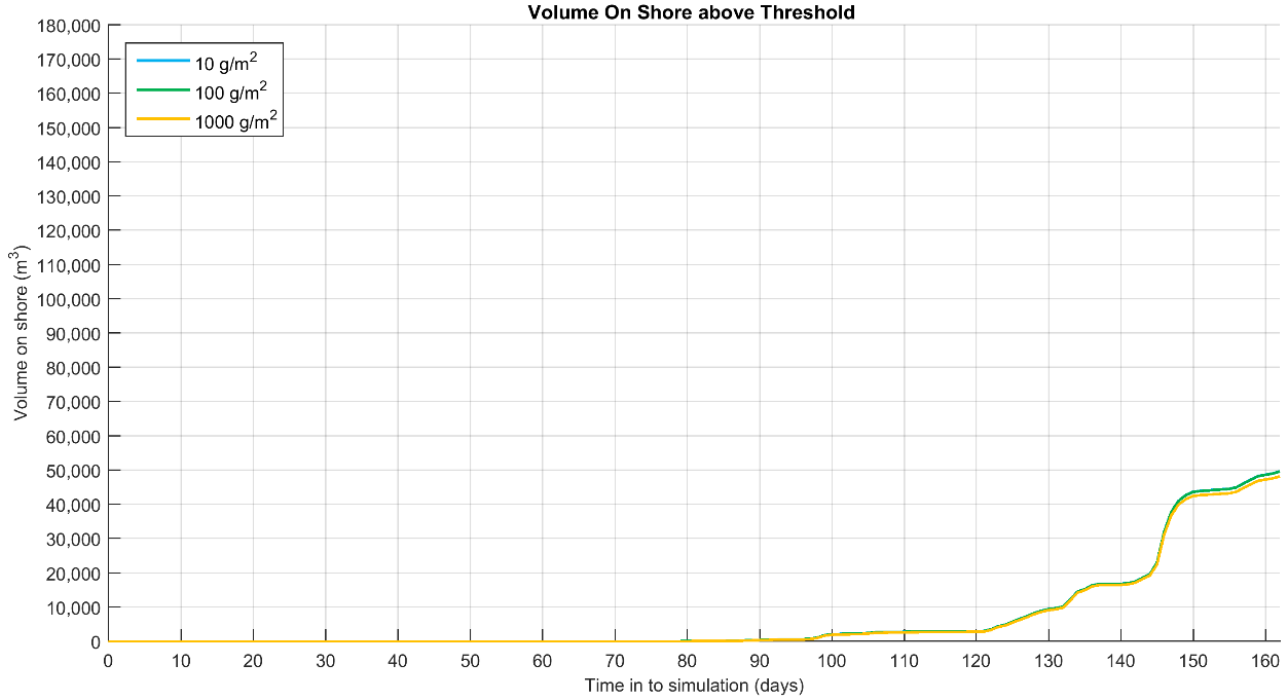


Figure 119: Three-dimensional profiles of the maximum potential entrained hydrocarbon exposure (time averaged) for the unmitigated (upper image) and mitigated (lower image) cases over the entire 162-day period. Based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days



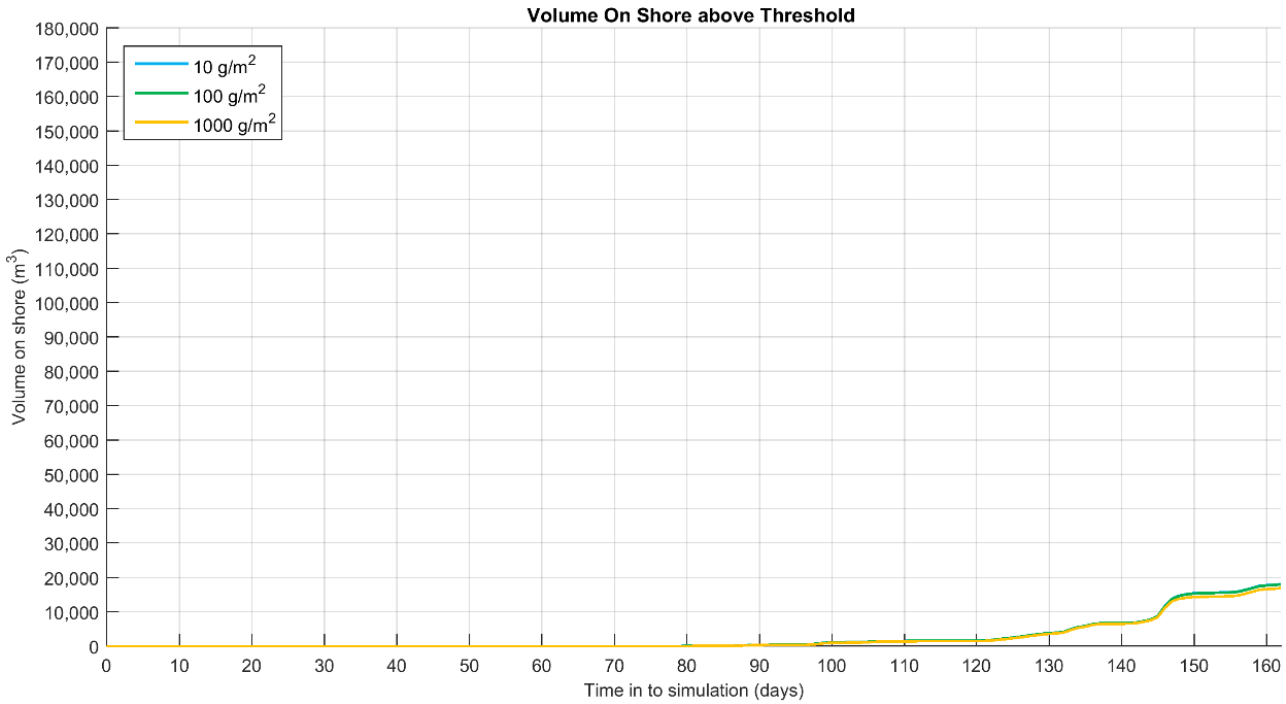


Figure 120: Mass on shore above each threshold for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

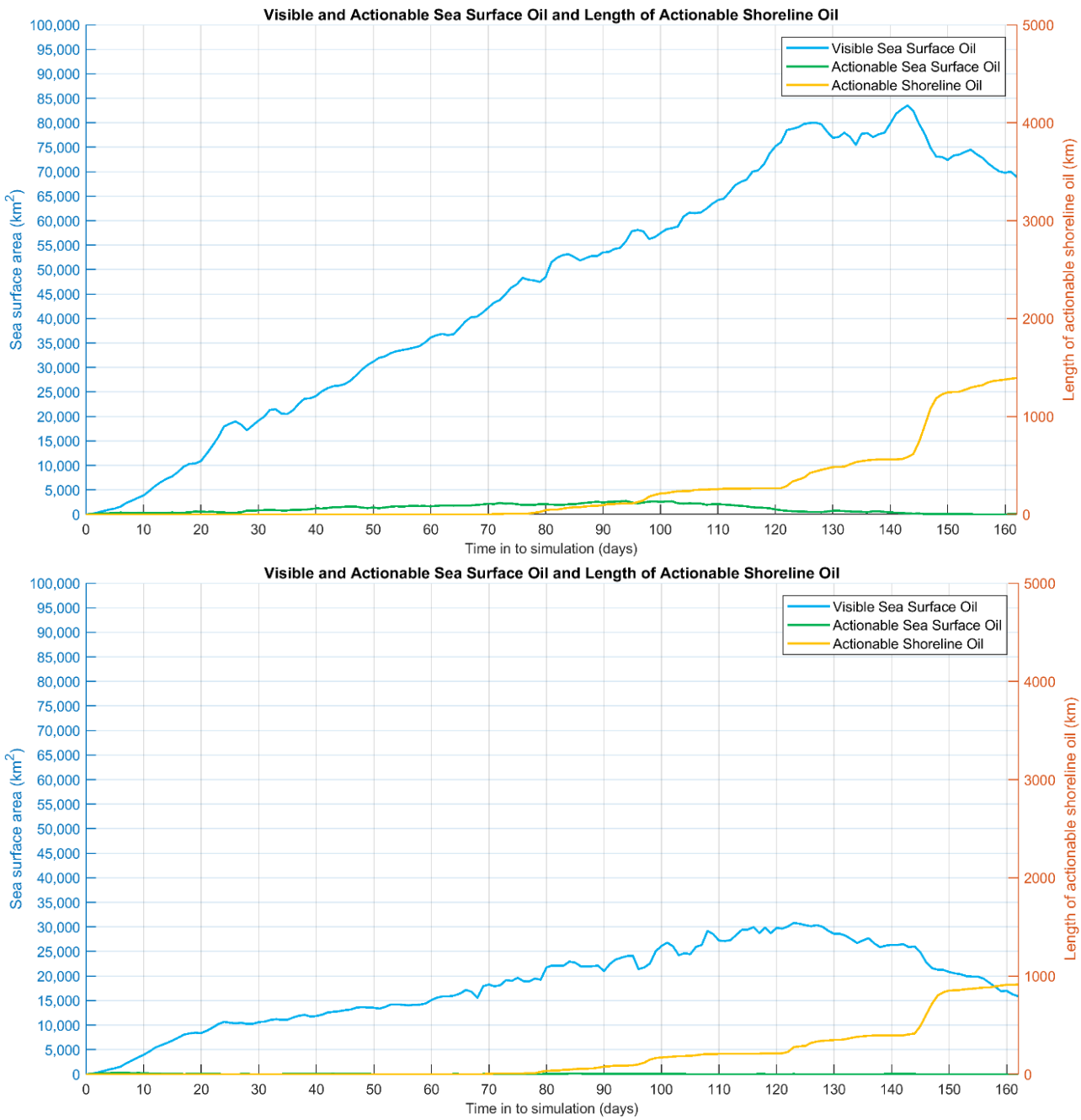


Figure 121: Area of sea surface exposure and length of shoreline oiled for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined an average 6,720 m³/day subsea release of crude oil over 102 days, tracked for 162 days

Figure 122 shows the predicted weathering and fates graphs for the unmitigated and mitigated modelling results. By the end of the simulation (day 162), 422,622 m³ and 72,642 m³ had evaporated and decayed, respectively, for the unmitigated model simulation. In comparison, 94,735 m³ and 461,615 m³ had evaporated and decayed, respectively, under the mitigated model conditions. The volume of weathered crude remaining ashore was predicted to be 50,195 m³ and 18,729 m³ for the unmitigated and mitigated modelling, respectively. Furthermore, 138,888 m³ and 49,180 m³ of weathered crude remained on the sea surface for the unmitigated and mitigated modelling, respectively. Entrained oil was higher for the mitigated simulation at 58,644 m³ compared to 149 m³ for the unmitigated simulation.

Table 60 provides a comparison of the mass balance at day 102 and 162, for the unmitigated and mitigated cases. Sea surface exposure to fresh oil at day 102 based on unmitigated and mitigated cases were 12,368 m^3 and 9,106 m^3, respectively. While, no fresh oil was predicted to remain on the sea surface under either unmitigated or mitigated case conditions at the end of the simulations (day 162), 138,888 m^3 and 49,180 m^3 of weathered oil was predicted to occur on the sea surface at day 162 under unmitigated or mitigated case conditions, respectively. At day 102, 196,594 m^3 and 56,323 m^3 of weathered oil was on the sea surface for the unmitigated and mitigated cases, respectively. Shoreline contact by fresh oil was not predicted to occur on day 102 or 162 under unmitigated or mitigated case conditions. Alternatively, volumes of weathered oil ashore for the unmitigated and mitigated case at day 102 was 2,239 m^3 and 1,183 m^3, respectively). At day 102, the mitigated simulation had a higher volume of entrained oil at 150,433 m^3 compared to the unmitigated case at 2,239 m^3.

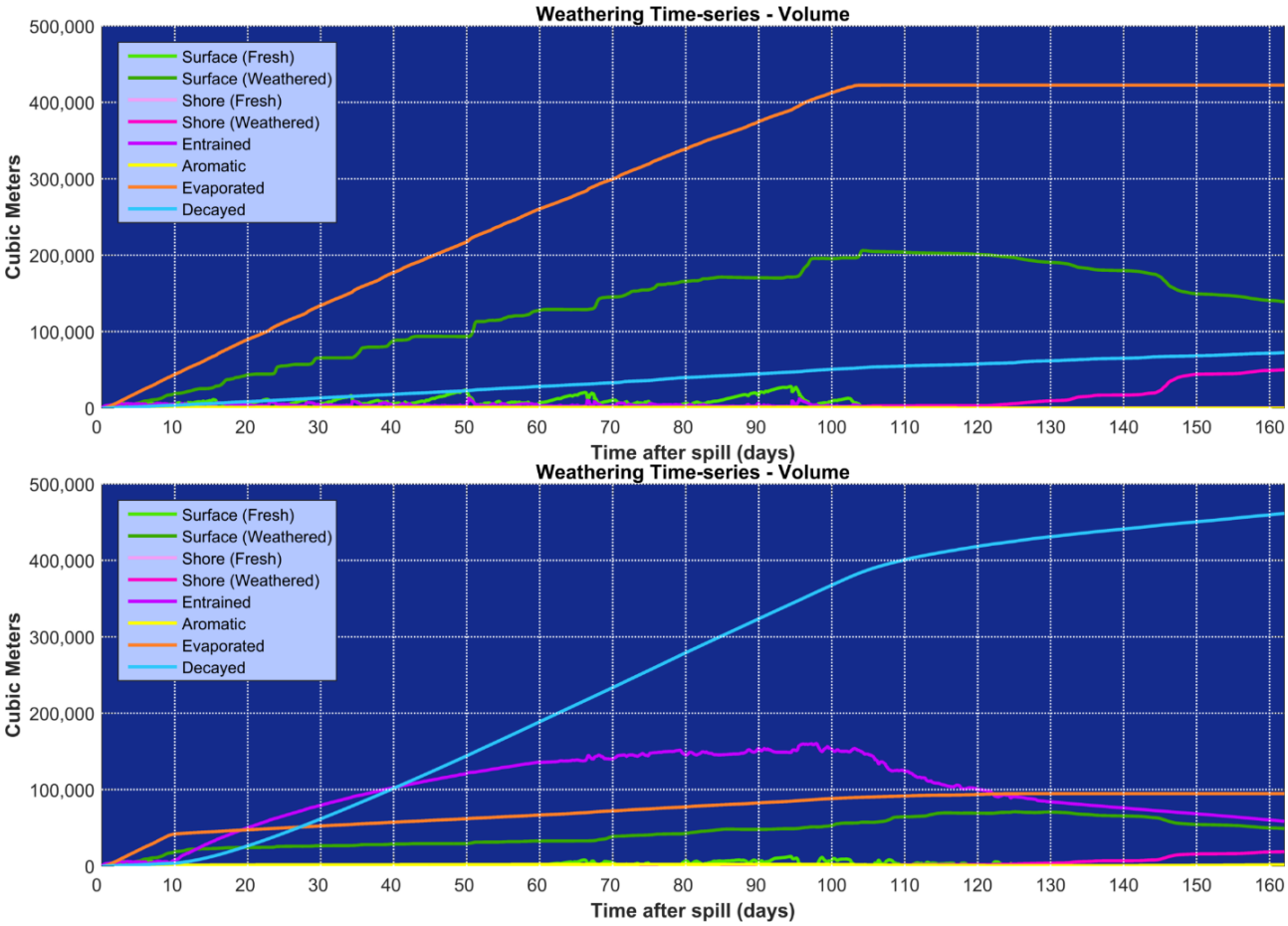


Figure 122: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases. Based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Table 60: Summary of the mass balance at day 102 and 162, for the unmitigated and mitigated cases. Based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined an average 6,720 m^3/day subsea release of crude oil over 102 days, tracked for 162 days

Exposure metrics	At Day-102 the end of the release		At Day-162 end of the simulation	
	Unmitigated	Mitigated	Unmitigated	Mitigated
Surface Fresh (m^3)	12,438	9,106	0	0
Surface Weathered (m^3)	196,594	56,323	138,888	49,180
Ashore Fresh (m^3)	0	0	0	0
Ashore weathered (m^3)	2,219	1,183	50,195	18,729
Entrained (m^3)	2,239	150,433	149	58,644
Aromatic (m^3)	727	2,074	0	1,722
Evaporated (m^3)	418,842	89,227	422,622	94,736
Decay (m^3)	51,625	376,335	72,643	461,615

12 SCENARIO 3 OUTCOMES – CAPPING STACK SUCCESS AT END DAY 15

This scenario examined the effectiveness of the capping stack at end Day 15, during which an average of 7,596 m^3/day of crude was released subsea for 15 days and tracked for a total of 55 days. The mitigation efforts were also assessed by incorporating the application of ADA from Day 2 to 15 and SSDI from Day 9 to Day 15.

12.1 Fastest time before oil contact to shorelines

The “fastest time to shore” simulation was used to assess the potential change (if any) for the proposed mitigation methods.

Figure 123 compares maps of the actionable oil, respectively for the unmitigated and mitigated modelling results over the entire 55-day period.

Figure 124 shows maps of sea surface exposure for the unmitigated and mitigated modelling results. Figure 125 illustrates the shoreline loading for the two cases.

The oil exposure on the sea surface and shoreline contact was similar between the unmitigated and mitigated cases, though had reduced dramatically with the addition of the capping stack compared to the 102 day well kill.

The extent of fresh oil on the sea surface was limited to <100 km from the well. Low to moderate weathered surface oil concentrations in nearshore waters was limited to South Australia and no other states.

Weathered oil contacting the shoreline was now restricted to South Australia only, and no longer contacted Victoria and Tasmania. Potentially high shoreline loadings (>1000 g/m^2) were limited to Flinders Island, Port Lincoln and Yorke Peninsula.

Figure 126 and Figure 127 show maps of potential entrained hydrocarbon and dissolved hydrocarbon (time averaged) exposure in the 0–10 m depth, respectively, for the unmitigated and mitigated modelling results. The in-water oil exposure was similar for the two cases.

