**Great Australian Bight
Exploration Program**

Great Australian Bight
Exploration Drilling Program

FATE AND EFFECTS OIL SPILL MODELLING ASSUMPTIONS, PARAMATERS AND RESULTS

**Rev 0
19 November 2015**

Revision	Comment	Date
Rev 0	Issued for public information	19 November 2015

Rev 0

Table of Contents

1. Introduction

BP Developments Australia Pty Ltd (BP), in its capacity as operator of the proposed Great Australian Bight (GAB) Exploration Drilling Program, proposes to drill four exploration wells in Commonwealth marine waters in the Great Australian Bight (GAB).

The Environment Plan (EP) and Oil Pollution Emergency Plan (OPEP) for the drilling program were submitted to the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) on 1 October 2015. BP also released a summary of the EP on the project website (www.bpgabproject.com.au) so that project stakeholders and other interested individuals are able to review project details and provide feedback on the project.

This document contains the modelling assumptions, parameters and results of the worst case scenario from an oil spill arising from the drilling program. The purpose of the model is to guide preparation for response strategies, and consequently a conservative approach is taken. For example, the model not only takes the worst case for flowrates and oil type, it also assumes that neither BP nor any government agency takes any steps to recover or disperse oil whilst the spill is in progress. In reality, multiple strategies will be used. This is helpful for response preparedness and planning because it means all eventualities are considered, but it is important not to confuse the model with a possible expected outcome.

2. OSCAR Model Description

The SINTEF Oil Spill Contingency And Response model (OSCAR) is BP's preferred oil spill fate and trajectory model.

OSCAR is a 3-dimensional model that calculates and records the distribution (as mass and concentrations) of contaminants on the water surface, on shorelines, in the water column and in sediments. The model allows multiple release simulations, each with a specified beginning and end to the release. For sub-surface releases (e.g., well blowout), the near-field part of the simulation is conducted with a multi-component integral plume model that is embedded in the OSCAR model. The near-field model accounts for buoyancy effects of oil and gas, as well as effects of ambient stratification and cross flow on the dilution and rise time of the plume.

The model computes surface spreading, slick transport, entrainment into the water column, evaporation, emulsification and shoreline interactions to determine oil drift and fate at the surface. In the water column, horizontal and vertical transport by currents, dissolution, adsorption, settling and degradation are simulated. The varying solubility and volatility of oil components are accounted by representing the oil in terms of a number of pseudo-components. By modelling the fate of individual pseudo-components, changes in the oil composition due to evaporation and degradation may be accounted for.

Both single spill (deterministic) scenarios and stochastic (random probability) scenarios with variable start times can be simulated in the OSCAR model. In the stochastic simulations, a specified number of scenarios are simulated sequentially in one run. The set of scenarios to be run may be specified either by selecting the number of scenarios to be simulated within a specified time period (single year statistics), or by specifying the number of scenarios to be run each year in a specified season (multiyear statistics). In order to provide data for computing oil drift statistics, certain oil drift parameters are accumulated for each scenario in each impacted grid cell. These results are in the end used to calculate probabilities for impact in a given cell – defined in terms of exceeding certain threshold values for oil concentrations. The results are presented as probability maps for the different environmental compartments (sea surface, water column and shoreline).

OSCAR accepts as input both 2- and 3-dimensional current data from hydrodynamic models, and single point or gridded wind data from meteorological models.

3. Hydrodynamic and Wind Data

The 3-D current and 2-D wind fields used in the OSCAR simulations to drive pollutant transport were generated using the Imperial College Regional Environmental Model System (ReEMS). The model was run in hind cast mode to generate current and wind datasets for the region covering a 5-year period (2006-2010).

The ReEMS for Australia was set up with the Regional Ocean Modeling System model (ROMS) (http://www.myroms.org/). ROMS is a free-surface, terrain-following, primitive equations ocean model widely used by the scientific community for a diverse range of applications. The atmospheric forcing in the form of 6-hourly surface winds, precipitation, radiation and surface air temperature is from the Climate Forecast Reanalysis (http://www.myroms.org/). The boundary ocean files are taken from the 1/12^{o} HYCOM re-analysis (http://hycom.org/dataserver/glb-analysis) and the tides from the OTIS Regional Tidal Solutions (http://volkov.oce.orst.edu/tides/IO.html). Bathymetry is from Global Multi-Resolution Topography (http://www.marine-geo.org/portals/gmrt/) and the river input from RiverDis v1.1 (http://www.RiVDis.sr.unh.edu/).

