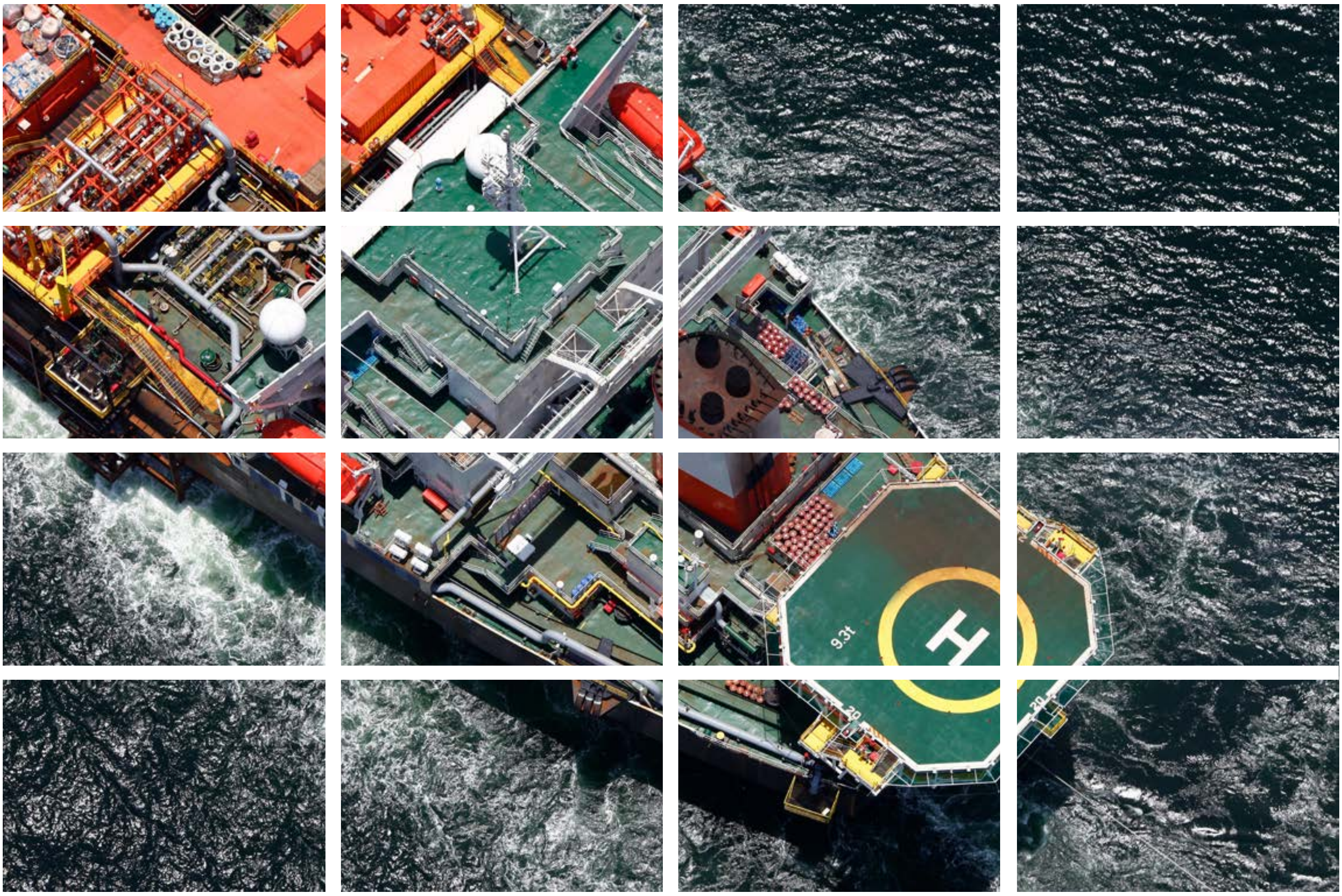

# VOLUME II

# Tweneboa, Enyenra, Ntomme (TEN) Project, Ghana

## Final Environmental Impact Statement

Doc no:  00002-E78-ES-RPT-0007 – REV 1

5 September 2014

*The world's leading sustainability consultancy*

**Tullow Ghana Limited**

# Tweneboa, Enyenra, Ntomme (TEN) Project, Ghana

## VOLUME II

### Final Environmental Impact Statement

Doc no: 00002-E78-ES-RPT-0007 – REV 1

EIA documentation includes the following:

Volume I: Final Environmental Impact Statement and Consultation Report

**Volume II: EIS Annexes**

**Prepared by:**

Environmental Resources Management in collaboration with ESL Consulting and SRC Consulting Limited

For and on behalf of
Environmental Resources Management

Approved by: Mark Irvine

Signed:

Position: Technical Director

Date: 5 September 2014

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Annex A

# Air Dispersion Modelling Report

*CONTENTS*

# A1 INTRODUCTION

## A1.1 OVERVIEW

This report sets out the results of the air dispersion modelling study and air quality impact assessment that was undertaken to inform the TEN Project EIA. The assessment addresses the potential impact of emissions associated with commissioning and operation of the offshore facilities on onshore receptors. The assessment considered the following.

- Impacts arising at onshore locations.
- Impacts arising around the FPSO and wellheads (during drilling), where transient receptors may be present (ie fishing vessels).
- Impacts arising at protected habitats.

Consideration was made of both commissioning and operational phases.

During commissioning, consideration was made of the emissions from the Mobile Offshore Drilling Unit (MODU) and the Floating Production, Storage and Offloading (FPSO) vessel as this will be operational for first oil whilst the final wells are still being drilled.

During operation, consideration was made of emissions associated with the FPSO vessel including emissions from power generation and emissions associated with occasional flaring during process upsets and for safety reasons.

The sources from the TEN FPSO that have been considered in the assessment are as follows.

- Compressor combustion turbines (three operational units and one standby unit).
- Deck boilers (one operational unit and one standby unit).
- Two fire water pump engines.
- Emergency generator (one unit).
- Two deck crane engines.
- One combined High Pressure/Low Pressure (HP/LP) flare.

Consideration was also made of cumulative impacts associated with the operation of the nearby Jubilee oil field. Impacts were assessed during normal operation of TEN and Jubilee; and when flaring events were occurring at TEN and Jubilee. The Jubilee FPSO (Kwame Nkrumah) is located approximately 30 km to the east of the TEN fields at 511990 m E, 508074 m N (UTM 30 N) and has been operational since November 2010. The assessment has assumed that the Jubilee FPSO to be similar in configuration to the proposed TEN FPSO.

## A1.2 SCOPE OF ASSESSMENT

The assessment is focussed on the potential impact of emissions from the commissioning and operational phases of the FPSO. The study area consisted of three key locations.

1) The Ghana/Ivory Coast to the North of the proposed TEN Project. Impacts were considered over a 140 km stretch of coast; this was considered likely to capture the maximum impacts given the prevailing south-easterly winds.

2) The area surrounding the TEN FPSO and MODUs where transient receptors may be present.

3) Sensitive ecological receptors on the Ghanaian coast.

Operations at the onshore base at Takoradi Port and the air force base have not been considered in the assessment on the basis of the scale of potential impacts from these sources. Onshore operations are primarily associated with movements of equipment and supplies using Heavy Goods Vehicles (HGVs) estimated at about two HGVs per day as well as crew transfers via helicopter. Emissions from these activities are not considered significant given the limited number of movements and the absence of large combustion sources.

Emissions from increased marine vessel movements have also been scoped out of the assessment. According to available technical guidance[1], when there are less than 5,000 vessels per year using a port (13 vessels per day) and no sensitive receptors within 250 m of shipping activities there is no requirement to assess shipping emissions, as there will be negligible risk of air quality standards being exceeded. The number of marine vessel movements during the drilling, installation and operational phases are expected to be well below this level of activity and has therefore been scoped out of the assessment.

No assessment has been made of fugitive emissions, for example arising from the venting of blanketing gases. Fugitive emissions have been minimised in the design of the FPSO through the selection of a hydrocarbon gas (fuel gas) blanketing connected to a Vapour Recovery Unit (VRU) which returns the gases to the process. When this system is not available, or its use is not possible, for example during maintenance and inspection periods, then inert gases will be used, for example boiler exhausts (predominantly carbon dioxide), and as these would have normally been emitted to atmosphere they have been accounted for in the emission calculations.

(1)( 1)UK Department of Environment, Food and Rural Affairs (2009) Local Air Quality Management Technical Guidance TG(09)

## *A1.3 POLLUTANTS OF INTEREST*

Based on the proposed activities (power generation, oil processing and occasional gas flaring) and the applicable national and international air quality standards, the following pollutants were assessed:

- nitrogen dioxide (NO2);
- oxides of nitrogen (NOx);
- sulphur dioxide (SO2);
- particles <10µm in aerodynamic diameter (PM10);
- particles <2.5µm in aerodynamic diameter (PM2.5); and
- carbon monoxide (CO).

## A2 LEGAL FRAMEWORK AND GUIDANCE

### A2.1 OVERVIEW

The air quality impact assessment has been undertaken in line with Ghanaian air quality standards; guidelines set out by the IFC; in line with international best practice as advocated by the IFC guidance[1], and where appropriate, to international air quality standards and guidelines. In addition, impacts at sensitive ecological receptors due to emissions of NOX and SO2 have been assessed. CO has been assessed against air quality guidelines as set out by the World Health Organisation.

### A2.2 NATIONAL AIR QUALITY LEGISLATION

The Ghanaian air quality standards used in this assessment are set out in the EPA Guidelines for Environmental Assessment and Management in the Offshore Oil and Gas Development and the EPA General Environmental Quality Guidelines for Ambient Air[2].

### A2.3 INTERNATIONAL AIR QUALITY LEGISLATION AND GUIDANCE

The following international legislation and guidance concerning air quality has been utilised in the assessment.

Guidance

- World Health Organisation (WHO). Air Quality Guidelines Global Update (2005).
- IFC Environmental, Health, and Safety Guidelines General EHS guidelines: environmental Air emissions and ambient air quality (2007).

Relevant international legal standards

- Directive on Clean Air for Europe (2008).

In addition, for the protection of sensitive ecological receptors, reference has been made to those wetland sites protected under the international Ramsar convention of which Ghana and Ivory Coast are both signatories, and nationally protected habitats.

(1) International Finance Corporation (2007) Environmental, Health, and Safety (EHS) Guidelines General EHS Guidelines: Introduction.
(2) http://www.epa.gov.gh/ghanalex/policies/EPAguidelines%20Report.pdf

## A3 METHODOLOGY

### A3.1 OVERVIEW

This section sets out the methodology and criteria for the assessment of potential impacts that may arise from the operation of the facility.

The potential for impacts to air quality due to emissions arising from the project are assessed by comparing the predicted impacts against standards and guidelines for the protection of human health, and critical levels for the protection of sensitive ecology as described above. The assessment uses dispersion modelling to predict the ground level increases in pollution concentrations attributable to project sources to establish whether there is the potential for significant impacts to occur.

### A3.2 POINT SOURCE DISPERSION MODELLING

#### A3.2.1 Overview

Dispersion modelling was used to predict concentrations of pollutants at locations on the coastline, at locations around the emission sources and at coastal habitats. Five years of hourly sequential meteorological data are used, so that inter-annual variability is incorporated in the model. The results of the assessment are based upon the worst case result for any of the five meteorological years used.

#### A3.2.2 Dispersion Model

The model used in the assessment is the United States Environmental Protection Agency's AERMOD dispersion model.

AERMOD is characterised by two main features:

- the description of the boundary layer in terms of both the boundary layer depth and the Monin-Obhukov length; and
- dispersion under convective meteorological conditions uses a modified Gaussian concentrations distribution.

AERMOD is recognised by a number of regulatory agencies including the IFC, US EPA and the UK Environment Agency as being fit for purpose for this type of assessment.

#### A3.2.3 Assessment Scenarios

The air quality assessment has evaluated impacts from the following four operating scenarios.

**Scenario 1** (normal operation, TEN FPSO only).

- Combustion turbines (two operational units).
- Deck boilers (one operational unit).
- Two fire water pump engines.
- Emergency generator (one unit).
- Two deck crane engines.
- No flaring.

**Scenario 2** (short term assessment only, normal operation with maximum flaring event, TEN FPSO only).

- Combustion turbines (two operational units);
- Deck boilers (one operational unit).
- Two fire water pump engines.
- Emergency generator (one unit).
- Two deck crane engines.
- Sixty minutes of emergency flaring event.

**Scenario 3** (normal operation, TEN FPSO and Jubilee FPSO).

- Combustion turbines (two operational units at each FPSO).
- Deck boilers (one operational unit at each FPSO).
- Two fire water pump engines at each FPSO.
- Emergency generator (one unit at each FPSO).
- Two deck crane engines at each FPSO.
- No flaring.

**Scenario 4** (normal operation at TEN FPSO; and well drilling emissions).

- Combustion turbines (two units operational on TEN).
- Deck boilers (on operational unit).
- Two fire water pump engines.
- Emergency generator (one unit).
- Two deck crane engines.
- One commissioning MODU (engine and flare operational).

**Scenario 5** (short term assessment only, normal operation with maximum flaring event at TEN FPSO; normal operation with maximum flaring event at Jubilee FPSO; and well drilling emissions):

- Combustion turbines (two operational units at each FPSO);
- Deck boilers (on operational unit at each FPSO);
- Two fire water pump engines at each FPSO;
- Emergency generator (one unit at each FPSO);
- Two deck crane engines at each FPSO; and
- Sixty minutes emergency flaring event on both FPSOs.

- One commissioning MODU (engine and flare operational).

### A3.2.4 *Model Inputs for Turbines, Boilers, Engines and Generators*

*Overview*

Each FPSO comprises following relevant emission sources.

- Combustion turbines (two operational units).
- Deck boilers (one operational unit).
- Two fire water pump engines.
- Emergency generator (one unit).
- Two deck crane engines.

Of these emission sources only the combustion turbines operate continuously. To calculate long term impacts, the emission loads ($gs^{-1}$) of non-continuous emission sources have therefore been factored to account for the actual working hours per year. For the short term impacts no factor has been used to reflect actual peak emission loads. As a consequence the short term impacts are substantially overestimated since the model assumes that all the emission sources will operate at the same time.

The assumption is made that emissions from the TEN FPSO and the Jubilee FPSO are the same for all sources, except the flare. In the case of the flare, there are lower emissions for Jubilee, reflecting the lower gas generation rate. This approach is conservative, as it is known that Jubilee is a smaller FPSO compared with TEN reflecting the fact that Jubilee has a lower production capacity. However, as the exact specifications of the Jubilee FPSO are unknown, this, conservative, approach has been adopted.

*FPSO Emissions*

The stack parameters for the emission sources for the TEN and Jubilee FPSOs are set out in *Table A3.1*. The pollutant emissions data for these sources that has been used in the assessment are set out in *Table A3.2*. As some of the design of the plant is still unknown, accurate emission data is not always available, therefore, where indicated emission data based on emission factors from literature were utilised(1). The emissions inventory for the TEN FPSO is set out in *Table A3.3*.

The impact assessment presented in *Section A4* is based upon modelling of emissions at design limits.

(1)AP-42 Compilation of Air Pollutant Emission Factors; http://www.epa.gov/ttnchie1/ap42/

*Table A3.1 Summary of Stack Parameters for TEN and Jubilee FPSOs*

| Installation | | Combustion turbines | Boilers[3] | Fire Water Pumps | Emergency Generator | Deck Crane Engines |
|---|---|---|---|---|---|---|
| **Number of installations** | | 3 (of which 1 in standby) | 1 | 2 | 1 | 2 |
| **Parameter** | Units | | | | | |
| Number of stacks | | 3 | 1 | 2 | 1 | 2 |
| Stack height actual | m | 43 | 59.4 | 47 (aft)<br>80.8 (fwd) | 23.2 | 48.9 |
| Flue diameter | m | 2.8 | 1.6[1] | 0.499 | 0.6[1] | 0.522 |
| Stack Area | $m^2$ | 6.16 | 2.01[1] | 0.196 | 0.283[1] | 0.214 |
| Emission velocity | m/s | 33.6[2] | 14.8[1] | 22 | 15[1] | 9.54 |
| Emission temperature gas fired (actual) | Kelvin | 829 | 493[4] | 593[5] | 593[5] | 593[5] |
| Operating regime | | 8,760 hr/yr | 21.9 days for 20 hrs = 438 hr/yr | 1h/week = 52 hr/yr | assume 1h/week = 52 hr/yr | |

[1] ASSUMPTION: emission velocity set to ~15m/s (based on relevant project experience) by adjusting stack diameter/area and using flow rate data

SENSITIVITY: decreasing stack diameter/area will increase emission velocity and therefore increase dispersion

[2] The choice between Single Annular Combustion (SAC) and Dry Low Emission (DLE) burners has not been made yet. Both types of turbines can run on natural gas or liquid fuel (0.1 % S). Specified volume flow rate is the highest of the four possible configurations burner/fuel to create maximum dispersion (highest impacts at long distance).

[3] Two boilers will be present on the FPSO: deck boiler and auxiliary boiler. The deck boiler will run on natural gas or diesel (in the absence of natural gas). The auxiliary boiler will only run when the deck boiler is out of order and runs only on diesel. Specified volume flow rate is the highest of the 3 possible configurations boiler/fuel to create maximum dispersion (highest impacts at long distance).

[4] ASSUMPTION: based upon literature (1)

SENSITIVITY: lower temperature will reduce dispersion

[5] ASSUMPTION: based upon relevant project experience for diesel engines

(1)Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for Large Combustion Plants; July 2006; p. 376

### *Table A3.2 Pollutant Emissions Data for TEN FPSO*

| Pollutant | Units | Emissions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CTs[1] | | Boilers[2] | | Fire Water Pumps | | Emergency Generator | | Deck Crane Engines | |
| | | ST | LT | ST | LT | ST | LT | ST | LT | ST | LT |
| $NO_x$ | g/s | 49.6 | 32.9 | 5.6 | 0.28 | 2.1 | 0.01 | 1.0 | 0.006 | 0.51 | 0.003 |
| $SO_2$ | g/s | 3.84 | 0 | 18.1 | 0.9 | 0.09 | 0.0005 | 0.025 | 0.0001 | 0.61 | 0.004 |
| PM | g/s | 0.392[3] | 0 | 0.55 | 0.028 | 0 | 0 | 0 | 0 | 0.013 | 0.000075 |
| CO | g/s | 2.2 | | 43.0 | | 0.837 | | 1.2 | | 0.43 | |

ST=short term/LT=long term

For the Combustion turbines, short term emissions are based upon the worst case emissions when operating on gas or diesel, and worst case of either DLE or SAC turbines. Long Term emissions are based upon the worst case emissions when operating on gas of either DLE or SAC turbines.

For CO no consideration is made of Long Term emissions, and the air quality standards are short term.

[1] The choice between Single Annular Combustion (SAC) and Dry Low Emission (DLE) burners hasn't been made yet. Both types of turbines can run on NATURAL GAS or liquid fuel (0.1 % S). Above emission rates are the highest of the 4 possible configurations burner/fuel for each pollutant and are not necessarily from the same configuration burner/fuel. Emissions are per CT.

[2] Two boilers will be present on the FPSO: deck boiler and auxiliary boiler. The deck boiler will run on natural gas or diesel (in the absence of natural gas). The auxiliary boiler will only run when the deck boiler is out of order and runs only on diesel. Above emission rates are the highest of the 3 possible configurations boiler/fuel for each pollutant and are not necessarily from the same configuration boiler/fuel.

[3] calculated with AP-42 emission factor (5.16 mg/MJ)

*Table A3.3 Emissions Inventory or TEN FPSO*

| Period | Equipment | Emission Type | Fuel Used | Rating | Units | Runtime | | Estimated Emissions (tonnes) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | h/d | days/yr | PM10 | SOx | NOx | VOC | CO | CO2 | CH4 | CO2e |
| **Well Drilling & Completion** | Per Well | | | | | | | | | | | | | | |
| | West Leo MODU (8 x Rolls Royce Bergen Diesel (4 rooms)) | Point source | Diesel | 36.8 | MW | 24 | 90 | 34 | 782 | 1,160 | 34 | 266 | 56,060 | 3 | 56,130 |
| | Vessels (work 1) | Mobile source (manoeuvring) | MGO | 8,500 | hp | 24 | 90 | 5 | 123 | 145 | 5 | 30 | 9,817 | 0 | 9,819 |
| | Vessels (work 2) | Mobile source (at sea) | MGO | 8,500 | hp | 24 | 90 | 3 | 110 | 181 | 3 | 15 | 8,927 | 0 | 8,928 |
| | Vessels (AHTS) | Mobile source (manoeuvring) | MGO | 10,000 | hp | 24 | 90 | 6 | 145 | 171 | 6 | 35 | 11,549 | 0 | 11,552 |
| | Tug (tow vessel) | Mobile source (at sea) | MGO | 7,000 | hp | 24 | 2 | 0 | 2 | 3 | 0 | 0 | 163 | 0 | 163 |
| | Flaring (fluid) | Point source | N/A | N/A | N/A | | 2 | - | - | 1 | 4 | 3 | 516 | 4 | |
| | Total per well | | | | | | | 49 | 1,162 | 1,660 | 53 | 350 | 87,032 | 7 | 87,202 |
| | **Total for all wells** | **Number of wells:** | **24** | | | | | **1,165** | **27,880** | **39,849** | **1,267** | **8,390** | **352,961** | **30** | **353,651** |
| **Subsea Flowline/ Umbilical /Injector installation** | Pipeline vessel | Mobile source (manoeuvring) | MGO | 20,000 | hp | 24 | 365 | 52 | 1,176 | 1,385 | 52 | 287 | 93,675 | 1 | 93,699 |
| | Supply vessel | Mobile source (at sea) | MGO | 8,500 | hp | 24 | 365 | 11 | 444 | 733 | 11 | 61 | 36,203 | 0 | 36,208 |
| | Pipelay umbilical vessel | Mobile source (manoeuvring) | MGO | 16,000 | hp | 24 | 365 | 42 | 941 | 1,108 | 42 | 230 | 74,940 | 1 | 74,959 |
| | Light construction vessel | Mobile source (manoeuvring) | MGO | 13,400 | hp | 24 | 365 | 35 | 788 | 928 | 35 | 193 | 62,762 | 1 | 62,778 |
| | Pre-commissioning vessel | Mobile source (manoeuvring) | MGO | 13,400 | hp | 24 | 365 | 35 | 788 | 928 | 35 | | | 1 | 62,778 |
| | Heavy lift vessel | Mobile source (at sea) | MGO | 20,000 | hp | 24 | 365 | 26 | 1,045 | 1,725 | 26 | 144 | 85,183 | 1 | 85,195 |
| | Heavy lift vessel | Mobile source (at sea) | MGO | 20,000 | hp | 24 | 365 | 26 | 1,045 | 1,725 | 26 | 144 | 85,183 | 1 | 85,195 |
| | Heavy lift vessel | Mobile source (at sea) | MGO | 20,000 | hp | 24 | 365 | 26 | 1,045 | 1,725 | 26 | 144 | 85,183 | 1 | 85,195 |
| | Heavy lift vessel | Mobile source (at sea) | MGO | 20,000 | hp | 24 | 365 | 26 | 1,045 | 1,725 | 26 | 144 | 85,183 | 1 | 85,195 |
| | Crew boat | Mobile source (at sea) | MGO | 1,000 | hp | 24 | 365 | 1 | 52 | 86 | 1 | 7 | 4,259 | 0 | 4,260 |
| | **Total for all subsea connections** | | | | | | | **281** | **8,369** | **12,066** | **281** | **1,546** | **675,334** | **6** | **675,463** |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FPSO Installation** | FPSO (manoeuvring) | Mobile source (manoeuvring) | MGO | 29,091 | hp | 24 | 120 | 25 | 562 | 662 | 25 | 137 | 44,797 | 0 | 44,808 |
| | FPSO (at sea) | Mobile source (at sea) | MGO | 29,091 | hp | 24 | 2 | 0 | 8 | 14 | 0 | 1 | 679 | 0 | 679 |
| | AHV/AHTS | Mobile source (manoeuvring) | MGO | 10,000 | hp | 24 | 120 | 9 | 193 | 228 | 9 | 47 | 15,399 | 0 | 15,403 |
| | Supply vessel | Mobile source (at sea) | MGO | 8,500 | hp | 24 | 120 | 4 | 146 | 241 | 4 | 20 | 11,902 | 0 | 11,904 |
| | **Total for FPSO Installation** | | | | | | | **37** | **910** | **1,145** | **37** | **206** | **72,776** | **1** | **72,794** |
| **Commissioning** | Flaring (commissioning and start-up) | Point source | N/A | N/A | N/A | | 280 | - | - | 420 | 3,503 | 2,347 | 980,765 | 3,503 | 1,061,328 |
| | Essential Services Generator A | Point source | MGO | 1,100 | kW | 24 | 120 | - | 12 | 38 | 1 | 11 | 2,236 | 0 | 2,239 |
| | Essential Services Generator B | Point source | MGO | 1,100 | kW | 24 | 120 | - | 12 | 38 | 1 | 11 | 2,236 | 0 | 2,239 |
| | Essential Services Generator C | Point source | MGO | 1,100 | kW | 24 | 120 | - | 12 | 38 | 1 | 11 | 2,236 | 0 | 2,239 |
| | **Total for FPSO Commissioning** | | | | | | | **-** | **36** | **533** | **3,507** | **2,379** | **987,473** | **3,503** | **1,068,044** |
| **Operation** | At FPSO | | | | | | | | | | | | | | |
| | Combustion Turbine A | Point source | Fuel Gas | 27 | MW | 24 | 365 | - | - | 1,037 | 2 | 70 | 100,684 | 8 | 100,865 |
| | Combustion Turbine B | Point source | Fuel Gas | 27 | MW | 24 | 365 | - | - | 1,037 | 2 | 70 | 100,684 | 8 | 100,865 |
| | Combustion Turbine C (S/B Unit) | Point source | Fuel Gas | 27 | MW | 24 | - | - | - | - | - | - | - | - | - |
| | Deck Boiler (Gas-Firing) | Point source | Fuel Gas | Undetermined | | 20 | 22 | - | - | 6 | 0 | 5 | 6,867 | 0 | 6,870 |
| | Deck Boiler(Oil-Firing) | Point source | MGO | Undetermined | | 20 | 1 | 0 | 2 | 0 | 3 | 4 | 357 | 2 | 402 |
| | Auxiliary Boiler | Point source | MGO | Undetermined | | 20 | 1 | 0 | 2 | 0 | 3 | 4 | 357 | 2 | 402 |
| | Aft Firewater Pump | Point source | MGO | 900 | kW | 1 | 52 | - | 0 | 0 | 0 | 0 | 33 | 0 | 33 |
| | Forward Firewater Pump | Point source | MGO | 900 | kW | 1 | 52 | - | 0 | 0 | 0 | 0 | 33 | 0 | 33 |
| | Emergency Generator | Point source | MGO | 1290 | kW | 1 | 52 | - | 0 | 0 | 0 | 0 | 47 | 0 | 47 |
| | Deck Crane Engine Portside | Point source | MGO | 460 | kW | 1 | 52 | 0 | 0 | 0 | 0 | 0 | 17 | 0 | 17 |
| | Deck Crane Engine Starboard | Point source | MGO | 460 | kW | 1 | 52 | 0 | 0 | 0 | 0 | 0 | 17 | 0 | 17 |
| | Flaring | Point source | N/A | N/A | N/A | Non-routine | | - | - | 75 | 626 | 420 | 175,387 | 626 | 189,794 |
| | Venting of crude storage | Point source | N/A | N/A | N/A | 20 | 27 | - | - | - | 187 | - | 325 | 10 | 566 |
| | **Total for Operations** | | | | | | | **0** | **3** | **2,157** | **823** | **572** | **384,809** | **657** | **399,912** |

### A3.2.5 *Model Inputs for Flares*

The stack and emissions parameter for the TEN and Jubilee flares are set out in *Table A3.4*. For the purposes of the modelling, the Jubilee flare is assumed to be of the same design to TEN, but will process a lower gas flow. For the purposes of the assessment the short term (ST) emissions reflect the 60 minute peak emission; the long term (LT) emissions reflect the expected operational schedule of the flares.

***Table A3.4 Stack and Emissions Parameters for Flaring Events (TEN and Jubilee)***

| Parameter | Unit | TEN | | Jubilee | |
|---|---|---|---|---|---|
| | | LT | ST | LT | ST |
| Base Elevation [m] | m | 20 | 20 | 20 | 20 |
| Release Height [m] | m | 100 | 100 | 100 | 100 |
| Gas Exit Temperature [K] | K | 1,273 | 1,273 | 1,273 | 1,273 |
| Gas Exit Velocity [m/s] | $ms^{-1}$ | 338 | 338 | 135 | 135 |
| Inside Diameter [m] | M | 0.609 | 0.609 | 0.609 | 0.609 |
| NOx | $gs^{-1}$ | 2.52 | 98.68 | 0.391 | 15.65 |
| CO | $gs^{-1}$ | | 715.9 | | 85.13 |

### A3.2.6 *Model Inputs for MODUs*

The development of the TEN oilfield requires drilling of wells using a MODU. Towards the end of the well drilling process, there will be one MODU in use, and the FPSO will also be receiving first oil. To capture the worst case, the assessment considers impacts arising from the FPSO whilst flaring in combination with the emissions from the MODU. Upon completion of well drilling the MODU is moved off-site.

The emissions from the MODU arise from the use of diesel powered engines and from flaring of gas and fluids. The model inputs for the MODUs are set out in *Table A3.5*.

***Table A3.5 Model Inputs for MODUs***

| Parameter | | Units | Flare | Engine |
|---|---|---|---|---|
| X | | m | 481,654 | 481,644 |
| Y | | m | 510,168 | 510,168 |
| Base height | | m | 25 | 25 |
| Release Height | | m | 40 | 20 |
| Emission rate | $PM_{10}$ | $gs^{-1}$ | | 4.35 |
| | $SO_2$ | $gs^{-1}$ | | 100.6 |
| | $NO_x$ | $gs^{-1}$ | 15.941 | 149.2 |
| | CO | $gs^{-1}$ | 115.649 | 34.2 |
| Temperature | | K | 1,273 | 593 |
| Temperature | | C | 1,000 | 320 |
| Diameter | | m | 0.609 | 1.45 |
| Velocity | | $ms^{-1}$ | 54.53 | 15.0 |
| Volume flow rate | | $m^3 s^{-1}$ | 15.87 | |

### A3.2.7 *Meteorological Data Selection*

The meteorological data used in the model is reflective of the local conditions. However, there are only a very limited number of meteorological stations along the West African Coast which measure all of the parameters required by the model. In addition, onshore meteorological stations are considered unlikely to be representative of conditions offshore around the FPSO which will dominate dispersion of pollutants. Therefore, five years of MM5 modelled meteorological data for the FPSO location for 2007-2011 was sourced from Lakes Environmental(1).

### A3.2.8 *Consideration of Terrain Effects*

Changes in terrain elevations (*ie* hills or mountains) can have a significant impact on dispersion of emissions, in terms of funnelling of plumes and changing local wind flows. Terrain effects are typically considered important where there are sustained gradients of 1:10 or greater. Since the terrain here is mostly open ocean, terrain was not considered in the model.

### A3.2.9 *Consideration of Building Downwash*

When air flow passes over buildings a phenomenon known as building downwash occurs where the air is entrained in the lee of the building and drawn down to ground level. This effect can bring the plume from the stack down to ground level more quickly than would otherwise be the case, and therefore increase the ground level concentration relative to a case where there are no buildings. For this assessment building downwash has not been considered because the distance from emission source to sensitive receptor (shoreline) ranges beyond the influence of building downwash effects.

### A3.2.10 *Conversion of $NO_x$ to $NO_2$*

The combustion process generates $NO_x$. In the exhaust gases from the stack, these are in the ratio of approximately 95% NO to 5% $NO_2$. With regard to the assessment of impact on human health $NO_2$ is the pollutant of interest as NO is largely inert in the human body. Within the atmosphere various processes oxidise NO to create $NO_2$ but this process will not occur quickly or completely before the plume reaches ground level. Therefore it is overly pessimistic to assume 100% conversion from NO to $NO_2$ and it is necessary to use a factor to estimate ground level concentrations of $NO_2$ based upon total $NO_x$ emitted.

A number of international agencies have developed guidelines for including in assessments the conversion of NO to $NO_2$. A summary of the main guidelines are set out below in *Table A3.6*. The ratios set out in *Table A3.4* indicate that a wide range of ratios to convert NO to $NO_2$ are recommended by a variety of country agencies as set out in *Table A3.6.* These conversion factors have been applied in the results interpretation.

(1) Lakes Environmental (2012) MM% meteorological data supplied to ERM, for FPSO location, 6th March 2012

*Table A3.6 Recommended NO to $NO_2$ Conversion Ratio*

| Country | Averaging Period | Recommended NO to $NO_2$ Conversion Ratio |
|---|---|---|
| United States Environmental | 24 hour | 75% |
| Protection Agency | Annual | 75% |
| German Federal Environment | 24 hour | 60% |
| Agency | Annual | 60% |
| United Kingdom Environment | Short term (1 hour) (screening) | 50% |
| Agency | Annual (screening) | 100% |
| Ontario Ministry of the | 24 hour | 52% |
| Environment, Canada | Annual | 68% |

Taking a conservative approach a conversion factor of 50% for the short term and 100% for long term was adopted. This applies only to the assessment of impacts on sensitive human receptors. When assessing impacts on sensitive ecological receptors total $NO_x$ is assessed and therefore no conversion is required.

### *A3.2.11 Non-Routine Events*

TGL will avoid routine operational gas flaring as a means of disposal of associated gas. Any flaring will be kept to a minimum during any production or well clean-up tests, and during plant commissioning, start-ups, operation and operational upsets. There will be no continuous operational flaring or venting by design.

Non-routine flaring events are typically short term but have the potential to result in short term elevated emissions. Non-routine flaring may be required for the safe disposal of oil or gas during upset conditions. This is achieved by diverting oil and/or gas to flares where it can be burned off until the plant operations are restored to normal.

The FPSO design includes High Pressure/Low Pressure flaring equipment to combust oil and/or gas from non-routine events related to maintenance and emergencies. Typical flaring events will occur for less than 60 minutes. The flaring event selected for modelling represents the worst case volume of gas reasonable expected to be flared from anticipated non-routine events. The composition of gas expected from TEN is the same as for the Jubilee field and is set out in *Table A3.7*.

*Table A3.7 Composition of TEN Gas*

| Component | Mol % |
|---|---|
| Nitrogen | 0.2410% |
| CO2 | 1.4400% |
| H2S | 0.0000% |
| Methane | 78.1271% |
| Ethane | 8.9430% |
| Propane | 7.2410% |
| i-Butane | 0.8920% |
| n-Butane | 2.1180% |
| i-Pentane | 0.4530% |
| n-Pentane | 0.4000% |
| 2-Mpentane | 0.0000% |
| 3-Mpentane | 0.000% |
| n-Hexane | 0.0745% |
| Mcyclopentan | 0.0100% |
| Benzene | 0.0100% |
| Cyclohexane | 0.0000% |
| 2-Mhexane | 0.0059% |
| 3-Mhexane | 0.0098% |
| n-Heptane | 0.0100% |
| Mcyclohexane | 0.0100% |
| Toluene | 0.0003% |
| n-Octane | 0.0066% |
| E-Benzene | 0.0002% |
| m-Xylene | 0.0006% |
| o-Xylene | 0.0002% |
| n-Nonane | 0.0009% |
| n-Decane | 0.0001% |
| H2O | 0.0056% |
| TEGlycol | 0.0001% |
| Salt | 0.000% |

## A3.3 ASSESSMENT CRITERIA

### A3.3.1 Overview

The potential impacts of the emissions from the TEN FPSO on human health are assessed in relation to air quality standards and guidelines. Consideration is made of the contribution from the TEN FPSO itself as well as the cumulative contribution of both the TEN FPSO and the Jubilee FPSO. The potential impact on sensitive habitats is assessed through comparison with relevant critical levels. The assessment criteria used in this assessment are set out in this section.

### A3.3.2 Assessment Criteria for the Protection of Human Health

As discussed in *Section A2*, Ghanaian and IFC/WHO air quality standards have been used in the assessment. These are set out in *Table A3.8*.

*Table A3.8 Air Quality Guidelines*

| Pollutant | Averaging Period | Guideline Value (µgm⁻³) WHO | Ghana Residential and Rural | Ghana Industrial/ Commercial |
|---|---|---|---|---|
| **$SO_2$** | 1-year mean | | 50 | 80 |
| | 24-hour maximum | 125 (Interim target-1)<br>50 (Interim target-2)<br>20 (guideline) | 50 | 100 |
| | 1-hour maximum | | 700 | 900 |
| **$NO_2$** | 1-year mean | 40 (guideline) | 80 | 100 |
| | 1-hour maximum | 200 (guideline) | 200 | |
| **$PM_{10}$** | 1-year mean | 70 (Interim target-1)<br>50 (Interim target-2)<br>30 (Interim target-3)<br>20 (guideline) | | |
| | 24-hour assessed as the third highest 24 hour period (99th percentile) | 150 (Interim target-1)<br>100 (Interim target-2)<br>75 (Interim target-3)<br>50 (guideline) | | |
| | 24-hour maximum | | 150 | 260 |
| **$PM_{2.5}$** | 1-year mean | 35 (Interim target-1)<br>25 (Interim target-2)<br>15 (Interim target-3)<br>10 (guideline) | | |
| | 24-hour maximum | 75 (Interim target-1)<br>50 (Interim target-2)<br>37.5 (Interim target-3)<br>25 (guideline) | | |
| **CO** | 1 hour maximum | 60,000 | 30,000 | |
| | 8 hour maximum | 30,000 | 10,000 | |

### A3.3.3 *Assessment Criteria for the Protection of Ecological Habitats*

Impacts relating directly to air quality (*ie* $NO_x$, $SO_2$) are not habitat or species specific and are the same for all sites. In the absence of habitat specific national air quality standards the criteria used in this assessment are from the European Directives (see *Section A2*), and are set out *Table A3.9.*

*Table A3.9 Air Quality Critical Levels used for the Assessment of Impacts on Sensitive Ecological Receptors*

| Pollutant | Averaging Period and Statistic | Assessment Criterion (µgm⁻³) |
|---|---|---|
| $NO_x$ | Annual mean | 30 |
| $SO_2$ | Annual mean | 20 |

### A3.4 SIGNIFICANCE CRITERIA

The magnitude of impacts was quantified using predictive techniques based on detailed dispersion modelling. The magnitude of the impact is the 'Process Contribution (PC)'. This is the impact arising solely from project related emissions. To consider the significance of those impacts, consideration is required of the existing baseline. The PC added to the existing baseline is described as the Predicted Environmental Concentration (PEC). The significance of the PC and PEC is then determined following IFC guidance, as described here.

The significance of the predicted impacts was ascertained by means of comparison to air quality guidelines as set out in *Section A3.3.2*.

IFC differentiates the significance of impacts, based upon the existing baseline air quality in the vicinity of a proposed development. Essentially, this is based upon whether the existing pollution concentrations at receptors are in excess of the guidelines with 'undegraded' airsheds being those where air quality standards are currently met, and 'degraded' airsheds being those where air quality standards are not currently met.

The significance of impacts is, therefore, defined in terms of the magnitude of impacts (the *ie* Process Contribution), and whether the baseline pollution concentrations are above or below the air quality standards (AQS). Using this approach, the significance criteria for air quality have been defined. These are set out in *Table A3.10*. On the basis of a review of likely baseline conditions (see *Section A4*) the airshed for this assessment is assumed to be undegraded.

***Table A3.10 Significance Criteria for Assessment of Airborne Pollutants[1]***

| Significance of Impact | Magnitude of Impact |
|---|---|
| **No significant impact** | PC <25% of AQS |
| **Minor** | PC between 25% and 50% of AQS and PEC <100% of AQS |
| **Moderate** | PC between 50% and 100% of AQS, and PEC <100% AQS; or |
| | PC between 25% and 50% of AQS, and PEC >100% of AQS |
| **Major** | PC > 100% of AQS |

(1) The significance for humans and ecology are treated as the same in light of no alternative information.

# A4 BASELINE AND RECEPTORS

## A4.1 BASELINE CONDITIONS

The assessment of impacts on air quality undertaken for shoreline receptors in Ghana and Ivory Coast included coastline of a distance of approximately 140 km to east and west from the nearest onshore point from TEN FPSO. This is considered adequate to capture the point of maximum onshore impacts, given the prevailing winds from the southeast. In addition, impacts were identified at locations between the FPSO and the shoreline to capture impacts on transient receptors.

With regard to the shoreline receptors, no baseline monitoring data is available for this area. The baseline levels of $NO_x$, $NO_2$, CO and $SO_2$ are considered to be low along most of the shoreline since there are very few industrial installations in the area. More elevated concentrations will however occur in more densely populated areas (*eg* towns of Half Assini, Bonyere, Axim, Esiama, Efasu and Grand-Bassam due to combustion sources used for cooking and heating, road traffic, local industry etc. The baseline conditions of $PM_{10}$ and $PM_{2.5}$ may be elevated in the study area due to local and regional sources. These will primarily be natural sources, associated with the dry season. However, within more densely populated areas the baseline concentrations may be somewhat elevated due to combustion sources used for cooking and heating, road traffic, local industry *etc*.

With regard to the offshore location the baseline concentrations of the pollutants of interest are assumed to be negligible. The main sources of emissions are the TEN and Jubilee oilfields, which have been considered in the assessment.

## A4.2 RECEPTORS

The air quality standards and guidelines apply primarily at fixed receptors on the shoreline. However, as a worst case they have also been applied for transient offshore receptors. These are primarily those within 5 km of the FPSO and therefore within the advisory zone around the FPSO. To capture the maximum onshore impacts the assessment utilises a grid of receptors (500 m resolution) which follows the shoreline over a distance of approximately 140 km perpendicular to the east and west of the nearest point onshore of the TEN FPSO and going inland for 1.5 to 2 km. This will capture impacts at all sensitive receptors, as small scale variations in pollution concentrations at this distance downwind will be negligible. To capture the offshore impacts a grid of receptors measuring 90 km by 200 km has been defined; this includes the area around the TEN and Jubilee FPSOs.

## A5 RESULTS

### A5.1 OVERVIEW

Results for the five scenarios described in *Section A3.6.3* are outlined in this section.

### A5.2 PREDICTED IMPACTS AT HUMAN SENSITIVE RECEPTORS

The results of the modelling assessment for human receptors are set out in *Table A5.1* to *Table A5.5. T*he tables set out:

- the pollutant of interest;
- the averaging period;
- the air quality standard or guideline;
- the PC; and
- the magnitude and significance of the predicted impacts.

The significance of the predicted impacts is assessed using the criteria set out in *Section A3.4*. The PCs presented are the highest impact predicted anywhere on the shoreline, as previously described, for any of the five years of meteorological data.

For scenario 2 and 5 where FPSO flaring is included, short term impacts are presented as flaring events only occur for the short term. For scenario 4 and scenario 5, flaring events at the MODU is considered in the long term on the basis of the total volume of gas to be flared during commissioning (13.57 Bscf over 40 weeks).

The results of the dispersion modelling demonstrate that under no circumstances are air quality standards predicted to be exceeded at onshore locations. Furthermore, there are not predicted to be any significant impacts at onshore locations for any pollutant and any scenario.

The greatest impacts will be from $NO_2$ and $SO_2$ emissions close to the release points at the FPSO and, during commissioning, in close proximity to the MODU. On this basis, the defining of the exclusion zone to 500 m is a reasonable precaution to ensure that transient receptors are not exposed to unacceptable air pollution.

*Table A5.1 Summary of Maximum Predicted Impacts, for any Meteorological Year - Scenario 1*

| Location | Pollutant | Averaging Period | WHO ($\mu gm^{-3}$) | GHANA ($\mu gm^{-3}$) | PC ($\mu gm^{-3}$) | PC/WHO (%) | PC/GHANA (%) | Significance WHO | Significance Ghana |
|---|---|---|---|---|---|---|---|---|---|
| All locations | $NO_2$ | 1 hour maximum | 200 | 200 | 43 | 21 | 21 | *Not Significant* | *Not Significant* |
| | $NO_2$ | Annual average | 40 | 80 | 2.2 | 5 | 3 | *Not Significant* | *Not Significant* |
| | $SO_2$ | Annual average | | 50 | 0.079 | | 0.16 | *N/A* | *Not Significant* |
| | $SO_2$ | 24 hour maximum | 20 | 50 | 13 | 64 | 26 | *Moderate* | *Minor* |
| | $SO_2$ | 1 hour maximum | | 700 | 41 | | 5.9 | *N/A* | *Not Significant* |
| | $PM_{10}$ | Annual average | 20 | | 0.00240 | 0.012 | | *Not Significant* | *N/A* |
| | $PM_{10}$ | 24 hour maximum | | 150 | 0.5 | | 0.3 | *N/A* | *Not Significant* |
| | $PM_{10}$ | 24 hour 99-percentile, not to be exceeded more than 3 times per year | 50 | | 0.46 | 1 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | Annual average | 10 | | 0.00240 | 0.024 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | 24 hour maximum | 25 | | 0.5 | 2 | | *Not Significant* | *N/A* |
| | CO | 1 hour maximum | 60,000 | 30,000 | 95.2 | 0.16 | 0.32 | *Not Significant* | *Not Significant* |
| | CO | 8 hour maximum | 30,000 | 10,000 | 67.9 | 0.23 | 0.68 | *Not Significant* | *Not Significant* |
| Coastal locations | $NO_2$ | 1 hour maximum | 200 | 200 | 8.1 | 4 | 4 | *Not Significant* | *Not Significant* |
| | $NO_2$ | Annual average | 40 | 80 | 0.211 | 0.53 | 0.26 | *Not Significant* | *Not Significant* |
| | $SO_2$ | Annual average | | 50 | 0.00533 | | 0.011 | *N/A* | *Not Significant* |
| | $SO_2$ | 24 hour maximum | 20 | 50 | 1.61 | 8 | 3.2 | *Not Significant* | *Not Significant* |
| | $SO_2$ | 1 hour maximum | | 700 | 6.1 | | 0.9 | *N/A* | *Not Significant* |
| | $PM_{10}$ | Annual average | 20 | | 0.000160 | 0.0008 | | *Not Significant* | *N/A* |
| | $PM_{10}$ | 24 hour maximum | | 150 | 0.061 | | 0.04 | *N/A* | *Not Significant* |
| | $PM_{10}$ | 24 hour 99-percentile, not to be exceeded more than 3 times per year | 50 | | 0.044 | 0.09 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | Annual average | 10 | | 0.000160 | 0.0016 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | 24 hour maximum | 25 | | 0.061 | 0.2 | | *Not Significant* | *N/A* |
| | CO | 1 hour maximum | 60,000 | 30,000 | 13.2 | 0.02 | 0.04 | *Not Significant* | *Not Significant* |
| | CO | 8 hour maximum | 30,000 | 10,000 | 8.0 | 0.03 | 0.08 | *Not Significant* | *Not Significant* |

PC: Process Contribution. N/A: Not Applicable

*Table A5.2 Summary of Maximum Predicted Impacts, for any Meteorological Year - Scenario 2*

| Location | Pollutant | Averaging Period | WHO ($\mu gm^{-3}$) | GHANA ($\mu gm^{-3}$) | PC ($\mu gm^{-3}$) | PC/ WHO (%) | PC/ GHANA (%) | Significance | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | WHO | Ghana |
| All locations | $NO_2$ | 1 hour maximum | 200 | 200 | 64 | 32% | 32 | *Minor* | *Minor* |
| | $SO_2$ | 1 hour maximum | | 700 | 41 | | 5.9 | *N/A* | *Not Significant* |
| | CO | 1 hour maximum | 60,000 | 30,000 | 532.4 | 0.89% | 1.77 | *Not Significant* | *Not Significant* |
| Coastal locations | $NO_2$ | 1 hour maximum | 200 | 200 | 11.7 | 6% | 6 | *Not Significant* | *Not Significant* |
| | $SO_2$ | 1 hour maximum | | 700 | 6.1 | | 0.9 | *N/A* | *Not Significant* |
| | CO | 1 hour maximum | 60,000 | 30,000 | 76.9 | 0.13% | 0.26 | *Not Significant* | *Not Significant* |

PC: Process Contribution. N/A: Not Applicable

*Table A5.3 Summary of Maximum Predicted Impacts, for any Meteorological Year - Scenario 3*

| Location | Pollutant | Averaging Period | WHO ($\mu gm^{-3}$) | GHANA ($\mu gm^{-3}$) | PC ($\mu gm^{-3}$) | PC/ WHO (%) | PC/ GHANA (%) | Significance WHO | Significance Ghana |
|---|---|---|---|---|---|---|---|---|---|
| All locations | $NO_2$ | 1 hour maximum | 200 | 200 | 53 | 26 | 26 | *Minor* | *Minor* |
| | $NO_2$ | Annual average | 40 | 80 | 2.2 | 6 | 3 | *Not Significant* | *Not Significant* |
| | $SO_2$ | Annual average | | 50 | 0.079 | | 0.16 | *N/A* | *Not Significant* |
| | $SO_2$ | 24 hour maximum | 20 | 50 | 14 | 69 | 27 | *Moderate* | *Minor* |
| | $SO_2$ | 1 hour maximum | | 700 | 53 | | 7.6 | *N/A* | *Not Significant* |
| | $PM_{10}$ | Annual average | 20 | | 0.00240 | 0.012 | | *Not Significant* | *N/A* |
| | $PM_{10}$ | 24 hour maximum | | 150 | 0.5 | | 0.3 | *N/A* | *Not Significant* |
| | $PM_{10}$ | 24 hour 99-percentile, not to be exceeded more than 3 times per year | 50 | | 0.5 | 1 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | Annual average | 10 | | 0.00240 | 0.024 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | 24 hour maximum | 25 | | 0.5 | 2 | | *Not Significant* | *N/A* |
| | CO | 1 hour maximum | 60,000 | 30,000 | 123.7 | 0.21 | 0.41 | *Not Significant* | *Not Significant* |
| | CO | 8 hour maximum | 30,000 | 10,000 | 78.1 | 0.26 | 0.78 | *Not Significant* | *Not Significant* |
| Coastal locations | $NO_2$ | 1 hour maximum | 200 | 200 | 9.0 | 5 | 5 | *Not Significant* | *Not Significant* |
| | $NO_2$ | Annual average | 40 | 80 | 0.376 | 0.9 | 0.47 | *Not Significant* | *Not Significant* |
| | $SO_2$ | Annual average | | 50 | 0.0095 | | 0.019 | *N/A* | *Not Significant* |
| | $SO_2$ | 24 hour maximum | 20 | 50 | 1.97 | 10 | 4.0 | *Not Significant* | *Not Significant* |
| | $SO_2$ | 1 hour maximum | | 700 | 7.0 | | 1.0 | *N/A* | *Not Significant* |
| | $PM_{10}$ | Annual average | 20 | | 0.000290 | 0.0015 | | *Not Significant* | *N/A* |
| | $PM_{10}$ | 24 hour maximum | | 150 | 0.074 | | 0.05 | *N/A* | *Not Significant* |
| | $PM_{10}$ | 24 hour 99-percentile, not to be exceeded more than 3 times per year | 50 | | 0.055 | 0.11 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | Annual average | 10 | | 0.000290 | 0.0029 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | 24 hour maximum | 25 | | 0.074 | 0.3 | | *Not Significant* | *N/A* |
| | CO | 1 hour maximum | 60,000 | 30,000 | 15.1 | 0.03 | 0.05 | *Not Significant* | *Not Significant* |
| | CO | 8 hour maximum | 30,000 | 10,000 | 8.6 | 0.03 | 0.09 | *Not Significant* | *Not Significant* |

PC: Process Contribution. N/A: Not Applicable

*Table A5.4* *Summary of Maximum Predicted Impacts, for any Meteorological Year - Scenario 4*

| Location | Pollutant | Averaging Period | WHO ($\mu gm^{-3}$) | GHANA ($\mu gm^{-3}$) | PC ($\mu gm^{-3}$) | PC/ WHO (%) | PC/GHANA (%) | Significance | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | **WHO** | **Ghana** |
| All locations | $NO_2$ | 1 hour maximum | 200 | 200 | 272 | 136 | 136 | *Major* | *Major* |
| | $NO_2$ | Annual average | 40 | 80 | 26.4 | 66 | 33 | *Moderate* | *Minor* |
| | $SO_2$ | Annual average | | 50 | 0.08 | | 0 | *N/A* | *Not Significant* |
| | $SO_2$ | 24 hour maximum | 20 | 50 | 13 | 64 | 26 | *Moderate* | *Minor* |
| | $SO_2$ | 1 hour maximum | | 700 | 41 | | 5.9 | *N/A* | *Not Significant* |
| | $PM_{10}$ | Annual average | 20 | | 0.002 | 0.0 | | *Not Significant* | *N/A* |
| | $PM_{10}$ | 24 hour maximum | | 150 | 0.5 | | 0.3 | *N/A* | *Not Significant* |
| | $PM_{10}$ | 24 hour 99-percentile, not to be exceeded more than 3 times per year | 50 | | 0.46 | 1 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | Annual average | 10 | | 0.002 | 0.0 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | 24 hour maximum | 25 | | 0.5 | 2 | | *Not Significant* | *N/A* |
| | CO | 1 hour maximum | 60,000 | 30,000 | 585.1 | 0.98 | 1.95 | *Not Significant* | *Not Significant* |
| | CO | 8 hour maximum | 30,000 | 10,000 | 462.6 | 1.54 | 4.63 | *Not Significant* | *Not Significant* |
| Coastal locations | $NO_2$ | 1 hour maximum | 200 | 200 | 47.6 | 24 | 24 | *Not Significant* | *Not Significant* |
| | $NO_2$ | Annual average | 40 | 80 | 1.80 | 4.5 | 2.25 | *Not Significant* | *Not Significant* |
| | $SO_2$ | Annual average | | 50 | 0.005 | | 0.0 | *N/A* | *Not Significant* |
| | $SO_2$ | 24 hour maximum | 20 | 50 | 1.6 | 8 | 3.2 | *Not Significant* | *Not Significant* |
| | $SO_2$ | 1 hour maximum | | 700 | 6.1 | | 0.9 | *N/A* | *Not Significant* |
| | $PM_{10}$ | Annual average | 20 | | 0.0002 | 0.00 | | *Not Significant* | *N/A* |
| | $PM_{10}$ | 24 hour maximum | | 150 | 0.061 | | 0.04 | *N/A* | *Not Significant* |
| | $PM_{10}$ | 24 hour 99-percentile, not to be exceeded more than 3 times per year | 50 | | 0.044 | 0.1 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | Annual average | 10 | | 0.0002 | 0.00 | | *Not Significant* | *N/A* |
| | $PM_{2.5}$ | 24 hour maximum | 25 | | 0.061 | 0.2 | | *Not Significant* | *N/A* |
| | CO | 1 hour maximum | 60,000 | 30,000 | 94.0 | 0.16 | 0.31 | *Not Significant* | *Not Significant* |
| | CO | 8 hour maximum | 30,000 | 10,000 | 54.0 | 0.18 | 0.54 | *Not Significant* | *Not Significant* |

PC: Process Contribution. N/A: Not Applicable

*Table A5.5 Summary of Maximum Predicted Impacts, for any Meteorological Year - Scenario 5*

| Location | Pollutant | Averaging Period | WHO (μgm-3) | GHANA (μgm-3) | PC (μgm-3) | PC/WHO (%) | PC/GHANA (%) | Significance WHO | Ghana |
|---|---|---|---|---|---|---|---|---|---|
| All locations | $NO_2$ | 1 hour maximum | 200 | 200 | 272 | 136% | 136% | *Major* | *Major* |
| | $SO_2$ | 1 hour maximum | | 700 | 53 | | 7.6% | *N/A* | *Not Significant* |
| | CO | 1 hour maximum | 60,000 | 30,000 | 585.1 | 0.98% | 1.95% | *Not Significant* | *Not Significant* |
| Coastal locations | $NO_2$ | 1 hour maximum | 200 | 200 | 47.6 | 24% | 24% | *Not Significant* | *Not Significant* |
| | $SO_2$ | 1 hour maximum | | 700 | 7.0 | | 1.0% | *N/A* | *Not Significant* |
| | CO | 1 hour maximum | 60,000 | 30,000 | 103.6 | 0.17% | 0.35% | *Not Significant* | *Not Significant* |

PC: Process Contribution. N/A: Not Applicable

## A5.3 *Predicted Impacts On Sensitive Ecological Receptors*

Two nationally important ecologically sensitive sites were identified on the Ghanaian coast:

- Amansuri Wetlands; and
- Domini Lagoon.

In addition there are three internationally important wetland sites (Ramsar sites) on the Ivory Coast:

- Grand-Bassam;
- N'Ganda N'Ganda; and
- Iles Ehotilé-Essouman.

The approach taken was to assess the maximum potential impacts on the coasts. Where onshore impacts are not significant, impacts at any nationally or internationally designated habitats will also be not significant.

*Table A5.6, Table A5.7* and *Table A5.8* set out the results of the impact assessment compared to Air Quality Critical Levels for Sensitive Ecological Receptors. No assessment is required of the impacts of flaring events on sensitive ecological receptors as the small overall increase in impact associated with the short term use of flaring is anticipated to have a negligible effect on the overall annual mean concentrations. There is predicted to be no significant impact for all pollutants at all habitats.

***Table A5.3 Scenario 1: Predicted Annual Mean Concentrations of $NO_X$ and $SO_2$ at Sensitive Ecological Receptors (TEN FPSO Emissions)***

| Habitat | Pollutant | Critical Level (µg/m³) | PC (µg/m³) | PC/ AQS (%) | Significance |
|---|---|---|---|---|---|
| Amansuri Wetlands | $NO_x$ | 30 | 0.07028 | 0.2% | *Not Significant* |
| | $SO_2$ | 20 | 0.00143 | 0.007% | *Not Significant* |
| Domini Lagoon | $NO_x$ | 30 | 0.18131 | 0.6% | *Not Significant* |
| | $SO_2$ | 20 | 0.00432 | 0.022% | *Not Significant* |
| Grand-Bassam Ramsar | $NO_x$ | 30 | 0.02148 | 0.072% | *Not Significant* |
| | $SO_2$ | 20 | 0.000470 | 0.0024% | *Not Significant* |
| N'Ganda N'Ganda Ramsar | $NO_x$ | 30 | 0.0434 | 0.14% | *Not Significant* |
| | $SO_2$ | 20 | 0.001020 | 0.0051% | *Not Significant* |
| Iles Ehotilé-Essouman Ramsar | $NO_x$ | 30 | 0.07969 | 0.27% | *Not Significant* |
| | $SO_2$ | 20 | 0.00174 | 0.0087% | *Not Significant* |

***Table A5.4 Scenario 3: Predicted Annual Mean Concentrations of $NO_X$ and $SO_2$ at Sensitive Ecological Receptors (TEN FPSO and Jubilee FPSO Emissions)***

| Habitat | **Pollutant** | **Critical Level ($\mu gm^{-3}$)** | **PC ($\mu gm^{-3}$)** | **PC/ AQS (%)** | **Significance** |
|---|---|---|---|---|---|
| Amansuri Wetlands | $NO_x$ | 30 | 0.183 | 0.6% | *Not Significant* |
| | $SO_2$ | 20 | 0.004 | 0.020% | *Not Significant* |
| Domini Lagoon | $NO_x$ | 30 | 0.369 | 1.2% | *Not Significant* |
| | $SO_2$ | 20 | 0.00914 | 0.046% | *Not Significant* |
| Grand-Bassam Ramsar | $NO_x$ | 30 | 0.0377 | 0.13% | *Not Significant* |
| | $SO_2$ | 20 | 0.000810 | 0.0041% | *Not Significant* |
| N'Ganda N'Ganda Ramsar | $NO_x$ | 30 | 0.0663 | 0.22% | *Not Significant* |
| | $SO_2$ | 20 | 0.00153 | 0.0077% | *Not Significant* |
| Iles Ehotilé-Essouman Ramsar | $NO_x$ | 30 | 0.111 | 0.37% | *Not Significant* |
| | $SO_2$ | 20 | 0.00246 | 0.012% | *Not Significant* |

***Table A5.5 Scenario 4: Predicted Annual Mean Concentrations of $NO_X$ and $SO_2$ at Sensitive Ecological Receptors (TEN FPSO and Drill Rig Emissions)***

| Habitat | **Pollutant** | **Critical Level ($\mu gm^{-3}$)** | **PC ($\mu gm^{-3}$)** | **PC/ AQS (%)** | **Significance** |
|---|---|---|---|---|---|
| Amansuri Wetlands | $NO_x$ | 30 | 0.432 | 1.4% | *Not Significant* |
| | $SO_2$ | 20 | 0.00143 | 0.007% | *Not Significant* |
| Domini Lagoon | $NO_x$ | 30 | 1.384 | 4.6% | *Not Significant* |
| | $SO_2$ | 20 | 0.00432 | 0.022% | *Not Significant* |
| Grand-Bassam Ramsar | $NO_x$ | 30 | 0.1751 | 0.58% | *Not Significant* |
| | $SO_2$ | 20 | 0.00047 | 0.0024% | *Not Significant* |
| N'Ganda N'Ganda Ramsar | $NO_x$ | 30 | 0.3824 | 1.27% | *Not Significant* |
| | $SO_2$ | 20 | 0.00102 | 0.0051% | *Not Significant* |
| Iles Ehotilé-Essouman Ramsar | $NO_x$ | 30 | 0.838 | 2.79% | *Not Significant* |
| | $SO_2$ | 20 | 0.00174 | 0.009% | *Not Significant* |

## A6 CONCLUSION

The assessment was undertaken throughout on the basis of particularly unfavourable worst case assumptions. Even with these worst case assumptions, the assessment identified that there will be no air quality standards exceeded in any circumstance at any onshore locations, even under the theoretical absolute worst case scenario. With regard to impacts on transient receptors, there are predicted to be significant impacts in close proximity to the FPSO, and the MODUs where these are in use. On this basis, setting an exclusion zone of 500 m around the FPSO and MODUs is reasonable to ensure that these receptors are not exposed to excessive air pollution.

With regard to sensitive habitats, there are no significant impacts predicted at any protected habitats.

Annex B

# Environmental Baseline Survey Report

# Tweneboa, Enyenra, and Ntomme Final Environmental Baseline Survey

November 2011

Prepared for:

Tullow Ghana, Ltd.
71 George Bush Highway (Tetteh Quarshie Int)
North Dzorwulu
Accra, Ghana

Prepared by:

CSA International, Inc.
8502 SW Kansas Avenue
Stuart, Florida 34997
United States

# Tweneboa, Enyenra, and Ntomme Final Environmental Baseline Survey

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**Page**



**APPENDICES**

# List of Figures

## LIST OF IMAGES

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| AVS | acid-volatile sulfide |
| $CH_3Cl_2$ | methylene chloride |
| $CO_2$ | carbon dioxide |
| CoC | chain-of-custody |
| CSA | CSA International, Inc. |
| CTD | conductivity, temperature, and depth |
| DGPS | differential global positioning system |
| DQO | data quality objective |
| DWT | Deep Water Tano |
| EBS | Environmental Baseline Survey |
| EHS | Environmental, Health, and Safety |
| EIA | Environmental Impact Assessment |
| EOM | extractable organic matter |
| ESL | ESL Consulting Limited |
| G&A | Germano and Associates |
| GF/F | glass-fiber filter |
| GPS | global positioning system |
| $H_2S$ | hydrogen sulfide |
| HDPE | high-density polyethylene |
| ICP | inductively coupled plasma |
| IFC | International Finance Corporation |
| ITT | Invitation to Tender |
| LPSA | Laser Particle Size Analyzer |
| $MgCO_3$ | magnesium carbonate |
| MDS | multi-dimensional scaling |
| NELAP | National Environmental Laboratory Accreditation Program |
| NTU | nephelometric turbidity unit |
| O&G | oil and grease |
| OES | optical emission spectroscopy |
| OM | organic matter |
| PAH | polycyclic aromatic hydrocarbons |
| ppb | part per billion |
| ppm | parts per million |
| psu | practical salinity unit |
| PUC | plan-view underwater camera |
| TBT | tributyl tin |
| TEN | Tweneboa, Enyenra, and Ntomme |
| TGL | Tullow Ghana, Ltd. |
| TOC | total organic carbon |
| TPH | total petroleum hydrocarbons |
| USBL | ultra-short baseline |
| USEPA | U.S. Environmental Protection Agency |

Tullow Ghana, Ltd. (TGL) plans to develop the Tweneboa, Enyenra, and Ntomme (TEN) Area in the Deep Water Tano Block offshore Ghana (**Figure 1**). These reservoirs located west of the Jubilee Field are approximately 50 km offshore in a water depth that ranges from 1,000 to 1,800 m. TGL contracted CSA International, Inc. (CSA) to conduct the Environmental Baseline Survey (EBS) of the DWT Block within the TEN development area and along a designated gas export pipeline route in support of an environmental impact assessment (EIA) for the project. The TEN EBS was conducted by CSA concurrently with the TGL Jubilee Field Drill Cuttings Study in March 2011.

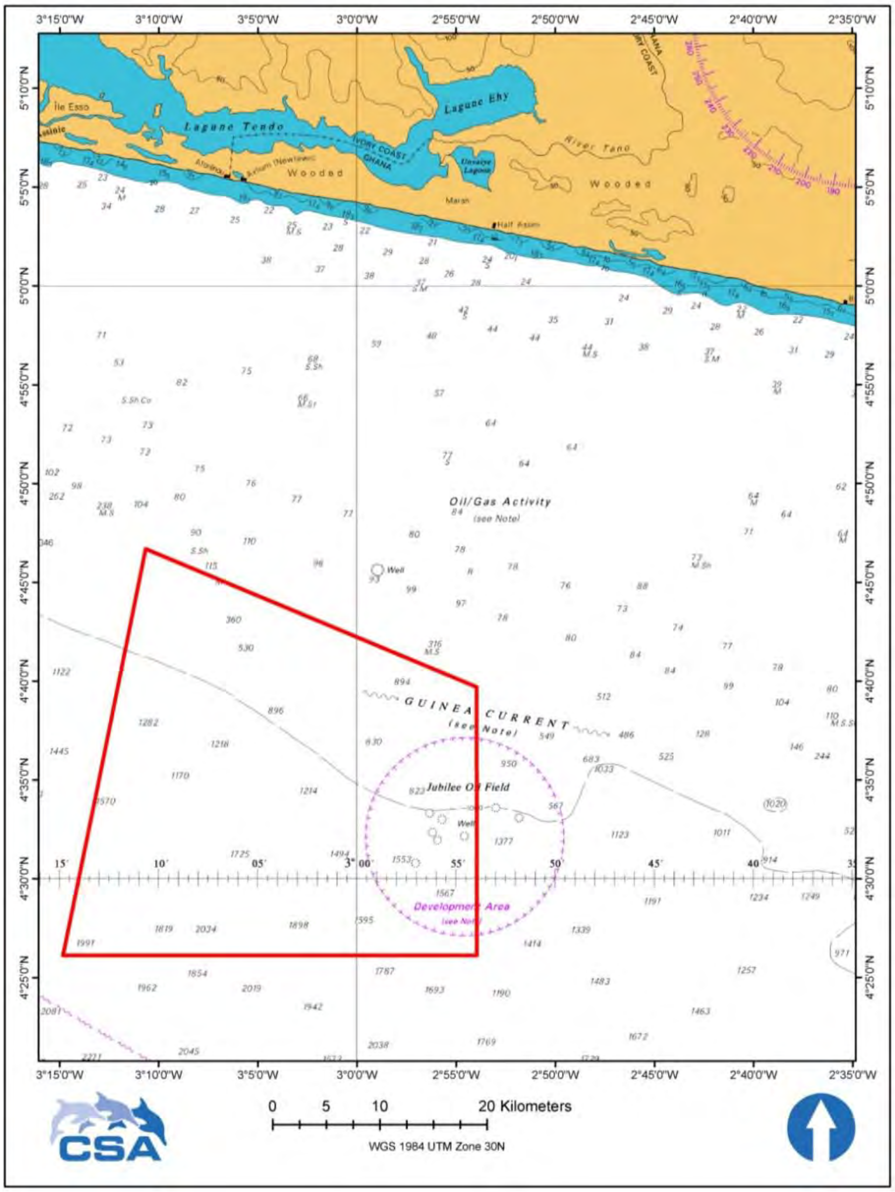



Figure 1. Location of the Deep Water Tano Block offshore Ghana shown relative to the coastline and bathymetric contours.

## 1.1 PURPOSE AND OBJECTIVE

The purpose of the TEN EBS is to provide a baseline description of existing environmental conditions within the planned development area and along the gas export pipeline route. Data collected during the TEN EBS may be used to assess and potentially monitor the effects of future operations. The objectives of the survey were to:

- Determine environmental baseline conditions (i.e., biological, chemical, and physical) prior to development operations;
- Provide baseline conditions of the environment against which effects from future operations can be compared; and
- Identify parameters within the ecosystem that may be sensitive to change and provide a reference point to evaluate future claims of impacts.

## 1.2 SURVEY DESIGN

The EBS sampling conducted in the Deep Water Tano Block TEN development area and along a designated gas export pipeline route involved the following sampling activities:

- Daily water column profiling and water collection;
- Seafloor sediment sampling at 15 sampling stations; and
- Reconnaissance seafloor plan-view imagery.

The 15 sediment and imagery sampling stations occupied during the TEN EBS include 10 stations at the deep water TEN development area (Stations 1 to 10) (hereinafter collectively referred to as the development area) and 5 stations along the shallower gas export pipeline route (Stations C1 to C5) (hereinafter collectively referred to as the pipeline route). **Figure 2** shows sampling station locations relative to well locations and depicts the local bathymetry in the area. Geographic coordinates of sampling stations provided by TGL are listed in **Table 1**.

Table 1. Geographic coordinates (WGS84) and water depth of sampling stations.

| Station | Latitude (North) | Longitude (West) | Water Depth (m) |
|---|---|---|---|
| Tweneboa, Enyenra, and Ntomme Development Area | | | |
| 1 | 4°32’13.823" | 3°11’12.898" | 1,659 |
| 2 | 4°33’26.895" | 3°09’23.441" | 1,463 |
| 3 | 4°33’08.818" | 3°08’02.302" | 1,091 |
| 4* | 4°32’02.649" | 3°05’55.510" | 1,631 |
| 5 | 4°36’09.763" | 3°07’03.734" | 1,272 |
| 6 | 4°35’27.277" | 3°08’32.930" | 1,409 |
| 7 | 4°38’02.828" | 3°08’42.929" | 1,181 |
| 8 | 4°37’13.082" | 3°07’44.316" | 1,302 |
| 9 | 4°38’08.625" | 3°06’13.887" | 1,094 |
| 10* | 4°40’32.403" | 3°08’06.851" | 997 |
| Gas Export Pipeline Route | | | |
| C1* | 4°51’16.552" | 3°05’44.158" | 77 |
| C2 | 4°48’16.448" | 3°06’21.104" | 91 |
| C3 | 4°45’58.755" | 3°06’51.019" | 341 |
| C4 | 4°44’36.261" | 3°07’06.766" | 496 |
| C5 | 4°42’48.703" | 3°07’28.978" | 807 |

* Conductivity, temperature, and depth (hydrographic) and water column sampling station.

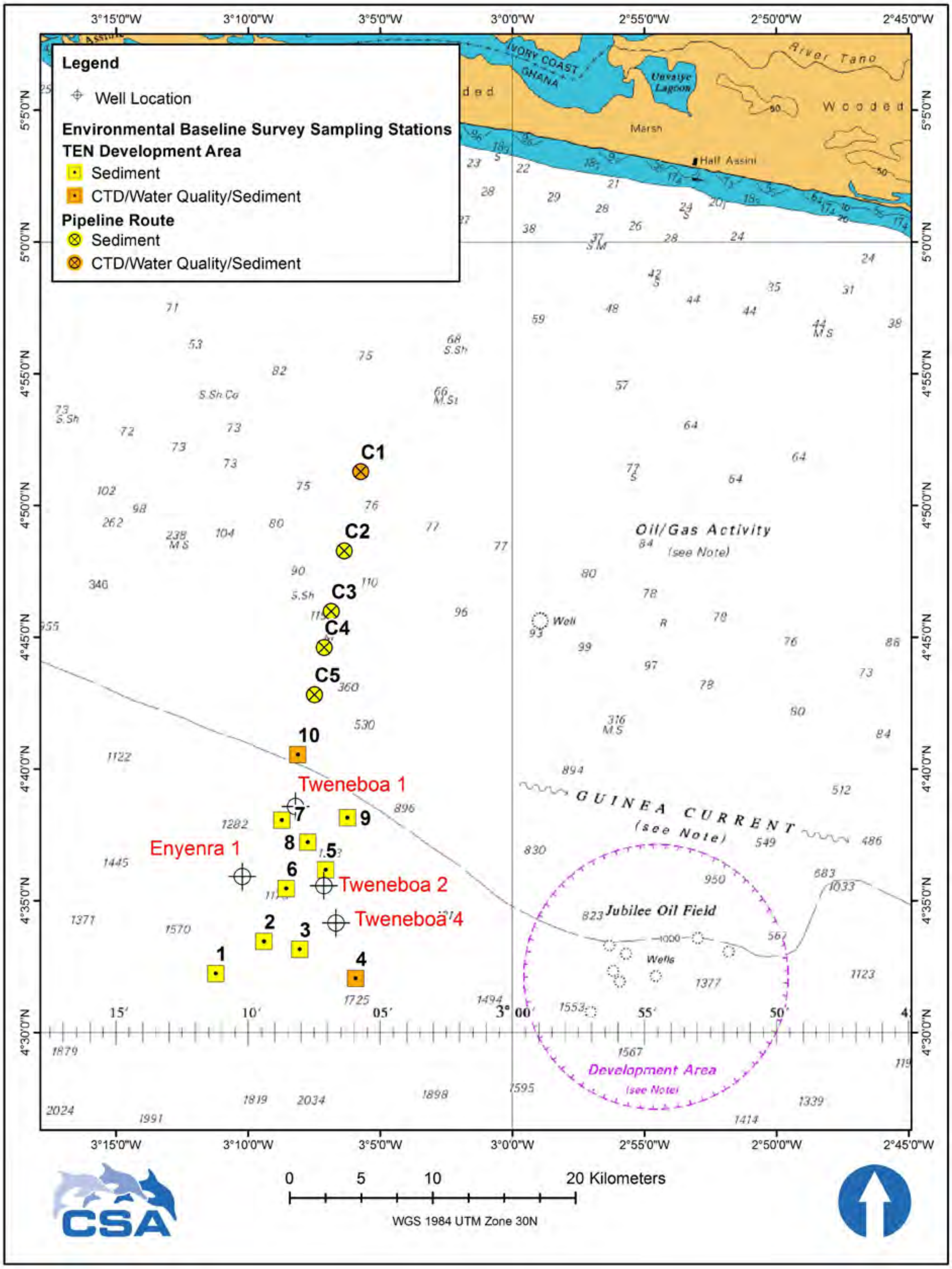



Figure 2. Sampling station locations for the TEN Environmental Baseline Survey, relative to well locations and regional bathymetry.

Sampling at the 15 EBS stations included sediment and seafloor photography. Sediment sampling was conducted to characterize chemical, physical, and biological parameters. The seafloor in the survey area was qualitatively characterized by means of photographic data acquired using an underwater camera system. The water column was sampled daily during survey operations to quantify chemical, hydrographic, and biological parameters. Quality assurance (QA)/quality control (QC) samples were collected for both water and sediment chemistry parameters.

### 1.3 REPORT ORGANIZATION

The main sections of the report are as follows:

- **1.0 Introduction** – provides an overview of the project and information about the scope and organization of the EBS report;
- **2.0 Methods** – describes field and laboratory sample and data processing and analysis methods;
- **3.0 Results** – summarizes field and analytical data from seawater and sediment samples collected in the field;
- **4.0 Discussion** – reviews and discusses study results and observed spatial patterns in datasets; and
- **5.0 Summary** – provides a synopsis of the EBS project.

Appendices provide supporting information for the EBS report. **Appendix A** identifies the specifications for the survey vessel. **Appendix B** provides clarification for cooperatively decided modifications to sampling analytes and protocols as originally defined by TGL in the Invitation to Tender (ITT) reference TGHA 02077. **Appendix C** provides survey station location information. **Appendix D** provides representative plan view camera photographs from each seabed survey station. **Appendix E** presents the hydrographic profile parameters. **Appendix F** provides a composite taxonomic listing of macroinfauna collected during the EBS. **Appendix G** contains tabular data for aliphatic hydrocarbon and polycyclic aromatic hydrocarbon fractions in sediments.

## 2.1 FIELD METHODS

### 2.1.1 Vessel Operations

The RV *J.W. Powell*, owned and operated by TDI Brooks International and based in Port Harcourt, Nigeria, was used to conduct TEN EBS field operations. Descriptive material is available from the TDI Brooks International, Inc. website and provided in **Appendix A** (http://www.tdi-bi.com/vessels/powell.htm). The survey vessel was mobilized with personnel and equipment in Takoradi, Ghana.

### 2.1.2 Required Personnel

The survey involved 24-hour operations during the field sampling effort. A four-person field survey team with two people on each 12-hour shift was required to meet Environmental, Health, and Safety (EHS) considerations. CSA provided two experienced personnel (i.e., Field Scientist and Marine Supervisor) and Germano and Associates (G&A) provided two experienced personnel to conduct seafloor photography. CSA provided three experienced personnel and ESL Consulting Limited (ESL) provided an experienced field biologist during EBS water and sediment sampling. On-board assistance during sampling operations was provided by the experienced vessel crew. An on-board TGL representative provided logistical support and assisted in-field decisions.

### 2.1.3 Navigation

Methods for accurate positioning were used during the collection of all cruise data. A modular computer software and hardware package interfaced various data collection sensors with a differential global positioning system (DGPS) receiver. All sampling locations were pre-plotted and stored in the navigation software program prior to cruise mobilization. A DGPS receiver was used to navigate the survey vessel to the sampling stations. Positional accuracy of ±50 m was targeted for sampling stations (i.e., a 50-m sampling radius was established around each station). The DGPS and vessel fathometer were connected to an on-board computer equipped with navigation and data acquisition software. An ultra-short baseline (USBL) transponder was attached to the box core and underwater camera system to record their position relative to the vessel position recorded with DGPS. Accuracy of the sampling position based on the USBL was approximately 10 to 15 m; the positional accuracy of the USBL was 2 to 3 m. Overall positional accuracy was 20 m. While in the field, the actual positions of all collected samples were recorded and stored by the navigational software program.

## 2.2 SAMPLE COLLECTION

Sample collection stations, matrices, and associated analytes for the TEN EBS were generally defined by TGL in the ITT reference TGHA 02077. The selected sampling matrices and associated analytes were selected to generally characterize baseline conditions of the environment against which effects from future oil and gas operations can be compared; and would identify physical, chemical, and biological parameters within the ecosystem that may be sensitive to change providing reference for evaluating future claims of impacts. Specific modifications concerning various sampling analytes and protocols were presented to TGL for their consideration in a CSA memorandum dated 29 December 2010. TGL provided their responses and concurrence for the various CSA-recommended sampling modifications, which are presented in **Appendix B**.

### 2.2.1 Water Column

The chemical and physical parameters of the water column were evaluated with the results obtained from water sampling and hydrographic profiling as discussed below.

*Water Sampling*

Seawater samples were collected daily from two water depths with pre-cleaned, 5-L Niskin and GO-Flo water samplers mounted on a Rosette sampler. Water samples from the deepwater development area were collected from near surface and at 100-m water depths. Water samples from the gas export pipeline route were collected from near surface and near bottom (i.e., <5 m from the seabed). Seawater sampling parameters and processing specifications are summarized in **Table 2**. Nutrient analytes for seawater samples included total nitrogen (N) and total phosphorous (P). Two sets of sample containers were prepared for each seawater sample to ensure sample security.

Table 2. Specifications for seawater sample parameters.

| Parameter/ Analyte(s) | Minimum Sample Volume (L) | Container Type and Size | Handling, Storage Conditions, and/or Preservation Method | Holding Time |
|---|---|---|---|---|
| Oil and grease | 1 | 1-L amber glass bottle | Cool to 4 °C; 20 mL $CH_2Cl_2$ | 40 d with addition of $CH_2Cl_2$ |
| Nutrients | 1 | 1-L HDPE plastic bottle | Frozen | 28 d |
| Chlorophyll *a* | 1 | Wide-mouth 1-L amber HDPE plastic bottle | Filter with GF/F filter treated with $MgCO_3$; freeze filter; ship on ice | Indefinite when filtered and frozen |

$CH_2Cl_2$ = methylene chloride/dichloromethane; GF/F = glass-fiber filter; HDPE = high-density polyethylene; $MgCO_3$ = magnesium carbonate.

The volume of all samples was 1 L. The extraction process for the oil and grease water samples was initialized using 20 mL of methylene chloride (dichloromethane; $CH_2Cl_2$). The use of sulphuric acid (pH <2) preserves oil and grease water samples and was originally proposed to extend the holding time of the sample to 28 days. Due to potential delays associated with international shipping of these samples to the analytical laboratory located in the United States, methylene chloride was used to begin organic extraction and provide contingency for shipping delays by maximizing the sample holding time to 40 days. Nutrient samples were stored frozen, similarly extending the holding time of these samples to 28 days. Chlorophyll *a* water samples were vacuum filtered through glass fiber filters and stored frozen.

*Hydrographic Profiles*

Hydrographic measurements were collected with a factory-calibrated Sea-Bird CTD SBE-19+ profiler mounted on the water collection Rosette sampler. Hydrographic parameters (**Table 3**) were measured and recorded at 0.5-sec intervals as the rosette sampler and profiler were lowered through the water column at a relatively constant speed. The water column was profiled for conductivity, temperature, and depth (CTD) daily from a depth of approximately 1 m below the sea surface continuously to approximately 1 m above the seabed.

Table 3. Hydrographic sampling parameters and measurement units.

| Parameter | Unit |
|---|---|
| Conductivity (salinity) | µS/cm (psu) |
| Temperature | ºC |
| Depth | m |
| Dissolved oxygen | mg/L |
| Turbidity | NTU |

NTU = nephelometric turbidity unit; psu = practical salinity unit; S = Siemens.

### 2.2.2 Sediment

Two sizes of stainless steel Gray O'Hara box cores were used to collect sediment samples. Sediment samples from all stations in the deep water development area and Stations C4 and C5 along the shallower gas export pipeline route in water depths >400 m were collected with a 0.5-m x 0.5-m (0.25-$m^2$) box core. Sediment samples from stations along the shallower gas export pipeline route on the continental shelf were collected with a 0.3-m x 0.3-m (0.09-$m^2$) box core. Sediment sampling equipment was deployed and retrieved with a winch and A-frame system. As each sediment sample was retrieved, it was visually examined to determine if it was acceptable for processing. Samples with evidence of sediment loss (e.g., corner "wash out"), over penetration, or insufficient sediment penetration were considered unacceptable.

Sediments were sampled and analyzed for both biological and physicochemical parameters. At development area Stations 1 through 10, a single acceptable box core was collected for sampling of both macroinfauna and physicochemical parameters. At pipeline route Stations C4 and C5 in water depths greater than >400 m, two grab samples were acquired, one to sample both the macrofauna and physicochemical parameters and one to analyze only macrofauna. Sediment sampling along the shallower gas export pipeline route (Stations C1, C2, and C3) required three grab samples for analyses, two for macrofauna and one for physicochemical parameters. The position in UTM coordinates, date, time, and water depth were recorded for each sample (individual grab); the datum and projection system for the area was WGS84, UTM Zone 30 North. Prior to processing, a digital photograph was taken of the surface of each box core sample, including an identification number indicating the station and, as appropriate, replicate.

*Macroinfauna*

Initial processing of sediment for macroinfaunal analysis was slightly different for samples collected with the larger (0.25-$m^2$) box core. The overlying water was siphoned off with flexible tubing (e.g., Tygon) to expose the sediment surface on acceptable cores. Overlying water was siphoned through a 0.5-mm sieve; filtered organisms on the sieve were included with the macroinfaunal sample. The sediment in the larger box core was partitioned with a 0.35-m x 0.35-m stainless steel insert (**Image 1**). Macroinfaunal (macrobenthos) samples were collected from the top 15 cm of the larger box core, within the 0.12 $m^2$ surface area of the insert. For stations sampled with the smaller 0.09-$m^2$ box core, the full content of the box core was used for the macroinfaunal analysis.

Sediment collected for macroinfaunal analyses was elutriated and wet-sieved on board over a 0.5-mm mesh sieve with gentle streams of seawater using a floatation (overflow barrel) technique (**Image 2**) that minimized trauma to the macroinfaunal organisms and facilitated their separation from the sediment.

Image 1. Collection of deep water development area macroinfaunal samples from an insert within the box core sample.

Image 2. Macroinfaunal sample sieving apparatus consisting of an upper holding barrel and lower spillover barrel.

The sieving procedure for each macroinfaunal sample was as follows:

1. A sieve bucket (fitted with a 0.5-mm mesh screen for consistency with previously collected data) was placed into the lower spillover barrel of the sieving apparatus and held with the sieve screen slightly below the water surface.
2. The filtered seawater hose (i.e., input hose) was placed into the upper holding barrel, and the spillover pipe was adjusted to pass directly into the sieve bucket.
3. The extracted sample slurry within the upper holding barrel was stirred by hand to suspend all sediment, macroinfauna, and debris.
4. Water flow into the upper holding barrel was adjusted so that the suspended material flowed at a steady and controllable rate onto the sieve bucket screen.
5. The sieve bucket was gently shaken to facilitate the passage of fine material through the filter screen. If the screen became clogged and the water level within the bucket rose, the input hose in the upper holding barrel was withdrawn (stopping flow) until the material was cleared. This process continued until the entire sample was transferred through the sieve bucket screen.
6. The sieved sample, containing macroinfauna, residual sediment, and debris, was transferred to a sample container(s) to be relaxed in magnesium chloride, fixed, and preserved using a 10% borax-buffered formalin solution stained with Rose Bengal dye.

Box core samples for macroinfauna were placed and stored in either 500-mL or 1-L plastic jars, depending on the sample volume. Sample jars were labeled, taped, and then properly stored aboard the vessel.

*Physicochemical Parameters*

Physical and chemical parameters included sediment granulometry (particle size analysis), total organic carbon (TOC), inorganic nutrients (total phosphorous, total nitrogen, acid-volatile sulfides [AVS]), total metals (aluminum [Al], arsenic [As], barium [Ba], cadmium [Cd], cobalt [Co], chromium [Cr], copper [Cu], iron [Fe], lead [Pb], mercury [Hg], nickel [Ni], tin [Sn], vanadium [V], and zinc [Zn]), total petroleum hydrocarbons (TPH), aliphatic hydrocarbons, and polycyclic aromatic hydrocarbons (PAHs).

All physicochemical samples, with the exception of sediment grain size, were collected from the top two centimeters of sediment; grain size samples were collected from the top 10 cm of sediment. Care was taken to ensure that sub-sampling areas did not overlap. Physicochemical sediment samples were collected from 1) the untouched sediment surrounding the stainless-steel insert while using the larger (0.25-$m^2$) box core; and 2) an individual grab sample (i.e., a separate replicate) taken with the smaller 0.09-$m^2$ box core. Processing of the sediment chemistry samples followed appropriate U.S. Environmental Protection Agency (USEPA) sampling protocols.

All samples were placed in pre-cleaned (as appropriate for specified parameters) and labeled sample containers. Samples for inorganic nutrients and metals analysis, with the exception of Hg, were stored in pre-cleaned 250-mL plastic wide-mouth jars with screw-top lids. Sediment samples for Hg and hydrocarbons analysis were stored in 250-mL glass wide-mouth jars with screw-top lids. Samples for grain size and TOC were stored in plastic bags. **Table 4** summarizes sample handling and storage requirements for sediment samples for physical and chemical parameters.

Table 4. Handling and storage requirements for sediment physical and chemical sample parameters.

| Parameter/Analyte(s) | Minimum Weight (g) | Container Type and Size | Handling, Storage, and Preservation Method | Holding Time |
|---|---|---|---|---|
| Particle size distribution; TOC | 100 | Ziploc bag | Store frozen; ship on ice | Indefinite when frozen |
| Inorganic nutrients (total, nitrogen, total phosphorus, and AVS) | 100 | 250-mL wide-mouth plastic jar | Store frozen; ship on ice | Indefinite when frozen |
| Total metals (Al, As, Ba, Cd, Co, Cr, Cu, Fe, Ni, Pb, Sn, V, and Zn) | 50 | 250-mL wide-mouth plastic jar | Store frozen; ship on ice | Indefinite when frozen |
| Total Hg | 50 | 250-mL wide-mouth glass jar | Store frozen; ship on ice | 28 d |
| Total hydrocarbons (TPH, aliphatic hydrocarbons, and PAHs) | 300 | 250-mL amber wide-mouth glass jar | Store frozen; ship on ice | 28 d |

Al = aluminum; As = arsenic; AVS = acid-volatile sulfides; Ba = barium; Cd = cadmium; Co = cobalt; Cr = chromium; Cu = copper; Fe = iron; Hg = mercury; Ni = nickel; PAH = polycyclic aromatic hydrocarbons; Pb = lead; Sn = tin; TOC = total organic carbon; TPH = total petroleum hydrocarbons; V = vanadium; and Zn = zinc.

### 2.2.3 Seabed Photography

High-quality color digital still imagery of the seabed was acquired at each station using a plan-view underwater camera. An Ocean Imaging Model DSC6000 plan-view underwater camera (PUC) system with two Ocean Imaging Model 400-37 Deep Sea Scaling lasers mounted to the camera frame was used to collect plan-view photographs of the seafloor surface. To aid in field survey efficiency, a Benthos Model 2216 Deep Sea Pinger was also attached to the camera frame; the pinger emits a 12-kHz pulse at 1-sec intervals. Pinger output was monitored on deck with a precision depth recorder; when the camera strobe discharges during each lowering, the ping rate doubles for 10 sec, signaling successful image acquisition. The PUC imagery was used to generally characterize the soft bottom substrates and associated biota.

## 2.3 QUALITY CONTROL

Field QC included equipment blanks (rinsates), sample duplicates, and data checks.

*Equipment Blanks*

After the water-sampling bottle was cleaned according to the standard operating procedure, an equipment blank was prepared by pouring deionized water through the sampling bottle and collecting the deionized water rinsate in a pre-cleaned 1-L sample container bottle that was preserved, labeled, and shipped to the laboratory in the same fashion as the other samples.

*Sample Security*

Sample duplicates (backup/redundant samples) were prepared for various sampling parameters as a sample security measure. The redundant set of samples was stored under secure, appropriate conditions (e.g., refrigerated or frozen in client warehouse or local laboratory) until it was confirmed that appropriate laboratories received the samples in good condition and analyses were successfully started and completed for the experimental sample set.

*Sea-Bird Profiler Data Check*

During or soon after a water column profile cast was completed, Sea-Bird hydrographic data were examined by a CSA scientist to ensure the collected data were within expected ranges (for the conditions at the study area) and the equipment was functioning normally.

### 2.3.1 Sample Handling and Transport

After sample collection, proper sample handling protocols were followed to ensure that valid results were obtained from the analysis of each sample. All stages of sample collection, storage, and handling were documented in a bound field logbook. All pertinent information concerning field activities and sampling was recorded in the logbook; this was one of the primary responsibilities of the Field Scientist or his designated representative.

All samples were shipped under a chain-of-custody (CoC) process. Proper CoC was maintained for all samples, and a CoC record accompanied all samples. Each person involved with sample custody was required to sign the appropriate forms and ensure that the samples were properly handled, stored, transported, and/or analyzed. Each sample had a unique identifier that could be directly tracked to the field logbook or data sheets. Labels were waterproofed by covering with clear tape to securely fasten the label to the container. Labels contained information on the sample type, station designation, and date and time of collection. Shipping containers were adequate to protect the sample and avoid breakage. Dividers were used to separate all glass containers. Containers were secured to be leak proof, avoid cross-contamination, and prevent sample loss during shipment.

Sample analysis requests/instructions were prepared by the CSA QA/QC Officer to accompany all samples shipped to the analytical laboratories. A custody seal was placed on each container (i.e., cooler) so that it could not be opened without breaking the seal. The CSA QA/QC Officer ensured and confirmed by telephone or e-mail that all samples were delivered and logged at each designated laboratory.

Samples were shipped to the appropriate laboratory for analysis as soon as possible after collection. Each sample was tracked through the CoC forms accompanying each batch of samples to their respective laboratories. Shipping was coordinated so that sample holding times were strictly followed.

### 2.3.2 Document and Data Security

Document and data security measures taken during the survey included the following:

- Job number, station, location, date, and time were indicated on all data sheets;
- Copies of completed CoC forms were requested from the respective laboratories;
- Digital field data files were regularly saved to a computer file and backed up on separate media; and
- Backup media with field data were stored and transported separately from the field computer.

## 2.4 DATA PROCESSING AND LABORATORY METHODS

### 2.4.1 Sediment and Seawater Analysis

**Table 5** provides a list of the laboratories designated for sample analysis on this project, summarizes the role(s) of each laboratory, and gives the key point of contact. Weatherford Laboratories of Houston, Texas, conducted the analyses of particle size distribution/grain size and TOC. TDI Brooks/B&B Laboratories of College Station, Texas, a research and contract laboratory with extensive experience in the analysis of organics in seawater and marine sediments, conducted the organics analyses. Columbia Analytical Services (CAS) of Kelso, Washington, a NELAP[1]-accredited contract laboratory with extensive experience analyzing seawater and marine sediments, conducted the metals, nutrient, and AVS analyses. Chesapeake Biological Laboratory of Solomons, Maryland, a research and contract marine laboratory, performed the seawater nutrient and chlorophyll *a* analyses. ESL Consulting Limited of Accra, Ghana, conducted the macroinfaunal sample analysis.

Table 5. Designated laboratories, roles, and points of contact.

| Laboratory | Responsibility | Contact |
|---|---|---|
| Weatherford Laboratories, Ltd.<br>Houston, Texas | Sediment particle size (grain size) and TOC analyses | J. Monti |
| TDI Brooks/B&B Laboratories, Inc.<br>College Station, Texas | Seawater (oil and grease) and sediment (TPH, aliphatic hydrocarbons, and PAHs) organic analyses | Dr. T. MacDonald |
| Columbia Analytical Services, Inc.<br>Kelso, Washington | Sediment total metals, nutrients, and AVS analyses | E. Wallace |
| Chesapeake Biological Laboratory<br>Nutrient Analytical Services Laboratory<br>University of Maryland<br>Solomons, Maryland | Seawater nutrients and chlorophyll *a* analyses | C. Zimmermann |
| ESL Consulting Limited<br>Accra, Ghana | Macroinfaunal analysis | A.K. Armah |

AVS = acid-volatile sulfides; PAHs = polycyclic aromatic hydrocarbons; TOC = total organic carbon; and TPH = total petroleum hydrocarbons.

[1] National Environmental Laboratory Accreditation Program

*Sediment Particle Size (Grain Size)*

Sediment grain size (particle size analysis or granulometry) was determined using a Malvern 2000 Mastersizer Laser Particle Size Analyzer (LPSA), certified yearly and calibrated before the start of analysis. Particle sizes were computed by the Mie Model for Light Scattering and summed into normal American Society for Testing and Materials (ASTM) size classes. LPSA uses Wentworth distribution classifications for 0.02- to 2,000-μm size classes.

*Total Organic Carbon*

To analyze TOC between 20.0 and 200.0 mg, the sample was weighed into a Pyrex beaker and treated with hydrochloric acid (HCl) to dissolve carbonates. The remaining sample was filtered, rinsed to remove residual acid, transferred to a LECO crucible, and dried. An accelerator was added and the sample combusted in a LECO model C230 combustion furnace. Carbon dioxide ($CO_2$) generated by the combustion of organic matter in the sample was quantitatively measured using an infrared detector. The quantity of organic matter in a sediment sample is expressed as percent TOC.

*Hydrocarbons*

Hydrocarbon components were analyzed for both sediments and seawater. Analytical methods for sediment hydrocarbon analytes (i.e., TPH, aliphatic hydrocarbons, and PAHs) are presented in **Table 6**.

Table 6. Analytical methods for sediment hydrocarbon analytes.

| Hydrocarbon Component | Methodology |
|---|---|
| Total petroleum hydrocarbons | USEPA Methods 1664/8100/8015 (solvent extraction; GC-FID) |
| Aliphatic hydrocarbons | |
| Polycyclic aromatic hydrocarbons | USEPA Method 8100 (GC-MS) |

GC-FID = gas chromatography flame ionization detector; GC-MS = gas chromatography mass spectrometry; USEPA = U.S. Environmental Protection Agency.

Oil and grease (O&G) in seawater was determined as extractable organic matter (EOM) using modification of USEPA Method 1664A with solvent extraction.

*Nutrients*

Sediment nutrient analyses included total nitrogen and phosphorus. Total nitrogen was determined by the macro-Kjedahl digestion method (ASTM D1426-93B Modified). To determine total phosphorus, samples were acid digested and phosphorus determined by the molybdo-phosphoric blue colorimetric method (USEPA Method 365.3M).

Seawater total nitrogen and phosphorous were determined by the persulfate digestion and automated wet chemistry (colorimetric) methods. The persulfate oxidation for nitrogen and phosphorus under initially alkaline conditions results in nitrate as the sole nitrogen product. Phosphate is the sole phosphorus product after acidic conditions are achieved following further autodecomposition of the persulfate in the heated oxidation tube. To determine total nitrogen, digested samples were passed through a granulated copper-cadmium column to reduce nitrate to nitrite. Nitrate then was determined by the diazo colorimetric method. The nitrite then is determined by diazotizing with sulfanilamide and coupling with N-1- naphthylethylenediamine dihydrochloride to form a colored azo dye. Color is proportional to nitrogen concentration. Total phosphorus in the digested sample was determined by the molybdo-phosphoric blue colorimetric method. Ammonium molybdate and antimony potassium tartrate react in an acid medium with dilute solutions of phosphorus to form an antimony-phospho-molybdate complex that is reduced to an intensely blue-colored complex by ascorbic acid. Color is proportional to phosphorus concentration.

*Sulfides*

Acid-volatile sulfides were determined from sediment treated with cold hydrochloric acid. The evolved $H_2S$ gas from the sediment and acid mixture was captured and analyzed with a gas chromatograph to determine the AVS present.

*Total Recoverable Metals*

Sediment metal analysis for Al, Ba, and Fe was conducted on digested sediments (USEPA Method 3050B) using inductively coupled plasma (ICP) optical emission spectroscopy (ICP-OES/EPA Method 200.7). ICP mass spectrometry analysis (USEPA Methods 200.8) was used to analyze As, Cd, Co, Cr, Cu, Ni, Pb, Sn, V, and Zn concentrations. Analysis of mercury concentrations in sediments was conducted using cold vapor atomic absorption spectrophotometry (USEPA Method 7471A).

*Chlorophyll a*

Chlorophyll *a* was determined using 90% acetone extraction with fluorometric measurement. Chlorophyll was concentrated by filtering through a glass fiber filter; the pigments on the filter were extracted in acetone. Fluorescence is proportional to chlorophyll concentration. Fluorescence of the extract was measured before and after acidification using a fluorometer to determine of phaeophytin concentrations.

*Macroinfauna*

Replicate samples collected along the gas export pipeline route were analyzed separately for faunal identification. Biological material from formalin-preserved samples was picked out from the remaining coarse sediment and shell matter. A method of coarse elutriation was used when needed to aid the sorting process by allowing the removal of light faunal material such as polychaetes and crustaceans from the residual fraction containing heavier organisms such as molluscs and echinoderms. To increase sorting efficiency, fine material was sorted with the aid of a low-power (6x magnification) binocular microscope.

Where possible, all organisms from each sample were identified to species level. The abundance of each taxon was recorded; partial specimens were included in counts only if the head of the organism was present. Juveniles were recorded separately because they may introduce a seasonal bias. An in-house reference collection has been maintained to enable checking and verification of taxonomic identifications.

### 2.4.2 Hydrographic Profiles

Digital data files from hydrographic casts taken with the Sea-Bird SBE19+ CTD profiler were processed by a CSA technician using Sea-Bird Data Processing software. The SBE Data, Loop Edit, and Bin Average Modules were used to convert the data from the raw hexadecimal format to engineering units in a text file, extract the downcast section, remove any loops in the record, smooth the data, and import the file into a spreadsheet. Hydrographic profile graphics and a tabular listing of hydrographic data were generated from the spreadsheet.

### 2.4.3 Seabed Photography

The plan-view images were reviewed to provide information about the landscape ecology and sediment characteristics (e.g., texture and local topography) at each sampling station. The scale information provided by the underwater lasers enables accurate density counts (i.e., number per square meter) of epibiota and sediment features (e.g., burrow openings) that may be observed in the photographs. This photographic information can be used to generally discern spatial heterogeneity of both sediment type and associated biota within the survey area.

### 2.4.4 Data Analysis

Statistical analysis of the macroinfauna data was conducted with PRIMER v6 software (Clarke and Gorley, 2006). Pattern analysis was conducted using the CLUSTER and multidimensional scaling (MDS) routines. Densities were standardized to 1 $m^2$ because the macroinfaunal samples were collected with two different box corers. The macroinfaunal density data were transformed using log (x+1), and the Bray Curtis similarity measure was used to compute similarities between individual samples. The dominant species that were primarily responsible for the similarities among the samples in the individual cluster analysis groupings were identified with the SIMPER routine.

Statistical analysis of the faunal data included:

- Shannon-Weiner Diversity Index;
- Simpson's Diversity Index;
- Pielou Evenness Index;
- Cluster analysis; and
- Multidimensional scaling.

Other analyses were performed to establish relationships between community composition and environmental variables (e.g., sediments). The BEST routine was used to examine the relationship between the macroinfaunal assemblage patterns and the environmental parameters, which were square-root transformed and normalized.

## 3.1 HYDROGRAPHIC DATA

Summary data for the hydrographic profiles are presented as 50-m bin averaged values for Stations 4 and 10, and 10-m bin-averaged values for Station C1 in **Table 7**. A complete listing of the 1-m bin averaged values for each profile is provided in **Appendix E**. A description of the water column profiles is provided in **Section 4.2**.

Table 7. 50-m and 10-m bin averaged values of water column parameters for Stations 4, 10, and C1 sampled from 26 through 28 March 2011.

| Depth (m) | Temperature (°C) | Conductivity (mS/cm) | Salinity (psu) | Oxygen (mg/L) | Oxygen (% saturation) |
|---|---|---|---|---|---|
| Station 4 (Data Collected 26 March 2011) | | | | | |
| 50 | 21.05 | 49.92 | 35.73 | 5.06 | 70.64 |
| 100 | 17.39 | 46.23 | 35.78 | 3.52 | 45.60 |
| 150 | 16.05 | 44.77 | 35.66 | 3.34 | 42.04 |
| 200 | 14.81 | 43.37 | 35.51 | 2.72 | 33.48 |
| 250 | 12.63 | 40.97 | 35.23 | 1.79 | 21.05 |
| 300 | 10.58 | 38.78 | 35.01 | 1.80 | 20.15 |
| 350 | 9.54 | 37.71 | 34.89 | 2.10 | 22.99 |
| 400 | 8.76 | 36.92 | 34.81 | 2.42 | 26.08 |
| 450 | 7.96 | 36.13 | 34.73 | 2.68 | 28.38 |
| 500 | 7.51 | 35.70 | 34.69 | 2.72 | 28.45 |
| 550 | 6.86 | 35.07 | 34.63 | 3.09 | 31.88 |
| 600 | 6.38 | 34.63 | 34.60 | 3.34 | 33.99 |
| 650 | 5.81 | 34.11 | 34.57 | 3.67 | 36.93 |
| 700 | 5.48 | 33.82 | 34.55 | 3.92 | 39.14 |
| 750 | 5.29 | 33.66 | 34.55 | 4.09 | 40.58 |
| 800 | 5.05 | 33.48 | 34.55 | 4.27 | 42.20 |
| 850 | 4.89 | 33.36 | 34.57 | 4.41 | 43.42 |
| 900 | 4.81 | 33.33 | 34.58 | 4.49 | 44.09 |
| 950 | 4.70 | 33.28 | 34.61 | 4.61 | 45.20 |
| 1,000 | 4.64 | 33.27 | 34.64 | 4.76 | 46.62 |
| 1,050 | 4.58 | 33.27 | 34.67 | 4.90 | 47.92 |
| 1,100 | 4.54 | 33.29 | 34.71 | 5.10 | 49.83 |
| 1,150 | 4.51 | 33.32 | 34.75 | 5.31 | 51.87 |
| 1,200 | 4.48 | 33.35 | 34.80 | 5.62 | 54.83 |
| 1,250 | 4.44 | 33.37 | 34.84 | 5.89 | 57.44 |
| 1,300 | 4.39 | 33.37 | 34.87 | 6.14 | 59.85 |
| 1,350 | 4.31 | 33.35 | 34.90 | 6.45 | 62.69 |
| 1,400 | 4.25 | 33.33 | 34.92 | 6.62 | 64.26 |
| 1,450 | 4.20 | 33.31 | 34.93 | 6.75 | 65.52 |
| 1,500 | 4.15 | 33.30 | 34.94 | 6.89 | 66.73 |
| Station 10 (Data Collected 27 March 2011) | | | | | |
| 50 | 20.08 | 48.90 | 35.71 | 4.60 | 63.38 |
| 100 | 16.39 | 45.14 | 35.71 | 3.36 | 42.57 |
| 150 | 15.54 | 44.19 | 35.61 | 3.05 | 38.06 |
| 200 | 14.45 | 42.97 | 35.46 | 2.37 | 28.90 |

Table 7. (Continued).

| Depth (m) | Temperature (°C) | Conductivity (mS/cm) | Salinity (psu) | Oxygen (mg/L) | Oxygen (% saturation) |
|---|---|---|---|---|---|
| 250 | 12.98 | 41.36 | 35.28 | 1.82 | 21.52 |
| 300 | 10.85 | 39.07 | 35.04 | 1.74 | 19.69 |
| 350 | 9.79 | 37.97 | 34.92 | 1.95 | 21.46 |
| 400 | 8.98 | 37.15 | 34.83 | 2.47 | 26.68 |
| 450 | 8.21 | 36.38 | 34.75 | 2.65 | 28.23 |
| 500 | 7.49 | 35.68 | 34.69 | 2.77 | 28.98 |
| 550 | 6.88 | 35.09 | 34.64 | 3.12 | 32.19 |
| 600 | 6.50 | 34.75 | 34.61 | 3.28 | 33.56 |
| 650 | 5.95 | 34.24 | 34.58 | 3.57 | 36.06 |
| 700 | 5.44 | 33.77 | 34.55 | 3.95 | 39.38 |
| 750 | 5.20 | 33.58 | 34.55 | 4.15 | 41.14 |
| 800 | 5.03 | 33.47 | 34.56 | 4.29 | 42.30 |
| 850 | 4.91 | 33.38 | 34.57 | 4.39 | 43.22 |
| 900 | 4.80 | 33.32 | 34.59 | 4.52 | 44.38 |
| 950 | 4.75 | 33.31 | 34.60 | 4.57 | 44.84 |
| 1,000 | 4.72 | 33.32 | 34.62 | 4.62 | 45.30 |
| Station C1 (Data Collected 28 March 2011) | | | | | |
| 10 | 28.47 | 57.09 | 35.25 | 6.52 | 102.12 |
| 20 | 27.38 | 56.03 | 35.32 | 6.56 | 100.99 |
| 30 | 22.92 | 51.65 | 35.57 | 5.99 | 85.64 |
| 40 | 20.86 | 49.69 | 35.70 | 4.98 | 68.75 |
| 50 | 19.25 | 48.14 | 35.80 | 3.93 | 52.63 |
| 60 | 18.49 | 47.38 | 35.82 | 3.65 | 48.23 |
| 70 | 18.01 | 46.88 | 35.81 | 3.35 | 43.81 |

psu = practical salinity unit; S = Siemens.

## 3.2 WATER COLUMN DATA

Results of the water column sampling for nutrients and chlorophyll conducted at three TEN locations sampled from 26 through 28 March 2011 are listed in **Table 8**. Water samples were collected at near surface and 100-m depths at Stations 4 and 10; near surface and near bottom samples were collected at Station C1. Total nitrogen and phosphorus were present in all samples with minor differences among samples from the same water depth at the three stations. Differences in total nitrogen and total phosphorus were more evident among samples collected at different depths. At each station, there was much higher total nitrogen and total phosphorus in samples from deeper levels (<0.24 to 0.40 total nitrogen and 0.0335 to 0.0545 mg/L total P) than from near surface samples (<0.15 to 0.22 total nitrogen and 0.0141 to 0.0161 mg/L total P) (i.e., 100-m or near bottom values vs. near surface values). There were no apparent differences in chlorophyll and phaeophytin values between Stations 10 and C1. The differences in nutrients between near surface and at depth can be attributed to differences in productivity and organic mineralization. At the near surface, photosynthesis will be active, resulting in uptake of nutrients, depressing total nitrogen and total phosphorus in the water column. At depth (100 m at Stations 4 and 10, or 77 m near bottom at C1), organic mineralization will be greater, resulting in higher total nitrogen and P. The lack of differences in chlorophyll and phaeophytin among stations suggest that the near surface water columns among the three stations likely have the same water mass.

Table 8. Total nitrogen, total phosphorus, chlorophyll (total and active), and phaeophytin for Stations 4, 10, and C1 sampled from 26 to 28 March 2011.

| Station | Level | Total Nitrogen (mg/L) | Total Phosphorus (mg/L) | Total Chlorophyll (µg/L) | Active Chlorophyll (µg/L) | Phaeophytin (µg/L) |
|---|---|---|---|---|---|---|
| 4 | Near surface | 0.15 | 0.0141 | -- | -- | -- |
| | 100 m | 0.40 | 0.0525 | -- | -- | -- |
| 10 | Near surface | 0.22 | 0.0144 | 0.68* | 0.56* | 0.29* |
| | 100 m | 0.40 | 0.0545 | 0.68* | 0.56* | 0.29* |
| C1 | Near surface | 0.15 | 0.0161 | 0.68 | 0.56* | 0.30 |
| | Near bottom | 0.24 | 0.0335 | 0.68* | 0.48 | 0.29* |

* detection limit; "-- = not sampled.

Hydrocarbon data for water column samples are not available because of sample contamination. Methylene chloride used for preservation and extraction was sourced locally in Ghana, and was likely contaminated with hydrocarbons. Elevated hydrocarbons were present in both ambient samples and blanks prepared for QC. Efforts to procure and analyze a sample of the solvent used for sample preservation were unsuccessful due to international shipping difficulties. Water column data from previous surveys are discussed in **Section 4.3** to provide reference concerning regional water column hydrocarbon concentrations.

## 3.3 SEDIMENT GRAIN SIZE

Results of sediment grain size analysis (particle distribution) are presented in **Table 9**. Based on Folk's classification, sediment samples from the development area stations and the most seaward and deepest of the pipeline route stations are primarily clayey silt while the sediment from four of the pipeline route stations are silty sand. **Figure 3** is a ternary diagram depicting the relative proportions of the primary sediment components from the various sampling stations (development area and pipeline route).