Figure 128 shows the predicted weathering and fates graphs for the unmitigated and mitigated modelling results. By the end of the simulation (day 55), 72,891 m^3 (~64% of the total release volume) and 9,802 m^3 (~9%) had evaporated and decayed, respectively under unmitigated model conditions. In comparison, 47,244 m^3 (~42%) and 36,863 m^3 (~32%) had evaporated and decayed, respectively, under the mitigated model conditions. The volume of weathered crude remaining ashore was predicted to be 9,408 m^3 (~8%) and 6,849 m^3 (~6%) for the unmitigated and mitigated modelling, respectively. Furthermore, 26,789 m^3 (~24%) and 16,433 m^3 (~14%) of weathered crude remained on the sea surface for the unmitigated and mitigated simulations. For the unmitigated simulation, 69 m^3 (<1%) was predicted to remain entrained in the water column compared to 11,856 m^3 (~10%) for the mitigated simulation.

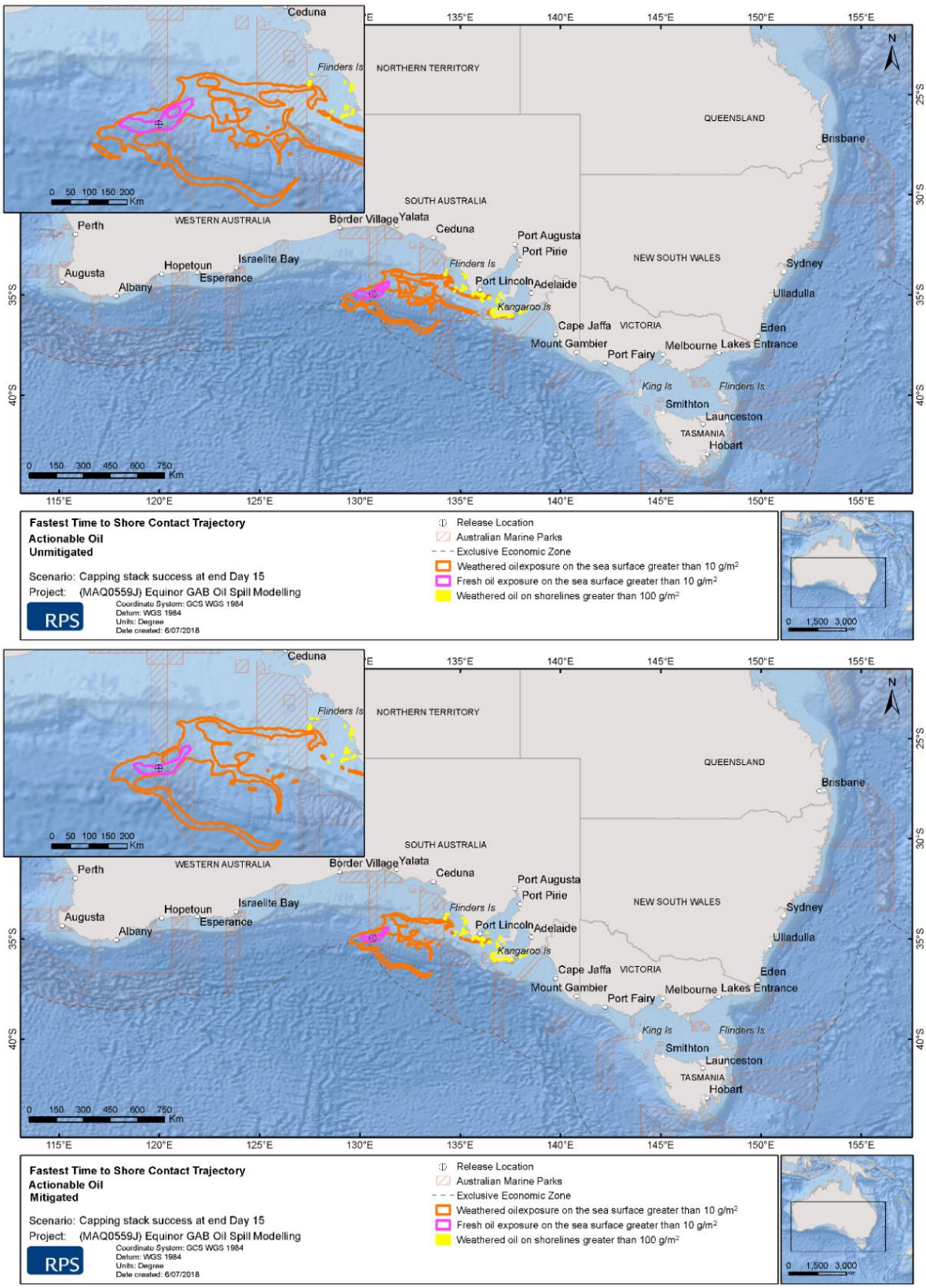


Figure 123: Predicted actionable oil for the unmitigated (upper image) and mitigated (lower image) cases over the entire 55-day period. Results are based on the simulation with the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined a 7,596 m³/day subsea release of crude oil over 15 days

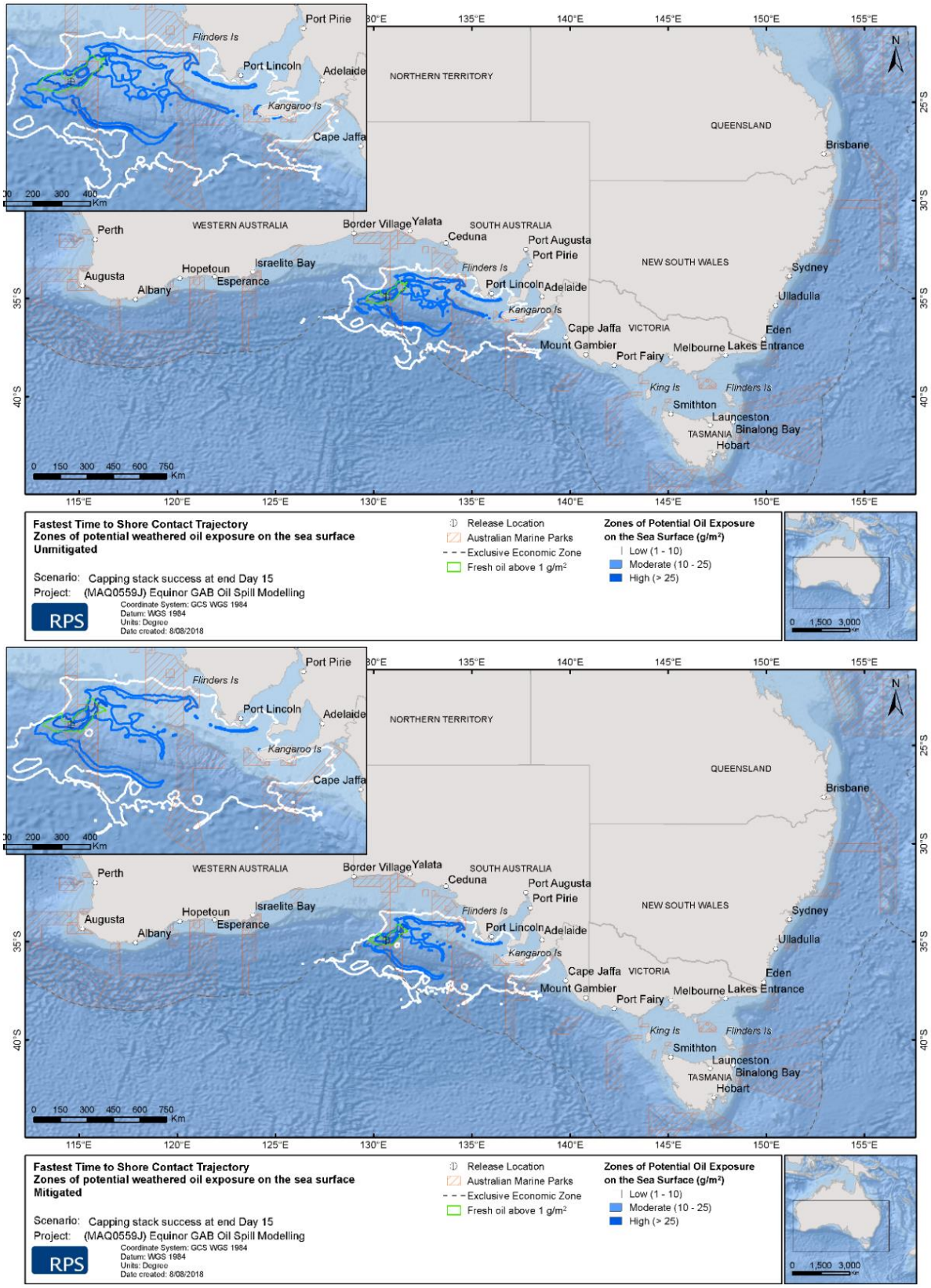


Figure 124: Sea surface exposure for the unmitigated (upper image) and mitigated (lower image) cases over the entire 55-day period. Results are based on the simulation with the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined a 7,596 m³/day subsea release of crude oil over 15 days

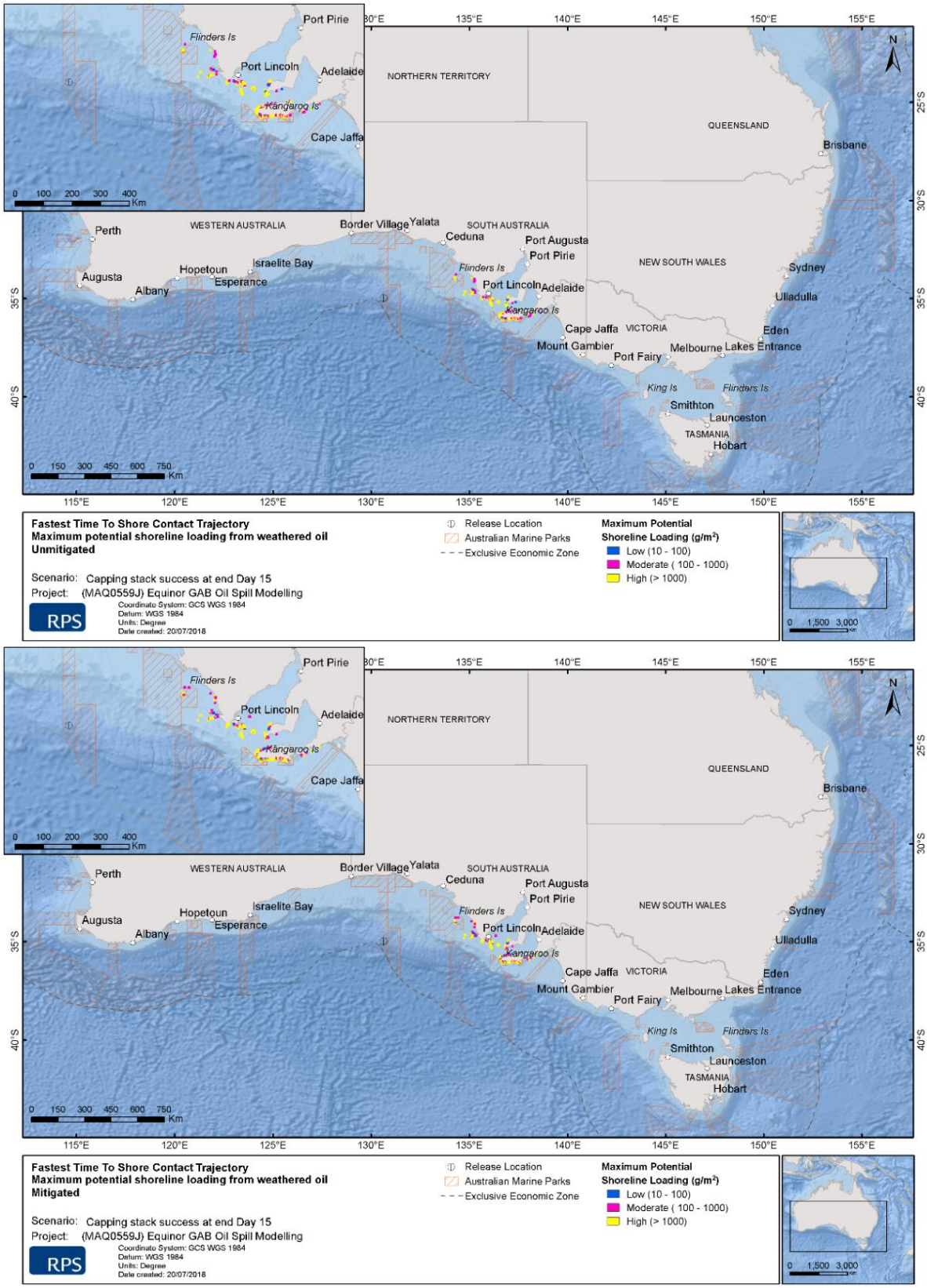


Figure 125: Shoreline contact for the unmitigated (upper image) and mitigated (lower image) cases over the entire 55-day period. Results are based on the simulation with the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined a 7,596 m³/day subsea release of crude oil over 15 days

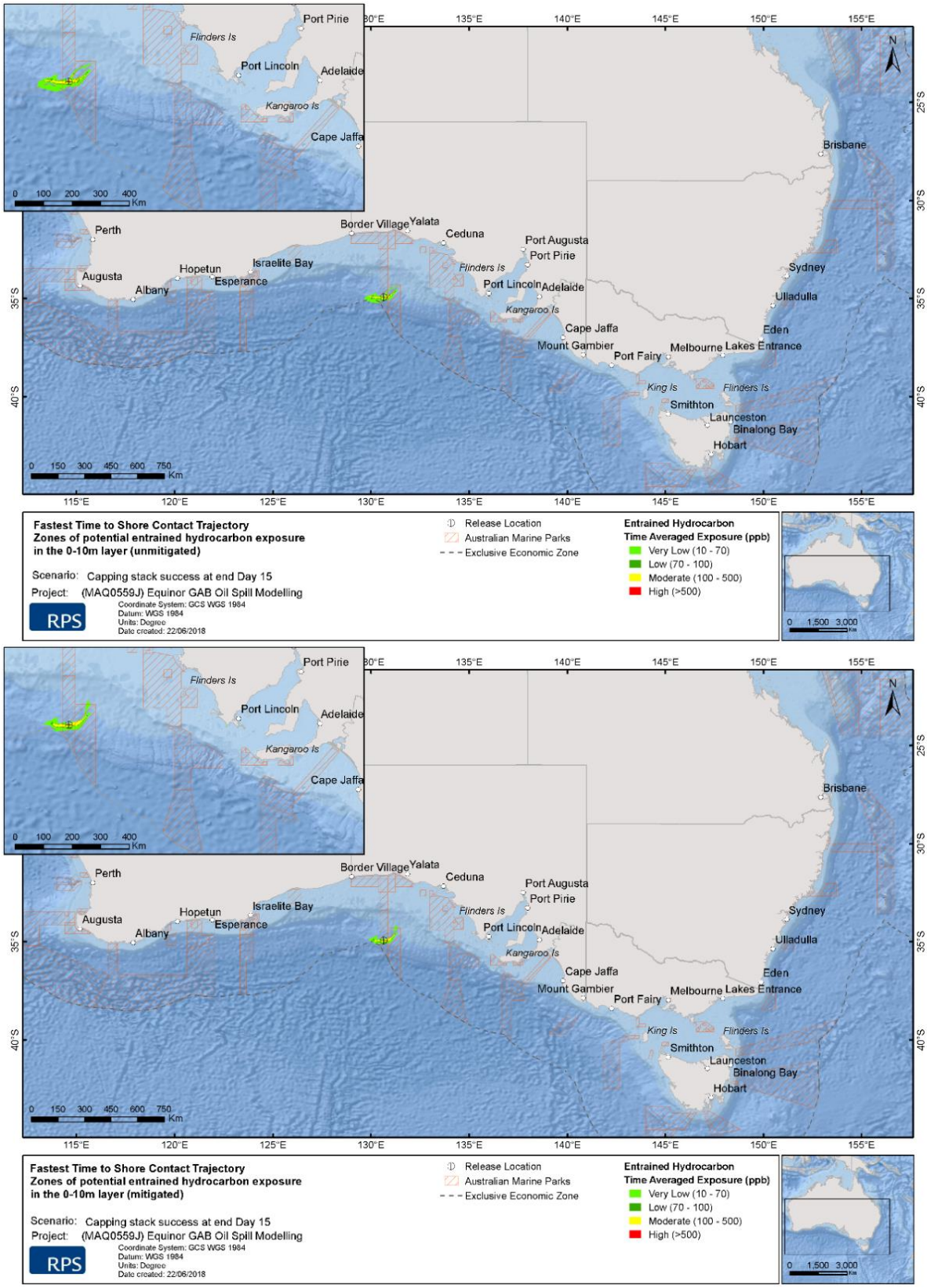


Figure 126: Potential entrained hydrocarbon exposure in the 0-10 m layer for the unmitigated (upper image) and mitigated (lower image) cases over the entire 55-day period. Results are based on the simulation with the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined a 7,596 m^3/day subsea release of crude oil over 15 days