The ocean model has a 1/20^{o} longitude and 1/24^{o} latitude horizontal resolution and covers the time period of the 1st January 2006 to 31st December 2010. The model domain covers 39.5°S to 31.5°S and 117°E to 140°E. The vertical resolution is 35 sigma levels (terrain following). For the OSCAR simulation these are sub-sampled at 3-hourly intervals.

The ReEMS model was used to extract average monthly temperature and salinity versus depth profiles (over the period 2006 to 2010) for the well location. The data was then used to produce hydrographical profiles for each 'seasonal' time period employed in the stochastic simulations.

4. Model settings and assumptions

The model settings and assumptions used in the modelling are summarised in Table 1.

Table 1 - Model settings and assumptions

Capping stack scenario (35-day release duration), stochastic modelling	
Permit block	EPP 39
Water depth	2,248 m
Release season	All seasons modelled (winter [June to September], summer [October to March] and transitional [April and May]) Only summer season results presented (worst-case)
Number of simulations	10 per month, from January 2006 to December 2010
Simulation period	150 days
Temperature of oil at release	75.2°C
Air temperature	20°C
Spatial resolution of concentration grid	2 km (horizontal and vertical, longitude and latitude) and 10 m (vertical)
Spatial resolution of surface grid	2 km (longitude and latitude)
Depth for concentration grid	100 m

5. Hydrocarbon Characteristics

OSCAR may compute oil weathering from crude assay data, although more reliable results are produced if the target oil has been through a standardized set of laboratory weathering procedures established by the SINTEF laboratories. Alternatively, the model may use oil weathering properties from oils for which data already exists, selecting the crude oil in the oil database that most closely matches the composition of the oil of concern.

The wells to be drilled for this project are exploratory and wells previously drilled in the GAB (between 1972 and 2003) did not yield any hydrocarbon discoveries. Hence, it was not possible for the model to take into account oil weathering properties from crude assay data or weathering analysis, given the absence of hydrocarbon samples from the GAB region. However, petroleum fluid properties for BP's exploration wells have been predicted through petroleum system geological modelling. This analysis predicts oil properties summarised in Table 2. Given these predicted properties, the most suitable analogue oil from the SINTEF oil database was determined to be Snorre Tension Leg Platform (TLP) oil (North Sea).

Table 2 - Oil property predictions for the most likely hydrocarbon fluid associated with the BP exploration drilling program and the best analogue oil from the OSCAR oil database

Property	GAB prediction	Interpretation of GAB prediction	Analogue oil (Snorre TLP)
API gravity	36.0 (Group II)	American Petroleum Institute (API) gravity is a standard method of measuring the density of crude oil. As a reference, water has an API of 10. The less dense the oil, the higher the API gravity ('light' crude), the more dense the oil, the lower the API gravity ('heavy' crude). This predicted GAB crude oil falls within the Group II classification ('light' oil).	38.2
Specific gravity	0.845	Specific gravity (SG) determines whether oil will float on water or sink. The SG of seawater is 1.025. The predicted GAB crude oil will float if spilled.	0.834
Pour point	1°C	This is the temperature below which the oil will not flow. The predicted GAB crude oil will remain fluid at sea surface and water column temperatures (it would become solid at 0°C).	3°C
Wax content	8.2 wt%	Wax content measures the volume of solid hydrocarbon that may be present in the hydrocarbon. High wax oils tend to be more viscous than low wax oils. This predicted GAB crude oil is therefore likely to weather at a slower rate than Group II oils with a lower wax content.	5.2 wt%
Viscosity	1.6 cP	This is a measure of the resistance to flow (the notion of 'thickness'), which usually decreases with rising temperatures and increases with lower temperatures. This predicted GAB crude oil is predicted to be of low viscosity, meaning it will flow easily.	8 cP

Hydrocarbon Weathering Profile

Weathering data obtained from the SINTEF database on the Snorre TLP oil, used as the analogue for the GAB drilling program spill modelling, was undertaken in 1992 (and confirmed to remain valid in a follow up study in 2004). This study provides the following weathering profile based a water temperature of 15°C and with wind speeds of 2 m/s:

- Evaporation - 30% of the oil had evaporated after 24 hours (increasing to 40% with a wind speed of 15 m/s).
- Flash point - the oil remains a fire hazard on the sea surface for the first 1.5 hours, is a fire hazard in tankage for 9 hours, and thereafter is no longer a fire hazard. The flash point is 60°C.
- Pour point – predicted to increase in approximately 9 hours, thereby increasing the viscosity to a point where dispersant efficacy is reduced.
- Viscosity - the oil increases in viscosity to about 200 cP after 24 hours and to 500 cP after 5 days, making it likely that it will form stable oil-in-water emulsions. In high-energy environments such as the GAB, the likelihood of emulsification increases.
- Water content - the oil will contain 25% water after 6 hours and 70% after 24 hours, meaning it will form a strong oil-in-water emulsion. The oil would be amenable to dispersant while it is <2,000 cP, which is only for the first 24 hours (stronger winds reduce the time it remains amenable to dispersant).
- Mass balance – after one day, 70% of the oil remains, reducing to about 65% after five days.

6. Determining Worst Credible Discharge

Flow Rate

The worst credible discharge (WCD) rate from a well is determined based on a range of factors, including predicted rock properties of the formations to be penetrated such as porosity, permeability, temperature and pressure. The WCD rate for the GAB exploration wells was calculated by BP subject matter experts following the methodology outlined in BP's global Engineering Practice.

Duration

In the event of a loss of well control event, it is BP's intention to initiate both well capping activities and relief well drilling operations.

Historically, well blowouts were controlled by drilling a relief well to 'kill' the well and permanently stop well flow. However, since the Deepwater Horizon accident in the Gulf of Mexico, the oil and gas industry has developed significant capability to cap well blowouts, leading to a substantial reduction in the anticipated duration of uncontained hydrocarbon flow.

BP has conducted logistics and engineering studies to examine the mobilisation of various well capping equipment to the drilling area in the event of a loss of well control event. These studies estimate that capping equipment can be mobilised and deployed to site within 35 days of a loss of well control event occurring. Once the well is capped, discharge of hydrocarbons is contained, preventing further release of hydrocarbons into the marine environment until the well is permanently controlled (via a relief well or top kill).

Given the deployment of capping stacks to contain uncontrolled well flow is a proven and tested technology, this 35 day flow duration is therefore considered the WCD scenario, and is the oil spill duration used to inform the assessment of environmental impacts outlined in this EP.

Note that oil spill preparedness and response will be scalable, and will include plans and resources to respond to a longer duration spill (based on timing to drill a relief well, which has been calculated at around 149 days).

7. Response and Environmental Thresholds

The OSCAR model is able to track oil on the sea surface, in the water column and on the shoreline to levels that have little relevance from a response or environmental impact perspective. Therefore, threshold levels have been specified for each of these impact compartments (Table 2).

Table 3 - Hydrocarbon spill thresholds used for the GAB drilling oil spill trajectory modelling

