Appendix 4-D

Stochastic Spill Modelling

Report

Hydrodynamic and Stochastic Hydrocarbon Spill Modelling for the Port of Gladstone, South of Embley Project

18 MARCH 2013

Prepared for

RTA Weipa

42626934

URS

Project Manager:

…………………………….
Mike Bricks
Senior Associate Scientist

URS Australia Pty Ltd

Level 17, 240 Queen Street
Brisbane, QLD 4000
GPO Box 302, QLD 4001Australia

T: 61 7 3243 2111
F: 61 7 3243 2199

Principal-In-Charge:

…………………………….
Chris Pigott
Senior Principal

Author:

…………………………….
Oleg Makarynskyy
Senior Associate Scientist

Reviewer:

…………………………….
Peter Collins
Senior Consultant Marine Ecologist

Date: **18 March 2013**
Reference: 42626934/3/1
Status: Final

Disclaimer

This report has been prepared on behalf of and for the exclusive use of RTA Weipa Pty Limited, and is subject to and issued in accordance with the agreement between RTA Weipa and URS Australia Pty Limited. Without limitation to the terms of that agreement, URS accepts no liability or responsibility whatsoever for it in respect of any use of or reliance upon this report by any third party.

Copying this report without the permission of RTA Weipa is not permitted.

Document delivery

URS Australia provides this document in either printed format, electronic format or both. URS considers the printed version to be binding. The electronic format is provided for the client's convenience and URS requests that the client ensures the integrity of this electronic information is maintained. Storage of this electronic information should at a minimum comply with the requirements of the Commonwealth Electronic Transactions Act (ETA) 2000.

Where an electronic only version is provided to the client, a signed hard copy of this document is held on file by URS and a copy will be provided if requested.

Table of Contents

Tables

URS

Figures

Abbreviations

Abbreviation	Description
ADCIRC-2DDI	ADvanced CIRCulation - Two-Dimensional Depth-Integrated
ADIOS	Automated Data Inquiry for Oil Spills
AMSA	Australian Maritime Safety Authority
BRAN	BLUElink ReANalysis
CIRES	Cooperative Institute for Research in Environmental Sciences
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EIS	Environmental Impact Statement
GBRMP	Great Barrier Reef Marine Park
GBRNHP	Great Barrier Reef National Heritage Place
GBRWHA	Great Barrier Reef World Heritage Area
GNOME	General NOAA Oil Modeling Environment
HAZMAT	Hazardous Materials Response Division
NCAR	National Center for Atmospheric Research
NCEP	National Centers For Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
OFAM	Ocean Forecasting Australia Model
RTA	Rio Tinto Alcan Pty Ltd
DSEWPAC	Department of Sustainability, Environment, Water, Population and Communities
SoE	South of Embley
TMR	Transport and Main Roads
TOPEX	TOPography EXperiment
URS	URS Australia Pty Ltd
USEPA	United States Environmental Protection Agency
WCS	Worst Case Spill

Executive Summary

The Tailored EIS Guidelines issued by the Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) for the South of Embley (SoE) Project Environmental Impact Statement (EIS) require stochastic modelling of potential hydrocarbon spill scenarios in high risk geographic areas associated with the Project-related shipping. This report provides the results of the modelling.

The scenarios and locations that have been modelled in this report have been developed in consultation with, and approved by, DSEWPaC and the Great Barrier Reef Marine Park Authority (GBRMPA). The modelled scenarios were selected on the basis that a spill during refuelling in the Port of Gladstone represents the highest probability of a marine oil spill from Project-related shipping. This is supported by the *Assessment of the Risk of Pollution from Marine Oil Spills in Australian Ports and Waters* (DNV 2011) prepared for the Australian Maritime Safety Authority (AMSA), which states that "The main accident types are spills from bunkering of bulk carriers and cargo transfer on oil tankers." The report identifies high risk areas as being Hay Point, Gladstone and Brisbane, with the spill frequency for transfer spills in Australia being 0.09 per year and spills in port being 67% of the total spill frequency (DNV 2011). The *Port of Gladstone First-Strike Oil Spill Response Plan* also identifies a spill of 5 t of petroleum products during vessel bunkering operations as one of the spill scenarios used in spill planning and preparedness for the port (Transport and Main Roads 2011).

The Tailored EIS Guidelines requires RTA to undertake an assessment of the "the most likely scenarios (e.g. geographic areas, pollutant types and relative amounts) for a shipping incident and include stochastic modelling for those areas including likely worst case scenario for each high risk geographic area". The "likely worst case scenario" would most reasonably equate to the "Maximum credible spill volume" definition of a spill volume as defined in the AMSA Interim Technical Guideline for the Preparation of Marine Pollution Contingency Plans for Marine and Coastal Facilities (November 2012): "The largest spill that is considered possible given the spill prevention, control and other mitigation methods in place. Generally, the Worst Case Spill (WCS) assumes a failure of one or two levels of spill prevention or control". An indicator provided for a spill size of this volume is the "largest spill volume known to have occurred based on recent (50 year) data."

The largest spill volume known within the Great Barrier Reef Marine Park (GBRMP) over the last 50 years was a 25 t (equivalent to 25.25 m^3 as used in this study) spill in Gladstone Harbour from the Global Peace in 2006. Therefore, a spill of 25.25 m^3 of petroleum products was identified for this spill type.

At present, SoE bauxite shipping uses predominantly heavy grades of fuel oil, although diesel products are also used for some on-board machinery. In response to increasingly stringent fuel sulphur content regulations it is possible that bunker fuel types will include more light grades of oil (e.g. diesel) in the future.

The stochastic modelling of different spill volumes was undertaken at two locations: the Fisherman's Landing Wharf or the South Trees Wharf terminals in Gladstone. These two locations have the highest probability for both a refuelling and collision spill event to occur. This is because refuelling of SoE bauxite vessels in Australia will only take place at these two locations, and due to the fact that the Global Peace spill in the Gladstone Harbour occurred during a berthing operation when a tug boat came into contact with a bulk carrier.

The modelling of spilled hydrocarbon behaviour for each of the locations was conducted for dry season and wet season ambient conditions. The modelling incorporated two different components. The first component was modelling of hydrocarbon weathering, including the processes of evaporation from the water surface and vertical dispersion in the water column, typical for the chemical and physical characteristics of the spilled hydrocarbons and season-dependent water salinity and temperature. The second component was modelling of slick spreading and drift/transport due to seasonally varying currents and winds.

The spatially varying wind data for the locations modelled were obtained from the archived dataset from the National Centers for Environmental Prediction (NCEP) model reanalysis program. The ocean currents were based on global model hindcasts from BRAN (BLUElink Reanalysis) and regional model results from the ADvanced CIRCulation (ADCIRC) model. The oil weathering and trajectory assessments for each of the seasons used a number of input data sets and two different oil spill models, ADIOS2 (Automated Data Inquiry for Oil Spills) and GNOME (General NOAA Oil Modeling Environment).

The threshold for modelling the zone of potential impact from an oil spill was selected to be 0.01 mm (10 microns) oil thickness on the water surface (equivalent to 1 litre of oil covering an area of 100 m^2 if surface cover is continuous). The basis for the 0.01 mm threshold is that this thickness of oil has the potential to cause a smothering effect on directly exposed wildlife. Below this threshold the likelihood of any environmental harm resulting from the surface oil is considered to be very low (for example, if the full volume of the oil was dispersed into the water column, the concentration of oil in the water column 1 meter below a 0.01 mm slick would be only 10 parts per million, not taking account horizontal dilution effects). This is also the thickness at which some kind of physical or chemical response to the spill becomes logistically feasible (depending on the site conditions and fuel type). The use of the 0.01 mm threshold is recommended in the *Interim Technical Guideline for the Preparation of Marine Pollution Contingency Plans for Marine and Coastal Facilities* released by AMSA in July 2012. There is no equivalent recommendation for oil thickness when modelling oil on shore. Therefore, a more conservative threshold of 0.001 mm (1 micron) was used for oil on shore and this is consistent with the thickness used for oil on shoreline modelling in other published Environmental Impact Assessments (Asia Pacific Applied Science 2005, DHI Water and Environment 2010, URS 2011).

The results presented in this report are based on the probability of oil thicker than 0.01 mm on water and 0.001 mm on shore being present at any location based on 100 events/model runs. For example, on water areas exhibiting >0-20% probability were areas exposed to oil slicks thicker than 0.01 mm for up to 20% of the total number of simulated events/model runs. The presented probability plots do not represent, and should not be interpreted as, the extent of any one slick, or extents of on-shore oiling, resulting from a single spill event. Slicks resulting from any single spill event will be significantly smaller than the areas presented in the probability plots. In addition, the study simulation periods should not be interpreted as an indication of slicks 0.01 mm or thicker staying on water, or oil 0.001 mm or thicker staying on shore over the entire duration of the model runs.

The oil on water and oil on shore probabilities were modelled based upon no mitigation measures being implemented. However, if an emergency situation occurred, Gladstone Ports Corporation would implement a spill response plan in accordance with the “First-strike Oil Spill Response Plan” (TMR, 2011). Implementing the plan would be expected to limit oil spreading and propagation within the study area.

The GBRMP does not include islands, waters of any bay, gulf, estuary, river, creek, port or harbour that are within the limits of Queensland in accordance with the *Seas and Submerged Lands Act 1973*

(Cth). The GBRMP boundary starts at the low water mark for the islands within the GBRMP. Although these features are not included in the GBRMP, they are included in the Great Barrier Reef World Heritage Area (GBRWHA) and the Great Barrier Reef National Heritage Place (GBRNHP).

Stochastic modelling results for a 5 m^3 diesel spill from Fisherman's Landing suggest that, during both a dry and a wet season, the hydrocarbon slick propagation would generally be limited by the nearest, adjacent continental coastline and the south-western and south-eastern coasts of Curtis Island. Spills would reach the nearest shore within the first 1.5 hours after release; up to 90% of the spilled volume of diesel might be beached at any particular moment in time. The highest probabilities of 0.001 mm or thicker oil on shore, up to 60%, would be at the nearest coastal sites to the spill location. The probability would decrease with distance from the spill location.

Modelling results for 5 m^3 diesel spill from South Trees Wharf suggest that in numerical 7-day simulations for the two considered seasons, water-surface slicks would mostly affect the adjacent areas, up to 40% and 60% probability of exposure to 0.01 mm or thicker oil on water during dry and wet seasons respectively. Diesel originating from this spill would reach the nearest shore within an hour after release; up to 90% of spilled volume of diesel might be beached at a time. There would be up to 60% probability of 0.001 mm or thicker oil on shore.

Stochastic modelling results for slicks 0.01 mm or thicker from a 5 m^3 spill of fuel oil (No.6) at Fisherman's Landing suggest that water surface fuel oil slicks would propagate in all directions from the spill location, though oil spreading would mainly be steered by the continental coastline, the southern coasts of Curtis Island and the nearest inner islands within the port area. Slicks would beach within 1.5 hours after the spill; up to 96% of spilled volume would beach at a time. The results suggest that there would be up to 60% probability of 0.001 mm or thicker oil on shores of Curtis Island and the continental coasts nearest to the spill location.

Modelling of a 5 m^3 spill of fuel oil (No.6) at South Trees Wharf indicates that, during both considered seasons, water-surface slicks would mostly affect adjacent water areas, with up to 60% probability of exposure to 0.01 mm or thicker oil. Fuel oil slicks would reach the nearest shore within an hour after release, and there would be a 100% chance of the spilled oil reaching a shore under both wet and dry season ambient conditions; up to 96% of spilled volume might be beached. The model results suggest that there would be up to 60% probability of 0.001 mm or thicker oil on shore at several coastal locations.

The results of the 5 m^3 spill modelling suggest that for these oil spill scenarios the water-surface slicks 0.01 mm or thicker would be entirely contained within the Port of Gladstone limits and would not enter into the Great Barrier Reef Marine Park (GBRMP).

Modelling results for a 25.25 m^3 spill of fuel oil (No.6) at Fisherman's Landing suggest that there would be up to an 80% probability of water surface exposure to 0.01 mm or thicker oil in the direct vicinity of the spill location, if such a spill occurs. Decreasing with distance from the spill location, there would be up to 20% probability of water surface exposure to the slicks in the upper reaches of the Narrows, near the western shores of Facing Island and the southern shores of Curtis Island. Such a spill might result in 100% probability of 0.001 mm or thicker oil on shores of Curtis Island and the continental shores closest to the spill location. The probability would decrease, with the coasts exposed to up to 40% probability in the upper reaches of the Narrows, and up to 20% probability west of South Trees Island, at the western coast of Facing Island and south-eastern coast of Curtis Island.

Stochastic modelling of a 25.25 m^3 spill at South Trees Wharf indicated that, during both considered seasons, the adjacent water areas and continental shores, as well as south of Curtis Island, middle of Facing Island and north of South Trees Island would be exposed to up to 60% probability of 0.01 mm or thicker water-surface slicks, if such a spill occurs. The middle section of the Narrows, the strait between Curtis and Facing Islands and areas north and south of Facing Island would be exposed to the 0.01 mm or thicker water-surface slicks with up to 20% probability. The model results suggest that there would be up to 100% probability of exposure to slicks greater than 0.001 mm on the southern and south-eastern coast of Curtis Island, the western coast of Facing Island, and lower reaches of the Narrows if such a spill occurs. The probability of exposure to 0.001 mm or thicker oil on shore would decrease to 20% farther away from the spill location, in the upper reaches of the Narrows, south from Cape Capricorn, the southern tip of Facing Island, and south-east from South Trees Island.

The results of the 25.25 m^3 spill modelling suggest that there would be a possibility of a 0.01 mm or thicker water-surface slick crossing the GBRMP boundary. Within the GBRMP boundary, there is a maximum probability of 6% for a slick to occur in those modelled cells which have the possibility of oil on water.

1

Introduction

Section 4.5, Part B, item c), viii) of the Tailored EIS Guidelines that have been issued by the Department of Sustainability, Environment, Water, Population and Communities (DSEWPAC) for the South of the Embley (SoE) Project EIS requires stochastic modelling of potential spill scenarios in high risk geographic areas associated with the Project-related shipping. This report provides the results of the modelling. URS Australia Pty Ltd (URS) has been commissioned by RTA to conduct this modelling.

The report *Assessment of the Risk of Pollution from Marine Oil Spills in Australian Ports and Waters* (DNV 2011) prepared for the Australian Maritime Safety Authority (AMSA) identifies the highest risk geographic area in the vicinity of Project-related shipping activities as the Port of Gladstone. The report states that (DNV 2011):

> *For the purpose of emergency planning, it is desirable to understand which regions of the Australian coast experience the highest oil spill risks.*

With respect to Queensland, the report identifies the following geographic areas as relatively high risks:

> *Queensland coast centred on QLD4 but also including QLD3, QLD5 and QLD6. This arises mainly from trading ships in ports such as Hay Point (QLD4), Gladstone (QLD5) and Brisbane (QLD6).*

With respect to the type of incidents, the report states that:

> *The main accident types are spills from bunkering of bulk carriers and cargo transfer on oil tankers. There are also significant contributions to smaller spills from small commercial vessels and shore-based activities.*

The spill frequency for transfer spills in Australia is 0.09 per year with spills in port being 67% of the total spill frequency (DNV 2011). The *Port of Gladstone First-Strike Oil Spill Response Plan* (Transport and Main Roads 2011) identifies a spill of 5 t of petroleum products during vessel bunkering operations as one of the spill scenarios used in spill planning and preparedness for this port.

The Tailored EIS Guidelines requires RTA to undertake an assessment of the "the most likely scenarios (e.g. geographic areas, pollutant types and relative amounts) for a shipping incident and include stochastic modelling for those areas including likely worst case scenario for each high risk geographic area". The "likely worst case scenario" would most reasonably equate to the "Maximum credible spill volume" definition as defined in the AMSA Interim Technical Guideline for the Preparation of Marine Pollution Contingency Plans for Marine and Coastal Facilities (AMSA 2013). AMSA (2013) define the "Maximum credible spill volume" as:

> *The largest spill that is considered possible given the spill prevention, control and other mitigation methods in place. Generally, the worst case scenario (WCS) assumes a failure of one or two levels of spill prevention or control.*

An indicator provided by AMSA (2013) for a spill size of this volume is:

> *Largest spill volume known to have occurred based on recent (50 year) data.*

1 Introduction

Based on the Great Barrier Reef Marine Park Authority (GBRMPA) historical shipping incident data, the largest spill volume recorded within the Great Barrier Reef Marine Park (GBRMP) over the last 50 years is a 25 t (equivalent to 25.25 m^3 as used in this study) spill in Gladstone Harbour from the Global Peace in 2006.

Therefore, based on the above information a spill of 25 t (25.25 m^3) of petroleum products was determined to be the most likely worst case scenario for project-related shipping. Additional details regarding the probability of a spill of this magnitude are provided in **Section 4.2.3**.

At present, SoE bauxite shipping uses predominantly heavy grades of fuel oil, although diesel products are also used for some on-board machinery. In response to increasingly stringent fuel sulphur content regulations it is possible that bunker fuel types will include more light grades of oil (e.g. diesel) in the future.

The stochastic modelling of two spill volumes/amounts was undertaken at the same two locations: the Fisherman's Landing Wharf or the South Trees Wharf terminals in Gladstone (for locations see **Figure 1-1**). These two locations have the highest probability for both a refuelling and collision spill event to occur associated with Project-related shipping. This is because refuelling of Project-related bauxite vessels in Australia would only take place at these two locations, and due to the fact that the Global Peace spill in the Gladstone Harbour occurred during a berthing operation when a tug boat came into contact with the bulk carrier.

Modelling for a 5 m^3 spill was undertaken for both diesel and fuel oil No.6. Modelling for a 25.25 m^3 spill was undertaken for fuel oil No.6 as the location of the diesel tanks on the bulk carriers means that they are much less likely to be affected in scenarios with the potential to result in larger spills (such as collisions during berthing operations).

The oil on water and oil on shore probabilities were modelled based upon no mitigation measures being implemented. However, if an emergency situation occurred, the Gladstone Ports Corporation would implement a spill response plan in accordance with the "First-strike Oil Spill Response Plan" (TMR, 2011). Implementing the plan would be expected to limit oil spreading and propagation within the study area.

The GBRMP does not include islands, waters of any bay, gulf, estuary, river, creek, port or harbour that are within the limits of Queensland in accordance with the *Seas and Submerged Lands Act 1973* (Cth). The GBRMP boundary starts at the low water mark for the islands within the GBRMP. Although these features are not included in the GBRMP, they are included in the Great Barrier Reef World Heritage Area (GBRWHA) and the Great Barrier Reef National Heritage Place (GBRNHP).

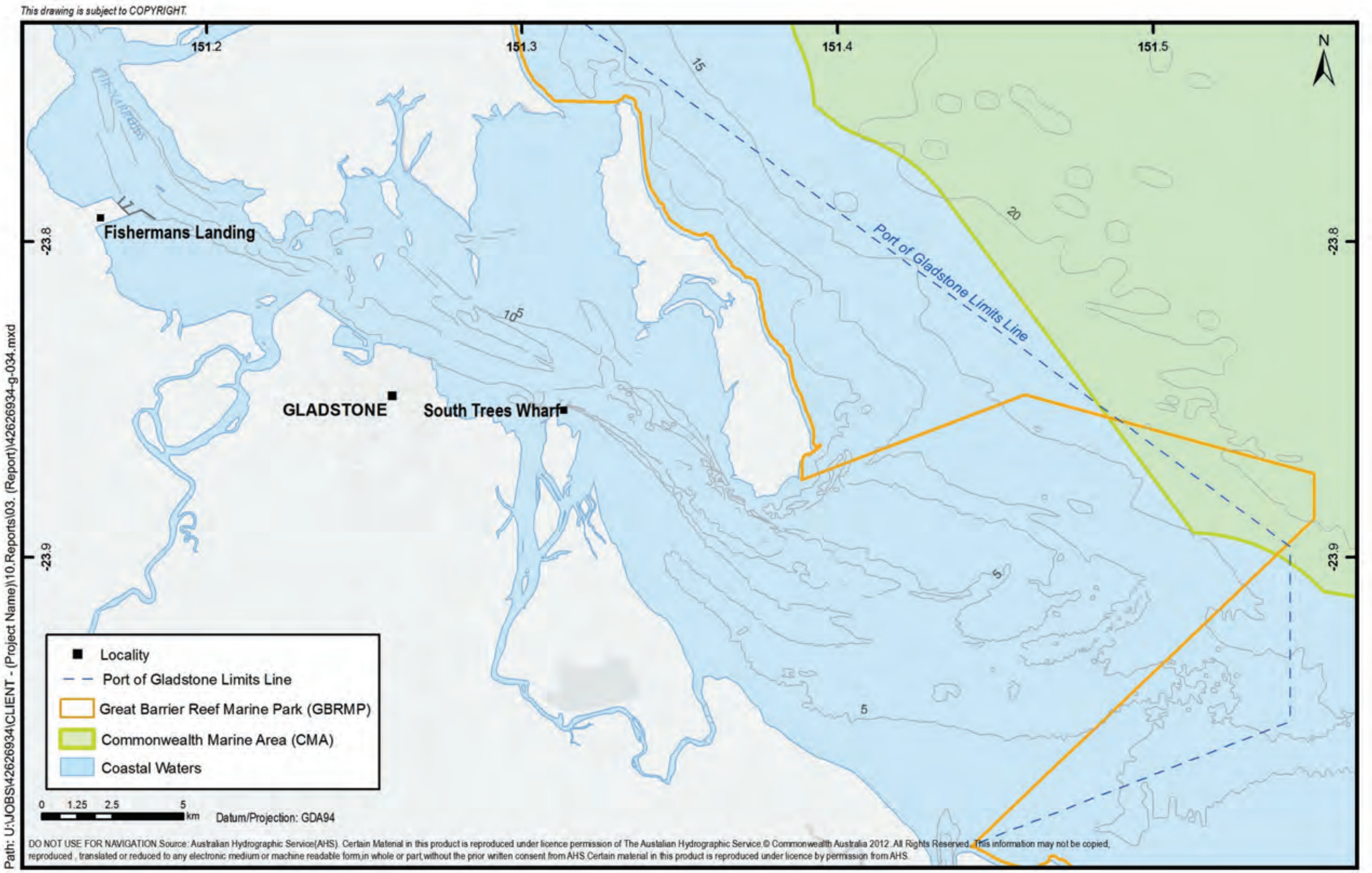


Figure 1-1 Modelled Spill locations within Port of Gladstone

Ambient Conditions

Typical ambient climatological parameters for the locations modelled, which contribute to hydrocarbon transport (wind and water currents), evaporation (wind, air and water temperature), and weathering (wind, air and water temperature), are briefly described below.

The Port of Gladstone is located in the Coral Sea. The climate of the region is monsoonal and seasonally controlled by the meridional position of the large high pressure cells, which pass from west to east across the Australian continent (e.g. Osborne *et al*. 2000). These pressure systems, with their anticlockwise wind circulation, migrate from latitudes of 25°-30°S in winter to 35°-40°S in summer (Pierce *et al*. 2003). Following this pattern and consistent with the large scale atmospheric processes, the wet season prevailing winds in Gladstone are from the north-east through to south-east (see **Figure 2-1** and **Figure 2-2**), swinging to the dry season south and south-southwesterlies (see **Figure 2-3** and **Figure 2-4**, as well as RTA 2011). In coastal areas however local sea-breezes, generated by the temperature difference between land and sea, may dominate the seasonal patterns.