Table 9. Total organic carbon (TOC) content and grain size distribution of sediment samples.

| Station | TOC (%) | Sand (%) | Silt (%) | Clay (%) | Classification |
|---|---|---|---|---|---|
| Development Area | | | | | |
| 1 | 2.431 | 1.0 | 78.0 | 21.0 | Clayey silt |
| 2 | 2.546 | 1.4 | 75.2 | 23.4 | Clayey silt |
| 3 | 2.789 | 1.6 | 75.7 | 22.7 | Clayey silt |
| 4 | 2.326 | 0.7 | 74.3 | 25.0 | Clayey silt |
| 5 | 2.689 | 1.3 | 77.6 | 21.0 | Clayey silt |
| 6 | 2.565 | 1.5 | 78.4 | 20.2 | Clayey silt |
| 7 | 2.457 | 1.9 | 75.4 | 22.7 | Clayey silt |
| 8 | 2.523 | 3.6 | 68.3 | 28.1 | Clayey silt |
| 9 | 2.612 | 2.3 | 77.5 | 20.3 | Clayey silt |
| 10 | 2.546 | 3.5 | 76.3 | 20.2 | Clayey silt |
| Pipeline Route | | | | | |
| C1 | 0.988 | 53.5 | 36.9 | 9.6 | Silty sand |
| C2 | 0.820 | 58.0 | 32.2 | 9.8 | Silty sand |
| C3 | 1.178 | 49.8 | 34.3 | 15.9 | Silty sand |
| C4 | 2.016 | 26.9 | 57.1 | 16.0 | Silty sand |
| C5 | 2.553 | 4.6 | 77.1 | 18.3 | Clayey silt |

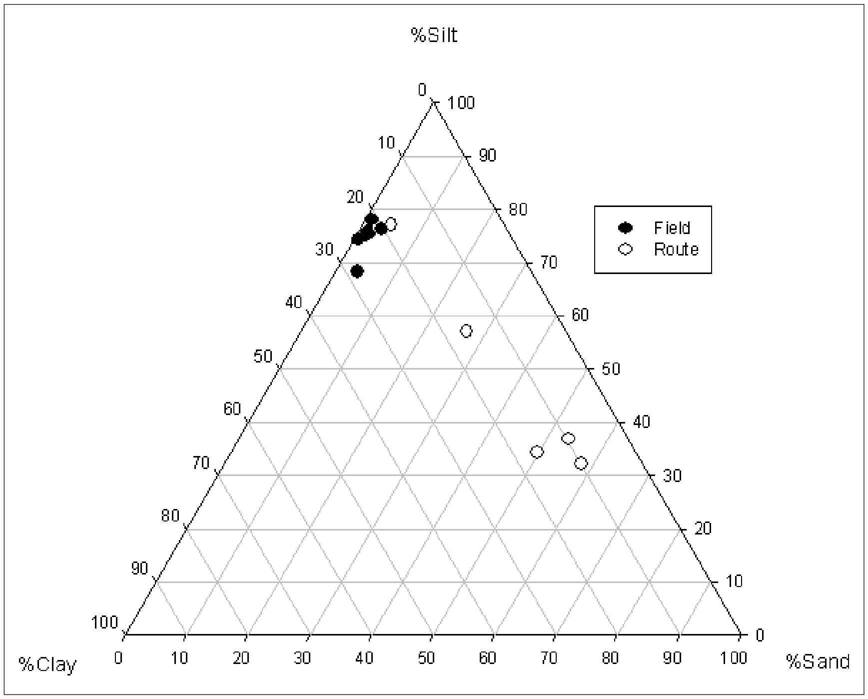



Figure 3. Ternary diagram of sediment grain size for development area (field) and pipeline route (route) samples.

## 3.4 TOTAL ORGANIC CARBON

The differences in grain size distribution between sediment samples collected from stations in the development area and along the pipeline route are also reflected in the differences in TOC concentrations. **Table 9** lists TOC concentrations in sediment samples from all stations. Lower and more variable TOC concentrations are associated with sandier sediments collected at shallower stations located on the shelf. TOC concentrations of samples collected from the pipeline route (Stations C1 to C5) ranged from 0.8% to 2.6%, with an average of 1.3%. TOC concentrations of samples collected from the deeper development area (Stations 1 to 10) ranged from 2.3% to 2.8%, with an average TOC of 2.5%.

## 3.5 ORGANICS

Results of sediment TPH analyses are provided in **Table 10**. Extractable organic matter (EOM) is reported along with TPH and is an operationally defined parameter that is equivalent to, or an index of, oil and grease content. Sediment EOM concentrations were generally higher at the development area stations than at the pipeline route stations. Development area EOM concentrations ranged from 216 to 296 µg/g (µg/g is parts per million [ppm]) with an average of 251 µg/g, while the pipeline route sediment sample EOM concentrations ranged from 102 to 351 µg/g, with an average of 200 µg/g. EOM values for pipeline route stations were more variable than the development area stations. The highest EOM values recorded were at Stations 10 and C5.

Table 10. Total petroleum hydrocarbons and extractable organic matter (µg/g) in sediment samples collected from 26 to 28 March 2011.

| Station | Total Petroleum Hydrocarbons (µg/g) | Total Resolved Hydrocarbons (µg/g) | Unresolved Complex Mixture | Extractable Organic Matter (µg/g) |
|---|---|---|---|---|
| Development Area | | | | |
| 1 | 65 | 32 | 33 | 224 |
| 2 | 53 | 32 | 21 | 251 |
| 3 | 42 | 25 | 17 | 249 |
| 4 | 30 | 19 | 10 | 240 |
| 5 | 38 | 23 | 15 | 253 |
| 6 | 37 | 25 | 12 | 248 |
| 7 | 36 | 22 | 14 | 275 |
| 8 | 40 | 32 | 9 | 260 |
| 9 | 35 | 29 | 7 | 216 |
| 10 | 49 | 32 | 17 | 296 |
| Average | 42 | 27 | 16 | 251 |
| Range | 30–65 | 19–32 | 7–33 | 216–296 |
| Pipeline Route | | | | |
| C1 | 24 | 15 | 10 | 114 |
| C2 | 23 | 13 | 10 | 102 |
| C3 | 34 | 22 | 12 | 226 |
| C4 | 43 | 27 | 16 | 208 |
| C5 | 54 | 34 | 20 | 351 |
| Average | 36 | 22 | 14 | 200 |
| Range | 23–54 | 13–34 | 10–20 | 102–351 |

Similar differences between development area and pipeline route stations were observed in sediment TPH concentrations. TPH concentrations at development area stations ranged from 30 to 65 µg/g (average of 42 µg/g) and were generally higher than concentrations observed at pipeline route stations which ranged from 23 to 54 µg/g (average of 36 µg/g). There are no defined standards or guidelines for TPH and EOM/total oil and grease levels in marine sediment. The lack of defined standards for hydrocarbons is related to difficulties associated with developing standards for parameters that are operationally defined and vary depending on location, anthropogenic activities, natural seeps of hydrocarbons, and, where applicable, the nature or composition of the hydrocarbons.

Total aliphatic hydrocarbons and PAHs detected in samples collected during the TEN EBS are provided in **Table 11**. Reflecting sediment TPH levels, total aliphatic hydrocarbon concentrations were generally higher at development area stations (average of 4 µg/g) than at pipeline route stations (average of 2 µg/g). The highest total aliphatic hydrocarbon concentrations were in sediment samples collected at Stations 1 and 2 in the development area and Station C5 along the pipeline route. The highest total PAH concentrations were in sediment samples collected at Station 1 and 2. The average total PAH values were correspondingly higher at development area stations (average of 504 ng/g, range of 161 to 2,111 ng/g) compared with the shallower pipeline route stations (average of 160 ng/g, range of 50 to 346 ng/g). The complete listing of aliphatics and PAHs are provided in **Appendix G**.

Table 11. Total polycyclic aromatic petroleum hydrocarbons in sediment samples collected from 26 to 28 March 2011.

| Station | Total Aliphatic Hydrocarbons (µg/g) | Total PAHs (ng/g) |
|---|---|---|
| Development Area | | |
| 1 | 5.7 | 2,111 |
| 2 | 6.7 | 1,211 |
| 3 | 3.6 | 161 |
| 4 | 2.9 | 239 |
| 5 | 3.3 | 225 |
| 6 | 3.4 | 207 |
| 7 | 3.0 | 169 |
| 8 | 3.4 | 274 |
| 9 | 3.3 | 230 |
| 10 | 4.0 | 213 |
| Average | 4 | 504 |
| Range | 3–7 | 161–2,111 |
| Pipeline Route | | |
| C1 | 1.4 | 49.6 |
| C2 | 1.5 | 113 |
| C3 | 2.4 | 65.8 |
| C4 | 3.0 | 227 |
| C5 | 4.2 | 346 |
| Average | 2 | 160 |
| Range | 1–4 | 50–346 |

## 3.6 METALS

**Table 12** summarizes metals concentrations in sediment samples collected during the TEN EBS relative to values for average marine sediments and continental crust. Because sediment samples collected in the offshore stations consisted primarily of silt (see **Section 3.3**), most metals concentrations in these sediments were generally higher than or comparable with values typically reported for average marine sediments (Salomons and Förstner, 1984). Average seafloor sediments generally consist of a mixture of abundant aluminosilicate clays and iron oxides, with minimal amounts of calcium carbonate and quartz sand, the latter of which tend to be depleted in metal levels, thereby diluting the amount of aluminosilicate clay.

Aluminum concentrations were generally high with an average of 85,830 mg/kg (mg/kg = ppm) in the offshore development area samples collected near the previously drilled wellsites (previous wellsites). Concentrations of aluminum at the pipeline route stations were generally low (average of 38,960 mg/kg). Sediment aluminum concentrations from 6 of the 10 development area stations were above average marine sediment and continental crust reference values. Aluminum concentrations in sediment from pipeline route stations were, in general, below average marine sediment and continental crust reference values.

Table 12. Total metals concentrations in sediment samples collected during the TEN Environmental Baseline Survey (mg/kg dry weight), with comparisons to average marine sediments (Salomons and Förstner, 1984) and continental crust (Wedepohl, 1995) values.

| Station | Water Depth (m) | Aluminum | Arsenic | Barium | Cadmium | Cobalt | Chromium | Copper | Iron | Mercury | Nickel | Lead | Tin | Vanadium | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Development Area | | | | | | | | | | | | | | | |
| 1 | 1,659 | 74,000 | 7.2 | 753 | 0.19 | 9.18 | 54.1 | 25.5 | 36,600 | 0.07 | 42.5 | 13.2 | 1.29 | 51.2 | 61.2 |
| 2 | 1,463 | 66,200 | 7.9 | 550 | 0.23 | 8.61 | 53.2 | 23.6 | 34,100 | 0.06 | 38.5 | 12.4 | 1.02 | 50.2 | 57.7 |
| 3 | 1,091 | 69,300 | 5.8 | 594 | 0.21 | 5.98 | 45.4 | 16.5 | 36,200 | 0.06 | 28.7 | 8.11 | 0.715 | 35.5 | 45 |
| 4 | 1,631 | 154,000 | 7.1 | 887 | 0.44 | 13.6 | 114 | 40.5 | 74,500 | 0.08 | 65.1 | 15.4 | 1.63 | 113 | 96.9 |
| 5 | 1,272 | 80,500 | 8.4 | 599 | 0.22 | 8.42 | 55.4 | 22 | 40,300 | 0.07 | 36.5 | 11.6 | 0.983 | 47.8 | 57.6 |
| 6 | 1,409 | 88,300 | 8.3 | 695 | 0.22 | 8.72 | 54.9 | 23.3 | 46,800 | 0.1 | 38.8 | 12.2 | 1.04 | 49.7 | 57.9 |
| 7 | 1,181 | 95,100 | 8.5 | 658 | 0.22 | 8.58 | 60 | 22.7 | 48,300 | 0.07 | 38.7 | 12 | 1.08 | 50.6 | 61.3 |
| 8 | 1,302 | 71,000 | 5.8 | 444 | 0.14 | 6.2 | 40.6 | 14.5 | 41,100 | 0.07 | 25.7 | 7.56 | 0.736 | 33.1 | 41.2 |
| 9 | 1,094 | 79,900 | 7.9 | 670 | 0.24 | 7.8 | 55.9 | 20.4 | 43,700 | 0.07 | 34.8 | 10.7 | 0.964 | 44.7 | 56.2 |
| 10 | 997 | 80,000 | 13.1 | 469 | 0.22 | 7.82 | 55.9 | 19.8 | 44,800 | 0.07 | 36.3 | 10.7 | 0.946 | 43 | 55.1 |
| Average | | **85,830** | **8.0** | **631.9** | **0.233** | **8.491** | **58.94** | **22.88** | **44,640** | **0.072** | **38.56** | **11.387** | **1.0404** | **51.88** | **59.01** |
| Range | | **66,200–154,000** | 5.8–13.1 | **444–887** | **0.14–0.44** | **5.98–13.6** | **40.6–114** | **14.5–40.5** | **34,100–74,500** | 0.06–0.1 | **25.7–65.1** | **7.56–15.4** | **0.715–1.63** | **33.1–113** | **41.2–96.9** |
| | | | | | | | | | | | | | | | |
| Pipeline Route | | | | | | | | | | | | | | | |
| C1 | 77 | 20,000 | 8.6 | 67 | 0.1 | 3.18 | 34 | 3.7 | 31,800 | ND | 12.2 | 4.12 | 0.257 | 18.7 | 23.3 |
| C2 | 91 | 15,400 | 7.1 | 53.1 | 0.17 | 2.6 | 29.6 | 3.5 | 22,400 | ND | 11.5 | 2.9 | 0.229 | 15.2 | 19.6 |
| C3 | 341 | 33,400 | 14.7 | 105 | 0.14 | 5.25 | 69.5 | 5.2 | 64,900 | 0.02 | 17 | 4.44 | 0.505 | 29.9 | 43 |
| C4 | 496 | 47,500 | 6.5 | 202 | 0.17 | 5 | 49.3 | 8.4 | 39,700 | 0.04 | 20.5 | 5.1 | 0.512 | 25.1 | 38.3 |
| C5 | 807 | 78,500 | 5.8 | 384 | 0.27 | 5.34 | 49.1 | 15.6 | 40,600 | 0.07 | 30.3 | 7.7 | 0.685 | 36.5 | 45.7 |
| Average | | 38,960 | 8.54 | 162.22 | 0.17 | 4.274 | 46.3 | 7.28 | 39,880 | 0.043 | 18.3 | 4.852 | 0.4376 | 25.08 | 33.98 |
| Range | | 15,400–78,500 | 5.8–14.7 | 53.1–384 | 0.1–0.27 | 2.6–5.34 | 29.6–69.5 | 3.5–15.6 | 22,400–64,900 | 0.02–0.07 | 11.5–30.3 | 2.9–7.7 | 0.229–0.685 | 15.2–36.5 | 19.6–45.7 |
| Average marine sediments | | ***72,000*** | ***7.7*** | ***460*** | ***0.17*** | ***3–6**** | ***72.0*** | ***33*** | ***41,000*** | 0.190 | ***52*** | 19.0 | NA | ***20–***150** | ***95*** |
| Continental crust | | ***79,600*** | ***1.7*** | ***584*** | ***0.1*** | 24 | 126.0 | ***25*** | ***44,300*** | ***0.040*** | ***56*** | 14.8 | 2.3 | 98 | ***65*** |

* Atlantic Ocean sediment from Hamilton (1998).
** Vanadium in "typical sediments" in Moore (1991).
**BOLD** = Metals concentrations in development area stations relatively higher than inshore pipeline route stations.
**BOLD** and ***ITALIC*** = At least one metal concentration for development area stations exceeded the reference values for average marine sediments and continental crust.

Metals with potential environmental impacts or considered to be priority pollutants include arsenic, cobalt, chromium, copper, lead, nickel, tin, and zinc. Tin is not a priority pollutant metal, but it has been associated with environmental impacts from the use of tributyl tin (TBT) in antifouling paint on ship hulls.

Concentrations of arsenic were generally high for both deep water development area and shallower pipeline route stations with averages of 8.0 and 8.54 mg/kg, respectively. For both sample groups, arsenic levels were considerably higher than continental crust values and only slightly elevated above the average marine sediment reference value of 7.7 mg/kg.

Cobalt, chromium, copper, lead, nickel, tin, and zinc concentrations in sediment from stations at both the development area and pipeline route area were within the expected ranges based on the reference values provided for average marine sediments and continental crust for these analytes, with minor exception. Nickel and zinc concentrations at development area Station 4 exceeded average marine sediment and continental crust reference values. Levels of cobalt, chromium, copper, lead, nickel, and tin were higher in development area stations than in the pipeline route stations.

Barium is a primary component of barite-based drilling fluids employed in oil and gas exploration and development drilling operations. Barium concentrations in the development area samples were generally high (average of 631.9 mg/kg), which is typical of sediments found near wellsites where barium-related drilling discharges have occurred. Barium concentrations in 7 of the 10 development area stations were higher than average marine sediment and continental crust reference values. In contrast, barium levels were relatively low in pipeline route samples (average of 162.22 mg/kg); along the pipeline corridor, barium concentrations at all stations were below average marine sediment and continental crust reference values.

Cadmium and mercury are two heavy metals that are a concern because of their potential environmental impacts. The International Finance Corporation (IFC) provides environmental guidelines for offshore oil and gas activities that include maximum cadmium (<3 mg/kg) and mercury (<1 mg/kg) content in barite used for offshore drilling. Concentrations of cadmium in development area samples were generally high (average of 0.233 mg/kg) while concentrations in pipeline route samples (with the exception of the deepest station, C5) were comparable (average of 0.17 mg/kg) to levels normally found in average marine sediments. Nine of the 10 development area stations had sediment cadmium concentrations above reference values for average marine sediments and continental crust. Concentrations of mercury were low for both development area and pipeline route stations (averages of 0.072 and 0.043 mg/kg, respectively) and were in the expected range for typical marine sediments.

Vanadium is not a priority pollutant but is usually associated with oil and gas activities. Vanadium concentrations in sediments were considerably higher from development area stations than from pipeline route stations with averages of 51.88 and 25.08 mg/kg, respectively. Vanadium levels in sediment from all stations are consistent with expected ranges based on the reference values provided for average marine sediments for this analyte.

Iron concentrations were generally higher in the development area than in the pipeline route stations with averages of 44,640 and 39,880 mg/kg, respectively. One third of the sampling stations had iron concentrations that were above the range between average marine sediments and continental crust reference values.

## 3.7 SEDIMENT NUTRIENTS AND ACID VOLATILE SULFIDES

**Table 13** summarizes total nitrogen and total phosphorus concentrations in TEN EBS sediments. Acid-volatile sulfides were analyzed but were not detected in any of the sampled sediments. The average total nitrogen concentration in the development area stations was higher and less variable (average of 3,559 mg/kg with a range of 2,780 to 4,110 mg/kg) than in the pipeline route stations (average of 1,934 mg/kg with a range of 1,010 to 4,120 mg/kg). Average total phosphorus concentrations were higher and less variable in pipeline route stations (average of 672 mg/kg with a range of 540 to 770 mg/kg) compared to development area stations (average of 514 mg/kg with a range of 292 to 750 mg/kg).

Table 13. Total nitrogen, total phosphorus, and acid volatile sulfide concentrations (mg/kg) in sediment samples collected during the TEN Environmental Baseline Survey.

| Station | Total Nitrogen | Total Phosphorus | Acid Volatile Sulfide |
|---|---|---|---|
| Development Area | | | |
| 1 | 3,720 | 710 | ND |
| 2 | 3,570 | 590 | ND |
| 3 | 2,780 | 590 | ND |
| 4 | 4,110 | 292 | ND |
| 5 | 3,760 | 349 | ND |
| 6 | 3,920 | 382 | ND |
| 7 | 3,590 | 620 | ND |
| 8 | 3,310 | 455 | ND |
| 9 | 2,990 | 397 | ND |
| 10 | 3,840 | 750 | ND |
| Average | 3,559 | 514 | -- |
| Range | 2,780–4,110 | 292–750 | -- |
| Pipeline Route | | | |
| C1 | 1,050 | 540 | ND |
| C2 | 1,010 | 710 | ND |
| C3 | 1,300 | 760 | ND |
| C4 | 2,190 | 580 | ND |
| C5 | 4,120 | 770 | ND |
| Average | 1,934 | 672 | -- |
| Range | 1,010–4,120 | 540–770 | -- |

ND = not detected.

## 3.8 MACROINFAUNA

**Tables 14** and **15** summarize macroinfaunal density and taxonomic richness by major taxa in samples collected during the TEN EBS. Polychaetes, bivalves, gastropods, crustaceans, and echinoderms were the main taxa found in the TEN macroinfaunal samples. The average total density of macroinfauna in development area stations was 634 individuals/$m^2$ (range of 449 to 808 individuals/$m^2$) while in pipeline route stations the average was 508 individuals/$m^2$ (range of 189 to 978 individuals/$m^2$). In both development area and pipeline route stations, polychaetes and crustaceans were numerically dominant. While the average polychaete densities did not differ markedly between development area and pipeline route stations (292 vs. 326 individuals/$m^2$), crustacean densities differed markedly (199 vs. 71 individuals/$m^2$).

Table 14. Macroinfaunal density (individuals/$m^2$) by major taxa in grab samples collected during the TEN Environmental Baseline Survey.

| Station | Total | Polychaeta | Bivalvia | Gastropoda | Crustacea | Echinodermata | Other Taxa |
|---|---|---|---|---|---|---|---|
| Development Area | | | | | | | |
| 1 | 604.1 | 293.9 | 32.7 | 8.2 | 179.6 | 0.0 | 89.8 |
| 2 | 449.0 | 220.4 | 16.3 | 24.5 | 187.8 | 0.0 | 0.0 |
| 3 | 808.2 | 351.0 | 73.5 | 49.0 | 204.1 | 16.3 | 114.3 |
| 4 | 506.1 | 195.9 | 57.1 | 0.0 | 228.6 | 8.2 | 16.3 |
| 5 | 522.4 | 334.7 | 32.7 | 8.2 | 73.5 | 16.3 | 57.1 |
| 6 | 767.3 | 293.9 | 89.8 | 16.3 | 236.7 | 24.5 | 106.1 |
| 7 | 767.3 | 351.0 | 57.1 | 32.7 | 187.8 | 32.7 | 106.1 |
| 8 | 432.7 | 187.8 | 40.8 | 8.2 | 73.5 | 32.7 | 89.8 |
| 9 | 677.6 | 261.2 | 32.7 | 8.2 | 261.2 | 8.2 | 106.1 |
| 10 | 808.2 | 432.7 | 0.0 | 16.3 | 359.2 | 0.0 | 0.0 |
| Average | 634 | 292 | 43 | 17 | 199 | 14 | 69 |
| Range | 449–808 | 188–433 | 0–90 | 0–49 | 74–359 | 0–33 | 0–114 |
| Pipeline Route | | | | | | | |
| C1a | 966.7 | 511.1 | 22.2 | 0.0 | 188.9 | 66.7 | 177.8 |
| C1b | 777.8 | 444.4 | 33.3 | 0.0 | 111.1 | 66.7 | 122.2 |
| C2a | 200.0 | 122.2 | 0.0 | 11.1 | 11.1 | 22.2 | 33.3 |
| C2c | 366.7 | 288.9 | 0.0 | 0.0 | 22.2 | 11.1 | 44.4 |
| C3b | 422.2 | 300 | 22.2 | 0.0 | 66.7 | 0.0 | 33.3 |
| C3c | 300.0 | 255.6 | 0.0 | 0.0 | 44.4 | 0.0 | 0.0 |
| C4a | 188.9 | 88.9 | 0.0 | 0.0 | 55.6 | 0.0 | 44.4 |
| C4b | 555.6 | 433.3 | 0.0 | 0.0 | 44.4 | 0.0 | 77.8 |
| C5a | 977.8 | 611.1 | 11.1 | 11.1 | 155.6 | 33.3 | 155.6 |
| C5b | 322.2 | 200.0 | 0.0 | 0.0 | 11.1 | 0.0 | 111.1 |
| Average | 508 | 326 | 9 | 2 | 71 | 20 | 80 |
| Range | 189–978 | 89–611 | 0–33 | 0–11 | 11–189 | 0–67 | 0–178 |

Note: Replicate macroinfauna samples along the pipeline route denoted by a, b, and/or c (e.g., C2a and C2c are replicate macroinfaunal samples from Station C2).

Table 15. Taxonomic richness (number of taxa) by major taxa in grab samples collected during the TEN Environmental Baseline Survey.

| Station | Total | Polychaeta | Bivalvia | Gastropoda | Crustacea | Echinodermata | Other Taxa |
|---|---|---|---|---|---|---|---|
| Development Area | | | | | | | |
| 1 | 34 | 17 | 2 | 1 | 10 | 0 | 4 |
| 2 | 24 | 12 | 2 | 1 | 9 | 0 | 0 |
| 3 | 35 | 17 | 3 | 1 | 9 | 2 | 3 |
| 4 | 28 | 11 | 4 | 0 | 11 | 1 | 1 |
| 5 | 34 | 18 | 3 | 1 | 7 | 2 | 3 |
| 6 | 36 | 13 | 4 | 1 | 10 | 3 | 5 |
| 7 | 38 | 14 | 3 | 2 | 11 | 3 | 5 |
| 8 | 33 | 15 | 3 | 1 | 7 | 3 | 4 |
| 9 | 31 | 13 | 3 | 1 | 12 | 1 | 1 |
| 10 | 27 | 17 | 0 | 1 | 9 | 0 | 0 |
| Average | 32 | 15 | 3 | 1 | 10 | 2 | 3 |
| Range | 24–38 | 11–18 | 0–4 | 0–2 | 7–12 | 0–3 | 0–5 |

Table 15. (Continued).

| Station | Total | Polychaeta | Bivalvia | Gastropoda | Crustacea | Echinodermata | Other Taxa |
|---|---|---|---|---|---|---|---|
| Development Area | | | | | | | |
| Pipeline Route | | | | | | | |
| C1a | 48 | 28 | 2 | 0 | 8 | 5 | 5 |
| C1b | 42 | 25 | 3 | 0 | 6 | 4 | 4 |
| C2a | 18 | 11 | 0 | 1 | 1 | 2 | 3 |
| C2c | 29 | 24 | 0 | 0 | 2 | 1 | 2 |
| C3b | 24 | 14 | 2 | 0 | 5 | 0 | 3 |
| C3c | 14 | 11 | 0 | 0 | 3 | 0 | 0 |
| C4a | 10 | 5 | 0 | 0 | 3 | 0 | 2 |
| C4b | 25 | 17 | 0 | 0 | 4 | 0 | 4 |
| C5a | 43 | 27 | 1 | 1 | 7 | 2 | 5 |
| C5b | 14 | 11 | 0 | 0 | 1 | 0 | 2 |
| Average | 27 | 17 | 1 | 0 | 4 | 1 | 3 |
| Range | 10–48 | 5–28 | 0–3 | 0–1 | 1–8 | 0–5 | 0–5 |

Note: Replicate macroinfauna samples along the pipeline route denoted by a, b, and/or c (e.g., C2a and C2c are replicate macroinfaunal samples from Station C2).

Polychaeta and Crustacea also were the dominant taxonomic groups (i.e., taxonomic richness) among development area and pipeline route stations. The average number of taxa in development area stations (32 taxa) was generally similar to pipeline route stations (27 taxa) although the range in number of taxa was greater in pipeline route stations (10 to 48 taxa) compared to development area stations (24 to 38 taxa).

## 3.9 EPIFAUNA (PLAN VIEW CAMERA DATA)

A review of plan view images from Stations 1 to 10 and C1 to C5 revealed a soft bottom substrate characterized by a mixture of fine and coarse sediments (**Appendix D**). Stations 1 to 10 and Station C4 were observed to have predominantly fine sediments while Stations C1 to C3 and C5 had predominantly coarse sediments. The majority of these stations exhibited evidence of biological activity (i.e., bioturbation) on the substrate including small burrows, depressions, and tracks. The level of observed bioturbation and biota at the majority of the stations indicates a relatively productive and active macrobenthic community.

Biota observed at these stations included epifaunal species (i.e., on the substrate) and also within the near bottom water column. Epifaunal species included translucent holothuroids, crustaceans, solitary hard coral, fireworm (*Hermodice* sp.), burrowing anemones (Ceriantharia), long-spined sea urchins (Echinoidea), decapod shrimp, and brittlestars (Ophiuroidea). Species observed within the near bottom water column included various unidentified fishes, pteropod molluscs, and jellyfishes.

## 4.1 DATA QUALITY

The primary objective of CSA's project QA Program was to ensure that the data produced during the sampling and analysis were accurate, representative, comparable, and of sufficient quality to address the scientific questions posed at the initiation of the project. A data quality objective (DQO) is a target or goal describing a level of expected data quality. The primary DQO for the TEN EBS was to characterize the physicochemical environment with a high degree of confidence. Other DQOs included using an accepted sample collection system and processing procedures, utilizing laboratories with extensive experience in the required analytical methodologies, and maintaining laboratory QC for taxonomic identification.

The degree of congruence between a population of interest and a sample of the population determines its representativeness. A representative sample 1) allows generalizations to be made about the population without examining the entire population, and 2) typifies the targeted characteristics of the media of interest at the time of collection. Obtaining representative samples was of primary importance for an accurate description of the environment. The use of established sample collection systems, sampling at multiple stations to characterize an environment, and use of a highly experienced survey team and laboratory contributed to the representative attributes of the TEN EBS dataset.

In order to collect a representative sample that will yield the information required, study objectives (including data quality requirements) must be understood in the context of the system to be sampled and artifacts of the sampling process must be minimized. Field personnel were experienced and trained to use proper sample collection techniques, be alert to conditions that could compromise the quality of a sample, and be aware of possible sources of error to ensure the integrity of the sample. Apart from use of proper sample collection techniques, sufficient QC samples were collected to ensure sample representativeness and integrity and to meet study criteria.

Data comparability was a necessary goal, as sampling conditions, procedures, and sample storage and preservation techniques used in the project had to be consistent with accepted protocols. Analytical methods and data reporting units also were consistent throughout the project. In addition, the procedures and techniques used were state of the-art and conformed to widely accepted industry standards and conventions. Data comparability also was ensured through rigorous QC.

Precision is calculated from multiple measurements as the relative standard deviation (i.e., the ratio of the standard deviation to the mean of the replicate analyses). Accuracy is calculated as percent recovery in matrix spikes as the ratio of the difference between spiked and unspiked aliquots to the actual concentration of the spike added. Completeness is calculated as the ratio of the number of valid measurements made to the number of measurements necessary to achieve a specified level of confidence. Precision, accuracy, and completeness were attained during the TEN EBS collection and analysis.

## 4.2 HYDROGRAPHIC DATA

Results of the water column profiling conducted at the three TEN locations sampled from 26 through 28 March 2011 are shown in **Figure 4**. The profile collected on 26 March (**Figure 4a**) was taken at Station 4 at approximately 1,500-m water depth. The profile collected on 27 March (**Figure 4b**) was taken at Station 10 at approximately 1,000-m water depth. A profile was taken at the much shallower Station C1 (**Figure 4c**) at approximately 77-m water depth on 28 March.

The water column profiles of hydrographic data from the TEN development area are typical of tropical open ocean conditions. The two deep profiles looked very similar; the profile at the shallower Station C1 showed the same general pattern as the deeper stations, however, it was compressed due to its shallower depth. Surface waters were warm (~28°C) at Stations 4 and 10, with the temperature significantly decreasing with increasing depth. The temperature approached 4°C at the seafloor. The water column at Station C1 showed decreasing temperatures, ranging from 28°C at the surface to 18°C at near bottom. The water column salinity measurements at the deeper stations exhibited considerable variation within surface waters, ranging from 35 practical salinity units [psu]) to a maximum of 35.8 psu at ~50 m. The salinity profile at the shallower sampling station was much more linear. The water column was well oxygenated (above 6 mg/L) at the surface, with DO decreasing below the surface-mixed layer. Turbidity was not plotted, but data show nephelometric turbidity unit (NTU) values at zero, indicating the water was clear through the entire profile.

For the most part, the top 20 to 50 m of the water column was isothermal in the three profiles. Below the surface-mixed layer, the temperature dropped by almost 10°C (thermocline) near the halocline. The 26 March profile showed a strong thermocline between 50 and 60 m (**Figure 4a**). There also was a strong thermocline at 50 m in the profiles from 27 March (**Figure 4b**). There was a wedge of much lower salinity water (35.1 psu; ~0.7 psu less) on the surface (down to 50 m) compared to lower layers evident in all three profiles. Below the surface-mixed layer, salinity decreased to a minimum near 34.5 psu at about the 700- to 800-m depth, below which salinity increased slightly near the bottom (34.6 psu). Similar patterns in temperature and salinity, albeit less pronounced, were present in the shallow Station C1 (**Figure 4c**). The thermocline and halocline occurred between 20 and 30 m with a maximum salinity of 35.8 psu at a depth of ~50 m. The average near surface temperature at Stations 4 and 10 located in deep water were significantly lower than the average near surface temperature at Station C1.

The DO profiles reflect water column processes of primary productivity and respiration/mineralization. Typically in the open ocean, DO values are highest at the near surface where sunlight allows the highest rates of primary production (resulting in oxygen evolution). DO is highest not at the surface, but just below the water surface due to the actinic effects of sunlight on photosynthesis. Below the surface-mixed layer, decreasing light availability depresses primary productivity and mineralization of organic matter results in lower DO concentrations down to the oxygen minimum at the ~300-m depth. DO decreases with depth as organic matter from the productive photic surface layers is mineralized and oxygen is consumed in the process.

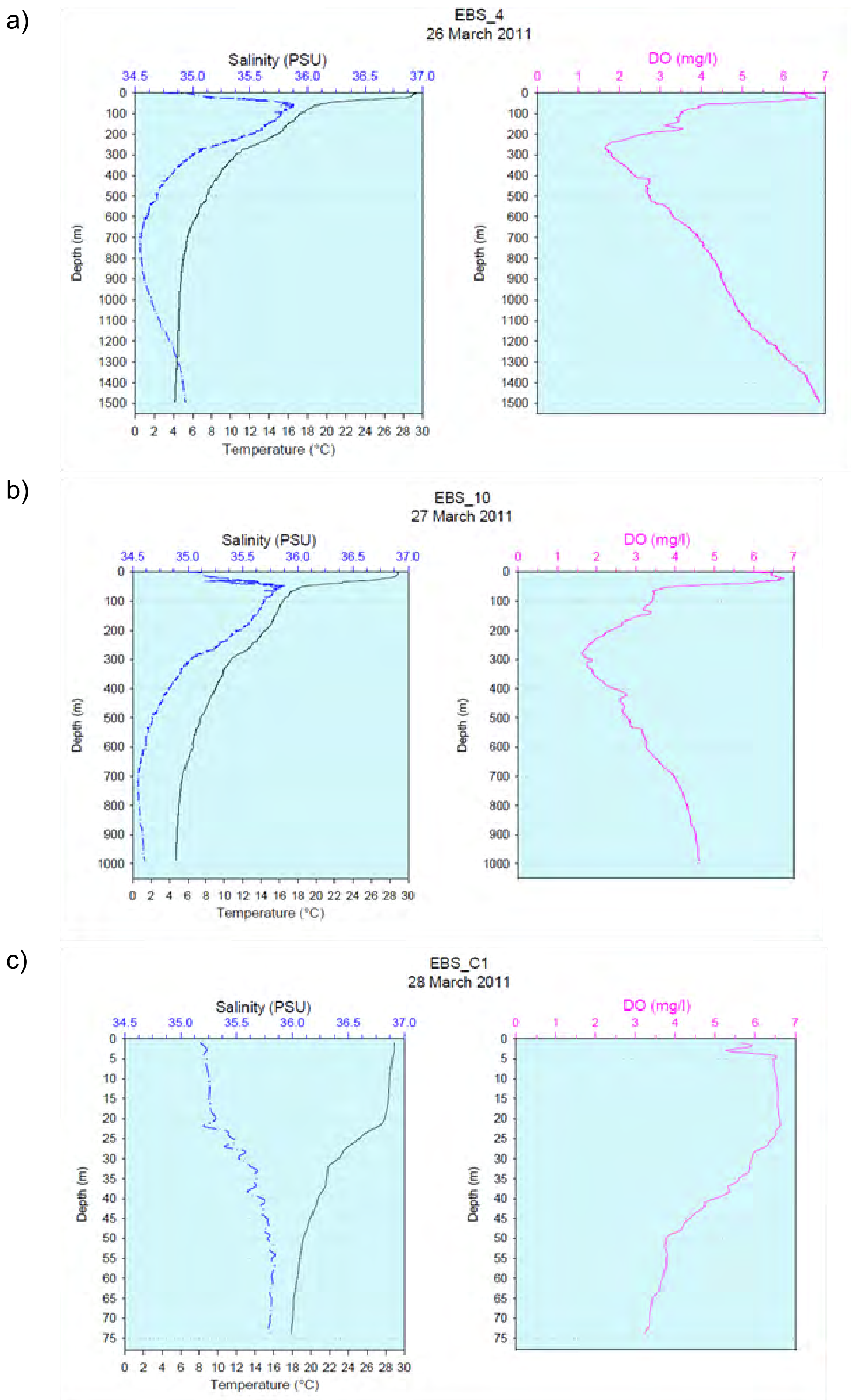



Figure 4. Water column profiles collected during the TEN Environmental Baseline Survey, Stations 4, 10, and C1 from 26 and 28 March 2011.

DO values were highest (6 to 6.5 mg/L) at the near surface or surface-mixed layer, decreasing significantly below 50 m to under 4 mg/L, then decreasing less dramatically down to a depth of ~200 m. Below 200 m, DO gradually decreased to an oxygen minimum at ~250- to 300-m depth. The DO profiles almost mirror the temperature profiles down to the 300-m depth. DO ranged from 1.5 to 6.5 mg/L through the water column. In the 26 March profile, DO slightly increased at the near surface (above or at the halocline depth) and then sharply decreased with depth to ~3.5 mg/L at the 60- to 70-m level (**Figure 4a**). From this depth down to 200 m, the decrease in DO was slight. Between 200 and 300 m, DO decreased sharply to 1.5 mg/L at the DO minimum (300-m depth). Below the DO minimum, DO increased gradually with depth to levels near what were observed on the surface (up to 5 mg/L). Similar patterns in DO can be seen in the 27 March profile for Station 10 (**Figure 4b**). In the 28 March profile at Station C1 (**Figure 4c**), there was an evident depression of DO at the near surface at depths less than 5 m and maximum DO of 6.5 mg/L at a depth of 5 to 23 m before decreasing with depth. The lowest DO levels were at the near bottom where respiration from the seabed would further reduce DO levels. The near surface depression of DO may be attributed to the actinic effects of sunlight decreasing photosynthesis.

Turbidity was very low throughout the water column at all stations, generally just above zero NTU at the surface and zero NTU to the bottom. Low turbidity is typical of an open ocean environment with minimal riverine influence. The patterns observed in the hydrographic data are typical for tropical open ocean conditions with surface layers only slightly influenced by rainfall and riverine discharge. Although rainfall in Ghana is high (1,100 to 2,100 mm annually), the Deep Water Tano Block is located more than 40 km from shore. In addition, there are no large rivers immediately inshore or in proximity to the block, and the predominant currents run to the east, likely driving riverine discharges eastward, away from the Deep Water Tano Block.

## 4.3 WATER COLUMN DATA

Measured water quality parameters are consistent with hydrographic parameters and are indicative of open ocean conditions with low levels of nutrients, chlorophyll, and suspended solids. Because the same water mass covers much of the area of interest, horizontal spatial variability would be minimal. With limited activity offshore, water quality is expected to be very good.

Hydrocarbons in seawater collected during the survey are not presented because of contamination of seawater samples from the organic solvent used for preservation and extraction. Methylene chloride sourced locally was likely contaminated with hydrocarbons because elevated hydrocarbons were detected in both ambient samples and blanks prepared for QC. Following initial seawater hydrocarbon analyses, CSA provided comprehensive instructions and shipping supplies to facilitate the shipment of a sample of the methylene chloride to be analyzed to confirm the source of contamination. The shipped sample of methylene chloride arrived broken and was unsuitable for analysis. TGL was subsequently notified of the shipped methylene chloride sample condition.

Due to contamination of the EBS seawater hydrocarbon samples, data from previous surveys conducted by CSA in the area of the Jubilee Field (unpublished data) are discussed for reference. Hydrocarbon data from a field survey conducted in Jubilee Field (i.e., several kilometers east of the Deep Water Tano Block) on 24 January 2010 showed TPH values in seawater at the near surface ranging from 22 to 30 µg/L and 18 to 33 µg/L at a depth of 150 m (µg/L = parts per billion, ppb). Total PAHs ranged from 40.8 to 58.2 µg/L in near surface samples and from 32.4 to 38.1 µg/L in samples collected at a depth of 150 m. A second survey during the same period and within the same area showed very low seawater TPH levels (i.e., at background levels), with concentrations ranging from non-detectable to 86 µg/L.

Seawater hydrocarbon determinations from the Jubilee Field are comparable with results from other deepwater surveys conducted worldwide. TPH concentrations determined by CSA offshore Malaysia ranged from <56.53 to 222.64 µg/L in water depths to 1,100 m. Highest values from the Malaysia study were at stations near an oil seep. TPH concentrations from a CSA deepwater survey off Trinidad & Tobago ranged from 26 to 1,174 µg/L during the dry season and from <14.61 to 60 µg/L during the wet season. All TPH analyses from deepwater surveys off Malaysia, Trinidad & Tobago, and Ghana (Jubilee Field) were conducted using identical analytical methods by the same analytical laboratory.

## 4.4 SEDIMENT GRAIN SIZE

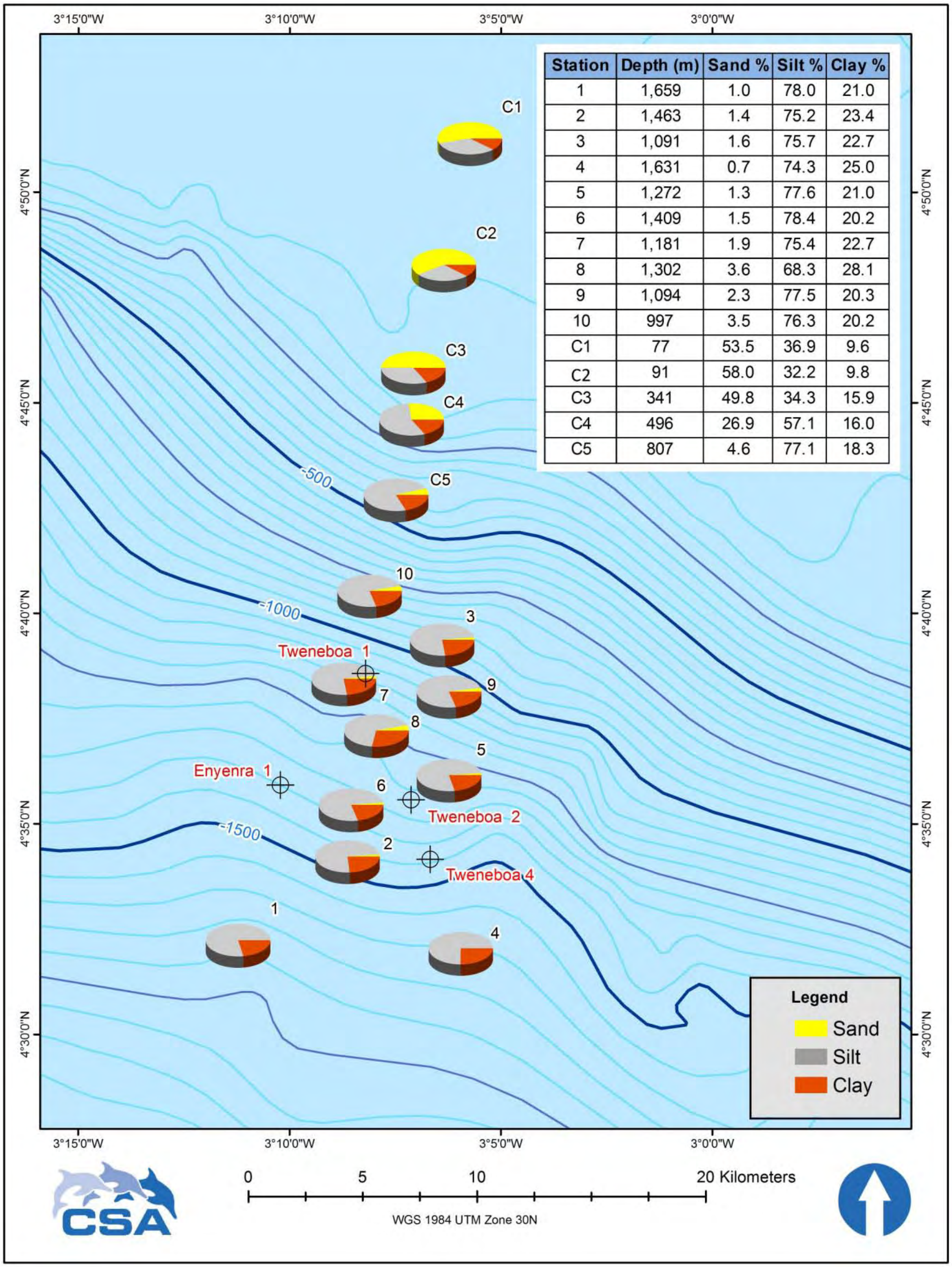
The close similarity of sediments from the development area locations is evident and contrasts against the sediments from the shallower pipeline route stations, the latter of which show differences that relate to depth or distance from shore. **Figure 5** is a geographic information system (GIS)-based thematic map depicting the grain size distribution at each station. The large contribution of sand-sized particles at shelf stations decreases with distance from shore and is clearly replaced by silt-sized particles at the slope stations. There is a less evident increase in the proportion of clay-sized particles with increasing depth.

Further, there do not appear to be differences in the proportion of coarser particles in sediments collected from those development area stations that are close to existing wells. Coarser sediment may indicate the influence of cuttings deposited from well drilling activities. Except for Station 8, there is no apparent increase in the coarser sediment fractions among the development area stations. Proximity to previous wellsites does not appear to be associated with greater coarse sediment fractions.

Differences between pipeline route shelf sediments and development area slope sediments may be attributed to differences in sediment supply and energy. The deep water is primarily a low energy depositional environment while the shelf is a higher energy, erosional environment where stronger currents and tidal streams can winnow out the smaller sized particles that are carried offshore.

## 4.5 TOTAL ORGANIC CARBON

Total organic carbon concentrations increased with depth along the shallower pipeline route stations (Stations C1 to C4) and were highest among development area stations (**Figure 6**). Of the development area stations, Stations 3 and 5, close to and north of previous wellsites, exhibited the highest TOC concentrations. The lowest TOC values among the development area stations were recorded at the deepest locations, Stations 1 and 4. However, TOC concentrations within the development area were very similar at all stations. Typically, higher organic matter content (e.g., TOC) is associated with finer sediments. Higher TOC values were noted in development area samples, where finer grained sediments are found. Differences in TOC between development area stations compared to pipeline shore route stations may be a function of differences in grain size rather than an enrichment of the sediment organic matter arising from nearby oil and gas activity.



| Station | Depth (m) | Sand % | Silt % | Clay % |
|---|---|---|---|---|
| 1 | 1,659 | 1.0 | 78.0 | 21.0 |
| 2 | 1,463 | 1.4 | 75.2 | 23.4 |
| 3 | 1,091 | 1.6 | 75.7 | 22.7 |
| 4 | 1,631 | 0.7 | 74.3 | 25.0 |
| 5 | 1,272 | 1.3 | 77.6 | 21.0 |
| 6 | 1,409 | 1.5 | 78.4 | 20.2 |
| 7 | 1,181 | 1.9 | 75.4 | 22.7 |
| 8 | 1,302 | 3.6 | 68.3 | 28.1 |
| 9 | 1,094 | 2.3 | 77.5 | 20.3 |
| 10 | 997 | 3.5 | 76.3 | 20.2 |
| C1 | 77 | 53.5 | 36.9 | 9.6 |
| C2 | 91 | 58.0 | 32.2 | 9.8 |
| C3 | 341 | 49.8 | 34.3 | 15.9 |
| C4 | 496 | 26.9 | 57.1 | 16.0 |
| C5 | 807 | 4.6 | 77.1 | 18.3 |



Figure 5. Sediment grain size distribution at sampling stations during the TEN Environmental Baseline Survey.

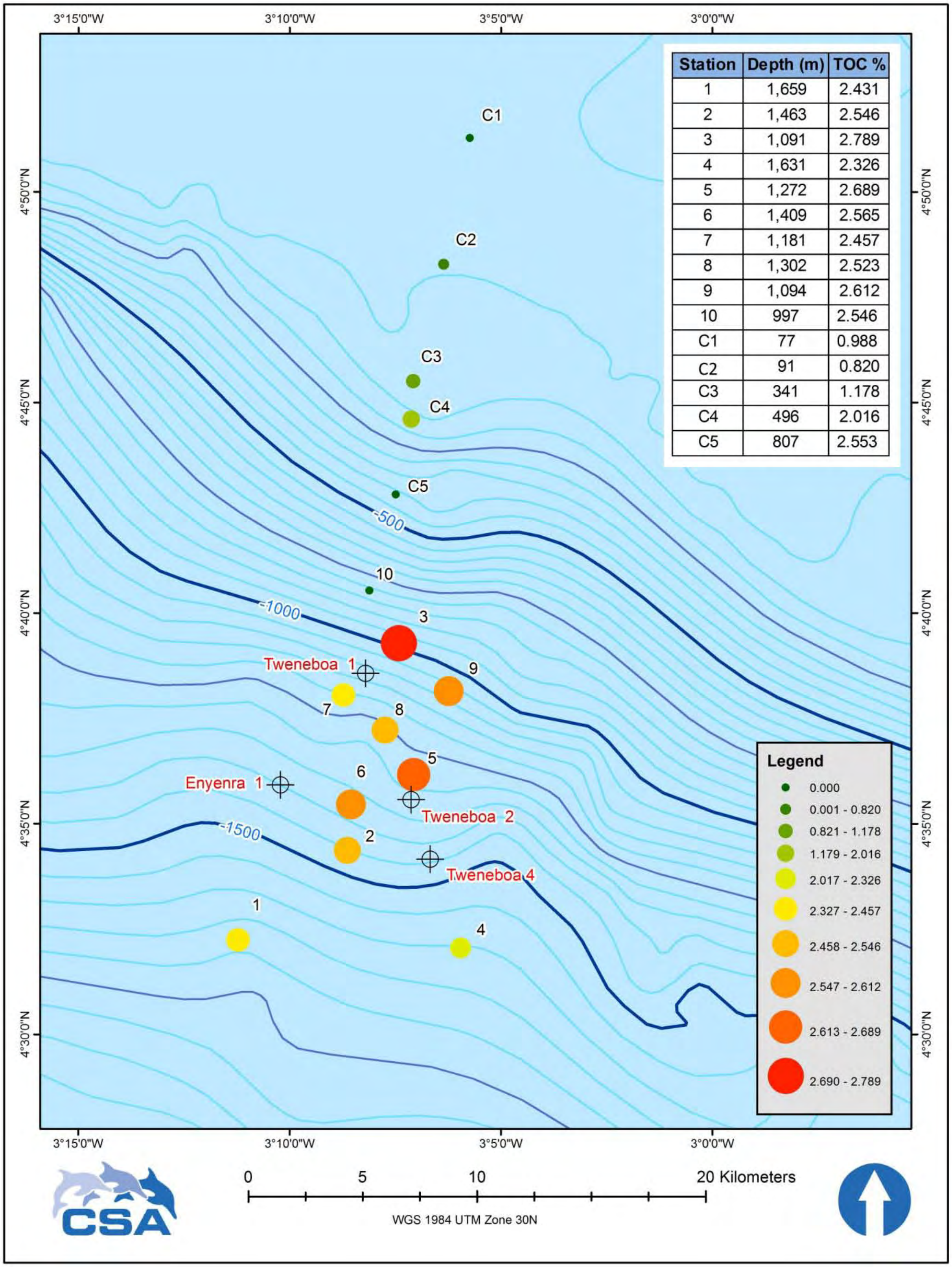



Figure 6. Total organic carbon (TOC) determinations at sampling stations during the TEN Environmental Baseline Survey.

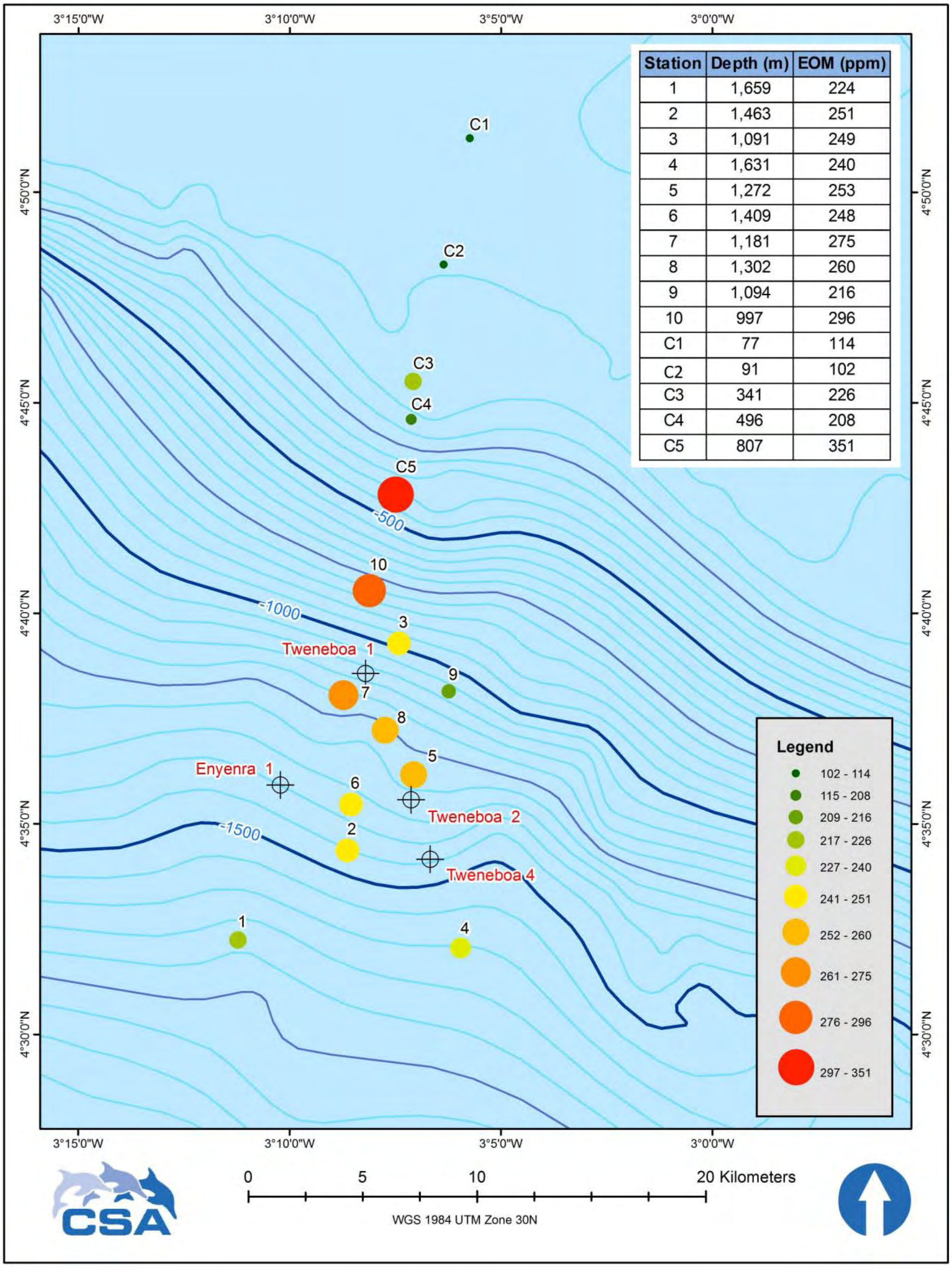
## 4.6 ORGANICS

Concentrations of four separate sediment organics from each sampling station are shown in **Figures 7** through **10**. **Figure 7** shows comparatively high EOM concentrations in the development area stations while lowest EOM concentrations were found in the shallowest pipeline route stations (Stations C1 and C2). Highest EOM concentrations were in sediments from Stations C5 and 10 located along the slope at the shoreward interface between the development area and the pipeline route. Although there is no defined EOM concentration gradient based on distance from wellsites, higher EOM concentrations in sediment may be correlated with proximity to previous wellsites. This possible correlation is confounded by the most distal stations (i.e., distal from previous wellsites), which have the lowest EOM concentrations and are characterized by coarse sediments. Because lower EOM concentrations would be expected for the coarser sediments (as found on the shelf along the shallower pipeline route stations), it is uncertain which factor(s) most influences the observed EOM concentrations.

Sediment TPH concentrations generally indicate that proximity to previous wellsites may be associated with higher hydrocarbon concentrations (**Figure 8**). TPH follows similar spatial trends as EOM concentrations – the most distal stations from previous wellsites have the lowest sediment TPH concentrations. Average TPH concentrations for the development area and the pipeline route stations are 42 and 36 µg/g, respectively. TPH concentrations were highest at Station 1 and at development area stations (except for Station 4), and along the slope at the shoreward interface between the development area and the pipeline route (Stations C5 and C4). The two highest TPH concentrations were found at Stations 1 and C5; these stations are located at bathymetric extremes along the slope within the survey area and over 5 km from any previous wellsites. There is no defined TPH concentration gradient associated with proximity to previous wellsites. Local spatial variability in TPH concentrations in proximity to previous wellsites may be related to local hydrographic and topographic conditions affecting sediment and discharge transport; these conditions may confound the detection of small scale gradients based on a limited number of EBS data points.

Aliphatics are straight-chain hydrocarbon components of TPH in sediment. Total aliphatic hydrocarbon concentrations in sediments are shown on **Figure 9**. As was the case with TPH determinations, the highest total aliphatic hydrocarbon concentrations were found at Stations 1, 2, and C5. There is an apparent increase in total aliphatic hydrocarbon concentrations along the pipeline route stations with depth. As with the other hydrocarbon components, there is relatively high spatial variability concerning total aliphatic hydrocarbon concentrations in the vicinity of the previous wellsites; the most distal station from the previous wellsites exhibited the lowest aliphatic hydrocarbon levels.

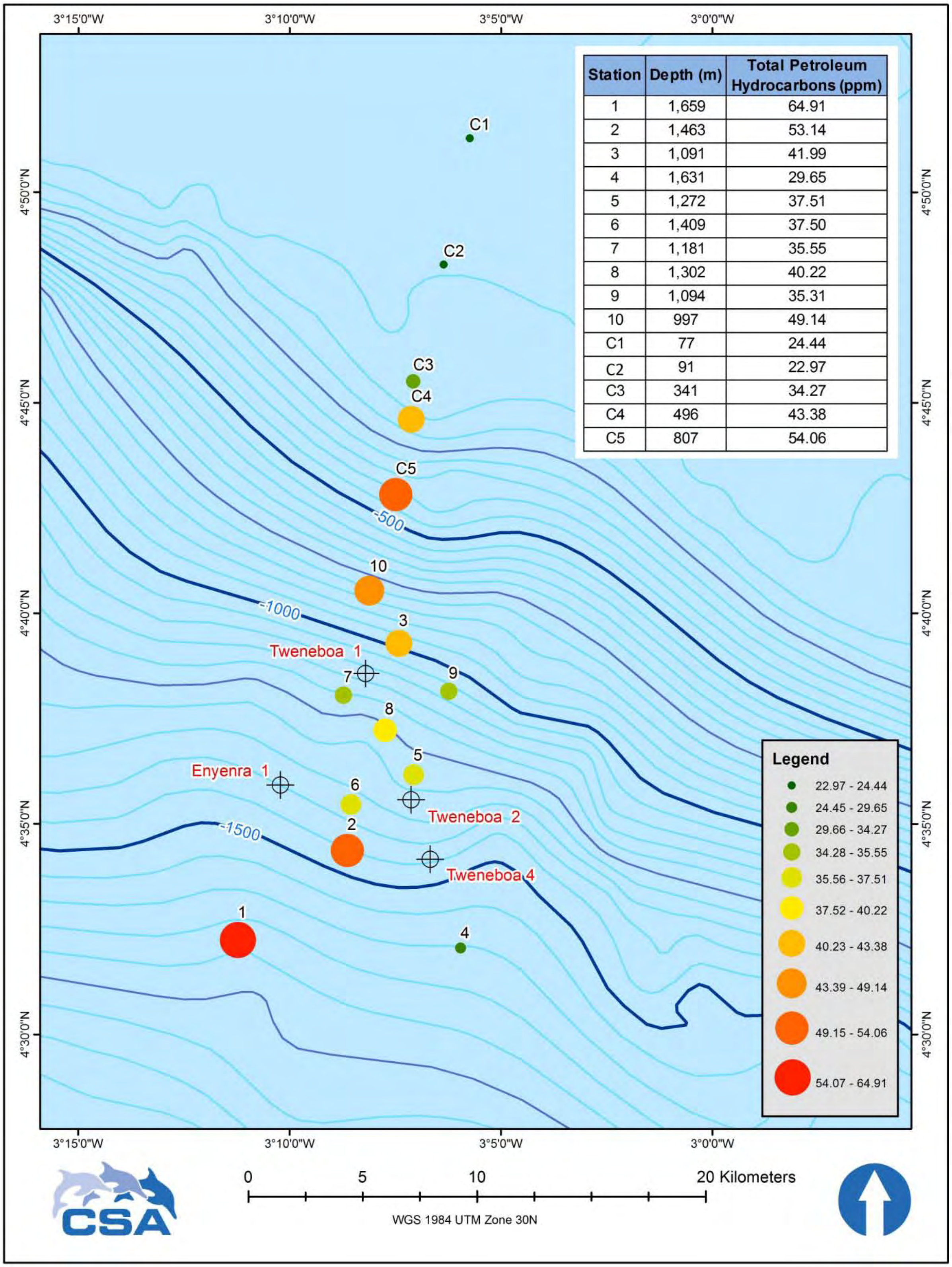
Polycyclic aromatic hydrocarbons are the aromatic (cyclic ring) hydrocarbon components of TPH in sediment. **Figure 10** depicts sediment total PAH concentrations. PAH concentrations exhibit similar spatial patterns noted for TPH. This is a consistent finding given that PAHs are a component of the TPH in a sample, albeit at very low concentrations (ng/g units for PAH verses µg/g units for TPH; ng/g = ppb; µg/g = ppm). As with the other hydrocarbon components, there is no defined PAH concentration gradient related to distance from previous wellsites. There is relatively high spatial variability in PAH concentrations in the vicinity of the previous wellsites, with the most distal station from previous wellsites having the lowest PAH levels. This finding would indicate there is a large-scale positive correlation between PAH concentrations and proximity to previous wellsites. Stations 1 and 2 within the development area had the highest total PAH concentrations while the pipeline route stations most distal to previous wellsites had the lowest total PAH concentrations.



| Station | Depth (m) | EOM (ppm) |
|---|---|---|
| 1 | 1,659 | 224 |
| 2 | 1,463 | 251 |
| 3 | 1,091 | 249 |
| 4 | 1,631 | 240 |
| 5 | 1,272 | 253 |
| 6 | 1,409 | 248 |
| 7 | 1,181 | 275 |
| 8 | 1,302 | 260 |
| 9 | 1,094 | 216 |
| 10 | 997 | 296 |
| C1 | 77 | 114 |
| C2 | 91 | 102 |
| C3 | 341 | 226 |
| C4 | 496 | 208 |
| C5 | 807 | 351 |

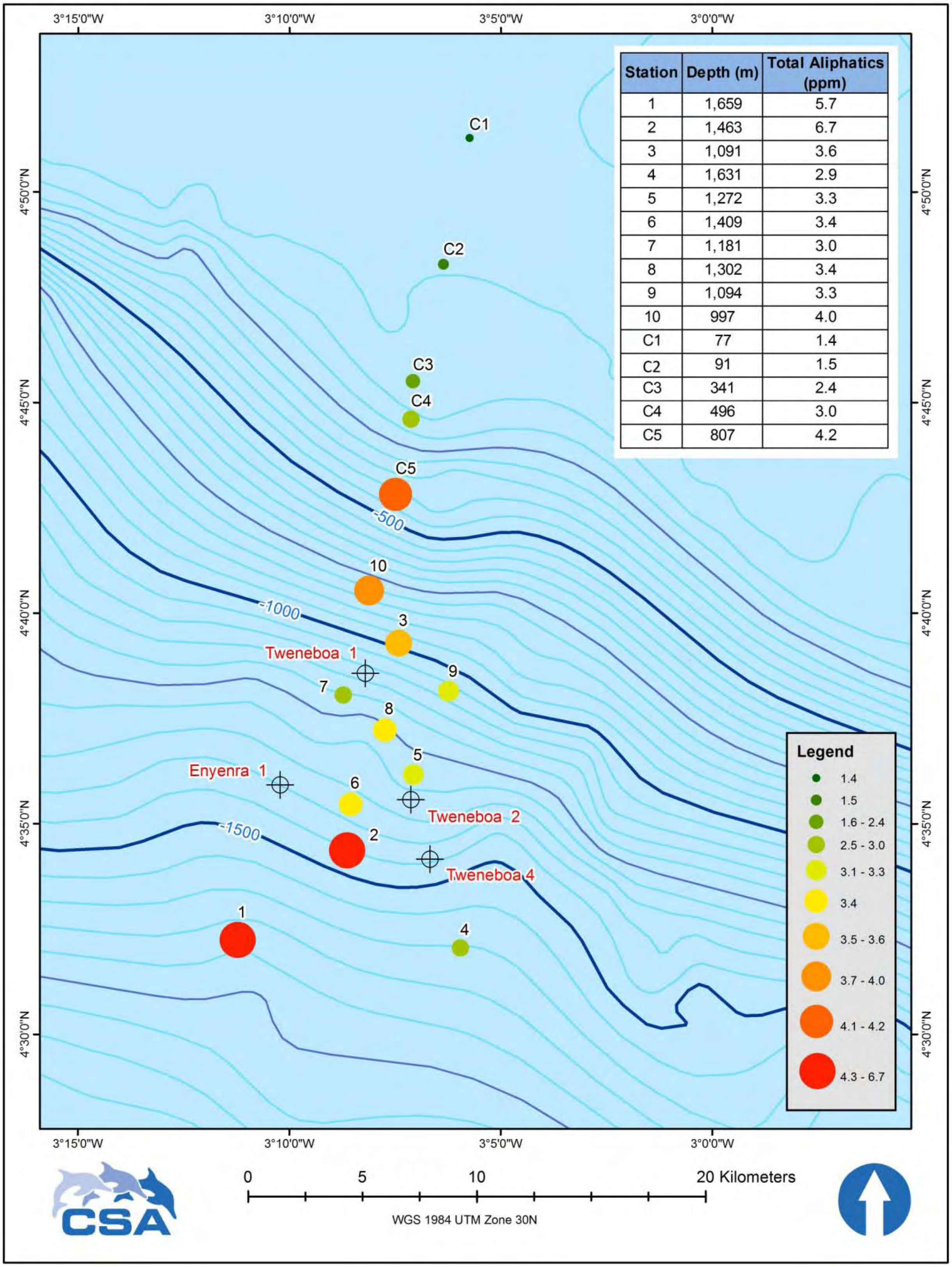


Figure 7. Sediment extractable organic matter (EOM) concentrations (ppm) at sampling stations during TEN Environmental Baseline Survey.



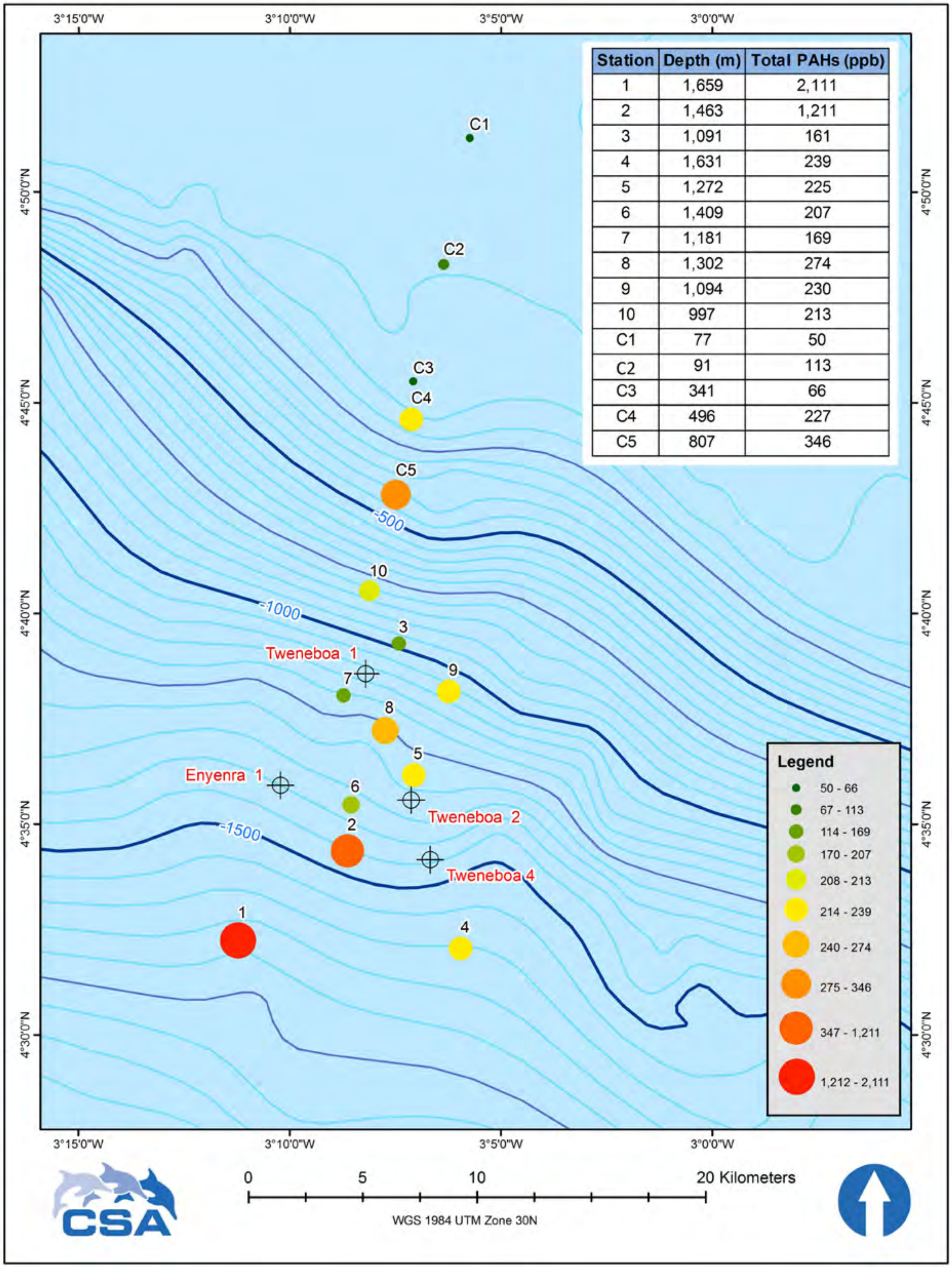

| Station | Depth (m) | Total Petroleum Hydrocarbons (ppm) |
|---|---|---|
| 1 | 1,659 | 64.91 |
| 2 | 1,463 | 53.14 |
| 3 | 1,091 | 41.99 |
| 4 | 1,631 | 29.65 |
| 5 | 1,272 | 37.51 |
| 6 | 1,409 | 37.50 |
| 7 | 1,181 | 35.55 |
| 8 | 1,302 | 40.22 |
| 9 | 1,094 | 35.31 |
| 10 | 997 | 49.14 |
| C1 | 77 | 24.44 |
| C2 | 91 | 22.97 |
| C3 | 341 | 34.27 |
| C4 | 496 | 43.38 |
| C5 | 807 | 54.06 |

Figure 8. Total petroleum hydrocarbons concentrations (ppm) at sampling stations during the TEN Environmental Baseline Survey.




| Station | Depth (m) | Total Aliphatics (ppm) |
|---|---|---|
| 1 | 1,659 | 5.7 |
| 2 | 1,463 | 6.7 |
| 3 | 1,091 | 3.6 |
| 4 | 1,631 | 2.9 |
| 5 | 1,272 | 3.3 |
| 6 | 1,409 | 3.4 |
| 7 | 1,181 | 3.0 |
| 8 | 1,302 | 3.4 |
| 9 | 1,094 | 3.3 |
| 10 | 997 | 4.0 |
| C1 | 77 | 1.4 |
| C2 | 91 | 1.5 |
| C3 | 341 | 2.4 |
| C4 | 496 | 3.0 |
| C5 | 807 | 4.2 |

Figure 9. Total aliphatics concentrations (ppm) at sampling stations during the TEN Environmental Baseline Survey.




| Station | Depth (m) | Total PAHs (ppb) |
|---|---|---|
| 1 | 1,659 | 2,111 |
| 2 | 1,463 | 1,211 |
| 3 | 1,091 | 161 |
| 4 | 1,631 | 239 |
| 5 | 1,272 | 225 |
| 6 | 1,409 | 207 |
| 7 | 1,181 | 169 |
| 8 | 1,302 | 274 |
| 9 | 1,094 | 230 |
| 10 | 997 | 213 |
| C1 | 77 | 50 |
| C2 | 91 | 113 |
| C3 | 341 | 66 |
| C4 | 496 | 227 |
| C5 | 807 | 346 |

Figure 10. Total polycyclic aromatic hydrocarbons concentrations (ppb) at sampling stations during the TEN Environmental Baseline Survey.

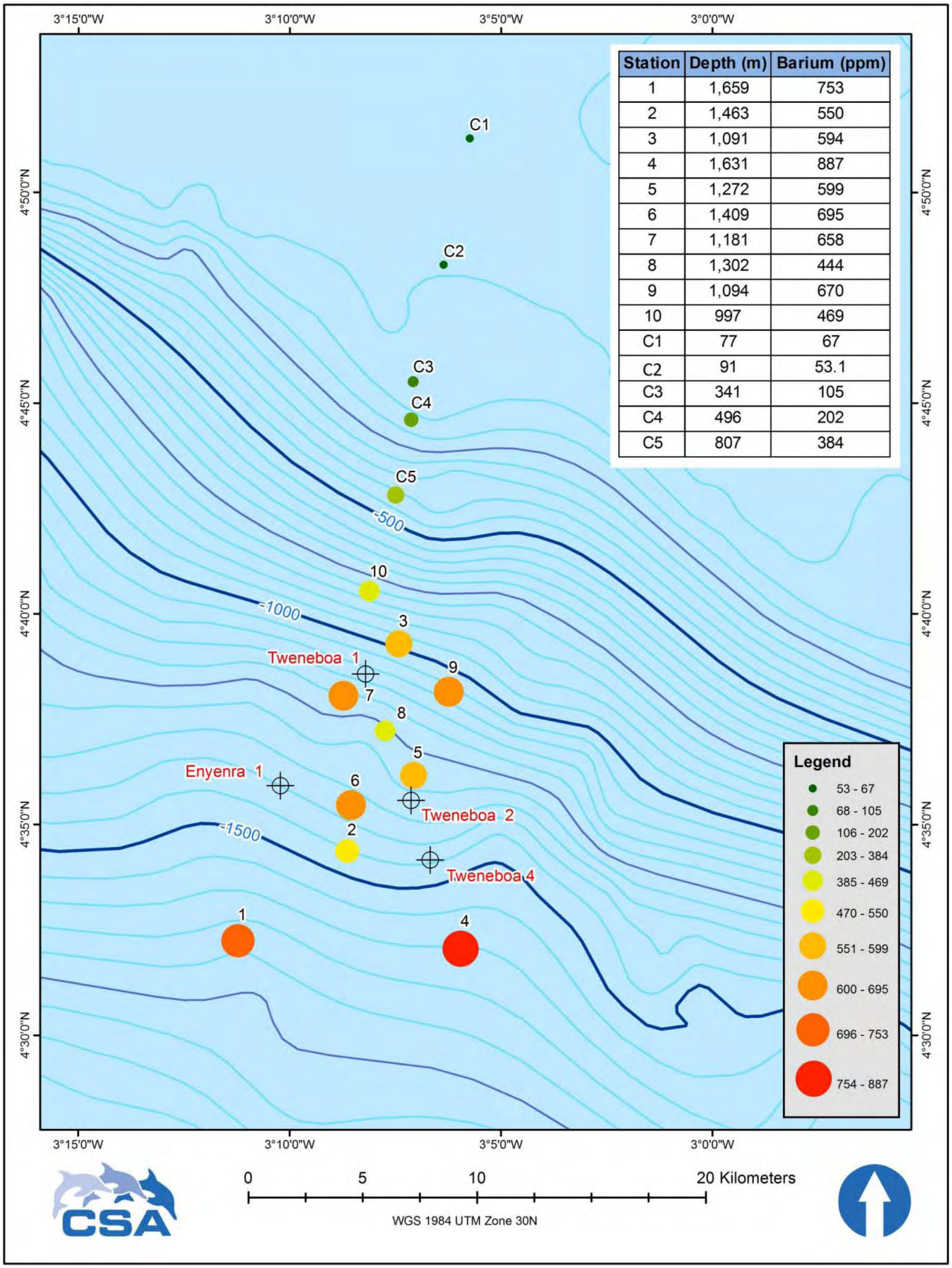
The spatial patterns from EOM, TPH, and total PAH data indicate that these elevated organics concentrations are generally associated with development area stations, the latter of which are in closer proximity to the previous wellsites than most of the pipeline route stations (i.e., C1 through C4).

## 4.7 METALS

Metals concentrations by station are shown in **Figures 11** through **15**. At the TEN offshore development area stations (Stations 1 to 10), sediments consisting primarily of silt (with some clay) generally exhibited elevated metals concentrations. At shallower pipeline route stations (Stations C1 to C5), sediment were predominantly sand and exhibited lower metals concentrations.

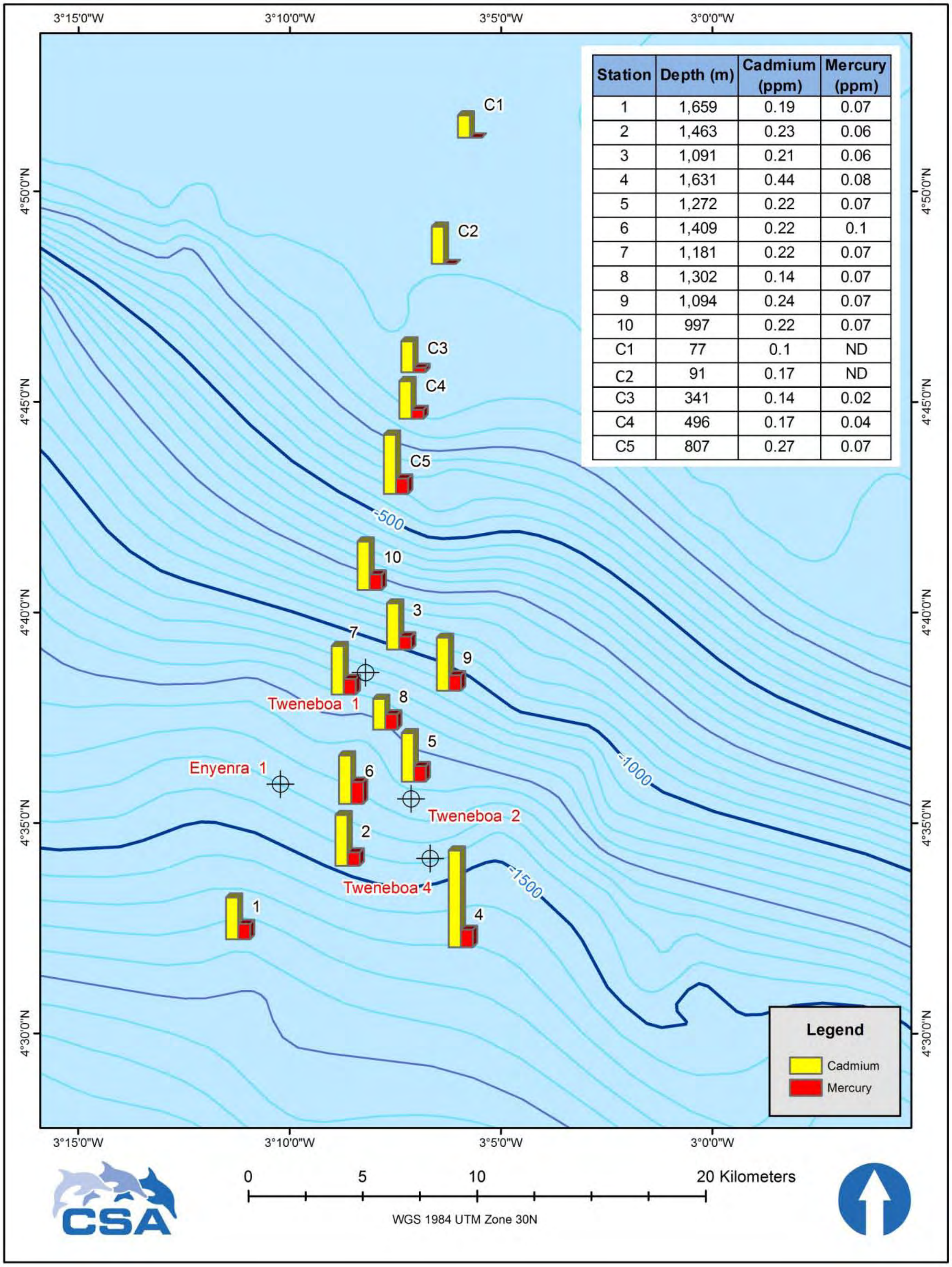
The common use of barite (barium sulfate) as a weighting agent in drilling fluids, when coupled with the discharge of drilling fluids and cuttings, makes barium a good tracer of oil and gas activity. Concentrations of barium in sediments are shown in **Figure 11**. Differences in barium concentrations between the development area (where Ba levels were higher) and pipeline route stations are very apparent. A gradient in barium concentrations with distance from shore among the pipeline route stations is also evident, with lowest barium concentrations found at pipeline stations most distal from previous wellsites. Among the development area stations, highest barium concentrations were noted at the deepest stations (Stations 1 and 4); these stations are located farther from the other development area stations and are not as close to previous wellsites. There is no defined small-scale barium concentration gradient related to distance from previous wellsites. However, there is relatively high spatial variability concerning barium concentrations in the vicinity of the previous wellsites. Stations most distal from the previous wellsites exhibited the lowest barium levels, suggesting there is a large-scale correlation of higher barium concentrations at locations in proximity to previous wellsites. Spatial variability concerning the relatively elevated barium concentrations near the previous wellsites may be related to water depth and local features (e.g., topography and bottom currents) affecting sediment transport which would confound development of small scale concentration gradients for this analyte.

**Figure 12** shows the concentrations of cadmium and mercury at TEN stations. There is an observable gradient in cadmium and mercury concentrations with distance from shore among the pipeline route stations; lowest concentrations of both cadmium and mercury were observed along the most shoreward portion of the pipeline route. There is not a defined concentration gradient for cadmium and mercury related to distance from previous wellsites, however, higher concentratiosn of these metals were observed in the development area stations and at pipeline route Station C5, all of which are in relatively close proximity to the wellsites. The highest cadmium concentration was noted at Station 4, which is located within 5 km of the closest wellsite. There are no apparent differences in mercury concentration among development area stations that relate to proximity to previous wellsites. Mercury levels at Station 4, located farther from previous wellsites, are similar to other deepwater field stations located closer to previous wellsites.



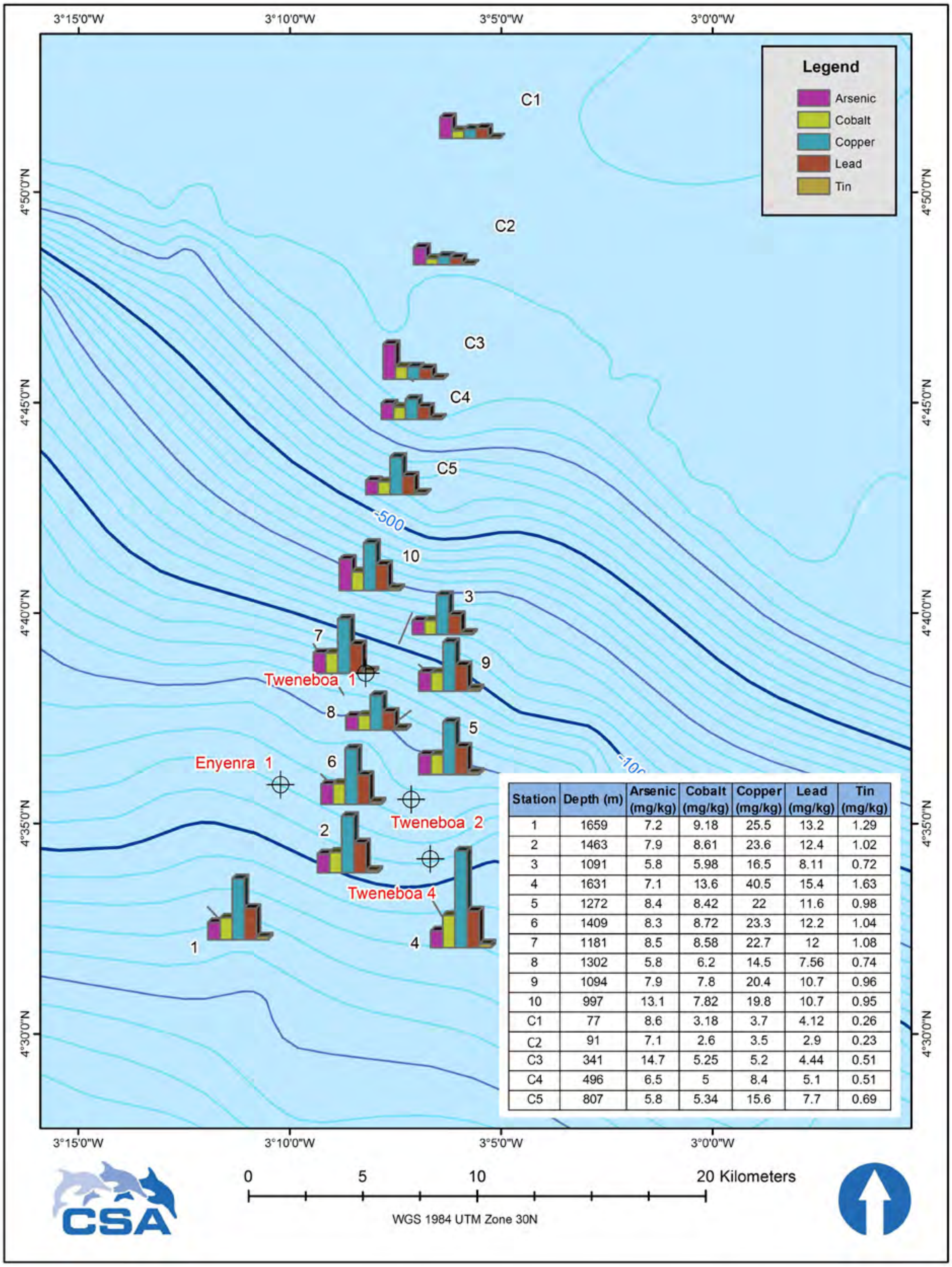

| Station | Depth (m) | Barium (ppm) |
|---|---|---|
| 1 | 1,659 | 753 |
| 2 | 1,463 | 550 |
| 3 | 1,091 | 594 |
| 4 | 1,631 | 887 |
| 5 | 1,272 | 599 |
| 6 | 1,409 | 695 |
| 7 | 1,181 | 658 |
| 8 | 1,302 | 444 |
| 9 | 1,094 | 670 |
| 10 | 997 | 469 |
| C1 | 77 | 67 |
| C2 | 91 | 53.1 |
| C3 | 341 | 105 |
| C4 | 496 | 202 |
| C5 | 807 | 384 |

Figure 11. Barium concentrations (ppm) at sampling stations during the TEN Environmental Baseline Survey.



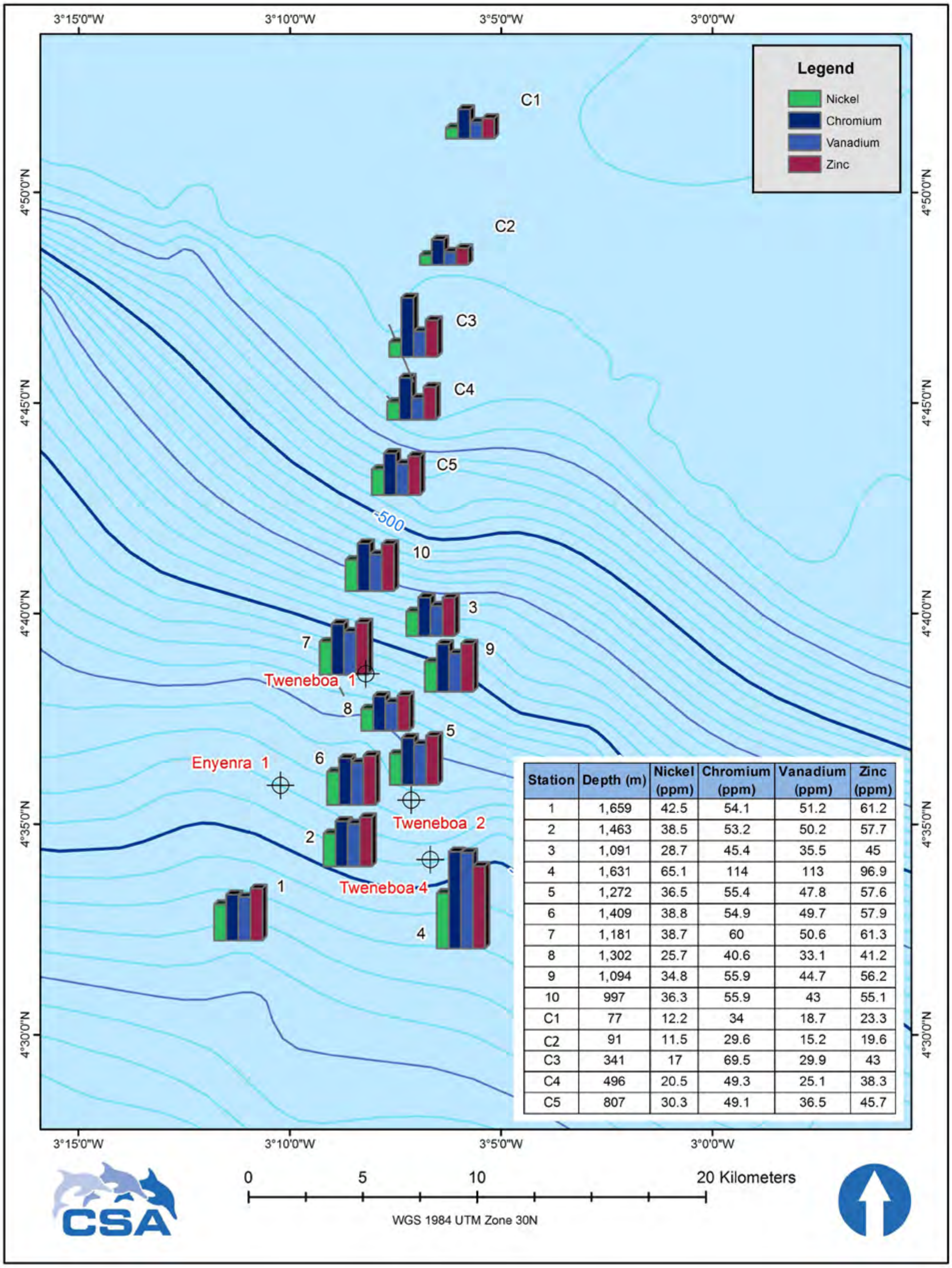

| Station | Depth (m) | Cadmium (ppm) | Mercury (ppm) |
|---|---|---|---|
| 1 | 1,659 | 0.19 | 0.07 |
| 2 | 1,463 | 0.23 | 0.06 |
| 3 | 1,091 | 0.21 | 0.06 |
| 4 | 1,631 | 0.44 | 0.08 |
| 5 | 1,272 | 0.22 | 0.07 |
| 6 | 1,409 | 0.22 | 0.1 |
| 7 | 1,181 | 0.22 | 0.07 |
| 8 | 1,302 | 0.14 | 0.07 |
| 9 | 1,094 | 0.24 | 0.07 |
| 10 | 997 | 0.22 | 0.07 |
| C1 | 77 | 0.1 | ND |
| C2 | 91 | 0.17 | ND |
| C3 | 341 | 0.14 | 0.02 |
| C4 | 496 | 0.17 | 0.04 |
| C5 | 807 | 0.27 | 0.07 |

Figure 12. Cadmium and mercury concentrations (ppm) at sampling stations during TEN Environmental Baseline Survey.



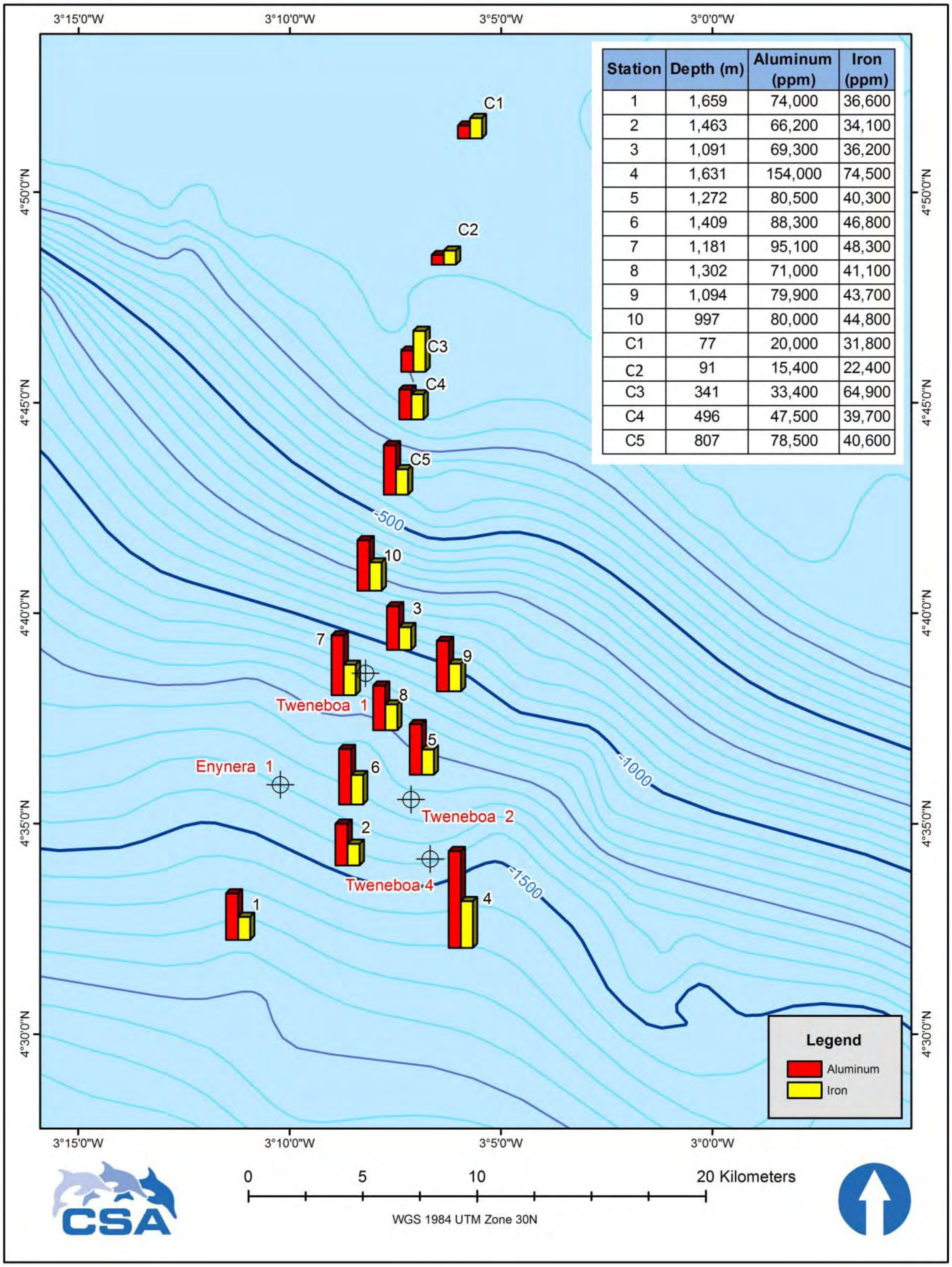

| Station | Depth (m) | Arsenic (mg/kg) | Cobalt (mg/kg) | Copper (mg/kg) | Lead (mg/kg) | Tin (mg/kg) |
|---|---|---|---|---|---|---|
| 1 | 1659 | 7.2 | 9.18 | 25.5 | 13.2 | 1.29 |
| 2 | 1463 | 7.9 | 8.61 | 23.6 | 12.4 | 1.02 |
| 3 | 1091 | 5.8 | 5.98 | 16.5 | 8.11 | 0.72 |
| 4 | 1631 | 7.1 | 13.6 | 40.5 | 15.4 | 1.63 |
| 5 | 1272 | 8.4 | 8.42 | 22 | 11.6 | 0.98 |
| 6 | 1409 | 8.3 | 8.72 | 23.3 | 12.2 | 1.04 |
| 7 | 1181 | 8.5 | 8.58 | 22.7 | 12 | 1.08 |
| 8 | 1302 | 5.8 | 6.2 | 14.5 | 7.56 | 0.74 |
| 9 | 1094 | 7.9 | 7.8 | 20.4 | 10.7 | 0.96 |
| 10 | 997 | 13.1 | 7.82 | 19.8 | 10.7 | 0.95 |
| C1 | 77 | 8.6 | 3.18 | 3.7 | 4.12 | 0.26 |
| C2 | 91 | 7.1 | 2.6 | 3.5 | 2.9 | 0.23 |
| C3 | 341 | 14.7 | 5.25 | 5.2 | 4.44 | 0.51 |
| C4 | 496 | 6.5 | 5 | 8.4 | 5.1 | 0.51 |
| C5 | 807 | 5.8 | 5.34 | 15.6 | 7.7 | 0.69 |

Figure 13. Arsenic, cobalt, copper, lead, and tin concentrations (mg/kg) at sampling stations during the TEN Environmental Baseline Survey.




| Station | Depth (m) | Nickel (ppm) | Chromium (ppm) | Vanadium (ppm) | Zinc (ppm) |
|---|---|---|---|---|---|
| 1 | 1,659 | 42.5 | 54.1 | 51.2 | 61.2 |
| 2 | 1,463 | 38.5 | 53.2 | 50.2 | 57.7 |
| 3 | 1,091 | 28.7 | 45.4 | 35.5 | 45 |
| 4 | 1,631 | 65.1 | 114 | 113 | 96.9 |
| 5 | 1,272 | 36.5 | 55.4 | 47.8 | 57.6 |
| 6 | 1,409 | 38.8 | 54.9 | 49.7 | 57.9 |
| 7 | 1,181 | 38.7 | 60 | 50.6 | 61.3 |
| 8 | 1,302 | 25.7 | 40.6 | 33.1 | 41.2 |
| 9 | 1,094 | 34.8 | 55.9 | 44.7 | 56.2 |
| 10 | 997 | 36.3 | 55.9 | 43 | 55.1 |
| C1 | 77 | 12.2 | 34 | 18.7 | 23.3 |
| C2 | 91 | 11.5 | 29.6 | 15.2 | 19.6 |
| C3 | 341 | 17 | 69.5 | 29.9 | 43 |
| C4 | 496 | 20.5 | 49.3 | 25.1 | 38.3 |
| C5 | 807 | 30.3 | 49.1 | 36.5 | 45.7 |

Figure 14. Chromium, nickel, vanadium, and zinc concentrations (ppm) at sampling stations during the TEN Environmental Baseline Survey.




| Station | Depth (m) | Aluminum (ppm) | Iron (ppm) |
|---|---|---|---|
| 1 | 1,659 | 74,000 | 36,600 |
| 2 | 1,463 | 66,200 | 34,100 |
| 3 | 1,091 | 69,300 | 36,200 |
| 4 | 1,631 | 154,000 | 74,500 |
| 5 | 1,272 | 80,500 | 40,300 |
| 6 | 1,409 | 88,300 | 46,800 |
| 7 | 1,181 | 95,100 | 48,300 |
| 8 | 1,302 | 71,000 | 41,100 |
| 9 | 1,094 | 79,900 | 43,700 |
| 10 | 997 | 80,000 | 44,800 |
| C1 | 77 | 20,000 | 31,800 |
| C2 | 91 | 15,400 | 22,400 |
| C3 | 341 | 33,400 | 64,900 |
| C4 | 496 | 47,500 | 39,700 |
| C5 | 807 | 78,500 | 40,600 |

Figure 15. Total aluminum and iron concentrations (ppm) at sampling stations during the TEN Environmental Baseline Survey.

Other metals with potential environmental impacts or considered as priority pollutants include arsenic, cobalt, copper, lead, and tin (**Figure 13**). Concentrations of arsenic were generally similar for both pipeline route and development area stations and do not show any apparent spatial trends (**Figure 12**) that relate to proximity to wellsites. Concentrations of cobalt, copper, lead, and tin were generally higher at development area stations than at pipeline route stations, although there was no defined small-scale concentration gradient for any of the metals related to the proximity to wellsites. For example, cobalt was highest in Station 4, although it was located farther away from wellsites than other development area stations (**Figure 13**).

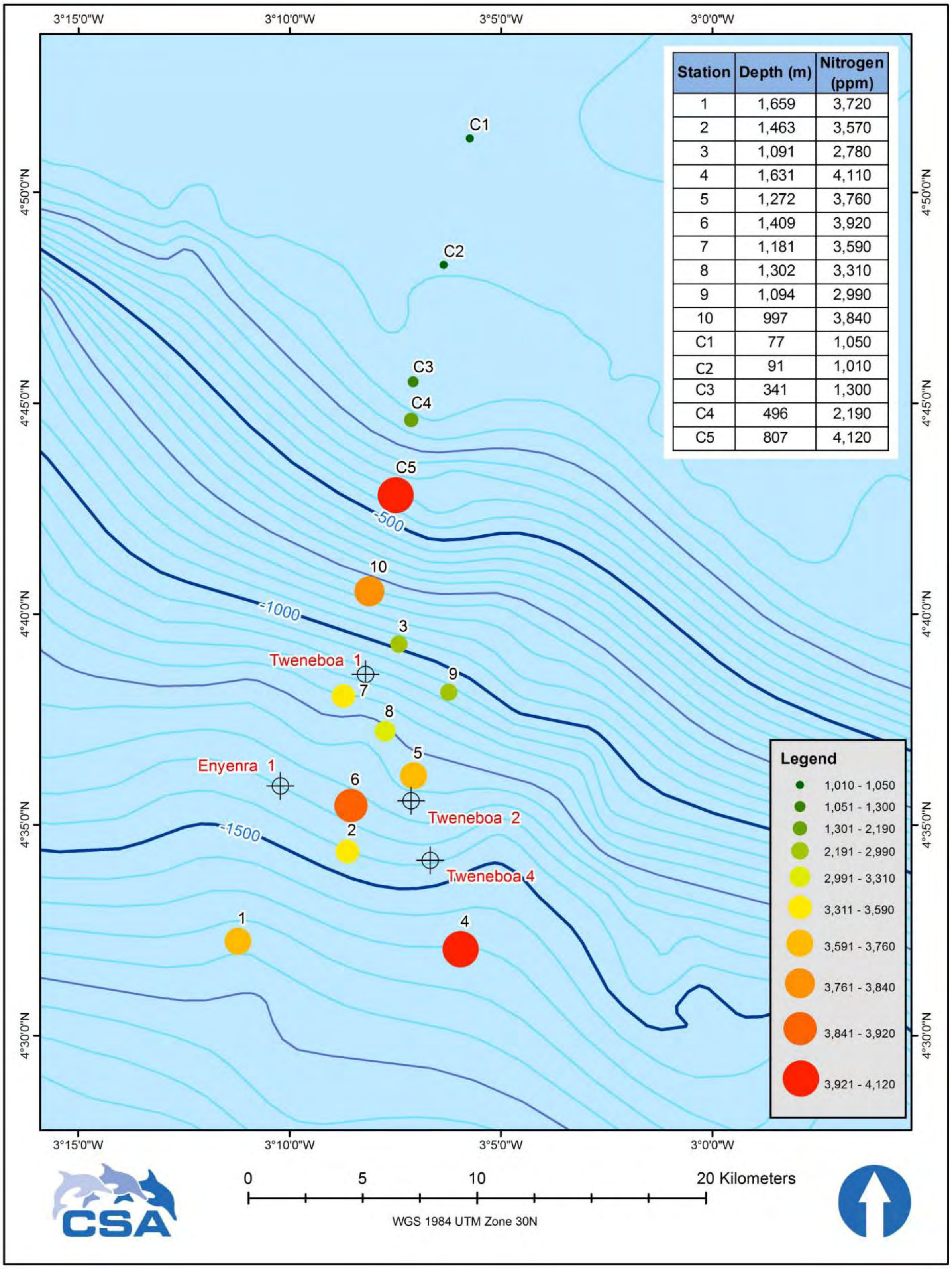
Concentrations of chromium, nickel, vanadium, and zinc are shown in **Figure 14**. As previously discussed with other metal analytes, concentrations of chromium, nickel, vanadium, and zinc were generally higher at development area stations than at pipeline route stations although there was no defined small-scale concentration gradient for any of the metals related to the proximity to wellsites. Although the average chromium concentration in development area stations was higher than pipeline route stations (59 ppm versus 46 ppm), one pipeline route station (C3) had a chromium concentration that was higher than 9 of the 10 development area stations (**Figure 14**).

Levels of aluminum and iron (which are not priority pollutants) are shown in **Figure 15**. Concentrations of both aluminum and iron are generally higher at development areas stations than at pipeline route stations. Average levels of aluminum and iron for development area and pipeline route stations are 85,830 ppm versus 38,960 ppm and 44,640 ppm versus 39,880 ppm, respectively. The differences in average concentration of aluminum and iron between development area and pipeline route stations would indicate that higher concentrations are related to proximity to wellsites within the development area. However, there is no defined concentration gradient associated with proximity to wellsites. These determinations are likely a result of local spatial variability related to local hydrographic and topographic conditions affecting sediment and discharge transport within the study area. Highest concentrations of both aluminum and iron were observed at Station 4.

## 4.8 SEDIMENT NUTRIENTS

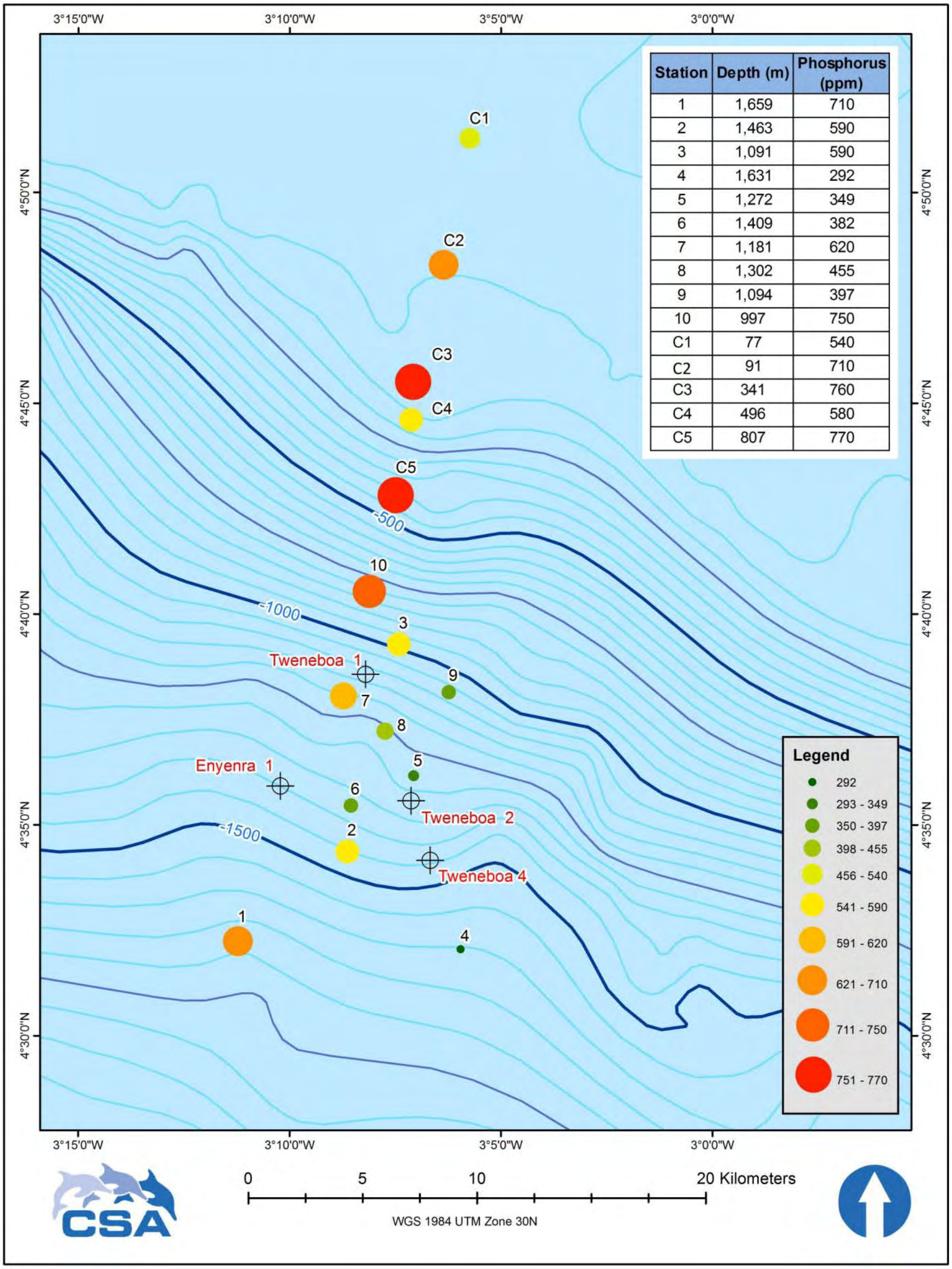
**Figure 16** depicts the total nitrogen concentrations in TEN sediments. Higher sediment nitrogen concentrations were observed in stations closer to the wellsites. Stations 4 and 6 had the highest total nitrogen concentrations in the development area while Stations 5 and 7 located closest to previous wellsites showed intermediate total nitrogen concentrations. There is an evident difference in total nitrogen concentrations between the development area stations and pipeline route Station C5, relatively close to wellsites, compared to the more shoreward pipeline route stations, which are farther from the wellsites. There is a marked depth-related increase in total nitrogen concentrations among the pipeline route stations.

In general, total phosphorus concentrations were higher at pipeline route stations compared to development area stations. Total phosphorus was highest in Stations C3 and C5 along the pipeline route. There was less variability in total phosphorus concentrations in development area stations than was observed for nitrogen (**Figure 17**). Higher concentrations of total nitrogen in development area stations may relate to greater organic content associated with finer sediment, while higher total phosphorus at pipeline route stations may be due to increased supply from terrestrial sources.




| Station | Depth (m) | Nitrogen (ppm) |
|---|---|---|
| 1 | 1,659 | 3,720 |
| 2 | 1,463 | 3,570 |
| 3 | 1,091 | 2,780 |
| 4 | 1,631 | 4,110 |
| 5 | 1,272 | 3,760 |
| 6 | 1,409 | 3,920 |
| 7 | 1,181 | 3,590 |
| 8 | 1,302 | 3,310 |
| 9 | 1,094 | 2,990 |
| 10 | 997 | 3,840 |
| C1 | 77 | 1,050 |
| C2 | 91 | 1,010 |
| C3 | 341 | 1,300 |
| C4 | 496 | 2,190 |
| C5 | 807 | 4,120 |

Figure 16. Total nitrogen concentrations (ppm) from sediments at sampling stations during the TEN Environmental Baseline Survey.




| Station | Depth (m) | Phosphorus (ppm) |
|---|---|---|
| 1 | 1,659 | 710 |
| 2 | 1,463 | 590 |
| 3 | 1,091 | 590 |
| 4 | 1,631 | 292 |
| 5 | 1,272 | 349 |
| 6 | 1,409 | 382 |
| 7 | 1,181 | 620 |
| 8 | 1,302 | 455 |
| 9 | 1,094 | 397 |
| 10 | 997 | 750 |
| C1 | 77 | 540 |
| C2 | 91 | 710 |
| C3 | 341 | 760 |
| C4 | 496 | 580 |
| C5 | 807 | 770 |

Figure 17. Total phosphorus concentrations (ppm) from sediments at sampling stations during the TEN Environmental Baseline Survey.

## 4.9 MACROINFAUNA

Macroinfaunal data by station are shown in **Figures 18** through **21**. Total macroinfaunal density was highest at pipeline route Stations C1 and C5 followed by development area Stations 3 and 10. A progressive decline in total macroinfaunal density with increased water depth was apparent among development area stations. There is no indication from the TEN EBS macroinfaunal data that there is a relationship between wellsite proximity and macroinfaunal density (i.e., spatial patterns indicate that lower macroinfaunal density is not associated with proximity to previous wellsites). Total richness also was highest at pipeline route Stations C1 and C5 followed by development area Stations 6 and 7 (**Figure 19**).

Total macroinfaunal density by major taxa is shown in **Figure 20**. Polychaetes had the highest density among the major taxa at pipeline route stations. The dominance of polychaetes was reduced at the development area stations with a corresponding increase in contributions from crustaceans and other taxa. As evident in **Figure 21**, the taxonomic richness of polychaetes was greatest at the pipeline route stations where they comprised at least 50% of the total number of taxa. In the development area stations, polychaetes were not as dominant and crustacean taxa comprised a higher proportion of the community.

**Table 16** lists macroinfaunal community indices for each TEN EBS station. Two consistent differences in the three community indices were noted between development area and pipeline route stations. Evenness (Pielou's Index J') appears to be higher (less diverse) at pipeline route stations compared to development area sites. While the Shannon-Wiener diversity determinations were very similar among the development area stations, the index was more variable among the pipeline route stations. No spatial trends were evident among Simpson's diversity determinations.