Threshold	Justification
Shorelines	
100 ml/m^2 (approx. equal to 100 g/m^2 or 0.1 litre per m^2 or 500 ml oil per metre strip down the beach)	The International Tank Owners Pollution Federation (ITOPF) guidelines for the recognition of oil on shorelines (ITOPF, 2011) were used to define the response threshold for shoreline oiling. The definition for 'light oiling' is selected as the most appropriate threshold and is described in the guidelines as an oil band of average oil thickness 0.1 mm and a width of 5 m, equivalent to a volume threshold of 0.1 litre/m^2, or less than 0.5 litres of oil per metre strip down the beach. The 100 ml/m^2 threshold (considered a 'stain' or 'film') is assumed as the lethal threshold for invertebrates on hard substrates and sediments (mud, silt, sand, gravel) in intertidal habitats based on Owens & Sergy (1994) and French-McCay (2009). A threshold of 100 g/m^2 oil thickness would be enough to coat the animal and likely impact its survival and reproductive capacity, while stain (<100 g/m^2) would be less likely to have an effect (French-McCay, 2009).
Sea surface	
5 µm (microns) (approx. equal to 5 g/m^2) Rainbow sheen	Consultation undertaken by BP within the oil spill response community and literature reviews indicated that oil appearing as metallic on the water surface (5 to 50 µm, based on the Bonn Agreement Oil Appearance Code (BAOAC)) might lead to a successful response (if weathering conditions and oil characteristics allows it). The minimum thickness of oil that may result in harm to seabirds through ingestion from preening of contaminated feathers, or loss of thermal protection from their feathers, has been estimated by different researchers to range between 10 µm (10 g/m^2) to 25 µm (25 g/m^2) (French-McCay, 2009). Given seabirds are considered sensitive to oiling, this 10 µm threshold is also often applied to other wildlife as a conservative measure. The selection of the 5 µm threshold thus represents a conservative basis upon which to model an oil spill for impact assessment and spill response planning purposes.
Water column (dissolved and entrained, top 100 m)	
58 ppb total hydrocarbons (THC)	Based on extensive toxicity tests of crude oils and oil components on marine organisms, the OLF (the Norwegian Oil Industry Association) *Guideline for risk assessment of effects on fish from acute oil pollution* (2008) concluded that threshold concentration for an expected No Observed Effect Concentration (NOEC) for acute exposure for THC ranges from 50 to 300 ppb. Work undertaken by Neilson *et al* (2005, as reported in OLF, 2008) proposed a value for acute exposure to dispersed oil of 58 ppb, based on the toxicity of chemically dispersed oil to various aquatic species, which showed the 5% effect level is 58 ppb. The 58 ppb threshold for the NOEC for oil dissolved and entrained oil in the water column was thus selected based on the conclusion in the OLF guideline. This is consistent with the ANZECC/ARMCANZ guidelines (2000), which indicate that concentrations of benzene (one of the more soluble toxic hydrocarbons, and the only BTEX for which there is a guideline criteria) of less than 500 ppb in marine waters would be expected to impact less than 1% of species. The guidelines also state that a 99% species level of protection for the PAH naphthalene is 50 ppb in marine waters.

8. Modelling Results

Stochastic Simulation Results

For each subsea WCD scenario, separate stochastic simulations were carried out to represent the following weather 'seasons':

- Summer (October to March) - predominantly S, SE winds.
- Winter (June to September) - mainly N, NW winds.
- Transitional (April and May) - no real wind pattern.

Ten simulations per month were run (varying the start time) to cover the season in question using data for winds and water currents from January 2006 through December 2010. This equated to 261 individual simulations for the 'summer' season relief well scenario stochastic assessment, thus ensuring that the predicted transport and weathering of an oil spill simulation is subjected to a range of prevailing wind and water current conditions that is historically representative of the time period in question.

Although each simulation has the same release information, they have differing trajectory paths, due to the varying start times and associated wind and water current conditions.

During each simulation, the model records the grid cells contacted by the oil spill trajectory, as well as the time elapsed. Once the stochastic modelling is complete, OSCAR produces statistical outputs that include:

1. Probability of sea surface, water column or shoreline contact that may occur at a given grid cell; and
2. Minimum time before contact could occur at a given a grid cell.

The stochastic model output <u>does not</u> represent the extent of any one oil spill event (this is predicted by deterministic modelling, discussed below) but rather, provides a summary of all the predicted individual simulations. Stochastic modelling results are therefore used to determine the <u>probability</u> of spill direction based on these aggregated results.

Table 3 presents the results of the stochastic modelling for the summer season (October to March). Only the summer season results are presented because they represent the worst case season for a spill (shortest shoreline arrival times and peak volume of oil ashore). It should be noted that these results are for 'no response' scenarios (i.e., no oil spill response measures are deployed). In reality, a number of response measures would be deployed, such as dispersant application and mechanical recovery. These results are therefore considered as highly conservative.

Further details of shoreline contact predicted for all seasons is summarised in Table 4 below.

Table 4 - Summer season stochastic modelling results: Capping stack scenario (35 days duration) with no oil spill response