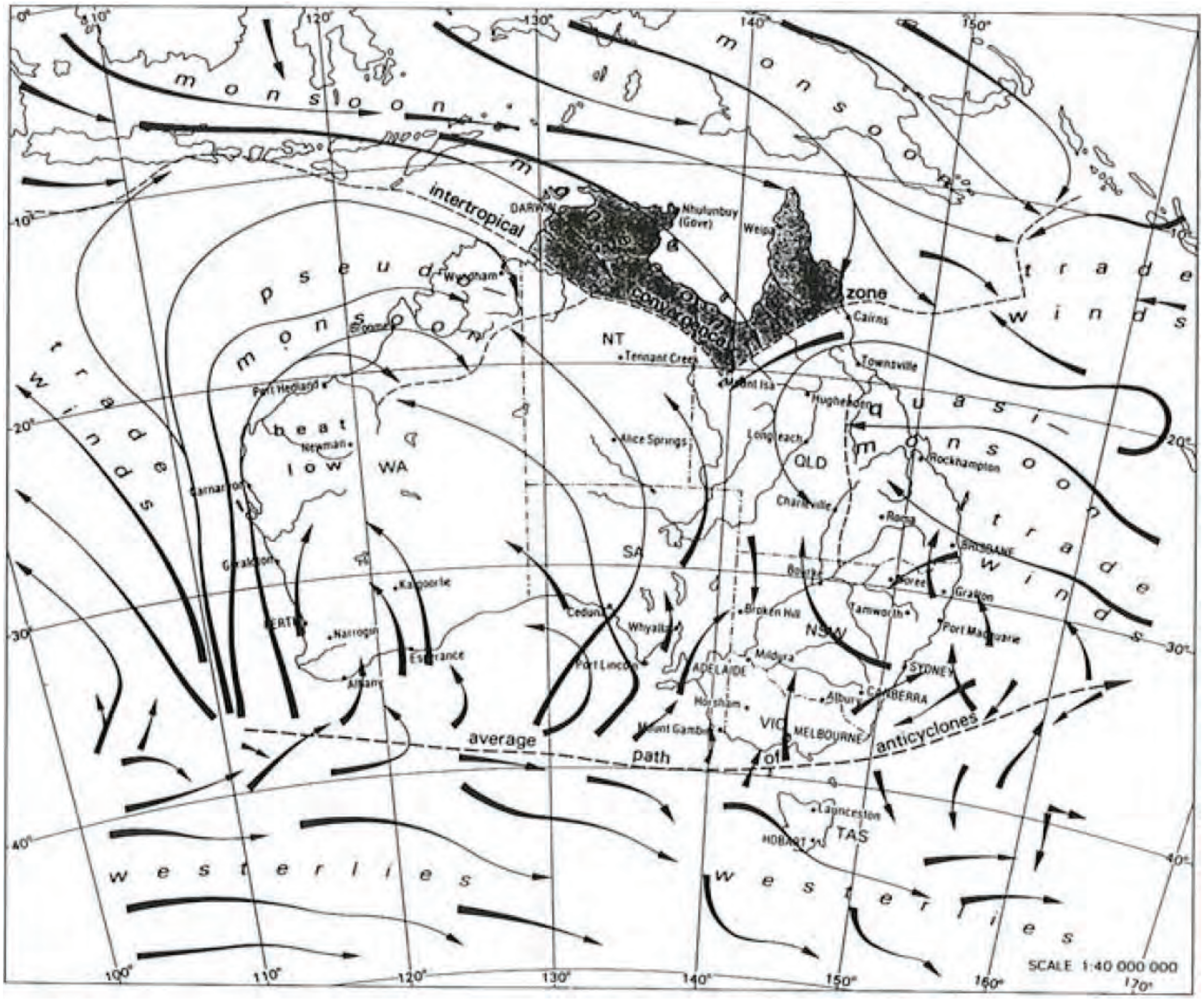


Figure 2-1 Wet season (summer) airstreams over Australia (top panel, from Swan et al., 1994)

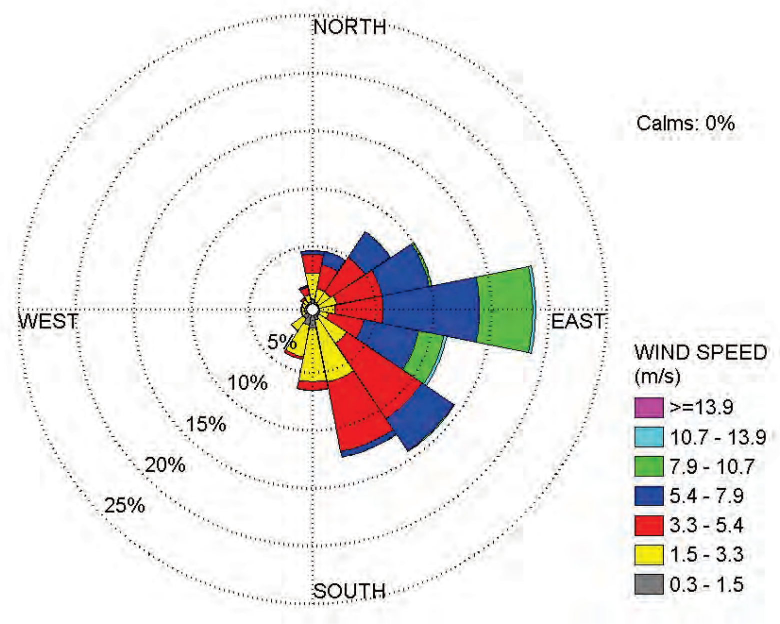


Figure 2-2 Wet season (summer) wind rose at Gladstone Airport

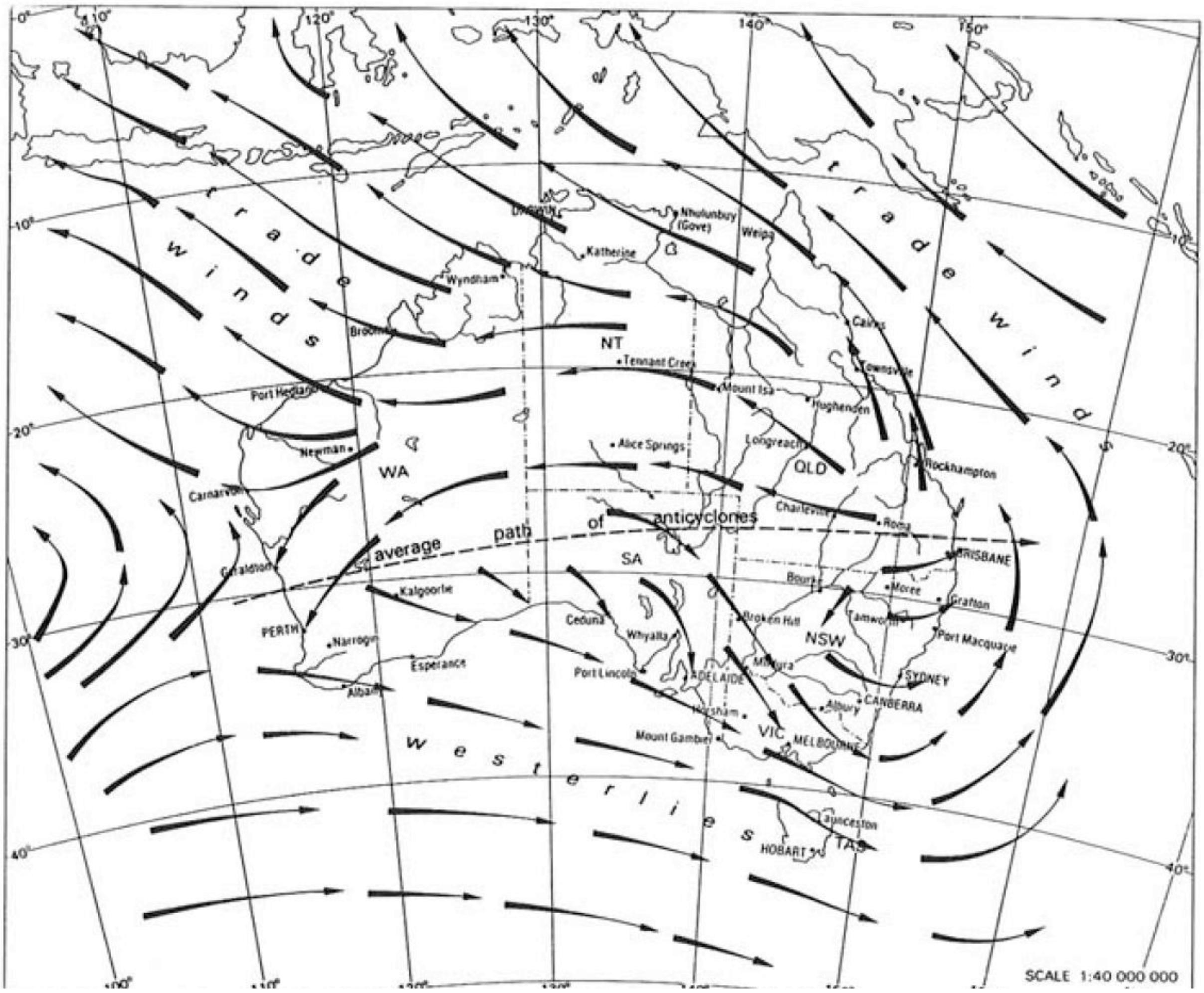


Figure 2-3 Dry season (winter) airstreams over Australia (top panel, from Swan et al., 1994)

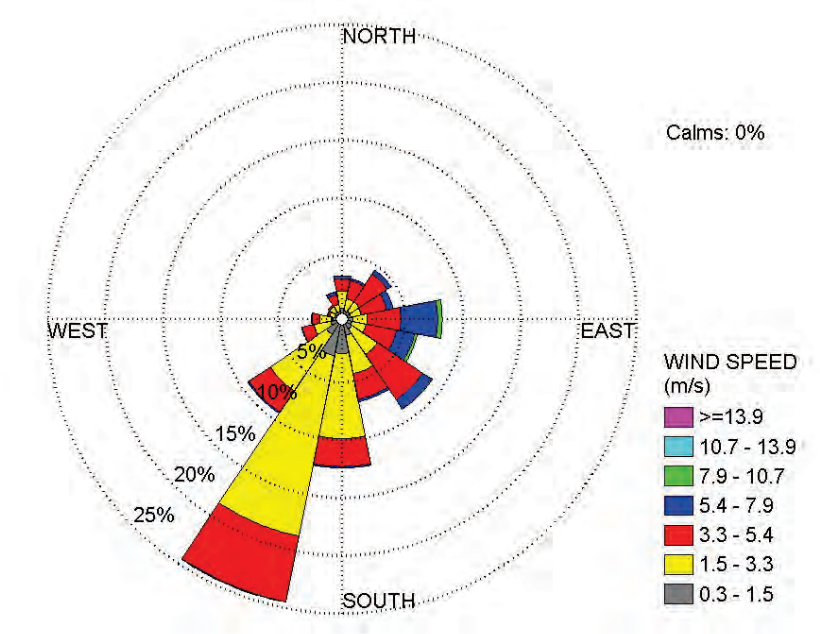


Figure 2-4 Dry season (winter) wind rose at Gladstone Airport

Shallow water currents in the study area are affected by tides with amplitudes of up to 4.49 m (see http://www.msq.qld.gov.au/Tides/King-tides.aspx). Meantime, both shallow and deeper water near-surface currents demonstrate seasonality under the influence of seasonal wind regime variations.

The climatic mean monthly surface water temperature and salinity vary from around 22°C and 35.2 parts per thousand (ppt) during the dry season (winter) to around 27°C and 35.4 ppt during the wet season (summer) in the Gladstone area. **Figure 2-5** and **Figure 2-6** illustrate climatic fields of sea surface temperature and salinity for the study region and adjacent oceanic areas for corresponding central season months (see Locarnini *et al*., 2010 and Antonov *et al*., 2010).

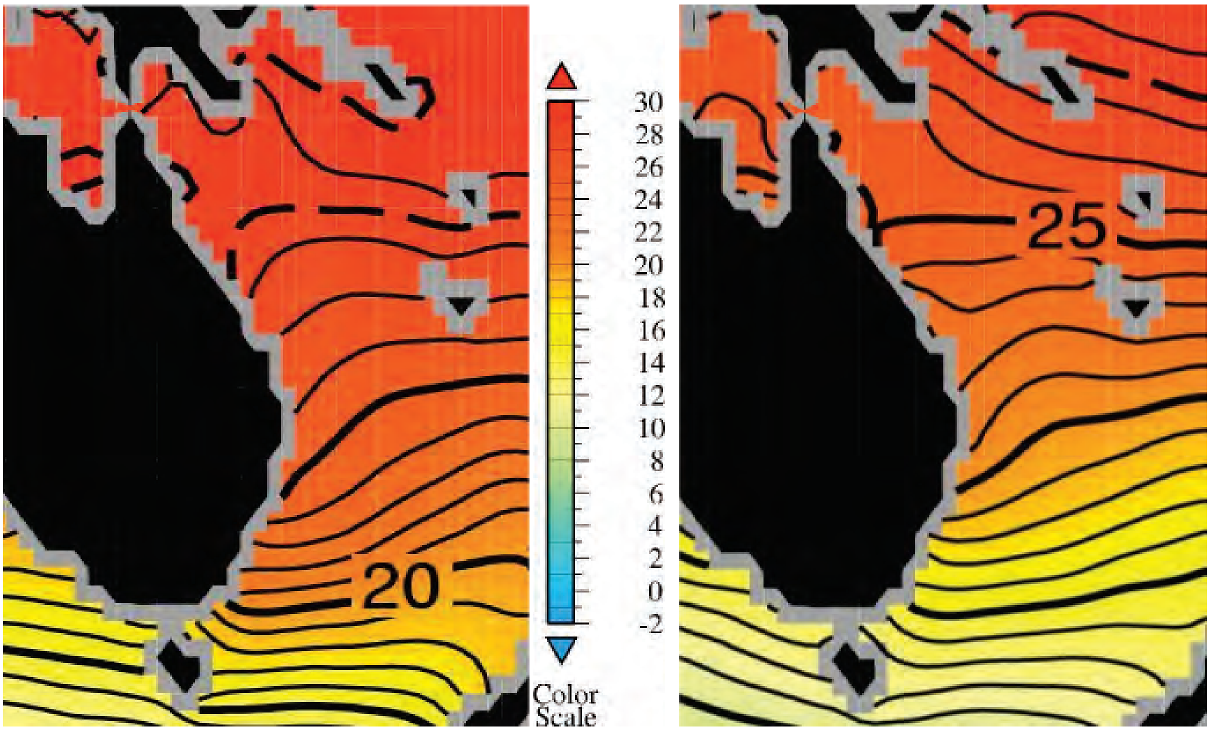


Figure 2-5 Climatic fields of sea surface temperature (°C) for months of January-March (left panel) and July-September (right panel); from World Ocean Atlas 2009, contour interval 1°C

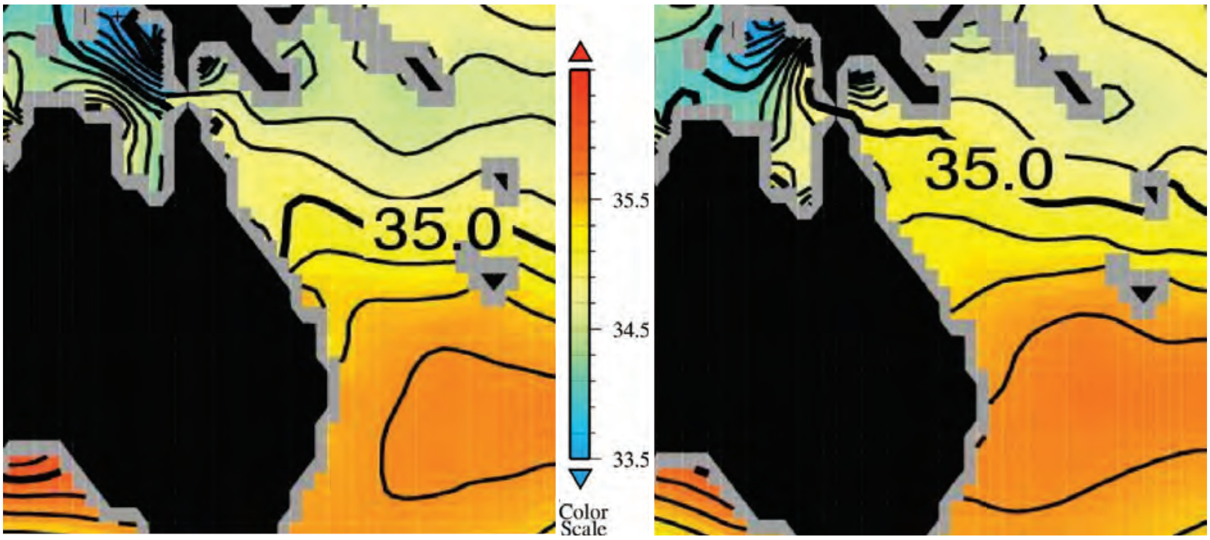


Figure 2-6 Climatic fields of sea surface salinity (ppt) for months of January-March (left panel) and July-September (right panel); from World Ocean Atlas 2009, contour interval 0.2 ppt

Modelling Methodology

Several data sets and several different models were used in this study to quantify the probability of exposure to water surface and shorelines due to hydrocarbon spills. The datasets used and models applied are described in the following sections.

3.1 Input Data

For the Port of Gladstone and surrounding areas, two bathymetric data sets of variable resolutions were obtained, processed and merged together to provide the necessary inputs into both the hydrodynamic and oil spill models. A larger area, adjacent to the port was covered by data purchased from the Australian Hydrographic Service, while the inner port channels and berth areas were based on data provided by the Gladstone Ports Corporation.

Wind hindcasts for the study region were obtained from the output of a global numerical atmospheric model run by the NCEP/NCAR Model Reanalysis Project, NOAA-CIRES Climate Diagnostics Center in Boulder, Colorado, USA (see http://www.cdc.noaa.gov). Wind speeds and directions for the 10 m elevation level at 3-hourly intervals were extracted from the NCEP/NCAR archives and used in the hydrodynamic and hydrocarbon spill modelling.

Ocean water temperature and salinity were obtained from World Ocean Atlas 2009 (see Locarnini *et al*., 2010; Antonov *et al*., 2010).

Large-scale ocean currents were obtained from BRAN (BLUElink ReANalysis), which is based on a global ocean model called OFAM (Ocean Forecasting Australia Model) and was developed as part of the BLUElink partnership program between the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Australian Bureau of Meteorology, and the Royal Australian Navy (Schiller *et al*., 2008). The BRAN is run using the wind stress from the European Centre for Medium-Range Weather Forecasts, as well as heat and freshwater fluxes; it also assimilates satellite measurements, including altimeter, and in situ oceanographic data.

3.2 Models

The hydrodynamic regime of the relatively shallow Port of Gladstone and the adjacent areas is dominated by tidal currents, directions of which are mainly steered by the continental and island coastlines and local bathymetric features. The hydrocarbon spills to be modelled are instantaneous and spilled at the water surface, and thus do not carry a potential to be entrained and/or transported by either near bottom or mid water layer currents. The port basin is well sheltered from wind waves, therefore the entrainment potential by wind waves is also considered low.

Based on the above considerations, a two-dimensional hydrodynamic model was developed and applied to represent the patterns of water circulation, necessary for hydrocarbon spill simulations in the Port of Gladstone. Wind wave modelling was not considered necessary for the study area.

3.2.1 ADCIRC hydrodynamic model

The ADCIRC-2DDI (ADvanced CIRCulation - Two-Dimensional Depth-Integrated) model was used to estimate current patterns in the study area. The ADCIRC model is a numerical finite element hydrodynamic model specifically developed for applications on shelves, near coasts and in estuaries. ADCIRC-2DDI is based on the depth-integrated equations of mass and momentum, ruled by the hydrostatic assumption and the Boussinesq approximation (Westerink *et al*., 1994). The ADCIRC-2DDI model is implemented using linear triangular elements for elevation, velocity and depth. The elevation and velocity solutions are computed by the equal order finite element interpolating functions. The boundary conditions include tidal constituents, wind stress at the water surface and bottom friction. During the last 20 years, the model has been extensively tested and applied in different ocean and coastal regions (see Luettich *et al.*, 1992; Blain, 1998; Fortunato *et al*., 1998).The ADCIRC model runs were conducted using an unstructured mesh with 4890 computational nodes/8943 elements (**Figure 3-1**). The mesh had 62 open ocean boundary nodes and 318 continental land boundary nodes, as well as 480 land boundary nodes around the ten largest islands accounted for in the model runs.

The size of the meshes used was variable with coarser meshes used for deeper, outer parts of the model domain. Finer meshes were used in more bathymetrically complex near-shore areas and over the areas of specific interest, e.g. around islands (**Figure 3-1**).

Tidal forcing applied at the open ocean boundary of the model domain was obtained from the Le Provost tidal database (e.g. Le Provost, 2000; Ponchaut *et al*., 2001). The tidal data were derived from a tidal global dynamical model with assimilation of TOPEX/Poseidon satellite altimeter observations (e.g. Lefevre *et al*., 2002).

Wind data used to define the effects of wind stress on currents were sourced from the NCEP/NCAR Model Reanalysis Project (see **Section 3.1**).

A constant quadratic bottom friction coefficient equal to 0.005 was selected as a result of preliminary model tuning and used in all numerical modelling computations.

The model was run for the months of December through to February (wet season) and June through to August (dry season) to simulate current speeds and directions formed under the ambient conditions for both seasons. These included several periods of spring tides.

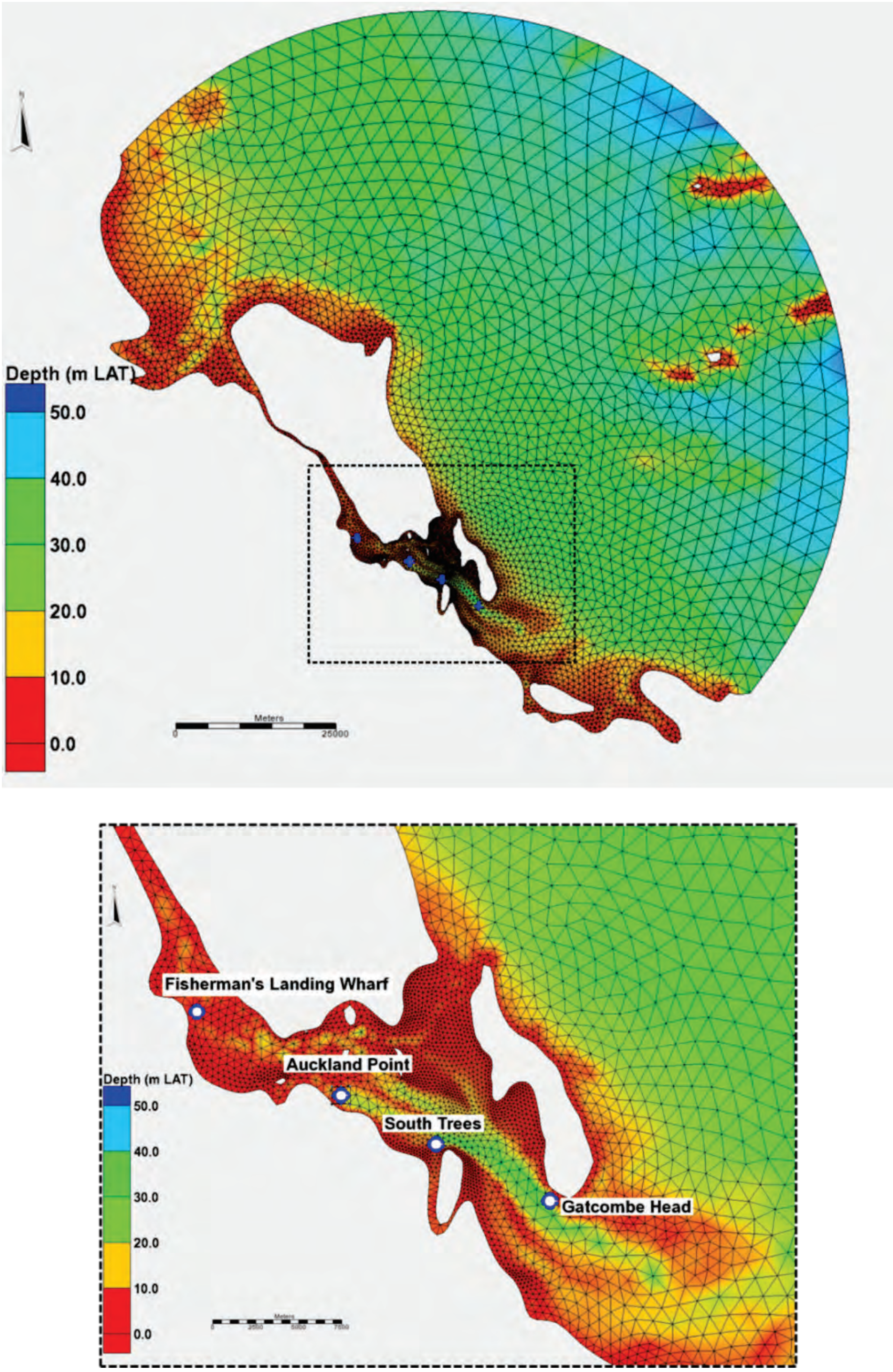


Figure 3-1 ADCIRC computational mesh and model bathymetry for Gladstone area (top panel); tide gauge locations used in model validations are also shown in zoomed in box (bottom panel)

3.2.2 Combined BRAN and ADCIRC hydrodynamic models

Two different types of model currents, from the BRAN global-scale hydrodynamic model system and from the ADCIRC local-scale hydrodynamic model, were combined to prepare representative current fields for the hydrocarbon spill simulations at the Port of Gladstone. Such a combination was necessary because BRAN model outcomes are coarse-scale and thus do not resolve either fine spatial or fine temporal scale current variability. As a result, shallow near-shore areas and tidal currents are not covered by/reflected in the BRAN model outcomes (see **Figure 3-2**).

The ADCIRC model was meanwhile specifically developed and tested to resolve and represent estuarine, near-shore and shallow water hydrodynamic processes. **Figure 3-3** demonstrates an example of ADCIRC modelled currents for the same time as in **Figure 3-2,** with ADCIRC modelled currents covering areas where BRAN currents were missing.

The results from both these models were combined to enable both coarse scale and finer scale conditions to be represented, as well as to represent fine temporal current variability. To illustrate the outcomes of such a combination, **Figure 3-4** demonstrates the combined currents for the same time as in **Figure 3-2**. Note that the areas of higher mesh resolutions have more current vectors plotted.

