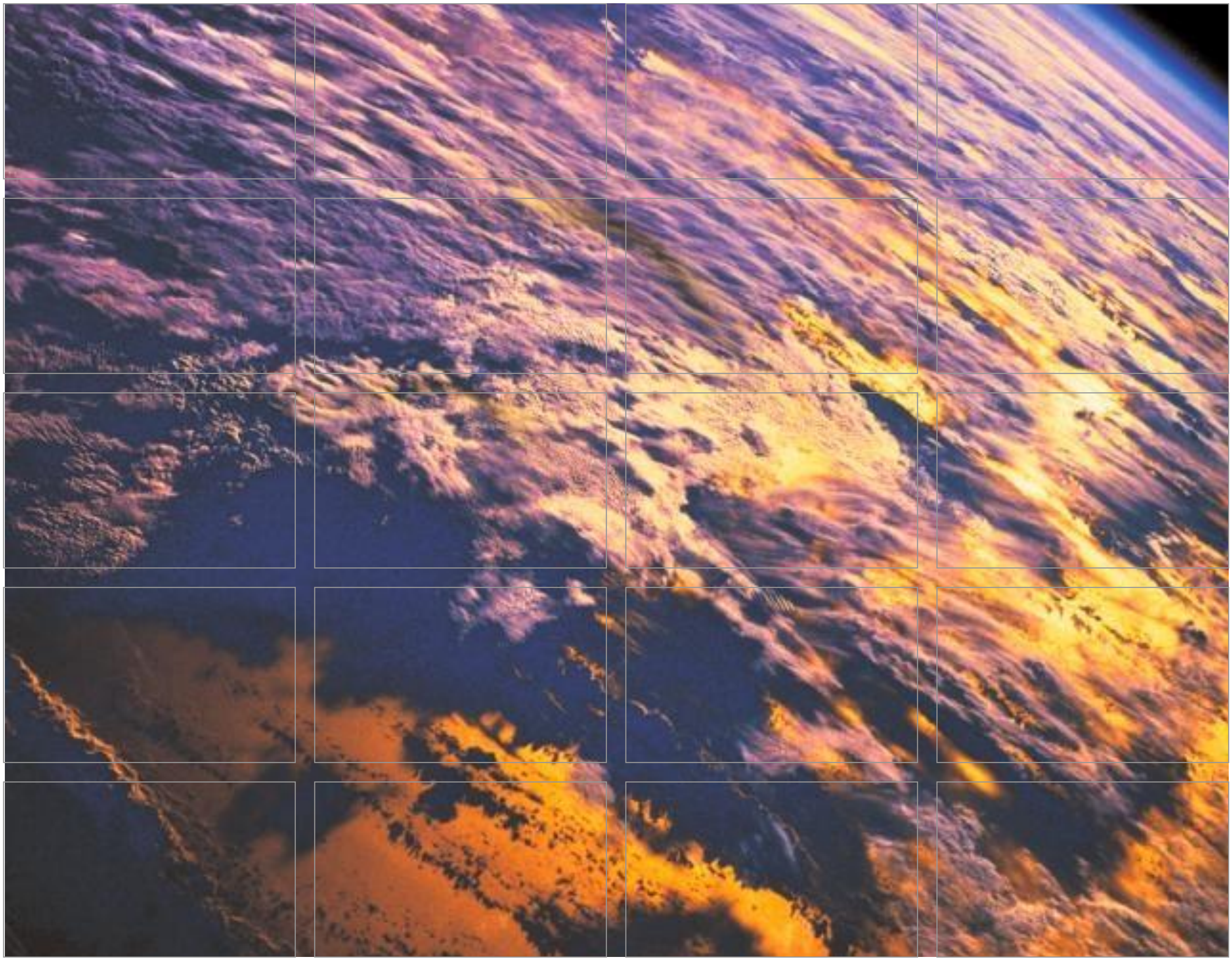
Annex D4

Oil Spill Modelling

An oil spill modelling study was undertaken by ERM to assess the impact of a potential oil spill due to the proposed drilling.



Environmental Impact Assessment:

Oil Spill Modelling Report

Exploration of the Block ER236 Block, South Africa

December 5, 2018

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Eni Upstream - AMTE and Eni South Africa BV

Environmental Impact Assessment for Proposed Exploration Drilling in Block ER 236, offshore of Kwa-Zulu Natal Coast of South Africa – Oil Spill Modelling Report

December 5, 2018

For and on behalf of
Environmental Resources Management

Prepared by:	**Reviewed by:**	**Approved by:**
Michael J. Fichera, P.E.	*William Schew, Ph.D.*	*Shwet Prakash*

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LIST OF ACRONYMS

Acronym	Explanation
BAOAC	Bonn Agreement Oil Appearance Code
BOP	Blowout Preventer
CE-QUAL-W2	Corps of Engineers' water quality model
DAH	Dissolved-phase Aromatic Hydrocarbon
DEM	Digital Elevation Model
ERM	Environmental Resources Management
GEBCO	General Bathymetric Chart of the Oceans
GEMSS	Generalized Environmental Modelling System for Surface waters
GEMSS-COSIM	GEMSS Chemical and Oil Spill Impact Module
GEMSS-GIFT	GEMSS Generalized Integrated Fate and Transport module
GEMSS-HDM	GEMSS Hydrodynamic Module
GEMSS-TAM	GEMSS Thermal Analysis Module
GEMSS-UDC	GEMSS User Defined Constituent module
GLLVHT	Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport
GUI	Graphical User Interface
HYCOM	HYbrid Coordinate Ocean Model
LC_{50}	Lethal Concentration 50
NADF	Non-Aqueous Drilling Fluid
NCDC	NOAA's National Climatic Data Center
NOAA	National Oceanographic and Atmospheric Administration
SBM	Synthetic oil-based Mud
TSS	Total Suspended Solids

GLOSSARY OF TECHNICAL TERMS

Technical Term	Meaning in this Report
Bathymetry	Study of underwater depth of lake or ocean floors
Benthic communities	Organisms that are part of the benthic zone and live in close relationship to the substrate bottom
Biota	The total collection of organisms of a geographic region or a time period
Dissolved–phase Aromatic Hydrocarbon	Hydrocarbon, such as benzene, with alternating double and single bonds between carbon atoms forming rings
Drill cuttings	Broken bits of solid material removed from a borehole drilled by rotary, percussion, or auger methods
Drill fluid	Used to aid the drilling of boreholes into the earth, often used while drilling oil and natural gas wells
Drill muds	Used to impart stability to boreholes through soft seabed sediments prior to running structural or conductor casing
Drilling production wells	Offshore wellbore is drilled through the seabed, typically used to explore and extract petroleum
Environmental Impact Study	Formal process used to predict the environmental consequences (positive or negative) of a plan, policy, program, or project prior to the decision to move forward with the proposed action
General Bathymetric Chart of the Oceans	Publicly available bathymetry of the world's oceans
Hydrodynamic Modelling	Used in complex aquatic systems to represent detailed transport patterns
Impact Assessment	see "Environmental Impact Study"
Lethal Concentration 50	Concentrations of a chemical in air or water that kills 50% of the test animals during the observation period, exposure period much be included in this measuring
Low toxicity oil based mud	see "Drill muds"
Total suspended solids	Water quality measurement of filterable solids
Toxicological assessment	Principles and methods for evaluating data to characterizes risk to human or ecological development, growth, survival, and function

CONTENT OF THE SPECIALIST REPORT CHECKLIST

The content of this report has been prepared in terms of Regulation GNR 326 of 2014, as amended, Appendix 6, as shown in *Table i.*

Table i. Specialist Report Checklist

Contents of this report in terms of Regulation GNR 982 of 2014, Appendix 6	Cross-reference in this report
(a) details of— the specialist who prepared the report; and the expertise of that specialist to compile a specialist report including a curriculum vitae;	Section 9
(b) a declaration that the specialist is independent in a form as may be specified by the competent authority;	Section 9
(c) an indication of the scope of, and the purpose for which, the report was prepared;	Section 2
(cA) an indication of the quality and age of base data used for the specialist report;	Section 4
(cB) a description of existing impacts on the site, cumulative impacts of the proposed development and levels of acceptable change;	Section 3.2.2, 3.2.3
(d) the duration, date and season of the site investigation and the relevance of the season to the outcome of the assessment;	Section 3.2
(e) a description of the methodology adopted in preparing the report or carrying out the specialised process inclusive of equipment and modelling used;	Section 3.2
(f) details of an assessment of the specific identified sensitivity of the site related to the proposed activity or activities and its associated structures and infrastructure, inclusive of a site plan identifying site alternatives;;	N/A
(g) an identification of any areas to be avoided, including buffers;	Section 1.2
(h) a map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers;	Section 1.2
(i) a description of any assumptions made and any uncertainties or gaps in knowledge;	Section 3, Section 4
(j) a description of the findings and potential implications of such findings on the impact of the proposed activity or activities.	Section 6
(k) any mitigation measures for inclusion in the EMPr;	N/A
(l) any conditions for inclusion in the environmental authorisation;	N/A
(m) any monitoring requirements for inclusion in the EMPr or environmental authorisation;	N/A
(n) a reasoned opinion— (i) whether the proposed activity, activities or portions thereof should be authorised; (iA) regarding the acceptability of the proposed activity or activities; and (ii) if the opinion is that the proposed activity, activities or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan;	N/A
(o) a description of any consultation process that was undertaken during the course of preparing the specialist report;	N/A
(p) a summary and copies of any comments received during any consultation process and where applicable all responses thereto; and	N/A
(q) any other information requested by the competent authority.	N/A

SUMMARY

Eni Upstream - Eni South Africa BV instructed *Environmental Resources Management* (hereinafter ERM) to conduct specialist studies as input to the Environmental Impact Assessment (EIA) for a Proposed Exploration Drilling Programme in Block ER236, offshore of the Kwa-Zulu Natal Coast of South Africa. The concession area is located off the east coast of South Africa in the Indian Ocean and, at its furthest point approximately 300 km from the coast.

This study evaluates the impacts of three unplanned events (i.e. releases into the environment of an accidental nature outside of planned discharges and designed effluents) in the form of hypothetical oil spill scenarios, which are expected to have a very low probability of occurring (as per OGP Report 434-02, 2010; and Oil Tanker Spill Statistics 2015).

Three (3) scenarios were evaluated at two locations in the northern Area of Interest and one location in the Southern Area of Interest in Block ER236:

- Scenario 1 - diesel spill associated with a vessel collision happening during drilling of a well;
- Scenario 2 – a deep blowout of crude oil during exploration; and
- Scenario 3 - release of non-aqueous drilling fluid (NADF) due to the accidental disconnection of the riser occurring during drilling.

It is also important to note that, in line with international best practice, all three of the modelling scenarios have been run with the assumption that no oil spill response measures would be implemented and that no mitigating actions would be taken at the point of spillage. Therefore, the results of the modelling present the 'worst case scenario' that could result from any particular oil spill.

The evaluation of impacts on surface waters and the shoreline was done using a comprehensive modelling approach centered on a single modelling system, GEMSS®. Various modules in GEMSS, in addition to an external hydrodynamic model [(1)], were used to estimate the transport and fate of the oil released.

Three (3) criteria have been identified in order to analyse the worst cases for each scenario:

- Criterion 1: Largest Amount of the Water Surface Area Oiled
- Criterion 2: Most Amount of Shoreline Oiling Mass
- Criterion 3: Fastest Time for Shoreline Oiling to Occur

(1) Hydro Hydrodynamic data (Currents, water temperature and Salinity) from HYCOM model was used in modelling. Wave data were obtained from NOAA WAVEWATCH III model to compute longshore currents internally inside COSIM module of GEMSS.

Scenario 1 - Diesel Spill: A spill of 794.9 m^3 (5,000 bbl) of diesel fuel oil was modelled and is likely to travel predominantly in the southwest direction with the strong influence of Agulhas Currents parallel to the coastline. It is unlikely that such a spill at any of the three spill locations would carry an oil slick with a thickness greater than the minimum smothering thickness to an area within 20 km off of the South African coastline. Assuming an absence of response efforts for a worst case evaluation which is an unrealistic condition, the slick of oil with potential to impact wildlife is able to travel over 200 km from the release points before weathering away into a thinner sheen within 2 days. Regions with oil above the thickness threshold for risks to birds and wildlife (1.0 µm) extend as narrow and long streaks parallel to South African coastline. The locations of shoreline impact from the a diesel spill (without considering intervention measures that will be adopted in case of an unplanned event) can range from the Durban to East London but the probability of shoreline impact due to a spill is less than 7.5%. In the cases of a spill event at two northern well locations within the block, the shoreline area near the Richards Bay area was the earliest to potentially be contacted by oil. A shoreline stretch south of Durban was the earliest to potentially be contacted by oil in the case of a spill originating from an assumed southern well location within the block. In either case, in the absence of response efforts a diesel spill will likely reach shoreline within four days.

Scenario 2 – **Blowout**: In the blowout scenario, simulations were performed at two locations, a north well and a south well, for two events – a cessation of the spill by a hole collapse, and from installation of a capping system. For the hole collapse scenario, at the north well, 750 m^3/day of crude oil was assumed to be released from the wellhead over a period of 7 days. For the south well, 1,050 m^3/day of crude oil was assumed to be released over 7 days. For the capping system event scenario, the same release rates were applied for 20-day releases. Shoreline oiling from the blowout scenarios takes longer to occur than the diesel spill scenario, taking 4 to 7 days or more to potentially reach shoreline. However, in these blowout scenarios and without intervention, the oil mass disperses within the water column and travels on the surface parallel to the coastline due to the strong influence of the Agulhas Currents, such that oil reaching the shorelines would be below the significant impact threshold. An oil slick thicker than the minimum smothering thickness would stay off the coastline.

Scenario 3 - Riser Disconnect: in the riser disconnect scenario, released base oil travels similarly to the diesel spill scenario, predominantly in the south and southwest directions, and potentially reaching shorelines within 4 days. However, shorelines were contacted in less than 9% of the cases examined. In the riser disconnection scenario, while the base oil from the NADF rises to form a slick, oily solid particles will settle to the seafloor. Particle sizes of the solid portion of NADF are small and hence have low settling velocities. These small particles get transported and dispersed to a large area settling on the ocean floor at insignificant thicknesses due to the strong currents offshore South Africa. TSS concentration near the surface did not exceed the threshold value of 35 mg/L. Particles are quickly transported and dispersed into smaller TSS concentrations.

It has to be stated that **<u>three scenarios described are very unlikely unplanned events and the modelling assumptions do not take into account any mitigation and/or intervention</u>** measure which will be adopted promptly in case on an unplanned event occurrence.

Note that this report was reviewed independently by Mr. Stephen A. Luger of PRDW, Cape Town, South Africa. This revision of the report includes responses to Mr. Luger’s comments regarding this report.

1 INTRODUCTION

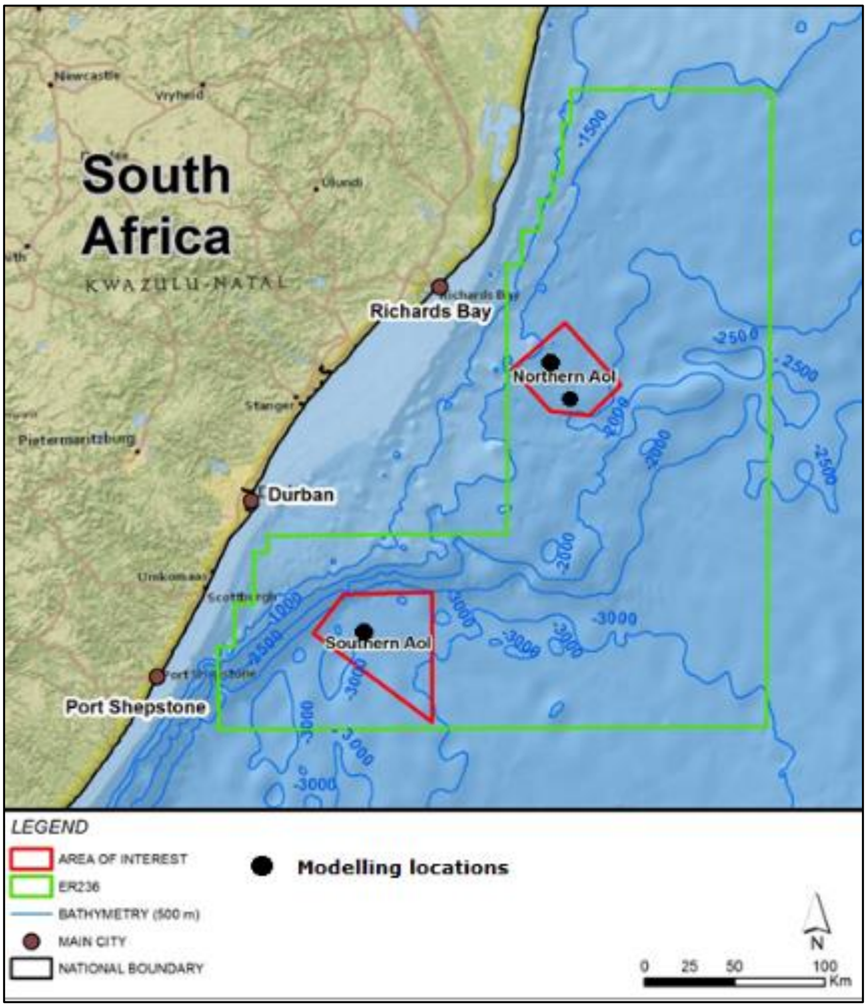
1.1 BACKGROUND

The main objective of this assignment was to conduct oil spill modelling to assess potential environmental impacts resulting from unplanned (accidental) releases of hydrocarbons associated with drilling activity and potential vessel collisions in the exploration area (ER236) off the east coast of South Africa. The results of this modelling report will be taken into account in the environmental impact evaluation included in the Environmental Impact Assessment (EIA) study that will be submitted to the South African authorities.

1.2 DESCRIPTION OF PROJECT AND LOCATION

Three spill locations were used originating in Block ER 236 (Figure *1-1*). These are N1 (Lat. -29.171510347, Lon. 32.773259341), N2 (Lat. -29.361772647, Lon. 32.901946107), and S (Lat. -30.539622500, Lon. 31.779959861), the midpoint between well locations in the southern region of the Block under consideration for well locations, but not confirmed at the time of this writing. For the two blowout scenarios, N1 and S were used.

Figure 1-1 Location Map Showing the Location of Block ER 236



2 SCOPE OF WORK

ERM conducted this oil spill modelling to assess potential environmental impacts resulting from unplanned releases of hydrocarbons associated with exploratory drilling activity and potential vessel collisions. Models were used to predict the spatial extent of oil spillage associated with three scenarios:

- Scenario 1: Diesel spill from a vessel collision near the well;
- Scenario 2: Blowout from the wellhead; and
- Scenario 3: Release of Non Aqueous Drilling Fluid (NADF) also known as low-toxicity oil-based muds, after a riser disconnection.

These three spill scenarios were modelled in order to simulate the:

- Spill trajectories;
- Potential locations of the sea surface slicks and their potential to impact wildlife;
- Potential shoreline locations at risk of oiling; and
- Minimum travel time for the slick to arrive at the shoreline.

For the assessment of potential impacts related to the release of the NADF, the settling of the solid particles from the mud were modelled separately to simulate the size, location and thickness of the deposits on the seafloor in addition to the concentration of total suspended solids (TSS) added to the water column.
At this stage, it is important to note that the scenarios presented and simulated, in particular for Scenario 2 (the blowout event), are the very worst case in line with international requirements.

A number of **assumptions** have been made in order to determine the scenario to be modelled. These include the following:

- **The event is completely uncontrolled, with no intervention for avoidance /reduction (unrealistic situation because the emergency response team and equipment, such as a blowout preventer (BOP), will be present and immediately activated).**
- **The use of spill/blow out containment or reduction systems (BOP, boom, skimmer etc.) hasn't been included in the simulation (unrealistic situation).**
- **No depletion/reduction in flowrate has been taken into account for the full simulated release period (unrealistic situation).**

The above assumptions depict an improbable situation by assuming no intervention that will be adopted in case of any unplanned event; however the modelling of the worst case scenario is in line with best practice and is required for the development of the emergency preparedness and response plans (and associated sensitivity mapping). In particular, in the case of an accidental event, an emergency response team (this team will be available at all times during the drilling activities) will be immediately activated (in accordance with the Oil Spill Contingency Plan) to react to the event in order to reduce the spill dimension and, in case of blow out, shut-in the well.

3 APPROACH

3.1 DEFINITIONS

The term “scenario” in this report refers to the conditions that describe a specific spill event, including the type of oil spilled, as well as the volume, duration, location, and depth of the release. A “simulation” is a model run for a specific period of time (e.g. autumn condition). For stochastic analyses, each simulation is repeated multiple times within the specified time period (2013 through 2017), but selecting from many start dates over multiple years for a range of wind and current conditions. Each of these runs repeated within a stochastic simulation is called an “iteration.”

3.2 MODELLING METHODOLOGY

The modelling was performed using GEMSS® and its oil spill module, COSIM. The theoretical formulation of COSIM can be found in Kolluru *et al* (1994).

A COSIM application requires three types of data:

- Spatial - primarily the waterbody shoreline and bathymetry, but also the locations, elevations, and configurations of man-made structures;
- Temporal - i.e., time-varying data defining currents and meteorological conditions, and spill release rates; and
- Chemical property and volumetric proportions of the spilled substances.

For input to the model, the spatial data are encoded primarily in two input files: the control and the bathymetry. The data in these files are georeferenced. The temporal data are encoded in many files, each file representing a set of time-varying conditions. Each record in the boundary condition files is stamped with a year-month-day-hour-minute address. Chemical property and volumetric proportion values are stored in a database read by the COSIM control file. This database contains properties of various chemicals and oil types and the constituent compounds comprising them.

Time-varying, numerical hydrodynamic and transport models can be run in two modes: deterministic mode and stochastic mode. Deterministic simulations are used primarily for hindcasts, i.e., reproducing a historical period using datasets that represent actual conditions for the historical period being simulated.

Stochastic models may run multiple iterations at random start dates over a period of many years. The simulation uses observed winds and modelled currents for the randomly selected dates. This process is repeated multiple times to simulate a range of conditions.

The stochastic (or probabilistic) mode allows prospective analysis of the model results by repeatedly sampling a statistical representation of the temporal data. Form the stochastic model the worst cases have been subsequently highlighted based on the following criteria:

- Criterion 1: Largest Amount Of The Water Surface Area Oiled
- Criterion 2: Most Amount Of Shoreline Oiling Mass
- Criterion 3: Fastest time for shoreline oiling to occur

Regarding Scenario 1 (diesel spill) and 3 (riser disconnection) a single worst case (not seasonal) has been identified for each location (N1, N2 and S) (respectively Sections 5.4 and 5.6).

Scenario 2 (crude blowout, Section 5.5) is considered the most critical in terms of impact relevance if compared to the previous Scenarios 1 and 3. For this reason, a more detailed analysis has been implemented by identifying the worst cases for two blowout scenarios examining two seasons (Season 1 summer and autumn [1 December to 31 May]and Season 2 for winter and spring{1 June to 30 November }) in order to provide an in-depth analysis of potential impacts. From the two north wells, N1 was chosen as the focus since it is closer to the coast and had the higher risk of shoreline impact compared to N2. This analysis provides a deeper look at potential impacts especially on offshore marine fauna components in terms of seasonal migratory and feeding behaviors, and seasonal fisheries activities occurring within the Area of Interest.

3.2.1 *Oil Spill Modelling Probability and Contour Diagrams*

Oil spill model results forecasting hypothetical events are generally shown as probability diagrams, intended to represent the range of locations potentially affected by the presence of oil under conditions that define the scenario and simulation. These probability diagrams are composites of multiple iterations where an individual iteration represents a single spill event. The use of multiple iterations, therefore, presents a summary of multiple potential outcomes.

At each location on a grid at a specified frequency (e.g., hourly) the concentrations of constituents are calculated. At the end of the simulation the probability of exceeding a value of interest (e.g., a regulatory limit or toxicological threshold) at each of the cells is computed and the probability is contoured. The contouring can be done only for a specific constituent concentration. For example, a probabilistic plot might show the probability of exceeding 0.5 mg/l and the contours would show areas in which the probability of exceeding this limit is 10%, 50%, and 90%. In addition, a contour map can be generated showing the probability that a single oil particle will reach that location.

Of note, the probabilistic summaries do not represent the outcome of a single spill; rather these summaries show the probability of presence of oil at various locations. A single iteration, representing an individual spill event, would cover only a portion of the area shown. Single iterations are displayed in this report for each of the identified “worst case” simulations.

3.2.2 *Oil Spill Modelling Outputs and Thresholds*

Table 3-1 summarizes the significance of the spill modelling outputs and how they can be used in an overall risk assessment.

Table 3-1 COSIM Outputs

Output component	Importance of information	Potential use of information
Geographic distribution and probability of the slick	Understanding relative risk and extent of a spill event	Risk analysis and response planning
Geographic distribution of oil thicknesses	Understanding extent of significant oil mass per area and the risk of smothering biota	Response planning and ecological effects
Arrival time	Understanding risk to coastal receptors and extent of shoreline oiling	Risk analysis and response planning (time to intercept before shoreline oiling or clean-up extent)
Mass of shoreline oiling per unit area	Understanding the potential for oil on the shoreline to cause an impact if contacted by wildlife	Response planning and risk analysis

Two critical threshold assumptions were used in the design of the models and interpretation of results. These assumptions address critical thresholds for oil slick thickness and shoreline flux and relate directly to the ecological effects. *Table 3-2* summarizes these assumptions.

Table 3-2 Threshold Assumptions

Assumption	Value	Importance	Source
Significant slick thickness	1.0 µm	Minimum thickness for smothering of aquatic organisms and wildlife. Range of 1-10 µm minimum smothering thicknesses cited in the literature.	Peakall *et al*. (1985); French-McCay (2009)
Significant shoreline mass flux	100 g oil/m² of shoreline	Provides a lower-limit to delineate significance for impacting wildlife making contact with shoreline deposits.	French-McCay (2009)

“Significant surface oiling” is defined as any oil having a thickness above the minimum thickness threshold, a value that delineates where oil becomes visible and below which aquatic biota are at near zero risk of smothering from a crude oil. The first clearly visible oil appears as a silvery sheen at thicknesses between 0.04 µm to 0.3 µm based on values cataloged in the 2006 Bonn Agreement Oil Appearance Code (BAOAC) (Lewis, 2007). Table *3-3* summarizes the thickness descriptors represented by the BAOAC standard color designations.

Table 3-3 Oil Thickness Descriptions

Color	Thickness (µm)
Silver sheen	0.1 – 0.3
Rainbow sheen	0.3 – 5
Metallic	5 – 50
Discontinuous true color	50 – 200
Continuous true color	200 and up

A minimum threshold thickness value was defined as 0.1 µm. Oil at this thickness may be visible and potentially wash upon the shore as a silver sheen, but is not expected to cause physical injury (e.g., oiling, smothering) to wildlife contacting it.

Research has been done in estimating exposure thresholds for birds and mammals contacting an oil slick. Peakall *et al*. (1985) and French-McCay (2009) found that oil slicks less than 1 µm were not harmful to seabirds; therefore visible oil between 0.1 µm and 1 µm was chosen as the low risk exposure thickness range. Additional studies found that aquatic birds and marine mammals may be affected at slick thicknesses in the range of 10 µm and 25 µm [Engelhardt (1983), Clark (1984), Geraci and St. Aubin (1988), Jenssen (1994), and Scholten *et al* (1996)]. Thus, a moderate exposure threshold is defined as oil with a thickness between 1 µm and 10 µm, while a high exposure threshold is defined as any oil with a thickness above 10 µm. Model output of the surface oiling and arrival time is filtered to remove oil thinner than 1 µm.

For evaluating the potential for oil impacts to birds and wildlife on the shorelines for use in environmental risk assessment studies, French-McCay (2009) published an evaluation of various animals' sensitivity to oil. French-McCay recommended a threshold of 100 g/m^2 as a reasonable value to indicate when a sufficient amount of oil mass per unit area may cause an impact to shorebirds and wildlife on or along the shore.

3.2.3 *Modelling of Mud Particle Deposition*

With respect to Scenario 3, while the GEMSS-COSIM module was used to simulate the fate and transport of the base oil from the NADF, the GEMSS® particle deposition module, GIFT (Generalized Integrated Fate and Transport) was used to estimate the potential impacts from the portions of the release settling upon the sea floor.

The modelling was performed assuming a total separation of oil from the particles takes place in order to provide a conservative assessment of the oil that may have reached the surface. For the particle deposition modelling, it is likely that some oil may adhere to the particles and settle, transporting hydrocarbons to the sea floor. However, for a more conservative estimate of the depositional thickness, the bulk density of the particles was not diluted by mixing the higher density solids with lower density oil, (the higher the density of the particles, the greater the settling velocity, and the greater the chance of the particles depositing in the same vicinity on the seafloor.)

For the particle deposition simulation, GIFT provides estimates of the locations and thickness of deposited materials, and computes the concentration increase of TSS above the ambient values.

Depositional Thickness

With respect to Scenario 3, the solid portion of NADF will create a footprint on the seabed. The deposition of muds may result in physical damage and habitat loss or disruption over a defined area of the seabed. The discharge of muds and cuttings may affect seabed habitats through physical smothering.

Burial by drilling muds may adversely impact benthic communities. The severity of burial impacts depends on the sensitivity of the benthic organism, the thickness of deposition, the amount of oxygen depleting material, and the duration of the burial. The potential impact of the thickness can vary depending on the benthic species and the degree of oxygen depletion, which may occur, causing anoxic conditions beneath the depositional layer.

Thickness thresholds vary by species and sediment impermeability. Current practices suggest using threshold thickness value of 5 cm above a substratum for a month deposition as a threshold for impacting benthic communities (Ellis and Heim, 1985 and MarLIN, 2011). Threshold values as low as 1 mm have been reported (e.g., Smit *et al*., 2006), however they are associated with instantaneous burials on benthic species, not gradual smothering effects.

Total Suspended Solids

With respect to Scenario 3, increases in concentration of TSS will occur due to discharges of drill cuttings and mud. The highest concentration increases will naturally exist at the point of discharge or at the seafloor during upper well section drilling, and decrease over time and distance as the suspended solids plume dissipates. Larger particles will settle out more quickly than fine particles, such that the TSS plume of tiny particles may linger and travel further than plumes of larger grain-sizes. As such, elevated TSS may form in regions where tiny suspended particles linger in a cloud and mix with subsequent discharges.

Impacts related to elevated TSS may occur if light penetration is impeded significantly for long periods of time reducing the ability of plants and phytoplankton to photosynthesize. Though not directly imposed on offshore discharge of cuttings, a general guidance value which can be applied is a maximum concentration of 35 mg/L TSS, designated as a threshold value for effluent discharges of hydrotest water at LNG facilities (IFC, 2017). MARPOL also lists 35 mg/L TSS as an offshore effluent discharge standard for TSS (IMO, 2006).

3.3 GEMSS SUITE DESCRIPTION

The Generalized Environmental Modelling System for Surfacewaters (GEMSS) is an integrated system of three-dimensional hydrodynamic and transport modules embedded in a geographic information and environmental data system. GEMSS is in the public domain and has been used for hydrodynamic and water quality studies in the USA and worldwide. ERM staff contribute to the source code and have completed many applications with the model. Organizations in Korea (Ewha Womans University, National Institute of Environmental Research), Canada (Golder Associates Ltd., Stantec Inc., Matrix Solutions Inc.), Norway (Norwegian Institute for Water Research and Akvaplan-niva AS), Poland (Maritime Institute in Gdańsk) and Sweden (Royal Institute of Technology), among others, routinely use GEMSS.

GEMSS was developed in the mid-80s as a hydrodynamic platform for transport and fate modelling of many types of constituents introduced into waterbodies. The hydrodynamic platform ("kernel") provides three-dimensional flow fields from which the distribution of various constituents can be computed. The constituent transport and fate computations are grouped into modules. GEMSS modules include those used for thermal analysis, water quality, sediment transport, particle tracking, oil and chemical spills, entrainment, and toxics.

The theoretical basis of the hydrodynamic kernel of GEMSS is the three-dimensional Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport (GLLVHT) model which was first presented in Edinger and Buchak (1980) and subsequently in Edinger and Buchak (1985). The GLLVHT computation has been peer reviewed and published (Edinger and Buchak, 1995; Edinger, *et al*., 1994 and 1997; Edinger and Kolluru, 1999). The kernel is an extension of the well-known longitudinal-vertical transport model written by Buchak and Edinger (1984) that forms the hydrodynamic and transport basis of the Corps of Engineers' water quality model CE-QUAL-W2 (U. S. Army Engineer Waterways Experiment Station, 1986). Improvements to the transport scheme, construction of the constituent modules, incorporation of supporting software tools, GIS interoperability, visualization tools, graphical user interface (GUI), and post-processors have been developed by Kolluru *et al*. (1998; 1999; 2003a; 2003b) and by Prakash and Kolluru (2006).

GEMSS development continues as additional applications are completed. A second hydrodynamic kernel, the Princeton Ocean Model (POM), has been added as an alternative to GLLVHT for deep ocean systems. In addition, new constituent modules have been developed and tested, including source water protection (Kolluru and Prakash, 2012), watershed nutrient load allocation (Kolluru *et al*., 2009), chlorine and chlorine by-products fate and transport (Kolluru *et al*., 2012); mine pit lake analysis (Vandenberg, *et al*., 2011; Prakash, *et al*., 2012); debris fouling at cooling water intakes (Prakash *et al*., 2012); coliform fate and transport (Tryland *et al*., 2012); thermal avoidance calculations (Buchak, *et al*., 2012); impact assessment (Fichera *et al*., 2013); and contaminated sediment transport (Kolluru *et al*., 2006.)

GEMSS applications to estuarine and coastal waterbodies have been validated by comparisons to extensive, field-collected datasets. These include currents, temperature and chlorine and chlorine by-products offshore Qatar (Kolluru *et al*., 2005; Adenekan *et al*., 2009; Febbo *et al*., 2012; Kolluru *et al*., 2003; Kolluru *et al*., 2012); currents, temperatures and nutrient water quality in Puget Sound (Albertson *et al*., 2009); nutrients in coastal Delaware (Kolluru and Fichera, 2003), and the Vistula River in Poland (Kruk *et al*., 2011); currents and temperatures in the New York Harbor area (Edinger *et al.*, 1997); larval populations in coastal Alaska (Edinger *et al*.,1994); and, mine tailings ponds (Prakash *et al*., 2011).

For inland waterbodies, GEMSS has been validated for temperatures in cooling lakes (Buchak *et al*., 2012 and Long *et al*., 2011); temperatures and nutrients in the Han River and Lake Paldang, Korea (Kim and Park, 2012a and 2012b; Na and Park, 2005 and 2006, respectively); temperature and fecal coliforms in Norwegian water supply reservoirs (Tryland *et al*., 2012). Many other inland, estuarine and coastal waterbody validations have been completed and published as client reports.

Customization of the suite of hydrodynamic, transport and water quality models to reflect the needs of each application is easily done because of the modular design of GEMSS. A list of modules available within GEMSS are shown in *Figure 3-1* and *Figure 3-2*.

Figure 3-1 GEMSS Modules: First Set

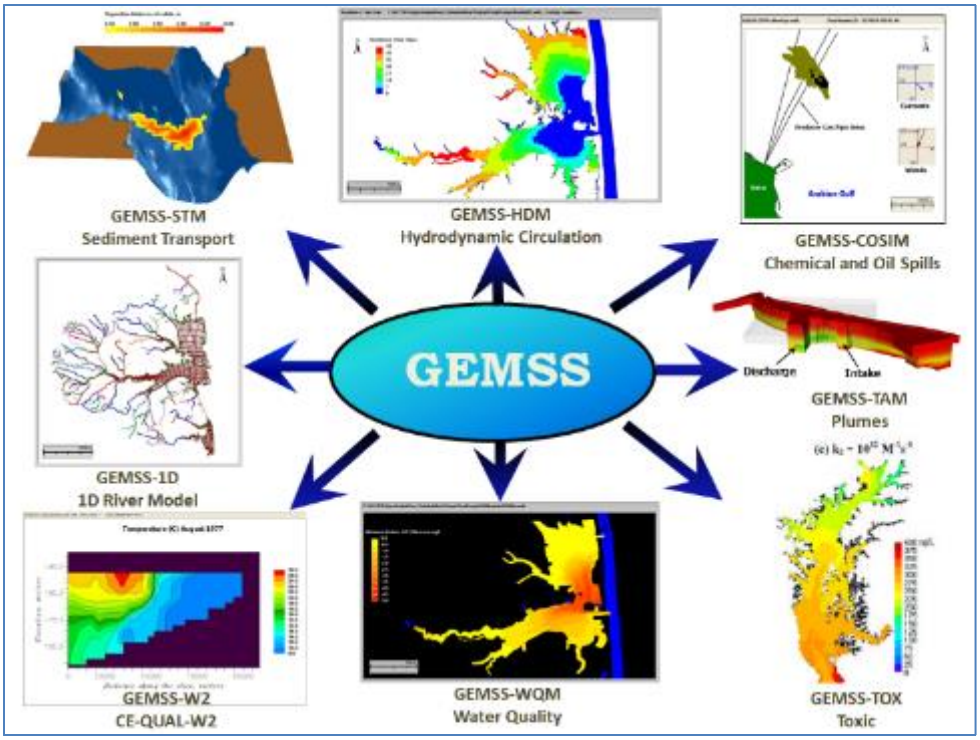
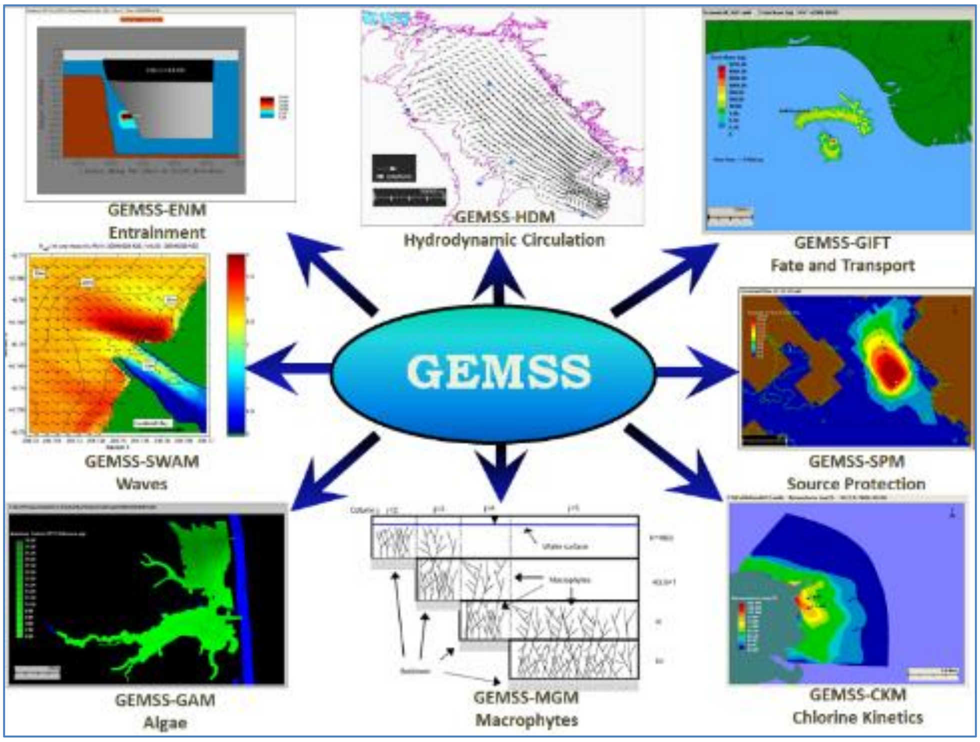


Figure 3-2 GEMSS Modules: Second Set



3.3.1 *GEMSS-COSIM*

GEMSS-COSIM is the three-dimensional oil spill module of GEMSS. The model operates both in Lagrangian and Eulerian frameworks. In the Lagrangian framework, the oil/chemical on the surface and in the water column is represented by a series of particles. The particles are advected in x-, y- and z-directions due to the combined action of tides, winds and density forcing (Kolluru, 1999). The particles are diffused using 3-D random walk method (Bear and Verruijt, 1987) in x-, y- and z-directions. The spatial and temporal variation of hydrodynamic currents, salinity and temperature can be either obtained from GEMSS-HDM or specified from other model and/or data sources. The Eulerian framework follows the scheme provided in TOXI5 model of U.S. EPA, and it can be run simultaneously with GEMSS-HDM to obtain potential toxic concentrations in the water column. The entrainment of potential toxic substances from the oil/chemical on the surface and into the water column is supplied as time and spatially variant sources in the transport equation solved in GEMSS-HDM.

3.3.2 *GEMSS-GIFT*

Modelling of the particle deposition for the riser disconnect scenario was performed using GEMSS® and its particle discharge module, GIFT. GIFT simulates the fate of particulate material discharged from dredging barges, mine tailings, drill cuttings, muds, and produced water. This three-dimensional particle-based model uses Lagrangian algorithms in conjunction with currents, specified mass load rates, release times and locations, particle sizes, settling velocities, and shear stress values.

The modelling methodology is based on a deterministic mode of simulation. In deterministic single event simulations, the starting date and current speed and direction at each time step are chosen from a database of properties in the selected periods.

The sinking movement of minerals and crystals within the mud were modelled as particles. Movement in the vertical direction resulted in the settling and deposition on the seabed. The combined action of erosion and deposition, based on particle size distribution and the intensity of release, resulted in the net accumulation on the seabed.

Modelling data requirements included:

- mud type;
- grain size distribution;
- mud density; and
- mud release rates, duration, and discharge depth.

4 AMBIENT CONDITIONS

Oil spill modelling requires hydrodynamic and meteorological data for several fate and transport parameters. These data include ocean currents, water temperature and salinity, air temperature and wind velocity (speed and direction) over the five-year study period (2013 through 2017). Data from 2018 were also collected for the October 2017 blowout scenarios, which continue into 2018.

4.1 HYDRODYNAMIC MODELLING

Hydrodynamic modelling is used to simulate the transport and mixing of the waterbody in which a spill is simulated. The hydrodynamics of the ocean within the spill model's domain comprised three main components: offshore currents, nearshore currents, and wave-influenced currents. Offshore currents were obtained externally from an independent hydrodynamic model. Nearshore currents and wave influences were computed internally within COSIM.

4.1.1 Ocean Currents, Water Temperature and Salinity

Accurate modelling requires time-varying currents, water temperature and salinity on a three-dimensional grid. To that end, data including depth-varying daily current, salinity, and water temperature were obtained from a generalized ocean model known as HYCOM (HYbrid Coordinate Ocean Model), a data assimilative, hybrid isopycnal-sigma-pressure coordinate model (www.hycom.org).

Model data are available for the earth's oceans at every 1/12° (0.0833°) spacing in latitude and longitude. Vertically, values of current, salinity, and temperature are available every 10 m for depths 0–30 m, 25 m for 50–150 m, 50 m for 200–300 m, 100 m for 400–1500 m, and continue with increased spacing to 5500 m (where available). Figure *4-1* and Figure *4-2* provide an example of the output from the HYCOM model for the current speed vectors at the water surface. Note the high velocities of the Agulhas Current southwesterly and parallel to the eastern African coastline, as well as the various circulating eddies along the Tugela Shelf, off the continental shelf (such as in the Natal Bight where Eni has an Exploration Right), and below the African continent where the warm Agulhas Current meets the cold Benguela Current from the west coast.

Figure 4-1 HYCOM Current Velocities, January 1, 2015 (water surface)

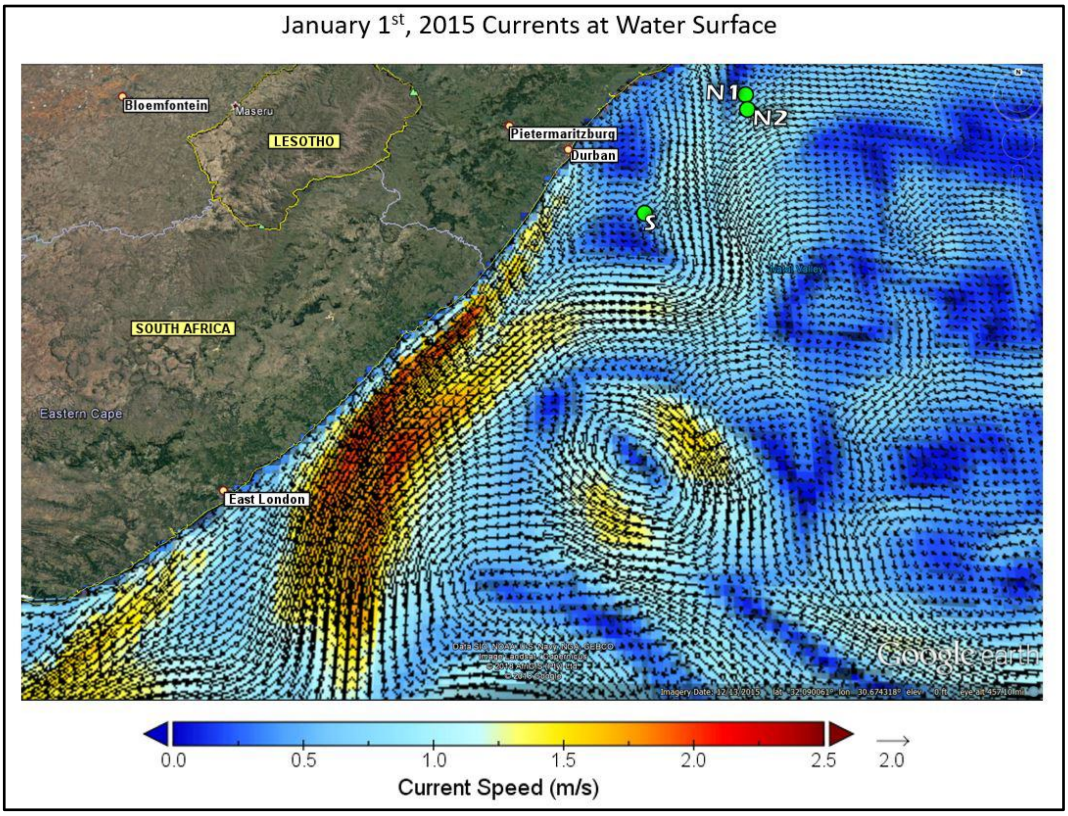
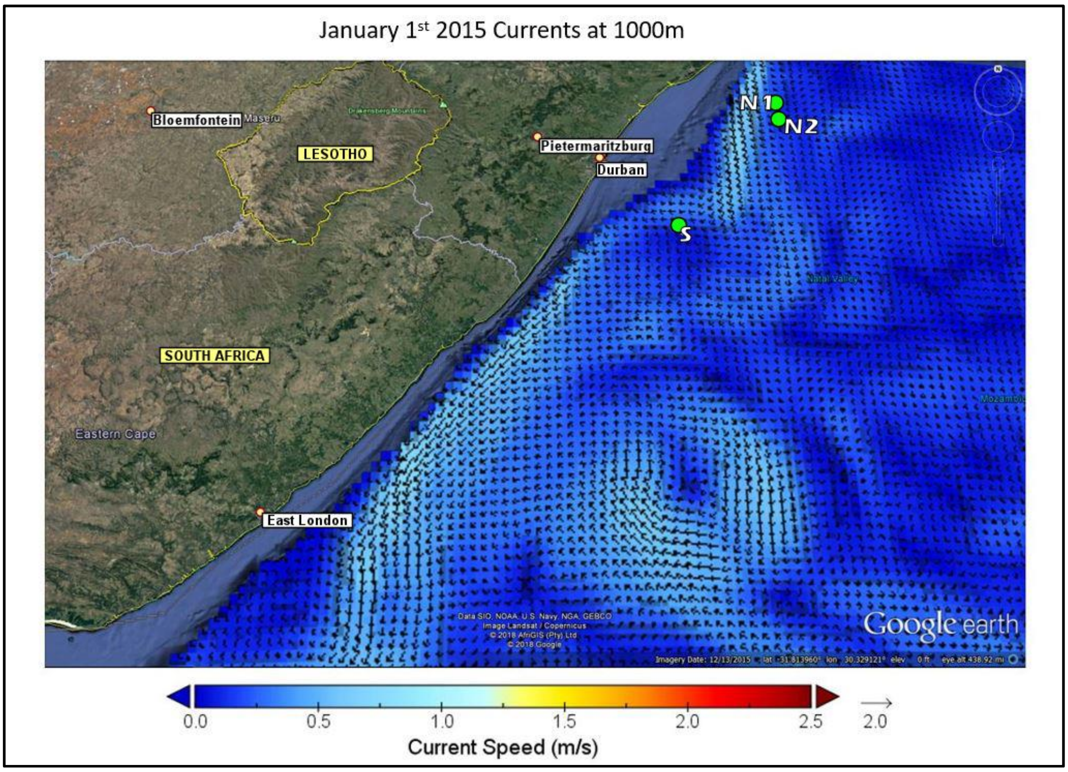


Figure 4-2 HYCOM Current Velocities, January 1, 2015 (1000 m depth)

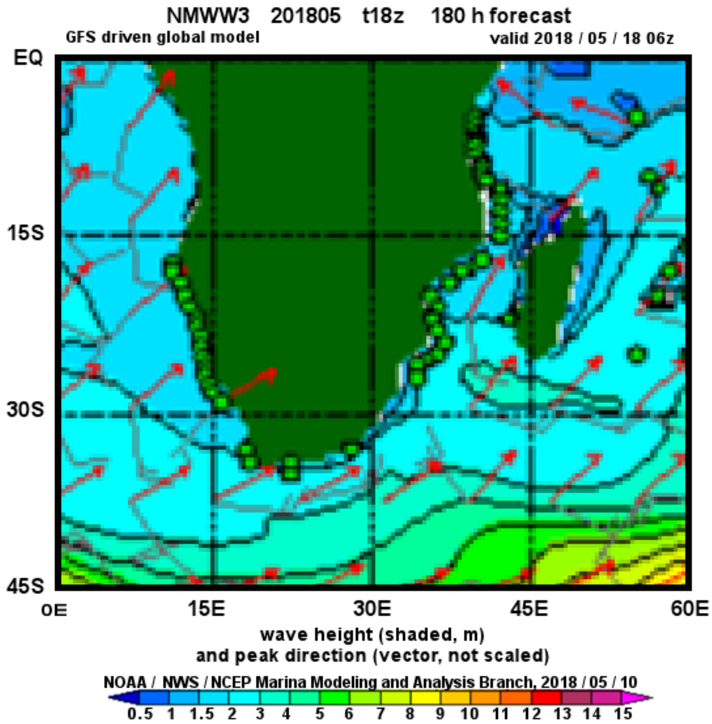


4.1.2 Wave Data

The HYCOM global circulation model does not include wave induced stresses on the current velocity. Therefore, wave data were applied to COSIM in addition to HYCOM's current velocities. Wave data were obtained from NOAA

WAVEWATCH III®, a publicly available product from the U.S. National Oceanic and Atmospheric Administration (NOAA), and their Marine Modelling and Analysis Branch of the Environmental Modelling Center at the National Centers for Environmental Prediction (Figure *4-3*). Within WAVEWATCH III®, the Global database for the Atlantic and Indian Oceans was used to obtain wave heights, wave periods, and peak directions every three hours in a grid spaced with data every 0.5° latitude and longitude.