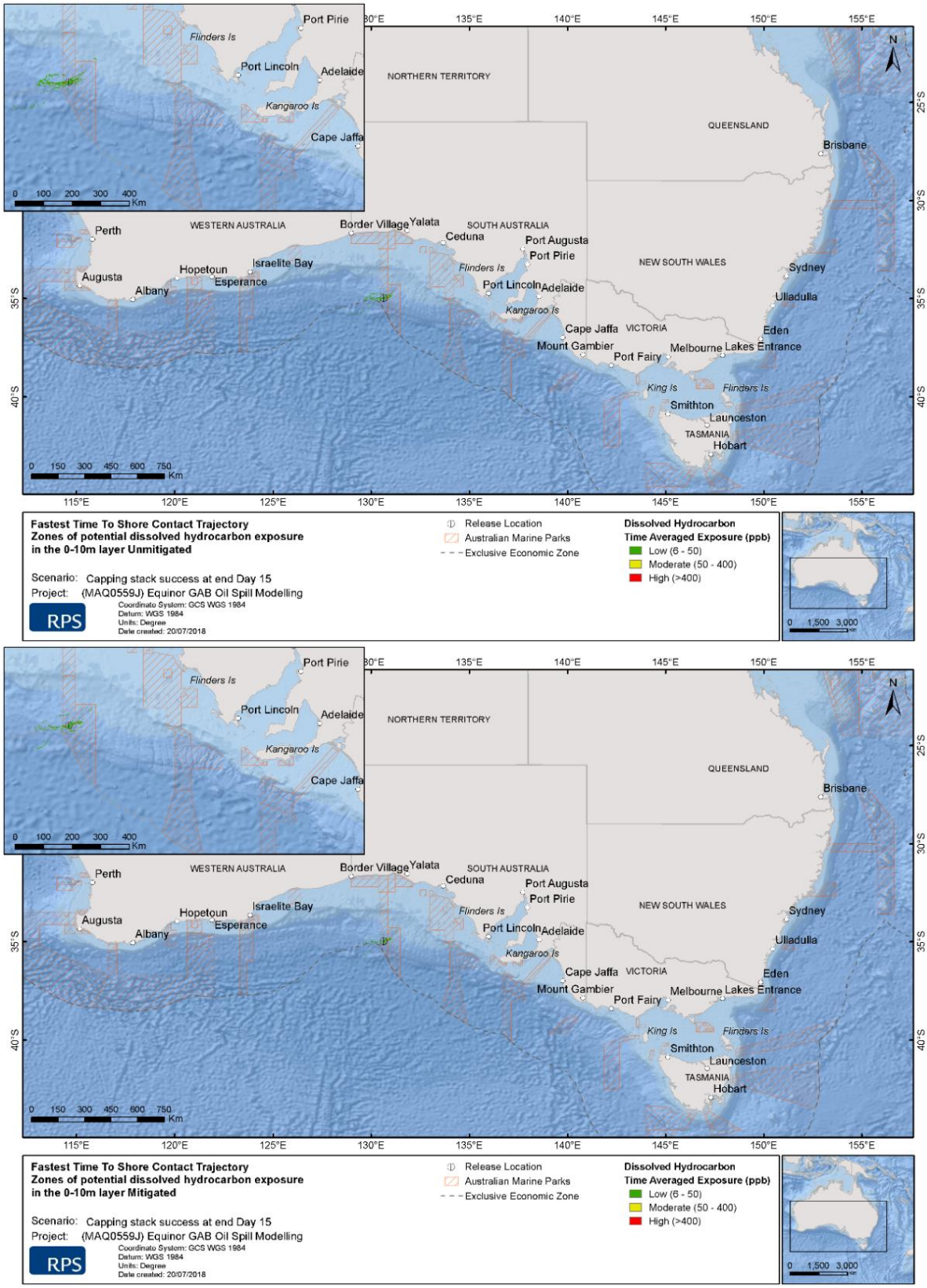


Figure 127: Potential dissolved hydrocarbon (time averaged) exposure in the 0-10 m layer for the unmitigated (upper image) and mitigated (lower image) cases over the entire 55-day period. Results are based on the simulation with the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined a 7,596 m^3/day subsea release of crude oil over 15 days

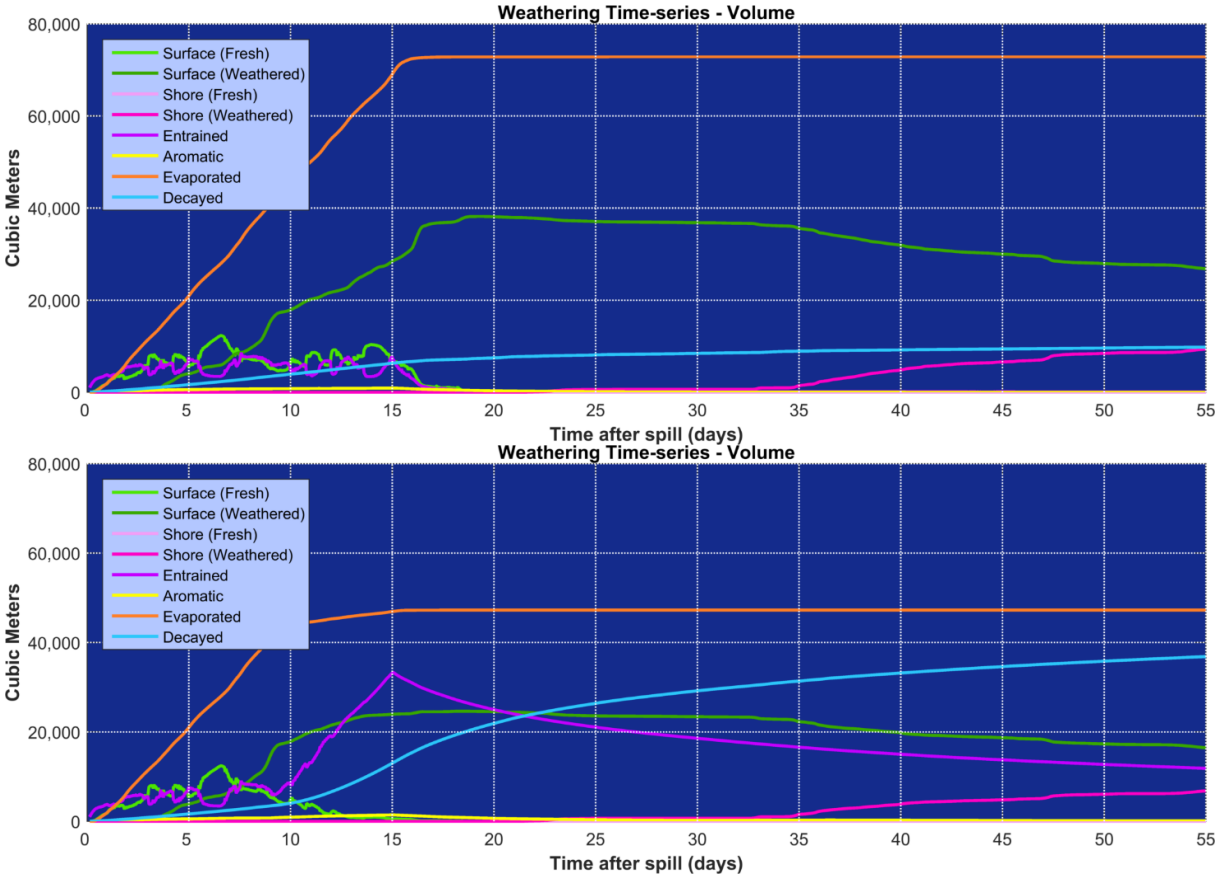


Figure 128: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases. Results are based on the simulation with the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined a 7,596 m^3/day subsea release of crude oil over 15 days, tracked for 55 days

12.2 P50 reference case

The spill identified as resulting in the P50 (50th percentile) volume of weathered oil ashore between November to February ("target window" or most likely operational window) was used to assess the potential change (if any) for the proposed mitigation methods.

Figure 129 compares maps of the actionable oil, respectively for the unmitigated and mitigated modelling results over the entire 55-day period.

Figure 130 shows maps of sea surface exposure for the unmitigated and mitigated modelling results. No shoreline contact above reporting threshold was predicted.

The oil exposure on the sea surface was similar between the unmitigated and mitigated cases, though had reduced dramatically with the addition of the capping stack compared to the 102 day well kill.

Figure 131 and Figure 132 show maps of potential entrained hydrocarbon and dissolved hydrocarbon (time averaged) exposure in the 0–10 m depth, respectively, for the unmitigated and mitigated modelling results. The in-water oil exposure was similar for the two cases.

Figure 133 shows the predicted weathering and fates graphs for the unmitigated and mitigated modelling results. By the end of the simulation (day 55), 69,981 m^3 (~61% of the total release volume) and 8,864 m^3 (~8%) had evaporated and decayed, respectively under unmitigated model conditions. In comparison, 45,419 m^3 (~40%) and 34,772 m^3 (~31%) had evaporated and decayed, respectively, under the mitigated model conditions. The volume of weathered crude remaining on the sea surface for the unmitigated and mitigated simulations was 35,208 m^3 (~31%) and 22,649 m^3 (~20%). For the unmitigated simulation, 60 m^3 (<1%) was predicted to remain entrained in the water column compared to 11,479 m^3 (~10%) for the mitigated simulation.

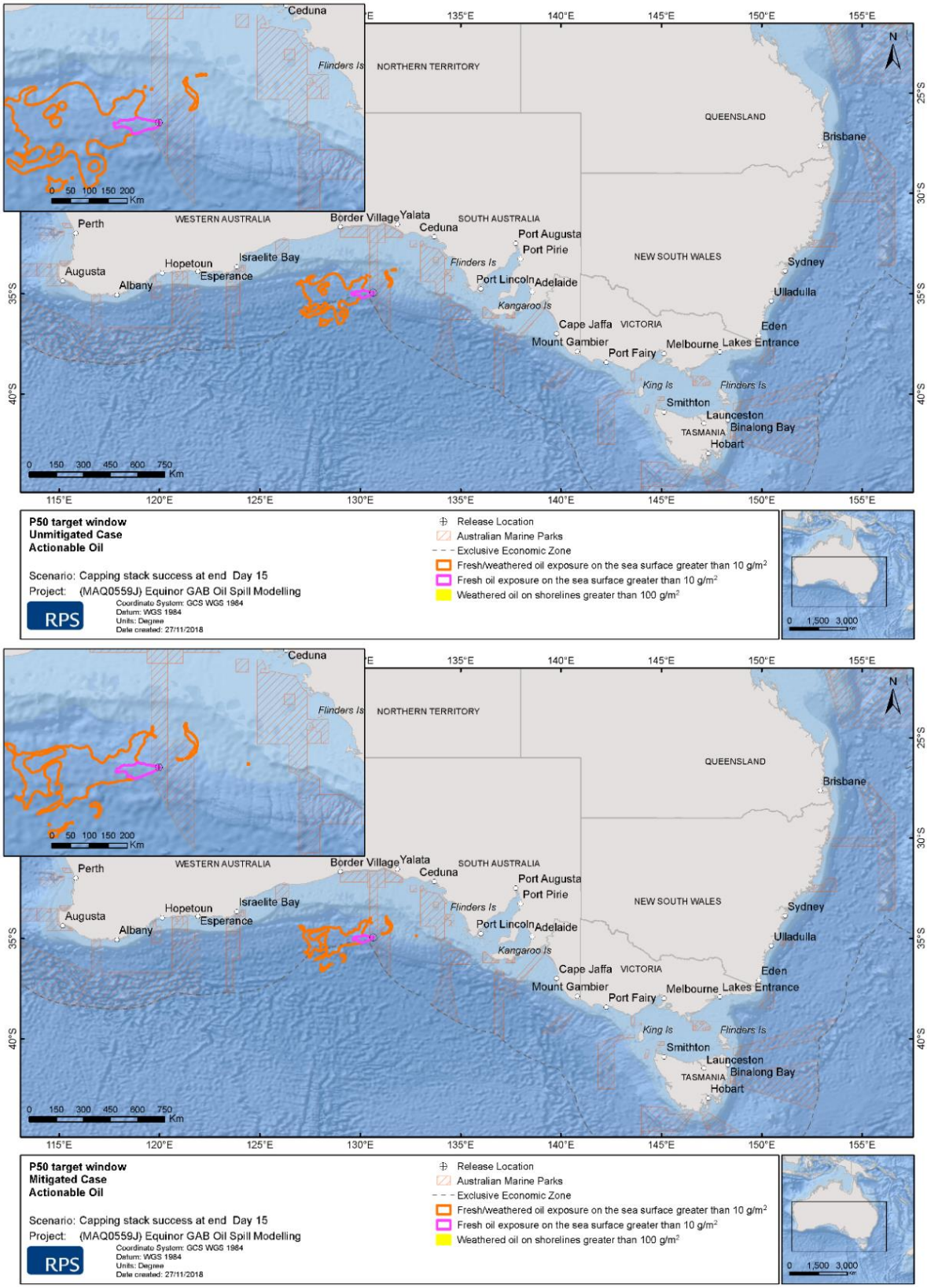


Figure 129: Predicted actionable oil for the unmitigated (upper image) and mitigated (lower image) cases over the entire 55-day period. Results are based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined a 7,596 m³/day subsea release of crude oil over 15 days

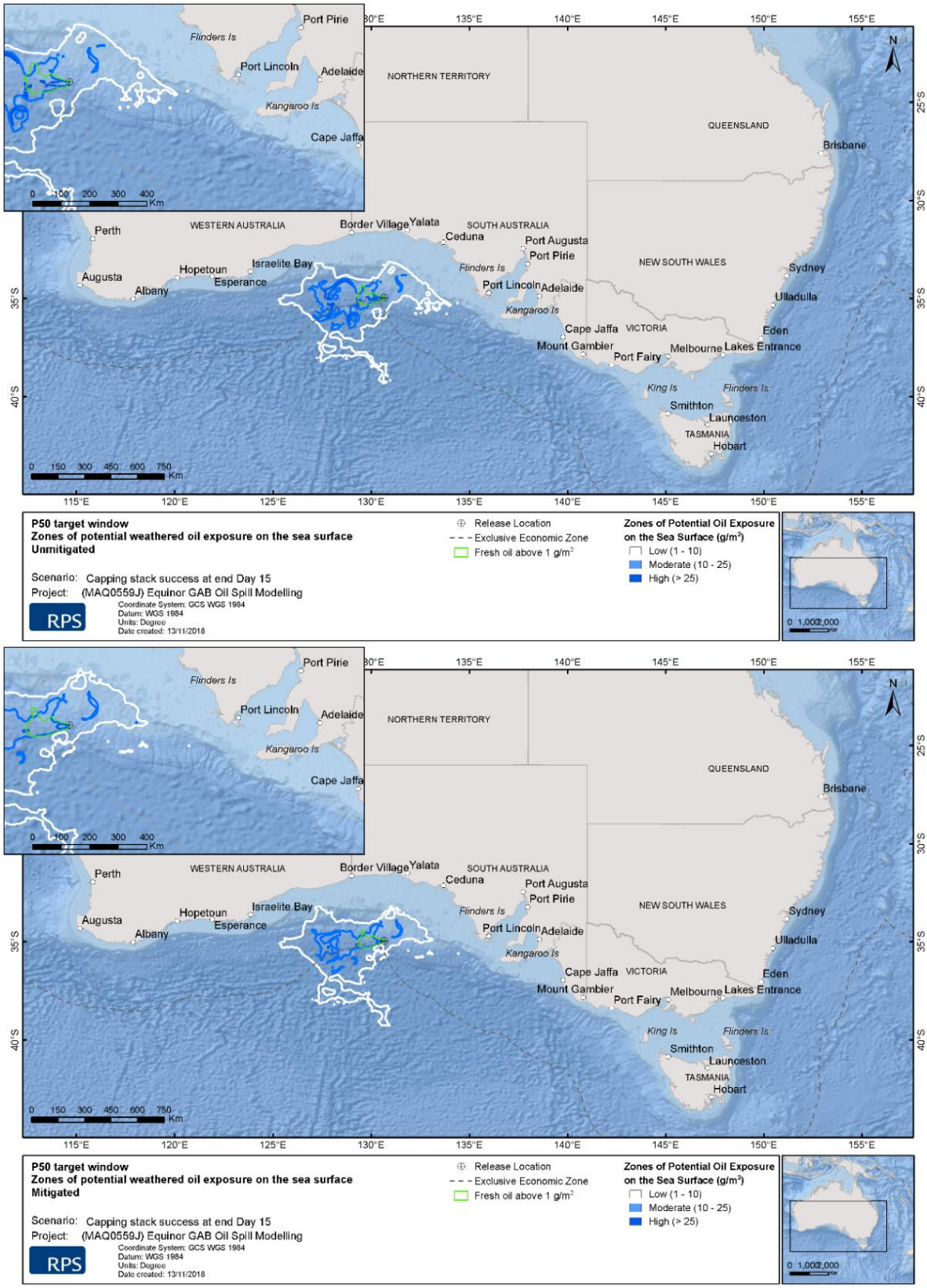
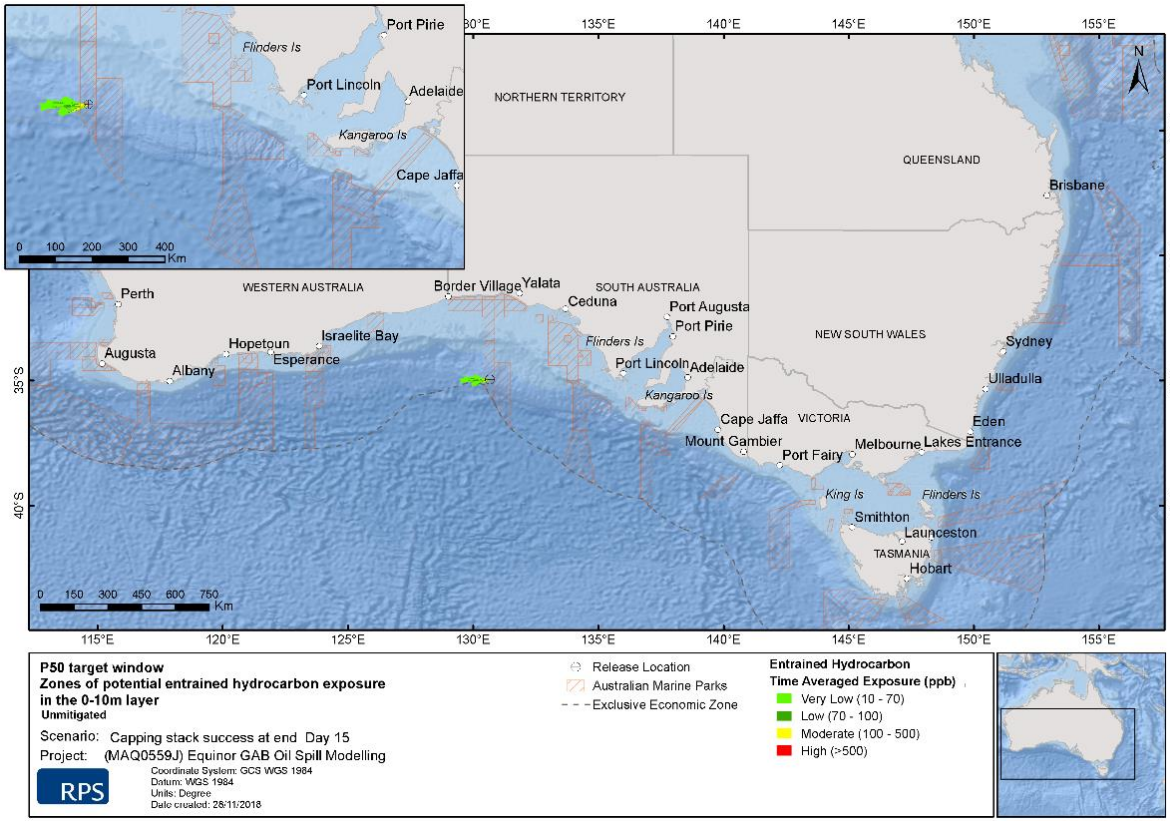