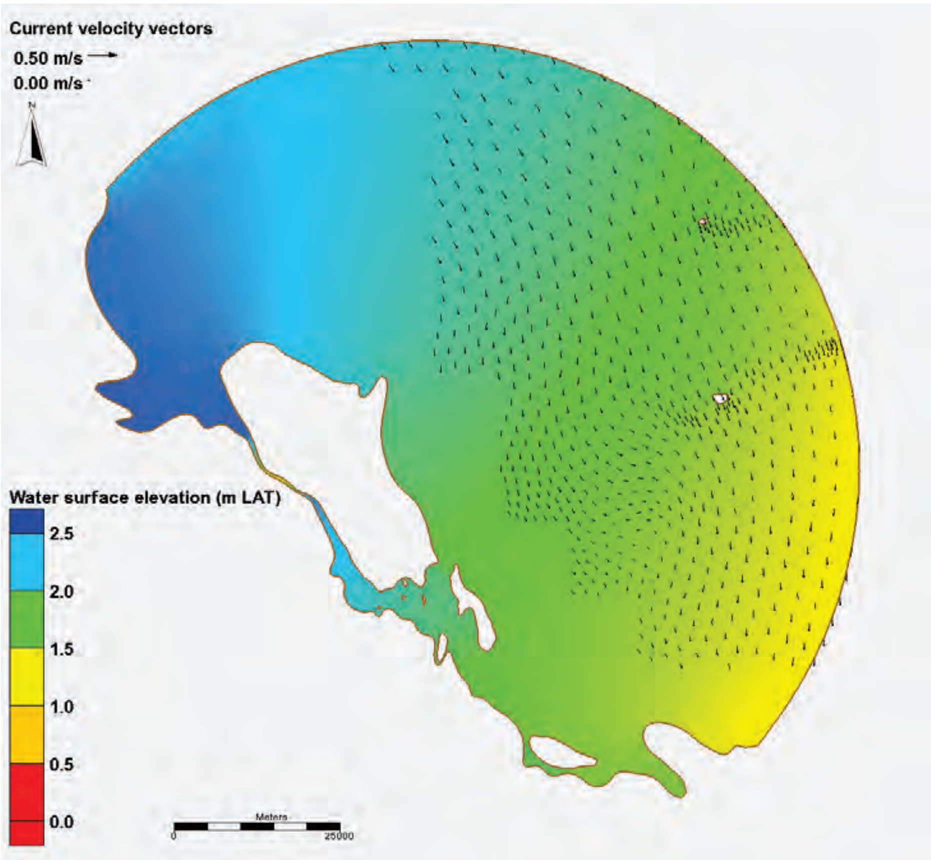


Figure 3-2 Typical BRAN model current field interpolated into ADCIRC computational mesh for Gladstone

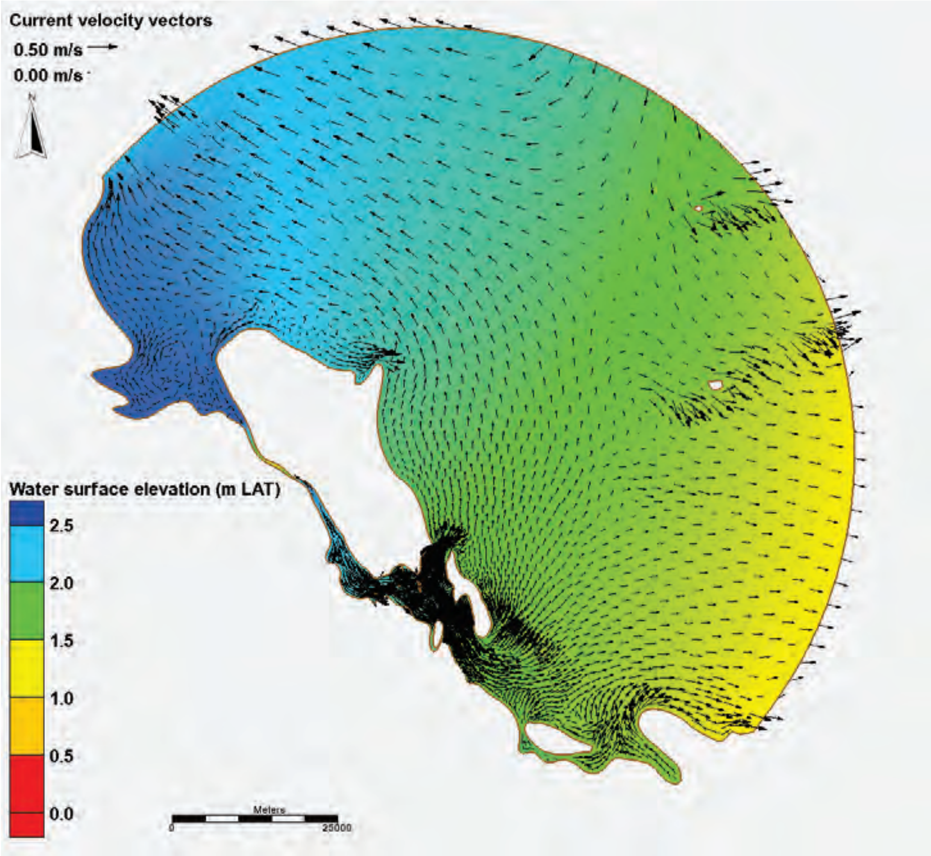


Figure 3-3 Typical ADCIRC model current field for Gladstone

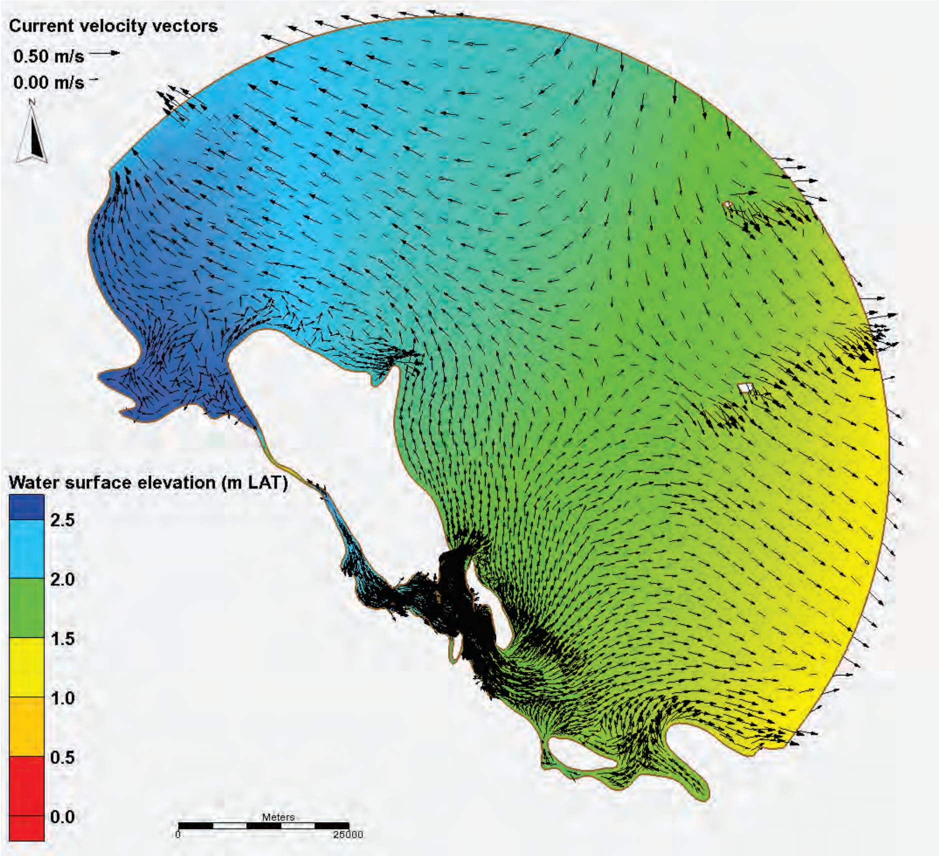


Figure 3-4 Combined BRAN and ADCIRC current field for Gladstone

3.2.3 Model validation

Tidal measurements were provided by the Tidal Unit Maritime Safety Queensland. For locations of the tidal gauges see **Figure 3-1**; geographic coordinates of the gauges and durations of the tidal records used in this study are also presented in **Table 3-1**.

Table 3-1 Tidal gauge locations and measurement durations used in model validations for Port of Gladstone and Port of Weipa

Gauge name	Coordinates	Duration
Gatcombe Head	23°53'S, 151°22'E	21/09/2006-22/11/2006
Fisherman's Landing Wharf	23°47'S, 151°10'E	25/09/2006-21/11/2006
South Trees	23°51'S, 151°18'E	01/03/2006-21/11/2007
Auckland Point	23°49'S, 151°15'E	01/06/2007-31/08/2007

Inter-comparisons of the modelled and measured tidal elevations over several typical spring-neap tidal cycles at the mentioned locations are presented in **Figure 3-5** through to **Figure 3-7**. A review of the graphs show the ADCIRC modelled magnitude and timing of tidal variations as well as both the spring and the neap tidal phases are similar to measured.

Figure 3-5 through to **Figure 3-7** demonstrate that for the Port of Gladstone transition, wet and dry season conditions, the model provided conservative estimates of tidal levels, in some cases underestimating the range of tidal variations. Underestimating the range and thus current velocities leads to conservative estimates of oil thickness and higher probabilities of oil of certain thickness on water.

Such discrepancies are usual model limitations accepted in any modelling exercise due to the inherent uncertainties in the boundary conditions, such as smoothed bathymetric and topographic features (especially the ones in shallow, near-shore area) and types of sea bed materials, the use of large-scale model winds and tidal forcing at the model domain open boundary.

Underestimated tidal ranges in some cases may lead to slower water currents in the study area and thus more conservative estimates of oil spreading and transport processes compared to the cases where tidal ranges are larger and tide-generated currents are faster.

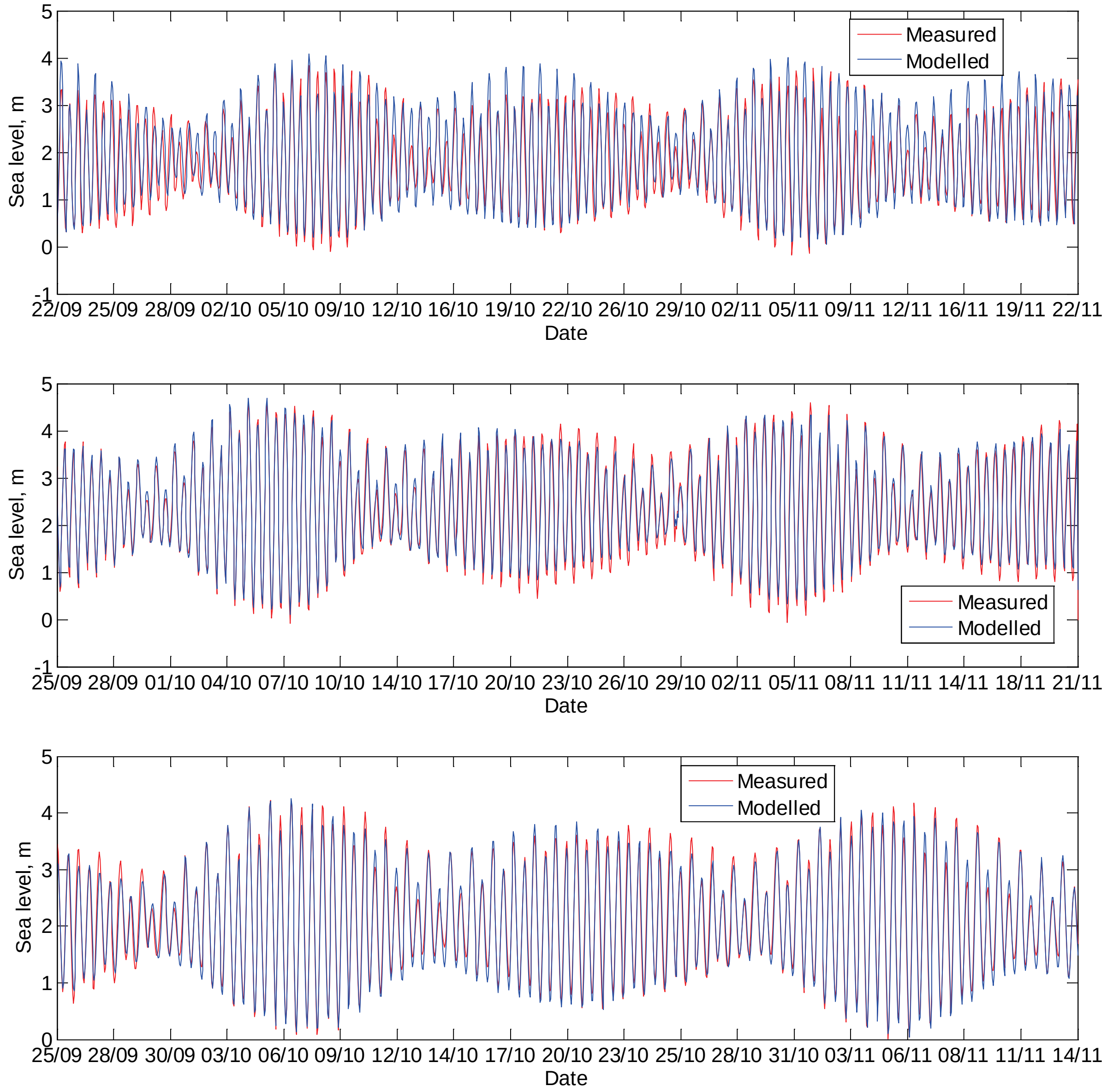


Figure 3-5 Tidal record versus model result inter-comparison at Beacon E3 Gatcombe Head (top panel), Fishermans Landing Warf QCL (middle panel) and South Trees Storm Surge (bottom panel) tide gauge locations, Port of Gladstone, spring months

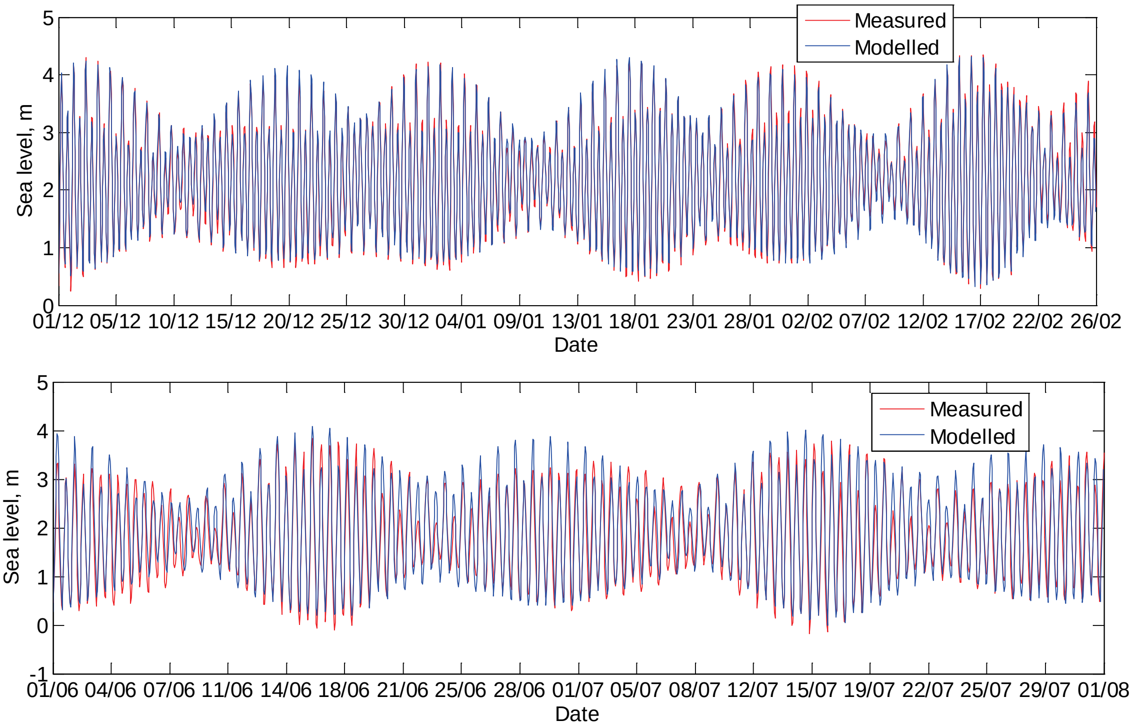


Figure 3-6 Tidal record versus model result inter-comparison at South Trees Storm Surge tide gauge location for wet (wet panel) and dry (bottom panel) seasons, Port of Gladstone

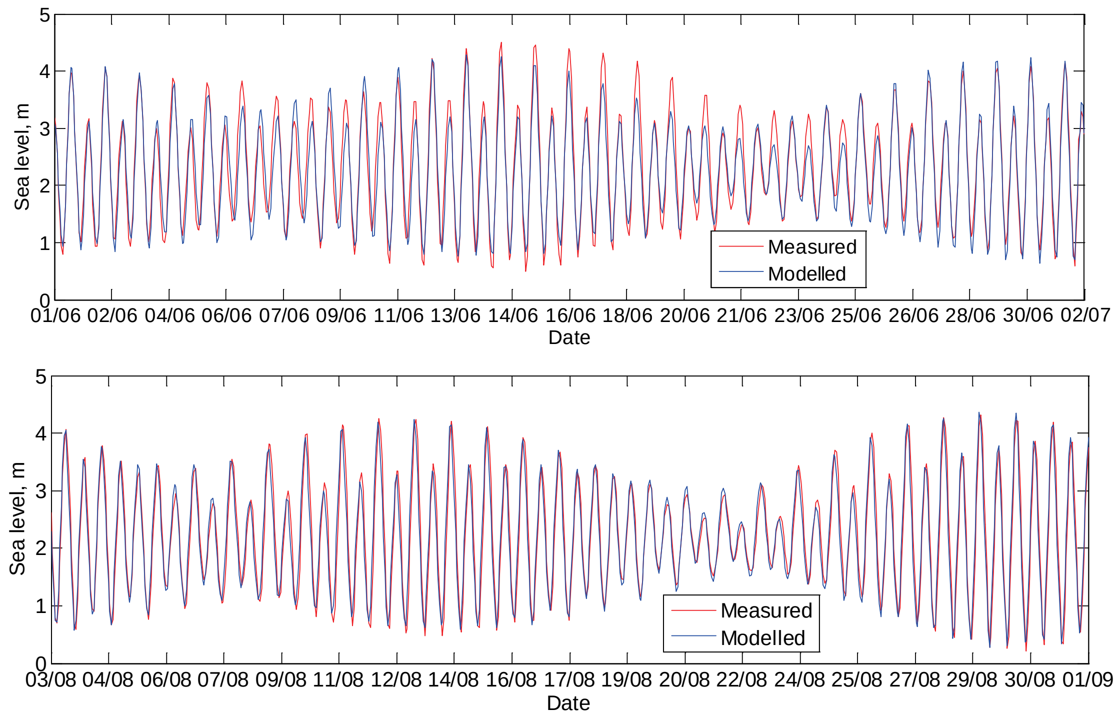


Figure 3-7 Tidal record versus model result inter-comparison at Gladstone Auckland Point tide gauge location for dry season, Port of Gladstone

3.2.4 Hydrocarbon spill scenarios and weathering curves

The hydrocarbon spill scenarios are summarised in **Table 3-2** based on the rationale discussed in the Introduction.

Table 3-2 Summary of hydrocarbon spill scenarios

Scenario	Spill volume	Release duration
Surface diesel spill from refuelling incident	5 m^3	instantaneous
Surface fuel oil (No.6) spill from refuelling incident	5 m^3	instantaneous
Surface fuel oil (No.6) spill from collision incident	25.25 m^3	instantaneous

Each spill was simulated to occur at the water surface and was modelled for the wet and the dry seasons, for different phases of several spring-neap cycles.

There are several different physical, chemical and biological processes, which affect hydrocarbon slick behaviour after a spill (e.g. ExxonMobil, 2008). A schematic plot itemising the basic processes and showing their approximate timeframes is presented in **Figure 3-8**. This section focusses solely on hydrocarbon weathering processes (mostly due to hydrocarbon evaporation from the water surface and vertical dispersion in the water column), while the next section describes a modelling approach to estimating spatial spreading and drift/transport of slicks due to physical forcing, such as wind and water current action.

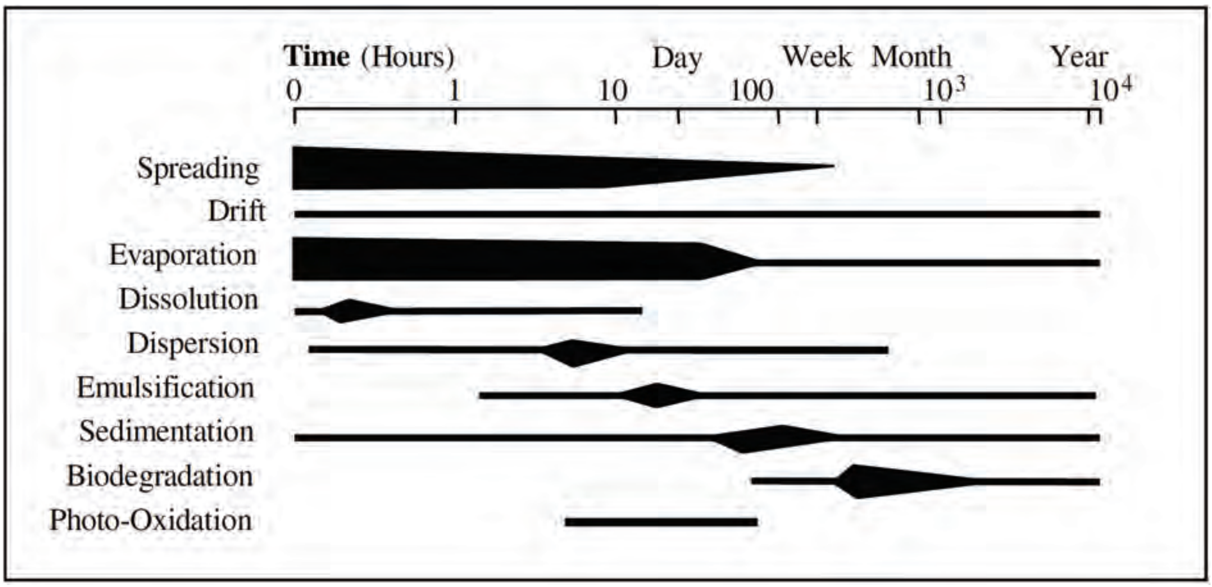


Figure 3-8 Schematic representation of "process versus time" for spilled on water surface hydrocarbon (from ExxonMobil, 2008)

Two different types of hydrocarbons were modelled in this study: diesel fuel oil and fuel oil No.6. To estimate the weathering processes typical for the two hydrocarbons modelled and for the seasonal ambient conditions, ADIOS2 (Automated Data Inquiry for Oil Spills) was used.

The ADIOS2 model is an oil spill response tool used to assist in making decisions on potential oil spill contingency and response strategies (see Lehr, 2001 and Lehr *et al.*, 2002). The ADIOS2 model asks for information on the spill itself as well as the ambient conditions, with several choices provided for entering and calculating the oil leak rate from the source of the spill.

This modelling tool integrates a library of approximately one thousand oils with a short-term oil weathering model estimating the time that spilled oil will remain in the marine environment. The oil library was compiled from a number of different sources, including Environment Canada, the U.S. Department of Energy, the International Oil Companies' European Organization for Environmental and Health Protections, and industry. Information about the location, density, viscosity, flash point, pour point, hydrocarbon group analysis, and distillation data are also included in the database.

Generally, in the field, more favourable hydrocarbon weathering conditions would primarily be due to higher water and air temperatures and stronger winds. The ADIOS2 modelling results for the two considered types of hydrocarbons suggest that the diesel weathering is affected by different season metocean conditions (wind speed, air and water temperature), while fuel oil No.6 weathering is rather independent of them. **Figure 3-9** and **Figure 3-10** illustrate how diesel would weather under the dry and the wet season conditions. **Figure 3-11** and **Figure 3-12** illustrate weathering of fuel oil No.6.

Figure 3-9 and **Figure 3-10** demonstrate that for diesel, within the first 24 hours after the spill (dashed vertical line in the figure), 19% to 34% and 23% to 38% of this hydrocarbon would evaporate during the dry and the wet seasons respectively. The rest of the spilled diesel would be removed from the water surface by way of vertical dispersion in the water column within 30 hours after the spill (solid vertical line in the figures).

Figure 3-11 exhibits general weathering curves, which suggest that up to 70-75% of the spilled fuel oil No.6 may persist on water surface after 5 days. **Figure 3-12** shows separately evaporated and dispersed in water percentages of the spilled hydrocarbon, when uncertainties in metocean parameters are taken into consideration. The top panel in **Figure 3-12** suggests that fuel oil No.6 would slowly evaporate, with around 8% removed from the water surface by the end of the modelled period. 18% to 64% of this hydrocarbon may be dispersed in water (bottom panel in **Figure 3-12**), with the percentage essentially dependent on the ambient conditions.

Taking the above into the account, the study simulation periods should not be interpreted as an indication of oil of certain thickness staying on either water or shore over the entire duration of the model run.

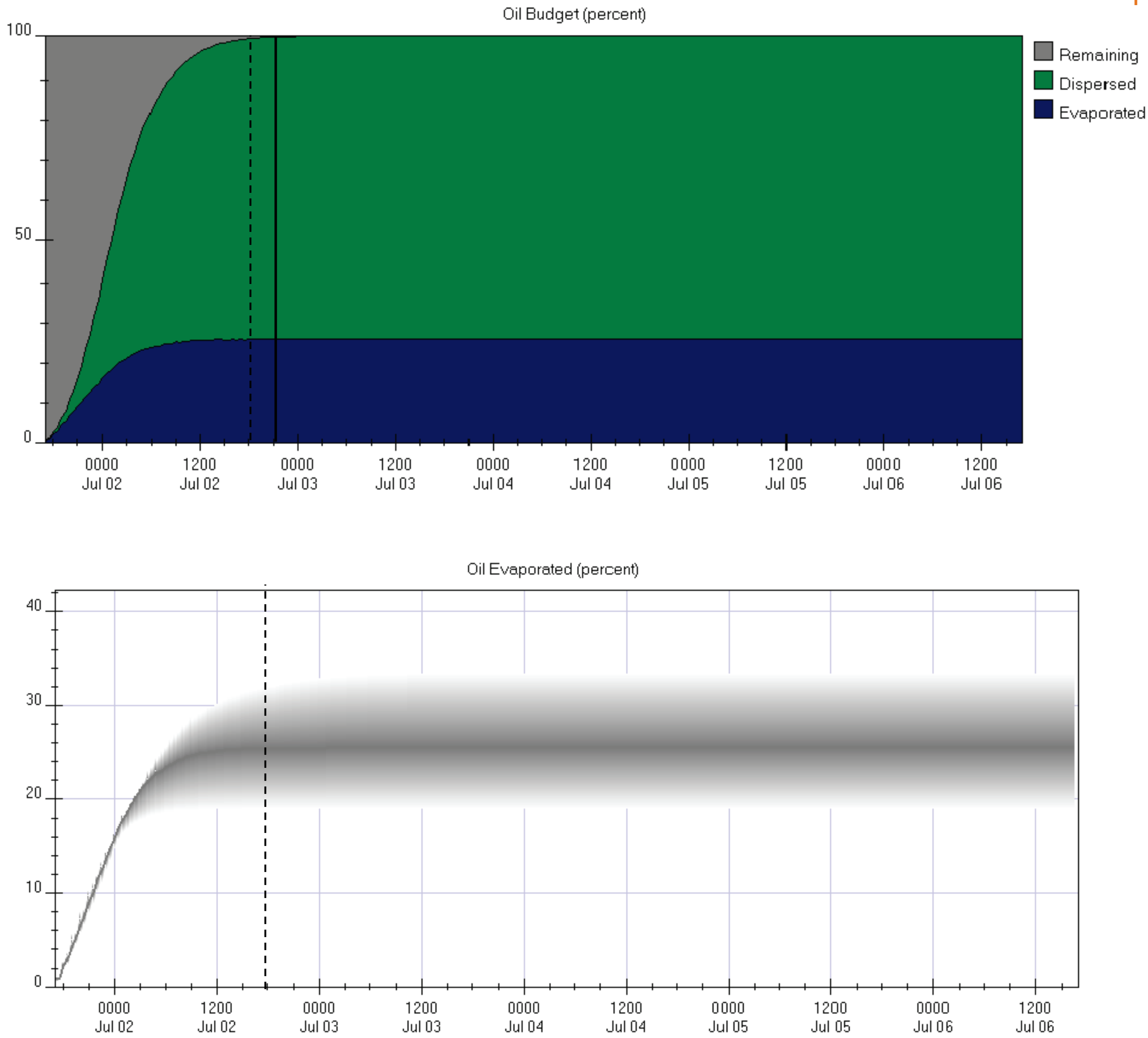


Figure 3-9 Weathering of diesel fuel oil under dry season conditions; darker grey in bottom panel indicates "the best estimate", while lighter grey represents range of possible values affected by metocean parameter (water temperature and salinity, winds and currents) uncertainties