Figure 4-3 WAVEWATCH III® Output for the Atlantic Ocean Region (Source: NOAA, 2018)



4.1.3 *Nearshore Currents*

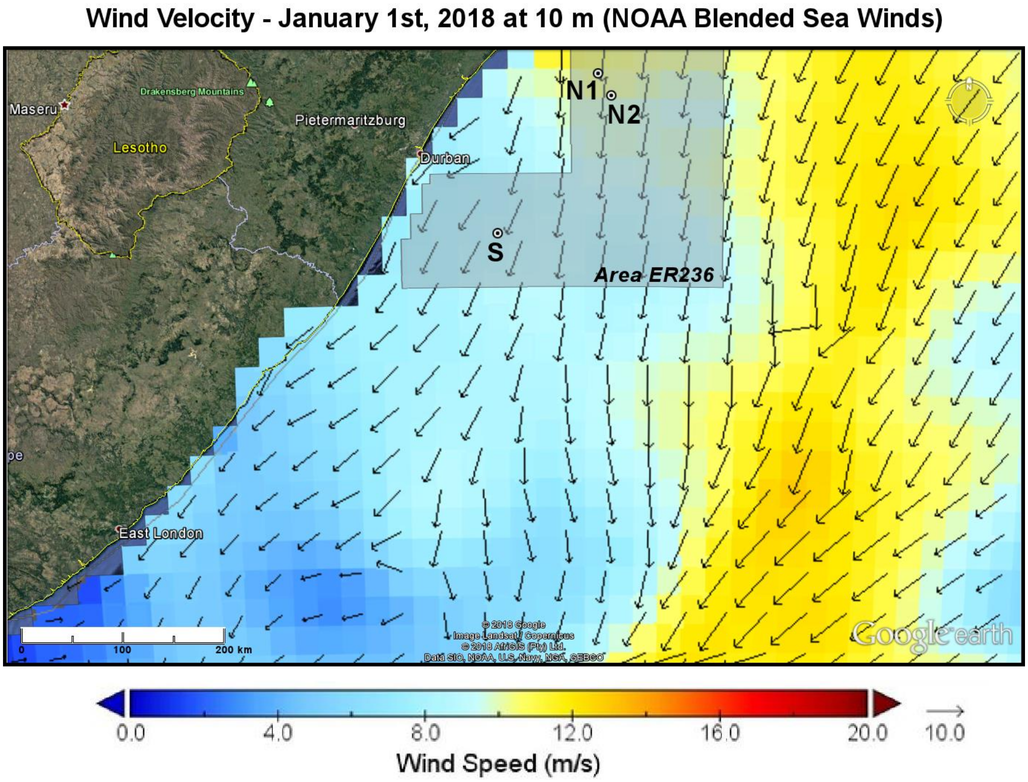
COSIM includes a built-in nearshore module to compute longshore currents within several hundred meters from the coastline. The module uses wave data to compute current vectors as a function of distance to shoreline, coastal slope, wave approach angle, wave frequency, and other factors. In addition to longshore currents, the module also computes Stoke's wave drift and local wave heights and orbital velocities.

4.2 *METEOROLOGY*

4.2.1 *Wind Data*

Wind data were gathered from the Blended Sea Winds database (Zhang *et al*, 2006), a product of the NOAA's National Climatic Data Center (NCDC). The database includes ocean surface wind speeds and directions and wind stress on a global grid with 0.25 x 0.25 arc-degree resolution (Figure *4-4*). The wind data are generated by interpolating among multiple-satellite observations to fill in the temporal and spatial data gaps of individual-satellite samples and reduce the subsampling alias and random errors. The spill model reads spatially and temporally varying winds with values every six hours for the period of January 2013 to February 2018. The model will respond with an approximate wind value if the database is absent a value at a location where the simulated oil is present.

Figure 4-4 Example Wind Speed Vectors along the East African Coastline



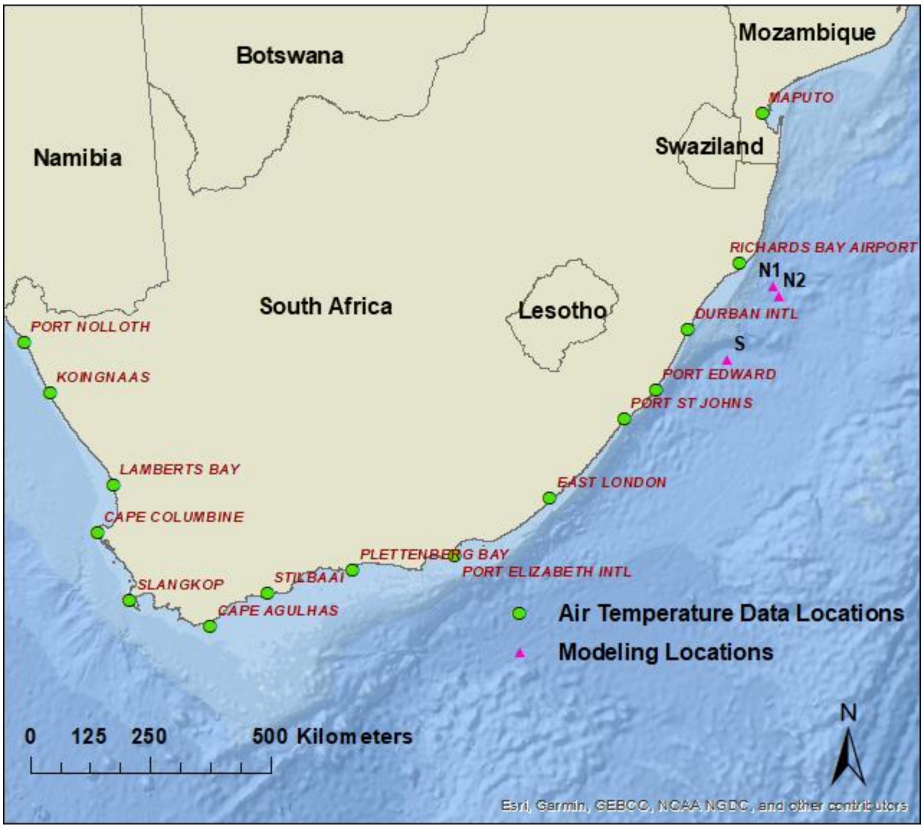
Wind speed affects the rate of evaporation and the amount of natural dispersion entraining oil droplets at the water surface by wave energy. The wind speed and direction also influences the transport of a surface slick by applying a wind shearing force upon the floating oil layer. Though wind also affects the movement of the water beneath the slick, those influences are already implemented into the hydrodynamic model used in these analyses.

4.2.2 *Air Temperature Data*

Air temperature affects the weathering of oil floating on the water surface. Measured hourly, air temperature data was obtained from the US NOAA's National Center for Environmental Information (NCEI)[1]. NCEI provides a geospatial database of weather stations. From this data, 15 stations were selected from which hourly air temperature data was obtained. The locations and names of these stations are provided in Figure 4-5.

[1] https://gis.ncdc.noaa.gov/maps/ncei/cdo/hourly

Figure 4-5 Locations of NOAA NCEI Air Temperature Stations Used



5 OIL SPILL MODELLING

5.1 SCENARIO DESIGN

As discussed previously, three spill scenarios were evaluated as part of this study. These three scenarios are:

- Scenario 1 – vessel collision releasing diesel;
- Scenario 2 – blowout at the wellhead; and
- Scenario 3 – riser disconnect releasing NADF.

A total of ten (10) simulations were conducted, which included two scenarios at the three drilling locations (2 scenarios x 3 locations = 6 simulations) for Scenarios 1 and 3, and two blowout scenarios at two drilling locations for Scenario 2 (2 scenarios x 2 locations = 4 simulations). Each simulation included multiple iterations covering a range of hydrodynamic and meteorological conditions. These iterations were started with the spill release beginning at equally spaced time intervals throughout a five-year period from January 2013 to October 2017. For each of the ten simulations, the model was run for 120 iterations throughout these five years.

Table 5.1 shows the spill volume released for each scenario, the release depth, and the spill duration. The model was run to simulate 7 additional days after release (diesel, riser disconnect) ended, or 14 days after the two blowout releases has stopped. The total simulation duration for each scenario is also listed in *Table 5.1*

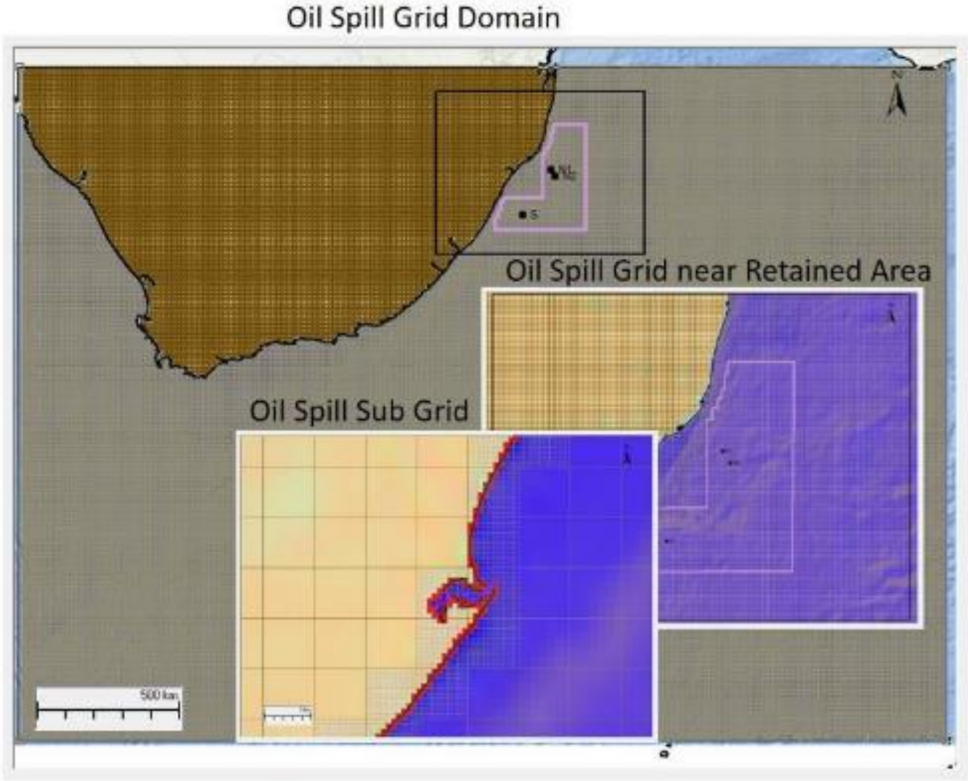
Table 5-1 Release Descriptions

Scenario	Description	Amount Released	Spill / Simulation Durations	Release Depth (from surface)
Scenario 1	Diesel Spill – Vessel Accident	N1/N2/S: 5000 bbl (794.9 m^3)	1 hour / 7 days	N1: 0.5 m N2: 0.5 m S: 0.5 m
Scenario 2a	Crude Blowout – Hole Collapse	Constant Release Rate N1: 4,717 bpd (750 m^3/d) S: 6,604 bpd (1,050 m^3/d	7 days/ 21 days	N1: 1,623 m S: 2,883 m
Scenario 2b	Crude Blowout – Cap Install		20 days/ 34 days	
Scenario 3	NADF Release - Riser Disconnect	N1: 1,867 bbl (296.9 m^3) N2: 2,094 bbl (332.9 m^3) N2: 3,318 bbl (527.5 m^3)	1 hour / 7 days	N1: 0.5 m N2: 0.5 m S: 0.5 m

For Scenario 3, the base oil is assumed to be 60% of the NADF volume, based on typical proportions provided in a database of historical riser disconnect events published by the US Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE, 2011). The remaining 40% of the volume is assumed to be minerals and crystals used for the particle deposition modelling.

An oil spill grid with 600 by 445 cells was constructed to cover an area approximately 3,131 km by 2,280 km in the east-west and north-south directions, respectively. Each grid cell was classified as land, water, or shoreline. Particles representing the oil may only move in water cells. Every water grid has a depth value assigned to it. Shoreline grid cells, which act as a barrier between water and land cells, were further divided into 100 sub-grid cells to provide a finer delineation of the coastline. Shoreline oiling occurs when a modelled particle contacts a shoreline cell. The oil spill grid, with an inset of the shoreline subgrid, is shown in *Figure 5-1*.

Figure 5-1 Oil Spill Grid Domain with Close-Up of the Shoreline Subgrid



5.2 *MODEL INPUTS*

Modelling oil behavior in oceanic environments requires consideration of both winds and currents. The direct influence of winds on oceanic transport is primarily near the surface, and decreases rapidly with depth. The fate and transport of oil within the water column below the surface are primarily a function of ambient ocean currents at those depths.

Available datasets for these forcing functions that represent conditions offshore of the Kwa-Zulu Natal coast of South Africa near the hypothetical spill location were obtained and used in the modelling effort. As noted earlier, both winds and currents were applied for the actual dates of each iteration, selection of which was made such that individual iterations represented a range of observed conditions in the region.

This modelling study used data obtained from publicly available records. Spatially and temporally varying data were collected to characterize this area and determine appropriate simulation periods.

Model inputs were gathered and formatted for use with COSIM and GIFT. These input data included:

- Previous studies of the site with respect to coastal oceanography and available hydrodynamic data from global circulation models;
- Regional bathymetric data;
- Shoreline shapefiles;
- Hydrodynamic data (current speed and direction; water temperature; salinity);
- Wave data (significant height of combined wind waves and swell, primary wave mean period, primary wave direction);
- Meteorological data (air temperature, wind speed and direction); and
- Oil and NADF properties.

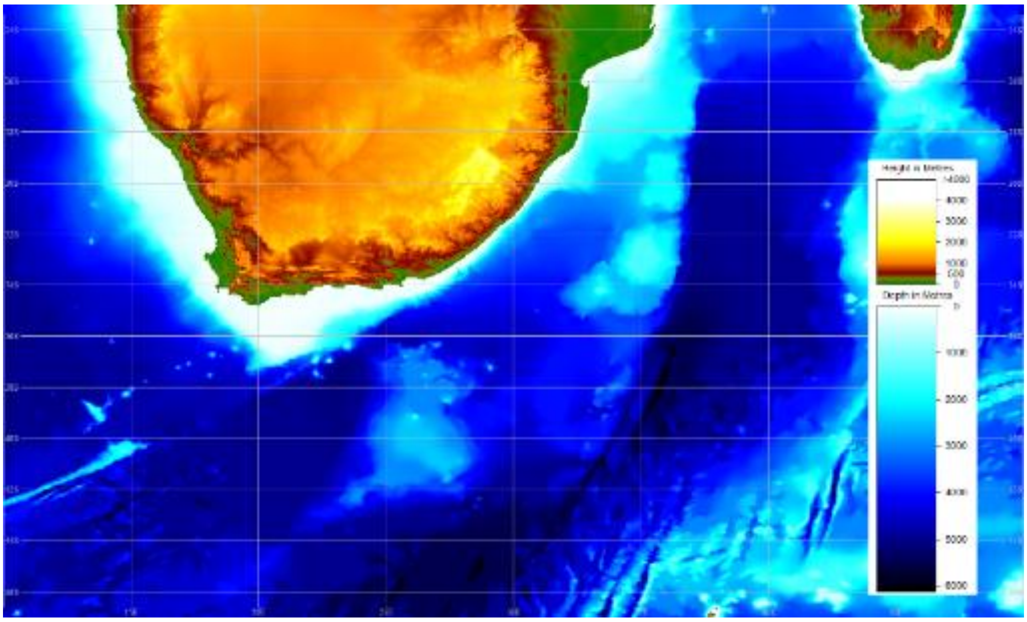
Hydrodynamic and meteorological data are described in Section 4.1 and Section 4.2 respectively. The other datasets are described in the following sections as spatially or temporally varying data.

5.2.1 *Spatial Data*

The bathymetric data is the primary spatial dataset used to describe the depth and shape of the seafloor. These are used to develop grids for the oil spill models. The General Bathymetric Chart of the Oceans (GEBCO) was used to extract seafloor bathymetry at the study site (IOC *et al*., 2003). The database used for this study is the GEBCO_08 Grid which has a 30 arc-second resolution. GEBCO bathymetry offshore of South Africa is presented in *Figure 5-2.*

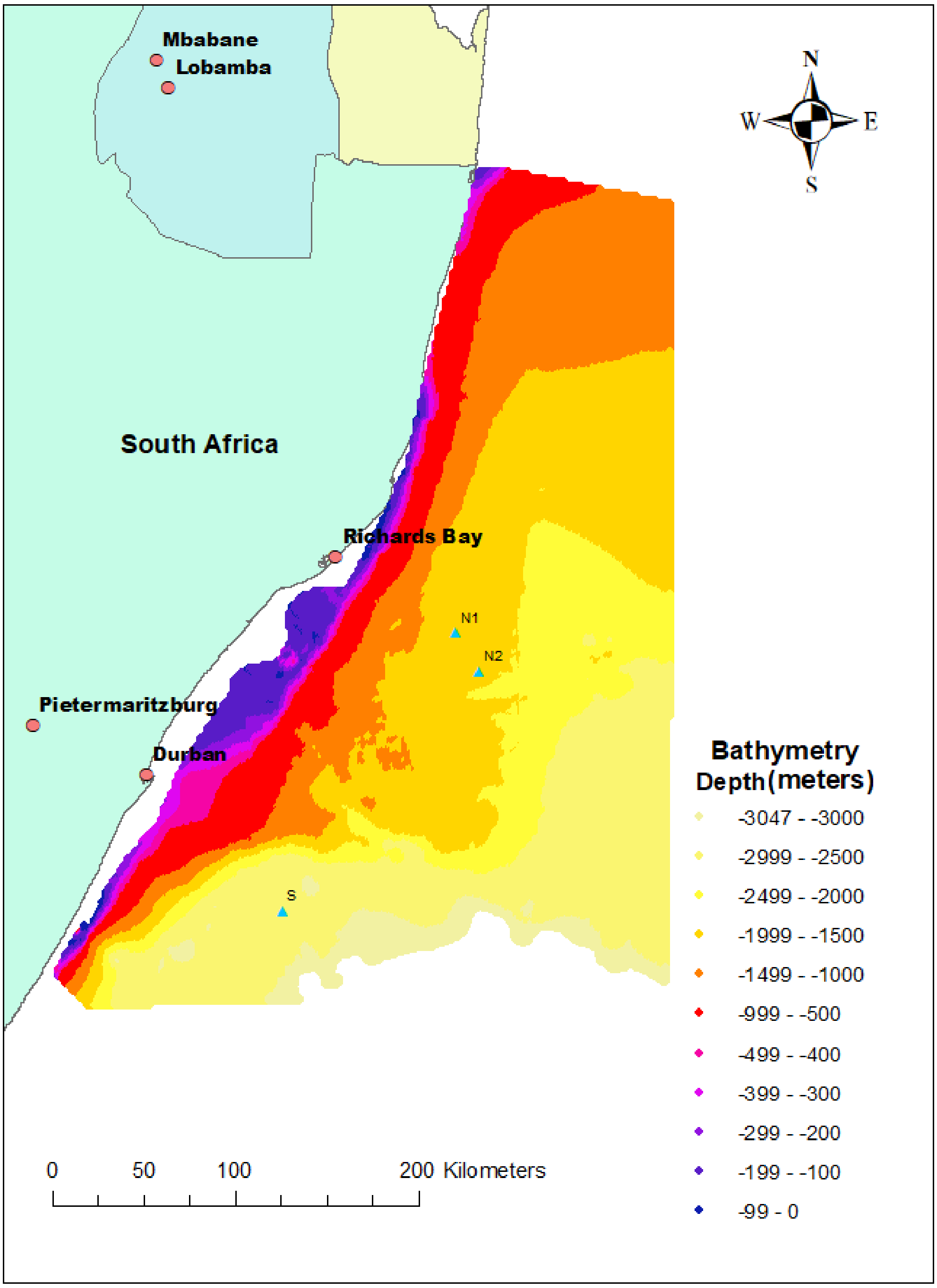
Geo-referencing the model's spatial data enabled accurate and consistent mapping within the GEMSS® framework. In addition, polyline shapefiles of the African coastline, and nearby islands act as a boundary in the model domain between land and water. Shapefiles of these coastlines were obtained from ESRI's World Boundaries and Places Alternate product.

Figure 5-2 GEBCO Bathymetry Source: GEBCO (IOC et al, 2014)



In addition, Eni SA provided high-resolution bathymetric data in the vicinity of the block location (Figure 5-3). Depth values were provided every 1 km in an orthogonal grid roughly in the shape of a triangle approximately 450 km in the east-west direction by 330 km in the north-south direction along the coast.

Figure 5-3 High-Resolution Bathymetry (Source: Eni, 2018)



5.2.2 *Time-varying Data*

The time-varying data for the model include ocean current speed and direction; water temperature and salinity; wave data, wind speed and direction; and air temperature. Ocean currents, water temperature, and salinity were provided by the HYCOM model, as described in Section 4.1.1. Information on wave data and nearshore current calculations are provided in Section 4.1.2 and Section 4.1.3

respectively. Sources of the meteorological data (wind velocity) were obtained from NOAA SEAWINDS, as described in Section 4.2.1. Measured air temperature data were obtained from NOAA's National Climatic Data Center (NCDC) and details are provided in Section 4.2.2.

5.2.3 *Oil Properties*

The chemical compounds within oil vary in terms of solubility, vapor pressure, density, and other properties. As such, the fate of the oil will likewise vary compound by compound such that over time, soluble and volatile components will exit the liquid oil first leaving behind a more insoluble and nonvolatile weathered oil. For modelling purposes in this study, the oil is divided into several major component classes so that the fate of each class can be computed separately.

COSIM calculates the fate and transport of each component of the oil separately. The total volume released is divided between each component group based on the mass proportions. The mass proportions are converted into volumetric proportions based on each component group's average density.

Components of a typical diesel (*Table 5.2*) and their properties (such as density, boiling point, solubility, etc.) were obtained from ERM's COSIM database of oil properties.

The base oil used in the NADF release simulation was assumed to be similar to a Baroid Alkane™ (Halliburton, 2010) paraffin-based synthetic fluid with a density of 793 kg/m^3. This low-toxicity base oil is comprised primarily of alkanes. Using properties of an example low toxicity base oil, AMC SARAPAR 147 (AMC Oil & Gas, 2012), aromatics comprise less than 0.01% of the oil by mass, while the saturated paraffinic oil mainly had carbon chain lengths in the C14 to C18 range. A range of aliphatics between C5 and C20 were assumed, with a parabolic distribution of volumes emphasizing those in the middle range (*Table 5.3*).

The properties of the crude oil were not available for this study. Therefore, the modelled crude oil was based on other western African crude oil analyses using data (American Petroleum Institute [API] gravity of 30.8, dynamic viscosity of 2.4 centipoise at 25°C) with additional information gathered from ERM's database of crude oil properties compiled from other assays. The crude oil component properties are simplified into the following nine groups:

- BTEX Monoaromatics;
- CC5-CC6 Cycloalkanes;
- C5-C6 Aliphatics;
- C7-C10 Aliphatics;
- C11-C17 Aliphatics and Cycloalkanes;
- C18-C22 Aliphatics;
- C23-C27 Aliphatics;
- C28-C35 Aliphatics; and

- C36-C40 Aliphatics & Heavy Residuals.

The volumetric proportions of these nine components are provided in *Table 5.4.* The volume of crude oil released in Scenario 2 is assumed to be absent of the dissolved gases (such as methane) which typically escape from the oil following extraction from the reservoir after the pressure surrounding the oil is reduced to atmospheric pressure. Therefore, the volumetric proportions of the crude oil components are absent of the dissolved gases and the flow rates for is assumed to be in "stock tank barrel" units per day.

Table 5.2 Volumetric Proportions of Diesel

Component	Volume %	Component	Volume %
Benzene	0.30%	Octane	9.13%
Toluene	1.50%	Indane	3.30%
Ethylbenzene	2.50%	Indene	0.90%
Xylenes	9.20%	Decalin	5.90%
Naphthalene	2.70%	Decane	15.90%
Heptane	9.13%	Pentane	9.13%
Methylcyclohexane	21.30%	Hexane	9.13%
Total			100.0%

Table 5.3 Volumetric Proportions of Base Oil

Component	Volume %	Component	Volume %
MAH	0.34%	C15	14.44%
PAH	0.34%	C16	5.24%
C5-C10	12.91%	C17	4.58%
C10-C14	27.75%	C18-C19	3.81%
C14	27.75%	C20	2.84%
Total			100.0%

Table 5.4 Volumetric Proportions of Crude Oil

Component	Volume %	Component	Volume %
MAH	3.00%	C18-C22	11.20%
CC5-CC6 Cyclo	1.65%	C23-27	9.07%
C5-C6	5.56%	C28-C35	9.98%
C7-C10	13.62%	C36-C40	23.68%
C11-C17 / Cyclo	22.24%		
Total			100.0%

5.2.4 *NADF Solids Properties*

NADF is a mixture of base oil with solid particles (typically barium sulfate with other minerals and crystals such as calcium chloride, calcium hydroxide, silica, etc.). A density of 1,150 kg/m³ has been used for this simulation. For the deposition modelling, assuming a complete separation of the oil and solid particles, the density of the solid particles was calculated as 1,735 kg/m³ by computing the volumetric weighted average of 40% solids and 60% oil. These density values for the NADF and its two primary components are summarized in *Table 5.5*.

Table 5.5 Assumed Densities of NADF and its Components

Substance	Density (kg/m³)	% of SBM
Base oil	760	60%
Solid particles	1,735	40%
SBM + base oil	1,150	100%

A typical grain size distribution of NADF particles used in this study was provided by a confidential client of ERM and is listed in *Table 5.6.*

Table 5.6 NADF Grain Size Distribution

Class	Particle Size (µm)	Percent Volume
1	4	7%
2	6	8%
3	9	5%
4	12	10%
5	15	13%
6	16	14%
7	20	19%
8	28	19%
9	46	4%
10	77	1%

5.3 *MODEL RESULTS*

Summaries of the model results of worst case iterations of vessel collision diesel spill, the crude oil blowout and the NADF release together with their shoreline and surface oiling probabilities are presented in *Table 5.7* through Table *5.10*. Worst cases iterations presented in this report include:

- **Criterion 1**: Largest Amount of the Water Surface Area Oiled (Worst Case Surface Oiling)
    - o Area where surface oil thickness is greater than 1.0 µm but less than 10.0 µm (i.e. moderate exposure threshold surface oiling – see explanation in Section 3.2.2)
    - o Area where surface oil thickness is greater than 10.0 µm (i.e. high exposure threshold surface oiling – see explanation in Section 3.2.2)

    - Areas in both moderate and high exposure threshold categories (oil thickness is greater than 1.0 µm) are depicted in the model output figures.
- **Criterion 2**: Most Amount of Shoreline Oiling Mass (Worst Case Shoreline Oiling)
    - Length of coastline where oil is reaching and accumulating on the coastline. For the blowout scenarios, a threshold is applied defining impacts when oiling is greater than 100 g/m² (i.e. significant shoreline oiling – see explanation in Section 3.2.2)
- **Criterion 3**: Fastest Time for Shoreline Oiling to Occur (Fastest Shoreline Oiling)
    - The shortest number of days for first contact to occur between oil and the shoreline. No threshold for oil mass per shoreline area is considered.

As described within Section 3.2, worst cases for Scenario 2 have been analysed for two seasons (Season 1 for summer and autumn, and Season 2 for winter and spring) for releases at N1 and S for two blowout scenarios, while for Scenario 1 and Scenario 3, one single worst case has been reported for each location (N1, N2 and S). The results are described in detail in Section 5.4 (Scenario 1), Section 5.5 (Scenario 2) and Section 5.7 (Scenario 3).

Table 5.7 Diesel Spill Modelling Worst Cases Results Summary – Scenario 1

Drilling Location	Criterion 1: Largest Amount of the Water Surface Area Oiled above 1 µm Threshold (km²)	Criterion 1: Largest Amount of the Water Surface Area Oiled above 10 µm Threshold (km²)	Criterion 2: Most Amount of Shoreline Oiling Mass - Shoreline Length (km)	Criterion 3: Fastest Time for Shoreline oiling to Occur (days)	Probability of Any Shoreline Contact with Oil
N1	1,896	210	205	2.60	7.5%
N2	1,684	147	366	3.30	3.3%
S	2,848	243	336	2.80	15.0%

(Note: this is modelled without the inclusion of any mitigation /containment measures, which represents an unrealistic condition)

Table 5.8 Modelling Worst Cases Results Summary - Crude Oil Release from Hole Collapse – Scenario 2a

Season	Criterion 1: Largest Amount of the Water Surface Area Oiled above 1 µm Threshold (km²)	Criterion 1: Largest Amount of the Water Surface Area Oiled above 10 µm Threshold (km²)	Criterion 2: Most Amount of Shoreline Oiling Mass > 100 g/m² - Shoreline Length (km)	Criterion 3: Fastest time for Shoreline Oiling to Occur (days)	Probability of Any Shoreline Contact with Oil
Season*	**Drilling Location N1**				
Season 1	401	0	0	5.75	70.0%
Season 2	348	0	0	4.25	55.0%
	Drilling Location S				
Season 1	3,049	0	0	6.00	73.3%
Season 2	669	0	0	5.00	80.0%

*Season 1 = summer/autumn; Season 2= winter/spring

(Note: this is modelled without the inclusion of any mitigation /containment measures, which represents an unrealistic condition)

Table 5.9 Modelling Worst Cases Results Summary - Crude Oil Release before a Cap Installation – Scenario 2b

Season	Criterion 1: Largest Amount of the Water Surface Area Oiled above 1 µm Threshold (km²)	Criterion 1: Largest Amount of the Water Surface Area Oiled above 10 µm Threshold (km²)	Criterion 2: Most Amount of Shoreline Oiling Mass > 100 g/m² - Shoreline Length (km)	Criterion 3: Fastest Time for Shoreline Oiling to Occur (days)	Probability of Any Shoreline Contact with Oil
	Drilling Location N1				
Season 1	615	0	0	5.75	96.7%
Season 2	695	0	0	7.00	90.0%
	Drilling Location S				
Season 1	4,386	0	0	6.50	96.7%
Season 2	1,391	0	0	5.25	96.7%

*Season 1 = summer/autumn; Season 2= winter/spring

**(Note: this is modelled without the inclusion of any mitigation /containment measures, which represent an unrealistic condition*)*

Table 5.10 Riser disconnect modelling worst cases results summary – Scenario 3

Drilling Location	Criterion 1: Largest Amount of the Water Surface Area Oiled above 1 µm Threshold (km²)	Criterion 1: Largest Amount of the Water Surface Area Oiled above 10 µm Threshold (km²)	Criterion 2: Most Amount of Shoreline Oiling Mass - Shoreline Length (km)	Criterion 3: Fastest Time for Shoreline Oiling to Occur (days)	Probability of Any Shoreline Contact with Oil
N1	1,232	0	119	2.5	8.3%
N2	873	0	249	3.2	5.8%
S	2,046	0	186	2.7	15.0%

(Note: this is modelled without the inclusion of any mitigation/containment measure, which represents an unrealistic condition)

5.4 SCENARIO 1 – VESSEL COLLISION DIESEL RELEASE

The vessel collision scenario simulates the loss of diesel fuel oil as a result of an accidental collision. The volume of release is 5,000 bbls, assumed to occur over a one-hour period. The simulation continued to track the spill for 7 days after the end of the release, for a total of 7 days simulated. The model was run multiple times (mostly biweekly) to simulate releases from January 2013 through October 2017 as described in Section 5.1. The results are summarized in Table *5.11*. From these iterations, model output diagrams are provided for worst case iterations describing the shortest time for shoreline oiling to occur, the most amount of shoreline oiling, and the largest amount of the water surface area oiled.

It has to be stated that the following results and maps refer to very unlikely and rare unplanned events without accounting for any mitigation and intervention measure that will be performed.

Regarding the selection of a spill volume of 5,000 bbl: usually fuel on board a large vessel is never stored in one single tank, particularly for rig stability. Commonly Semisub/Drilling Ship have a capacity of fuel from about 2,000 m^3 - 12,000 bbls, split in multiple tanks, with differences based on ship design. For example, Saipem 12000, one of the biggest drilling ships, consumes a maximum of 30 to 35 metric tons of fuel during drilling and 40 to 45 metric tons during navigation with a total fuel load capacity of 6,700 m^3 equivalent to around 42,000 bbls. A standard supply vessel that will transport fuel to the drilling units has usually a total fuel capacity of 800 m^3 equivalent to 5,000 bbls, with about 4 to 6 tanks, each with a capacity of about 150 m^3 (~950 bbls). In conclusion, 5,000 bbl of diesel is overestimating a spill from supply vessel or when considering the spill from large tanks of the drilling ship.

Table 5.11 Diesel spill modelling worst cases results summary – Scenario 1

Drilling Location	Criterion 1: Largest Amount of the Water Surface Area Oiled above 1 μm Threshold (km²)	Criterion 1: Largest Amount of the Water Surface Area Oiled above 10 μm Threshold (km²)	Criterion 2: Most Amount of Shoreline Oiling Mass - Shoreline Length (km)	Criterion 3: Fastest Time for Shoreline oiling to Occur (days)	Probability of Any Shoreline Contact with Oil
N1	1,896	210	205	2.6	7.5%
N2	1,684	147	366	3.3	3.3%
S	2,848	243	336	2.8	15.0%

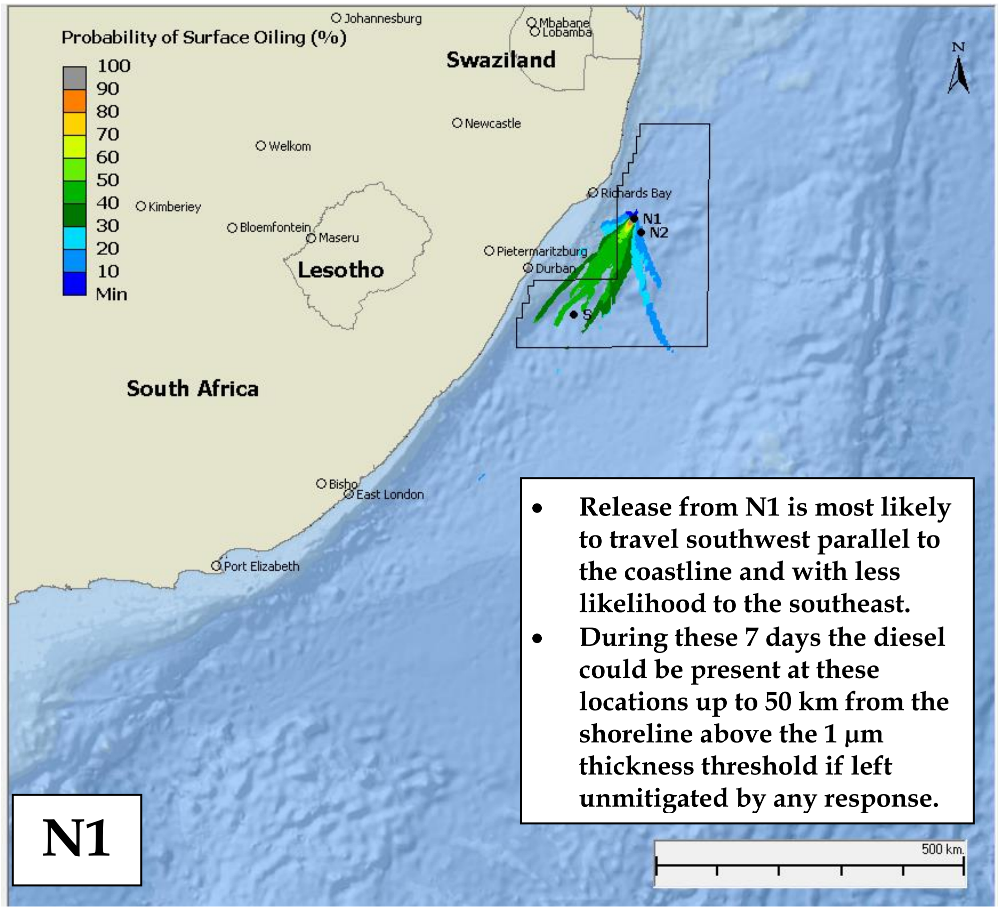
(Note: This is modelled without the inclusion of any mitigation /containment)

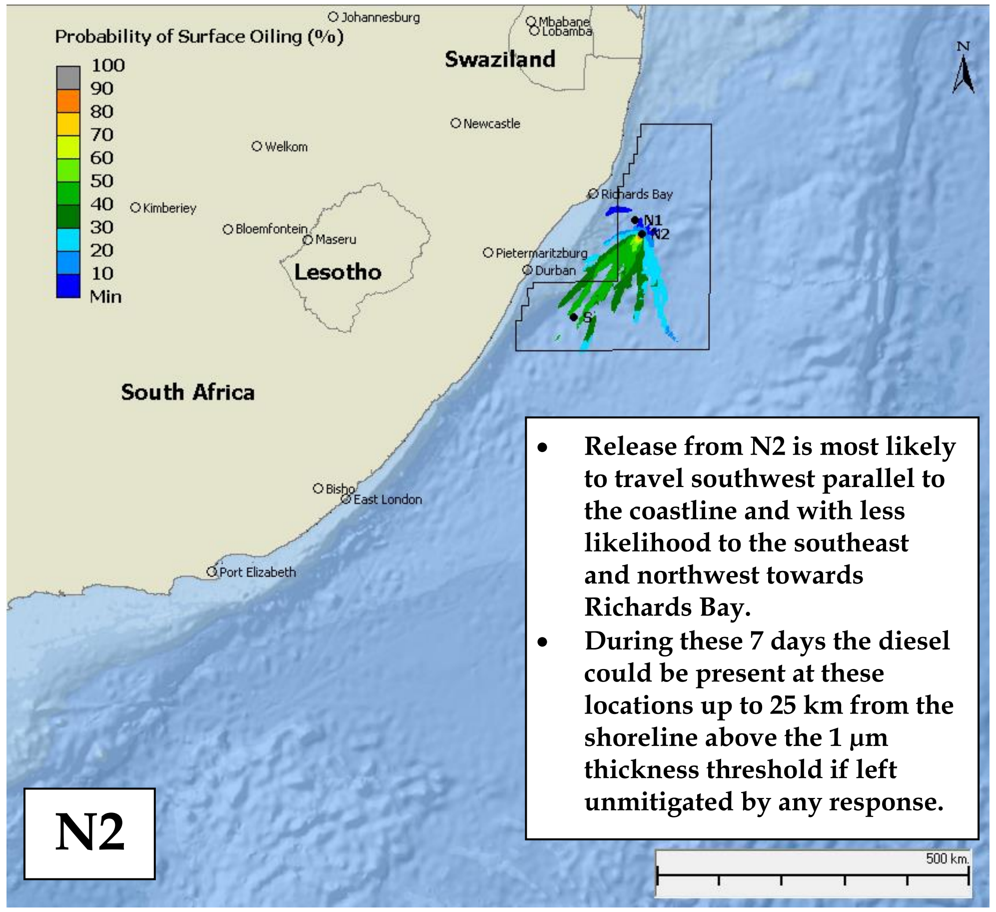
Figure 5-4 presents the full extents of where oil thickness is greater than a 1.0 μm minimum thickness for smothering of aquatic organisms and wildlife after vessel collision diesel spills at three modelling locations (N1, N2 and S). The area of potential surface trajectories are coloured according to the probability of oil travelling to a given location **at least once through the five-year analysis**. As described in the Scenario Design in Section 5.1, each spill scenario is run 120 times (iterations) with the spill's start date evenly spaced across the five year period. This provides for a variety of combinations of wind and ocean current combinations to predict the range of potential spill trajectories. The most common trajectory occurs in south-west direction with the strong influence of Agulhas Currents parallel to the coastline.

It is unlikely that such a spill at any of the three spill locations (N1, N2 and S) would carry oil slick with thickness greater than the 1.0 μm minimum smothering thickness to an area within 20 km off South African coastline. In the absence of response efforts, the smothering slick of oil is able to travel over 230 km, 215 km, and 320 km from the release points N1, N2 and S respectively before weathering away into a thinner sheen.