Figure 130: Sea surface exposure for the unmitigated (upper image) and mitigated (lower image) cases over the entire 55-day period. Results are based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined a 7,596 m³/day subsea release of crude oil over 15 days



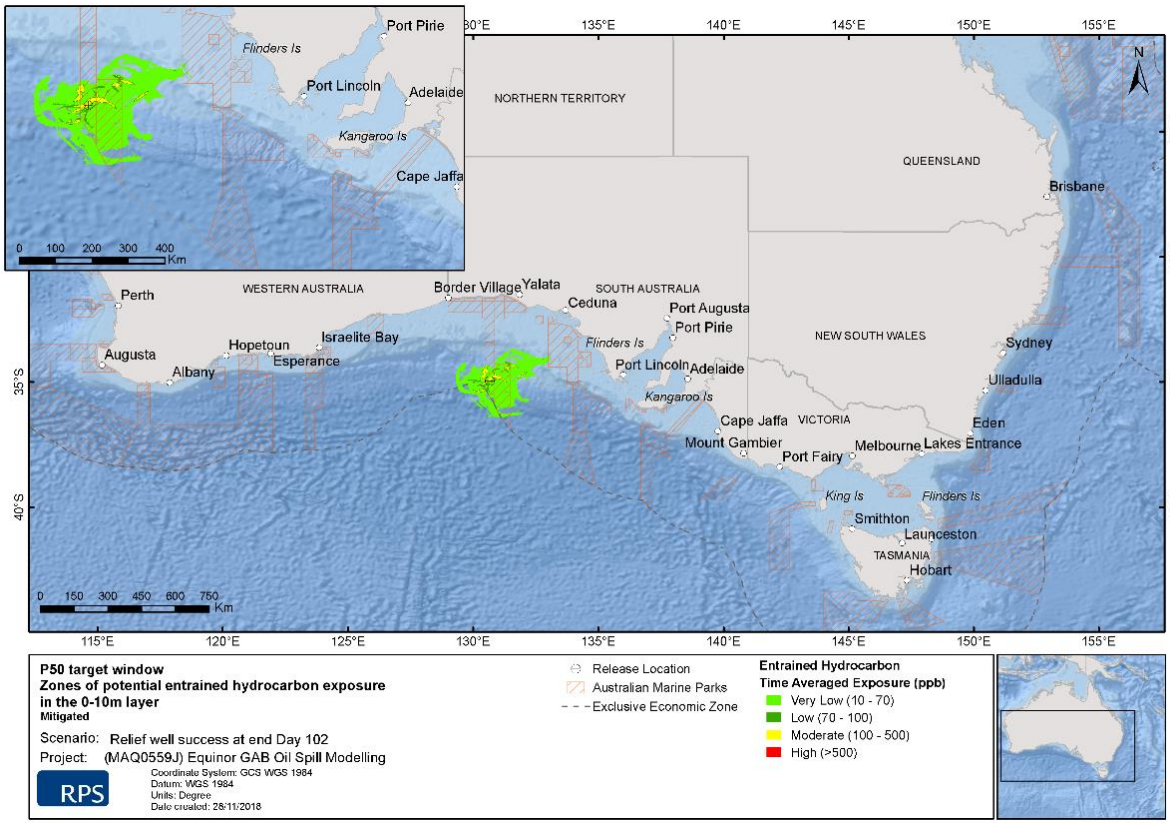
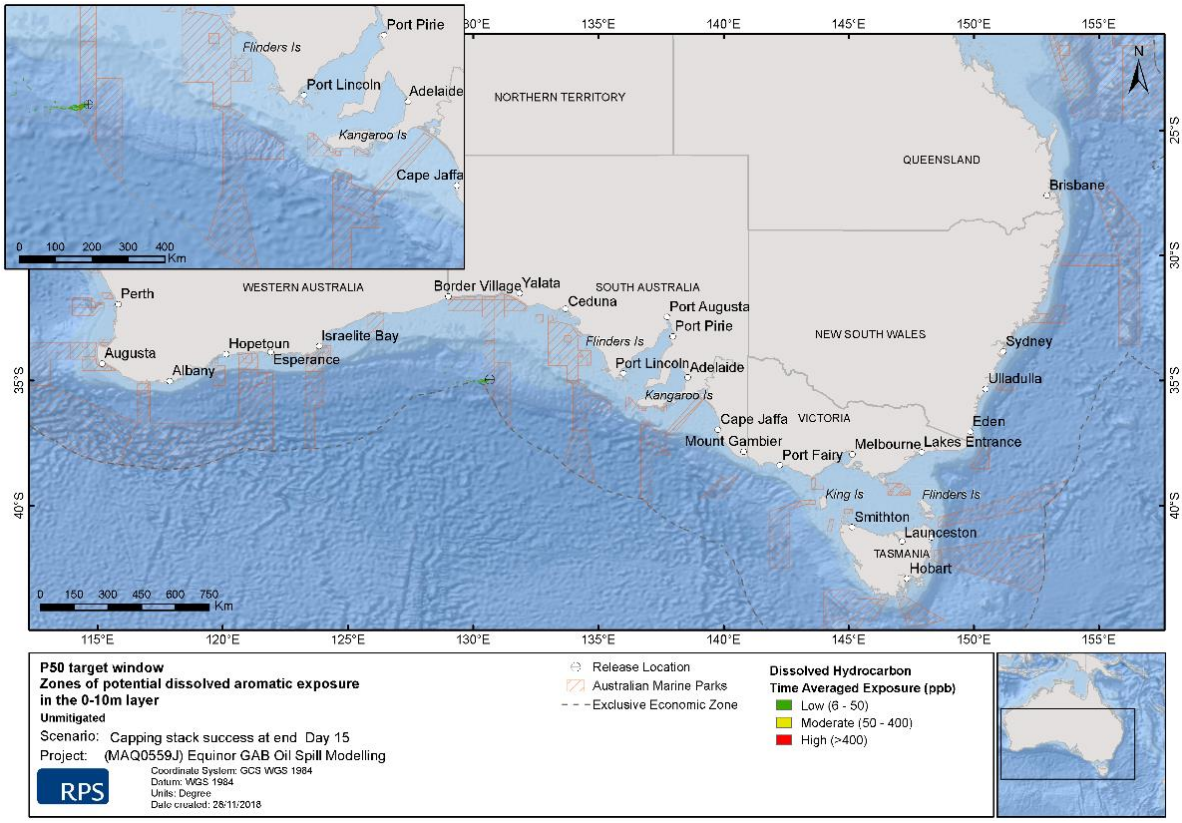


Figure 131: Potential entrained hydrocarbon exposure in the 0-10 m layer for the unmitigated (upper image) and mitigated (lower image) cases over the entire 55-day period. Results are based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined a 7,596 m^3/day subsea release of crude oil over 15 days



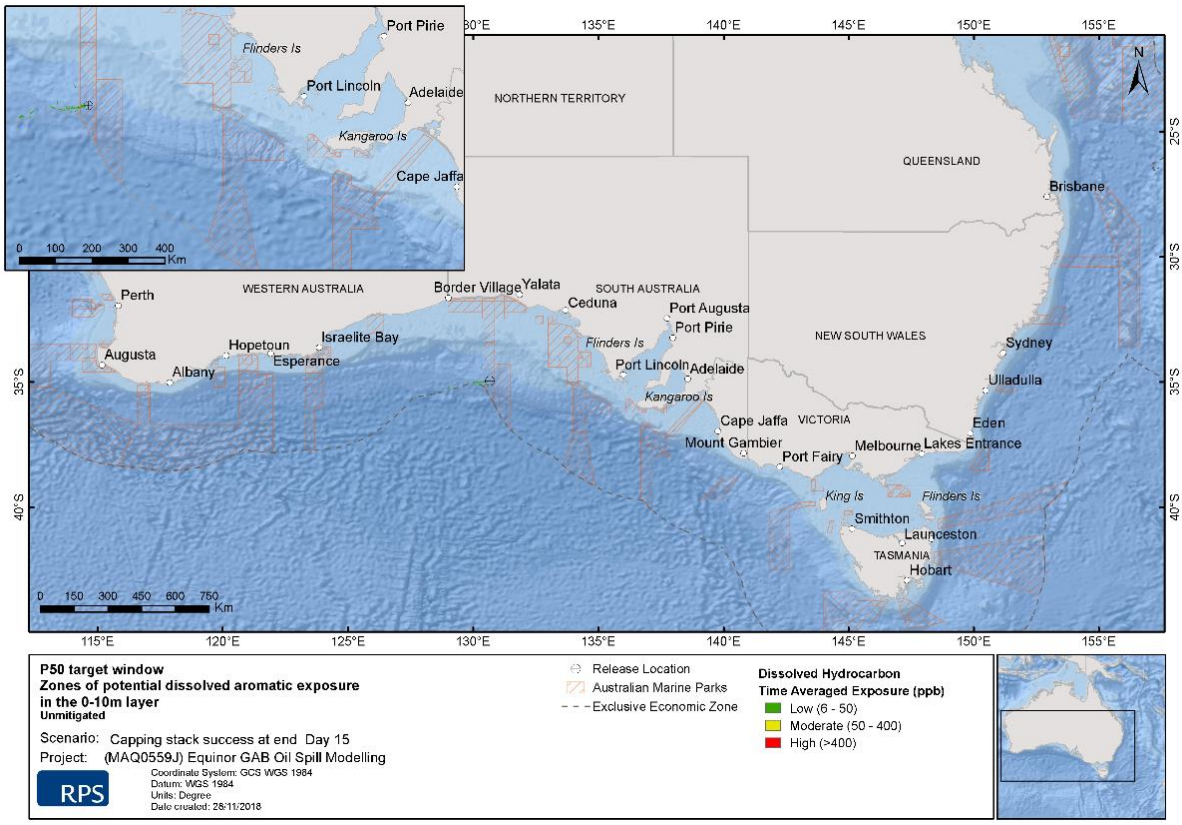


Figure 132: Potential dissolved hydrocarbon (time averaged) exposure in the 0-10 m layer for the unmitigated (upper image) and mitigated (lower image) cases over the entire 55-day period. Results are based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined a 7,596 m^3/day subsea release of crude oil over 15 days

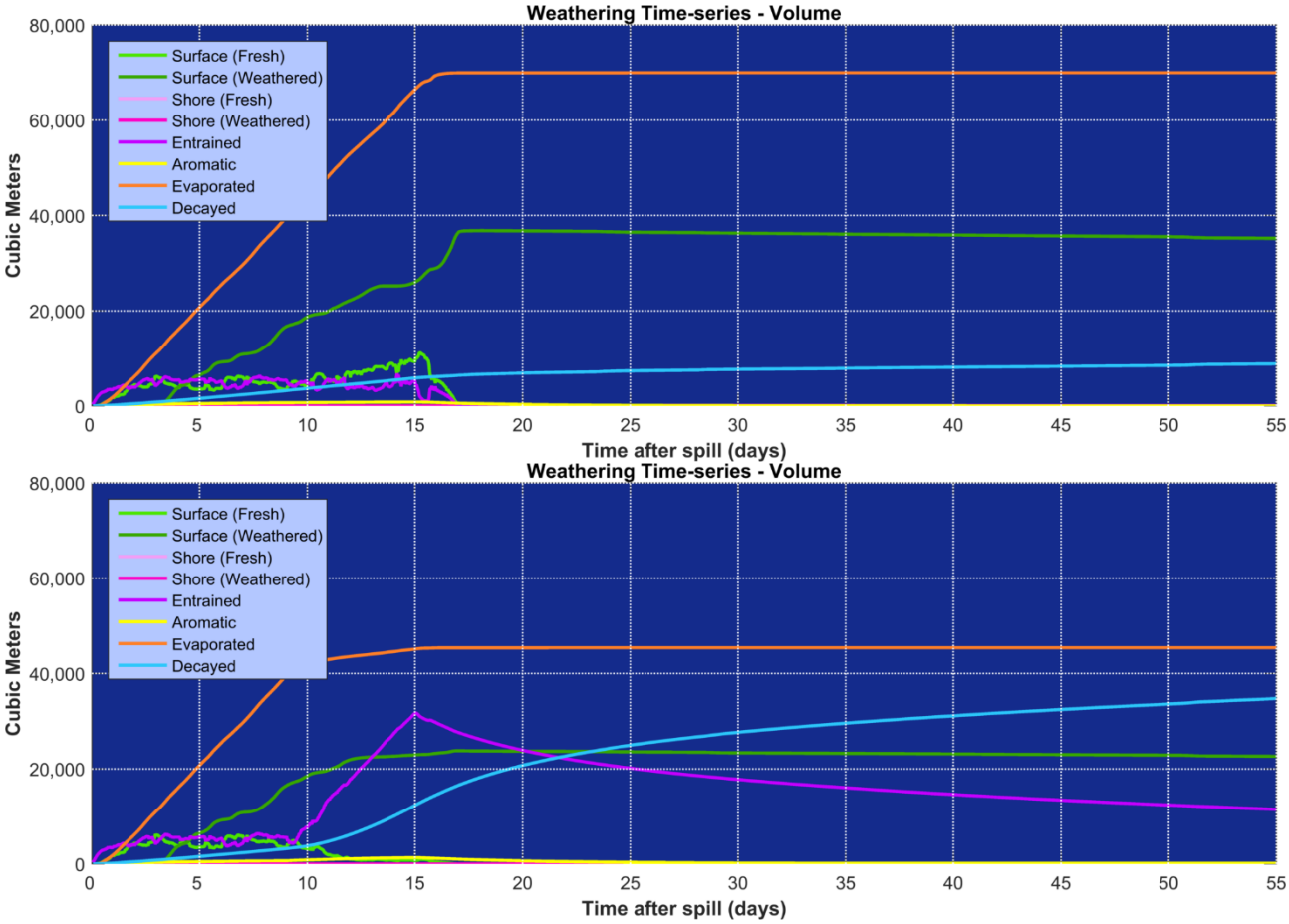


Figure 133: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases. Results are based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined a 7,596 m^3/day subsea release of crude oil over 15 days

13 SCENARIO 4 OUTCOMES – BOP CLOSURE SUCCESS AT END OF DAY-1

13.1 Fastest time before oil contact to shorelines

The “fastest time to shore” simulation was used to assess the potential change (if any) for the proposed mitigation methods.

Modelling was carried out to assess the potential change (if any) following the BOP closure success at end of day-1, for unmitigated and mitigated cases. The day-1 unrestricted annulus flow rate of 7,749 m^3 was simulated as a subsea release and tracked for 45 days. As part of the model inputs for the mitigation case, aerial surface dispersant was applied from Day 2 until there was no fresh surface oil amenable to dispersant application. The unmitigated and mitigated simulations had used the same start time of 30 May 2011 at 20:00 hrs as the simulation identified in Section 11.1.2, which resulted in the fastest time (i.e. minimum) before oil contact to shorelines.

Figure 134 compares maps of the predicted actionable oil for the unmitigated and mitigated modelling results over the entire 45-day simulation period.

Figure 135 shows maps of sea surface exposure for the unmitigated and mitigated modelling results. Figure 136 illustrates the shoreline loading for the two cases.

Figure 137 shows the predicted weathering and fates graphs for the unmitigated and mitigated modelling results. No change was evident between the modelling results. By the end of the simulation (day 45), 4,772 m^3 (~62% of the total release volume) and 715 m^3 (~9%) had evaporated and decayed, respectively. By day 45, the volume of weathered crude remaining ashore was predicted to be 1,302 m^3 (~17%). Additionally, 1,040 m^3 (~13%) of weathered crude was predicted to remain on the sea surface at the end of simulation for the unmitigated and mitigated modelling results.