Shoreline and nearshore	
Summary of shoreline contact during summer	<6% probability of shoreline contact (moderate to heavy oiling) along the Nuytsland Nature Reserve coastline of WA. <3% probability of shoreline contact (light to moderate oiling) along the Cape Arid and Fitzgerald River National Parks coastline of WA. Typical arrival times along the Nuytsland Nature Reserve coastline range from 40 to 75 days. In SA, the earliest beaching event occurred after 22 days along the Eyre Peninsula. Further details of shoreline contact predictions are provided in Table 5.
Earliest oil reaching shore	21 days (near Esperance, WA)
Probability of surface oil with a thickness >5 µm (metallic) at coast	>0.1% (from Albany, WA to Beachport, SA)
Surface exposure time at the same location	From 0-1 days near the coast, to 25-30 days near the release site
Peak oil ashore	50-150 days after blowout
Average / maximum mass of oil ashore (tonnes) at: - 25 days	1 / 81
- 50 days	22 / 451
- 100 days	76 / 783 (peak = 0.3% of total release)
- 150 days	70 / 660
- 300 days	-
Sea surface	
Maximum extent of area with >50% probability exposure	190 km SW-NE x 330 km NW-SE direction
Shortest arrival time to shore (50% of cases)	<61 days
Surface exposure time at the same location	>14 days, limited to radius of 100 km of release site
Water column (top 100 m)	
Probabilities for Total Petroleum Hydrocarbons (TPH) concentrations >58 ppb	>90% for an area extending out to 110 km from the release point
Exposure time of dispersed oil >58 ppb in top 100 m of water column - offshore	>14 days
Exposure time of dispersed oil >58 ppb in top 100 m of water column – coastal waters	< 1 day
Maximum time-averaged water column concentrations exceeding 10 ppb	Does not extend beyond 150 km of spill site

Table 5 – Stochastic modelling results - summary of shoreline contact: Capping stack scenario (35 day duration) with no oil spill response

Shoreline	Season	Probability of shoreline contact	Minimum time before shoreline contact (days)	Level of stranding
Kangaroo Island	Summer	<12%	32	Light – heavy
	Winter	<37%	21	Light - heavy
	Transitional	<29%	22	Light - heavy
Eyre Peninsula	Summer	<11%	27	Light - heavy
	Winter	<21%	40	Light - moderate
	Transitional	<9%	23	Light - heavy
Yorke Peninsula	Summer	<2%	55	Moderate – heavy
	Winter	<4%	40	Light - moderate
	Transitional	<2%	53	Light - moderate
Nullarbor	Summer	<1%	85	Light
	Winter	<2%	147	Light
	Transitional	No contact	No contact	No contact
Western Australia	Summer	<6%	23	Light - heavy
	Winter	<2%	92	Light - moderate
	Transitional	<1%	113	Light

Deterministic Simulation Results

Deterministic simulations were also carried out to model the fate of oil during and after a subsea blowout scenario. Deterministic simulations predict the trajectory of a single spill at a defined time. The single spill trajectory from each stochastic simulation that gave the maximum tonnage of oil reaching the shoreline was chosen for the deterministic simulation.

The deterministic simulation for the summer season showed that the maximum amount of oil on the shoreline peaked at 810 tonnes after 86 days, with 227 km of coastline impacted. This increased to a maximum of 240 km of coastline after 100 days due to the remobilisation and re-deposition of oil on the shoreline due to wave action and tidal cycling.

This deterministic trajectory (maximum oil ashore) is illustrated in Figure 1.