Figure *5-5* presents the probability of shoreline oiling for vessel collision diesel spills at three modelling locations (N1, N2 and S). The locations of impact from the 7-day simulations within the five-year period range from the Durban to East London. The longest length of shoreline oiling in the individual worst case shoreline oiling iterations are 205 km, 366 km and 336 km for spills at locations N1, N2 and S respectively. Regardless of the shoreline oiling threshold, out of the 120 iterations over the five years, the probability of any shoreline oiling occurring at any shore is 7.5%, 3.3% and 15.0% of the time for locations N1, N2 and S respectively. However, as shown in the colored shorelines in Figure *5-5* any individual location has less than a 10% chance of oil contacting it. **Note that unlike crude oil, diesel fuel is unlikely to form sticky emulsions or tarballs. Shoreline cleanup is often not needed as diesel typically degrades naturally.**

Figure 5-4 Scenario 1: Vessel Collision Diesel Spill - Probability of smothering surface oiling (>1.0 µm) for spill at N1, N2 and S





Figures Description

Scenario 1 Vessel Collision Diesel Spill

These figures show the probability of oil being present at a location on the water surface over a 7-day period from a ***very unlikely*** oil spill due to a vessel collision resulting in an oil thickness above the threshold level for potentially smothering birds and wildlife (> 1 µm). The colored contours depict the probability of oil's presence at a location at least once out of 120 spill simulations with spill release dates starting twice monthly over a five year period.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

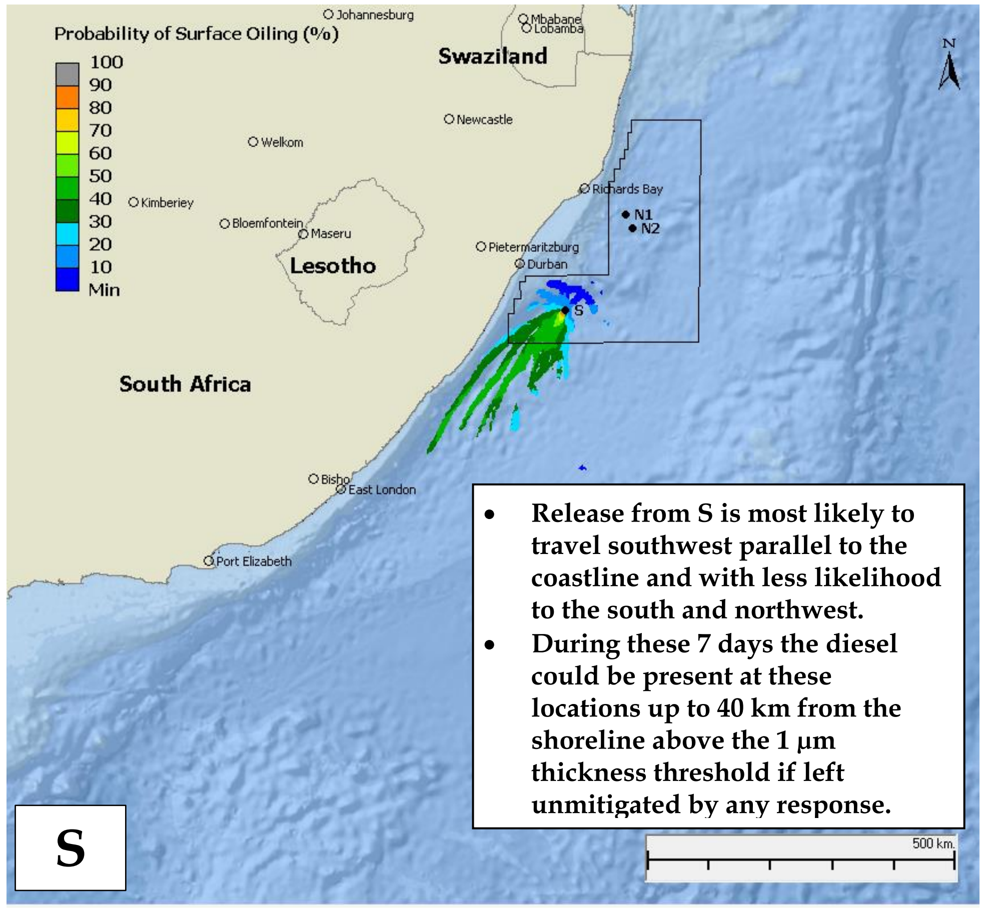
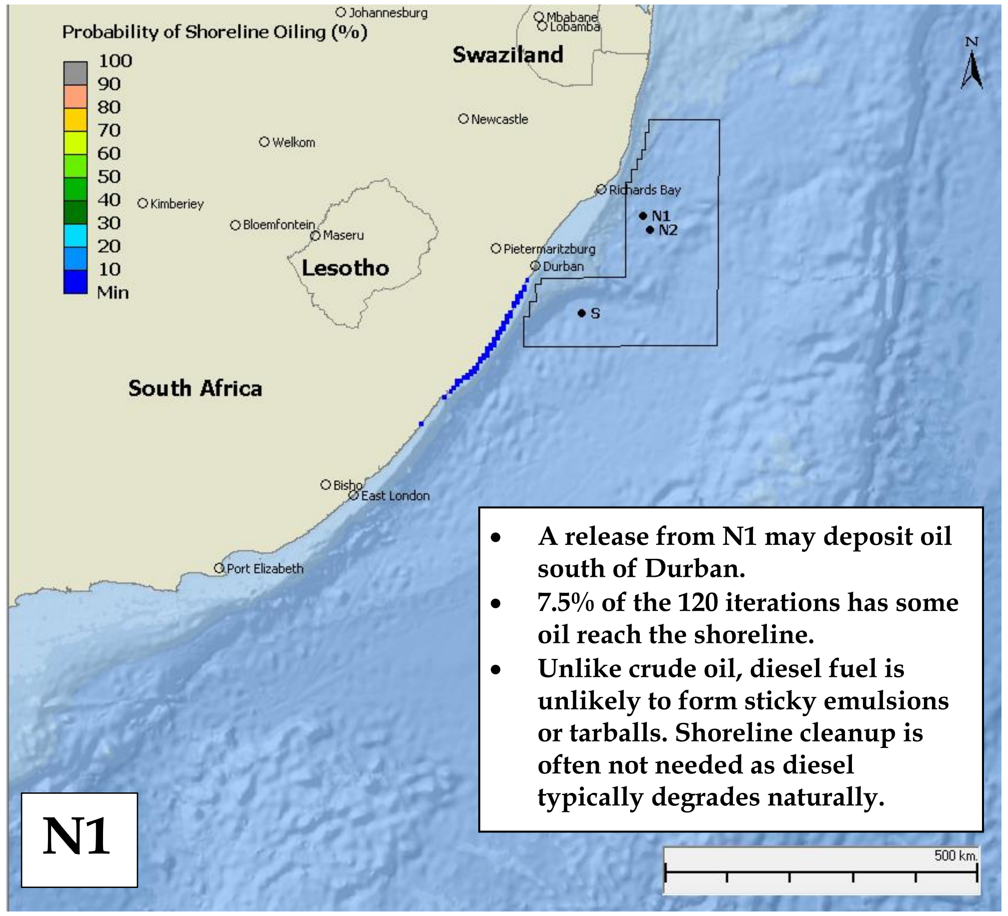
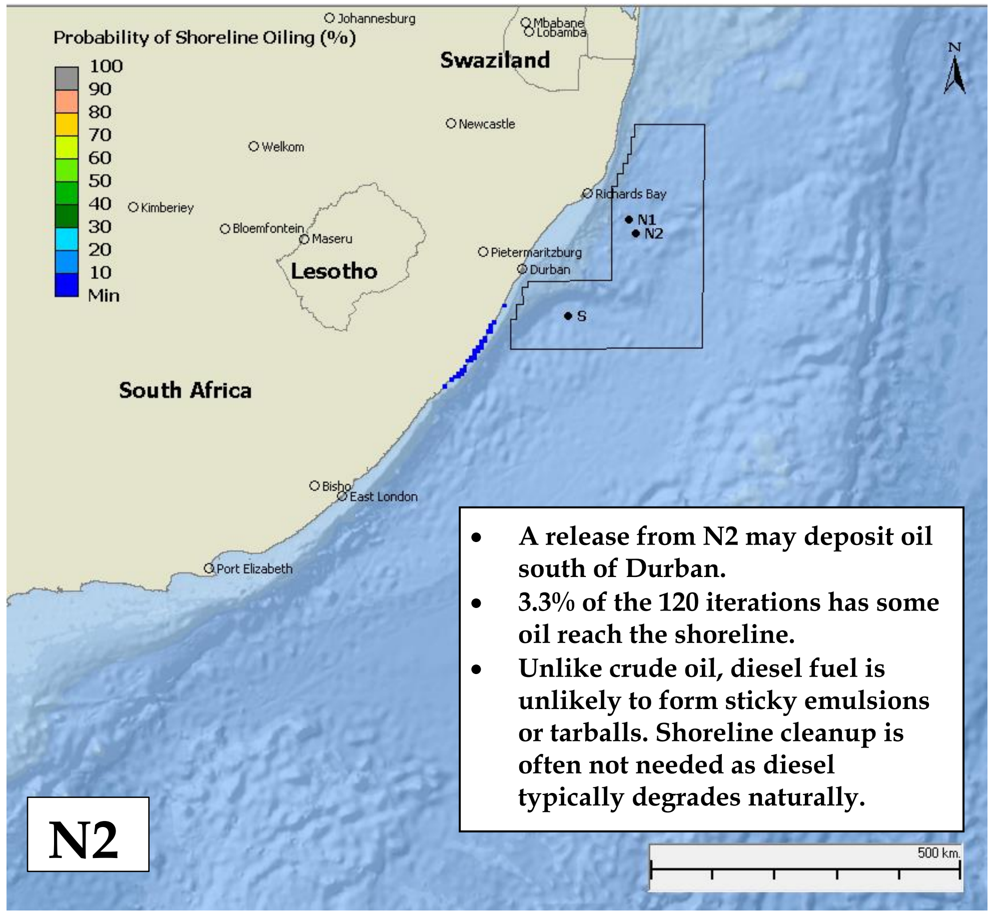


Figure 5-5 Scenario 1: Vessel Collision Diesel Spill –Shoreline oiling probability for spill at N1, N2 and S



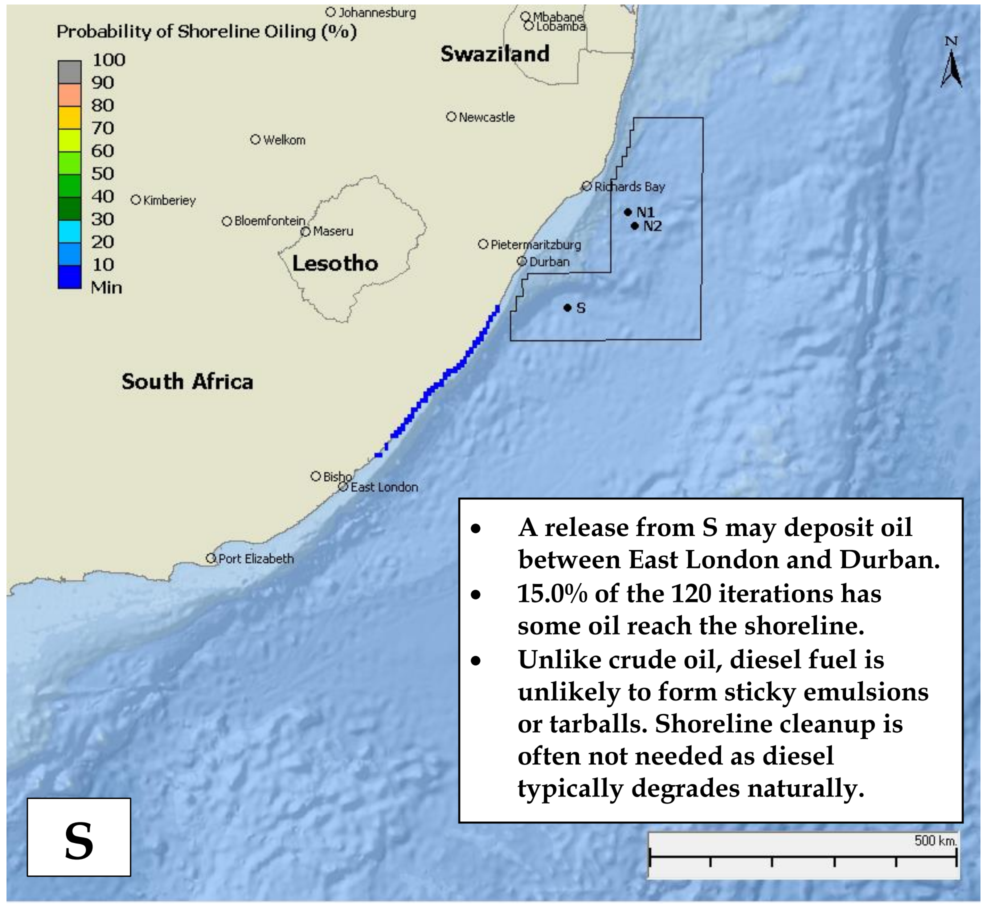


Figures Description

Scenario 1 Vessel Collision Diesel Spill

These figures show the probability of oil being present at a location on the shoreline over a 7-day period from a ***very unlikely*** oil spill due to a vessel collision. (No consideration for thickness thresholds were made in this scenario.) The colored contours depict the probability of oil's presence at a location at least once out of 120 spill simulations with spill release dates starting twice monthly over a five year period.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.



Mass balance diagrams of the diesel simulations are presented in *Figure 5-6*, Figure *5-7*, and Figure *5-8* for N1, N2, and S. Each curve on the diagrams represent the phases and forms the oil may become including liquid droplets ("dispersed") formed naturally by wind/wave energy, dissolved, biodegraded, surface slick, evaporated into the atmosphere or washed ashore. The curves represent the median percentage of each form over all iterations for each season. Above and below each median curve are dashed lines representing the 5th percentile value and 95th percentile value across the iterations. Thus the 5th percentile value represents the value of which 5% of all values across the iterations are at are below the given value, while 95% of all the values are at or below the 95th percentile value.

In seven days, between 40% to 50% of diesel was evaporated. Most of the remaining diesel oil is was either evaporated or entrained into the water column at the end of the seven-day simulation period. The amount of oil on water surface, which forms the surface oil slick, drops rapidly below 10% in the first day and nearly disappeared by seven days.

Figure 5-6 Scenario 1: Vessel Collision Diesel Spill - Median Percentage Mass Balance (solid lines) of Diesel at N1 (dashed lines represent 95th and 5th percentile values)

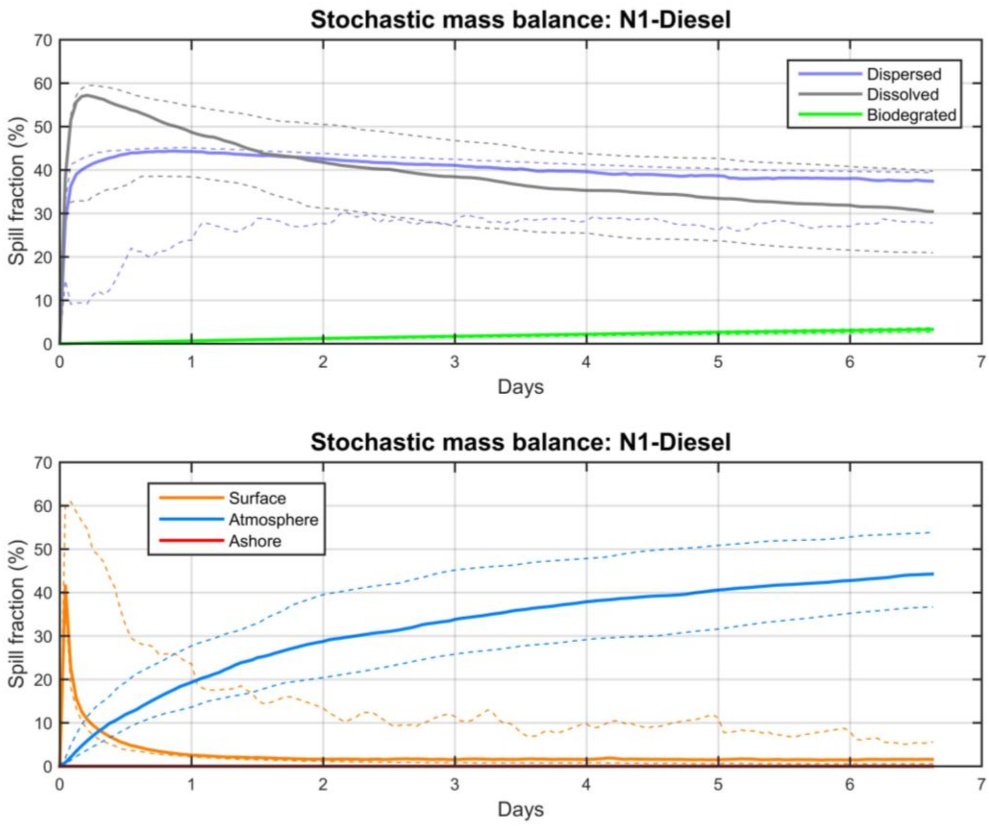
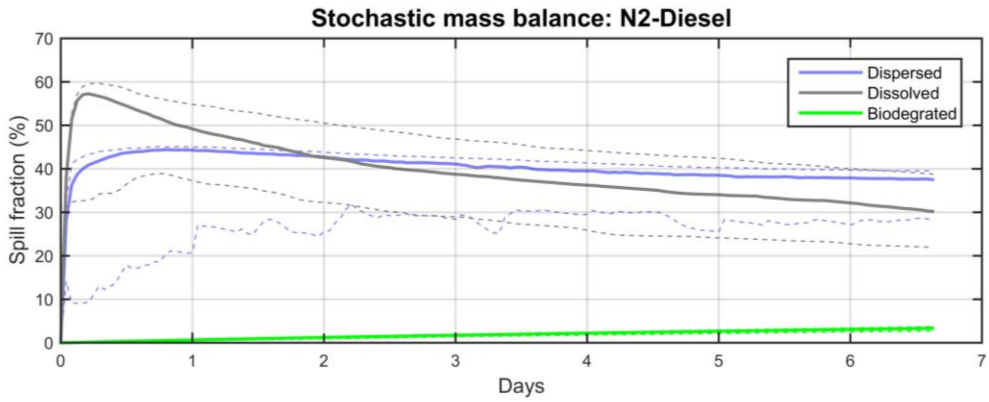


Figure 5-7 Scenario 1: Vessel Collision Diesel Spill - Median Percentage Mass Balance (solid lines) of Diesel at N2 (dashed lines represent 95th and 5th percentile values)



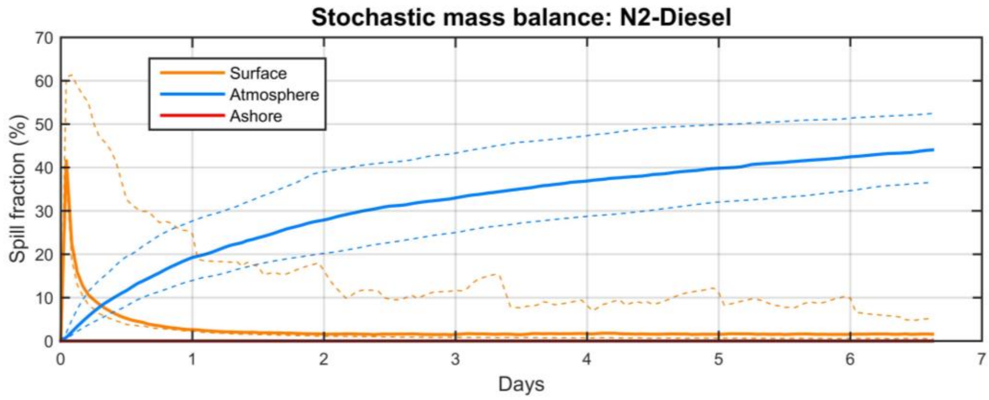
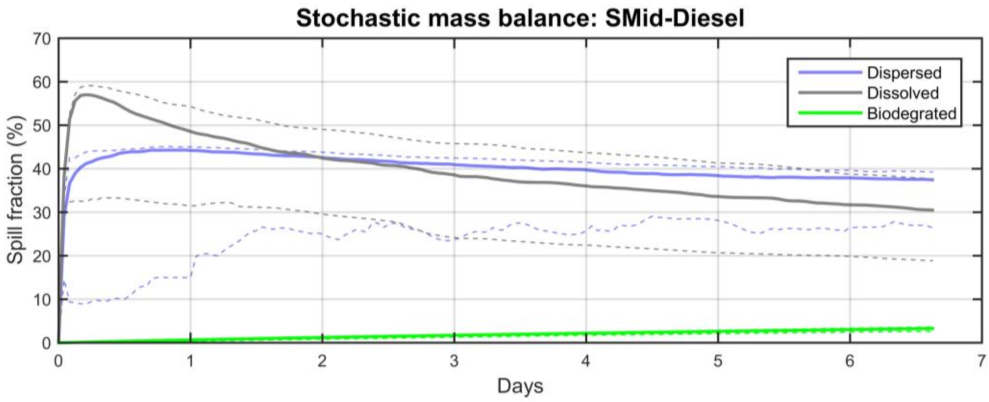
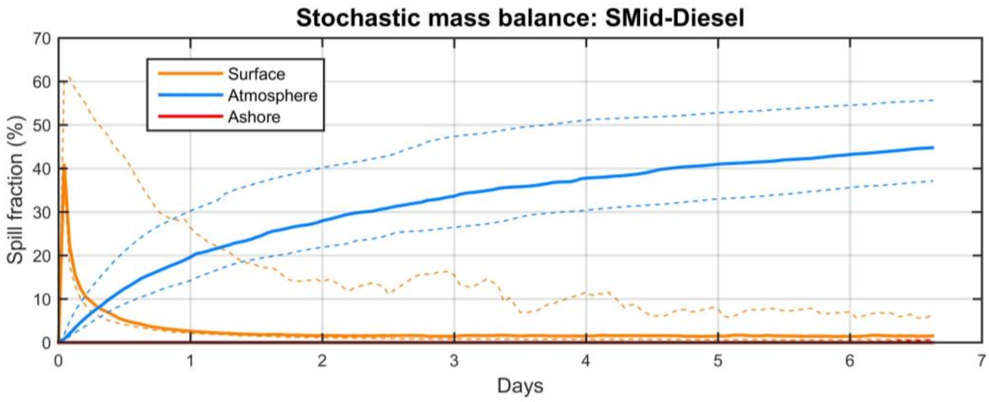


Figure 5-8 Scenario 1: Vessel Collision Diesel Spill - Median Percentage Mass Balance (solid lines) of Diesel at S (dashed lines represent 95th and 5th percentile values)

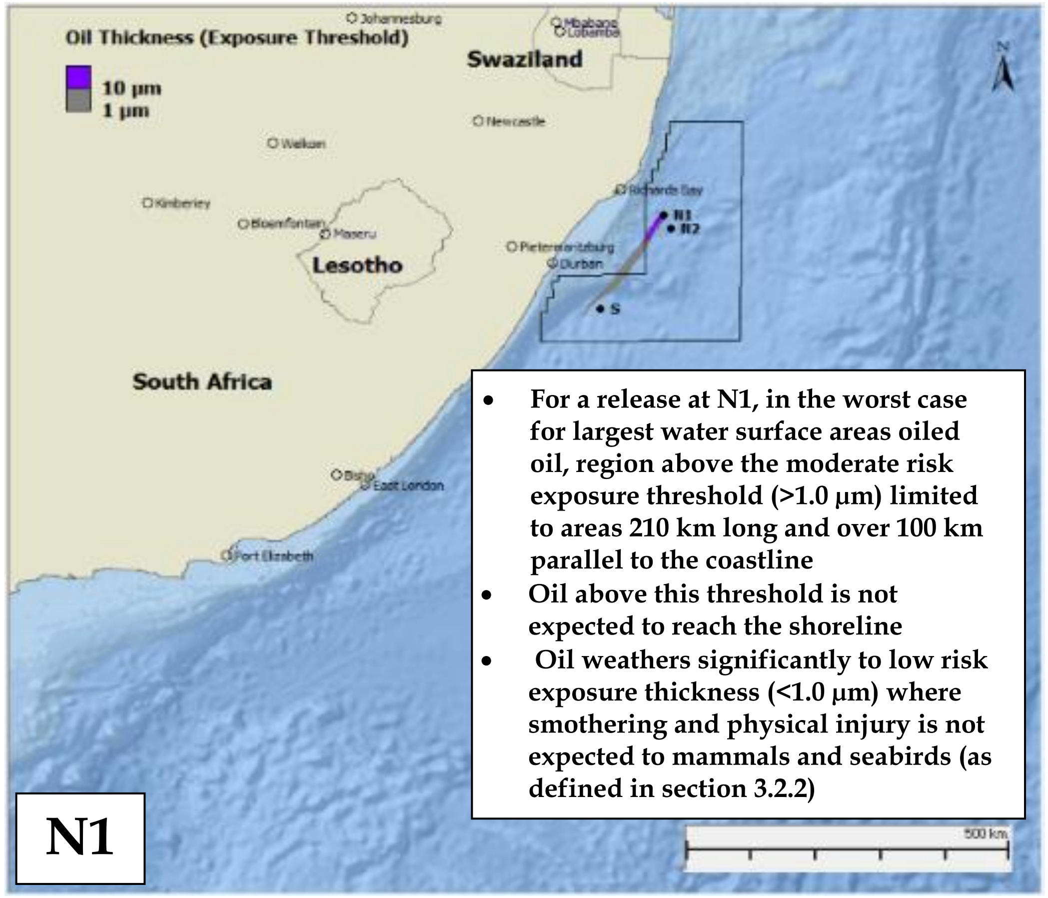


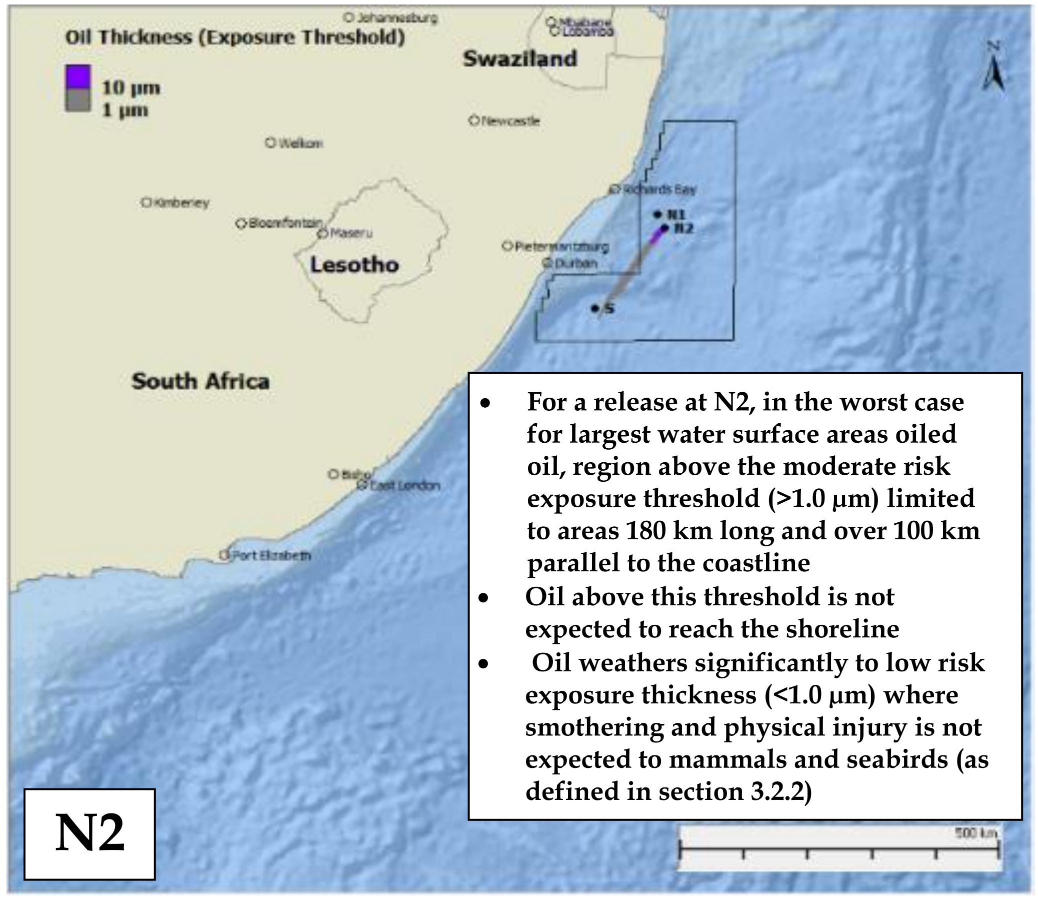


5.4.1 *Criterion 1: Largest Amount of Water Surface Area Oiled*

Figure 5-9 presents the trajectory of single iterations of the model representing the worst cases for most surface area oiled for spills at three modelling locations (N1, N2 and S). The most common trajectory occurs in south-west direction with the strong influence of Agulhas Currents parallel to the coastline. It is unlikely that such a spill at any of the three spill locations (N1, N2 and S) would carry an oil slick with thickness greater than the minimum smothering thickness (1.0 µm) to an area within 20 km off South African coastline. **In these iterations, the total area on the water surface that was contacted by smothering thickness (1.0 µm) or higher, at some point, in the 7-day simulation were 1,896 km^2, 1,684 km^2 and 2,848 km^2 for the releases at N1, N2 and S respectively.** In the absence of response efforts, regions above the 1.0 µm threshold for risks to birds and wildlife extend as narrow and long streaks parallel to South Africa coastline due to the strong influence of Agulhas Currents up to a distance of 210 km, 180 km and 310 km from the discharge locations N1, N2 and S respectively before weathering into a thinner sheen.

Figure 5-9 Scenario 1: Vessel Collision Diesel Spill - Thickness – Criterion 1: Worst Case Surface Oiling for Spill at N1, N2 and S





Figures Description

Scenario 1 Vessel Collision Diesel Spill

These figures show the maximum thickness of oil on the water surface over a 7-day period for the worst case scenario under Criterion 1 for the largest amount of water surface area oiled from a ***very unlikely*** oil spill due to a vessel collision. The colored contours depict the thickness of the oil in the moderate exposure threshold (1 μm to 10 μm) and above the high exposure threshold (>10 μm).

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

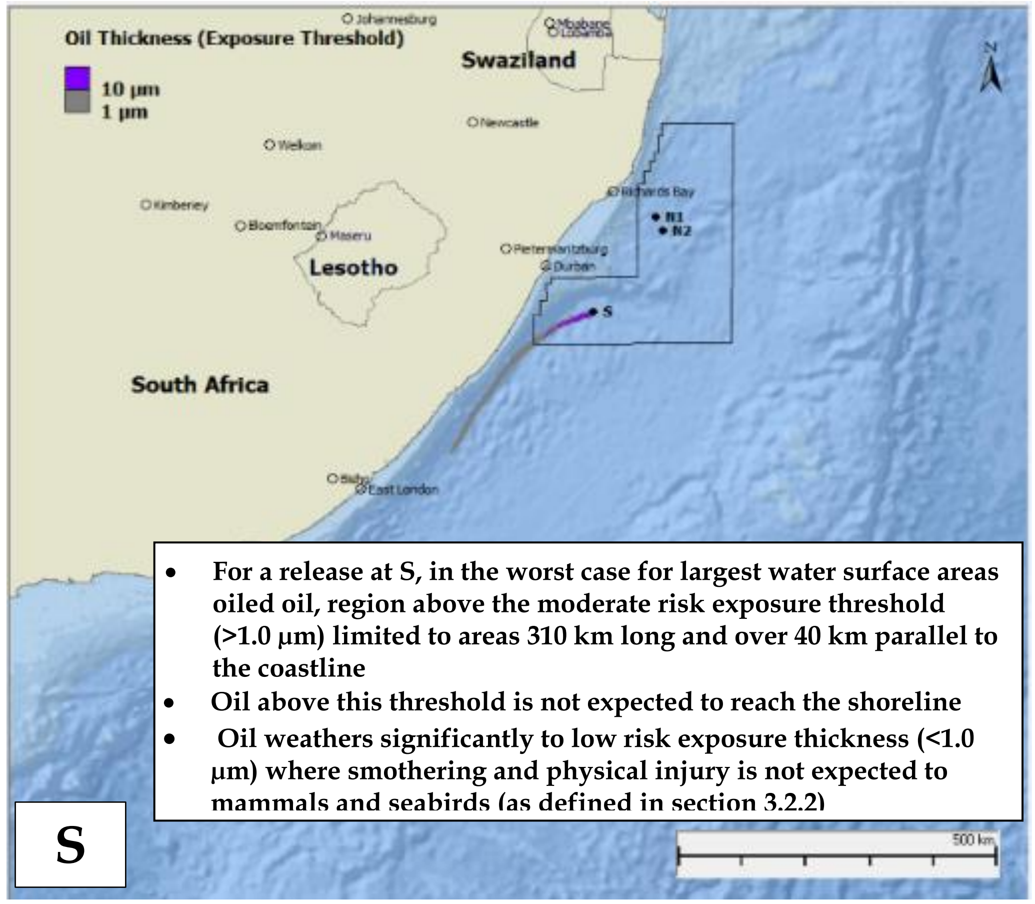
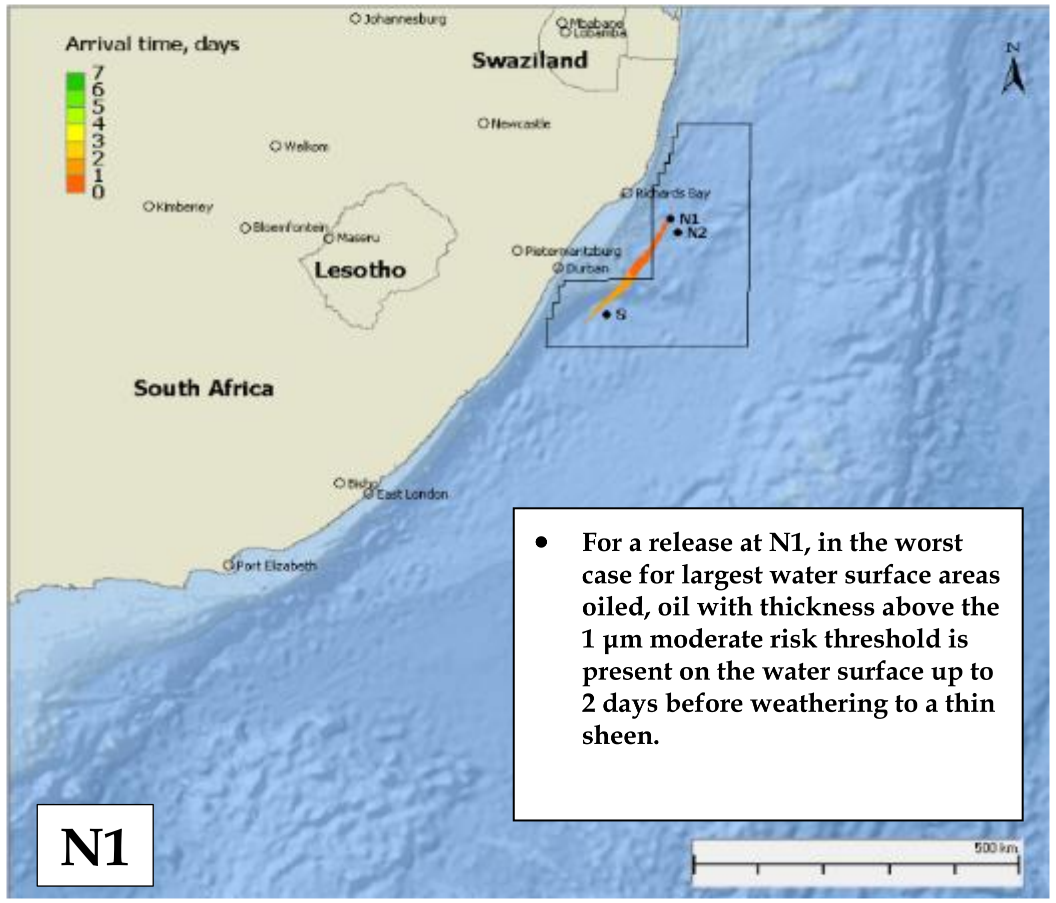
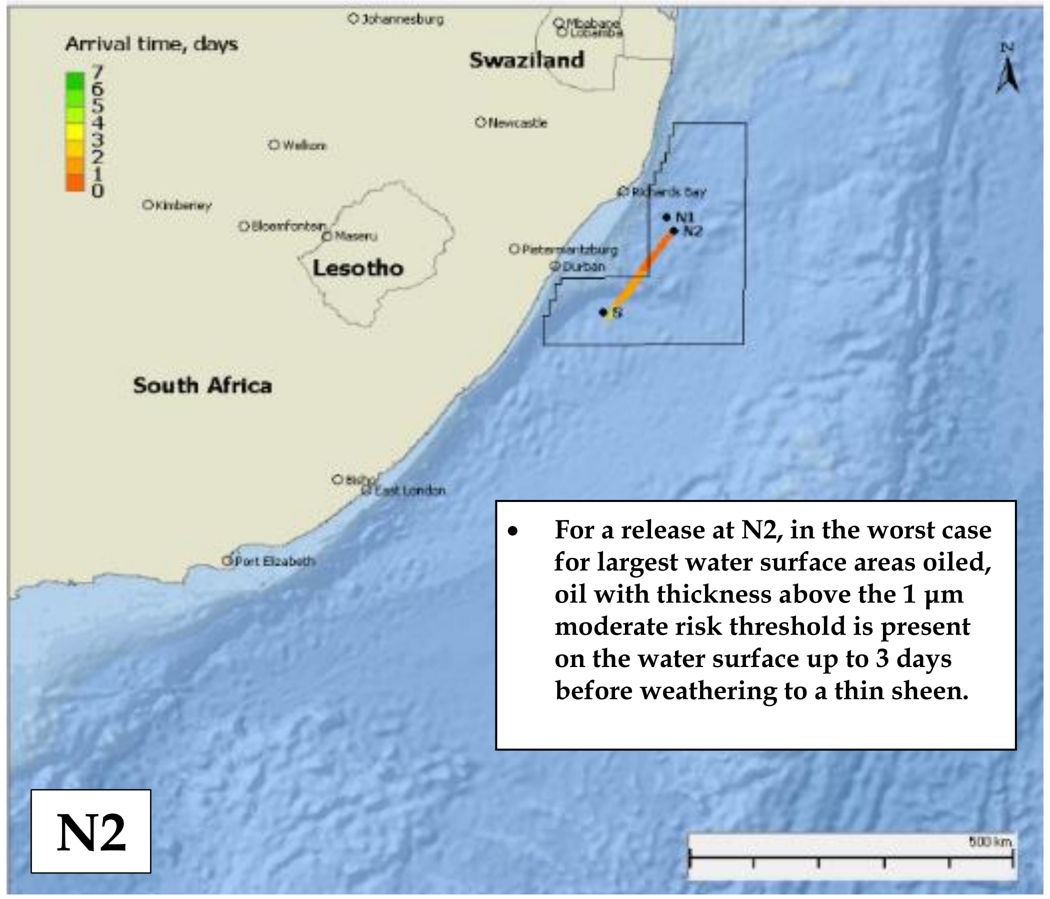


Figure *5-10* presents the arrival times of the oil slicks thicker than the minimum thickness threshold (>1.0 µm) for smothering of aquatic and marine organisms and wildlife for worst case surface oiling iterations for a vessel collision diesel spill at N1, N2 and S.

Figure 5-10 Scenario 1: Vessel Collision Diesel Spill – Arrival Time – Criterion 1: Worst Case Surface Oiling for Spill at N1, N2 and S



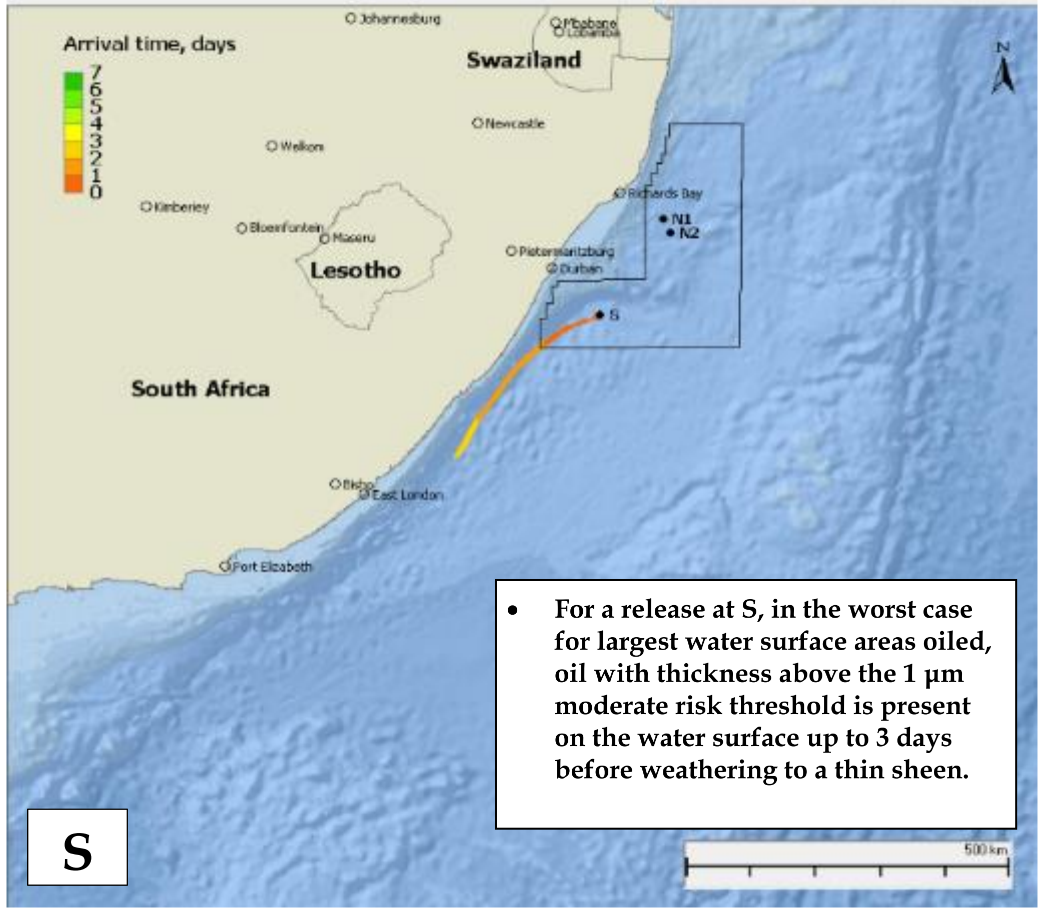


Figures Description

Scenario 1 Vessel Collision Diesel Spill

These figures show the shortest arrival time of oil on the water surface over a 7-day period for the worst case scenario under Criterion 1 for the largest amount of water surface area oiled from a ***very unlikely*** oil spill due to a vessel collision. The colored contours depict the first time in the simulation (in days from the start of the release) for oil to be present at a given location with thickness greater than the moderate exposure threshold (1 µm).

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.



5.4.2 *Criterion 2 (Most Amount of Shoreline Oiling Mass) and Criterion 3 (Fastest Time for Shoreline Oiling to Occur)*

The locations of shoreline impact from the 7-day simulations within the five-year period range from Durban to East London, however the probability of shoreline impact due to a spill from any of the spill locations is less than 15%.

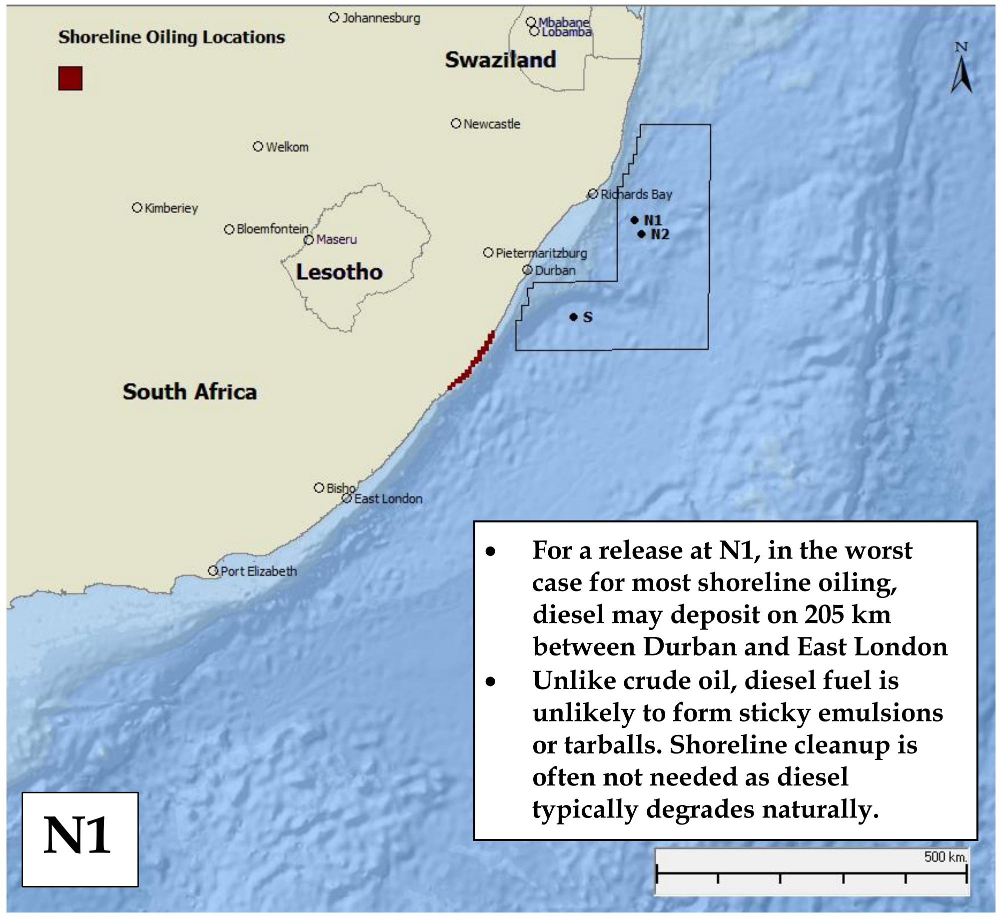
Depictions of the shoreline oiling in the worst case shoreline oiling and fastest time to reach shoreline cases for spills at N1 are presented in Figure *5-11* and Figure *5-12* respectively. The shoreline area near Richards Bay area was the earliest for oil to make contact from all the iterations (2.6 days).

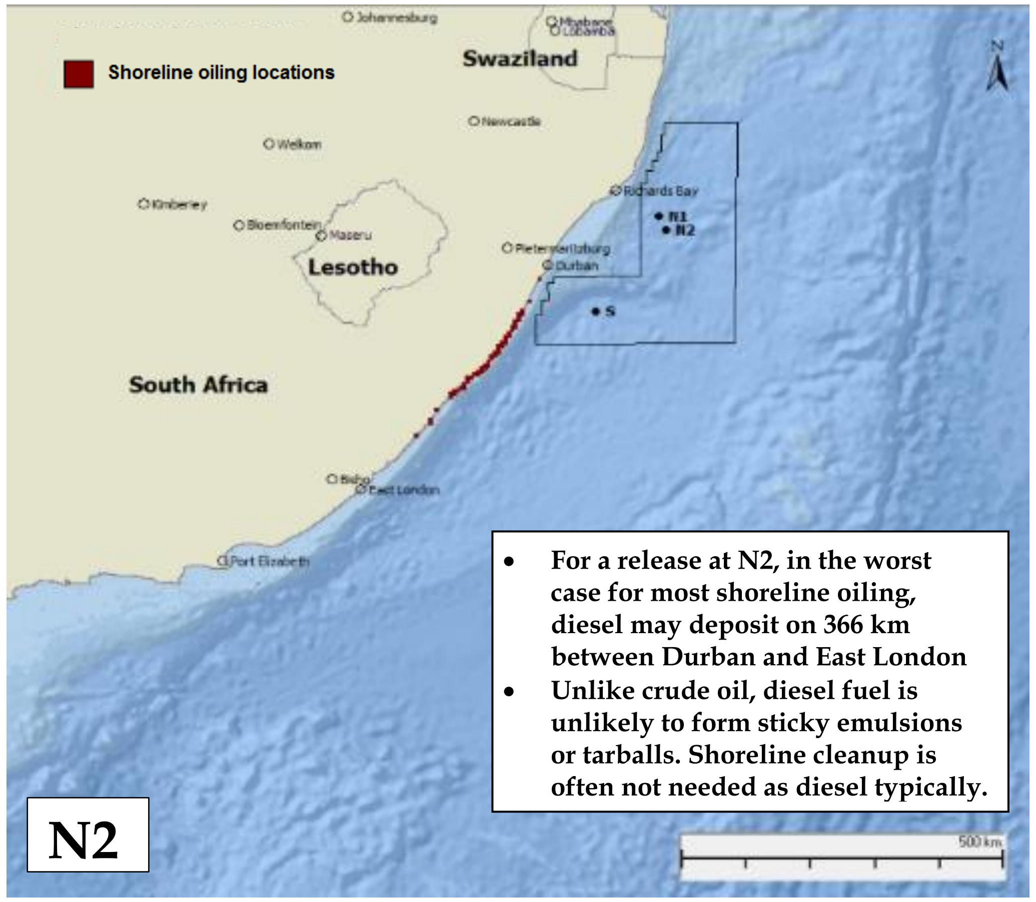
Shoreline oiling in the worst case shoreline oiling iteration and fastest time to reach shoreline cases for spills at N2 are also presented in *Figure 5-11* and Figure *5-12* respectively. Similar to the discharges at N1, the shoreline area near Richards Bay area was the earliest for oil to make contact (3.3 days).

Worst case shoreline oiling as well as the fastest time to reach the shoreline occurs at the same iteration for spills at S. Shoreline oiling and fastest time to reach shoreline for this iteration are also presented in *Figure 5-11* and Figure *5-12* respectively. The shoreline stretch south of the Durban area was the earliest for oil to make contact (2.8 days).

Arrival time figures for worst case most amount of shoreline oiling mass and fastest shoreline oiling iterations are not presented here because the surface trajectories are very narrow with short streaks. Oil slicks in those iterations thin out into sheens within 1 or 2 days and do not extend more than about 50 km from their release locations. Oil slicks greater than the minimum smothering thickness (>1.0 μm) did not contact shorelines in the worst case iterations.