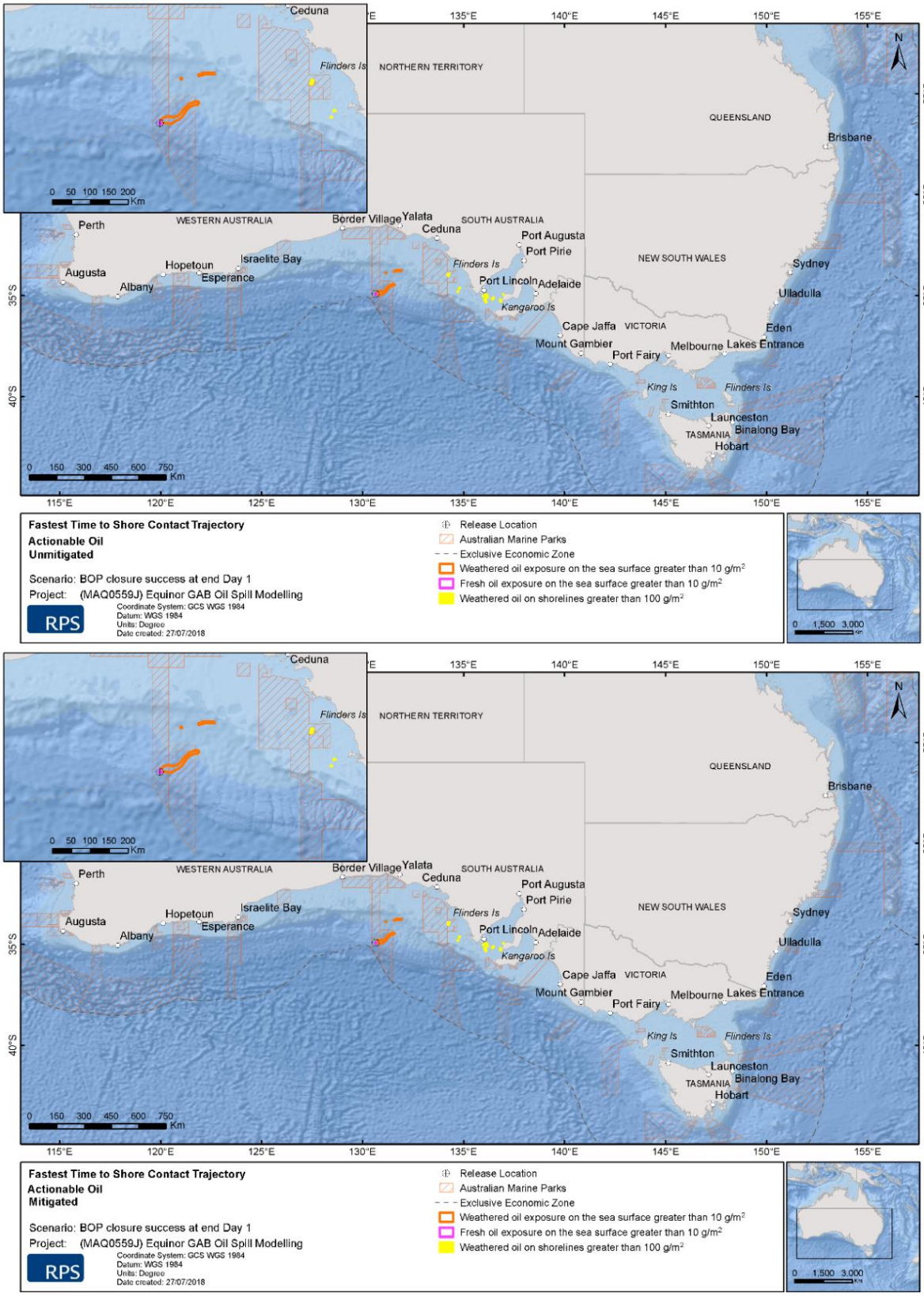


Figure 134: Predicted actionable oil for the unmitigated (upper image) and mitigated (lower image) cases over the entire 45-day period. Results are based on the simulation with the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined a 7,749 m³ subsea release of crude oil over 1 day, tracked for 45 days

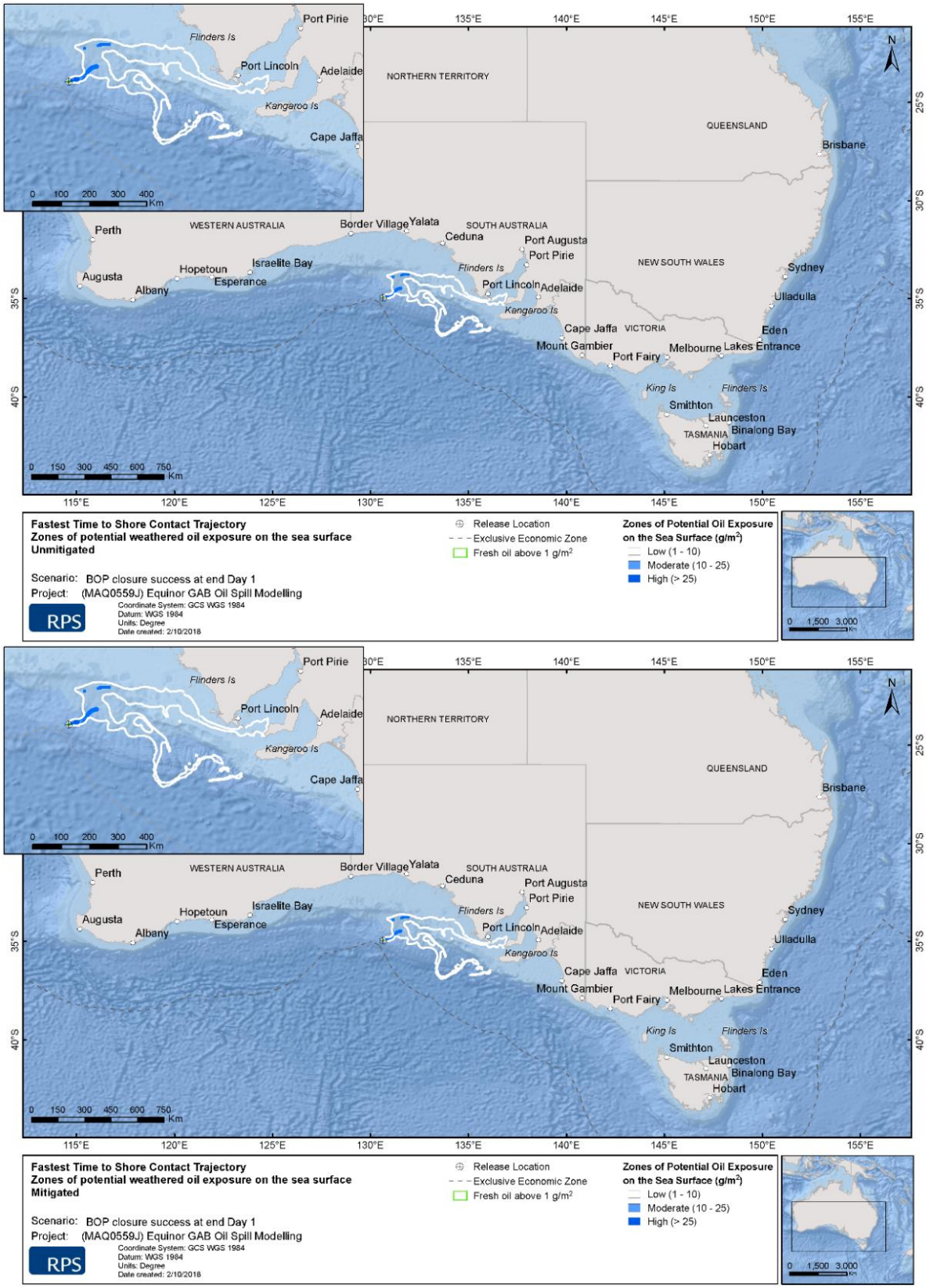


Figure 135: Sea surface exposure for the unmitigated (upper image) and mitigated (lower image) cases over the entire 45-day period. Results are based on the simulation with the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined a 7,749 m^3 subsea release of crude oil over 1 day tracked for 45 days

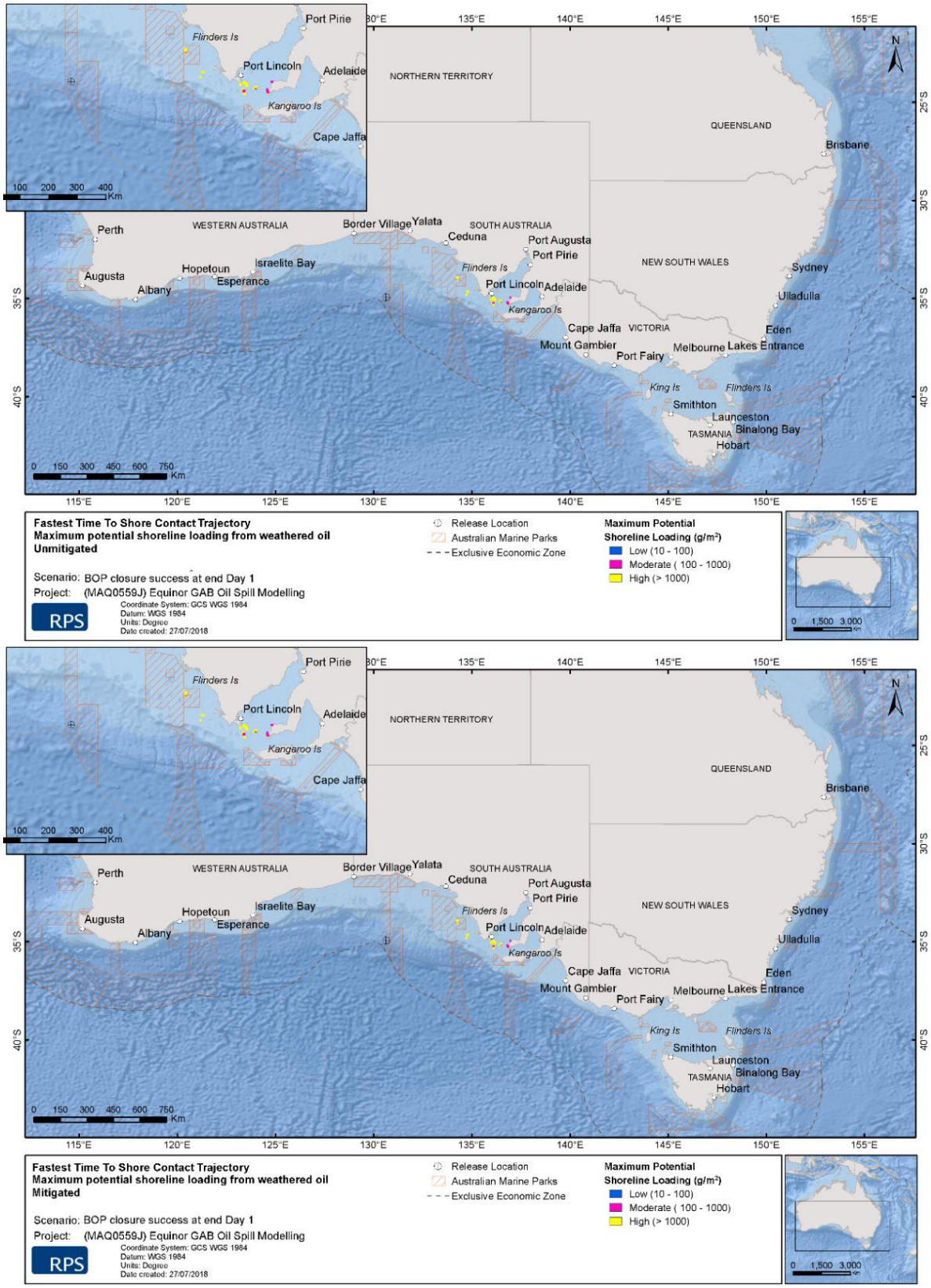


Figure 136: Shoreline loading for the unmitigated (upper image) and mitigated (lower image) cases over the entire 45-day period. Results are based on the simulation with the fastest time before oil contact to shorelines commencing 30 May 2011 at 20:00 hrs. Modelling examined a 7,749 m³ subsea release of crude oil over 1 day tracked for 45 days

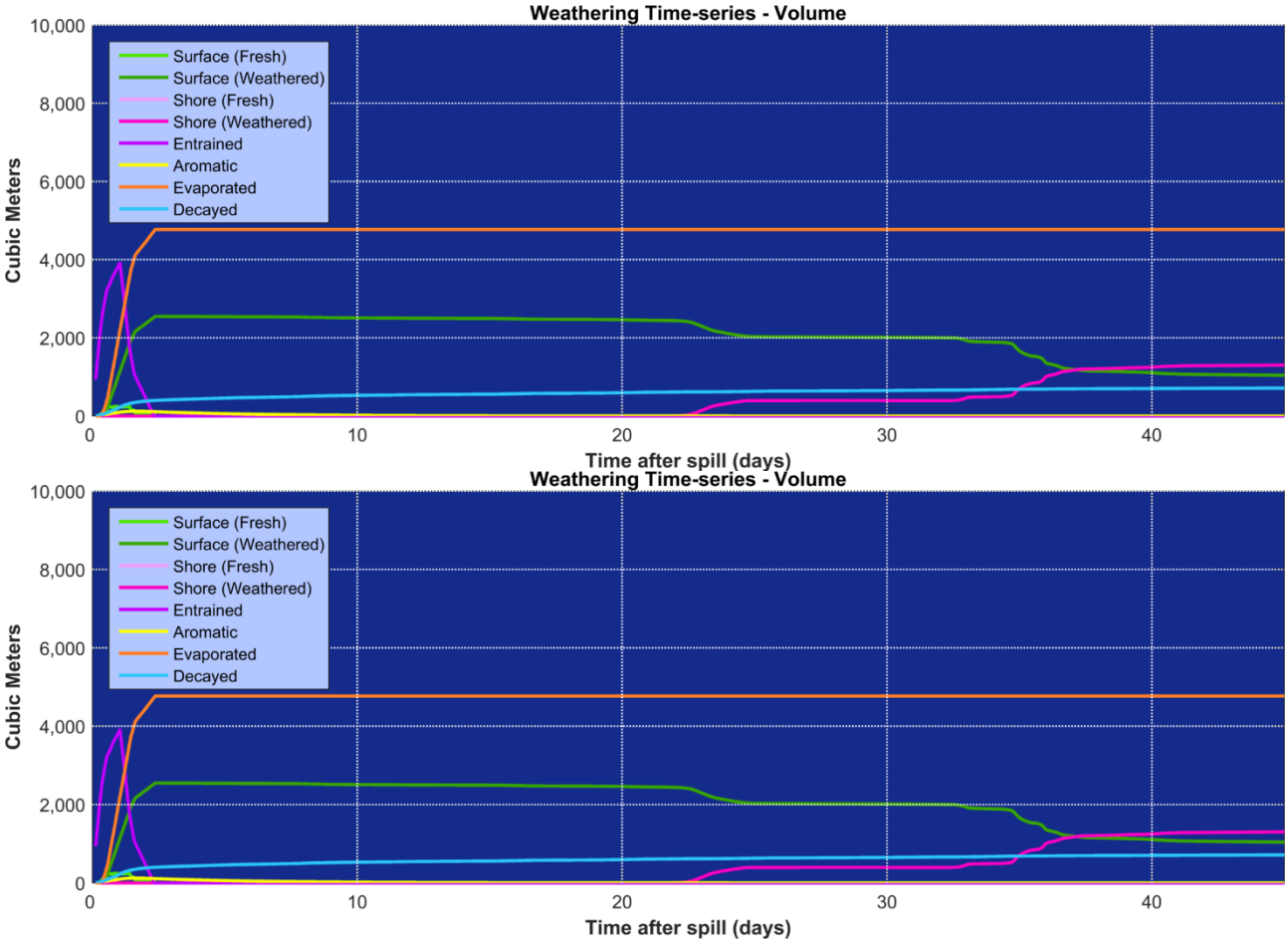


Figure 137: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases. Results are based on the oil spill simulations commencing 31 May 2011 at 20:00 hrs. Modelling examined a 7,749 m^3 subsea release of crude oil over 1 day tracked for 45 days

13.2 P50 reference case

The spill identified as resulting in the P50 (50th percentile) volume of weathered oil ashore between November to February ("target window" or most likely operational window) was used to assess the potential change (if any) for the proposed mitigation methods.

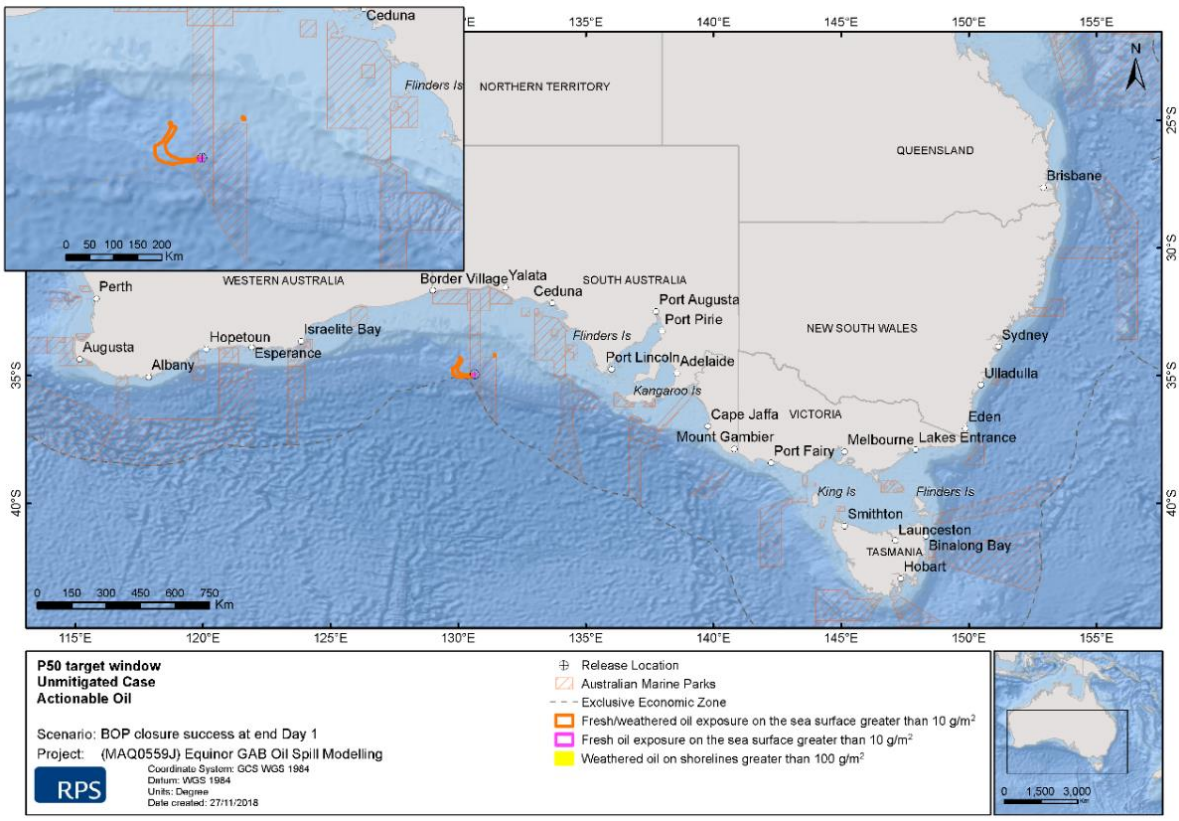
Modelling was carried out to assess the potential change (if any) following the BOP closure success at end of Day 1, for unmitigated and mitigated cases. The Day 1 unrestricted annulus flow rate of 7,749 m^3 was simulated as a subsea release and tracked for 45 days. As part of the model inputs for the mitigation case, aerial surface dispersant was applied from Day 2 until there was no fresh surface oil amenable to dispersant application. The unmitigated and mitigated P50 simulations had used the same start time of 7 February 2009 at 02:00 hrs.