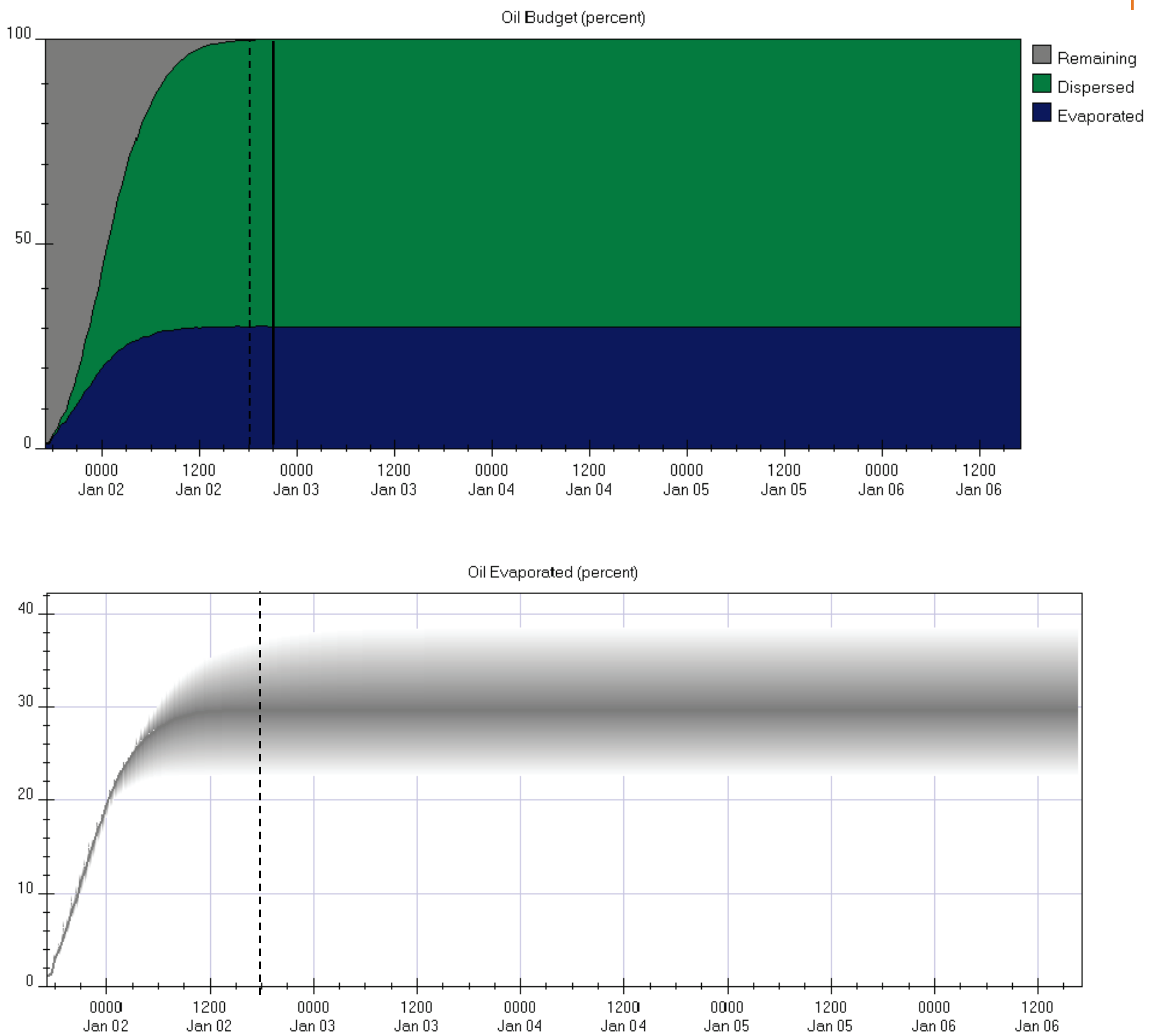


Figure 3-10 Weathering of diesel fuel oil under wet season conditions; darker grey in bottom panel indicates "the best estimate", while lighter grey represents range of possible values affected by metocean parameter (water temperature and salinity, winds and currents) uncertainties

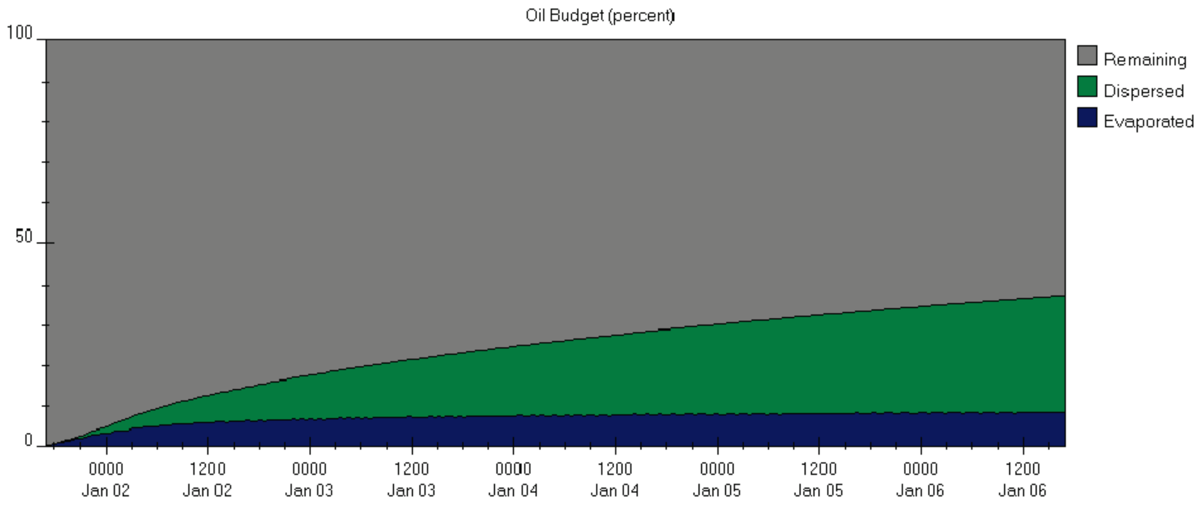


Figure 3-11 Weathering of fuel oil No.6

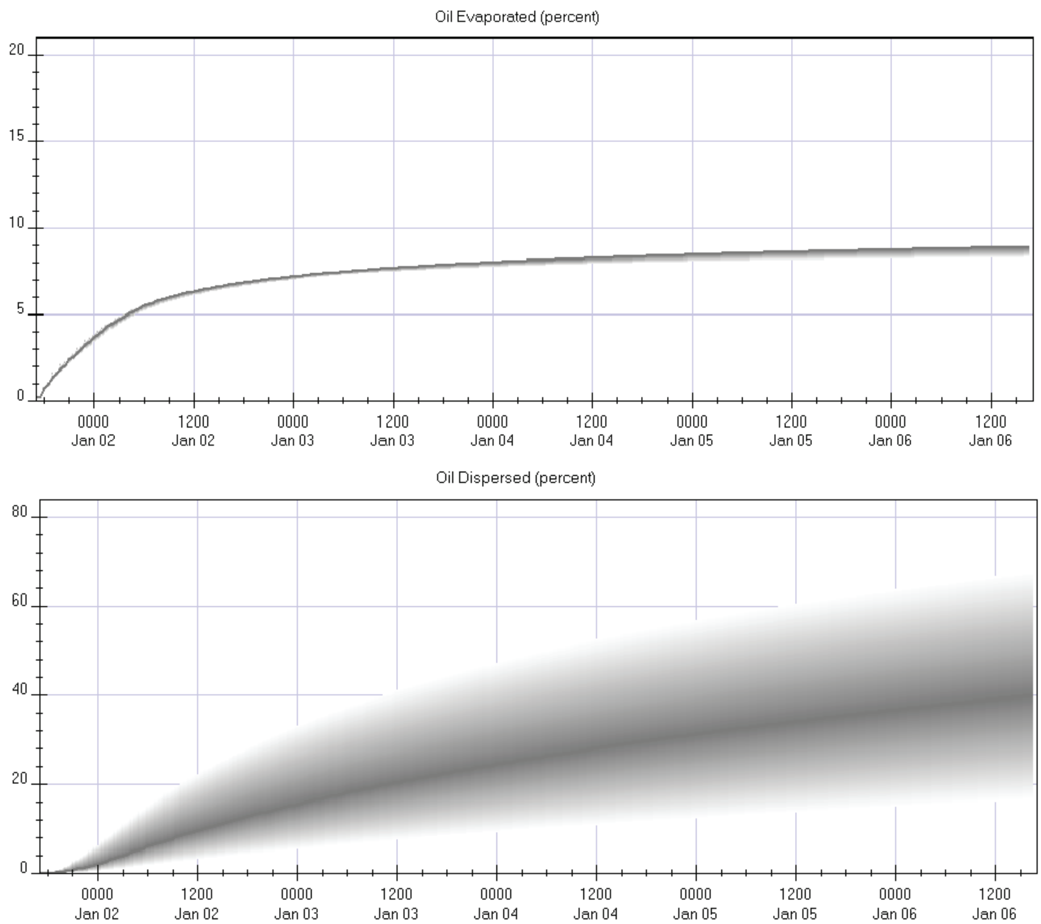


Figure 3-12 Evaporation (top panel) and vertical dispersion (bottom panel) of fuel oil No.6; darker grey in both panels indicates "the best estimate", while lighter grey represents range of possible values affected by metocean parameter (water temperature and salinity, winds and currents) uncertainties

3.2.5 Spill trajectory modelling

Spill trajectory modelling was carried out using a purpose-developed oil spill trajectory and fates model, GNOME (General NOAA Oil Modeling Environment). This model is designed to simulate the spreading on the water surface, drift/transport and weathering processes that affect the outcomes of hydrocarbon spills to the sea, accounting for the specific hydrocarbon type, spill situation and ambient wind and current patterns (see Beegle-Krause, 2001).

The GNOME model supports the National Oceanic and Atmospheric Administration (NOAA)/ Hazardous Materials Response Division (HAZMAT) standards by providing information about where the spill most likely to go and the uncertainty boundary.

The GNOME model can be used to predict the fate of a single spill under defined conditions, or of multiple spills that occur under a random selection of prevailing conditions (also known as stochastic modelling). The stochastic model performs a large number of simulations for a given spill site, randomly varying the spill time within a defined period, so that the spreading on the water surface, drift/transport and weathering of each slick are subject to a different set of wind and current conditions. During each simulation, the model records which areas were contacted by discrete (Lagrangian) oil particles.

In this study, the stochastic modelling approach was used to produce quantitative estimates of probability of exposure for the identified hydrocarbon spill scenarios. The stochastic approach involved repeated simulation of each scenario (in this study, 100 model trajectories, or runs; see below), using different samples of ambient conditions each time. These samples of time varying conditions were selected randomly from the model database of current and wind data produced for the study area. Such a sampling approach provides an objective measure of the possible outcomes of a spill, because environmental conditions would be selected at a rate that would be proportional to the likelihood that these conditions occur in the study area. The most commonly occurring conditions would be selected most often, while conditions that are unusual would be represented less frequently. Results of such simulations would represent the probability that a certain area within the model domain may be exposed to hydrocarbon slicks; this is calculated from the frequency of exposure during all model runs.

The 100 individual trajectories were simulated for each scenario. The threshold for modelling the zone of potential impact from an oil spill was selected to be 0.01 mm (10 microns) oil thickness on the water surface (equivalent to 1 litre of oil covering an area of 100 m^2 if surface cover is continuous); this would appear on the water surface as yellowish brown (see NOAA HAZMAT Report 96-7; **Figure 3-13**).

The basis for the 0.01 mm threshold is that this thickness of oil has the potential to cause a smothering effect on directly exposed wildlife. The likelihood of any environmental harm resulting from the surface oil below this threshold is considered to be very low. For example, if the full volume of the oil was dispersed into the water column, the concentration of oil in the water column 1 metre below a 0.01 mm slick would be only 10 parts per million, not taking account of horizontal dilution effects. This is also the thickness at which some kind of physical or chemical response to the spill becomes logistically feasible (depending on the site conditions and fuel type). The use of the 0.01 mm threshold is supported in the *Interim Technical Guideline for the Preparation of Marine Pollution Contingency Plans for Marine and Coastal Facilities* released by the Australian Maritime Safety Authority in July 2012.

There is no equivalent recommendation for oil thickness when estimating oil on shore; therefore, a more conservative threshold of 0.001 mm (1 micron), which would appear as dull colours, see **Figure**

3-13) was used for oil on shore. This is consistent with the thickness used for oil on shoreline modelling in other published Environmental Impact Assessments (Asia Pacific Applied Science 2005, DHI Water and Environment 2010, URS 2011).

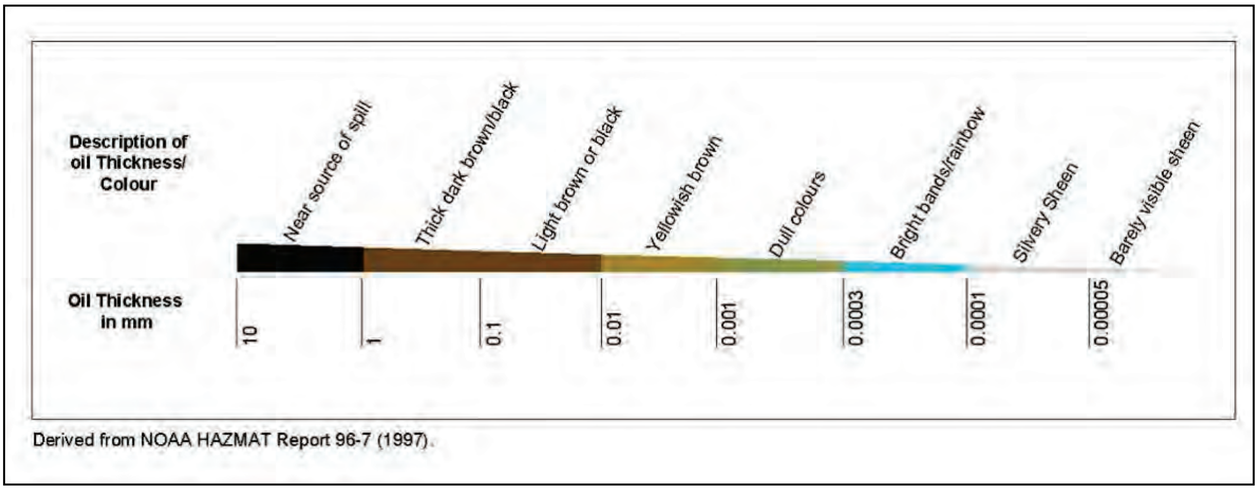


Figure 3-13 Oil slick colours as function of hydrocarbon layer thickness (source: NOAA HAZMAT Report 96-7)

Hydrocarbon Spill Modelling Results

The following sections present spill simulation results for the hydrocarbon spill scenarios from **Table 3-2** modelled for the wet and dry seasons. The probabilities of oil on water surface (for oil 0.01 mm and thicker) and on shore (for oil 0.001 mm and thicker) were calculated independently for each spill location modelled. Given the different thicknesses modelled, it is possible for there to be instances where there is a probability shown of oil on shore in locations where there is no probability shown for oil on the water surface.

Note that the plotted probabilities do not represent the extent of any one spill trajectory/event, or on-shore oiling, which will all be significantly smaller, but are a summary of probability for the 100 events/model runs. For example, the areas exhibiting >0-20% probability were exposed/contacted by model oil particles by up to 20% of the total number of simulated spill trajectories. Locations with higher probabilities were exposed to a greater number of spill trajectories, suggesting that the combination of the prevailing wind and current conditions resulting in the exposure had occurred more frequently. Taking into account highly variable coastal conditions and sensitive nature of the coastal habitats, a very conservative approach was used for estimating oil on shore probabilities, which were calculated for any oil, including barely visible sheen. The areas outside of the >0-100% probability coverage suggest that exposure will be unlikely under the range of simulated spill and ambient conditions.

The modelling is based on no mitigation measures being implemented. However, if an emergency situation occurred, the Gladstone Ports Corporation would implement a spill response plan in accordance with the “First-strike Oil Spill Response Plan” (TMR, 2011). Implementing the plan would affect oil distribution and transport patterns within the study area.

4.1 Diesel Spills

4.1.1 5 m^3 spill at Fisherman’s Landing

Stochastic modelling results for a 5 m^3 diesel spill from Fisherman’s Landing suggest that, during both a dry and a wet season, the hydrocarbon slick propagation would generally be limited by the nearest, adjacent continental coastline and the south-western and south-eastern coasts of Curtis Island (see **Figure 4-1** and **Figure 4-2**). There would be up to 40% probability of water surface exposure to 0.01 mm or thicker oil over the affected area, generally within 5 km from the spill location. The results suggest no water-surface oil slicks of 0.01 mm or thicker from a 5 m^3 spill at Fisherman’s Landing would be transported into the GBRMP.

The numerical modelling results suggest that diesel originating from a Fisherman’s Landing spill would reach the nearest shore within the first 1.5 hours after release. There would be a 100% chance for the spilled diesel to reach a shore, i.e. this occurred in each of the 100 conducted trajectory simulations, each lasting for 7 days. Up to 90% of the spilled volume of diesel might be beached at any one particular moment in time during both dry and wet season spills.

Probabilities of oiling of different stretches of the shoreline for dry and wet season releases are depicted in **Figure 4-3** and **Figure 4-4** respectively. The results suggest that the highest probabilities of oiling by 0.001 mm or thicker oil film, would be up to 60%, at the nearest coastal sites to the spill location. The probability would decrease with distance from the spill location, down to and below 20% at the eastern end of Curtis Island, the western shore of Facing Island, and at the coasts in the middle of the Narrows.

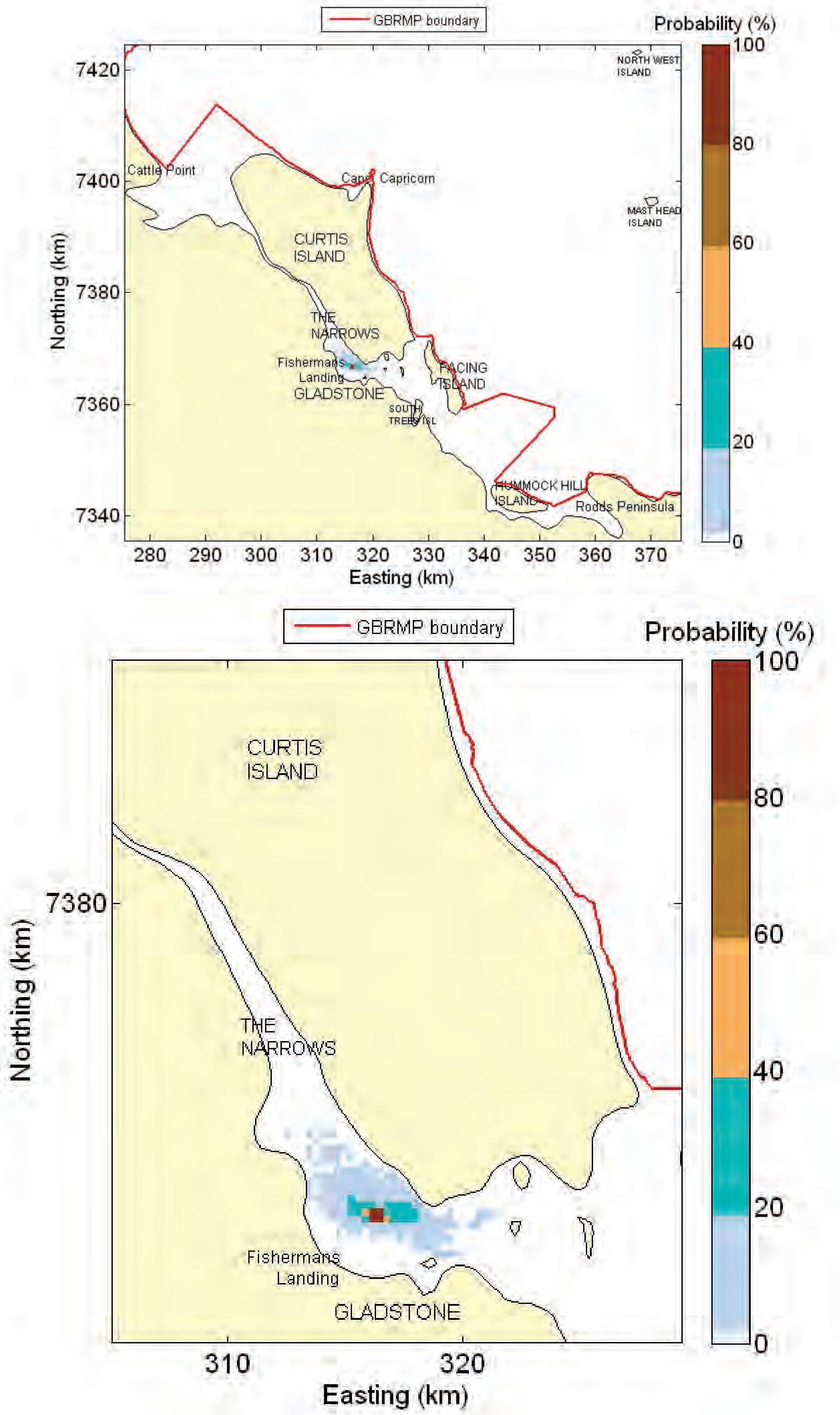


Figure 4-1 Probability of ≥ 0.01 mm oil thickness in dry season from 5 m^3 diesel spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)

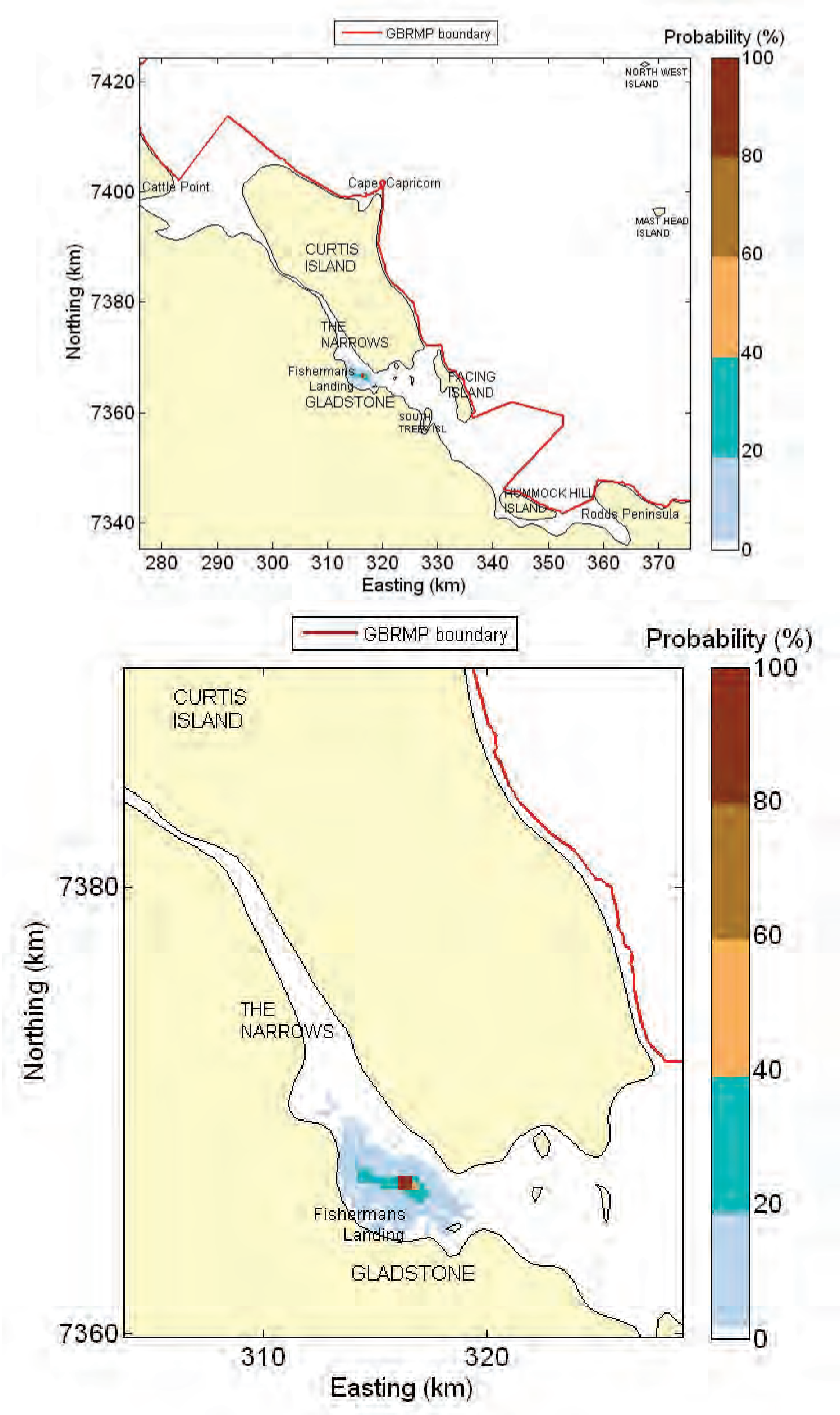


Figure 4-2 Probability of ≥ 0.01 mm oil thickness in wet season from 5 m^3 diesel spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)

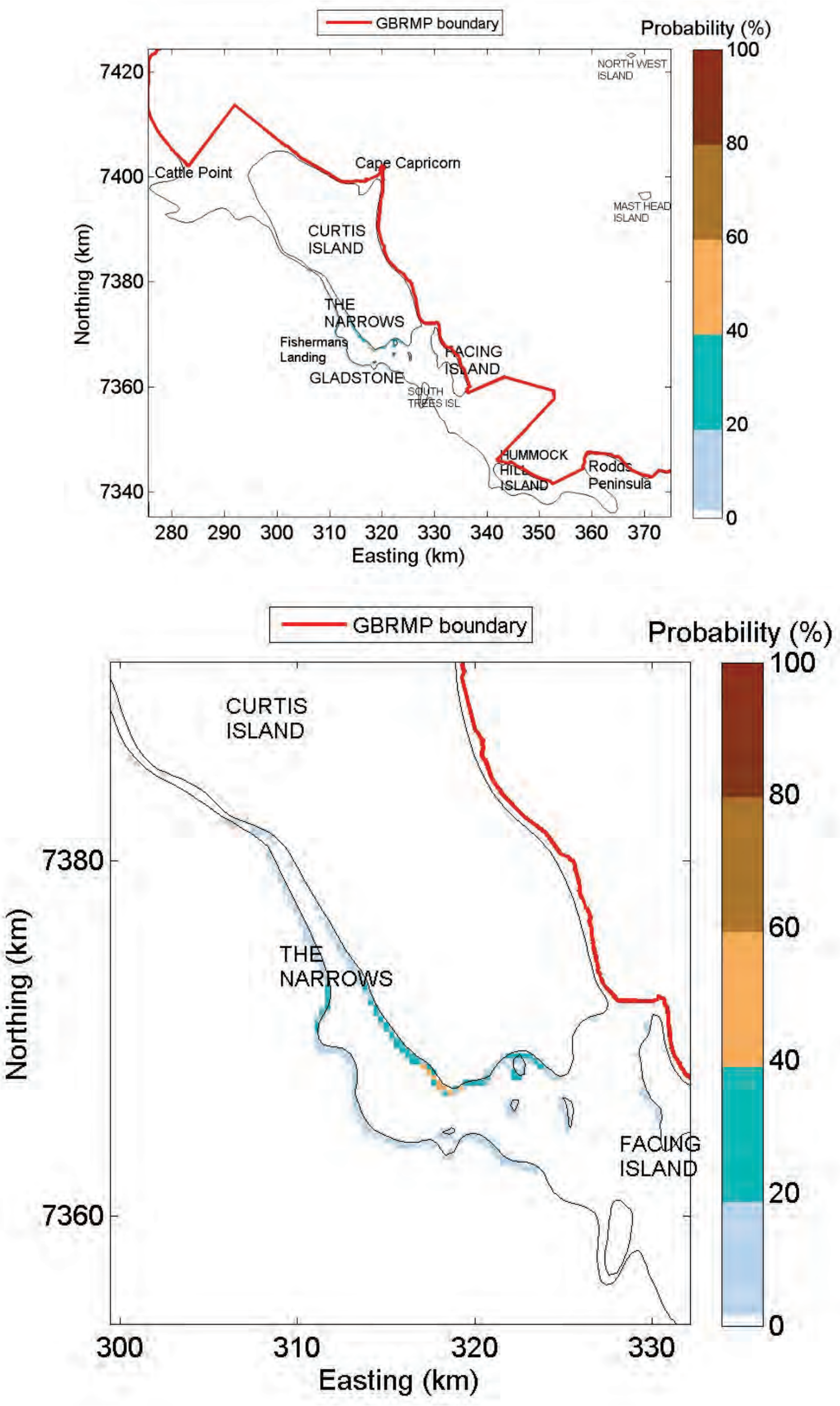


Figure 4-3 Probability of ≥ 0.001 mm oil thickness on shore in dry season from 5 m^3 diesel spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)