Figure 5-11 Scenario 1: Vessel Collision Diesel Spill – Criterion 2: Worst case most shoreline oiling mass for Spill at N1, N2 and S





Figures Description

Scenario 1 Vessel Collision Diesel Spill

These figures show the shoreline oiling locations after a 7-day period for the worst case scenario under Criterion 2 for the most amount of shoreline oiling from a ***very unlikely*** oil spill due to a vessel collision. (Note that any amount of oil mass on the shoreline is depicted; no shoreline threshold criteria has been applied)

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

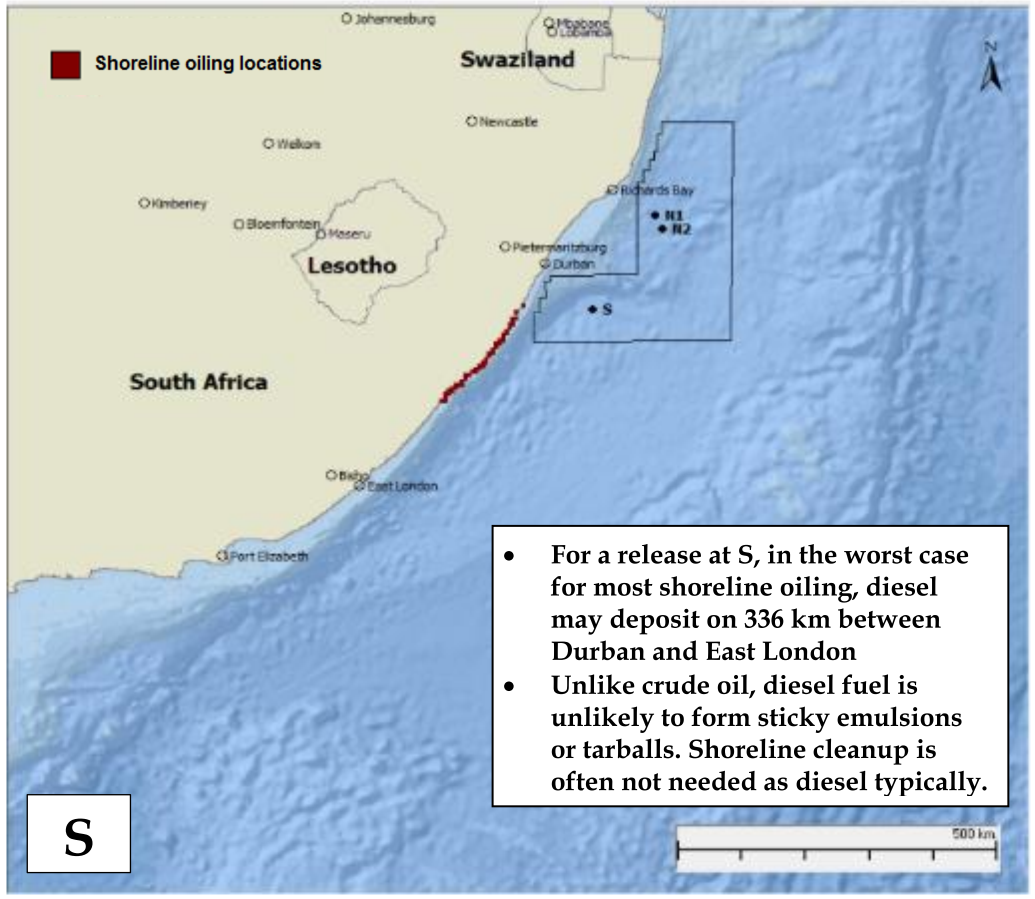
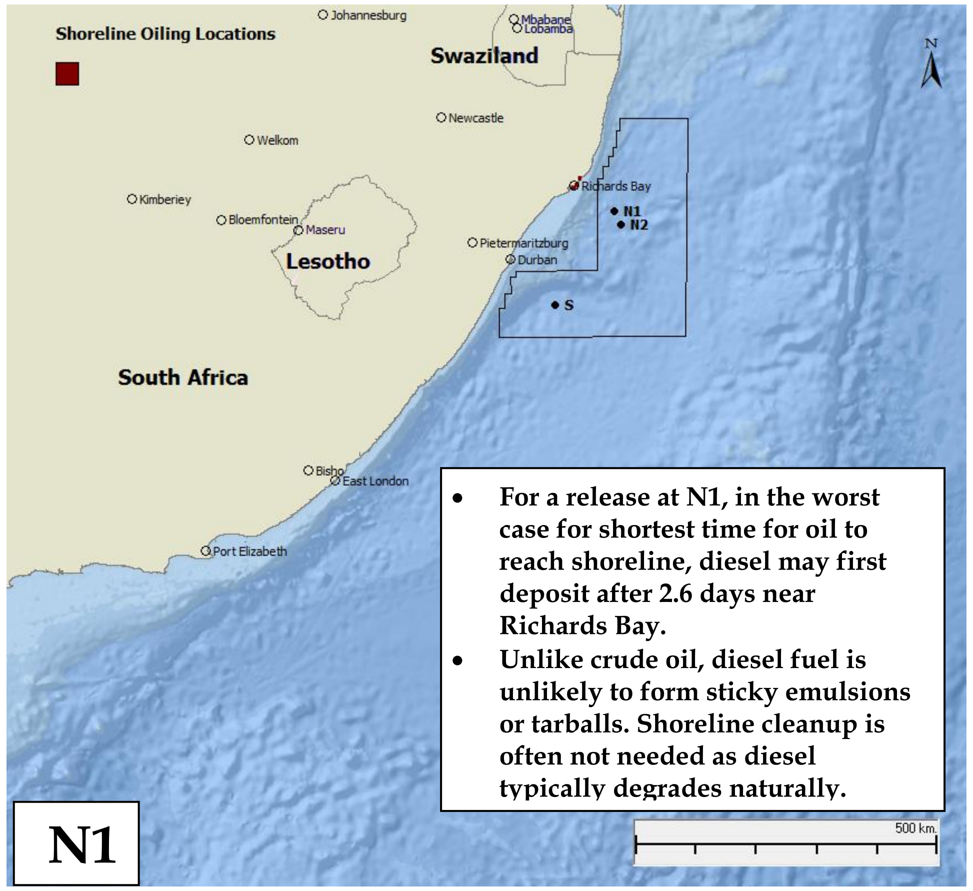
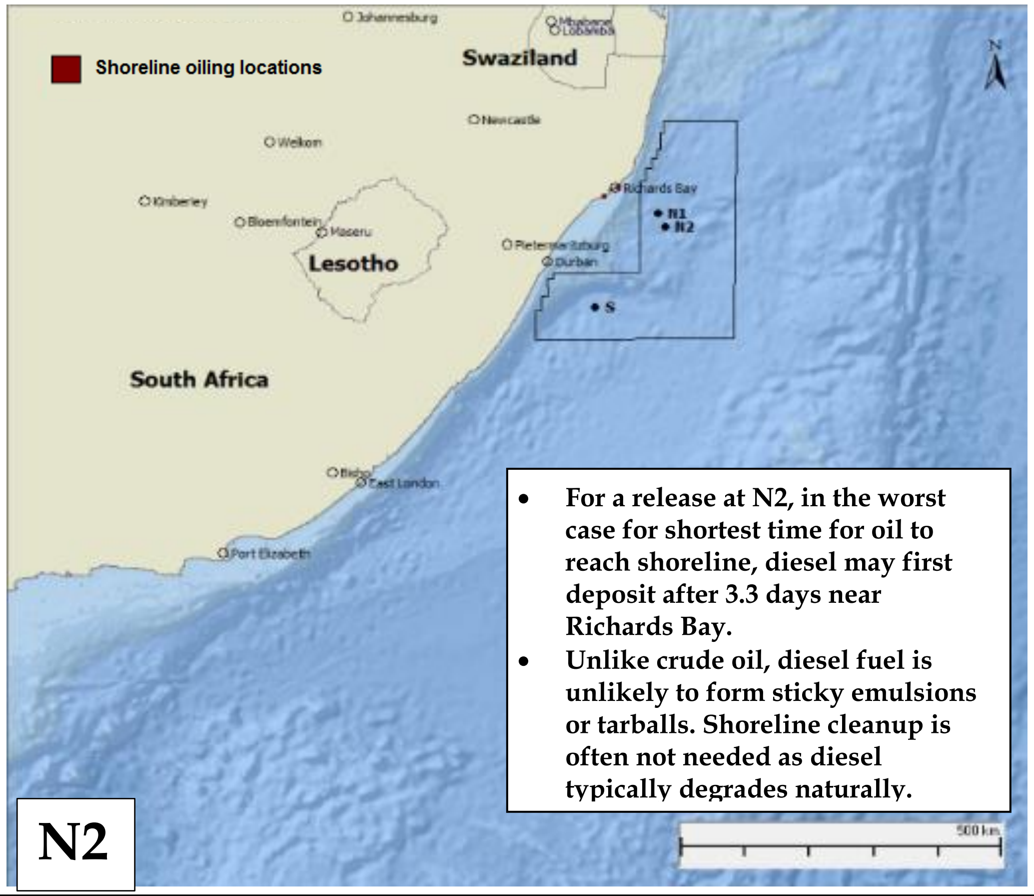


Figure 5-12 Scenario 1: Vessel Collision Diesel Spill – Criterion 3: Fastest time for shoreline oiling to occur for Spill at N1, N2 and S



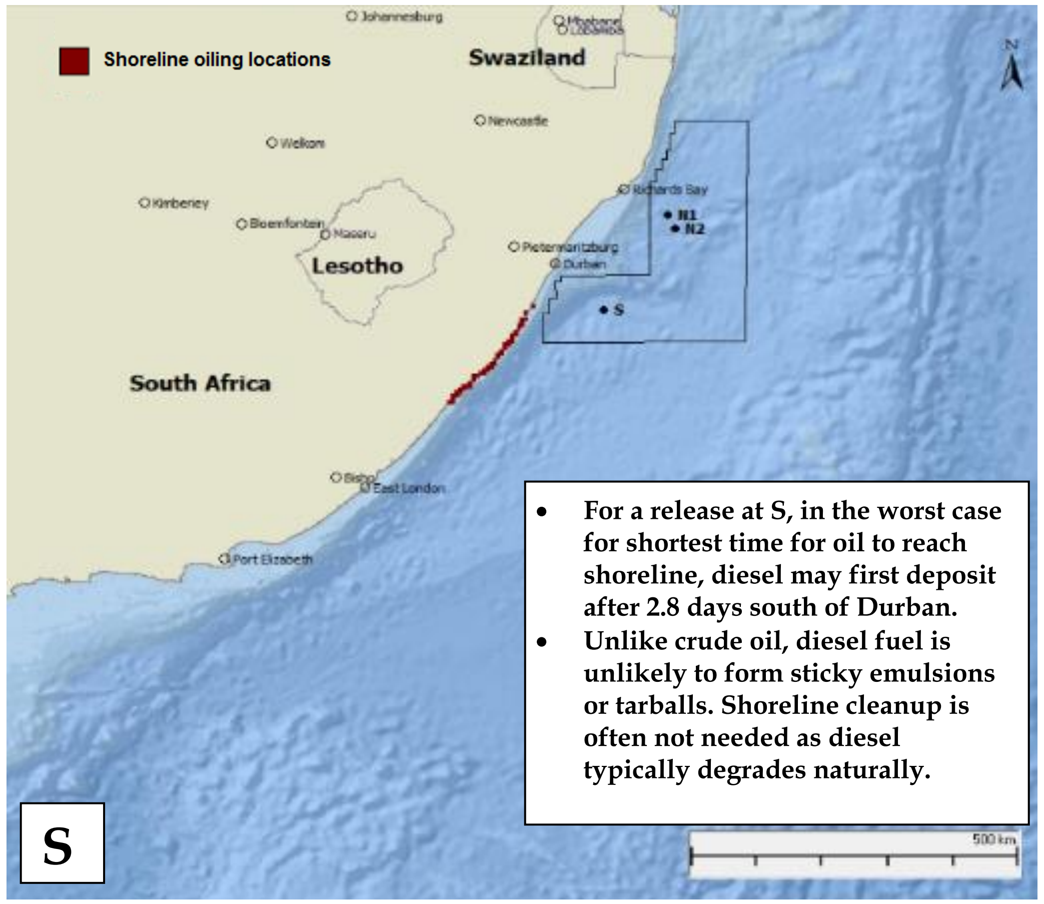


Figures Description

Scenario 1 Vessel Collision Diesel Spill

These figures show the shoreline oiling locations after a 7-day period for the worst case scenario under Criterion 3 for the shortest time for shoreline oiling to occur from a ***very unlikely*** oil spill due to a vessel collision. (Note that any amount of oil mass on the shoreline is depicted; no shoreline threshold criteria has been applied)

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.



5.5 *SCENARIO 2A – 7-DAY CRUDE OIL BLOWOUT WITH HOLE COLLAPSE*

The crude oil blowout scenarios simulate the continuous loss of crude oil from the reservoir for a 7-day (Scenario 2a) and 20-day period (Scenario 2b) from the seafloor. It should be noted again here that the spill modelled is the worst case scenario and does not take into consideration the implementation of any mitigation measures.

In Scenario 2a, the release was assumed to be constant at 4,717 bpd (750 m^3/day) from a well at N1 and 6,604 bpd (1,050 m^3/d) from a well at S. The simulations continued for 14 days after the end of the release, for a total of 21 days simulated in Scenario 2a. The model was run 120 times to simulate releases on different starting days from January 2013 through October 2017 as described in Section 5.1. The results are summarized in Table *5.12*

Table 5.12 Modelling Worst Cases Results Summary - Crude Oil Release from Hole Collapse – Scenario 2a (

Season	Criterion 1: Largest Amount of the Water Surface Area Oiled above 1 µm Threshold (km²)	Criterion 1: Largest Amount of the Water Surface Area Oiled above 10 µm Threshold (km²)	Criterion 2: Most Amount of Shoreline Oiling Mass > 100 g/m² - Shoreline Length (km)	Criterion 3: Fastest time for Shoreline Oiling to Occur (days)	Probability of Any Shoreline Contact with Oil
	Drilling Location N1				
Season 1	401	0	0	5.75	70.0%
Season 2	348	0	0	4.25	55.0%
	Drilling Location S				
Season 1	3,049	0	0	6.00	73.3%
Season 2	669	0	0	5.00	80.0%

*Season 1 = summer/autumn; Season 2= winter/spring

(Note: this is modelled without the inclusion of any mitigation /containment measures, which represents an unrealistic condition)

Regarding the selected rate of release chosen for this simulation: The input data provided for the model run are based on lithology and preliminary reservoir assessment and interpretation starting from seismic data. During the second quarter of 2018, new data interpretation were available from 2D/3D seismic data acquired by some multi-client providers in 2016 and 2018.

Based on the analysis already finalized, the reservoir and production profiles are expected to be very similar to the same available in other subsea fields developed by Eni in Africa. For this reason the PI (productivity index), porosity, hydrocarbon properties and expected flow rate have been re-calculated and optimized using real data from those similar fields.

The confirmation of those assumption will be provided after the drilling of first explorative well. In addition:

- The pore pressure prediction is computed using a sophisticated technology from the velocity analysis coming from the recent (2016) 3D seismic volume. Moreover, for all the wells drilled in a similar deepwater environment, an analogue approach has been utilized for preparing the casing design and mud density, to keep the well under control while drilling. In the recent development of some African deepwater field, Eni has confirmed that those estimation has been confirmed during the subsequent drilling of the wells.

During the Macondo/Deepwater Horizon blowout, a very high flowrate from the reservoir occurred for different reasons: different geology (Macondo target Miocene turbidite sands as compared to the geological formation at ER236 South Africa where the reservoir rocks from the Upper Cretaceous age are thought to be slope - basin floor fans) and pore pressure, different well construction and different profile. For these reasons, the Macondo well and reservoir couldn't be used as reference for Block ER236, as opposed to Eni's experience in similar lithology in West Africa, which has allowed for optimizing the flowrate and PI parameters that, in the unrealistic situation that no mitigation (e.g. BOP closure) will be applied, should provide a better estimation of flow rates.

This section describes Scenario 2a. Section 5.6 describes Scenario 2b.

Scenario 2a: 7-Day Blowout Release with Hole Collapse

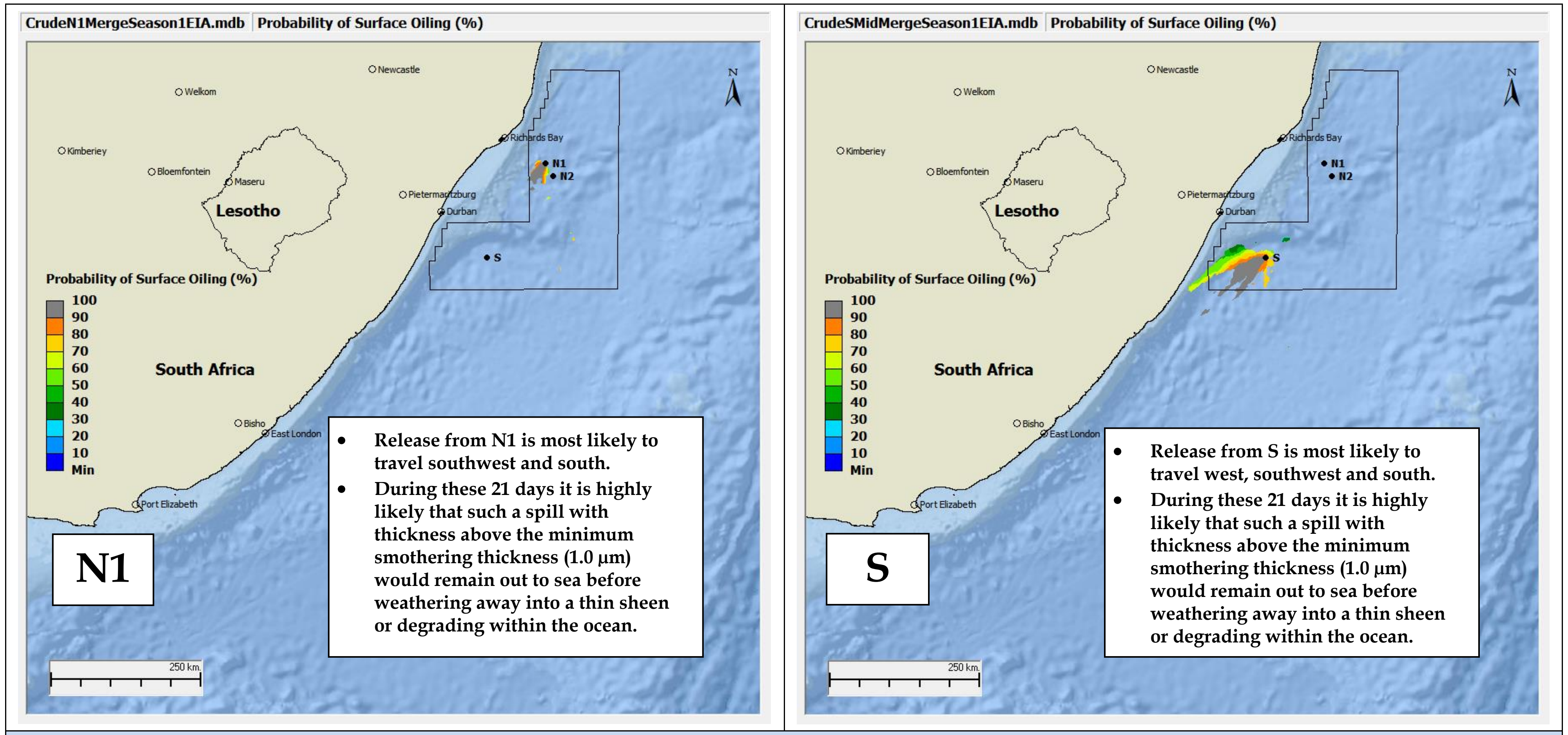
In this scenario, the model simulated a release lasting seven days due to a blowout at the reservoir. This is a self-killing event in which the reservoir hole naturally collapses upon itself, thereby terminating the release. The transport and fate of the oil continued to be tracked by the model for an additional 14 days after the termination of the release for a total of 21 days simulated.

Oil spill model results forecasting hypothetical events represent the range of locations potentially affected (shown using probability) due to the presence of oil under conditions that define the scenario and simulation. Model results in Scenario 2a indicate that it is unlikely that significant shoreline oiling (>100 g/m^2) will reach shorelines along the coast.

For Season 1 (summer/autumn) and Season 2 (winter/spring) respectively, *Figure 5-13* and Figure *5-14* present the full extents of where oil thickness is greater than minimum thickness (1.0 µm) for smothering of aquatic organisms and wildlife after a crude oil blowout at two modelling locations (N1 and S). The area of potential surface trajectories are coloured according to the probability of oil traveling to a given location **at least once in the 120 iterations through the five-year analysis**. As described in the Scenario Design in Section 5.1, each spill scenario is run 120 times (iterations) with the spill's start date evenly spaced across the five year period. This provides for a variety of combinations of wind and ocean current combinations to predict the range of potential spill trajectories. The most common trajectory occurs in south-west direction with the strong influence of Agulhas Currents parallel to the coastline.

It is highly likely that such a spill at either of the two spill locations (N1 and S) with thickness greater than the minimum smothering thickness (1.0 µm) would remain out to sea before weathering away into a thin sheen. In the absence of response efforts, the smothering slick of oil is able to travel almost 50 km and 150 km from the release points N1 and S respectively before weathering away into a thinner sheen.

Figure 5-13 Scenario 2a: 7-Day Crude Oil Blowout –Probability of smothering surface oiling (>1.0 µm) for spill at N1 and S in Summer/Autumn



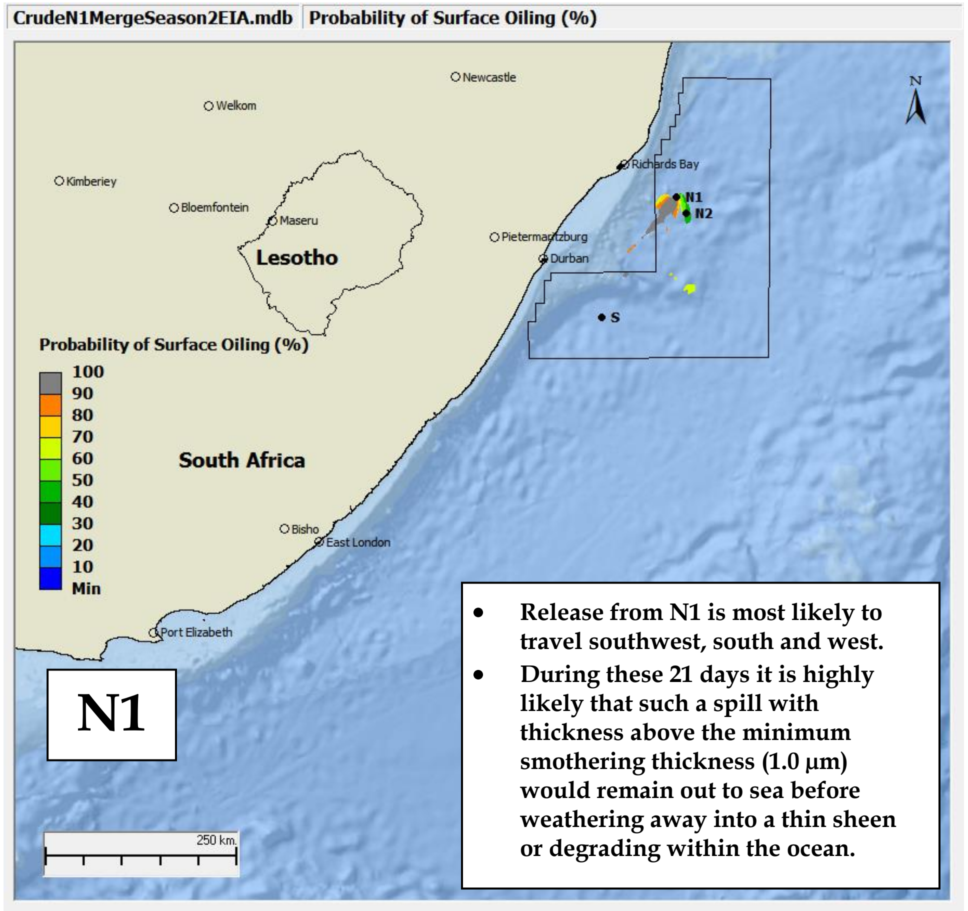
Figures Description

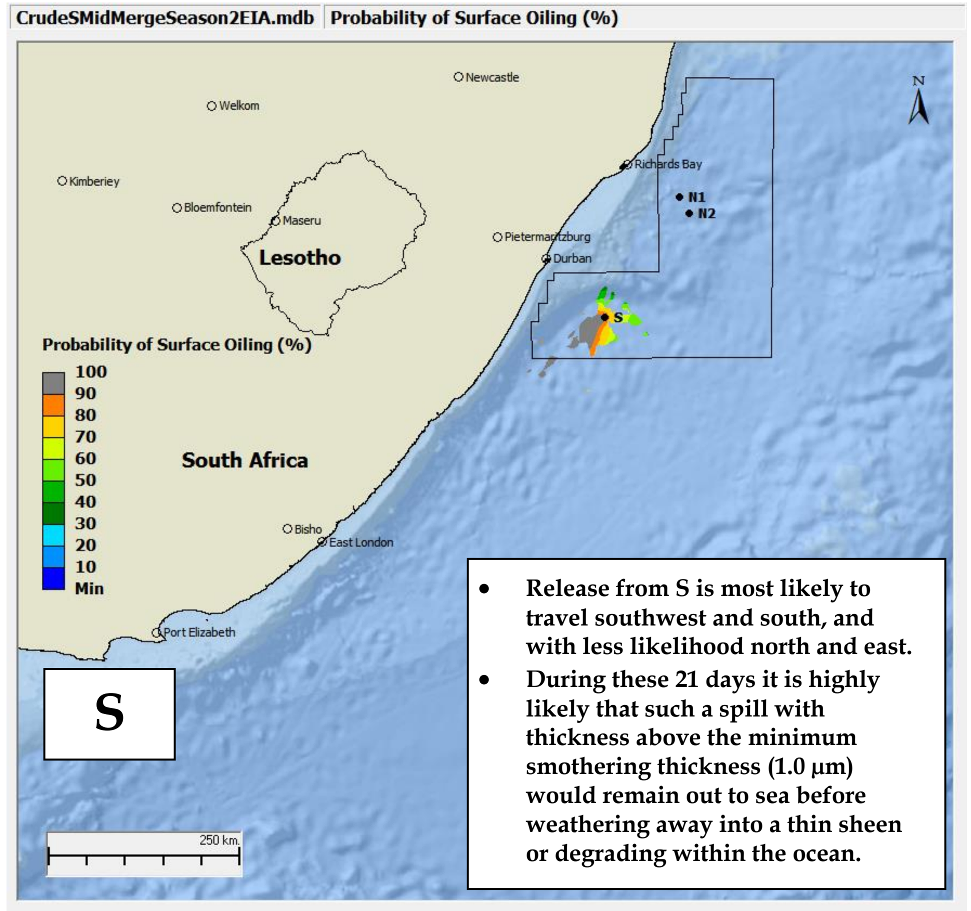
Scenario 2a 7-Day Crude Oil Blowout

These figures show the probability of oil being present from a 7-day blowout at a location on the water surface over a 21-day period from a ***very unlikely*** oil spill resulting in an oil thickness above the threshold level for potentially smothering birds and wildlife (> 1 µm). The colored contours depict the probability of oil's presence at a location at least once out of 120 spill simulations with spill release dates starting twice monthly over a five year period.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

Figure 5-14 Scenario 2a: 7-Day Crude Oil Blowout –Probability of smothering surface oiling for spill at N1 and S in Winter/Spring





Figures Description

Scenario 2a 7-Day Crude Oil Blowout

These figures show the probability of oil being present from a 7-day blowout at a location on the water surface over a 21-day period from a ***very unlikely*** oil spill resulting in an oil thickness above the threshold level for potentially smothering birds and wildlife (> 1 µm). The colored contours depict the probability of oil's presence at a location at least once out of 120 spill simulations with spill release dates starting twice monthly over a five year period.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

Diagrams describing the mass balance across all iterations of the Scenario 2a crude blowout simulation is presented in *Figure 5-15* and *Figure 5-16* for the north well, N1 and *Figure 5-17* and *Figure 5-18* for the southern well, S. Each curve on the diagrams represent the phases and forms the oil may become including liquid droplets ("Dispersed") rising to the surface from the blowout or naturally dispersed by wind/wave energy, dissolved, biodegraded, surface slick, evaporated into the atmosphere or washed ashore. The curves represent the median percentage of each form over all iterations for each season. Above and below each median curve are dashed lines representing the 5^{th} percentile value and 95^{th} percentile value across the iterations. Thus the 5^{th} percentile value represents the value of which 5% of all values across the iterations are at are below the given value, while 95% of all the values are at or below the 95^{th} percentile value.

As expected most of the oil (70%) is entrained initially in the water column as liquid droplets from crude oil blowout. At the end of simulation period, over 40 percent (40%) of oil remains in the water column as tiny liquid droplets ("entrained oil"). Dissolved oil components, unlike other dissolved constituents of which concentrations only decrease over time, can both increase and decrease depending on the entrainment of surface oil into the water column and subsequent resurfacing of the oil droplets in water column back to the surface slick. Strong current and wind shear stresses, which is the case offshore South Africa, entrains oil into the water column and contributes to the reduction of surface oil slick thickness. Such entrained oil will resurface intermittently when winds and wave energy subsides. In such situations, oil slicks can reemerge on the water surface and appear as isolated patches, as presented in some oil thickness and travel time figures in this section.

Sedimentation of oil mass was not included in the model due to the absence of a number of variable model inputs required for an accurate assessment. However, there could potentially be a significant transfer of oil from the water column to the sea floor. Studies after the Deepwater Horizon incident (e.g. Romero, et al., 2017) have indicated that hydrocarbons from a blowout may rise from the seafloor to the water surface, and return back again bound with marine snow (aggregates of organic and inorganic particles containing bacteria, phytoplankton, zooplankton, minerals, detritus, etc. which fall to the sea floor). The exact location of deposits are dependent on the concentration of marine snow encountering oil near the surface or in the water column, and the subsequent pathways of deposition, affected by the various ocean currents. In the case of Deepwater Horizon, a zone approximately 50 km in diameter around the well was estimated to have received the most concentrated deposits (13%) of the contaminated "marine oil snow" (MOS), while possibly an additional 7% spread out across a much larger area (Passow and Ziervogel, 2016). Other studies estimate 14% of the oil mass sank as MOS (Daly, et al, 2016). While the potential means in which MOS could impact the ecosystem have been postulated, including ingestion, smothering, suboxic or anoxic conditions, transfer of hydrocarbons through the marine food-web, and others possible effects, a precise quantification of the impacts from sinking or deposited MOS is unknown and would depend on the natural quality of baseline marine snow (Daly, et al, 2016).

Figure 5-15 Scenario 2a Median Percentage Mass Balance (solid lines) of Crude Oil – N1 Summer/Autumn (dashed lines represent 95th and 5th percentile values)

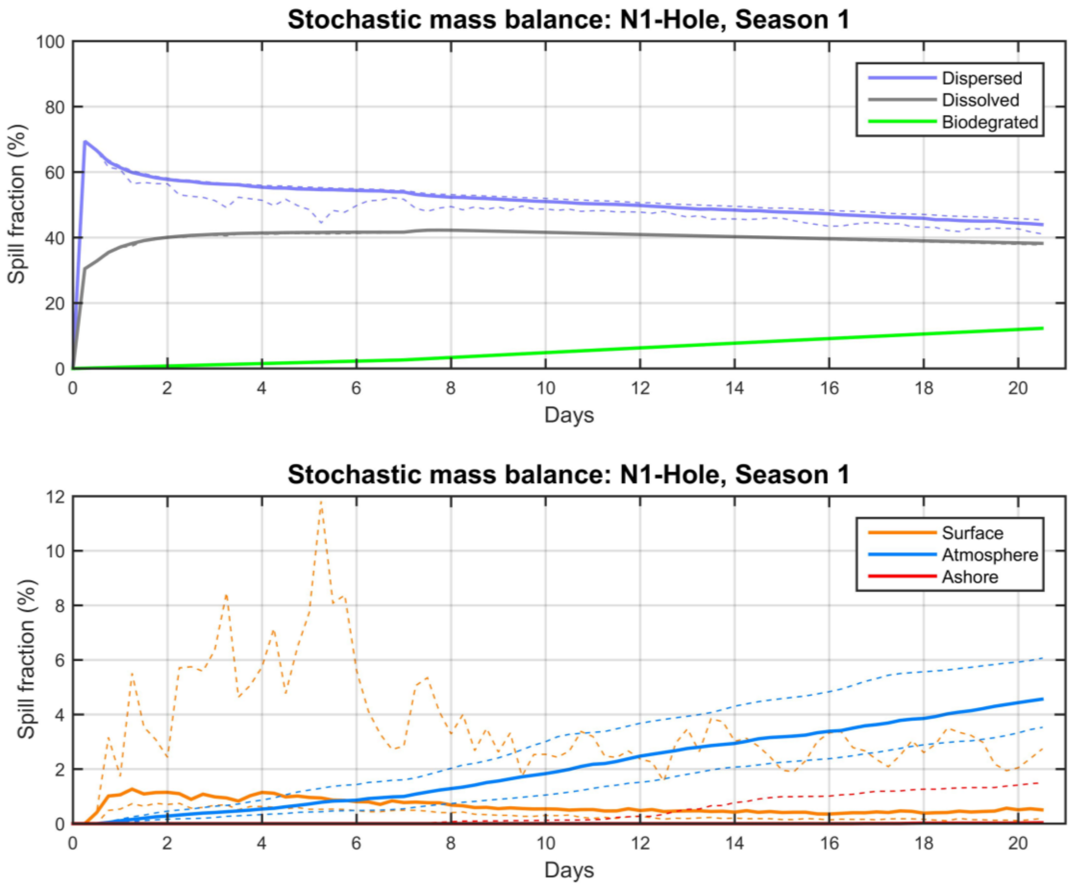


Figure 5-16 Scenario 2a Median Percentage Mass Balance (solid lines) of Crude Oil – N1 Winter/Spring (dashed lines represent 95th and 5th percentile values)

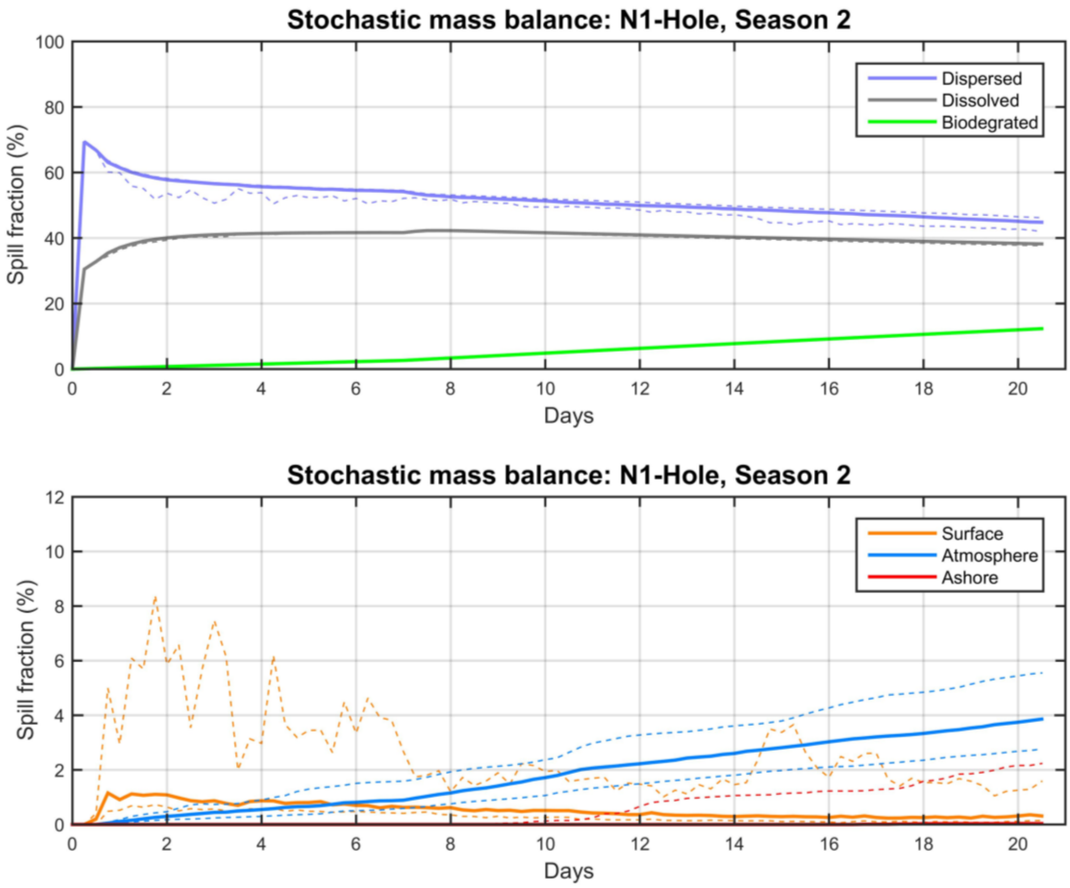


Figure 5-17 Scenario 2a Median Percentage Mass Balance (solid lines) of Crude Oil – S Summer/Autumn (dashed lines represent 95th and 5th percentile values)

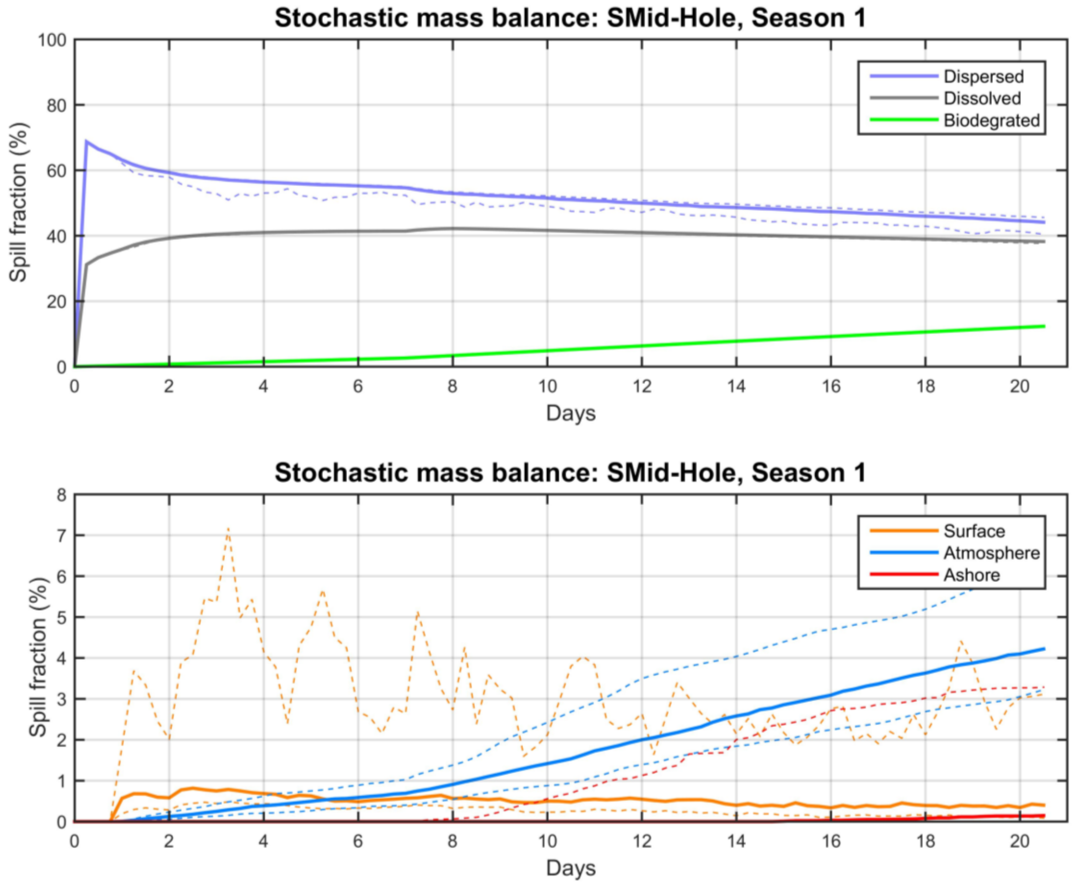
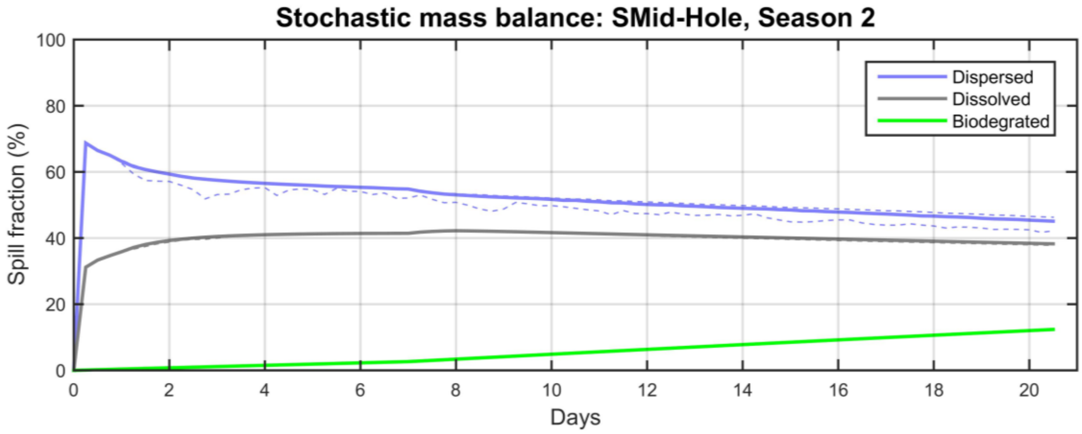
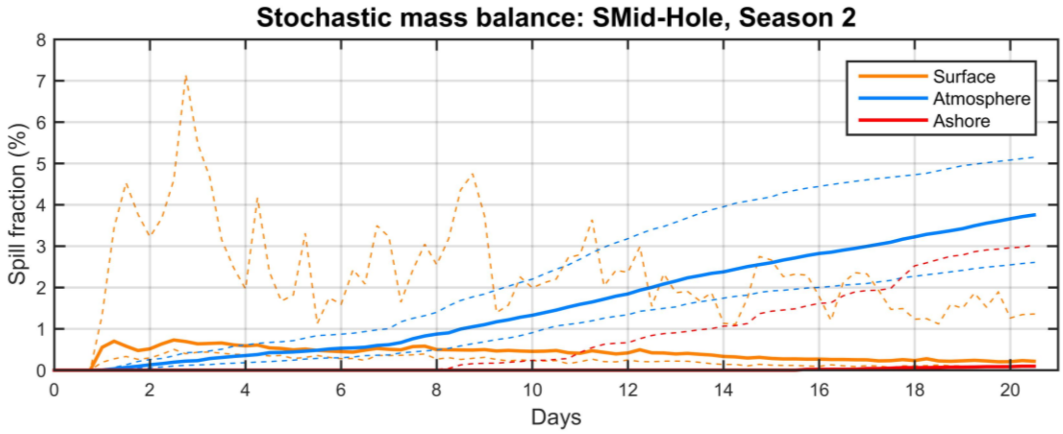


Figure 5-18 Scenario 2a Median Percentage Mass Balance (solid lines) of Crude Oil – S Winter/Spring (dashed lines represent 95th and 5th percentile values)





In addition, information has been extracted from these modelled iterations to understand the following worst cases:

- the largest amount of the water surface area oiled;
- the most amount of shoreline oiling mass; and
- the fastest time for shoreline oiling to occur;

Worst cases identified with these three criteria have been analysed for two combined seasons of the year within the period 2013-2017:

- Season1: Summer / Autumn: from 1 December to 31 May;
- Season 2: Winter/Spring: from 1 June to 30 November.

For Scenario 2a, there was no iteration in which a significant amount of shoreline oiling (above the 100 g/m² threshold) was identified.

It has to be stated that the following results and maps refer to very unlikely and rare unplanned events without accounting for any mitigation and intervention measures that will be performed.

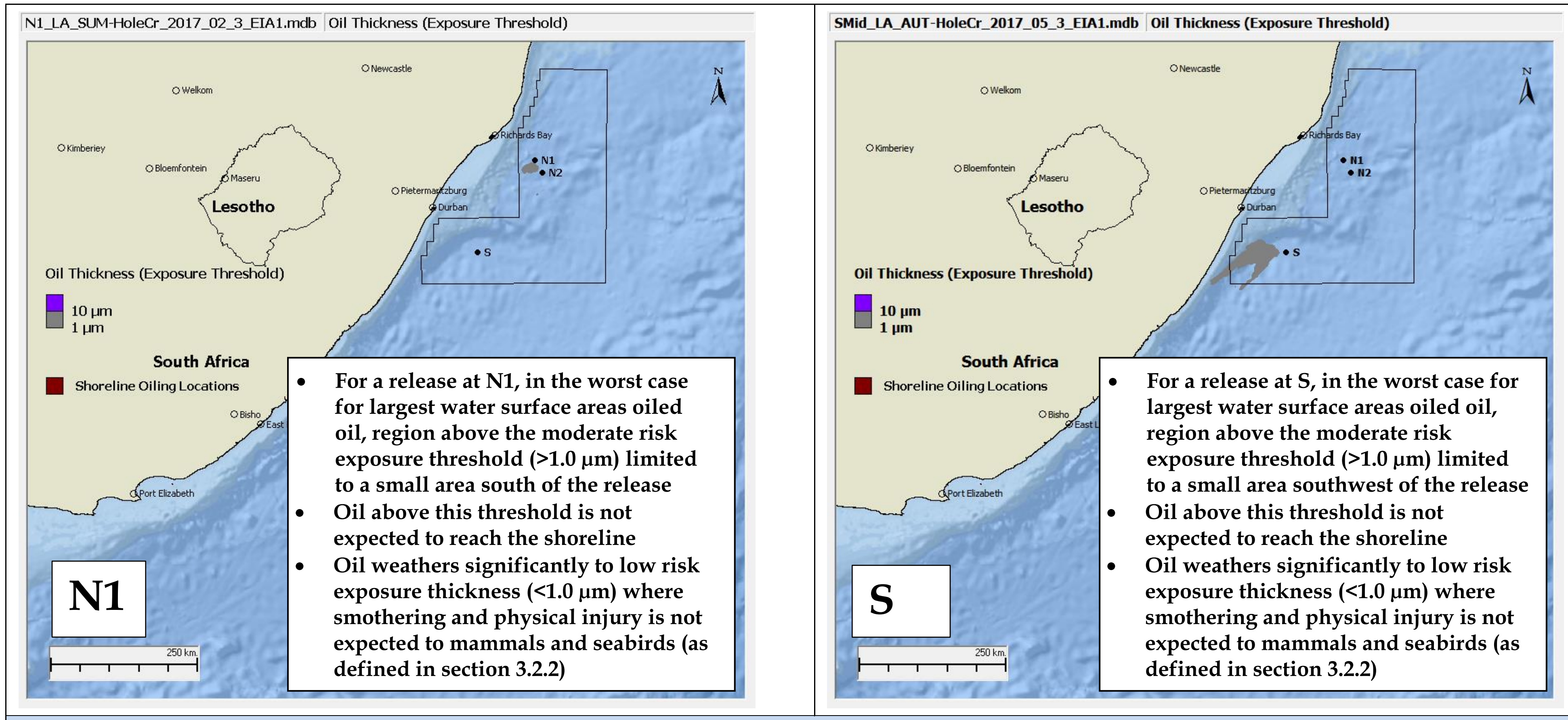
5.5.1 *Criterion 1: Largest Amount of Water Surface Area Oiled*

Table 5.13 presents the surface area of single iterations of the model representing the worst cases for most surface area oiled for spills at two modelling locations (N1 and S) for the two combined seasons, Season 1 (spring/autumn) and Season 2 (winter/spring). In these iterations, the total area on the water surface that was contacted by smothering thickness or higher (1.0 µm) at some point in the 21-day simulation during the very worst case was 401 km^2 and 348 km^2 for the releases at N1 for Season 1 and 2 respectively, and 3,049 km^2 and 669 km^2 for the releases at S for Season 1 and 2 respectively. No regions exceeded the 10.0 µm threshold for high risks to birds and wildlife (see threshold explanation in *Section 3.2.2*).