Table 16. Community indices for macroinfauna samples.

| Station | Pielou Index J' | Shannon-Wiener H'(loge) | Simpson's 1-Lambda' |
|---|---|---|---|
| 1 | 0.9435 | 3.177 | 0.9525 |
| 2 | 0.9103 | 2.814 | 0.9234 |
| 3 | 0.8885 | 2.992 | 0.9308 |
| 4 | 0.9211 | 2.888 | 0.9315 |
| 5 | 0.8924 | 3.065 | 0.9229 |
| 6 | 0.9075 | 3.024 | 0.9388 |
| 7 | 0.9044 | 3.045 | 0.9370 |
| 8 | 0.9617 | 3.096 | 0.9513 |
| 9 | 0.8793 | 2.865 | 0.9206 |
| 10 | 0.8370 | 2.587 | 0.8913 |
| C1a | 0.9376 | 3.435 | 0.9588 |
| C1b | 0.9377 | 3.307 | 0.9505 |
| C2a | 1.0000 | 2.565 | 0.9295 |
| C2c | 0.9916 | 3.151 | 0.9589 |
| C3b | 0.9335 | 2.749 | 0.9245 |
| C3c | 0.8892 | 2.209 | 0.8607 |
| C4a | 0.9866 | 1.768 | 0.8333 |
| C4b | 0.8831 | 2.552 | 0.8920 |
| C5a | 0.9366 | 3.246 | 0.9535 |
| C5b | 0.9163 | 2.197 | 0.8685 |

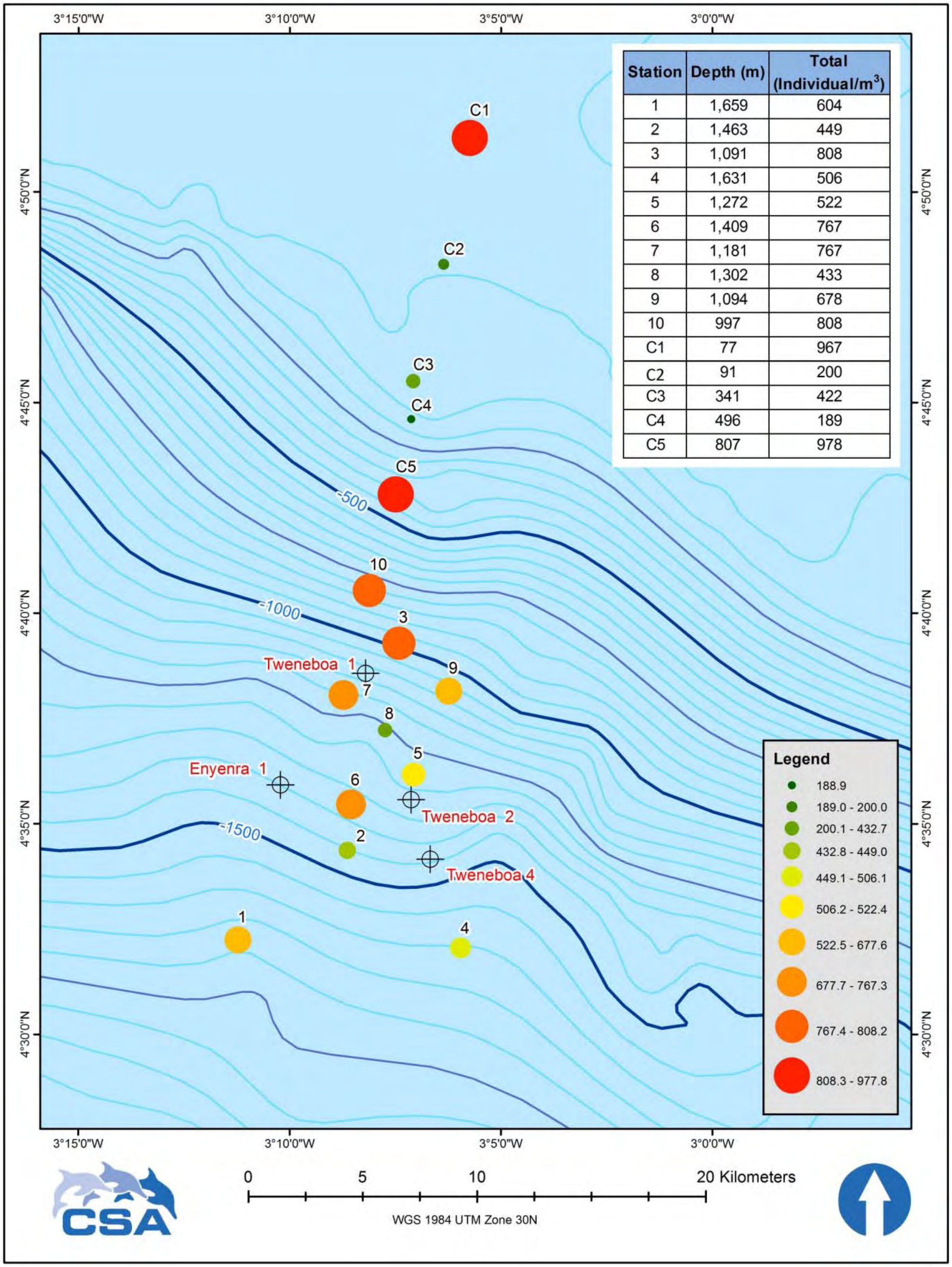



Figure 18. Total macroinfaunal density at sampling stations during the TEN Environmental Baseline Survey.

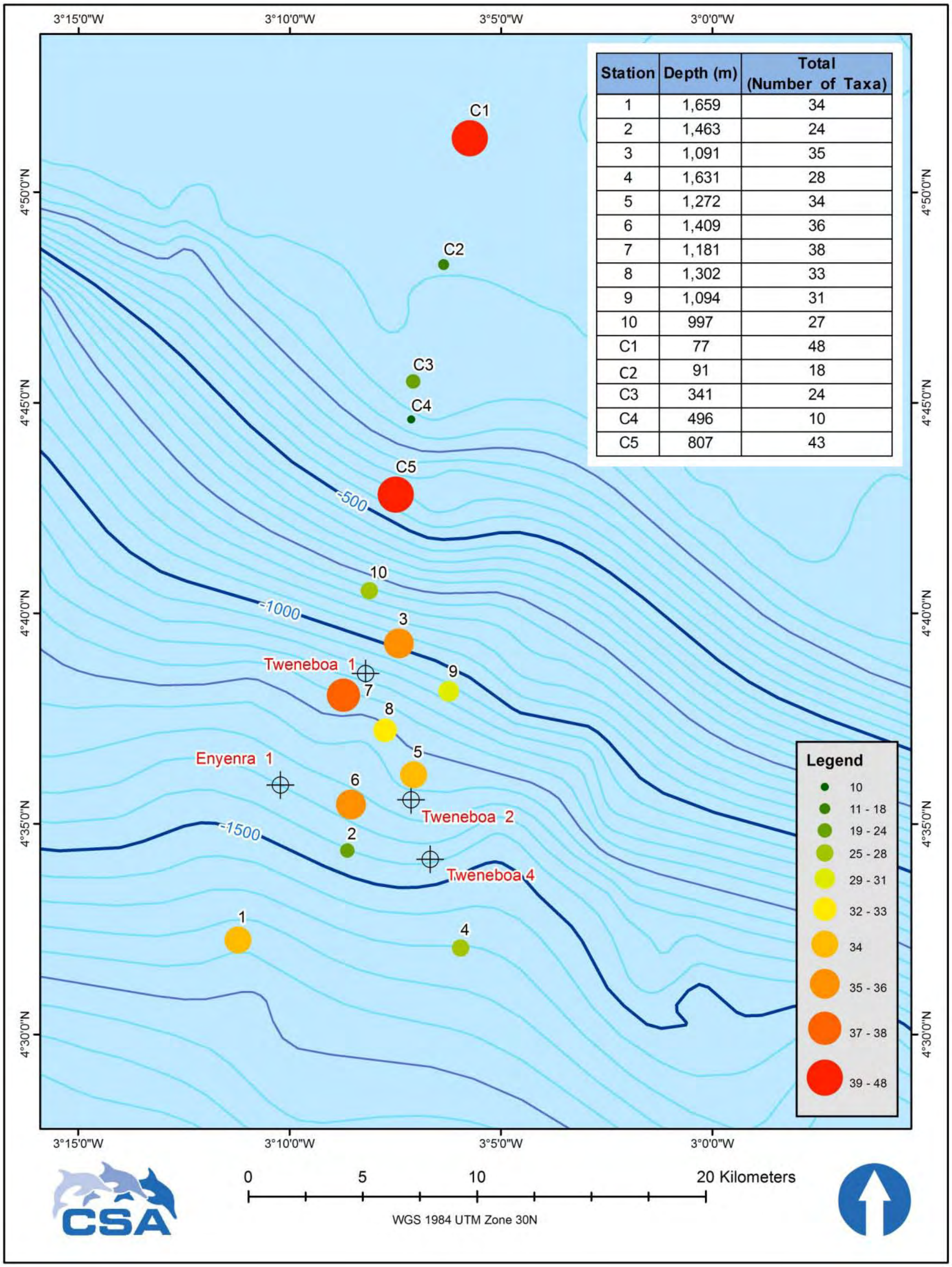



Figure 19. Total taxonomic richness at sampling stations during the TEN Environmental Baseline Survey.

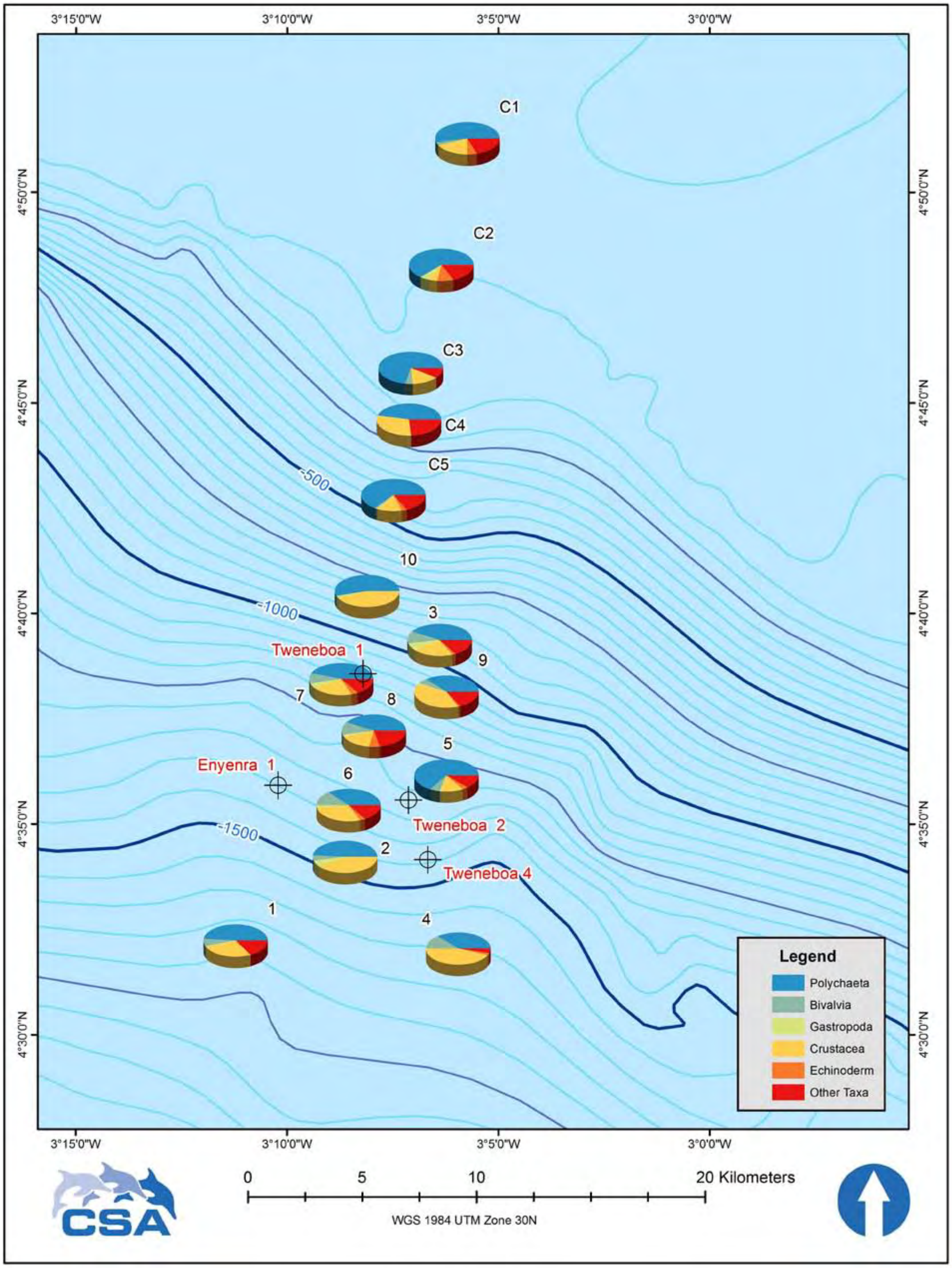



Figure 20. Total macroinfaunal density by major taxa at sampling stations during the TEN Environmental Baseline Survey.

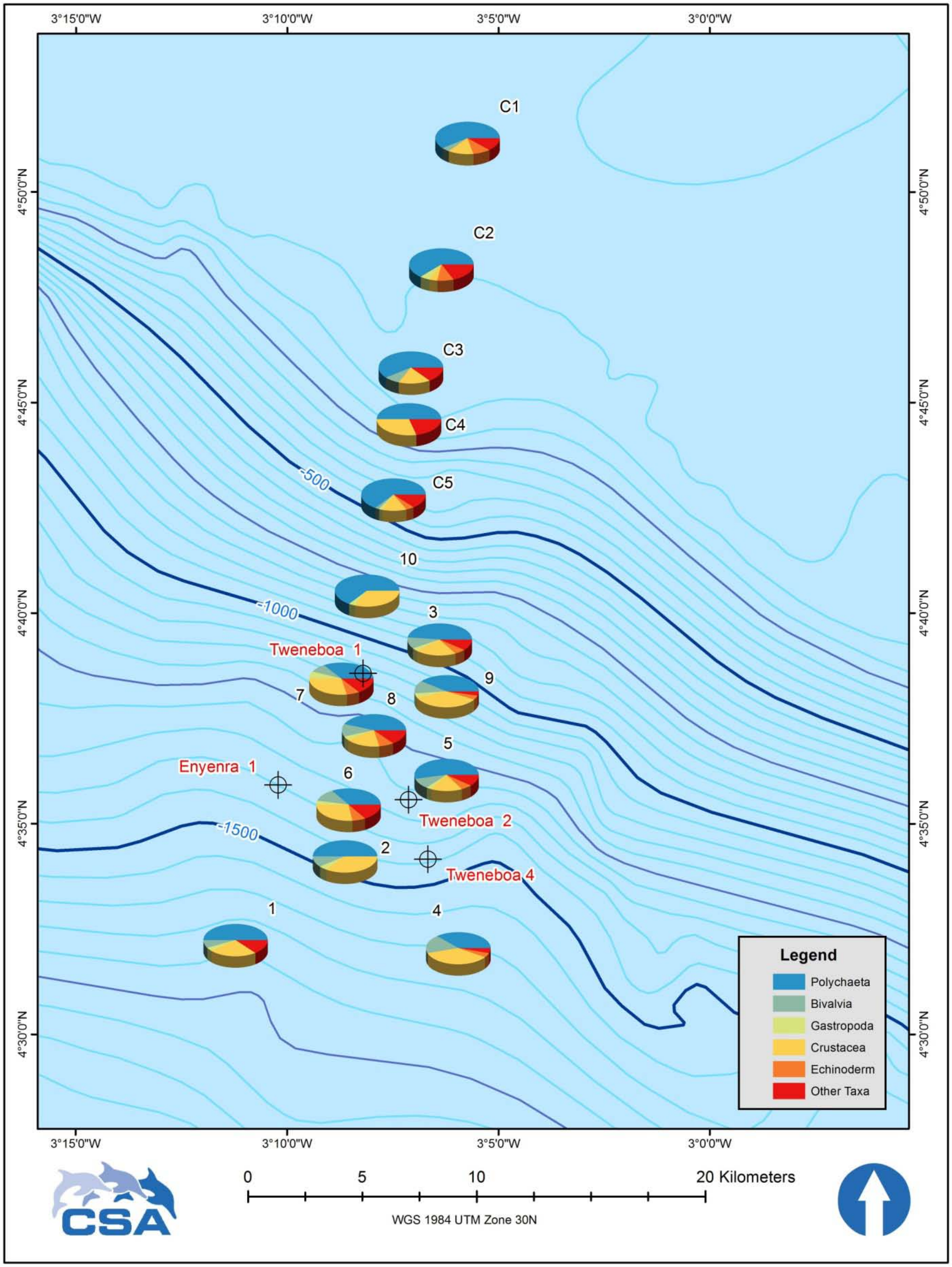



Figure 21. Species richness by major taxa at sampling stations during the TEN Environmental Baseline Survey.

The results of the pattern analysis, including cluster analysis and MDS, are presented in **Figures 22** and **23**, respectively. The stress value for the MDS is somewhat elevated but shows a pattern among the samples similar to that observed in the cluster analysis. The deepwater samples were distinct from the samples collected on the continental shelf. Of the deepwater development area sites, Station 8 was distinct from the other nine stations, which had similar taxonomic composition (similarity >38%). The taxonomic composition of pipeline route sites was more variable. For Stations C1 and C3, the macroinfaunal composition from the two replicate box cores (a and b) was similar (similarity >31%). In contrast, the macroinfaunal community at Stations C2, C4, and C5 was not as similar (similarity <25%), based on comparison of two replicates from each station. There are no readily identifiable factors that have produced this macroinfaunal community variability (i.e., patchiness).

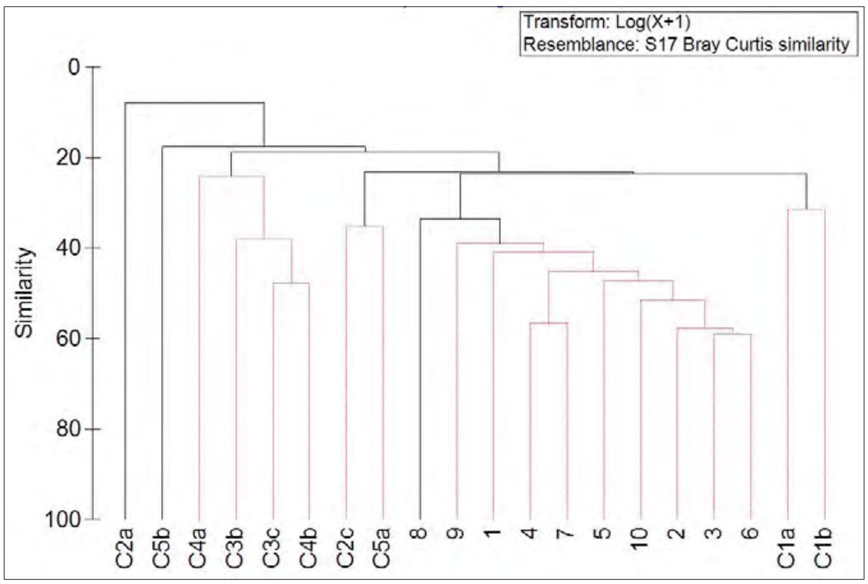



Figure 22. Dendrogram of the results of the pattern analysis.

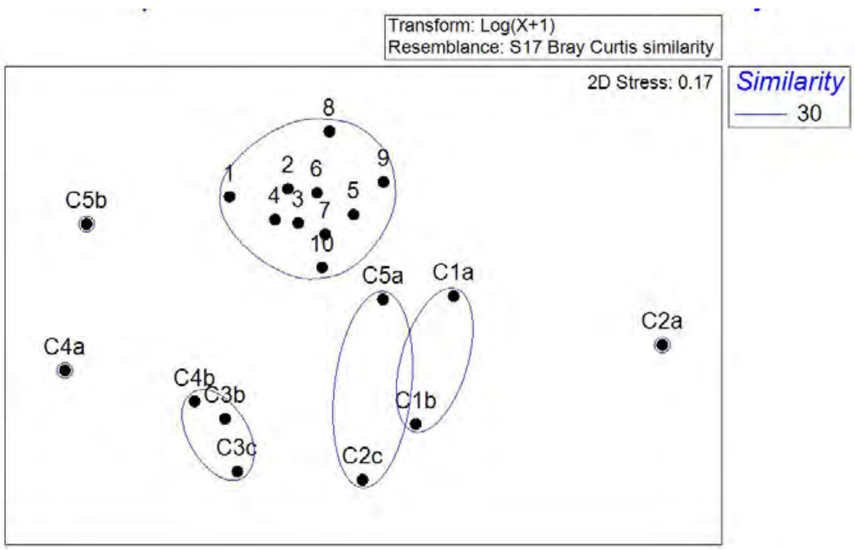



Figure 23. Multidimensional scaling plot of the results of the pattern analysis.

The most abundant species associated with the sample groups identified in the cluster analysis are presented in **Table 17**, based on SIMPER analysis. All the development area stations, with the exception of Station 8, were characterized by the presence of the microcrustacean species *Harpinia* sp. and *Joeropsis* sp., polychaetes *Aedicira* sp. A, *Polyophthalmus pictus*, *Paraonis gracilis oculata*, and *Prionospio cirrifera*, and the gastropod mollusk *Chaetoderma* sp. While *Harpinia* sp. also was present, the predominant species at Station 8 included several different polychaete and bivalve species not encountered at any of the other TEN EBS stations.

Table 17. Predominant species identified in the SIMPER analysis, based on results of the cluster analysis and subsequent station grouping.

| Sample Grouping from the Cluster Analysis | | Taxa* | |
|---|---|---|---|
| C2a | | *Chloeia cf. inermis* (P)<br>*Eunice vittata* (P)<br>*Marphysa* sp. *B* (P)<br>*Diopatra neapolitana capensis* (P)<br>*Harmothoe* sp. *A* (P)<br>*cf. Plesionika heterocarpus* (C)<br>*Amphipholis* sp. *A* (E) | *Tharyx dorsobranchialis* (P)<br>*Marphysa* sp. *A* (P)<br>*Glycera longipinnis* (P)<br>*Scoloplos* sp. *A* (P)<br>*Chaetoderma* sp. (G)<br>*Amphioplus archeri* (E) |
| C5b | | *Aricidea longobranchiata* (P)<br>*Spiophanes* sp. (P) | *Prionospio cf. steenstrupi* (P) |
| C3b<br>C4a | C3c<br>C4b | *Paraonis gracilis oculata* (P)<br>*Aricidea (Acmira) simplex* (P) | *Prionospio sexoculata* (P)<br>*Magelona cincta* (P) |
| 2c | 5a | *Isolda cf. pulchella* (P)<br>*Tharyx* sp. *A* (P)<br>*Aglaophamus (Nephthys) lyrochaeta* (P) | *Capitella capitata* (P)<br>*Eunice vittata* (P)<br>*Paraonides* sp. *A* (P) |
| C1a | C1b | *Paralacydonia paradoxa* (P)<br>*Polyophthalmus pictus* (P)<br>*Caulleriella cf. acicula* (P) | *Tharyx dorsobranchialis* (P)<br>*Amphioplus archeri* (E) |
| 8 | | *Harpinia sp.* (C)<br>*Nephthys* sp. *A* (P)<br>*Aricidea (Acmira) cerrutii* (P)<br>*Nucula* sp. (B) | *Aricidea (Acmira) lopezi* (P)<br>*Tharyx dorsobranchialis* (P)<br>*Paraonides lyra lyra* (P)<br>*Tellina* sp. *C* (B) |
| 1<br>3<br>5<br>7<br>10 | 2<br>4<br>6<br>9 | *Harpinia* sp. (C)<br>*Joeropsis* sp. (C)<br>*Chaetoderma* sp. (G)<br>*Aedicira* sp. *A* (P) | *Polyophthalmus pictus* (P)<br>*Paraonis gracilis oculata* (P)<br>*Prionospio cirrifera* (P) |

* Major taxonomic level identified in parentheses after taxon name.
B = Bivalvia; C = Crustacea; E = Echinodermata; G = Gastropoda; P = Polychaeta.

Results of the SIMPER analysis also revealed four separate groupings among the pipeline route stations. Very few species co-occurred among the groups (**Table 17**). While each station grouping contained species unique to that grouping, several species such as the the brittlestar *Amphioplus archeri* and the polychaete *Tharyx dorsobranchialis* were present in multiple pipeline station groupings. A limited amount of faunal overlap was also evident between development area and pipeline route taxonomic groupings (e.g., *Tharyx dorsobranchialis*, *Paraonis gracilis oculata*).

The relationships between sample groups and environmental data were examined with the BEST program (BIOENV method for all combinations). The macroinfaunal samples considered in the analysis included development area Stations 1 through 10 and pipeline route Stations C1a, C2a, C3b, C4a, and C5a. The set of environmental parameters consisted of the following:

- Metals concentrations (Al, Ar, Ba, Cd, Cr, Co, Cu, Fe, Pb, Hg, Ni, Sn, V, and Zn);
- Organics concentrations (TPH, EOM, total PAHs, and TOC);
- Sediment particle size classifications (sand, silt, and clay);
- Sediment nutrient concentrations (nitrogen and phosphorus); and
- Water depth.

Results of this analysis indicate that several parameters are correlated with the similarities and differences evident among the macroinfaunal samples. Environmental parameters that influence macroinfaunal community composition and faunal distribution include sediment TOC concentrations, sediment particle size, and water depth. Sediment chemical and nutrient levels did not have a detectable correlation with similarities or differences in macroinfaunal samples.

## 4.10 EPIFAUNA (PLAN VIEW CAMERA DATA)

Observations from the plan-view camera are summarized in **Table 18**. Plan view camera imagery provided visual documentation of the substrate; results show differences between deepwater (development area and C5) stations and pipeline route stations located on the shelf, and supported the grain size analysis data. Fish, holuthrians, crustaceans, molluscs, sea urchins, anemones, and shrimps were observed on the seabed of both environments. Similar levels of bioturbation and biota were observed in both environments. The macrobenthic community was relatively productive and active throughout the TEN EBS study area.

Table 18. Substrate, biological activity, and observations of epifauna in the development area and pipeline route stations.

| Station (**Appendix D Image No.**) | Substrate | Biological Activity | Biota Observed |
|---|---|---|---|
| Development Area | | | |
| 1 (1) | Soft bottom; fine sediment | Bioturbation: small burrows, tracks | Unidentified fish, holothuroid echinoderm |
| 2 (2) | Soft bottom; fine sediment | Bioturbation: small burrows, tracks | None |
| 3 (3) | Soft bottom; fine sediment | Bioturbation: small depressions, tracks | Holothuroid echinoderm |
| 4 (4) | Soft bottom; fine sediment | None | Crustacean |
| 5 (5) | Soft bottom; fine sediment | Bioturbation: tracks | Molluscs |
| 6 (6) | Soft bottom; fine sediment | None | None |
| 7 (7) | Soft bottom; fine sediment | Bioturbation | Unidentified pelagic |
| 8 (8) | Soft bottom; fine sediment | None | Unidentified pelagics, molluscs, jellyfish |
| 9 (9) | Soft bottom; fine sediment | Bioturbation | None |
| 10 (10) | Soft bottom; fine sediment | None | Molluscs, coral |
| Pipeline Route | | | |
| C1 (11) | Soft bottom; coarse sediment | Bioturbation: tracks | Fireworm (*Hermodice* sp.), anemones |
| C2 (12) | Soft bottom; coarse sediment | Bioturbation: small burrows | Anemones |
| C3 (13) | Soft bottom; coarse sediment | None | Urchins, demersal fish |
| C4 (14) | Soft bottom; fine sediment | Bioturbation: small burrows; tracks | Shrimp, anemones, duckbill eel |
| C5 (15) | Soft bottom; coarse sediment | None | Small invertebrates, brittlestar, fish |

## 4.11 THREATENED AND ENDANGERED SPECIES

No sensitive habitats or threatened or endangered species were identified during the course of the TEN EBS effort.

# 5.0 SUMMARY

In support of efforts to develop the Tweneboa, Enyenra, and Ntomme (TEN) development area in the Deep Water Tano Block, TGL contracted CSA to conduct an EBS within the TEN development area and along a designated gas export pipeline route. Results of the EBS will be utilized in support of an EIA for the project. The objectives of the TEN EBS were to:

- Determine environmental baseline conditions (i.e., biological, chemical, and physical) prior to development operations;
- Provide baseline conditions of the environment against which effects from future operations can be compared; and
- Identify parameters within the ecosystem that may be sensitive to change and provide a reference point to evaluate future claims of impacts.

The TEN EBS sampling effort included water column profiling and seawater collection, seafloor sediment sampling at 15 sampling stations, and seafloor documentation using plan-view imagery. The water column was sampled daily during survey operations for hydrographic and physicochemical parameters. Sediment sampling also was conducted to analyze physical, chemical, and biological parameters of the seafloor. The seafloor in the survey area was qualitatively characterized using an underwater camera system.

Hydrographic and water column sampling results characterized conditions that are typical of tropical open ocean conditions with good water quality, i.e., a warm, saline, well oxygenated, and clear water in the upper portion of the water column with low nutrients, productivity, and suspended solids. Temperature, dissolved oxygen, and salinity typically decrease with increasing depth in the water column.

Hydrocarbons in seawater collected during the survey were not presented because of contamination of seawater samples from the organic solvent used for preservation and extraction. Data from previous surveys conducted in the area of the Jubilee Field were discussed for reference. Seawater hydrocarbon determinations from the Jubilee Field are comparable with results from other deepwater surveys conducted worldwide.

Sediment sampling characterized the seabed within the study area; in general, survey results indicate that the substrate is different between the offshore development area and the pipeline route. Sediments along the pipeline route have higher proportions of the sand fraction, while development area sediments are predominantly silts and, to a lesser extent, clays. TOC concentrations increased with depth along the shallower pipeline route stations and were highest among development area stations. Results of sediment organics analyses indicate that although higher organics concentrations are associated with the development area, there is no defined organic concentration gradient associated with proximity to previous drilling operations (i.e., wellsites). Similarly, sediment metals data indicate that elevated levels of most metals were observed at the development area stations, however, there is no defined gradient associated with metals concentrations and proximity to previous wellsites. Most sediment metals concentrations are within the range for average marine sediments. Only barium exhibited a concentration gradient. Lowest barium concentrations were found at pipeline stations most distal from previous wellsites, while highest barium levels were noted at the deepest development area stations. Relatively high spatial variability concerning barium concentrations was evident in the vicinity of previous wellsites; stations most distal from previous wellsites exhibited the lowest barium levels, suggesting there is a large-scale correlation of higher barium concentrations at locations near previous wellsites.

Higher sediment nitrogen concentrations were observed in stations closer to the wellsites. In general, total phosphorus concentrations were higher at pipeline route stations compared to development area stations. There was less variability in total phosphorus concentrations in development area stations than was observed for nitrogen.

Total macroinfaunal density was highest at two pipeline route stations, followed by two development area stations. A progressive decline in total macroinfaunal density with increased water depth was apparent among development area stations. There is no indication from the TEN EBS macroinfauna data that there is a relationship between wellsite proximity and macroinfauna density (i.e., spatial patterns indicate that lower macroinfaunal density is not associated with proximity to previous wellsites). As exhibited with macroinfaunal density, total richness also was highest at two pipeline route stations followed by two development area stations. Polychaetes, bivalves, gastropods, crustaceans, and echinoderms were the primary taxonomic groups comprising the macroinfauna. In both development area and pipeline route stations, polychaetes and crustaceans were numerically dominant, exhibiting the highest densities. The average number of taxa in development area stations was generally similar to pipeline route stations. However, the number of taxa was more variable at pipeline route stations than development area stations.

In terms of macroinfaunal community metrics, consistent differences were evident in two community indices. Evenness (Pielou's Index J') appears to be higher (less diverse) at pipeline route stations compared to development area sites. While the Shannon-Wiener diversity determinations were very similar among the development area stations, the index was more variable among the pipeline route stations. No spatial trends were evident among Simpson's diversity determinations.

The results of the pattern analysis, including cluster analysis and multidimensional scaling, indicated that deepwater samples were distinct from the samples collected along the pipeline corridor (on the continental shelf). Of the deepwater development area sites, one station was distinct from the other nine stations, which had similar taxonomic composition (similarity >38%). The taxonomic composition of pipeline route sites was more variable.

Results of the multivariate analysis indicated total organic carbon, sediment particle size, and water depth were correlated with the similarities and diffrerences among the macroinfaunal samples. The seabed imagery showed bioturbation and biota at the majority of stations, indicating a relatively productive and active macrobenthic community.

The EBS data indicate that water column conditions in the Deep Water Tano Block are good; while there is evidence of oil and gas drilling activity present on the TEN seafloor, no impacts on the seafloor biota are evident. Differences between the development area and pipeline route stations relative to the chemical analyte concentrations are most probably related to proximity to previous wellsites and associated oil and gas activities. Chemical analyte concentrations were variable within the development area; there were no defined small-scale concentration gradients associated with analytes and proximity to previous wellsites. Local spatial variability for various analyte concentrations in proximity to the previous wellsites was most likely related to local hydrographic and topographic conditions affecting sediment and discharge transport.

# 6.0 LITERATURE CITED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# APPENDICES

# APPENDIX A

## RV *J.W. Powell* Specifications

# RV *J.W. Powell*


**The RV *J.W. Powell***

## REGISTRATION

| | |
|---|---|
| **Owner** | TDI-Brooks International, Inc. |
| **Operator** | TDI-Brooks International, Inc. |
| **Official Number** | 501390 |
| **Registry** | USA |
| **Home Port** | Galveston, Texas |
| **Radio Call Sign** | WDA 6172 |
| **Classification** | Unclassed, Uninspected with USCG Designation as Oceanographic Research Vessel (ORV) |
| **Builder** | American Marine Corporation, New Orleans 1964, Hull Number 889 |
| | Major Refit to present Research Configuration in 1983/84 by U.S.G.S. with new stability and trim calculations. International Load Line Certificate 1999. |

| PRINCIPAL DIMENSIONS | ACCOMMODATIONS | CAPACITIES |
|---|---|---|
| Length: 142.33 ft (43.38 m) | 25 air conditioned berths in:1 - one person room and 6 - four person rooms | Fuel Oil - 41,000 g #2 diesel |
| Breadth: 35.0 ft (10.67 m) | 3 showers, 3 heads | Lube Oil - 360 g |
| Depth: 12.0 ft (3.65 m) | Full service galley and mess | Potable Water - 10,500 g |
| Draft: 10.042 ft (3.06 m) | General purpose room | Water Maker - Village Marine RO unit @ 1,000 gpd |
| Freeboard: 2.021 ft (0.61 m) | Recreation/lounge with TV/VCR | Fuel Consumption - 90 gph cruise, —50 gph working/survey |
| Tonnage: 297 GRT, 202 NRT; ITC-474 Gross, 192 Net | Laundry - washer and dryer | Speed - 12 kts |
| Deck Space: 2,758 $ft^2$ of open deck with longest dimensions of 100 ft x 32 ft (30.5 m x 9.7 m) | 1-walk-in freezer | Endurance/Range – 19 days/5,500 nm |
| | Walk-in refrigerator | |
| | Dry food storage room | |

## NAVIGATION & COMMUNICATION

| |
|---|
| Gyrocompass - Sperry MK 227 |
| Autopilot - Sperry, Model 1882521 |
| Magnetic Compass - Ritchie 5", B453 |
| Radars (2) - Simrad RA 722VA, Furuno 1731 Mk 2 |
| Fathometers (2) - FurunoFCV-1000, and Furuno FCV-382 |
| GPS - Furuno GP70 Mk 2 |
| MF/HF - Furuno FS-1562-15 with Furuno DSC-6 and DSC Watch Receiver Furuno Model AA- -50 |
| VHF (3)- 2 Furuno VHF/DSC FM-850 , 1 Hummingbird DC-25 |
| VHF Handhelds (4) - 2 Standard Communications Corp. HX230S, 2 Furuno FM-77 |
| Satellite Communications - |
| INMARSAT A -Magnavox 2400 (voice, telex, fax) |
| Mnini-M - KHV Tracphone 50 |
| INMARSAT C- Furuno IB581, Felcom 12IC-212 |
| TELEX - Furuno IB-581 |
| PetroCom cellular telephone (voice & fax) standard cellular service and offshore Gulf of Mexico |
| Meteorological - Weather Fax, Radio Holland Nav 5 NavTex receiver |
| Intercom - Hose McCann 10 station |
| Loud Hailer - bow and stern |
| Sound Powered Telephone - 4 station |

## OTHER FEATURES

| |
|---|
| 2 - stern mounted 2 speed manual and hydraulic Barients capstans |
| 2 - 24" moon pools with bottom fairing |
| 18' x12' internal transducer well |
| Acoustically transparent window in transducer well and array of 16 transducers |
| Hull mounted 12 and 3.5 KHz transducers |
| Pedestal mounts for 2 - 20 ISO standard ocean containers |
| Deck crane |
| Shop with drill press, welding/cutting, power tools |
| Stern A-frame - hydraulically articulated, inside clearances 25' horizontal, 35 vertical, 15' astern |
| Starboard A-frame - hydraulically articulated, inside clearances 10.5' vertical, 7.5 horizontal |
| 2 - 15' skimmer booms, port and starboard stern |
| 10' side gates, port and starboard midships |
| 22' stern gate opening |
| Bulwarks height - 42" |
| 24 - 2" screw in pad eyes on 7' centers on main deck |
| Portable utility and lab vans on request |

## MACHINERY

| | |
|---|---|
| **MAIN PROPULSION** | Twin screw installation, 2 Caterpillar D-398 turbocharged diesel engines developing 1,530 hp @ 1,200 rpm with 3192 Caterpillar reduction gears driving 4 blade fixed pitch propellers (72" diameter x 62" pitch) in outboard rotation. |
| **GENERATORS** | 2 non-parallel Caterpillar D-334, 175 Kw each |
| **STEERING SYSTEM** | Vickers hydraulic unit with 2 hydraulic pumps and 5 hp electric motors; Schrader bellows. |
| **CENTRIFUGE** | Alfa Laval, 250 gpm |
| **WATER MAKER** | Village Marine Reverse Osmosis unit, 1,000 gpd, MSD |
| **HYDRAULICS POWER** | Hydura pump unit with 30 hp electric motor, controlling stern F-frame and twin stern catheads. |
| **ANCHOR WINDLASS** | Ideal Windlass TRW2C2O, 15 hp, double drum double cathead; connected via 9 shots of 11/4" chain to twin 2,000 lb stockless anchors. |
| **ENGINEERS CONTROL ROOM** | For continuous monitoring of propulsion engines and power generation for RPM, temperature, and pressures with abnormalities indicated by alarm. DeLaval fuel level selector and indicator system and alarm. Emergency steering and control station. |
| **PRIMARY CORING WINCH** | Diesel direct through torque convertor. 5,000 m of 1/16" wire rope. Line counter and tensiometer. Rated at 22,000 lb pull. |

## SAFETY EQUIPMENT

| |
|---|
| 2 - 25 man life rafts (200% capacity) |
| Type I PFD - 50 (200% capacity) |
| 275 lb Kidde Halon system for main engine room |
| Smoke detectors (17 in all occupied and living spaces) |
| Emergency lighting (24 volt installed, and portable power out systems in all occupied spaces) |
| 5 fire fighting stations |
| 1 - 3 m MOB/rescue boat w/40 hp outboard |
| 2 Fire fighter suits |
| 2 SCBA and 4 air bottles |
| Fire fighting and safety equipment to meet safe manning and SOLAS requirements |
| GMDSS |
| EPIRB - SEA 406 |
| SARTS (3) - 1 Raytheon Serpes IESM, 2 Jotron Tron-SARTS |
| Extensive first aid and medical supplies including trauma kit, evacuation litters, breathing oxygen, and lifeboat first aid kits. |

# APPENDIX B

## Modifications to Sampling Analytes and Protocols

CSA International, Inc.
www.csaintl.com
8502 SW Kansas Avenue
Stuart, Florida 34997
Phone: 772-219-3000
Fax: 772-219-3010

TO: Alan Lupton, Tullow Ghana Ltd.
FROM: Luis Lagera Jr, PhD. and Bruce Graham Senior Scientists, CSA International, Inc.
DATE: 29 December 2010
RE: Technical Concerns on RFP Specified EBS Methods

---

CSA International, Inc. (CSA) is preparing the proposal for the Deep Water Tan Environmental Baseline and Geophysical/Geotechnical Surveys and as part of our preparation we have conducted a review of the Scope of Work (SOW) specific to the Deep Water Tano Environmental Baseline Survey. As part of the review, we have prepared the following responses and recommendations to address technical concerns of the provided SOW. The intention of this memorandum is to work with TGL in providing a scientifically sound and cost-effective technical approach for meeting the EBS and EIA objectives. CSA would very much appreciate your attention and consideration in these matters.

**Infauna**

The RFP specifies use of a 50 x 50 cm boxcore and a 22 x 22 cm insert for collecting an infauna sample. Is the size of the insert based on a specific reason or technical basis? In-lieu of a specific reason for the specified insert size, CSA requests that variance from the RFP specifications be allowed so that an insert of different size can be used. Could we recommend a 0.1225 $m^2$ insert which is being used for the Jubilee Field Drill Cuttings Study infauna sampling? This would provide an adequate sample size and would be best to use a similar insert size for comparison purposes.

**This recommendation would be acceptable - It is important that there is comparability where possible with the Jubilee field infaunal sampling.**

**Sulphate-Sulfur**

The RFP specifies that sulphate/sulfur is to be analyzed in seawater and sediment samples. With extensive experience conducting EBS for oil and gas projects world wide, CSA has not measured sulphate-sulfur in sediment. Is there a specific reason for the collection of these sampling parameters? Sulfate is a major component of seawater and is typically not considered a nutrient that figures as significantly in water column or benthic productivity as much as nitrogen, phosphorus, and silicate. Could we recommend the measurement of chlorophyll *a* in seawater as a more meaningful parameter for characterizing the baseline environment concerning nutrient levels, especially for the nearshore. In sediment, a measurement of sulphide concentration will be indicative of redox conditions while sulphate in surface sediments will most likely reflect concentration in the seawater at the sediment surface. In the sediment, if necessary to characterize the redox status could we recommend the sampling of acid volatile sulfide at the near surface which is a better index of redox status/history than sulfate.

**Agreed – Please modify the programme of work as follows**

1. **Omit the requirement for sulphate/sulfur in both water and sediment.**
2. **For Seawater - Replace with the requirement to analyse chlorophyll *a* (same number of samples)**
3. **For sediments - Replace with the requirement to an of acid volatile sulfide (same number of samples – samples to be taken from top 2 cm of sediment)**

**Sediment Metals**

The RFP specifies that heavy metals must be analyzed in the <63μm size fraction of the sediment. Is there a specific reason for the analysis of metals specific to the fine fraction of the sediment? Typically, industry programs do not measure for metals in a specified size fraction but analyzes the whole sediment.

By specifying a particular size fraction, the comparability of these sediment data with other results may be limited since most data for sediment metals are for whole sediments. Fractionation of the sediment could bias the data during the drying and sieving process. Additionally, the fractionation requirement will increase the overall sample size requirement and add to the analytical cost. CSA would recommend that whole sediment be analyzed to determine metal concentrations.

The RFP specifies that for sediment metals "*Analysis shall be conducted using Inductively Coupled Plasma Mass Spectroscopy (ICPMS)*." Please indicate if the laboratories have flexibility in the utilization of analytical methods. In general, the RFP is very prescriptive concerning analytical methods and may limit the laboratories in providing the highest quality services. For example, using ICP-MS to analyze for Al, Ca, and Fe in seawater is atypical as concentrations of these metals are very high relative to trace metals and ICP-MS sensitivity may be overwhelmed by interference from gross anion concentrations (salts) subsequently confounding the analytical results.

Additionally, requiring that "*Any soluble barium sulphate is fused in an alkali medium to liberate barium*." will involve a non-standard method that would add to the analytical cost and is probably not warranted for developing a baseline for the EIA. This specific procedure may not be necessary depending on the analytical method used for the determination of barium concentrations in sediments.

If there is flexibility concerning analytical methods, CSA would recommend that the specific methods and target detection limits for each metal from selected analytical labs be described instead of requiring a laboratory to comply with the letter of the RFP relative to analytical methods. For the purposes of an EIA, specific analytical methods are probably not warranted and the EIA process will be better served by specifying minimum detection limits.
**The methodology stated in the RFP is that used routinely for analysis of sediment metals in the UK North Sea. However, TGL are keen to ensure that there is as much comparability as possible with the sampling/analyses already undertaken in the Jubilee Field. For this reason we agree that there can be some flexibility in the analytical methodology from that stated in the RFP. It is essential, however, that the final methodology selected (and therefore presumably the analytical laboratory chosen) be as comparable as possible with that used for previous samples in the area.**

**Number of Seawater Samples**
Please indicate if there is any flexibility concerning the number of seawater samples. CSA believes that the number of seawater samples is excessive and would recommend that seawater sampling be done from near surface and near bottom for each day the survey is conducted for each EBS element. For the purposes of establishing a baseline for the open-ocean and nearshore, a daily sampling of the water column conditions should be adequate for the purposes of the EIA.
**Agreed – sample all water quality parameters on a daily basis (single surface and near bottom sample per day). However, if both open ocean and nearshore sampling is undertaken in a single day then water quality sampling should be undertaken in both.**

**Heavy/Trace Metals in Seawater**
For the purposes of the EIA, CSA does not recommend analyzing for metals in seawater. The accurate analysis of metals in seawater is a major technical challenge due to the typically ultra-low levels present in seawater in the open ocean. Most U.S. EPA methods for analysis of metals are not adequate for determining their concentration in seawater. On their own, ICP-MS methods are not adequate due to the salt interference. Due to the low concentrations of metals in seawater, reductive precipitation methods are recommended for some metals followed by ICP-MS for lower (more sensitive) detection limits. For some metals analysis by ICP-OES is more appropriate. The proper analysis of metals in seawater also requires very clean and tedious sampling methods that will require additional time, materials, and QC in the field all of which adds to the cost.
**Agreed – Omit requirement to undertake seawater metals sampling / analysis**

**Total Dissolved Solids (TDS)**
The RFP specifies that TDS be determined in seawater samples. Is there a specific reason for the collection of this sampling parameter? TDS in seawater is a gross measurement that will not vary much

among stations/samples in the open ocean where the salinity is relatively similar. The collection of conductivity and temperature measurements to determine salinity are adequate for characterizing the water column dissolved solids for the EIA. TDS is typically measured in freshwater, not seawater and would have very little utility in an EIA for characterizing an oceanic system.
**Agreed – Omit requirement to undertake seawater TDS sampling / analysis**

**Total Suspended Solids (TSS)**
In Table 4.2 of the RFP TDS/TSS was to be determined using a "*TDS/TSS meter In field measurement*". We are not aware of a TDS/TSS meter. Please see note above regarding TDS. TSS as defined by APHA and U.S. EPA would be measured by filtration and gravimetric procedures. Instead of sampling for total suspended solids we would recommend sampling turbidity in nephlometric turbidity units (NTUs) within the water column. Turbidity is the cloudiness of a fluid related to individual particles suspended within the fluid and is a measurement of light transmissivity within the water column and provides an index for suspended solids. CSA can equip its CTD with a turbidity sensor to measure turbidity with depth.
**Agreed – Please modify methodology to:**

1. **Omit seawater TSS sampling/analysis**
2. **Equip the CTD with a turbidity sensor to measure turbidity with depth.**

**Total Organic Matter/Fractionated Organic Carbon**
Section 4.5.4 states the following:
"*4.5.4 Sediments - Total Organic Matter*
*Air dried ground samples should, following carbonate removal treatment, be analysed using Loss on Ignition (dry soil basis). Fractionated Organic Carbon (FOC) Ground and dried acid digested samples should be analysed using the appropriate laboratory standard.*"

Please provide clarification concerning the reference to fractionated organic carbon. The second sentence seems out of place and analysis of fractionated organic carbon does not seem warranted for determination of TOM.
**Noted - Error in the RFQ – please restrict analysis to TOM**

**Sediment Redox**
Is there a specific reason for the collection of this sampling parameter? Although the measurement can be done, measuring redox of the sediment at a single point in the sediment sample does not provide a good characterization of the sediment redox status. At some depth, all sediments will become reducing and anoxic. If possible, CSA would recommend removing this parameter as it is technically difficult to measure correctly and the utility of the data from single point measurements in the sediment will be minimal for establishing baseline of an EIA.
**Agreed – Omit Redox analysis. As discussed above, sediment sulphide analysis will adequately sample redox.**

**Seawater pH**
The pH in seawater is not mentioned in Section 4.4 but is listed as a parameter in Table 4.2 as an in-field measurement. Unless there is a good scientific question being considered, measurement of pH in highly buffered seawater is probably not warranted for the EIA.
**Agreed – omit seawater pH measurements**

**QA Requirements**
CSA operates under a QA Program but has no formal QMS in place. However, its QA Plan addresses quality requirements and QA/QC procedures will be implemented under its proposed scope. CSA can prepare a Sampling Analysis Plan for the Deep Water Tano EBS and GGS but will not be compliant with ISO requirements for a QA Plan. CSA would ask TGL to consider our QA Program for the Deep Water Tano Sampling Program which was acceptable for the Jubilee Field Drill Cuttings Study.
**Agreed – as CSA has already undertaken a successful sampling/analytical programme for TGL a QA programme similar to that produced for the Jubilee field work will be acceptable**

# APPENDIX C

## Geographic Coordinates of Hydrographic Profiling Locations and Water and Sediment Sampling Station Locations

Table C-1. Geographic coordinates of sampling stations (WGS84, UTM Zone 30 North) and water depths.

| Station | Easting | Northing | Latitude (North) | Longitude (West) | Water Depth (m) | Distance to Shore (km) |
|---|---|---|---|---|---|---|
| Tweneboa/Enyera Development Area (Deep Water Field) | | | | | | |
| 1 | 479265.62 | 501507.13 | 4°32’13.823" | 3°11’12.898" | 1,659 | 62 |
| 2 | 482638.89 | 503750.00 | 4°33’26.895" | 3°09’23.441" | 1,463 | 57 |
| 3 | 485138.89 | 503194.44 | 4°33’08.818" | 3°08’02.302" | 1,091 | 47 |
| 4* | 489045.44 | 501162.11 | 4°32’02.649" | 3°05’55.510" | 1,631 | 60 |
| 5 | 486944.44 | 508750.00 | 4°36’09.763" | 3°07’03.734" | 1,272 | 53 |
| 6 | 484196.00 | 507446.00 | 4°35’27.277" | 3°08’32.930" | 1,409 | 55 |
| 7 | 483888.89 | 512222.22 | 4°38’02.828" | 3°08’42.929" | 1,181 | 50 |
| 8 | 485694.44 | 510694.44 | 4°37’13.082" | 3°07’44.316" | 1,302 | 51 |
| 9 | 488480.80 | 512399.40 | 4°38’08.625" | 3°06’13.887" | 1,094 | 49 |
| 10* | 485001.30 | 516814.70 | 4°40’32.403" | 3°08’06.851" | 997 | 45 |
| Gas Export Pipeline Route (Shore Route) | | | | | | |
| C1* | 489400.09 | 536592.53 | 4°51’16.552" | 3°05’44.158" | 77 | 25 |
| C2 | 488261.29 | 531062.62 | 4°48’16.448" | 3°06’21.104" | 91 | 31 |
| C3 | 487339.14 | 526834.91 | 4°45’58.755" | 3°06’51.019" | 341 | 36 |
| C4 | 486853.64 | 524301.99 | 4°44’36.261" | 3°07’06.766" | 496 | 38 |
| C5 | 486168.83 | 520999.57 | 4°42’48.703" | 3°07’28.978" | 807 | 41 |

* Conductivity, temperature, and depth (hydrographic) and water column sampling station.

# APPENDIX D

## Plan View Photographs

Image 1. Soft bottom substrate characterized by various bioturbation including small burrows and tracks was observed at Station 1 of the TEN development area. An unidentified fish and translucent holothuroid are visible in the lower center of the image.

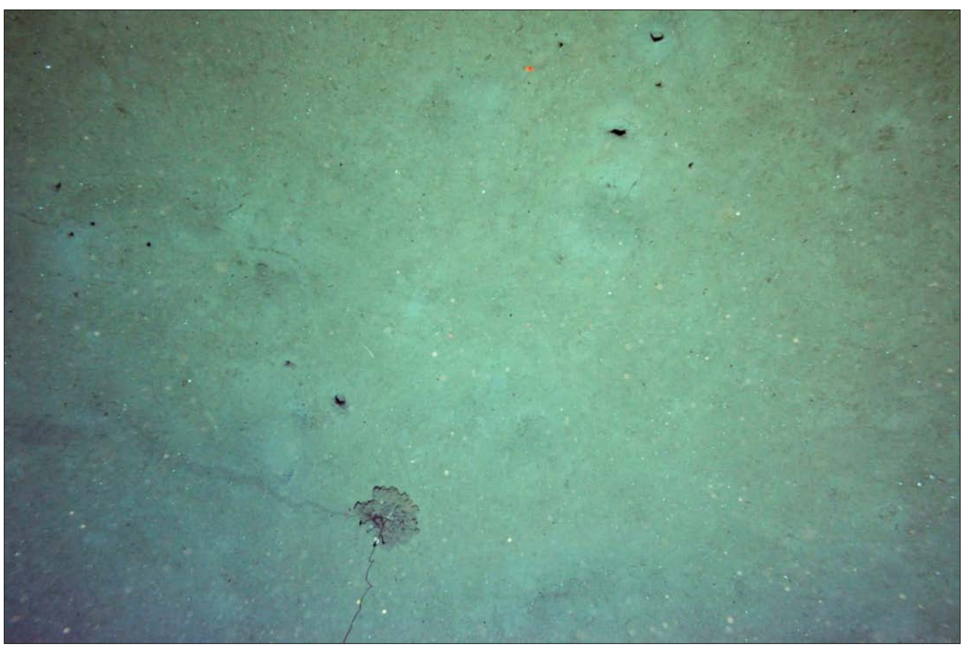

Image 2. Soft bottom substrate characterized by various bioturbation including small burrows and tracks was observed at Station 2 of the TEN development area. Level of observed bioturbation would indicate a relatively productive and active infaunal community.

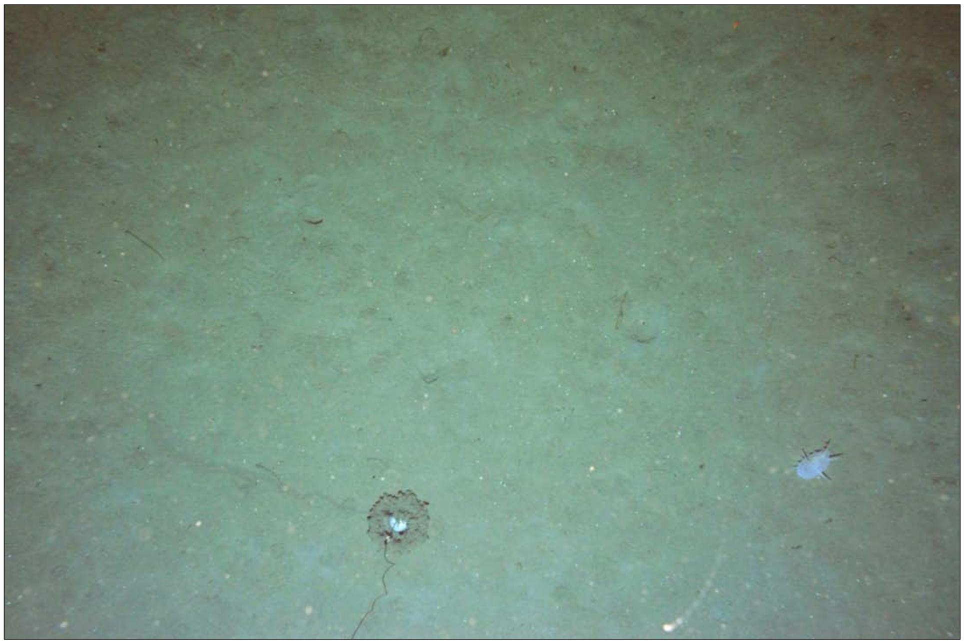

Image 3. Soft bottom substrate characterized by various bioturbation including small depressions and tracks was observed at Station 3 of the TEN development area. A translucent holothuroid is visible in the lower right of the image.

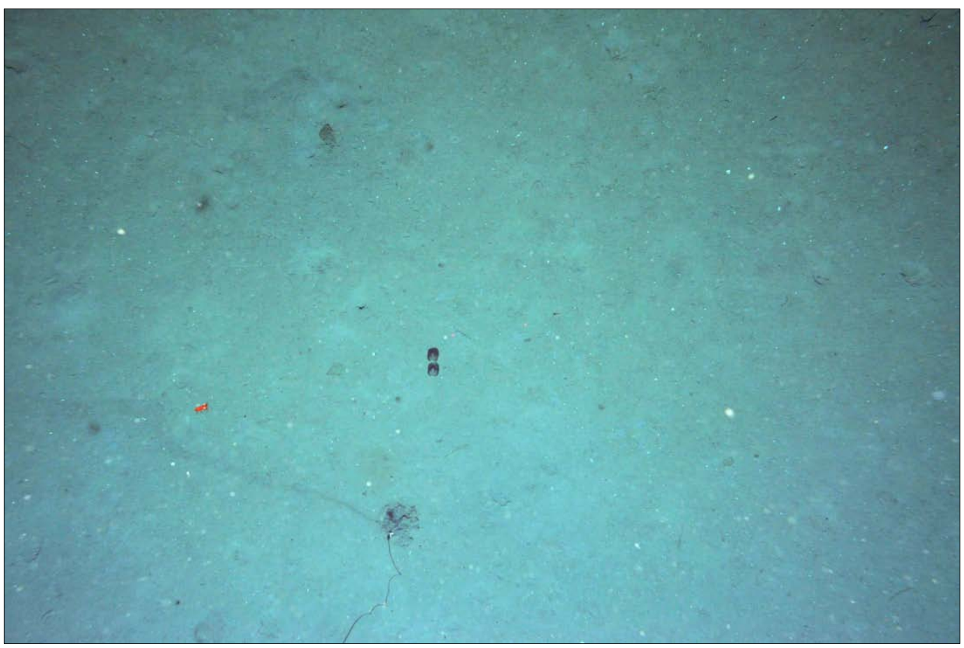

Image 4. Soft bottom substrate was observed at Station 4 of the TEN development area. A small bright orange crustacean is visible in the middle left of the image.

Image 5. Soft bottom substrate etched with various bioturbations was observed at Station 5 of the TEN development area. What appear to be pteropod molluscs are visible in the near bottom water column.

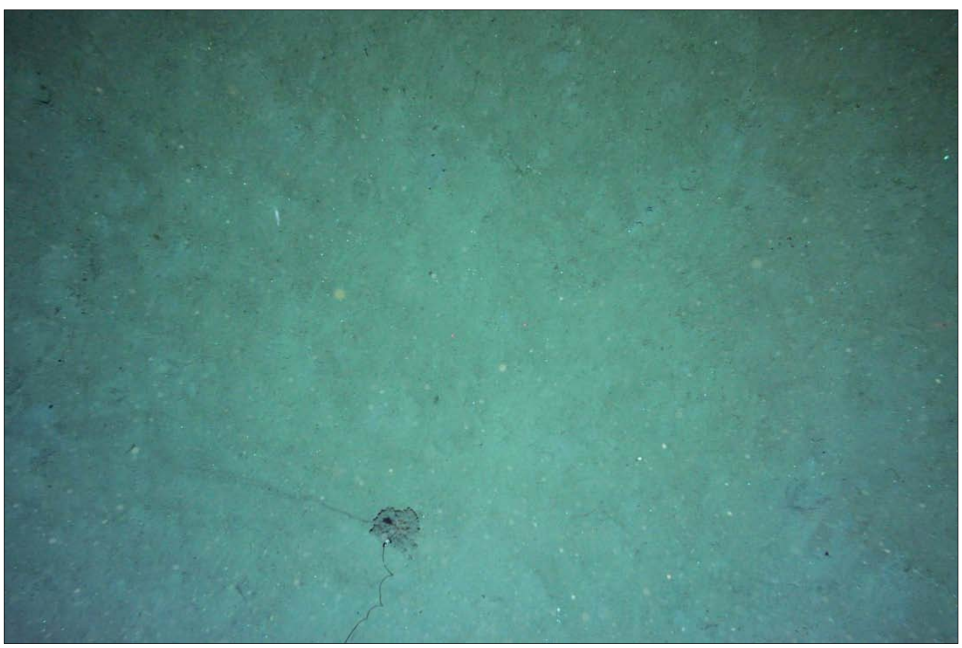

Image 6. Soft bottom substrate was observed at Station 6 of the TEN development area.

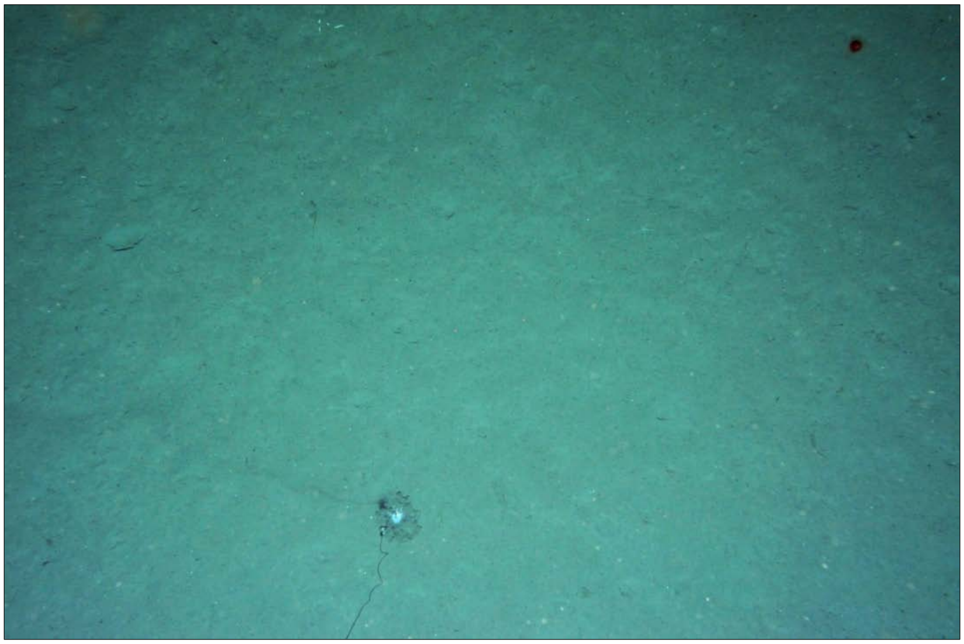

Image 7. Soft bottom substrate with subtle bioturbations was observed at Station 7 of the TEN development area. An unidentified bright red pelagic organism (possibly a jellyfish) is visible in the upper right of the image.

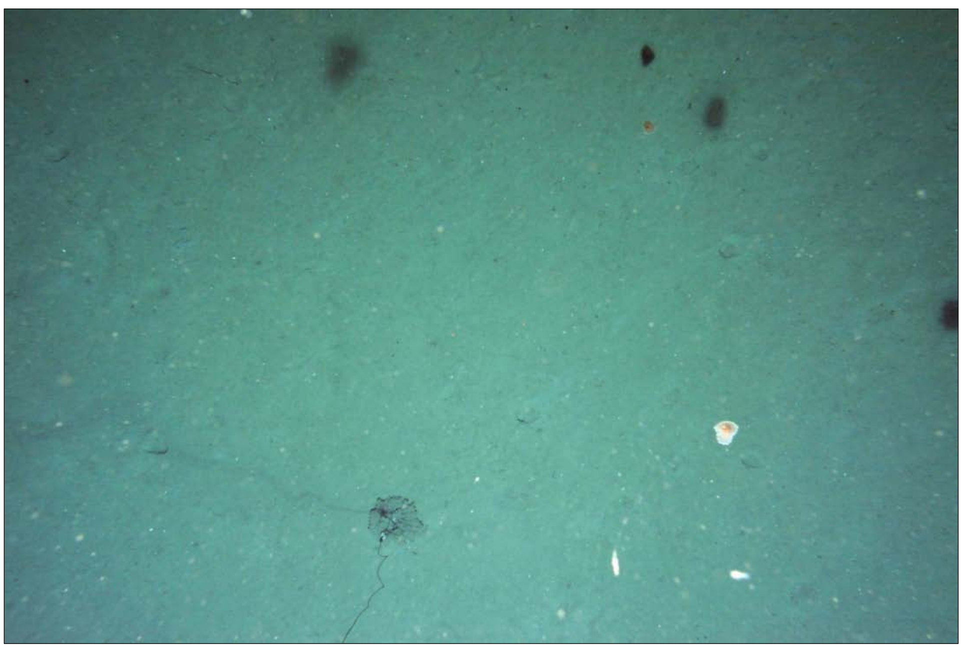

Image 8. Soft bottom substrate was observed at Station 8 of the TEN development area. Various unidentified pelagic organisms, including what appear to be pteropod molluscs and jellyfish, are visible in the near bottom water column.

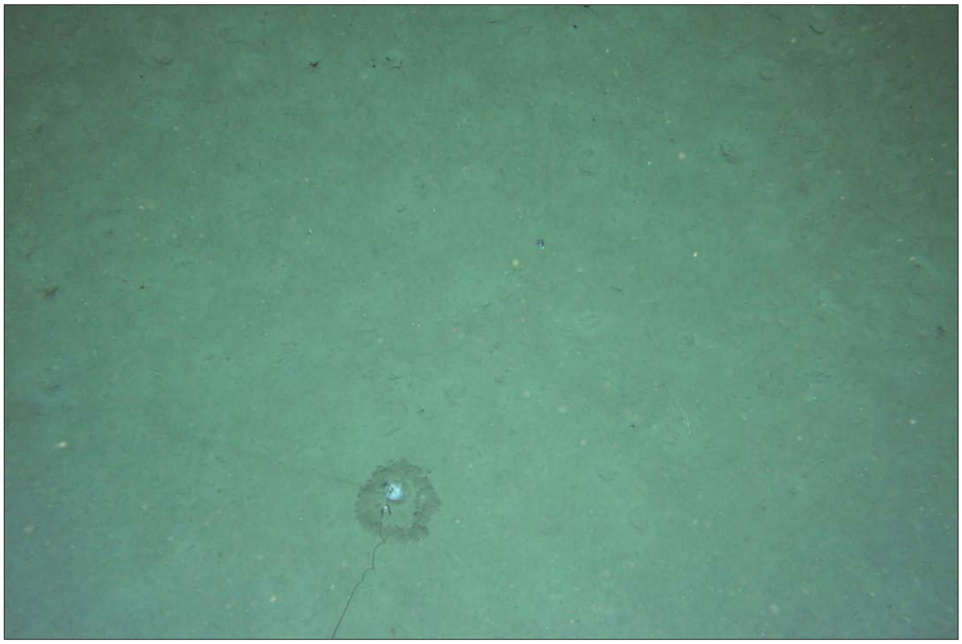

Image 9. Soft bottom substrate with subtle bioturbations was observed at Station 9 of the TEN development area.

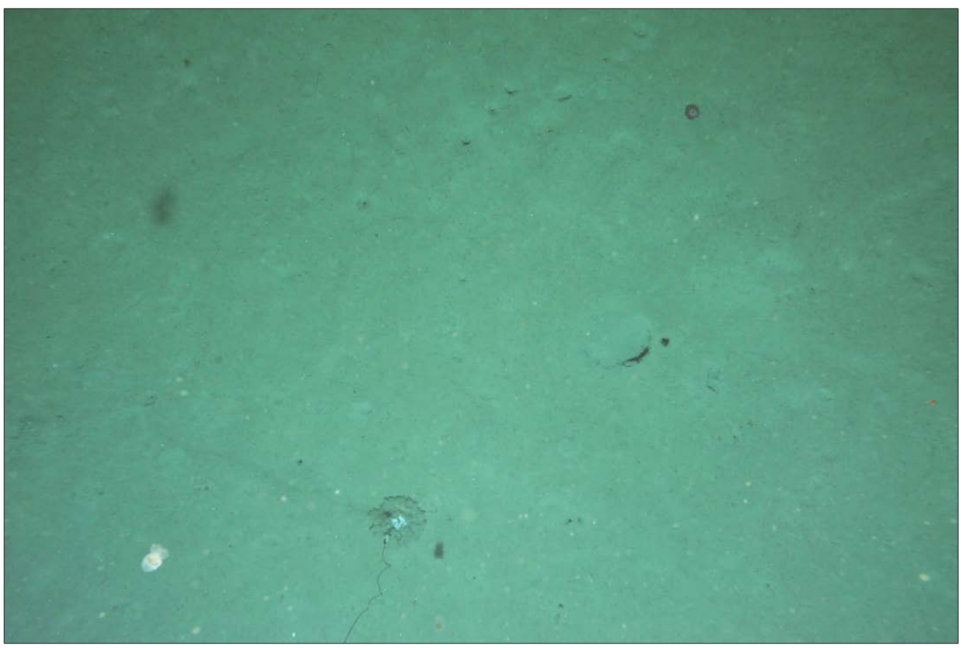

Image 10. Soft bottom substrate was observed at Station 10 of the TEN development area. Invertebrates, including what appear to be a pteropod mollusc (lower left) and possibly a solitary hard coral (upper right), are visible in the image.

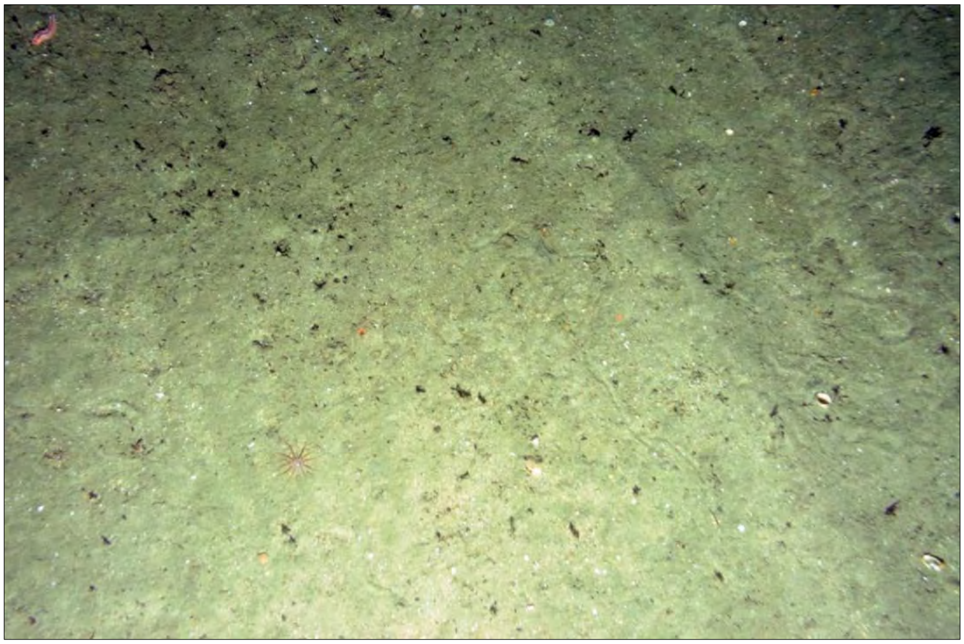

Image 11. Soft bottom substrate characterized by coarse sediments and etched with bioturbations was observed at Station C1 along the gas export pipeline route. Invertebrates including a fireworm, *Hermodice* sp., (upper left) and two burrowing anemones (Ceriantharia) (lower left) are visible in image.

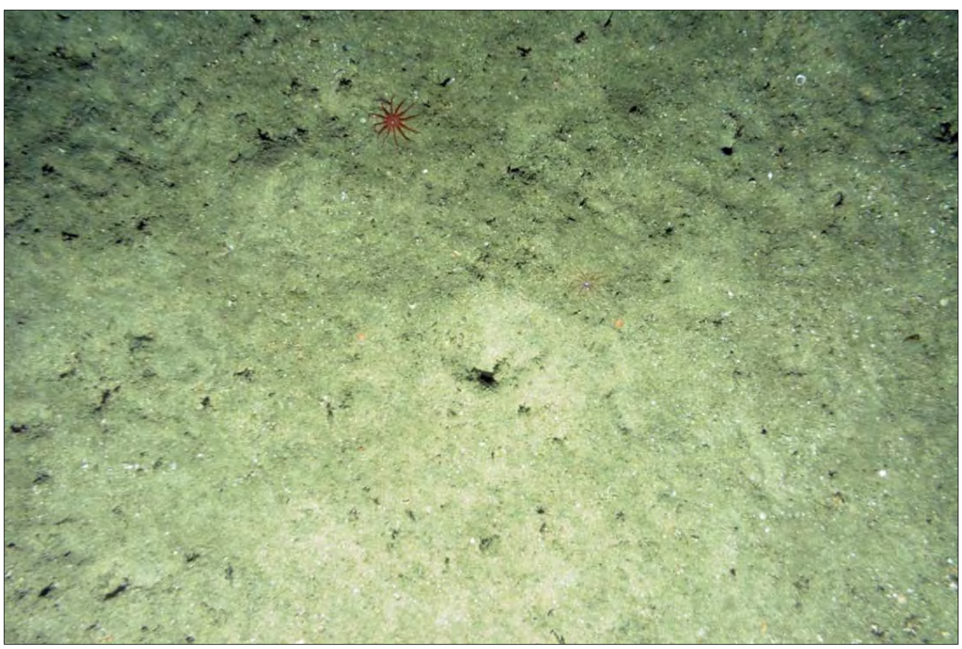

Image 12. Soft bottom substrate characterized by coarse sediments was observed at Station C2 along the gas export pipeline route. A prominent burrow formation and a couple of burrowing anemones (Ceriantharia) are visible in image.

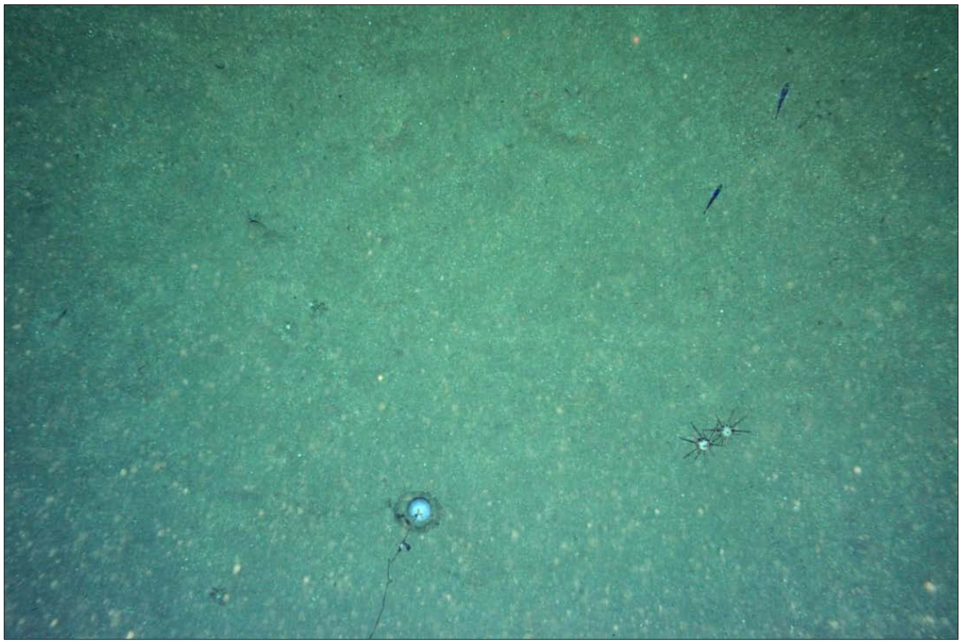

Image 13. Soft bottom substrate characterized by coarse sediments was observed at Station C3 along the gas export pipeline route. A pair of long-spinned urchins (Echinoidea) and unidentified demersal fish are visible in the image.

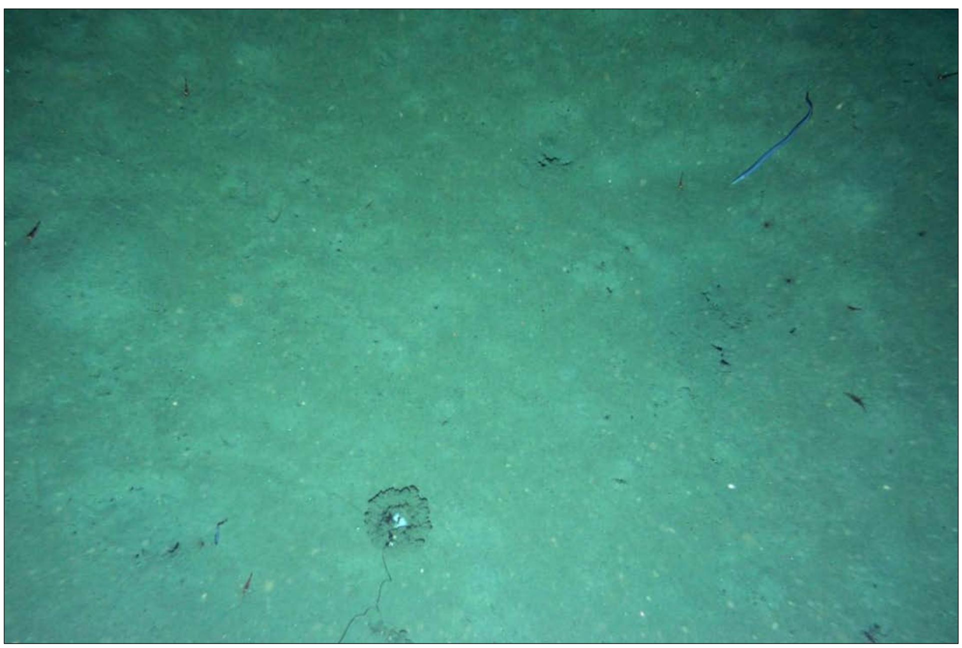

Image 14. Soft bottom substrate characterized by various bioturbation including small burrows and tracks was observed at Station C4 along the gas export pipeline route. Numerous decapod shrimp, anemones (Ceriantharia) occupying many of the small burrows, and a duckbill eel (?Nettastomidae) are visible in the image. Level of observed bioturbation and biota would indicate a relatively productive and active macrobenthic community.

Image 15. Soft bottom substrate characterized by coarse sediments was observed at Station C5 along the gas export pipeline route. Numerous diminutive invertebrates including a brittlestar (Ophiuroidea) and fish are visible in the image.

# APPENDIX E

## Hydrographic Profile Parameters

*(Media file provided separately.)*

# APPENDIX F

## Macroinfaunal Taxonomic Listing

Table F-1. Macroinfaunal taxonomic listing from samples collected during the TEN Environmental Baseline Survey from 26 to 28 March 2011.

| Species | Sample | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | C1a | C1b | C2a | C2c | C3b | C3c | C4a | C4b | C5a | C5b |
| **POLYCHAETA** | | | | | | | | | | | | | | | | | | | | |
| **Ampharetidae** | | | | | | | | | | | | | | | | | | | | |
| *Ampharete acutifrons* | | | | | | | | | | | | | | | | | | | 2 | |
| Ampharetidae indet. | | | | | | | | | | | 1 | | | | | | | | 1 | |
| *Isolda cf. pulchella* | | | | | | | | | | | | | | 1 | | | | | 2 | |
| *Melinnopsides* sp. | | | | | | | | | | | 1 | | | | | | | | | |
| **Amphinomidae** | | | | | | | | | | | | | | | | | | | | |
| Amphinomidae indet. | | | | | | | | | | 2 | | | | | | | | | | |
| *Chloeia cf. inermis* | | | | | | | | | | | | | 1 | 1 | | | | | | |
| **Arabellidae** | | | | | | | | | | | | | | | | | | | | |
| *Arabella* sp. | | | | | | | | | | | | | | | | | | | | |
| **Capitellidae** | | | | | | | | | | | | | | | | | | | | |
| *Capitella capitata* | | | | | | | | | | | | | | 1 | 1 | | | | 1 | |
| Capitellidae indet. | | | | | | | | | 1 | 2 | 2 | | 1 | | | 1 | | 1 | | |
| *Dasybranchus* sp. A | | | | | | | | | | | | | | | | | | | 3 | |
| *Leiochrides africanus* | | | | | 1 | | | | | | | | | | | | | | | |
| *Notomastus latericeus* | | | | | | | | | | | | | | 1 | | | | | | |
| *Notomastus* sp. A | | | | | | | | 1 | | | 2 | | | 1 | | | | | | |
| *Pulliella armata* | | | | | 1 | | | | | | 1 | | | 1 | | | | | | |
| **Cirratulidae** | | | | | | | | | | | | | | | | | | | | |
| *Caulleriella cf. acicula* | | | | | | | | | | | 1 | 2 | | | | | | | | |
| *Caulleriella* sp. A | | | | | | | | | | | | 1 | | | | | | | | |
| Cirratullidae indet. | | | | | | | | | | | | | 1 | | | | | | | |
| *Cirratulus africanus* | | | | | | | | | | | | | | | 1 | | | | | |
| *Cirratulus* sp. A | | | 1 | | 1 | | | | | | | | | | | | | | | |
| *Tharyx dorsobranchialis* | | | | | 1 | 2 | | 2 | 1 | | 5 | 4 | 1 | 1 | | | | | | |
| *Tharyx filibranchia* | | | | | 1 | | | 1 | | | | | | | | | | | | |
| *Tharyx* sp. A | | | 1 | 2 | 1 | | | | 1 | 2 | | 2 | | 1 | 2 | 1 | | 4 | 7 | 1 |
| *Tharyx* sp. B | 1 | | | | | | 1 | | | | | | | | | | | | | |
| **Cossuridae** | | | | | | | | | | | | | | | | | | | | |
| *Cossura coasta* | 2 | | | | | | | | | 1 | 1 | | | | | | | 1 | | |
| **Dorvillidae** | | | | | | | | | | | | | | | | | | | | |
| *Dorvillea rudolphi* | | | | | | | | | | | | 1 | | | | | | | | |
| *Protodorvillea biarticulata* | | | | | | | | 1 | | | 1 | 1 | | | | | | | | |
| **Lacydoniidae** | | | | | | | | | | | | | | | | | | | | |
| *Paralacydonia paradoxa* | | | | | | | | | | 1 | 5 | 8 | | 1 | | | | | 5 | |

Table F-1. (Continued).

| Species | Sample | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | C1a | C1b | C2a | C2c | C3b | C3c | C4a | C4b | C5a | C5b |
| **Eunicidae** | | | | | | | | | | | | | | | | | | | | |
| *Eunice* sp. A | | | | | | | | | | | | | | 1 | | | | | | |
| *Eunice vittata* | | | | | | | | | | | 3 | 1 | 1 | 1 | | | | | 1 | |
| *Marphysa cf. adenensis* | | | | | | | | | | | | 1 | | | | | | | | |
| *Marphysa sanguinea* | | | | | | | | | | | | | | 1 | | | | | | |
| *Marphysa* sp. A | | | | | | | | | | | | | 1 | | | | | | 2 | |
| *Marphysa* sp. B | | | | | | | | | | | | | 1 | | | | | | | |
| **Glyceridae** | | | | | | | | | | | | | | | | | | | | |
| *Glycera longipinnis* | | | | 2 | 2 | | 4 | | 1 | | 1 | | 1 | | | | | 1 | | |
| *Glycera* sp. A | | | 3 | | | 1 | | | | | | | | | | | | | | |
| *Glycinde kameruniana* | | | | | | | | | | | | | | | | | | 1 | 1 | |
| *Goniada* sp. A | 3 | | 1 | | | | | | | 1 | | | | | | | | | | |
| **Hesionidae** | | | | | | | | | | | | | | | | | | | | |
| *Ophiodromus* sp. | | | | | | | | | | | | | | | | | | | | 1 |
| **Iospilidae** | | | | | | | | | | | | | | | | | | | | |
| *Phalacrophorus cf. pictus* | 1 | | | | | 1 | | | | | | | | | | | | | | |
| **Lumbrineridae** | | | | | | | | | | | | | | | | | | | | |
| *Lumbrineris aberrans* | | | | | 1 | | | | | 1 | 2 | | | | | | | | 2 | |
| *Lumbrineris albidentata* | | | | | | | | | 1 | | | | | | | | | | | |
| *Lumbrineris cf. cavifrons* | | | | | | | | | | | | 1 | | | | | | | | |
| *Lumbrineris cf. meteorana* | | | | | | | | | | | | 1 | | | | | | | | |
| *Lumbrineris latreilli* | | | 1 | 1 | | | 1 | | | | 1 | | | | | | | | 1 | 1 |
| *Lumbrineris magalhaensis* | | | | | | | | | | | | | | 1 | | 1 | | | | |
| *Lumbrineris* sp. A | | | | | | | | | 1 | 1 | | | | | | | | | | |
| *Lumbrineris* sp. B | | | | | | | | | | | | | | | | | | | 2 | |
| **Magelonidae** | | | | | | | | | | | | | | | | | | | | |
| *Magelona capensis* | | | | | | | | | | | 1 | | | | | | | | | |
| *Magelona cincta* | | | | | | | | | | | | 1 | | 1 | 4 | 2 | | 10 | | |
| **Maldanidae** | | | | | | | | | | | | | | | | | | | | |
| *Euclymene oerstedi* | | | | | | | | | | | | | | | 1 | | | | | |
| *Macroclymene* sp. | | 2 | | | | | | | | | | | | | | | | | | |
| *Maldane sarsi* | | | | | | | | | | | | | | | 2 | | | | | |
| *Maldanella cf. capensis* | | | | | | | 1 | | | | | 1 | | | | | | | | |
| *Maldanella* sp. A | | | | | | 1 | | | | | | | | | | | | | | |
| Maldanidae indet. | | | | | | | | | 2 | | | | | | | | | 1 | | |
| *Rhodine cf. gracilior* | | | | | | | 2 | | | | | | | | | | | | | |
| *Rhodine* sp. A | | | | | | | | | | | | | | | | | 2 | 2 | | |

Table F-1. (Continued).

| Species | Sample | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | C1a | C1b | C2a | C2c | C3b | C3c | C4a | C4b | C5a | C5b |
| **Nephtyidae** | | | | | | | | | | | | | | | | | | | | |
| *Micronephthys* sp. | 2 | | | | | | | | | | | | | | | | | | | |
| *Aglaophamus (Nephthys) dibranchis* | 1 | | 1 | | | 4 | | 1 | | | 2 | | | | | | | 1 | 4 | 1 |
| *Aglaophamus (Nephthys) lyrochaeta* | | | | | | | | | | | | | | 1 | | | | | 1 | |
| *Nephthys capensis* | | | | | | | | 1 | | | | 1 | | | 1 | 3 | | 1 | | |
| *Nephthys* sp. A | | 2 | 1 | 2 | 2 | | 1 | 3 | 2 | | 1 | 1 | | | | | | | 1 | |
| **Nereidae** | | | | | | | | | | | | | | | | | | | | |
| Nereidae indet. | | | | | | | | | | | | | | | | | 1 | | | |
| **Onuphidae** | | | | | | | | | | | | | | | | | | | | |
| *Augneria tentaculata* | | | | | | | | | | | | | | | | | | | 1 | |
| *Diopatra neapolitana capensis* | | | | | | | | | | | | | 1 | | | | | | | |
| *Epidiopatra* sp. A | | | | | | | | | | | | | | | 1 | | 2 | | | |
| *Hyalinoecia* sp. A | | | | | | | | | | | | | | | 1 | 7 | | | | |
| *Hyalinoecia tubicola* | | | | | | | | | | | 1 | | | | | 1 | | | | |
| *Onuphis* sp. A | | | | | | | | | | | | | | 2 | | | | | | |
| **Oenonidae** | | | | | | | | | | | | | | | | | | | | |
| *Drilonereis* sp. A | | | 1 | | | | | | | | 1 | | | | | | | | | |
| **Opheliidae** | | | | | | | | | | | | | | | | | | | | |
| *Polyophthalmus pictus* | 5 | 8 | 14 | | 13 | 9 | 12 | | 12 | 14 | 3 | 2 | | | | | | 1 | | 1 |
| **Orbiniidae** | | | | | | | | | | | | | | | | | | | | |
| Orbiniidae indet. | | | | | | | | | | | | | | 1 | | | | | | |
| *Scoloplos madagascariensis* | | | | | | | | 1 | | | | 1 | | | | | | | | |
| *Scoloplos* sp. A | | | | | | | | | | 3 | 1 | | 1 | | | | | | | |
| **Paraonidae** | | | | | | | | | | | | | | | | | | | | |
| *Aedicira* sp. A | | 3 | 3 | 2 | 4 | 4 | 4 | 1 | | 3 | | | | | | | | | 1 | |
| *Aricidea (Acmira) lopezi* | 1 | 1 | | | 2 | 1 | | 4 | | 1 | 2 | | | | | | | | | 1 |
| *Aricidea (Acmira) cerrutii* | | | | | | | | 2 | | | | | | | | | | | | |
| *Aricidea longobranchiata* | 2 | 1 | | | | 4 | | | | | | | | | | | | | | 4 |
| *Aricidea* sp. A | 6 | | | | | | | | | | | | | | | | | 2 | | |
| *Aricidea (Acmira) simplex* | 1 | 3 | 6 | 6 | | 1 | 3 | | | 7 | 1 | 1 | | 1 | 4 | 4 | | 2 | | |
| *Cirrophorus branchiatus* | | | | | | | | | | 1 | | | | | | | | | | |
| *Cirrophorus* sp. A | | | | | 1 | | | | | | | | | 1 | | | | | | |
| *Paraonides lyra lyra* | | 1 | | 1 | | | 1 | 2 | | | | | | | | | | | | |
| *Paraonides* sp. A | | | | | | | | | | | | | | 1 | | | | | 1 | |
| *Paraonis gracilis* | 1 | | | 2 | | 2 | 1 | | 6 | | 1 | | | 1 | 1 | | | | 4 | |
| *Paraonis* sp. A | 3 | 2 | | | | | | | | | | | | | | | | | | |
| *Paraonis gracilis oculata* | 4 | 2 | 4 | 4 | 1 | 5 | 1 | 1 | | 4 | | 2 | | 1 | 5 | 1 | 1 | 1 | 1 | 1 |

Table F-1. (Continued).

| Species | Sample | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | C1a | C1b | C2a | C2c | C3b | C3c | C4a | C4b | C5a | C5b |
| **Phyllodocidae** | | | | | | | | | | | | | | | | | | | | |
| *Phyllodoce longipes* | | | | | | | | | | | 1 | | | | | | | | | |
| **Pilargidae** | | | | | | | | | | | | | | | | | | | | |
| *Ancistrosyllis cf. constricta* | | | | | | | | | 2 | | 1 | | | | | | | | 1 | |
| *Sigambra parva* | | | | | | | | | | | | | | | | | | | | |
| *Sigambra robusta* | 1 | | 1 | | 2 | | 3 | | | 3 | 1 | | | | 1 | 1 | | 5 | 1 | |
| Ancistrosyllis sp. A | 1 | 1 | | | | | | | | | | | | | | | | | | |
| Pilargidae indet. | | | | | | | | 1 | | | | | | | | | | | | |
| *Sigambra tentaculata* | | | | | | | | | | | | 1 | | | | | | | | |
| **Polynoidae** | | | | | | | | | | | | | | | | | | | | |
| *Antinoe cf. aequiseta* | | | | | | | | | | | | 1 | | | | | | | | |
| *Harmothoe* sp. A | | | | | | | | | | | | | 1 | | | | | | | |
| **Sabellidae** | | | | | | | | | | | | | | | | | | | | |
| *Sabellides* sp. | | | | | | | | | | | | | | | 2 | | | | | |
| **Scalimbregidae** | | | | | | | | | | | | | | | | | | | | |
| *Leanira hystricis* | | | 1 | | | | | | | | | | | | | | | | | |
| *Scalibregma inflatum* | | | | | | | | | | | | | | | | | | | | 1 |
| **Sternaspidae** | | | | | | | | | | | | | | | | | | | | |
| *Sternaspis scutata* | | | | | | | | 1 | | | | | | 1 | | | | | 1 | |
| **Spionidae** | | | | | | | | | | | | | | | | | | | | |
| *Aonidella cirrobranchiata* | 1 | | | | | | | | | | | | | | | | | | | |
| *Polydora* sp. | | | 1 | | | | | | | | | | | | | | | | | |
| *Paraprionospio cf. pinnata* | | | | | | | | | | | | 1 | | | | | | | | |
| *Prionospio cf. steenstrupi* | | | | | | | | | | | | | | | | | | 3 | 4 | 4 |
| *Prionospio cirrifera* | | 1 | 2 | 1 | 3 | 1 | 8 | | 1 | 6 | 2 | | | | | | | | 3 | |
| *Prionospio sexoculata* | | | | | | | | | | | | 2 | | 2 | | 1 | 2 | 2 | | |
| *Prionospio* sp. A | | | 1 | | | | | | | | | | | | | | | | | |
| Spionidae indet. | | | | 1 | | | | | | | | | | | | | | | | |
| *Spiophanes* sp. | | | | | 3 | | | | 1 | | | | | | | | | | | 2 |
| **Terebellidae** | | | | | | | | | | | | | | | | | | | | |
| *Streblosoma* sp. | | | | | | | | | | | | | | | | | | | 1 | |
| *Terebellides stroemii* | | | | | 1 | | | | | | | 1 | | | | | | | | |
| **Syllidae** | | | | | | | | | | | | | | | | | | | | |
| *Syllis gracilis* | | | | | | | | | | | | 1 | | | | | | | | |

Table F-1. (Continued).

| Species | Sample | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | C1a | C1b | C2a | C2c | C3b | C3c | C4a | C4b | C5a | C5b |
| **MOLLUSCA** | | | | | | | | | | | | | | | | | | | | |
| **Bivalvia** | | | | | | | | | | | | | | | | | | | | |
| *Nuculana tuberculata* | | | | | | | | | | | 1 | | | | 1 | | | | | |
| *Nucula* sp. | | 1 | 2 | | | 2 | | 2 | | | | 1 | | | | | | | | |
| *Nuculana* sp. A | | | | | | | 1 | | | | | | | | 1 | | | | | |
| *Quadrans chetelati* | | | | | 1 | | | | 1 | | | 1 | | | | | | | | |
| *Tellina mars* | 2 | | | | 2 | 1 | 1 | | | | | | | | | | | | | |
| *Tellina hyalina* | | 1 | 1 | | | | | | | | | | | | | | | | | |
| *Tellina* sp. A | | | | | | | | | | | | 1 | | | | | | | | |
| *Tellina* sp. B | 2 | | | 3 | | | | | | | | | | | | | | | | |
| *Tellina* sp. C | | | 6 | 2 | 1 | 4 | 5 | 2 | 1 | | | | | | | | | | 1 | |
| *Tellina* sp. D | | | | 1 | | | | 1 | 2 | | | | | | | | | | | |
| Tellinidae indet. | | | | 1 | | 4 | | | | | | | | | | | | | | |
| **Gastropoda** | | | | | | | | | | | | | | | | | | | | |
| *Cavolinia* sp. | | | | | | | | | | | 1 | | | | | | | | | |
| Gastropoda indet. | | | | | | | 1 | 1 | | | | | | | | | | | | |
| **Aplacophora** | | | | | | | | | | | | | | | | | | | | |
| *Chaetoderma* sp. | 1 | 3 | 6 | | 1 | 2 | 3 | | 1 | 2 | | | 1 | | | | | | 1 | |
| **CRUSTACEA** | | | | | | | | | | | | | | | | | | | | |
| *Accalathura* sp. A | | | | | 1 | | | | | | | | | | | | | | | |
| *Ampelisca* sp. | | 2 | 3 | | 1 | 2 | 1 | 1 | | 2 | 7 | 1 | | | | 2 | | | | |
| *Ampithoe* sp. A | 2 | 1 | 1 | | | 1 | | | 2 | | | | | | | | | | | |
| *Ananthura* sp. A | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | | | | | | 1 | | 2 | | | |
| *Apseudopsis acutifrons* | 1 | | | | | | | | | | | | | | | | | 1 | | |
| *Apseudes cf. grossimanus* | | | | 1 | | | | | | | | | | | | | | | | |
| Apseudidae indet. | | | | | | | | | | | | | | | | | | | | 1 |
| *Argissa* sp. | | | | | | | | | 4 | | | | | | | | | | | |
| Astyridae indet. | | | | | | | | | 1 | | | | | | | | | | | |
| *Atylus* sp. | | | | | | | 2 | | 1 | | 1 | | | | | 1 | | 1 | | |
| *Bodotria* sp. A | | 1 | | 2 | | | 2 | | | | | | | | | | | 1 | | |
| *Bradyetes* sp. | | | | | | | | | 1 | | | | | | | | | | | |
| Calanoida indet. | | | 3 | | | | 2 | | | 3 | | | | | 1 | | 1 | | 2 | |
| *Calanus* sp. | 2 | | | | | 2 | 4 | | | | | | | | | | | | | |
| *cf. Plesionika heterocarpus* | | | | | | | | | | | | | 1 | | | | | | | |
| Copepoda indet. (centropages) | 1 | | | | | | | | | | | | | | | | | | | |
| Crustacea indet. | | | | | 2 | 1 | | | | | | | | | | | | | | |
| *Diastylis denticulata* | 1 | | | | | | | | | | | | | | | | | | | |
| *Diastylis* sp. A | | | | 1 | | | 1 | | | 1 | | | | | | | | | | |

Table F-1. (Continued).

| Species | Sample | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | C1a | C1b | C2a | C2c | C3b | C3c | C4a | C4b | C5a | C5b |
| *Diastylis* sp. B | | | | | | | | | 2 | | | | | | | | | | | |
| *Harpinia* sp. | 5 | 8 | 4 | 8 | 1 | 8 | 3 | 3 | 6 | 7 | 1 | | | | 2 | | 2 | | 3 | |
| Anomura indet. (hermit crab) | | | | | | | | | | | | 1 | | | | | | | 1 | |
| *Iphinoe senegalensis* | | | | | | | | | | | 1 | | | | | | | | | |
| *Iphinoe* sp. A | 2 | 2 | 2 | | 1 | 6 | | | 3 | 6 | | 2 | | | | | | | | |
| *Iphinoe stebbingi* | | | | | | | | | | | 1 | | | | | | | | | |
| *Joeropsis* sp. | 4 | 4 | 6 | 6 | 2 | 1 | 4 | 1 | 8 | 21 | | | | 1 | | | | | 3 | |
| *Lembos* sp. | | | | | | | | | | | | | | | 1 | | | | | |
| Mysida indet. | | | | | | | | | | | 4 | 4 | | 1 | | 1 | | | | |
| Oedicerotidae indet. | | | | 2 | | | | | | 1 | | 1 | | | | | | 1 | | |
| Ostracoda indet. | | 1 | | 1 | | 1 | | 1 | | | | | | | | | | | 1 | |
| *Parapseudes* sp. | | | | | | | | | | | | | | | | | | | | |
| Paratanaidae indet. | | 3 | 2 | 3 | | 6 | 1 | 1 | 1 | 2 | | | | | 1 | | | | 3 | |
| *Paromola cuvieri* | | | | | | | | | | | 1 | | | | | | | | | |
| Phyllocarida indet. | | | 2 | | | | | | | | | | | | | | | | | |
| *Stegocephalus* sp. | | | | 1 | | | 1 | 1 | | 1 | 1 | | | | | | | | | |
| *Synalpheus* sp. | | | | | | | | | 1 | | | | | | | | | | | |
| *Synchelidium* sp. | | | | | | | | | | | | 1 | | | | | | | | |
| Tanaidacea sp. A | 3 | | | 2 | | | | | | | | | | | | | | | 1 | |
| *Wildus* sp. | | | | 2 | | 1 | | 1 | | | | | | | | | | | | |
| **ECHINODERMATA** | | | | | | | | | | | | | | | | | | | | |
| *Amphilimna* sp. | | | | | | | | | | | 1 | | | | | | | | | |
| *Amphioplus archeri* | | | | | | | | | | | 2 | 2 | 1 | | | | | | | |
| *Amphipholis nudipora* | | | | | | | | | | | 1 | | | | | | | | | |
| *Amphipholis* sp. A | | | | | | 1 | 1 | | | | | | 1 | | | | | | | |
| *Amphiura* sp. | | | | | | | | | 1 | | | | | | | | | | | |
| *Amplioplus congensis* | | | | | | | | | | | | 1 | | | | | | | | |
| *Asteroidea* sp. A | | | | | | 1 | | 1 | | | | | | | | | | | | |
| Asteroidea sp. B | | | 1 | | 1 | 1 | | | | | | | | | | | | | | |
| Asteroidea sp. C | | | | 1 | | | | | | | | | | | | | | | | |
| Diadematidae sp. A | | | | | | | 1 | | | | | | | | | | | | | |
| Echinoidea indet. | | | | | 1 | | 2 | 2 | | | | | | | | | | | 1 | |
| Holothuroidea indet. | | | 1 | | | | | | | | 1 | | | 1 | | | | | | |
| *Ophiura grubei* | | | | | | | | | | | 1 | 1 | | | | | | | | |
| *Ophiura* sp. A | | | | | | | | 1 | | | | | | | | | | | | |
| Ophuiroidea indet. | | | | | | | | | | | | 2 | | | | | | | 2 | |

Table F-1. (Continued).

| Species | Sample | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | C1a | C1b | C2a | C2c | C3b | C3c | C4a | C4b | C5a | C5b |
| **OTHER** | | | | | | | | | | | | | | | | | | | | |
| Chaetognatha ? indet. | 1 | | | | | 1 | 1 | | | | | | | | | | | | | |
| *Digenea indet.* (fluke) | | | | | | | | | | | | 1 | 1 | | | | | | | |
| Enteropneusta indet. | | | | | | | | | | | | | | | 1 | | | 2 | | |
| Pisces (fish juvenile) indet. | | | | | | 1 | | | | | 1 | | | | | | | | | |
| Nematoda indet. | 5 | | 11 | | | 3 | 3 | 2 | 13 | | 1 | 5 | 1 | 1 | 1 | | 2 | 3 | 4 | 2 |
| Nemertea indet. | 1 | | | | | | 1 | | | | 3 | 1 | | | | | | | 4 | |
| Oligochaeta indet. | | | | | | | | | | | | | | | | | | 1 | | |
| *Pontobdella* sp. (marine leech) | | | | | | | | | | | | | | | | | | | 1 | |
| Priapulida indet. | | | | | | | | | | | 1 | | | | | | | | | |
| Sipuncula indet. | 4 | | 2 | | 5 | 7 | 7 | 5 | | | 10 | 4 | | 3 | 1 | | 2 | 1 | 4 | 8 |
| Turbellaria indet. | | | | | | | | | | | | | | | | | | | | |
| **FORAMINIFERA** | | | | | | | | | | | | | | | | | | | | |
| *Elphidium* sp. | | | | | 1 | | | | | | | | | | | | | | | |
| Foraminifera indet. | | | | | | | 1 | 3 | | | | | 1 | | | | | | 1 | |
| *Nodosaria* sp. | | | 1 | | | | | | | | | | | | | | | | | |
| *Rotalia* sp. | | | | | 1 | | | | | | | | | | | | | | | |
| Total | 74 | 55 | 99 | 62 | 64 | 94 | 94 | 53 | 83 | 99 | 87 | 70 | 18 | 33 | 38 | 27 | 17 | 50 | 88 | 29 |

# APPENDIX G

## Total Aliphatic and Polycyclic Aromatic Hydrocarbon Concentrations

Table G-1. Sediment aliphatic hydrocarbon determinations, n-$C_{10}$ through n-$C_{34}$, TEN Environmental Baseline Survey.

| Station | n-$C_{10}$ | n-$C_{11}$ | n-$C_{12}$ | n-$C_{13}$ | n-$C_{14}$ | n-$C_{15}$ | n-$C_{16}$ | n-$C_{17}$ | Pristane | n-$C_{18}$ | Phytane | n-$C_{19}$ | n-$C_{20}$ | n-$C_{21}$ | n-$C_{22}$ | n-$C_{23}$ | n-$C_{24}$ | n-$C_{25}$ | n-$C_{26}$ | n-$C_{27}$ | n-$C_{28}$ | n-$C_{29}$ | n-$C_{30}$ | n-$C_{31}$ | n-$C_{32}$ | n-$C_{33}$ | n-$C_{34}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.01** | 0.01** | 0.06 | 0.52 | 1.39 | 0.86 | 0.19 | 0.08 | 0.04 | 0.09 | 0.02 | 0.04 | 0.02 | 0.13 | 0.02 | 0.03 | 0.03 | 0.04 | 0.04 | 0.15 | 0.09 | 0.46 | 0.15 | 0.55 | 0.17 | 0.33 | 0.15 |
| 2 | 0.01** | 0.04 | 0.11 | 0.57 | 1.72 | 1.25 | 0.31 | 0.09 | 0.03 | 0.07 | 0.02 | 0.04 | 0.02 | 0.18 | 0.02 | 0.03 | 0.03 | 0.04 | 0.04 | 0.13 | 0.08 | 0.44 | 0.12 | 0.54 | 0.19 | 0.34 | 0.19 |
| 3 | 0.01 | 0.01** | 0.03 | 0.07 | 0.07 | 0.07 | 0.04 | 0.03 | 0.02 | 0.12 | 0.01** | 0.03 | 0.02 | 0.22 | 0.02 | 0.03 | 0.03 | 0.05 | 0.04 | 0.18 | 0.11 | 0.59 | 0.15 | 0.76 | 0.22 | 0.39 | 0.23 |
| 4 | 0.01 | 0.01** | 0.02 | 0.07 | 0.16 | 0.12 | 0.04 | 0.09 | 0.01** | 0.06 | 0.01** | 0.03 | 0.01** | 0.15 | 0.01** | 0.02 | 0.03 | 0.04 | 0.04 | 0.14 | 0.10 | 0.45 | 0.12 | 0.53 | 0.18 | 0.30 | 0.16 |
| 5 | 0.01** | 0.01** | 0.02 | 0.06 | 0.12 | 0.11 | 0.04 | 0.09 | 0.02 | 0.09 | 0.01** | 0.03 | 0.01** | 0.20 | 0.02 | 0.03 | 0.03 | 0.05 | 0.04 | 0.16 | 0.10 | 0.52 | 0.15 | 0.64 | 0.18 | 0.38 | 0.17 |
| 6 | 0.01** | 0.01** | 0.03 | 0.11 | 0.21 | 0.18 | 0.06 | 0.05 | 0.02 | 0.07 | 0.01** | 0.03 | 0.01** | 0.17 | 0.01** | 0.03 | 0.03 | 0.04 | 0.04 | 0.16 | 0.11 | 0.51 | 0.14 | 0.60 | 0.21 | 0.37 | 0.18 |
| 7 | 0.02 | 0.02 | 0.04 | 0.08 | 0.10 | 0.08 | 0.04 | 0.06 | 0.02 | 0.08 | 0.15 | 0.03 | 0.01** | 0.19 | 0.01** | 0.03 | 0.03 | 0.04 | 0.03 | 0.13 | 0.08 | 0.44 | 0.11 | 0.60 | 0.19 | 0.26 | 0.11 |
| 8 | 0.01 | 0.02 | 0.04 | 0.06 | 0.10 | 0.07 | 0.03 | 0.07 | 0.01** | 0.09 | 0.19 | 0.03 | 0.01** | 0.18 | 0.01** | 0.03 | 0.03 | 0.04 | 0.04 | 0.16 | 0.10 | 0.50 | 0.14 | 0.65 | 0.23 | 0.33 | 0.21 |
| 9 | 0.02 | 0.02 | 0.06 | 0.08 | 0.13 | 0.09 | 0.06 | 0.08 | 0.02 | 0.12 | 0.01** | 0.04 | 0.01** | 0.20 | 0.02 | 0.03 | 0.03 | 0.05 | 0.04 | 0.15 | 0.11 | 0.51 | 0.14 | 0.68 | 0.19 | 0.29 | 0.09 |
| 10 | 0.01 | 0.01** | 0.03 | 0.08 | 0.11 | 0.11 | 0.05 | 0.06 | 0.02 | 0.12 | 0.01** | 0.04 | 0.02 | 0.26 | 0.02 | 0.04 | 0.03 | 0.05 | 0.04 | 0.19 | 0.12 | 0.63 | 0.16 | 0.82 | 0.22 | 0.49 | 0.24 |
| C1 | 0.01 | 0.01** | 0.02 | 0.04 | 0.05 | 0.05 | 0.03 | 0.02 | 0.01** | 0.06 | 0.01** | 0.02 | 0.01** | 0.13 | 0.01** | 0.01** | 0.01** | 0.02 | 0.02 | 0.05 | 0.04 | 0.16 | 0.03 | 0.32 | 0.03 | 0.11 | 0.04 |
| C2 | 0.01** | 0.01** | 0.03 | 0.07 | 0.11 | 0.07 | 0.05 | 0.03 | 0.01** | 0.07 | 0.01** | 0.03 | 0.01** | 0.13 | 0.01** | 0.01** | 0.01** | 0.01** | 0.01** | 0.04 | 0.03 | 0.15 | 0.02 | 0.26 | 0.07 | 0.14 | 0.04 |
| C3 | <0.01* | 0.01** | 0.02 | 0.05 | 0.07 | 0.07 | 0.07 | 0.02 | 0.01** | 0.07 | 0.01** | 0.02 | 0.05 | 0.25 | 0.01** | 0.02 | 0.01 | 0.03 | 0.11 | 0.11 | 0.08 | 0.28 | 0.05 | 0.52 | 0.13 | 0.20 | 0.09 |
| C4 | 0.02 | 0.03 | 0.05 | 0.12 | 0.19 | 0.14 | 0.08 | 0.04 | 0.02 | 0.12 | 0.01** | 0.04 | 0.01** | 0.26 | 0.01** | 0.02 | 0.01 | 0.03 | 0.02 | 0.12 | 0.07 | 0.40 | 0.08 | 0.59 | 0.09 | 0.28 | 0.09 |
| C5 | 0.02 | 0.03 | 0.06 | 0.12 | 0.19 | 0.14 | 0.08 | 0.04 | 0.02 | 0.18 | 0.02 | 0.05 | 0.03 | 0.34 | 0.02 | 0.03 | 0.02 | 0.05 | 0.04 | 0.18 | 0.11 | 0.59 | 0.14 | 0.84 | 0.20 | 0.43 | 0.21 |

Qualifiers: J = below the method detection limit; U = not detected.