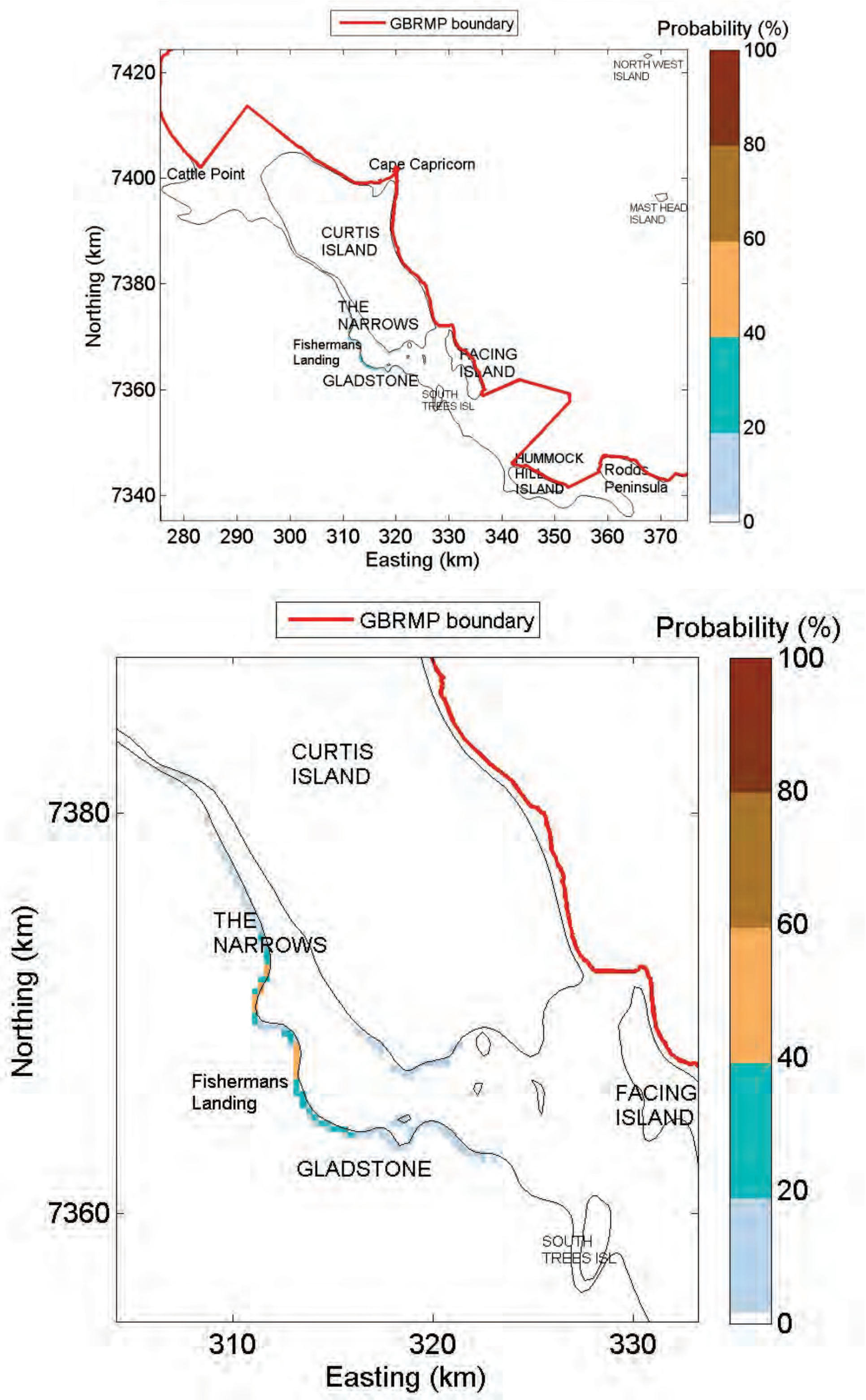


Figure 4-4 **Probability of ≥ 0.001 mm oil thickness on shore in wet season from 5 m^3 diesel spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)**

4.1.2 5 m^3 spill at South Trees Wharf

Modelling results for this scenario suggest that in numerical 7-day simulations for the two considered seasons, water-surface slicks would mostly affect adjacent areas (up to 40% and 60% probability of exposure to 0.01 mm or thicker oil during dry and wet seasons respectively, see **Figure 4-5** and **Figure 4-6**), with the slicks spreading up to 5-7 km from the spill location. The results for this scenario suggest no water-surface oil slicks 0.01 mm or thicker would be transported into the GBRMP as a result of a 5 m^3 spill at South Trees Wharf.

The modelled results suggest that diesel originating from a South Trees Wharf spill would reach the nearest shore within an hour after release, and there would be a 100% chance of the spilled diesel reaching a shore. Up to 83% and 90% of spilled volume of diesel may be beached at a time after a dry and a wet season spill respectively.

Probabilities of the coastline (i.e. any specific stretch of the coastline) exposure to beached diesel are presented in **Figure 4-7** and **Figure 4-8**, dry and wet season releases respectively. During a dry season, there is up to a 60% probability of 0.001 mm or thicker oiling occurring on shore at Facing Island (**Figure 4-7**, bottom panel) if a spill occurs. During a wet season, there is up to a 60% probability of shore oiling occurring west of South Trees Island, near Gladstone (**Figure 4-8**, bottom panel) if a spill occurs. The results suggest that there would be up to 40% and 20% probability of diesel from a 5 m^3 spill at South Trees Wharf beaching near Fisherman’s Landing and in the middle of the Narrows respectively.

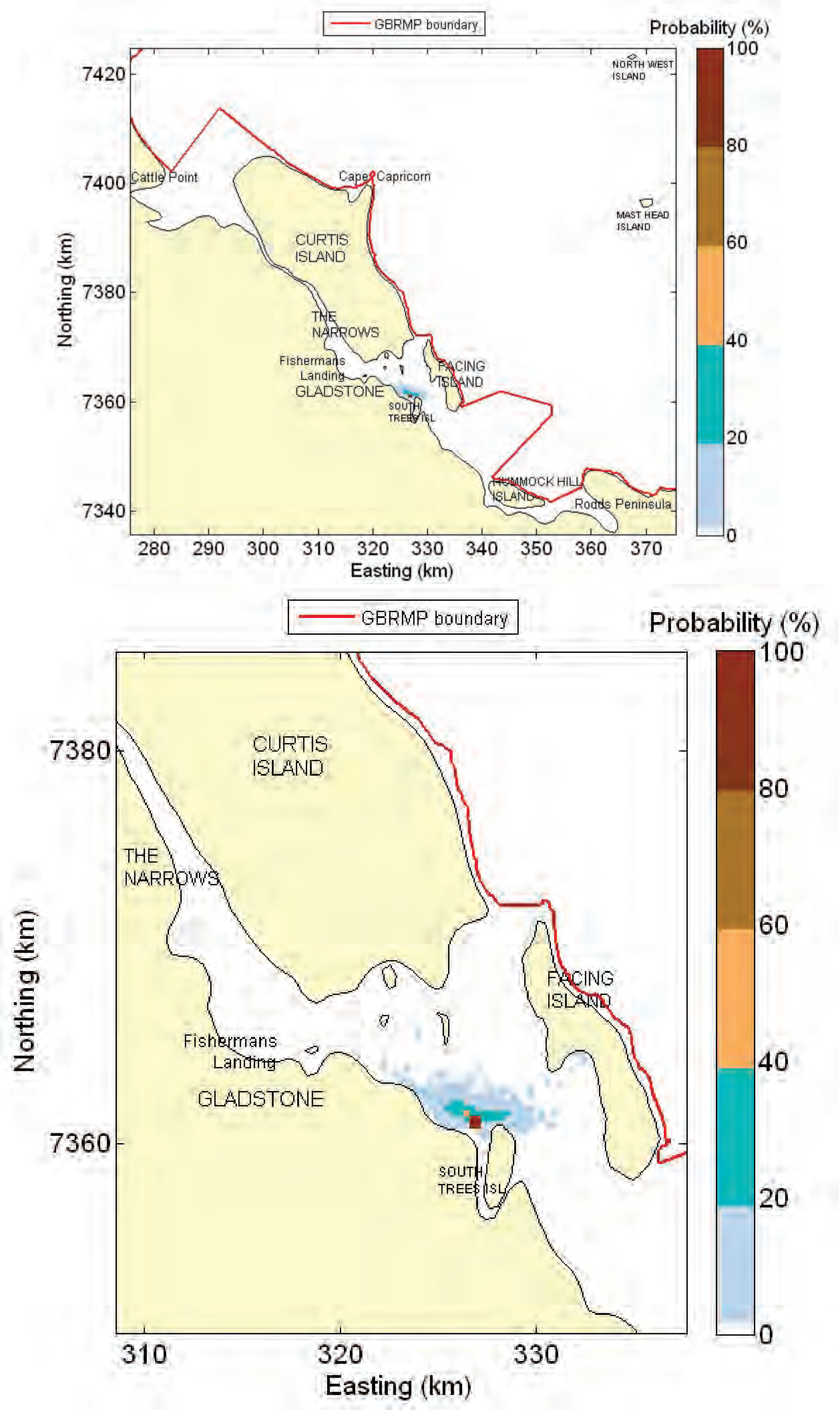


Figure 4-5 Probability of ≥ 0.01 mm oil thickness in dry season from 5 m^3 diesel spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)

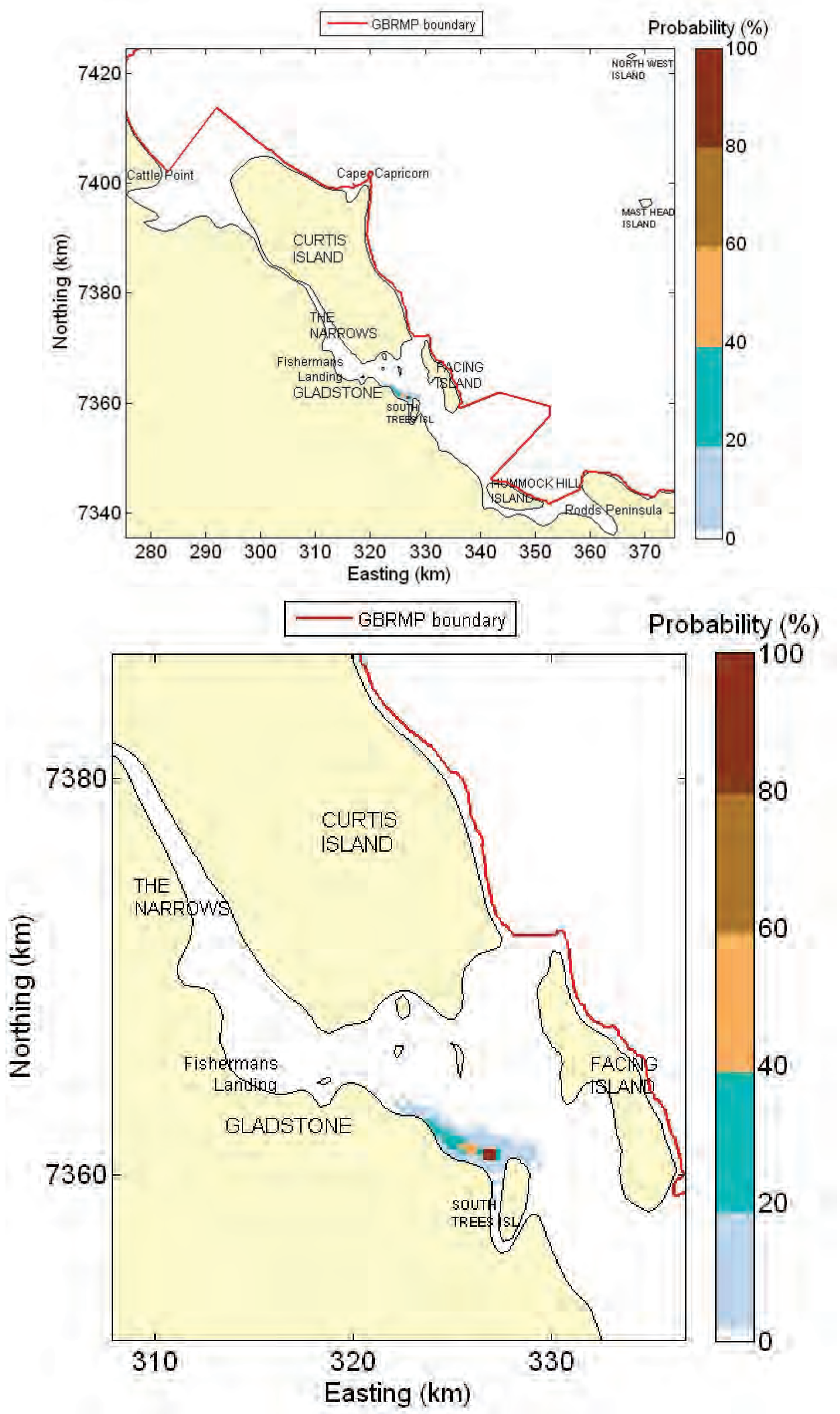


Figure 4-6 Probability of ≥ 0.01 mm oil thickness in wet season from 5 m^3 diesel spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)

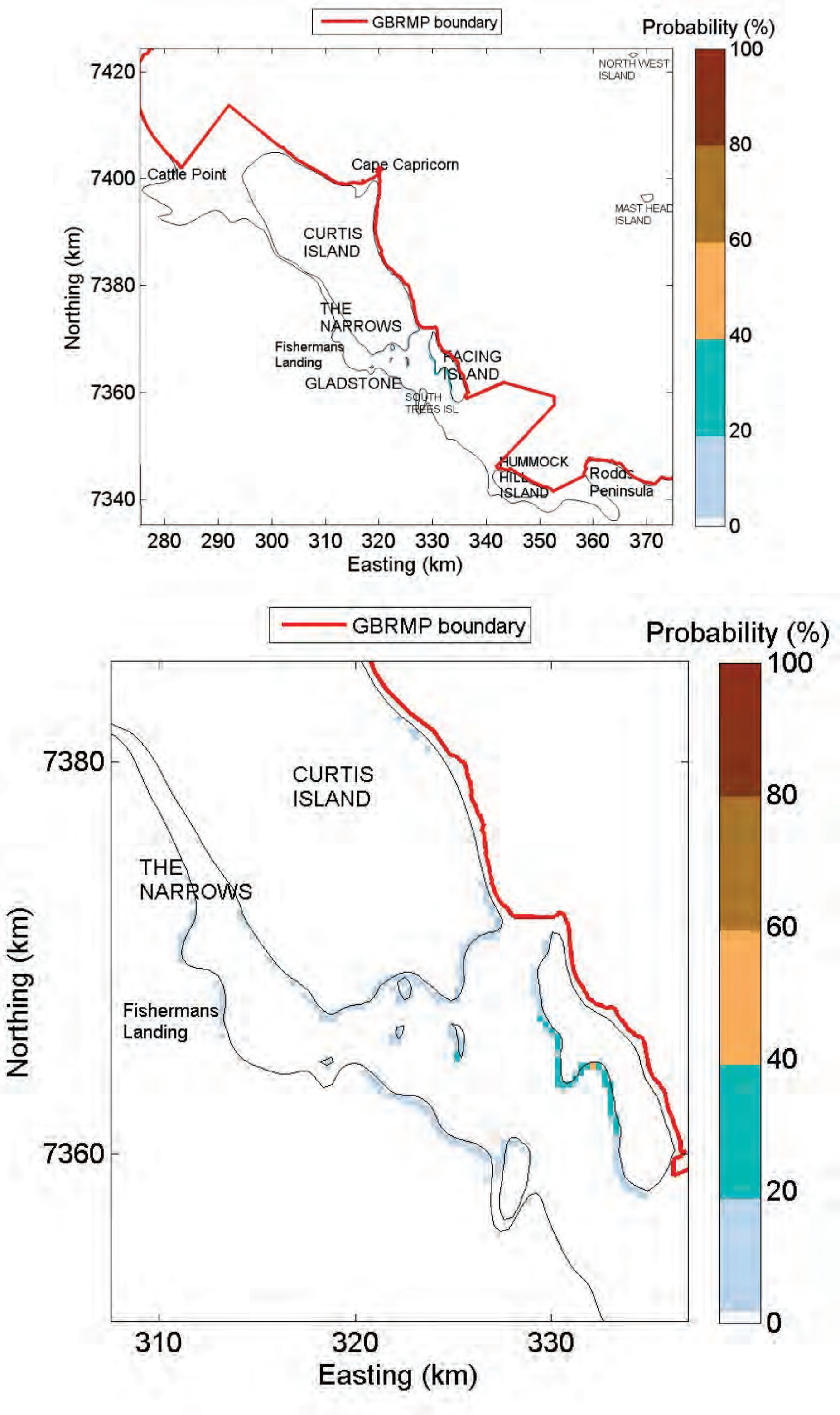


Figure 4-7 Probability of ≥ 0.001 mm oil thickness on shore in dry season from 5 m^3 diesel spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)

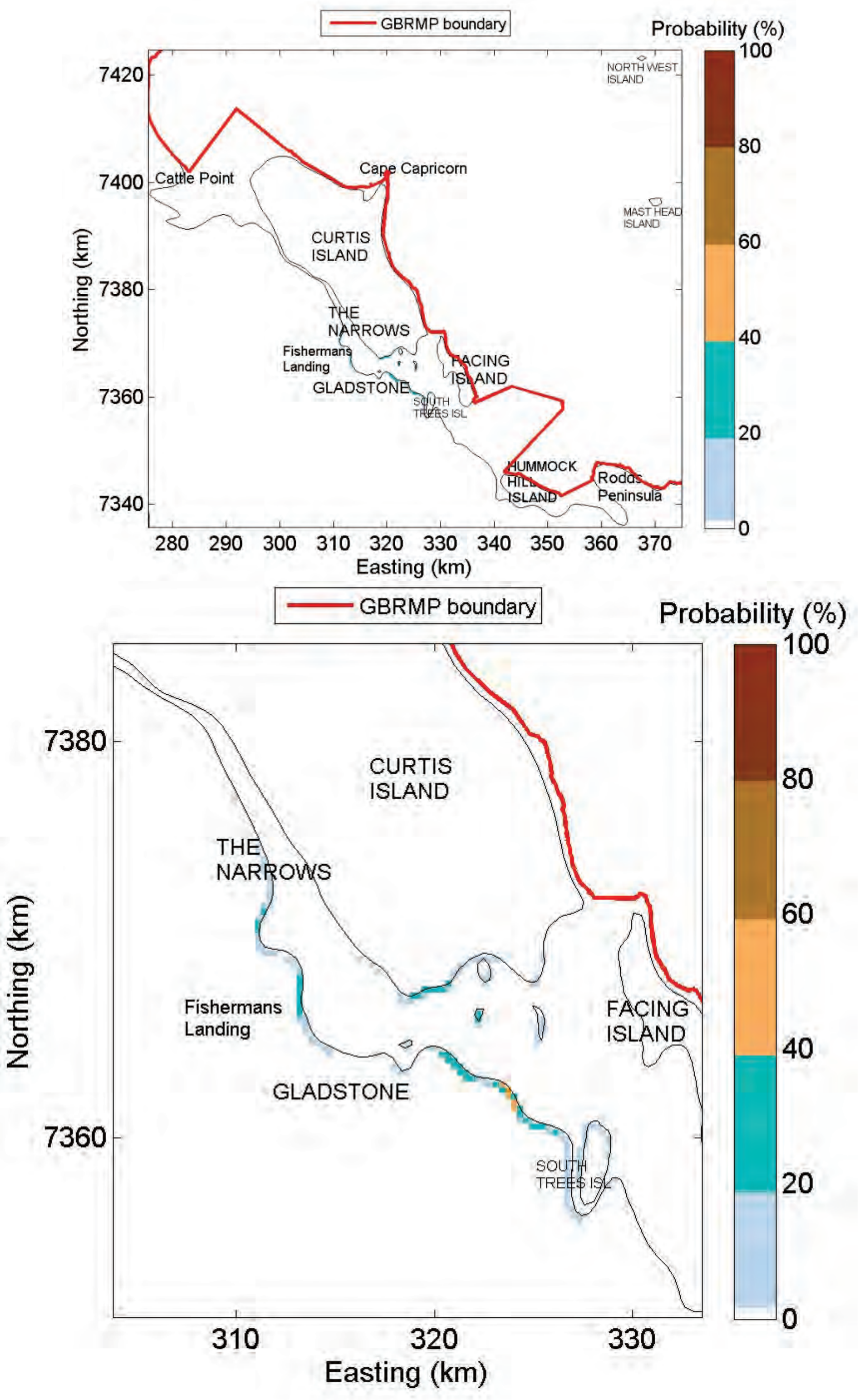


Figure 4-8 Probability of ≥ 0.001 mm oil thickness on shore in wet season from 5 m^3 diesel spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)

4.2 Fuel oil No.6 Spills

4.2.1 5 m^3 spill at Fisherman's Landing

Stochastic modelling results for a 5 m^3 spill of fuel oil (No.6) at Fisherman's Landing suggest that water surface fuel oil slicks would propagate in all directions from the spill location, though oil spreading would mainly be steered by the continental coastline, the southern coasts of Curtis Island and the nearest inner islands within the port area (**Figure 4-9** and **Figure 4-10**). There would be up to 60% probability of water surface exposure to 0.01 mm or thicker oil near the spill location. The results suggest no water-surface oil slicks 0.01 mm or thicker from a 5 m^3 spill of fuel oil (No.6) at Fisherman's Landing would be transported into the GBRMP.

Fuel oil No.6 originating from a Fisherman's Landing spill would beach within 1.5 hours after spill. There would be a 100% chance for the spilled fuel oil to reach a shore, i.e. this occurred in each of the 100 conducted trajectory simulations. This type of oil undergoes slow weathering; which would result in up to 96% of the spilled volume beached at a time.

Figure 4-11 and **Figure 4-12** present probabilities of 0.001 mm or thicker oil on different stretches of the shoreline for the dry and wet season as a result of a 5 m^3 fuel oil (No.6) spill at Fisherman's Landing. The results suggest that there would be up to a 60% probability of oiling of the Curtis Island shoreline (dry season simulations, bottom panel in **Figure 4-11**) and continental shores (wet season simulations, bottom panel in **Figure 4-12**) nearest to the spill location. The probability would decrease with distance, with up to a 20% probability of oiling occurring on shore in the middle of the Narrows (both continental and Curtis Island sides), at the north-east facing shore of Curtis Island, and at the western facing shores of Facing Island if a spill occurs.