Table 5.13 Surface Area Oiled (Worst Case)

Season	Largest Amount of The Water Surface Area Oiled above 1 µm Threshold (km^2)	Largest Amount of The Water Surface Area Oiled above 10 µm Threshold (km^2)
Location N1		
Season 1	401	0
Season 2	348	0
Location S		
Season 1	3,049	0
Season 2	669	0

Figure 5-19 Scenario 2a: 7-Day Crude Oil Blowout – Thickness – Criterion 1: Worst Case Surface Oiling for a Spill at N1 and S in Summer/Autumn



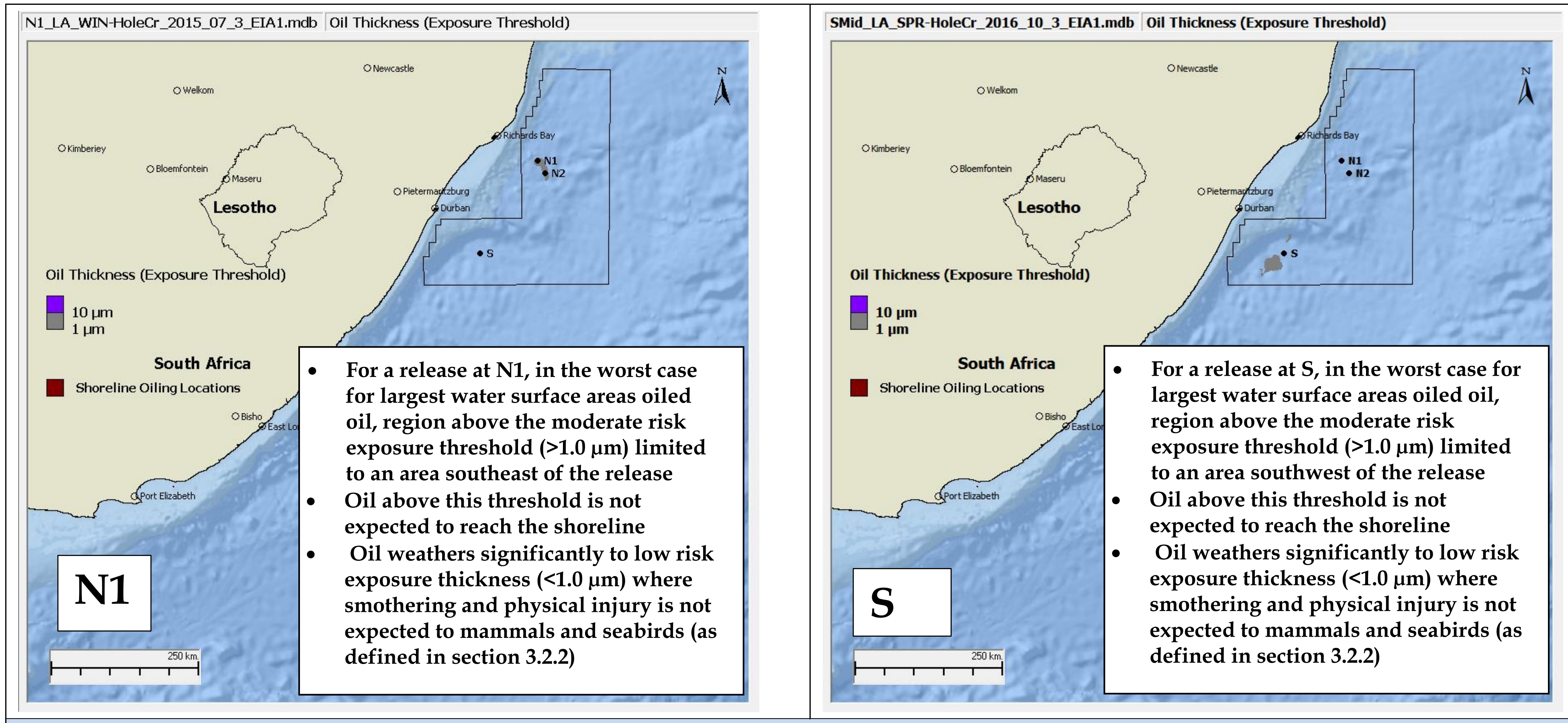
Figures Description

Scenario 2a 7-Day Crude Oil Blowout

These figures show the maximum thickness of oil on the water surface from a 7-day blowout over a 21-day period for the worst case scenario under Criterion 1 for the largest amount of water surface area oiled from a ***very unlikely*** oil spill. The colored contours depict the thickness of the oil in the moderate exposure threshold (1 µm to 10 µm) and above the high exposure threshold (>10 µm).

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

Figure 5-20 Scenario 2a: 7-Day Crude Oil Blowout – Thickness – Criterion 1: Worst Case Surface Oiling for a Spill at N1 and S in Winter/Spring



Figures Description

Scenario 2a 7-Day Crude Oil Blowout

These figures show the maximum thickness of oil on the water surface from a 7-day blowout over a 21-day period for the worst case scenario under Criterion 1 for the largest amount of water surface area oiled from a ***very unlikely*** oil spill. The colored contours depict the thickness of the oil in the moderate exposure threshold (1 µm to 10 µm) and above the high exposure threshold (>10 µm).

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

5.5.2 *Criterion 2: Most Amount of Shoreline Oiling Mass*

Although oil is predicted to have limited contact with shorelines in Scenario 2a, none of the cases simulated indicate the oil would exceed the significant shoreline oiling flux threshold (> 100 g/m²). Over time, as the oil weathers, the crude oil on the surface slick may form tar balls and arrive on shorelines in a heavily weathered state where most of the soluble and volatile toxic components such as the aromatics are absent. Modelling of tar ball formation and transport was not included in this exercise.

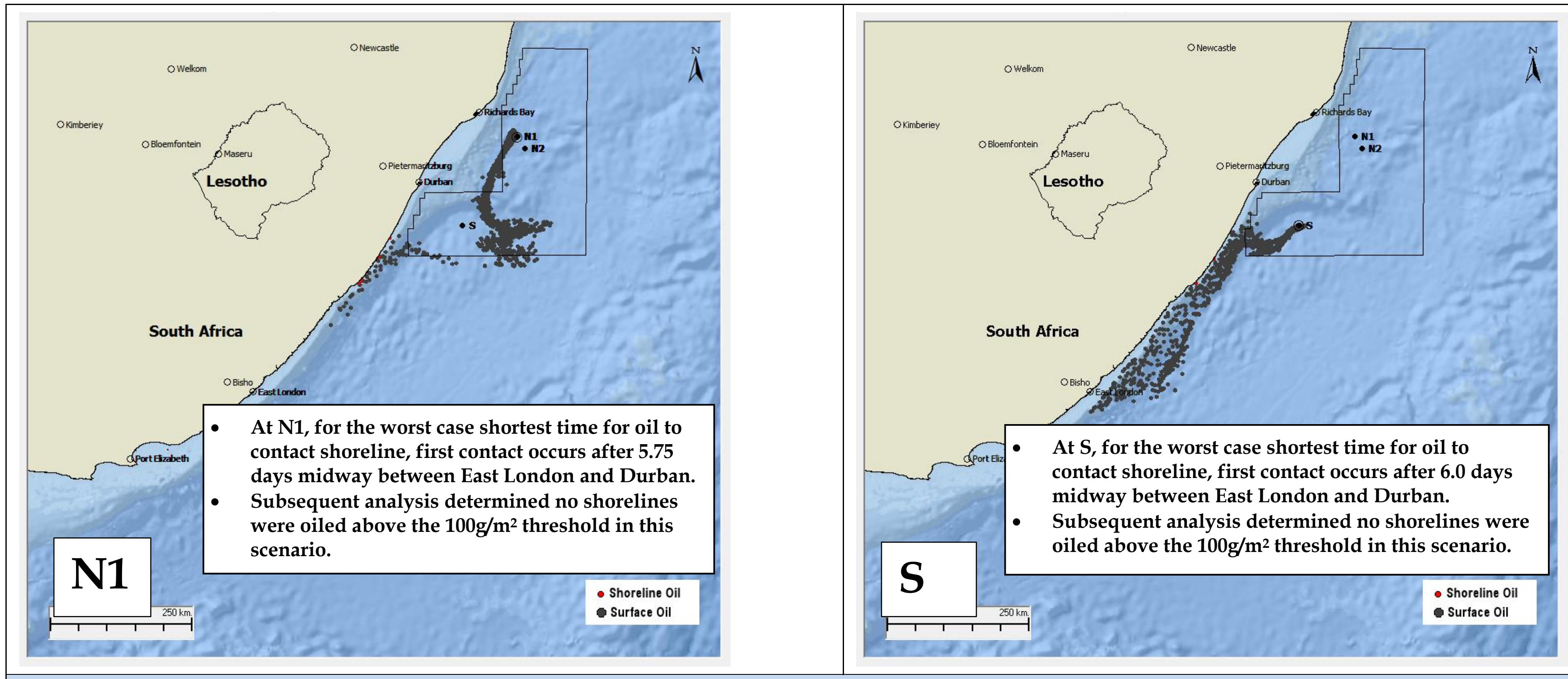
5.5.3 Criterion 3: Fastest Time for Shoreline Oiling to occur

Table *5.14* summarises the fastest shoreline oiling worst case for any amount of shoreline oiling (regardless of the 100 g/m² threshold). In no cases did oil accumulate on shorelines above the 100 g/m² significant shoreline oiling flux threshold due to 7-day crude blowouts at N1 and S for each season. The time when first shoreline contact occurs under Criterion 3 are shown in Figure *5-16* and Figure *5-17*. The fastest shoreline oiling occurs due to the transverse dispersion of the oil slick when it is carried by strong Agulhas Currents, which flows parallel to the coastline. Therefore, significant shoreline oiling is reduced in the fastest shoreline oiling iterations. These results, again, do not take into account any mitigation/intervention measures to be pursued.

Table 5.14 Fastest Time to Shoreline Oiling

Season	Fastest time for shoreline oiling to occur (days)
Location N1	
Summer-Autumn	5.75
Winter-Spring	4.25
Location S	
Summer-Autumn	6.00
Winter-Spring	5.00

Figure 5-21 Scenario 2a: 7-Day Crude Oil Blowout – Trajectory when Shoreline Contact First Occurs – Criterion 3: Fastest Time for Shoreline Oiling from N1 and S in Summer/Autumn



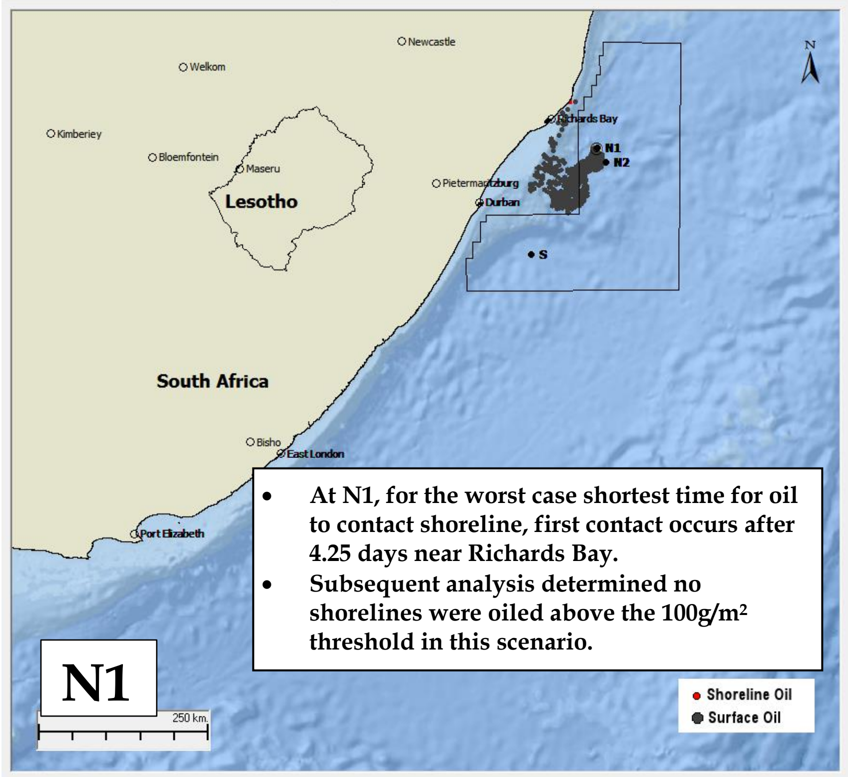
Figures Description

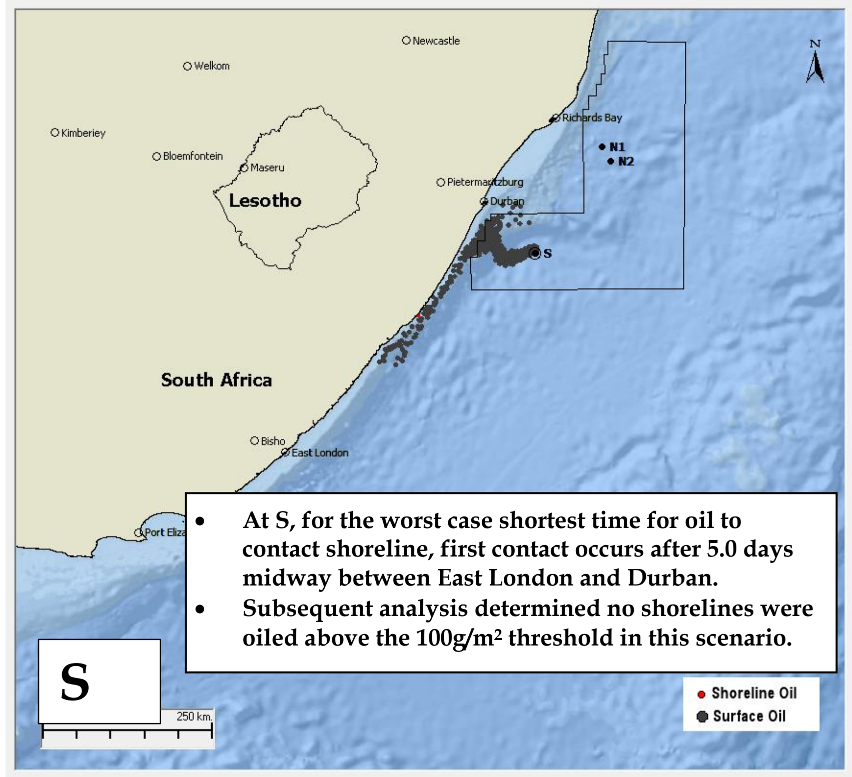
Scenario 2a 7-Day Crude Oil Blowout

These figures show the location of oil during a 7-day blowout over a 21-day period at the first moment oil contacts a shoreline under Criterion 3 for the shortest time to contact shoreline from a ***very unlikely*** oil spill. The black dots represent the oil mass while the red dots represent the shoreline oiling locations. Note that shoreline oiling may contain any level of oil mass, without application of the 100 g/m^2 shoreline impact threshold.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

Figure 5-22 Scenario 2a: 7-Day Crude Oil Blowout – Trajectory when Shoreline Contact First Occurs – Criterion 2: Fastest Time for Shoreline Oiling from N1 and S in Winter/Spring





Figures Description

Scenario 2a 7-Day Crude Oil Blowout

These figures show the location of oil during a 7-day blowout over a 21-day period at the first moment oil contacts a shoreline under Criterion 3 for the shortest time to contact shoreline from a ***very unlikely*** oil spill. The black dots represent the oil mass while the red dots represent the shoreline oiling locations. Note that shoreline oiling may contain any level of oil mass, without application of the 100 g/m^2 shoreline impact threshold.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

5.6 *Scenario 2b – 20-Day Crude Oil Blowout with Capping Stack*

In this scenario, Scenario 2b, the model simulated a release lasting 20 days due to a blowout at the reservoir. On the 20th day, a capping stack is successfully installed and the release is terminated. The transport and fate of the oil continued to be tracked by the model for an additional 14 days after the termination of the release for a total of 34 days simulated. As in Scenario 2a, in Scenario 2b the release was assumed to be constant at 4,717 bpd (750 m^3/day) from a well at N1 and 6,604 bpd (1,050 m^3/d) from a well at S. The results are provided in Table *5.9*.

Table 5.15 Modelling Worst Cases Results Summary - Crude Oil Release during a Cap Installation – Scenario 2b

Season	Criterion 1: Largest Amount of the Water Surface Area Oiled above 1 µm Threshold (km²)	Criterion 1: Largest Amount of the Water Surface Area Oiled above 10 µm Threshold (km²)	Criterion 2: Most Amount of Shoreline Oiling Mass > 100 g/m² - Shoreline Length (km)	Criterion 3: Fastest Time for Shoreline Oiling to Occur (days)	Probability of Any Shoreline Contact with Oil
	Drilling Location N1				
Season 1	615	0	0	5.75	96.7%
Season 2	695	0	0	7.00	90.0%
	Drilling Location S				
Season 1	4,386	0	0	6.50	96.7%
Season 2	1,391	0	0	5.25	96.7%

*Season 1 = summer/autumn; Season 2= winter/spring

(Note: this is modelled without the inclusion of any mitigation /containment measures, which represents an unrealistic condition)

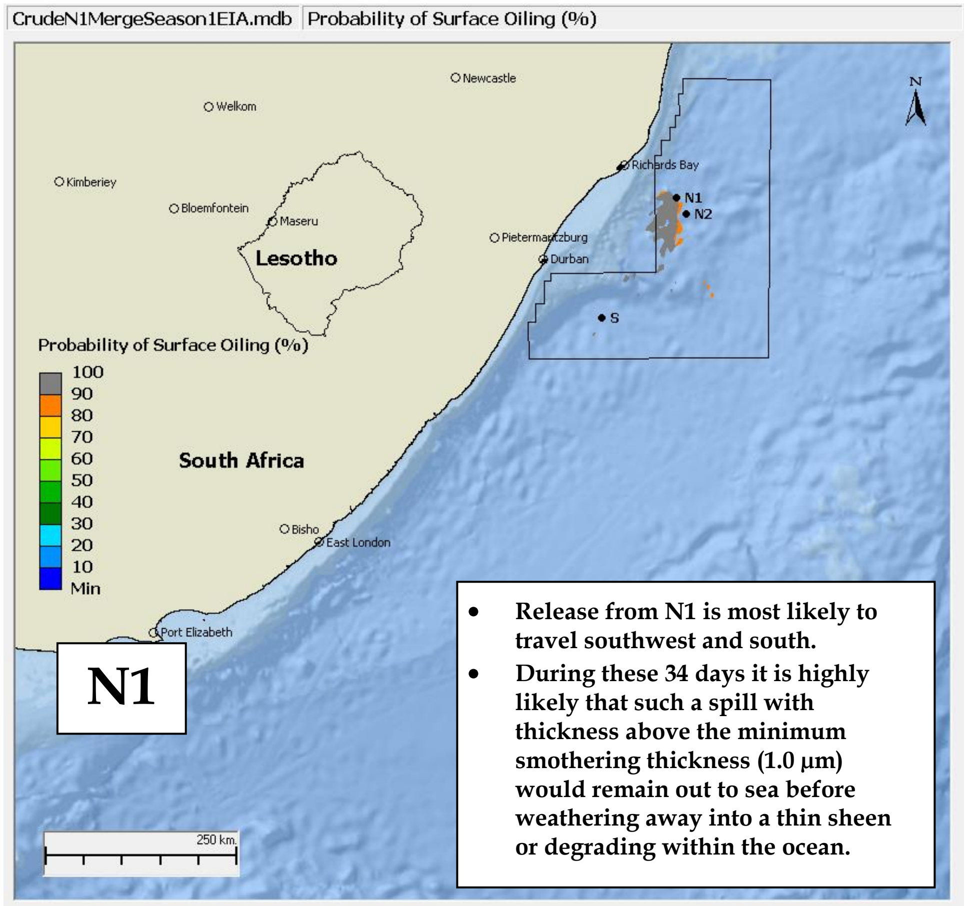
See Section 5.5 for comments regarding the selected rates of release chosen for Scenarios 2a and 2b.

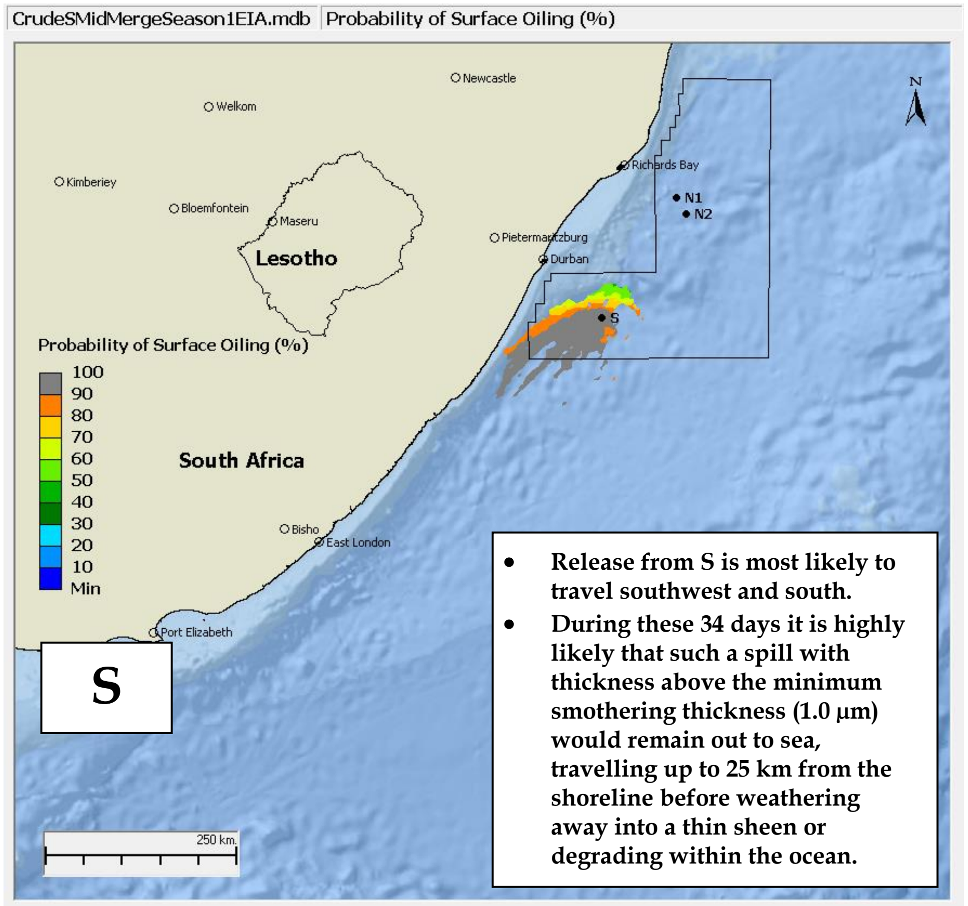
Oil spill model results forecasting hypothetical events represent the range of locations potentially affected (shown using probability) due to the presence of oil under conditions that define the scenario and simulation. Model results in Scenario 2b indicate that it is unlikely that significant shoreline oiling (>100 g/m²) will reach shorelines along the coast.

For Season 1 (summer/autumn) and Season 2 (winter/spring) respectively, *Figure 5-23* and *Figure 5-24* present the full extents of where oil thickness is greater than minimum thickness for smothering of aquatic organisms and wildlife (1.0 µm) after a crude oil blowout at two modelling locations (N1 and S). The area of potential surface trajectories are coloured according to the probability of oil traveling to a given location **at least once out of the 120 iterations through the five-year analysis**. As described in the Scenario Design in Section 5.1, each spill scenario is run 120 times (iterations) with the spill's start date evenly spaced across the five year period. This provides for a variety of combinations of wind and ocean current combinations to predict the range of potential spill trajectories. The most common trajectory occurs in south-west direction with the strong influence of Agulhas Currents parallel to the coastline.

It is highly likely that such a spill at either of the two spill locations (N1 and S) with thickness greater than the minimum smothering thickness (1.0 µm) would remain out to sea before weathering away into a thin sheen. In the absence of response efforts, the smothering slick of oil is able to travel almost 100 km and 250 km from the release points N1 and S respectively before weathering away into a thinner sheen.

Figure 5-23 Scenario 2b: 20-Day Crude Oil Blowout –Probability of smothering surface oiling (>1.0 µm) for spill at N1 and S in Summer/Autumn





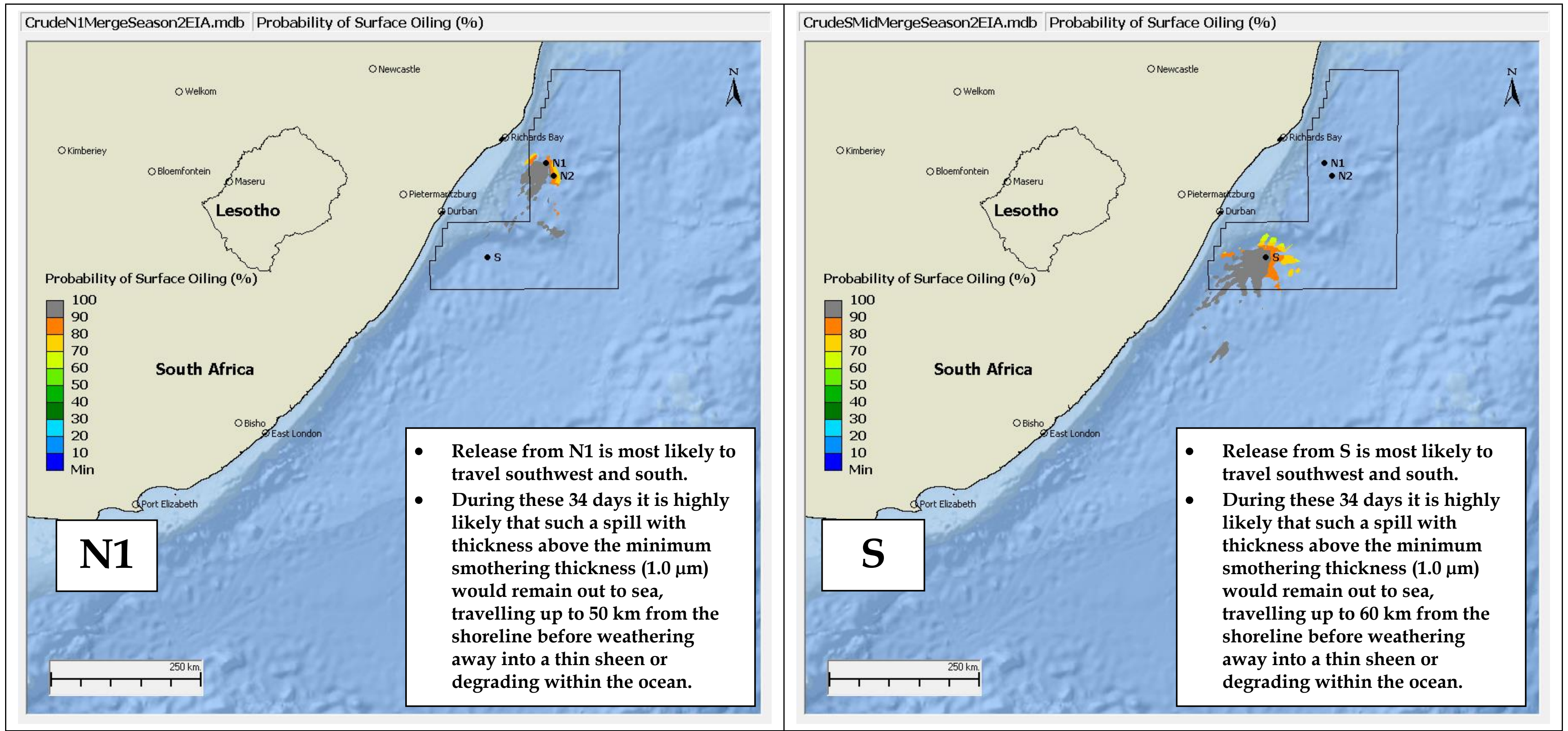
Figures Description

Scenario 2b 20-Day Crude Oil Blowout

These figures show the probability of oil being present from a 20-day blowout at a location on the water surface over a 34-day period from a ***very unlikely*** oil spill due to a blowout resulting in an oil thickness above the threshold level for potentially smothering birds and wildlife (> 1 µm). The colored contours depict the probability of oil's presence at a location at least once out of 120 spill simulations with spill release dates starting twice monthly over a five year period.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

Figure 5-24 Scenario 2b: 20-Day Crude Oil Blowout –Probability of smothering surface oiling for spill at N1 and S in Winter/Spring



Figures Description

Scenario 2b 20-Day Crude Oil Blowout

These figures show the probability of oil being present from a 20-day blowout at a location on the water surface over a 34-day period from a ***very unlikely*** oil spill due to a blowout resulting in an oil thickness above the threshold level for potentially smothering birds and wildlife (> 1 µm). The colored contours depict the probability of oil's presence at a location at least once out of 120 spill simulations with spill release dates starting twice monthly over a five year period.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

Diagrams describing the mass balance across all iterations of the Scenario 2b crude blowout simulation is presented in Figure *5-25* and Figure *5-26* for the north well, N1 and Figure *5-27* and Figure *5-28* for the southern well, S. Each curve on the diagrams represent the phases and forms the oil may become including liquid droplets ("Dispersed") rising to the surface from the blowout or naturally dispersed by wind/wave energy, dissolved, biodegraded, surface slick, evaporated into the atmosphere or washed ashore. The curves represent the average percentage of each form over all iterations for each season. Above and below each average curve are dashed lines representing the 5th percentile value and 95th percentile value across the iterations. Thus the 5th percentile value represents the value of which 5% of all values across the iterations are at are below the given value, while 95% of all the values are at or below the 95th percentile value.

As expected most of the oil (70%) is entrained initially in the water column as liquid droplets from crude oil blowout. At the end of simulation period, about 40 percent (40%) of oil still remains in water column as entrained oil. Oil, unlike other dissolved constituents of which concentration only decreases over time, can show both increase and decrease depending on entrainment of surface oil into the water column and resurfacing of oil in water column to the surface slick. Strong current and wind shear stresses, which is the case offshore South Africa, entrains oil into water column and contributes to the reduction of surface oil slick thickness. Such entrained oil will resurface intermittently during its stay on water surface when wind and current generated shear stresses are less than their thresholds for entrainment. In such situations, oil slicks can become thicker than the significant oil thickness (1 µm) at location farther from the discharge location and can appear as isolated patches, as presented in some oil thickness and travel time figures in this section.

Figure 5-25 Scenario 2b Median Percentage Mass Balance (solid lines) of Crude Oil – N1 Summer/Autumn (dashed lines represent 95th and 5th percentile values)

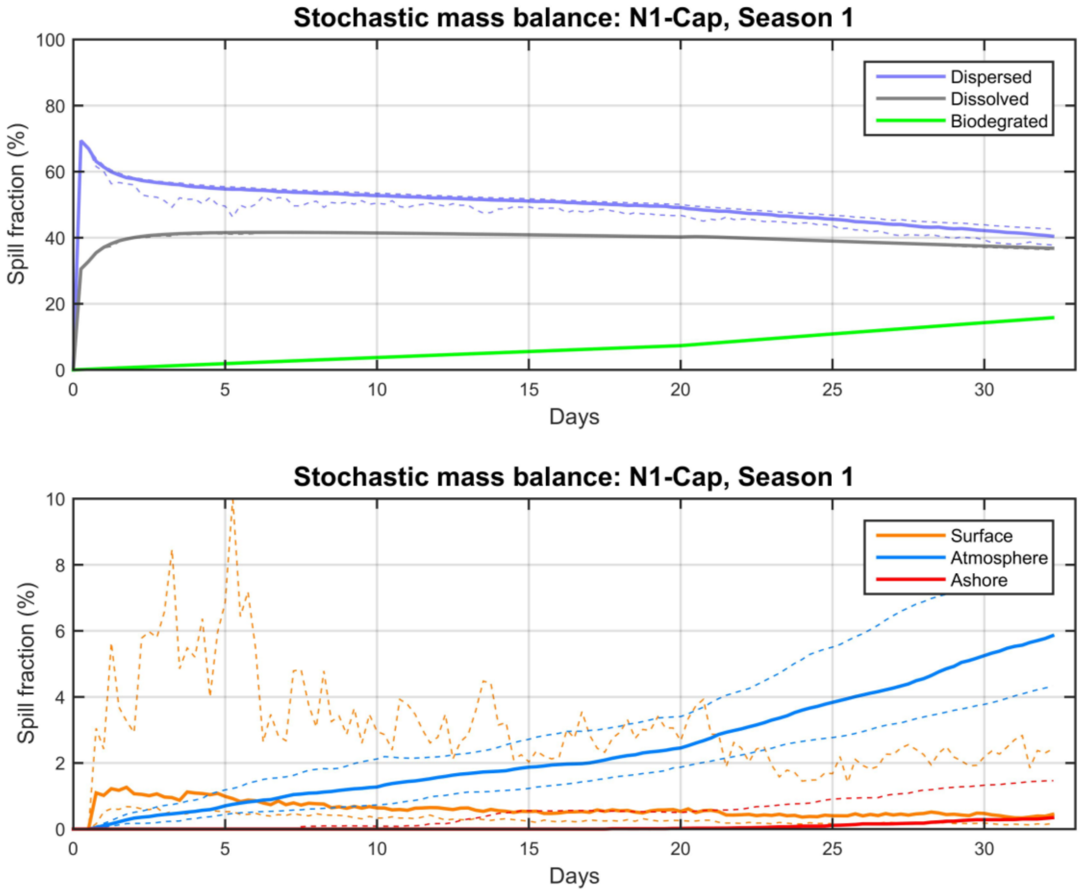


Figure 5-26 Scenario 2b Median Percentage Mass Balance (solid lines) of Crude Oil – N1 Winter/Spring (dashed lines represent 95th and 5th percentile values)

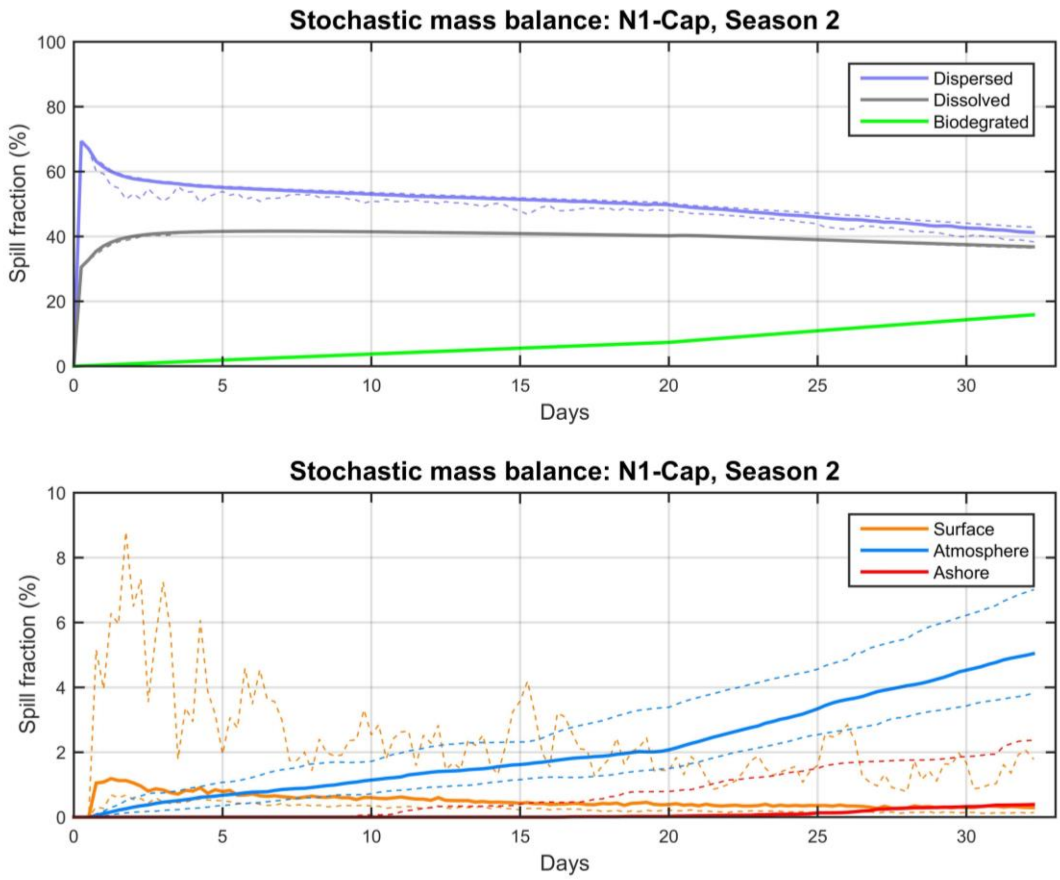


Figure 5-27 Scenario 2b Median Percentage Mass Balance (solid lines) of Crude Oil – S Summer/Autumn (dashed lines represent 95th and 5th percentile values)

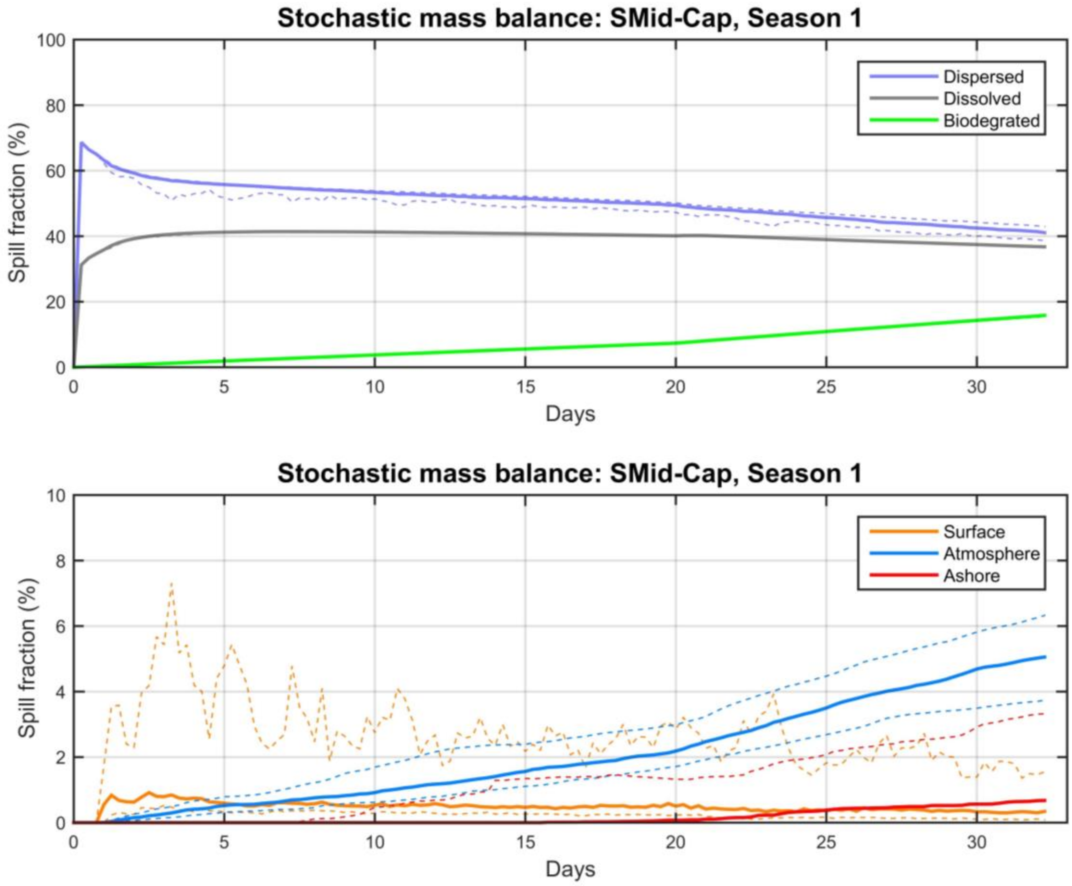
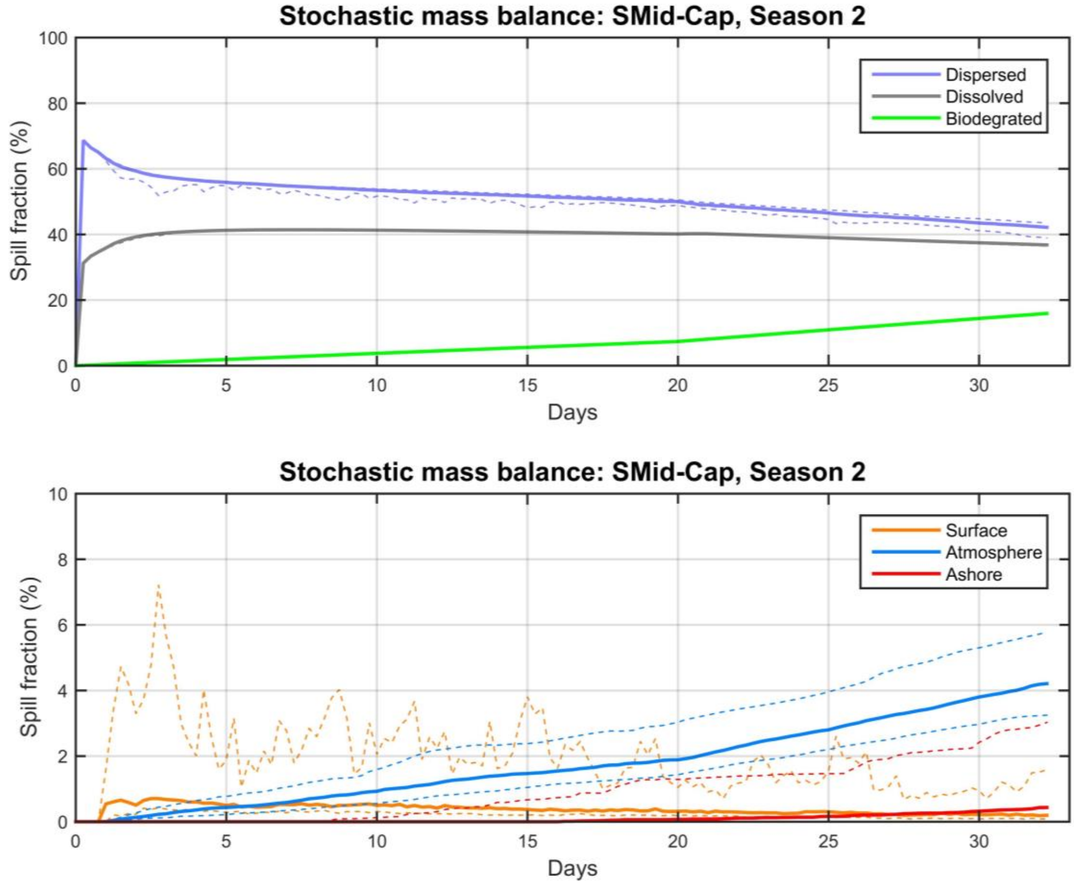


Figure 5-28 Scenario 2b Median Percentage Mass Balance (solid lines) of Crude Oil – S Winter/Spring (dashed lines represent 95th and 5th percentile values)



In addition, information has been extracted from these modelled iterations to understand the following worst cases:

- the largest amount of the water surface area oiled;
- the most amount of shoreline oiling mass; and
- the fastest time for shoreline oiling to occur;

Worst cases identified with these three criteria have been analysed for two combined seasons of the year within the period 2013-2017:

- Season1: Summer / Autumn: from 1st December to 31st May;
- Season 2: Winter/Spring: from 1st June to 30th November.

For Scenario 2b, there was no iteration in which a significant amount of shoreline oiling (above the 100 g/m² threshold) was identified.

It has to be stated that the following results and maps refer to very unlikely and rare unplanned events without accounting any mitigation and intervention measure that will be performed.

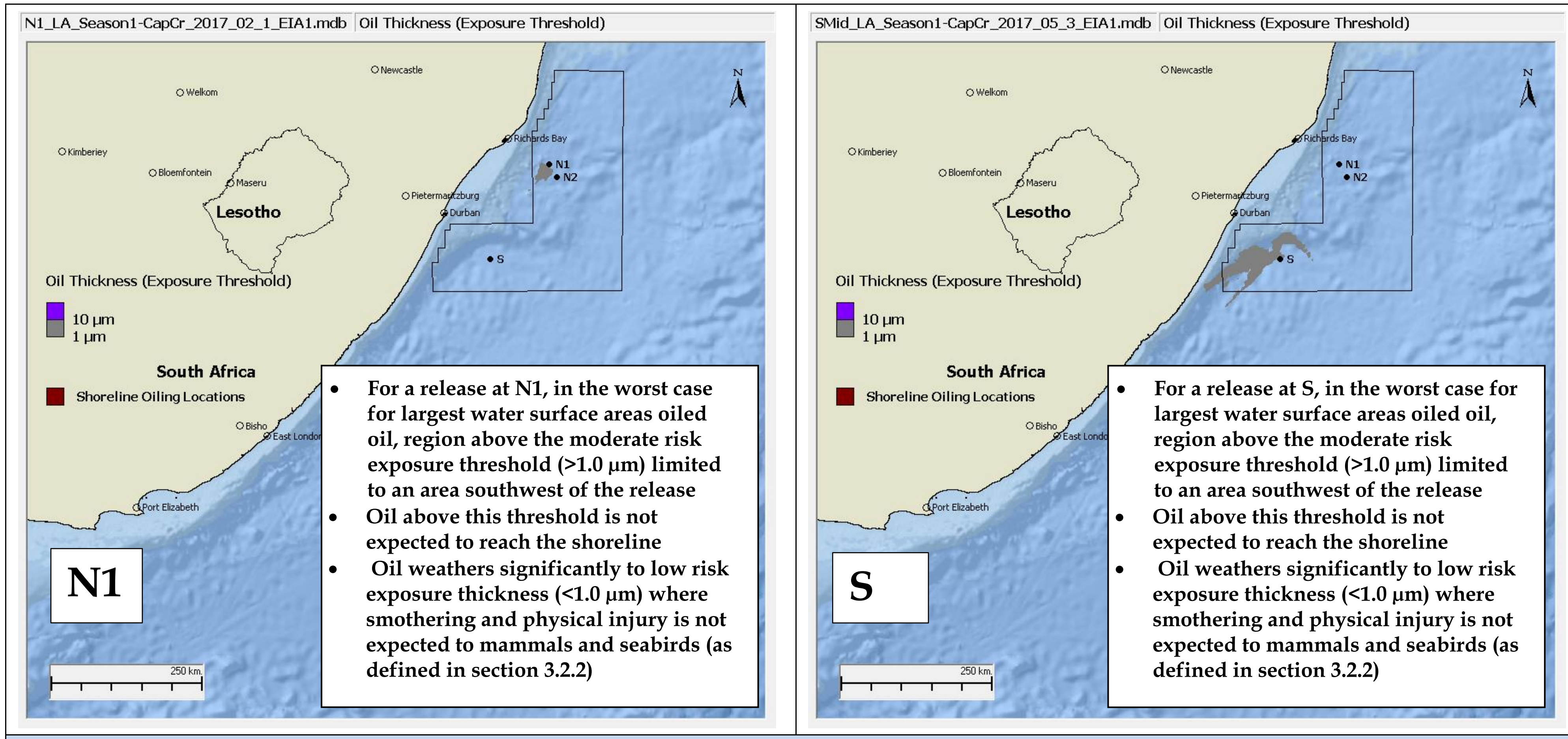
5.6.1 *Criterion 1: Largest Amount of Water Surface Area Oiled*

Table *5.16* presents the surface area of single iterations of the model representing the worst cases for most surface area oiled for spills at two modelling locations (N1 and S) for the two combined seasons, Season 1 (spring/autumn) and Season 2 (winter/spring). In these iterations, the total area on the water surface that was contacted by smothering thickness or higher (1.0 µm) at some point in the 34-day simulation during the very worst case was 615 km^2 and 695 km^2 for the releases at N1 for Season 1 and 2 respectively and 4,386 km^2 and 1,391 km^2 for the releases at S for Season 1 and 2 respectively. No regions exceeded the 10.0 µm threshold for high risks to birds and wildlife (see threshold explanation in *Section 3.2.2*).