Table G-2. Sediment polycyclic aromatic hydrocarbon determinations, decalins through fluorenes, TEN Environmental Baseline Survey.

| Sample | cis/trans Decalin | C1-Decalins | C2-Decalins | C3-Decalins | C4-Decalins | Naphthalene | C1-Naphthalenes | C2-Naphthalenes | C3-Naphthalenes | C4-Naphthalenes | Benzothiophene | C1-Benzothiophenes | C2-Benzothiophenes | C3-Benzothiophenes | C4-Benzothiophenes | Biphenyl | Acenaphthylene | Acenaphthene | Dibenzofuran | Fluorene | C1-Fluorenes | C2-Fluorenes | C3-Fluorenes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6.9 | 13.5 | 371 | 856 | 760 | 4.3 | 3.0 | 6.3 | 3.4 | 2.4 | 0.1 (J) | 0.7 | <0.3 (U) | <0.3 (U) | <0.3 U) | 13.8 | 1.5 | <0.1 (U) | 4.7 | 1.7 | 1.7 | 4.3 | <0.4 (U) |
| 2 | 5.7 | 44.5 | 185 | 464 | 396 | 4.8 | 2.6 | 4.3 | 3.3 | 2.0 | 0.1 (J) | 1.3 | 1.3 | <0.3 (U) | <0.3 (U) | 14.3 | 1.0 | <0.1 (U) | 5.0 | 1.1 | 1.2 | 5.1 | <0.4 (U) |
| 3 | 6.9 | 0.8 | 8.8 | 34.0 | 18.3 | 4.8 | 2.8 | 3.7 | 3.2 | 1.6 | 0.1 (J) | <0.3 (U) | <0.3 (U) | <0.3 (U) | <0.3 (U) | 2.2 | 0.6 | 1.1 | 2.4 | 1.3 | 1.6 | 4.3 | 3.7 |
| 4 | 6.6 | 34.4 | 16.9 | 52.7 | 32.4 | 5.8 | 3.0 | 3.2 | 2.2 | 3.1 | 0.1 (J) | 1.2 | <0.3 (U) | <0.3 (U) | <0.3 (U) | 1.8 | 0.6 | 1.3 | 2.6 | 1.4 | 1.2 | 6.4 | <0.4 (U) |
| 5 | 7.5 | 32.5 | 11.8 | 41.6 | 23.4 | 5.3 | 2.7 | 3.4 | 2.8 | 1.8 | 0.1 (J) | 1.0 | <0.3 (U) | <0.3 (U) | <0.3 (U) | 2.6 | 0.9 | 0.2 | 2.6 | 1.5 | 1.4 | 4.7 | <0.4 (U) |
| 6 | 6.3 | 0.9 | 18.2 | 59.6 | 38.5 | 4.8 | 2.7 | 3.1 | 3.0 | 2.5 | 0.1 (J) | <0.3 (U) | <0.3 (U) | <0.3 (U) | <0.3 (U) | 1.6 | 0.5 | 1.1 | 2.4 | 1.3 | 1.2 | 3.9 | <0.4 (U) |
| 7 | 6.7 | 1.3 | 8.6 | 34.1 | 29.6 | 6.4 | 4.1 | 4.5 | 2.9 | 2.1 | 0.1 (J) | 1.0 | <0.3 (U) | <0.3 (U) | <0.3 (U) | 1.9 | 0.4 | 0.4 | 2.9 | 1.8 | 1.7 | 4.9 | <0.4 (U) |
| 8 | 7.2 | 33.0 | 13.2 | 60.9 | 49.5 | 5.9 | 3.7 | 4.1 | 3.6 | 2.3 | 0.1 (J) | 0.9 | <0.3 (U) | <0.3 (U) | <0.3 (U) | 2.4 | 0.6 | 0.2 | 3.2 | 1.8 | 1.3 | 6.0 | 4.1 |
| 9 | 6.6 | 26.0 | 11.2 | 43.8 | 30.1 | 6.5 | 4.3 | 5.5 | 6.5 | 5.0 | 0.2 (J) | 1.6 | <0.3 (U) | <0.3 (U) | <0.3 (U) | 2.1 | 0.6 | 0.3 | 3.4 | 2.3 | 1.7 | 5.2 | 3.7 |
| 10 | 9.5 | 22.1 | 9.3 | 27.4 | 26.3 | 5.9 | 3.4 | 4.8 | 3.3 | 2.8 | 0.2 | 1.4 | <0.3 (U) | <0.3 (U) | <0.3 (U) | 2.7 | 0.7 | 0.3 | 3.5 | 2.3 | 1.8 | 7.5 | <0.4 (U) |
| C1 | 5.2 | <0.3 (U) | <0.3 (U) | <0.3 (U) | <0.3 (U) | 2.4 | 1.7 | 2.9 | 2.2 | 1.5 | 0.1 (J) | <0.3 (U) | <0.3 (U) | <0.3 (U) | <0.3 (U) | 1.2 | 0.1 (J) | 0.2 | 1.7 | 1.2 | 1.2 | 3.2 | <0.4 (U) |
| C2 | 4.8 | 0.8 | 5.3 | 28.5 | 23.8 | 3.2 | 2.3 | 3.6 | 2.6 | 1.8 | <0.2 (U) | <0.3 (U) | <0.3 (U) | <0.3 (U) | <0.3 (U) | 1.1 | 0.3 | 0.3 | 2.2 | 1.5 | 1.1 | 2.5 | 2.5 |
| C3 | 4.4 | <0.3 (U) | <0.3 (U) | <0.3 (U) | <0.3 (U) | 3.2 | 2.2 | 3.4 | 2.3 | 2.2 | 0.1 (J) | 0.6 | <0.3 (U) | <0.3 (U) | <0.3 (U) | 1.1 | 0.3 | 0.8 | 2.1 | 1.3 | 1.1 | 2.5 | <0.4 (U) |
| C4 | 8.5 | 0.9 | 10.2 | 59.7 | 51.4 | 7.9 | 6.2 | 6.9 | 4.0 | 3.2 | 0.1 (J) | 1.9 | <0.3 (U) | <0.3 (U) | <0.3 (U) | 2.4 | 0.5 | 0.5 | 4.7 | 3.4 | 2.3 | 4.3 | <0.4 (U) |
| C5 | 15.2 | 1.6 | 13.4 | 76.2 | 61.8 | 12.2 | 8.1 | 10.7 | 6.4 | 4.5 | 0.2 | 2.1 | 1.4 | <0.3 | <0.3 (U) | 5.3 | 1.2 | 0.7 | 6.5 | 4.4 | 3.5 | 6.9 | <0.4 (U) |

Qualifiers: J = below the method detection limit; U = not detected.

Table G-3. Sediment polycyclic aromatic hydrocarbon determinations, carbazole through naphthobenzothiophenes, TEN Environmental Baseline Survey.

| Sample | Carbazole | Anthracene | Phenanthrene | C1-Phenanthrenes/Anthracenes | C2-Phenanthrenes/Anthracenes | C3-Phenanthrenes/Anthracenes | C4-Phenanthrenes/Anthracenes | Dibenzothiophene | C1-Dibenzothiophenes | C2-Dibenzothiophenes | C3-Dibenzothiophenes | C4-Dibenzothiophenes | Fluoranthene | Pyrene | C1-Fluoranthenes/Pyrenes | C2-Fluoranthenes/Pyrenes | C3-Fluoranthenes/Pyrenes | C4-Fluoranthenes/Pyrenes | Naphthobenzothiophene | C1-Naphthobenzothiophenes | C2-Naphthobenzothiophenes | C3-Naphthobenzothiophenes | C4-Naphthobenzothiophenes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.6 | 0.4 | 4.5 | 2.5 | 4.8 | <0.3 (U) | <0.3 (U) | 0.4 | 0.4 | 0.8 | 1.2 | <0.3 (U) | 3.0 | 2.0 | 1.4 | 2.5 | 2.1 | 2.3 | 1.3 | 0.9 | 1.3 | 0.9 | 0.8 |
| 2 | 0.8 | 0.5 | 3.8 | 2.2 | 4.8 | <0.3 (U) | <0.3 (U) | 0.3 | 0.3 (J) | 0.6 | 0.9 | <0.3 (U) | 3.5 | 2.4 | 1.4 | 3.3 | 1.9 | 3.2 | 2.3 | 1.1 | 2.0 | 1.9 | 1.0 |
| 3 | 0.9 | 0.6 | 4.5 | 2.5 | 4.5 | <0.3 (U) | <0.3 (U) | 0.3 | 0.4 | 0.5 | 0.8 | 0.5 | 3.7 | 2.8 | 1.8 | 3.2 | 2.4 | 1.9 | 1.3 | 1.0 | 1.6 | 0.9 | <0.4 (U) |
| 4 | 0.9 | 0.5 | 4.8 | 2.5 | 4.6 | <0.3 (U) | <0.3 (U) | 0.4 | 0.4 | 0.6 | 0.9 | <0.3 (U) | 4.0 | 2.4 | 1.8 | 3.7 | 2.1 | 1.9 | 2.3 | 1.3 | 2.5 | 1.4 | 1.1 |
| 5 | 1.0 | 1.0 | 8.9 | 3.1 | 5.3 | 2.1 | <0.3 (U) | 0.7 | 0.4 | 0.6 | 0.9 | 0.6 | 5.4 | 3.3 | 2.0 | 3.6 | 2.2 | 2.4 | 0.9 | 1.2 | 1.8 | 1.7 | 1.2 |
| 6 | 0.8 | 0.4 | 4.4 | 2.2 | 3.7 | <0.3 (U) | <0.3 (U) | 0.4 | 0.4 | 0.6 | 0.6 | <0.3 (U) | 3.5 | 2.6 | 1.5 | 3.0 | 2.6 | 2.2 | 1.1 | 0.9 | 2.4 | 1.0 | 0.7 |
| 7 | 0.9 | 0.5 | 5.3 | 2.4 | 4.1 | <0.3 (U) | <0.3 (U) | 0.4 | 0.4 | 0.4 | <0.3 (U) | <0.3 (U) | 3.5 | 2.6 | 1.9 | 2.9 | 1.8 | <0.4 (U) | 1.3 | 1.0 | 1.6 | 0.9 | 0.6 |
| 8 | 1.1 | 0.6 | 5.3 | 2.7 | 4.6 | 1.6 | 1.2 | 0.5 | 0.4 | 0.6 | 0.9 | 0.9 | 4.2 | 2.7 | 1.8 | 3.4 | 2.1 | 3.1 | 1.6 | 1.1 | 2.2 | 2.4 | 1.1 |
| 9 | 0.9 | 0.6 | 6.4 | 2.7 | 4.6 | <0.3 (U) | <0.3 (U) | 0.5 | 0.4 | 0.5 | 0.9 | 0.6 | 4.2 | 3.3 | 2.1 | 2.5 | 1.9 | 1.6 | 1.8 | 0.9 | 2.2 | 1.7 | <0.4 (U) |
| 10 | 1.1 | 0.7 | 7.4 | 3.4 | 5.1 | <0.3 (U) | <0.3 (U) | 0.5 | 0.5 | 0.9 | 1.0 | <0.3 (U) | 5.0 | 3.1 | 2.3 | 3.6 | 2.9 | 3.3 | 1.7 | 1.3 | 3.2 | 2.0 | 0.8 |
| C1 | 0.5 | 0.3 | 3.8 | 2.0 | 4.2 | <0.3 (U) | <0.3 (U) | 0.2 | 0.3 (J) | 0.5 | <0.3 | <0.3 (U) | 1.7 | 1.0 | 1.1 | <0.4 (U) | <0.4 (U) | <0.4 (U) | <0.2 (U) | <0.4 (U) | <0.4 (U) | <0.4 (U) | <0.4 (U) |
| C2 | 0.4 | 0.3 | 5.4 | 2.0 | 3.5 | <0.3 (U) | <0.3 (U) | 0.3 | 0.2 (J) | 0.5 | <0.3 (U) | <0.3 (U) | 1.5 | 1.0 | 0.9 | 1.2 | 1.2 | <0.4 (U) | <0.2 (U) | <0.4 (U) | <0.4 (U) | <0.4 (U) | <0.4 (U) |
| C3 | 0.5 | 0.4 | 4.4 | 2.0 | 3.7 | 1.3 | <0.3 (U) | 0.2 | 0.2 (J) | 0.5 | 0.6 | 0.4 | 1.6 | 1.6 | 1.1 | 1.2 | 1.6 | <0.4 (U) | 0.4 | 0.5 | 0.8 | 0.8 | 0.4 (J) |
| C4 | 0.8 | 0.5 | 8.0 | 2.9 | 4.7 | <0.3 (U) | <0.3 (U) | 0.4 | 0.4 | 0.7 | 1.1 | 0.5 | 2.8 | 2.1 | 1.6 | 2.2 | 2.1 | <0.4 (U) | <0.2 (U) | <0.4 (U) | <0.4 (U) | <0.4 (U) | <0.4 (U) |
| C5 | 1.4 | 1.1 | 11.0 | 4.6 | 6.4 | 3.4 | <0.3 (U) | 0.7 | 0.7 | 1.2 | 1.6 | 1.2 | 6.5 | 4.4 | 3.1 | 3.5 | 2.5 | 3.5 | 2.6 | 1.6 | 3.8 | 3.5 | 1.4 |

Qualifiers: J = below the method detection limit; U = not detected.

Table G-4. Sediment polycyclic aromatic hydrocarbon determinations, benz(a)anthracene through benzo(g,h,i)perylene and total PAHs, TEN Environmental Baseline Survey.

| Station | Benz(a)anthracene | Chrysene/Triphenylene | C1-Chrysenes | C2-Chrysenes | C3-Chrysenes | C4-Chrysenes | Benzo(b)fluoranthene | Benzo(k,j)fluoranthene | Benzo(a)fluoranthene | Benzo(e)pyrene | Benzo(a)pyrene | Perylene | Indeno(1,2,3-c,d)pyrene | Dibenzo(a,h)anthracene | Benzo(g,h,i)perylene | **Total PAHs** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.8 | 2.3 | 1.4 | 2.3 | 1.8 | 2.5 | 2.8 | 0.8 | 0.2 (J) | 1.2 | 1.1 | 1.5 | 1.6 | 0.5 | 1.5 | **2,111** |
| 2 | 1.0 | 2.6 | 1.5 | 2.3 | 2.9 | 5.4 | 3.2 | 1.0 | 0.3 | 1.5 | 1.4 | 1.8 | 2.0 | 0.6 | 2.0 | **1,211** |
| 3 | 1.2 | 2.7 | 1.4 | 2.1 | <0.3 (U) | <0.3 (U) | 3.5 | 1.1 | 0.6 | 1.5 | 1.5 | 3.2 | 2.1 | 0.6 | 1.9 | **161** |
| 4 | 1.1 | 2.8 | 1.3 | 2.6 | <0.3 (U) | <0.3 (U) | 3.7 | 1.1 | 0.4 | 1.5 | 1.4 | 2.0 | 2.1 | 0.6 | 2.0 | **239** |
| 5 | 1.6 | 3.1 | 1.7 | 2.9 | <0.3 (U) | <0.3 (U) | 4.7 | 0.6 | 0.4 | 1.6 | 1.6 | 2.6 | 2.5 | 0.7 | 2.3 | **225** |
| 6 | 0.9 | 2.8 | 1.1 | 1.6 | <0.3 (U) | <0.3 (U) | 3.4 | 1.0 | 0.3 | 1.5 | 1.4 | 1.8 | 2.1 | 0.6 | 2.0 | **207** |
| 7 | 1.0 | 2.6 | 1.2 | 1.9 | <0.3 (U) | <0.3 (U) | 3.3 | 1.0 | 0.3 | 1.5 | 1.3 | 2.4 | 2.2 | 0.6 | 2.0 | **169** |
| 8 | 1.2 | 2.9 | 1.4 | 2.8 | <0.3 (U) | <0.3 (U) | 3.6 | 1.1 | 0.4 | 1.5 | 1.3 | 2.6 | 2.2 | 0.6 | 2.0 | **274** |
| 9 | 1.2 | 2.8 | 1.1 | 2.3 | <0.3 (U) | <0.3 (U) | 3.5 | 1.1 | 0.4 | 1.6 | 1.6 | 3.3 | 2.0 | 0.6 | 1.9 | **230** |
| 10 | 1.6 | 3.0 | 1.6 | 1.7 | <0.3 (U) | <0.3 (U) | 4.3 | 1.4 | 0.8 | 1.9 | 2.0 | 4.0 | 2.8 | 0.8 | 2.6 | **213** |
| C1 | 0.5 | 0.8 | <0.3 (U) | <0.3 (U) | <0.3 (U) | <0.3 (U) | 1.5 | 0.3 | <0.2 (U) | 0.7 | 0.8 | 2.5 | 0.9 | 0.3 | 1.1 | **49.6** |
| C2 | 0.4 | 0.8 | <0.3 (U) | <0.3 (U) | <0.3 (U) | <0.3 (U) | 1.0 | 0.4 | <0.2 (U) | 0.5 | 0.7 | 1.6 | 0.7 | <0.2 (U) | 1.4 | **113** |
| C3 | 0.6 | 1.0 | 0.9 | 2.0 | <0.3 (U) | <0.3 (U) | 1.4 | 0.5 | <0.2 (U) | 0.7 | 0.8 | 2.9 | 1.1 | 0.3 | 2.1 | **65.8** |
| C4 | 0.8 | 1.7 | 1.0 | <0.3 (U) | <0.3 (U) | <0.3 (U) | 2.2 | 0.8 | 0.3 | 1.1 | 1.2 | 4.1 | 1.5 | 0.4 | 2.7 | **227** |
| C5 | 2.1 | 3.8 | 2.0 | <0.3 (U) | <0.3 (U) | <0.3 (U) | 5.3 | 1.8 | 0.7 | 2.4 | 2.5 | 6.8 | 3.3 | 0.9 | 3.3 | **346** |

Qualifiers: J = below the method detection limit; U = not detected.

Annex C

# Marine Mammal and Turtle Observation Reports

Annex C1

# MMO Report 9 March 2011

# JUBILEE FIELD

# MARINE MAMMAL AND TURTLE

# OBSERVATION REPORT

# GHANA

| | |
|---|---|
| Gardline Project Ref. | 8391 |
| Fieldwork Dates | 17th November 2009 – 30th January 2011 |
| Report Status | Final |
| Issue Date | 9th March 2011 |

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# EXECUTIVE SUMMARY

- Tullow Oil Ghana (TGL) commissioned this report to evaluate data gathered on marine mammals and turtle sightings at the Jubilee Field.

- Watches for marine animals were conducted during offshore operations at, and on route to, the Jubilee field.

- The Jubilee field is located 60km offshore Ghana, and the main route to the site is from the port of Takoradi. Sightings data collected on this route are also included in this report.

- Sightings were recorded from a number of platforms, most commonly from the *M.V. Orient* and *M.V. Oceanix Orion.*

- Data was collated between from 17th November 2009 to 31st January 2011 from both trained observers and untrained vessel personnel.

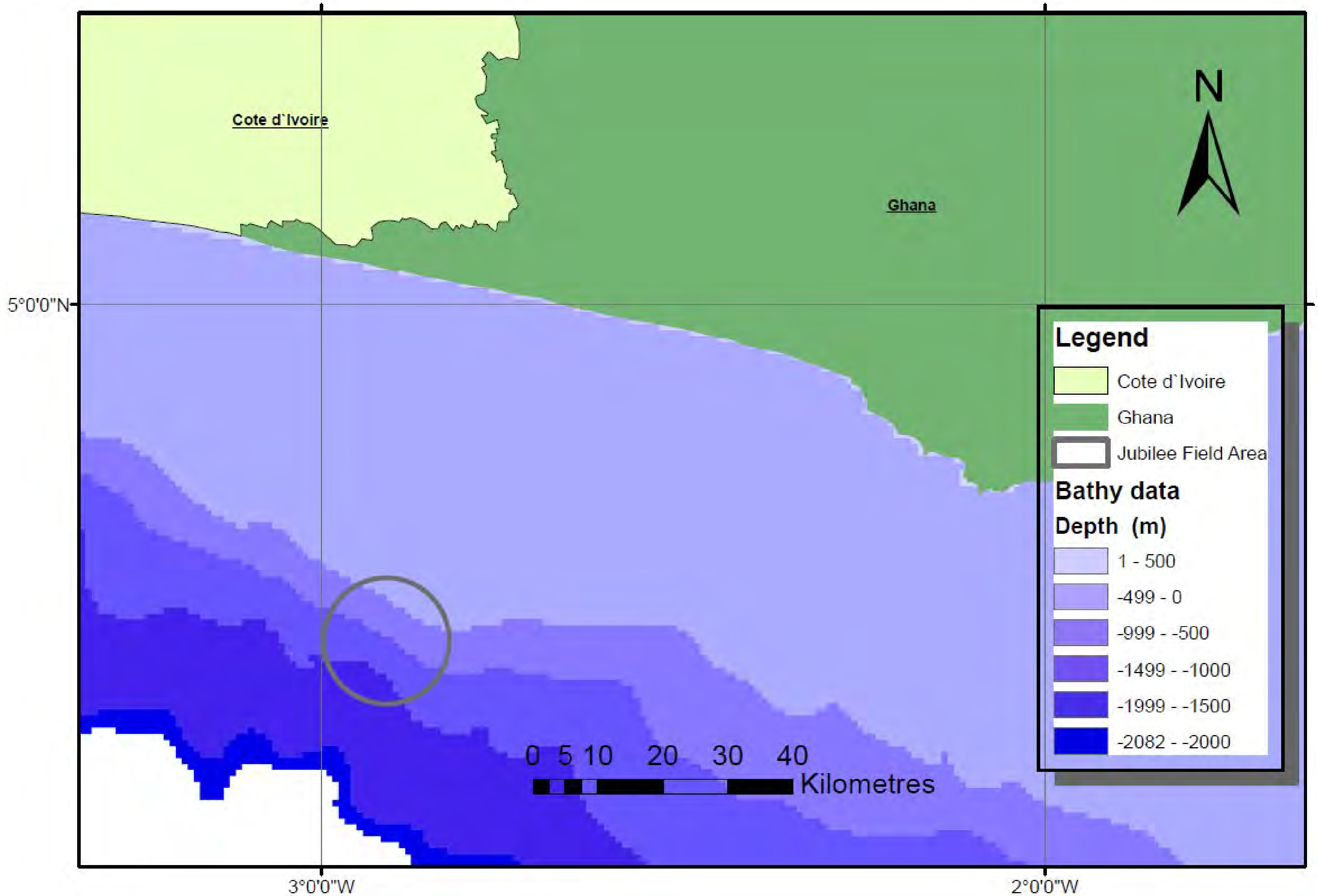
- TGL commissioned the training of offshore personnel in April and June 2010 to gather *ad hoc* data.

- All data collected has been subsequently analysed by trained and experienced marine biologists. A taxonomic grading was applied to sightings without supporting information to verify the sighting.

- A total of ten different species were recorded, with the majority of sightings (43%) being of 'dolphin species'. The most commonly identified species recorded was the short-finned pilot whale.

- A dedicated survey by experienced personnel is recommended to obtain an accurate representation of abundance and distribution of marine mammal and turtle species in the region.

SURVEY LOCATION



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# 1. Introduction

## 1.1 Background

The development of the Jubilee Field, 60 km offshore Ghana, by Tullow Ghana Limited (TGL) has been subject to a full Environmental Impact Assessment (EIA) (Irvine *et al*, 2009) under the Ghana Environmental Assessment Regulations (1999).

The Jubilee oil field was discovered in mid 2007 with subsequent exploration and appraisal wells drilled in Deepwater Tano and West Cape Three Points concession areas. These blocks are in an area where water depths range from 1,100 to 1,700 m, and is highly diverse in its marine life. The Jubilee field is the first deepwater development of hydrocarbon resources in Ghana. Installation of the FPSO (Floating, Production, Storage and Offloading vessel) was completed in June 2010 and First Oil was celebrated on the 15th December 2010, when first production commenced. The FPSO Kwame Nkrumah (Figure 1) will offload crude oil to export tankers to deliver to the global market.

Offshore operations on this scale have the potential to affect marine mammals and turtles via the propagation of noise, increased vessel traffic in the natural environment. While this potential exists, mitigation measures are put in place to reduce impacts to acceptable levels. The findings of the EIA concluded a number of mitigation measures are required in order to minimise the impact on the marine environment during the Jubilee Field Phase 1 development, including the use of trained observers, noise monitoring and avoidance procedures.

TGL is committed to avoiding significant adverse impacts on the environment, wherever possible, and reducing the impact to acceptable levels through appropriate and practicable mitigation measures where not. TGL understands that although little is known regarding the abundance and distribution of marine mammals and turtles in offshore Ghana, there is still the potential to cause behavioural and/or physiological disturbance.

**Figure 1 FPSO Kwame Nkrumah**

## 1.2 Objective

This report presents the findings of incidental and *ad hoc* recordings of marine animals between 17th November 2009 and 31st January 2011. The observations were conducted by Tullow Ghana Limited personnel onboard various vessels operating in the Jubilee Field, including the *M.V. Orient* and *M.V. Oceanix Orion*.

2. The Marine Environment

## 2.1 Physical Environment and Oceanographic Features

The ocean is a highly heterogeneous environment, with both large- and small-scale spatial patterns in oceanography (Hunt & Schnieder, 1987). Fluctuations in physical and biological factors within the ocean environment will have an effect on the abundance and distribution of marine fish and zooplankton, which in turn will be reflected in specific marine populations (Thompson & Ollason, 2001). Physical processes such as circulatory patterns may have large-scale implications on the dispersion of all marine life. Equally important small-scale features, or localised episodes, will also have an overall affect. Oceanographic features vary on a temporal scale, with seasonal formation of fronts and annual fluctuations in temperature, salinity and primary production (le Fèrve, 1986; Ellett & Blindheim, 1992).

The distribution of marine mammals is extremely irregular and is generally related to the distribution of their food source. Marine mammals feed on a variety of foodstuffs and thus their distribution is related to the movement or abundance of such food sources (e.g. Evans, 1990; Harrison *et al*, 1994; Begg & Reid, 1997). As the distribution and abundance of marine mammals is influenced by oceanographic characteristics it is important to describe the topography and marine processes in the study area.

The Jubilee Unit Area covers part of the Deepwater Tano and West Cape Three Points licence areas. The area lies in water depths of between 1,100 and 1,700 metres and covers an area of approximately 110 sq km. The Guinea Current flows east along West Africa and the coast of Ghana obtaining velocities up to 100 cm $s^{-1}$ (Richardson and Reverdin, 1987). The current has two sources; the North Equatorial Counter current and the Canary current and as with most currents the Guinea Current is characterised by areas of upwelling (Bakun, 1978) and increased biological productivity (Binet, 1997). The Guinea Current has been observed by several researchers to show a minimum velocity in winter and a maximum velocity in summer (Bakun, 1978; Philander, 1979).

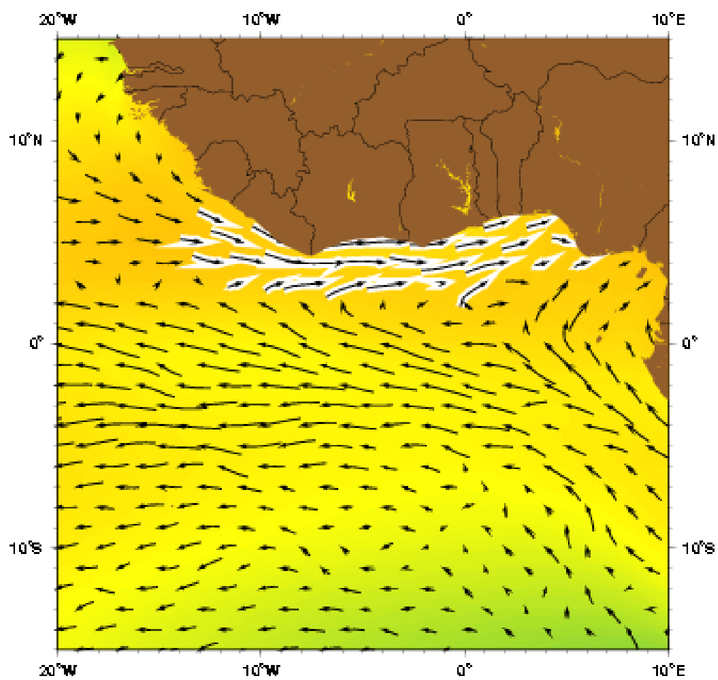


**Figure 2 The Guinea Current as represented by the Mariano Global Surface Velocity Analysis (Gyory *et al,* 2005)**

## 2.2 Marine Communities

The Guinea Current Large Marine Ecosystem is considered a Class I, highly productive (>300 gC/$m^{2\text{-}yr}$) ecosystem based on SeaWiFS global primary productivity estimates. The phytoplankton off the coast of Ghana show seasonal changes, demonstrating two seasons with high productivity, one in the upwelling season (June - September) and a another production during flooding of larger rivers (September – October) (Binet & Marchal, 1993).

This is concurrent with phytoplankton levels recorded during the Jubilee Field Phase 1 EIA sampling which also indicated a system of relatively high productivity, due to the coastal ecosystem undergoing seasonal upwelling in the northern Gulf of Guinea that commence in July (Irvine *et al*, 2009).

Along this coast of West Africa there are several commercially important target species off the coast including round sardinella (*Sardinelia aurita),* chub Mackerel (*Scomber japonicus)* and the European anchovy (*Engraulis encrasicolus).*

There are many species of shark present in the area although only two which are protected under CITES, the whale shark and great white shark. Although records are few, they appear to support a year round occurrence of whale sharks in offshore waters in the Gulf of Guinea (Weir, 2010). The shark fishery in Ghana is currently unregulated and driven by the Asian market for shark fin. These species also have a protracted life history increasing the risk of exploitation. The blue shark is the most abundant and wide ranging species. In the eastern Atlantic Ocean it ranges from Norway to South Africa and over the entire mid-Atlantic. Shortfin mako have also been reported in the Gulf of Guinea (Castro & Mejuto, 1995).

In Ghanaian waters there has been little scientific research on marine mammals and turtles and as such there is minimal knowledge of species' distribution and abundance in coastal and offshore areas. The extent of the species assemblage has been studied using landings, stranding, sightings and historical records, although given the widely dispersed nature of the fishery records may only represent a fraction of what is true take. Studies are predominantly onshore, the majority of which are land-based sea turtle nesting surveys. Previous monitoring efforts have included Ghana Wildlife Society's Marine Turtle Conservation Project (commenced 1995) to identify nesting sites, carry out conservation education, and implement legislation (Formia *et al.* 2003); and most recently the Ghana Olive Ridley Project (Seaturtle.org & Fl Gulf Coast University). Due to data deficiency of Ghanaian marine macrofauna Ghana's ecological importance is unknown.

### 2.3 Marine mammal distribution and abundance in Ghana

A variety of marine mammal species have been recorded off the west coast of Africa, however, the distribution of marine mammals in Ghana is poorly understood. There is controversy over the total number of cetacean species present in this area; the two most detailed studies have come to different conclusions regarding total numbers observed. While it is likely that the difference in total number lies in different paper methodologies and data sources, looking at both sources, they provide clear evidence for species identification and therefore its possible to combine their findings.

The validated list compiled by Van Waerebeek *et al.* (2009) used skull morphometric study, specimens from deliberate/accidental capture and stranding to identify species present. Although it is widely acknowledged that there are many problems associated with the reporting of individuals caught at sea or stranded (Norman *et al*, 2004) it provides useful insight on a wider scale. This method confirmed recordings for 17 odontocete and one mysticete species within Ghanaian waters, confirming that the only mysticete recorded in these waters is the humpback whale (*Megaptera novaeangliae*). Based on these dolphin capture records, Clymene dolphin appears to be the most common cetacean in Ghanaian waters.

The species list compiled by Weir (2010) primarily uses visual identification from at sea sightings throughout the Gulf of Guinea with strict validation on basis of observer and reliance on supporting material due to the difficulty of species identification at sea. This study reported 17 species in Ghanaian waters from records including whaling, capture, stranding and at sea sightings. Bottlenose, Atlantic and Pantropical spotted, and rough-toothed dolphins are regularly seen, along with sperm, dwarf sperm, and humpback whales.

Under IUCN's Redlist, the only current Ghanaian cetacean species noted as 'vulnerable' (Taylor *et al*. 2008) is the sperm whale. However blue whales, listed as 'endangered' in the Redlist (IUCN, 2010), are cosmopolitan to the world's oceans (Sears 2002), and have been recorded off Angola (Best, 1994) and therefore may occur in Ghanaian waters. Fin and sei whales, also listed as 'endangered' in the Redlist (IUCN, 2010), have been recorded in West African waters, including four fin whales off Angola between 2003-2006 (Weir, 2008), and therefore may occur in Ghanaian waters. Best (1996) recorded evidence of Bryde's whales, IUCN listed as 'data deficient' (Reilly *et al.* 2008), migrating in the southeast Atlantic, and N. Robinson (2005, per. Comm.) has observed Bryde's whales in the Gulf of Guinea off Gabon.

The West African manatee is unique to the West African region, along with the Atlantic humpbacked dolphin population, which is believed to have been dramatically reduced due to coastal fishing. Both species are currently listed as 'vulnerable' by IUCN (2010). The West African manatee occurs around the west Africa coastline, and subsequent inland rivers and estuaries between Senegal and Angola, however coastally they are restricted to shallow areas due to there location of their food source, sea grass (Shirihai & Jarrett, 2006, Reynolds and Powell, 2002). Due to this manatees tend to be found in water depths of around three meters, thus at the Jubilee field may only be encountered near port entries. The area has been proposed as an important migration route and breeding ground for the humpback dolphin, about which little is known (Van Waerebeek *et al.* 2003, Van Waerebeek & Ofori-Danson, 1999). In 2009, Van Waerebeek *et al.* published results of data collected from fisheries between 1996-2004 concluding that despite the suitable coastal habitat, the Atlantic humpbacked dolphin remains unrecorded in Ghanaian waters.

Marine mammals in Ghanaian waters are fully protected under the Wildlife Conservation Regulations LI 685 1971 of the Wildlife Animals Preservation Act 1961, Act 43. In Ghana, the Wildlife Conservation Regulation, L.I 680, 1971, protects marine turtles and the hunting, capturing or destruction is absolutely prohibited. In addition to this, marine mammals and turtle habitats are protected by The Convention for the Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region (Abidjan Convention, enforced 1984), Accra Declaration of the Ministerial Committee of the Gulf of Guinea Large Marine Ecosystem (GOG-LME, 1998) and the Abuja Declaration of the Guinea Current Large Marine Ecosystem Project (2006).

## 2.4 Turtle distribution and abundance in Ghana

There are five species of marine turtles recorded within the Gulf of Guinea as also determined by bycatch and nesting studies (ERM,2009). These species are the leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*) and olive ridley (*Lepidochelys olivacea*). Three of the recorded species, leatherback, green and olive ridley, are known to nest on the Ghanaian coast (Armah, 1997).These species are IUCN listed as critically endangered, endangered and vulnerable respectively (ICUN, 2010). Despite their protected status adults and eggs are harvested as bushmeat (ERM, 2009). Marine turtles are particularly sensitive to anthropogenic disturbance as these species are philopatric to nesting areas but highly migratory and have a protracted life history.

Past studies reported the occurrence of five species of marine turtles off the Ghana coast. These were: leatherback, green (Hirth, 1997), olive ridley, hawksbill (Loverage & Williams, 1957, Irvine, 1947, and Anon. 1971) and the loggerhead (Figure 3). A more recent study carried out in 1994 by the Coastal Wetlands Management Project did not record hawksbill and loggerhead, however leatherback, green and olive ridley were all found to be nesting along the coast.

**Figure 3 Loggerhead turtle**

# 3. Methodology

## 3.1 Observer Procedures

Observers recorded incidental marine mammal and turtle sightings whilst onboard vessels conducting support and security duties on behalf of Tullow Ghana Limited (TGL) within, and on transit to, the Jubilee Field, offshore Ghana.

The primary observation technique used to spot marine mammals was to scan the visible area of sea using the naked eye and, where available and required, scanning areas of interest with binoculars (e.g. waves going against the prevailing direction, white water during calm periods, bird activity, etc.). This technique gives both a wide field of view and the ability to have a sufficient range of three to four kilometres in ideal conditions. Where possible, photographs were also taken to aid identification of the species of the animal.

The majority of identifications, where provided, are based the observer's previous experience. However during April and June 2010 TGL commissioned the formal training of nine security and environmental advisor staff working at the Jubilee Field. These staff, upon completion of their training, were issued with two tools to aid identification. These tools are a turtle identification key (Appendix A), and a Shirihai & Jarrett (2006) identification guide book. These observers were also given a sightings form to complete in the event of encounters (Appendix B). In addition three members of vessel crew were also trained in basic identification skills, in order to assist the fully trained observers.

The information recorded by observers included the date and time, the vessel's position, the species and number of animals, and where possible the behaviour, and the details on the features used to identify the animals. All data collected was reviewed sightings downgraded depending on description and all photographs provided.

Once the data was compiled, the species identification was reviewed by trained and experienced observers onshore. Identifications which did not include accompanying descriptive justification or photographic evidence were 'downgraded' and classified into lower taxonomic groups: I.E turtle species (Order Testudines), dolphin species (Family Delphindae), and whale species (Suborder Mysticetes, and the Odontocete families of Physeteridae, and Ziphidae). This method is explained in Table 1. Those species names provided by the observer with evidence that could be verified were included at this taxonomic level.

**Table 1 Taxonomic 'downgrading'**

| | Whale species | | Dolphin Species | Turtle species |
|---|---|---|---|---|
| **Order** | Cetacean | Cetacean | Cetacean | Testudines |
| **Suborder** | Odontocetes | Mysiticetes | Delphinidae | [All} |
| **Family** | Physeteridae & Ziphidae only | [All] | [All] | |
| **Ghanaian examples** | Sperm whale, Dwarf sperm whale | Sei whale, Humpback whale | Pilot whale, Spinner dolphin, Spotted dolphin | Green turtle, Hawksbill turtle, Loggerhead turtle |

### 3.2 Survey Area

The Jubilee Field is located 60 km from the Ghanaian coastline, and 130 km southwest of the port city of Takoradi. The Jubilee Field is situated in the Tano Basin in an area of water depths between 1,100 and 1,700 metres and covers an area of approximately 110 square kilometres. The position of the site is shown in the Location Map, and locations of platforms within the Jubilee field can be found in Table 2.

**Table 2 Survey location**

| Jubilee Field (Datum WGS84) | Latitude | Longitude |
|---|---|---|
| FPSO Kwame Nkrumah | 04 35' 47" N | 002 53' 31" W |
| Drilling Rig Eirik Raude | 04 53' 57" N | 002 90' 96" W |

### 3.3 Survey Vessels

The majority of recordings were carried out onboard the *M.V. Orient* and M.V. *Oceanix Orion* from 17th November 2009 to 31st January 2011. These vessel details are as displayed in Table 3.

**Table 3 Vessel Specifications**

| | | |
|---|---|---|
| **Vessel** | *M.V. Oceanix Orion* | *M.V. Orient* |
| **Class** | BV | ABS + A1 |
| **Flag** | Netherlands Antilles | Netherlands Antilles |
| **Length** | 45.22 m | 47.60 m |
| **Breadth** | 10.6 m | 12.2 m |
| **Draft** | 2.75 m | 2.8 m |
| **Built** | 1984, Norway | 1981 |
| **Main Engine** | 2 x Caterpillar 3412/ 1040 BHP | 2 x Detroit Diesels 12V 149, 1350 hp |
| **Propellers** | 2 x 3 bladed pitch propeller | 2 x Fixed pitch |
| **Accommodation** | 44 berths | 33 berths |
| **Owners** | workshipsafrica | workshipsafrica |
| **Cruising Speed** | 9 Knots | 10 – 12 Knots |

# 4. Results

## 4.1 Survey Coverage

The Jubliee Field data was collected between 17th November 2009 and 31st January 2011 on board various platforms including the *M.V. Orient* and the *M.V. Oceanix Orion*. The majority of these vessels hold a security role for the operating platforms of the Jubilee Field, therefore as of June 2010 when the FPSO arrived on site the effort was concentrated in the vicinity of this platform. Prior to the arrival of the FPSO effort was concentrated around the drilling rig the Eirik Raude (see Table 2 for location information).

## 4.2 Field Effort

There was no dedicated field effort undertaken during the Jubilee field operations, with incidental sightings only recorded.

## 4.3 Marine Animal Sightings

There was a total of 101 sightings of marine animals throughout the duration of the data collection period, from 17th November 2009 to 31st January 2011. All sightings have been plotted on the sightings maps below (Figures 6 & 7). The raw data can be found in Appendix C.

43% of all sightings were recorded dolphin species (Figure 4, n= 44), with approximately equal numbers of sightings recorded for both whale and turtle species groups. Additionally 79% of all observations were recorded whilst within a 2.5nm radius of the centre of the Jubilee field (Figure 5). The sightings within the Jubilee field central area are displayed in Figure 7.

Sightings which were not supplied with location coordinates are displayed in Figure 6 as a list box.

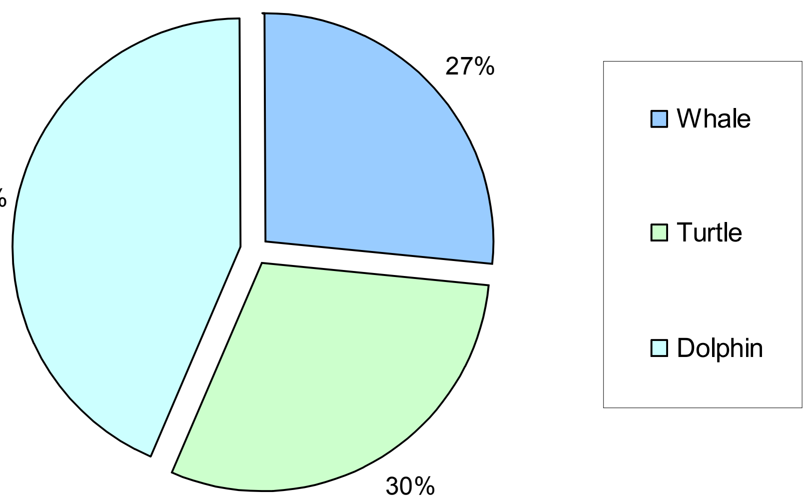


**Figure 4 Proportion of species groups recorded at the Jubilee Field**

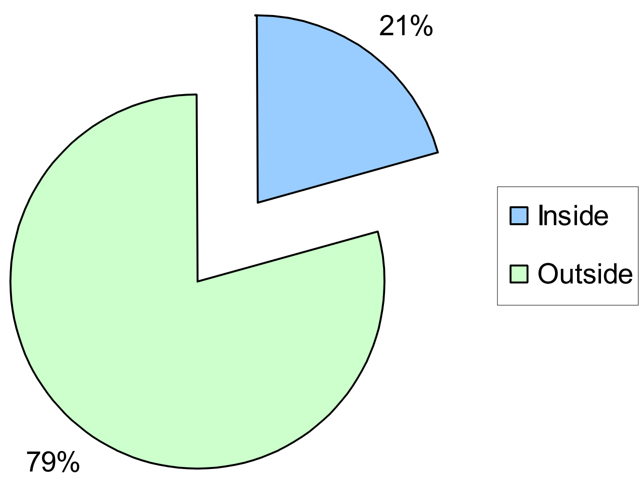


**Figure 5 Percentage of observations within and outside of the Jubilee Field 2.4nm area**

There were a total of nine different species recorded, five of which were positively identified sightings, either through the supply of photographic evidence or sufficient description. These were; Pilot whale, Pantropical spotted dolphin, common dolphin, Sei whale and green turtle. Additionally a further four species (Clymene and rough-toothed dolphins, and Brydes and humpback whales) were recorded however no verification could be given to these. Those sightings where the species could not be determined were listed as 'whale species', 'dolphin species' or 'turtle species' as discussed in the Methods section of this report. Further details of all of these encounters are detailed below.

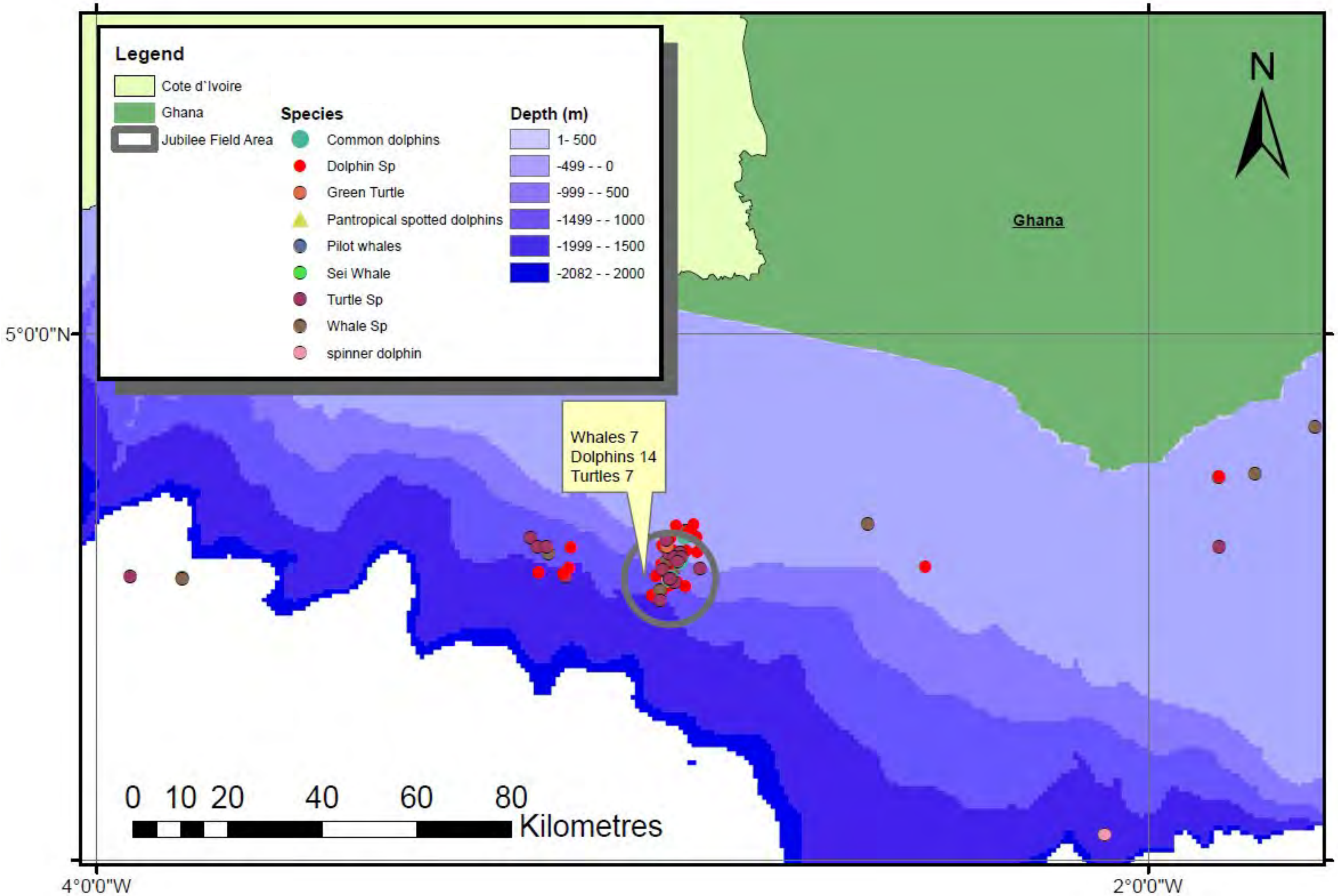


**Figure 6** **Sightings Distribution Map**

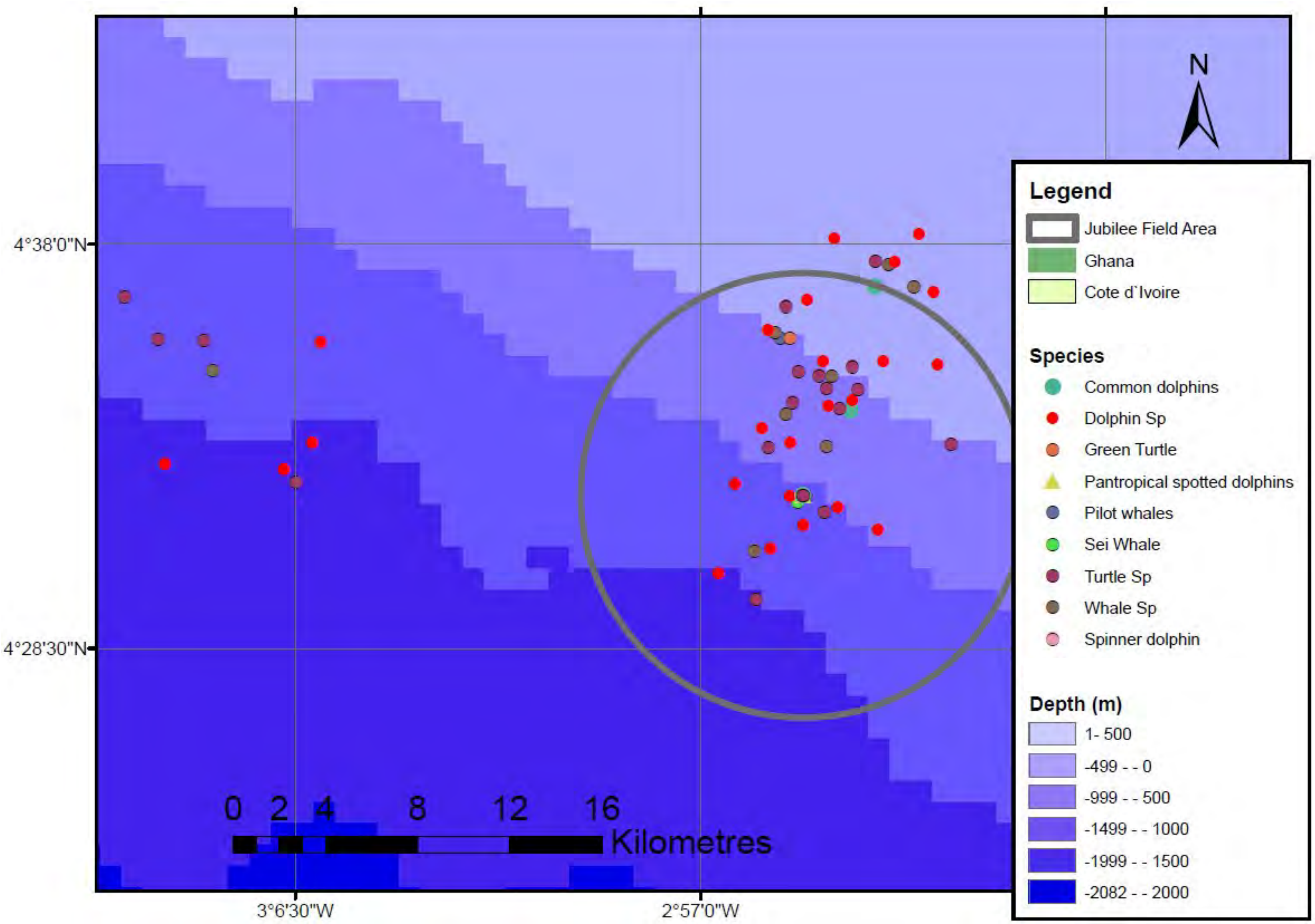


**Figure 7** **Sightings within the Jubilee Field**

Figures 8- 10 display the distribution of sighting across the data collection period. Conclusions as to the seasonal distributions cannot be drawn from the data gathered due to the lack of effort data. Despite this the number of sightings recorded (Table 4) can be assumed to correlate to vessel activity, in such that since the FPSO arrival in June 2010, and commencement of production in November 2010, sightings recorded have been more frequent.

**Table 4 Monthly sightings count**

| Month & Year | Nov 09 | Dec 09 | Jan 10 | Feb 10 | Mar 10 | Apr 10 | May 10 | Jun 10 | Jul 10 | Aug 10 | Sep 10 | Oct 10 | Nov 10 | Dec 10 | Jan 11 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. sightings | 5 | 0 | 4 | 1 | 2 | 7 | 6 | 4 | 1 | 7 | 13 | 6 | 5 | 11 | 29 | 101 |

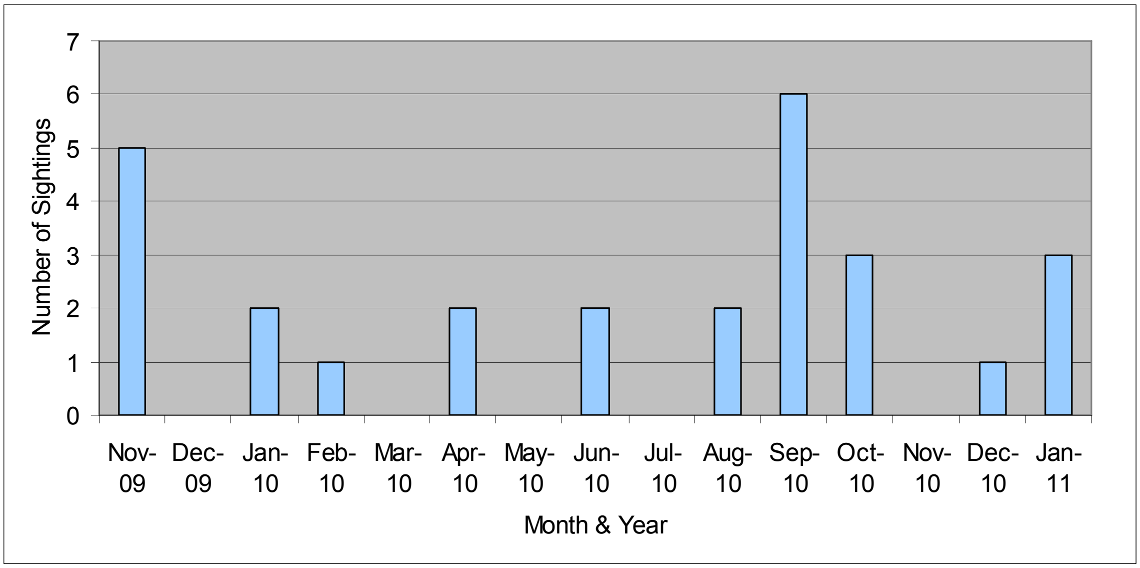


**Figure 8 Whale species sightings between 17th November 2009 and 31st January 2011**

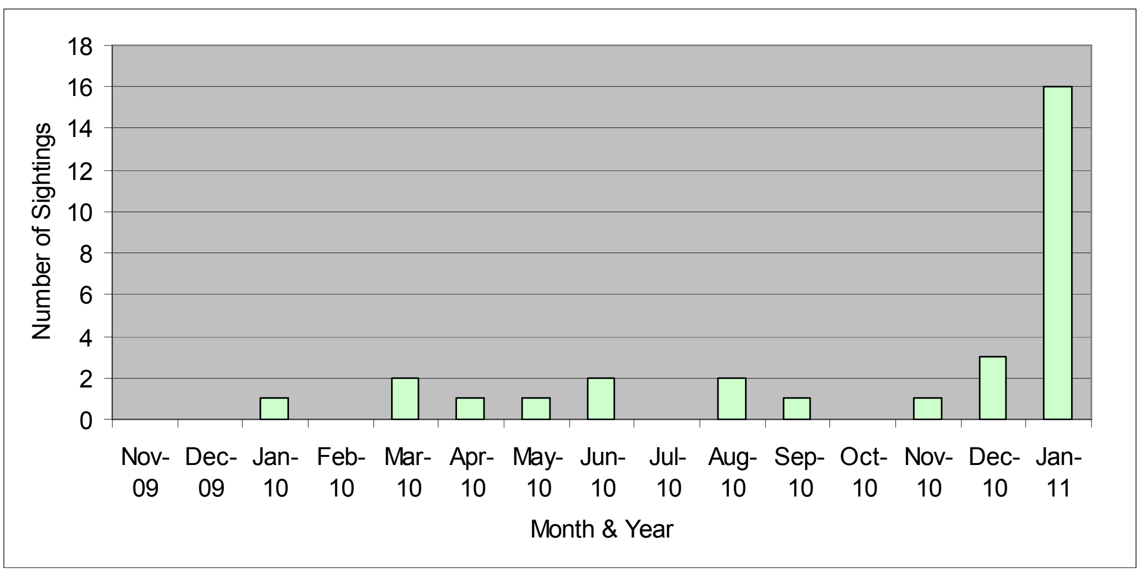


**Figure 9 Turtle species sightings between 17th November 2009 and 31st January 2011**

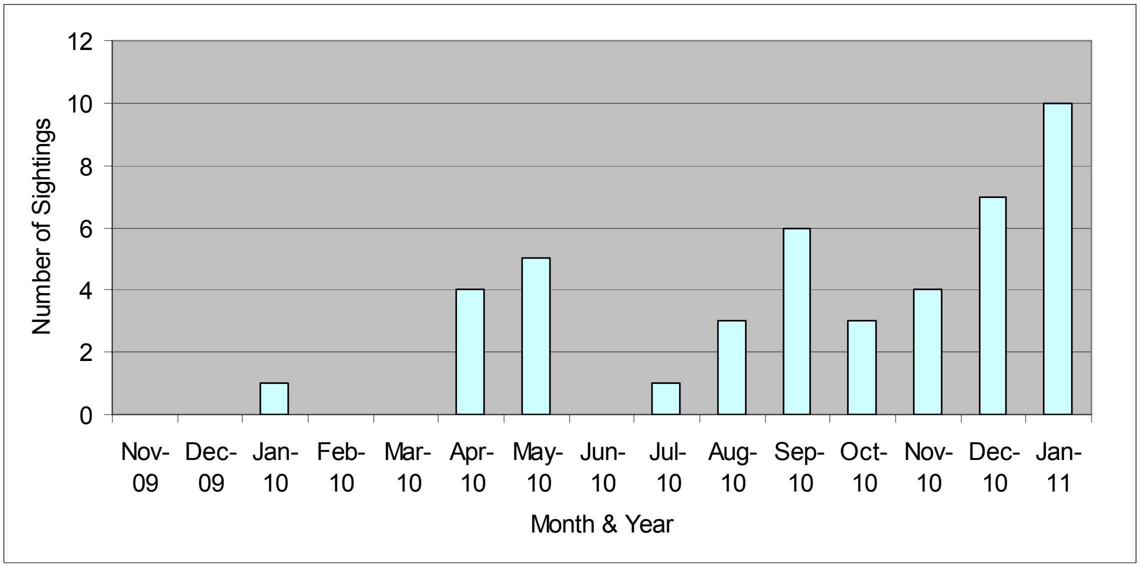


Figure 10 Dolphin species sightings between 17th November 2009 and 31st January 2011

## 4.4 Confirmed marine mammal sightings

### 4.4.1 Sei Whale (Balaenoptera borealis)

*The sei whale can be found in every open ocean, from the tropics to the Polar Regions, although they are more restricted to the temperate regions than other rorqual whales. Very similar to brydes whales, they are up to 18 meters in length and 30 tonnes in weight (Jefferson et al, 1993). Their streamlined body has a dorsal fin that rises at a sharp angle from the back, and has a single prominent ridge down the rostrum (the brydes whale has three) (Jefferson et al, 1993). Colouration is dark grey, with a whitish area on the belly. They produce a small blow, only up to three meters in height. Sei whales are often seen in small groups of two to five individuals, and are possibly the fastest swimmers of all cetaceans. When swimming slowly, both the dorsal fin and blowhole tend to be seen at the same time, unlike the fin whale (Shirihai & Jarret, 2007). Unlike other rorqual whales, sei whales tend to be skim feeders, skimming copepods and other small prey types from the surface rather than lunging or gulping. Due to heavy exploitation, and a large reduction in population size by whaling, sei whales are classified as endangered by the IUCN (IUCN, 2009).*

There was one sighting of a Sei whale between 17th November 2009 and 31st January 2011 as seen in Figure 11. A single Sei whale was sighted at 13:30h on 4th April 2010 on the Jubilee site. The encounter lasted an hour and a half, during which time the individual came within 10 meters of the vessel. Identification was determined through the provision of photographs displaying the colouration and dorsal fin shape, along wit information gathered about the size of the animal.

**Figure 11 Sei whale sighting at 13:30h on 4th April 2010.**

### 4.4.2 Common Dolphin (*Delphinus delphis*)

*Common dolphins are found in all seas throughout the world. They are a largely oceanic dolphin, but are known to occur quite regularly in coastal waters. The common dolphin is a moderately slender animal with a tall falcate dorsal fin. They have a medium to long beak. Common dolphins are strikingly marked with a dark back, white belly, and tan anterior flank patch. This patch dips below the dorsal fin and combines with streaks of light grey on the tail stock to produce an obvious 'hourglass' pattern (Jefferson et al,1993). The common dolphin can measure up to 2.7 m and weigh around 70-110 kg (Shirihai & Jarret, 2007). The habitats they occupy are diverse, ranging from rocky reefs to calm lagoons and open waters. They tend to prey on small shoaling and squid. Common dolphins have been reported individually but are usually found in herds that range in size from several dozen to 10,000 (Jefferson et al, 1993). They are powerful swimmers and acrobatic in nature. They live at least 30 years (approximately). The estimated current population is unknown, but it is believed to be relatively common, and they are classified as Least Concern on IUCN Red List (IUCN, 2009).*

There were two sightings recorded of common dolphins. The first recording was of over 150 individuals observed at 06:50h on 23rd May 2010. The group was seen transiting alongside the *MV Orient* for 30 minutes at a distance of 300 metres. The second sighting was recorded on 29th September 2010. A group of approximately 200 dolphins were observed at the Jubilee Field. Common dolphins are frequently found in groups of this size *(Jefferson et al, 1993)*.

### 4.4.3 Green turtle (Chelonia mydas)

*Green turtles inhabit tropical and subtropical waters throughout the world. They usually remain within the 20°C isotherms (Marquez, 1990), although individuals may also stray into temperate waters. It is believed that they inhabit coastal waters of more than 140 counties (Groombridge and Luxmoore, 1989). The green turtle has an olive green, nearly circular or heart-shaped carapac, it grows up to 1.5 m in length and can weight up to 200 kg. Green turtles spend their first five to ten years drifting on ocean currents (Carr, 1987). During this pelagic phase, they are often found in association with driftlines and rafts of floating marine plant (Robins et al, 2002). Once green turtles reach 30 to 40 cm in length, they settle in shallow benthic foraging habitats such as tropical tidal and sub-tidal coral and rocky reef habitat or inshore seagrass beds. The shallow foraging habitat of adults contains seagrass beds or algae mats on which green turtles mainly feed (Musick and Limpus 1997). Breeding males and females move from their feeding grounds to areas near nesting beaches for mating. The males then return to their feeding grounds, and the females come up onto the beach to lay their eggs, usually on several different nights (Robins et al, 2002). They nest in over 80 countries worldwide (Hirth, 1997). The main current threats to green turtles are disturbance (e.g. light disturbance) and habitat damage due to coastal development; by-catch from fisheries and shark control measures; predation on nests; boat strikes; entanglement and ingestion of marine debris; and in some areas, indigenous harvesting (Lanyon et al, 1989).This turtle species is listed under Appendix I of the Convention on International Trade in Endangered Fauna and Flora (CITES) and under Appendix II of the Convention on Migratory Species (CMS) and it is considered Endangered globally in the IUCN Red List (IUCN, 2009).*

There were three sightings of green turtles recorded at the Jubilee Field. The turtles were identified by the colour of the carapace and the head shape. These were observed on the 29$^{th}$ May 2010, 9$^{th}$ and 13$^{th}$ January 2011. The first observation as made whilst the animal surfaced to breathe, and was captured on video, which was viewed by the experienced observer who determined identification. The second sighting exhibited the same behaviour. The third observation of a green turtle was made by a member of security crew who retrieved the individual from a fisherman’s canoe, entangled in fishing net. Prior to freeing the animal from the net and releasing it back into the water the observer noted key identification features and was positive in the identification.

### 4.4.4 Pantropical Spotted Dolphin *(Stenella attenuate)*

*The pantropical spotted dolphin is one of the most abundant cetaceans on the planet, even though its numbers have been seriously reduced in some areas by incidental killing. This species is found in all tropical to warm temperate oceanic and pelagic waters and they can be found both as a few individuals and in large groups of several thousand (Culik, 2010). They may also be found in large, multispecies aggregations including spinner dolphins (S. longirostris) and yellowfin tuna (Thunnus albacares) and these groups may be segregated by sex and/or age (Perrin, 2009). This species varies geographically in body size and colouration with adults ranging between 166 and 257 cm and weighing up to 119 kg. In general, they have a slender body, a relatively small but strongly falcate dorsal fin, light coloured dorsal spots and a long, slender beak which is white on the tip. Calves are born without spots (Culik, 2010). Aerial behaviour such as leaping, bow-riding and porpoising are common in spotted dolphins. Their diet varies with region but mainly includes fish, squid and crustaceans (Perrin, 2009). The current population is estimated to be more than 2.5 million and their IUCN status is "Least Concern" (IUCN, 2008).*

The identification of this group was made by an experienced observer whilst training TGL personnel onboard the *M.V. Oceanix Orion* on the 29th May 2010. The group was approximately 20 in number and displaying transiting behaviour. Juveniles were noted within the group.

**Figure 12 Sighting of Pantropical Spotted dolphins, 29th April 2010.**

### 4.4.5 Short-finned Pilot Whale (*Globicephala macrorhynchus)*

*Short-finned pilot whales are a member of the dolphin family, and are also known as 'blackfish'. They occur in warm temperate to tropical waters of the world, generally in deep offshore areas. They are all black to coal grey in colour, with a white or light grey anchor-shaped patch on the ventral surface and a faint grey saddle patch behind the dorsal fin (Jefferson et al, 1993). Pilot whales have a distinct rounded head with a very slight beak and an up-curved mouthline. The dorsal fin is prominent, falcate and located on the forward part of the back, and the flippers are sickle shaped. Adult males can reach up to 6.1 m in length and weigh up to 3 tons, becoming sexually mature at 12 years of age, while adult females measure up to 5.5 m, weigh up to 1.5 tons and reach sexual maturity around nine years of age (Jefferson et al, 1993). Short-finned pilot whales are most often found in deep tropical waters, such as those found at the edges of the continental shelves and submarine canyons, where they feed primarily on deep sea squid, although they are known to eat octopus, cuttlefish, herring and other small fish. They are a very social species, living in tight social units and are commonly found in groups of 15 to 50 individuals (Shirihai & Jarret, 2007), occasionally associated with other species of cetacean, such as the bottlenose dolphin. Despite exploitation in some areas such as Japan and the Caribbean, they are considered a common species. They are classified by IUCN as a Data Deficient species (IUCN, 2009).*

There were three occasions where a number of short-finned pilot whales were recorded. The first sighting was a group of around 20 animals milling, on 6th June 2010 within the Jubilee Field. The individuals were indentified by their characteristic rounded head, black colouration and the wide base to their dorsal fins. The observer is experienced in identification and took photographs of the group, as shown in Figure 13 A, and B. The second sighting was at 15:30h on 15th June 2010 where the whales were seen surfacing around the *M.V. Oceanix Orion*. On the 22nd October 2010 the final observation of two pilot whales were recorded porpoising.

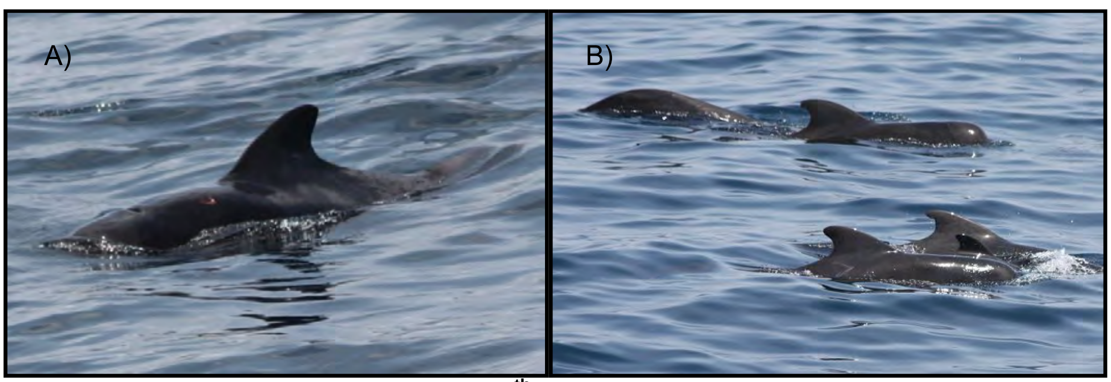


**Figure 13 Sighting of pilot whales, 6th June 2010.**

A) shows an adult with a legion, B) shows a calf amongst the group.

### 4.5 Possible species recorded

#### 4.5.1 Spinner dolphin (Stenella longirostris)

*The spinner dolphin is one of the most taxonomically complex groups of delphinids with several different forms of in different regions of the world (Shirihai & Jarret, 2007). Although they present a considerable identification challenge they all share the following charactersistics. They all have a streamlined body, a long, slender beak, small pointed flippers and the dorsal fin ranges from slightly falcate to erect and triangular (Jefferson et al,1993). There is a black stripe from the eye to the flipper and their colour pattern is generally three-tone, ranging from dark grey on the dorsal surface to a light or white belly (Jefferson et al, 1993). Adults can reach up to 2.4 m in length, and up to 75 kg in weight (Shirihai & Jarret, 2007). Females reach sexual maturity at about four to seven years of age, males at about seven to ten years. Spinner dolphins tend to feed at night and their diet consists of small fish and squid (Shirihai & Jarret, 2007). Spinner dolphins are extremely acrobatic and together with the closely related Clymene dolphin (Stenella clymene) are the only species' of dolphin known to leap out of the water and spin in mid-air. They can throw themselves up to 3 m into the air and spin up to 7 times in a single leap (Jefferson et al, 1993). Groups are often large of 1000+ animals, and frequently travel with other species of cetacean such as the spotted dolphin (Stenella frontalis), or with fish, such as yellowfin tuna (Thunnus albacares) (Perrin et al, 2002). The IUCN lists the spinner dolphin as a data deficient species (IUCN, 2009).*

A group of possible spinner dolphins were recorded (8$^{th}$ January 2010) displaying feeding activity for 30 minutes. The group was estimated to have approximately 60 individuals. A group of over 60 dolphins were also recorded in January 2011. The group was viewed for 20 minutes displaying surface activity such s porpoising and leaping.

#### 4.5.2 Short finned Pilot whales

As well as the pilot whales recorded in section 4.4.5, there was a further five occasions when pilot whales were thought to have been sighted. These were recorded in April, October, December and January. On one of the occasions the observer suggested the animals may have been pygmy killer whales however from reviewing the thorough description provided, the animals are thought to more likely be pilot whales. In January 2011 a mixed species group was recorded, which were determined by the observer to be a large pod common dolphins and several pilot whale individuals. This association is common of the pilot whales.

#### 4.5.3 Clymene dolphin (Stenella clymene)

*The Clymene dolphin is one of the poorest known cetaceans. Its distribution seems to be restricted to tropical and warm temperate regions of the Atlantic Ocean. Clymene dolphins have a typical dolphin shape with a relatively small, slightly falcate dorsal fin which is positioned about half way along the back. The beak has a distinctive black tip, which continues narrowly to the base. The animals have a dark "cape" along their backs, with paler grey flanks, a white chin and a white, often pinkish, belly (Shirihai & Jarret, 2007). A dark, ill-defined band sometimes develops on the mid-body, and a dark grey stripe runs between the eye and flipper; dark and pale eyestripes and dark nasal markings form on the beak. The flippers are dark, slender and sharply pointed, and the dolphins have a slightly enlarged post-anal keel below the tailstock. Clymene's reach a body length of up to 2 m and can weight at least 85 kg (Jefferson et al, 1993). Their diet consists of mesopelagic fish and squid, and they apparently feed mainly at night. The species is a fast swimmer and often spins awkwardly. Pods frequently number less than 50, and they are often seen with other similar-sized dolphin species. Its population size is unknown, but the species seems naturally uncommon within its range. Due to lack of information for the species, Clymene dolphin is classified as Data Deficient by IUCN (IUCN, 2009).*

A recording of a group of 40 possible Clymene dolphins were recorded porpoising within 700 m of the vessel, in shortly after dawn in January 2011.

#### 4.5.4 Brydes whale (Balaenoptera edeni)

*Bryde's whales are found in the tropics and are not known to move poleward of 40º. They are found in both offshore and coastal areas, but are not known to make extensive migrations like other large baleen whales. Bryde's whales are very similar to sei whales, however have three prominent ridges on their rostrum (other rorquals such as the sei whale, generally only have one) (Jefferson et al, 1993). The dorsal fin is tall and falcate, and the height of the blow is variable, since Bryde's whales tend to exhale under water and then surface with little or no blow (Jefferson et all., 1993). Colouration is dark grey dorsally, becoming lighter in colour ventrally. Adults can reach up to 15.6 meters in length (Shirihai & Jarret, 2007), and weigh up to 25 tonnes. The Bryde's whale does not have a defined breeding season in many areas, with births occurring throughout the year. Bryde's whales are usually found alone or in pairs, although they can be found in groups of up to 20 on feeding grounds. This species is a very active lunge feeder, primarily feeding on fish, but occasionally taking invertebrates. The Bryde's whale is one of the few species of large whale not classified as endangered; however, unfortunately this may only be because insufficient is known about the status of the population (IUCN, 2009).*

On 17th September 2010 two adult possible Brydes whales were seen approximately 300 m. the observer determined this identification due to the shape of the fin and behaviour.

#### 4.5.5 Humpback whale (Megaptera novaeangliae)

*The humpback whale is a widely distributed species, occurring seasonally in all oceans from the Arctic to the Antarctic, with distinct populations located in virtually every sea. All populations of humpback whale undertake migrations between breeding and feeding grounds. This is a familiar whale, with a stout body and very long pectoral fins or flippers (up to 1/3 of the body length) that have lumps upon which barnacles may grow (Jefferson et al, 1993). The head is rounded and flat, apart from the raised lumps ('tubercles'). The dorsal fin is varied in size and shape between individuals, and tail flukes are large and almost 'wing-shaped'. The humpback whale is black to blue-black in colour, with pale to white undersides that can show black markings that are varied according to individual. They measure between 11-16 m in length, with the females generally larger than the males, and they weigh up to 35 tonnes (Jefferson et al, 1993). The specie has a bushy but high visible blow (2.5 to 3 m) (Shirihai & Jarret, 2007). Humpback whales are inclined to feed within 50 m of the water's surface, taking krill and shoaling fish. This is a 'gulp' feeding whale, filtering food from the water through baleen plates after engulfing a mouthful. Unlike other whales, the humpback whale has many varied methods of feeding, including lunge feeding, tail flicking and bubble-netting. Humpback whales often congregate in large, loose groups for breeding and feeding and they are most commonly associated with their 'singing'. Their longevity is believed to be around 50 years. The estimated current population for Northern Atlantic is unknown, but with and estimate of 3% of population growing, and the IUCN status is Least Concern (IUCN, 2009).*

The first five of the sightings (17th – 27th November 2009) recorded during the data collection period were listed as probable humpback whales. One of which was recorded with juveniles. A further probable sighting was recorded in September 2010 showing fin slapping and breaching behaviour, which are both common behaviours for this species.

### 4.5.6 Green turtles

On two occasions in January 2011 (2nd & 11th) possible green turtles (see section 4.4.4) were recorded. These sightings were not provided with sufficient detail to verify the record. The second individual was viewed within five metres of the vessel.

### 4.5.7 Pantropical spotted dolphins

This species was recorded twice (24th July 2010 & 17th September 2011) in addition to those noted in section 4.4.5, however neither were confirmed. Both observations were of the dolphins bow-riding so identification features were likely to be obvious. The first sighting consisted of around 35 animals, whilst the second sighting consisted of 15-20 animals.

### 4.5.8 Common dolphins

On the 11th September 2010 40 possible common dolphins with calves were observed. Later in the same on the 26th an observer recorded a group of spinner dolphins. The details of this sighting have been reviewed, and due to the yellow and white colouration given they were re-named as common dolphins as this is the only species with yellow colouration in the west African region

### 4.5.9 Rough-toothed dolphins (*Steno bredanensis)*

*The rough-toothed dolphin is a widely distributed species inhabiting deep tropical and warm temperate waters worldwide. Routh-toothed dolphins are relatively large head with no distinct melon to beak crease. Their long beak is poorly defined and usually has a whitish-pink tip. The prominent dorsal sits central along the length of the animal, and most of the body is covered in scratches and spots. The extent of white on the underbelly varies, and older individuals have a whitish-pink underside that can extend to the lower jaw. Adults tend to have mottled colouration, whereas as younger individuals are darker and more uniform in colour. Fully grown adults are 2.1-2,.5 m long (Shirihai and Jarrett, 2007). The animals move in close-knit groups of 10-20, and rarely 50-300 individuals. Rough-toothed dolphins breach in a shallow leap fashion, and typically swims with its beak above the water.*

There was one sighting recorded as a possible pantropical dolphin or spinner dolphin group. The group of 25 dolphins were recorded breaching and tail slapping at 10:30h on the 14th May 2010. The observer describes the dolphins in having a distinct pink under belly with spots. This description is indicative of rough-toothed dolphins, hence

.

# 5. Discussion

## 5.1 Marine Mammal and Turtle Detection

From the sighting data gathered during the survey, its number and diversity, it is reasonable to conclude that the survey area is well inhabited by cetacean and marine turtle fauna. Nonetheless, the full species list is difficult to deliver due to lack of definite species ID or ID verification information (i.e animal descriptions and photographs). The distribution of marine mammals in these waters is poorly understood but it is assumed that up to 20 different species of cetaceans could inhabit Ghanaian waters. The most abundant species seem to be Clymene dolphin (Waerebeek et al, 2009), bottlenose, Atlantic and Pantropical spotted, rough-toothed dolphin as well as following whale species: sperm, dwarf sperm and humpback whale (Weir, 2010). From the survey data gathered here, few species were confirmed: spinner dolphin, common dolphin, Pantropical spotted dolphin, sei whale and pilot whale whereas several species were probable due to lack of definite ID clues and these are humpback whale, spotted dolphin, Bryde's whale, and clymene dolphin. In addition to this, an unverified encounter from the Jubilee Field has recorded potential Fraser's dolphin (*Lagenodelphis hosei*) presence (D. Prisse, 2010, pers. comm. 28$^{th}$ May 2010). The Fraser's dolphin is a species whose distribution is predominantly unknown, however Weir *et al.* 2008 reviewed records in the Gulf of Guinea where three specimens have been confirmed in Ghana from bycatch at fishing ports, and at sea sightings have occurred off the coast of Nigeria and Angola.

There were nine marine turtle sightings in total while the only turtle species definitely confirmed was green turtle. This species is known to inhabit the Ghanaian waters and there are nesting sites along the coastline. Seven turtle observations were made of turtles in local fishing canoes. Several of the turtles were found tangled in fishing line and debris, and those which were still alive when the security came alongside were freed from the netting and released back into the water. These sightings may have skewed the data for the Jubilee Field area, as the animals may have been caught outside of the Jubilee Field, and only transited into the area via the canoes. Despite this the turtles were likely to have been from the immediate vicinity and therefore were included in this report.

As discussed in the Section 2, there are several environmental factors that influence distribution of marine animals but the most important for this area seems to be upwelling which is in turn related to food availability. Seasonal upwelling conditions are favourable for marine mammals as well as for fisheries, and therefore it would be expected that marine mammal and turtle sightings, distribution and abundance would be correlated to this. The Guinea currents, present in Ghanaian waters, is associated with the areas of upwelling which have seasonal character. Having said that, it is expected that marine mammal and turtle distribution exhibits certain seasonal pattern as well. In order to obtain a full picture of marine animal presence and distribution, full year survey and data collection would be required.

Together with frontal zones, bathymetric features may provide means of predicting important foraging habitats for marine mammals (Bost et al, 2009). There are three physical characteristic of the area that are favourable for the presence of the diverse spectre of cetacean species. Relatively high water depth (between 1000 and 1700 m) of the site area would indicate presents of deep diving and mesopelagic species of marine mammals while quite a steep slope would attract diverse species that forage on the continental shelf areas. The lack of recordings of sirenians is not unexpected due to the depths of the survey area operations Additionally, closeness of the coastline (approximately 50 km) would certainly indicate presence of coastal populations. The proximity to the coastline and nesting grounds of marine turtles (leatherback, green and olive ridley turtles) would have a high impact on the increased seasonal presence of turtles during nestling periods (August to March). Taking into the account all above, the site area has indeed favourable conditions for the presence of rich and diverse community of marine mammals and marine turtles.

During the survey, there were several records of whale calves present. From the available literature, it is known that Gulf of Guinea is the established breeding and wintering grounds (June – November) for humpback whales breeding stock B1 (Collins et al., 2009). Therefore, it would be more than beneficial to gather accurate sighting data on humpback calves presence in the survey area to get an insight of the importance of this habitat as a potential humpback whales breeding ground.

The observations made of the Sei whale and possible Bryde's whale are important recordings for this region as there has previously only been recordings of these species in the wider Gulf of Guinea region. The only mystciete recorded by Van Waerebeek *et al.* (2009) was the humpback whale, whilst Weir (2010) recorded Bryde's whale in Ghana through whaling records.

## 5.2 Marine Mammal and Turtle Observation

There were several limitations of this survey that affected the observation effort. Firstly, only few crew members were trained in marine observation techniques hence having non-experienced observers significantly effected positive identification of marine mammals and turtles. Some species of marine mammals and turtles are easily identified due to prominent and specific features, however others are easily confused with each other. Having said that, making sure that all members of crew involved in data gathering are fully trained in cetacean and turtle ID is of paramount to assure data quality and increase the number of positive IDs. If animals could not be fully identified, then photographs should be taken and detailed description of sightings recorded in data sheets.

Whist the vessels spent time of standby on the Jubilee field site, there were no real effort since the area covered was minimal and it was only possible to record species that would approach in the visual range of the observers.

## 5.3 Recommendations

The number of sightings and species (probable and confirmed) identified during the survey reflect a broad cetacean diversity in the area. However, these results do not reveal much more than only a certain species presence, while information on their abundance and distribution as well conclusions on the habitat importance (feeding, breeding, resting) is still lacking.

This survey set up gave a good background on cetacean and turtle presence in the area, but at the same time, it has opened many additional questions. Those questions could be answered with additional surveys in the area. It is highly recommended to carefully plan a year around survey in order to cover larger area, have in place survey lines designed to assure equal coverage, have dedicated observers in order to utilise maximum day light hours and record observation effort that would allow further abundance analysis. Moreover, such detailed and planned survey year around survey would be able to give insight into difference in species presence and distribution due to seasonal changes in the marine environment. Given the 'vulnerable', 'endangered' or 'unknowns status ( IUCN Red List) of many species that could potentially be encountered in the area, such results would contribute to the global knowledge and fulfil information gaps left open due to lack of dedicated scientific research in the area.

Additionally, further training of observers is a paramount in order to improve data collection and minimise number of unidentified or probable species, but to allow higher lever of certainty of species ID. Use of photo cameras and designed sighting forms should be compulsory, as well as collection of behavioural data in order to evaluate habitat utilisation and importance (resting, breeding, migrating or foraging).

In conclusion, this survey has offered an excellent opportunity to create a species check-list for Ghanaian water and fulfil the knowledge gap relating under-researched cetacean and marine turtle populations in the area, but further work on data collection is needed in order to draw significant and important conclusions on Ghanaian marine fauna.

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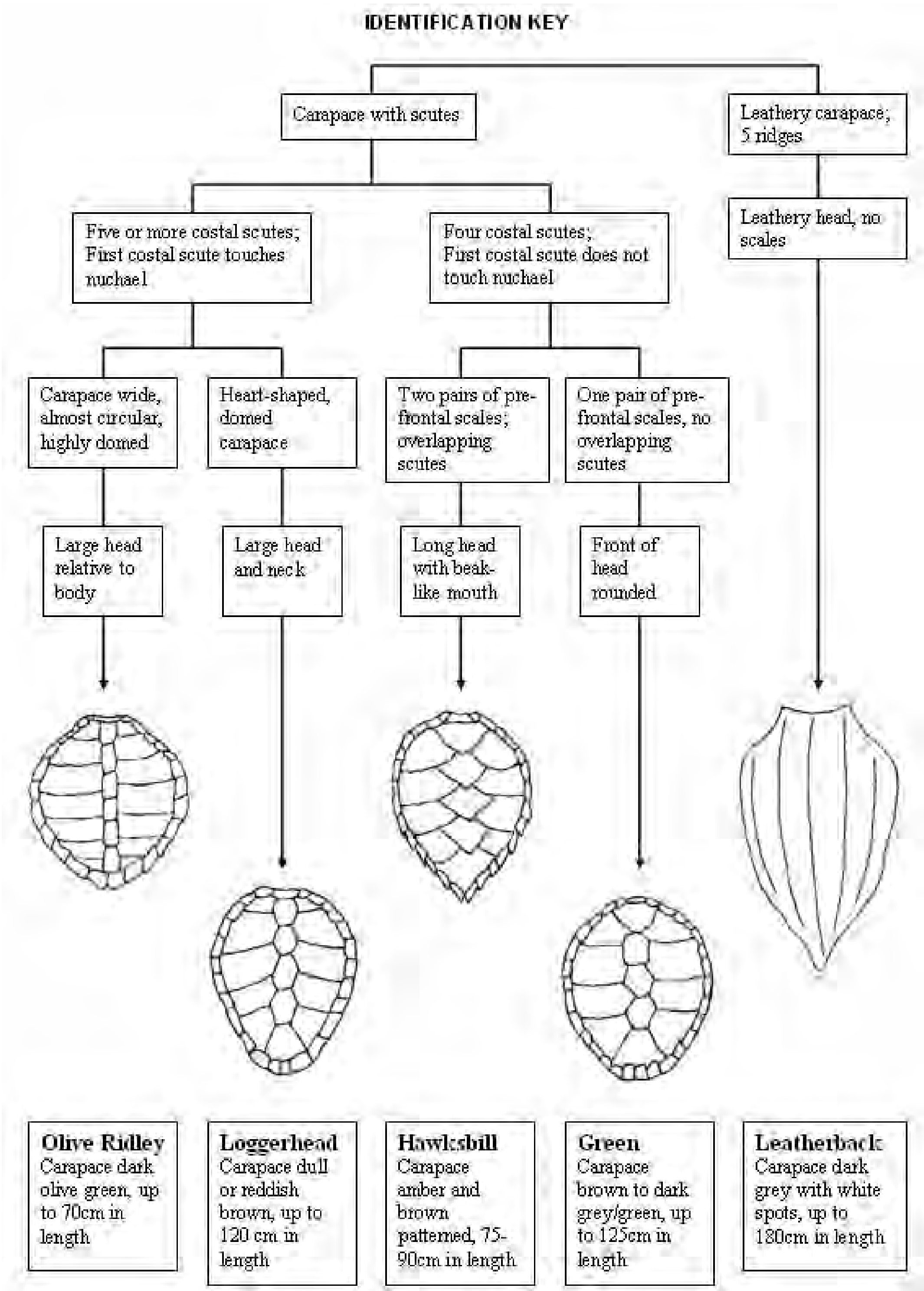
# 7. Appendices

## Appendix A: Turtle Identification Form



## Appendix B: Sighting Form

GARDLINE ENVIRONMENTAL

### SIGHTINGS FORM

TULLOW

| Platform Type<br>☐ FPSO<br>☐ Vessel<br>☐ Helicopter<br>☐ Rig | Platform name | Sighting number (start at 1 for first sighting of survey) | Water depth (metres) |
|---|---|---|---|
| Date | Number of observers/ Name(s) | Time at start of encounter (24hr clock) | Time at end of encounter (24hr clock) |

| | |
|---|---|
| How did the sighting occur<br>☐ while you were keeping a continuous watch for marine mammals<br>☐ spotted incidentally by you or someone else<br>☐ Eye ☐ Binoculars ☐ Range finder | Position (latitude and longitude) |
| Group<br>☐ Turtle ☐ Definite<br>☐ Whale ☐ Probable<br>☐ Dolphin ☐ Possible<br>☐ Manatee<br><br>Species<br>☐ Definite<br>☐ Probable<br>.................................... ☐ Possible | Total number<br><br>Number of adults<br><br>Number of calves |

Description (include features such as overall size; shape of head; colour and pattern; size, shape and position of dorsal fin; height, direction and shape of blow)

Photo Taken
Yes ☐ No ☐

| Marine Mammal Behaviour | Turtle Behaviour |
|---|---|
| ☐ Surfacing<br>☐ Porpoising<br>☐ Breaching<br>☐ Spy hopping<br>☐ Logging<br>☐ Fluking<br>☐ Tail slapping<br>☐ Other ............................................ | ☐ Basking<br>☐ Swiming<br>☐ Mating<br>☐ Surface breaths<br>☐ Diving<br>☐ Other................................................ |

| Direction of travel (relative to ship) | Direction of travel (compass points) |
|---|---|
| ☐ towards ship ☐ crossing ahead of ship<br>☐ away from ship ☐ variable<br>☐ parallel to ship in same direction as ship ☐ milling<br>☐ travelling in opposite direction to ship ☐ other | ☐ N ☐ S<br>☐ NE ☐ SW<br>☐ E ☐ W<br>☐ SE ☐ NW<br>☐ variable |

Range when first seen (metres)

Closest distance of animals from source (metres) Time (24hr clock)

| Drilling operational when animals first detected? | Drilling operational when animals last detected? | Platform Activity |
|---|---|---|
| ☐ Yes- full power<br>☐ Yes- reduced power<br>☐ No | ☐ Yes- full power<br>☐ Yes- reduced power<br>☐ No | ☐ Transit<br>☐ Offloading<br>☐ Landing<br>☐ Drilling<br>☐ Standby |

## Appendix C: Sighting Records

| DATE | Original No. and ID | ID by GEL | Time | Longitude | Latitude | Observer Remarks |
|---|---|---|---|---|---|---|
| 17/11/2009 | 2-4 whales | whale Sp (Prob humpback) | 07:30:00 | 4° 44'.1 N | 1° 47'.8W | Very Big Dark Brown, Gray/black half of body came out of the sea with a jump… Blow 15-25m Shape of head and body - Long and wide |
| 19/11/2009 | 1-2 whales | whale Sp (Prob humpback) | 17:19:00 | 4° 38'.7N | 2° 08'.5W | Very Big Dark Brown, Gray/black two thirds of body came out of the sea with a jump. Shape of head and body - Long and wide |
| 22/11/2009 | 1-2 whales | whale Sp (Prob humpback) | 06:30:00 | 4° 39'.58N | 2° 02'.63W | Very Big Dark Brown, Gray/black two thirds of body came out of the sea with a jump. Shape of head and body - Long and wide |
| 27/11/2009 | 1-2 humpback | whale Sp (Prob humpback) | 17:30:00 | 4° 45'.24N | 01° 50'.36W | White and black fin, single blow vertical |
| 27/11/2009 | 1 adult, 1 juv humpbacks | whale Sp (Prob humpback) | 17:45:00 | 4° 46'.24N | 01° 49'.00W | black grey, single blow vertical tail seen frequently |
| 04/01/2010 | Turtle x 1 | Turtle Sp | 07:23:00 | Jubilee Field | | Fisherman had caught |
| 10/01/2010 | Baby Mammals x 3 | Dolphin Sp | 11:15:00 | Jubilee Field | | Caught in fishermen's net, found after boat was boarded to advise them of restrictions. |
| 12/01/2010 | Whale & Calf | Whale Sp | 18:49:00 | Jubilee Field | | Circling Oceanix Orion approx 1m South of EIRIK RAUDE |
| 17/01/2010 | Whale & Calf | Whale Sp | 06:37:00 | Jubilee Field | | Circling Oceanix Orion approx 1m South of EIRIK RAUDE |
| 22/02/2010 | whale | Whale sp | [none] | N 04º 38,4 | W 002º 32,2 | reported by helicopter crew as big splash only |
| 12/03/2010 | Sea Turtle x 1 | Turtle Sp | 14:35:00 | 41 34.912N | $2^0$ 54.218W | >1m diameter, Surface swimming, East |
| 30/03/2010 | Tutle x 1 | Turtle Sp | 15:05:00 | Jubilee Field | | The turtle was about 1 m long, upside down within a fishing canoe, tangled in a fishing net. The turtle was transferred to the RHIB, untangled and released back into the sea. The turtle disappeared immediately below the surface and was not seen again |
| 04/04/2010 | Single Whale | Sei Whale | 13:30:00 | 04' 31.936 N | 002' 54.722 W | A single whale was sighted about 60m from the OCEANIX ORION. It remained within the area of the vessel for about an 90 mins. When we moved the whale followed. Length was about 20m. The closest distance the whale came to the vessel was about 10m. ID was confirmed by photo ID by a trained observer. |

| DATE | Original No. and ID | ID by GEL | Time | Longitude | Latitude | Observer Remarks |
|---|---|---|---|---|---|---|
| 05/04/2010 | Single Whale | Whale Sp | 13:40:00 | 04' 32.065 N | 002' 54.532 W | A single whale was again sighted from the OCEANIX ORION. It is more than likely the same whale sighted as on the 04.04.10. It continued to follow the vessel and remain in our general area. |
| 14/04/2010 | A Pod of between 80 and 120 Dolphins | Dolphin Sp | 06:00:00 | Jubilee Field | | The Pod followed the ORIENT for around 45 minutes circling the vessel slowly before departing. |
| 20/04/2010 | A Pod of about 100 Dolphins | Dolphin Sp | 09:00:00 | 4° 31.825' N | 2° 53.785' W | The Pod followed the OO for around 45 minutes before departing. |
| 23/04/2010 | 1 x Turtle | Turtle Sp | 13:45:00 | 04°34.2824N | 002°54.8415W | About 80 cm of diameter. |
| 29/04/2010 | A pod of dolphins, at least 200 | Dolphin Sp | 10:00:00 | 04º31.2840'N | 002º52.8427'W | An important pod of dolphins circled the area for more than 45 minutes before moving away. |
| 29/04/2010 | A pod of around 10 big black dolphins. | Dolphin Sp. (Poss Pilot whales) | 02:30:00 | 04º33.2505'N | 002º54.0490'W | The pod followed the ORIENT for 15 minutes then moved away. |
| 29/05/2010 | Pantropical spotted dolphins | Pantropical spotted dolphins | [none] | Jubilee Field | | Confirmed ID by trained observer with Photo verification |
| 06/05/2010 | Dolphins 100+ | Dolphin Sp | 17:00:00 | 04* 30.85N | 002* 55.36W | Large pod frontage over 200 meters Breaching approx 500 meters from RIG. Changed direction when ORIENT attempted getting closer. Radioed ORION of their possible approach. |
| 11/05/2010 | Dolphins 10 | Dolphin Sp | 17:00:00 | 04* 30.27N | 002* 56.584W | Swimming |
| 14/05/2010 | Dolphins description fits Pantropical or Spinner< 25 | Dolphin sp (poss rough-toothed) | 10:30:00 | 04* 3-.00N | 002* 5-.00W | Breaching, Some Sync Acrobatics, Tail slapping, Swimming, (Distinct pink under belly with spots). Coincided with some biggish Tuna >1m surfing the boat |
| 23/05/2010 | Dolphins. Well over 150 in number. | Common dolphins | 06:50:00 | 04°37.0088' N | 002°52.9163'W | Small Grey Dolphins with a lighter belly, approx 2m in length maximum.The dolphins were all around the ORIENT. If the ORIENT was the centre of the circle the circle would have had a radius of 300m. The dolphins followed the ORIENT for 30 minutes plus. |
| 29/05/2010 | Turtle | Green Turtle | 11:40:00 | Jubilee Field | | see video |
| 06/06/2010 | Pilot whales | Pilot whales | [none] | Jubilee Field | | Confirmed ID by trained observer with Photo verification |
| 10/06/2010 | 1x turtle | Turtle Sp | 10:15:00 | 04' 35.8 N | 001' 51.9W | [none] |

| DATE | Original No. and ID | ID by GEL | Time | Longitude | Latitude | Observer Remarks |
|---|---|---|---|---|---|---|
| 15/06/2010 | Pilot Whales. About 15 | Pilot whales | 15:30:00 | 04' 32.703 N | 002' 55.128 W | Pilot Whales, adults and calves, were sighted surfacing in and around the area of ORION. |
| 23/06/2010 | 1x turtle | Turtle Sp | 08:55:00 | 04' 36.77 N | 003' 10.50W | Freed from canoe |
| 24/07/2010 | Possibly 35x atlantic spotted dolphins | Dolphin Sp (Poss Pantropical spotted) | 17:50:00 | 04' 31.39 N | 002' 54.59 W | The Dolphins tracked the ORIENT often leaping and Bow Riding. Once the Vessel came to a halt the Dolphins departed. |
| 06/08/2010 | Large pod of Dolphins | Dolphin Sp | 18:25:00 | 04' 33.498N | 002' 25.440W | The large pod of Dolphins included very young and were seen of the port side of the vessel, travelling in the same direction. |
| 11/08/2010 | Group of (approx 15) Turtles | Turtle Sp | 06:50:00 | 04°37.6' N | 002°52.9'W | Swimming shallow sub-surface. As MV ORION approached to examine the group swam in different directions which broke the group up.Captain MV ORION report (considering his position and previous experience with mammal scientists accepted as credible) |
| 11/08/2010 | Very Large Whale breaching and blow hole | Whale Sp | 09:40:00 | 04°37.' N | 002°52.'W | Fleeting spectacular Approx 300m SW of EIRIK RAUDE & MV INVINCIBLE. |
| 12/08/2010 | Pod of dolphins (N0.s 4+/- 2) | Dolphin Sp | 18:20:00 | 04°33.328' N | 002°54.896'W | Less than 2 metres in length.fleeting spy hopping of pair generally swimming / surfing to the North. First seen within 50 m of ORIENT. Camera prepared but did not reappear. |
| 17/08/2010 | 1 x Unknown Whale | Whale Sp | 09:10:00 | 4º 49.437N | 1º 40.989W | Was seen approx 200m of the port side travelling in the same direction. |
| 20/08/2010 | 1 x Dolphin | Dolphin Sp | 17:18:00 | Jubilee Field | | The Dolphin had been caught by the fisherman and was being used as bate on their hooks. |
| 26/08/2010 | 1 x Turtle | Turtle Sp | 08:32:00 | Jubilee Field | | The turtle had been caught in the nets of the fisherman. The turtle appeared well and when released, immediately swam down into deeper water. |
| 10/09/2010 | Whales X 2 | Whale Sp | 07:48:00 | 04º30.7910'N | 002º55.7310'W | The whales stayed below the surface only coming up to breath and blow. Observation sheet completed. |
| 11/09/2010 | Dolphin x 10 | Dolphin Sp | 12:05:00 | 04º32.0900'N | 002º54.9'W | The dolphins were approximately 150m from the ORIENT |
| 11/09/2010 | Common Dolphin x 40 | Dolphin sp (Common dolphins ) | [none] | 5 º34.0962'N | 002 53.4833'W | Dolphins approximately 50m from ORIENT. A number of juveiles (6) were seen. |
| 12/09/2010 | 1 x 12 m Humpback whale | Humpback whale | 19:15:00 | 04º35.03'N | 003º08.43'W | The whale was fin slapping and breaching and surfacing and blowing whilst circling around the Guardian. |

| DATE | Original No. and ID | ID by GEL | Time | Longitude | Latitude | Observer Remarks |
|---|---|---|---|---|---|---|
| 14/09/2010 | Whale x 1 | Whale Sp | 13:18:00 | 04°34.900'N | 002°53.9256'W | A single whale was seen blowing approximately 0.75nm from the ORIENT. |
| 15/09/2010 | 40 Dolphins | Dolphin Sp | 13:30:00 | Jubilee Field | | One of the crew saw the dolphins 2 nights ago. The dolphins were swimming around the ORIENT for about 20 minutes. They were grey in colour with a beak, 1.5m long, surfacing and porpoising. |
| 15/09/2010 | 1 x Whale | Whale Sp | 15:45:00 | Jubilee Field | | ! x Whale seen blowing twice and then disappeared. |
| 17/09/2010 | Possibly Bryde's Whale x 2 | Whale Sp (Poss Brydes) | 10:30:00 | 04' 37.528N | 002' 52.596W | 2 x Whales were sighted surfacing and blowing about 300m from the vessel. From the shape of the dorsal fin and their behaviour it was determined that they were quite possibly Bryde's Whales. |
| 17/09/2010 | Atlantic Spotted Dolphins. About 15-20 | Dolphin Sp (Pantropical. spotted) | 13:00:00 | 04' 38.240N | 002' 51.876W | The Dolphins were seen surfacing around the Bow of the Vessel. A couple were leaping but they only remained in the area for about 10 mins before they got bored and left. |
| 26/09/2010 | Spinner Dolphins. 150 plus | Dolphin Sp (Prob. Common) | 12:30:00 | 04°33.692'N 002°55.558'W | 04°33.692'N 002°55.558'W | The dolphins which appeared to be spinner dolphins were all around the OCEANIX ORION for approximately 15 minutes. They were porpoising, bow riding, leaping and spinning. A lot of them appeared to have yellow / white bellies. |
| 28/09/2010 | 1 Whale | Whale Sp | 10:12:00 | Jubilee Field | | 1 unidentified type of whale seen blowing in the distance. No other details reported. |
| 29/09/2010 | Approx 200 Common Dolphins | Common dolphins | 10:40:00 | Jubilee Field | | The Dolphins were observed moving through the Jubilee Field. |
| 30/09/2010 | 1 x Turtle | Turtle Sp | 11:15:00 | Jubilee Field | | The turtle was seen on the surface for only a couple of seconds. It was facing in a southerly direction. The carapace appeared to be very light tan in colour and was less than 1m long. |
| 05/10/2010 | 1 x unknown Whale | Whale Sp | 07:33:00 | Jubilee Field | | The whale was seen moving approx 500m from the side of the FPSO. The Whale appeared to be small in size and dark grey or black in colour. |
| 16/10/2010 | Small pod of Dolphins | Dolphin Sp | 09:16:00 | 5 35.256N | 002 54. 128W | The Dolphins were identified slowly moving through the area. |
| 22/10/2010 | Pilot whales >2 | Pilot whales | 10:30:00 | 4* 43.729N | 1* 51.923W | Porposing, venting then tail dive. Estimate biggest approx 15M+. On same heading 244* swimming 3Kts est |

| DATE | Original No. and ID | ID by GEL | Time | Longitude | Latitude | Observer Remarks |
|---|---|---|---|---|---|---|
| 27/10/2010 | Dolphins 2 meter grey | Dolphin Sp | 07:50:00 | 4* 35.918N | 2* 55.254W | Small pod 5-7, porposing, Not interested interest in bow riding (insufficient speed?) |
| 31/10/2010 | Pilot Whales 10 – 15 | Prob Pilot whales | 07:10:00 | 4*35.99N | 2* 55.42W | Pilot whales floating or swimming less than 1 Knt. and blowing repetitively in sun (impression; vocal). Possibly in two groups. One larger whale: two scars right hand leading edge of dorsal fin 2nd slightly behind and parallel (because of symmetry possibly spiralling strike, (propeller, harpoon?) no blood in the water). Although large, this whale was central to pod. |
| 31/10/2010 | 10-20 Dolphins | Dolphin Sp | [none] | 4*35.99N | 2* 55.42W | Dolphins (of different sizes) porposing, slowly one observing (snout out of water) – central to dolphin group. Dolphin pod appeared to be swimming a same pace as Whales, slightly ahead; both in line and at 90* (possibly more cooperative than random?). |
| 03/11/2010 | Common / Spinners | Dolphin Sp | 15:40:00 | 04’35.26N | 002’52.72W | Some moving very slow and others faster with the acrobats, Moving East wards |
| 07/11/2010 | Dark coloured Dolphins | Dolphin Sp | 08:30:00 | Jubilee Field | | Four Dolphins were reported to have a pointed beak. After approx 15 mins they departed the area. |
| 11/11/2010 | Dolphins – 30 to 40 | Dolphin Sp | 08:40:00 | 04º38.148 | 002º53.869 | Between 30 to 40 small dolphins seen porpoising in the area around 400m from the Orient. The dolphins were around 1.5m in length and had a dark curved dorsal fin similar to the Clymene Dolphin. The dolphins were observed at a distance for around 10 minutes. |
| 24/11/2010 | Dolphins x 2 | Dolphin Sp | 14:05:00 | 04º37.578’N | 002º 52.449’W | Two dolphins appeared for a very short time approximately 20m from the RHIB whilst it was patrolling but moving very slowly (5 kts). The dolphins were less than 2m in length and appeared to have a concave narrow and pointed dorsal fin. They were light grey in colour, only a small portion of the back of the dolphins and fin was visible for about 10 seconds before they descended below the surface. |
| 25/11/2010 | Green turtle x 1 | Turtle Sp | 10:10:00 | 04º29.648’N | 002º55.700W | The turtle approx 1m in length was sighted close to the ORIENT. It was at the surface breathing and flapping it’s fins. At times the turtle was spinning around in circles. On closer inspection the turtle appeared to be tangled in some fishing net. The RHIB was launched to try and release the turtle but on approaching the animal, it dived and did not surface in the area again. |
| 01/12/2010 | 2 x Turtles | Turtle Sp | 09:28:00 | 4º 32.405 N | 3º 06.491W | Turtles swimming amongst debris heading in an easterly direction. |

| DATE | Original No. and ID | ID by GEL | Time | Longitude | Latitude | Observer Remarks |
|---|---|---|---|---|---|---|
| 05/12/2010 | 1 x Dolphin | Dolphin Sp | 18:07:00 | 5 35.179 N | 002 51. 438 W | The Dolphin was seen jumping in the close proximity to the Pacific Wyvern |
| 06/12/2010 | 12-15 Dolphins | Dolphin Sp | 02:30:00 | 04º33.327 N | 03º06.107 W | Dolphins following the OO. Seem to be in good spirits, jumping and playing. 2x calves seen. On the vessel stopping dolphins swam around the OO |
| 08/12/2010 | Turtle | Turtle Sp | 10:55:00 | 04* 32.37N | 02* 56.19 W | Dove once close sighted by the on watch Naval rating. |
| 08/12/2010 | Dolphin activity | Dolphin Sp | 13:00:00 | 04* 32.37N | 02* 56.19 W | Porposing – Pod approx 10 |
| 09/12/2010 | 6-10 pilot whales | Poss Pilot whales | 12:50:00 | 5 34.00N | 002 55.00W | The whales were observed moving through the JUBILEE FIELD to the east. |
| 10/12/2010 | 10-15 Dolphins | Dolphin Sp | 20:15:00 | 4º32.700N | 3º06.768W | 1x calve with mother seen. Stayed around the OCEANIX ORION for approx 20 min. |
| 12/12/2010 | 15-20 Dolphins | Dolphin Sp | 08:45:00 | 5 36.886N | 002 51.543W | Several Dolphins were seen passing through the immediate area of the Pacific Wyvern for 30 minutes. |
| 16/12/2010 | 40 Dolphins | Dolphin Sp | 14:40:00 | 5 35.7N | 003 05.9W | The Dolphins were observed jumping and being playful as they moved south. |
| 18/12/2010 | 20-30 Small approx 1m | Dolphin Sp | 06:26:00 | 04* 34.2N | 002* 54 W | Porposing  Occasional acrobatics |
| 25/12/2010 | Turtle with baby turtles | Turtle Sp | 14:10:00 | 04* 31.7N | 002* 54.1W | > 1m in diameter. Initially appeared that the turtle was distressed and being attacked by other fish. It was swimming in circles with fish darting in. The photo'@' when downloaded onto computer showed that many of the surrounding 'creatures' appear to be baby turtles. |
| 02/01/2011 | Possibly Clymene Dolphins. About 40+ | Dolphin Sp (Poss Clymene dolphins) | 07:10:00 | 04' 36.7 N | 002' 54.5 W | A number of Dolphins were sighted off the Port Bow at a distance of about 700m. The Dolphins were surfacing and porpoising. Their direction of travel was S/SW. |
| 02/01/2011 | 1 x Green Turtle | Turtle Sp (Poss Green Turtle) | 15:20:00 | 04' 35.0 N | 002'54.7 W | A single Green Turtle swimming along the surface. Head and Carapace visible. Carapace was a Dark Grey/Green in colour. After 15mins the Turtle disappeared below the surface and out of sight. |
| 05/01/2011 | Approx 80 x Dark Coloured Dolphins | Dolphin Sp | 14:00:00 | Jubilee Field | | The Dolphins were sighted porpoising between the two Rigs. They remained visible for about 5 mins. Length of the Dolphins was about 1.5m |

| DATE | Original No. and ID | ID by GEL | Time | Longitude | Latitude | Observer Remarks |
|---|---|---|---|---|---|---|
| 07/01/2011 | 40 to 50 dolphins | Dolphin Sp | 05:30:00 | Jubilee Field | | The dolphins were seen porpoising in a N Easterly direction and were about 1m to 1.5m in length. Colour and a description of the dolphins was difficult due to the darkness. |
| 08/01/2011 | Possibly about 60+ Spinner Dolphins. | Dolphin Sp (Poss Spinner dolph) | 14:25:00 | Jubilee Field | | A large number of Dolphins were seen circling a shoal of fish. Some of the Dolphins were leaping and porpoising. Others were surfacing. After about 30 mins all disappeared under the water. |
| 08/01/2011 | 3 – 5 dolphins | Dolphin Sp | 15:30:00 | Jubilee Field | | The dolphins were seen porpoising and were about 1m to 1.5m in length. They were dark grey in colour. |
| 09/01/2011 | A Green Turtle over 1m in length. | Green Turtle | 16:45:00 | 04' 35.8 N | 002' 54.9W | A single Green Turtle swimming along the surface surrounded by smaller fish. On approaching our Port Bow the Turtle disappeared under the water. It was identified by the colour of the carapace and the rounded head. |
| 11/01/2011 | 1 x Turtle | Turtle Sp (Poss Green) | 19:50:00 | 04°35.760' N | 003°09.717'W | One turtle around 80cm in length was seen swimming just below the surface very close, approx 5m, from the EA, It stayed in the area for around 1 minute and then dived out of view. From the shape and colour of the carapace it could have been a green turtle. |
| 12/01/2011 | 1 x Turtle | Turtle Sp | 09:40:00 | 04°35.730' N | 003°08.638'W | One turtle around 60 – 80cm in length was seen swimming on the surface with it's head out of the water, approx 10m, from the EA, It stayed in the area for around 1 minute and then dived out of view. The predominant colour appeared to be a shade of cream / pale yellow. |
| 13/01/2011 | Green Turtle | Green Turtle | 12:50:00 | Jubilee Field | | A positive identification was made of a green turtle that had been caught by fishermen. It was around 70cm in length. The fishermen released the turtle, as soon as the turtle was back in the water it immediately dived out of sight. The crew on the EA were all very happy to see it released safely. |
| 14/01/2011 | 1 x Turtle | Turtle Sp | 13:05:00 | 04°32.165'N | 003°50.257'W | The turtle was dark olive green in colour, possible Olive Ridley, and around 60cm in length. It was approx 15m from the ship and was swimming just below the surface. After 1minute the turtle dived out of sight. |

| DATE | Original No. and ID | ID by GEL | Time | Longitude | Latitude | Observer Remarks |
|---|---|---|---|---|---|---|
| 14/01/2011 | Whale 1 possibly 2 | Whale Sp | 16:15:00 | 04°79.386N | 003°58.389W | Through the fog there appeared to be one possibly two whales in the distance, the whales were blowing but were too far away and the view obscured by the weather to make a positive identification and confirm that it was indeed whales. The height of the blowing looked to be around 1.5 to 2m. |
| 15/01/2011 | Two groups o f whales 70 to 80 in one group and 10 to 15 in the other | Poss Pilot whales | 07:00:00 | 04°33.058'N | 002°50.208W | A large group whales was seen swimming in a southerly direction. The whales were dark grey almost black in colour with a falcate pointed dorsal fin. The head was rounded. Size was around 2m or a little more and the body appeared to be muscular / stocky. They were swimming very slowly almost lazily porpoising as they went and at times they would lift their heads out of the water. Possibly Pygmy Killer Whales. |
| 20/01/2011 | 1 x large turtle | Turtle Sp | 17:30:00 | 5 33.213N | 002 55.409W | The turtle was identified swimming on the surface surround by small fish. The turtle appeared to be in good condition and was moving in a NW direction. |
| 21/01/2011 | 3 x large turtle | Turtle Sp | 10:00:00 | Jubilee Field | | The turtle was identified swimming on the surface. It appeared to be in a good condition. |
| 21/01/2011 | Large Pod of Common Dolphins & several short finned pilot whales | Dolphin Sp (Poss Commons and Pilots) | 15:00:00 | Jubilee Field | | The pod of Dolphins and Whales were seen slowly moving the Jubilee Field between the ER and the FPSO. Several Dolphins were seen jumping. |
| 21/01/2011 | 1 x large tutle | Turtle Sp | 16:49:00 | Jubilee Field | | The turtle was identified swimming on the surface. It appeared to be in a good condition. |
| 21/01/2011 | Large pod of Dolphins | Dolphin Sp | 06:59:00 | Jubilee Field | | The pod of Dolphins was seen moving through the west side of the Jubilee Field. Several Dolphins were seen jumping. |
| 22/01/2011 | Small pod of Dolphins | Dolphin Sp | 18:15:00 | 5 34.334N | 002 53.442W | The Dolphins were leisurely heading east through the Jubilee Field |
| 22/01/2011 | 1 x Turtle | Turtle Sp | 06:50:00 | 5 35.120N | 002 52.363W | The Turtle was on the surface surrounded by smaller fish and heading in an northerly direction. |
| 23/01/2011 | 1 x Turtle | Turtle Sp | 09:35:00 | 5 34.600N | 002 54.045W | The Turtle was on the surface surrounded by smaller fish and heading in an northerly direction. |

| DATE | Original No. and ID | ID by GEL | Time | Longitude | Latitude | Observer Remarks |
|---|---|---|---|---|---|---|
| 23/01/2011 | Possibly about 60+ Spinner Dolphins | Dolphin Sp (Poss Spinner dolph) | 17:38:00 | $04^0$32.84 N | $003^0$09.56 W | A large pod of Dolphins were seen following the Orient. Some were porpoising and leaping whilst others were surfacing for approximately 20 minutes. They were heading in a SE direction before they disappeared underwater. |
| 24/01/2011 | Large pod of Dolphins | Dolphin Sp | 14:27:00 | Jubilee Field | | The pod of Dolphins were seen slowly moving through the water heading in a NW direction. |
| 24/01/2011 | Approx 10 whales | Whale Sp | 16:50:00 | Jubilee Field | | The whales were slowly moving through the water also heading in NW direction. There appeared to be some small whales, possibly calf's within the group. |
| 26/01/2011 | 1 Large Turtle | Turtle Sp | 14:05:00 | Jubilee Field | | The turtle was identified on the fishing canoe. The turtle was alive and appeared to be ok. When released back into the water, the turtle successfully moved away and clear of the immediate area. |
| 28/01/2011 | 1 x large turtle | Turtle Sp | 07:59:00 | 5 36.541N | 002 55.003W | The turtle was seen on the surface of the water heading in a northerly direction. |
| 28/01/2011 | 1 x Turtle | Turtle Sp | 16:20:00 | 04°33.29'N | 002°51.129W | I x turtle was sighted very close to the AALESUND bow, the turtle was just below the surface and surrounded by fish. It was around 1m in length and dark green in colour most likely a Green Turtle. |
| 29/01/2011 | 1 x large turtle | Turtle Sp | 17:30:00 | 5 34.576N | 002 53.313W | The turtle was seen on the surface of the water heading in a northerly direction. The turtle was also surrounded by smaller fish. |
| 31/01/2011 | 1 large turtle | Turtle Sp | 09:30:00 | 5 34.127N | 002 53.737W | The turtle was seen swimming on the surface heading in a NW direction. |

Annex C2

# MMO Report 9 March 2011

# TULLOW GHANA LIMITED

# MARINE MAMMAL AND TURTLE

# OBSERVATION REPORT

# GHANA

| | |
|---|---|
| Gardline Project Ref. | 8391 |
| Fieldwork Dates | 8th March – 31st December 2011 |
| Report Status | Final |
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**SERVICE WARRANTY**

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# EXECUTIVE SUMMARY


- Tullow Oil Ghana (TGL) commissioned this report to evaluate data gathered on marine mammals and turtle sightings at the Jubilee and Tweneboa Fields.