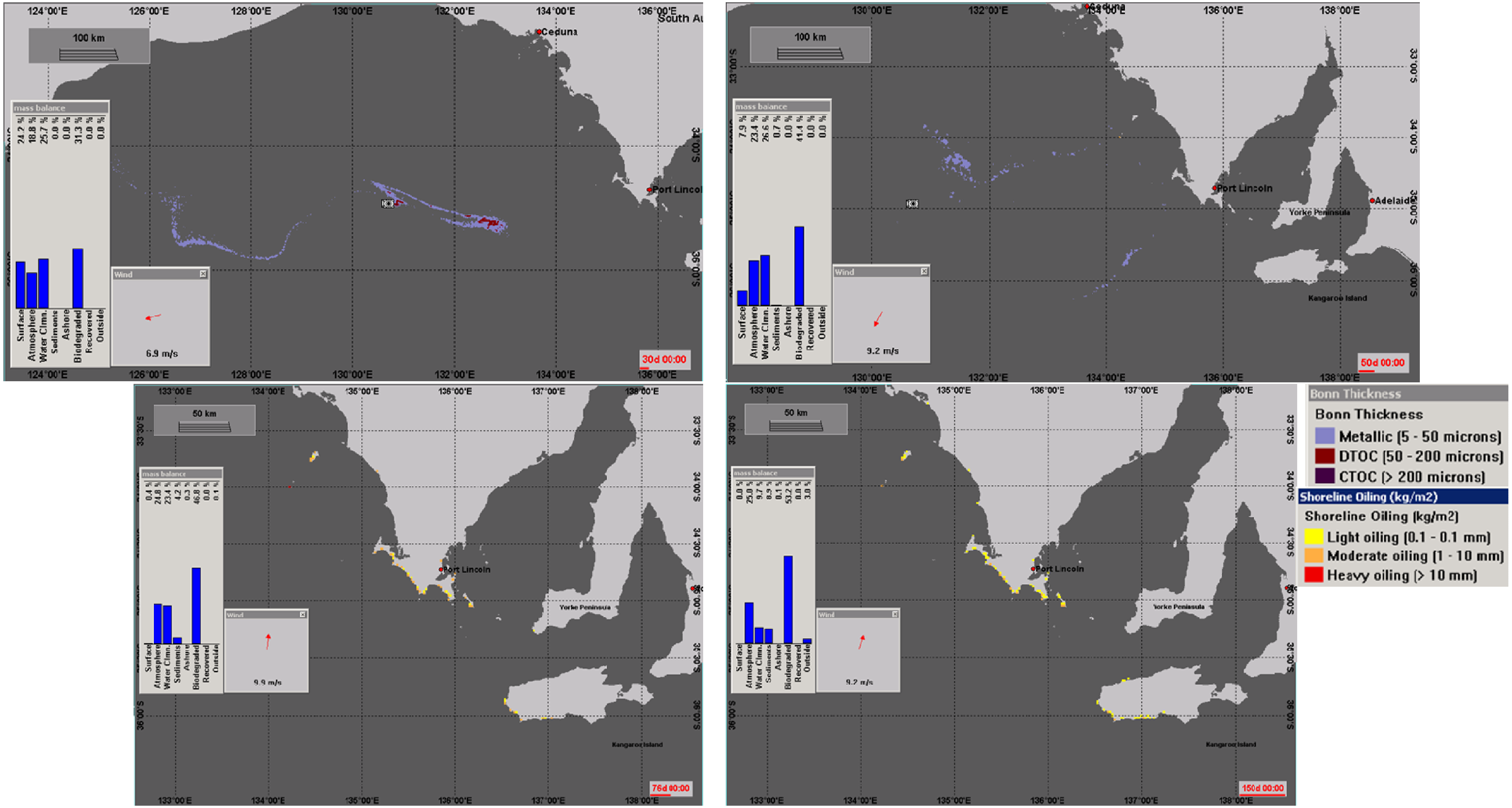

Figure 1 - Capping stack scenario (35 day duration). Maximum oil ashore simulation (summer season). Snapshot maps showing extent of the surface slick and shoreline oiling (clockwise from top left) 30, 50, 75 and 150 days after the start of the release for the oil spill trajectory that resulted in the highest amount of oil reaching the shore with no oil spill response

9. Utilisation of Modelling Results

The fate and effects oil spill modelling is used to predict both the probability of different geographical areas that may be contacted in the event of a spill, and the volume of oil that may contact these different areas.

This information is then utilised to prepare oil pollution response plans and to determine what equipment is required and where the equipment should be located.

A summary of the response tactics that are available, and would be employed in the unlikely event of an oil spill, is provided on the GAB project website http://www.bpgabproject.com.au. Each of the summaries contains a brief description of the tactic and the key facts that relate to the tactic such as: response organisation, resources available, limitations of the tactic and where appropriate decision guides and checklists. Each of these tactics is defined in greater detail in either the Oil Pollution Emergency Plan (OPEP) or where appropriate in a specific Tactical Response Plan such as the 'Shoreline Tactical Response Plan'.

10. References

ANZECC/ARMCANZ. 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

French-McCay, D. P. 2009. State-of-the-art and research needs for oil spill impact assessment modelling. In: *Proceedings of 32nd Arctic and Marine Oil Spill Program (AMOP) Technical Seminar.* Ottawa, Canada, 601–653.

ITOPF. 2011. Recognition of Oil on Shorelines. Technical Information Paper 6. The International Tanker Owners Pollution Federation Ltd. London.

OLF. 2008. Guideline for risk assessment of effects on fish from acute oil pollution. The Norwegian Oil Industry Association. Norway.

Owens, E. H. and Sergy, G. A. 1994. Field guide to the documentation and description of oiled shorelines. Environment Canada, Environmental Technology Centre. Environment Canada.