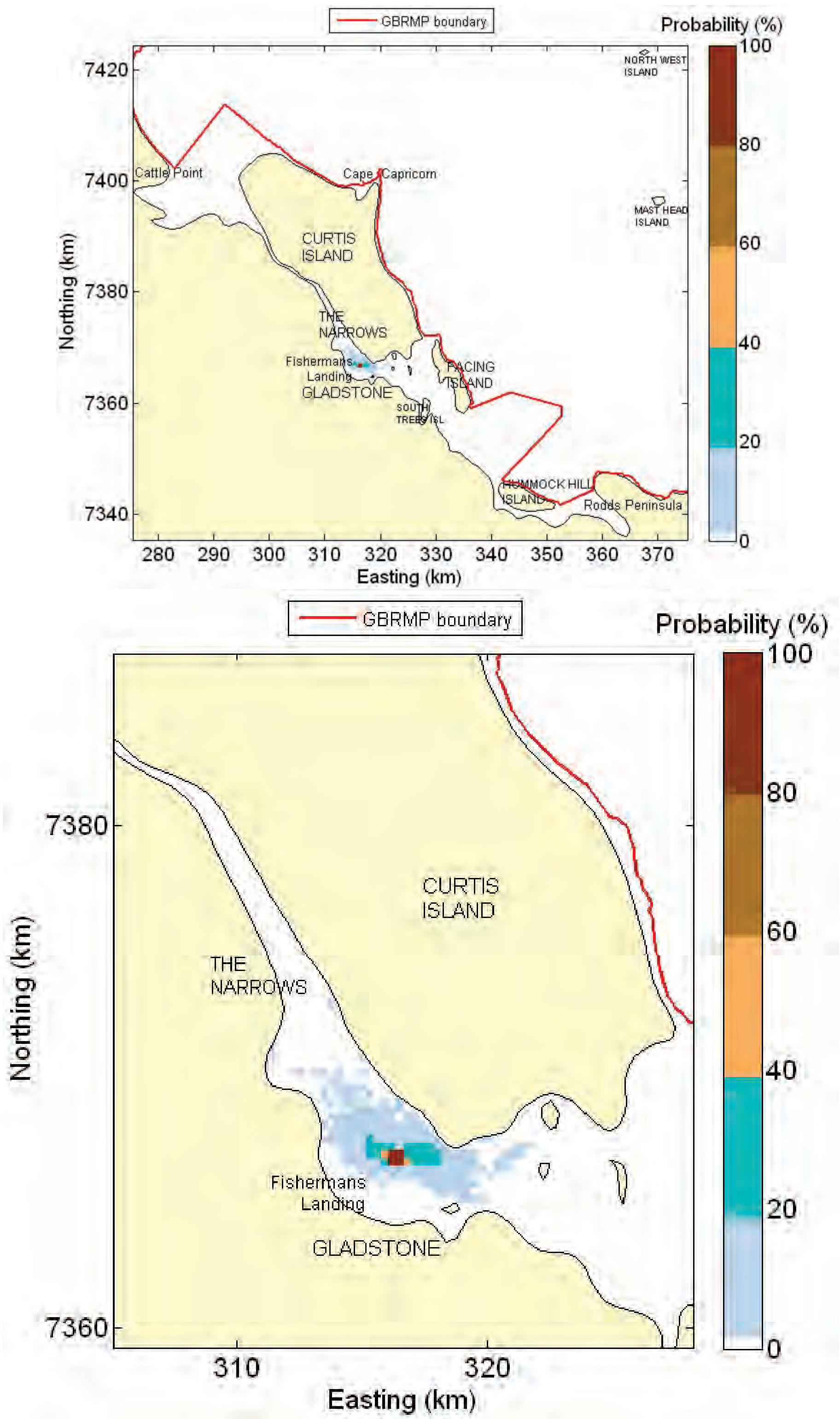
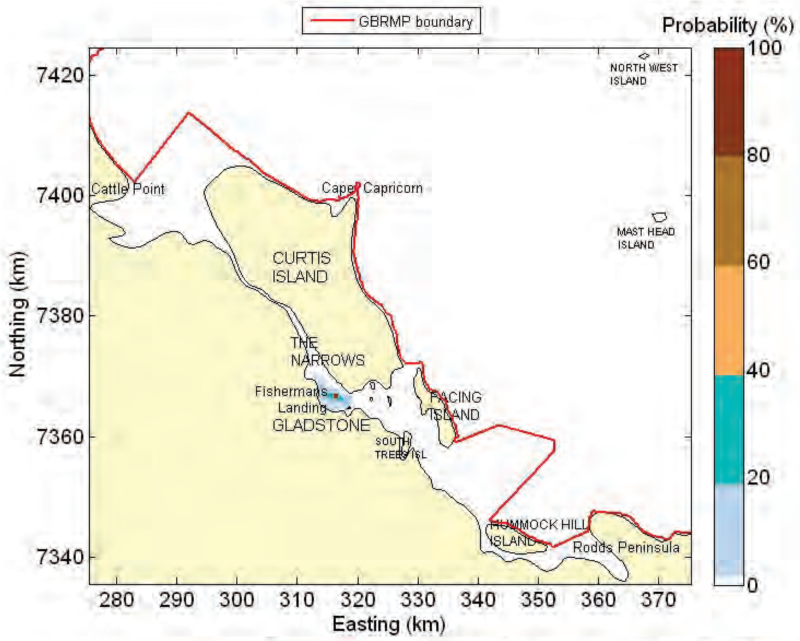


Figure 4-9 Probability of ≥ 0.01 mm oil thickness in dry season from 5 m^3 fuel oil No.6 spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)



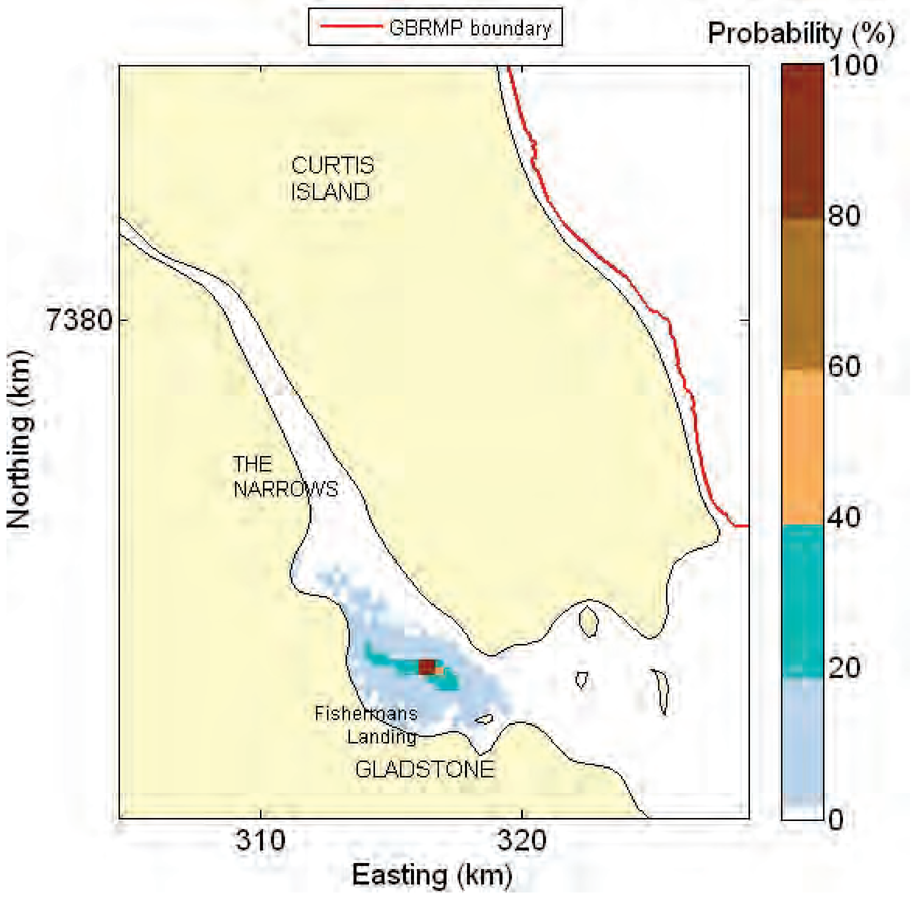


Figure 4-10 Probability of ≥ 0.01 mm oil thickness in wet season from 5 m^3 fuel oil No.6 spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)

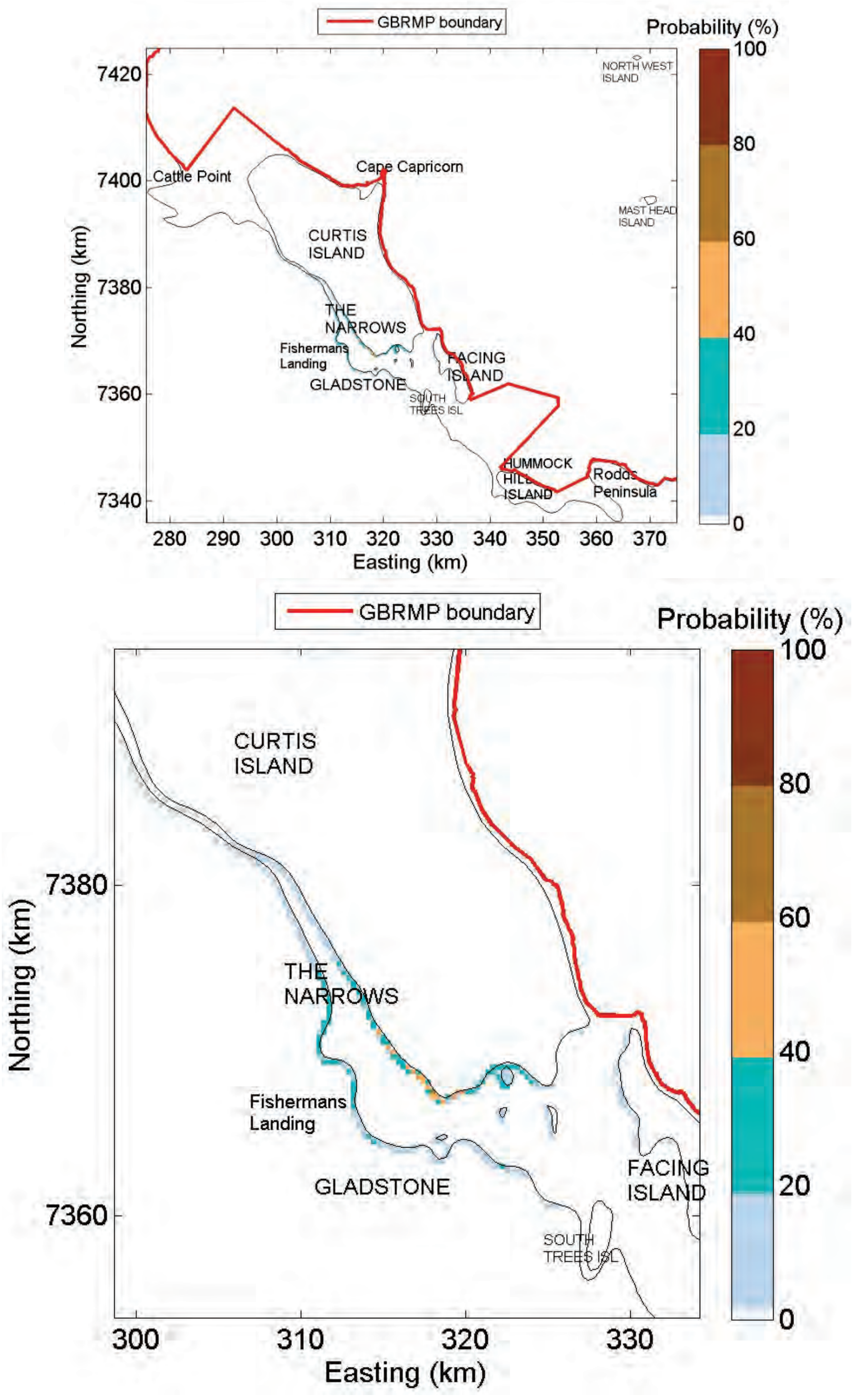


Figure 4-11 Probability of ≥ 0.001 mm oil thickness on shore in dry season from 5 m^3 fuel oil No.6 spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)

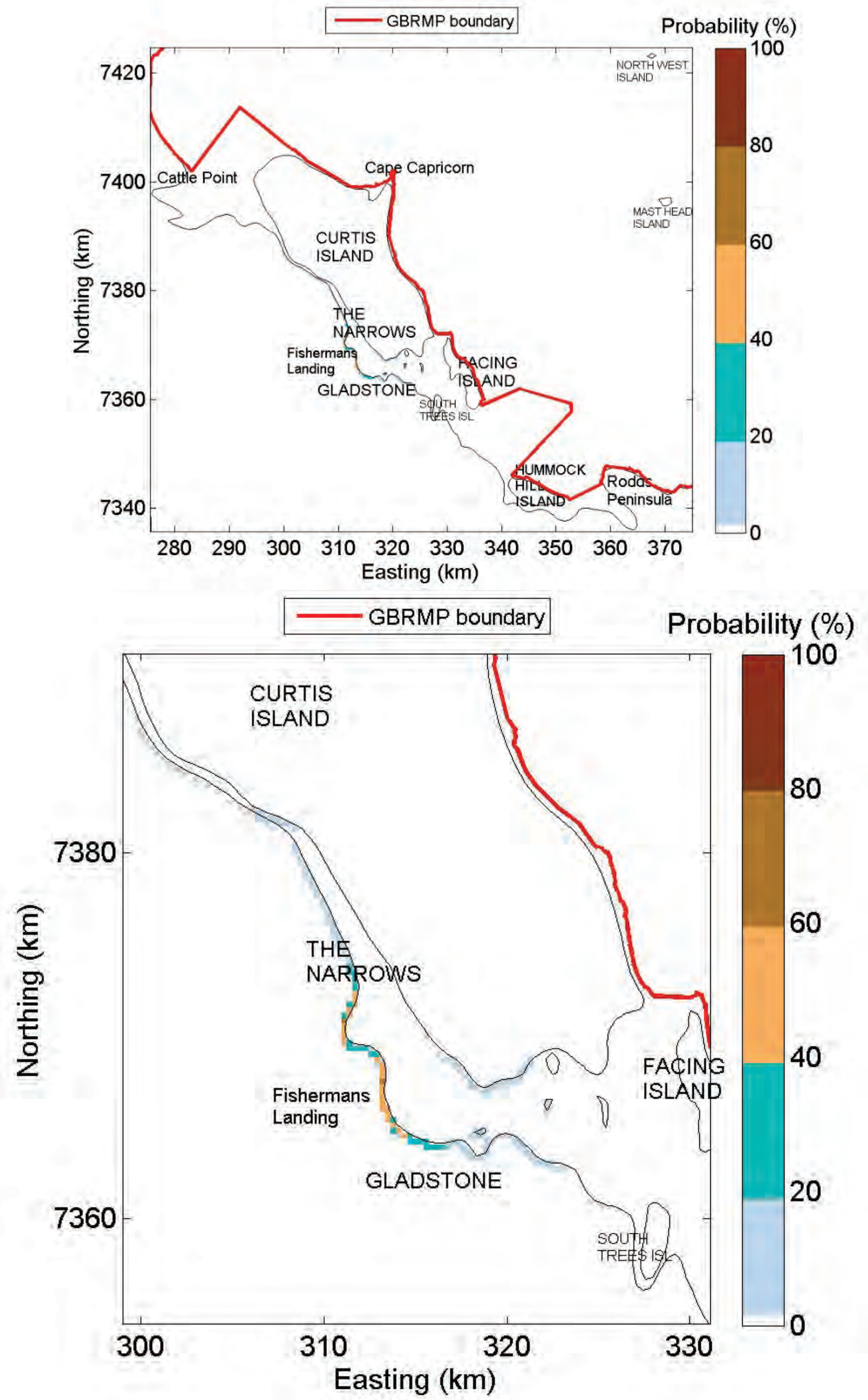


Figure 4-12 Probability of ≥ 0.001 mm oil thickness on shore in wet season from 5 m^3 fuel oil No.6 spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)

4.2.2 5 m^3 spill at South Trees Wharf

Modelling of a 5 m^3 spill of fuel oil (No.6) at South Trees Wharf indicates that, during both the wet and dry seasons, there is up to a 60% probability of 0.01 mm or thicker water surface oil affecting the adjacent areas (refer **Figure 4-13** and **Figure 4-14**) and a probability of up to 40% of 0.01 mm or thicker oil approaching the continental coastline and South Trees Island. There is up to a 20% probability of the south-west of Facing Island being exposed to 0.01 mm or thicker water surface oil. The results for this scenario suggest no water-surface oil slicks 0.01 mm or thicker would be transported into the GBRMP as a result of a 5 m^3 spill of fuel oil (No.6) at South Trees Wharf.

The results suggest that there would be a 100% chance of a 5 m^3 fuel oil (No.6) spill originating from South Trees Wharf resulting in a 0.001 mm or thicker oiling of the nearest shore within an hour after release (simulated in 100 trajectory model simulations) under both wet and dry season ambient conditions. Up to 93% of the spilled volume may reach shore after a dry season spill, and up to 96% of the spilled volume may reach shore after a wet season spill.

Probabilities of exposure of any specific stretch of the coastline to0.001 mm or thicker film of fuel oil (No.6) from a 5 m^3 spill at South Trees Wharf during a dry and a wet season are presented in **Figure 4-15** and **Figure 4-16**, respectively. The model results suggest that there would be up to 60% probability of oil on shore on the western coast of Facing Island (**Figure 4-15**, bottom panel) from a dry season spill. The probability of exposure to 0.001 mm or thicker oil on shore would decrease farther away from the spill location, down to 20% in the southern reaches of the Narrows, at the eastern facing shore of Curtis Island, on South Trees Island and west and south-west from it. There would be up to 60% probability of 0.001 mm or thicker oil on shore at a few continental coast locations near Gladstone and the nearest part of Curtis Island from a wet season spill, and a 20% probability of 0.001 mm or thicker oil on shore in the middle of the Narrows, on South Trees Island and west and south-west from it (**Figure 4-16**, bottom panel).

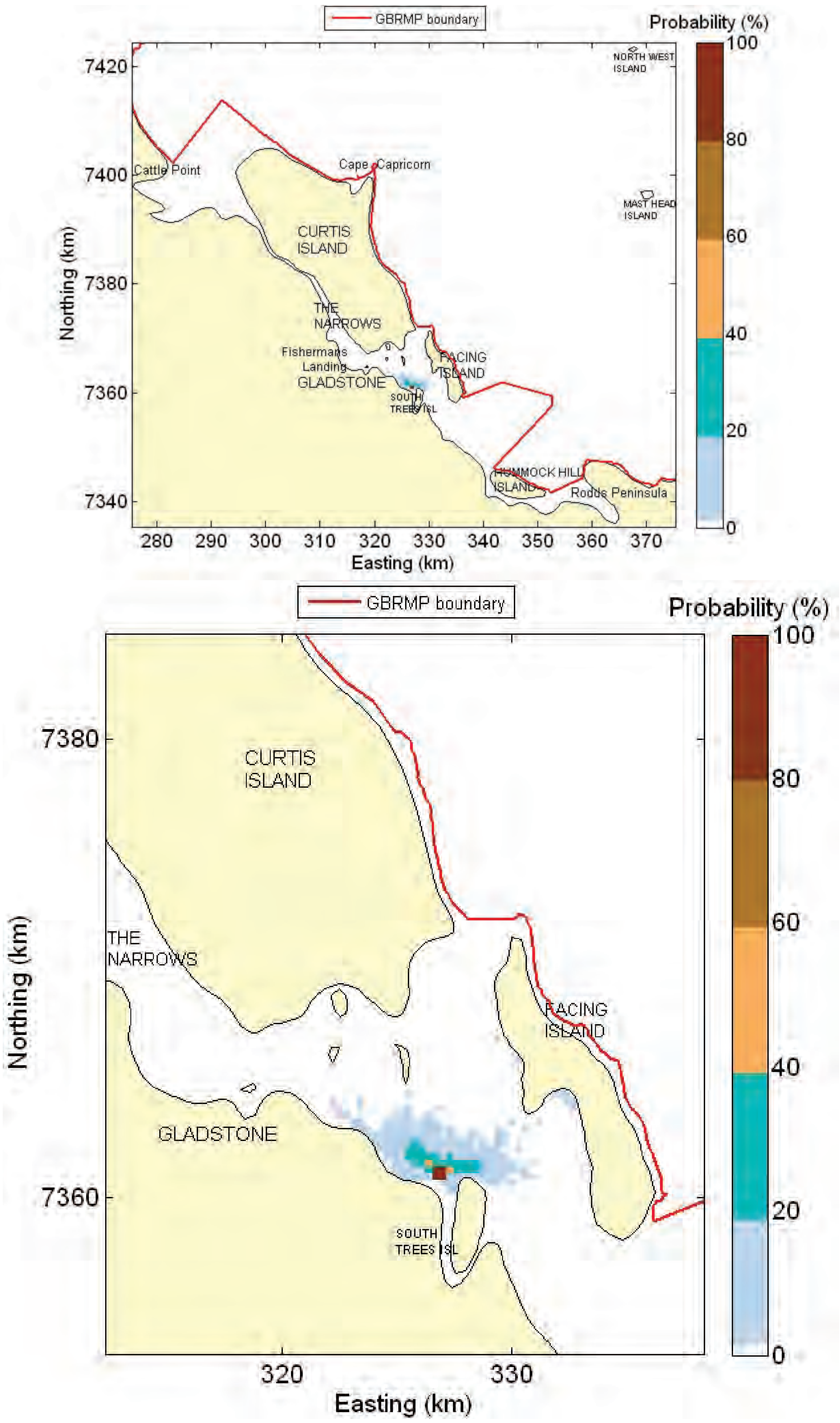


Figure 4-13 Probability of ≥ 0.01 mm oil thickness in dry season from 5 m^3 fuel oil No.6 spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)

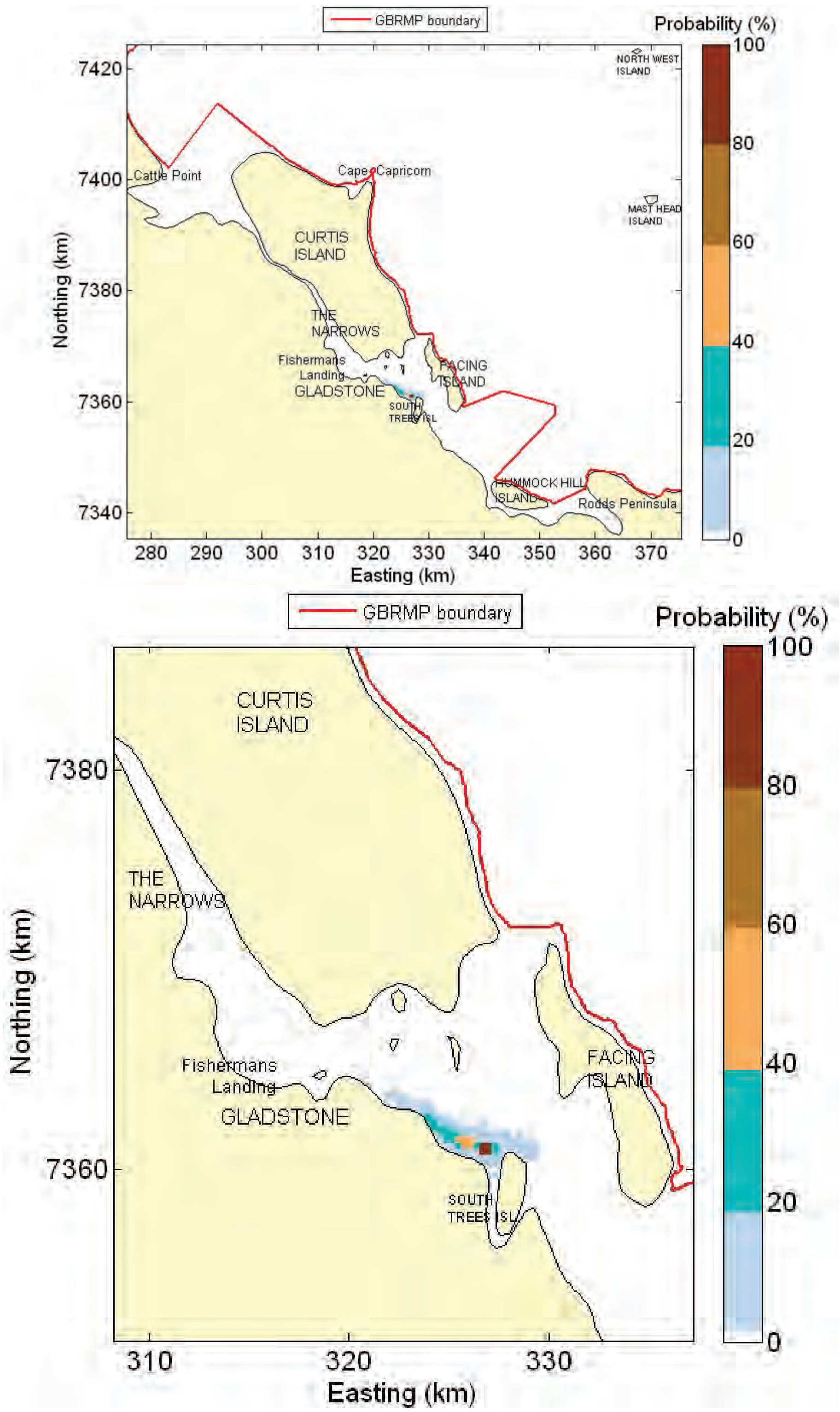


Figure 4-14 Probability of ≥ 0.01 mm oil thickness in wet season from 5 m^3 fuel oil No.6 spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)

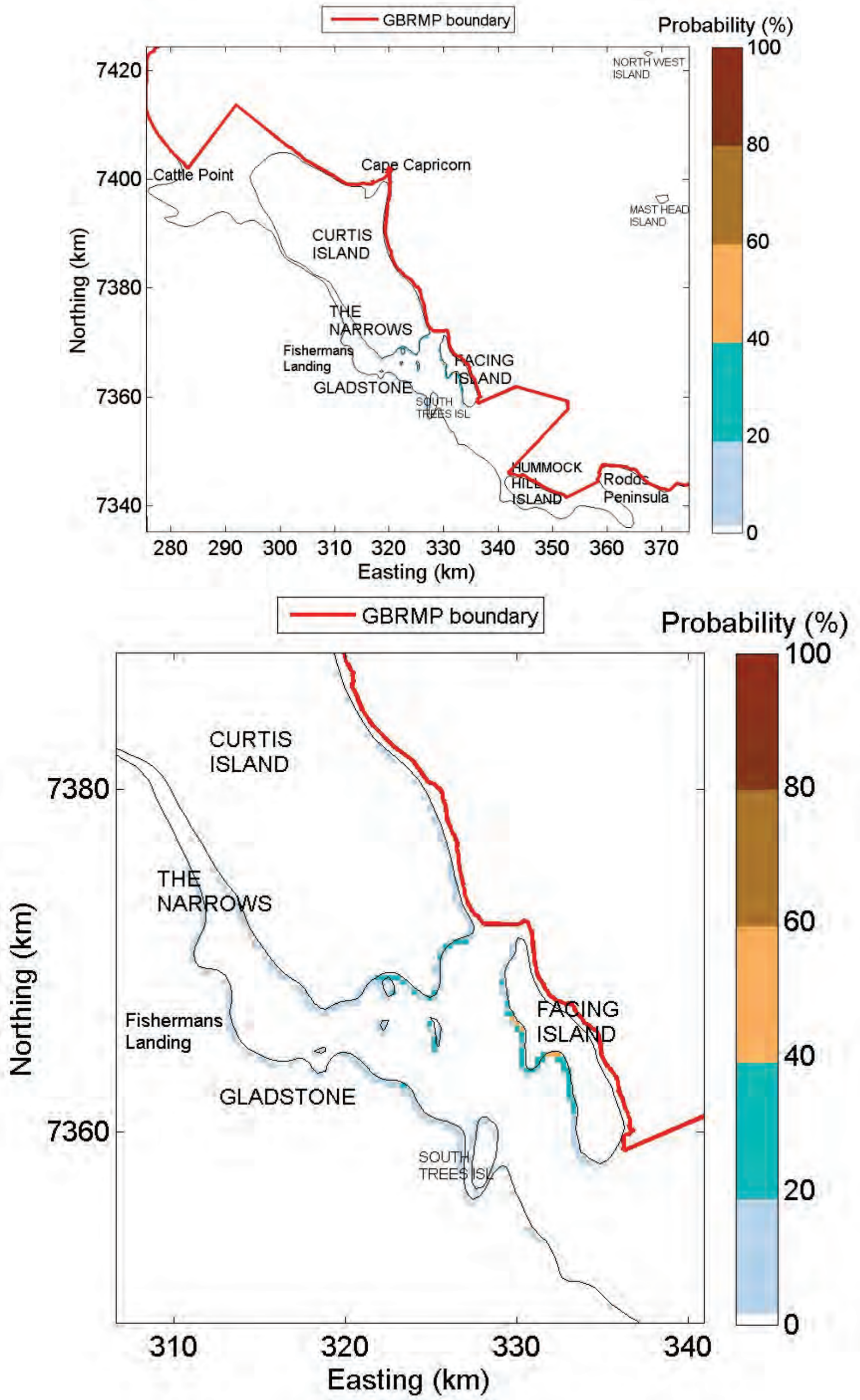
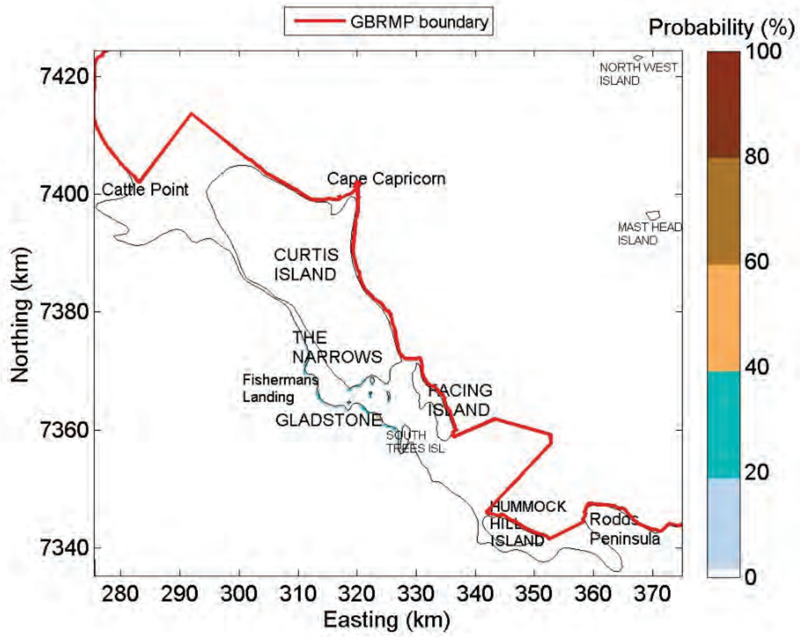


Figure 4-15 Probability of ≥ 0.001 mm oil thickness on shore in dry season from 5 m^3 fuel oil No.6 spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)



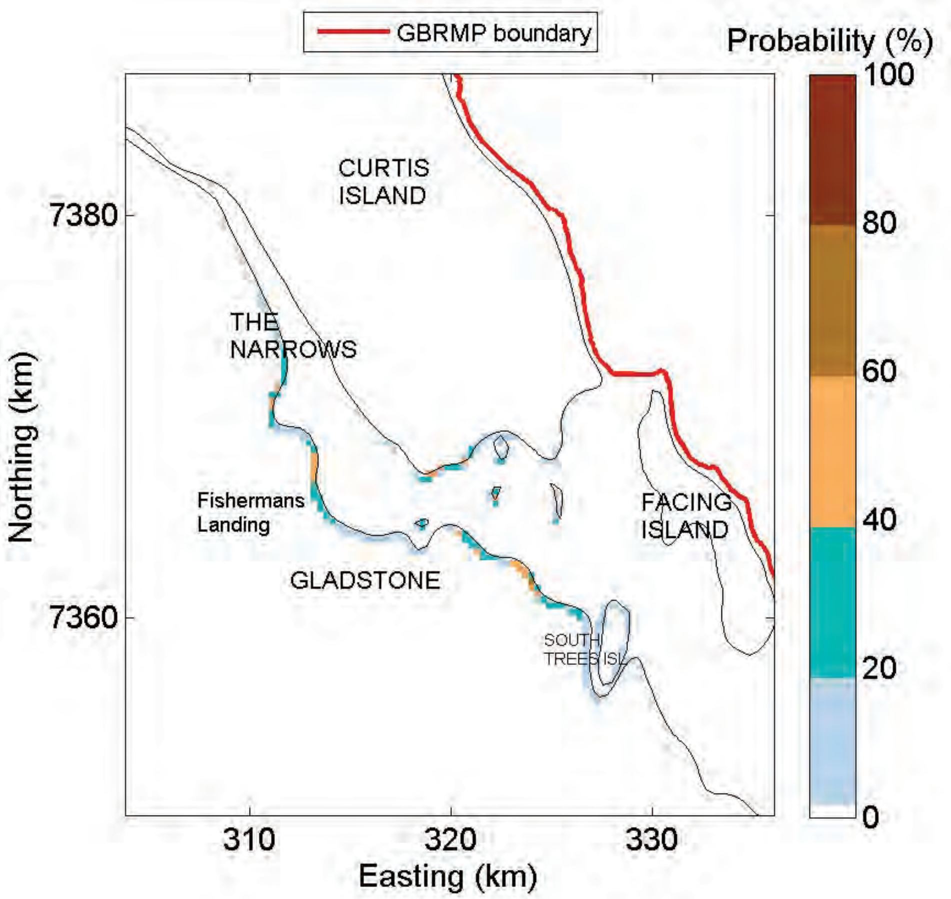


Figure 4-16 Probability of ≥ 0.001 mm oil thickness on shore in wet season from 5 m^3 fuel oil No.6 spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)

4.2.3 Probability of larger spills

The DNV Final Report Assessment of the Risk of Pollution from Marine Oil Spills in Australian Ports and Waters for AMSA (DNV, 2011) identified that in 2010 the probability of a spill greater than 10 t for all Australian shipping was 0.511, or nearly once every two years, for both trading ships at sea and trading ships in port. The report identified that this probability was related to 26,235 trading vessel arrivals in Australia. The number of arrivals did not include vessels leaving an Australian port for a non-Australian port destination, thus under-representing the total number of ship movements.