- Incidental sightings of marine animals were collected during offshore operations at, and on route to, the Jubilee and Tweneboa Fields.

- The Jubilee Field is located 60 km offshore Ghana, with the Tweneboa Field located 25 km to the west of the Jubilee Field.

- Sightings were recorded from the security vessels the *M.V. Seacor Master* and *M.V. Seacor Merchant*, along with their associated support RHIBs.

- Data was collated between 8th March and 31st December 2011, by both trained and untrained vessel personnel.

- All data collected has been subsequently analysed by trained and experienced marine biologists. A taxonomic and certainty grading was applied to sightings without supporting information to verify the sighting.

- In total there were 99 sightings of marine animals, 75% of which were dolphins, 8% were whales and 15% were turtles. In addition there was one sighting of a probable manta ray and one of a probable hammerhead shark

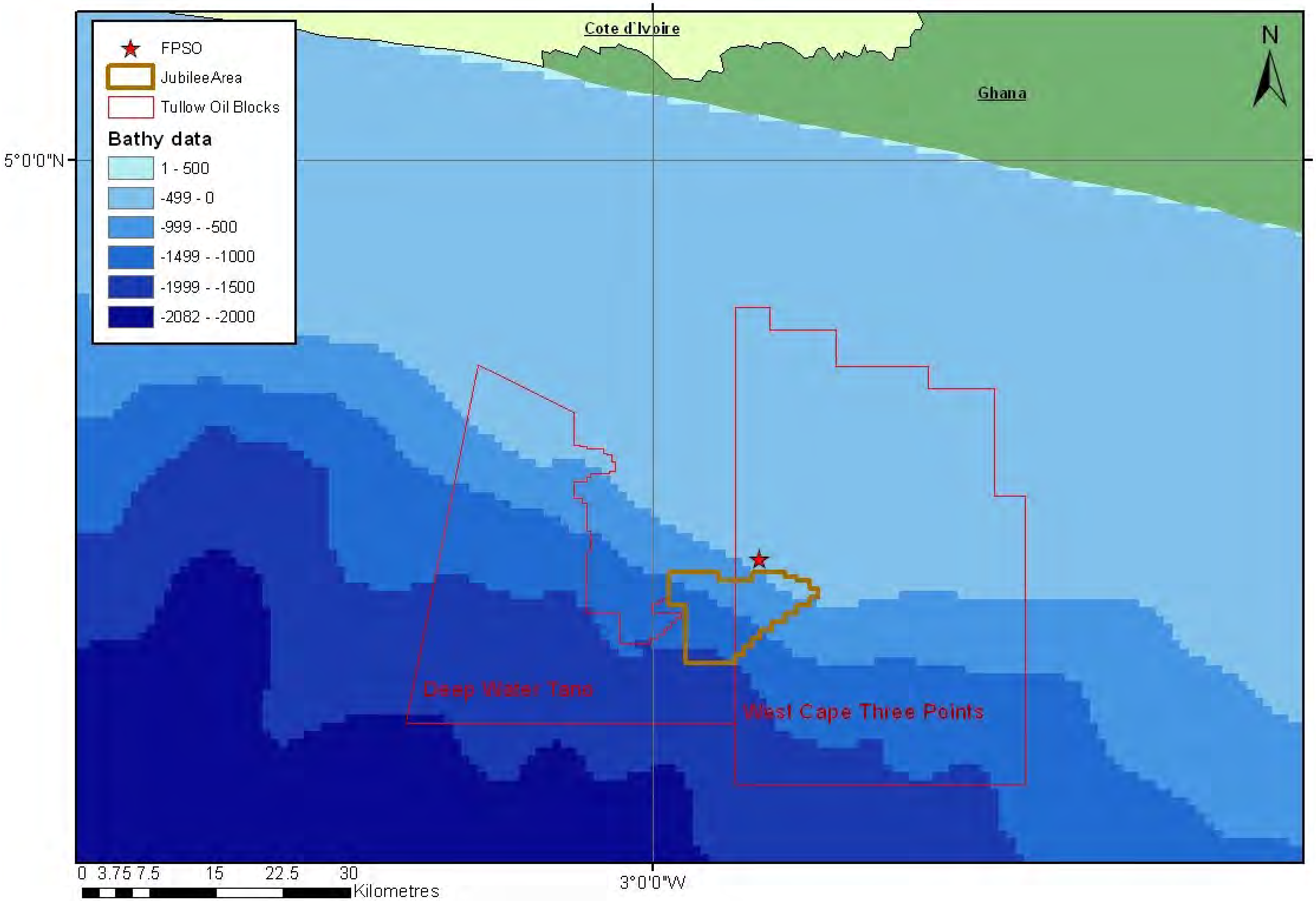
- A total of 13 confirmed species were recorded along with two additional species identified with probable certainty. The most commonly identified species was the short-finned pilot whale.

- Particularly interesting records included confirmed sightings of Fraser's dolphin, Atlantic spotted dolphin and melon-headed whale; species as yet unrecorded as at sea sightings in the published literature for Ghana.

- Of the recorded sightings 31% occurred on the Jubilee Field and 23% on the Tweneboa Field. In addition, 20% of sightings occurred within the wider West Cape Three Points licence area, and 23% in the wider Deep Water Tano licence area.

- A dedicated survey by experienced personnel is recommended to obtain an accurate representation of abundance and distribution of marine mammal and turtle species in the region.

SURVEY LOCATION



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# 1. INTRODUCTION

## 1.1 Background

The development of the Jubilee Field, 60 km offshore Ghana, by Tullow Ghana Limited (TGL) has been subject to a full Environmental Impact Assessment (EIA) (Irvine *et al.*, 2009) under the Ghana Environmental Assessment Regulations (1999).

The Jubilee oil field (Figure 1) was discovered in mid-2007 with subsequent exploration and appraisal wells drilled in the Deep Water Tano and West Cape Three Points licence areas. The Jubilee Field is the first deepwater development of hydrocarbon resources in Ghana. Installation of the FPSO (Floating, Production, Storage and Offloading vessel) was completed in June 2010 and First Oil was celebrated on the 15th December 2010, when production commenced. The FPSO Kwame Nkrumah will offload crude oil to export tankers to deliver to the global market.

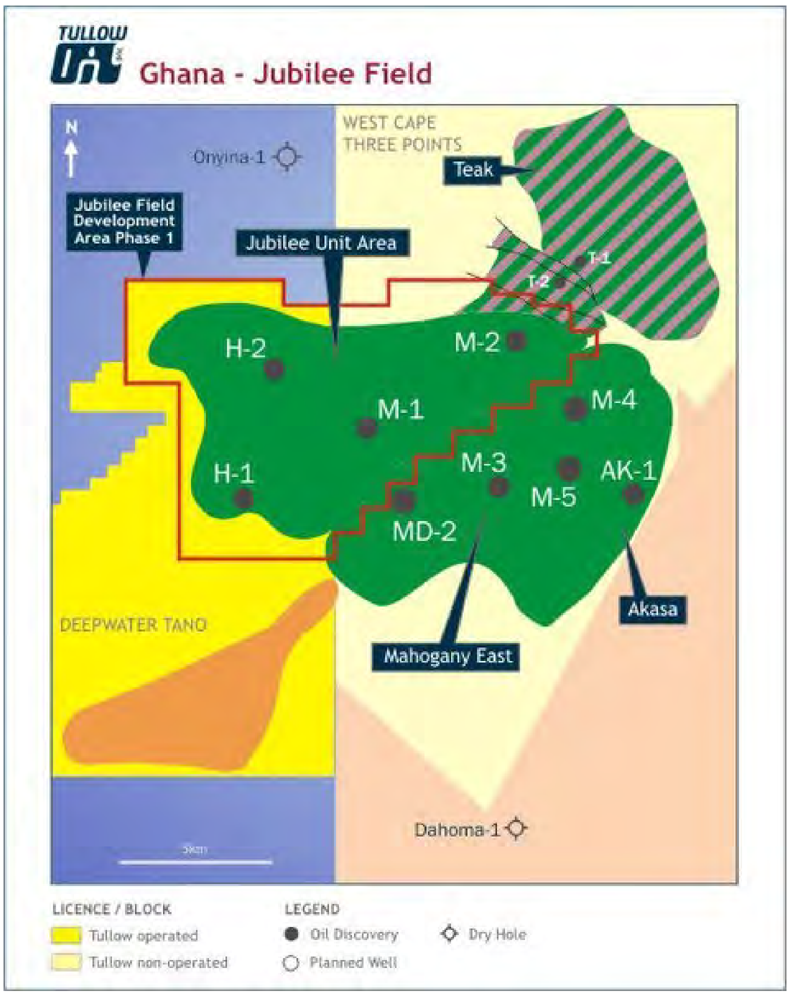


**Figure 1** **Ghana Jubilee Field (www.tullowoil.com)**

The Tweneboa Field (Figure 2) is located in the Deep Water Tano licence area, 25 km from the Jubilee Field. Exploration wells first discovered a light hydrocarbon accumulation in March 2009, and a full exploratory appraisal programme commenced in 2010.


**Figure 2** **Ghana Tweneboa Field ([www.tullowoil.com](www.tullowoil.com))**

Both the Deep Water Tano and West Cape Three Points licence areas are located in an area where water depth ranges from 1,100 to 1,700 m, and is highly diverse in its marine life.

Offshore operations on this scale have the potential to affect marine mammals and turtles via the propagation of noise and increased vessel traffic in the natural environment. While this potential exists, mitigation measures are put in place to reduce impacts to acceptable levels. The findings of the EIA concluded a number of mitigation measures are required in order to minimise the impact on the marine environment during the Jubilee Field Phase 1 development, including the use of trained observers, noise monitoring and avoidance procedures.

TGL is committed to avoiding significant adverse impacts on the environment, wherever possible, and reducing the impact to acceptable levels through appropriate and practicable mitigation measures. TGL understands that although little is known regarding the abundance and distribution of marine mammals and turtles in offshore Ghana, there is still the potential to cause behavioural and/or physiological disturbance.

### 1.2 Objective

This report presents the findings of incidental and *ad hoc* recordings of marine animals between 8th March and 31st December 2011. The observations were conducted by TGL personnel onboard the *M.V. Seacor Master* and the *M.V. Seacor Merchant*, operating in the Jubilee and Tweneboa Fields.

# 2. THE MARINE ENVIRONMENT

## 2.1 Physical Environment and Oceanographic Features

The ocean is a highly heterogeneous environment, with both large- and small-scale spatial patterns in oceanography (Hunt & Schnieder, 1987). Fluctuations in physical and biological factors within the ocean environment will have an effect on the abundance and distribution of marine fish and zooplankton, which in turn will be reflected in specific marine populations (Thompson & Ollason, 2001). Physical processes such as circulatory patterns may have large-scale implications on the dispersion of all marine life. Equally important small-scale features, or localised episodes, will also have an overall affect. Oceanographic features vary on a temporal scale, with seasonal formation of fronts and annual fluctuations in temperature, salinity and primary production (le Fèrve, 1986; Ellett & Blindheim, 1992).

The distribution of marine mammals is extremely irregular and is generally related to the distribution of their food source. Marine mammals feed on a variety of prey and thus their distribution is related to the movement or abundance of such food sources (e.g. Evans, 1990; Macleod *et al.,* 2004; Friedlaender *et al.*, 2006). The distribution of marine turtles is related to nesting and feeding sites, with movement between specific areas primarily using ocean currents (Luschi *et al.,* 2003). As the distribution and abundance of marine animals is influenced by oceanographic characteristics it is important to describe the topography and marine processes in the study area.

The Jubilee Field covers part of the Deep Water Tano and West Cape Three Points licence areas, covering an area of approximately 110 $km^2$. The Tweneboa Field lies 25 km to the west of the Jubilee Field in the Deep Water Tano licence area (see Location Map). Both fields are located on the continental shelf offshore of Ghana in water depths of between 1,100 and 1,700 m. The region is characterised by deep trenches which cross the continental shelf (Environmental Resources Management, 2010). The Guinea Current flows east along West Africa and the coast of Ghana (Figure 3) obtaining velocities up to 100 cm $s^{-1}$ (Richardson & Reverdin, 1987). The current has two sources; the North Equatorial Counter current and the Canary current and as with most currents is characterised by areas of upwelling (Bakun, 1978) and increased biological productivity (Binet, 1997). The Guinea Current has been observed to show a minimum velocity in winter and a maximum velocity in summer (Bakun, 1978; Philander, 1979).

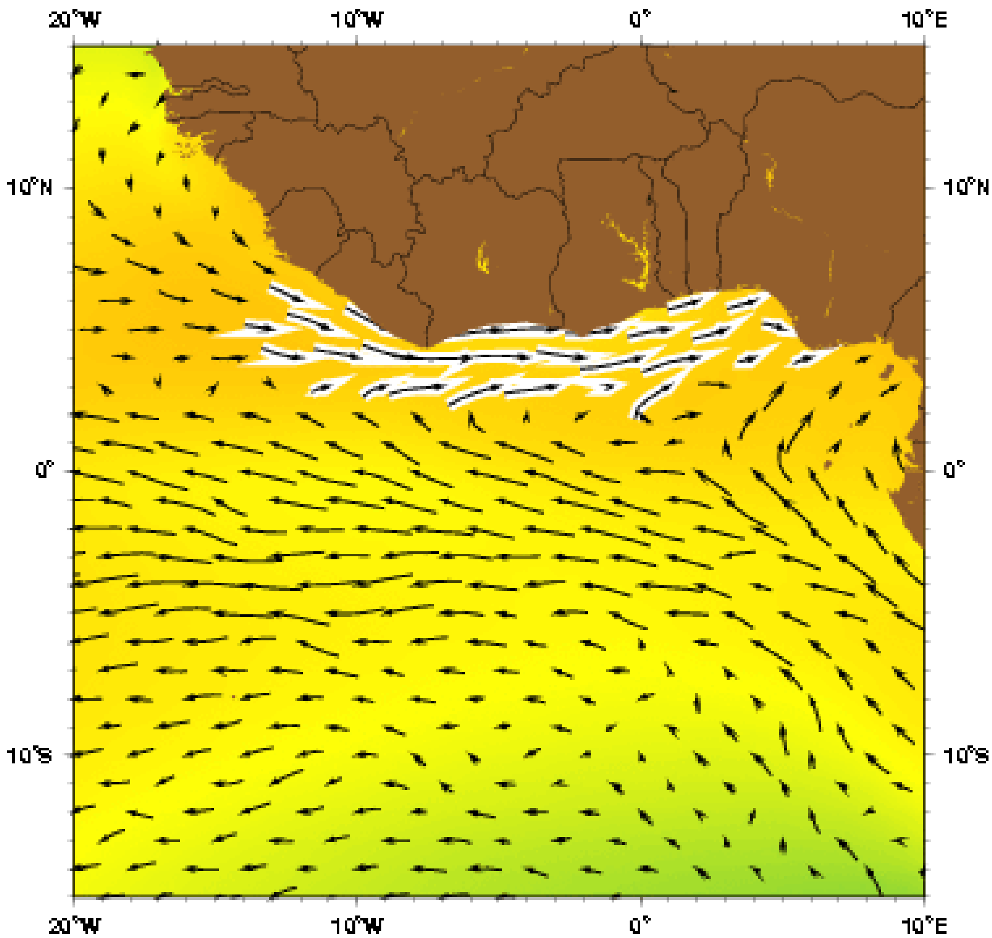


**Figure 3 The Guinea Current as represented by the Mariano Global Surface Velocity Analysis (Gyory *et al*., 2005)**

## 2.2 Marine Communities

The Guinea Current Large Marine Ecosystem is considered a Class I, highly productive (>300 gC/m$^{2\text{-yr}}$) ecosystem based on SeaWiFS global primary productivity estimates. The phytoplankton off the coast of Ghana show seasonal changes, demonstrating two seasons with high productivity, one in the upwelling season (June - September) and another during flooding of large rivers (September – October) (Binet & Marchal, 1993).

This is concurrent with phytoplankton levels recorded during the Jubilee Field Phase 1 EIA sampling which also indicated a system of relatively high productivity, due to the coastal ecosystem undergoing seasonal upwelling in the northern Gulf of Guinea that commences in July (Irvine *et al.*, 2009). Diatoms tend to dominate the phytoplankton during such upwelling periods, while dinoflagellates dominate during periods of thermal stratification (Waife, 2010). The spatial variation of zooplankton is mainly driven by phytoplankton abundance, except during major upwelling when water temperature governs distribution (Waife, 2010).

Along this coast of West Africa there are several commercially important target fish species including round sardinella (*Sardinelia aurita),* flat sardinella (*Sardinella maderensis*), chub mackerel (*Scomber japonicus)* and the European anchovy (*Engraulis encrasicolus)*. Larger pelagic species include tuna and billfish (Environmental Resources Management, 2010).

There are many species of shark present in the area although only two are protected under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the whale shark (*Rhincodon typus*) and the great white shark (*Carcharodon carcharias*). Although records are few, they appear to support a year round occurrence of whale sharks in offshore waters in the Gulf of Guinea (Weir, 2010a). The blue shark (*Prionace glauca*) is one of the most abundant and wide ranging species of pelagic shark. In the eastern Atlantic Ocean it ranges from Norway to South Africa and over the entire mid-Atlantic (Kohler *et al*., 2002). Catches in the Gulf of Guinea indicate a large proportion of gravid females present in the area (Castro & Mejuto, 1995). Another wide ranging pelagic species, the shortfin mako (*Isurus xyrinchus*), has also been reported in the Gulf of Guinea (Castro & Mejuto, 1995).

In Ghanaian waters there has been little scientific research on marine mammals and turtles and as such there is minimal knowledge of species' distribution and abundance in coastal and offshore areas. The extent of the cetacean species assemblage has been studied using landings, stranding, sightings and historical records (Van Waerebeek *et al*., 2009; Weir, 2010b). Studies of marine turtles are predominantly conducted onshore; monitoring efforts include the Ghana Wildlife Society's Marine Turtle Conservation Project (commenced 1995) which aims to identify nesting sites, carry out conservation education, and implement legislation (Formia *et al.,* 2003); and more recently the Ghana Olive Ridley Project, a joint project of seaturtle.org and the Florida Gulf Coast University. Due to the data deficiency of Ghanaian marine macrofauna Ghana's ecological importance is unknown.

Marine mammals in Ghanaian waters are fully protected under the Wildlife Conservation Regulations LI 685 1971 of the Wildlife Animals Preservation Act 1961, Act 43. In Ghana, the Wildlife Conservation Regulation, L.I 680, 1971, protects marine turtles and hunting, capturing or destruction of nests is absolutely prohibited. In addition to this, marine mammal and turtle habitats are protected by The Convention for the Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region (Abidjan Convention, enforced 1984), Accra Declaration of the Ministerial Committee of the Gulf of Guinea Large Marine Ecosystem (GOG-LME, 1998) and the Abuja Declaration of the Guinea Current Large Marine Ecosystem Project (2006).

## 2.3 Marine Mammal Distribution and Abundance in Ghana

A variety of marine mammal species have been recorded off the west coast of Africa (Weir, 2010b), however their distribution in Ghana is poorly understood. There are some discrepancies over the total number of cetacean species present in Ghanaian waters, with the two most detailed studies reaching different conclusions. While it is likely that such differences lie in different paper methodologies and data sources, looking at both sources, they provide clear evidence for species identification and therefore it is possible to combine their findings (Table 1).

**Table 1 Cetacean species of Ghana including species sighted in 2010 at Jubilee Field and their IUCN status**

| Species | Latin Name | IUCN Status | Recorded in 2010 & certainty |
|---|---|---|---|
| Bryde's Whale | *Balaenoptera edeni* | Endangered | Yes - possible |
| Sei Whale | *Balaenoptera borealis* | Endangered | Yes - confirmed |
| Humpback Whale | *Megaptera novaeangliae* | Least Concern | Yes - possible |
| Sperm Whale | *Physeter macrocephalus* | Vulnerable | |
| Dwarf Sperm Whale | *Kogia sima* | Data Deficient | |
| Cuvier's Beaked Whale | *Ziphius cavirostris* | Least Concern | |
| Killer Whale | *Orcinus orca* | Data Deficient | |
| Short-finned Pilot Whale | *Globicephala macrorhynchus* | Data Deficient | Yes - confirmed |
| False Killer Whale | *Pseudorca crassidends* | Data Deficient | |
| Melon-headed Whale | *Peponocephala electra* | Least Concern | |
| Rough-toothed Dolphin | *Steno bredanensis* | Least Concern | Yes - possible |
| Risso's Dolphin | *Grampus griseus* | Least Concern | |
| Bottlenose Dolphin | *Tursiops truncatus* | Least Concern | |
| Pantropical Spotted Dolphin | *Stenella attenuata* | Least Concern | Yes - confirmed |
| Atlantic Spotted Dolphin | *Stenella frontalis* | Data Deficient | |
| Spinner Dolphin | *Stenella longirostris* | Data Deficient | Yes - possible |
| Clymene Dolphin | *Stenella clymene* | Data Deficient | Yes - possible |
| Short-beaked Common Dolphin | *Delphinus delphis* | Least Concern | Yes - confirmed |
| Long-beaked Common Dolphin | *Delphinus capensis* | Data Deficient | |
| Fraser's Dolphin | *Lagenodelphis hosei* | Least Concern | |

(Based on Weir, 2010b, Van Waerebeek *et al*., 2009, GEL, 2011, IUCN, 2011)

The validated list compiled by Van Waerebeek *et al.* (2009) used skull morphometric studies of specimens from deliberate/accidental capture and stranding to identify species present. Although it is widely acknowledged that there are many problems associated with the reporting of individuals caught at sea or stranded (Norman *et al.*, 2004) it provides a useful insight on a wider scale. This method confirmed recordings for 17 odontocete (toothed whales and dolphins) and one mysticete (baleen whale), the humpback whale (*Megaptera novaeangliae*). Based on these records, the Clymene dolphin (*Stenella clymene*) appears to be the most common cetacean in Ghanaian waters (Van Waerebeek *et al.,* 2009).

The species list compiled by Weir (2010b) primarily uses visual identification from at sea sightings throughout the Gulf of Guinea with strict validation on the basis of observer and reliance on supporting material due to the difficulty of species identification at sea. This study reported 17 cetacean species in Ghanaian waters from records including whaling, capture, stranding and at sea sightings. At sea sightings in Ghanaian waters were confirmed for pantropical spotted dolphin (*Stenella attenuata*), spinner dolphin (*Stenella longirostris*), Clymene dolphin, rough-toothed dolphin (*Steno bredanensis*) and killer whale (*Orcinus orca*).

Weir (2010b) includes the Bryde's whale (*Balaenoptera edeni*) based on historical whaling records. Bryde's whale typically inhabits tropical waters and do not tend to make extensive migrations to high latitude feeding grounds (Best, 2001). Numerous recent sightings have been reported off of Angola (Weir, 2010b) and Gabon (N. Robinson, 2005 – per. Comm.) indicating the species still occurs in the region and could potentially be still present off Ghana.

Although there is considerable doubt over the identification of many historical records of sei whale (*Balaenoptera borealis*) from the region and no recent published reports (Weir, 2010b: Van Waerebeek *et al*., 2009), experienced marine biologists were able to confirm an at sea sighting on the Jubilee Field in 2010 (GEL, 2011), indicating the species does utilise this habitat.

Under the International Union for Conservation of Nature (IUCN) Red List, the only current Ghanaian cetacean species noted as 'vulnerable' is the sperm whale (Taylor *et al*., 2008). The Bryde's whale is listed as 'data deficient' (Reilly *et al*., 2008). The 'vulnerable' Atlantic humpback dolphin (*Sousa teuszii*) remains unrecorded in Ghana (Van Waerebeek *et al*., 2009), although suitable coastal habitat is present and the species is reported in Gabon and Angola (Van Waerebeek *et al*., 2004).

The West African manatee (*Trichechus senegalensis*) occurs along the coast of West Africa and in subsequent inland rives and estuaries from southern Mauritania to Angola. Coastally the species is restricted to shallow areas where their food source, predominantly sea grass, is found (Powell & Kouadio, 2008). As such it is unlikely manatees will be encountered offshore on the Jubilee and Tweneboa Fields, although they could be encountered near port entries.

## 2.4 Marine Turtle Distribution and Abundance in Ghana

All six species of marine turtle are recorded along the Atlantic coast of Africa (Formia *et al*., 2003), five of which have been recorded in the Gulf of Guinea region (Irvine *et al*., 2009). Three of these have been recorded nesting along the coast of Ghana, the leatherback turtle (*Dermochelys coriacea*), green turtle (*Chelonia mydas*) and olive ridley turtle (*Lepidochelys olivacea*) (Armah *et al.,* 1997). Hawksbill turtles (*Eretmochelys imbricata*) are known to nest within the Gulf of Guinea region (Rader *et al*., 2006) and loggerhead turtles (*Caretta caretta*) are recorded in the region also (Formia *et al*., 2003). Marine turtles are known to migrate between nesting and foraging areas, often showing high philopatry to specific nesting and foraging sites (Broderick *et al*., 2007; Tucker, 2010). Therefore all of these species of marine turtle could be encountered in the offshore waters of Ghana, and all except the hawksbill are captured with some regularity in fishing nets (Irvine *et al*., 2009). The leatherback turtle is listed as 'critically endangered', the green turtle as 'endangered' and the olive ridley turtle as 'vulnerable' by the IUCN (IUCN, 2011). Despite their protected status adults and eggs are harvested as bushmeat (Adjei *et al*., 2001).

# 3. METHODOLOGY

## 3.1 Observer Procedures

Observers recorded incidental marine mammal and turtle sightings whilst onboard vessels conducting support and security duties on behalf of TGL within, and on transit to, the Jubilee and Tweneboa Field, offshore Ghana.

The primary observation technique used to spot marine animals was to scan the visible area of sea using the naked eye and, where available and required, scanning areas of interest with binoculars (e.g. waves going against the prevailing direction, white water during calm periods, bird activity, etc.). This technique gives both a wide field of view and the ability to have a sufficient range of 3 to 4 km in ideal conditions. Where possible, photographs were taken to aid identification of the species.

The majority of identifications, where provided, are based the observer's previous experience. During April and June 2010 TGL commissioned the formal training of nine security and environmental advisor staff. These staff, upon completion of their training, were issued with two tools to aid identification; a turtle identification key (Appendix A) and a Shirihai & Jarrett (2006) identification guide book. Sightings forms were made available as part of the daily Environmental Report, to be completed by all personnel in the event of an encounter (Appendix B).

The information recorded by observers included the date and time, the vessel's position, the species and number of animals, and where possible the behaviour, and the details on the features used to identify the animals. Observers also recorded the certainty of their identification of species, recording definite, probable or possible.

In addition to recording information on sightings, vessel personnel completed a daily Environmental Report (Appendix B). Information recorded included current location, wind direction and speed, current direction and speed, wave height and direction, cloud cover, visibility and whether there had been any rain or squalls in the previous 24 hours.

Once the data was compiled, the species identification was reviewed by trained and experienced marine biologists onshore. Identifications by untrained personnel which did not include accompanying descriptive justification or photographic evidence were 'downgraded' and classified into lower taxonomic groups: i.e. turtle species (Order Testudines), dolphin species (Family Delphindae), and whale species (Suborder Mysticetes, and the Odontocete families of Physeteridae, and Ziphidae). This method is explained in Table 2.

Identifications to species level from trained observers, with descriptive justification, and / or photographs, remained classified as definite. Identifications which did not include accompanying descriptive justification or photographic evidence were 'downgraded' from definite to probable.

Identifications to species level from untrained observers, with descriptive justification were 'downgraded' from definite to probable, unless photographic evidence was provided to confirm identification.

**Table 2 Taxonomic 'downgrading'**

| | Whale species | | Dolphin Species | Turtle species |
|---|---|---|---|---|
| **Order** | Cetacean | Cetacean | Cetacean | Testudines |
| **Suborder** | Odontocetes | Mysiticetes | Delphinidae | [All} |
| **Family** | Physeteridae & Ziphidae only | [All] | [All] | |
| **Ghanaian examples** | Sperm whale, Dwarf sperm whale | Sei whale, Humpback whale | Pilot whale, Spinner dolphin, Spotted dolphin | Green turtle, Hawksbill turtle, Loggerhead turtle |

### 3.2 Survey Area

The Jubilee Field is located 60 km from the Ghanaian coastline, and 130 km southwest of the port city of Takoradi. The Jubilee Field covers an area of approximately 110 $km^2$ and is located in the Deep Water Tano and West Cape Three Points licence area. The Tweneboa Field is located 25 km to the west of the Jubilee Field in the Deep Water Tano licence area. Both fields are situated in the Tano Basin, in an area of water between 1,100 and 1,700 m deep. The position of the Jubilee Field, the Tullow Oil owned licence areas, and the FPSO are shown in the Location Map.

### 3.3 Survey Vessels

Incidental recordings of marine mammals and turtles were carried out onboard the security vessels the *M.V. Seacor Master* and the *M.V. Seacor Merchant*, between the 8$^{th}$ March and 31$^{st}$ December 2011. These vessel details are as displayed in Table 3.

**Table 3 Vessel Specifications**

| **Vessel** | *M.V. Seacor Master* | *M.V. Seacor Merchant* |
|---|---|---|
| **Class** | BV SV DYNAPOS | BV |
| **Flag** | Marshall Islands | Marshall Islands |
| **Length** | 46m | 46 m |
| **Breadth** | 11 m | 11 m |
| **Draft** | 3 m | 3 m |
| **Built** | 2002, USA | 2002, USA |
| **Main Engine** | 2 x Cummins K38 M2 | 2 x Caterpiller 3508B |
| **Propellers** | 2 x 72 x 58 | 2 x 72 x 58 |
| **Accommodation** | 26 berths | 30 berths |
| **Owners** | SEACOR Marine | SEACOR Marine |
| **Cruising Speed** | 10 knots | 10 knots |

# 4. RESULTS

## 4.1 Survey Coverage

Data on marine animal sightings was collected between 8th March and 31st December 2011 onboard the vessels *M.V. Seacor Master* and *M.V. Seacor Merchant.* These vessels hold a security role for the operating platforms of the Jubilee and Tweneboa Fields.

## 4.2 Field Effort

There was no dedicated field effort undertaken during operations, with incidental sightings only recorded.

## 4.3 Environmental Conditions

Environmental conditions recorded by each vessel between 8th March and 31st December 2011 were variable. It should be noted that the environmental conditions presented here show the combined recordings from both vessels simultaneously. Wind direction was predominantly from the south west and south south-west (Figure 4), wind speed varied between 1 and 25 knots, with the highest average wind speeds recorded during June (Figure 5).

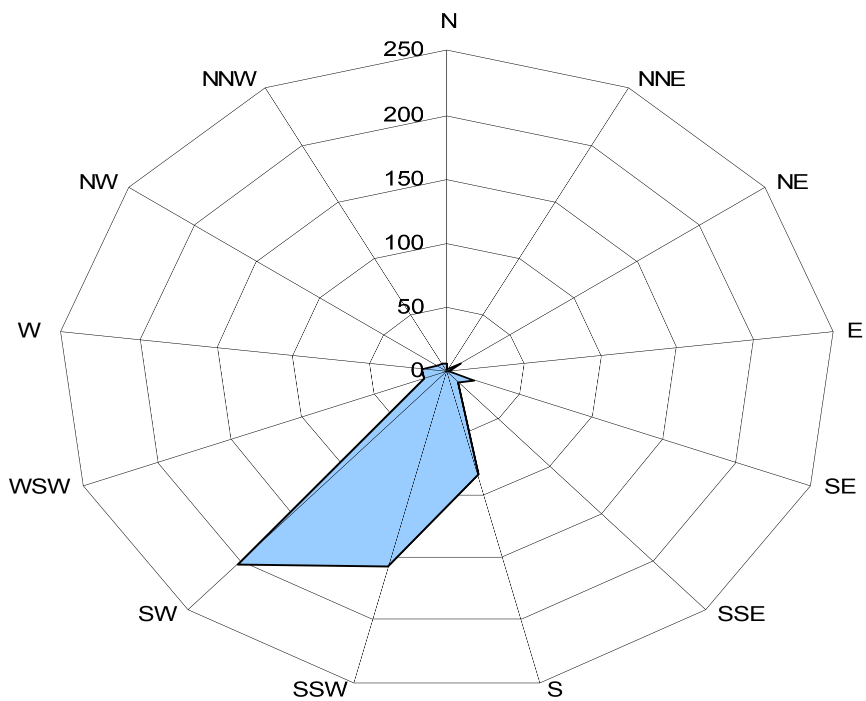


**Figure** 4 **Wind rose showing the number of days recorded under different wind conditions between 8th March and 31st December 2011**

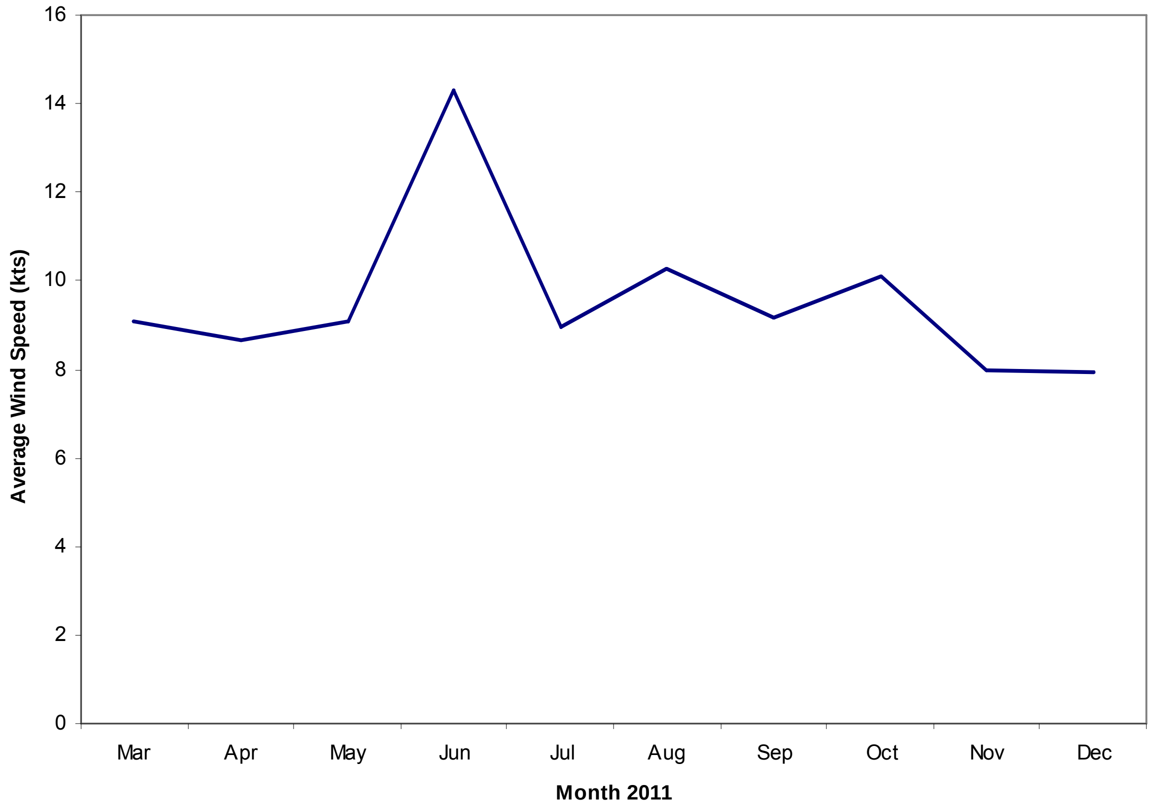


**Figure 5 Average wind speeds each month between 8th March and 31st December 2011**

Wave height varied between 0 and 3 m across the data collection period. Average wave height each month varied between 1.1 and 2.2 m, peaking in June (Figure 6). Cloud cover was highly variable throughout the data collection period (Figure 7) while visibility was predominantly excellent (>10 km) (Figure 8). Squalls in the previous 24 hours were recorded on 16% of days, with the number of days peaking between April and June (Figure 9).

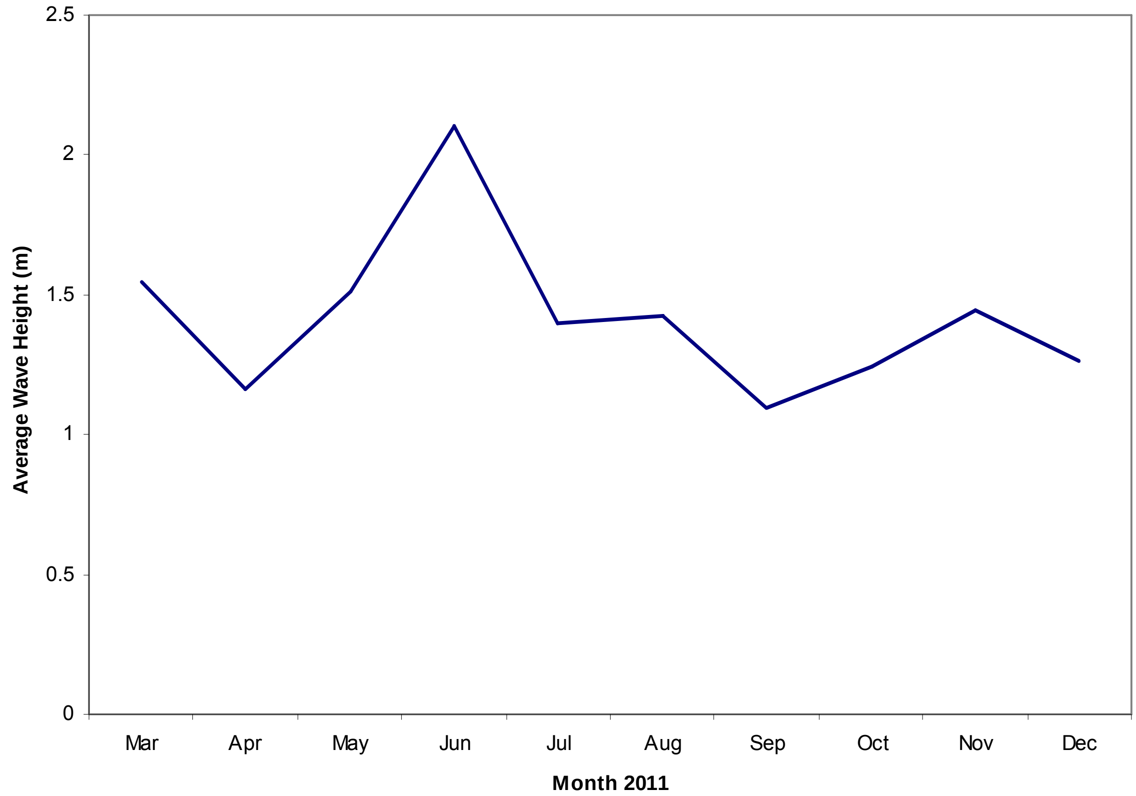


**Figure 6 Monthly average wave height between 8th March and 31st December 2011**

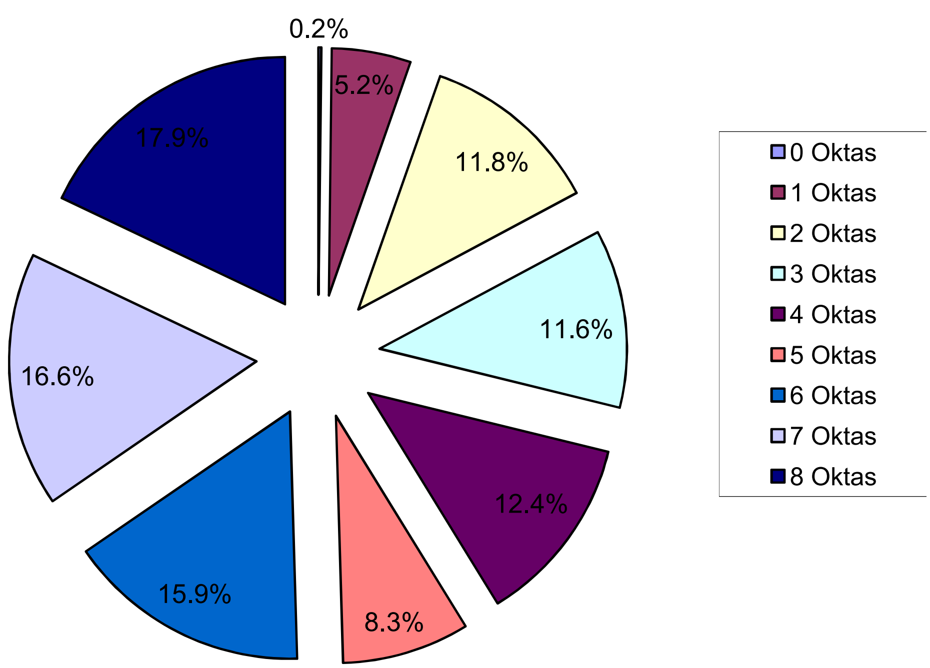


**Figure 7 Cloud cover in Oktas recorded between 8th March and 31st December 2011**

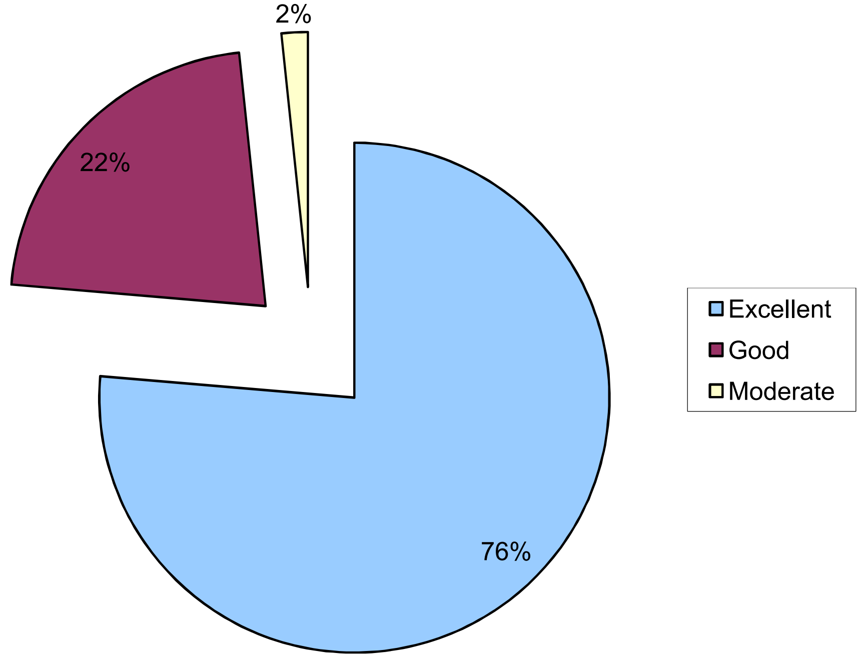


**Figure 8 Visibility recorded between 8th March and 31st December 2011**

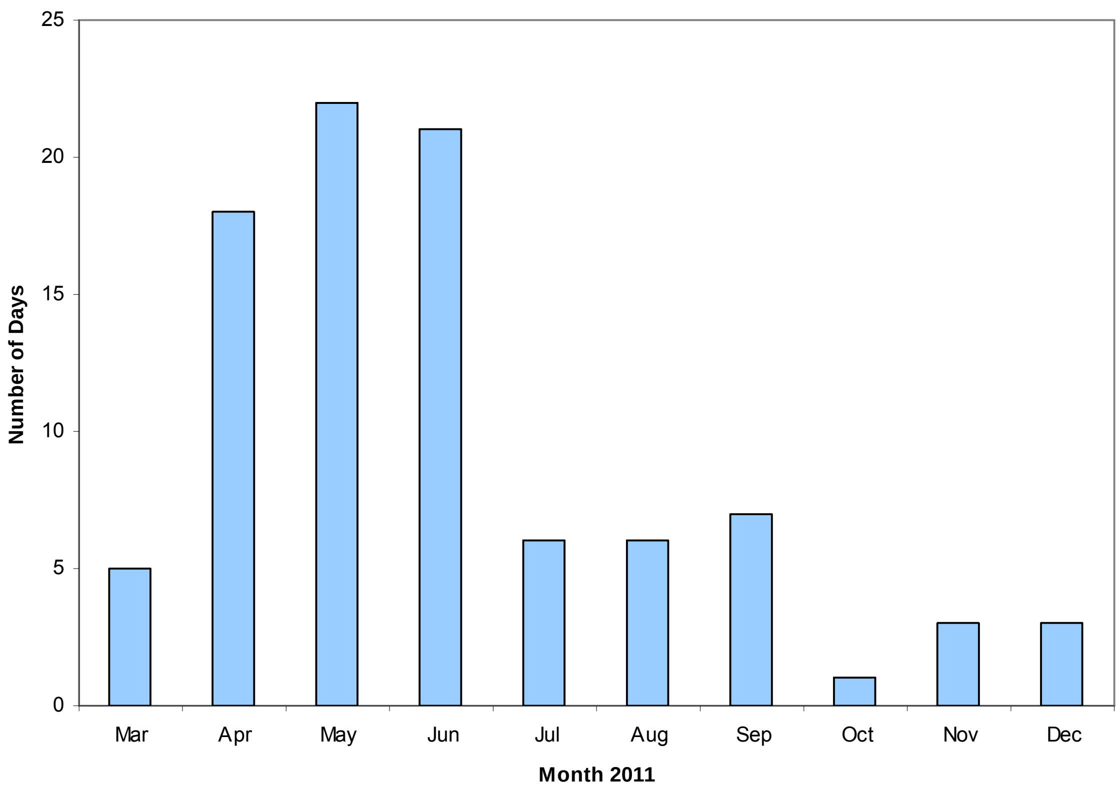


**Figure 9 Number of days where squalls in the previous 24 hours were recorded between 8th March and 31st December 2011**

### 4.4 Marine Animal Sightings

There were a total of 99 recorded sightings of marine animals recorded throughout the the data collection period, from 8th March to 31st December 2011. Selected raw sightings data can be found in Appendix C.

Of these sightings, 75% were confirmed as dolphin species, 8% as whale species and 15% as marine turtle species (all of which include those identified to species level, Figure 10).

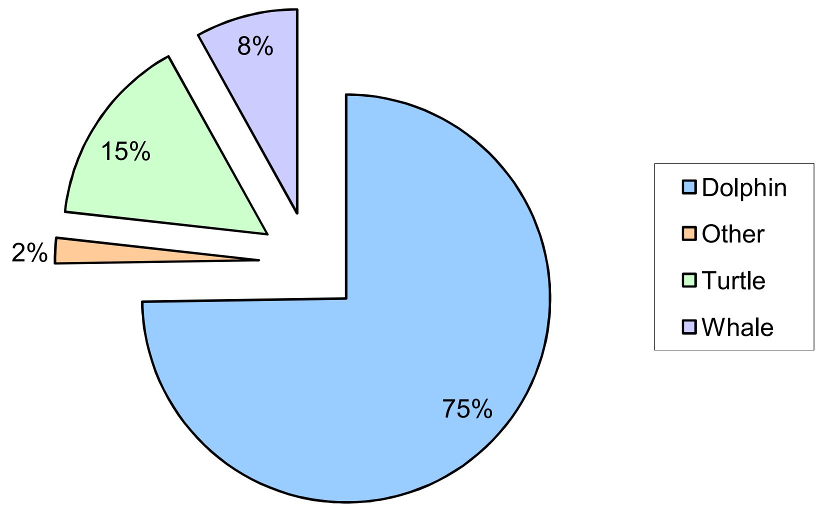


**Figure 10 Proportion of each species group recorded between 8th March and 31st December 2011**

In total 15 different species of marine animal were recorded, 13 of which were positively identified to species level, either through photographic evidence or sufficient description. This includes 10 species of cetacean and three species of marine turtle (Table 4). A further two species were identified as 'probable'; a manta ray (*Manta birostris*) and a species of hammerhead shark (Sphrynidae).

Additionally based on analysis of identification descriptions by experienced marine biologists, a further two cetacean species were recorded as 'possible', the common bottlenose dolphin (*Tursiops truncatus*) and the striped dolphin (*Stenella coeruleoalba*). However no photographic evidence was available to verify this and the sightings were recorded as 'dolphin' species. Further details of all encounters are detailed below, and full catalogue of all the photographs provided with sightings are presented in Appendix D.

Based on positions of sightings plotted in ArcGIS, 31% occurred on the Jubilee Field and 22% on the Tweneboa Field. In addition 23% of sightings occurred within the wider Deep Water Tano licence area and 20% in the wider West Cape Three Points licence area, including 9% within 3 km of the FPSO (Figure 11). Figure 12 shows the location of all marine animal sightings recorded during the data collection period, while Figure 13 shows the distribution of sightings across the Jubilee and Tweneboa Fields with associated bathymetry.

**Table 4 Marine animal species positively identified to species level between 8th March and 31st December 2011**

| Species | Latin Name |
|---|---|
| Clymene Dolphin | *Stenella clymene* |
| Common Dolphin | *Delphinus* sp. |
| Fraser's Dolphin | *Lagenodelphis hosei* |
| Humpback Whale | *Megaptera novaeangliae* |
| Melon-headed Whale | *Peponocephala electra* |
| Pantropical Spotted Dolphin | *Stenella attenuata* |
| Short-finned Pilot Whale | *Globicephala macrorhynchus* |
| Rough-toothed Dolphin | *Steno bradanensis* |
| Spinner Dolphin | *Stenella longirostris* |
| Atlantic Spotted Dolphin | *Stenella frontalis* |
| Leatherback Turtle | *Dermochelys coriacea* |
| Olive Ridley Turtle | *Lepidochelys olivacea* |
| Green Turtle | *Chelonia mydas* |

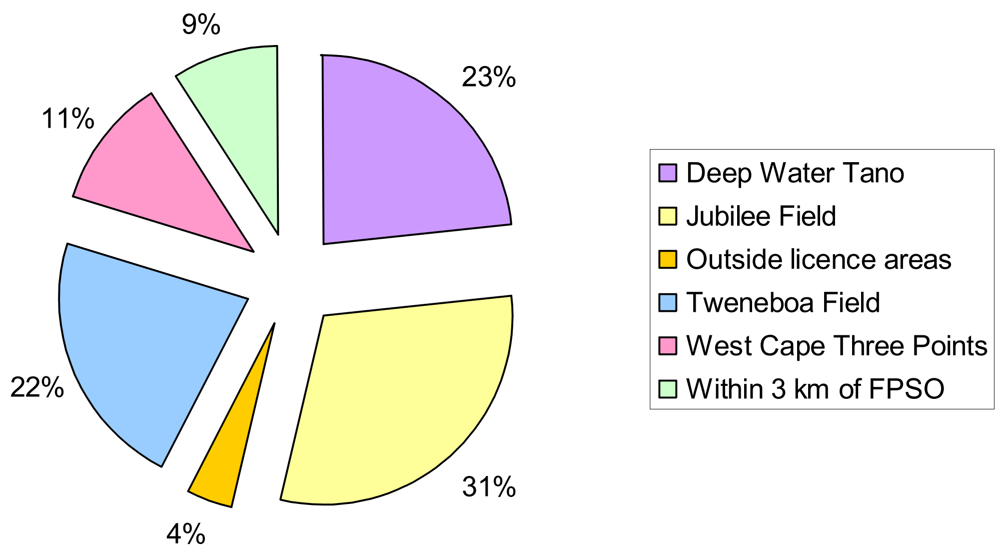


**Figure 11 Percentage of sightings across licence areas between 8th March and 31st December 2011**

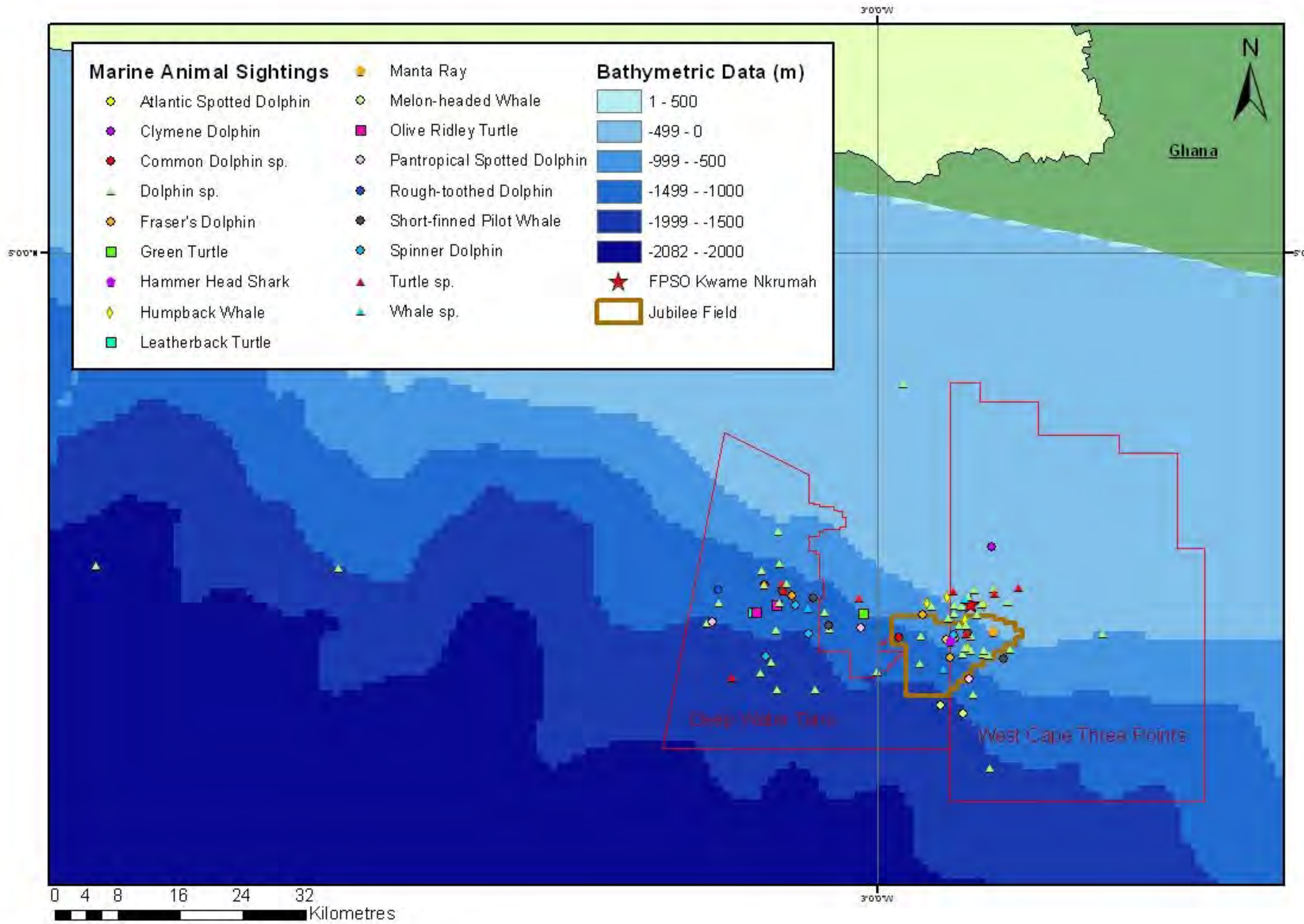


**Figure 12** **Distribution of all marine animal sightings recorded between 8th March and 31st December 2011**

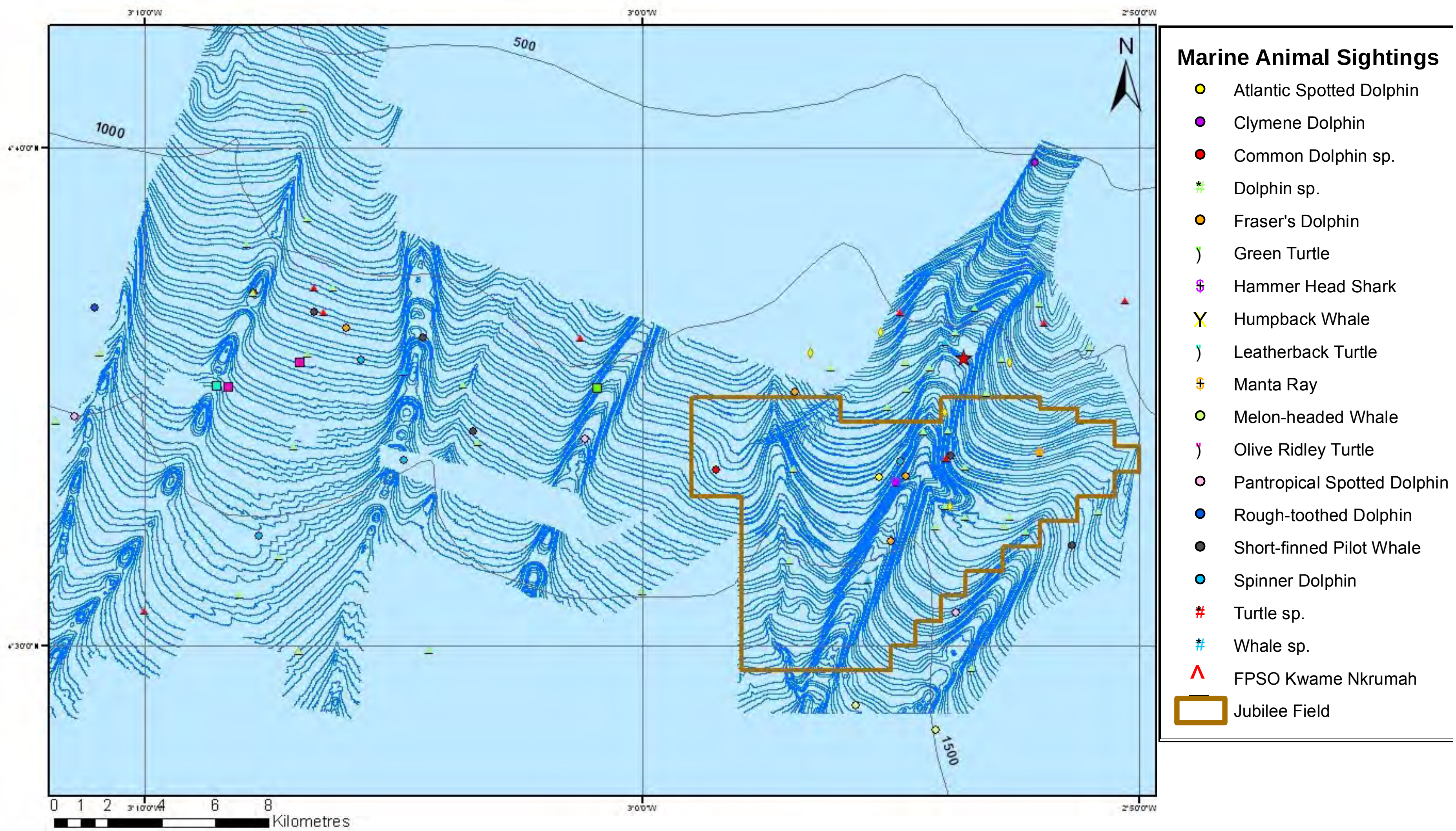


**Figure 13** **Marine animal sightings within the Jubilee and Tweneboa Fields with associated bathymetry**

Sightings of marine animals were recorded in all months of the data collection period (Figure 14). Dolphins were recorded in all months (Figure 15), whilst the majority of whale sightings occurred between August and November (Figure 16). Marine turtle sightings were also spread across the data collection period (Figure 17).

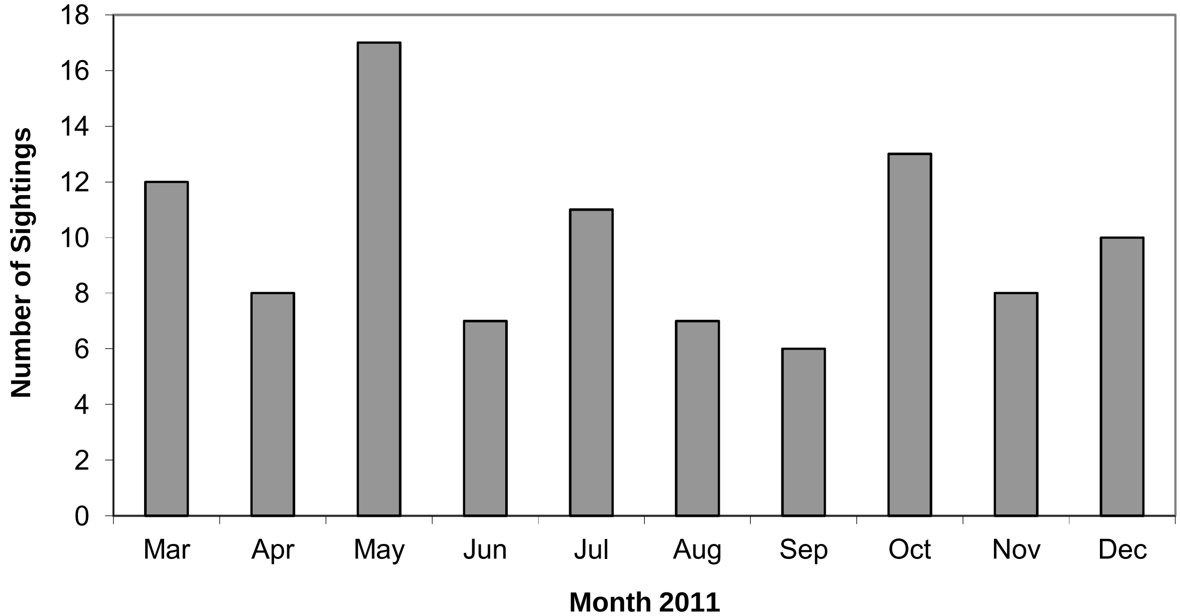


**Figure 14 Number of marine animal sightings each month between 8th March and 31st December 2011**

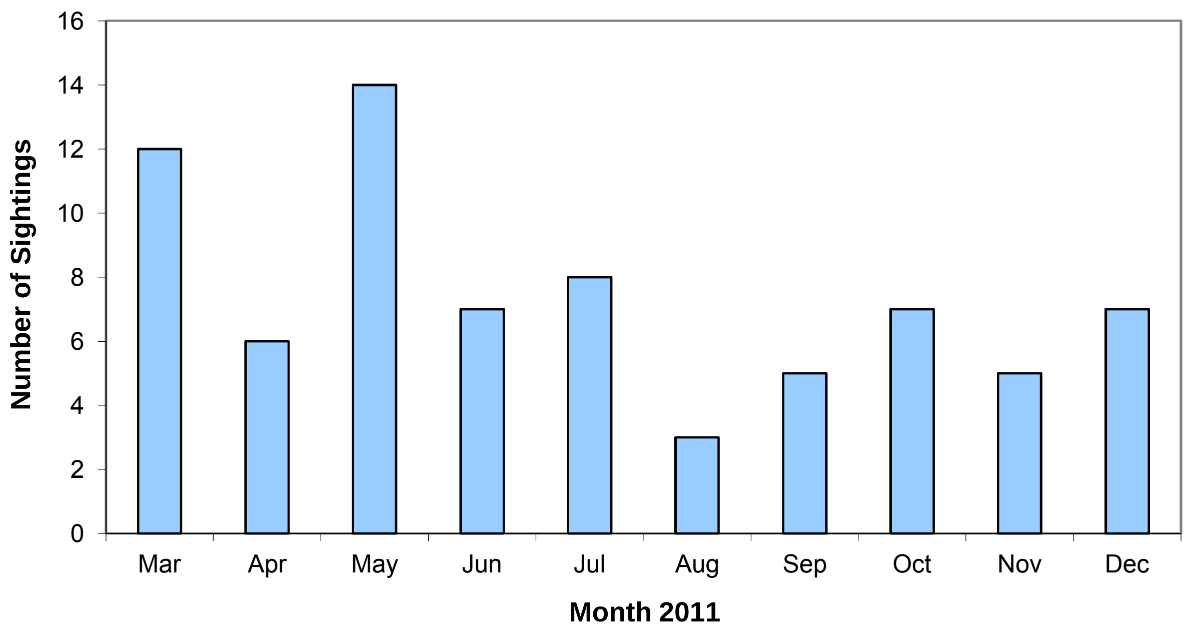


**Figure 15 Total number of dolphin sightings each month between 8th March and 31st December 2011**

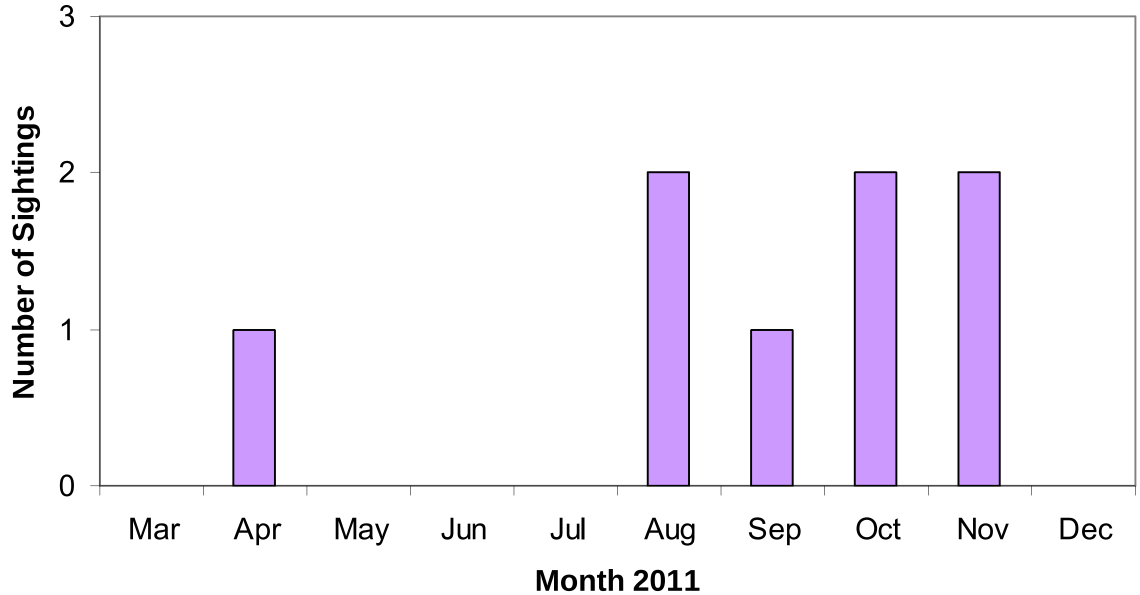


**Figure 16 Total number of whale sightings each month between 8th March and 31st December 2011**

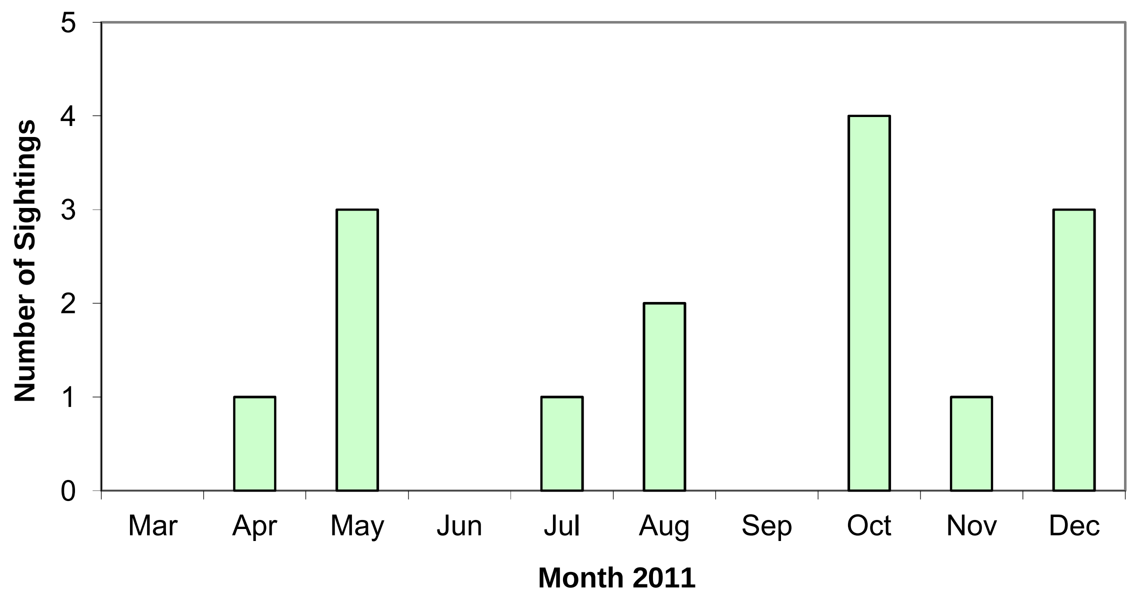


**Figure 17 Total number of marine turtle sightings each month between 8th March and 31st December 2011**

## 4.5 Confirmed Marine Mammal Sightings

### 4.5.1 Clymene Dolphin (*Stenlla clymene*)

*The Clymene dolphin is a small, rather stocky dolphin with a moderately long beak. The colouration is tripartite, with a white belly (that often appears pinkish), light grey flanks and dark grey cape. Body size reaches between 1.7 and 2 m, with weights up to 80 kg (Culik, 2011). The beak has a distinctive black tip which continues narrowly to the base, a distinctive feature is the dark and pale eye stripes and nasal markings which form a 'moustache' on the beak (Shirihai & Jarrett, 2006). The Clymene dolphin is distributed throughout tropical and warm, temperate waters of the Atlantic Ocean in waters predominantly between 40 and 4500 m deep (Culik, 2011). The species frequently occurs in groups of 50 of less and often in mixed species groups (Shirihai & Jarrett, 2006). Feeding occurs predominantly at night on small mesopelagic fish and squid (Culik, 2011). Population size is unknown with difficulties in distinguishing it from similarly marked species at sea (Culik, 2011). The species is listed as 'data deficient' on the IUCN Red List (IUCN, 2011).*

There were two definite sightings of Clymene dolphin during the data collection period. The first sighting occurred at 11:15h on 7th May, when a group of 40+ Clymene dolphins were sighted on the Tweneboa Field (Figure 18). The group was initially sighted 300 m from the *M.V Seacor Master*, before coming to within 5 m, and was suspected to be in a mixed group with spinner dolphins. The second sighting occurred at 08:05h on 15th August when a pod of 50+ came in close to the *M.V Seacor Master* in the Jubilee Field. The group was observed for 15 minutes, breaching, porpoising and bow and wake riding whilst the vessel was in transit.

**Figure 18 Sighting of Clymene dolphins, 7th May 2011**

### 4.5.2 Common Dolphin sp. (*Delphinus sp.*)

*All common dolphins were considered a single species until 1994, when research confirmed two distinct species, the long-beaked and short-beaked common dolphin (Kington & Rosel, 2004). It is however difficult to distinguish between the two species at sea. Common dolphins are distinguished from other species by their unique colour pattern with a dark back, white belly and tan anterior flank patch, which dips below the dorsal fin and combines with streaks of light grey to produce an obvious 'hourglass' pattern (Jefferson et al., 1993). In short-beaked common dolphin this colour pattern is crisp and more colourful than in the long-beaked common dolphin. The chin to flipper stripe is broader in long-beaked common dolphins, which also lack the white often seen in the dorsal fin and pectoral fins of short-beaked common dolphins. Long-beaked common dolphins also tend to have a more slender body and longer beak (Culilk, 2011). Short-beaked common dolphins are widely distributed in warm temperate and tropical waters if the Atlantic and Pacific, typically in offshore waters between 10 and 20°c and more than 180 m deep (Culik, 2011). Long-beaked common dolphins typically prefer warmer, shallower waters and generally occur closer to the coast. The overall distribution of both species remains unclear due to past confusions (Culik, 2011). Both species reach up to approximately 2.5 m in length (Shirihai & Jarrett, 2006) although long-beaked common dolphins tend to be slightly longer and heavier (Culik, 2011). Both prey on small shoaling fish and squid, often using co-operative feeding techniques to herd schools (Cuilk, 2011). They are often found in large, active schools but group size is known to vary seasonally and by time of day and they can be encountered individually (Culik, 2011). No population abundances currently exist for long-beaked common dolphins and the species is listed as 'data deficient' on the IUCN Red List (IUCN, 2011). Population estimates are available for short-beaked common dolphins in several areas, according to which the species is abundant (Culik, 2011). The species is listed as 'least concern' by the IUCN (IUCN, 2011).*

There were two sightings of common dolphin sp. recorded. In both cases the species of common dolphin could not be confirmed based on descriptions and no photographs were available. The first sighting occurred at 07:05h on 26th March, when a group of approximately 15 probable common and possible spinner dolphins were sighted on the Tweneboa Field. The second sighting of definite common dolphins occurred at 06:15h on 1st May and consisted of over 100 individuals, also on the Tweneboa Field.

### 4.5.3 Fraser's Dolphin (*Lagenodelphis hosei*)

*The Fraser's dolphin was considered extinct until 1971 when it was rediscovered as a living species (Rice, 1998). It is a pantropical, pelagic dolphin typically found in deep, offshore waters (Cuilk, 2011). Although the distribution is poorly known, it is suggested to be typically found in tropical and warm temperate waters of the Pacific and Indian Ocean (Hammond et al., 2008a). It is relatively scare in the Atlantic Ocean, but has been recorded in the Gulf of Mexico and off West Africa (Culik, 2011: Weir et al., 2008). A stocky dolphin with a short beak, small dorsal fin and flippers, Fraser's have a distinctive but variable black stripe that extends from the eye to the anus. The back is dark blue-grey to brownish-grey, with paler lower sides and belly which often appears flushed pink (Shirihai & Jarrett, 2006). They tend to travel in large, tightly packed groups, porpoising quickly and leaving a distinct wake. The species often associates with other species such as melon-headed whale and short-finned pilot whales*

*(Shirihai & Jarrett, 2006). A deep diving species, Fraser's dolphin feed on mesopelagic fish, shrimps and squid to depths of 600 m (Culik, 2011). Estimates of population size are only known from a few areas and the current global population is unknown. The species is classified as 'least concern' on the IUCN Red List (IUCN, 2011).*

There were two probable and two definite sightings of Fraser's dolphin during the data collection period. The first occurred at 10:20h on 1st May when a group of 50+ were observed porpoising and bow riding the *M.V Seacor Master* on the Tweneboa Field. The second sighting occurred at 06:15h on 5th May when a group of 100+ individuals were again sighted bow riding and breaching alongside the *M.V Seacor Master* on the Tweneboa Field.

The third sighting of probable Fraser's dolphins was recorded at 08:05h on 10th June on the Jubilee Field. On this occasion a group of approximately 20 dolphins were sighted crossing ahead of the vessel, approaching to within 5 m. The fourth sighting of probable Fraser's dolphins occurred at 07:45h on 23rd June, when a group of approximately 30 individuals were sighted on the Jubilee Field.

### 4.5.4 Melon-headed Whale (*Peponocephala electra*)

*The melon-headed whale is a member of the 'blackfish', a group of dolphins traditionally classified as the Globicephaline. The species is mostly dark grey with a faint grey cape that narrows at the head. A distinctive dark eye patch, broadening as it extends from the eye to the melon is often present, while the lips are often white. It can be difficult to distinguish between this species and the pygmy killer whale (Feresa attenuata) at sea, although melon-headed whales have a more pointed head and sharply pointed flippers (Culik, 2011). Adult males reach up to 2.6 m, with females slightly smaller, and weigh up to 228 kg (Perryman, 2009). A pantropical dolphin they range throughout continental shelf waters of tropical and subtropical waters. Highly social, they usually occur in large, tightly packed groups of 100 to 500 individuals and may often associate with other species of dolphin (Shirihai & Jarrett, 2006). Diet consists of squid and small fish (Culik, 2011). Population estimates exist for some regions, where the species appears relatively abundant (Culik, 2011). It is listed as 'least concern' on the IUCN Red List (IUCN, 2011).*

There were two confirmed sightings of melon-headed whale, both identified from photographs by experienced marine biologists. Two groups were encountered separately on the 19th October on the Jubilee Field. The first group of approximately 30 individuals was sighted between 15:20h and 15:40h (Figure 19), while the second group of approximately 20 individuals were sighted between 16:00h and 16:10h. Both groups were observed milling around the vessel at a distance of approximately 200 m, and could potentially have been the same group.

**Figure 19 Sighting of melon-headed whale, 19th October 2011**

### 4.5.5 Pantropical Spotted Dolphin *(Stenella attenuata)*

*The pantropical spotted dolphin is one of the most abundant cetaceans, despite numbers being seriously reduced in some areas by incidental killing (Culik, 2011). The species is found in all tropical to warm temperate oceanic and pelagic waters and can be encountered both as a few individuals and in large groups of several thousand (Culik, 2011). They may also be found in large, multispecies aggregations including spinner dolphins and yellowfin tuna (Thunnus albacares) and these groups may be segregated by sex and/or age (Perrin, 2009a). The species varies geographically in body size and colouration with adults ranging between 166 and 257 cm and weighing up to 119 kg (Perrin, 2009a). In general, they have a slender body, a relatively small but strongly falcate dorsal fin, light coloured dorsal spots and a long, slender beak which is white on the tip. Calves are born without spots (Culik, 2011). Aerial behaviour such as leaping, bow-riding and porpoising is common. Their diet varies with region but mainly includes fish, squid and crustaceans (Perrin, 2009a). The current population is estimated to be more than 1.7 million (Culik, 2011) and their IUCN status is 'least concern' (IUCN, 2011).*

There were three confirmed sightings of pantropical spotted dolphin during the data collection period. The first occurred at 07:05h on 15th September on the Jubilee Field, when a group of 10 individuals were observed breaching and porpoising ahead of the *M.V Seacor Master*, before approaching to bow ride (Figure 20). The second sighting occurred at 17:30h on 28th October on the Tweneboa Field, and consisted of a group of 14-20 individuals including approximately six juveniles. The third sighting occurred at 17:50h on 3rd November, also at the

Tweneboa Field, when a mixed group of pantropical spotted and possible spinner dolphins approached the *M.V Seacor Master* to bow ride.

**Figure 20 Sighting of pantropical spotted dolphin, 15th September 2011**

#### 4.5.6 Short-finned Pilot Whale (*Globicephala macrorhynchus)*

*Short-finned pilot whales are a member of the Delphinidae, of the subfamily Globicephaline and are also known as 'blackfish' (Shirihai & Jarrett, 2006). They occur circum-globally in warm temperate to tropical waters of the world, generally in deep offshore areas (Culik, 2011). They are all black to coal grey in colour, with a white or light grey anchor-shaped patch on the ventral surface and a faint grey saddle patch behind the dorsal fin (Jefferson et al., 1993). Pilot whales have a distinct rounded head with a very slight beak and an up-curved mouthline. The dorsal fin is prominent, falcate and located on the forward part of the back, and the flippers are sickle shaped (Shirihai & Jarrett, 2006). Adult males can reach up to 7.2 m in length and weigh up to 3,200 kg while adult females measure up to 5.5 m and weigh up to 1.5 tons (Jefferson et al., 1993). Short-finned pilot whales are most often found in deep tropical waters, such as those found at the edges of the continental shelves and submarine canyons, where they feed primarily on deep sea squid, although they are known to eat octopus, cuttlefish, herring and other small fish (Culik, 2011). They are a very social species, living in tight social units and are commonly found in groups of 15 to 50 individuals occasionally associated with other species of cetacean, such as the bottlenose dolphin (Shirihai & Jarrett, 2006). Population estimates are known for some areas where it is considered common, although the species is classified as 'data deficient' by the IUCN (IUCN, 2011).*

There were seven recorded sightings of short-finned pilot whale, including one probable sighting. The first sighting occurred at 16:50h on 26th March, when a group of approximately 10 individuals were sighted on the Tweneboa Field. The group was sighted initially from the *M.V Seacor Master* logging (resting motionless at the surface) at a distance of 200 m. A second group of 10 short-finned pilot whales was then sighted at 17:00h by the support RHIB at a distance of 100 m, before approaching to within 20 m. It is likely these sightings are of the same group. The third sighting occurred at 14:03h on the 30th March on the Tweneboa Field. On this occasion a group of approximately eight individuals was sighted travelling 100 m parallel to the *M.V Seacor Master*, before approaching to within 20 m. The fourth sighting occurred at 08:11h on 14th April on the Jubilee Field, when a group of 15 individuals was observed moving slowly away from the *M.V Seacor Merchant* (Figure 21). The final three sightings all occurred during May. At 15:22h on 8th May a group of 15 probable short-finned pilot whales were observed travelling in the opposite direction to the *M.V Seacor Merchant* on the Jubilee Field. A group of approximately 40 individuals, including juveniles, was observed at 06:10h on 22nd May on the Tweneboa Field. The last sighting occurred at 10:00h on 29th May on the Tweneboa Field, when a group of approximately 16 individuals including five juveniles were observed travelling in the opposite direction to the *M.V Seacor Master*.

**Figure 21 Sighting of short-finned pilot whale, 14th April 2011**

### 4.5.7 Rough-toothed Dolphin (*Steno bredanensis*)

*The rough-toothed dolphin is widely distributed in tropical and warm temperate waters worldwide, predominantly in deep water offshore, beyond the continental shelf (Culik, 2011). The species is named from the vertical ridges in the teeth which gives them a roughened appearance. It is the only long beaked species of dolphin with a smoothly sloping melon that blends with the beak, which usually has a whitish-pink tip, extending to the lips and lower jaw (Shirihai & Jarett, 2006). A large and prominent dorsal fin sits centrally on a rather stocky body. The species has white bellies and black to dark grey backs, often covered in scars and scratches, with adults in particular appearing mottled in colour. The extent of white on the underbelly varies, and in older individuals this can extend to the lower jaw (Shirihai & Jarrett,* *2006). Adult males reach 2.8 m and 155 kg, with female slightly smaller (Culik, 2011). The species is predominantly found in small groups of 10-20, although occasionally larger groups are reported (Shirihai & Jarrett, 2006). Individuals often surface close together in a shoulder-shoulder formation, with the tip of the beak and chin out of the water (Shirihai & Jarrett, 2006). In areas where abundance has been estimated the species is reasonably common, and it has been listed as 'least concern' on the IUCN Red List (IUCN, 2011).*

There was one sighting of rough-toothed dolphin, confirmed from photographs. This occurred at 14:35h on 17th November when a group of approximately 25 individuals was sighted on the Tweneboa Field. The group was observed for 30 minutes breaching, tail slapping and porpoising parallel to the *M.V Seacor Master* (Figure 22).

**Figure 22 Sighting of rough-toothed dolphin, 17th November 2011**

### 4.5.8 Spinner Dolphin (*Stenella longirostris*)

*The spinner dolphin is one of the most taxonomically complex groups of delphinids with several different forms in different regions of the world (Shirihai & Jarrett, 2006). The nominate subspecies S.l. longirostris occurs in the tropical Atlantic, Indian and western and central Pacific Oceans, although its distribution in the Atlantic is poorly known especially in African waters (Culik, 2011). The species can be detected from long distances due to its behaviour of spinning high in the air, up to seven times, and landing with a large splash. The body is slender and the colouration tripartite, with a dark grey cape, pale grey flank and white belly. A dark band also runs from the eye to the flipper, bordered by a thin light line (Culik, 2011). The dorsal fin ranges from slightly falcate to erect and triangular, while the flippers are small and* *pointed (Jefferson et al., 1993). Adults range from 1.3 to 2.3 m and weigh between 23 and 80 kg (Culik, 2011). In tropical waters the species is associated with inshore waters, and are often found in sheltered bays and lagoons during the day resting. They feed predominantly at night on small mesopelagic fish and squid, down to depths of between 200 – 300 m (Culik, 2011). Group size is often large with 1000+ individuals, although smaller groups of 10s or 100s are usually encountered in near shore waters. The species is frequently seen in association with other species such as pantropical spotted dolphin and yellowfin tuna (Perrin, 2009b). Quantitative abundance estimates exits for several areas which indicate the species is abundant; despite this the IUCN lists the species as 'data deficient' on the Red List (IUCN, 2011).*

There were five sightings of spinner dolphin during 2011 including two definite sightings and three probable sightings. The first occurred at 11:15h on 7th May, when a mixed pod of Clymene and probable spinner dolphins were sighted on the Tweneboa Field. The second sighting occurred at 18:05h on 27th July on the Tweneboa Field, when a group of 30+ probable spinner dolphins were recorded at a distance of 1500 m from the *M.V Seacor Master*, approaching to within 100 m. The third sighting occurred at 10:45h on 28th October on the Jubilee Field; on this occasion a group of approximately 30 probable spinner dolphins were observed porpoising within 100 m of the *M.V Seacor Master*. The fourth sighting occurred at 17:50h on 3rd November, on the Tweneboa Field. A mixed group of between 20 and 25 pantropical spotted and spinner dolphins were observed porpoising and breaching towards the *M.V Seacor Master*. The final sighting occurred at 09:40h on the 30th December during transit between the Tweneboa and Jubilee Fields. On this occasion a group of 20 individuals were initially observed heading straight for the *M.V Seacor Master*, before continuing to breach and porpoise approximately 200 m from the vessel for a further 2 hours 40 minutes.

### 4.5.9 Atlantic Spotted Dolphin (*Stenella frontalis*)

*The Atlantic spotted dolphin is distributed in the tropical and warm temperate waters of the Atlantic Ocean. They primarily occur in continental shelf (<200 m) and continental slope (200 m – 2000 m) waters (Culik, 2011). Juveniles, and some unspotted adults, look similar to common bottlenose dolphins, with a robust body and stocky beak. The back is dark grey with light grey sides and white belly; compared to common bottlenose dolphins, Atlantic spotted dolphins tend to have a clearer dark cape, greyer sides and whiter bellies. Colouration is bipartite compared with the tripartite colouration of pantropical spotted dolphins. Spots develop in most, but not all, adults and a pale blaze is present just in front of the dorsal fin, unlike in pantropical spotted dolphins (Shirihai & Jarrett, 2006). Adults range between 1.6 and 2.3 m and weigh up to 143 kg, with marked regional variations in body shape and size (Culik, 2011). The species tends to occur in small to moderately sized groups of fewer than 50, coastal groups typically occur in groups of between five and 15 animals. Group structure tends to be very fluid, with segregated schools of subadults, adults and adults and calves are often observed and are mixed species groups with common bottlenose dolphins (Culik, 2011). Atlantic spotted dolphins feed on a wide variety of fish and squid and in some regions has been reported feeding in a coordinated manner, herding fish into dense balls (Culik, 2011). Although no population estimates exist for West Africa and the mid and east Atlantic, numerous estimates have been produced for the western Atlantic, where the species is recorded as one of the most abundant species (Culik, 2011), despite this the species is listed as data deficient on the IUCN Red List (IUCN, 2011).*

There was one confirmed sighting of Atlantic spotted dolphin during the data collection period, identified from photographs. This occurred at 08:15h on 5th June, when a pod of approximately 15 dolphins were recorded porpoising and bow riding the *M.V Seacor Master* on the Jubilee Field (Figure 23).

**Figure 23 Sighting of Atlantic spotted dolphin, 5th June 2011**

#### 4.5.10 Humpback Whale (*Megaptera novaeangliae*)

*The humpback whale is a widely distributed species, occurring seasonally in all oceans from the Arctic to the Antarctic, with distinct populations located in virtually every sea. All populations of humpback whale undertake migrations between low latitude breeding and high latitude feeding grounds (Fleming & Jackson, 2011). This is a familiar whale, with a stout body and very long flippers (up to 1/3 of the body length) that have lumps upon which barnacles may grow (Jefferson et al., 1993). The head is rounded and flat, with raised lumps known as 'tubercles'. The dorsal fin varies in size and shape between individuals, and the tail flukes are large and almost 'wing-shaped'. The humpback whale is black to blue-black in colour; with pale to white undersides with black markings that vary between individuals (Shirihai & Jarrett, 2006). They measure between 11-16 m in length, with the females generally larger than males, and weigh up to 35 tonnes (Jefferson et al., 1993). The species has a bushy but visible blow, 2.5 to 3 m high (Shirihai & Jarret, 2006). Humpback whales generally feed within 50 m of the water's surface, taking krill and shoaling fish. This is a 'gulp' feeding whale, filtering food from the water through baleen plates after engulfing a mouthful. Unlike other whales, the humpback whale has many varied methods of feeding, including lunge feeding, tail flicking* *and bubble-netting (Fleming & Jackson, 2011). Humpback whales often congregate in large, loose groups for breeding and feeding and are most commonly associated with their 'singing' (Perrin et al., 2002). Population estimates for different humpback whale populations exist along with some information on trends, which generally show increasing populations (Fleming & Jackson, 2011). The species is now listed as 'least concern' on the IUCN Red List (IUCN, 2011).*

There were a total of five sightings of humpback whale during the data collection period, including three probable sightings. This first occurred at 08:12h on 13th August on the Jubilee Field, when two adults and one juvenile whale were observed crossing ahead of the *M.V Seacor Master* at a distance of approximately 400 m. The second sighting occurred at 08:08h on the 19th August on the Jubilee Field, when a single probable humpback whale was observed crossing 400 m ahead of the *M.V Seacor Master*. Two sightings of probable humpback whales were recorded on the 13th October on the Jubilee Field. An adult and juvenile whale was observed at 09:10h, breaching and fin slapping approximately 3 nautical miles from the *M.V Seacor Master*. There was a further sighting of an adult and juvenile whale at 16:00h, again actively breaching and fin slapping this time 1 nM from the vessel. The fifth sighting occurred at 17:00h on 10th November on the Jubilee Field. On this occasion one adult humpback whale was observed surfacing towards the *M.V Seacor Master*, approaching to within 70 m of the vessel (Figure 24).

**Figure 24 Sighting of humpback whale, 10th November 2011**

#### 4.5.11 Olive Ridley Turtle (*Lepidochelys olivacea*)

*The olive ridley is one of the smallest marine turtles, measuring between 55 and 75 cm in straight carapace length and weighing between 30 and 50 kg. The carapace is plain olive grey in colour and nearly circular in shape, with usually six to eight lateral scutes. The head is medium sized and sub-triangular in shape (Márquez, 1990). A pantropical species the olive ridley is predominantly found in the northern hemisphere with the 20°c isotherms as its distributional boundaries (Márquez, 1990). Olive ridleys show high fidelity to nesting sites, returning to the same beaches to breed (Tripathy & Pandav, 2008). Post-breeding the turtles migrate long distances to forage in pelagic zones, although unlike some species they do not have migratory corridors and show no fidelity to specific feeding habitats (Plotkin, 2010). Olive ridley's are known to nest in nearly 60 countries and while migratory movements are not as well studied they are known to involve the waters of over 80 countries (Abreu-Grobois & Plotkin, 2008). The olive ridley is listed under Appendix I of CITES and under Appendix II of the Convention on Migratory Species (CMS). Although considered one of the most abundant marine turtle (Márquez, 1990) recent assessments indicate populations are decreasing and the species is listed as 'vulnerable' on the IUCN Red List (IUCN, 2011).*

There were a total of three sightings of olive ridley turtles during the data collection period, two of which were confirmed as definite using photographic evidence. The first sighting occurred at 08:46h on 6$^{th}$ May on the Tweneboa Field, when one turtle was sighted at the surface 50 m from the *M.V Seacor Master*, which approached to within 6 m of the individual. The second sighting occurred at 14:15h on 15$^{th}$ August when a probable olive ridley was briefly observed 10 km north of the FPSO. The third sighting occurred at 10:50h on 27$^{th}$ December when an olive ridley entangled in discarded fishing nets, was recovered onboard the *M.V Seacor Master* and the netting removed (Figure 25). The individual subsequently swam strongly away from the vessel on release.

**Figure 25 Olive ridley turtle recovered to the *M.V. Seacor Master*, 27th December 2011**

### 4.5.12 Leatherback Turtle (*Dermochelys coriacea*)

*The leatherback is the largest marine turtle, reaching up to 2 m in length. Adults are easily distinguished from all other species of turtle by their spindle-shaped, huge bodies and their leathery, unscaled carapace (Márquez, 1990). It also has the widest distribution of any turtle, due to it being adapted to colder water through a protective thick and oily dermis (Márquez, 1990) which allows it to maintain a constant body temperature even in colder waters. The leatherback turtle has a worldwide distribution and is found from tropical to sub-polar oceans (Sarti Martinez, 2000). Nesting occurs on tropical beaches, with the largest nesting populations found on the western coast of Mexico and in the Caribbean (Márquez, 1990). Post-breeding, leatherback turtles undertake extensive, long distance migrations in search of food following persistent migration corridors (Shillinger et al., 2008) often to specific, key feeding areas (James et al.,2005). Leatherback turtles are predominantly pelagic, spending their time in the open ocean, feeding on gelatinous zooplankton such as jellyfish (Spotilla, 2004). This prey is predominantly found in the epipelagic or surface layers where the majority of foraging dives occur (Southwood et al., 1999). However recent research indicates leatherbacks make infrequent, very deep dives in search of prey particularly during transit to foraging grounds (Houghton et al., 2008). The leatherback turtle is listed under Appendix I of the CITES and CMS, and are listed as 'critically endangered' on the IUCN Red List (IUCN, 2011).*

There was one sighting of a leatherback turtle during the data collection period; one individual was observed at 09:30h on 28th October on the Tweneboa Field. Although less than 1 m in length, the turtle was described as having a "matt shell", with a raised central line and smaller lateral lines running parallel on either side.

#### 4.5.13 Green Turtle (*Chelonia mydas*)

*The green turtle is widely distributed in tropical and subtropical waters throughout the world, predominantly within the 20°c isotherms. Occasionally, solitary non-breeding individuals may also stray into temperate waters (Márquez, 1990). Nesting occurs in more than 80 countries (Hirth, 1997) and they are believed to inhabit the coastal waters of more than 140 countries (Groombridge & Luxmoore, 1989). The green turtle's carapace varies from pale to dark and from plain to brilliant combinations of yellow, brown and greenish tones. The carapace is oval, with four lateral scutes and reaches up to 111 cm in length, with males tending to be slightly smaller than females (Márquez, 1990). Green turtles are highly migratory and use a wide range of habitats during their lifecycle, including open-ocean development grounds and neritic developmental areas rich in seagrass and marine algae. Adult turtles feed during the day in seagrass beds that grow in shallow waters and undertake long distance migrations between foraging and breeding grounds (Márquez, 1990). Female green turtles show high fidelity to nesting sites, often returning to their natal beach in order to lay their eggs (Allard et al., 1994). Recent population assessments indicate the green turtle populations are decreasing, in part due to a number of threats including habitat loss, bycatch and in some areas indigenous harvesting (Seminoff, 2004). The species is listed under Appendix I of CITES and Appendix II of the CMS, and is considered endangered on the IUCN Red List (IUCN, 2011).*

There was one sighting of a green turtle during the data collection period; this occurred at 06:10h on 23rd May when one individual was observed during transit between the Jubilee and Tweneboa Fields.

## 4.6 Probable Species Recorded

### 4.6.1 Manta Ray (*Manta birostris*)

*The manta ray is the largest living ray, reaching at least 7 m with anecdotal reports of individuals reaching up to 9 m. The species is widespread throughout tropical subtropical and temperate waters of the Atlantic, Pacific and Indian Ocean. The species is migratory, appearing seasonally in coastal and offshore sites (Marshall et al., 2011). Although little information currently exits on the movement, behaviour and ecology of the species, recent research indicates environmental factors such as lunar and tidal phase and bathymetry may have a significant influence on occurrence (Dewar et al., 2008). Overall global populations are unknown, although subpopulations in most cases appear to be small with the degree of interchange between subpopulations assumed to be low (Marshall et al., 2011). The manta ray is listed as vulnerable on the IUCN Red List (IUCN, 2011).*

There was one sighting of a probable manta ray at 22:15h on 18th July 2011. The individual was sighted at the surface 30 m from the *M.V Seacor Merchant* on the Jubilee Field.

### 4.6.2 Hammerhead Shark Sp. (Sphrynidae)

*Hammerhead sharks are amongst the most unmistakable marine fauna, with the eyes located on flattened lobes each side of a hammer-shaped head. Found in all temperate and tropical waters worldwide, many species are highly migratory and nomadic (Denham et al., 2007). Of the nine species, three are known to occur in African waters, the scalloped hammerhead (Sphyrna lewini), the smooth hammerhead (Sphyrna zygaena) and the great hammerhead (Sphyrna mokarran). All three are coastal-pelagic and semi-oceanic species, occurring in and offshore, over continental shelves as well as deep water. The species range between 2.2 and 6 m in length, with the great hammerhead shark being the largest and the smooth hammerhead shark generally the smallest. Diet consists of mesopelagic and demersal fish, squid and in some areas stingray (Denham et al., 2007; Casper et al., 2005; Baum et al., 2007). Although population estimates are generally unknown due to catches often being grouped as hammerhead sp, all species face threats from bycatch. The scalloped hammerhead is listed as 'endangered', the smooth hammerhead as 'vulnerable' and the great hammerhead as 'endangered' on the IUCN Red List (IUCN, 2011).*

There was one sighting of a probable hammerhead shark species during the data collection period. One individual was observed at 18:05h on 12th July at a distance of 50 m from the *M.V Seacor Merchant* on the Jubilee Field.

## 4.7 Possible Species Recorded

### 4.7.1 Common Bottlenose Dolphin (*Tursiops truncatus*)

*The common bottlenose dolphin is found worldwide in inshore and offshore, tropical and temperate waters (Shirihai & Jarrett, 2006). The species is a large, robust dolphin with a broad, curved dorsal fin. There is a pronounced melon, and obvious beak. Body colour is typically uniform dark grey or bluish-grey with pale lower sides and belly (Shirihai & Jarrett, 2006). Adult length ranges from 2 to 4.1 m and weights range between 150 and 650 kg, both varying geographically. Body size also tends to vary inversely with water temperature, with populations inhabiting warmer regions tending to be smaller (Shirihai & Jarrett, 2006). Group* *size is commonly between 2 and 15 individuals, although groups of several hundred are regularly encountered offshore. The species commonly associates with other cetacean species including pilot whales, forming mixed groups (Culik, 2011). Bottlenose dolphins tend to feed on shoaling and bottom dwelling species, feeding on a wide variety of fish and squid depending on local prey availability. Differences between inshore and offshore populations are also reflected in their diet (Culik, 2011). Recent assessments estimate a worldwide population of a minimum of 600,000 (Hammond et al., 2008b) and the species is listed as least concern on the IUCN Red List (IUCN, 2011).*

There were two possible sightings of common bottlenose dolphin during the data collection period, based on interpretation of observer's descriptions. The first occurred at 13:35h on 4th June on the Jubilee Field, when a group of between 10 and 12 dolphins were observed porpoising and bow riding the *M.V Seacor Master.* The dolphins were described as muscular in appearance, approaching 3 m in length, with a large snout. One also had a series of notches on the trailing edge of the dorsal fin. The second sighting of possible common bottlenose dolphins occurred at 06:40h on 8th July, when a mixed group of dolphins were sighted on the Jubilee Field. The dolphins at the head of this group were described as possible common bottlenose dolphins, at 2 m or slightly more in length, large, dark and muscular with prominent snouts. Those dolphins following were described as having no snouts, and were potentially a member of the 'blackfish' family. No photographic evidence was provided for either sighting, and the sighting remained as 'dolphin sp' in the analysis.

### 4.7.2 Striped Dolphin (*Stenella coeruleoalba*)

*The striped dolphin is distributed worldwide in tropical and temperate waters; they are a pelagic species ranging predominantly beyond the continental slope in deep waters (Culik, 2011). Striped dolphins have a long beak, well demarcated from the melon and a typical, falcate dorsal fin. The colour pattern consists of a white or pinkish belly, light grey flanks and dark grey back, a variable light grey blaze extends from the flank to under the dorsal fin. A dark stripe runs from the beak, around the eye and then widens, running along the flanks. There is also a flipper to eye stripe and an accessory stripe between the two (Jefferson et al., 1993). Striped dolphins range between 1.8 and 2.7 m in length, and weigh up to 156 kg (Shirihai & Jarrett, 2006). The species feeds on small schooling fish and squids down to 700 m (Culik, 2011). Group size tends to vary in composition and size (Culik, 2011) although large groups of hundreds of individuals can be regularly encountered they are more commonly between 20 and 50 (Shirihai & Jarrett, 2006). Population estimates exist for a number of regions, where the species appears to be abundant (Culik, 2011) and it is listed as least concern on the IUCN Red List (IUCN, 2011).*

There was one possible sighting of striped dolphin during the data collection period, when a group of 10 to 16 dolphins were observed at 16:35h on 2nd June, on the Tweneboa Field. The dolphins were described as having pink bellies, large slightly hooked dorsal fin, a strong nose and bodies striped with varying shades of grey. The group was originally identified as probable Fraser's dolphin, however this is contradicted by the description provided based on the strong nose and large dorsal fin. Fraser's dolphin has a short, stubby beak and generally a small triangular shaped dorsal fin. However no photographic evidence was provided and the sighting remained as 'dolphin species' in the analysis.

# 5. DISCUSSION

## 5.1 Marine Mammal and Turtle Detection

There are a number of factors that can affect the detection and identification of marine mammals and turtles at sea, including the training of observers and environmental conditions.

Observer's experience can affect the ability to detect marine animals (Evans & Hammond, 2004), with more experienced observers more likely to detect animals, particularly those with inconspicuous surfacing behaviour (Barlow *et al*., 2006). Observer experience will also influence the ability to correctly identify the species sighted, particularly more inconspicuous, cryptic or similar looking species. The formal training of nine security and environmental advisor staff in 2010, along with the introduction of a sightings form with the daily environmental report, has greatly enhanced the quality of data collected compared during 2010. The provision of detailed descriptions and photographs from untrained personnel also allowed a greater level of verification of species by experienced marine biologists. From the data collected in 2010, only 20% of sightings were identified to species level, including probable sightings (GEL, 2011). In 2011, 39% of sightings were identified to species level (including probable sightings).

An important factor affecting the detection of marine animals is weather, with increasing sea state, wind force, glare and decreasing visibility reducing the detection probability of marine animals (Forney, 2000), particularly those with inconspicuous surfacing behaviour such as beaked whales (Barlow *et al.,* 2006). The collection of daily environmental data from vessels provides an overview of the environmental conditions on the Tweneboa and Jubilee Fields during 2011, although establishing the influence of these on the sightings of marine animals would require further analysis and dedicated survey effort. However the results from these daily reports indicate that weather conditions were predominantly good for observing marine animals, with excellent visibility (>10 km) and mean wave height predominantly between 1 and 1.5 m. Wind direction was predominantly from the south west, with the highest average wind speeds occurring during June. Unsurprisingly average wave height was also highest during June. The number of days with squalls in the previous 24 hours was greatest between April and May. These periods of increased wind strengths, wave heights and squalls correlate with the expected seasonal weather patterns in the region, influenced by the migration of the Inter-Tropical Convergence Zone (ITCZ) where two air masses meet. The northward migration of the ITCZ results in warm, humid maritime air reaching further over the region between March and August (Irvine *et al*., 2009). Such periods of greater average wind speed and wave height, plus periods of squalls, could have affected the detection of marine animals.

## 5.2 Marine Mammal and Turtle Observation

There were a total of 99 marine animal sightings during 2011, 39% of which were identified to species level, comprising 15 species. In addition, two further species were identified as possible, based on interpretation of descriptions by experienced marine biologists. From the number and diversity of sightings gathered during this incidental data collection period it is reasonable to conclude that the area is inhabited by a diverse range of marine mammal and turtle fauna, as well as other large marine megafauna.

Sightings of dolphins occurred throughout the data collection period, between 8th March and 31st December 2011, whilst sightings of whales occurred predominantly between August and November. Despite the limitations of no effort data and low number of sightings, this suggests a seasonal appearance of whales in the area. The majority of whale sightings (60%) were of humpback whales, which are known to occur seasonally in the region between August and November (Van Waerebeek *et al*., 2009).

In total ten species of cetacean were confirmed during 2011, and similar to 2010, the most commonly identified species was the short-finned pilot whale. Eight of these ten species have previously been recorded in Ghanaian waters, although only five of these have been reported as sightings at sea (Van Waerebeek *et al*., 2009; Weir, 2010b). Confirmed sightings of Fraser's, Atlantic spotted, common dolphin and melon-headed whale could represent the first at-sea sightings in Ghanaian waters for these species. Fraser's dolphin has previously been recorded in Ghanaian waters as bycatch from fishing vessels (Weir *et al*., 2008), with an unverified at sea sighting on the Jubilee Field in 2010 (GEL, 2011) and confirmed at sea sightings recorded in the wider Gulf of Guinea region, off the coast of Nigeria and Angola (Weir *et al*., 2008). The melon-headed whale was previously only known in the Gulf of Guinea from bycatch records in Ghana, with at sea sightings reported in adjacent areas such as Angola (Van Waerebeek *et al*., 2009). Although sighted in adjacent coastal waters, records of Atlantic spotted dolphin in Ghanaian waters are based on captures (Van Waerebeek *et al*., 2009; Weir, 2010b). While Van Waerebeek *et al*., (2009) reports only long-beaked common dolphins from capture data, the taxonomic status of the species remains unresolved and both species are reported within the wider Gulf of Guinea region (Weir, 2010b). The confirmed sightings of these species in Ghanaian waters during this period of data collection provide valuable information on the distribution of this species in West African waters.

Of the possible species sighted, based on descriptions, the most interesting observation is of a group of possible striped dolphin. This species has currently not been recorded in Ghanian waters, although Wilson *et al*., (1987) reports a record from La'Côte d'Ivoire but no verifiable material is identifiable for this report. The species is however relatively common in deep waters off of Angola (Weir, 2007) and could be present in the Gulf of Guinea beyond the continental shelf. However it must also be remembered that due to the lack of photographic evidence this sighting remains unverified and should be treated with caution.

As in 2010 (GEL, 2011) humpback whales and calves were again recorded in the survey area during 2011. The Gulf of Guinea is known to be an established breeding and wintering ground (June-November) for the B1 breeding stock of humpback whales (Collins *et al*., 2009), although the precise geographic area and habitats utilized by the stock remains undefined and uncertain. Whilst the majority of available data in the northern part of the Gulf comes from research conducted off of Gabon (Rosenbaum & Collins, 2006) there have been reports of whales, including calves, westwards towards and including Ghana (Van Waerebeek *et al*., 2009). However little is known about the ecology and habitat use of humpback whales in the waters of Ghana or the relationship with other subpopulations of humpback whales further south. The data from the current sightings project provides further information on the importance of the waters off of Ghana as wintering habitat and potential breeding habitat for this population.

There were a total of 15 sightings of marine turtles during the survey, five of which were identified to species level comprising three species, green turtle, leatherback turtle and olive ridley turtle. All three of these species are known to nest along the Ghana coast and, along with the loggerhead and hawksbill turtle, they have been recorded in coastal waters (Armah *et al.,* 1997). The sightings of olive ridley turtles include one individual that was found drifting entangled in discarded fishing net. The animal was brought onboard the *M.V. Seacor Master* and the netting removed, before the turtle was released. Bycatch of turtles in fishing nets has been identified as a major contributing factor to the decline of population's worldwide (Abreu-Grobois & Plotkin, 2008). The issue of discarded or abandoned fishing gear and its impact on marine fauna is also a growing concern worldwide (Macfadyen *et al*., 2009).

There are several environmental factors that affect the distribution of marine animals, predominantly through the influence on prey availability (Friedlaender *et al*., 2006). The most important factor in this area appears to be upwellings (Irvine *et al*., 2009). Seasonal cold water upwellings and associated increases in primary productivity are important for zooplankton, fish and subsequently marine mammals and turtles (Waife, 2010). It is expected that, as with other coastal upwelling ecosystems, the distribution and abundance of marine animals would be influenced by these upwellings (Benson *et al*., 2002).

Along with such frontal zones, bathymetric features are also important factors influencing foraging habitat use by cetaceans (Keiper *et al*., 2005). There are three physical characteristics of the area which favour the presence of a diverse array of cetacean species. The relatively high water depths of between 1000 m and 1700 m in the area is beneficial to deep diving species and those feeding on mesopelagic fish species, while the steep slopes of canyons and the shelf would attract species that forage on continental slope areas. For this reason it is expected that deep diving species such as sperm whale and beaked whales could be encountered in the area. In addition to this the close proximity to the coastline could indicate the presence of coastal populations. Although the bathymetric and topographic information displayed in this report provides an excellent visualisation of the distribution of marine animals in relation to such features, it is not possible to speculate on their influence without systematic data collection and analysis.

The occurrence and distribution of marine animals is not only influenced by such environmental and physical oceanographic characteristics influencing prey availability. Many species exhibit seasonal patterns in occurrence related to breeding parameters. The presence of leatherback, green and olive ridley turtles in the area is likely to be strongly influenced by the presence of nesting beaches on nearby coastlines (Armah *et al*., 1997). Humpback whale presence is also likely to be related to breeding and overwintering rather than foraging habitat. Humpback whales are known to migrate from high latitude feeding grounds to breed in warmer waters during winter, rarely feeding whist in such low latitude areas (Fleming & Jackson, 2011).

In order to understand fully the occurrence and distribution of marine animals within the area, a full year, dedicated and standardised survey and data collection would be required.

### 5.3 Recommendations

The number of sightings and species (probable and confirmed) identified during the data collection period presented here significantly adds to the information on cetacean diversity in the area. In light of this it is highly recommended that these results are formally published in the scientific, peer-reviewed literature.

However, the results do not reveal much more than species presence, while information on their abundance and distribution as well conclusions on the habitat importance (feeding, breeding, resting) is still lacking.

The current method of incidental data collection by TGL vessel crew has continued to provide excellent background information on cetacean and turtle presence in the area, developing and enhancing the information gained in 2010. However, questions remain and new questions have been asked particularly associated with sightings of species previously not recorded as at sea sightings in Ghana, such as Fraser's dolphin. Such questions could be answered with dedicated surveys in the area conducted by experienced observers.

It is highly recommended to carefully plan a year round survey with survey lines designed to assure equal coverage and using dedicated, experienced observers that would allow further abundance and distribution analysis. Such detailed, planned and standardised surveys would provide an insight into the differences in species presence and distribution due to seasonal changes in the marine environment. In light of the results of the current data collection, in 2010 and 2011, in confirming the presence a number of species with at sea sightings such surveys would provide an invaluable contribution to the knowledge of West African populations. Given the 'vulnerable', 'endangered' and 'data deficient' IUCN Red List status of many species potentially encountered in the area, such contributions would be important to the global knowledge of species. In the absence of a year round survey and based on the monthly sightings recorded, it is recommended that a dedicated survey during October or November would cover a diverse range of species, encompassing all three main groups of interest.

Additionally, further training of observers and the provision of feedback to current observers is a paramount in order to improve data collection and minimise number of unidentified or probable species, and to allow higher level of certainty of species identification. Continued use of cameras and sighting forms should be considered compulsory, as well as collection of behavioural data in order to evaluate habitat utilisation and importance (resting, breeding, migrating or foraging). In light of the number of marine turtles being found caught in fishing gear and brought onboard for release it is also recommended that some training should be provided to vessel personnel regarding guidance on handling marine turtles. Mishandling of marine turtles can result in injury or in some instances death, equally important is the safety of personnel attempting to release turtles. Guidelines and protocols provide guidance on safe handling and techniques for removing gear with minimal injury to turtles and personnel (Epperly *et al*., 2004: Ketos Ecology, 2009).

It is also highly recommended that data is collated and inputted into a database on a monthly basis, in order to reduce the loss of data and highlight any discrepancies at an early stage.