Table 5.16 Surface Area Oiled (Worst Case)

Season	Largest Amount of The Water Surface Area Oiled above 1 µm Threshold (km^2)	Largest Amount of The Water Surface Area Oiled above 10 µm Threshold (km^2)
Location N1		
Season 1	615	0
Season 2	695	0
Location S		
Season 1	4,386	0
Season 2	1,391	0

Figure 5-29 Scenario 2b: 20-Day Crude Oil Blowout – Thickness – Criterion 1: Worst Case Surface Oiling for a Spill at N1 and S in Summer/Autumn



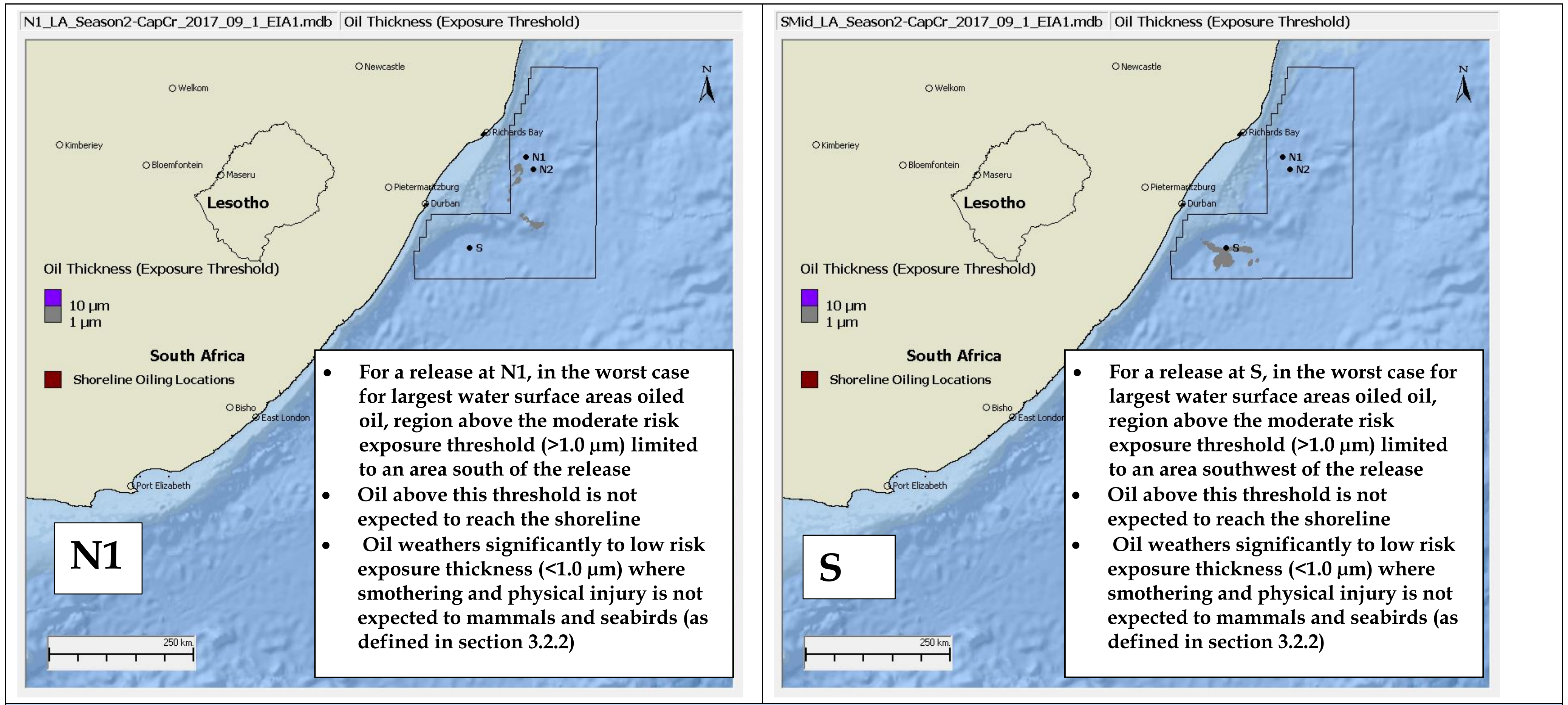
Figures Description

Scenario 2b 20-Day Crude Oil Blowout

These figures show the maximum thickness of oil on the water surface from a 20-day blowout over a 34-day period for the worst case scenario under Criterion 1 for the largest amount of water surface area oiled from a ***very unlikely*** oil spill. The colored contours depict the thickness of the oil in the moderate exposure threshold (1 µm to 10 µm) and above the high exposure threshold (>10 µm).

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

Figure 5-30 Scenario 2b: 20-Day Crude Oil Blowout – Thickness – Criterion 1: Worst Case Surface Oiling for a Spill at N1 and S in Winter/Spring



Figures Description

Scenario 2b 20-Day Crude Oil Blowout

These figures show the maximum thickness of oil on the water surface from a 20-day blowout over a 34-day period for the worst case scenario under Criterion 1 for the largest amount of water surface area oiled from a ***very unlikely*** oil spill. The colored contours depict the thickness of the oil in the moderate exposure threshold (1 µm to 10 µm) and above the high exposure threshold (>10 µm).

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

5.6.2 *Criterion 2: Most Amount of Shoreline Oiling Mass*

Although oil is predicted to have very limited contact the shoreline in Scenario 2b, none of the cases simulated indicate the oil would exceed the significant shoreline oiling flux threshold (1.0 µm). Over time, as the oil weathers, the crude oil on the surface slick may form tar balls and arrive on shorelines in a heavily weathered state where most of the soluble and volatile toxic components such as the aromatics are absent. Modelling of tar ball formation and transport was not included in this exercise.

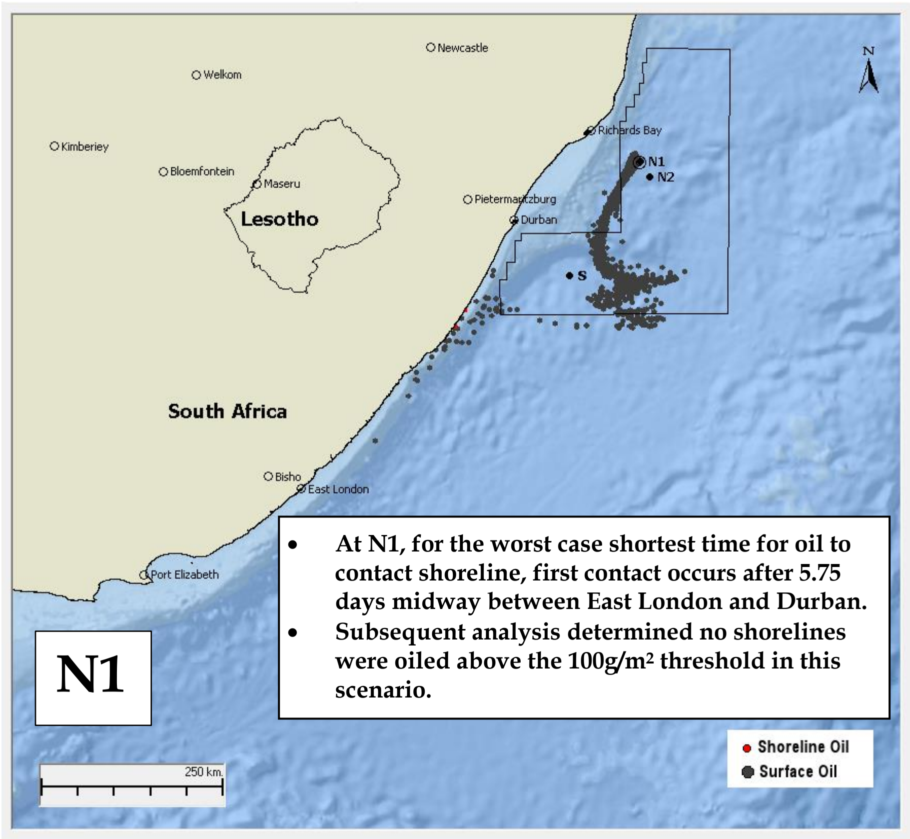
5.6.3 Criterion 3: Fastest Time for Shoreline Oiling to occur

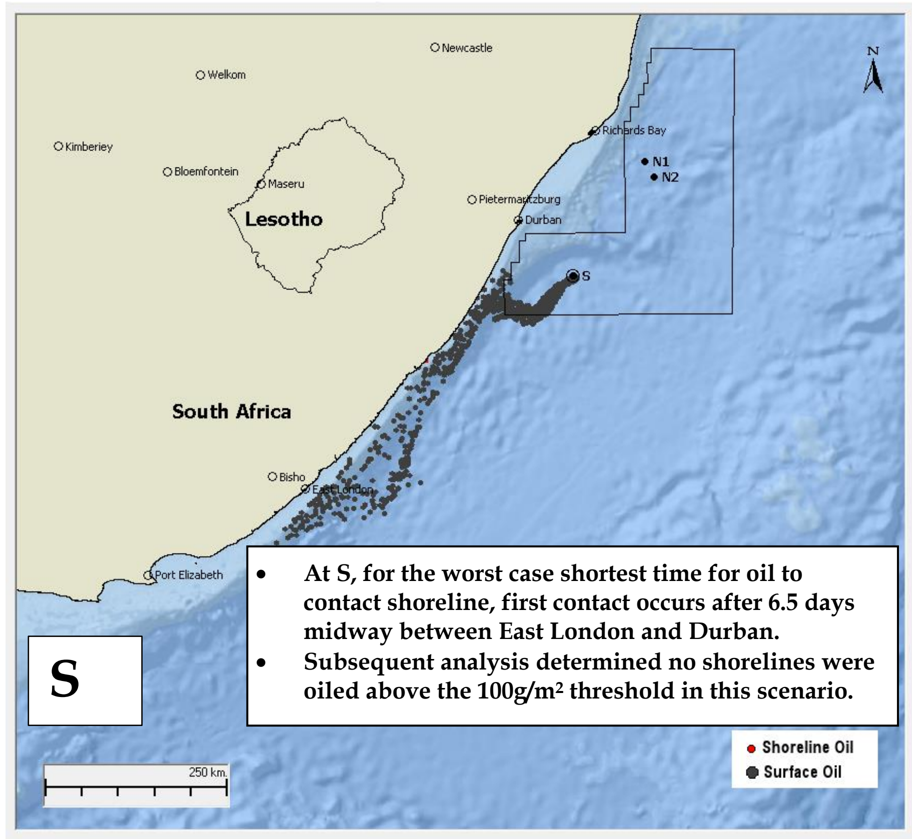
Table *5.17* summarises the fastest shoreline oiling of any amount of shoreline oiling regardless of thresholds. In no cases did oil contact shorelines above the significant shoreline oiling flux threshold (> 100 g/m^2) due to 20-day crude blowouts at N1 and S for each season. The time when first shoreline contact occurs under Criterion 3 are shown in Figure *5-31* and Figure *5-32*. The fastest shoreline oiling occurs due to the transverse dispersion of the oil slick when it is carried by strong Agulhas Currents, which flows parallel to the coastline. Therefore, significant shoreline oiling is reduced in the fastest shoreline oiling iterations. These results, again, do not take into account any mitigation or intervention measures to be pursued.

Table 5.17 Fastest Time to Shoreline Oiling

Season	**Fastest time for shoreline oiling to occur (days)**
Location N1	
Summer-Autumn	5.75
Winter-Spring	7.00
Location S	
Summer-Autumn	6.50
Winter-Spring	5.25

Figure 5-31 Scenario 2b: 20-Day Crude Oil Blowout – Dissolved Aromatic Hydrocarbons from N1 and S in Summer/Autumn



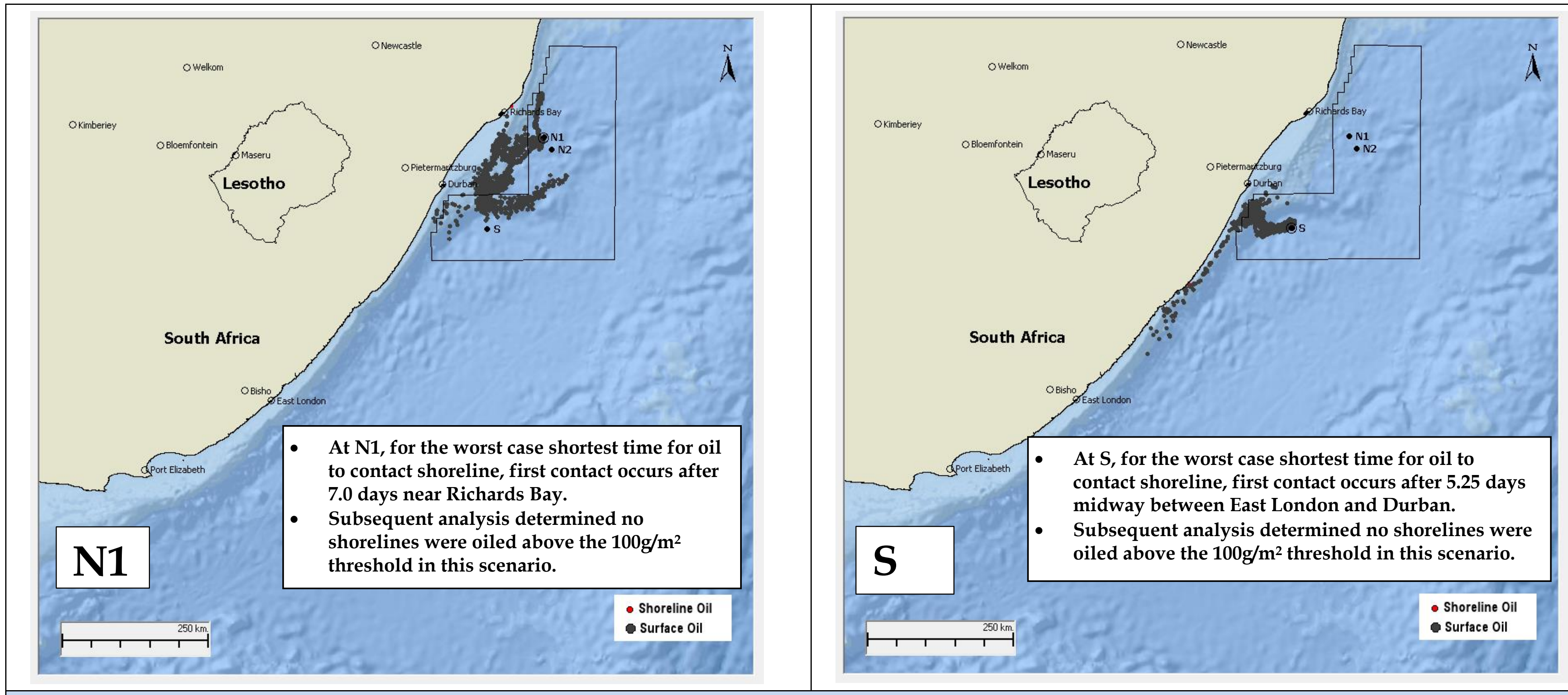


Figures Description

Scenario 2b 20-Day Crude Oil Blowout

These figures show the location of oil during a 20-day blowout over a 34-day period at the first moment oil contacts a shoreline under Criterion 3 for the shortest time to contact shoreline from a ***very unlikely*** oil spill. The black dots represent the oil mass while the red dots represent the shoreline oiling locations. Note that shoreline oiling may contain any level of oil mass, without application of the 100 g/m^2 shoreline impact threshold.

Figure 5-32 Scenario 2b: 20-Day Crude Oil Blowout – Trajectory when Shoreline Contact First Occurs – Criterion 3: Fastest Time for Shoreline Oiling from N1 and S in Winter/Spring



Figures Description

Scenario 2b 20-Day Crude Oil Blowout

These figures show the location of oil during a 20-day blowout over a 34-day period at the first moment oil contacts a shoreline under Criterion 3 for the shortest time to contact shoreline from a ***very unlikely*** oil spill. The black dots represent the oil mass while the red dots represent the shoreline oiling locations. Note that shoreline oiling may contain any level of oil mass, without application of the 100 g/m² shoreline impact threshold.

5.7 *SCENARIO 3 – ACCIDENTAL NADF RELEASE*

The riser disconnect scenario simulates the release of NADF mud at the water surface due to an accidental release of the drilling fluid within the entire riser pipe with the internal diameter of 19 inches. The releases were assumed to occur 3 m above the water surface and released "instantaneously" (however for modelling purposes, it was assumed to take place 0.5 m below the water surface within 1 hour).

Regarding the release volume assumed for this scenario: in case of an unwanted disconnection due to rig drift (e.g. lost position for GPS problem) during the drilling, the BOP will be immediately activated to close & cut drill pipe and pump shut-off. For this reason the spill will be limited to the amount of mud inside the riser connected to the rig and/or released at sea bottom. Please note the rig positioning has redundancy tool (beacon) to guarantee rig position and the weather forecast is always considered during operations. For this reason, in case of an adverse weather forecast, the marine riser is displaced with sea water and safely disconnected or, if weather conditions allow, stays in stand-by without disconnection.

The volume of oil within the riser pipe was split assuming 60% of the volume was base oil that could potentially form a slick, while 40% of the volume contained barite and other solid particles that could deposit on the seafloor. Therefore, for the oil spill simulations, release of 1,120 bbls, 1,256 bbls, and 1,991 bbls of base oil at locations N1, N2 and S respectively (equating to 60% of the 1,867 bbls, 2,094 bbls and 3,318 bbls NADF at N1, N2 and S respectively) were simulated.

The COSIM spill model simulated the fate and transport of the base oil for 7 days after the end of the release. The model was run 120 times to simulate releases from January 2013 through October 2017 as described in Section 5.1.

The solid particles within the NADF released were modelled separately using the GIFT model. The model estimated the deposition of the particles over a 48-hour period. The model was run twice for discharges at each location (during the months of minimum and maximum depth average currents at each location) allowing to observe a range of possible sediment thickness, and highest TSS concentrations. The months of minimum and maximum depth average currents are presented in *Table 5.18*.

Table 5.18 Months of Maximum and Minimum Depth Averaged Currents at Drilling Locations

Drilling Location	Year and Month of maximum depth average currents	Year and Month of minimum depth average currents
N1	April 2017	February 2014
N2	May 2015	September 2016
S	March 2013	April 2015

The results are summarized in *Table 5.19.* From these iterations, model output diagrams are provided for worst case scenarios describing the shortest time for shoreline oiling to occur, the most amount of shoreline oiling, and the largest amount of the water surface area oiled.

Table 5.19 Riser disconnect modelling worst cases results summary – Scenario 3

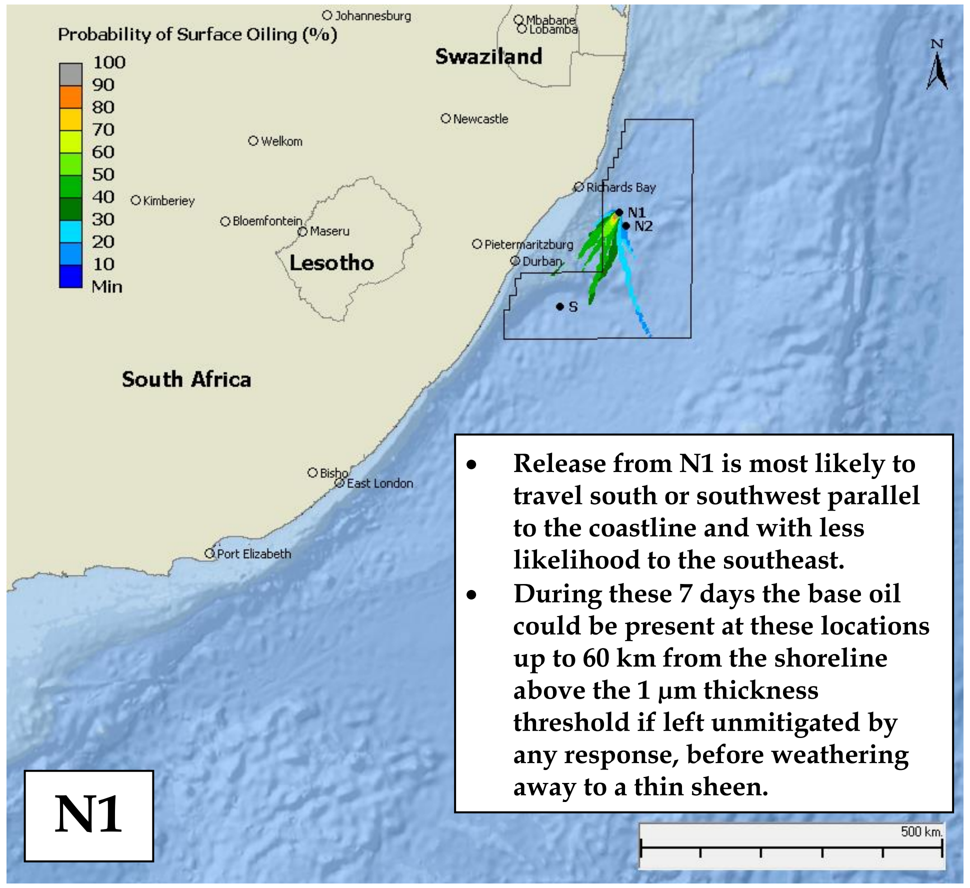
Drilling Location	Criterion 1: Largest Amount of the Water Surface Area Oiled above 1 µm Threshold (km²)	Criterion 1: Largest Amount of the Water Surface Area Oiled above 10 µm Threshold (km²)	Criterion 2: Most Amount of Shoreline Oiling Mass - Shoreline Length (km)	Criterion 3: Fastest Time for Shoreline Oiling to Occur (days)	Probability of Any Shoreline Contact with Oil
N1	1,232	0	119	2.5	8.3%
N2	873	0	249	3.2	5.8%
S	2,046	0	186	2.7	15.0%

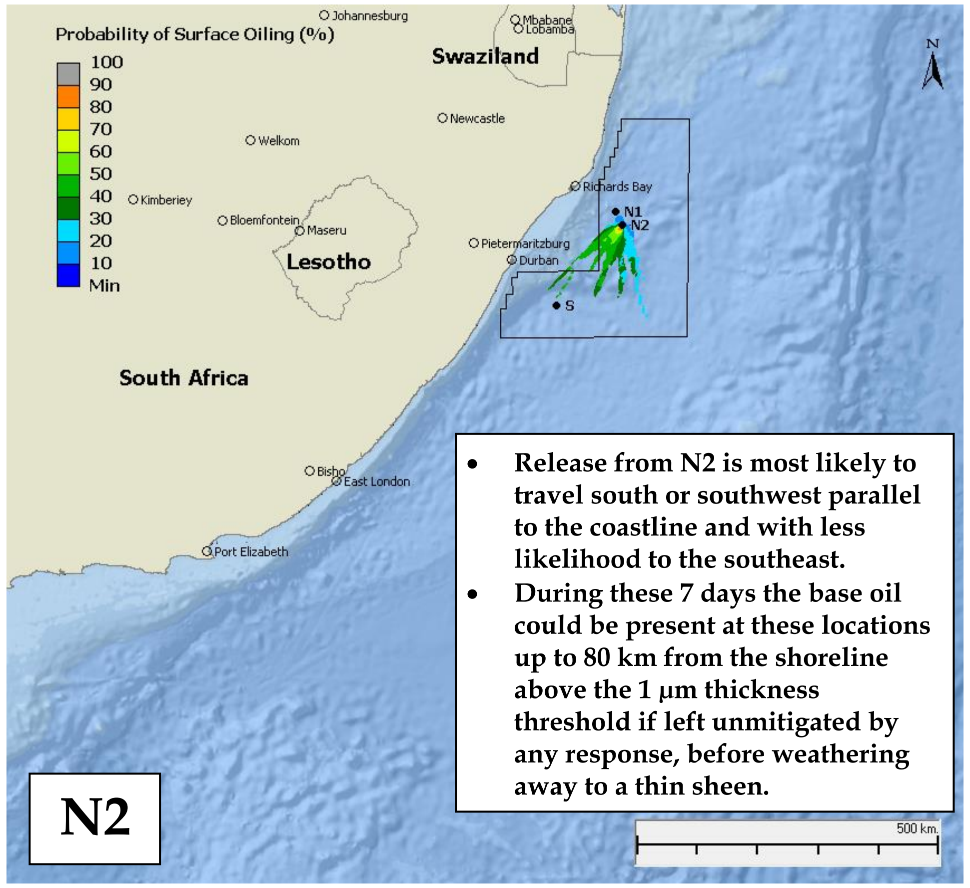
(Note: this is modelled without the inclusion of any mitigation /containment measure, which is an unrealistic condition).

Figure 5-33 presents the full extents of where oil thickness is greater than minimum thickness (>1 µm) for smothering of aquatic organisms and wildlife after accidental NADF release at three modelling locations (N1, N2 and S). The area of potential surface trajectories are coloured according to the probability of oil traveling to a given location **at least once through the five-year analysis**. As described in the Scenario Design in Section 5.1, each spill scenario is run 120 times (iterations) with the spill's start date evenly spaced across the five year period. This provides for a variety of combinations of wind and ocean current combinations to predict the range of potential spill trajectories. The most common trajectory occurs in south and south-west directions with the strong influence of Agulhas Currents parallel to the coastline.

It is unlikely that such a spill at any of the three spill locations (N1, N2 and S) would carry oil slick with thickness greater than the minimum smothering thickness (>1 µm) to an area within 25 km off South African coastline. In the absence of response efforts, the smothering slick of oil is able to travel over 215 km, 160 km, and 305 km from the release points N1, N2 and S respectively before weathering away into a thinner sheen.

Figure 5-33 Scenario 3: Accidental NADF Release –Probability of smothering surface oiling (>1.0 µm) for spill at N1, N2 and S





Figures Description

Scenario 3 NADF Release

These figures show the probability of oil being present at a location on the water surface over a 7-day period from a ***very unlikely*** oil spill due to a riser disconnect resulting in an oil thickness above the threshold level for potentially smothering birds and wildlife (> 1 µm). The colored contours depict the probability of oil's presence at a location at least once out of 120 spill simulations with spill release dates starting twice monthly over a five year period.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

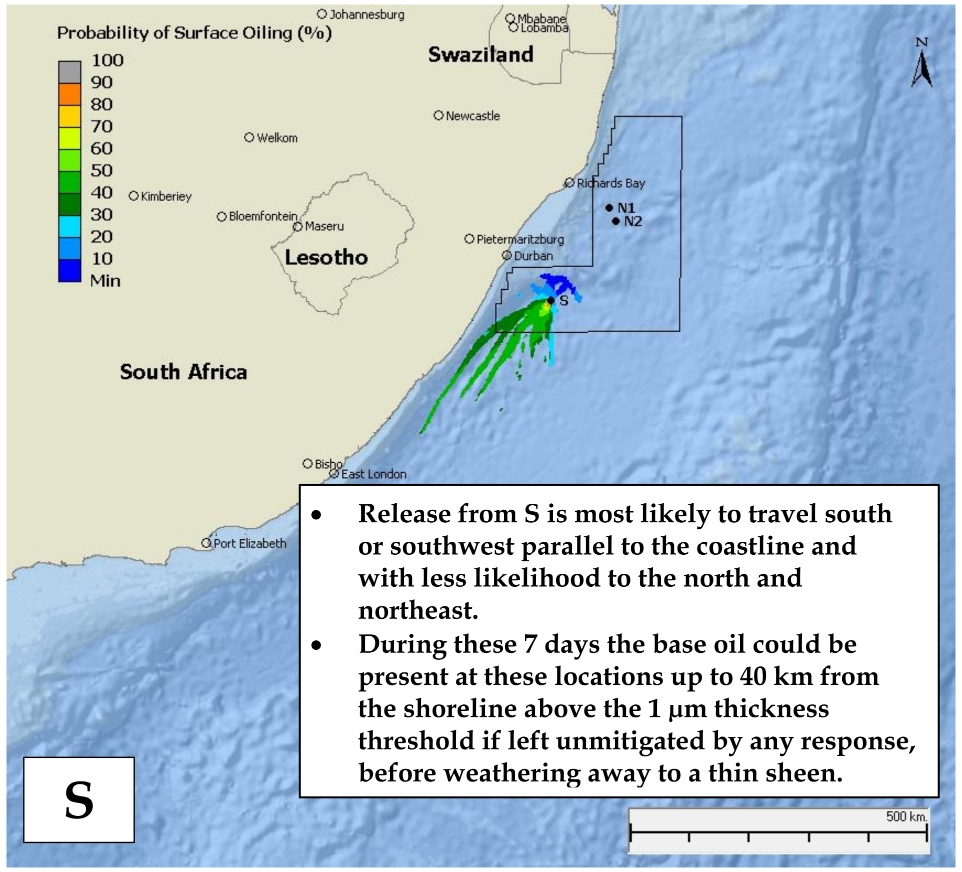
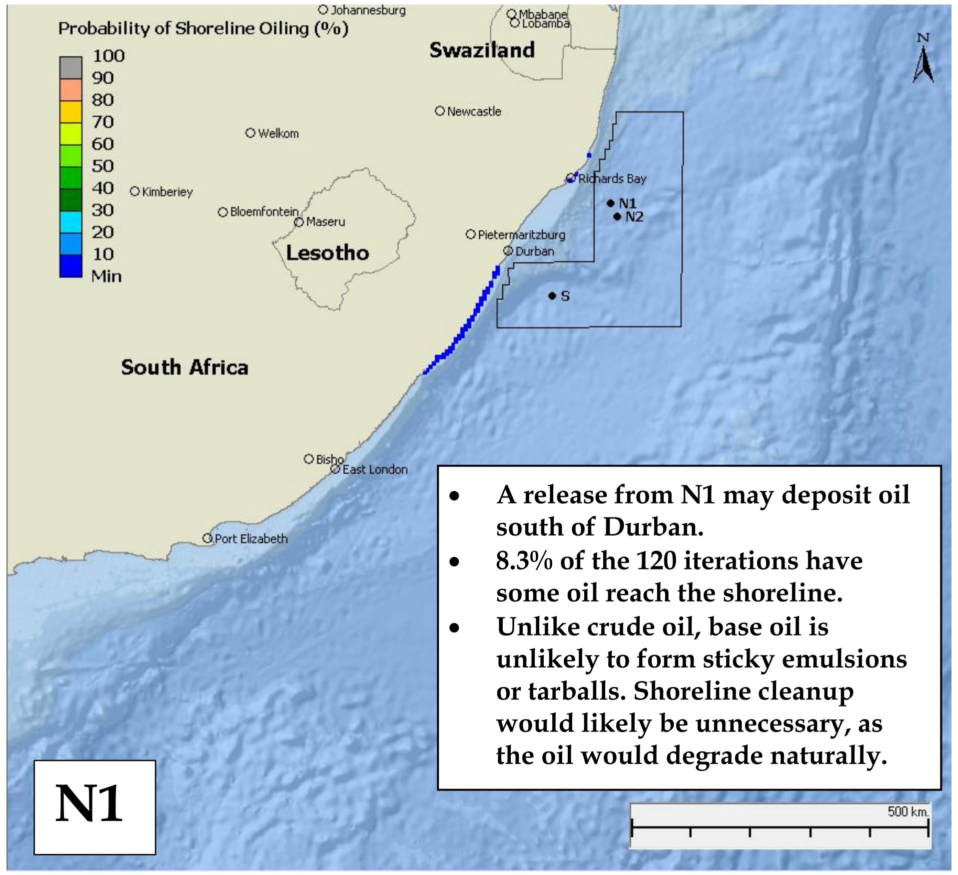
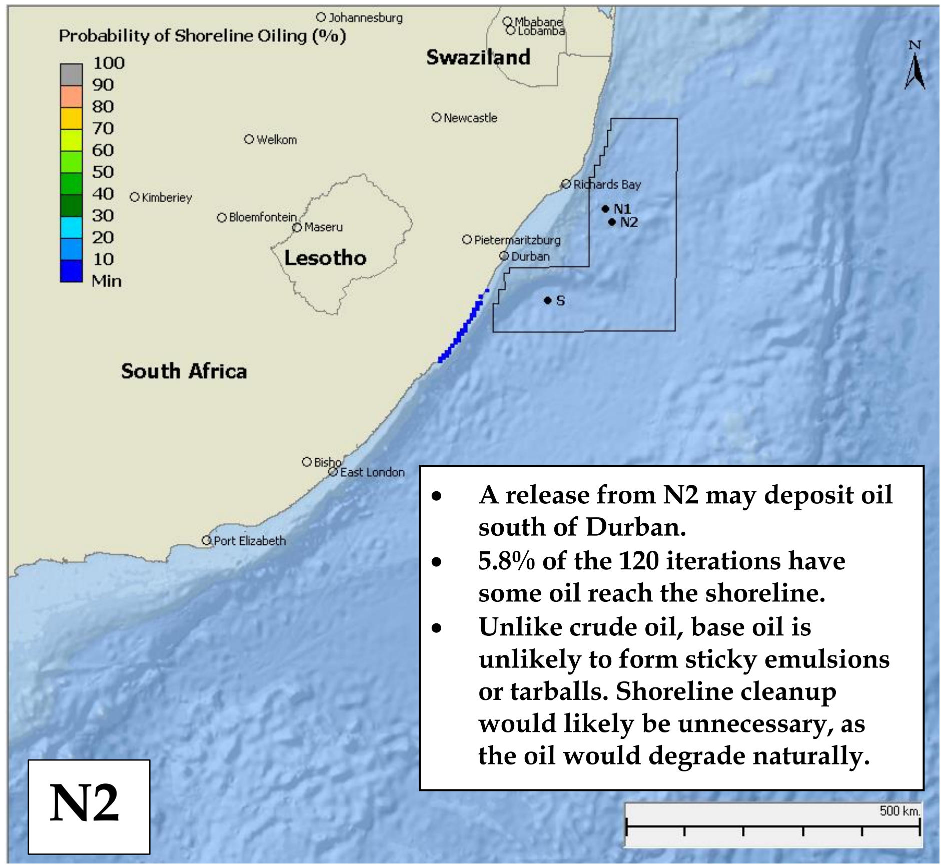


Figure 5-34 presents the probability of shoreline oiling for accidental NADF releases at three modelling locations (N1, N2 and S). The locations of impact from the 7-day simulations within five-year period range from the Durban to East London. **The base oil used in NADF is typically a biodegradable low-toxicity synthetic fluid similar to cooking oils, which would be unlikely to form a sticky emulsion or a viscous stain on shorelines requiring cleanup efforts.**

The longest lengths of shoreline oiling in the individual worst case for most shoreline oiling iterations are 119 km, 249 km and 186 km for spills originating at locations N1, N2 and S respectively. Regardless of the shoreline oiling threshold, out of the 120 iterations over the five years, the probability of any shoreline oiling occurring at any shore is 8.3%, 5.8% and 15.0% for locations N1, N2 and S respectively. However, as shown in the colored shorelines in *Figure 5-34*, any individual location has less than a 10% chance of oil contacting it.

Figure 5-34 Scenario 3: Accidental NADF Release –Worst Case Shoreline oiling probability for spill at N1, N2 and S



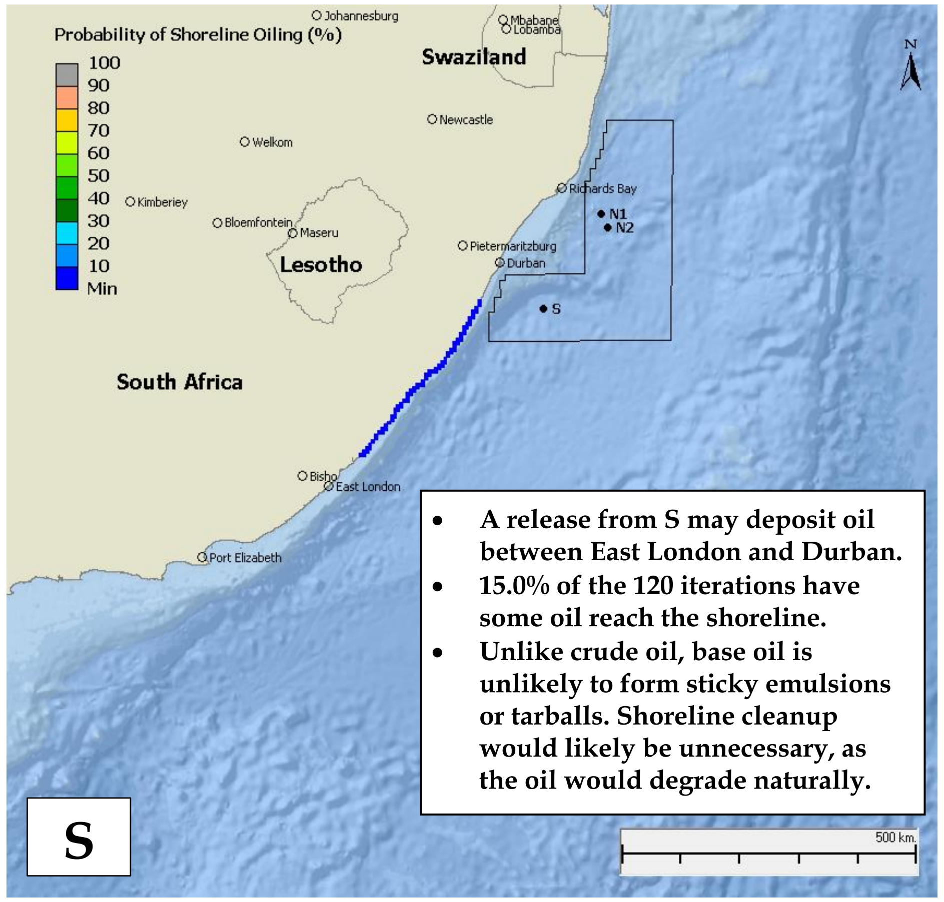


Figures Description

Scenario 3 NADF Release

These figures show the probability of oil being present at a location on the shoreline over a 7-day period from a ***very unlikely*** oil spill due to a riser disconnect. (No consideration for thickness thresholds were made in this scenario.) The colored contours depict the probability of oil's presence at a location at least once out of 120 spill simulations with spill release dates starting twice monthly over a five year period.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.



Mass balance diagrams of the base oil simulations are presented in *Figure 5-35*, Figure *5-36*, and Figure *5-37*. The curves represent the median percentage of each form over all iterations for each season. Above and below each median curve are dashed lines representing the 5th percentile value and 95th percentile value across the iterations. Thus the 5th percentile value represents the value of which 5% of all values across the iterations are at are below the given value, while 95% of all the values are at or below the 95th percentile value.

Most of the oil quickly became liquid droplets ("dispersed") within the water column and remained as such. The range of possible values in this state is large since it is dependent on the model iteration's start date for the wind and wave energy present during the spill. The oil mass floating on the surface is mostly removed within a day into the air (median around 10%) or in the water column (median below 80%).

Figure 5-35 Scenario 3 Median Percentage Mass Balance (solid lines) of Base Oil – N1 (dashed lines represent 95th and 5th percentile values)

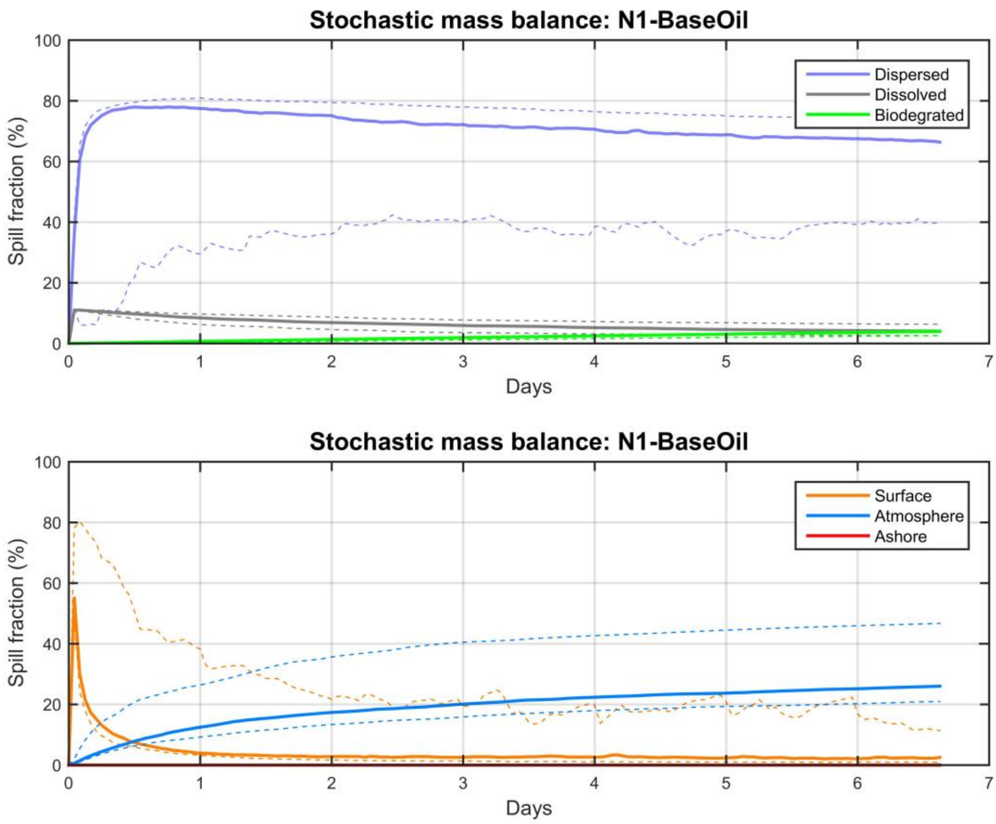
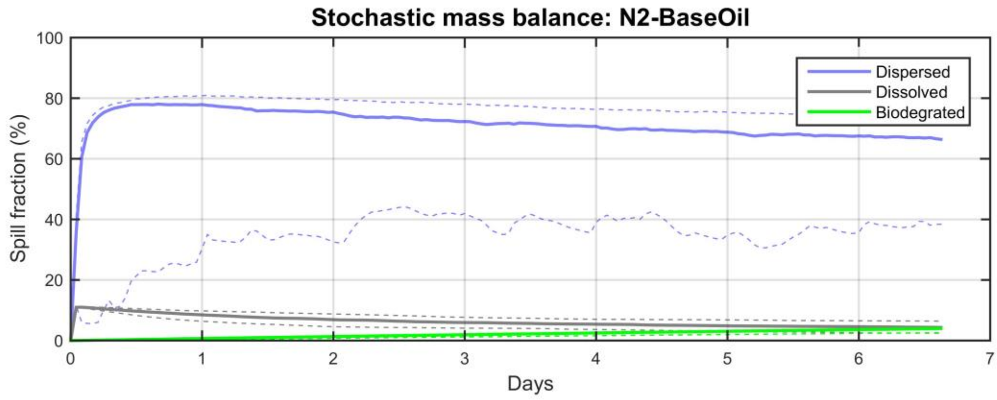


Figure 5-36 Scenario 3 Median Percentage Mass Balance (solid lines) of Base Oil – N2 (dashed lines represent 95th and 5th percentile values)



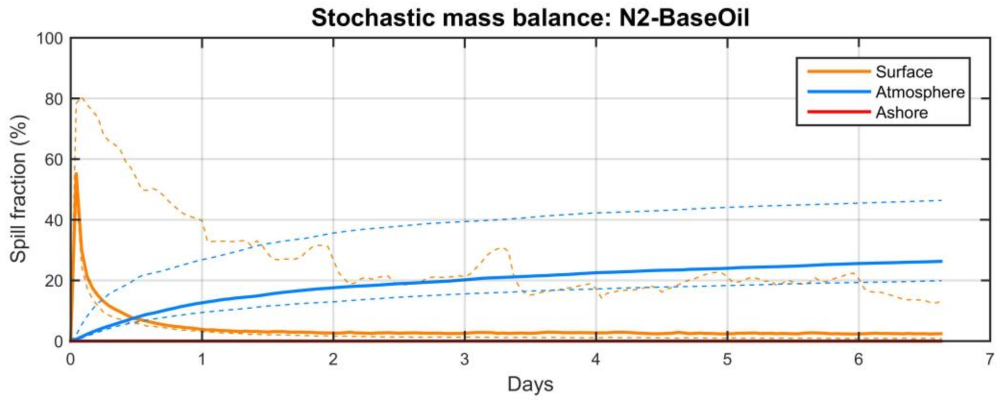
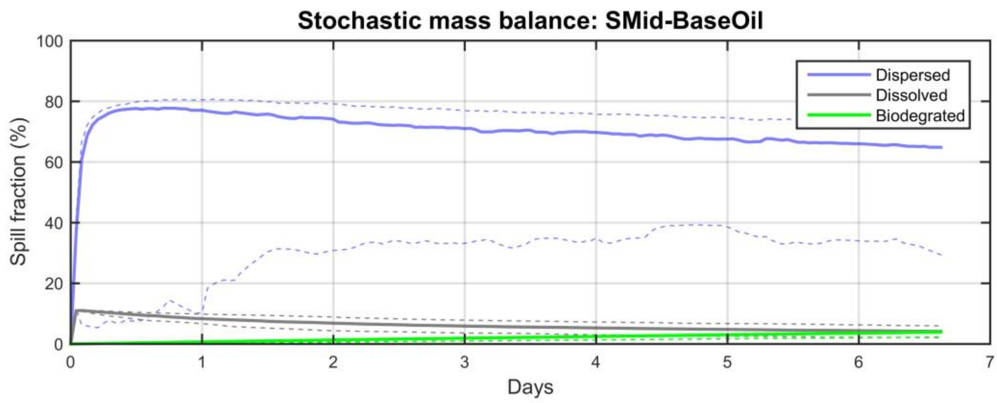
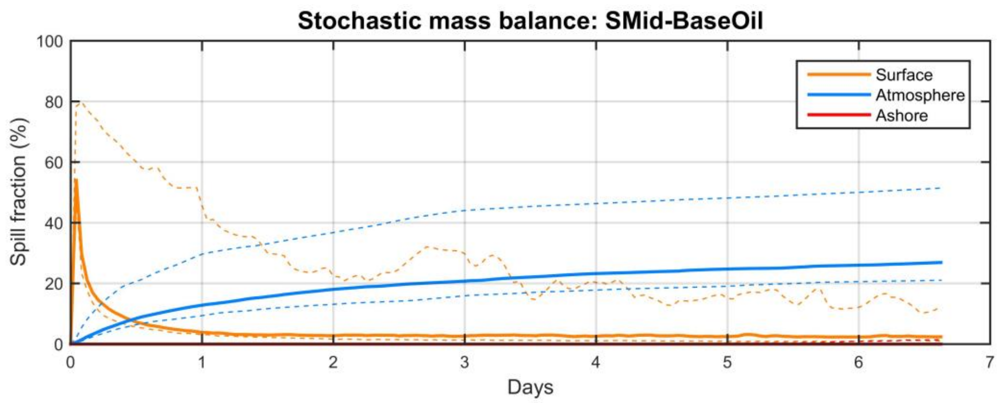