The greatest total annual vessel movements through the GBR for the SoE Project during its operation is expected to be 900 (600 bauxite vessel movements plus 300 barge movements), which equates to 0.0341 (~3.4%) of the 2010 traffic used by DNV to calculate the spill probability.

On this basis, the probability of an oil spill greater than 10 t from a Project-related vessel traversing the GBR is 0.0174 (result of 0.511*0.0341). This means there is a probability of a greater than 10 t spill once every 57 years, while the SoE Project lifespan is approximately 40 years. These calculations support that, as stated in the Introduction, modelling of 25 t (equivalent to 25.25 m^3 as used in this study) spill of fuel oil No.6 conservatively constitutes a likely worst case scenario.

4.2.4 25.25 m^3 spill at Fisherman's Landing

Modelling results for a 25.25 m^3 water-surface spill of fuel oil at Fisherman's Landing suggest that spreading and movements of water-surface oil slicks would be steered by the continental coastline and the inner-port area islands, and there would be up to 80% probability of water-surface exposure to 0.01 mm or thicker oil in the direct vicinity to the spill location (**Figure 4-17** and **Figure 4-18**).

During a dry season, there would be up to 60% probability of slicks near the southern and south-western shores of Curtis Island and near the middle of the Narrows (**Figure 4-17)**. Decreasing with the distance from the spill location, there would be up to 20% probability of water-surface exposure in the upper reaches of the Narrows and near the western shores of Facing Island. There would be up to 2% probability of these slicks occurring in one model cell within the GBRMP boundaries, north from the northern tip of Facing Island. The location where the 2% probability occurs within the GBRMP and near Curtis and Facing Islands (refer **Figure 4-17)** appear disconnected from the other higher-than-zero probability areas. This is because the slicks are modelled as discrete oil particles, and probabilities are plotted only for those modelled cells where there is an oil thickness equal or exceeding 0.01 mm.

During a wet season, there would be up to 60% probability of exposure to water-surface 0.01 mm or thicker slicks near the continental shores west of the spill location (**Figure 4-18**). The lower reaches of the Narrows and the southern shore of Curtis Island would be exposed to up to 20% probability of the slicks.

During both dry and wet seasons, the oil originating from a 25.25 m^3 spill at Fisherman's Landing would reach the shore within 1.5 hours after spill. There would be a 100% chance of 95-96% of the spilled volume reaching the shore.

Figure 4-19 and **Figure 4-20** present probabilities of shoreline oiling after dry and wet season spills respectively. The results suggest that a dry season spill of 25.25 m^3 of fuel oil (No.6) at Fisherman's Landing would result in 100% probability of 0.001 mm or thicker of on shore oiling on the south-western coast of Curtis Island (**Figure 4-19,** bottom panel). Further from the spill location, the probability would decrease, with the coasts exposed to up to 40% probability of oiling on shore in the upper reaches of the Narrows, and up to 20% probability of oiling on shore west of South Trees Island, at the northern coast of the island itself, and at the western coast of Facing Island if a spill occurs.

Results of wet season spill simulations presented in the top and bottom panels of **Figure 4-20** suggest that the probability of 0.001 mm or thicker oil on the shores of the Narrows, to the upper reaches, would be between 20% and 100% if a spill occurs. There would be up to 40% probability of on shore oiling at the continental coast east of Gladstone and at the southern tip of Curtis Island, while there would be up to 20% probability of 0.001 mm or thicker oil on shore (bottom panel of **Figure 4-20**) on the coast west of South Trees Island if a spill occurs.

4.2.5 25.25 m^3 spill at South Trees Wharf

Stochastic spill modelling of a 25.25 m^3 spill at South Trees Wharf indicated that, during both the wet and dry seasons, there would be up to 60% probability of 0.01 mm or thicker water-surface slicks on the adjacent water areas and continental shores, as well as the south of Curtis Island, middle of Facing Island and north of South Trees Island (**Figure 4-21** and **Figure 4-22**). There is a 20% probability of the middle section of the Narrows; the strait between Curtis and Facing islands; and areas north and south of Facing Island being exposed to 0.01 mm or thicker water-surface slicks as a result of a 25.25 m^3 spill at South Trees Wharf. There would be up to 6% probability of the surface slicks in several model cells within the GBRMP boundaries, chiefly in the vicinity of the western tip of Curtis Island and the northern tip of Facing Island, during the dry season as a result of a 25.25 m^3 spill at South Trees Wharf.

The stochastic modelling results suggest that there would be a 100% chance of a 25.25 m^3 fuel oil (No.6) spill originating from a South Trees Wharf reaching the nearest shore within an hour after release (i.e. oil on shore simulated in 100 trajectory model simulations) under both wet and dry season ambient conditions. Up to 92% of the spilled volume might reach the shore after a dry season spill, and up to 96% after a wet season spill.

Probabilities of exposure of any specific stretch of the coastline to beached fuel oil (No.6) from a 25.25 m^3 spill at South Trees Wharf during a dry and a wet season respectively are presented in **Figure 4-23** and **Figure 4-24**. The model results suggest that, after a dry season spill at South Trees Wharf, there would be up to 80% probability of 0.001 mm or thicker oil on shore at the southern and south-eastern coasts of Curtis Island and the western coast of Facing Island, and up to 60% probability of 0.001 mm or thicker oil on shore on the continental coast near Fisherman’s Landing (**Figure 4-23**, bottom panel) if a spill occurred. The probability of exposure to oil on shore would decrease farther away from the spill location, down to 20% in the upper reaches of the Narrows, south from Cape Capricorn, at the southern tip of Facing Island and south-east from South Trees Island.

After a wet season spill, several stretches of the continental coast west from South Trees Island up to the lower reaches of the Narrows and the south-eastern coast of Curtis Island would be exposed to 100% probability of 0.001 mm or thicker oil on shore (**Figure 4-24**, bottom panel). The upper reaches of the Narrows and the coast south-east of South Trees Island would be exposed to lower probabilities of beaching 0.001 mm or thicker oil, down to 20%.

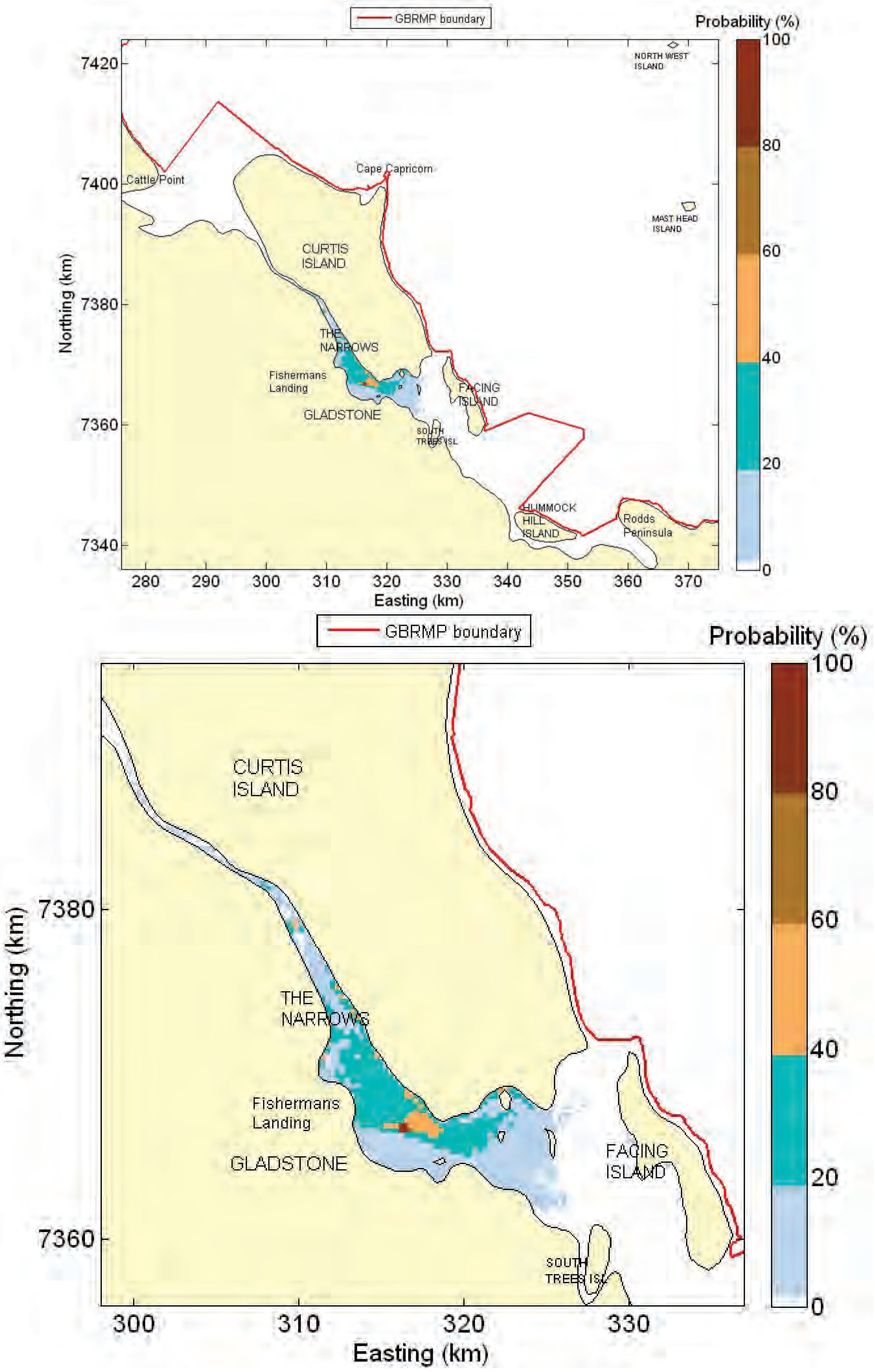


Figure 4-17 Probability of ≥ 0.01 mm oil thickness in dry season from 25.25 m^3 fuel oil No.6 spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)

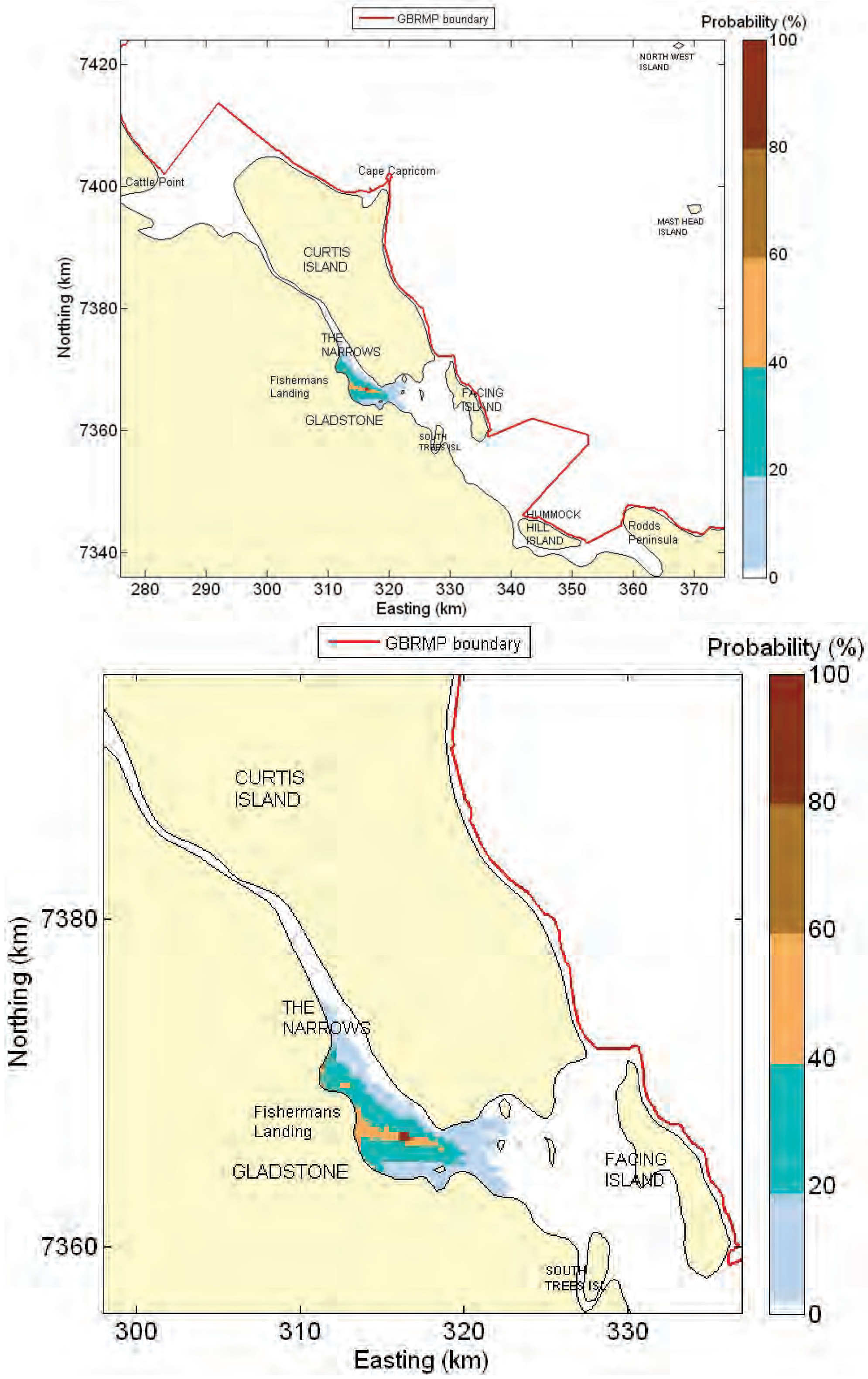


Figure 4-18 Probability of ≥ 0.01 mm oil thickness in wet season from 25.25 m^3 fuel oil No.6 spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)

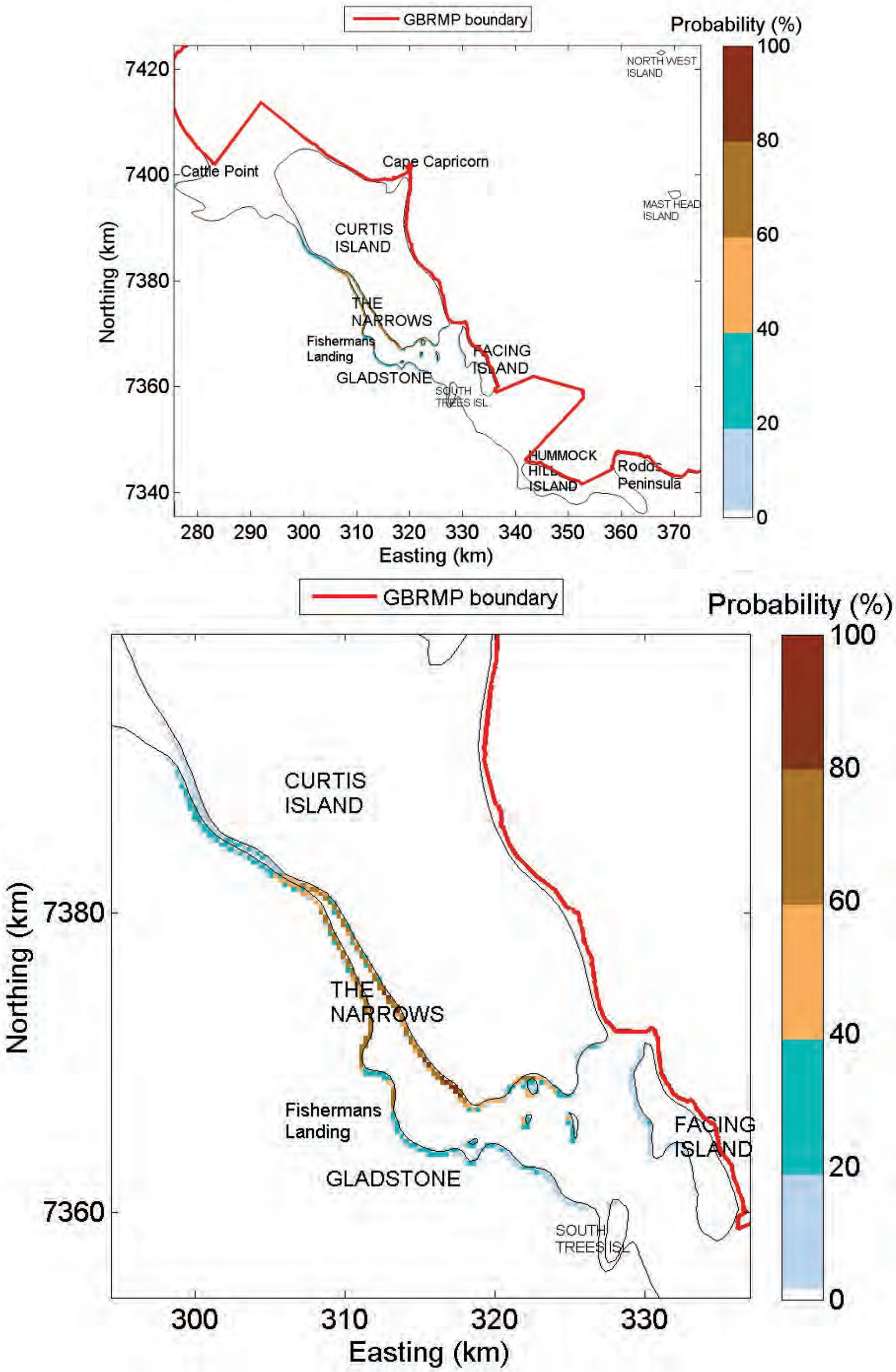


Figure 4-19 Probability of ≥ 0.001 mm oil thickness on shore in dry season from 25.25 m^3 fuel oil No.6 spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)

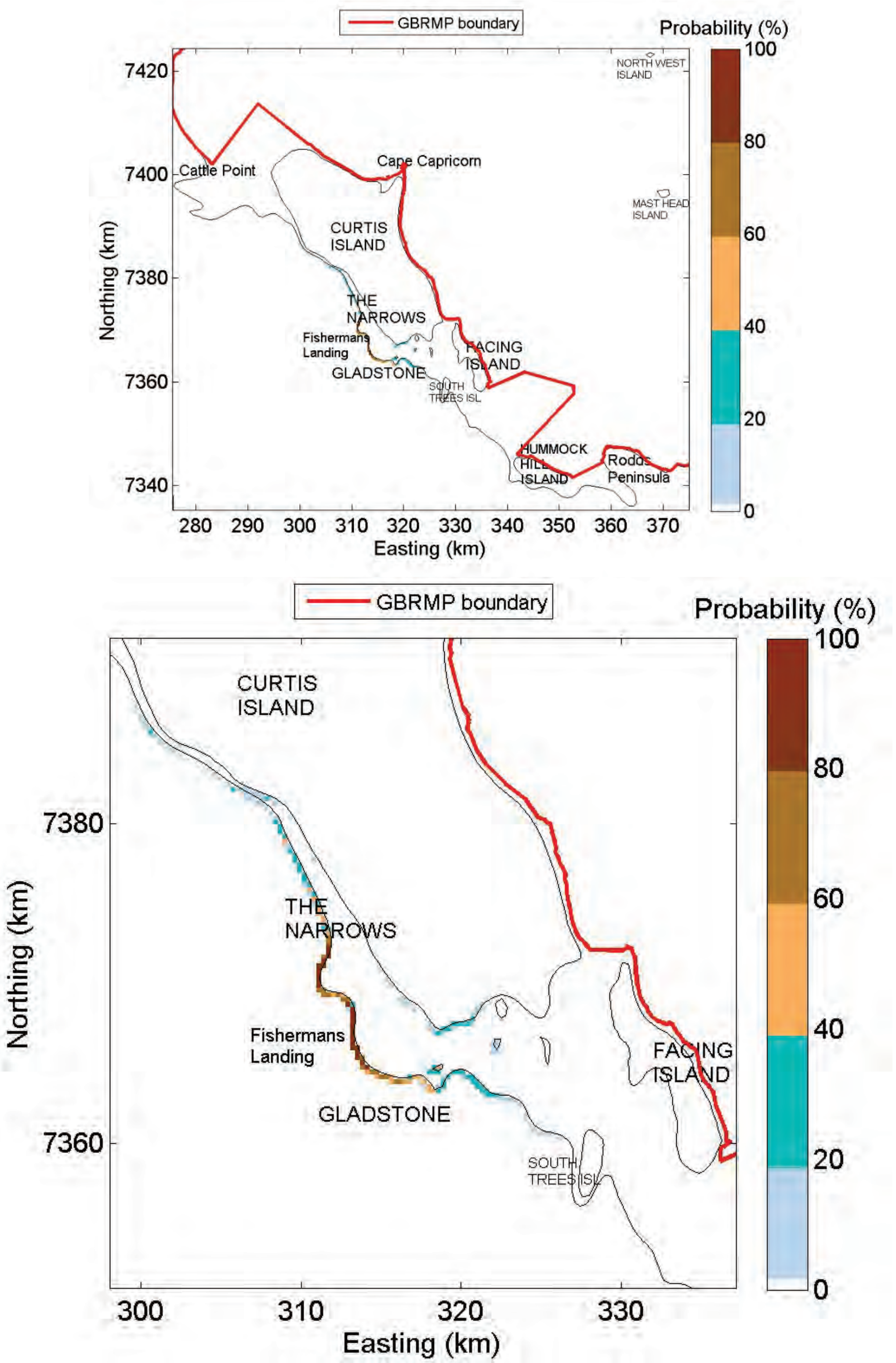


Figure 4-20 Probability of ≥ 0.001 mm oil thickness on shore in wet season from 25.25 m^3 fuel oil No.6 spill at Fisherman's Landing (top panel) and its enlarged view (bottom panel)