In summary, improvements in the quality of data collected throughout 2011 has enhanced the opportunity to collate a species check-list for Ghanaian waters and to fulfil the knowledge gap relating to under-researched cetacean and marine turtle populations in the area. However further work on data collection and training of observers, along with a dedicated survey is needed in order to draw significant and important conclusions on Ghanaian marine fauna.

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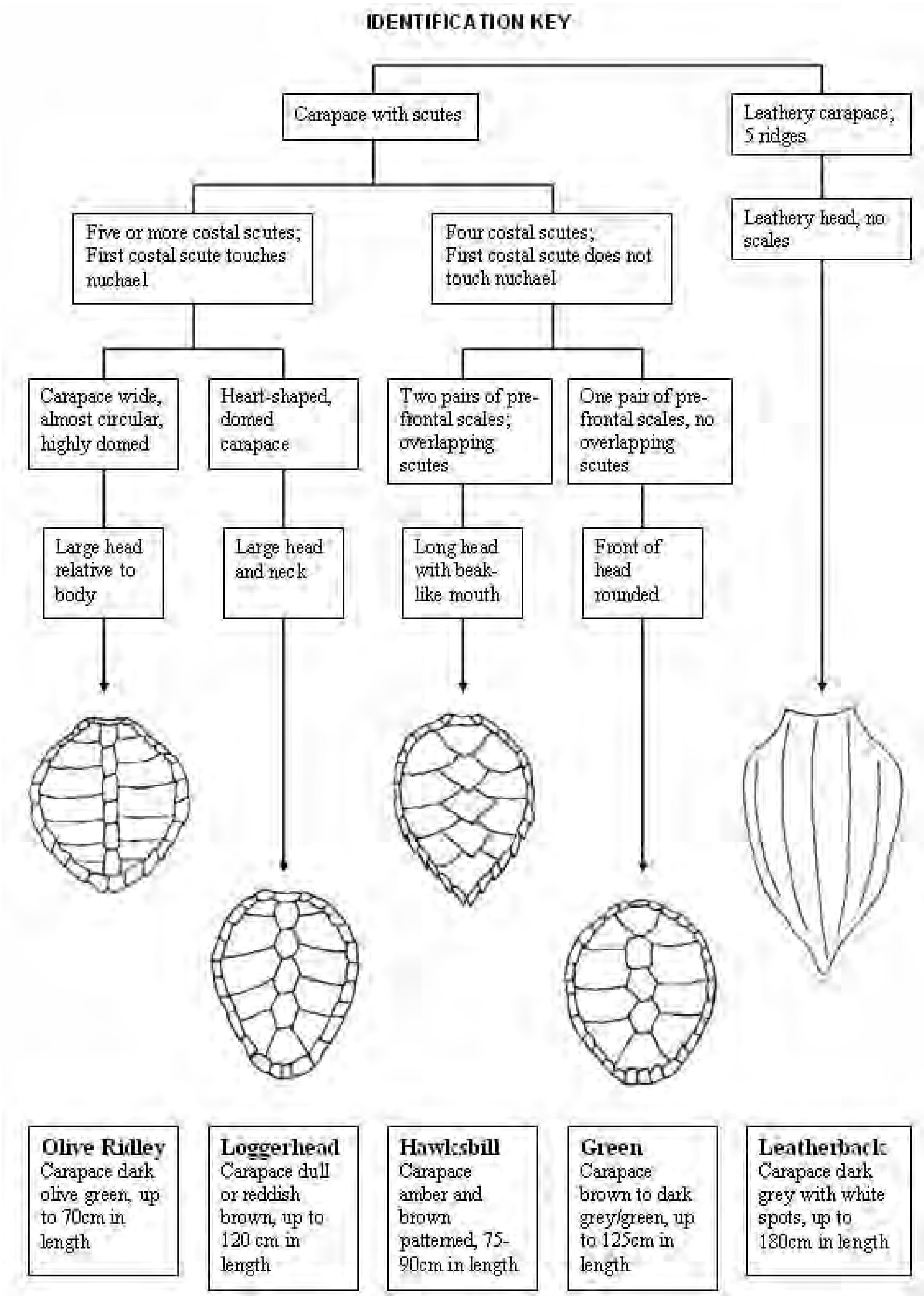
# 7. APPENDICES

## Appendix A: Turtle Identification Key



## Appendix B: Sighting Form and Daily Environmental Report Form

### SIGHTINGS FORM

| | | | |
|---|---|---|---|
| Platform Type<br>☐ FPSO<br>☐ Vessel<br>☐ Helicopter<br>☐ Rig | Platform name | Sighting number (start at 1 for first sighting of survey) | Water depth (metres) |
| Date | Number of observers/ Name(s) | Time at start of encounter (24hr clock) | Time at end of encounter (24hr clock) |
| How did the sighting occur<br>☐ while you were keeping a continuous watch for marine mammals<br>☐ spotted incidentally by you or someone else<br>☐ Eye ☐ Binoculars ☐ Range finder | | Position (latitude and longitude) | |
| Group<br>☐ Turtle ☐ Definite<br>☐ Whale ☐ Probable<br>☐ Dolphin ☐ Possible<br>☐ Manatee<br>Species<br>☐ Definite<br>☐ Probable<br>..................................... ☐ Possible | | Total number<br>Number of adults<br>Number of calves | |
| Description (include features such as overall size; shape of head; colour and pattern; size, shape and position of dorsal fin; height, direction and shape of blow)<br>Photo Taken<br>Yes ☐ No ☐ | | | |
| Marine Mammal Behaviour<br>☐ Surfacing<br>☐ Porpoising<br>☐ Breaching<br>☐ Spy hopping<br>☐ Logging<br>☐ Fluking<br>☐ Tail slapping<br>☐ Other ............................................ | | Turtle Behaviour<br>☐ Basking<br>☐ Swiming<br>☐ Mating<br>☐ Surface breaths<br>☐ Diving<br>☐ Other.................................................. | |
| Direction of travel (relative to ship)<br>☐ towards ship<br>☐ away from ship<br>☐ parallel to ship in same direction as ship<br>☐ travelling in opposite direction to ship<br>☐ crossing ahead of ship<br>☐ variable<br>☐ milling<br>☐ other | | Direction of travel (compass points)<br>☐ N ☐ S<br>☐ NE ☐ SW<br>☐ E ☐ W<br>☐ SE ☐ NW<br>☐ variable | |
| Range when first seen (metres) | | | |
| Closest distance of animals from source (metres) | | Time (24hr clock) | |
| Drilling operational when animals first detected?<br>☐ Yes- full power<br>☐ Yes- reduced power<br>☐ No | Drilling operational when animals last detected?<br>☐ Yes- full power<br>☐ Yes- reduced power<br>☐ No | Platform Activity<br>☐ Transit<br>☐ Offloading<br>☐ Landing<br>☐ Drilling<br>☐ Standby | |

# EHS Vessel Daily Report – Environmental

**24hrs to 06:00 on: from EHS vessel**

**On station at:**

## Metocean data

| | | | |
|---|---|---|---|
| Wind direction (from) | | Wind speed (knots) | |
| Current direction (to) | | Current speed (knots) | |
| Wave height (m) | | Wave direction (to) | |
| Rain in previous 24 hours | | Cloud cover (OKTAS) | |
| Visibility (km) | | Squalls in past 24hrs? | |

## Marine Mammals

| Type | Number of animals observed | MMO report # | Dead animals observed |
|---|---|---|---|
| Turtle | | | |
| | | | |
| | | | |
| Whales | | | |
| | | | |
| | | | |
| Dolphins/Porpoise | | | |
| | | | |
| | | | |

## Marine Avifauna

| Location | Number of animals observed | Time observed | Dead animals observed | Species (if known) | Behaviour |
|---|---|---|---|---|---|
| Observed congregating on or near EHS vessel | | | | | |
| Observed congregating on or near rigs/FPSO | | | | | |

## Oil Spill Response

| | | |
|---|---|---|
| Did the vessel undertake Prop washing in past 24 hours? | | YES / NO |
| If YES, around which asset? | | |
| Lat/Long of asset? | N ° ' " | E ° ' " |
| If known, what activity necessitated prop washing? | | |
| Was an oil slick observed? | | YES / NO |
| If YES, submit a POLREP | | |
| **TRAINING AND DRILLS** | | |
| Weekly check of oil spill kit undertaken | YES / NO<br>This will be done once the crew are trained on the equipment later this week by the OSR rep | |
| Weekly training in boom deployment | YES / NO | |
| If YES, describe training and list participants | | |
| Weekly training in dispersant spraying | YES / NO | |
| If YES, describe training and list participants | | |

## Other

## Appendix C: Sighting Record

## Appendix C – Legend to Sightings Form

| Column | Symbol | Meaning |
|---|---|---|
| **Certainty** | Def | Definite |
| | Prob | Probable |
| | Pos | Possible |
| **Direction of Travel Relative to Vessel** | P | Parallel to the vessel in the same direction |
| | C | Crossing ahead of the vessel |
| | T | Towards the vessel |
| | A | Away from the vessel |
| | O | Opposite direction to the vessel |
| | V | Variable direction |
| | X | Other |
| **Location** | J | Jubilee Field |
| | T | Tweneboa Field |
| | WC3P | Wider West Cape Three Points licence area |
| | 3 km of FPSO | Within 3 km of the FPSO |
| | DWT | Wider Deep Water Tano licence area |
| | O | Outside licence areas |

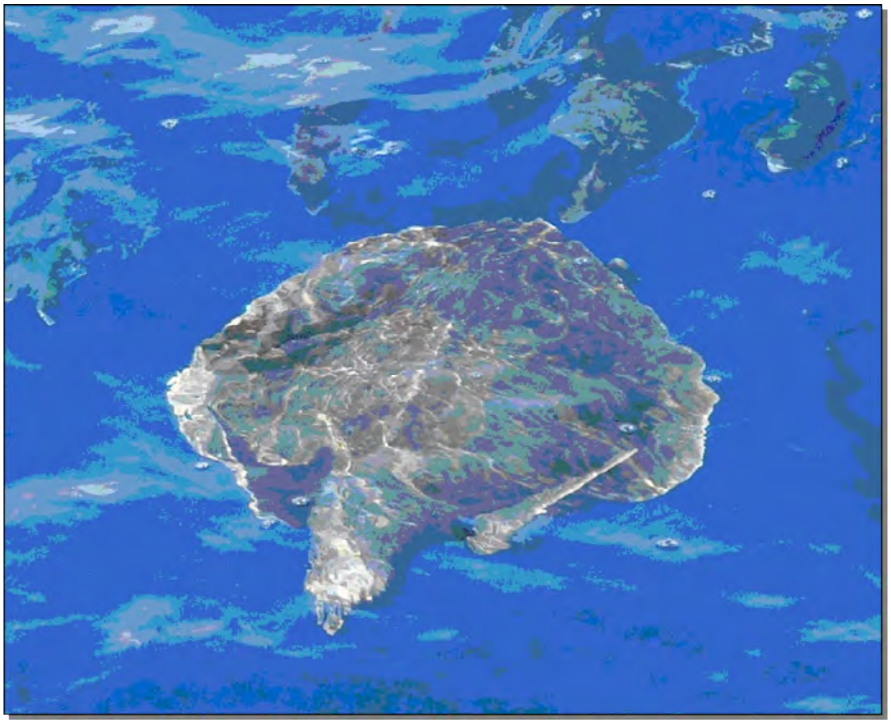
# Appendix D: Sightings Photographs

## D1. Short-finned Pilot Whale – 14th April 2011

### Photograph 1

## D2. Olive Ridley Turtle – 6th May 2011

**Photograph 1**



**Photograph 2**

## D3. Clymene Dolphin – 7th May 2011

### Photograph 1

### Photograph 2

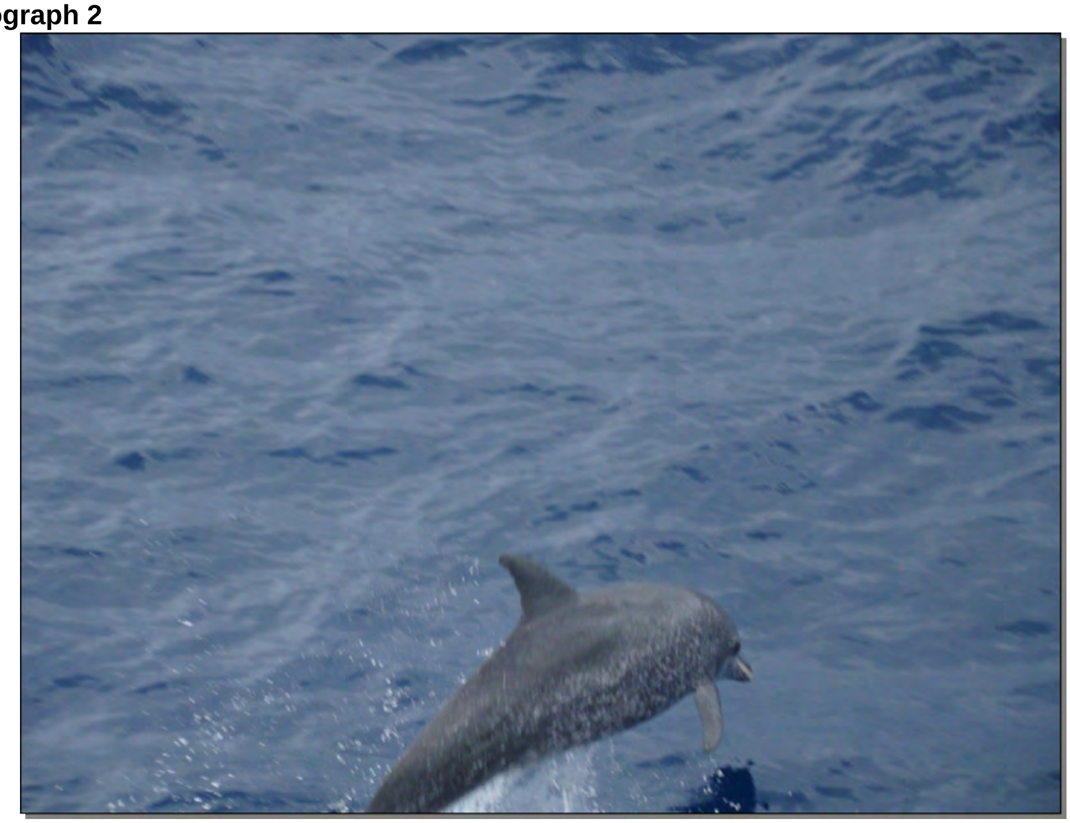
## D4. Short-finned Pilot Whale – 29th May 2011

### Photograph 1

## D5. Atlantic Spotted Dolphin – 5th June 2011

### Photograph 1

### Photograph 2



**Photograph 3**

## D6. Pantropical Spotted Dolphin – 15th September 2011

### Photograph 1

## D7. Melon-headed Whale – 19th October 2011

### Photograph 1

## D8. Humpback Whale – 10th November 2011

### Photograph 1

### Photograph 2

## D9. Rough-toothed Dolphin – 17th November 2011

### Photograph 1

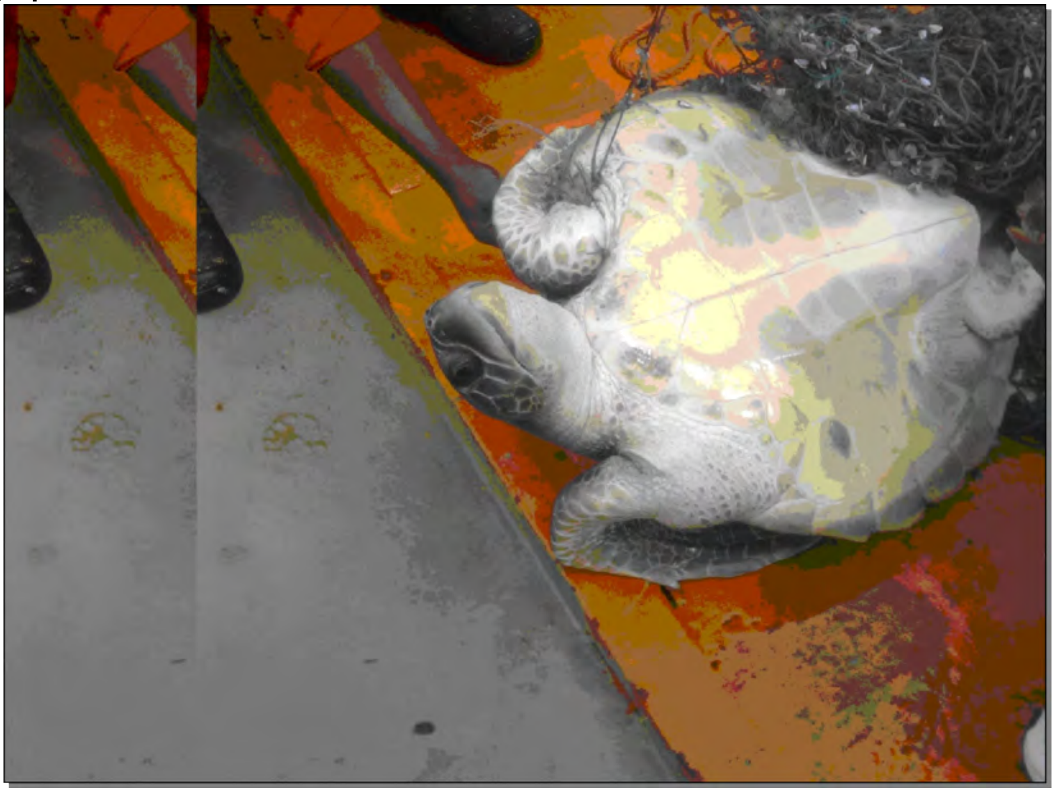
### Photograph 2

**Photograph 3**

**Photograph 4**

## D10. Olive Ridley Turtle – 27th December 2011

### Photograph 1



### Photograph 2

## D11. Unconfirmed Dolphin Sp – 7th September 2011

### Photograph 1

Annex D

# RPS-ASA Modelling Reports

Annex D1

# Oil Spill, Produced Water, Cooling Water, Brine Discharge, and Drilling Discharge Modelling, TEN Development, Offshore Ghana

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# Final Report

# Oil Spill, Produced Water, Cooling Water, Brine Discharge, and Drilling Discharge Modelling, TEN Development, Offshore Ghana

**AUTHOR(S):** Nicholas Cohn, Tatsu Isaji, Nicole Mulanaphy, Emily Chaite, Deb Crowley, Danielle Reich

**Project Manager:** Eric Comerma

**PROJECT NUMBER:**

ASA 11-053 and P12-347

**VERSION:** Final

**DATE:** 26 Sep. 2013

**CLIENT:**

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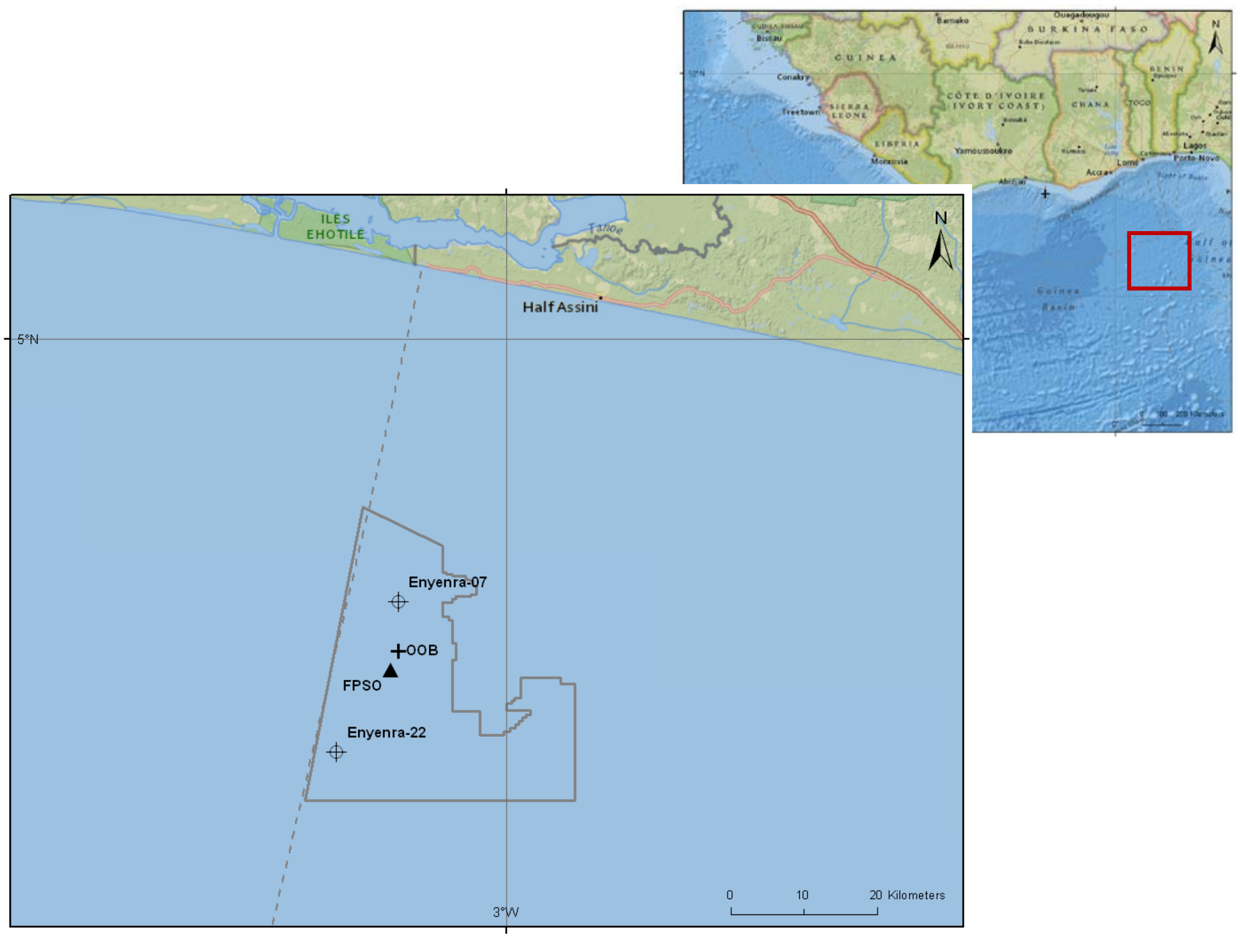

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## Title:

"Oil Spill, Produced Water, Cooling Water, Brine Discharge, and Drilling Discharge Modelling, TEN Development, Offshore Ghana"

## Location & Operator:

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## Disclaimer:

# Executive Summary

Environmental Resources Management (ERM) contracted Applied Science Associates, Inc. (dba RPS ASA) to simulate the transport and fate of different operational discharges (produced water, cooling water, muds and cuttings, oil discharges, and brine) and potential oil spills within the TEN development, offshore Ghana. This report presents the results of both an earlier study (ASA 11-053), finalized in July 2012, and a later study (ASA P12-347), drafted in January 2013. The 2013 simulations (accidental spills and planned discharges) were requested to be simulated for an updated location of the Floating Production Storage and Offloading vessel (FPSO). Some of these 2013 FPSO simulations are new, and some have replaced the ones from the 2012 report.

***Environmental Conditions (Section 2)***

The location of the Deep Water Tano (DWT) block is in the offshore waters of Ghana, near the Ivory Coast-Ghana maritime border. In this region, there is a steep continental shelf and as such there are large variations in the bathymetry between the various sites studied. Within the DWT block, four different representative sites were evaluated: Enyenra-07 (EN-7), Enyenra-22 (EN-22), FPSO and an Oil Offloading Buoy (OOB). Oil spill, produced water, cooling water, and brine discharges were simulated from the FPSO. The OOB site was assessed as a potential surface oil spill site, and EN-7 and EN-22 were assessed for subsurface oil blowouts, drilling, mud discharges and produced water discharges. The deepest studied site, EN-22, is situated in 1,851 m of water, while the shallowest and most nearshore site, EN-7, is in 992 m of water, despite the fact that the two locations are only about 20 km apart.

In this area the currents can vary in magnitude and direction spatially, temporally, and with depth. The surface currents tend to be oriented consistently toward the east throughout the year, predominantly influenced by the Guinea Current, with some reversal of flow particularly during the spring and summer. To capture the complex circulation in the area, outputs from the HYCOM global circulation model were used as inputs to the model simulations to define the temporally and spatially varying currents that influence pollutant (i.e. oil) transport. This dataset provides a time and space variable depiction of surface and subsurface currents, a critical input for the modelling study. Based on an analysis of the HYCOM dataset, subsurface current velocities near the well sites in this study tend to weaken drastically with depth and current directionality tends to be more variable in deeper waters than at the water surface; this is a reflection of the complex offshore counter-currents present in the region.

Local winds offshore Ghana are more consistent than the currents; however, wind patterns are temporally and spatially variable across the entire area of study (equatorial West Africa). Output from the NOGAPS global atmospheric model were used to assess the wind forcings in this area for the oil spill modelling portion of this study. Based on the NOGAPS dataset, the primary direction of winds varies slightly from month to month, with winds being more persistently from the southwest in the (boreal) summer and exhibiting slightly more variable directionality in the winter months. At the EN-22 well site, based on the NOGAPS dataset, winds are expected to be stronger in July (approximately 15 knots on average) and weaker in December (less than 8 knots on average). Winds are typically stronger offshore than in coastal waters. On the larger scale, winds outside of Ghana tend to follow a similar trend – with most coastal areas within the Gulf of Guinea exhibiting a southwesterly trend. However, winds further offshore (below 2° N) tend to be more consistently from the south than from the southwest, while winds toward the west (particularly in Liberia) tend to be more varied directionally and are more frequently from the south or southeast.

***Oil Spill Simulations (Sections 3 & 4)***

Six potential oil spill events were simulated using SIMAP, including a marine gas oil surface release from EN-7, subsurface blowouts of crude oil from EN-7 and EN-22, a surface crude oil release from the OOB, and two surface crude oil releases from the FPSO. EN-22 is no longer part of the TEN development plan, however, its location is used as indicative for wells towards the southern extent of the TEN fields in water depths greater than 1,800 m. Similarly, EN-7 is used as indicative of wells situated towards the northern extent of the TEN fields in water depths of approximately 1,000 m. The OOB is no longer part of the TEN development plan; instead the FPSO will offload crude oil to export tankers via a transfer hose. The modelled spill volume from the OOB can be used as indicative of that resulting from a transfer hose release. A transfer hose release would occur within close proximity to the FPSO, therefore the OOB spill scenario can be taken as representative of a release at a nominal location within the TEN fields.

A stochastic oil spill analysis was completed for each of the modelled oil spill scenarios, which predicted the footprint and associated probability of sea surface and shoreline oiling in response to the environmental conditions in the region. Subsequent to the stochastic analysis, a deterministic trajectory and fates model was used to analyse a representative (worst) case in more detail identified from the stochastic analyses. All the scenarios were simulated to occur at any given time during the year; i.e. no distinction in seasonality has been made.

***Surface Release Scenarios***

The surface spill scenarios included one marine gas oil (MGO) release from EN-7, a near-instantaneous spill of crude oil at the water surface from the OOB, and both a near-instantaneous spill with isolation and an hour-long spill without isolation of crude oil from the FPSO. Spill volumes ranged from 900 to 15,479 bbl. For these four spill events, the pollutant could potentially travel in many different directions, but predominantly moves towards the northeast (NE) sector following prevailing winds and easterly currents. The oil spill model predicted that oil could potentially reach the coastal regions of Ghana, Ivory Coast, Togo, and Benin with different probabilities of occurrence. Each of the spill scenarios starts at a different site, involves different quantities of oil, and involved different products (marine gas oil or crude oil), and therefore differences are observed in the directionality and extent of the stochastic footprint, as well as in the shoreline oiling statistics. However, due to the dominant southwesterly winds and easterly currents in the area, the transport of oil spilled is typically to the northeast from the spill sites. From these spills, oil could reach the coast of Ghana in 28 or fewer hours. Chances that oil would reach the coast ranged from 79-85% across all spills. On average, at the end of the simulations, it is predicted that approximately 12%, 60%, 61%, and 63% of the initial spill volume remains on the shoreline for the EN-7 diesel spill, FPSO near-instantaneous crude release with isolation, FPSO hour-long release without isolation, and OOB crude release, respectively.

The worst case spill events, chosen as one of the individual simulations which resulted in the maximum volume of oil to wash ashore, had a northward trajectory for all of the surface spill scenarios. The scenario pertaining to the MGO spill found that the oil evaporates very quickly and that over 70% of the oil is lost to the environment by the end of the simulation. In the case of the three crude spills, the relative amount of oil to remain along the coastline is much higher because there is slightly less entrainment of the oil and a much smaller volume of oil that evaporates.

***Blowout Scenarios***

For the two 600,000 bbl - 60 day continuous blowout scenarios that were modelled, a near-field model (OILMAP/Deep) was used to characterize location and size of the blowout plume - a mixture of oil, gas and entrained water - and the oil droplet sizes resulting from the turbulence near the well head. The properties of the two blowout events were the same except for the location and as such the near-field results were quite similar. The model predicts that the size of the plume is larger for the blowout at EN-22 due to the deeper water depth (higher pressure) relative to EN-7. The size of the droplets resulting from the blowouts is expected to be quite large (up to 10,000 microns) due to the low turbulence expected at the well head (mostly due to large pipe size). The average oil droplet from EN-7 would be expected to rise to the water surface in about 1.9 hours, while it would take 3.6 hours to reach the surface from EN-22 due to the deeper water depth.

The stochastic far-field results of the two blowout scenarios indicate that the predominant transport of the trajectories is towards the east/northeast sector. Both of the blowout scenarios (from EN-7 and EN-22) resulted in 100% of individual cases reaching some segment of the shoreline due to the proximity of the spill sites to the shoreline, the nature of the winds and currents in this region, and the long duration and volume of the spills.

For the potential blowout at EN-7, oil may reach the coast in less than 1.5 days, although on average it would take about 5 days to reach some part of the West African coastline. For this scenario, the oil spill model predicts that some particular coastal segments in western Ghana have a 99% chance of being oiled if no response measures are taken. In the EN-22 spills scenario, located further offshore, the easterly currents tend to transport the oil further to the east before making landfall. Because of this, no individual coastline segment exceeds a 90% chance of being oiled from a blowout at EN-22.

When considering even the smaller probability contours (1%), both spills oil could reach as far away as Liberia and Cameroon. Up to about 225,000 bbl of oil (about 38%) could be washed ashore from either of the blowout scenarios, with slightly more oil expected to wash ashore on average from a spill at the EN-22 location. Because EN-22 is located further offshore and in deeper water it takes on average 3 days longer for spilled oil to reach the coast relative to EN-7.

The worst case deterministic simulations for the blowouts were selected from those cases within the stochastic simulation that generate the largest amount of shoreline oiling. Due to the large amount of oil spilled and the duration, a single spill event could result in the oiling of a very large area. The spill from EN-7 resulted in oiling of surface waters in all countries between Liberia and Cameroon. About 223,500 bbl of oil was expected to wash ashore during the 75 day simulation, about half of which was in Ivory Coast. Because of the long duration of the spill, evaporation and decay play a major role in removing oil from the water surface with, about 146,000 bbl evaporated and 162,500 bbl decayed in this time. About 66,500 bbl of oil remained on the water surface at this time, with the remaining oil expected to be entrained in the water column. Similarly, the spill from EN-22 was expected to reach all countries between Ivory Coast and Cameroon, with over 138,000 bbl of oil sticking to the coastline in Ghana at the end of 75 days. Overall, about 222,000 bbl of oil was expected to remain along segments of the west African coast at this time, 67,500 bbl of oil was expected to remain on the water surface, 4,000 bbl was expected to be entrained in the water column, 144,500 bbl was expected to have evaporated, and 162,500 bbl had decayed.

***Drilling Discharge Simulations (Section 5)***

The discharge of drill cuttings and muds from two different well sites, EN-7 and EN-22, was analysed. To capture the variability in the subsurface currents throughout the year, simulations for each site were carried out for two distinctive periods, April and December, for a total of four simulations. In April the currents are more persistently to the east and are stronger in magnitude, whereas in December currents throughout the water column tend to be weaker and more variable in direction.

The resulting bottom deposition footprint from the discharges was analysed for each of the four scenarios. For each discharge event deposition greater than 10 mm was not expected to reach further than 50 m from the well site in any direction. However, deposition up to 0.1 mm could be observed as far away as 1,220 m. The deposition footprint is expected to extend further away from the release site in April than in December for both sites due to the faster and more vertically uniform currents that occur in April.

Because oil based muds (OBM), which adhere to the drill cuttings, are to be used to drill the third and fourth sections of the well, the bottom sediment hydrocarbon footprint was assessed for these discharges. It was assumed that a mass equivalent to 3 % of the discharged cuttings (by weight) was OBM and that these muds remained adhered to the cuttings throughout their descent through the water column without any dissolution. Based on this conservative approach it was predicted that concentrations of 50 ppm or higher could be observed up to 1,080 m away from the discharge, with concentrations at this level observed further away from the release site in April than in December due to the currents. Higher concentrations are normally expected closer to the well site, although the peak hydrocarbon concentrations may not be present right at the well head because OBMs were discharged with the cuttings at the water surface and thus subject to advection and dispersion which may cause the thickest deposition to occur away from the release site.

Additionally, total suspended solids (TSS) concentrations associated from the drilling discharges were assessed for each discharge scenario. Because the flow rate of muds and cuttings being discharged near the water surface (drilling sections #3 and #4) is very low, there is very little excess TSS near the water surface throughout any of the discharges. Instead, most of the excess TSS is observed near the seafloor resulting from the discharges released during the drilling of sections #1 and #2. During the drilling of these sections, the volumes of cuttings and muds are substantial and may result in a sediment plume in close proximity to the discharge pipe. However, it is expected that TSS concentrations associated with this plume will fall below 100 mg/L within 95 m of the well head and below 10 mg/L within 600 m of the discharge point.

***Produced, Cooling Water, and Brine Discharge Simulations (Section 6)***

Near-field discharge modelling of various scenarios of discharges originating from the FPSO into the offshore receiving waters was performed using CORMIX. The scenarios incorporated discharge characteristics (volume flux, temperature, salinity, density and discharge location) and different receiving water characteristics (temperature, density, current conditions [mean & high]). The produced water discharges were assumed to be released from amidships, portside, 3 m below the surface. The cooling water, brine, and combined cooling water & brine discharges were assumed to be released from the stern, portside, 7 m above the surface (overboard). All discharge scenarios simulate a release that originates close to the FPSO, meaning that the vessel draft of the FPSO can act as a physical barrier to the discharge plume. Therefore, all simulations were run by representing the FPSO as a 'river bank' (i.e. reproducing a relatively confined dispersion) and the location of the origin of the discharge in the water was located at the 'river' shoreline. This is a conservative approach as it does not allow the plume to spread into areas where the FPSO would be located.

Four produced water discharge scenarios were simulated using varying discharge flow rates and ambient current conditions. The produced water discharge is less dense than the receiving water and simulated released 3 m below the water surface. The density of the discharge resulted in a positively buoyant plume, which drove the plume towards the water surface, enhancing mixing throughout the ascent. These simulations showed that the produced water discharge pollutant (oil) concentration decreased rapidly with distance from the discharge point, reducing by greater than a factor of 20 within 20 m.

Two cooling water discharge scenarios were simulated with varying ambient current conditions for the same discharge flow characteristics. The discharge flow was hotter than the receiving water and therefore less dense (positively buoyant). The simulations showed that the initial excess temperature of 21.21° C decreased rapidly to an excess temperature of less than 3° C within 10 m of the discharge release location.

Two brine discharge scenarios were simulated with varying ambient current conditions for the same discharge flow characteristics. The discharge flow was assumed to be more saline than the receiving water and therefore more dense (negatively buoyant). The simulations showed that the plume diluted rapidly with increasing horizontal distance from the release. This rapid dilution is due to the enhanced mixing on the vertical descent of the heavy plume. The plume centreline concentrations were diluted over 1,000 times at a distance of 100 m.

Two combined (cooling water & brine) discharge scenarios were simulated using varying ambient current conditions for the same discharge flow conditions. Evaluated individually, the cooling water, due to its increased temperature, was shown to be a relatively large volume, positively buoyant (less dense than receiving water) plume, while the brine discharge, due to its increased salinity, was found to be a relatively small volume, negatively buoyant (more dense than receiving water) plume. In combination, due to the larger volume of the cooling water discharge, the combined discharge has properties similar to the cooling water discharge. The discharge flow was hotter than the receiving water and therefore less dense (positively buoyant). The simulations showed that the initial excess temperature of 21.03° C decreased rapidly to an excess temperature of less than 3° C within 10 m of the discharge release location. These figures show that the discharge dilutes quickly with distance from the release origin. Furthermore, at a distance of 100 m from the release origin, the plume centreline concentration is diluted by a factor of 60 and 90 for high and mean current conditions, respectively.

In all scenarios, the discharged plume mixes within the receiving water. This mixing is primarily driven by the density differences between the discharge and the receiving water, and by ambient currents. The density differential enhances mixing by driving the plume vertically (either upwards or downwards), mixing it within the vertical water column, while the ambient currents transport the plume and promote spreading in the horizontal direction. Both mechanisms of dilution entrain water into the plume, which lowers plume concentrations. Both the mean and high current conditions are sufficient to spread and transport the plume efficiently such that a large build-up of plume waters does not occur at the plume origin.

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# 1. Introduction

Environmental Resources Management (ERM) contracted Applied Science Associates, Inc. (dba RPS-ASA) to perform numerical simulations to address the fate of produced water, cooling water, brine discharges, drilling discharges, and potential oil spills from different locations within the Tweneboa, Enyenra, and Ntomme (TEN) development, offshore Ghana. This report presents the results of both an earlier study (ASA 11-053), finalized in July 2012, and a later study (ASA P12-347), drafted in January 2013. The 2013 simulations (accidental spills and planned discharges) were requested to be simulated for an updated location of the Floating Production Storage and Offloading vessel (FPSO). Some of these 2013 FPSO simulations are new, and some have replaced the ones from the 2012 report.

Six potential oil spill scenarios were simulated with the goal of assessing the impact of oil on nearby surface waters and shorelines from potential marine gas oil (MGO) and crude oil spills. The spill scenarios included one MGO release, two 60 day-long subsurface blowouts of crude oil, and three releases of crude oil at the water surface. Between the six different simulations, there were a total of four spill locations that were addressed as part of this study in order to represent the results from similar spills in the general area of the sites used.

To reproduce the near-field of the two blowout events, ASA's OILMAP/Deep modelling system was used. Both stochastic and deterministic model simulations were performed for each of the six spill scenarios, including both the blowouts and surface release cases, using ASA's SIMAP oil spill modelling system, to analyse the potential far-field surface, shoreline, and water column oiling. The stochastic modelling consists of an ensemble of many individual trajectory simulations of the same oil spill scenario, each run with a different spill start time, thus sampling the variability of meteorological and oceanographic conditions in the study area. The ensemble simulation results are evaluated statistically and provide insight into the probable behaviour of potential oil spills in response to environmental conditions in the study area. The deterministic trajectory and fate simulations provide an estimate of the oil's weathering for a particular individual (representative or worst case) environmental condition. The representative deterministic case was identified from the ensemble of simulations carried out in the stochastic analysis.

Four drilling discharge simulations were also performed, pertaining to two different well sites for two different drilling periods. Drill cuttings, water based muds, and oil based muds were simulated to be discharged into the environment as part of the drilling of wells in the TEN development. ASA's MUDMAP modelling system was used to predict the dispersion of these discharged solids, providing water column concentrations and deposition thicknesses of the resulting deposit.

For the FPSO, a number of simulations were conducted. Two oil spill scenarios were simulated to represent one crude oil release 'with isolation' and one crude oil release with 'no isolation'. The scenario with isolation assumed a total spilled volume of 3,453 bbl with a spill duration of 5 minutes and a total simulation duration of 21 days. The scenario without isolation assumed a total spilled volume of 15,479 bbl with a spill duration of 1 hour and a total simulation duration of 21 days.

Four produced water discharge scenarios were simulated using the CORMIX model (Appendix C) from amidships, portside, 3 m below the water surface. The scenarios were chosen to represent two different flow rates under two different current conditions. The low discharge flow rate used in the simulations was 37,500 bbl/day and the high discharge flow rate was 75,000 bbl/day. The two current speeds used in the simulations were a mean current speed of 0.355 m/s and a high current speed of 0.822 m/s.

Two cooling water discharge scenarios were simulated using the CORMIX model from the stern, portside, 7 m above the water surface. The two scenarios represent an overboard discharge of heated seawater under two current conditions. The excess temperature difference was then tracked by the model. The flow rate for both scenarios was 768,850 bbl/day and the current speeds used were 0.355 m/s and 0.822 m/s.

Two brine discharge scenarios were simulated using the CORMIX model from the stern, portside, 7 m above the water surface. The two scenarios represent an overboard discharge of denser water due to high saline concentrations (64.2 psu). Both scenarios used the same flow rate of 6,000 bbl/day and consisted of discharges at ambient temperature. The first scenario used a current speed of 0.355 m/s and the second scenario used a current speed of 0.822 m/s.

Two additional discharge scenarios were also simulated, combining the discharge of cooling water and brine from the stern, portside, 7 m above the water surface. These scenarios represent a combination of both the marine and topside cooling water discharges and the brine discharges. The CORMIX model tracked both difference in temperature and dilution over distance from the discharge site.

ASA's standard requirements for modelling studies of various spills and discharges include:

- All Modelling Studies
    - Geo-referenced shoreline (definition of the land and water boundaries)
    - A description of the major circulation features of the water body
    - Characterization of the vertical structure of the water column
    - Bathymetry in the area of interest
- Oil Spill Modelling Study
    - Characterization of the winds for the area of interest (preferably a long-term wind time series from an unobstructed coastal or offshore wind station)
    - Description of the spill scenarios to be simulated (e.g. volume and duration of the oil releases)
    - Description of the oil properties
- Drilling Discharge Modelling Study
    - Characterization of the cuttings and muds to be discharged
    - Description of the timing of the discharges
- Operational Discharges Modelling Study (e.g. Produced Water)
    - Characterization of the compounds within the produced water
    - Flow rate of discharge
    - Definition of the discharge conditions (pipe diameter, orientation, location)

Section 2 presents a general description of the study location, the predominant environmental conditions in the area of interest, and the input datasets used in the modelling study. Section 3 describes the modelling approach and results for the surface release oil spill scenarios. Section 4 provides a description of the modelling approach and the near-field and far-field results of the subsurface (blowout) oil spill scenarios. Section 5 provides results for the drilling discharge scenarios. Section 6 provides the results of the produced water modelling.

A more detailed description of the environmental datasets used in this modelling study (winds and currents) is presented in the Appendix A. An overview of ASA's oil spill modelling systems is presented in Appendix B (OILMAP/Deep) and Appendix C (SIMAP). A description of the MUDMAP modelling system is provided in Appendix D, and a description of the CORMIX model can be found in Appendix E.

# 2. Geographic Location and Environmental Analysis

## 2.1. Study Location

The TEN Development is comprised of three fields, Tweneboa, Enyenra, and Ntomme, located within the Deep Water Tano (DWT) block, offshore western Ghana. The expected development in this block includes the drilling of dozens of wells for the purpose of oil and gas exploration and production.

Up to four locations within the development area were assessed as part of this modelling study (Table 1). Various pollutants were modelled to be spilled or discharged from two oil production well sites (Enyenra-7 and Enyenra-22), from the floating production storage and offloading vessel (FPSO), and the oil offloading buoy (OOB). EN-22 and the OOB are no longer a part of the development plan, but have been used to represent similar spills in the surrounding area. The exact final location of the sites as well as their names may change slightly. Figure 1 shows the location of the sites addressed in this modelling study and local geographic points of reference including cities, international political boundaries, and water bodies.

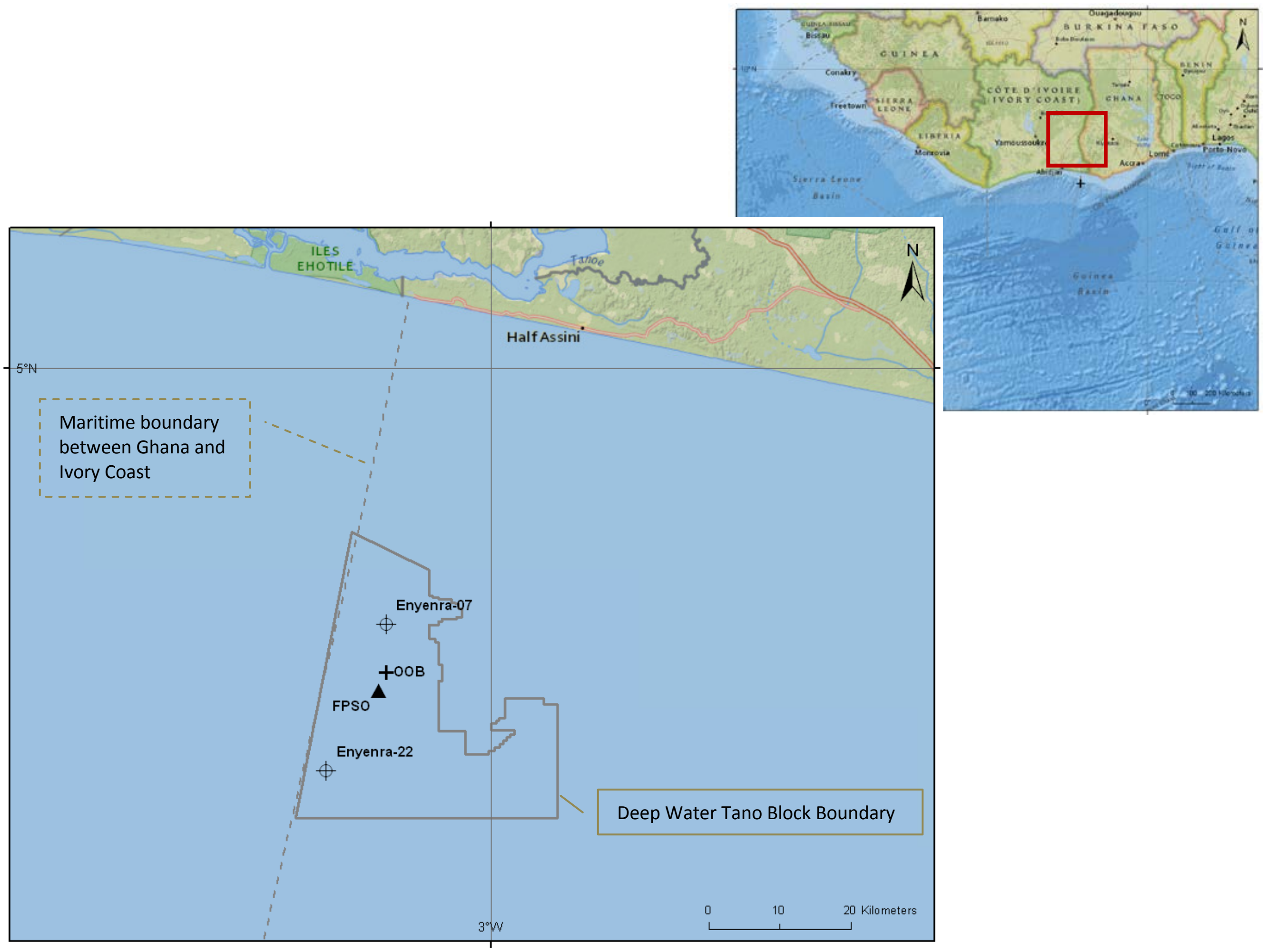



Figure 1. Location of the release sites in TEN development, within the Deep Water Tano Block, offshore Ghana.

Table 1. Coordinates of the release sites, offshore Ghana.

| Discharge / Spill Sites | Latitude | Longitude | Water Depth |
|---|---|---|---|
| Enyenra-7 (EN-7) | 4.676850 N | 3.132480 W | 992 m |
| Oil Offloading Buoy (OOB) | 4.615963 N | 3.132144 W | N/A |
| Floating Production Storage and Offloading Vessel (FPSO) | 4.590833 N | 3.141667 W | N/A |
| Enyenra-22 (EN-22) | 4.491345 N | 3.207922 W | 1,851 m |

## 2.2. Study Area Physical Characterization

One of the inputs required for the modelling study is a physical characterization of the region, including a description of the shoreline geometry, bathymetry and shoreline type.

Coastline geometry definition (i.e. distinction of the land and water boundaries) was obtained from the World Vector Shoreline 1-100,000 dataset (U.S. Government MIL-W-89012) for use in this study. Bathymetry within the study area is an important modelling input, particularly for drilling discharges and three-dimensional oil spill modelling. Offshore Ghana depths increase quickly, with water depths over 1,000 m within 100 km of the coast. Within the DWT block depths vary significantly, with EN-7 located in the northern portion of the development area situated in 992 m water depth, and EN-22 near the south of the oil and gas field situated in 1,851 m water depth. Bathymetry data for the larger study area was available from bathymetric contours provided in the GEBCO Digital Atlas (GEBCO, 2003). Figure 2 presents the bathymetry used for the modelling studies.

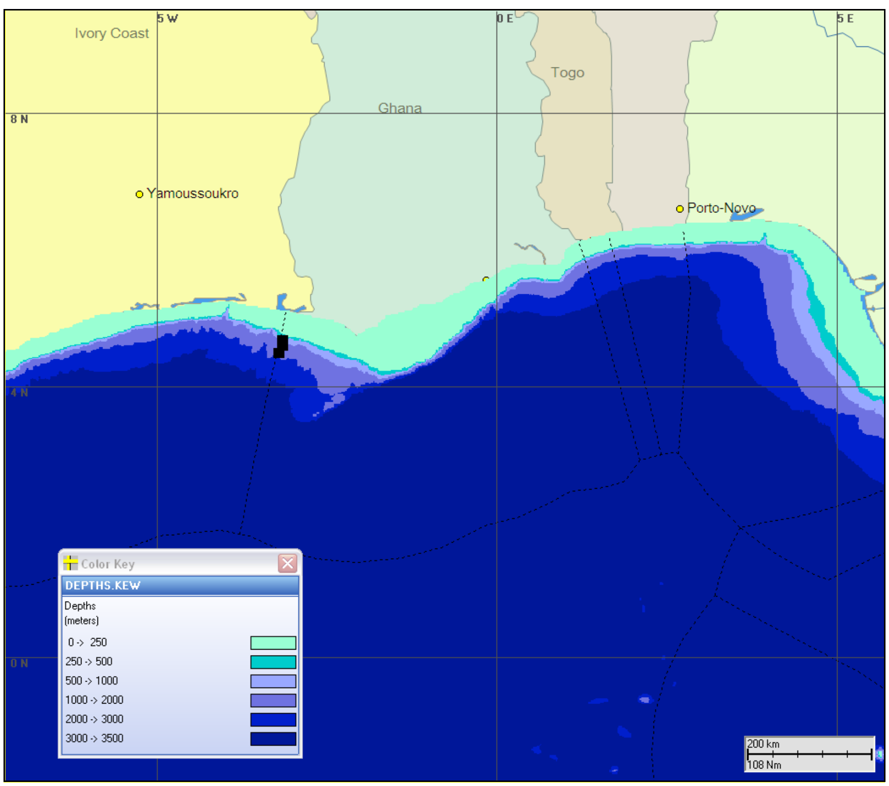



Figure 2. Bathymetry in the area of interest (international maritime boundaries shown in dashed lines).

ASA's oil spill models include an oil-shoreline interaction algorithm which is used to estimate the amount of oil that will be retained onshore when oil reaches the coast based on the definition of shoreline type. Shoreline type is an important parameter in understanding the potential oiling in an area. For example, flat sandy beaches typically retain much more oil than steep rocky coasts, and furthermore oil that cannot be retained on the shore is susceptible to being further transported offshore or along the coast, thereby potentially affecting other regions. Table 2 outlines the holding capacities for some generic beach types.

Table 2. Generic coastline holding capacities.

| **Type of Shore** | **Width (m)** | **Oil Holding Capacity (mm)** | | |
|---|---|---|---|---|
| | | Oil Viscosity < 30 cSt | Oil Viscosity 30 – 2,000 cSt | Oil Viscosity > 2,000 cSt |
| Sandy Beach | 10 | 4 | 17 | 25 |
| Rock Ledge | 1 | 1 | 2 | 2 |
| Exposed Rocky Shore | 3 | 1 | 2 | 2 |

Based on the limited available information relative to shoreline types, a simplified analysis was performed to characterize the main type of shorelines in the study area. While there are other types of small-scale shoreline features throughout West Africa, the majority of coastline type in the region is sandy beaches. Therefore, for the purpose of this study, the entire coast within the model domain was assigned a shoreline type of sandy beach.

## 2.3. Wind Analysis

Wind is one of the primary forcing factors used in surface pollutant modelling (e.g. oil spill simulations) as it is a dominant force in circulation and surface pollutant transport. From the standpoint of oil spill trajectory modelling, the events that result in the greatest extent of surface oil movement are characterized by persistent winds from the same general direction, whereas highly variable winds promote the further spreading and dispersion of the spill slick into multiple directions and patches.

ASA's oil spill models incorporate a transport term due to the wind stress applied on the oil slick floating on the water surface. This wind drift factor has been observed to range typically between 2.0 and 4.5% of the wind speed. For this study a value of 3.5% of the wind speed was used for the wind drift factor.

The stochastic analysis is a statistical analysis of the results from many different individual simulations run of the same spill event (characteristics), each run with a different spill start time selected at random from a relatively long-term window. The random start time allows for the same type of spill to be analysed under varying conditions, with longer windows of time required to best capture the range of environmental variability. In order to reproduce the natural variability of winds, the model requires wind data input which can vary both spatially (multiple points) and temporally (changing with time). The favoured approach is to use actual historical observed winds and perform the simulations over a time period coincident with the observations as this allows reproduction of the natural variability of the wind direction and speed. Optimally, the minimum window of time for stochastic simulations is at least five years and as such a minimum of five years of observed winds is desired for simulations. Since site-specific long-term historical observations are often not available, the alternative is to use a long-term record of wind data from the output of a numerical atmospheric model.

### *Wind Dataset - NOGAPS*

For this study, in the absence of an extended spatial coverage of long-term observed winds, wind data was obtained from the output of the Navy Operational Global Atmospheric Prediction System (NOGAPS). The version of the NOGAPS dataset used for this modelling study is originally derived from the publically available version hosted by the U.S. Global Ocean Data Assimilation Experiment (GODAE) and subsequently has a QuikSCAT correction applied by the HYCOM Consortium. This dataset of 10 m winds is provided at 0.5 degree horizontal resolution with a 3 hour time step provided from 2003 to present. The potential extent of the relatively long oil spill to be simulated was anticipated to be large and therefore wind data from dozens of NOGAPS model grid locations were used in this study. NOGAPS winds are one of the main driving forces used in global HYCOM, the hydrodynamic global currents dataset also used in this study (see next section).

Annual and monthly wind roses for the NOGAPS wind grid point at an offshore location closest to the spill sites are shown in Figure 3. Analysis of the wind roses indicates that near the spill sites, the wind regime is characterized by southwesterly winds throughout the year. From month to month there is some slight variability in the directional trend with more persistent southwesterly winds in the spring and summer and slightly more variability in the winter months. As indicated in Figure 4, average and peak velocities do vary throughout the year, with elevated wind speeds during June to September. The highest average velocities occur during July, while the weakest winds are typically in December. Overall, annual wind speeds are about 11 knots on average and the strongest wind speeds near the EN-22 well site are about 31 knots (occurring in July), as indicated by the NOGAPS model.

Figure 5 shows the statistical distribution of the annual wind roses offshore Ghana, illustrating that there is some spatial variability of wind patterns. Winds tend to be stronger offshore and weaken slightly nearshore. On the larger scale, winds outside of Ghana tend to follow a similar trend – with most coastal areas within the Gulf of Guinea exhibiting a southwesterly trend. However, winds further offshore (below 2° N) tend to be more consistently from the south than from the southwest. To the west (not shown on this map) winds tend to be more varied directionally and are more frequently from the south or southeast.

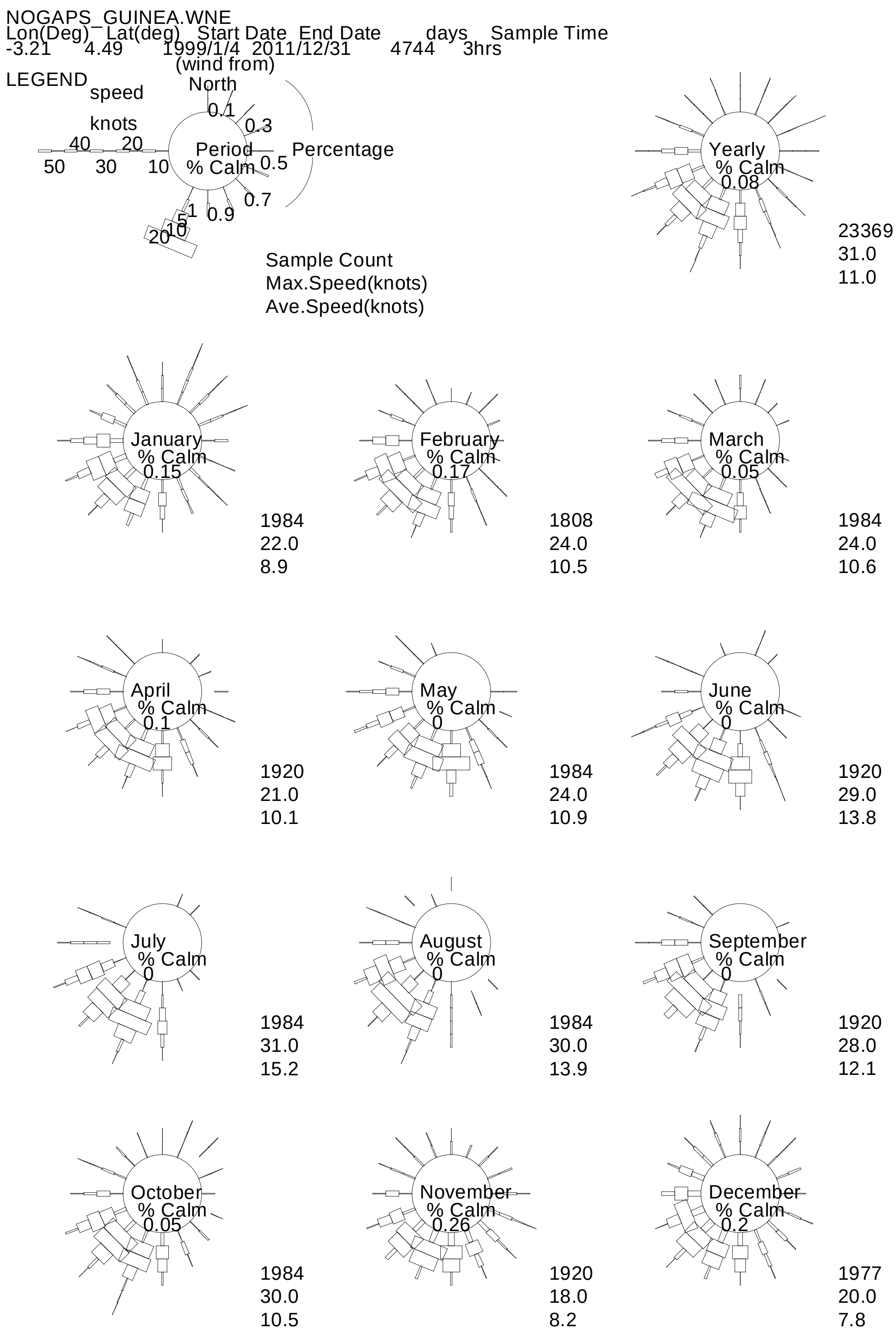



Figure 3.Monthly and yearly NOGAPS wind roses near EN-22 using meteorological convention (direction from).

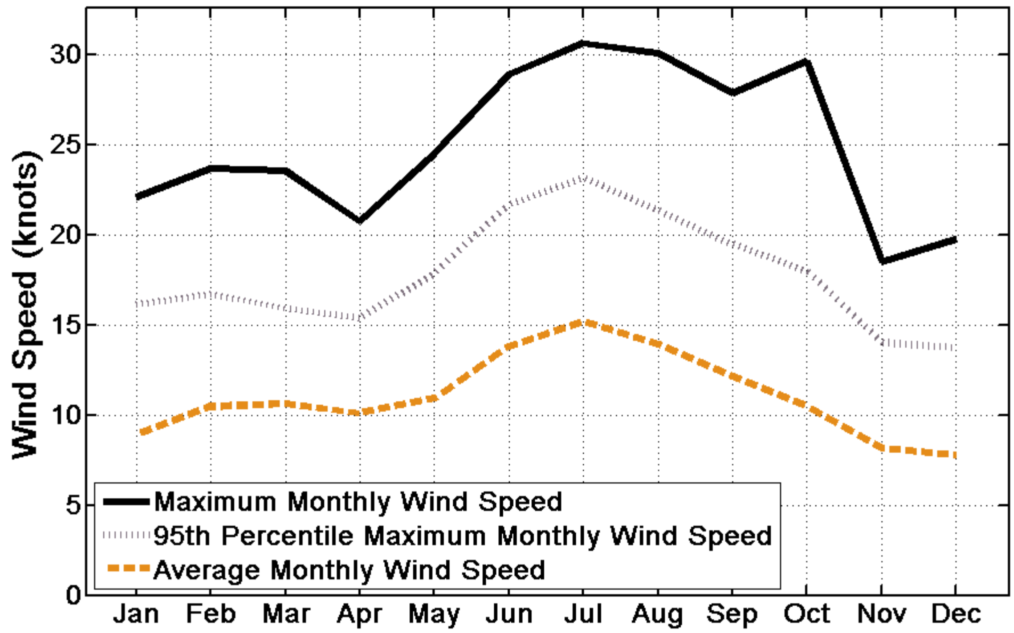



Figure 4. NOGAPS wind statistics near EN-22 site: average (orange dashed), 95th Percentile (grey dashed), and Maximum Monthly Wind Speeds (black solid).

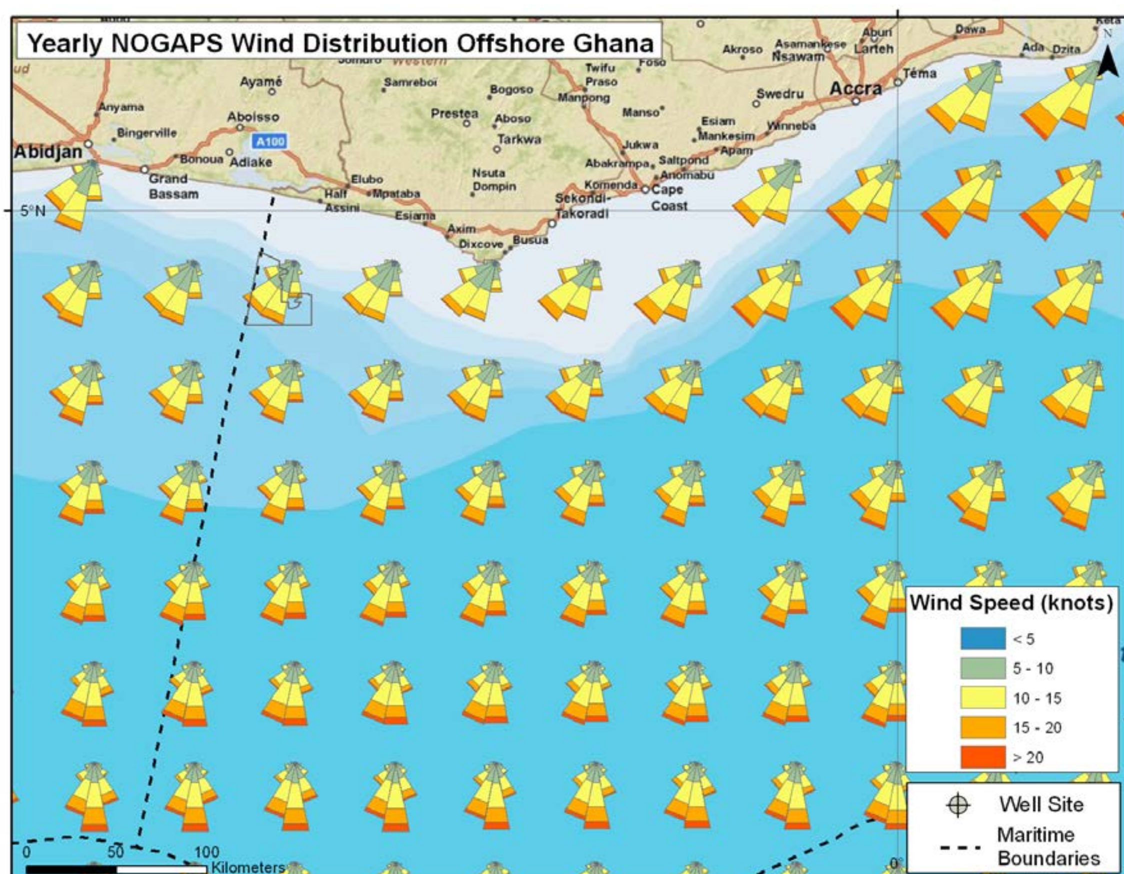



Figure 5. Yearly NOGAPS wind rose map, offshore Ghana using meteorological convention (direction from).

## 2.4. Ocean Circulation and Physical Attributes

The offshore waters of Ghana are dominated by the Guinea Current, which transports water eastward roughly along the 3°N latitude along the western coast of Africa. Average currents are oriented to the east, parallel to the coast of Ghana. Overall, currents within the Guinea Current typically follow the same trends throughout the year, with predominant easterly transport. However, several academics have noted that the Guinea Current exhibits minimum velocities during the dry season and maximum during the wet season (Colin, 1988). The dry season is defined as December-May while the wet season is defined as June-November. Additionally, current reversals have been observed at portions of the year, particularly during the dry season. These reversals in direction are not well understood, but have typically been attributed to the changes in flow of the North Equatorial Countercurrent, the Canary Current, and the Benguela Current (Gyory, 2005). Other oceanographers have proposed that these anomalous currents are due to surfacing of the Ivorian Undercurrent, which transports subsurface currents westward below the Guinea Current, or due to cyclonic eddy systems near the coast (Lemasson & Rebert, 1968; Ingham, 1970).

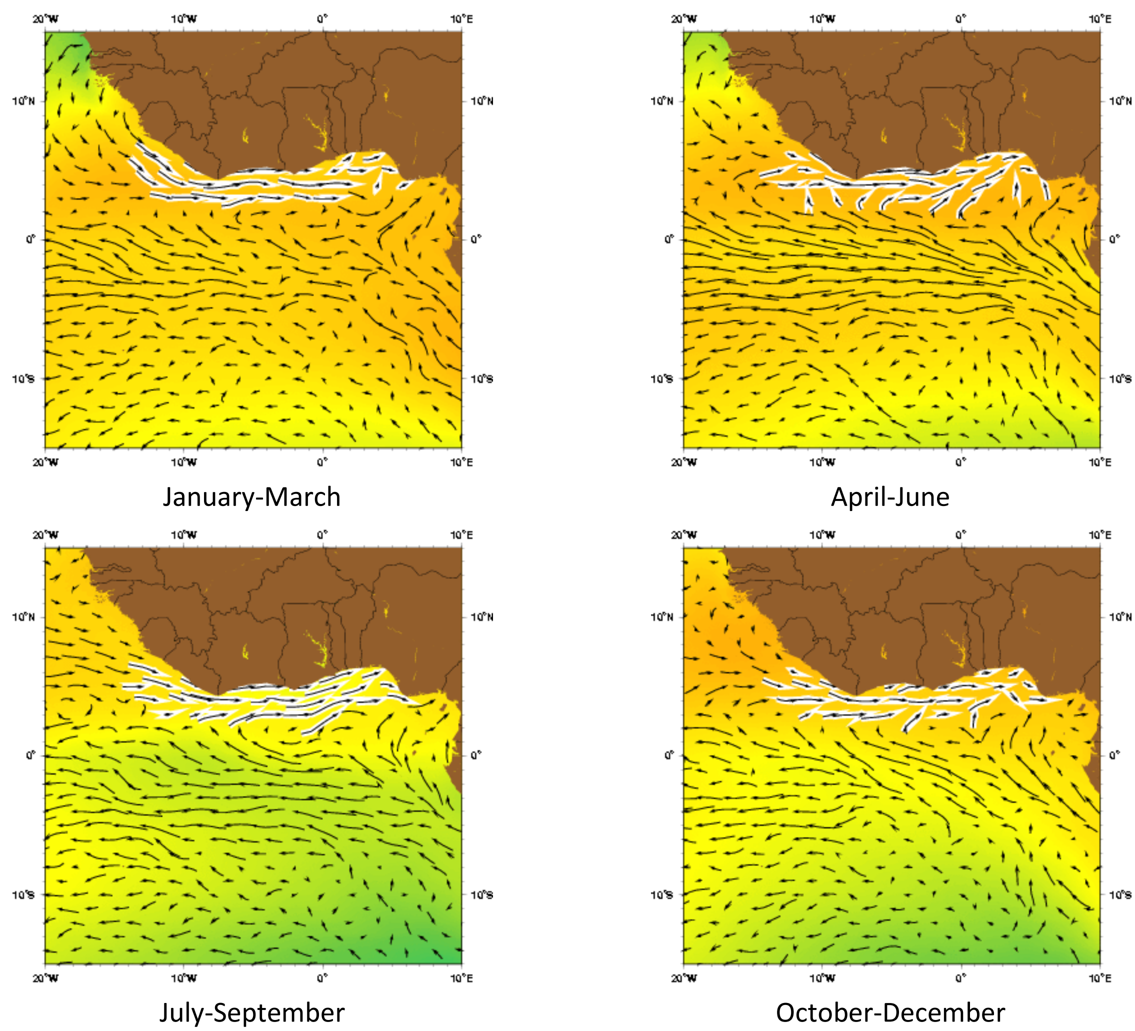



Figure 6. Seasonal trends of the Guinea Current (Source: Gyory et al., 2005). Vectors indicate the average current directionality for each period and the white outlined vectors mark the extent of the Guinea Current.

Just as large-scale current systems dominant surface circulation offshore Ghana, there are a number of regional features that affect subsurface currents. The Equatorial Undercurrent, the Equatorial Intermediate Current, the Ivory Undercurrent, and the Guinea Undercurrent all play some role in the underwater current structure near the study area (Noble Denton, 2008).

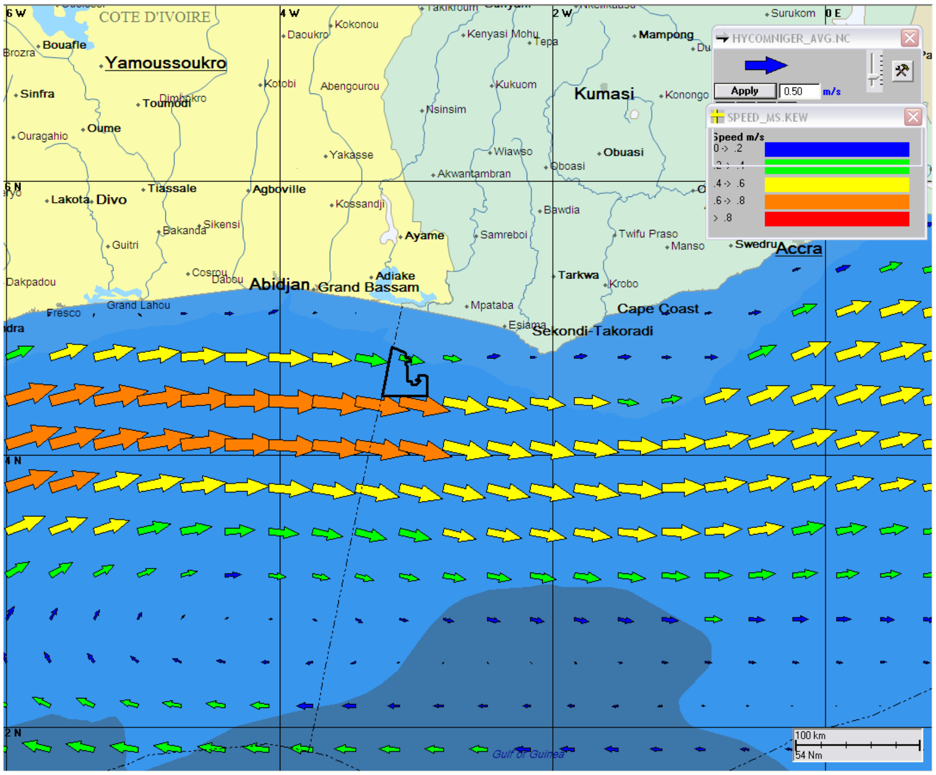
***Circulation Dataset- HYCOM Hindcast***

For this study, regional currents for the area were obtained from a hindcast analysis using inputs from HYCOM (HYbrid Coordinate Ocean Model) 1/12 degree global simulation assimilated with NCODA (Navy Coupled Ocean Data Assimilation) from the U.S. Naval Research Laboratory (http://www.hycom.org). The model domain has a spatial resolution defined by a 1/12 degree grid in the horizontal direction and a daily temporal resolution, which for this study was obtained for the period of November 2003 through December 2010.

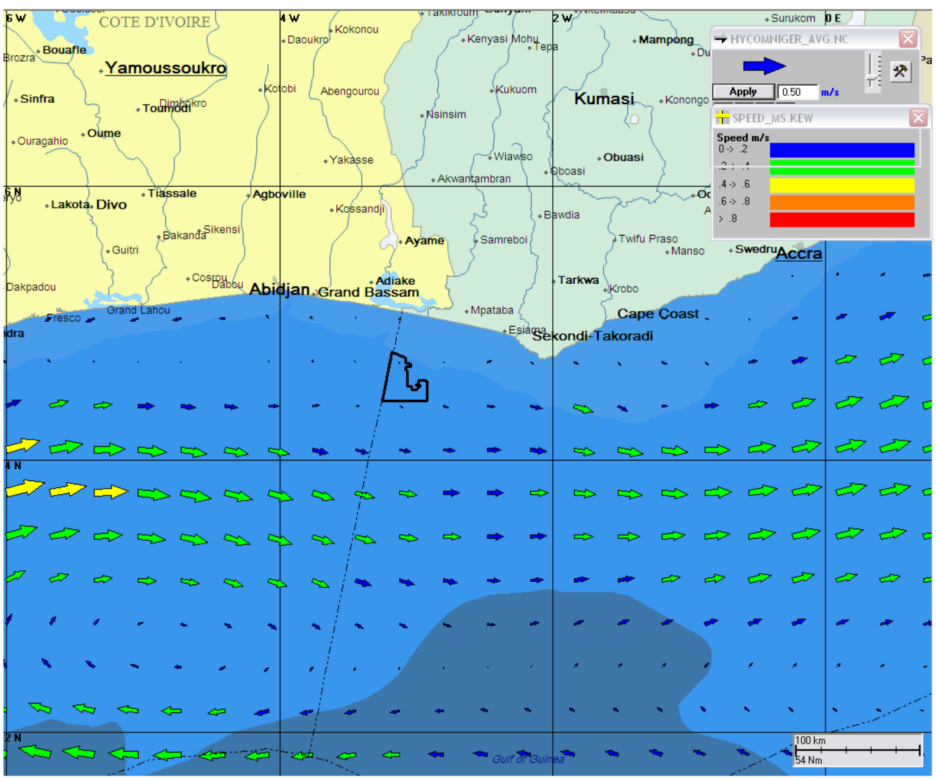
Figure 7 shows two different monthly averages of HYCOM surface currents in the vicinity of the study area. The top panel represents the average current field in April and the bottom panel represents the average current field in December. Overall, directionality between the two months is similar, with currents typically travelling eastward close to the coastline and westward offshore near the equator. However, there are major differences in the average velocities observed in each of those months, with average currents typically higher in April relative to December.

For the subsurface blowout simulations, a characterization of the vertical profile of currents is also needed to appropriately evaluate the transport of oil particles through the water column. Thus, current vertical profiles were also obtained from the HYCOM model outputs. Figure 8 shows the profile of current speeds with depth at the EN-22 well site (the deeper of the two wells assessed as part of this study). While surface currents may exceed 100 cm/s in extreme cases, currents at the water surface are on average about 40 cm/s. At 1,000 m, current speeds rarely exceed 20 cm/s and are on average about 5 cm/s. Variability in current speeds is partially attributed to seasonal trends. Surface current speeds tend to be slightly higher from April to July, although there is much less variability seasonally in the subsurface currents as shown in Figure 9.

In addition to some seasonal signatures in speed observed in the regional circulation, there are distinct patterns in directionality. Figure 10 and Figure 11 show the statistical distribution of currents for April and December, respectively. In April, near-surface currents are persistent toward the east. This trend tends to dissipate with depth, with currents at 500 m showing a reversal of flow toward the west and currents at 1000 m split almost equally between west-northwest and east-southeast. In December, the surface currents, despite having a net flow to the east, have significantly more variability in the directionality of flow. Flows move in all compass directions from surface to seafloor with most flows oriented toward the northwest or east-southeast.




a) April




b) December

Figure 7. HYCOM surface currents monthly averages corresponding to April (top) and December (bottom). The location of the TEN development is outlined in black.

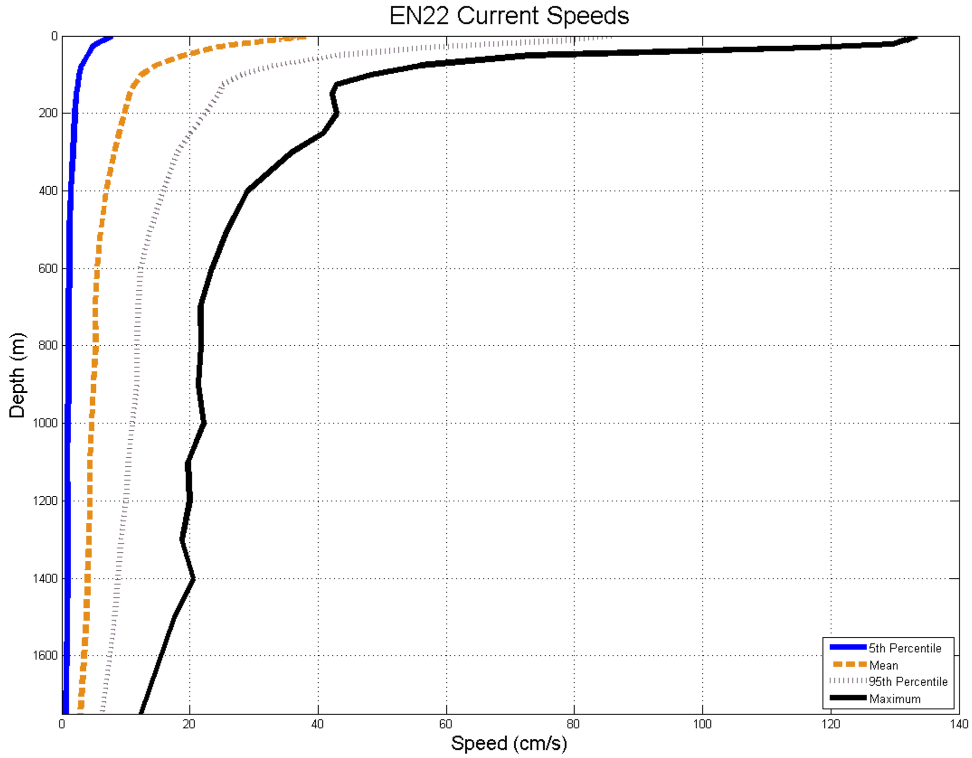
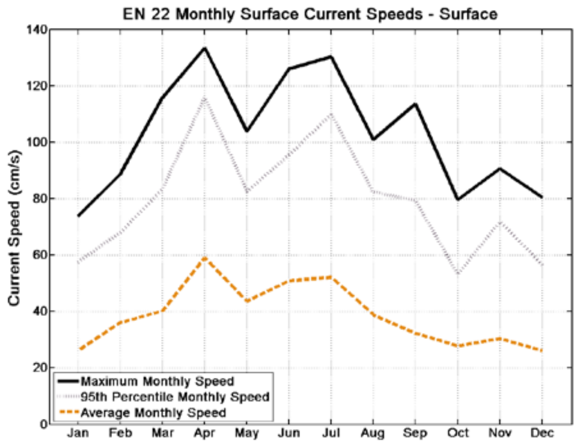
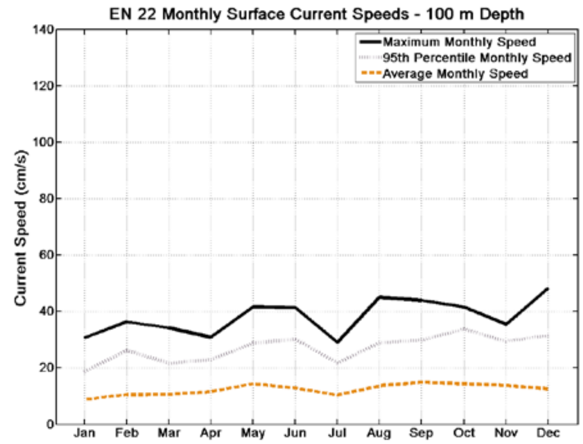


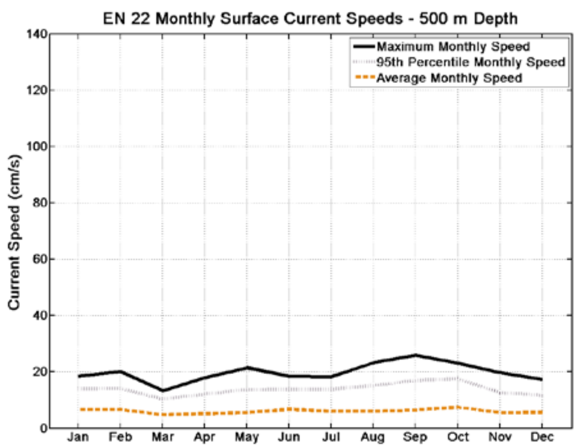

Figure 8. Vertical profile of HYCOM current speeds at EN-22 well site.



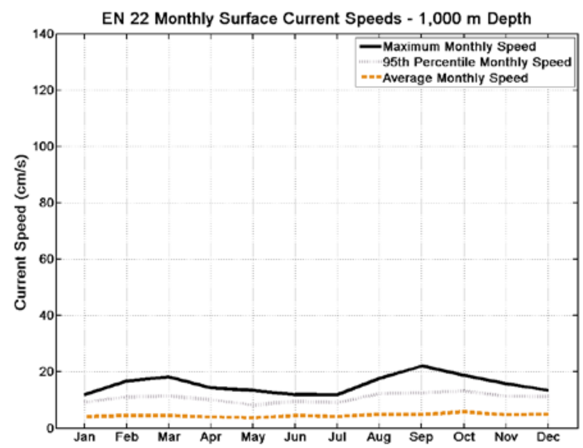

(a)




(b)

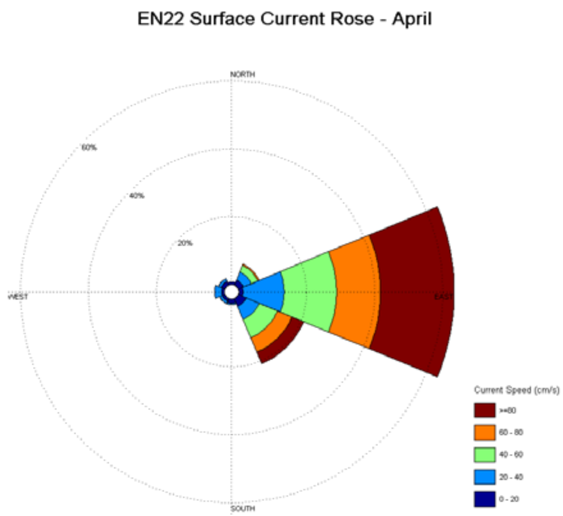



(c)

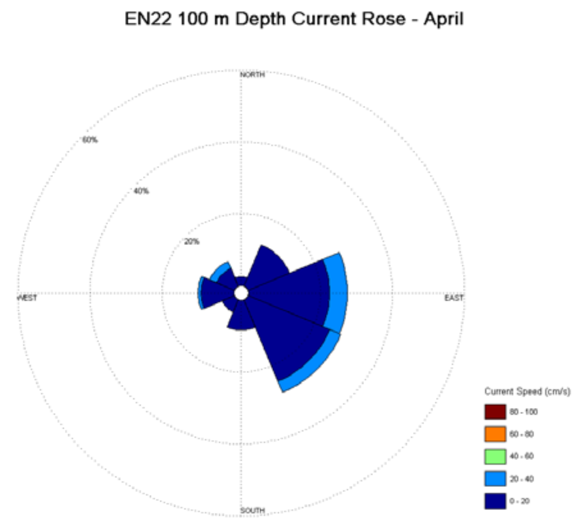



(d)

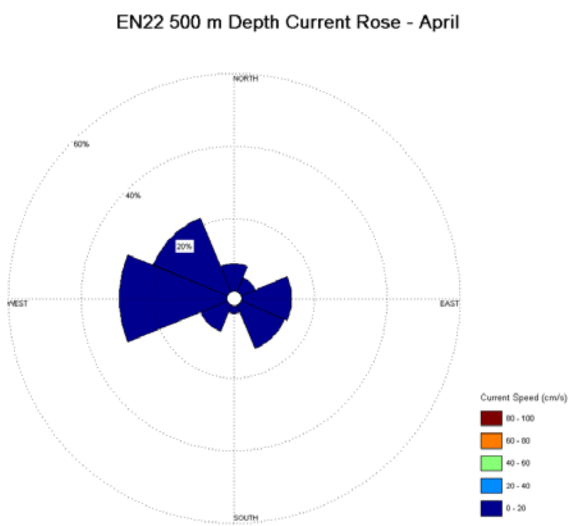
Figure 9. HYCOM Monthly current speed statistics at various water depths at EN-22.



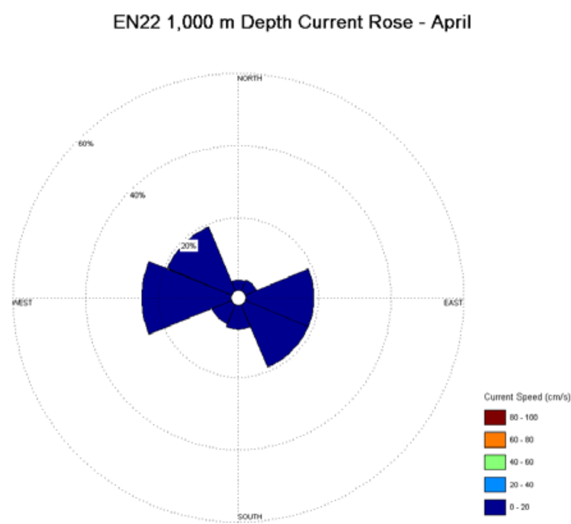

(a)




(b)




(c)




(d)

Figure 10. HYCOM current roses for April at various water depths at EN-22 (period 2004-2011) using oceanographic convention used (direction going to).


Figure 11. HYCOM current roses for December at various water depths at EN-22 (period 2004-2011) using oceanographic convention used (direction going to).

***Water vertical structure - temperatures and density profiles***

The subsurface spill modelling, which is described in detail in Section 3, has two separate components; near-field and far-field. The near-field analysis of the plume pertains to the region in which the plume buoyancy drives the transport of oil; the aim of this analysis is the characterization of the anticipated initial plume (geometry and oil particle size distribution). The far-field analysis, which uses input from the near-field analysis to define the spill in the water column, addresses the fate and transport of the released oil once the ambient currents dominate the transport. The near-field modelling requires additional details about the water column structure such as temperature and salinity vertical distribution. For this study, the information about the water column vertical structure was collected from the publicly available Levitus climatology (Boyer et al., 2004).

Figure 12 shows the yearly average vertical profile of temperature, salinity, and density in this area; temperature drops from 27°C at the surface layer to about 4.5°C at 1,000 m depth. Salinity remains nearly constant throughout the water column, ranging between 34.5 psu to 35.7 psu.

The plots also include the analytical curve of potential hydrate formation, according to the Bishnoi Equilibrium Curve (Englezos et al., 1988). Hydrates could potentially form for all the combinations of depths and temperature below the curve. As indicated in Figure 12, because of the cold temperature in deep waters, there is the potential for hydrate formation at depths from the seabed up to approximately 600 m below the water surface.

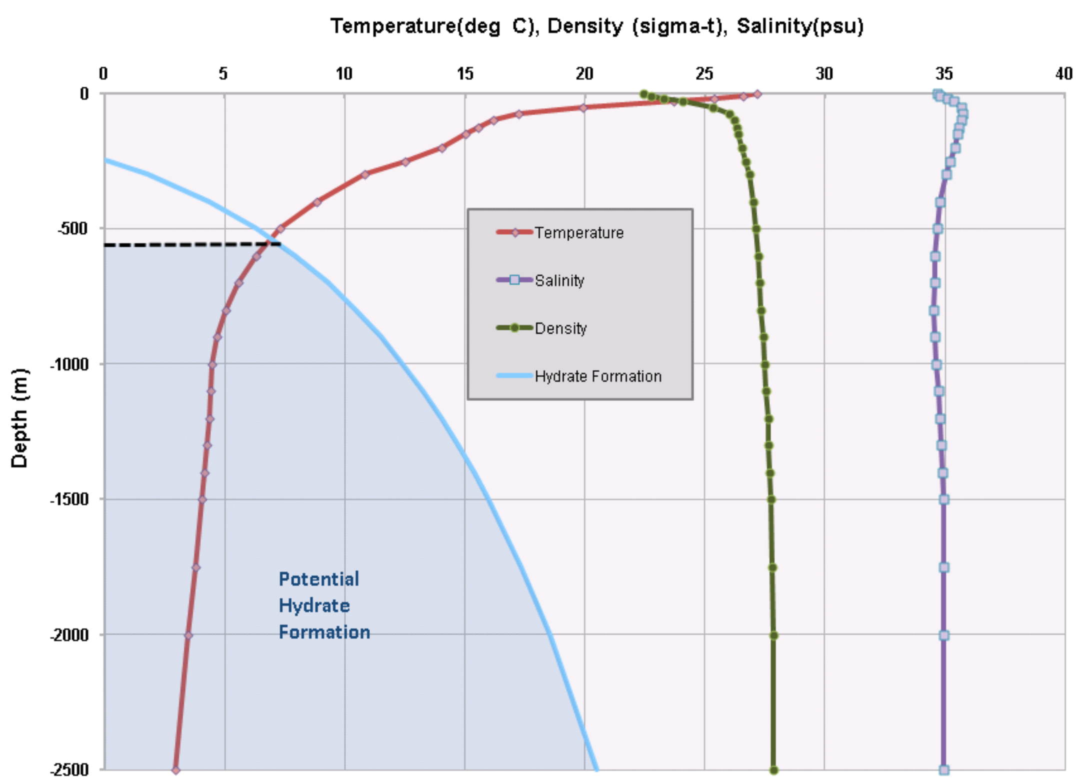



Figure 12. Yearly average temperature, salinity and density vertical profiles near the well site EN-22 and potential hydrate formation.

## 2.5. Seasonality

Ghana is situated in the tropical zone north of the equator on the western coast of Africa. Due to the equatorial proximity, air temperatures remain relatively constant throughout the year, generally ranging between 21 °C and 32 °C. In this part of the world seasons are defined by the relative location of the Inter-Tropical Convergence Zone (ITCZ), the zone near the equator where the winds from the northern and southern hemisphere converge. The dry season, December through May, occurs when the ITCZ is located to the south and is generally defined as a period with cool, dry winds from the Sahara which are commonly referred to as the Harmattan (Noble Denton, 2008). The wet season, June through November, occurs when the ITCZ is located toward the north. Trade winds tend to be stronger during this period.

While there are some climatic differences throughout the year, seasonal variability in winds and currents are relatively small, and therefore the potential wind or current-driven transport of spilled pollutants is expected to be relatively similar throughout the year. In other words, the variability sampled for the winter season will be similar to the variability sampled on an annual basis. Therefore, based on communication with the client, all stochastic oil spill scenarios were run on an annual basis and thus were not specifically run for any seasons. However, the drilling discharges simulations were run for two distinct periods (i.e. months) of the year. This will be further detailed in Section 5.

# 3. Surface Oil Spill Simulations

This portion of the study evaluated potential spills of marine gas oil (MGO) and crude oil on the water surface at three different sites offshore Ghana. Stochastic and worst-case deterministic simulations were performed for each of the scenarios. This section describes the modelling approach, the spill scenario parameters and oil properties, and the modelling results of the potential surface spills.

## 3.1. Spill Modelling Approach

ASA's 3-D oil spill modelling system, SIMAP, was used for all surface oil spill simulations performed in this study. Two different types of analysis using two different modelling components in SIMAP - the stochastic component and the trajectory/fates component - were used to analyse surface and shoreline oiling for the different potential spills.

The stochastic simulations provide insight into the probable behaviour of potential oil spills in response to temporally and spatially varying meteorological and oceanographic conditions in the study area. The stochastic model computes surface trajectories for an ensemble of hundreds of individual cases for each spill scenario, with each individual simulation start time selected randomly within the seasonal timeframe thus sampling the variability in the wind and current forcing.

The stochastic analysis provides two types of information: (1) the footprint of sea surface areas that might be oiled and the associated probability of oiling, and (2) the shortest time required for oil to reach any point within the areas predicted to be oiled. The probabilities of oiling within the predicted cumulative footprint are a product of statistical analysis performed on the sum of the individual simulations from the entire ensemble. This footprint represents the likely area of sea surface oiling from a spill in that location. It is important to note that any one simulation will encounter only a relatively small area of this footprint. In addition, the simulations provide shoreline oiling data expressed in terms of minimum and average times required for oil to reach shore, and the percentage of simulations in which oil is predicted to reach shore.

The individual runs from the stochastic analysis for each spill scenario are further evaluated to select a *representative or worst case* scenario to be analysed in more detail by performing a deterministic trajectory/fate simulation. The worst case scenario was selected based on the degree of shoreline oiling. Different parameters or indicators can be used to compare and assess the degree of shoreline oiling; for example "time to reach the coast", "oil volume to reach the coast" or "total length of oiled coastline". For this study the largest volume of oil to reach the shoreline was used to define the worst case. This case results in a scenario which necessitates a large clean-up response to protect shoreline habitats. For each spill scenario, one deterministic trajectory/fate simulation was run to investigate a single specific spill event that could potentially occur using the same combination of winds and current forcing used in the corresponding stochastic simulation.

## 3.2. Surface Spill Scenario Parameters

Four potential surface oil spill scenarios were simulated as summarized in Table 3. The surface spill scenarios included releases from three different locations and used two different oil types.

Table 3. Parameters of the surface spill scenarios.

| Spill Site | Oil Type | Spill Type | Season | Spill Duration | Total Spilled Volume | Simulation Duration |
|---|---|---|---|---|---|---|
| EN-7 | MGO | Bunkering - Surface Spill | Yearly | 30 seconds (assumed instant.) | 1,000 bbl | 14 days |
| FPSO | Crude | Surface Spill w/ isolation | Yearly | 5 minutes (assumed instant.) | 3,453 bbl | 21 days |
| FPSO | Crude | Surface Spill w/out isolation | Yearly | 1 hour | 15,479 | 21 days |
| OOB | Crude | Transfer Hose - Surface Spill | Yearly | 30 seconds (assumed instant.) | 900 bbl | 14 days |

## 3.3. Oil Characterization

Table 4 lists the two oil types that were used for the surface oil spill modelling portion of this study:

- An Enyenra crude oil; the client provided information concerning the properties of the crude oil to be found in TEN development (AEA, 2010; Tullow, 2011), including the evaporation curves, aromatic components, and physical properties.
- A marine gas oil (MGO). The client requested ASA assume a marine gas oil (MGO) for one of the surface spills. Since exact properties of the MGO to be spilled were not available, a proxy/generic MGO (diesel) was assumed whose properties were used to define the viscosity, surface tension, maximum (emulsion) water content, and other properties of the oil that are necessary to run the oil spill model. These properties were based on marine gas oil characterization from the Environmental Technology Center of Environment Canada.

Table 4. Summary of oil characterization data used in the simulations.

| Oil Type | Density ($g/cm^3$) | Viscosity (cP) | Surface Tension (dyne/cm) | Maximum Water Content (%) |
|---|---|---|---|---|
| Enyenra Crude | 0.857 | 21.984 @ 20°C | 27.0 | 82.0 |
| Marine Gas Oil | 0.831 | 2.760 @ 20°C | 27.5 | 0.0 |

Viscosity and interfacial surface tension affect the degree of spreading of the surface oil, which in turn influences the rates of evaporation, dissolution, dispersion, and photo-oxidation. The maximum water content is a measure, obtained in a laboratory, of the emulsion-formation tendency of the oil. Oils that form water-in-oil emulsions tend to be more persistent in the marine environment as they are less likely to be dissolved and/or evaporated; this increases their potential for reaching the shoreline. As the assumed MGO has no tendency in forming an emulsion, it is expected to be less persistent on the water surface relative to crude oils.

## 3.4. Stochastic Model Results - Surface and Shoreline Oiling

The SIMAP stochastic model was used to predict the probabilities of sea surface and shoreline oiling for each spill scenario described in the previous section. The stochastic results provide insight into the probable behaviour of each potential oil spill scenario under variable wind and current conditions.

### *Predicted Probabilities of Shoreline Oiling*

Table 5 summarizes the results of the stochastic analysis with respect to the probability of oil reaching the coastline predicted for each spill scenario. In this table, the percentage of simulations reaching shore indicates the likelihood that a particular spill event will reach nearby coastal areas at some point. This percentage is based on the total number of trajectories within the ensemble of individual simulations that reached the coast; only those trajectories that resulted in shore contact with more than 0.1% of the initial mass released have been included in the total. For those scenarios reaching the coast, the table also provides the maximum and average time to reach shore.

Note that a spill event with high probability of shoreline oiling does not imply that a particular section of the coast will be oiled. Depending on the variability of winds and currents used in the stochastic simulations, the stochastic results may show a high probability of oil reaching the coastline *at some location* in the study. However, the cumulative area potentially oiled can be spread over a wide region based on the trajectories of individual simulations; in those cases, a particular coastal segment may have a small probability of being oiled.

Table 5. Stochastic results - Probabilities of shoreline impact predicted for each surface spill scenario.

| Location | Oil Type | Spill Type | Duration | Total Volume Released (bbl) | Sims. reaching shore (%)[1] | Amount of oil ashore (bbl) | | | | Time to reach shore (hours) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Peak | | End of Simulation | | | |
| | | | | | | Max. | Avg. | Max. | Avg. | Min. | Avg. |
| EN-7 | MGO | Surface Spill | 30 seconds (assumed instant.) | 1,000 | 78.6 | 424 | 194 | 255 | 119 | 28 | 94 |
| FPSO | Crude | Surface Spill - isolation | 5 minutes (assumed instant.) | 3,453 | 85.0 | 2,579 | 2,258 | 2,120 | 2000 | 32 | 129 |
| FPSO | Crude | Surface Spill – no isolation | 1 hour | 15,479 | 85.5 | 10,900 | 7,114 | 9,523 | 6,831 | 28 | 129 |
| OOB | Crude | Surface Spill | 30 seconds (assumed instant.) | 900 | 83.2 | 692 | 623 | 594 | 564 | 28 | 101 |

(1) The percentage of simulations reaching shore is based on the number of trajectories out of the ensemble of stochastic individual simulations where more than 0.1% of the volume spilled reached the shore.

The following conclusions can be derived from Table 5:

- The stochastic model predicts about an 80% chance that oil will arrive to the coastline from any of the short duration (near-instantaneous) surface spills. Because the four surface spills differ in their location and oil properties, there are slight differences in the relative likelihood of oil arriving to shore as well as the minimum time that it could take for oil to reach the shore. Oil could arrive in as little as 28 hours from either the EN-7, the OOB, or the FPSO (without isolation) sites, while it would take at least 32 hours for oil to arrive at the coast from the FPSO site with isolation. The average time it would take oil to reach the shoreline from any of the sites ranges between approximately 4-5 days.

- Depending on the location of release, the oil type discharges, and the spill volume, there are differences in the potential volume of oil to reach the coast. In the case of the MGO spill, on average 119 bbl are expected to impact the coastline at the end of the 14 days, while up to 255 bbl of oil could be on the coast at the this time. At the end of the simulation for the crude spills, up to 9,523 bbl and 594 bbl could have accumulated along the coast from the FPSO (no isolation, 1 hour) and the OOB spills, respectively, while on average, the volume of oil along the coast would be slightly lower at 6,831 bbl and 564 bbl, respectively. Because of evaporation and decay processes which remove oil from the environment, the peak volume of oil to be stranded along the coasts is always higher than the volume of oil predicted at the end of the simulation.

### *Predicted Stochastic Footprint of Surface and Shoreline Oiling*

Figure 13 to Figure 16 present the spatial extent of surface oiling probabilities and associated minimum travel times for the spills. Note that in the presentation of probabilities and minimum travel time figures, all oil, regardless of slick thickness, is included. The minimum thickness of some oils can get very low (below 1 micron), thus this provides a conservative estimate of surface oiling that includes oil that is barely visible on the sea surface; a higher threshold of minimum thickness would result in a smaller extent of oiled area. For each scenario, two figures are presented:

1. **Probability of surface oiling**: The map defines the area in which sea surface oiling may be expected and the associated probability of oiling based on analysis of the resulting trajectories from the ensemble of individual simulations run for each spill scenario. The map does not imply that the entire contoured area would be covered with oil in the event of a spill. The map also does not provide any information on the quantity of oil in a given area.

2. **Minimum travel times**: The footprint on this map corresponds to the probability map, and illustrates the shortest time required for oil to reach any point within the footprint. These results are also based on the ensemble of all individual simulations.

Table 6 summarises the main modelling results for each spill scenario.

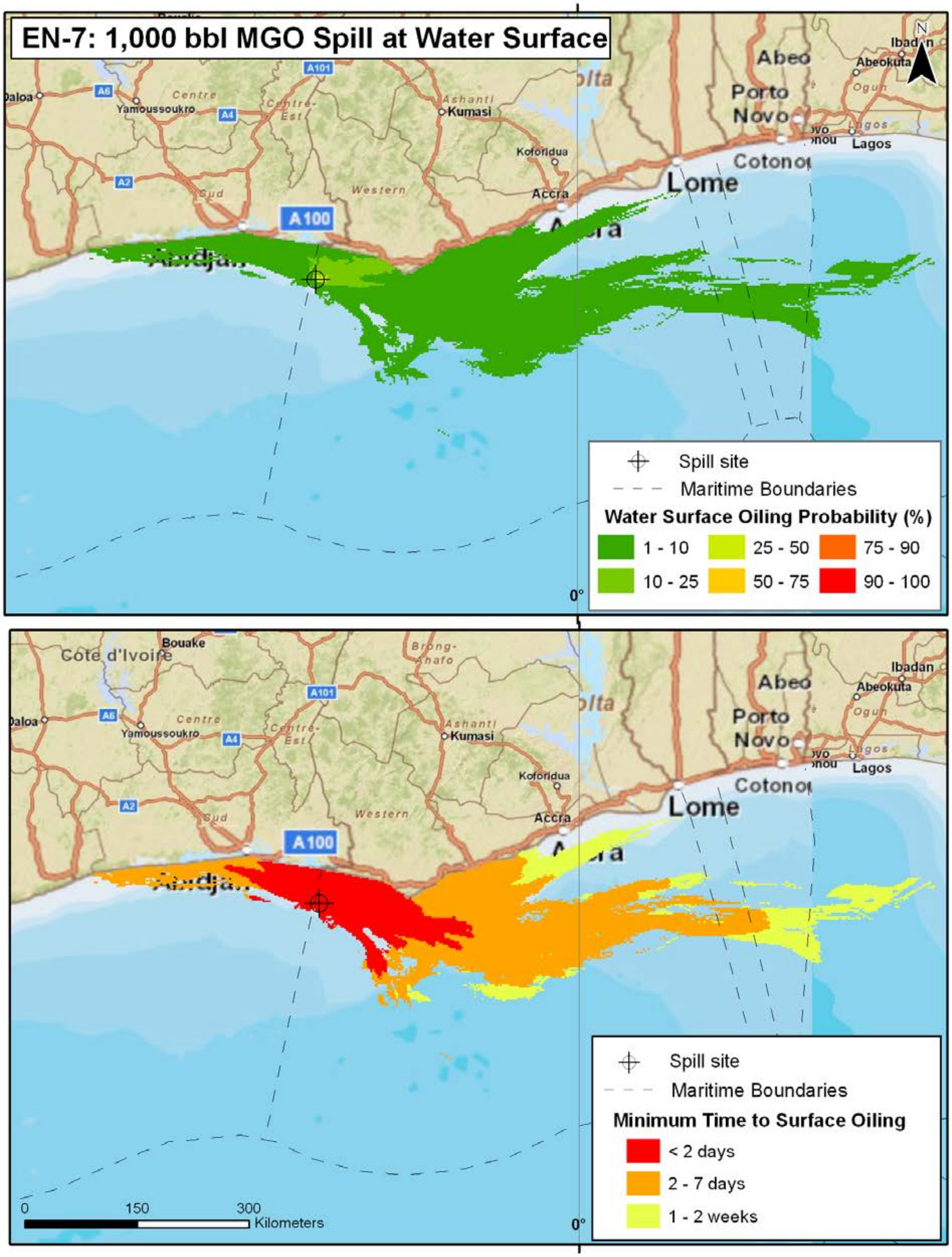



Figure 13. EN-7 1,000 bbl MGO Surface Spill - Water surface oiling probabilities (top image) and minimum time for surface oiling (bottom image).

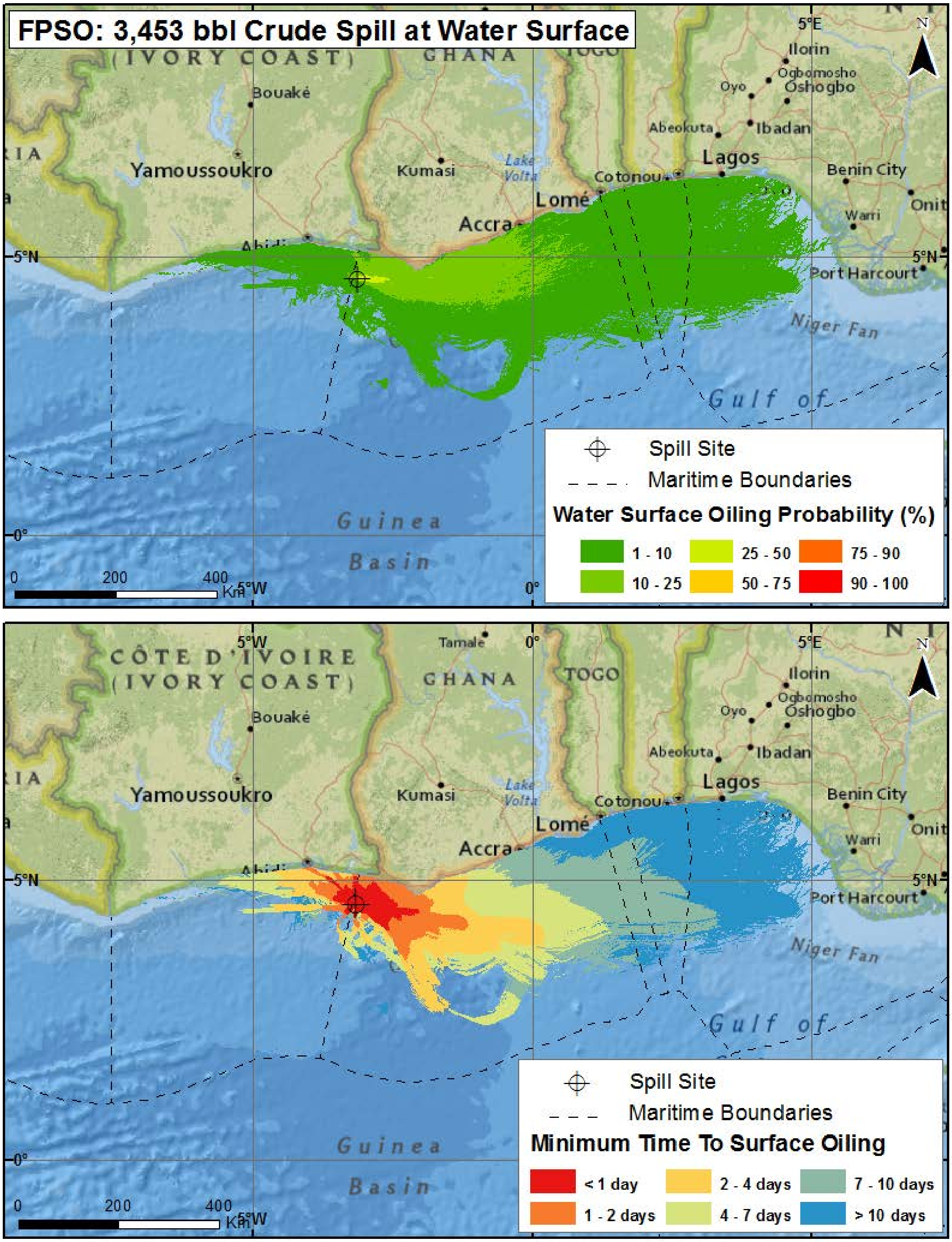



Figure 14. FPSO 3,453 bbl Crude Oil Surface Spill - Water surface oiling probabilities (top image) and minimum time for surface oiling (bottom image).

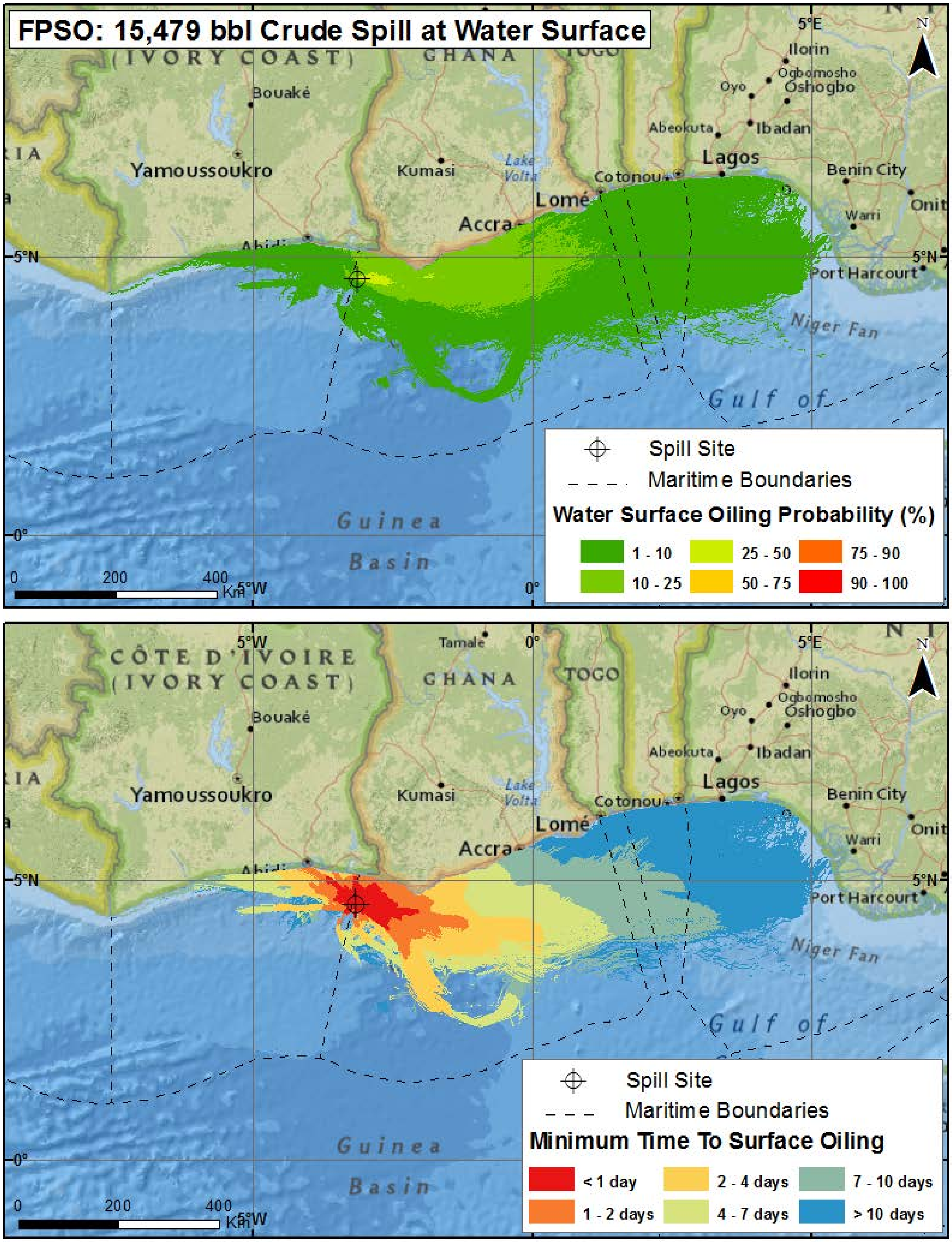



Figure 15. FPSO 15,479 bbl crude oil surface spill - Water surface oiling probabilities (top image) and minimum time for surface oiling (bottom image).