Figure 5-37 Scenario 3 Median Percentage Mass Balance (solid lines) of Base Oil – S (dashed lines represent 95th and 5th percentile values)



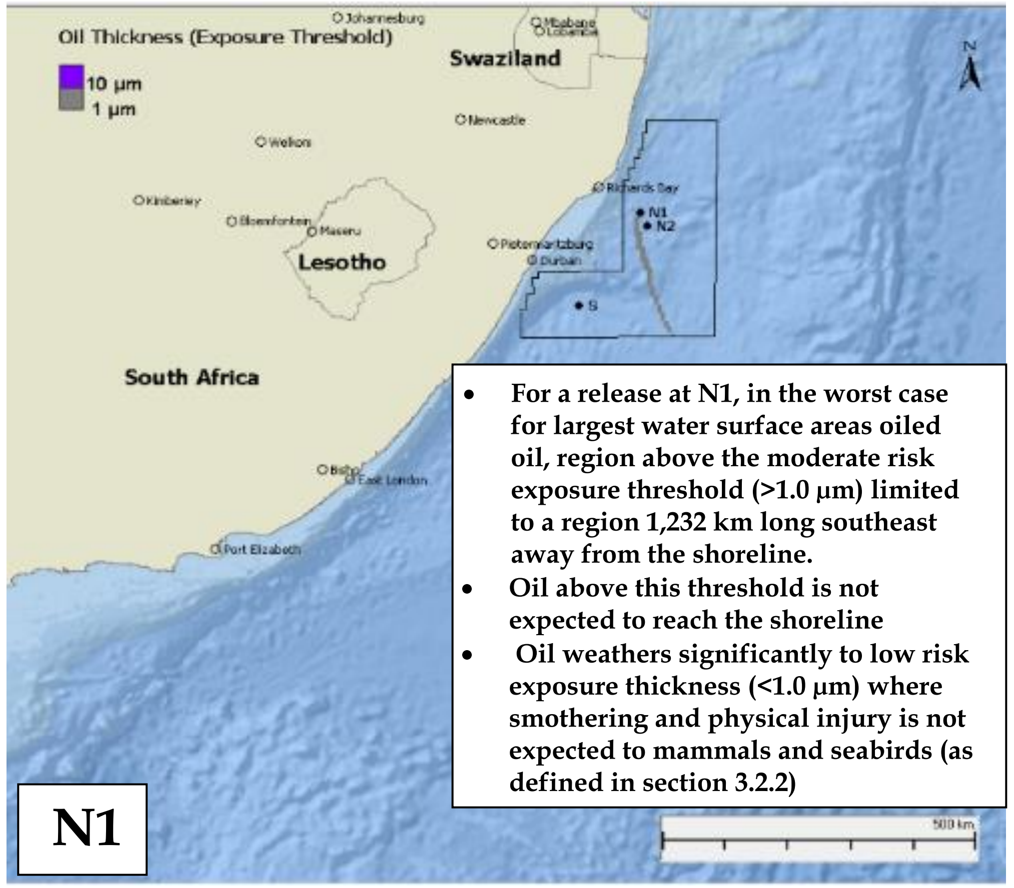


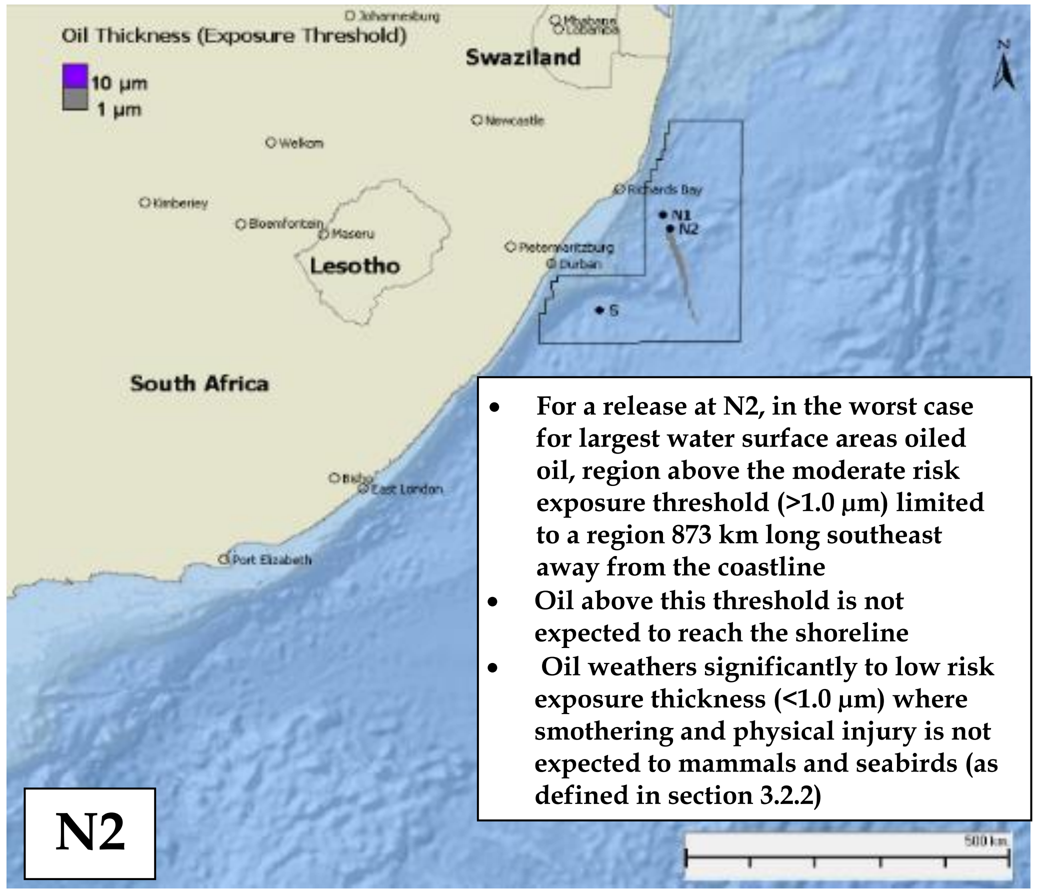
5.7.1 *Criterion 1: Largest Amount of Water Surface Area Oiled*

Figure *5-38* presents the trajectory of single iterations of the model representing the worst cases for most surface area oiled over seven days for spills at three modelling locations (N1, N2 and S). The most common trajectory occurs in south and south-west directions with the strong influence of Agulhas Currents parallel to the coastline. It is unlikely that such a spill at any of the three spill locations (N1, N2 and S) would carry oil slick with thickness greater than the minimum smothering thickness (1 µm) to an area within 25 km off South African coastline. In these iterations, the total area on the water surface that was contacted by the minimum smothering thickness or higher (>1.0 µm) at some point in the 7-day simulation were 1,232 km^2, 873 km^2 and 2046 km^2 for the releases at N1, N2 and S respectively. Regions above the 1.0 µm threshold for risks to birds and wildlife extend as narrow and long streaks towards south and parallel to South Africa coastline due to the strong influence of Agulhas, however do not contact the shoreline. The discharge trajectory above the 1 µm threshold travels up to a distance of 210 km, 155 km, and 310 km from the initial release at locations N1, N2 and S respectively.

Figure *5-39* presents the arrival times of the oil slicks above the thickness threshold (>1 µm) for impacting aquatic and marine organisms and wildlife for worst case surface oiling iterations of an accidental NADF release at N1, N2 and S. Arrival time figures for worst case shoreline oiling and fastest shoreline oiling iterations are not presented here because they are small, narrow and short patches of oil slicks around their release locations. Oil slicks in those iterations thin out into sheens within 1 or 2 days and do not extend more than about 25 km from their release locations. Oil slick greater than the minimum smothering thickness (>1 µm) did not contact shorelines in the worst case iterations.

Figure 5-38 Scenario 3: Accidental NADF Release - Thickness – Criterion 1: Worst Case Surface Oiling for Spill at N1





Figures Description

Scenario 1 NADF Release

These figures show the maximum thickness of oil on the water surface over a 7-day period for the worst case scenario under Criterion 1 for the largest amount of water surface area oiled from a ***very unlikely*** oil spill due to a riser disconnect. The colored contours depict the thickness of the oil in the moderate exposure threshold (1 µm to 10 µm) and above the high exposure threshold (>10 µm).

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

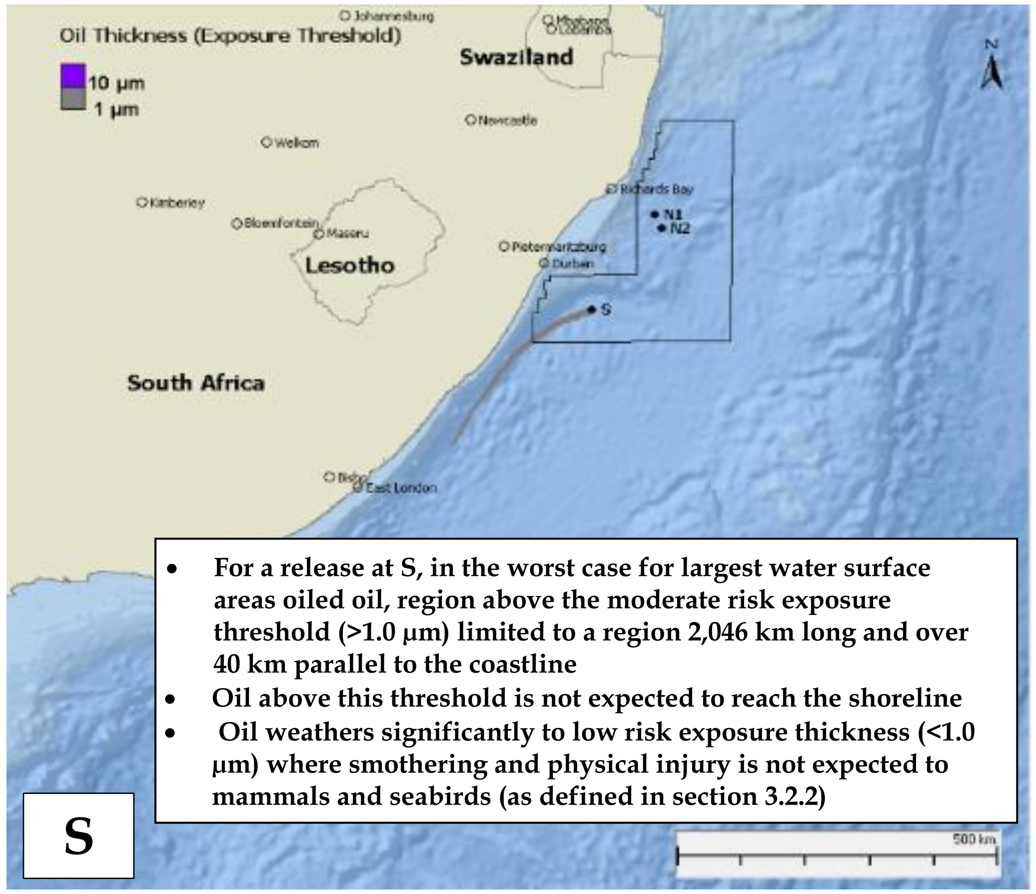
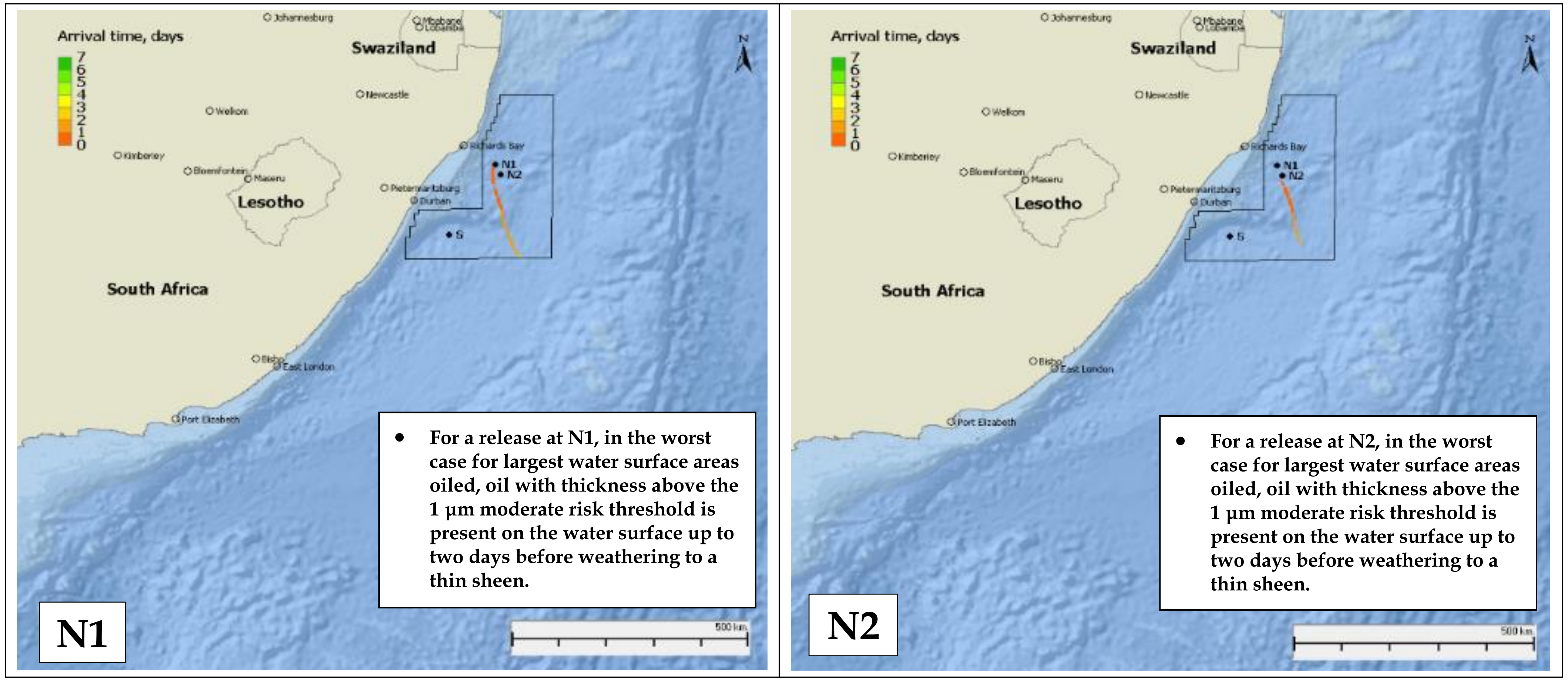


Figure 5-39 Scenario 3: Accidental NADF Release – Arrival Time – Criterion 1: Worst Case Surface Oiling for Spill at N1, N2 and S

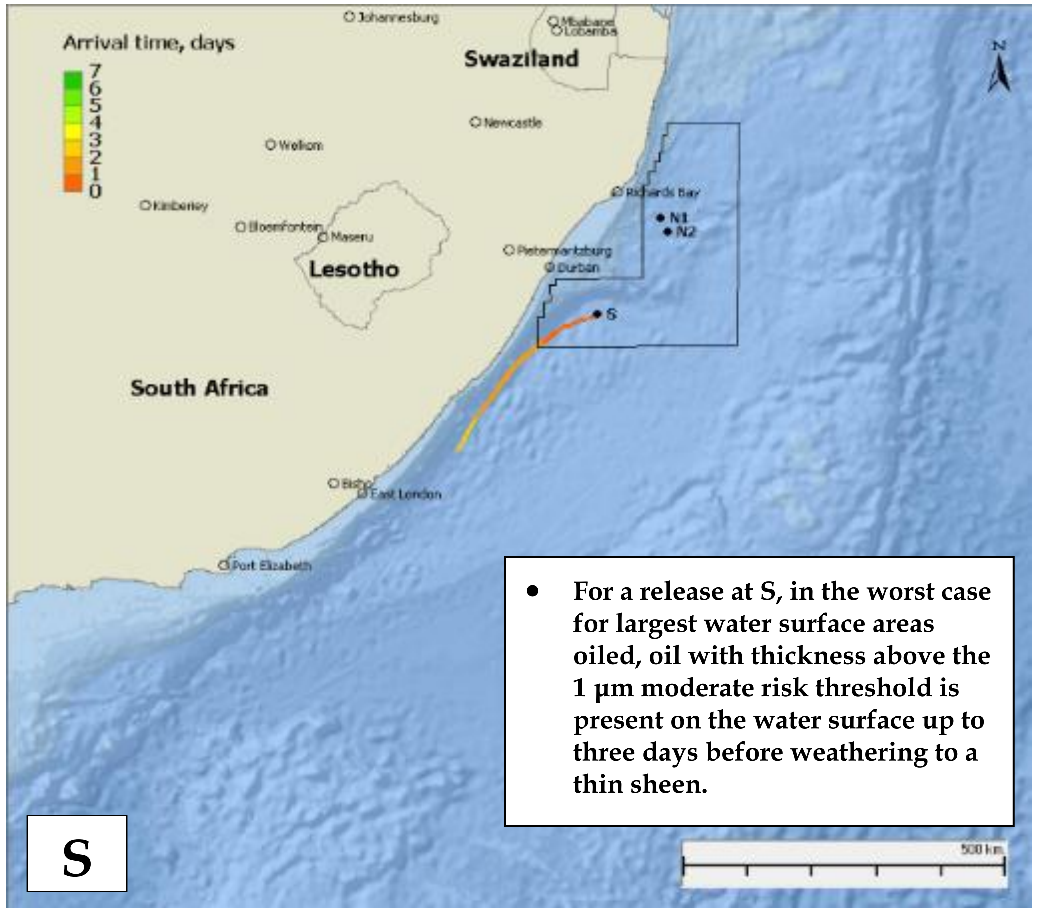


Figures Description

Scenario 3 NADF Release

These figures show the shortest arrival time of oil on the water surface over a 7-day period for the worst case scenario under Criterion 1 for the largest amount of water surface area oiled from a ***very unlikely*** oil spill due to a riser disconnect. The colored contours depict the first time in the simulation (in days from the start of the release) for oil to be present at a given location with thickness greater than the moderate exposure threshold (1 µm).

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.



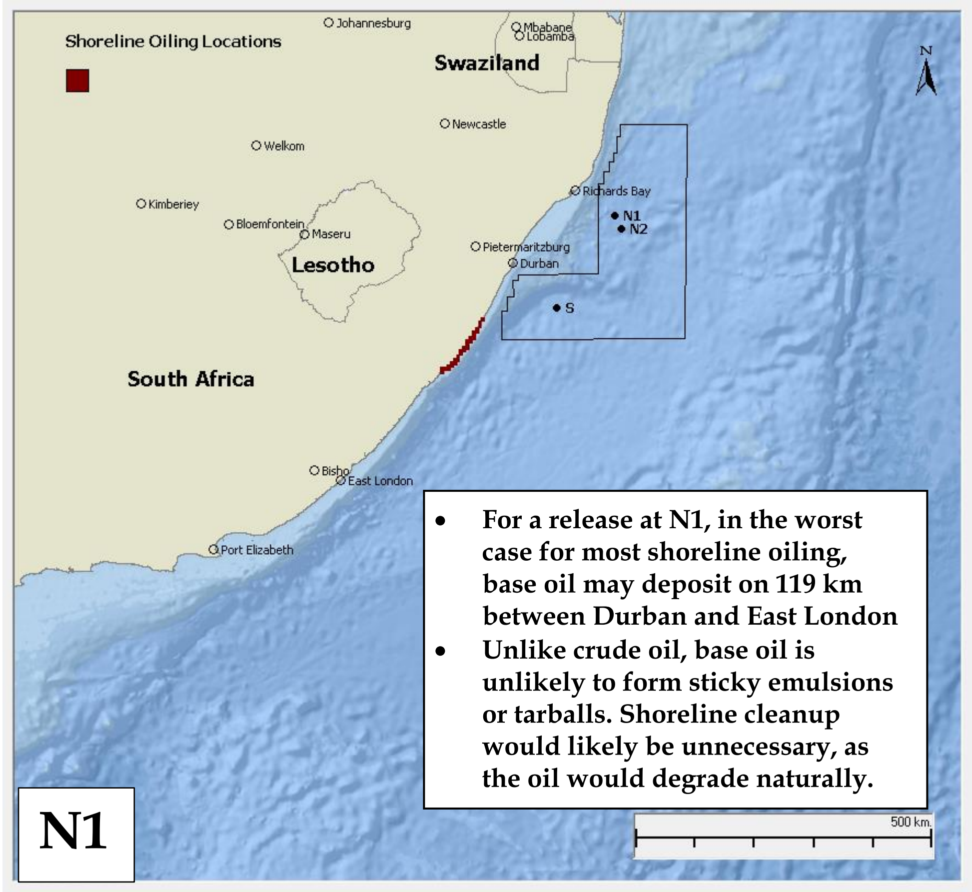
5.7.2 *Criterion 2 (Most Amount of Shoreline Oiling Mass) and Criterion 3 (Fastest Time for Shoreline Oiling to occur)*

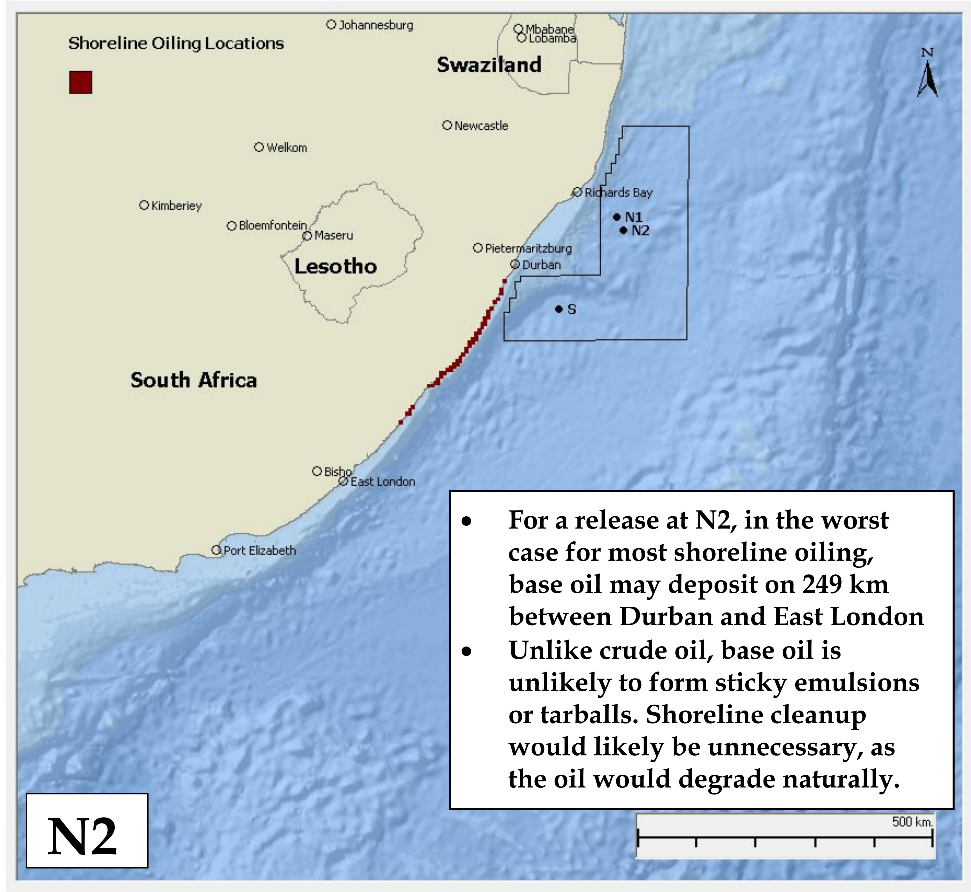
The locations of impact from the 7-day simulations within a five-year period range between Durban and East London. Depiction of the shoreline oiling in the worst case shoreline oiling iteration case for spills at N1 is presented in Figure *5-40*. The shoreline area near Richards Bay area was the earliest to oil (2.5 days - Figure *5-41*).

Shoreline oiling in the worst case shoreline oiling iteration case for spills at N2 are presented in Figure *5-40*. Similar to the discharges at N1, shoreline area near Richards Bay area was the earliest to oil (3.2 days - Figure *5-41*).

Worst case shoreline oiling (Figure *5-40)* as well as the fastest time to reach shoreline occurs at the same iteration for spills at S. Shoreline areas south of Durban was the earliest to oil (2.7 days - Figure *5-41*).

Figure 5-40 Scenario 3: Accidental NADF Release – Criterion 2: Worst Case Shoreline Oiling Mass for Spill at N1, N2 and S





Figures Description

Scenario 3 NADF Release

These figures show the shoreline oiling locations after a 7-day period for the worst case scenario under Criterion 2 for the most amount of shoreline oiling from a ***very unlikely*** oil spill due to a riser disconnect. (Note that any amount of oil mass on the shoreline is depicted; no shoreline threshold criteria has been applied)

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

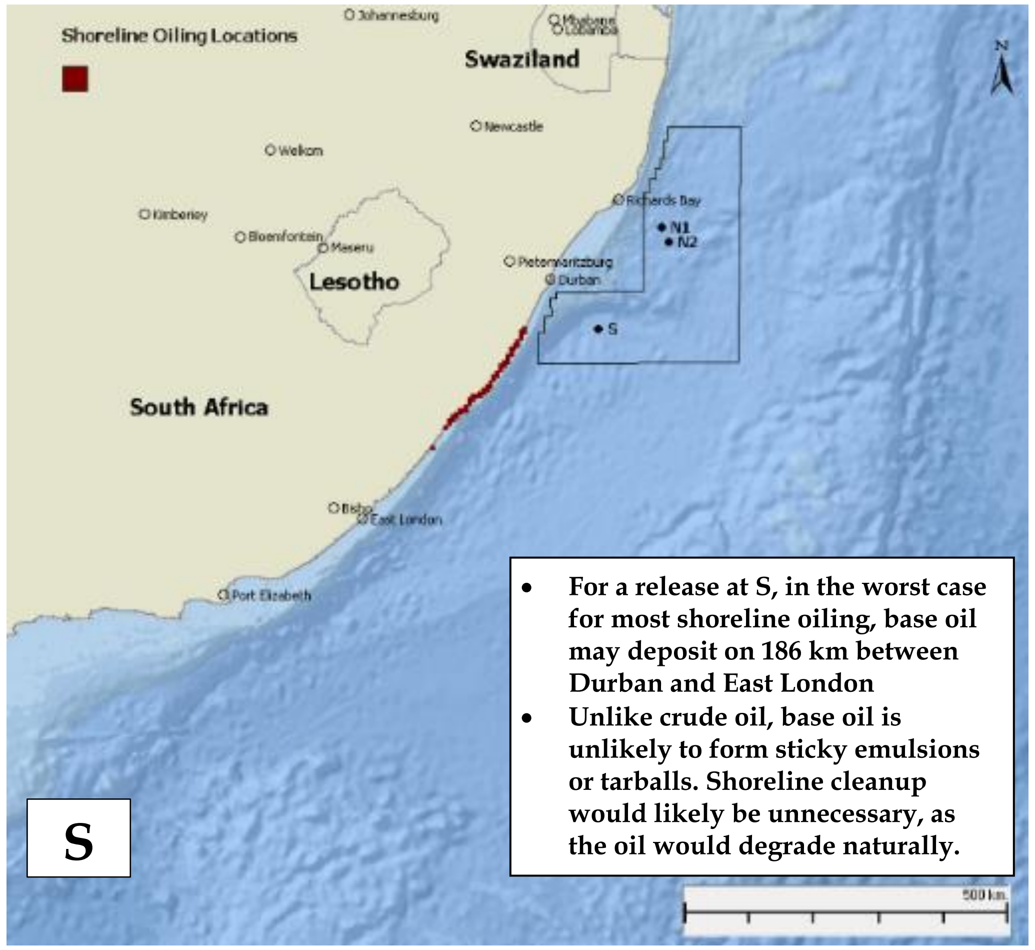
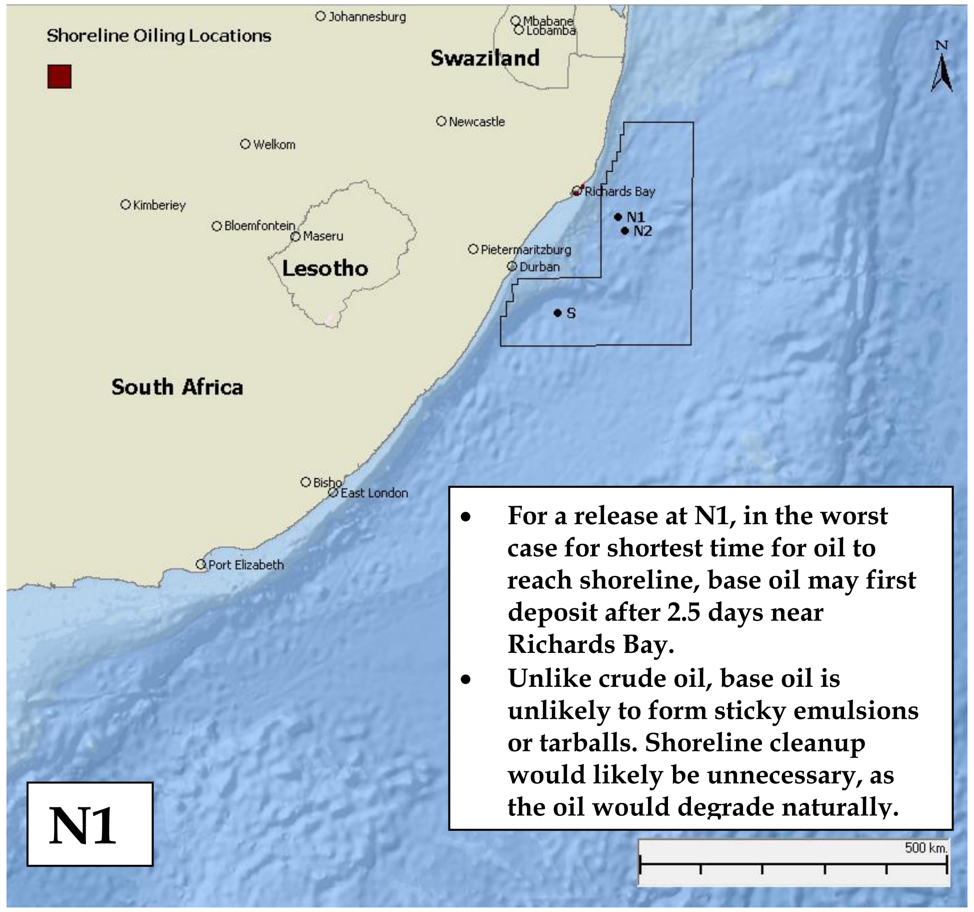
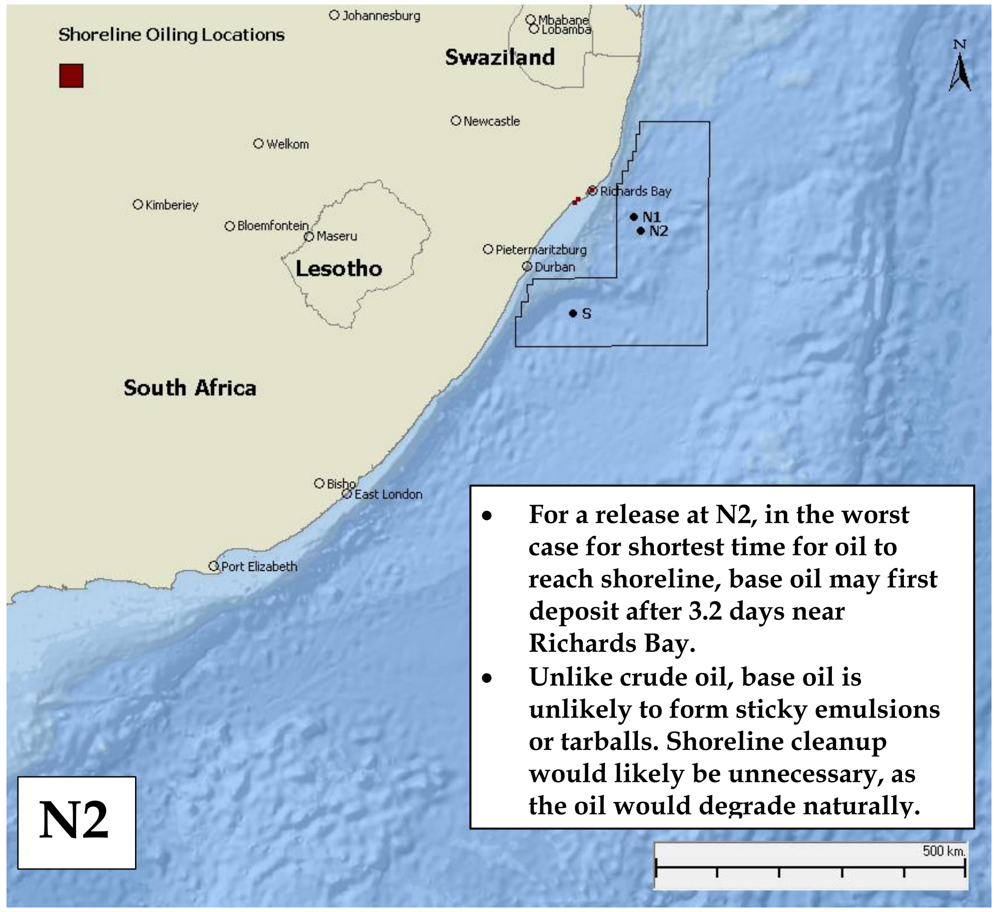


Figure 5-41 Scenario 3: Accidental NADF Release – Criterion 3: Fastest time for shoreline oiling to occur for Spill at N1, N2 and S



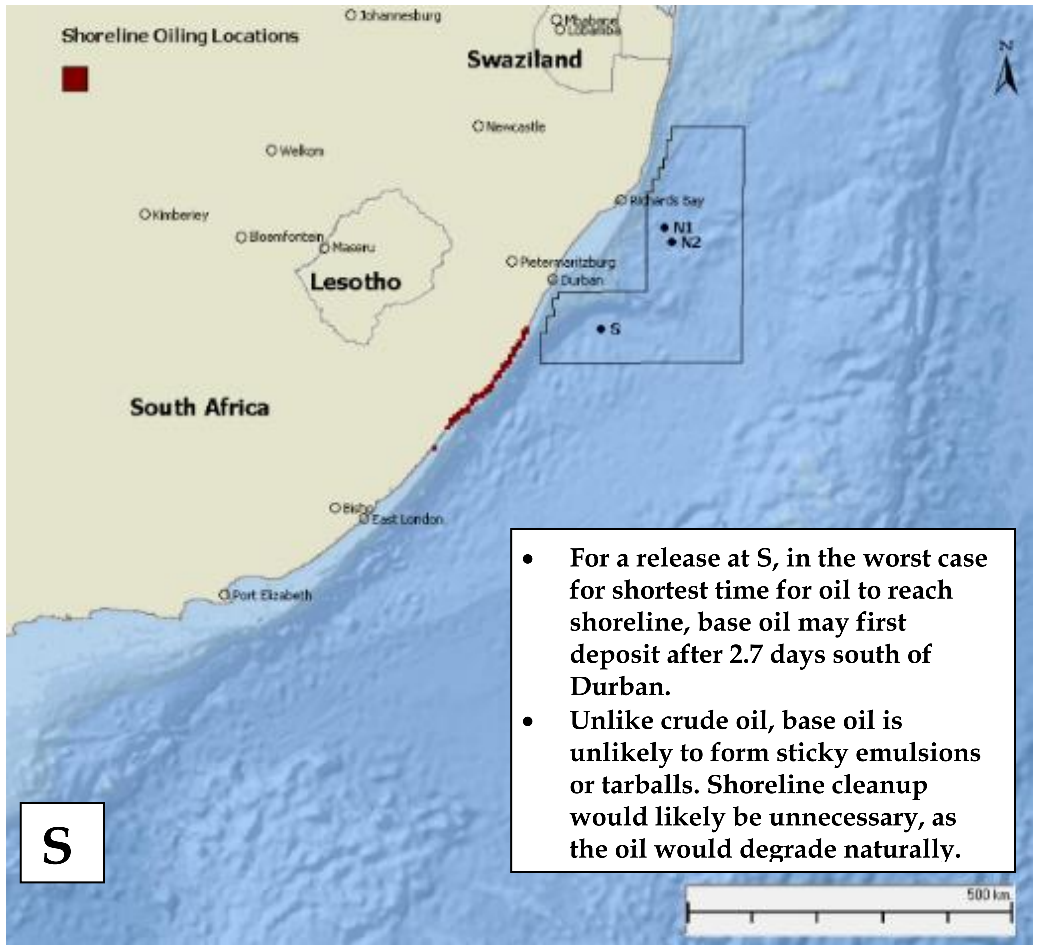


Figures Description

Scenario 3 NADF Release

These figures show the shoreline oiling locations after a 7-day period for the worst case scenario under Criterion 3 for the shortest time for shoreline oiling to occur from a ***very unlikely*** oil spill due to a riser disconnect. (Note that any amount of oil mass on the shoreline is depicted; no shoreline threshold criteria has been applied)

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.



5.7.3 *NADF Deposition Results*

The particles within the NADF released were modelled separately using the GIFT model to observe a range of possible sediment thickness, and highest TSS concentrations during the months of minimum and maximum depth average currents. In any of those simulations, particles did not settle on the ocean floor within the modelling domain (i.e. 10 km radius from their release locations). Particle sizes of the solid portion of NADF are small and hence have low settling velocities. Under the strong currents offshore South Africa, these small particles get transported and dispersed to large area settling on the ocean floor at insignificant thicknesses.

Figure 5-42 through *Figure 5-47* present the TSS plumes with maximum TSS concentrations near the surface resulting from accidental NADF release at N1, N2 and S. TSS concentration did not exceed the threshold value of 35 mg/L in any of these six conditions (also described in *Table 5.18*). Particles are quickly transported and dispersed into smaller TSS concentrations due to the strong currents offshore South Africa. As expected, TSS plumes under the maximum current conditions are extended longer (generally towards south) than the TSS plumes under the minimum current conditions.

Figure 5-42 Accidental NADF Release – Maximum TSS – Maximum Depth Averaged Currents at N1

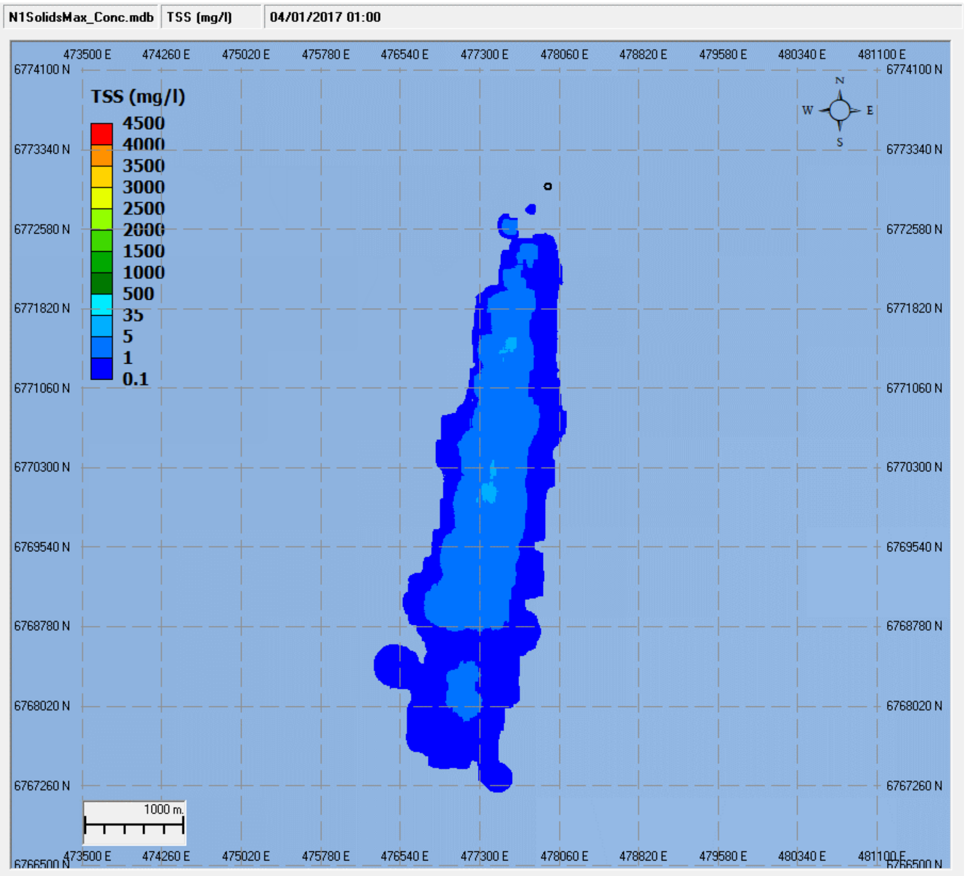


Figure 5-43 Accidental NADF Release – Maximum TSS – Minimum Depth Averaged Currents at N1

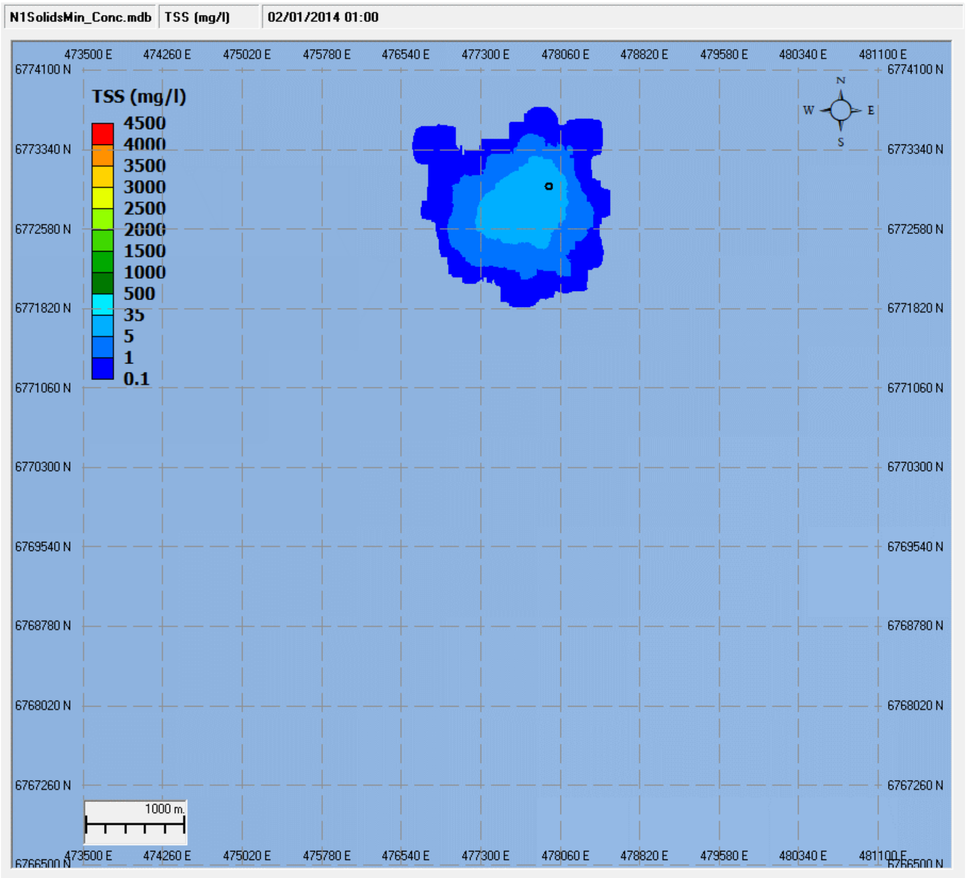


Figure 5-44 Accidental NADF Release – Maximum TSS – Maximum Depth Averaged Currents at N2

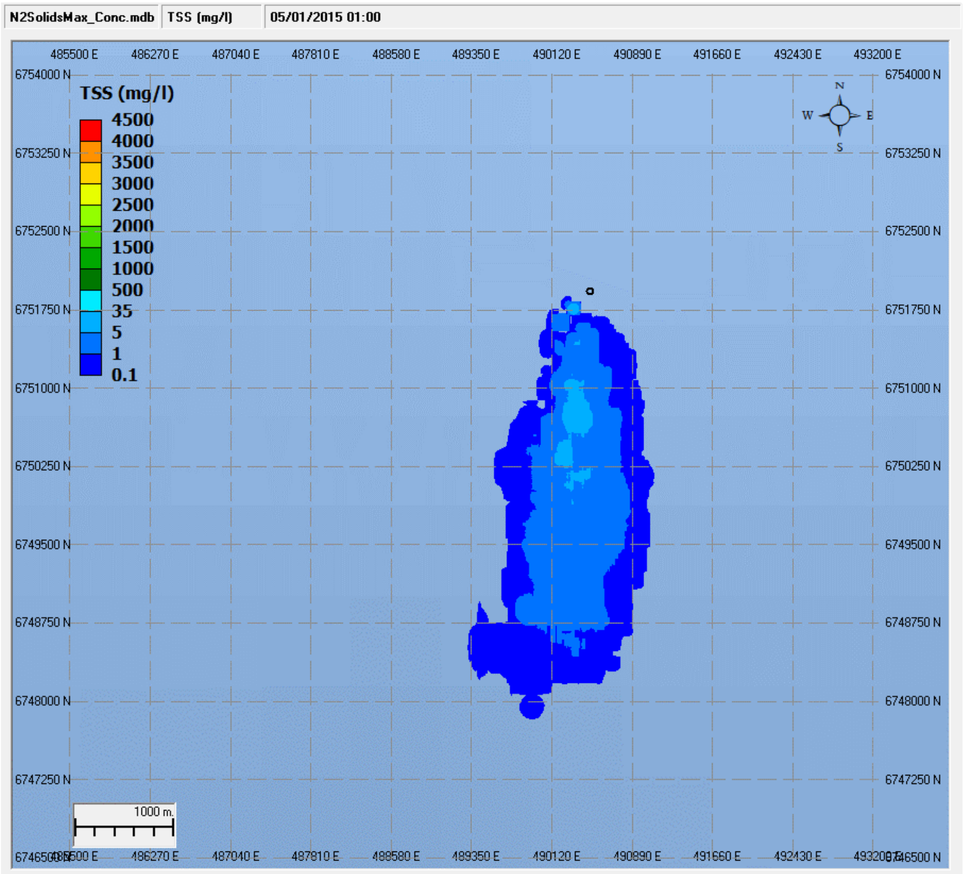


Figure 5-45 Accidental NADF Release – Maximum TSS – Minimum Depth Averaged Currents at N2