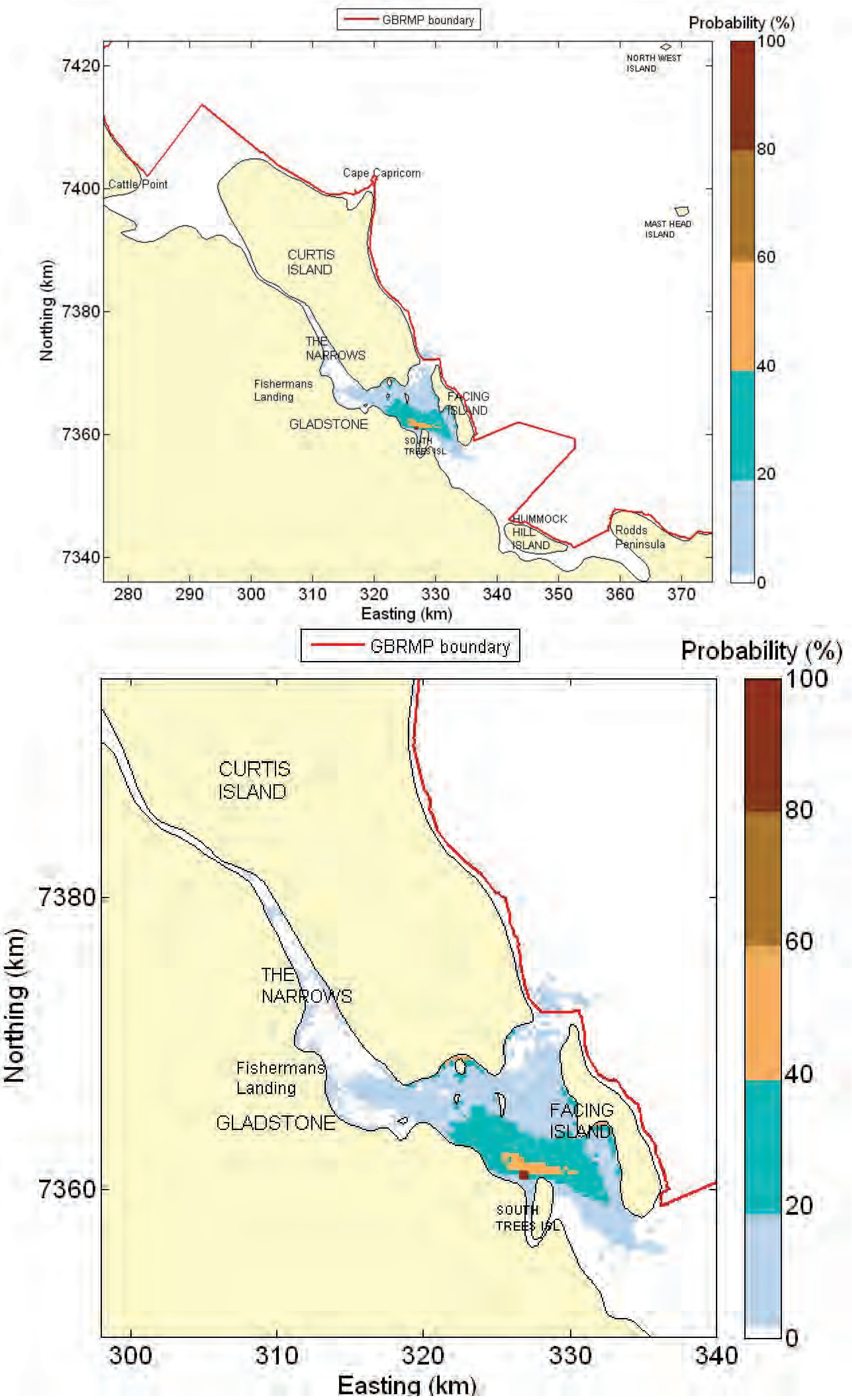


Figure 4-21 Probability of ≥ 0.01 mm oil thickness in dry season from 25.25 m^3 fuel oil No.6 spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)

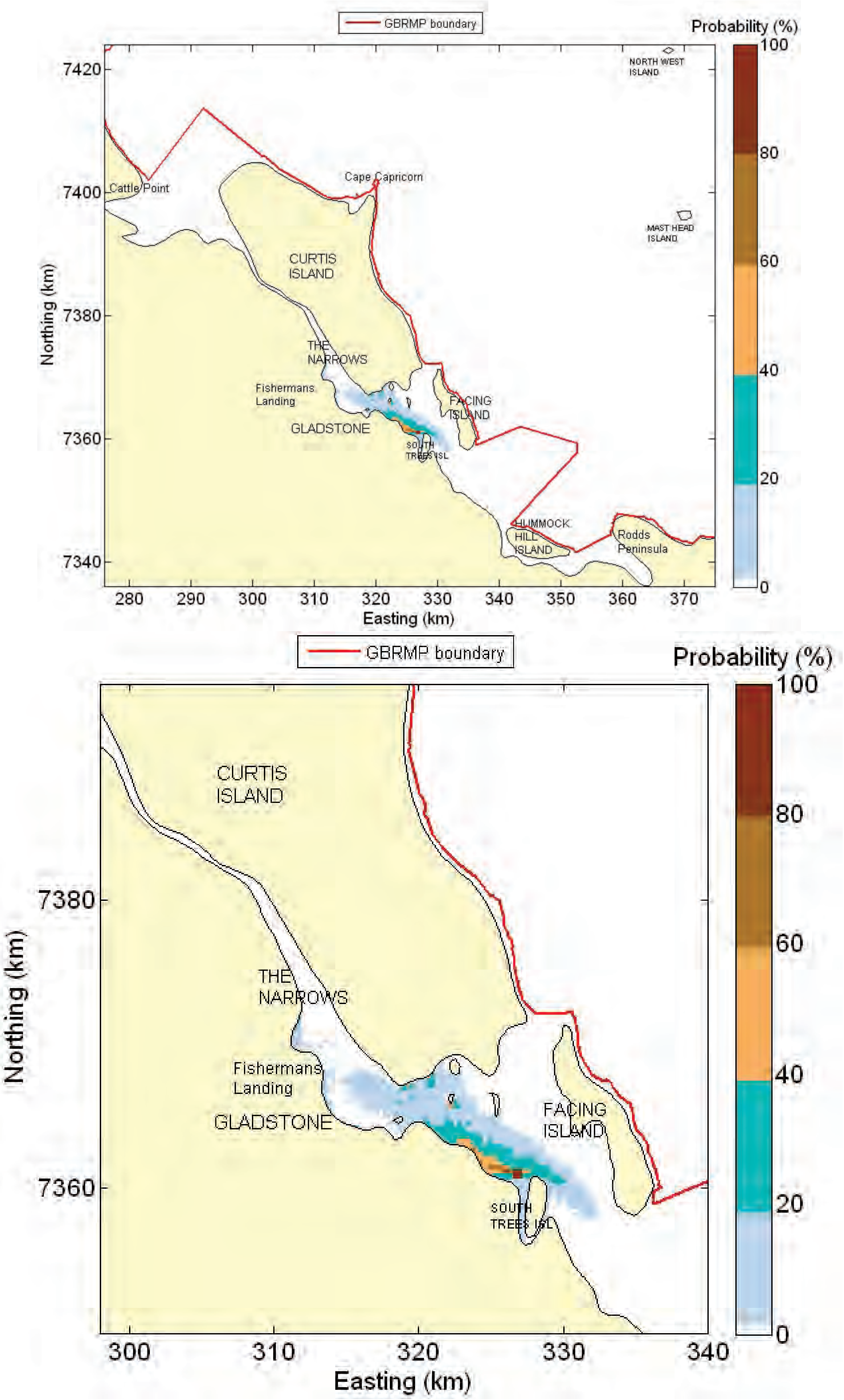


Figure 4-22 Probability of ≥ 0.01 mm oil thickness in wet season from 25.25 m^3 fuel oil No.6 spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)

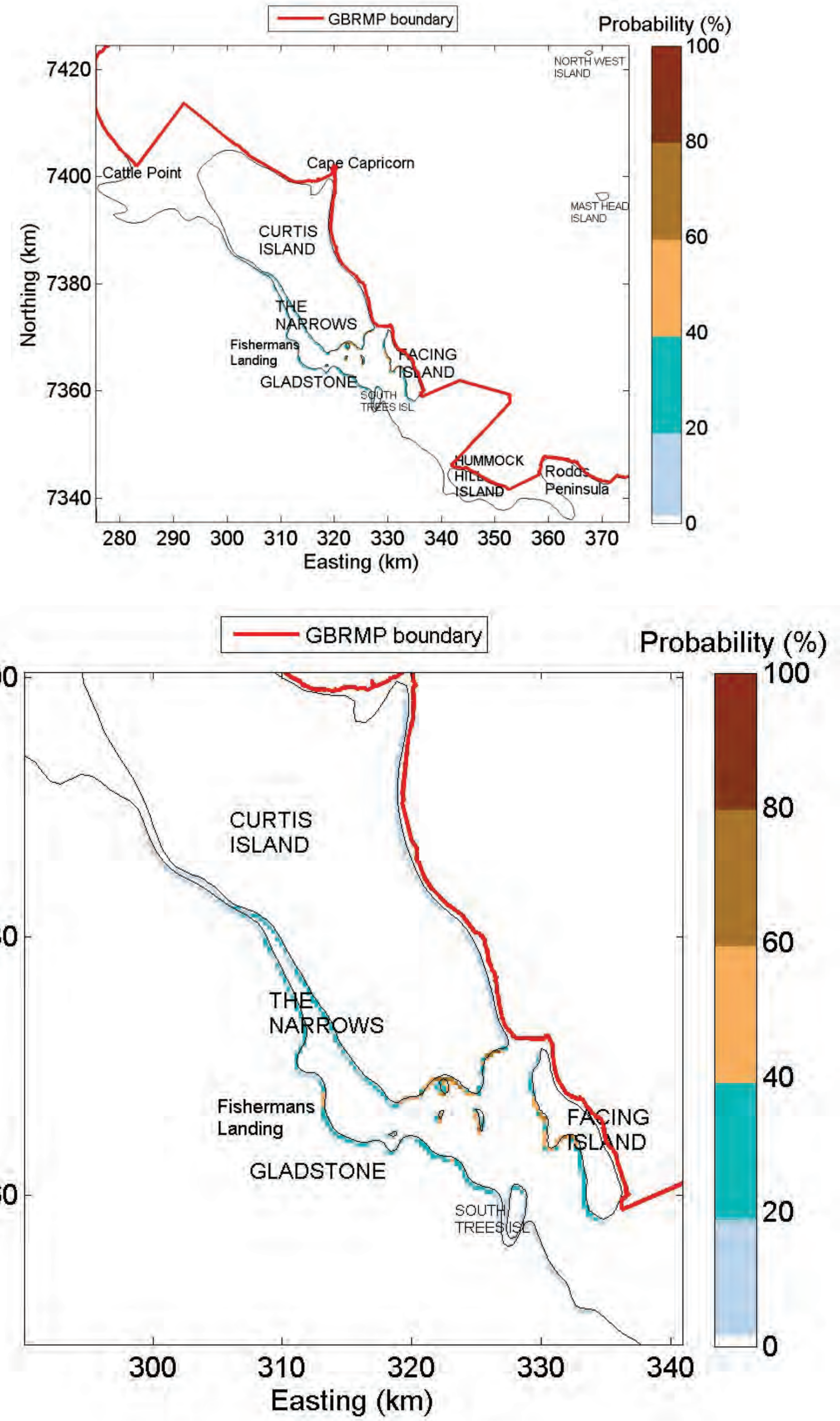


Figure 4-23 Probability of ≥ 0.001 mm oil thickness on shore in dry season from 25.25 m^3 fuel oil No.6 spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)

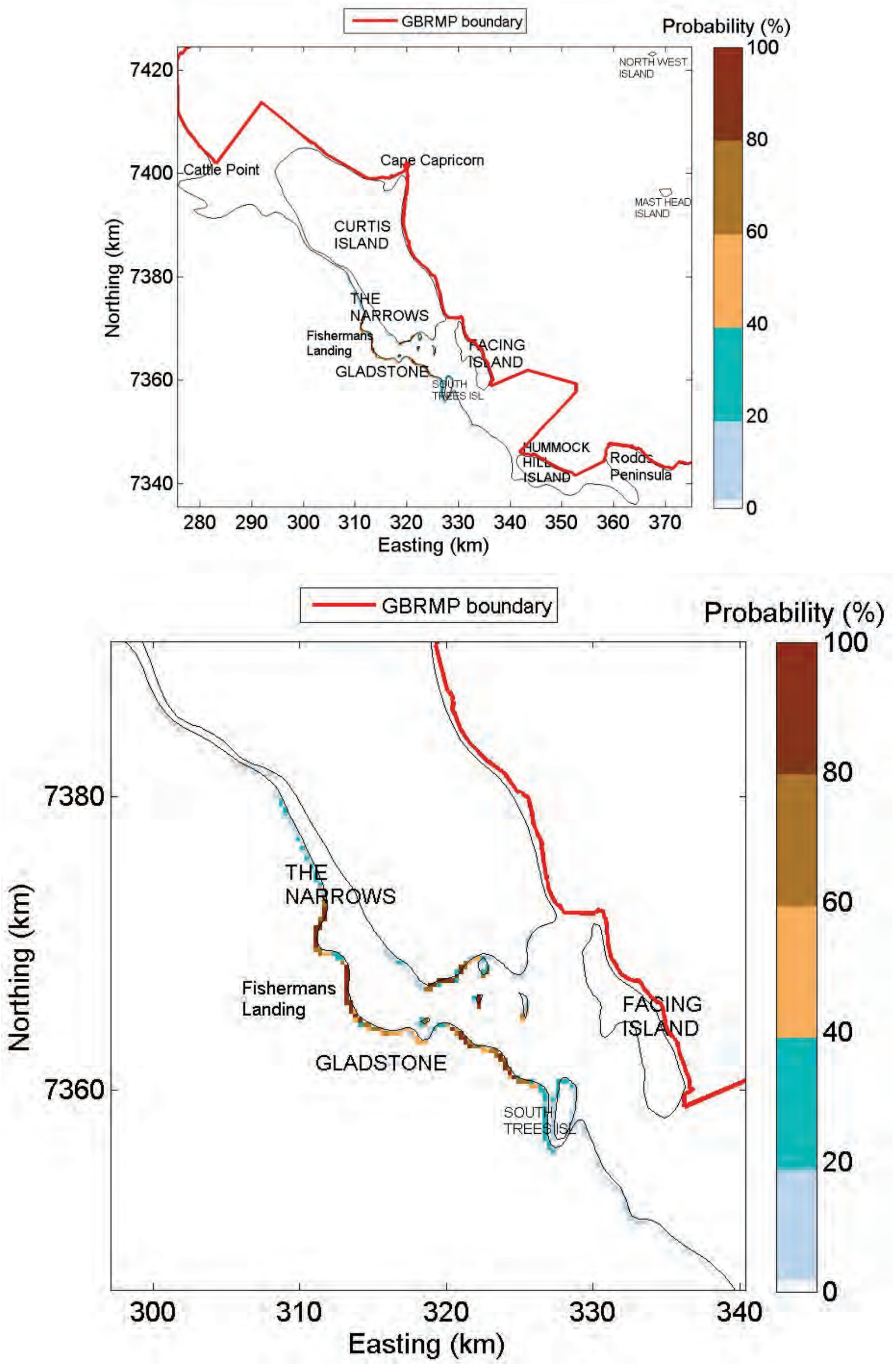


Figure 4-24 Probability of ≥ 0.001 mm oil thickness on shore in wet season from 25.25 m^3 fuel oil No.6 spill at South Trees Wharf (top panel) and its enlarged view (bottom panel)

Conclusions

This report presents spill simulation results for the hydrocarbon spill scenarios in the Port of Gladstone area for the wet and dry seasons. The probabilities of oil on water surface (for oil 0.01 mm and thicker) and on shore oiling (for oil 0.001 mm and thicker) were calculated independently for each computational model cell. A summary of probability for the 100 events/model runs was plotted for each spill scenario. The areas exhibiting >0-20% probability were exposed/contacted by model oil slicks by up to 20% of the total number of simulated spill trajectories. Locations with higher probabilities were exposed to a greater number of spill trajectories, suggesting that the combination of the prevailing wind and current conditions resulting in the exposure occurred more frequently. Note that the study simulation periods should not be interpreted as an indication of slicks 0.01 mm or thicker staying on water over the entire duration of the model runs. Taking into account variable coastal conditions and sensitive nature of the coastal habitats, a conservative approach was used for estimating oil on shore probabilities. The areas outside of the >0-100% probability coverage suggest that exposure will be unlikely under the range of simulated spill and ambient conditions.

The presented probability plots do not represent, and should not be interpreted as, the extent of any one slick, or extents of on-shore oiling, resulting from a single spill event. Slicks resulting from any simulated single spill event will be significantly smaller than the areas presented in the probability plots.

The presented probabilities were modelled based upon no mitigation measures (e.g. booms, dispersants, etc.) being implemented. Implementing those measures as specified in the spill response plan for the Port of Gladstone would be expected to limit oil spreading and propagation.

There are several different physical, chemical and biological processes, which affect hydrocarbon slick behaviour after a spill at different time scales. This study focussed on modelling of hydrocarbon weathering (including the processes of evaporation from the water surface and vertical dispersion in the water column) and hydrocarbon slick spreading as well as transport on the water surface (due to seasonally varying currents and winds).

Stochastic modelling results for a 5 m^3 diesel spill from Fisherman's Landing suggest the hydrocarbon slick propagation would generally be limited by the nearest, adjacent continental coastline and the south-western and south-eastern coasts of Curtis Island. The highest probabilities of coast oiling by 0.001 mm or thicker oil, up to 60%, would be at the nearest coastal sites to the spill location. The probability of both oil on water and oil on shore would decrease with distance from the spill location.

Modelling results for 5 m^3 diesel spill from South Trees Wharf suggest that water-surface slicks would mostly be affecting the adjacent areas, up to 40% and 60% probability of exposure to 0.01 mm or thicker oil during dry and wet seasons respectively, if a spill occurred. There would be up to 50-60% probability of 0.001 mm or thicker oil on shore if a spill occurred.

Stochastic modelling results for slicks 0.01 mm or thicker from a 5 m^3 spill of fuel oil (No.6) at Fisherman's Landing suggest that water surface fuel oil slicks would propagate in all directions from the spill location, though oil spreading would mainly be steered by the continental coastline, the southern coasts of Curtis Island and the nearest inner islands within the port area. The results suggested that there would be up to 60% probability of 0.001 mm or thicker oil on shore of the Curtis Island and continental coasts nearest to the spill location.

Modelling of a 5 m^3 spill of fuel oil (No.6) at South Trees Wharf indicates that water-surface slicks would mostly be affecting the adjacent water areas, with up to 60% probability of exposure to 0.01 mm or thicker oil, and there would be up to 60% probability of 0.001 mm or thicker oil on shore at several coastal locations if a spill occurred.

The results of the 5 m^3 spill modelling suggest that for all the considered oil spill scenarios the water-surface slicks 0.01 mm or thicker would be entirely contained within the Port of Gladstone limits and would not enter into the GBRMP.

Note that, when plotted at the above mentioned threshold of 0.01 mm, stochastic modelling results for diesel and fuel oil No.6 might look similar. However, when reviewed closely, they are different. The resulting probability distributions might look similar because the initial slick quickly spreads down to 0.01 mm thickness on the water surface due to currents and wind. These physical processes act very similarly on the relatively small spilled volumes (5 m^3) of both diesel and fuel oil No.6. In the considered scenarios, the hydrocarbon weathering processes (evaporation from the water surface and vertical dispersion in the water column) would start playing their roles in surface slick thinning at a later stage only, after slicks spread on the water surface.

Modelling results for slicks 0.01 mm or thicker from a 25.25 m^3 spill of fuel oil (No.6) at Fisherman's Landing suggest that there would be up to 80% probability of water surface exposure in the direct vicinity to the spill location, decreasing down to 20% in the upper reaches of the Narrows, near the western shores of Facing Island and the southern shores of Curtis Island. Such a spill might result in 100% probability of 0.001 mm or thicker oil on shore at Curtis Island and the continental shores.

Stochastic modelling of a 25.25 m^3 spill at South Trees Wharf indicated that the adjacent water areas and continental shores would be exposed up to 60% probability of 0.01 mm or thicker water-surface oil slicks. The middle section of the Narrows, the strait between Curtis and Facing Islands and areas north and south of Facing Island would be exposed to the 0.01 mm or thicker water-surface slicks with up to 20% probability if a spill occurred. There would be up to 100% probability of 0.001 mm or thicker oil on shore of the southern and south-eastern coasts of Curtis Island and the coast in the lower reaches of the Narrows if a spill occurred; the probability of oil on shore would decrease with distance from the spill location.

Modelling results for the 25.25 m^3 spill scenarios suggest that there would be a possibility of 0.01 mm or thicker water-surface slicks occurring within the GBRMP boundary during a dry season. For the modelled cells within the GBRMP where there is the possibility of a slick, the probability would be up to 2% for a spill from Fisherman's Landing and up to 6% for a spill from South Trees Wharf. The cells where slicks have been modelled as having a probability of occurring are chiefly in the vicinity of the western tip of Curtis Island and the northern tip of Facing Island.

References

Australian Maritime Safety Authority (AMSA), 2013. Interim Technical Guideline for the Preparation of Marine Pollution Contingency Plans for Marine and Coastal Facilities (AMSA 413 (02/13)), 69 p.

Antonov, J.I., Seidov, D., Boyer, T.P., Locarnini, R.A., Mishonov, A.V., Garcia, H.E., Baranova, O.K., Zweng, M.M., Johnson, D.R., 2010. World Ocean Atlas 2009, Volume 2: Salinity. S. Levitus, Ed. NOAA Atlas NESDIS 69, U.S. Government Printing Office, Washington, D.C., 184 p.

Asia Pacific Applied Science Associates. 2005. Draft Environmental Impact Statement / Environmental Review and Management Programme for the Proposed Gorgon Development. Technical Appendix B3 Modelling of Spills and Discharges.

Beegle-Krause, C.J., 2001. General NOAA oil modelling environment (GNOME): A new spill trajectory model. In Proceeding of the 2001 International Oil Spill Conference, Mira Digital Publ., St. Louis, Mo., vol. 2, 865–871.

Blain, C.A., 1998. Barotropic tidal and residual circulation in the Arabian Gulf. Estuarine and Coastal Modeling, Proceedings of the 5th International Conference. M. L. Spaulding and A. F. Blumberg, (eds), American Society of Civil Engineers, Reston, VA, 166–180.

Det Norske Veritas (DNV), 2011. Report for Australian Maritime Safety Authority, Ship Oil Spill Risk Models, 14 December 2011, 50p.

DHI Water and Environment. 2010. Draft Environmental Impact Statement / Environmental Review and Management Programme for the Proposed Wheatstone Project, July 2010. Technical Appendix Q2 Hydrocarbon Spill Modelling. Available online at:

https://www.chevronaustralia.com/Files/PDF/Wheatstone%20Draft%20EIS_ERMP%20Technical%20 Appendices%20Q2%20to%20Q5.pdf (accessed 27/02/2013).

ExxonMobil, 2008. Oil Spill Response Field Manual, Revised 2008, ExxonMobil Research and Engineering Company, 320p.

Fortunato, A.B, Baptista, A.M., Luettich, R. A. Jr., 1998. A three-dimensional model of tidal currents at the mouth of the Tagus Estuary. Continental Shelf Research, 17, 14, 1689–1714.

Lehr, W., 2001. Review of modeling procedures for oil spill weathering behavior. Oil spill modeling and process, WIT Press. 2001.

Lehr, W., Jones, R., Evans, M., Simecek-Beatty, D., Overstreet, R., 2002. Revisions of the ADIOS oil spill model. Environmental Modeling and Software, 17, 191-199.

Lefevre, F., Lyard, F. H., Le Provost, C., Schrama, E. J. O., 2002. FES99: a global tide finite element solution assimilating tide gauge and altimetric information. Journal of Atmospheric and Oceanic Technology, 19, 1345–1356.

Le Provost, C., 2001. Ocean tides. Satellite altimetry and Earth sciences. In: L. L. Fu and A. Cazenave (eds), Academic Press.

Luettich, R.A., Westerink, J.J., Scheffner, N.W., 1992. ADCIRC: an advanced three-dimensional circulation model for shelves, coasts, and estuaries, Report 1: Theory and Methodology of ADCIRC-2DDI and ADCIRC-3DL. Technical Report DRP-92-6, USAE, Vicksburg, MS, 137p.

6 References

Locarnini, R.A., Mishonov, A.V., Antonov, J.I., Boyer, T.P., Garcia, H.E., Baranova, O.K., Zweng, M.M., Johnson, D.R., 2010. World Ocean Atlas 2009. Volume 1: Temperature. S. Levitus, Ed. NOAA Atlas NESDIS 68, U.S. Government Printing Office, Washington, D.C., 184 pp.

Oke, P.R., Schiller, A., Griffin D.A., Brassington, G.B., 2005. Ensemble data assimilation for an eddy-resolving ocean model of the Australian region, Quarterly Journal of the Royal Meteorological Society, 131, 3301-3311.

Ponchaut, F., Lyard, F., Le Provost, C., 2001. An Analysis of the Tidal Signal in the WOCE Sea Level Dataset. Journal of Atmospheric and Oceanic Technology, 18, 77–91.

Rio Tinto Alcan, 2011. Environmental Impact Statement for South of Embley Project. May 2011. Section 4 – Climate.

Schiller, A., Oke, P.R., Brassington, G., Entel, M., Fiedler, R., Griffin, D.A., Mansbridge, J.V., 2008. Eddy-resolving ocean circulation in the Asian–Australian region inferred from an ocean reanalysis effort. Progress in Oceanography, 76(3), 334–365.

Smith, W. H. F., Sandwell, D.T., 1997. Global seafloor topography from satellite altimetry and ship depth soundings, Science, 277, 1957-1962.

Transport and Main Roads (TMR), 2011. Port of Gladstone, First-strike Oil Spill Response Plan, 10p.

URS. 2011. Darwin Port Expansion EIS, Appendix F – Oil Spill Modelling. URS Australia Pty Ltd.

Westerink, J.J., Blain, C.A., Luettich, R.A. Jr., Scheffner, N. W., 1994. ADCIRC: an advanced three-dimensional circulation model for shelves, coasts, and estuaries, Report II: User's Manual for ADCIRC-2DDI. Technical Report DRP-92-6, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, 156 p.

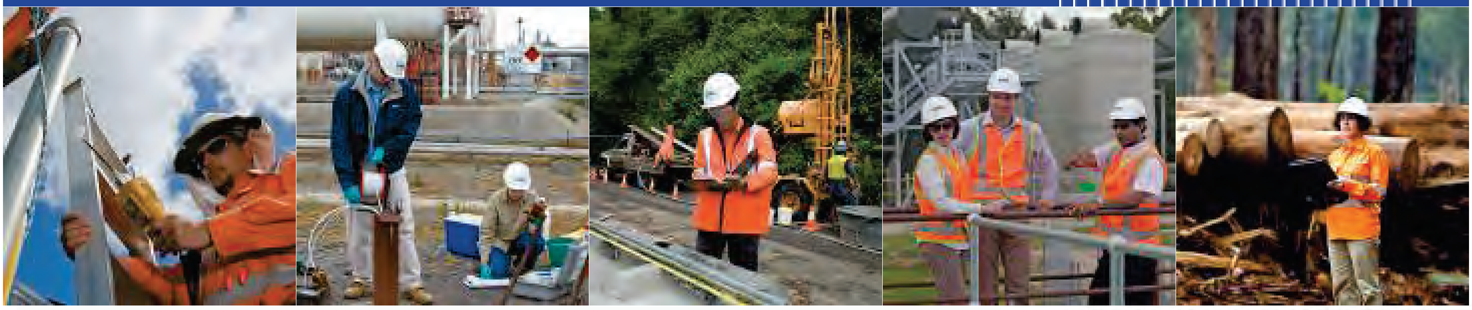
7 Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Rio Tinto Alcan Weipa Pty Ltd and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted modelling and data analysis practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purposes outlined in the Variation No.2 dated 30/05/2012 and Variation No.5 dated 27/11/2012.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between 01/06/2012-18/03/2013 and is based on the obtained metocean data and modelling outcomes at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.



URS Australia Pty Ltd
Level 17, 240 Queen Street
Brisbane, QLD 4000
GPO Box 302, QLD 4001Australia

T: 61 7 3243 2111
F: 61 7 3243 2199

www.ap.urscorp.com