Figure 138 compares maps of the predicted actionable oil for the unmitigated and mitigated modelling results over the entire 45-day simulation period.

Figure 139 shows maps of sea surface exposure for the unmitigated and mitigated modelling results. No shoreline contact above reporting threshold was predicted.

Figure 140 show maps of potential entrained hydrocarbon (time averaged) exposure in the 20–40 m depth, respectively, for the unmitigated and mitigated modelling results. The in-water oil exposure was similar for the two cases.

Figure 141 shows the predicted weathering and fates graphs for the unmitigated and mitigated modelling results. No change was evident between the modelling results. By the end of the simulation (Day 45), 4,757 m^3 (~61% of the total release volume) and 680 m^3 (~8%) had evaporated and decayed, respectively. Additionally, 2,392 m^3 (~31%) of weathered crude was predicted to remain on the sea surface at the end of simulation for the unmitigated and mitigated modelling results.



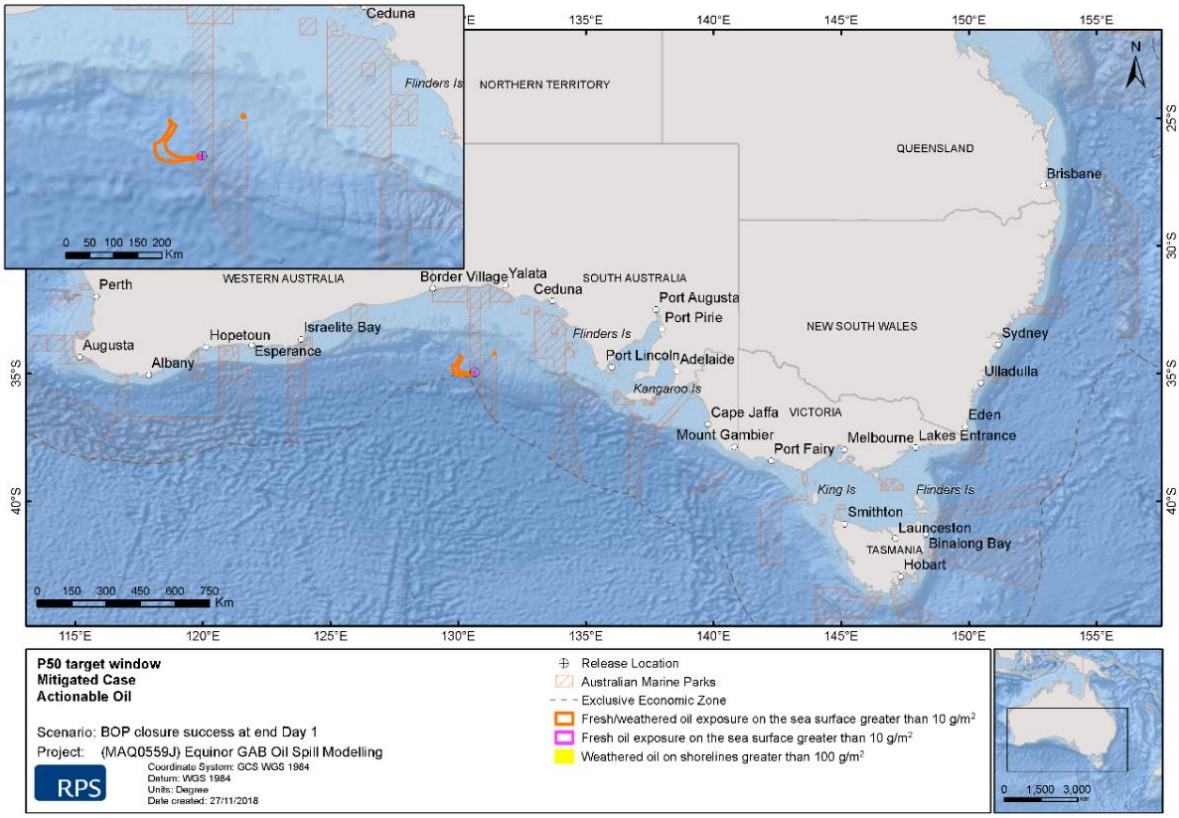


Figure 138: Predicted actionable oil for the unmitigated (upper image) and mitigated (lower image) cases over the entire 45-day period. Results are based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined a 7,749 m³ subsea release of crude oil over 1 day, tracked for 45 days

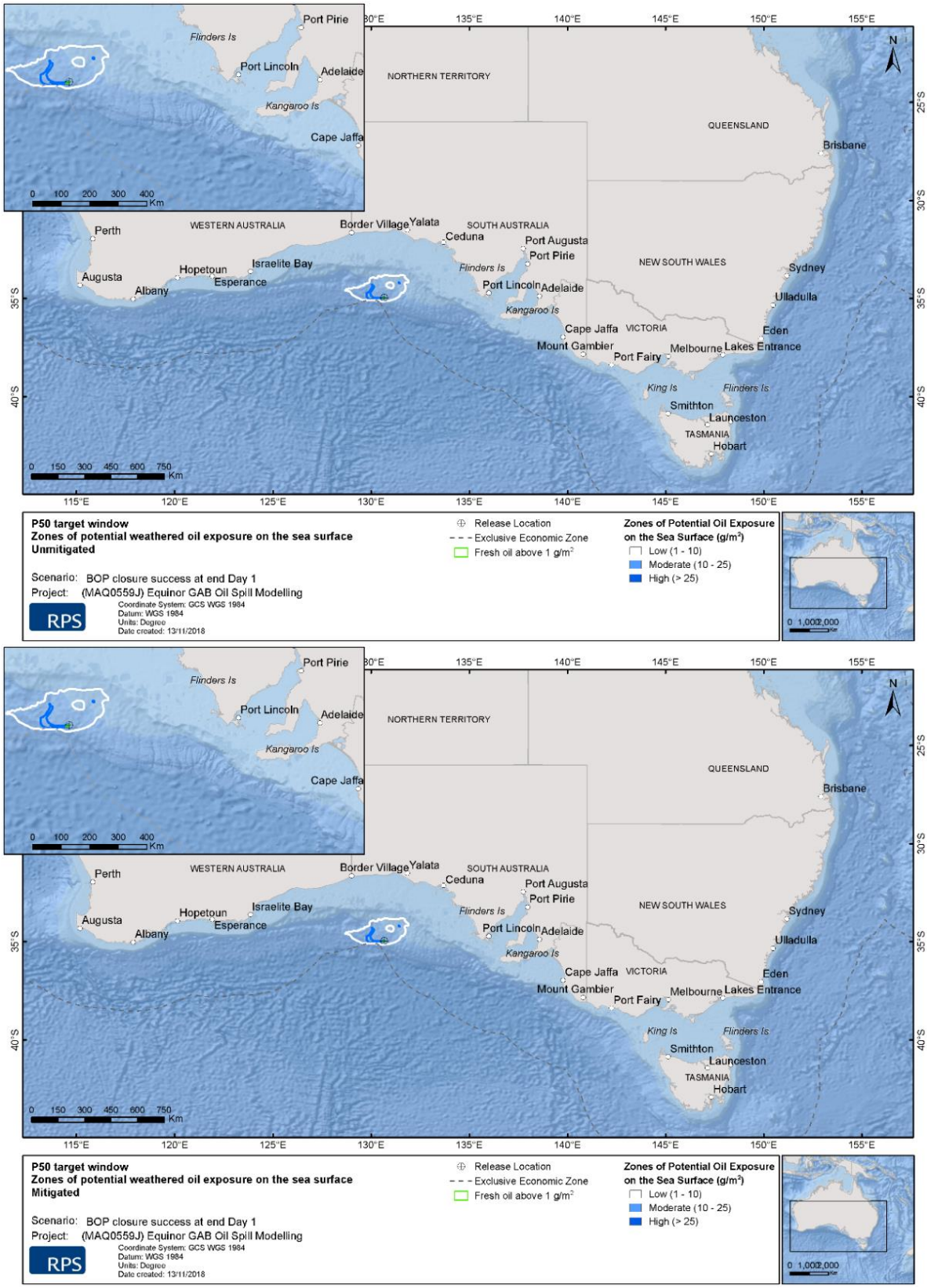
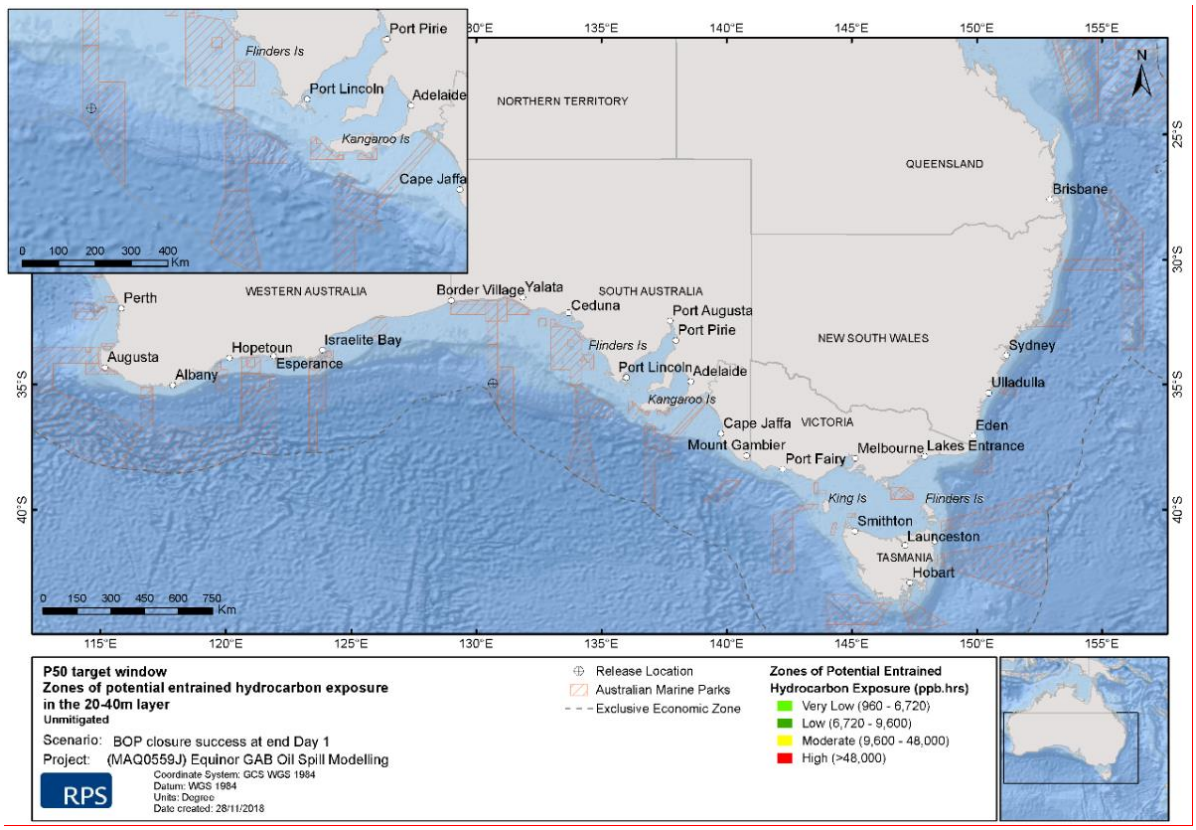


Figure 139: Sea surface exposure for the unmitigated (upper image) and mitigated (lower image) cases over the entire 45-day period. Results are based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined a 7,749 m³ subsea release of crude oil over 1 day, tracked for 45 days



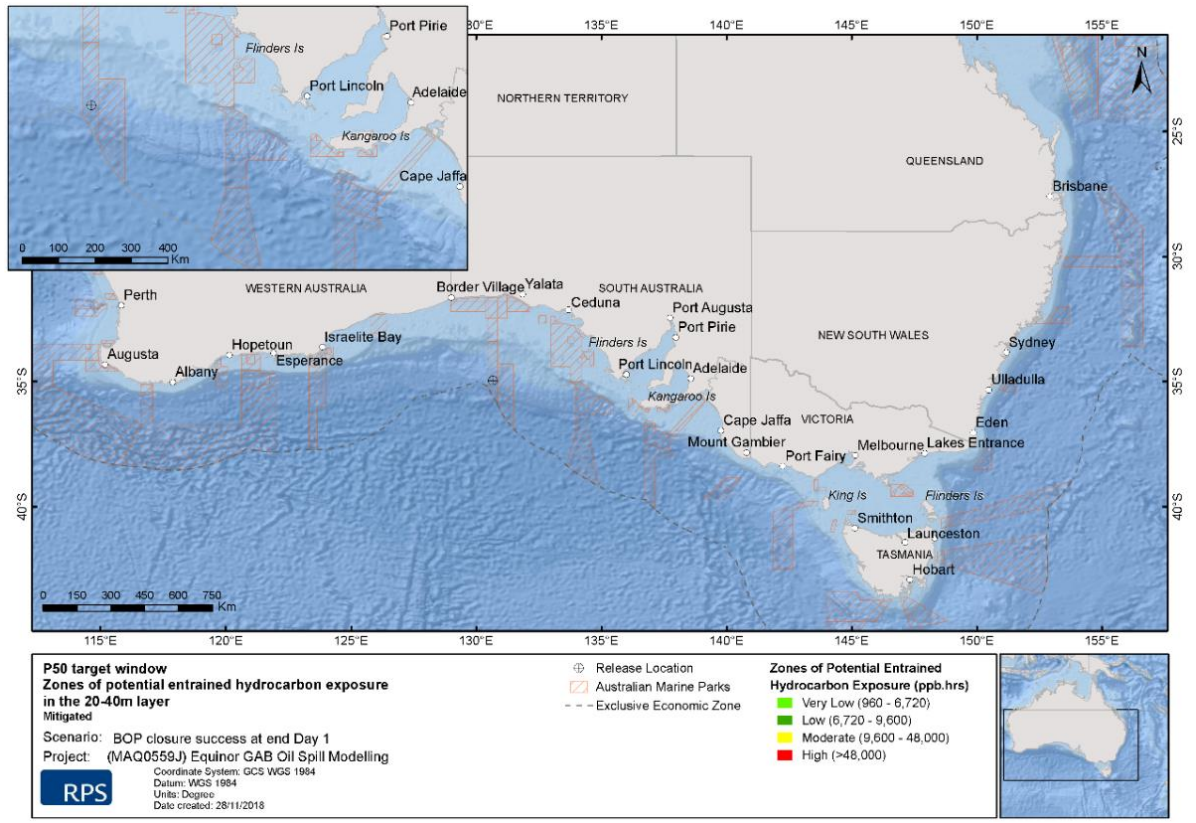


Figure 140: Potential entrained hydrocarbon exposure in the 20-40 m layer for the unmitigated (upper image) and mitigated (lower image) cases over the entire 45-day period. Results are based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined a 7,749 m^3 subsea release of crude oil over 1 day, tracked for 45 days

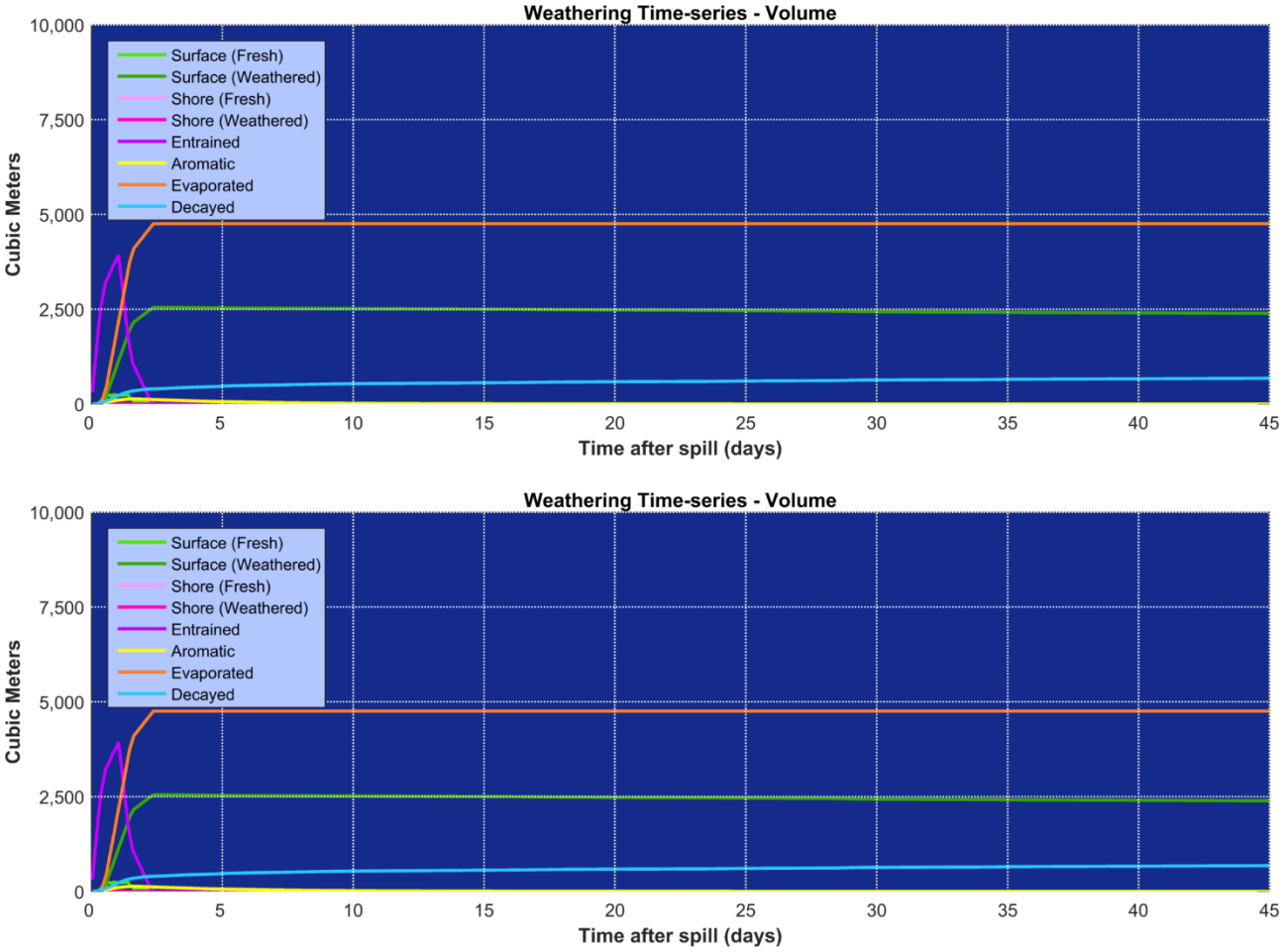


Figure 141: Predicted weathering and fates graphs for the unmitigated (upper image) and mitigated (lower image) cases. Results are based on the simulation resulting in the P50 (50th percentile) volume of weathered oil ashore commencing 7 February 2009 at 02:00 hrs. Modelling examined a 7,749 m^3 subsea release of crude oil over 1 day, tracked for 45 days

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Appendix A

Results

A.1 Seasonal analysis

The sections below present modelling results for the WCD scenario (Scenario 1) based on the "commonly used sea surface and in-water exposure values for oil spill modelling" as reported within the NOPSEMA Bulletin #1 (NOPSEMA, 2019), which were not established at the time that the initial report was submitted.