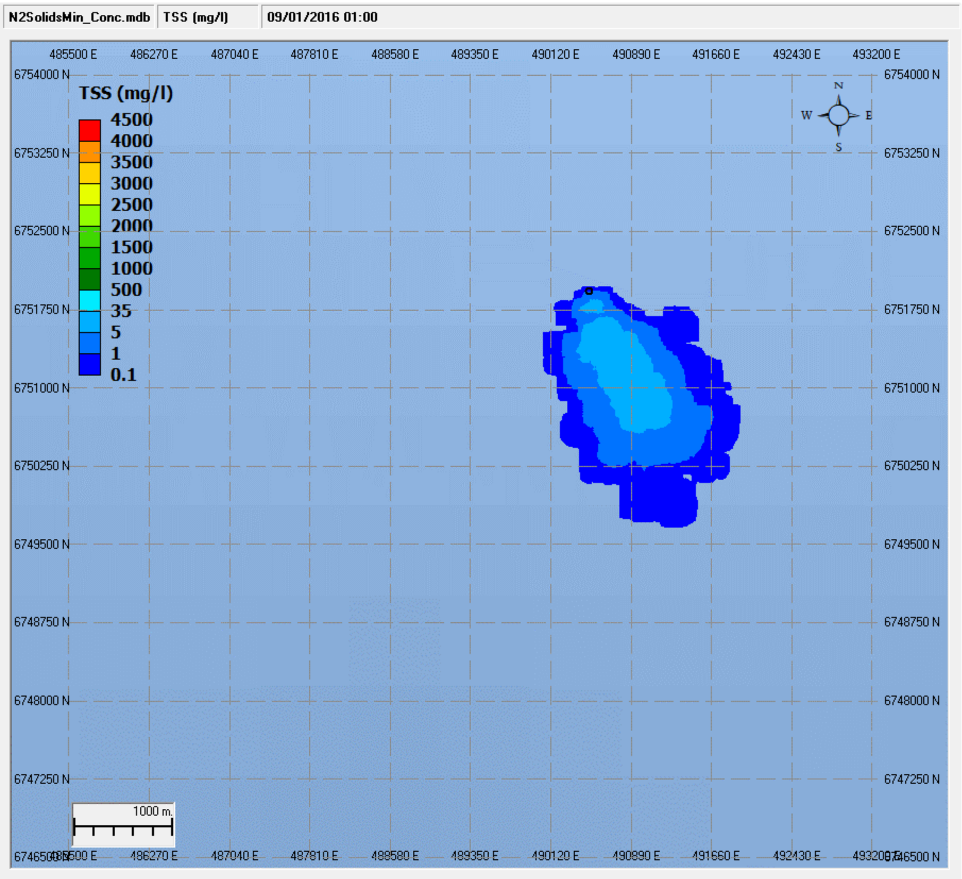


Figure 5-46 Accidental NADF Release – Maximum TSS – Maximum Depth Averaged Currents at S

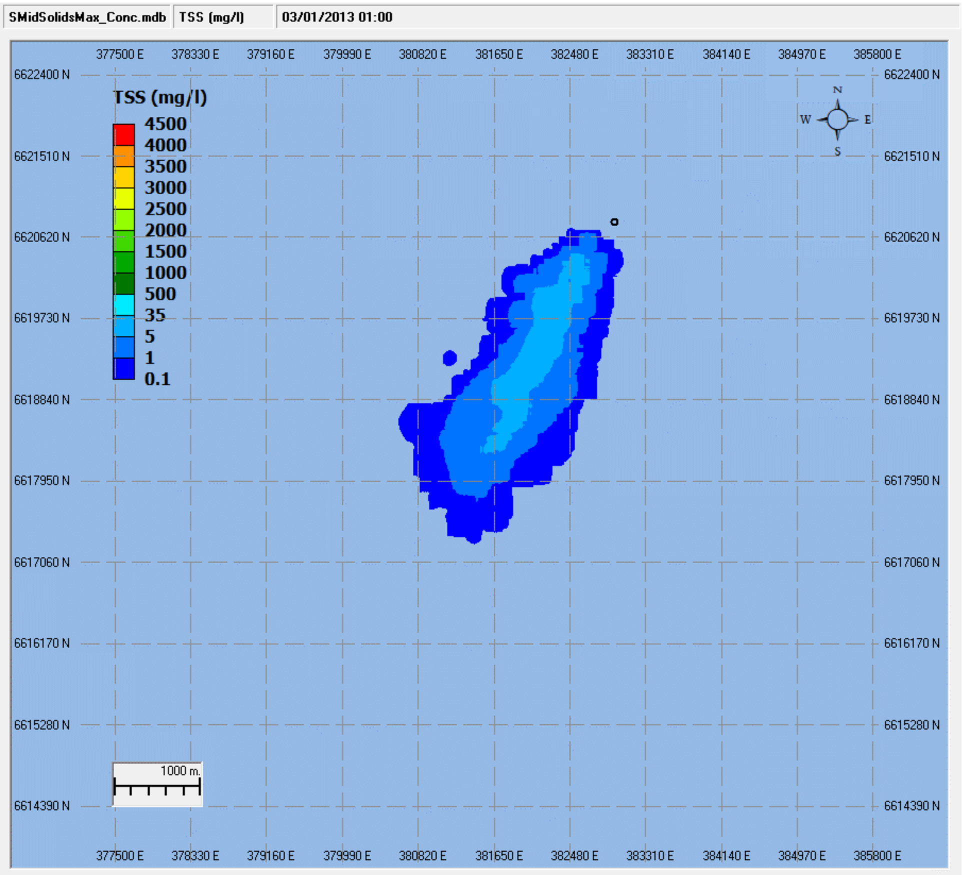
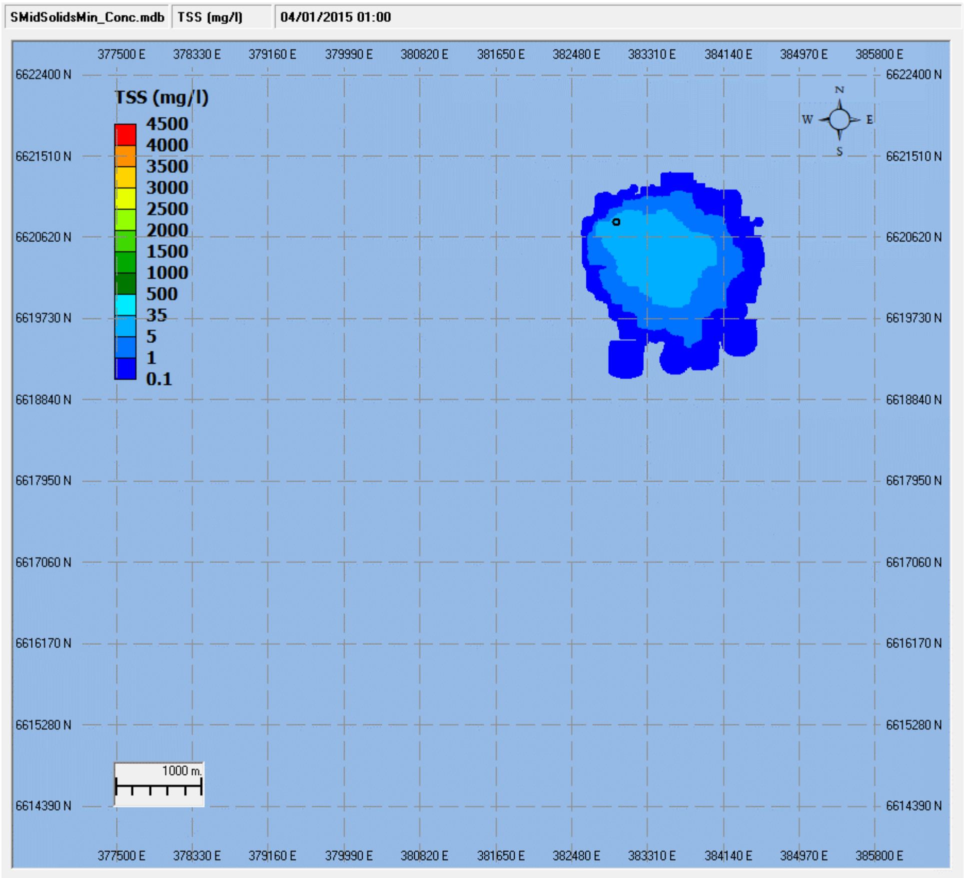


Figure 5-47 Accidental NADF Release – Maximum TSS – Minimum Depth Averaged Currents at S



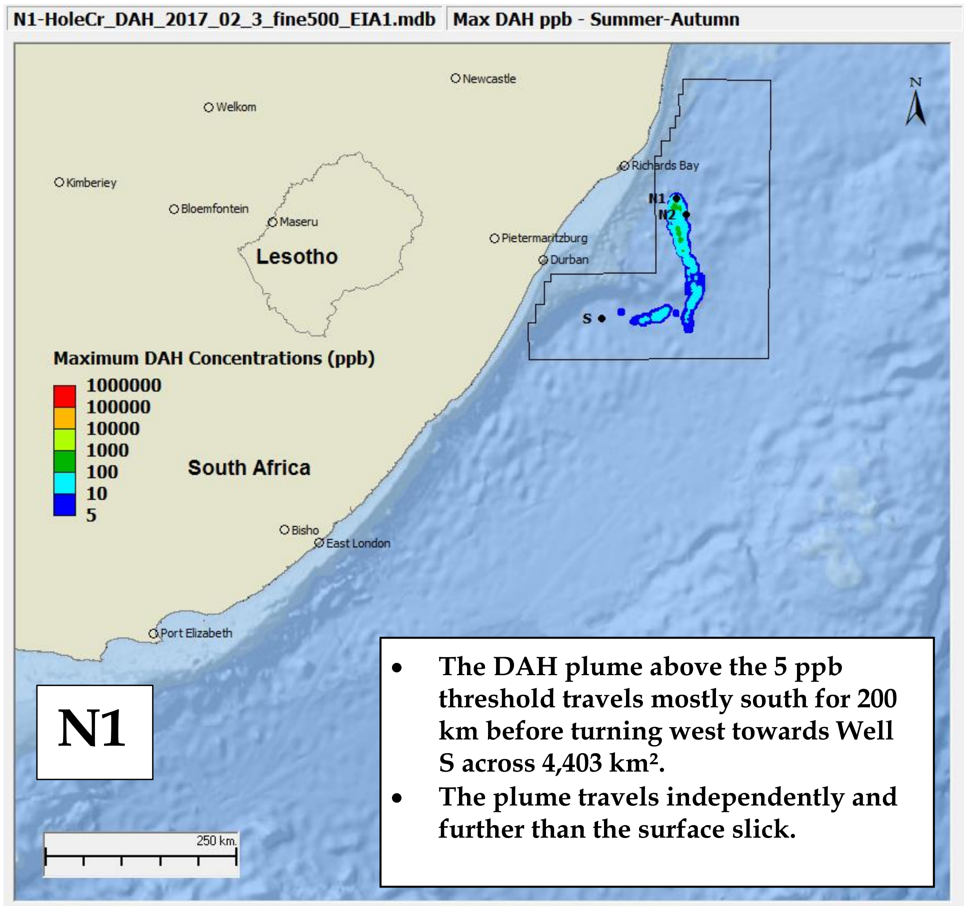
5.8 *EXAMINATION OF DISSOLUTION*

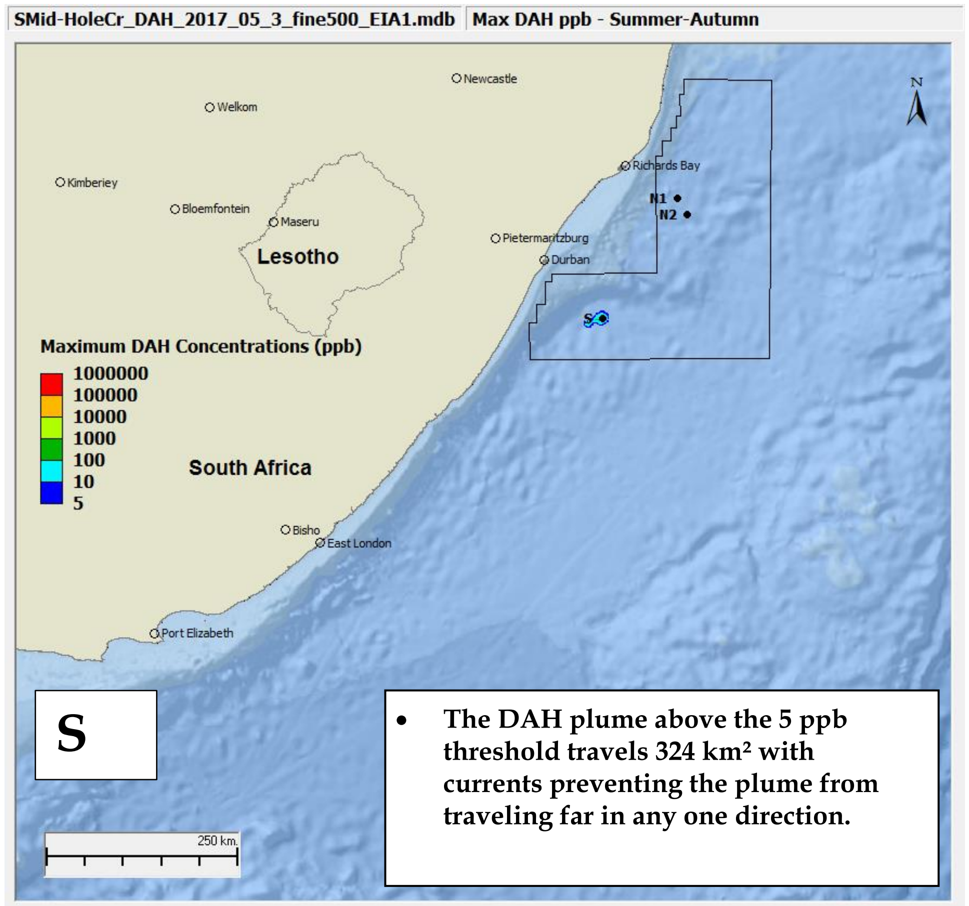
Though oil is generally described as a hydrophobic liquid with low solubility, components of the oil may dissolve with a sufficiently high solubility limit to cause an acute toxicological response (i.e. narcosis) given sufficient concentration and duration of exposure. Narcosis has typically been allocated to the dissolved aromatic hydrocarbons (DAH) within an oil (French McCay, 2000). According to ANZECC and ARMCANZ (2000) and French McCay (2000), dissolved aromatic 96-hour LC_{50} values range between 100 ppb and 1,000 ppb. Low Reliability Triggers, concentrations below which no toxic effects would be expected (effectively a No Observable Effects Concentration or NOEC), are assumed to be 10 to 100 times less than these 96-hour LC_{50} values. Assuming a reasonable NOEC of 10 ppb derived from an order of magnitude below a 100 ppb LC_{50} value, and additional half of that value was taken to enable a significant margin of safety, resulting in a highly conservative value of **5 ppb,** chosen as a 96-hour Low Reliability Trigger threshold for sensitive organisms.

Dissolved aromatic hydrocarbons (DAH) are a small fraction of the total oil volume, yet are predicted to likely be present at magnitudes which may cause acute narcosis (above the 5 ppb threshold). The regions typically affected are in the vicinity of the subsurface blowout, the plume of dissolved constituents rising with the release, and in the top few meters of the water column beneath the slick, particularly in the first week after reaching the surface before many hydrocarbon compounds evaporate or degrade. Within the water column, the dissolved aromatics may be present at different depth levels, as various-sized droplets rise to the surface at different rates releasing dissolved components during their trajectory to the surface. Some very tiny droplet sizes may become essentially trapped at lower depths creating a subsurface plume which will eventually dilute and biodegrade through naturally occurring microorganisms. Note that the surface slick may travel in different directions from the subsurface plume, especially in cases of a deep blowout, where the subsurface plume is sheltered from the wind shear’s effects that influences the direction of the slick's trajectory.

The model recorded the locations in which a concentration exceeded 5 ppb. The sum of all of these areas (regardless of depth) is provided Table *5.20* for releases at N1 and S for the two seasons examined for Scenario 2a, the 7-day blowout during the worst case for the largest surface area oiled (Criteria 1). The “largest surface area” worst case was chosen since it reflects the condition with the most area with dissolved components derived from the slick dissolved constituents would contact the most aquatic organisms. By contrast the worst cases for “most shoreline oiling” and “shortest time to oil shorelines” transfers sources of dissolved oil from the water column to the shorelines. Figure *5-48* and Figure *5-49* provide depictions of these areas.

Figure 5-48 Scenario 2a: 7-Day Crude Oil Blowout – Maximum Dissolved Aromatic Hydrocarbon Concentrations for Criterion 1: Worst Case Surface Oiling at N1 and S in Summer/Autumn





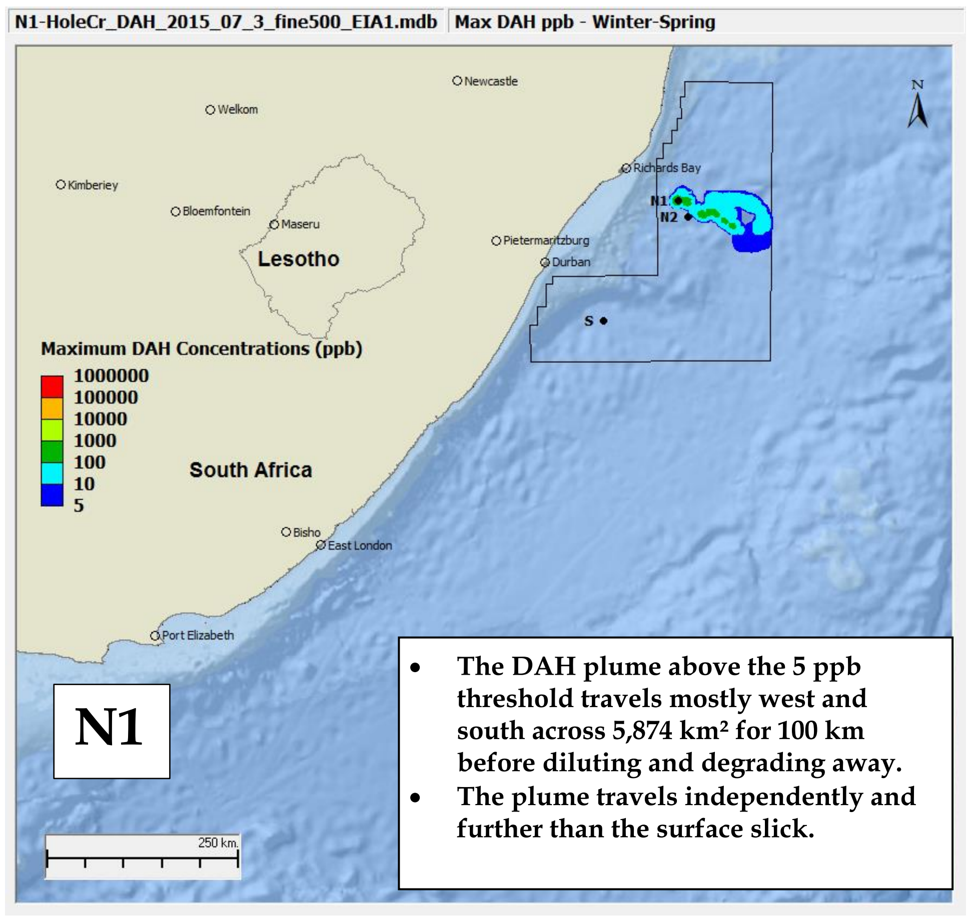
Figures Description

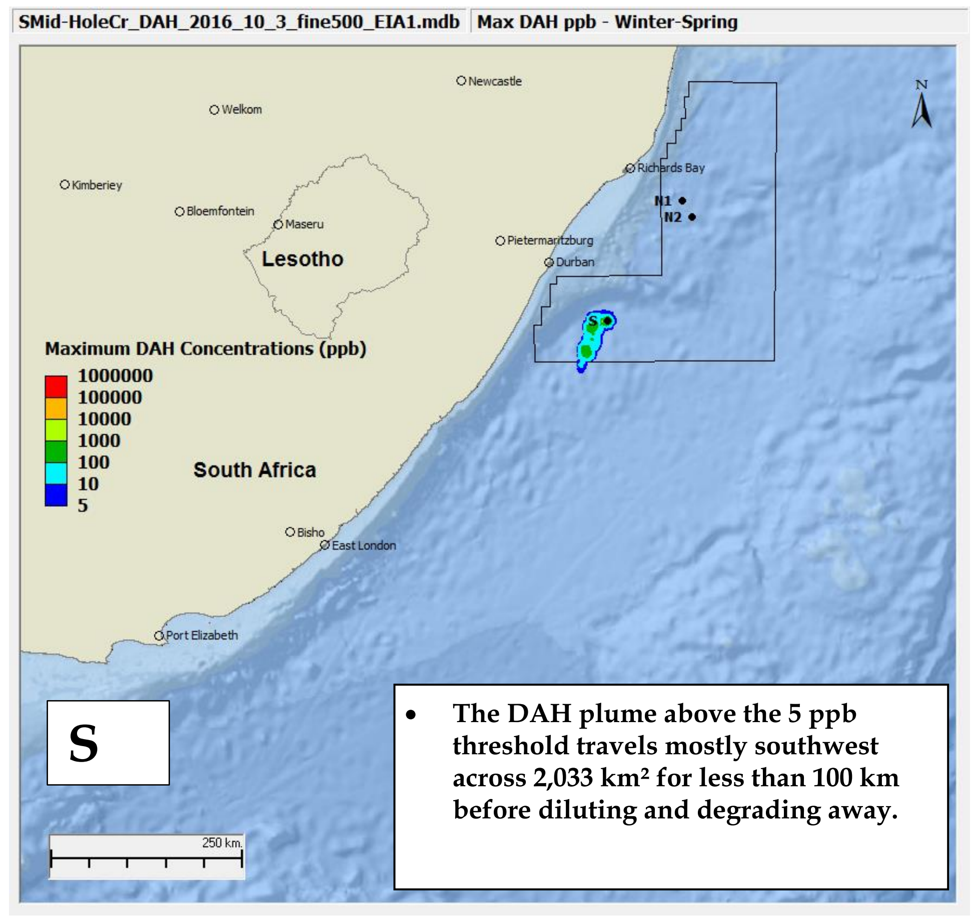
Scenario 2a 7-Day Crude Oil Blowout

These figures show the maximum concentrations of dissolved aromatics in the water from a 7-day blowout over a 21-day period from a ***very unlikely*** oil spill. The colored contours depict the DAH at various concentrations increasing by order of magnitude starting with 5 ppb, the designated acute toxic threshold. Note that this maximum value may be present at any depth, but if typically near the surface except for the plume of DAH rising from the blowout.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

Figure 5-49 Scenario 2a: 7-Day Crude Oil Blowout – Maximum Dissolved Aromatic Hydrocarbons Concentrations for Criterion 1: Worst Case Surface Oiling at N1 and S in Winter/Spring





Figures Description

Scenario 2a 7-Day Crude Oil Blowout

These figures show the maximum concentrations of dissolved aromatics in the water from a 7-day blowout over a 21-day period from a ***very unlikely*** oil spill. The colored contours depict the DAH at various concentrations increasing by order of magnitude starting with 5 ppb, the designated acute toxic threshold. Note that this maximum value may be present at any depth, but if typically near the surface except for the plume of DAH rising from the blowout.

This is an unrealistic condition based on no intervention measures being undertaken. By adopting standard practice intervention measures after the spill event, the probability is expected to be drastically reduced.

Table 5.20 Scenario 2a - Areas with DAH above 5 ppb threshold for worst case Criteria 1: Largest Surface Area

Location / Season	Area with DAH above 5 ppb Threshold (km^2)
Location N1	
Season 1 Summer/Autumn	4,403
Season 2 Winter/Spring	5,874
Location S	
Season 1 Summer/Autumn	324
Season 2 Winter/Spring	2,033

Across all five years of model iterations, the majority of cases in which a spill occurs at locations S and N1 include transport towards the southwest direction. Depth-varying currents over five years (2013 to 2017) at N1 and S were examined to derive the frequency of occurrence for flows towards various directions across all depths. As seen in Figure *5-50* and Figure *5-51*, 83% (from S) to 89% (from N1) of the currents flow towards the west, southwest and south. The worst cases for "largest area" releasing from N1 included some more rare currents towards the east and southeast away from the Agulhas Currents and the coastline. Dissolved plume transport north and northwest towards locations with an elevated risk of encountering coelacanth habitat is very low. Currents traveling towards the north, north-northwest, and northwest comprise 2% of currents from N1 and 3% of currents from S.

Figure 5-50 ***Current Roses (Distributions of Speed and Directions) across All Depths, 2013-2017 at N1 and S. Arrows depict direction of currents. (Source: HYCOM)***

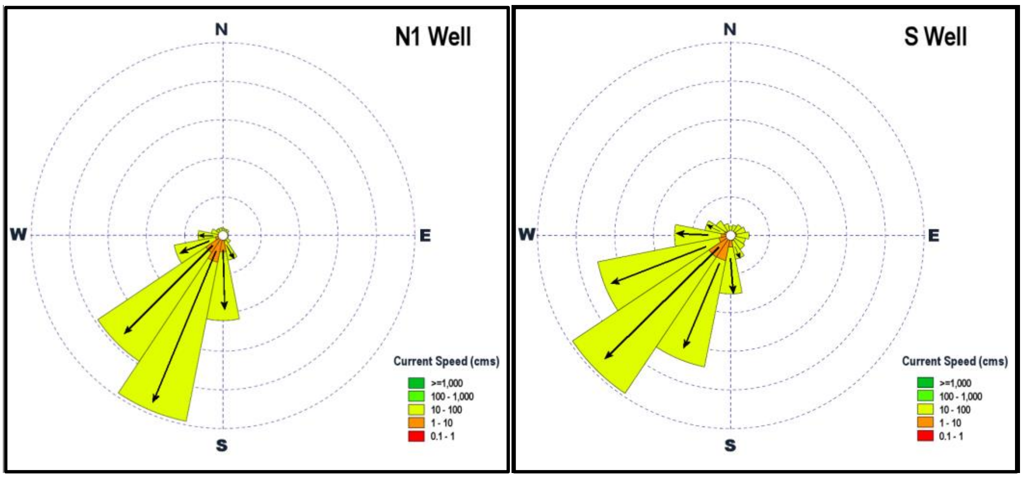
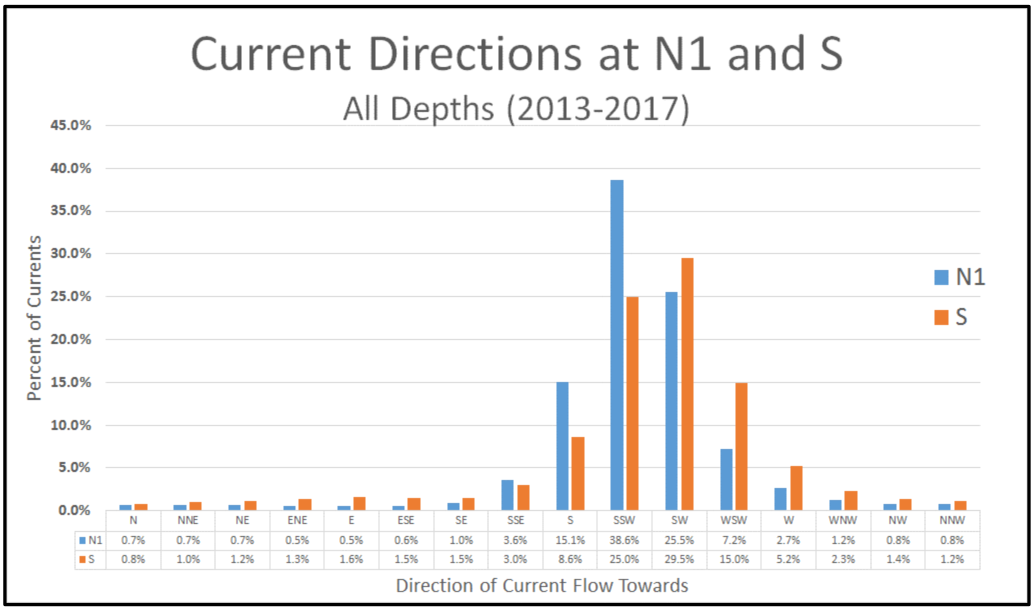


Figure 5-51 *Current Distributions of Directions across All Depths, 2013-2017 at N1 and S. (Source: HYCOM)*



6 CONCLUSION

Oil spill modelling was performed to simulate three different types of spill scenarios: a diesel spill associated with a vessel collision happening either during the drilling of wells or the operation phase (Scenario 1); a wellhead blowout releasing crude oil from the reservoir (Scenario 2); and a release of low toxicity oil-based muds (NADF) due to the accidental disconnection of the riser occurring during the drilling phase (Scenario 3). Scenario 2 was divided into two separate cases to examine different blowout situations to simulate different ways in which the release may be terminated. In Scenario 2a, the spill ended after 7 days when the hole collapsed upon itself. In Scenario 2b, a capping stack is installed on the 20th day of the release.

Regarding simulations, the following assumptions have been made in order to determine the scenario to be modelled. These include the following:

- **The event is completely uncontrolled, with no intervention for avoidance/reduction (unrealistic situation because the emergency response team and equipment, such as a BOP, will be present and immediately activated).**
- **The use of spill/blow out containment or reduction systems (BOP, boom, skimmer etc.) has not been included in the simulation (unrealistic situation).**
- **No depletion/reduction in flowrate has been taken into account for the full simulation period (unrealistic situation).**

The above assumptions depict an improbable situation by assuming no intervention that will be adopted in case of any unplanned event; however the modelling of the worst case scenario is in line with best practice and is required for the development of the emergency preparedness and response plans (and associated sensitivity mapping). In particular, in the case of an accidental event, an emergency response team (this team will be available at all times during the drilling activities) will be immediately activated (in accordance with the Oil Spill Contingency Plan) to react to the event in order to reduce the spill dimension and, in case of blow out, shut-in the well.

Scenario 1: a spill of 794.9 m^3 (5,000 bbl) of diesel fuel oil is likely to travel predominantly in the southwest direction as narrow and long streaks parallel to the South African coastline with the strong influence of Agulhas Currents parallel to the coastline. The spilled diesel will evaporate and disperse within two days until the slick will no longer be visible or pose a risk to birds and wildlife. The closest the slick with a thickness above the minimum threshold (1.0 µm) for risk to birds and wildlife is 20 km off South African coastline. The total length of this stretch at risk of oiling above the significant shoreline oiling flux threshold for wildlife injury (>100 g/m^2) is up to 366 km and the probability of shoreline oiling at any location due to a spill from any of the three spill locations is between 3.3% from a release from location N2 and 15.0% for a release from location S. Although any diesel reaching shoreline is predicted to be below the oil thickness threshold of 1 µm for risk to birds and wildlife, some oil mass may reach shorelines over time.

In the case of a spill event from the two northern well locations, diesel first reached a shoreline area near Richards Bay area in the shortest time over the five years of various start dates. Shoreline stretches south of the Durban area were the earliest to contact diesel in the case of a spill originating from the southern well location. In either case, the diesel has the potential to reach shoreline within 4 days but without considering any intervention measure by Eni to prevent the transport. **Even if some diesel did reach the shoreline, diesel fuel is not sticky and viscous like crude oils and would naturally degrade and evaporate on the shoreline over time**.

Scenario 2: In the blowout scenarios, crude oil was assumed to be released from the wellhead over a period of 7 days in Scenario 2a and 20 days in Scenario 2b. Blowouts from the northern well (N1) are assumed to release at a rate of 750 m^3/d, while blowouts from the southern well (S) was simulated to release at 1,050 m^3/d. The oil rises through the water column affected by different currents at the various vertical strata, where the oil either dissolves, volatilizes, degrades, or remains in the liquid state as a droplet until reaching the surface. On the water surface, a slick is formed. Though not included in the spill model, some oil may become bound with marine snow and fall to the sediment bed especially in the region surrounding the blowout where the dissolved and entrained oil plumes emanate. Due to the strong influence of Agulhas Currents, in the unlikely event of a blowout occurring, oil slicks would be transported parallel to the South African coastline.

Though some oil is predicted to contact shorelines within 4 days to 7 days, oil slicks thicker than the minimum smothering thickness (1.0 µm) would stay off the coastline as the strong Agulhas Currents run southwest parallel to the coastline, preventing shoreline deposits. For Scenario 2a there is a 55% to 80% probability that some oil will contact shoreline and for Scenario 2b, the probability increases to 90% to 97%, although these are not predicted to exceed the shoreline oiling flux threshold for wildlife injury (100 g/m^2).

For Scenario 2a and 2b, in the absence of response efforts, the smothering slick of oil (>1.0 µm) is able to travel almost 50 km and 150 km from the release points N1 and S respectively (Scenario 2a) and almost 100 km and 250 km from the release points N1 and S respectively (Scenario 2b) before weathering away into a thinner sheen. For Scenario 2a, the area above the 1.0 µm thickness threshold ranges between 348 km^2 to 3,049 km^2. In Scenario 2b, the area above the 1.0 µm thickness threshold ranges between 615 km^2 to 4,386 km^2.

Since much of the oil mass is estimated to be assimilated within the water column, and the volume reaching the surface weathers and disperses during the transport towards the shoreline, n**o shoreline oiling above significant shoreline oiling flux threshold for wildlife injury (>100 g/m^2) was predicted for either Scenario 2a or Scenario 2b.**

Scenario 3: In the riser disconnect scenario, base oil may rise to the surface to form a slick, while the oily solid particles settle to the seafloor. The released base oil travels similarly to the diesel spill scenario, predominantly in the south and southwest directions. Up to about 2,050 km^2 of water surface may be contacted by the oil slick with a thickness greater than the smothering thickness threshold (1.0 µm) for risks to birds and wildlife. The slick will weather and disperse into a thin sheen within 2 days but could potentially reach shorelines within 4 days below the 1.0 µm thickness threshold on the water surface. Overall, the probability of oil contacting any shoreline was at most 15%. The oil could potentially wash up anywhere within a region of shorelines approximately 320 km in length, although the oil itself is unlikely to be significant enough to cause toxic effects or physical fouling.

The model results may be perceived that the impacts from the blowout are "worse" than from the diesel spill. That is not necessarily the case, however, as the placement of the blowout relative to the Agulhas Currents have provided a rather unique hydrodynamic arrangement protecting the shoreline with the strong southwestern transport parallel to the shores.

First, the rates of the release of the two blowout cases per hour (31.25 m^3/hr and 43.75 m^3/hr in Scenario 2a and 2b, respectively) are more than an order of magnitude less than the diesel spill in Scenario 1 (800 m^3/hr). So, although the trajectory and mass transport of the diesel spill allow for the movement of more mass per unit time, it is only a single release of material. The blowout's impact is measured in duration as well as the concentration of mass per surface area or shore area. The impacts from the blowout cases include the persistence of a subsurface plume above the toxic threshold at various depths in the water column. This impact is greater than a short-lived aromatic plume beneath the diesel slick which dissipates quickly in comparison. With a short-lived plume of DAH only near the surface for the diesel spill, mobile fish can avoid the area by swimming to deeper depths.

Second, the depth of the blowout releases are very deep. In the Deepwater Horizon incident, considered a very deep blowout, the release occurred around 1,500 m below the surface. In these scenarios, the blowouts occur at 1,623 m and 2,883 m. These great distances from the surface provide a large region for the liquid droplets to linger, dissolve, and decay during the vertical rise or settle down to the seafloor after adhering to microbes and particles ("marine snow"). By comparison, in the Ixtoc spill in the Gulf of Mexico (Jernelov and Linden, 1981[1]), where the depth of the blowout was only 51 m deep and the oil very light, about 50% of the mass on the surface was estimated to have evaporated, 6% was removed by cleanup, 7% reached shorelines, while 25% remaining in the water column ultimately sinking to the seafloor. Had this been a deeper blowout, much less mass would have reached the surface to evaporate, contact shorelines, or need cleanup. Though mass balance values from Deepwater Horizon have been published, there is still much uncertainty. The final release rate amount determined by the courts was essentially just an average between two values under debate between BP and the government. The fraction that reached the surface is dependent on the

[1] Jernelov, A., O. Linden. (1981). "Ixtoc I: A Case Study of the World's Largest Oil Spill." Ambio, Vol 10, No. 6, pp. 299-306.

unknown amount that was retained in the water column as tiny droplets, or settled to the seafloor in the marine snow.

Third, although the mass balance diagrams indicate around 1% of the oil reaches the surface, the value ranges up to 7% at the 90^{th} percentile value among the iterations.

Finally, although more oil in the blowout cases reach the shorelines compared to the diesel and base oil spills, the threshold value qualifies the level of impact. Any shoreline oiling due to the diesel or base oil spill should not require response efforts due the nature of those types of oi. In all three scenarios, the protective Agulhas Currents spreads out the spilled mass reaching many shorelines, but below the threshold of concern.

For the particle deposition modelling component of the base oil release, particles scattered on the ocean floor beyond a 10 km radius from their release locations. Particle sizes of the solid portion of NADF are small and hence have low settling velocities. Under the strong currents offshore South Africa, these small particles get transported and dispersed to large area settling on the ocean floor at insignificant thicknesses (below the 50 mm thickness threshold). TSS concentration near the surface did not exceed the threshold value of 35 mg/L in any of the extreme simulation conditions. Particles are quickly transported and dispersed into smaller TSS concentrations due to the strong currents offshore South Africa.

In all three scenarios, there may be dissolved aromatic hydrocarbons (DAH) which could be a concern to marine organisms. Though oil is generally described as a hydrophobic liquid with low solubility, components of the oil may dissolve with a sufficiently high solubility limit to cause an acute toxicological response (i.e. narcosis) given sufficient concentration and duration of exposure. For the diesel and base oil scenarios (Scenario 1 and 3, respectively), DAH may exceed an acute toxic threshold of 5 ppb beneath the slick primarily in the top 3 m. This provides opportunity for fish and marine organisms to avoid the plume if mobile. However, in the blowout cases, a much larger area could be impacted by DAH as tiny liquid droplets of oil rise from the sea floor and travel at different rates, as a function of their droplet size. Where the droplets travel, dissolve concentrations may be released into the water column until only very insoluble components remain.

It should be reiterated here that, in line with international standards and in order to present a conservative analysis, no cleanup or response efforts were assumed in any of these simulations. In reality this would not be the case and Eni would implement measures to protect shorelines or prevent the spill trajectory from freely moving, therefore, these modelled results show the absolute worst case results.

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environmental affairs

Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

DETAILS OF SPECIALIST AND DECLARATION OF INTEREST

	(For official use only)
File Reference Number:	12/12/20/ or 12/9/11/L
NEAS Reference Number:	DEA/EIA
Date Received:	

Application for integrated environmental authorisation and waste management licence in terms of the-

(1) National Environmental Management Act, 1998 (Act No. 107 of 1998), as amended and the Environmental Impact Assessment Regulations, 2014; and

(2) National Environmental Management Act: Waste Act, 2008 (Act No. 59 of 2008) and Government Notice 921, 2013

PROJECT TITLE

Eni Upstream - AMTE and Eni South Africa BV - Environmental Impact Assessment for Proposed Exploration Drilling in Block ER 236, offshore of Kwa-Zulu Natal Coast of South Africa – Oil Spill Modelling Report

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4.2 The specialist appointed in terms of the Regulations_

I, Michael J. Fichera ______________________, declare that --

General declaration:

I act as the independent specialist in this application;
I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant;
I declare that there are no circumstances that may compromise my objectivity in performing such work;
I have expertise in conducting the specialist report relevant to this application, including knowledge of the Act, Regulations and any guidelines that have relevance to the proposed activity;
I will comply with the Act, Regulations and all other applicable legislation;
I have no, and will not engage in, conflicting interests in the undertaking of the activity;
I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing - any decision to be taken with respect to the application by the competent authority; and - the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority;
all the particulars furnished by me in this form are true and correct; and
I realise that a false declaration is an offence in terms of regulation 48 and is punishable in terms of section 24F of the Act.

Signature of the specialist:

ERM, Inc.

Name of company (if applicable):

2018-09-03

Date:

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Michael is a senior project engineer with experience since 1993 in water quality and oil spill modeling, natural resource damage assessments (NRDA), risk assessment, and project management. He is skilled in modeling hydrodynamics, oil spills, dredge disposal / drill cutting transport, thermal plumes, water quality, eutrophication, toxicity, and food web simulations. His oil spill modeling experience has been applied in response to major accidents for live trajectory predictions and injury estimations, for investigating potential origins of mysteriously oiled shorelines, and for predicting impacts due to hypothetical spills for environmental impact assessments.

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- Hudson Delaware Chapter of SETAC (HDC-SETAC)
- Water Environment Federation (WEF)
- Chi Epsilon Civil Engineering Society
- Tau Beta Pi Engineering Society

Languages

- English, native speaker

Fields of Competence

- Environmental Engineering
- Oil Spill Modeling
- Drilling Mud and Cuttings Modeling
- Water Quality Modeling
- Environmental Impact Assessments
- Environmental Chemistry

Key Industry Sectors

- Oil and Gas
- Power

Key Projects

Chemical/Oil Spill Emergency Response Plan
For a strategic initiative to develop a model to estimate the exposure, duration, and potential toxicological impacts of oil and chemical spills, worked to construct the Chemical / Oil Spill Impact Module (COSIM). The module, a plug-in component of ERM's Generalized Environmental Modeling System for Surfacewaters (GEMSS), was designed for use for emergency response, emergency planning or hindcasting. Within the GEMSS framework, COSIM can produce simulations of the fate and transport of the various oil constituents and produce 3-D visualizations and animations.

Oil Spill and Drill Cuttings Deposition Modeling
Performed oil spill and drill cuttings deposition modeling for Environmental Impact Assessments (EIA) for over 50 projects around the world including Argentina, Colombia, Guyana, around the African coast (including Algeria, Morocco, Mauritania, Ghana, Nigeria, Gabon, the Democratic Republic of the Congo, Angola, and Mozambique), northern and western Australian coasts, Southeast Asia (including Malaysia, Brunei, Sulawesi, Vietnam), New Zealand, Italy, and in the Gulf of Mexico.

Natural Resource Damage Assessments (NRDA)
Assessed the fate, transport, and toxicity of oil during several major US oil spills for Natural Resource Damage Assessments (NRDA). Acted as project manager for NRDA oil spill modeling during the Deepwater Horizon incident's aquatic injury assessment. Performed modeling processes concurrently with trustee-appointed modelers to facilitate the cooperative process. Assessed potential aquatic injuries associated with dissolved polyaromatic hydrocarbons (PAHs) in the water column. Designed and directed laboratory oil toxicity experiments.

Marine Oil Spill Models
Provided marine oil spill models for an oil company's terminals and pipelines as part of regulatory compliance with Washington State Dept. of Ecology and internal Oil Spill Preparedness & Response plans.

Oil Spill Study
Performed a baseline oil spill study for the Aleutian Islands Risk Assessment (AIRA). The goal of this study was to produce a comprehensive evaluation of the risk of vessel accidents and spills in the Aleutian Islands, with the ultimate goal of identifying risk reduction measures that can be implemented to improve the level of safety related to shipping operations in the region.

Expert Testimony
Provided oil spill modeling expertise for a class-action law suit related to large coastal oil spill.

Nutrient Water Quality Modeling
Designed, calibrated and validated a water quality model for a major phosphorus mine in Florida discharging into a local stream to assess potential water quality impacts and benefits related to relocation of the facility's effluent pipe.

Environmental Impact Assessment
Performed modeling to assess potential impacts related to dredging, dredge spoil deposition, and oil spills related to proposed construction of the Nicaragua Grand Canal.

Emergency Response Site Assessment
Provided emergency response site assessment for shoreline oiling and potential injury to local biota for the Port Mobil Explosion and Oil Spill, Staten Island, New York.

Hydrodynamic/Water Quality Modeling
Managed hydrodynamic / water quality modeling of the Delaware Inland Bays for TMDL analysis upon impaired waters on the State of Delaware 303(d) list. Modeling included linkage to USGS HSPF model for model input of non-point source loads.

Food Chain Modeling
Utilized food chain modeling from sediments, plankton, fish, and birds to determine pesticide contamination liability.

Sediment Chemistry Survey
Designed and managed a sediment chemistry survey / toxicity identification evaluation (TIE) for a U. S. Superfund site.

Acid Attenuation Modeling
Created an acid attenuation model to estimate the fate and transport of an acidic leak into an aquifer.

Publications

- Fichera, M. J., V. S. Kolluru, L.M.O'Hanlon, Jessica G. Webber, S. L. Friant and R. K. Markarian. 2001. Oil Spill Water Column Injury Assessment Using PAH Specific Hydrodynamic Fate and Transport Modeling. Society of Environmental Toxicology and Chemistry 22nd Annual Meeting, November 11-15, 2001. Baltimore, Maryland.
- Fichera, M. J., V. S. Kolluru, L. H. O'Hanlon, G. T. Gipson, R. K. Markarian, 2003. Oil Spill Water Column Modeling for Aquatic Injury Assessment – Refinements for Assessing Oil Toxicity. International Oil Spill Conference, 2003.
- Kolluru, V.S. and Mike Fichera, 2003. Development and Application of Combined 1-D and 3-D Modeling System for TMDL Studies. Proceedings of the Eighth International Conference on Estuarine and Coastal Modeling. American Society of Civil Engineers. pp. 108-127, 2003.
- Fichera, M. J., V. S. Kolluru, H. Mirsajadi and L. M. DiSanto, 2005. TMDL Modeling of Delaware's Inland Bays. Water Resources Conference, 2005.
- Fichera, M. J., V. S. Kolluru. 2007. GEMSS-GIFT: A comprehensive sediment discharge and transport modeling system. SETAC North America 28th Annual Meeting, 11-15 November 2007
- Kubitz, J.A., M. Fichera, R. Markarian and J. Slocomb. 2011. Use of Chemical/Oil Spill Impact Module (COSIM) to assess the toxicity of petroleum to estuarine organisms. International Oil Spill Conference Proceedings Mar 2011, Vol. 2011, No. 1 (March 2011) pp. abs180
- Kubitz, J., T. Havranek, L. Hostetter, R. Markarian, J. Slocomb, and M. Fichera. 2011. Use of Monte Carlo Analysis in the Chemical/Oil Spill Impact Module (COSIM) to address uncertainty in the assessment of petroleum toxicity. International Oil Spill Conference Proceedings: March 2011, Vol. 2011, No. 1, pp. abs182.
- Kolluru, V., S. R. Chitikela and M. J. Fichera, 2012. Watershed Water Quality Attainment Using TMDL – A Delaware USA Review. International Conference "Water, Environment, Energy and Society" (WEES-2009), 12-16 January, 2009. New Delhi, India.
- Fichera, M. J., V. S. Kolluru, C. Buahin, C. Reed, 2013. A Comprehensive Modeling Approach for EIA Studies in Oil and Gas Industry. Poster presentation at the 2013 International Association of Impact Assessment Conference on Impact Assessment: The Next Generation, 13-16 May 2013, Calgary, Alberta, Canada.
- Fichera, M. J., V.S. Kolluru, C. Buahin, C. Daviau, C. Reed. 2013. A Comprehensive Modeling Approach for EIA Studies in the Oil and Gas Industry. International Association for Impact Assessment. 13-16 May 2013, Calgary, Alberta, Canada.
  Tesch L., V. S. Kolluru, A. Southam, M. J. Fichera. 2015. "Synopsis of the 2010-2011 Aleutian Islands Oil Spill Risk Analysis" presented at the 38th AMOP Technical Seminar on Environmental Contamination and Response, Vancouver, British Colombia, Canada