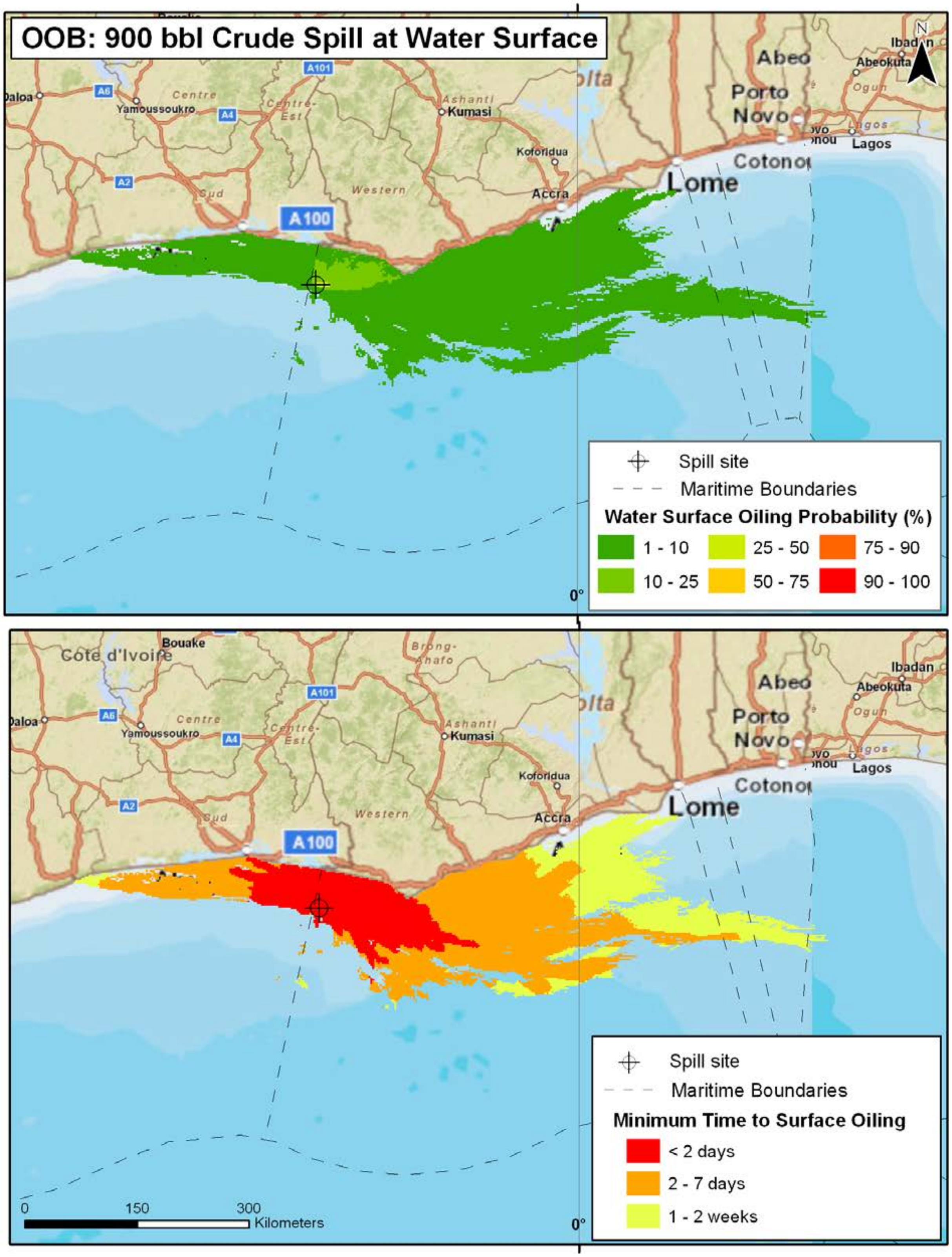



Figure 16. OOB 900 bbl Crude Oil Surface Spill - Water surface oiling probabilities (top image) and minimum time for surface oiling (bottom image).

Table 6. Stochastic result summaries for each individual spill scenario.

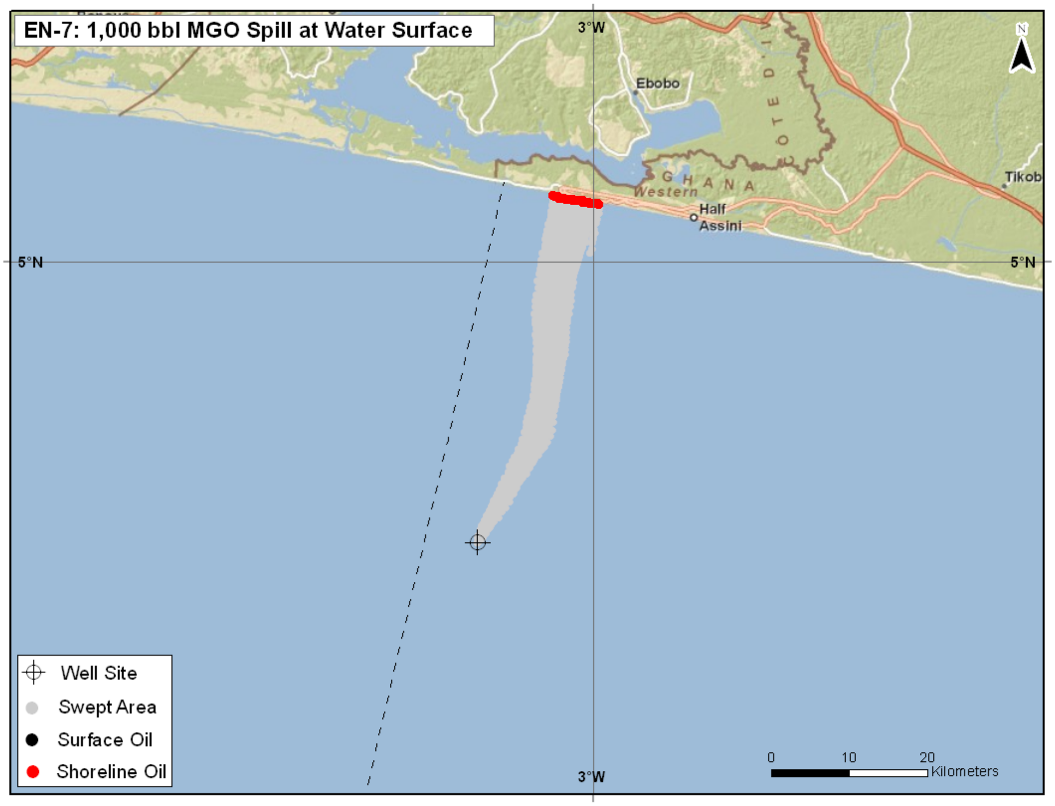
| Figure Number | Water Surface Oiling Summary | Shoreline Oiling Summary | Comments |
|---|---|---|---|
| *Scenario 1: 1,000 bbl MGO Spill at the EN-7 Well Site* | | | |
| Figure 13 | Footprint (> 1% probability) extends about 800 km to the east, past the waters of Ghana and into the offshore waters of Benin, Ivory Coast, Nigeria, and Togo.<br><br>High probability zones (> 50%) are isolated to within 6 km from the well site. Due to the winds and currents throughout the year, the high (>50%) and medium (25-50%) probability zones are oriented toward the east and northeast from the well site. | 78.6% chance that oil will arrive at the coastline. Over 900 km of shoreline has > 1% probability of being oiled, including the shorelines of Ghana and Ivory Coast; however, no individual coastal segment has > 10% probability of oiling.<br><br>While oil could arrive at the Ghanaian coastline in as little as 28 hours, the average time is about 4 days. | Less than 10% probability that some oil may get transported to the west and southeast during some periods of anomalous winds and currents. |
| *Scenario 2: 3,453 bbl Crude Spill at the FPSO Site* | | | |
| Figure 14 | Footprint (> 1% probability) extends about 950 km to the east and 400 km to the west, past the waters of Ghana and into the offshore waters of Benin, Ivory Coast, Nigeria, and Togo.<br><br>High probability zones (> 50%) are isolated to within about 7 km of the well site. Due to the winds and currents throughout the year, the high (> 50%) and medium (25-50%) probability zones are oriented predominantly toward the east and northeast of the well site. | 85% chance that oil will arrive at the coastline. Over 590 km of shoreline has > 1% probability of being oiled, including the shorelines of Ghana, Ivory Coast, and Benin; however, no individual coastal segment has > 15% probability of oiling.<br><br>Oil could arrive at the coastline in as little as 1.3 days, but the average time is about 5.4 days. | Less than 10% probability that some oil may get transported to the west and southeast during periods of anomalous winds and currents. |
| *Scenario 3: 15,479 bbl Crude Spill at the FPSO Site* | | | |
| Figure 15 | Footprint (> 1% probability) extends about 950 km to the east and 500 km to the west, past the waters of Ghana and into the offshore waters of Benin, Ivory Coast, Nigeria, Togo, and Liberia.<br><br>High probability zones (> 50%) are isolated to within about 10 km of the well site. Due to the winds and currents throughout the year, the high (> 50%) and medium (25-50%) probability zones are oriented predominantly toward the east and northeast of the well site. | 85.5% chance that oil will arrive at the coastline. Over 715 km of shoreline has > 1% probability of being oiled, including shoreline of Ghana, Ivory Coast, Benin, Togo, and Nigeria; however no individual coastal segment has > 15.5% probability of oiling.<br><br>Oil could arrive at the coastline in as little as 1.2 days, with the average time for oil to arrive to the coast being about 5.4 days. | Less than 10% probability that some oil may get transported to the west and southeast during periods of anomalous winds and currents. |
| *Scenario 4: 900 bbl Crude Spill at the OOB Site* | | | |
| Figure 16 | Footprint (> 1% probability) extends about 675 km to the east, past the waters of Ghana and into the offshore waters of Benin, Ivory Coast, Nigeria, and Togo.<br><br>High probability zones (> 50%) are isolated to within 6 km from the well site. Due to the winds and currents throughout the year, the high (>50%) and medium (25-50%) probability zones are oriented toward the east and northeast of the well site. | 83.2% chance that oil will arrive at the coastline. Over 900 km of shoreline has > 1% probability of being oiled, including shoreline of Ghana and Ivory Coast; however, no individual coastal segment has > 10% probability of oiling.<br><br>Oil could arrive at the Ghana coastline in as little as 28 hours, with the average time for oil to reach coast being about 4.2 days. | Less than 10% probability that some oil may get transported to the west and southeast during periods of anomalous winds and currents. |

## 3.5. Deterministic Model Results

For each stochastic spill scenario, one deterministic trajectory/fate simulation was run to investigate a specific spill trajectory identified in the previous stochastic analysis representing an event that resulted in high shoreline impacts. The trajectory/fate simulation was run using the same variable winds and current forcing used for the corresponding stochastic simulation.

For this study a worst case scenario was selected based on the degree of shoreline oiling, namely the ensemble scenario with the one of the largest volumes of shoreline oiling with oil reaching the coast in the shortest time possible. This criterion was chosen to represent the worst case because it would require the greatest clean-up response effort while also considering the necessary response time. Therefore, when several individual trajectories had similar volumes anticipated to be washed ashore, the one with the shortest time to shore was selected as the worst case as this would pose the most challenging response effort.

Figure 17 through Figure 20, accompanied by Table 7, present results of the deterministic simulations for the surface release oil spill scenarios. Two figures are shown for each case. The first illustrates the oil's trajectory on the water surface with sea surface areas that have been swept by oil shown in grey and oiled shorelines shown in red. The second figure of each pair shows the model-predicted mass balance for the spilled oil. The mass balance graphs show the degree of weathering that the oil undergoes during the period of the simulation. The following text summarizes the deterministic scenario results for each scenario.



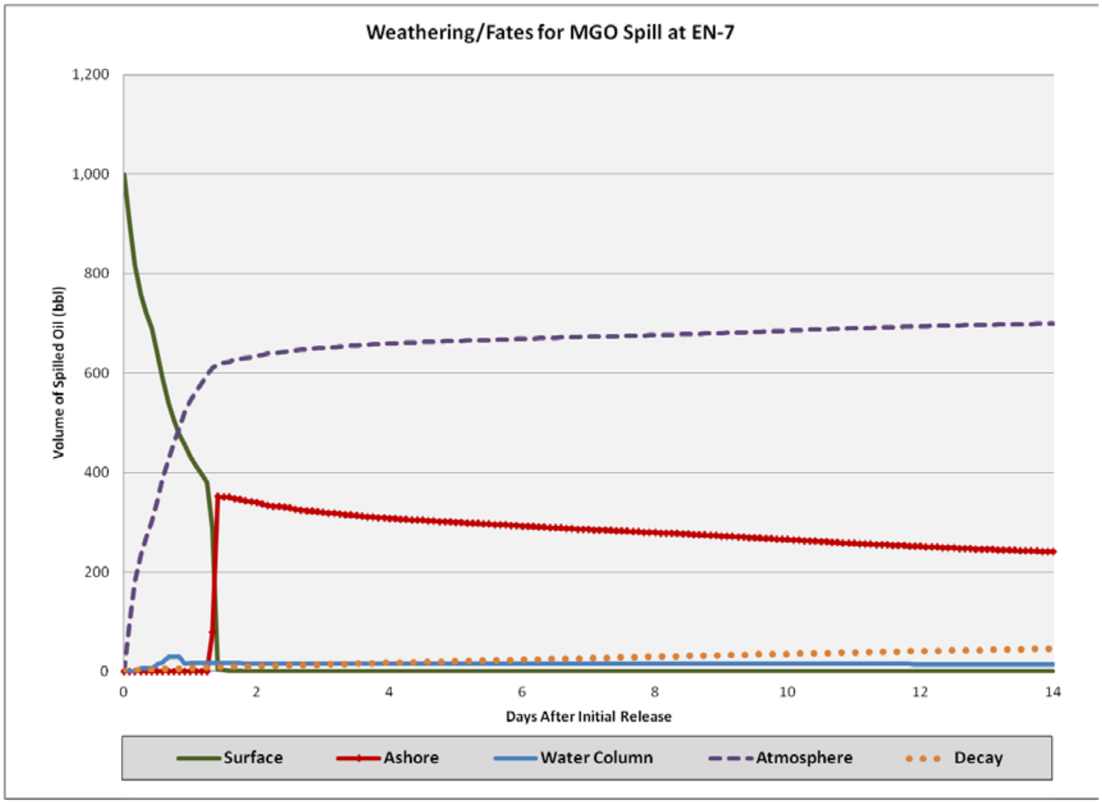




Figure 17. EN-7 1,000 bbl MGO Surface Spill – Deterministic trajectory (grey-swept areas, red - oiled shoreline) after the 14 day simulation and the associated mass balance graph results.

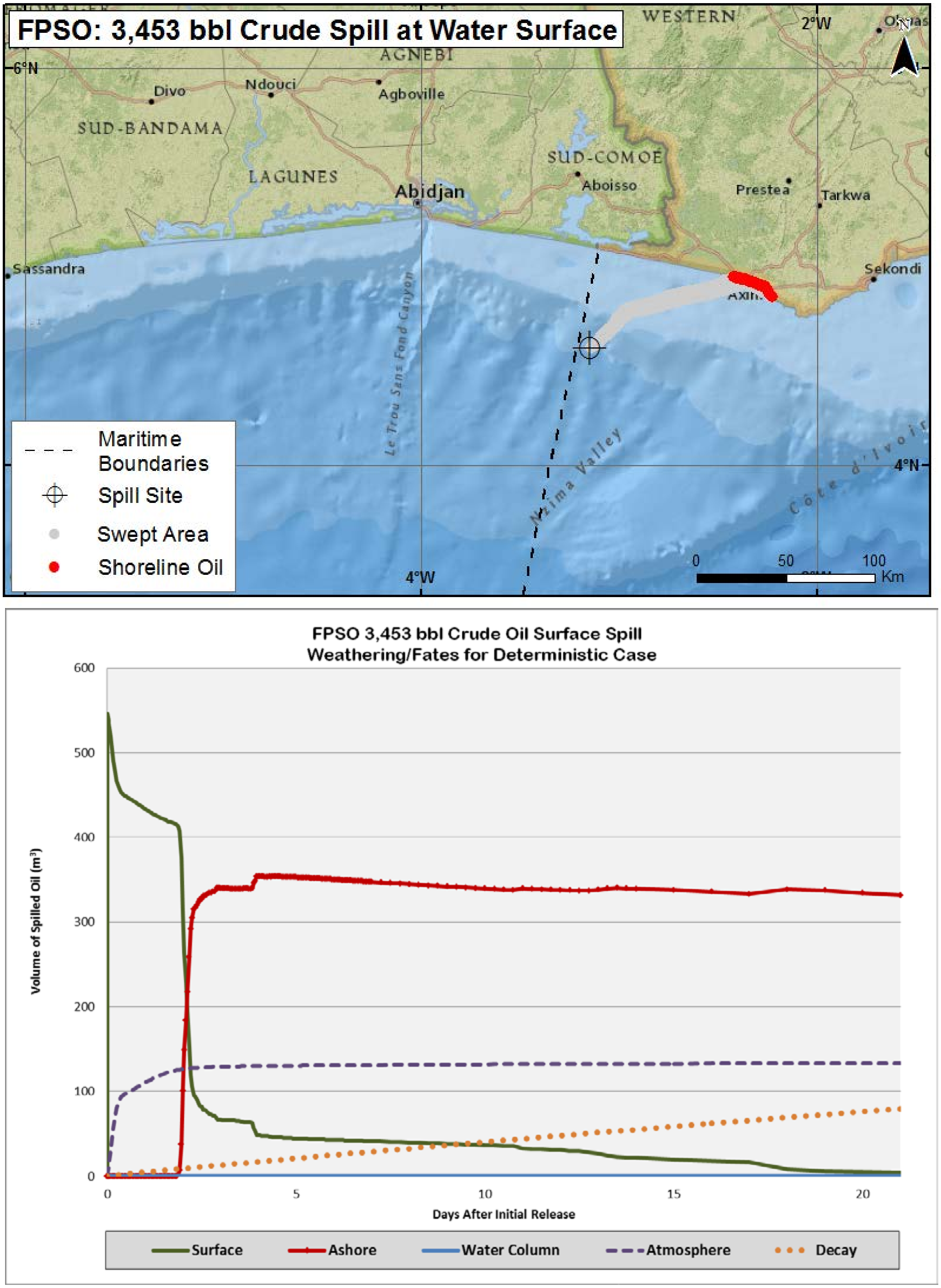
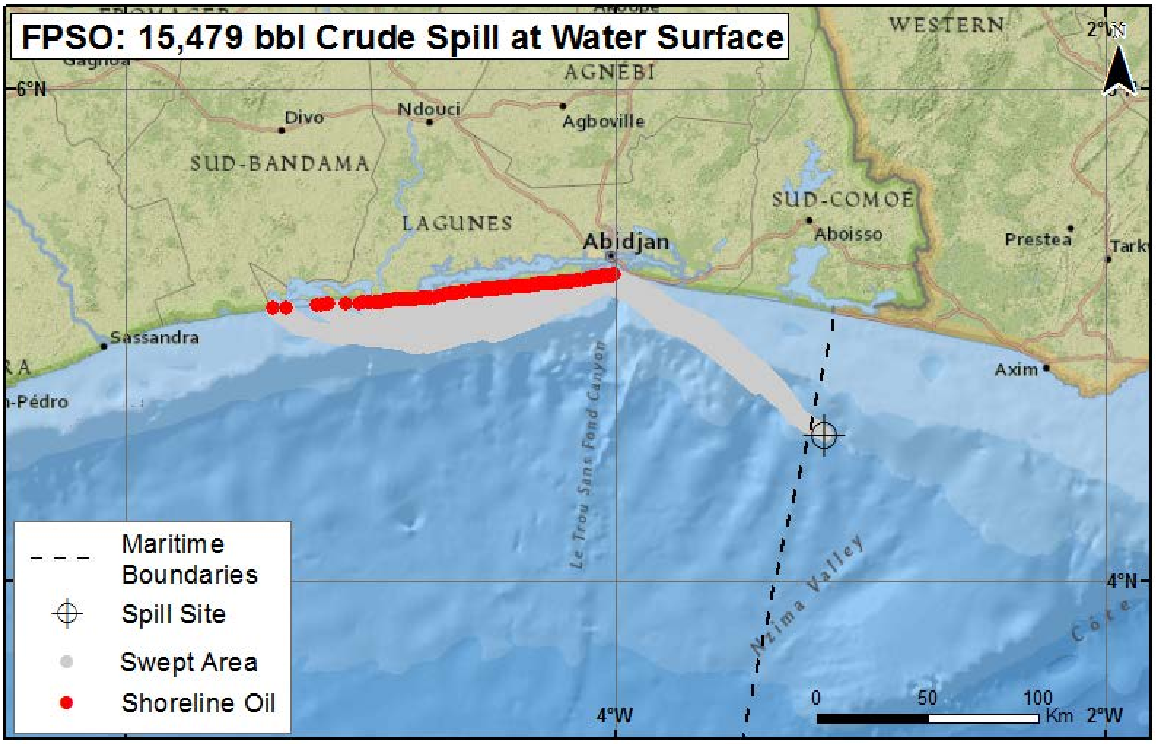



Figure 18. FPSO 3,453 bbl Crude Surface Spill – Deterministic trajectory (grey-swept areas, red - oiled shoreline) after the 21-day simulation and the associated mass balance graph results.



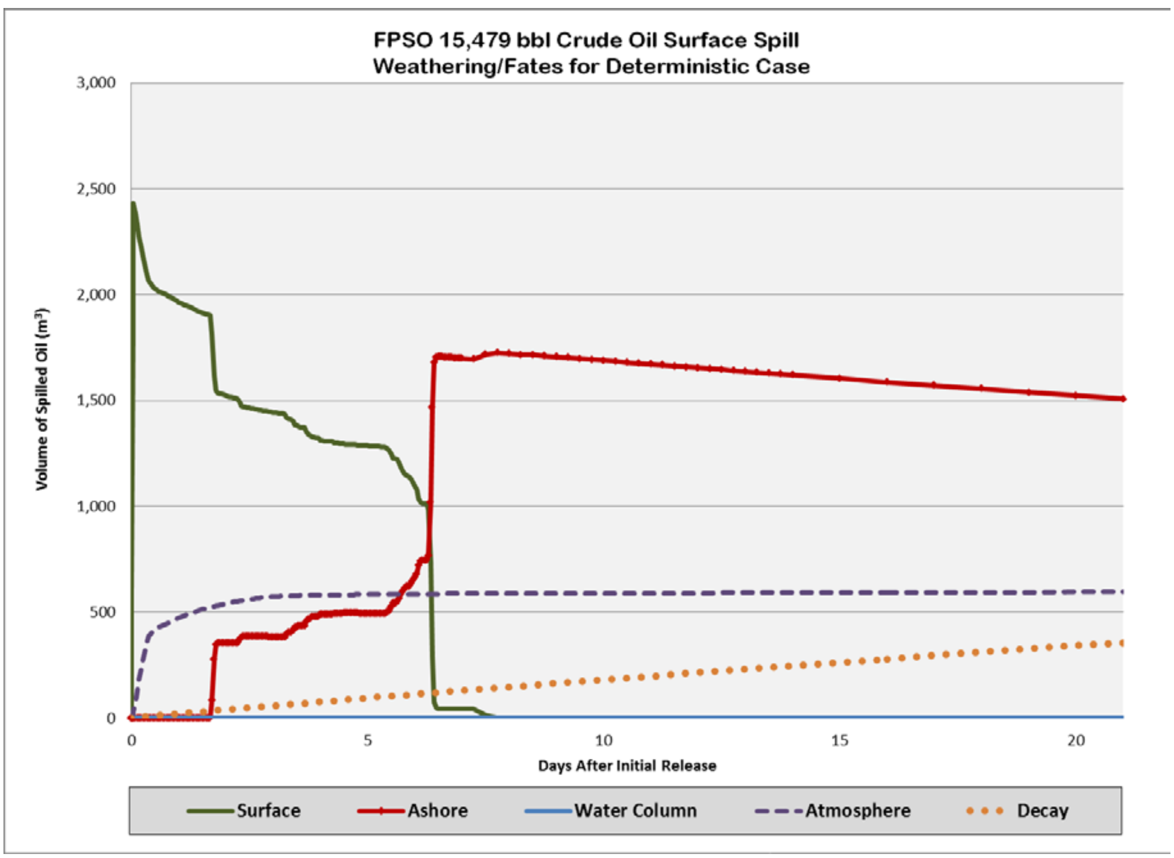
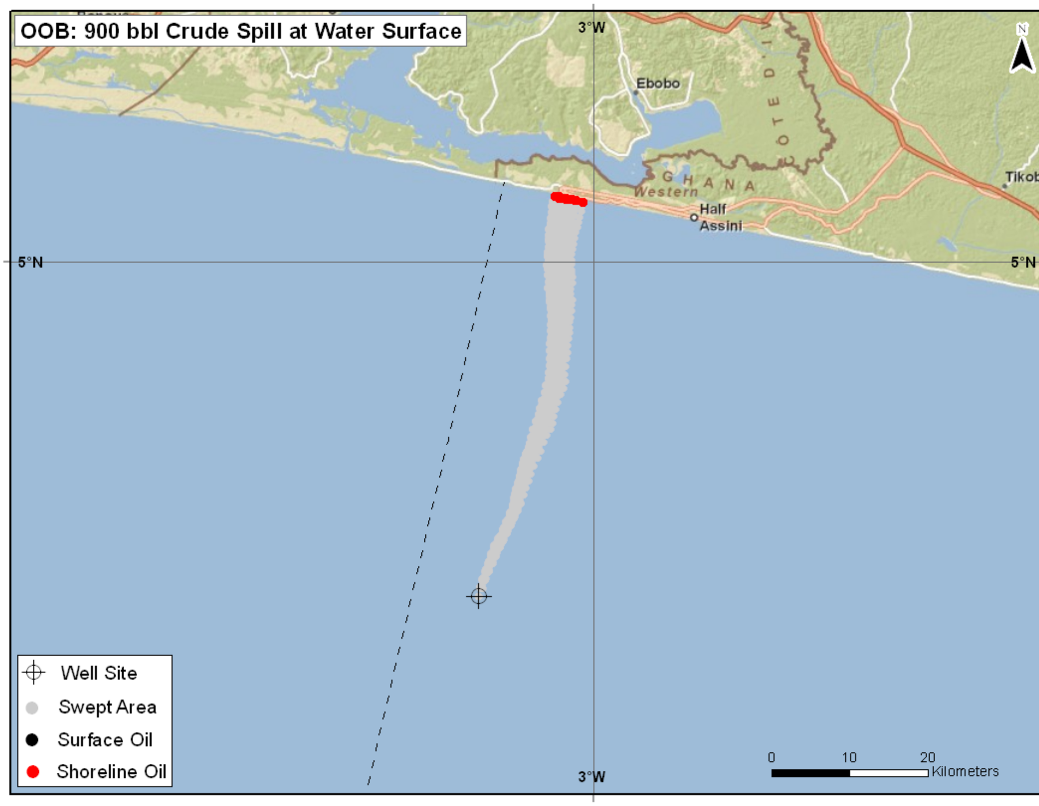




Figure 19. FPSO 15,479 bbl crude oil surface spill - deterministic trajectory (grey - swept areas, red - oiled shoreline) after the 21 day simulation and the associated mass balance graph results.



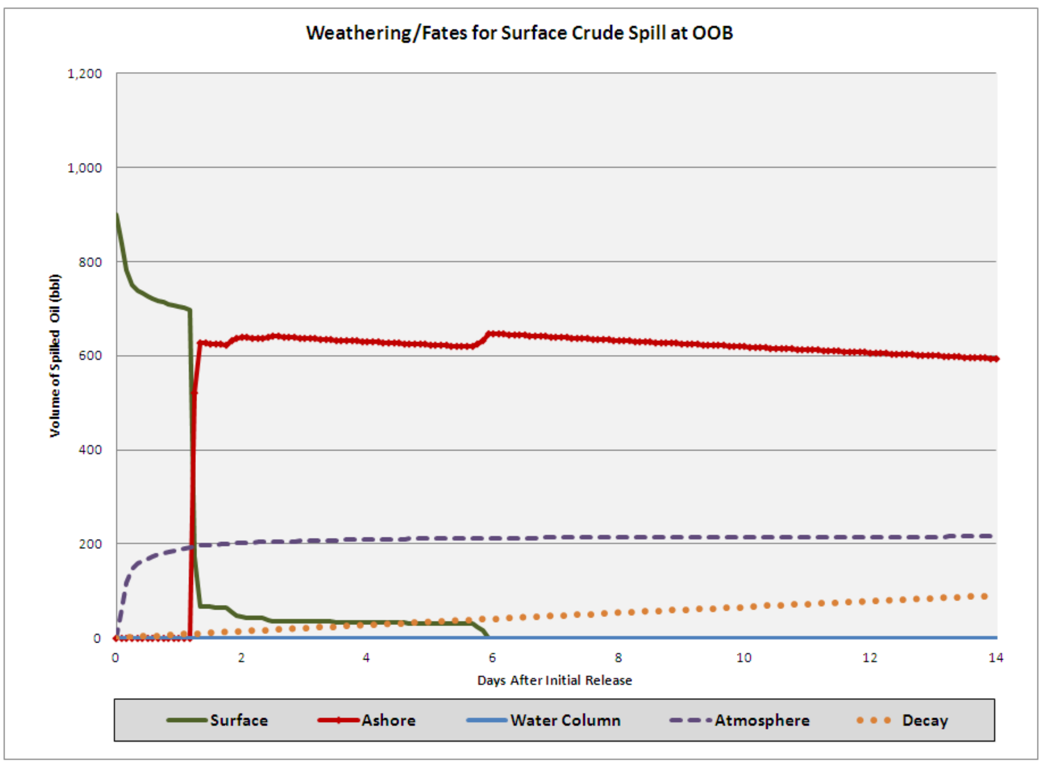




Figure 20. OOB 900 bbl Crude Surface Spill – Deterministic trajectory (grey-swept areas, red - oiled shoreline) after the 14 day simulation and the associated mass balance graph results.

Table 7. Deterministic results summaries for each surface spill scenario.

| Figure Number | Trajectory Description | Mass Balance Summary |
|---|---|---|
| *Scenario 1: 1,000 bbl Marine Gas Oil spill at the EN-7 Well Site* | | |
| Figure 17 | Trajectory heads to the north of the spill site. Because the spill was instantaneous, surface oil migrates in a cohesive single slick toward shore. Persistent winds move the oil relatively quickly to the coast. Once the slick reaches the coast, nearly the entire volume of oil remaining in the environment accumulates at the coastline, with no oil left on the water surface after 48 hours. While oil is never predicted to cross into the waters of Ivory Coast from this spill event, the oil makes landfall within 6 km of the Ghana-Ivory Coast border.<br><br>Time to shore: 32 hours<br>Length of shoreline oiled at end of simulation: 6 km along the westernmost coast of Ghana between Newtown and Half Assini | • Evaporation plays a major role in removal, with about 700 bbl (70%) evaporated, most of which occurred during the first 2 days after the spill.<br>• Decay processes, which include biodegradation and photo-oxidation of oil by sunlight, also play some role in oil removal, with 46 bbl (.046%) expected to be removed during the first 2 days after the spill.<br>• While natural processes do work to remove the bulk of the spilled oil from the environment, there is still 240 bbl (24%) oil expected to be stranded along the 6 km of coastline.<br>• About 14 bbl (.014%) of oil is expected to be entrained in the nearshore waters at very low concentrations. Some of this entrained oil remains just offshore of the oiled beach, although over time the subsurface oil will tend to migrate to the east due to along shore currents in this direction. |
| *Scenario 2: 3,453 bbl Crude Spill at the FPSO Site* | | |
| Figure 18 | Trajectory heads to the northeast of the spill site, with oil arriving at the coast approximately 45 hours after being released. At the end of the 21-day simulation, the model predicts that approximately 10 km of shoreline will be oiled between Esiama and Axim, Ghana.<br><br>Time to shore: 45 hours<br>Length of shoreline oiled at end of simulation: 10 km | • Evaporation plays a major role in removal, with about 837 bbl (24.2%) of oil evaporated, most of which occurred in the first day after the onset of the spill.<br>• Decay processes, which include biodegradation and photo-oxidation of oil by sunlight, also play some role in oil removal with 497 bbl (14.39%) expected to be removed in the simulation timeframe.<br>• While natural processes do work to remove the bulk of the spilled oil from the environment, there is still about 2,088 bbl (60.47%) of oil expected to be stranded along the coastline and about 25 bbl (.007%) of oil remaining on the water surface at the end of the simulation.<br>• A very small amount (about 0.6 bbl) of oil is expected to be entrained in the water column at very low concentrations. Some of this entrained oil remains just offshore of the oiled beach, although over time the subsurface oil will tend to migrate to the east due to the predominant currents. |
| *Scenario 3: 15,479 bbl Crude Spill at the FPSO Site* | | |
| Figure 19 | Trajectory heads to the northwest of the spill site, with oil arriving at the coast approximately 41 hours after being released. At the end of the 21-day simulation, the model predicts that approximately 64 km of shoreline will be oiled between Abidjan and Grand-Lahou, Ivory Coast.<br><br>Time to shore: 41 hours<br>Length of shoreline oiled at end of simulation: 64 km | • Evaporation plays a major role in removing oil from the environment, with about 3,742 bbl (24.17%) of oil evaporated, most of which occurred in the first day after the onset of the spill.<br>• Decay processes, which include biodegradation and photo-oxidation of oil by sunlight, also play some role in oil removal, with 2,245 bbl (14.5%) expected to be removed<br>• No oil remains on the water surface after 9 days of the simulation.<br>• While natural processes do work to remove the bulk of the spilled oil from the environment, there is still about 9,485 bbl (61.27%) of oil expected to be stranded along the coastline at the end of the simulation.<br>• A very small amount (about 2.5 bbl) of oil is expected to be entrained in the water column at very low concentrations. Some of this entrained oil remains just offshore of the oiled beach, although over time the subsurface oil will tend to migrate with the predominant currents. |

Table 7 (continued). Deterministic results summaries for each surface spill scenario.

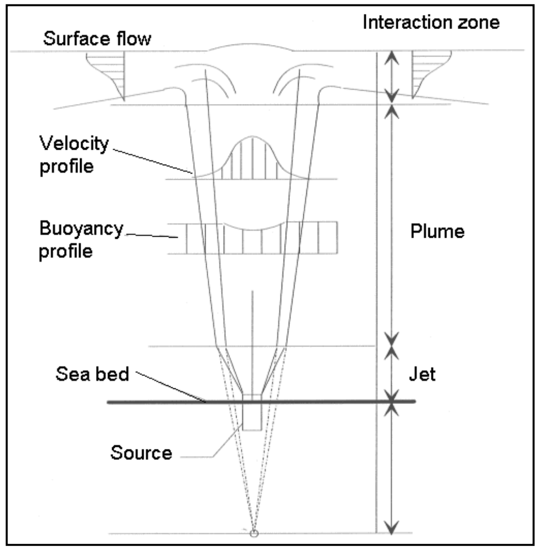
| Figure Number | Trajectory Description | Mass Balance Summary |
|---|---|---|
| *Scenario 4: 900 bbl Crude Spill at the OOB Site* | | |
| Figure 20 | The trajectory heads to the north-northeast from the spill site. The slick moves in a relatively straight trajectory toward the coast, making landfall along the westernmost coast of Ghana. Once the slick reaches the coast, most of the oil adheres to the shoreline. However, some of the oil (~50 bbl) remains on the water surface for an additional few days. This oil is slowly washed ashore and after 6 days there is no longer expected to be any surface oil remaining. While oil is never predicted to cross into the waters of the Ivory Coast from this spill event, the oil makes landfall within 7 km of the Ghana-Ivory Coast border.<br><br>Time to shore: 30 hours<br>Length of shoreline oiled at end of simulation: 4 km between Newtown and Half Assini | • Evaporation plays a major role in removing oil from the environment – although much less for this spill case relative to the release of MGO (Scenario 1).<br>• At the end of the simulation, about 216 bbl (24%) of oil had evaporated – most of which occurred in the first day after the onset of the spill.<br>• Decay processes, which include biodegradation and photo-oxidation of oil by sunlight, also play some role in oil removal with 90 bbl (10%) expected to be removed in that timeframe.<br>• While natural processes do remove some of the spilled oil from the environment, there is still 594 bbl (66%) oil expected to be stranded along the 7 km of coastline.<br>• A small fraction of oil (<1 bbl) is expected to be entrained in the nearshore waters at very low concentrations – forced into the water column by heavy winds and wave activity. Because the crude oil spilled at the OOB site can emulsify and become quite viscous when it is weathered, the volume of oil that becomes entrained in the water is much lower relative to the MGO spill case. |

# 4. Blowout Oil Spill Simulations

This study evaluated two potential subsurface blowout scenarios offshore Ghana. Stochastic and representative deterministic simulations were performed for these deep-sea blowout events. This section describes the modelling approach, the spill scenario parameters and oil properties, and the modelling results for the 3-D simulations.

## 4.1. Blowout Modelling Approach

***Description of a Blowout***




In a well blowout, discharged materials consisting of a mixture of gaseous and liquid hydrocarbon, go through three phases:

1) Momentum jet

The immediate pressure difference between inside the well and the ambient water drives the discharge. Due to the relative high-density of the deep ocean water, this jet momentum dissipates relatively quickly and is confined to the vicinity of the seabed (on the order of meters).

2) Buoyant density plume

As the discharge moves upward, the density difference between the expanding gas bubbles in the plume and the receiving water results in a buoyant force which drives the plume. As the plume rises, it continues to entrain sea water, reducing the plume's velocity and buoyancy and increasing its radius.

The oil in the release is rapidly mixed due to turbulence in the plume, resulting in a break up into small droplets. These droplets (typically a few micrometers to millimeters in diameter) are transported upward by the rising plume; their individual rise velocities contributing little to their upward motion.

3) Free rise and advection-diffusion.

As the plume reaches the sea surface or its *termination height* (when all momentum is lost), it can be deflected in a radial pattern within a horizontal / surface flow zone without appreciable loss of momentum. This radial jet carries the oil particles rapidly away from the center of the plume, while the velocity and oil concentrations in this surface flow zone decrease.

Subsequently, oil particles ascend to the surface solely by their own buoyancy. Rise velocities of oil droplets are much slower than the velocity of a buoyant gas-liquid plume, resulting in particle transport that may take considerably longer to reach the surface and result in transport farther (horizontally) from the release site due to ambient currents.

In order to reproduce this dynamic and complex process, blowout simulations are performed in two steps:

A. Near-field analysis, describing the oil/gas plume generated by the blowout that typically evolves vertically due to vertical processes (momentum and relative buoyancy), and
B. Far-field analysis, describing the long term transport and weathering of the released oil mixture, that typically evolves as a horizontal process due to currents and winds

The near-field model results provide the initial conditions for both the stochastic and deterministic modes of the far-field modelling. The near-field results depend more on the blowout conditions (flow rate, GOR, and pipe diameter), and less on the environmental conditions (e.g., seasonality). Conversely, the far-field modelling is highly dependent on the environmental conditions such as winds and currents as the main the drifting/driving forces.

**Near-field Blowout Modelling Overview**

The near-field modelling was completed using ASA's OILMAP/Deep model. The objective of this first step of the blowout modelling is to characterize the plume mixture (oil, gas and water) discharged from the wellhead blowout. In most cases the near-field region occurs only within a few hundred of meters of the wellhead.

The OILMAP/Deep model was developed as an enhanced version of the ASA's OILMAP modelling system. The blowout model solves equations for the conservation of water mass, momentum, buoyancy, and gas mass using integral plume theory, following work outlined in McDougall (1978). Equilibrium hydrate formation and dissociation for methane gas are determined by a multi-phase flash calculation developed by Bishnoi et al. (1979). An additional description of the OIMAP/Deep modelling system is provided in Appendix B.

The results of the near-field model provide a description of the behaviour of the blowout plume, its evolution within the water column and the expected initial dilution (concentration decrease) with distance from the wellhead (seafloor). It provides information about the termination height of the plume and the oil droplet size distribution(s) associated with the release.

The results obtained in the near-field analysis are used as initial conditions of the far-field modelling:

- Location and size of the plume at the termination height
- Characterization of the oil droplets size distribution

**Far-field Sub-surface Oil Spill Modelling Overview**

ASA's 3-D oil spill modelling system, SIMAP, was used to assess the fate of oil in the far-field, defined as the point at which ambient currents dominate the oil transport rather than the near-field blowout plume phase. The SIMAP model quantifies the transport and fate of different components of hydrocarbon mixtures in different compartments of the marine environment with respect to both spatial and temporal domains. SIMAP is a three dimensional Lagrangian model, and each component of the spilled oil (dispersed, dissolved, etc.) is represented by an ensemble of independent mathematical particles or "spillets". Each spillet is a sub-set of the total mass spilled and is transported by both currents and surface wind drift.

SIMAP's stochastic and trajectory and fates models were used to analyse surface and shoreline oiling for the potential subsurface blowout. The stochastic simulations provide insight into the probable behaviour of potential oil spills in response to typical meteorological and oceanographic conditions in the study area. The stochastic model computes surface trajectories for an ensemble of hundred of individual spill releases for each spill scenario, with each individual simulation start time selected randomly within the seasonal timeframe of interest specified thus sampling the variability in the wind and current forcing. The results of this ensemble of simulations are processed statistically to provide the spatial distribution of probability of surface and shoreline oiling as well as the associated travel times. The trajectory and fate simulations provide an estimate of the oil's weathering for a particular representative simulation anticipated to have significant or worst case impacts based on the stochastic analysis.

The stochastic analysis provides two types of information: (1) the footprint of sea surface areas that might be oiled and their associated probability of oiling, and (2) the shortest time required for oil to reach any point within the areas predicted to be oiled. The probabilities of oiling within the predicted cumulative footprint are a product of statistical analysis performed on the sum of the individual simulations from the entire ensemble. This footprint represents the likely area of sea surface oiling from a spill in that location. It is important to note that any one simulation will encounter only a relatively small area of this footprint. In addition, the simulations provide shoreline oiling data expressed in terms of times required for oil to reach shore, lengths of shoreline oiling, and the percentage of simulations in which oil is predicted to reach shore.

The trajectory/fate simulations provide an estimate of the oil's weathering under particular environmental conditions. A representative or "worst case" deterministic trajectory/fate simulation was performed under a specific set of wind and current conditions associated with individual simulation from the stochastic analysis. Due to long duration of the spill event, there is no clear metric to define the worst case, since all of the scenarios result in large areas of shoreline oiled and water surface covered. Therefore a representative case was chosen for further analysis which showed the general trends expected from a spill event and which resulted in a significant amount of oil at the shoreline.

Additional information on the SIMAP modelling system is contained in Appendix B.

## 4.2. Oil Spill Scenario Parameters

This study evaluated two potential subsurface spills, as outlined in Table 8. The spills involved the same blowout parameters (Table 9) with the only differences between the two modelled spill simulations being the location and depth of release.

Table 8. Parameters of the oil spill scenarios.

| Spill Site | Oil Type | Spill Type | Season | Spill Rate | Spill Duration | Total Spilled Volume | Simulation Duration |
|---|---|---|---|---|---|---|---|
| EN-7 | Crude | Subsurface Blowout | Yearly | 10,000 bbl/day | 60 days | 600,000 bbl | 75 days |
| EN-22 | Crude | Subsurface Blowout | Yearly | 10,000 bbl/day | 60 days | 600,000 bbl | 75 days |

The simulation duration was increased beyond the spill duration to allow sufficient time for the majority of the oil released to reach the shoreline or be degraded by weathering processes. Each of the scenarios was simulated for a total of 75 days.

Table 9. Blowout conditions used in the subsurface simulations.

| Water Depth | Gas to Oil Ratio | Pipe Diameter | Discharge Temperature |
|---|---|---|---|
| EN07 - 992 m<br>EN22 – 1,851 m | 159-210 $m^3/m^3$ (average) | 12.347 in | 80-110° C (average) |

## 4.3. Oil Characterization

The scenarios assumed a release of Enyenra Crude, similar to two of the surface spill scenarios. As previously stated, the client provided information concerning the properties of the crude oil, including the evaporation curves, aromatic components, and physical properties of the Enyenra crude. Table 10 provides a summary of the oil characteristics of the Enyenra Crude used in these simulations; note that these are the same parameters that were presented in Table 4.

Table 10. Summary of the oil characterization data used in the spill simulations.

| Oil Type | Density ($g/cm^3$) | Viscosity (cP) | Surface Tension (dyne/cm) | Maximum Water Content (%) |
|---|---|---|---|---|
| Enyenra Crude | 0.857 | 21.984 @ 20°C | 27.0 | 82.0 |

Viscosity and interfacial surface tension affect the degree of spreading of the surface oil, which in turn influences the rates of evaporation, dissolution, dispersion, and photo-oxidation. The maximum water content is a measure, obtained in a laboratory, of the emulsion-formation tendency of the oil. Oils that form water-in-oil emulsions tend to be more persistent in the marine environment as they are less likely to be dissolved and/or evaporated; this increases their potential for reaching the shoreline. Because the Enyenra Crude can emulsify, it tends to be more persistent in the environment relative to non-emulsified oils.

## 4.4. Near-Field Analysis - Blowout Plume Results

### 4.4.1. Termination Height and Radius

The results of the near-field modelling provide information about the formation of the blowout plume - the three dimensional extent of the mixture of gas/oil/water, and a characterization of the initial dispersion / mixing of the oil discharged during the blowout. Key factors in this analysis are the gas to oil ratio (GOR), the oil and gas flow rates, and water column conditions (oil and water temperature and water density) as they pertain to the potential for hydrate formation. Other factors such as duration of the blowout or ambient currents are also included but have less influence on the near-field model results.

Because there are no significant (observable) differences in the environmental conditions in very deep water near the well head (similar temperature, salinity, and density year around) only one set of near-field results are presented for the two deep sea blowout simulations.

Figure 21 and Figure 22 present the OILMAP/Deep modelling results for the specified blowout scenarios for the two well sites; these figures show:

- Plume radius plotted as a function of the height above the sea floor (well-head)
- Plume velocity along the centreline of the blowout as a function of the height above the seafloor. Plume centreline velocity defines the vertical movement of the mixture of gas, oil and water along the centre of the plume.

The model indicates that the velocity of the plume decreases quickly at heights further from the discharge point as it entrains heavier ambient seawater. As the plume continues to rise and entrain more ambient seawater, the centreline velocity gradually decreases, and approaches zero. From this termination height, gas bubbles and oil droplets will ascend to the water surface under free rise velocities determined by Stokes law. The free rise velocities of the oil droplets are significantly less than that of the gas due to the size and density differences.

The plume diameter increases linearly until about ~90% of the termination height has been reached, at which point the plume widens more quickly. Although the conditions (GOR, oil type, pipe diameter) are the same for the two well sites, the depths of the two sites differ. Because of this the density and pressure at the two sites (well-heads) are different and therefore the blowout plume dimensions will vary. At EN-7, the plume is expected to terminate approximately 69 m above the well head and have a radius of about 21 m. At EN-22, which is much deeper, the plume will extend about 120 m above the well head and will have a radius of about 42 m.

The characterization of the plume height and radius may be important to oil spill responders for determining the area for most effective dispersant application or subsurface collection of oil. In the near-field plume, during the jet momentum and density plume phases, concentrations of oil are the highest. After the oil leaves these phases, oil droplets begin to rise under their own buoyancy and are transported away from the discharge by advection and diffusion, both vertically and horizontally. Therefore, any sort of subsurface collection of the oil or application of dispersants would likely be most effective within the defined dimensions of the plume.

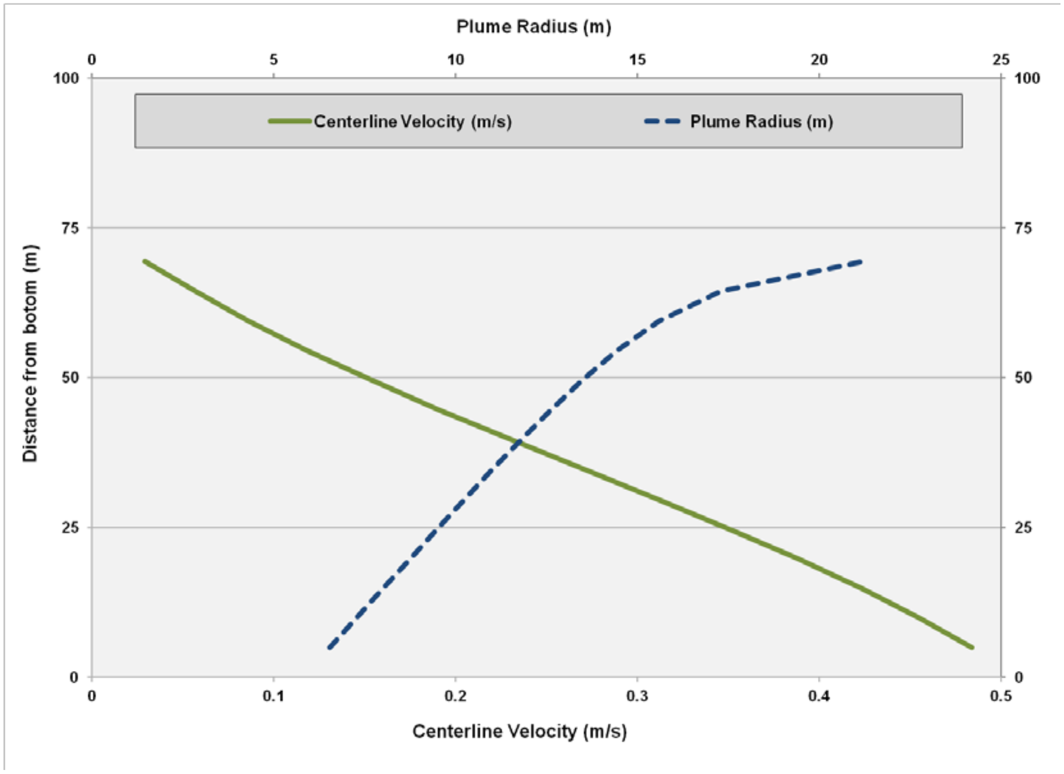



Figure 21. Predicted blowout plume centerline velocity and plume radius versus elevation above release point for the blowout event at EN-7.

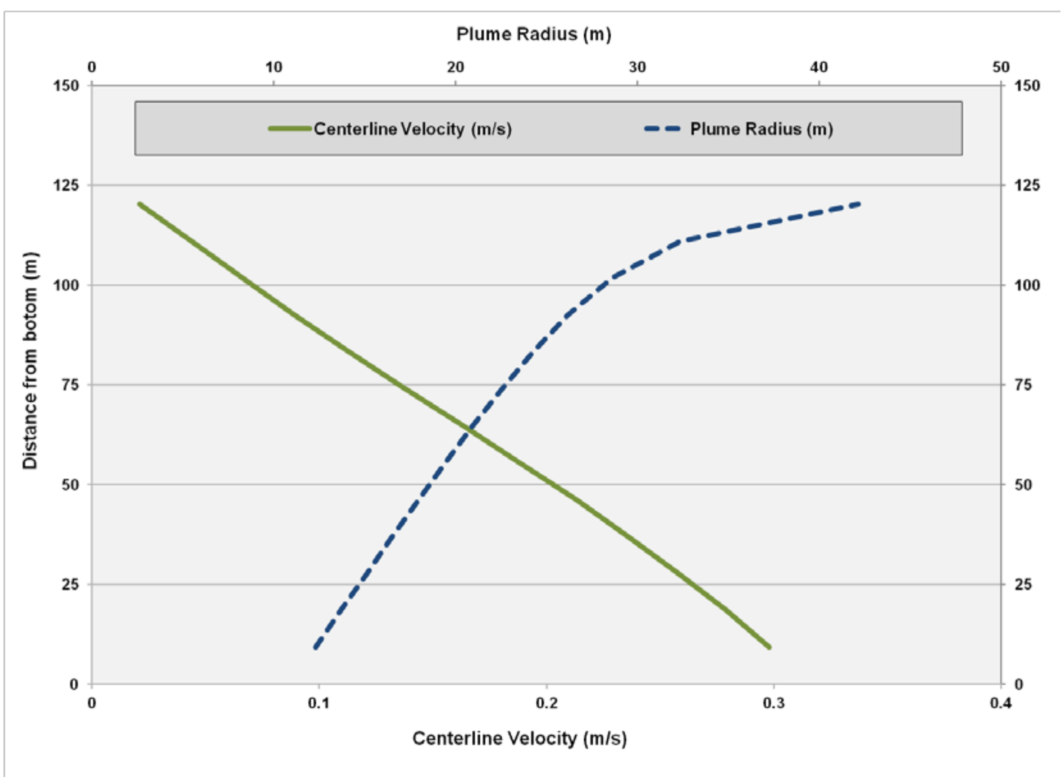



Figure 22. Predicted blowout plume centerline velocity and plume radius versus elevation above release point for the blowout event at EN-22.

### 4.4.2. Droplet Size Distribution

Near-field modelling results also provide a characterization of the oil droplet size distribution generated by the blowout. The distribution has a profound effect on how oil is transported after the initial plume, as the size dictates how long the oil droplet will remain suspended in the water column. Large droplets will reach the surface faster, potentially generating a floating oil slick that will drift much faster due to surface winds and currents; small droplets will remain in the water column longer and be subjected to the subsurface advection-diffusion transport. As the oil is transported by subsurface currents away from the well site, natural dispersion of the oil droplets quickly reduces aromatic and hydrocarbon component concentrations in the water column, with decreasing concentration at increasing distance away from the well site. However, lower rise velocities of the oil particles correspond to longer residence times of oil suspended in the water column and thus a larger volume of affected water.

Depending on the environmental conditions near the spill location, there may also be significant degradation and decay of the oil before surfacing occurs. The oil decay rate is typically much higher in warm water environments where biological productivity is high and microbial organisms may play an active role in the breakdown of oil. Thus if the oil remains in the water column longer, there may be significantly less oil by mass that eventually surfaces.

From a response perspective, a turbulent blowout that results in the formation of very small oil droplets essentially acts as a natural dispersant mechanism, as these smaller size particles effectively keep the oil from surfacing. On the other hand, with large particle sizes, there will be quick surfacing of oil which will limit the subsurface area exposed to oil, but result in a larger surface oil slick.

The particle size distribution predicted by OILMAP/Deep is calculated based on the Rosin-Rammler distribution and is most heavily influenced by the exit velocity of the discharged mixture of oil and gas which is an indicator of the energy associated with the release. However, other variables such as seawater density can also influence the predicted distribution. Just as the dimensions of the plumes will differ at the two sites due to depth variations, the oil droplet sizes produced from the two blowouts will also differ.

Table 11 summarizes the oil droplet size ranges and Figure 23 illustrates the model estimated droplet size distributions and time to surfacing for the assumed blowout scenario for EN-7. The specific conditions and parameters of the blowout scenario at EN-7 resulted in the formation of relatively large oil droplets. The smallest particles (500 microns) would rise to the surface in about 20 hours. The largest particles (10,000 microns) would surface in only 2 hours.

Table 12 summarizes the oil droplet size ranges and Figure 24 presents the model estimated droplet size distributions and time to surfacing for the assumed blowout scenario for EN-22. The specific conditions and parameters of the blowout scenario at EN-22 similarly resulted in the formation of relatively large oil droplets. The smallest particles (500 microns) would rise to the surface in about 38 hours. The largest particles (10,000 microns) would surface in about 4 hours.

Overall the particle size distributions predicted for EN-7 and EN-22 are very similar owing to the fact that the initial conditions (flow rate, pipe opening size, etc.) are identical. The slight differences predicted between the two sites result from the (gas) pressure difference resulting from difference in depth between the two well sites.

Table 11. Characteristics of the predicted oil droplets size distribution for the EN-7 well blowout.

| | Minimum Droplet Size | Median Volume Droplet Size | Maximum Droplet Size |
|---|---|---|---|
| **Size (microns)** | 500.0 | 6,000 | 10,000 |
| **Time to Surface (hours)** | 20.2 | 1.9 | 2.0 |

Table 12. Characteristics of the predicted oil droplets size distribution for EN-22 well blowout.

| | Minimum Droplet Size | Median Volume Droplet Size | Maximum Droplet Size |
|---|---|---|---|
| **Size (microns)** | 500.0 | 6,500 | 10,000 |
| **Time to Surface (hours)** | 37.9 | 3.6 | 3.7 |

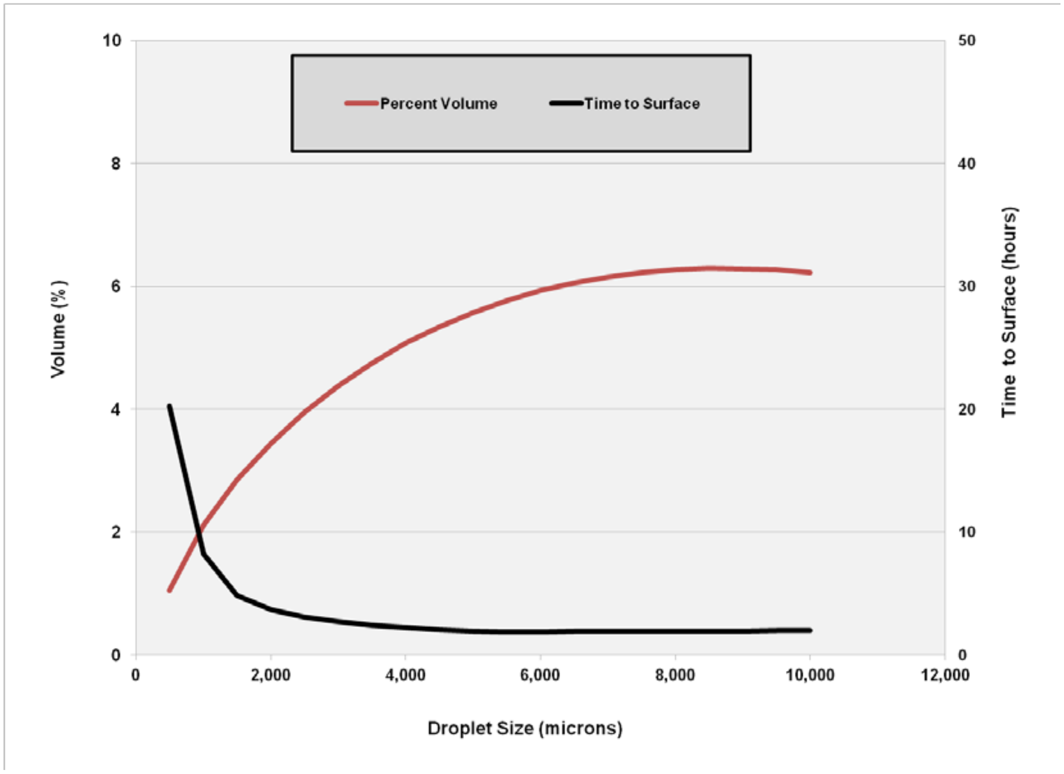



Figure 23. En-7 Predicted droplet size distribution and droplet rise times to the surface from a potential blowout.

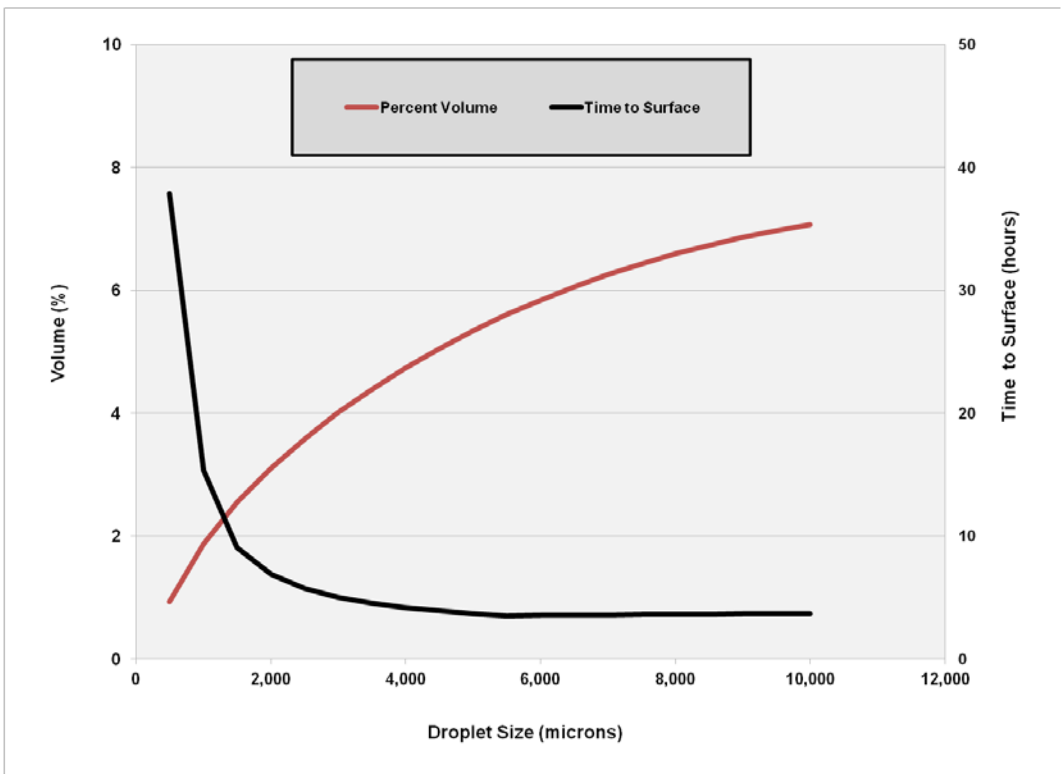



Figure 24. EN-22 Predicted droplet size distribution and droplet rise times to the surface from a potential blowout.

## 4.5. Far-Field Oil Spill Model Results

### 4.5.1. Stochastic Model Results

The SIMAP stochastic model was used to predict the statistical footprint of oiling associated with the two blowout scenarios.

#### *Predicted Probabilities of Shoreline Oiling*

Table 13 provides a summary of the oil spill modelling results in terms of shoreline oiling statistics. This table is presented to provide a sense of the degree of impact due to a potential large blowout from *the offshore site*, without focusing on the shoreline areas potentially affected. The table provides the percentage of individual simulations reaching shore, indicating the likelihood that a particular spill event will reach nearby coastal areas *at some point*, as well as the volume of oil and expected time for oil to reach the coast *at some point*.

The percentage is based on the total number of trajectories within the ensemble of individual simulations that reached the coast; only those trajectories that resulted in shore contact with more than 0.01% of the initial mass released have been included in the total.

Note that a spill event with high probability of shoreline oiling does not imply that a particular section of the coast will be oiled. Depending on the variability of winds and currents used in the stochastic simulations, the stochastic results may show a high probability of oil reaching the coastline *at some location* in the study area. However, the cumulative area potentially oiled can be spread over a wide region based on the trajectories of individual simulations; in those cases, a particular coastal segment may have a small probability of being oiled.

Table 13. Oil Spill Stochastic results – Predicted shoreline impacts.

| Location | Oil Type | Spill Type | Total Volume Released (bbl) | Sims. reaching shore (%) | Amount of oil ashore (bbl) | | | | Time to reach shore (hours) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Peak | | End of Simulation (75 days) | | | |
| | | | | | Max. | Avg. | Max. | Avg. | Min. | Avg. |
| EN-7 | Crude | Subsurface Blowout | 600,000 | 100 | 228,357 | 118,533 | 223,487 | 114,149 | 32 | 122 |
| EN-22 | Crude | Subsurface Blowout | 600,000 | 100 | 228,682 | 135,720 | 227,048 | 133,336 | 54 | 195 |

Some of the highlights of Table 13:

- Both of the blowout scenarios resulted in 100% of cases reaching some segment of the shoreline due to the proximity of the spill sites to the shoreline, the nature of the winds and currents in this region, and the long duration and volume of the spills.
- From the EN-7 well site, oil may reach the coast in less than 1.5 days, although on average it would take about 5 days to reach some part of the West African coastline.
- From EN-22, the spilled oil could reach shore in less than 2.5 days although would typically take about 8 days to reach some part of the coastline. Because EN-22 is located further offshore and in deeper water it takes on average 3 days longer for oil to reach the coast relative to EN-7.
- Of the 600,000 bbl of oil spilled, up to about 230,000 bbl (about 38%) could reach the coast. However, on average much less oil would reach the coastline from any particular spill event. For the EN-7 blowout scenario, on average about 114,000 bbl of oil (about 19%) is expected to remain along the coast at the end of the 75 day simulation. For the EN-22 simulation, on average the volume of oil predicted to wash ashore is expected to be slightly higher at 133,000 bbl (about 22% of the initial spilled volume).

### *Predicted Stochastic Footprint of Surface and Shoreline Oiling*

Figure 25 and Figure 26 illustrate the spatial extent of surface oiling probabilities and associated minimum travel times for the stochastic blowout scenarios. Two figures are presented for each scenario:

1. **Probability of oiling**: This map shows the potential oiling of sea surface areas with their associated probabilities of oiling. These results are based on the statistical analysis of the sum of trajectories resulting from the ensemble of independent simulations. The plots do not imply that the entire footprint would be covered or polluted with oil, but rather illustrate the cumulative extent of oiling from the ensemble of hundreds of simulations used to create the probabilities of sea surface oiling. Note that the plots also do not provide any information on the quantity of oil in a given area.

2. **Minimum travel times**: The footprint on this map corresponds to the probability map, and illustrates the shortest time required for oil to each any point within the footprint. These results are also based on the ensemble of all independent simulations.

For the EN-22 spill scenario, the model predicts that a larger volume of oil will, on average, reach the coastline and that there is a larger length of coastline with greater than a 50% chance of being oiled relative to the EN-7 spill event. However, the EN-7 spill scenario resulted in a higher likelihood of oil heading to the west (into Ivory Coast and Liberia). Additionally, because oil spilled at EN-7 had such a tendency of being transported directly to shore, the holding capacity of the coast was often met and thus the coast in the western region of Ghana would almost always be saturated with oil from such a spill. Because of this saturation, less oil was expected to be on the coast because it would be floating in the nearshore coastal waters – still posing major environmental and economic risks.

Table 14 summarises the main modelling results for each spill scenario.

Table 14. Stochastic results summaries for each individual subsurface spill scenario.

| Figure Number | Water Surface Oiling Summary | Shoreline Oiling Summary | Comments |
|---|---|---|---|
| *Scenario 5. 600,000 bbl Subsurface Blowout at EN-7* | | | |
| Figure 25 | Oil could be transported in any direction; however, there is a preference for transport to the north and east.<br><br>The 10% and 50% probability contours reach up to 1,290 km and 380 km away, respectively.<br><br>In the first week oil could be transported up to 450 km away, while in 4 weeks the oil could be transported up to 990 km away. | Oil reaches the coast in less than 1.5 days. There is a 100 % chance that oil would arrive to some segment of the coastline.<br><br>Shorelines potentially affected (and probability of oiling):<br>• Area between Half Assini and Axim (>90% chance)<br>• Near Accra ( 43% chance)<br>• Segments of Nigeria (34% chance)<br>• Segments of Equatorial Guinea (6% chance) | Because the crude oil can emulsify, it tends to be relatively persistent in the environment and has the potential to travel far distances away from the well site.<br><br>Although oil spilled from EN-7 can travel far away from the well site, oil is most commonly transported toward the northeast where it will reach the shore within a shorter extent.<br><br>Depending on the winds and current conditions during the actual spill event, the regions affected may differ. In particular, regional currents have the potential of driving oil far to the east in some circumstances |
| *Scenario 6. 600,000 bbl Subsurface Blowout at EN-22* | | | |
| Figure 26 | Oil could be transported in any direction; however, there is a preference for transport to the north and east.<br><br>The 10% and 50% probability contours reach up to 1,200 km and 640 km away, respectively.<br><br>In the first week oil could be transported up to 420 km away, while in 4 weeks the oil could be transported up to 1,120 km away. | Persistent southwesterly winds tend to drive floating surface oil toward the northeast, with oil reaching the coast in as little as 54 hours from the spill site. The spill simulations show that there is a 100 % chance that oil would reach some segment of the coastline, however, there is no individual coastal segment that has higher than a 90% chance of being oiled from this spill.<br><br>Shorelines potentially affected (and probability of oiling):<br>• Areas near Axim (>90% chance)<br>• Near Accra ( 57% chance)<br>• Segments of Nigeria (49% chance)<br>• Segments of Equatorial Guinea (8% chance) | Because the crude oil can emulsify, it tends to be relatively persistent in the environment and has the potential to travel far distances away from the well site.<br><br>Although oil spilled from EN-7 can travel far away from the well site, oil is most commonly transported toward the northeast where it will reach the shore within a shorter extent.<br><br>The likelihood of oil hitting the shoreline directly to the northeast of the spill site is slightly lower for the EN-22 relative to the EN-7 scenario. While winds at the two sites are quite similar, the EN-22 site is further offshore and here the easterly currents tend to drive oil further to the east before making landfall. |

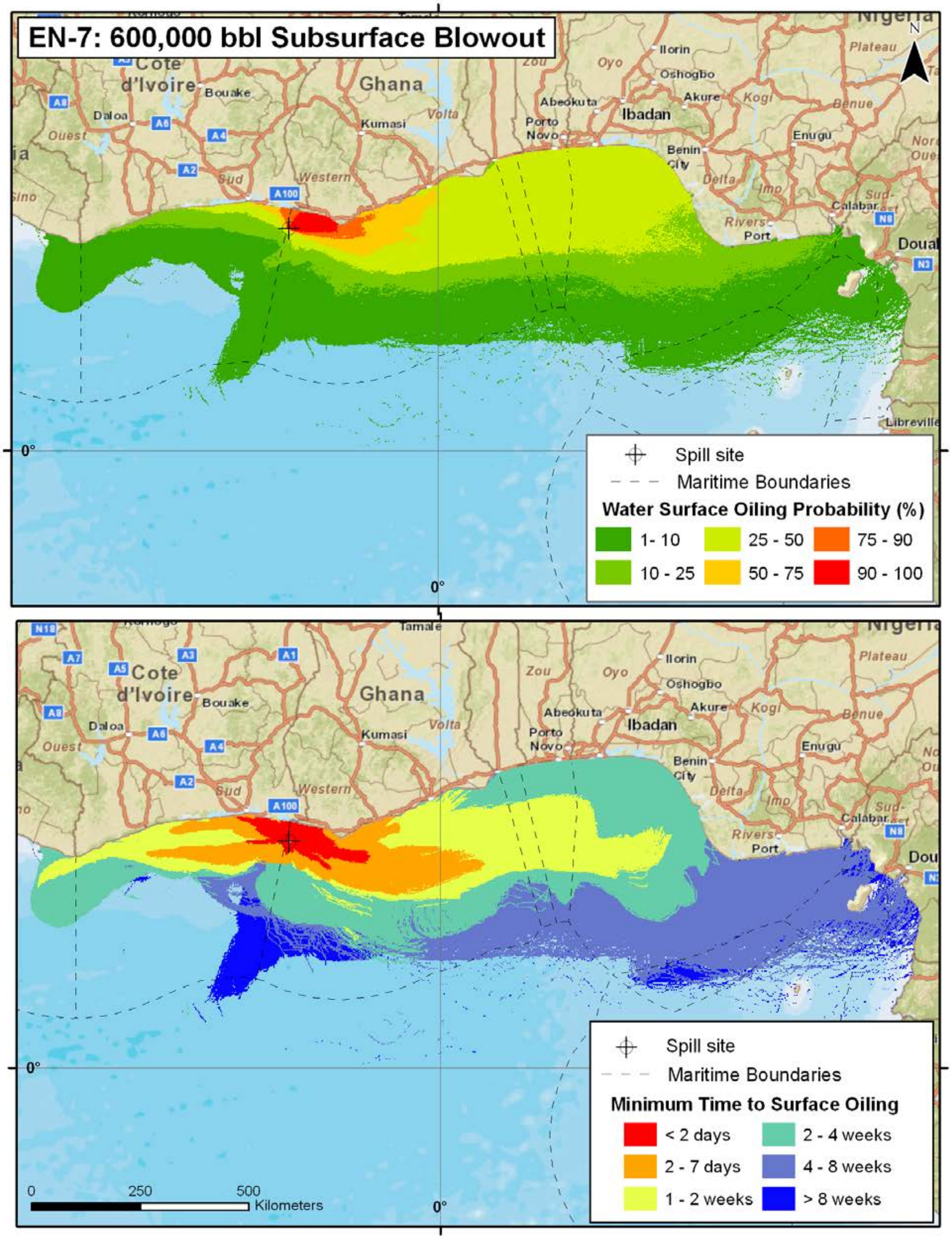



Figure 25. EN-7 600,000 bll Crude Subsurface Blowout - Water surface oiling probabilities (top image) and minimum time for surface oiling (bottom image).

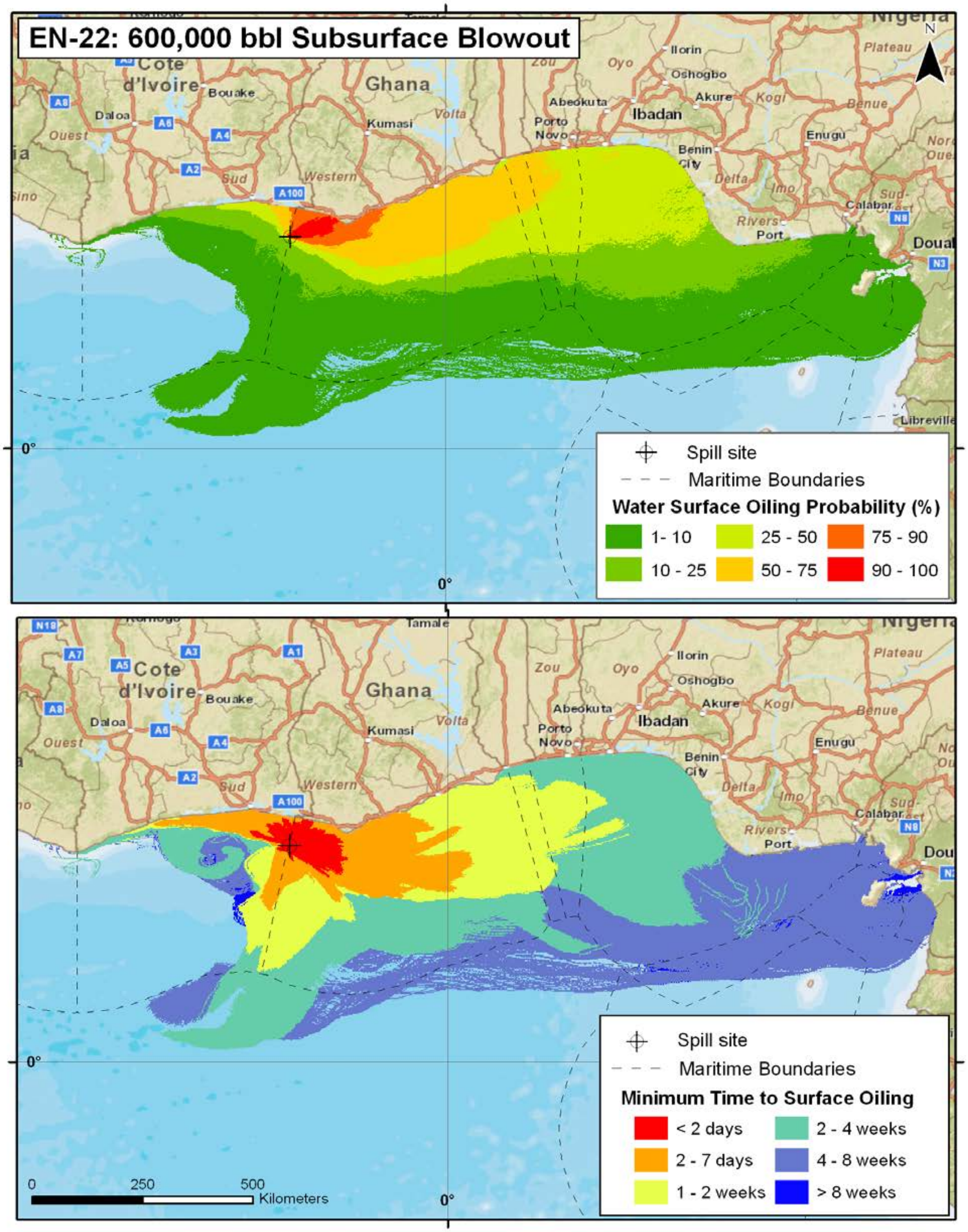



Figure 26. EN-22 600,000 Crude Subsurface Blowout - Water surface oiling probabilities (top image) and minimum time for surface oiling (bottom image).

### *Predicted Stochastic predicted Shoreline and EEZ oiling*

The following tables and plots provide an additional understanding of the blowout spill stochastic results:

- Table 15 and Table 16 provide information about the maximum distance from the spill site to given probability contours (Table 15) and time after the spill (Table 16) for each blowout scenario.

- Table 17 and Table 18 provide additional results of the oiling that can potentially reach each individual country's coastline and its regional waters (Economic Exclusive Zone) due each blowout scenario. Based on the number of individual trajectories within the stochastic ensemble that reach or crossed one particular area of interest, the table provides information about:
  - the maximum probability of oil crossing a particular EEZ or reaching one country coastline
  - minimum time to reach this particular region / shore
  - the maximum averaged oil concentration ($kg/m^2$) reaching the EEZ or coastline calculated as the average of the maximum concentration observed over the ensemble of individual trajectories

- Figure 27 presents a graphic version of the previous tables (minimum travel time and maximum averaged concentration). For example, the second plot (bottom), highlights the greater chance of a blowout in EN-7 to generate a larger impact (higher concentration of oil ashore) in Ivory Coast or Ghana while a blowout in EN-22 would generate a larger impact in countries further east from the sites.

- Figure 28 presents, for each blowout scenario, the total length of predicted shoreline oiled in each individual trajectory from the ensemble of stochastic simulations, ranked in order. This provides a sense of the distribution (likelihood) of each individual trajectory of impacting a section of the coast. For example, in half of the individual simulations, the total length of shoreline oiled is greater than 500km.

Table 15. Maximum distance to floating surface oil for given probability contours for blowout at EN-7 and EN-22.

| **Probability Contour** | **Maximum Distance to Floating Surface Oil (km)** | |
|---|---|---|
| | **From EN-7** | **From EN-22** |
| 1% | 1,470 | 1,470 |
| 10% | 1,290 | 1,200 |
| 25% | 960 | 950 |
| **50%** | **380** | **640** |
| 75% | 210 | 230 |
| 90% | 110 | 110 |

Table 16. Maximum distance to floating surface oil for given time contours for blowout at EN-7 and EN-22.

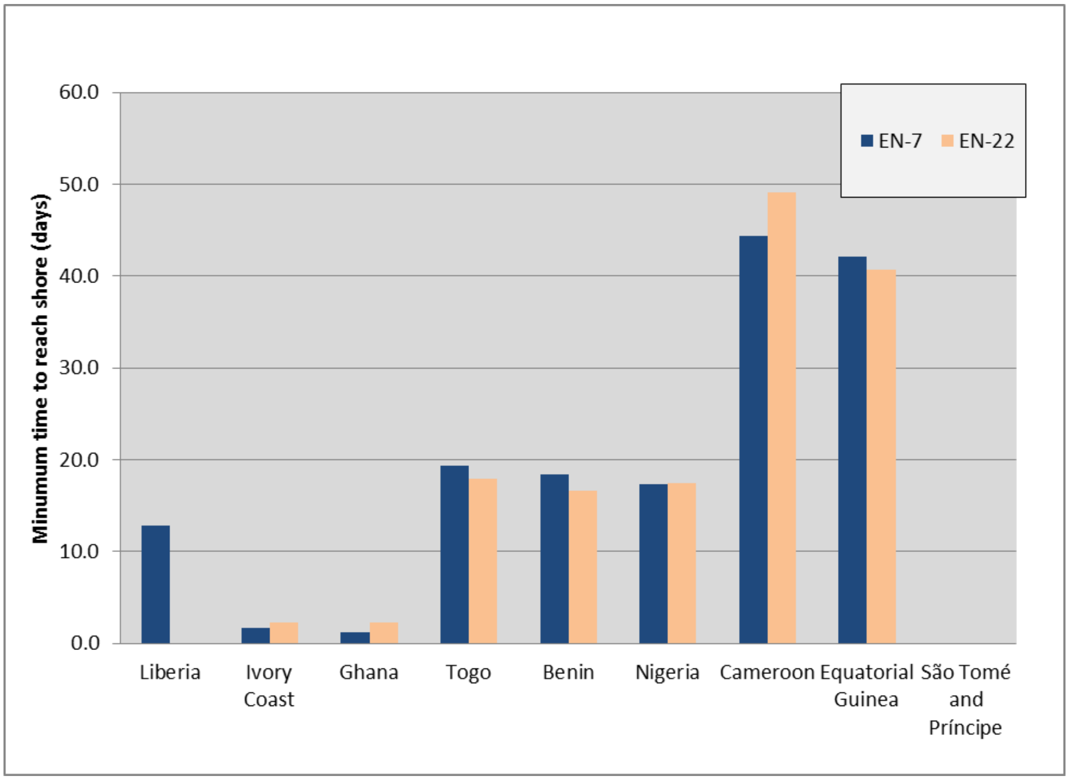
| **Time After Start of Spill** | **Maximum Distance to Floating Surface Oil (km)** | |
|---|---|---|
| | **From EN-7** | **From EN-22** |
| **2 Days** | **190** | **270** |
| 1 Week | 450 | 420 |
| 2 Weeks | 880 | 770 |
| **4 Weeks** | **990** | **1,120** |
| 8 Weeks | 1,460 | 1,470 |
| 75 Days | 1,470 | 1,470 |

Table 17. Summary of the stochastic model results of the EN-7 blowout simulations for each country in the region.

| **Country/ EEZ** | **Offshore /Exclusive Economic Zone (EEZ)** | | | **Shoreline** | | |
|---|---|---|---|---|---|---|
| | **Max probability of oiling** | **Time to reach region (hours)** | **Max. averaged concentration ($g/m^2$)** | **Max probability of oiling** | **Time to reach shore (hours)** | **Max. averaged concentration ($g/m^2$)** |
| Liberia | 7 % | 253 | 3 | 6 % | 309 | 164 |
| Ivory Coast | **88 %** | 5 | 330 | 88 % | 40 | 3,845 |
| Ghana | **100%** | 2 | 297 | 100% | 29 | 4,334 |
| Togo | 48 % | 202 | 2 | 34 % | 463 | 399 |
| Benin | 47 % | 214 | 1 | 34 % | 442 | 427 |
| Nigeria | 46 % | 235 | 5 | 34 % | 415 | 750 |
| Cameroon | 14 % | 989 | 8 | 8 % | 1,064 | 49 |
| Equatorial Guinea | 11 % | 883 | 7 | 6 % | 1,010 | 43 |
| São Tomé and Príncipe | 5 % | 821 | 2 | < 1 % | N/A | - |

Table 18. Summary of the stochastic model results of the EN-22 blowout simulations for each country in the region.

| **Country/ EEZ** | **Offshore /Exclusive Economic Zone (EEZ)** | | | **Shoreline** | | |
|---|---|---|---|---|---|---|
| | **Max probability of oiling** | **Time to reach region (hours)** | **Max. averaged concentration ($g/m^2$)** | **Max probability of oiling** | **Time to reach shore (hours)** | **Max. averaged concentration ($g/m^2$)** |
| Liberia | 2 % | 386 | 3 | 1 % | 1,700 | - |
| Ivory Coast | **96 %** | 5 | 238 | 79 % | 54 | 3,341 |
| Ghana | **100 %** | 4 | 242 | 90 % | 54 | 3,912 |
| Togo | **62 %** | 216 | 2 | 51 % | 429 | 740 |
| Benin | **59 %** | 234 | 3 | 50 % | 400 | 1,103 |
| Nigeria | **54 %** | 274 | 7 | 49% | 419 | 1,217 |
| Cameroon | 14 % | 871 | 2 | 7 % | 1,180 | 134 |
| Equatorial Guinea | 11 % | 875 | - | 8 % | 978 | 170 |
| São Tomé and Príncipe | 5 % | 935 | - | < 1% | N/A | - |



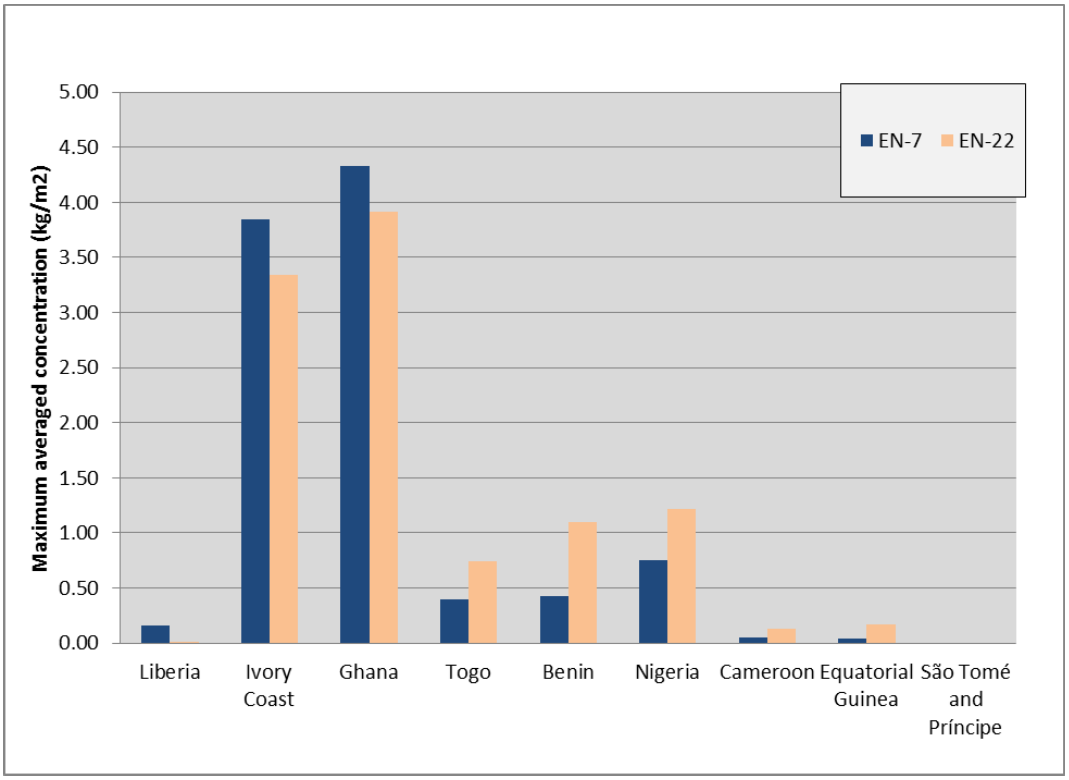
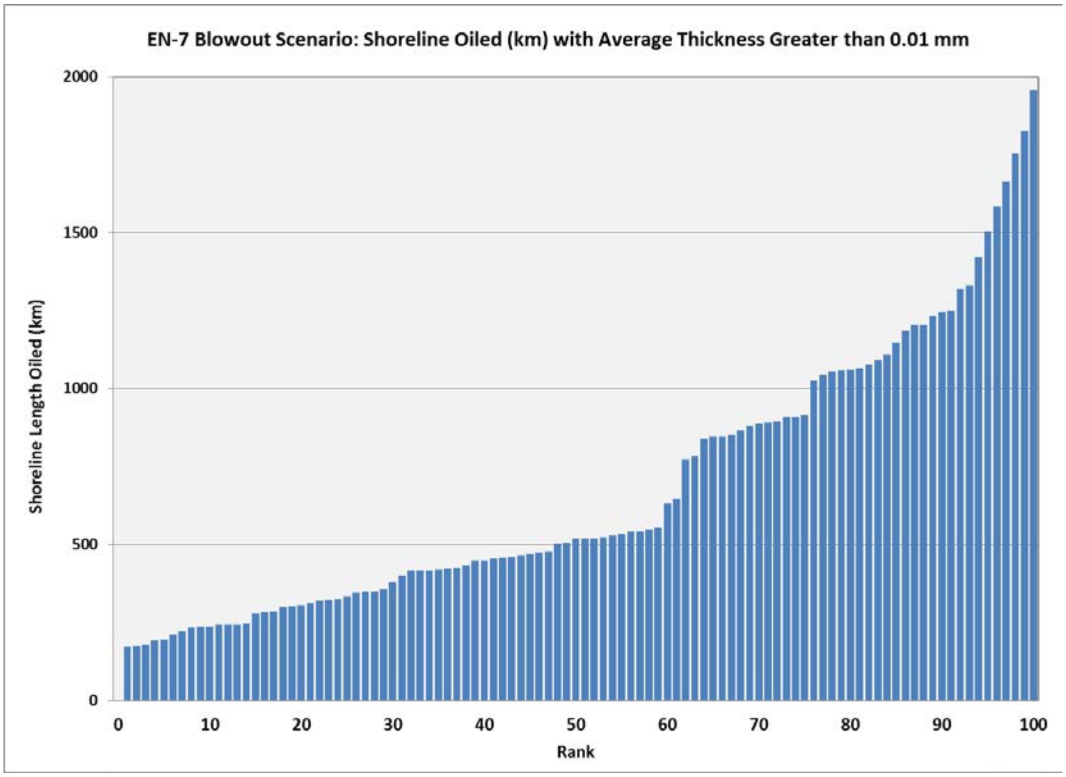




Figure 27. Predicted minimum time to reach shore and maximum averaged concentration due to the blowout at EN-7 and EN-22 classified by coastal countries potentially affected.



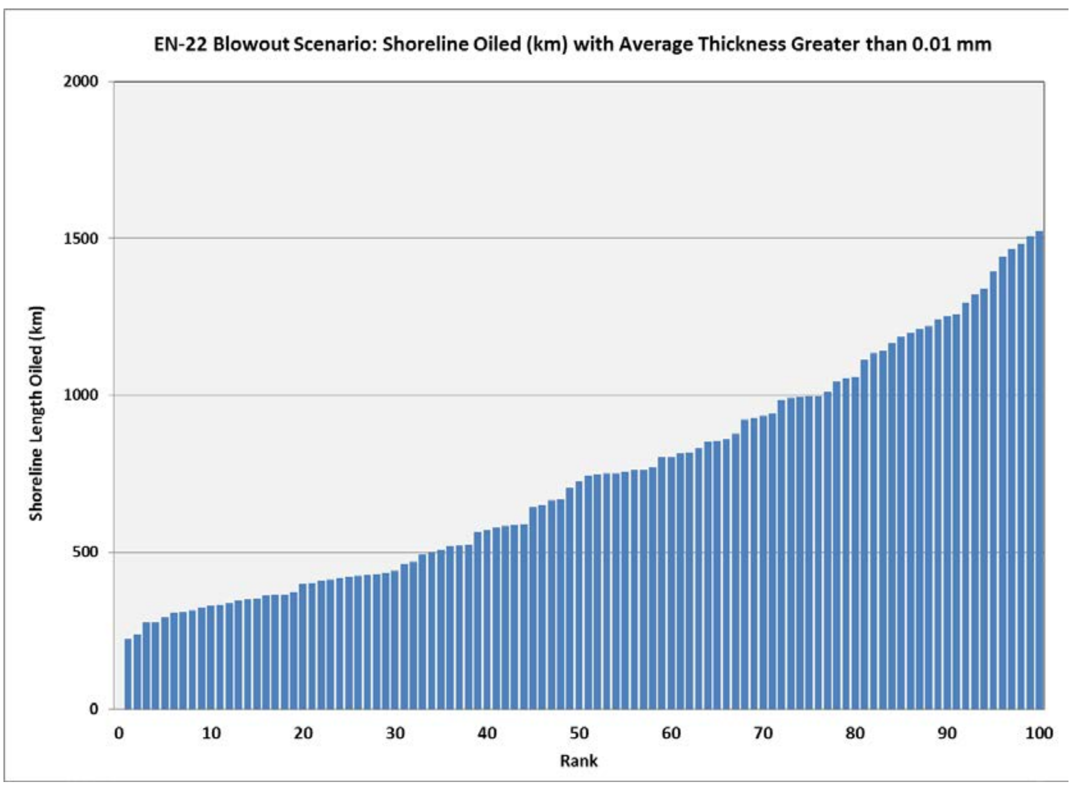




Figure 28. Predicted length of shoreline oiled in each individual trajectory simulation amongst the ensemble of stochastic simulation of a blowout at EN-7 (top) and EN-22 (bottom).

### 4.5.2. Deterministic Model Results

For each stochastic spill scenario, one deterministic trajectory/fate simulation was run to investigate a specific spill trajectory identified in the previous stochastic analysis representing an event that resulted in the highest volume of oil reaching the shoreline. The trajectory/fate simulation was run using the same variable winds and current forcing used for the corresponding stochastic simulation.

For this study a worst case scenario was selected based on the degree of shoreline oiling, namely the ensemble scenario with one of the largest volumes of oil to arrive to the coat in the shortest time possible. This criterion was chosen to represent the worst case because it would require the greatest clean-up response effort. In choosing this worst case simulation, consideration was also given to the scenario which resulted in shoreline oiling in a relatively short time frame - which would also necessitate the rapid response of clean-up crews posing a challenging response effort. Therefore, when several individual trajectories have similar volumes of shore anticipated to be washed ashore, the one resulting in the shortest time to shore was selected as the worst case.

Figure 29 to Figure 31 present results of the deterministic simulations for the blowout oil spill scenarios.

For each case the following modelling result is presented:

- The first figure (map) illustrates the oil's trajectory on the water surface with sea surface areas that have been swept by oil shown in grey, floating surface oil at the end of the simulation (75 days) shown in black, and oiled shorelines shown in red. On the bottom, it presents the wind and current roses of the actual values of winds and currents used for that particular simulation near the spill site. Note that the both roses use the oceanographic convention (direction heading towards).

- A table summarizing the amount of oil remaining in the water surface and on the shoreline at the end of the simulation, classified by countries.

- A second figure (plot) shows the model-predicted mass balance for the spilled oil. The mass balance graphs show the degree of weathering that the oil undergoes during the period of the simulation.

Table 21 summarizes the deterministic modelling scenario results.

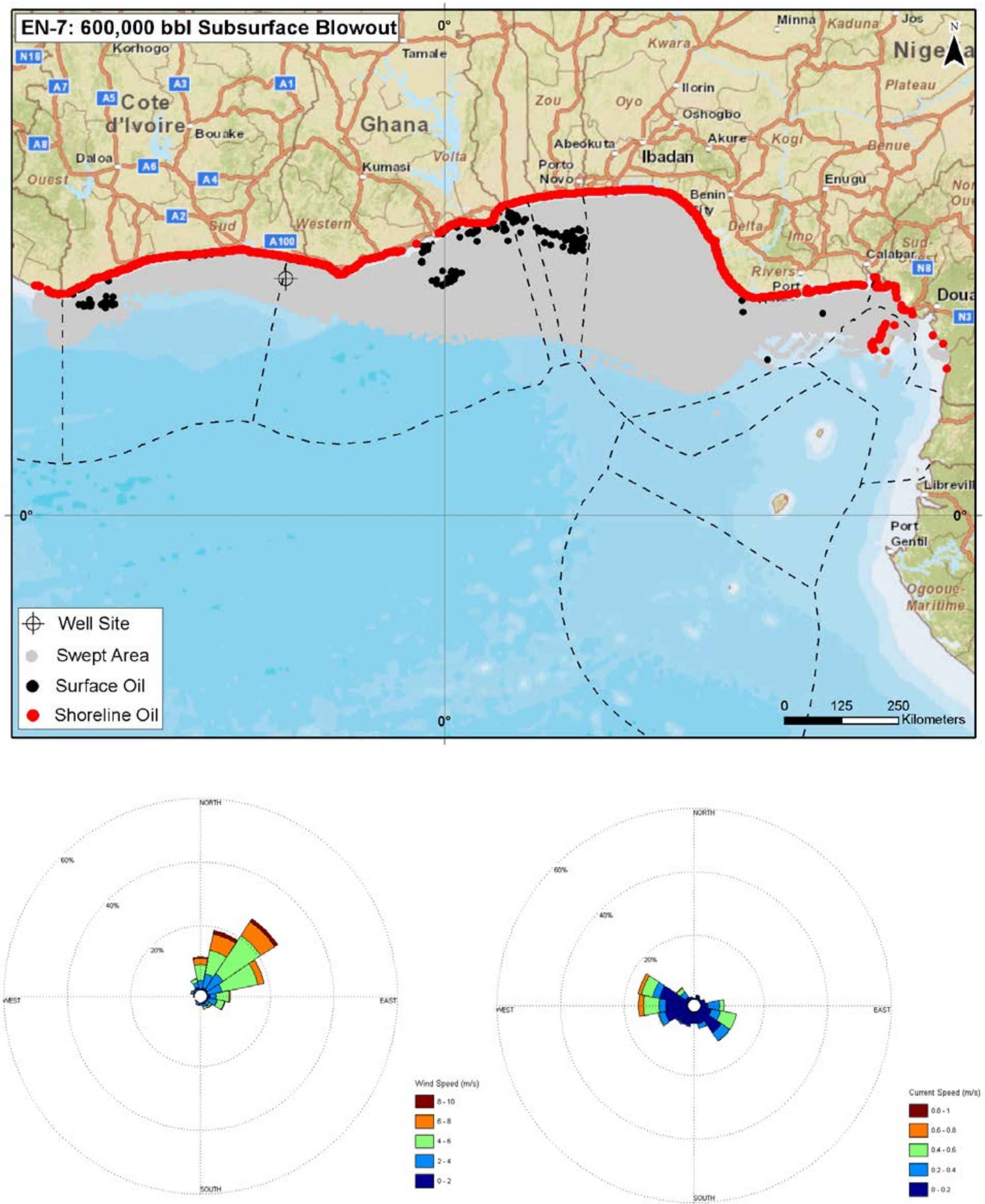



Figure 29. EN-7 600,000 bbl Crude Subsurface Blowout – Deterministic trajectory (grey - swept areas, red - oiled shoreline, black – fresh surface oil) after the 75 day simulation and the associated wind & current roses used in the simulation; roses are presented following oceanographic convention (direction heading towards).

Table 19. Summary of the deterministic model results of the EN-7 blowout simulations for each country in the region.

| Country / EEZ | Volume of oil at the End of Simulation (75 Days), in bbl | |
|---|---|---|
| | Water Surface | Shoreline |
| Liberia | 3,540 | 6,820 |
| **Ivory Coast** | **56,380** | **121,900** |
| Ghana | 3,500 | **56,720** |
| Togo | - | 320 |
| Benin | 30 | 1,090 |
| Nigeria | 3,000 | 36,420 |
| Cameroon | - | 20 |
| Equatorial Guinea | - | <10 |
| São Tomé and Príncipe | - | - |

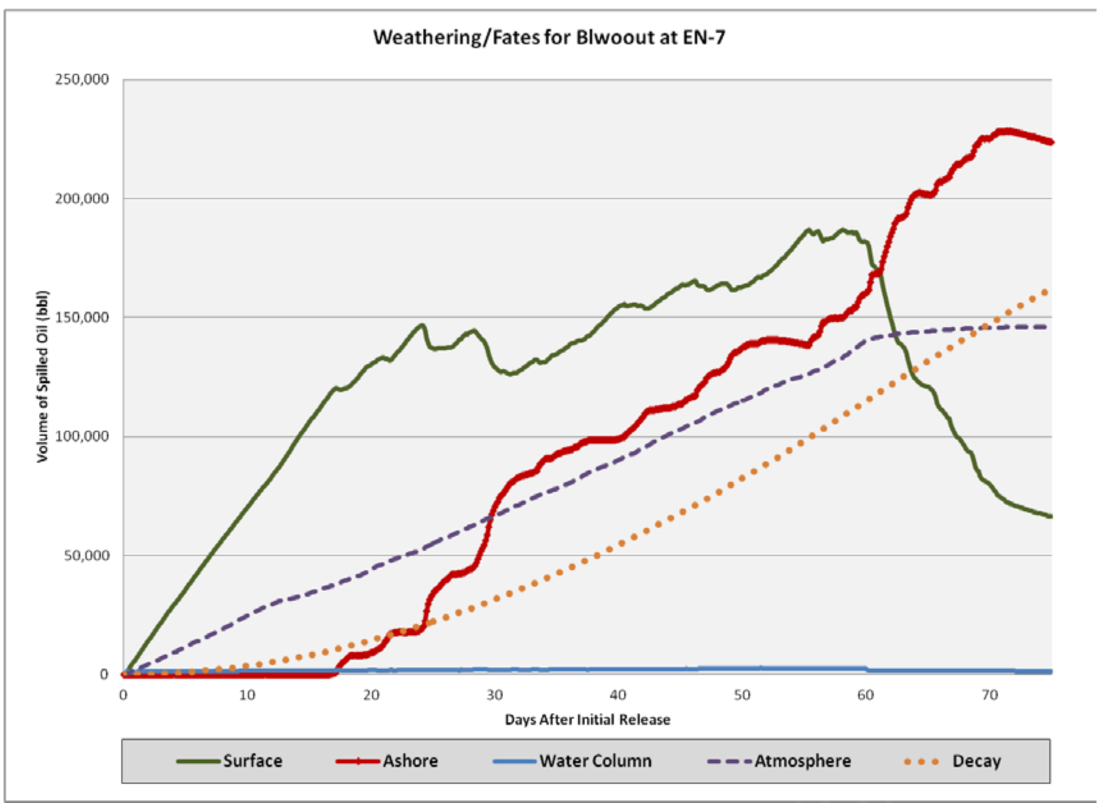



Figure 30. EN-7 600,000 bbl Crude Subsurface Blowout mass balance graph.

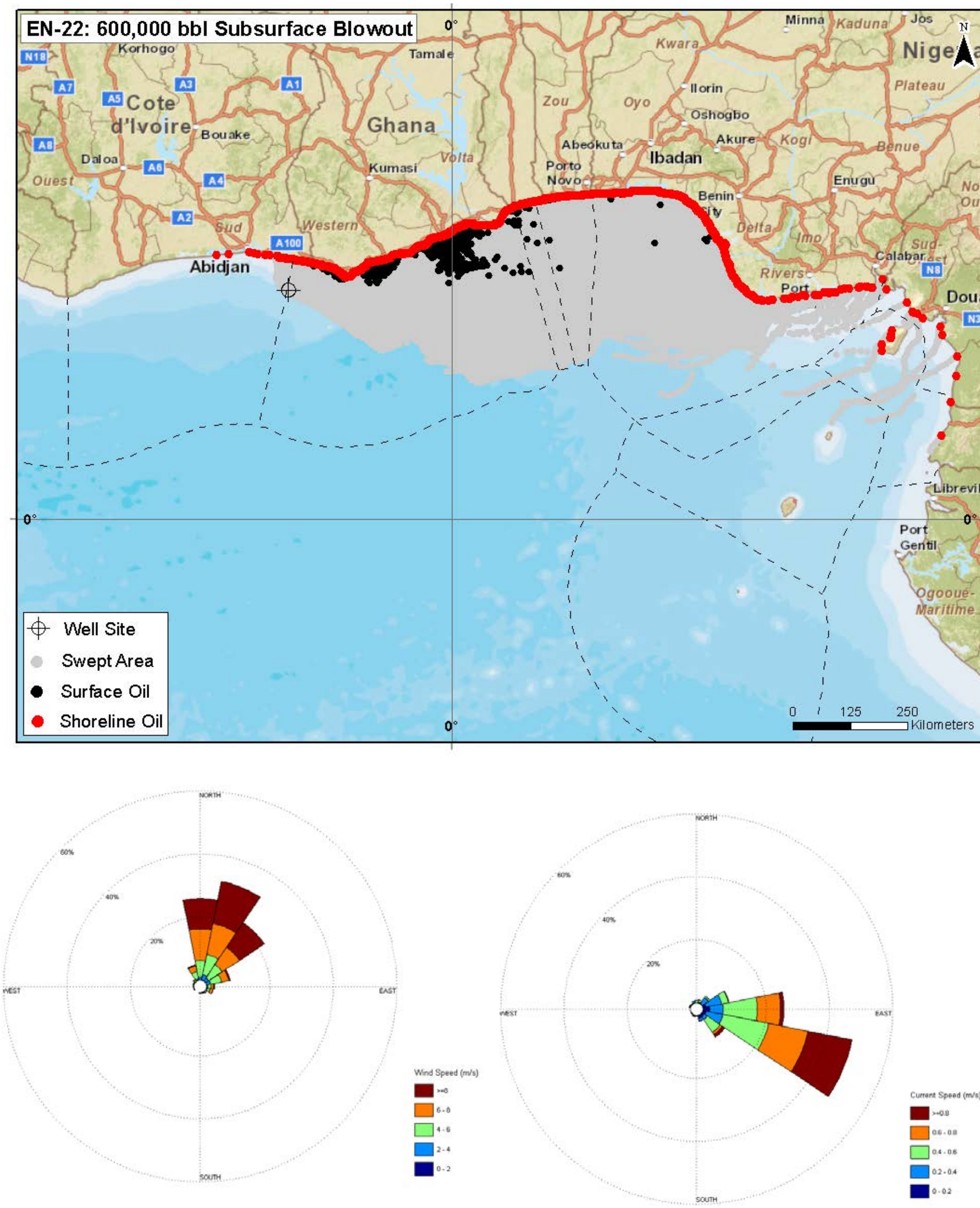



Figure 31. EN-22 600,000 bbl Crude Subsurface Blowout – Deterministic trajectory (grey - swept areas, red - oiled shoreline, black – fresh surface oil) after the 75 day simulation and the associated wind & current roses used in the simulation; roses are presented following oceanographic convention (direction heading towards).

Table 20. Summary of the deterministic model results of the EN-22 blowout simulations for each country in the region.

| Country / EEZ | Volume of oil at the End of Simulation (75 Days), in bbl | |
|---|---|---|
| | Water Surface | Shoreline |
| Liberia | - | - |
| **Ivory Coast** | - | 2,330 |
| **Ghana** | **64,440** | **138,060** |
| Togo | - | 5,180 |
| Benin | 750 | 25,750 |
| Nigeria | 2,260 | **50,630** |
| Cameroon | - | <10 |
| Equatorial Guinea | - | - |
| São Tomé and Príncipe | - | - |

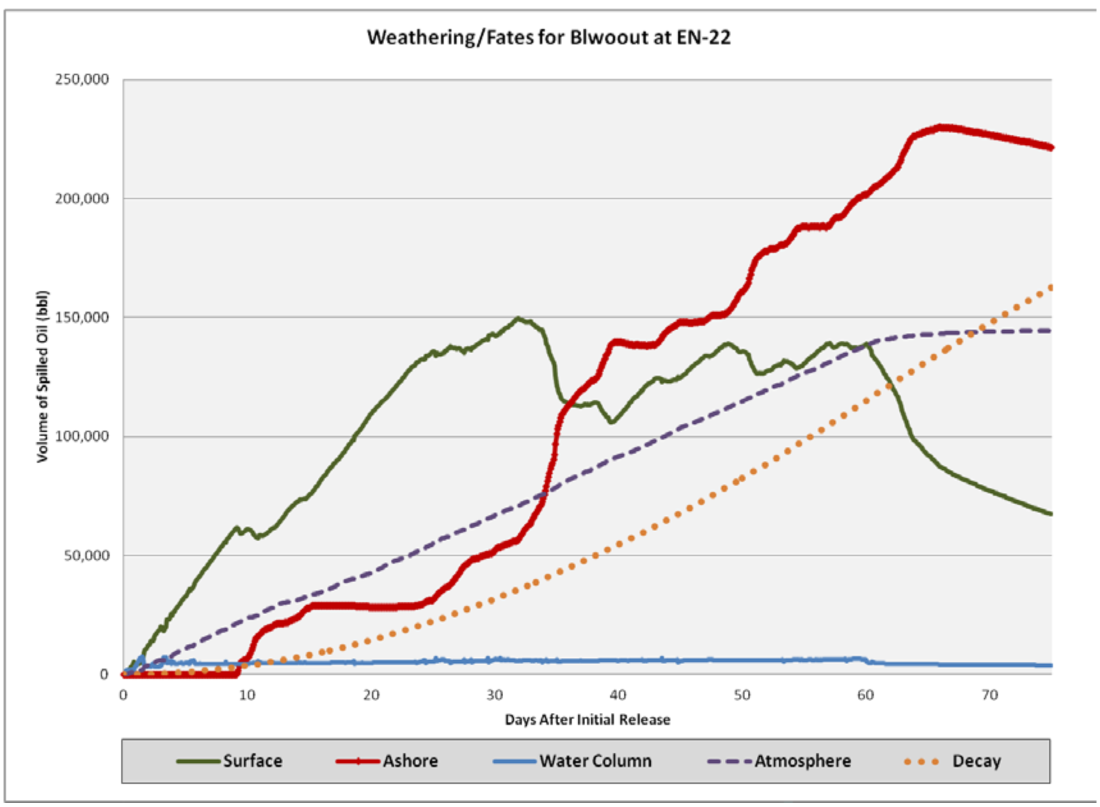



Figure 32. EN-22 600,000 bbl Crude Subsurface Blowout mass balance graph.

Table 21. Summaries of the deterministic results for each subsurface spill scenario.

| Figure and Table Numbers | Trajectory Description | Mass Balance Summary |
|---|---|---|
| *Scenario 5. 600,000 bbl Subsurface Blowout at EN-7* | | |
| Figure 29<br>Figure 30<br>Table 21 | Trajectory heads in all directions from the spill site, resulting in oil being transported throughout the Gulf of Guinea. Oil makes landfall in Liberia, Ivory Coast, Ghana, Togo, Benin, Nigeria, Cameroon, and Equatorial Guinea.<br><br>In this spill simulation, oil does not reach the coast until about 15.5 days after the start of this spill. At this time oil is expected to make landfall in both Ivory Coast and Ghana. The winds and currents during this period cause the oil to slowly migrate eastward, reaching the offshore waters of Togo in about 17 days. However, because the slick remains offshore, oil does not arrive to the Togolese shoreline until about 38 days into the spill, by which time oil has already made landfall in both Benin and Nigeria. Ultimately oil is spread over a large geographic range and by 75 days after the start of the spill, oil coats much of the shoreline between eastern Liberia and northwestern Cameroon.<br><br>Time to shore: 15.5 days | • At the end of the simulation, a substantial volume of oil remains on the water surface (56,380 bbl).<br>• Volume on the shoreline is 223,500 bbl at the end of the simulation. Over half of this volume is expected to be along the Ivory Coast.<br>• About 1,500 bbl remains in the water column through wave/wind driven entrainment and dissolution of the aromatic components of the oil in the water.<br>• At the end of the simulation, 146,000 bbl of oil had evaporated and 162,500 bbl had decayed through biodegradation and photo-oxidation.<br>• The largest amount of oil at the end of the simulation remains in the Ivory Coast waters. However, more than 36,000 bbl of oil reached and remained in the Nigeria coastline. |
| *Scenario 6: 600,000 bbl Subsurface Blowout at EN-22* | | |
| Figure 31<br>Figure 32<br>Table 19 | Trajectory heads in all directions from the spill site, resulting in oil being transported throughout the Gulf of Guinea. Oil makes landfall in Liberia, Ivory Coast, Ghana, Togo, Benin, Nigeria, Cameroon, and Equatorial Guinea.<br><br>Oil first makes landfall at the Ivory Coast shoreline approximately 8.5 days after the start of this spill and reaches the Ghana coast less than a day later. Because of the winds and currents during this period, oil slowly migrates eastward, reaching the offshore waters of Togo in about 10.5 days. However, because the slick remains offshore, oil does not arrive to the Togolese shoreline until about 34.5 days into the spill, by which time oil has already made landfall in Benin, Nigeria, and Cameroon. Ultimately oil is spread over a large geographic range and by 75 days after the start of the spill, it coats much of the shoreline between eastern Ivory Coast and eastern Nigeria, with some additional oiling eastward of this region.<br><br>Time to shore: 8.5 days | • At the end of the simulation, a substantial volume of oil remains on the water surface (67,500 bbl).<br>• Volume on the shoreline is 220,000 bbl at the end of the simulation. Over half of this volume is expected to be along the Ghanaian coast.<br>• About 4,000 bbl remains in the water column through wave/wind driven entrainment and dissolution of the aromatic components of the oil in the water.<br>• At the end of the simulation, 144,500 bbl of oil had evaporated and 162,500 bbl had decayed through biodegradation and photo-oxidation.<br>• The largest amount of oil at the end of the simulation remains in the Ivory Coast waters. However, more than 36,000 bbl of oil reached and remained in the Nigeria coastline. |

# 5. Drilling Discharge Simulations

The following section describes the model used for simulating releases of drilling discharges, the discharge scenario, and the results obtained from the model.