A.1.1 Oil exposure on the sea surface

Table 61 summarises the distances travelled by spill simulations on the sea surface (as weathered oil) for each threshold (i.e. low (1–10 g/m^2), moderate (10–50 g/m^2) and high (>50 g/m^2)). Weathered oil was presented as it travelled further than the fresh oil.

The maximum distance travelled by spill simulation at the moderate exposure threshold (10–50 g/m^2) was 1,913 km east from Stromlo-1. The 90th percentile ranked simulations had travelled a maximum distance of 817 km in an eastward direction, when tracked to the moderate threshold.

Table 61: Summary of the distances travelled by spill simulations on the sea surface (as weathered oil) for each threshold. Each simulation represents an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Statistics	Low	Moderate	High
Greatest distance travelled (km) and direction by a spill simulation	2,721 East	1,913 East	1,025 East-Southeast
99th percentile greatest distance travelled (km) by a spill trajectory	2,494 East	1,295 East	478 East-Southeast
95th percentile greatest distance travelled (km) by a spill trajectory	2,285 East	1,069 East	356 East-Southeast
90th percentile greatest distance travelled (km) by a spill trajectory	2,133 East	817 East	311 East-Southeast

Table 62 to

Table 65 presents the probability and minimum time before oil exposure on the sea surface within state waters, AMPs, KEFs and IMCRAs, respectively. The results were derived from 100 oil spill simulations (per case) with varied start dates and times between October and May conditions.

Tasmanian (23%), South Australian (98%), Victorian (78%) and New South Wales (1%) coastal waters were all predicted to experience sea surface oil exposure at the moderate threshold. The predicted minimum time before moderate exposure to the state based coastal waters ranged from 22.6 days (South Australia) to 145.3 days (New South Wales). South Australia (65%) and Victoria (5%) coastal waters were predicted to experience sea surface oil exposure at the high threshold.

South-east and South-west Network AMPs were predicted to experience sea surface oil exposure at the moderate threshold. No Temperate East Network AMPs were predicted to experience oil exposure at the moderate threshold (Table 63). The probability of moderate sea surface exposure was greatest for the following AMPs; Western Eyre (100%), Western Kangaroo Island (93%) and Murray (92%). The minimum time before moderate sea surface oil exposure to AMP's range between 14.4 days (Western Eyre) to 176.2 days (East Gippsland).

The KEF with the greatest probability of sea surface exposure at the moderate threshold was the surface waters immediately above the Ancient coastline at 90-120 m depth (100%, Table 64). Additional KEFs with high probabilities of moderate sea surface contact included Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings (99%) and Bonney coast upwelling (87%). The corresponding minimum times before moderate sea surface exposure at the Ancient coastline, Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings and Bonney coast upwelling was 14.2 days, 20.3 days and 35.2 days, respectively. Minimum times before moderate sea surface exposure for KEFs experiencing moderate exposure ranged between 14.2 days and 117.3 days (Commonwealth marine environment - Recherche Archipelago KEF).

The IMCRA meso-scale bioregions of Murat (100%), Eyre (100%) and Coorong (92%) recorded the greatest probability of sea surface exposure at the moderate threshold. The minimum time before moderate oil exposure within Murat, Eyre and Coorong was 11.4 days, 13.5 days and 32.6 days, respectively.

Table 62: Probability and minimum time before weathered oil exposure on the sea surface for each threshold within state waters. Results were derived from 100 oil spill simulations per case commencing during October to May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Coastal waters	Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
	Low	Moderate	High	Low	Moderate	High
Tasmania	85	23	0	54.5	64.5	0
South Australia	100	98	65	21.1	22.6	42.5
Western Australia	21	0	0	58.5	-	0
Victoria	92	78	5	43.5	52.1	85.0
New South Wales	74	1	0	66.0	145.3	0

Table 63: Probability and minimum time before weathered oil exposure on the sea surface for each threshold within Australian Marine Parks (AMPs). Results were derived from 100 oil spill simulations per case commencing during October to May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Australian Marine Park Network		Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
		Low	Moderate	High	Low	Moderate	High
South-east	Apollo	90	35	0	58.8	60.3	-
	Beagle	77	9	0	65.8	107.2	-
	Boags	72	0	0	59.8	-	-
	East Gippsland	42	1	0	91.0	176.2	-
	Flinders	44	0	0	82.1	-	-
	Franklin	79	12	0	56.5	91.0	-
	Freycinet	26	0	0	86.5	-	-
	Huon	30	0	0	97.9	-	-
	Murray	99	92	0	31.4	32.7	-
	Nelson	92	25	0	44.3	81.6	-
	South Tasman Rise	0	0	0	-	-	-
	Tasman Fracture	49	0	0	91.5	-	-
	Zeehan	90	30	0	50.8	62.8	-
South-west	Abrolhos	0	0	0	-	-	-
	Bremer	17	0	0	81.3	-	-
	Eastern Recherche	42	19	1	46.1	63.3	118.0
	Geographe	0	0	0	-	-	-
	Jurien	0	0	0	-	-	-
	Murat	39	2	0	34.5	34.8	-
	Perth Canyon	0	0	0	-	-	-
	South-west Corner	33	2	0	54.6	107.2	-
	Southern Kangaroo Island	94	85	2	33.6	33.9	150.6

Australian Marine Park Network		Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
		Low	Moderate	High	Low	Moderate	High
	Twilight	36	5	0	34.8	65.7	-
	Two Rocks	0	0	0	-	-	-
	Western Eyre	100	100	76	14.3	14.4	14.7
	Western Kangaroo Island	99	93	1	23.8	31.5	145.9
Temperate East	Central Eastern	5	0	0	147.0	-	-
	Cods Grounds	0	0	0	-	-	-
	Gifford	0	0	0	-	-	-
	Hunter	5	0	0	145.2	-	-
	Jervis	23	0	0	136.3	-	-
	Lord Howe	10	0	0	135.5	-	-
	Solitary Islands	0	0	0	-	-	-

Table 64: Probability and minimum time before weathered oil exposure on the sea surface above key ecological features. Results were derived from 100 oil spill simulations per case commencing during October to May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Key Ecological Features (KEFs)	Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
	Low	Moderate	High	Low	Moderate	High
Seamounts South and east of Tasmania	36	0	0	96.25	-	0
West Tasmania Canyons	91	32	0	48.88	56.7	0
Bonney Coast Upwelling	95	87	41	34.96	35.2	47.2
Upwelling East of Eden	68	16	0	81.96	116.7	-
Big Horseshoe Canyon	36	0	0	87.88	-	-
Commonwealth marine environment - Geographe Bay	0	0	0	-	-	-
Cape Mentelle upwelling	0	0	0	-	-	-
Naturaliste Plateau	0	0	0	-	-	-
Diamantina Fracture Zone	19	0	0	76.38	-	-
Albany Canyons group and adjacent shelf break	31	9	0	57.67	101.8	-
Commonwealth marine environment - Recherche Archipelago	26	5	0	57.67	117.3	-
Ancient coastline at 90-120m depth	100	100	65	13.17	14.2	14.3
Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings	100	99	69	13.04	20.3	24.2
Western rock lobster	0	0	0	-	-	-
Canyons on the eastern continental slope	34	0	0	117.17	-	-
Shelf rocky reefs	23	0	0	150.46	-	-
Western demersal slope and associated fish communities	0	0	0	-	-	-
Perth Canyon, adjacent shelf break, other west coast canyons	0	0	0	-	-	-
Commonwealth marine environment - West coast inshore lagoons	0	0	0	-	-	-

Table 65: Probability and minimum time before weathered oil exposure on the sea surface within Integrated Marine and Coastal Regionalisation of Australia (IMCRA) meso-scale bioregions. Results were derived from 100 oil spill simulations per case commencing during October to May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Integrated Marine and Coastal Regionalisation of Australia (IMCRA)	Probability of oil exposure on the sea surface (%)			Minimum time before oil exposure to receptor on the sea surface (days)		
	Low	Moderate	High	Low	Moderate	High
Central West Coast	0	0	0	-	-	-
Abrolhos Islands	0	0	0	-	-	-
Eucla	93	65	19	12.3	12.5	23.3
Murat	100	100	55	11.1	11.4	14.7
Leeuwin-Naturaliste	2	0	0	125.2	-	-
Eyre	100	100	82	13.2	13.5	14.2
North Spencer Gulf	1	0	0	182.0	-	-
Hawkesbury Shelf	15	0	0	151.5	-	-
WA South Coast	28	3	0	56.0	118.2	-
Spencer Gulf	73	14	0	38.3	73.3	-
St Vincent Gulf	95	71	0	32.6	58.2	-
Batemans Shelf	41	4	0	111.7	159.0	-
Coorong	99	92	0	32.3	32.6	-
Twofold Shelf	71	13	0	68.3	116.7	-
Otway	95	86	41	41.2	43.6	47.2
Central Victoria	90	40	0	60.8	63.0	-
Central Bass Strait	90	40	0	57.1	60.8	-
Flinders	80	24	0	64.7	94.0	-
Boags	73	0	0	59.3	-	-
Freycinet	22	0	0	86.0	-	-
Franklin	84	15	0	59.7	87.6	-
Bruny	34	0	0	93.1	-	-
Davey	47	0	0	73.0	-	-

Figure 142 is a map illustrating the oil exposure on the sea surface (inclusive of fresh and weathered oil), produced by overlaying the results from 100 oil spill simulations.

The results revealed that fresh oil exposure on the sea surface above the low threshold (>1 g/m^2; prior to emulsification or evaporation of all volatile components) remained offshore for all 100 simulations (see Table 41). Beyond this zone, would be a large area potentially affected by weathered oil, increasingly degraded with increasing distance from the well. The drift of the slick generally extends to the east of the well. The zone of potential moderate oil concentrations on the sea surface (10 - 50 g/m^2) occurred closest to shore near Ceduna, Port Lincoln, Kangaroo Island and Mount Gambia. Potential low concentrations (1 - 10 g/m^2) of weathered surface oil generally extended along the coastline from west of Augusta in WA to north of Sydney in NSW and includes Tasmania.

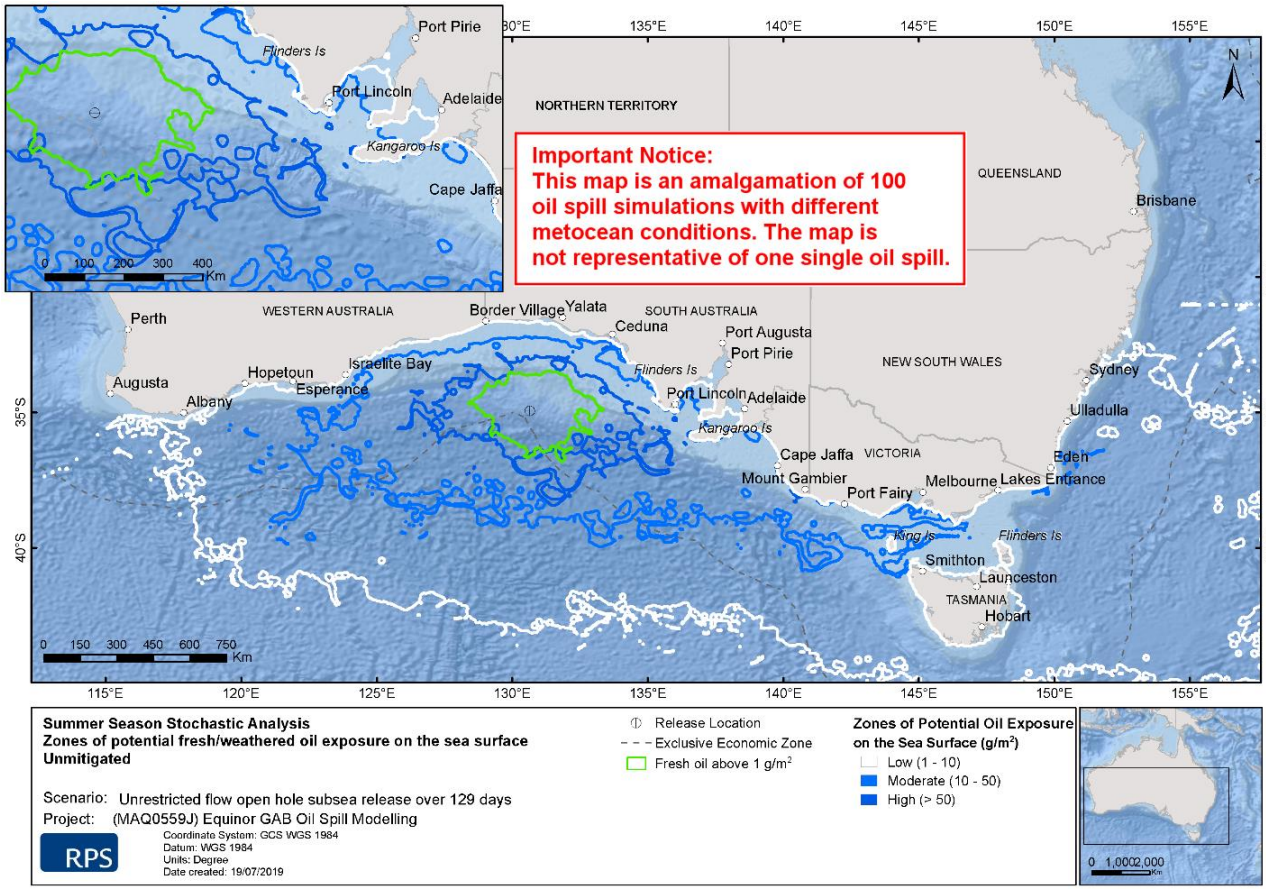


Figure 142: Zones of potential oil exposure on the sea surface. Results were produced from 100 oil spill simulations per case commencing during October to May conditions. Each simulation was based on an average 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days

A.1.2 In-water oil exposure

A.1.2.1 Entrained hydrocarbon exposure

Table 66 shows the probability of entrained hydrocarbon instantaneous exposure (0-10 m water depth) within state coastal waters (3 nm offshore) for each threshold (i.e. low (10–100 ppb) and high (>100 ppb)). Also presented is the maximum instantaneous concentrations. The results are based on the stochastic modelling (i.e. the outcomes from 100 oil spill simulations with varied start dates and times between October and May conditions).

Table 67 presents the maximum entrained hydrocarbon instantaneous exposure and probability of instantaneous exposure (0-10 m water depth) within AMPs. Western Kangaroo Island was predicted to experience concentration (103 ppb; high exposure), though the probability was only 1%.

Table 68 presents the maximum entrained hydrocarbon instantaneous exposure concentrations and probability for the 90-100 m water depth for KEFs.

Table 66: Maximum entrained hydrocarbon instantaneous exposure and probability for each threshold (0-10 m depth) within state waters. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Coastal waters	Maximum instantaneous exposure (ppb)	Probability of instantaneous exposure to entrained hydrocarbons (%) for each threshold	
		Low	High
Tasmania	71	31	0
South Australia	234	91	36
Western Australia	15	2	0
Victoria	603	81	61
New South Wales	49	22	0

Table 67: Maximum entrained hydrocarbon instantaneous exposure and probability for each threshold (0-10 m depth) within Australian Marine Parks (AMPs), derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Australian Marine Park Network	Australian Marine Parks (AMPs)	Maximum Instantaneous exposure (ppb)	Probability of entrained hydrocarbon instantaneous exposure (%) for each threshold	
			Low	High
South-east	Apollo	25	24	0
	Beagle	38	14	0
	Boags	13	1	0
	East Gippsland	13	1	0
	Franklin	16	3	0
	Murray	45	56	0
	Nelson	21	6	0
	Tasman Fracture	12	1	0
	Zeehan	25	11	0
South-west	Eastern Recherche	26	7	0
	Murat	38	2	0
	South-west Corner	23	1	0
	Southern Kangaroo Island	39	52	0
	Twilight	11	1	0
	Western Eyre	101	93	1
	Western Kangaroo Island	103	89	1

Table 68: Maximum entrained hydrocarbon instantaneous exposure and probability for each threshold (90-100 m depth) for Key Ecological Features (KEFs). Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

Key Ecological Features (KEFs)	Maximum Instantaneous exposure (ppb)	Probability of instantaneous exposure to entrained hydrocarbons (%) for each threshold	
		Low	High
Seamounts South and east of Tasmania	12	1	0
West Tasmania Canyons	30	11	0
Bonney Coast Upwelling	603	81	61
Upwelling East of Eden	28	16	0
Diamantina Fracture Zone	10	1	0
Albany Canyons group and adjacent shelf break	13	1	0
Commonwealth marine environment - Recherche Archipelago	18.78	1	0
Ancient coastline at 90-120 m depth	101.21	88	1
Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings	103.86	92	1
Canyons on the eastern continental slope	11.27	1	0

Figure 143 show the zones of potential entrained hydrocarbon instantaneous exposure in the surface layer (0-10 m). The images are based on the results from 100 oil spill simulations. Due to the drift of the slick, the entrained exposure generally extends to the east of the well. The zone of low exposure extended from Esperance (WA) in the west and Eden (NSW) to the east. The zone of high potential entrained hydrocarbon instantaneous exposure in the 0–10 m depth was restricted to offshore waters.

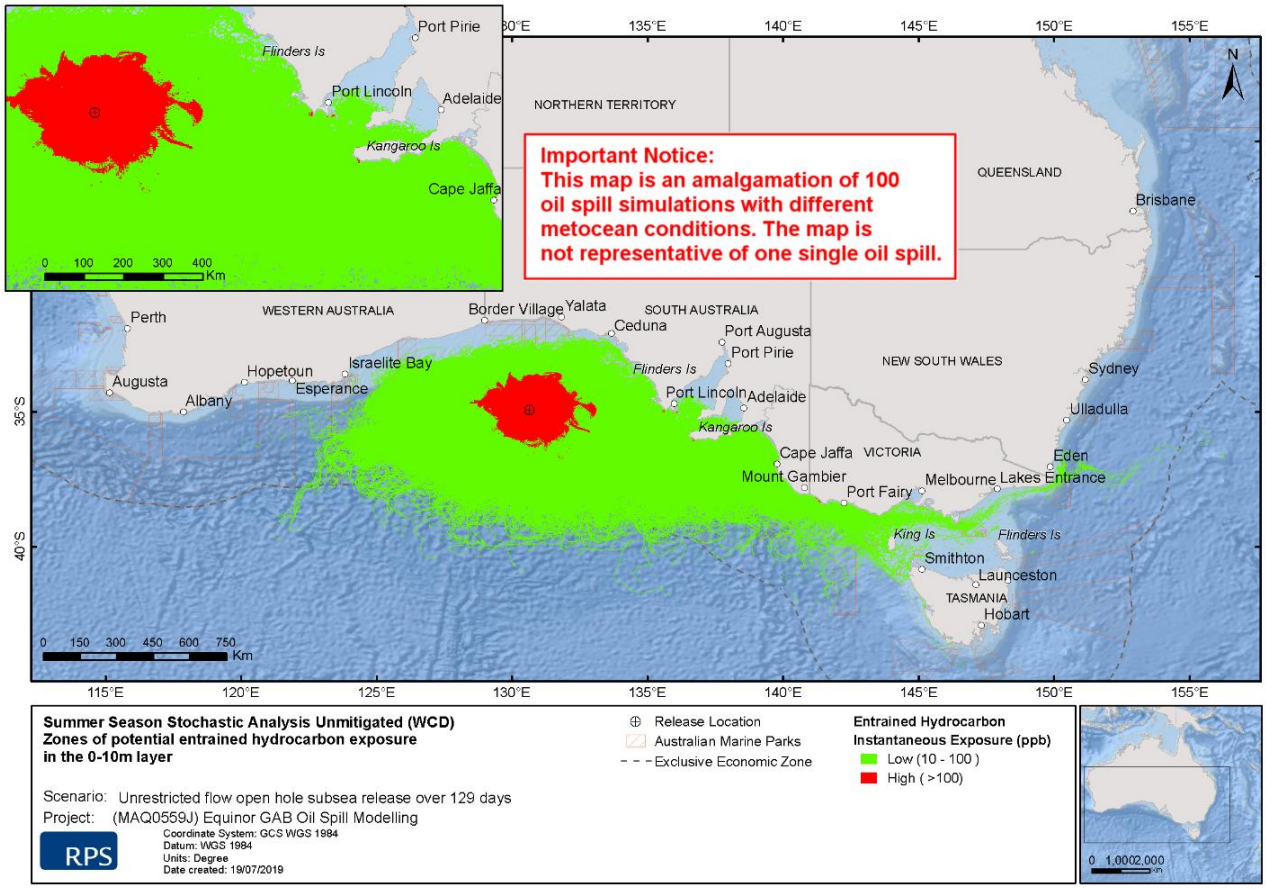


Figure 143: Zones of potential entrained hydrocarbon instantaneous exposure in the surface layer (0-10 m). Images were produced from the results of 100 oil spill simulations per case commencing between October and May conditions. Each simulation represents an average 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days

A.1.2.2 Dissolved hydrocarbon exposure

Table 69 shows the probability of dissolved hydrocarbon instantaneous exposure (0-10 m water depth) within state coastal waters (3 nm offshore) for each threshold (i.e. low (10–50 ppb), moderate (50–400 ppb) and high (>400 ppb)). Also presented is the maximum instantaneous concentrations. The results are based on the stochastic modelling (i.e. the outcomes from 100 oil spill simulations with varied start dates and times between October and May conditions).

Table 70 presents the maximum dissolved hydrocarbon instantaneous exposure and probability of instantaneous exposure (0-10 m water depth) within AMPs. Western Eyre was predicted to experience the greatest instantaneous dissolved hydrocarbon exposure concentration (472 ppb; high exposure).

Table 71 present the maximum dissolved hydrocarbon instantaneous exposure concentrations and probability for the 90-100 m water depth for KEFs.

Table 69: Maximum dissolved hydrocarbon instantaneous exposure and probability for each threshold (0-10 m depth) within state waters. Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days

Coastal waters	Maximum instantaneous exposure (ppb)	Probability of instantaneous exposure to dissolved hydrocarbon (%) for each threshold		
		Low	Moderate	High
Tasmania	0	0	0	0
South Australia	20	3	0	0
Western Australia	0	0	0	0
Victoria	0	0	0	0
New South Wales	0	0	0	0

Table 70: Maximum dissolved hydrocarbon instantaneous exposure and probability for each threshold (0-10 m depth) within Australian Marine Parks (AMPs), derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days

Australian Marine Park Network	Australian Marine Parks (AMPs)	Maximum instantaneous exposure (ppb)	Probability of dissolved hydrocarbon instantaneous exposure (%) for each threshold		
			Low	Moderate	High
South-east	Apollo	79	2	1	0
South-west	Western Eyre	472	21	8	1
	Western Kangaroo Island	33	3	0	0

Table 71: Maximum dissolved hydrocarbon instantaneous exposure and probability for each threshold (90-100 m depth) for Key Ecological Features (KEFs). Derived from the results of 100 oil spill simulations commencing between October and May conditions. Each simulation was based on an average 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days

Key Ecological Features (KEFs)	Maximum instantaneous exposure (ppb)	Probability of instantaneous exposure to dissolved hydrocarbons (%) for each threshold		
		Low	Moderate	High
Bonney Coast Upwelling	13	1	0	0
Ancient coastline at 90-120m depth	332	14	5	0
Kangaroo Island Pool, canyons, adjacent shelf break, Eyre Peninsula upwellings	613	19	11	2

Figure 144 show zones of potential dissolved hydrocarbon instantaneous exposure in the surface layer (0-10 m). The images are based on the results from 100 oil spill simulations. The zone of low exposure extended essentially offshore from Border Village (SA) and east toward Kangaroo Island (SA).

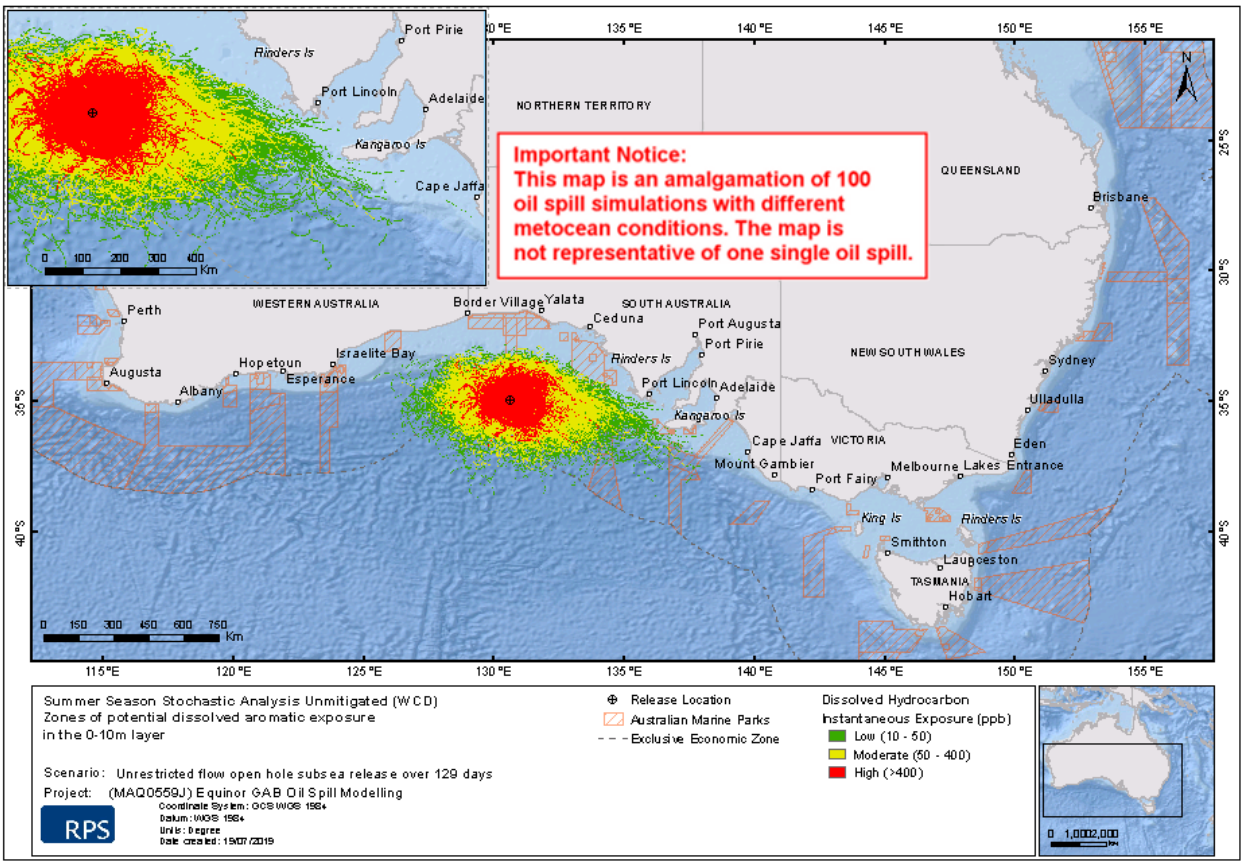


Figure 144: Zones of potential dissolved hydrocarbon instantaneous exposure in the surface layer (0-10 m). Images were produced from the results of 100 oil spill simulations per case commencing between October and May conditions. Each simulation represents an average 8,943 m^3/day subsea release of crude oil over 129 days, tracked for 189 days

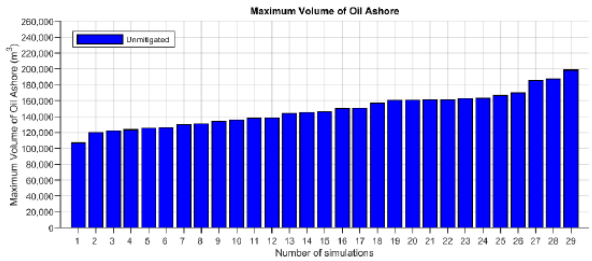
Appendix B

Maximum weathered oil ashore during winter

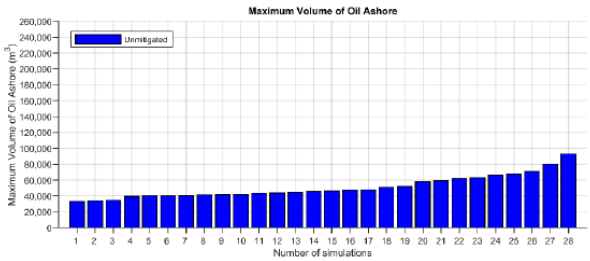
B.1 Maximum weathered oil ashore during winter

Figure 145 shows sorted bar plots of the maximum oil ashore weathered oil at or above the low threshold for each month for simulations commencing between June and September conditions. Each simulation was based on an average 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days

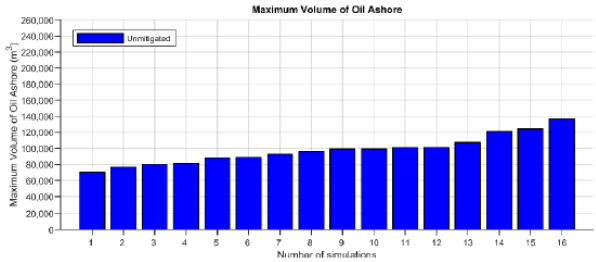
June



August



July



September

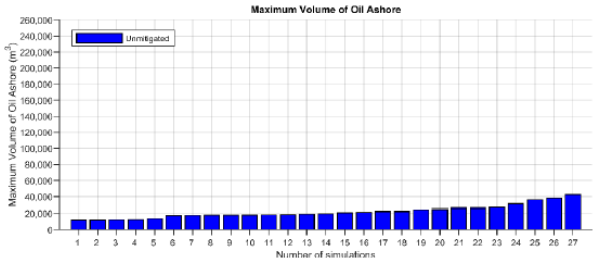


Figure 145: Sorted bar plots of the maximum oil ashore weathered oil at or above the low threshold for each month for simulations commencing between June and September conditions. Each simulation was based on an average 8,943 m³/day subsea release of crude oil over 129 days, tracked for 189 days.

Appendix C

WCD_{88} volume of oil ashore

C.1 Maximum volume ashore for the WCD_{88}

A drilling rig might be available on the North West Shelf during the Stromlo exploration drilling campaign, which could be used to drill the relief well in the event of the loss of well control. This would reduce the estimated time to kill the well from 129 days to 88 days.

As such, additional modelling was undertaken to examine the volume ashore based on the same conditions and flow rate as the WCD129 greatest volume ashore simulation, which had commenced 26 April 2009 at 06:00 hrs (run 60), however, the release duration being 88 days (referred to as WCD88). The total volume released over the 88 days was 868,615 m^3 (an average of 9870 m^3/day), The WCD88 daily average exceeds that of the WCD129 as in both cases the average is the total volume discharged when the well is killed divided by the number of days (88 and 129) when that occurs from an open hole and without any mitigation.

Table 72 is a summary of the predicted volume of weathered oil washed ashore during the WCD88 simulation at days 88, 100, 120, 140 and 148; running for 60 days after well kill and shows a total volume of 182,498 m^3 of oil may reach the shore over the 189 days.

Figure 146 shows the volume of oil ashore above each threshold (low, moderate and high).

Table 72: Summary of the predicted weathered volume ashore during the WCD_{88} simulation. Results are based on subsea release of crude oil over 88 days tracked for 148 days. The simulation commenced 26 April 2009 at 06:00 hrs

Days	Predicted weathered volume of oil ashore (m^3) for the WCD_{88} simulation
88	31,044
100	74,772
120	130,580
140	174,534
148	182,498

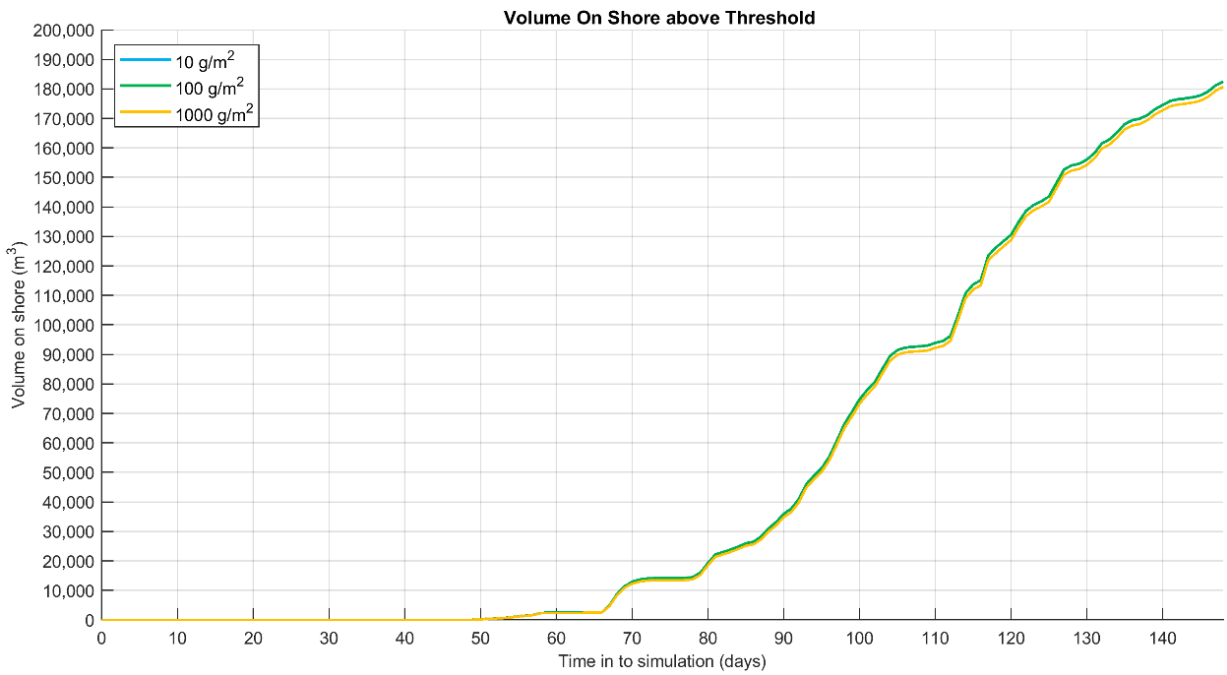


Figure 146: Volume of oil ashore above each threshold. Based on the same conditions as the WCD_{129} simulation resulting in the greatest volume of weathered oil ashore commencing 26 April 2009 at 06:00 hrs. Modelling examined average of 9,870 m^3/day subsea release of crude oil over 88 days tracked for 148 days