## 5.1. Model Description - MUDMAP

Drilling discharges simulations were completed using ASA's MUDMAP modelling system (Spaulding et al., 1994). MUDMAP is a numerical model developed by ASA to predict the near and far-field transport, dispersion, and bottom deposition of drilling mud and cuttings. In MUDMAP, the equations governing conservation of mass, momentum, buoyancy, and solid particle flux are formulated using integral plume theory and then solved using a Runge Kutta numerical integration technique. The model includes three stages: convective descent/ascent, dynamic collapse and far-field dispersion. It allows the transport and dispersion of the release to be modelled through all stages of its movement. The initial dilution and vertical spreading of the release is predicted in the convective descent/ascent process. The far-field process predicts the transport and dispersion of the release caused by the ambient current and turbulence fields. In the dynamic collapse process, the release impacts the surface or bottom, or becomes trapped by vertical density gradients in the water column.

The model output consists of definition of the movement and shape of the discharge plume, the concentrations of insoluble (i.e., cuttings and mud) discharge components in the water column, and the accumulation of discharged solids on the seabed. The model predicts the transport of discharged solids from the time of discharge to initial settling on the seabed. MUDMAP does not account for resuspension and transport of previously discharged solids; therefore it provides a conservative estimate of the potential seafloor depositions. The far-field and passive diffusion stage is based on a particle-based random walk model. More details about MUDMAP are included in Appendix C.

## 5.2. Discharge Scenario

Dispersion modelling of discharges was completed for both the EN-7 and EN-22 well sites according to the anticipated drilling program as described by the parameters in Table 22. The drilling program consists of four sections which use a combination of both water based muds (WBM) and oil based muds (OBM).

The period of the year where the discharges will occur was unknown and therefore a comprehensive analysis of the HYCOM currents dataset in proximity to each of the well sites was completed to evaluate the range of potential conditions. Based on the output from this model, the months of April and December were chosen to represent distinct seasonal periods that could result in differences in the trajectory of discharge released from the sites, particularly from the surface sections. In April, currents are relatively strong and oriented more commonly to the east (Figure 10), while in December currents are more variable in direction and typically weaker throughout the water column (Figure 11). Thus four total scenarios were simulated, corresponding to the two well sites for the two environmental conditions. For each of the four scenarios, vertically and time varied currents derived from the HYCOM model were used to drive the advection of the discharged solids.

For each of the scenarios a constant discharge rate was assumed during the drilling of each of the four individual drill sections. In the case of the bottom two sections, it was assumed that OBM remained adhered to the cuttings at a mass equivalent to 3% of the cuttings weight. As a conservative measure the OBM is assumed to remain on the cuttings throughout their descent through the water column without any dissolution, biodegradation, or decay.

Table 22. Drilling discharges modelling parameters for EN-7 and EN-22.

| Section | Cuttings Volume ($m^3$) | Mud Volume ($m^3$) | Mud Type | Duration (days) | Release Depth |
|---|---|---|---|---|---|
| 36" | 55 | 190 | WBM | 0.5 | 5 m Above Seabed |
| 26" | 245 | 1,200 | WBM | 1.3 | 5 m Above Seabed |
| 16" | 97 | 3% of cuttings | Low Tox. OBM | 1.1 | 15 m Below Water Surface |
| 12 ¼" | 87 | 3% of cuttings | Low Tox OBM | 5.5 | 15 m Below Water Surface |
| **TOTAL** | **484 $m^3$** | | | | |

## 5.3. Discharge Sediment Characteristics

In order to assess the fate of sediment and drilling byproducts in the marine environment, it is critical to characterize the components of the released materials. Water-based, oil-based, and synthetic drilling fluids (*drilling muds*) are each composed of different constituents which impact the density and weight of the discharged fluid, its toxicity, and the fall velocities of the material released in the water column.

For the discharges at the TEN well sites, the client provided a detailed breakdown of the expected components in the mud discharges, including the water, oil, and solids components of the various drilling fluids (Figure 33 and Figure 34).

The particle size distribution of cuttings from drilling operations is dependent on the type of drilling fluid and the treatment used. However, in the absence of local sample data, generic particle size distributions were assumed for the drill cuttings (Table 23). In order to provide a conservative estimate of benthic impacts, it was assumed that the OBM remained adhered to the cuttings particles and behaved as negatively buoyant particles in their descent through the water column. However, for the first two discharge sections, WBM is released which does include a fraction of solids particles (mud). For this modelling study, a generic size distribution was assumed for the WBM as described in Table 24.

The fall velocities are important for the model predictions since they dictate how fast each set of particle classes settles to the ocean bottom, contributing to the deposition thickness on the seabed. Typically, sand and gravel sized particles (cuttings) tend to settle quickly to the seafloor, while mud and drilling fluids are composed of smaller particle sizes and therefore can remain in the water column longer before settling to the bottom. Overall, the extent and accumulation of the deposition at the seabed are controlled by the fall velocities and the ocean current within the water column.

| | | | | | | |
|---|---|---|---|---|---|---|
| MI SWACO | DRILLING FLUID PROPOSAL<br>PRICED SUMMARY<br>**Well: Owo-1 RA** | Prepared date/by: 07/10/11 Snorre Lutnes | Total Personnel cost: | USD 69,600.00 | Tullow verification: | Date : |
| | | Verified date/by: | Total Material cost: | USD 810,619.30 | | Rev. No: 1 |
| | | Approved date/by: | Total Fluids cost: | USD 880,219.30 | Tullow approval: | |

**36 SECTION : Seawater / Guar Gum & PHG Sweeps**

| Depth m | MW (Guar gum Hi-Vis) ppg | YP (Guar gum Hi-Vis) lbs/100ft² | MW (Bentonite Hi-Vis) S.G. | YP (Bentonite Hi-Vis) lbs/100ft² | PV (Bentonite Hi-Vis) cP | pH (Bentonite Hi-Vis) | FV (Bentonite Hi-Vis) sec/l |
|---|---|---|---|---|---|---|---|
| From 1464 To 1547 Length: 83 | 8.5 - 8.6 | > 50 | 8.5 - 8.6 | > 50 | 15 - 20 | 8.5 - 9.5 | > 100 |

COMMENTS:

The 36" conductor will be jetted with seawater/Guar Gum sweeps. Pump 50bbl of Guar Gum Sweeps every half stand and spot 75bbl of PHG HiVis Sweeps at connection.

The 750 bbl of 16 ppg Kill mud will be built prior to spud and in the event of encountering shallow gas will be spotted to kill the well. If the Kill mud is not used for this purpose, it will remain in the surface pit to be used to make Pad Mud at the end of the 26" section 1900 bbls of 11.5 ppg Pad mud can be can be made by diluting the 750 bbls

| PRODUCTS TYPE | Unit | Size | Concentrations ppb New | Maint | Tot Unit | MT or m³ | VOLUMES [bbl] Allocation | bbl |
|---|---|---|---|---|---|---|---|---|
| **Guar Gum Hi-Viscous Mud for Sweeps** | | | | | | | **SWEEP VOLUMES** | |
| Guar Gum | kg | 25 | 3.50 | | 11 | 0.275 | Volume Guar Gum | 173 |
| Soda Ash | kg | 25 | 0.25 | | 1 | 0.025 | | |
| Safe-Cide | lt | 25 | 0.15 | | 1 | 0.025 | | |
| **PHG Mud for Sweeps / Spotting at TD** | | | | | | | **PHG VOLUMES** | |
| Bentonite | kg | 1000 | 25.00 | | 4 | 4.000 | Volume PHG | 288 |
| Caustic Soda | kg | 25 | 0.25 | | 2 | 0.050 | | |
| Soda Ash | kg | 25 | 0.25 | | 2 | 0.050 | | |
| | | | | | | | Total Sweeps / PHG | 461 |
| **Kill Mud** | | | | | | | | |
| Barite | kg | 1000 | 405.00 | | 138 | 138.000 | Volume Kill Mud | 750 |
| Bentonite | kg | 1000 | 20.00 | | 7 | 7.000 | | |
| Caustic Soda | kg | 25 | 0.25 | | 4 | 0.100 | | |
| Duovis | kg | 25 | 1.00 | | 14 | 0.350 | | |
| Polypac | kg | 25 | 1.50 | | 21 | 0.525 | | |
| Soda Ash | kg | 25 | 0.25 | | 4 | 0.100 | | |
| | | | | | | | **TOT. VOL.** | **1211** |
| Total mud material cost | | | | USD | 78,473.87 | | | |
| **Personnel requirements based on time / depth curve** | | | | | | | | |
| Sr Fluids Engineer | ea | | | | 2 | | | |
| Fluids Engineer | ea | | | | 2 | | | |
| Total personnel cost | | | | USD | 4,800.00 | | | |
| | | | | | | | Max Angle, deg. | 0 |
| Total section cost | | | | USD | 83,273.87 | | Dilut. Fac (bbl/bbl) | N/A |

**26 SECTION : Seawater / Guar Gum & PHG Sweeps**

| Depth m | MW (Guar gum Hi-Vis) ppg | YP (Guar gum Hi-Vis) lbs/100ft² | MW (Bentonite Hi-Vis) S.G. | YP (Bentonite Hi-Vis) lbs/100ft² | PV (Bentonite Hi-Vis) cP | pH (Bentonite Hi-Vis) | FV (Bentonite Hi-Vis) sec/l |
|---|---|---|---|---|---|---|---|
| From 1547 To 2264 Length: 717 | 8.5 - 8.6 | > 50 | 8.5 - 8.6 | > 50 | 15 - 20 | 8.5 - 9.5 | > 100 |

COMMENTS:

The 26" interval will be drilled with seawater and sweeps. Pump 50 bbl of Guar Gum Sweeps every half stand and spot 75 bbl of PHG HiVis Sweeps at connection.
It is recommended to pump 100 bbl of PHG Hi-Vis Sweep at interval TD. After circulating sweeps out of the hole displace the hole to 11.5 ppg CaCl2 inhibited PAD mud. The PAD mud will assist in keeping the hole open during the trip and in running casing.
POOH with BHA and Lubricate to run the 20" casing.

The 3676 bbl of 11.5 ppg CaCl2 inhibited PAD mud will be built and stored in the vessel tanks for the 26" open hole displacement. Extra volume of 3676bbl of Pad Mud for a double displacement must be build.

In case of emergency the Kill Mud prepared before commencement of the well, will be cut back with a combination of CaCl2 brine seawater and Viscosifiers to prepare the PAD mud.

750 bbl of 16 ppb Kill Mud blended with 1,160bbl of Seawater will give 1,975 bbl of 11.5 ppg PAD mud

Extra volum of PAD mud can be gained by blending barite and brine to the existing PAD mud

| PRODUCTS TYPE | Unit | Size | Concentrations ppb New | Maint | Tot Unit | MT or m³ | VOLUMES [bbl] Allocation | bbl |
|---|---|---|---|---|---|---|---|---|
| **Guar Gum Hi-Viscous Mud for Sweeps** | | | | | | | **SWEEP VOLUMES** | |
| Guar Gum | kg | 25 | 3.00 | | 102 | 2.550 | Volume Guar Gum | 1867 |
| Soda Ash | kg | 25 | 0.25 | | 9 | 0.225 | | |
| Safe-Cide | lt | 25 | 0.15 | | 1 | 0.025 | | |
| **PHG Mud for Sweeps / Spotting at TD** | | | | | | | **PHG VOLUMES** | |
| Bentonite | kg | 1000 | 25.00 | | 22 | 22.000 | Volume PHG | 1867 |
| Caustic Soda | kg | 25 | 0.25 | | 9 | 0.225 | | |
| Soda Ash | kg | 25 | 0.25 | | 9 | 0.225 | | |
| | | | | | | | Total Sweeps / PHG | 3734 |
| **Pad Mud** | | | | | | | | |
| Barite | kg | 1000 | 210.00 | | 351 | 351.000 | Volume PAD Mud 11.5 pp | 3676 |
| Bentonite | kg | 1000 | 20.00 | | 34 | 34.000 | | |
| Caustic Soda | kg | 25 | 0.25 | | 17 | 0.425 | | |
| Duovis | kg | 25 | 1.00 | | 67 | 1.675 | | |
| Polypac | kg | 25 | 1.50 | | 101 | 2.525 | | |
| Soda Ash | kg | 25 | 0.25 | | 17 | 0.425 | | |
| CaCl2 | kg | 25 | 15.00 | | 1001 | 25.025 | | |
| | | | | | | | **TOT. VOL.** | **7411** |
| Total mud material cost | | | | USD | 269,677.29 | | | |
| **Personnel requirements based on time / depth curve** | | | | | | | | |
| Sr Fluids Engineer | ea | | | | 8 | | | |
| Fluids Engineer | ea | | | | 8 | | | |
| Total personnel cost | | | | USD | 19,200.00 | | | |
| | | | | | | | Max Angle, deg. | 0 |
| Total section cost | | | | USD | 288,877.29 | | Dilut. Fac (bbl/bbl) | N/A |

Figure 33. Generic composition of water based drilling fluids for the 36" and 24" drill sections assumed for the TEN well sites.

**16 Section: Versaclean LTOBM**

| Depth m | MW ppg | YP lb/100sqft | PV cP | Oil/Water Ratio | $CaCl_2$ % Water | WPS mg/l | 6 rpm | HPHT FL @250°F (ml) | E.Stability volts | Excess Lime ppb | Pom ml | Drill Solids % vol | OOC % wt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| From 2264 To 2864 Length: 600 | 9,2 - 9,5 | 20 - 30 | alap | 70-30 | 21 - 23 by wt | as Cl⁻ >150,000 | 16 - 18 | < 4.0 no water | > 500 | > 2.5 | > 1.9 | < 5 | < 5.0 |

Displace the well to the Versaclean LTOBM 9.2 ppg. The choke, kill and booster lines should be displaced first and isolated.
Gradually increase the density from 9,2ppg to 9,5ppg by 2600m.
Care should be taken to ensure that once the displacement starts is should not be stopped until the Versaclean LTOBM is at the surface.
Pipe rotation will enhance the displacement. Any interface from the displacement should be

LOT will be performed with new mud in hole to 9,2ppg

Treat fluid with wetting agent and emulsifiers as drilling progresses to treat for attrition on solids removed. Treat system with sufficient VG Plus as to ensure good carrying capacity in the fluid, but be wary of overtreatment as the clay requires time to yield.
Optimise use of all solids control equipment at all times to minimise build up of drill solids.
Virtual Hydraulics will be run daily and the results sent in with the mud report.
Mud parameters to be plotted on trend graphs by the mud engineer and sent in daily with the mud report.

**PRODUCTS — Concentrations ppb**

| TYPE | Unit | Size | New | Maint | Tot Unit | MT or $m^3$ |
|---|---|---|---|---|---|---|
| Escaid 120 Base Oil | lt | 159 | 175.83 | 0.50 | 424 | 67.374 |
| Barite | kg | 1000 | 51.76 | 2.00 | 24 | 24.000 |
| CaCl2 | kg | 25 | 27.28 | 0.70 | 479 | 11.975 |
| Lime | kg | 25 | 6.00 | 2.2 | 303 | 7.575 |
| Versacoat | lt | 208 | 6.00 | 0.60 | 18 | 3.748 |
| Versatrol M | kg | 25 | 4.00 | 1.20 | 176 | 4.400 |
| Versawet | lt | 208 | 4.00 | 1.20 | 21 | 4.372 |
| VG Plus | kg | 22.7 | 6.00 | 0.40 | 142 | 3.221 |
| Water | lt | 159 | 90.53 | | 215 | 34.164 |
| Calcium Carbonate | kg | 22.7 | 15.00 | 1.50 | 409 | 9.274 |
| Total mud material cost | | | | USD | | 196,923.43 |
| **Personnel requirements based on time / depth curve** | | | | | | |
| Sr Fluids Engineer | ea | | | | 11 | |
| Fluids Engineer | ea | | | | 11 | |
| Total personnel cost | | | | USD | | 26,400.00 |
| Total section cost | | | | USD | | 223,323.43 |

**VOLUMES [bbl]**

| Allocation | bbl |
|---|---|
| Surface Volume | 1000 |
| Riser Volume | 1820 |
| Casing Volume | 895 |
| Open Hole Volume | 490 |
| Washout Volume | 49 |
| Dilution | 1077 |
| Total Hole Volume | 3253 |
| **Total Req. Volume** | **5330** |
| Mud Received | 4500 |
| **New Mud** | **830** |
| Mud Left | 4253 |
| Max Angle, deg. | 0 |
| Dilut. Fac (bbl/bbl) | 2.00 |

**12 1/4 Section: Versaclean LTOBM**

| Depth m | MW ppg | YP lb/100sqft | PV cP | Oil/Water Ratio | $CaCl_2$ % Water | WPS mg/l | 6 rpm | HPHT FL @250°F (ml) | E.Stability volts | Excess Lime ppb | Pom ml | Drill Solids % vol | OOC % wt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| From 2864 To 3926 Length: 1062 | 10,2-11 | 20 - 25 | alap | 70/30 75/25 | 21 - 23 by wt | as Cl⁻ >150,000 | 12 - 14 | < 4.0 no water | > 500 | > 2.5 | > 1.9 | < 5 | < 5.0 |

Start this section using the10,2ppg LTOBM. Gradually increase the density from 10,2ppg to 11ppg by 3200m
LOT will be performed to 12ppg using the 10,2ppg

Mud weight may be adjusted if the LOT, or any other indications seen while drilling, dictates this. Oil/Water ratio is to be maintained within Program Specifications. At no time should it be allowed to drop below 70/30. Treat the fluid with 15 ppb CaCO3 F, M & C. This will assist in enhancing filter cake quality and help to provide seepage losses.
Fluid loss will be tightened to a maximum of 4.0cc/30 min with Versatrol M additions. Although no losses are anticipated, it is recommeded to keep a LCM pill mixed on standby at all times. LCM materials F, M and C must be available at the rig at all times
Optimize use of all solids control equipment at all times to minimize build up of drill solids. Oil on cuttings from all equipment discharging overboard will be measured and reported on a daily basis.
A weighted sweep will be pumped around at TD and the observations of bottoms up at the shakers, noted on the daily mud report.
Virtual Hydraulics will be run daily and the results sent in with the mud report.
It is recommend to increase the oil content (O/W 75/25) if high values of PV are observed, high PV will increase ECD values during drilling.

**PRODUCTS — Concentrations ppb**

| TYPE | Unit | Size | New | Maint | Tot Unit | MT or $m^3$ |
|---|---|---|---|---|---|---|
| Escaid 120 Base Oil | lt | 159 | 161.62 | 6.00 | 595 | 94.546 |
| Barite | kg | 1000 | 161.62 | 2.00 | 85 | 85.000 |
| CaCl2 | kg | 25 | 22.23 | 0.25 | 467 | 11.675 |
| Lime | kg | 25 | 6.00 | 1.00 | 212 | 5.300 |
| Versacoat | lt | 208 | 6.00 | 0.75 | 23 | 4.789 |
| Versatrol M | kg | 25 | 4.00 | 0.25 | 103 | 2.575 |
| Versawet | lt | 208 | 4.00 | 1.00 | 21 | 4.372 |
| VG Plus | kg | 22.7 | 6.00 | 0.25 | 158 | 3.583 |
| Water | lt | 159 | 83.36 | | 262 | 41.632 |
| Calcium Carbonate | kg | 22.7 | 15.00 | 1.00 | 432 | 9.796 |
| Total mud material cost | | | | USD | | 265,544.71 |
| **Personnel requirements based on time / depth curve** | | | | | | |
| Sr Fluids Engineer | ea | | | | 8 | |
| Fluids Engineer | ea | | | | 8 | |
| Total personnel cost | | | | USD | | 19,200.00 |
| Total section cost | | | | USD | | 284,744.71 |

**VOLUMES [bbl]**

| Allocation | bbl |
|---|---|
| Surface Volume | 1000 |
| Riser Volume | 1820 |
| Casing Volume | 680 |
| Open Hole Volume | 508 |
| Washout Volume | 25 |
| Dilution | 1067 |
| Total Hole Volume | 3034 |
| **Total Req. Volume** | **5100** |
| Mud Received | 4000 |
| **New Mud** | **1100** |
| Mud Left | 4034 |
| Max Angle, deg. | 22 |
| Dilut. Fac (bbl/bbl) | 2.00 |

Figure 34. Generic composition of water based drilling fluids for the 16” and 12 ¼” drill sections assumed for the TEN well sites.

Table 23. Cuttings size distribution (adapted from Brandsma and Smith, 1999).

| Cuttings Particle Size (microns) | % Volume | Settling Velocity | |
|---|---|---|---|
| | | (cm/s) | (m/day) |
| 1.0 | 8 | 0.0001 | 0.12 |
| 3.5 | 6 | 0.0017 | 1.49 |
| 12.5 | 7 | 0.0223 | 19 |
| 41.1 | 3 | 0.238 | 206 |
| 107.7 | 2 | 1.48 | 1,276 |
| 217.2 | 18 | 4.07 | 3,518 |
| 616.8 | 16 | 9.90 | 8,552 |
| 1,049.5 | 15 | 13.65 | 11,792 |
| 3,585.1 | 25 | 26.21 | 22,647 |

Table 24. Mud size distribution (adapted from Brandsma and Smith, 1999).

| Mud Particle Size (microns) | % Volume | Settling Velocity | |
|---|---|---|---|
| | | (cm/s) | (m/day) |
| 3.7 | 1.0 | 0.0003 | 0.26 |
| 5.5 | 4.0 | 0.0006 | 0.52 |
| 8.6 | 19.2 | 0.0015 | 1.30 |
| 12.2 | 19.2 | 0.0031 | 2.68 |
| 14.8 | 13.3 | 0.0045 | 3.89 |
| 16.0 | 13.3 | 0.0053 | 4.58 |
| 17.9 | 10.0 | 0.0066 | 5.70 |
| 20.3 | 5.0 | 0.0085 | 7.34 |
| 46.5 | 8.0 | 0.0446 | 38.53 |
| 77.2 | 7.0 | 0.1222 | 105.58 |

## 5.4. Results of the Predicted Drilling Discharge Deposition

Table 25 summarizes the cumulative areas predicted to be covered by the discharges from the discharge scenarios. When drilling occurs in deep water (> 500 m), which is the case for both the EN-7 and EN-22 well sites, discharges from the near-water surface (at the platform) will not contribute largely to the observed deposition at the seafloor. In its descent to the seafloor, cuttings released near the surface will be dispersed over a larger area and will typically accumulate at very low concentrations (< 1 mm thickness). Therefore, in the absence of very large volume releases from the surface, large particle sizes, or very weak currents, the drilling sections with material released near the seabed (Sections 1 and 2) will result in significantly more deposition near the well site than any of the material released near the surface.

Figure 35 to Figure 38 present plan view extents of the accumulated model-predicted seabed deposition patterns from the drill cuttings discharges for simulations run with April and December environmental conditions for sites EN-7 and EN-22, respectively. Depending on the site and period of discharges, the extents vary. One key observation is that during April, the cumulative footprint of discharges extends further laterally from the well sites. Additionally, the discharges at EN-7 tend to cover a large cumulative area than the equivalent run for EN-22, primarily owing to the difference in depth and variability in currents between the two sites.

For each of the scenarios, deposition greater than 10 mm does not extend more than 50 m from the drill site in any direction (Table 26). These high deposition zones are primarily due to the cuttings discharged near the seabed, which are deposited quickly due to their fast settling rates. Deposition contours of 1 mm and 0.1 mm may extend up to 620 m and 1,220 m away, respectively (both corresponding to EN-22 April discharge event). In more moderate current conditions, such as those occuring in December, the discharged material does not travel as far away and remains closer to the well site. For the EN-7 scenario during this month, the 1 mm contour is limited to within 300 m of the platform, while for the EN-22 release in December this thickness level only extends 330 m from the discharge point.

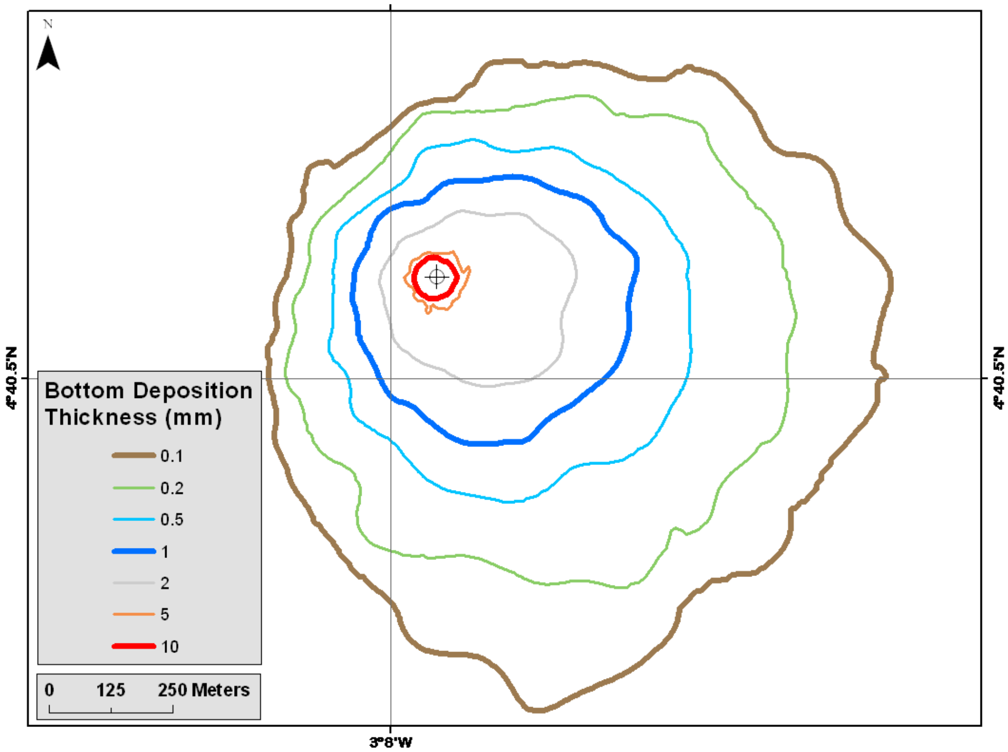



Figure 35. Drilling discharges predicted thickness deposition at EN-7 in April.

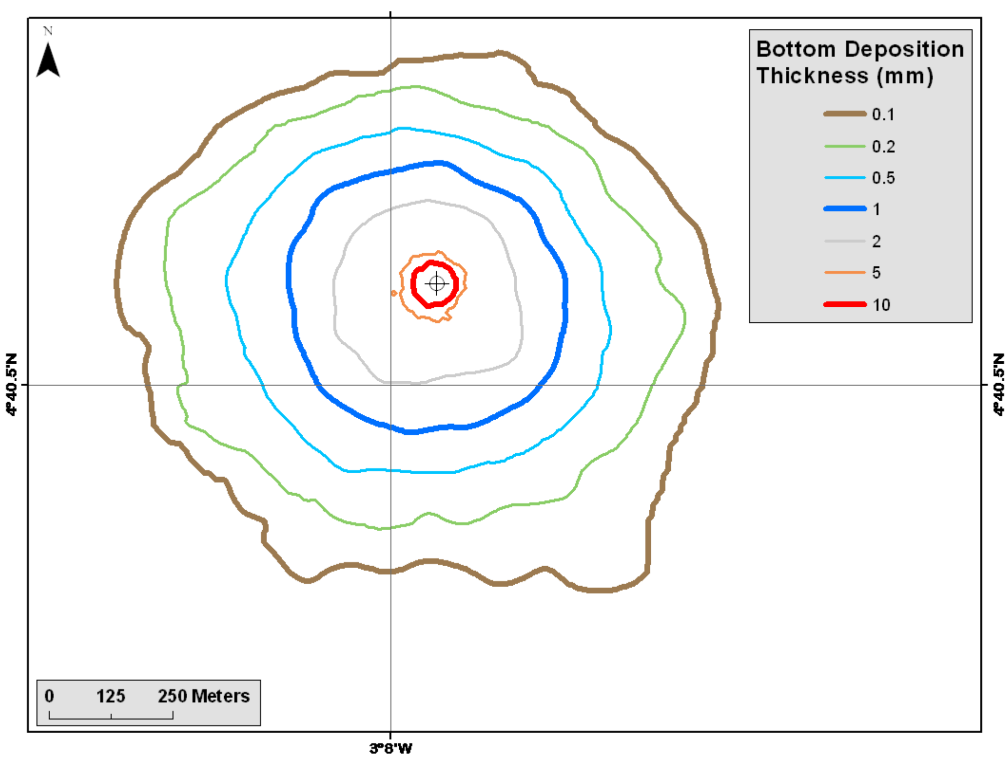



Figure 36. Drilling discharges predicted thickness deposition at EN-7 in December.

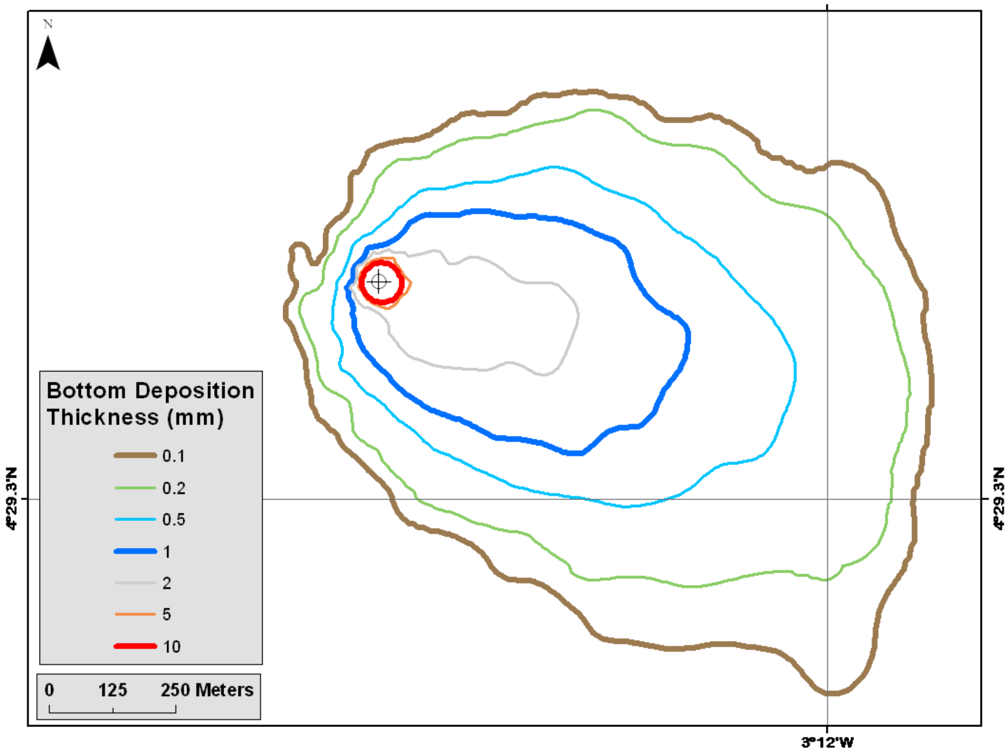



Figure 37. Drilling discharges predicted thickness deposition at EN-22 in April.

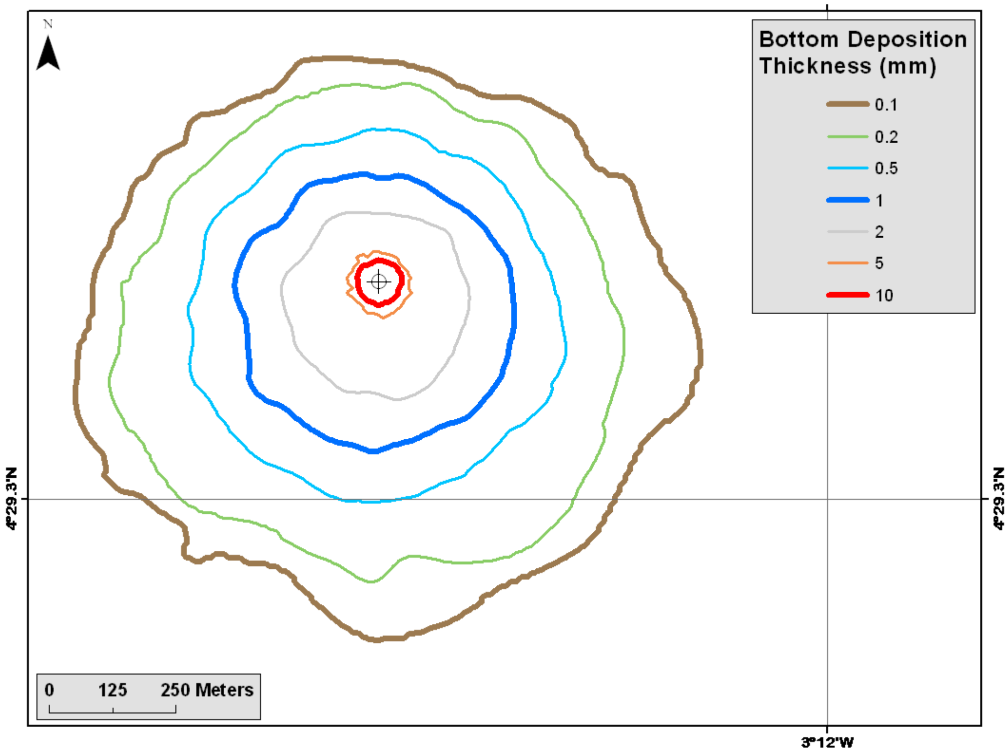



Figure 38. Drilling discharges predicted thickness deposition at EN-22 in December.

Table 25. Predicted areas affected by deposited material classified by thickness for each of the drilling locations.

| **Deposition Thickness (mm)** | **Cumulative Area Exceeding (km²)** | | | |
|---|---|---|---|---|
| | EN-7 | | EN-22 | |
| | April | December | April | December |
| 0.1 | 1.179 | 0.999 | 1.07 | 0.998 |
| 0.2 | 0.782 | 0.695 | 0.824 | 0.734 |
| 0.5 | 0.414 | 0.418 | 0.434 | 0.409 |
| 1 | 0.236 | 0.241 | 0.228 | 0.229 |
| 2 | 0.108 | 0.113 | 0.076 | 0.103 |
| 5 | 0.01 | 0.014 | 0.007 | 0.011 |
| 10 | 0.005 | 0.006 | 0.005 | 0.006 |
| 20 | 0.004 | 0.004 | 0.003 | 0.004 |
| 50 | 0.002 | 0.002 | 0.002 | 0.002 |

Table 26. Maximum distance of deposited material classified by thickness for each of the drilling locations.

| **Deposition Thickness (mm)** | **Maximum Extent from Discharge Point (m)** | | | |
|---|---|---|---|---|
| | EN-7 | | EN-22 | |
| | April | December | April | December |
| 0.1 | 930 | 730 | 1,220 | 700 |
| 1 | 400 | 300 | 620 | 330 |
| 10 | 40 | 40 | 50 | 50 |

## 5.5. Results of the Predicted Bottom Hydrocarbon Concentrations

The cuttings disposed at the sea surface from the TEN well sites are expected to contain some amount of oil based muds (OBM), which remains adhered to the cuttings. The MUDMAP model was used to predict accumulated bottom hydrocarbon concentrations at the seabed assuming that some of the OBM remained adhered to the discharged cuttings (3% by weight) and a 70/30 ratio of oil to water within the OBM. Implications of the settled hydrocarbons include bioaccumulation in local biota and the potential for generating anoxia in the surrounding waters (OGP, 2003). Thus modelling of hydrocarbon concentrations is important for both regulatory and environmental reasons.

Table 27 summarizes the geographic areas impacted by hydrocarbons and Table 28 shows the maximum predicted extent for various hydrocarbon levels. Figure 39 to Figure 42 show the model predicted hydrocarbon concentrations for each of the four simulated discharges.

The seafloor areas with hydrocarbon concentrations above 50 ppm are located in all directions around the well site and for some cases may be observed over 1 km laterally from the discharge point. For the discharges in April, the highest concentrations of bottom hydrocarbons are located eastward of the well site, while in December these high concentration zones are typically around and centred on the well site with a slight skew to the west. Because the OBM muds are discharged from the surface, the highest observed concentrations may not be oriented over the discharge point due to advection of the discharged solids by subsurface currents in their descent through the water column. Using this conservative set of assumptions, it is predicted that concentrations in excess of 500 ppm could be present up to 475 m from the well site. These model predictions provide a conservative (worst-case) estimate because it is assumed that the hydrocarbons remain adhered to the cuttings particles in the descent through the water column without any dissolution.

Table 27. Predicted areas affected by deposited material classified by bottom hydrocarbon concentration.

| **Hydrocarbon Concentration (ppm)** | **Cumulative Area Exceeding ($km^2$)** | | | |
|---|---|---|---|---|
| | EN-7 | | EN-22 | |
| | April | December | April | December |
| 50 | 0.750 | 0.656 | 0.788 | 0.773 |
| 100 | 0.518 | 0.583 | 0.577 | 0.556 |
| 200 | 0.314 | 0.312 | 0.301 | 0.334 |
| 500 | 0.132 | 0.141 | 0.054 | 0.094 |

Table 28. Maximum distance of deposited material classified by bottom hydrocarbon concentration for each of the drilling locations.

| **Hydrocarbon Concentration (ppm)** | **Maximum Extent from Discharge Point (m)** | | | |
|---|---|---|---|---|
| | EN-7 | | EN-22 | |
| | April | December | April | December |
| 50 | 1,000 | 630 | 1,080 | 630 |
| 500 | 430 | 275 | 475 | 245 |

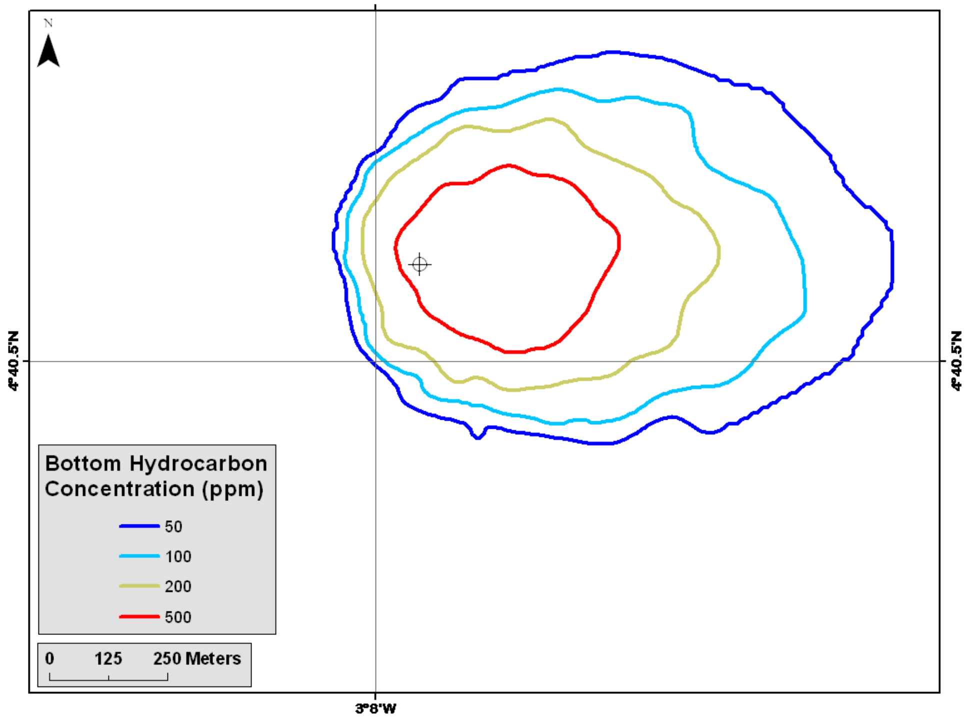



Figure 39. Drilling discharges predicted bottom sediment hydrocarbon concentrations from OBM sections at EN-7 in April.

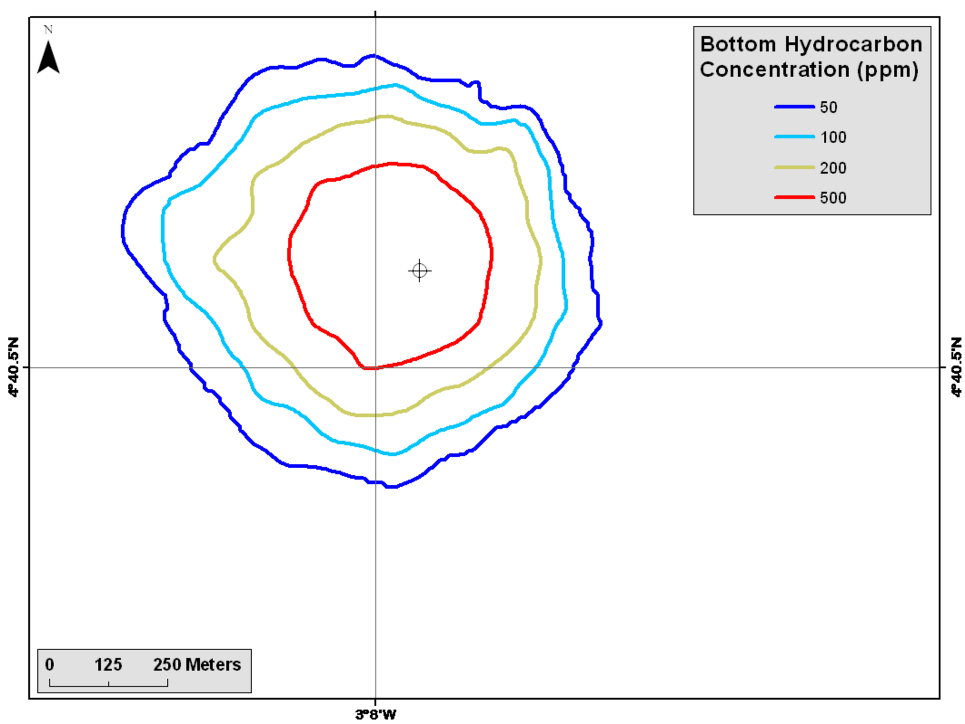



Figure 40. Drilling discharges predicted bottom sediment hydrocarbon concentrations from OBM sections at EN-7 in December.

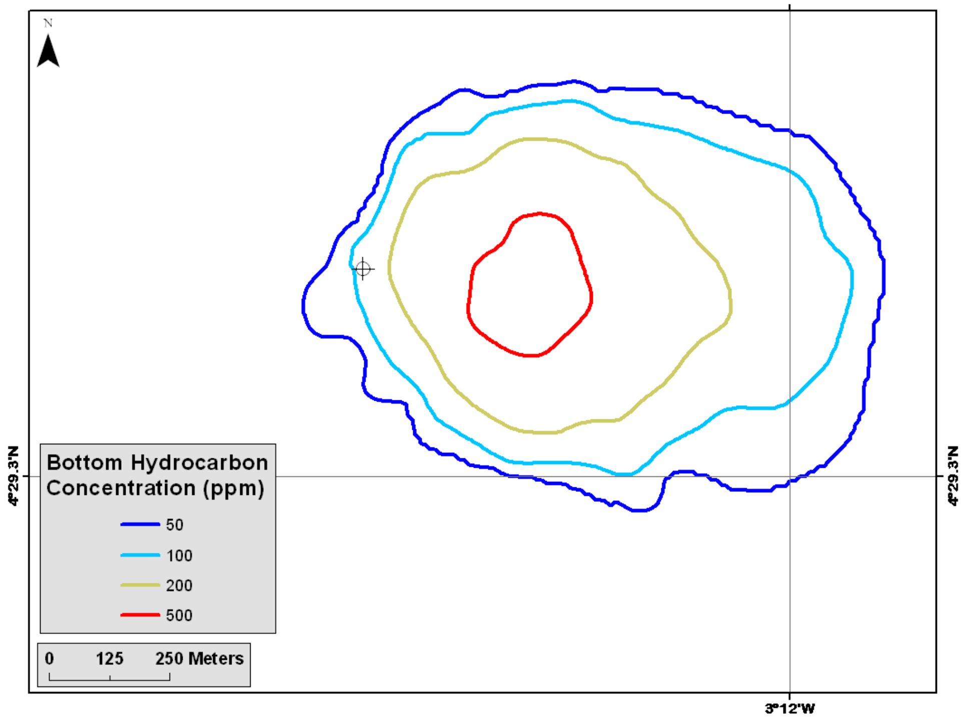



Figure 41. Drilling discharges predicted bottom sediment hydrocarbon concentrations from OBM sections at EN-22 in April.

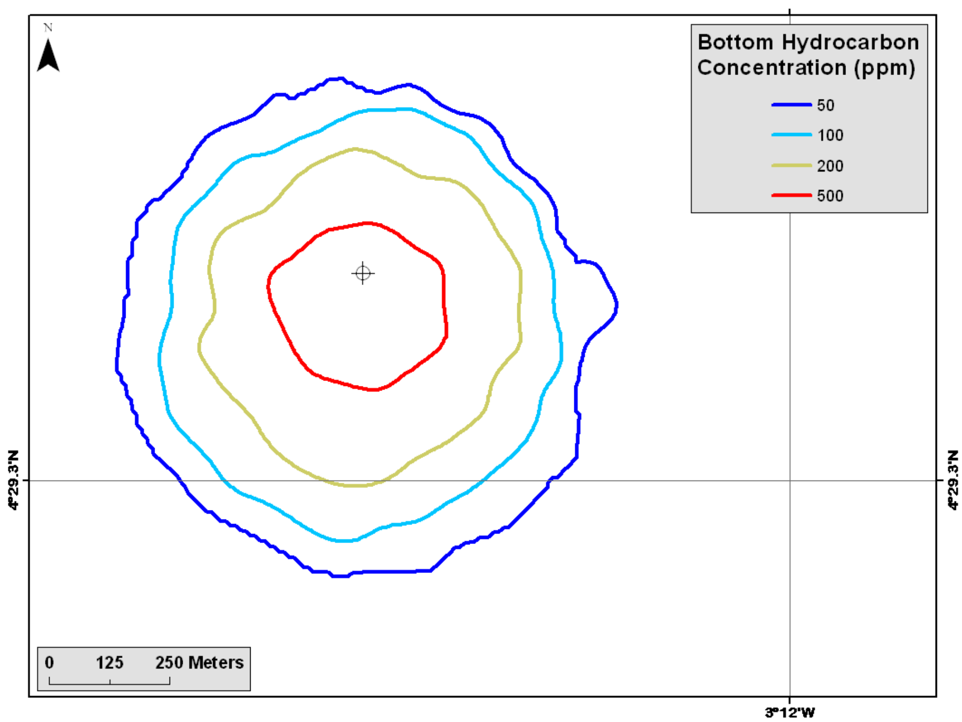



Figure 42. Drilling discharges predicted bottom sediment hydrocarbon concentrations from OBM sections at EN-22 in December.

## 5.6. Results of the Predicted Water Column Concentrations

The MUDMAP model was used to predict the fate of the discharged material, including its transport through the water column and deposition on the seafloor. Excess concentrations (above background) of Total Suspended Solids (TSS) are known to decline quickly with increasing distance from the discharge site due to dilution of the plume and rapid settling of larger particles. Within 10 m of the well site, it is typical to see a 100x reduction in water column concentrations of drilling discharges (Smith et al., 2004). For this reason, relatively high concentrations are expected in the immediate vicinity of the well site with a sharp reduction at increasing distance away from the release location. Table 29 summarizes the maximum distance of observed excess water column concentrations for 10 mg/L and 100 mg/L TSS concentrations for each of the four scenarios; the table refers to the maximum concentrations predicted during the discharges of all 4 sections for each discharge program. Because the flow rate of the solids discharges is the highest during the 26” section (245 $m^3$ cuttings and 1,200 $m^3$ WBM over 1.3 days), this section is the primary contributor to high TSS concentrations relative to any other section associated with the discharge program. Because the surface release sections (16” and 12 ¼“) have relatively low discharge rates of solids materials, the TSS concentrations from these sections are significantly lower than the discharges near the seabed. This table indicates that excess concentrations are typically observed further from the source in April relative to December.

Figure 43 to Figure 46 show the maximum time integrated excess TSS concentrations for the entire drilling program for each of the four simulated discharges. Overall, each of the four simulations show similar spatial trends, although the directionality of the main plume varies depending on the season and location of discharge.

Table 29. Maximum distance of maximum predicted water column concentrations.

| TSS Concentration (mg/L) | Maximum Extent from Discharge Point (m) | | | |
|---|---|---|---|---|
| | EN-7 | | EN-22 | |
| | April | December | April | December |
| 10 | 560 | 470 | 600 | 470 |
| 100 | 95 | 85 | 70 | 90 |

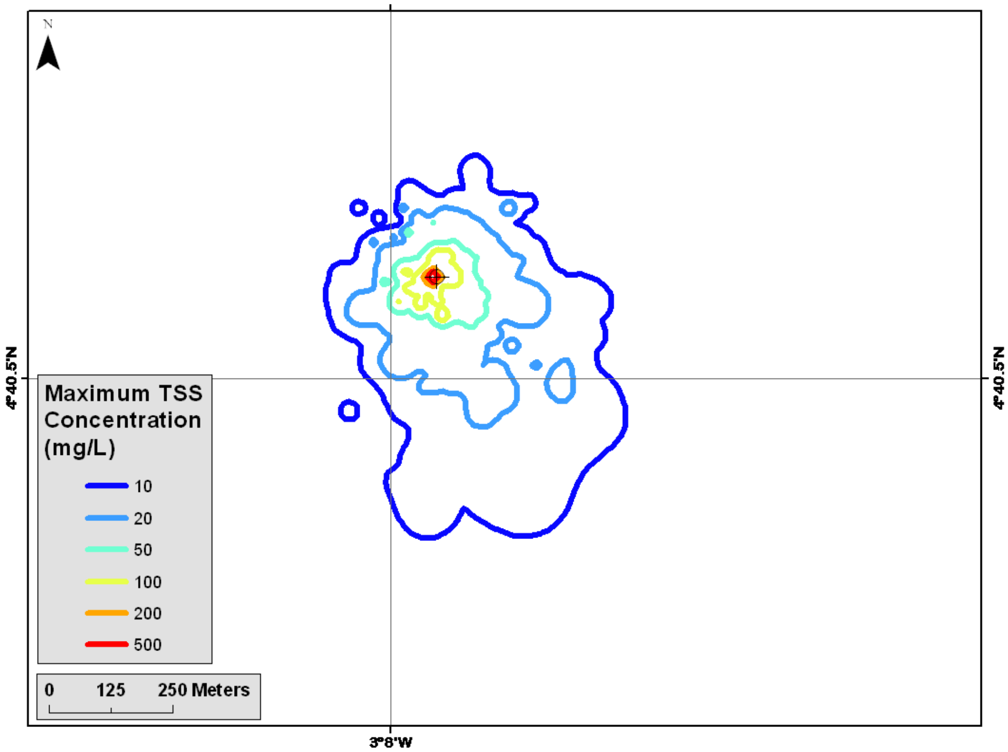



Figure 43. Drilling discharges maximum predicted TSS concentrations at EN-7 in April.

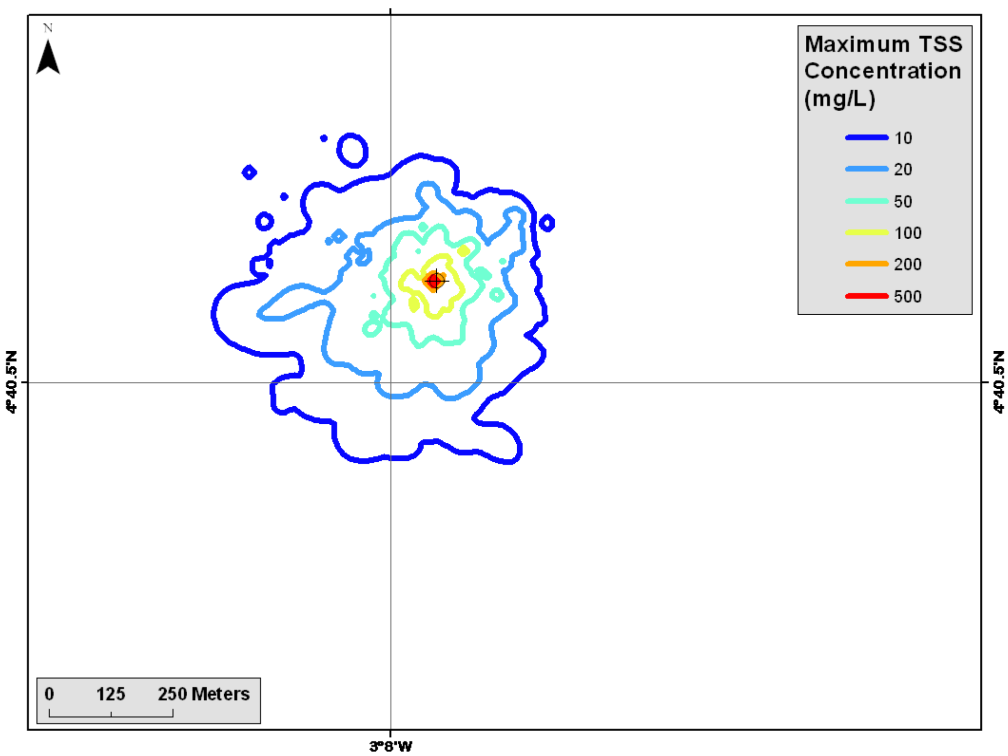



Figure 44. Drilling discharges maximum predicted TSS concentrations at EN-7 in December.

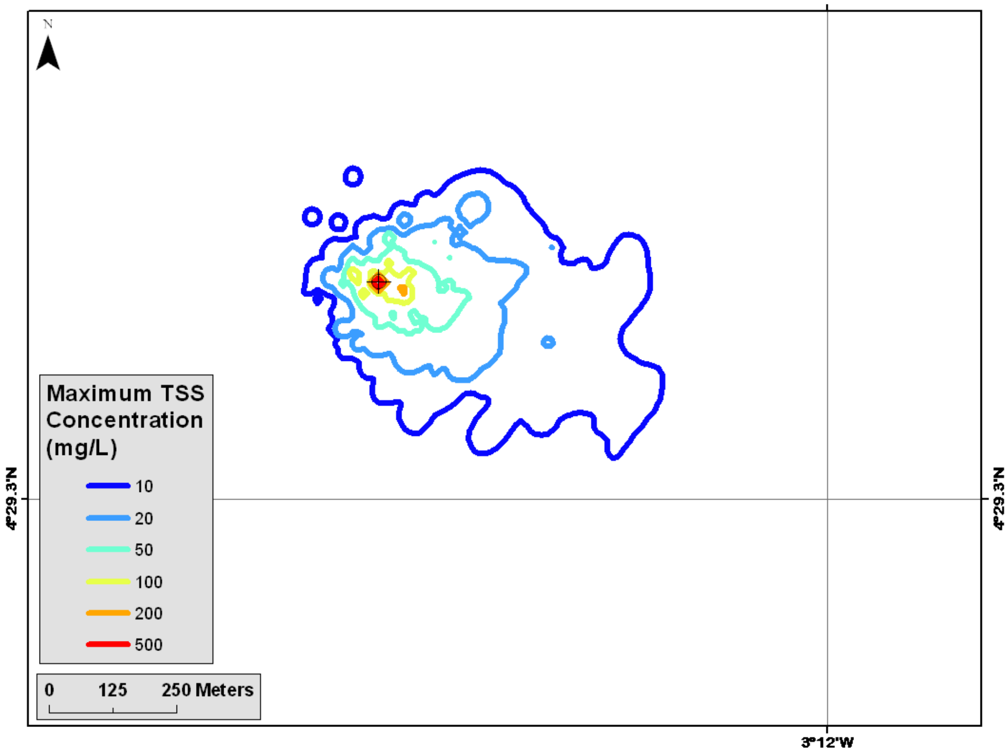



Figure 45. Drilling discharges maximum predicted TSS concentrations at EN-22 in April.

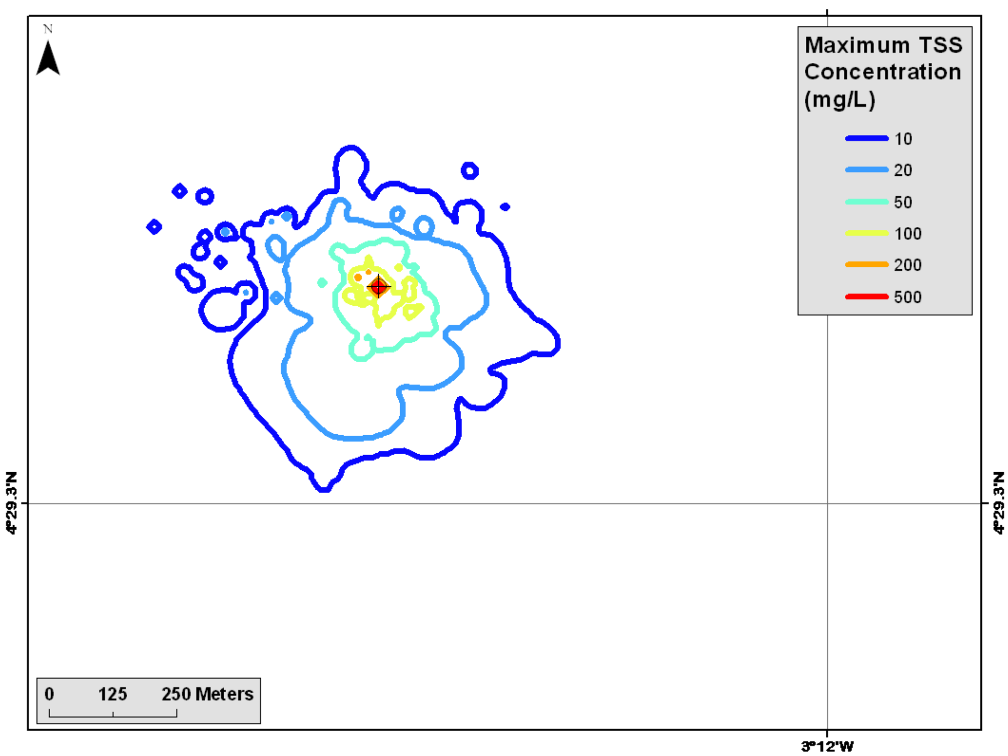



Figure 46. Drilling discharges maximum predicted TSS concentrations at EN-22 in December.

# 6. Produced Water Discharge Modelling

## 6.1. Modelling Approach

The discharge of produced/polluted water into the marine environment typically results in the formation of a plume. The nature of this plume, its location, extent, and spatial dilution characteristics are dependent on the discharge characteristics and the environmental conditions (e.g. receiving water density/temperature, current conditions) during the period of discharge, and particularly how they relate to each other (e.g discharge more or less dense than receiving water). The main physical processes that occur during the discharge of effluent into water bodies can be described by the following three stages:

Stage 1: **Convective decent/jet stage** – The first stage determines the initial dilution and spreading of the material in the immediate vicinity of the release location. This is calculated from the discharge velocity, momentum, entrainment and drag forces.

Stage 2: **Dynamic collapse stage** – The plume may float, sink or be neutrally buoyant. The second stage determines the spread and dilution of the released material as it either hits the sea surface or sea bottom or becomes trapped by a strong density gradient in the water column. Advection, density differences, and density gradients drive the transport of the plume.

Stage 3: **Dispersion stage –** In the final stage, transport and dispersion of the discharged material is driven by the local currents. Dispersion of the discharged material will be enhanced with increased current speeds and water depth, and with greater variation in current direction over time and depth.

In this study, only the first two stages of flow have been analysed ("near-field") using the CORMIX model (Appendix E). The model was applied to capture the near-field components of the flow, consisting of the convective descent/jet phase and the dynamic collapse phase. The output from this model predicts the immediate dispersion and dilution of the discharge plume due to a combination of factors such as the momentum of flow (as a function of the output speed), buoyancy of the plume, and the local ambient currents at the discharge site. This analysis provides insight into the potential effect of the discharged water in the immediate vicinity of the discharge (e.g., within ~ 100 m). CORMIX is a rule based model and plume properties are calculated using different algorithms depending on the CORMIX designated flow regime, and for the spatial extent of model predictions is limited to the extent in which the physics conform to the given flow regime. Produced/cooling/brine water discharges may contain dissolved/dispersed constituents which may create an impact into the marine environment; in addition, the discharge water may have a different temperature and/or density of the receiving water. CORMIX modelling results are presented as a dilution factor or plume centerline concentration (based on an initial stated value) as a function of distance from the discharge site in order to understand the dilution of these dissolved constituents within the discharge and can track the decrease (or increase) of an excess temperature relative to the receiving waters.

## 6.2. Discharge Conditions

The following table summarizes the environmental conditions of the receiving waters. Values were obtained from the Levitus climatology (annual surface seawater temperature and density) and from the HYCOM current dataset for the site of interest.

Two different sites of discharges have been specified:

- Amidships, Portside for the produced water discharges
- Stern, Portside for the cooling water & brine discharges

Table 30. Receiving waters conditions.

| Seawater Surface Temperature (° C) | Seawater Surface Density (kg/m³) | Surface Mean Current (m/s) | Surface High Current ($95^{th}$ Percentile, m/s) |
|---|---|---|---|
| 27 | 1,023 | 0.355 | 0.822 |

Since the maximum FPSO vessel length is about 340 m, it can be assumed that both discharges sites are about ~ 170 m apart. A sample picture of overboard discharges from a FPSO is presented in the following figure to provide a reference for the following discussion.

Figure 47. Example of operational overboard discharges from an FPSO (source: internet).

The following important considerations have been assumed in the CORMIX model setup in order to be on the conservative side - i.e. to assume those conditions that would minimize the dilution of the discharges:

1) CORMIX allows inclusion of a factor representing the amount of surface water/atmosphere heat exchange. For example, in a cold (air) environment, a surface water discharge will easily cool down. To be conservative, this was set to zero which reflects no exchange with the atmosphere.

2) In order to take into account the fact that the discharges are performed very close to the vessel, where the vessel draft may act as a physical barrier and reduce the potential for

mixing/spreading, the CORMIX simulations were run taking into account the bounding effect of a wall (e.g. river bank, shoreline, etc.). In that sense, all the discharge simulations were run as if it was a river discharge with the discharge located from the river bank, the discharge plume being limited to the effective vessel (FPSO) hull.

3) While the cooling water and brine discharges are performed from the stern (extreme of the FPSO), it has been assumed that the currents are parallel to the FPSO, advecting the plume along the length of the FPSO, where the FPSO is effectively acting as a river bank discharge.

## 6.3 Discharge Simulations

A summary of the four different produced water (PW) scenarios is presented in Table 31. All the PW discharge simulations were performed assuming the discharge was released from the amidships, portside, 3 m below the water surface. The four PW discharge scenarios reflect combinations of two different flow rates and two different current conditions. The temperature and total dissolved solids (TDS) concentration of the produced water was defined to be 60C and 13,351 mg/L respectively, the corresponding density based on these defined inputs was calculated to be 993 kg/m$^3$ which is much less dense than the receiving water. The simulations run were set up to track the dilution of a particular product - i.e. an initial oil concentration of 40 mg/L with distance from the discharge point.

Table 31. Produced water discharge scenarios (amidships, portside, 3 m below water surface).

| ID | Description | Current Speed (m/s) | Discharge Flow Rate (bbl/day) | Pipe Diameter (inches) | Discharge Temperature (° C) | Discharge TDS (mg/L) | Discharge Density (kg/m³) | Discharge Concentration (mg/L) |
|---|---|---|---|---|---|---|---|---|
| 1 | Low Discharge, Mean Current | 0.355 | 37,500 | 12 | 60 | 13,351 | 993 | 40 |
| 2 | Low Discharge, High Current | 0.822 | 37,500 | 12 | 60 | 13,351 | 993 | 40 |
| 3 | High Discharge, Mean Current | 0.355 | 75,000 | 12 | 60 | 13,351 | 993 | 40 |
| 4 | High Discharge, High Current | 0.822 | 75,000 | 12 | 60 | 13,351 | 993 | 40 |

The following plot presents the model predictions of the dilution as a function of distance of the initial discharge oil concentration (40 mg/L) from the produced water discharges. As can be seen in this figure, the concentration quickly decreased within the first few meters, by a factor of approximately 4, after which point the rate of decrease slowed down, however, concentrations still continued to decrease as a function of distance; in all cases the plume centreline concentration is less than 2 mg/L (diluted by a factor of 20) at a distance of 20 m from the discharge point.

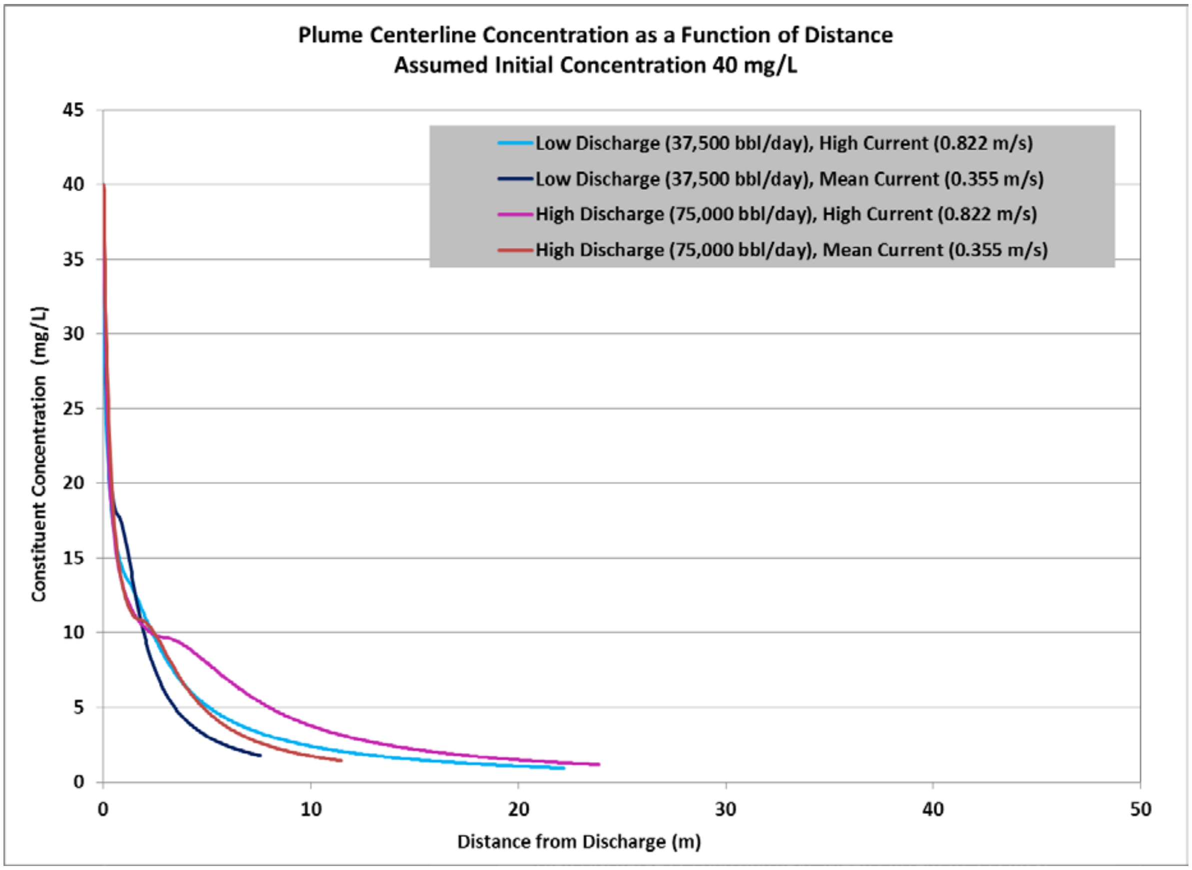



Figure 48. Produced water discharge modelling results – dilution of the 40 mg/L initial concentration as a function of distance from the discharge point.

## 6.4 Cooling Water Discharge Simulations

Table 32 provides a description of the cooling water (CW) discharge scenarios. All of the CW discharge simulations were performed assuming the discharge was released from the stern, portside, 7 m above the water surface (overboard or above keel) from a maximum pipe diameter of 24 inches (61 cm). The two CW discharge scenarios simulated the combined total (topsides plus marine) discharge of heated seawater discharged overboard (surface discharge), under two current conditions. The “topside” discharges consist of a maximum of 560,000 bbl/day with a discharge temperature of 55° C, while the “marine” discharges consist of a maximum of 208,850 bbl/day with a temperature of 30° C. The model was used to track the excess temperature (temperature rise over ambient temperature) difference, in order to be compared with the IFC standards (i.e. 3° C within 100 m).

Figure 49 presents the modelling results of the cooling water discharge simulations in terms of plume centreline excess temperature as a function of distance from the discharge initial location. This figure shows that under both current conditions, the excess temperature decreases rapidly from the discharge point, well below the 3° C IFC guideline. The plume centreline excess temperature is initially 21.21° C and it decreases rapidly to an excess less than 3° C at a distance of 10 m from the initial discharge location. The discharge is diluted quickly due to the characteristics of the discharge relative to the characteristics of the receiving waters. The above surface release location aids by enabling the discharge to plunge into receiving waters (which enhances mixing) and the lower density of the discharge (~10 kg/m³ less than receiving water) drives the buoyant plume to rise back to the surface, again enhancing mixing within the receiving waters. The ambient currents aid in advecting the plume which also contributes to the high initial dilution.

Table 32. Cooling water discharge scenarios (stern portside, 7 m above surface).

| ID | Description | Current Speed (m/s) | Discharge Flow Rate (bbl/day) | Pipe Diameter (inches) | Discharge Density (kg/m³) | Discharge Temperature (° C) | Discharge Salinity (psu) |
|---|---|---|---|---|---|---|---|
| 1 | Combined marine and topside discharge flow, Mean Current | 0.355 | 768,850 | 24 | 1,014.2 | 48.21 | 35.7 |
| 2 | Combined marine and topside discharge flow, High Current | 0.822 | 768,850 | 24 | 1,014.2 | 48.21 | 35.7 |

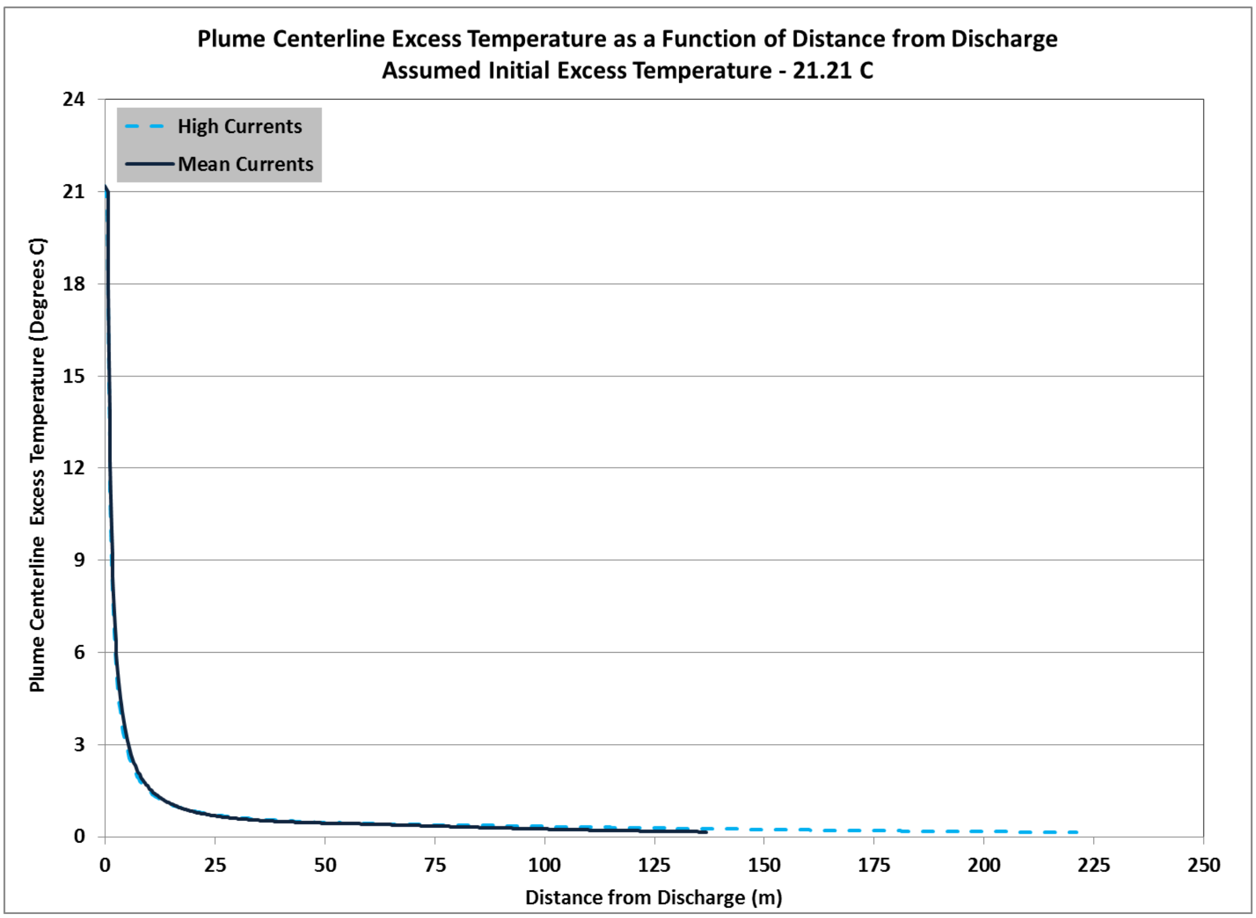



Figure 49. Cooling water discharge modelling results - decrease of the initial 21.21**° C** excess temperature over distance from the discharge point.

## 6.5 Brine Discharges Simulations

Table 33 provides a description of the brine discharge simulations; discharges were simulated assuming the discharge was released from the stern, portside, 7 m above the water surface (overboard or above keel) from a maximum pipe diameter of 24 inches (61 cm). The two brine discharge scenarios represent the same discharge characteristics: relatively weak discharge flow (6,000 bbl/day) at ambient temperature and high saline concentration (64.2 psu, twice the salinity of seawater), under two different ambient current conditions. The high discharge salinity results in relatively high discharge density compared to that of the receiving water (~20 kg/m$^3$ greater). The model was used to track the dilution of this discharge as a function of distance from the discharge site.

Table 33. Brine discharge scenarios (stern portside, 7 m above surface).

| ID | Description | Current Speed (m/s) | Discharge Flow Rate (bbl/day) | Pipe Diameter (inches) | Discharge Density (kg/m³) | Discharge Temperature (° C) | Discharge Salinity (psu) |
|---|---|---|---|---|---|---|---|
| 1 | Brine discharge, Mean Current | 0.355 | 6,000 | 24 | 1,045 | 25.00 | 64.2 |
| 2 | Brine discharge, High Current | 0.822 | 6,000 | 24 | 1,045 | 25.00 | 64.2 |

Figure 50 illustrates that the plume dilutes substantially within a short distance, with a dilution factor over 1,000 at a distance of 100 m from the discharge point. This plume dilutes quickly over a short horizontal distance mainly due to the enhanced dilution from the vertical descent of the plume; the discharge is approximately 20 kg/m$^3$ denser than the receiving water which creates a large negatively buoyant force driving the plume downward in the water column.

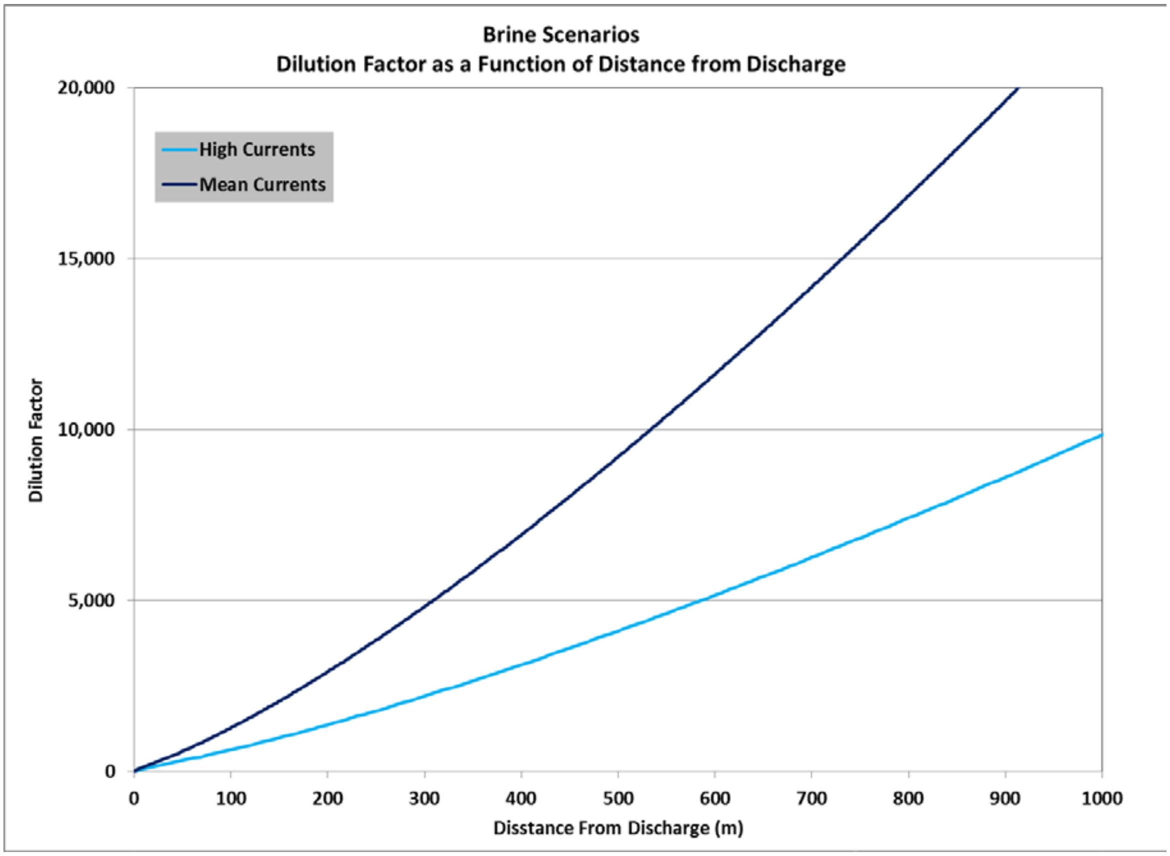



Figure 50. Brine discharge modelling results - dilution factor over distance from the discharge point.

## 6.6 Combined Cooling Water and Brine Discharges Scenarios

Table 34 provides a summary of the combined cooling water and brine discharge scenarios. The combined cooling water and brine scenarios simulated the plume associated with the combined discharge of cooling water and brine. The combined discharge is assumed to be released from a location from the stern, portside, 7 m above the water surface (overboard or above keel). Evaluated individually, the cooling water was shown to be a relatively large discharge volume of positively buoyant water due to its increased temperature (less dense than receiving water). The brine discharge was found to be a relatively small volume discharge of negatively buoyant water due to its increased salinity (more dense than receiving water). In combination, due to the larger volume of the cooling water discharge, the combined discharge has properties similar to the cooling water discharge.

Two scenarios were run which represented the combined discharge under two current conditions. Assuming that mixing within the piping system is great enough to produce a uniformly mixed discharge, the properties of the three individual discharges were volume weighted to determine the properties (temperature, salinity, and associated density) of the combined discharge. The model was used to track both plume centreline excess temperature and dilution as a function of distance from the discharge site.

Table 34. Cooling water and brine discharge scenarios (stern, portside, 7 m above surface).

| ID | Description | Current Speed (m/s) | Discharge Flow Rate (bbl/day) | Pipe Diameter (inches) | Discharge Density (kg/m³) | Discharge Temperature (° C) | Discharge Salinity (psu) |
|---|---|---|---|---|---|---|---|
| 1 | Combined marine and topside discharge flow and Brine discharge, Mean Current | 0.355 | 774,850 | 24 | 1,014.4 | 48.03 | 35.92 |
| 2 | Combined marine and topside discharge flow and Brine discharge, High Current | 0.822 | 774,850 | 24 | 1,014.4 | 48.03 | 35.92 |

The following figures present the model results of the combined cooling water and brine discharges:

- Model predicted excess temperature decreases as a function of distance (Figure 51)
- Model predicted dilution factor increases as a function of distance (Figure 52)
- Model predicted relative concentration decreases as a function of distance (Figure 53)

These figures show that the discharge dilutes quickly with distance from the release point. The excess temperature differential reduces from 21.03° C to less than an excess temperature of 3° C within 10 m. Furthermore at a distance of 100 m from the release origin, the plume centreline concentration is diluted by a factor of 60 and 90 for high and mean current conditions, respectively.

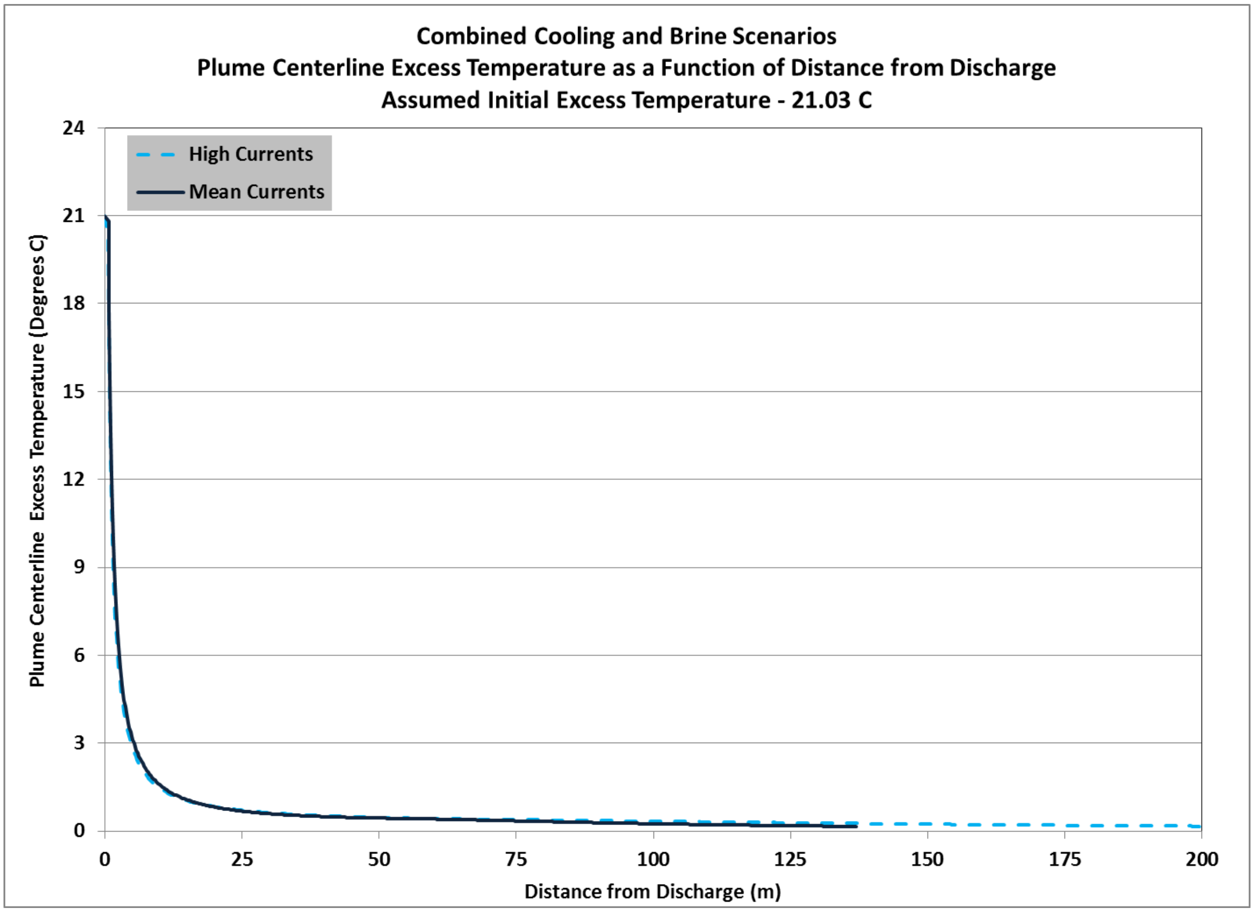



Figure 51. Combined cooling water & brine discharge modelling results - decrease of the initial 21.21**° C** excess temperature over distance from the discharge point.

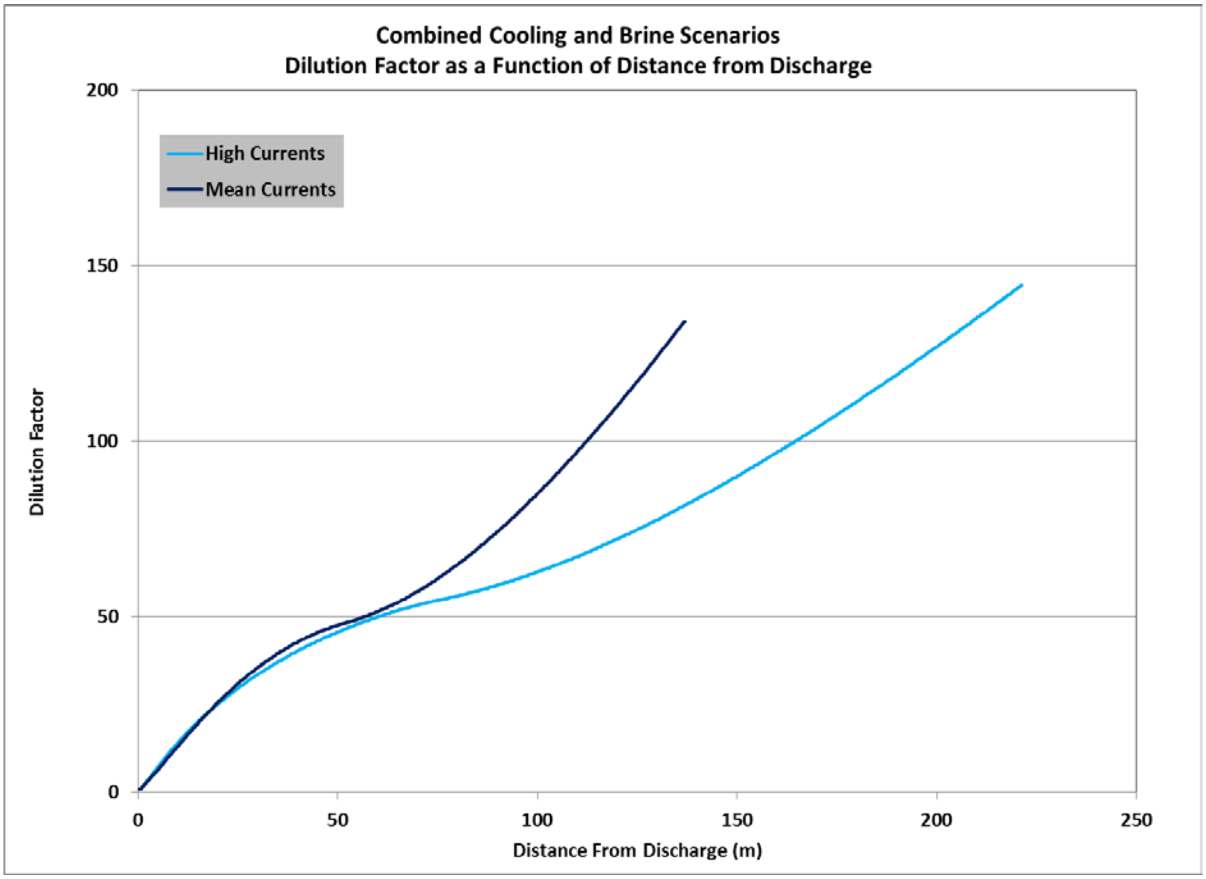



Figure 52. Combined cooling water & brine discharge modelling results - dilution factor over distance from the discharge point.

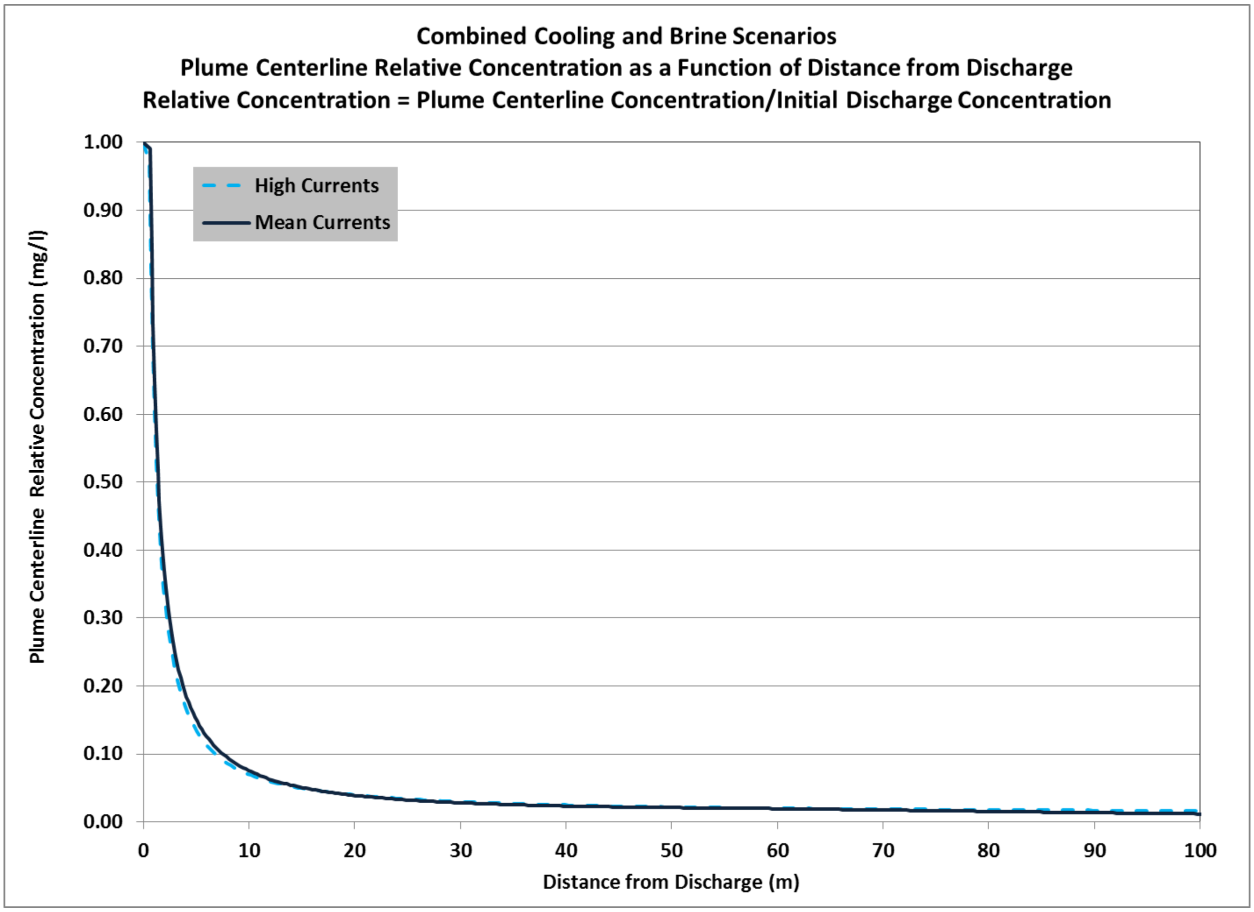



Figure 53. Combined cooling water & brine discharge modelling results - relative concentration over distance from the discharge point.

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# Appendix A: Environmental Datasets Description

### *Winds Dataset - NOGAPS*

Wind data was gathered from the Navy Operational Global Atmospheric Prediction System (NOGAPS), a state-of-the-art global spectral numerical meteorological model. The NOGAPS model has many features similar to other climate and numerical weather prediction (NWP) models and has been continuously developed over the past twenty years at the Naval Research Laboratory (NRL) in Monterey, CA. It is a robust global model that forms the backbone of the Navy's ensemble prediction system, providing forecasts of up to 10 days for a number of atmospheric parameters. It is additionally used as a research tool for understanding global atmospheric dynamics, air/sea interaction, tropical cyclone prediction, and meso-scale weather patterns, among a wide range of other applications.

NOGAPS predicts global atmospheric parameters for 18 vertical levels between the surface and 10 mb height, with a hybrid vertical coordinate system that is defined by the terrain at low levels and constant pressure surfaces at high levels (Bayler and Lewit, 1992). NOGAPS is capable of generating 60 different types of output fields for every forecast hour (Bayler and Lewit, 1992).

For this study the 10 m winds from the NOGAPS model were used. NOGAPS uses a sophisticated data assimilation process to incorporate previous model run data and current observational data to provide an updated Nowcast/Analysis (or Tau 0) for the globe. The observations used for this assimilation include a combination of in-situ point observations, satellite derived data, ship observations, and upper air observations. While the comprehensive assimilation process ensures that major features are captured in the model output, the NOAA National Oceanographic Data Center verification indicates that NOGAPS slightly under-analyzes and under-forecasts the 10 meter wind speeds stronger than 10 m/s, especially in coastal near shore locations. For this reason the particular NOGAPs 10 m wind dataset used for this study was sourced from a version of the dataset compiled by the HYCOM Consortium, which takes the original NOGAPS output hosted by the U.S. Global Ocean Data Assimilation Experiment (GODAE) and applies a QuikSCAT correction to them. NASA's Quick Scatterometer (QuickSCAT) SeaWinds satellite uses microwave radar to measure near-surface wind speed and direction over the Earth's oceans. Thus by assimilating the NOGAPS dataset with the QuikSCAT dataset, a more accurate representation of regional wind patterns is expected.

This HYCOM NOGAPS is provided at 0.5 degree horizontal resolution with a 3 hour time step from 2003 to present. This corresponds to the same wind dataset used to force the HYCOM global hydrodynamic model.

For more information, Hogan and Rosmond (1991) provide detailed documentation of the complete NOGAPS model.

### *Currents - Global HYCOM*

HYCOM (HYbrid Coordinate Ocean Model) is a primitive-equation ocean general circulation model that evolved from the Miami Isopycnic-Coordinate Ocean Model (MICOM) (Halliwell et al., 1998, 2000; Bleck, 2002). MICOM has become one of the premier ocean circulation models, having been subjected to validation studies (Chassignet et al., 1996; Roberts et al., 1996; Marsh et al., 1996) and used in numerous ocean climate studies (New and Bleck, 1995; New et al., 1995; Hu, 1996, 1997; Halliwell, 1997, 1998; Bleck 1998).

HYCOM is considered as the next generation operational model, with the U.S Navy planning to replace the operational forecast performed of NCOM with HYCOM by the end of 2011. HYCOM has an advantage over NCOM in that it incorporates tides, and has a higher resolution.

The HYCOM global ocean system is a 3-D dynamical model that is operationally run each day, providing a 5-day hindcast and 5-day forecast of oceanic currents. Hindcast data are used to validate the accuracy of each run to determine if modeled forcings produced results that match observational data. HYCOM uses Mercator projections between 78°S and 47°N and a bipolar patch for regions north of 47°N to avoid computational problems associated with the convergence of the meridians at the pole. The 1/12° equatorial resolution provides gridded ocean data with an average spacing of ~7km between each point. Several studies have shown that at least 1/10° horizontal resolution is required to resolve boundary currents and mesoscale variability in a realistic manner (Hurlburt and Hogan, 2000; Smith and Maltrud, 2000; Chassignet and Garaffo, 2001).

The HYCOM model works effectively in both deep and shallow waters. There are 32 vertical layers in a hybrid vertical coordinate scheme, where isopycnics are used in the deep ocean stratified interior (Halliwell, 2002). These isopycnals smoothly transition to z-level coordinates (isobaric) in the weakly stratified upper-ocean mixed layer, to terrain-following sigma coordinates in shallow water regions, and back to z-level coordinates in very shallow waters (Halliwell, 2002). Differential vertical mixing models improve performance including any one of the three available differential vertical mixing models: 1) nonlocal K-Profile Parameterization, 2) NASAGISS level 2 turbulence closure, and 3) Mellor-Yamada level 2.5 turbulence closure (Halliwell, 2004). Bathymetry is derived from the NRL DBDB2 dataset. Surface forcing is derived from the Navy Operational Global Atmospheric Prediction System (NOGAPS), which includes wind stress, wind speed, heat flux (using bulk formula), and precipitation.

Data is assimilated through the Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings, 2005). The NCODA system uses a Multi-Variate Optimal Interpolation (MVOI) scheme, which uses model forecasts as a first guess and then refines estimates from available satellite and in-situ temperature and salinity data that are applied through the water column using a downward projection of surface information (Cooper & Haines, 1996).

Hindcast currents generated using the HYCOM model are typically obtained for a long period. The current speed and direction data are provided at locations on a regular grid spaced at a distance of 1/12 degree. These currents are used in ASA pollutant transport model, to solve “long range” problems such as large / continuous oil spills.

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# Appendix B: OILMAP / DEEP Model Description

As offshore oil development proceeds into deeper water, the possibility of blowouts becomes of increasing concern. The principal issues are the difficulty in mounting effective containment and cleanup for such spills and of the impact from dispersed, subsurface oil that may travel many kilometers in the water column. As an example, oil released from the IXTOC blowout (Gulf of Mexico, September 1979) was dispersed throughout the water column and resulted in high concentrations of petroleum hydrocarbons in the vicinity of the well.

To address this issue, ASA's OILMAP system has been expanded with an embedded plume model, which was originally incorporated in the World Wide Oil Spill Model system (WOSM). This model system has been extended and applied to predict the transport and fate of oil and gas released from potential blowout sites. The basic plume model is appropriate for the modelling of the subsurface release of oil (e.g. a release from a sub-sea pipeline) and oil-and-gas mixtures (e.g. drilling accidental blowout). In January 2004, ASA incorporated the joint industry developed CDOG model plume and oil particle code into OILMAP, as well as an implementation of the CDOG Model Executable itself.

Where potential blowout sites occur in deep water, the "standard" oil spill model processes must be extended to include potential methane hydrate formation, and the resulting plume dynamics are of key importance for the model application. OILMAP/Deep includes both ASA's plume model and the CDOG plume model. Both plume models describe the movement of oil or oil and gas mixtures released sub-surface from a pipeline or blowout well head. ASA's plume model was developed with the assistance of Dr. Raj Bishnoi, Department of Chemical and Petroleum Engineering, University of Calgary, Alberta, Canada, to incorporate a hydrate formation/dissociation module.

***Blowout Model Theory***

In shallow water, oil and gas released from the sea bed are driven into the water column as a jet due to the momentum of the discharge (see the accompanying figure). The jet region is confined to the vicinity of the seabed. As the discharge moves upward, the density difference between the expanding gas bubbles in the plume and the receiving water results in a buoyant force which drives the plume. As the plume rises, it continues to entrain sea water, reducing the plume's velocity and buoyancy and increasing its radius. The oil in the release is rapidly mixed by the turbulence in the plume, causing it to break up into small droplets. These droplets (typically a few micrometers to millimeters in diameter) are rapidly transported upward by the rising plume; their individual rise velocities contributing little to their upward motion. As the plume reaches the sea surface it is deflected in a radial, surface flow zone without appreciable loss of momentum. This radial jet carries the oil particles rapidly away from the center of the plume. The velocity and oil concentrations in this surface flow zone decrease while the depth of the zone increases. In the far-field, where the plume buoyancy has been dissipated, ambient currents and wind generated waves determine the subsequent transport and dispersion of the oil.

There are several important modifications that may alter this basic description of jet/plume behaviour. If the buoyant driving force for the plume is dissipated by sea water entrainment before it reaches the surface, the oil droplets in the plume will be carried to the surface solely by their own rise velocities and the surface interaction zone will effectively disappear.

The plume behaviour can also be altered by variations in the ambient density field, which can cause trapping of the plume in the water column. Finally, in the presence of ambient currents the plume path can be substantially altered as the current forces the plume to bend from the vertical. If the current velocity profile varies with time and depth, the path of the plume can become very complicated.

ASA's oil blowout model is based on published work on plume formation and behaviour. A simplified integral jet theory is employed for the vertical and horizontal motions of the gas-oil plume. The necessary model parameters defining the rates of entrainment and spreading of the jet are obtained from laboratory studies. The gas plume analysis is described in McDougall (1978), Spaulding (1982) and Fanneløp and Sjøen (1980a). In 2004 we have incorporated the joint industry developed CDOG model implementations of subsurface plume and automatic oil particle size calculation Johanssen (2002) into the OILMAP/Deep system Yapa and Chen, (2003). The CDOG plume model formulations include model-calculations for droplet size distribution estimation and thermodynamic processes not included in the ASA model.

***Hydrate formation and dissociation***

As water depths become deeper (> 200 m) the basic dynamics of the oil/gas jet/plume become more complicated, principally due to the increase in hydrostatic pressure at the seabed which leads to the possibility of the formation of gas hydrates, a class of solids in which small molecules occupy almost spherical holes in ice-like lattices made up of hydrogen-bonded water molecules. The hydrate-forming gases include light alkanes, carbon dioxide, hydrogen sulfide, nitrogen and oxygen. Methane, the most typical gas likely to be released during a blowout, is known to form hydrates. A portion or the entire volume of released gas may be converted to hydrates. These hydrates, which typically form on the gas bubbles close to the release location, have specific gravities on the order of 0.92 to 0.96. The hydrate solids break into small particles and are transported by their rise velocity and the ambient currents. The conversion of the gas into gas hydrates, to the extent that it occurs, deprives the plume of its principal source of buoyancy, leaving the oil droplets and gas hydrates free to rise under the action of their own buoyancy. The oil and gas hydrates in this much less vigorously mixed plume may be carried over large distances in the water column before ultimately reaching the sea surface.

The most critical issue for deepwater blowouts is the formation rate of gas hydrates under the gas/oil flow rates, hydrostatic pressures, temperatures, and salinity at typical blowout sites. High pressure laboratory experiments by Bishnoi and Mainik (1979) demonstrated conditions under which hydrate formation will occur, as shown in the figure above. The actual hydrate formation pressures for any given case are highly dependent on the gas or hydrocarbon liquid compositions. None of the previous existing blowout models has included a hydrate formation component and hence none is applicable for deep water blowout simulations.

Hydrate formation rates are based on a model used to determine the mass of hydrate produced at equilibrium assuming that the blowout gas is pure methane. The amount of hydrate formed is assumed to depend on the ambient pressure, temperature, and water/gas ratio in the plume. The blowout plume and hydrate formation models are then used to predict the distributions of velocity, oil, and buoyancy as a function of the distance along the plume trajectory.

When the blowout plume reaches pressure and temperature conditions to the right of the equilibrium curve, the hydrates are assumed to immediately convert back to gaseous form. The hydrate particles are likely to be widely separated at this time by turbulent mixing processes and entrainment and the resulting gaseous methane is quickly transported to the sea surface.

With the integration of the blowout plume and hydrate formation models into OILMAP, stochastic and deterministic simulations may be run to predict impacts on surrounding waters, resources and shoreline from real or hypothetical shallow or deepwater blowout events. The figure above shows plan and section views of the oil particle distribution from a deep water blowout for the larger, faster-rising oil particles, seven days after the start of the blowout. The surface slick is seen here a ring, resulting from changes in the surface currents over the time course of the oil's surfacing.

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# Appendix C: SIMAP Model Description

SIMAP is a computer modelling software application that estimates physical fates and biological effects of releases of oil. In SIMAP, both the physical fates and biological effects models are three-dimensional. There is also a two-dimensional oil spill model for quick trajectories and screening of scenarios and a three-dimensional stochastic model for risk assessment and contingency planning applications. The models are coupled to a geographic information system (GIS), which contains environmental and biological data, and also to databases of physical-chemical properties and biological abundance, containing necessary inputs for the models.

SIMAP was derived from the physical fates and biological effects submodels in the Natural Resource Damage Assessment Models for Coastal and Marine and Great Lakes Environments (NRDAM/CME and NRDAM/GLE), which were developed for the U.S. Department of the Interior (USDOI) as the basis of Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) Natural Resource Damage Assessment (NRDA) regulations for Type A assessments (French et al., 1996; Reed et al., 1996). The physical fates model has been validated with more than 20 case histories, including the *Exxon Valdez* and other large spills (French McCay, 2003, 2004; French McCay and Rowe, 2004), as well as test spills designed to verify the model's transport algorithms (French et al., 1997). The wildlife mortality model has been validated with more than 20 case histories, including the *Exxon Valdez* and other large spills, verifying that these values are reasonable (French and Rines, 1997; French McCay 2003, 2004; French McCay and Rowe, 2004). The technical documentation for SIMAP is in French McCay (2003, 2004, 2009).

Applications for SIMAP include impact assessment; hindcast/forecast of spill response; Natural Resource Damage Assessment (NRDA); contingency planning; ecological risk assessment; cost-benefit analysis, and drills and education. The model may be run for a hindcast/forecast of a specific release, or be used in stochastic mode to evaluate the probable distribution of contamination. SIMAP contains several major components:

- The physical fates model estimates surface distribution and subsurface concentrations of the spilled oil and its components over time.
- The biological effects model estimates impacts resulting from a spill scenario on fish, shellfish, wildlife, and for each of a series of habitats (environments) affected by the spill.
- The probability of impact from an oil discharge is quantified using the three-dimensional stochastic model.
- Currents that transport contaminant(s) and organisms are entered using the graphical user interface or generated using a (separate) hydrodynamic model. Alternatively, existing current data sets may be imported.
- Environmental, chemical, and biological databases supply required information to the model for computation of fates and effects.
- The user supplies information about the spill (time, place, oil type, and amount spilled) and some limited environmental conditions at the time (such as temperature and wind data).

As with ASA's other modelling systems, SIMAP is easily applied to a wide variety of conditions. It is set up and runs within ASA's standard Geographic Information system (GIS) or ESRI's ArcView GIS, and can be applied to any aquatic environment (fresh or salt) in the world. It uses any of a variety of hydrodynamic data file formats (1-, 2- and 3-dimensional; time varying or constant) and allows 2-d vertically-averaged current files to be created within the program system when modelled currents are not available. Outputs include easily interpreted visual displays of dissolved and particulate concentrations and trajectories over time, as appropriate to the properties of the chemical being simulated. An optional biological exposure model is available to evaluate areas and volumes exposed above concentrations of concern and to predict the impacts on exposed fish and wildlife.

SIMAP specifically simulates the following processes:

- initial plume dynamics;
- slick spreading, transport, and entrainment of floating oil;
- evaporation and volatilization (to atmosphere);
- transport and dispersion of entrained oil and dissolved aromatics in the water column;
- dissolution and adsorption of entrained oil and dissolved aromatics to suspended sediments;
- sedimentation and re-suspension;
- natural degradation
- shoreline entrainment, and
- boom and dispersant effectiveness.

The physical and biological models require environmental, oil and biological data as inputs. One of ASA's strengths is the ability to synthesize data from disparate sources. The data come from many sources including government and private data services, field studies and research. Modelling techniques are used to fill in "holes" in the observational data, thus allowing complete specification of needed data. The environmental database is geographical, including data of the following types: coastline, bathymetry, shoreline type, ecological habitat type, and temporally varying ice coverage and temperature. This information is stored in the simplified geographic information system (GIS). The chemical database includes physical-chemical parameters for a wide variety of oils and petroleum products. Data have been compiled by ASA from existing, but diffuse, sources.

An oil spill is simulated using site-specific wind, current, and other environmental data gathered from existing information, on-line services, and/or field studies. Shoreline and habitat types, as well as bathymetry, are mapped and gridded for use as model input. The physical, chemical, and toxicological properties of the spilled oil are provided by the oil database or updated to the specific conditions of the release. The model estimates the fate of the oil over time. The model outputs are time-varying concentrations and mass per unit area on surfaces (i.e., water surface, shoreline, sediments), which quantifies exposure to aquatic biota and habitats. Atmospheric loading in space and time is also computed, and provides input to air dispersion models.

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# Appendix D: MUDMAP Model Description

MUDMAP is a personal computer-based model developed by ASA to predict the near and far-field transport, dispersion, and bottom deposition of drill muds and cuttings and produced water (Spaulding et al; 1994; Spaulding, 1994). In MUDMAP, the equations governing conservation of mass, momentum, buoyancy, and solid particle flux are formulated using integral plume theory and then solved using a Runge Kutta numerical integration technique. The model includes three stages:

> Stage 1: **Convective decent/jet stage** – The first stage determines the initial dilution and spreading of the material in the immediate vicinity of the release location. This is calculated from the discharge velocity, momentum, entrainment and drag forces.
>
> Stage 2: **Dynamic collapse stage** – The second stage determines the spread and dilution of the released material as it either hits the sea surface or sea bottom or becomes trapped by a strong density gradient in the water column. Advection, density differences and density gradients drive the transport of the plume.
>
> Stage 3: **Dispersion stage –** In the final stage the model predicts the transport and dispersion of the discharged material by the local currents. Dispersion of the discharged material will be enhanced with increased current speeds and water depth and with greater variation in current direction over time and depth.

MUDMAP is based on the theoretical approach initially developed by Koh and Chang (1973) and refined and extended by Brandsma and Sauer (1983) for the convective descent/ascent and dynamic collapse stages. The far-field, passive diffusion stage is based on a particle-based random walk model. This is the same random walk model used in ASA's OILMAP spill modelling system (ASA, 1999).

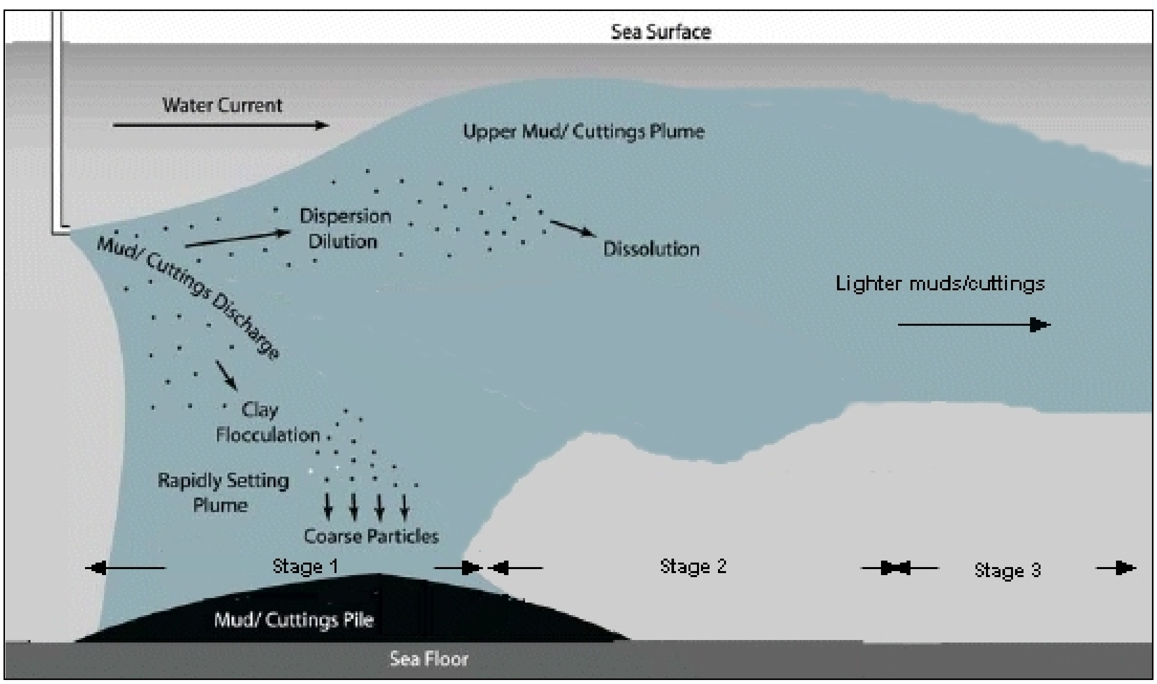


Figure 54. Conceptual diagram showing the general behaviour of cuttings and muds following the discharge to the ocean (Neff 2005) and the three distinct discharge phases.

The model's output consists of calculations of the movement and shape of the discharge plume, the concentrations of soluble (i.e. oil in produced water) and insoluble (i.e. cuttings and muds) discharge components in the water column, and the accumulation of discharged solids on the seabed. The model predicts the initial fate of discharged solids, from the time of discharge to initial settling on the seabed As MUDMAP does not account for resuspension and transport of previously discharged solids, it provides a conservative estimate of the potential seafloor concentrations (Neff 2005).

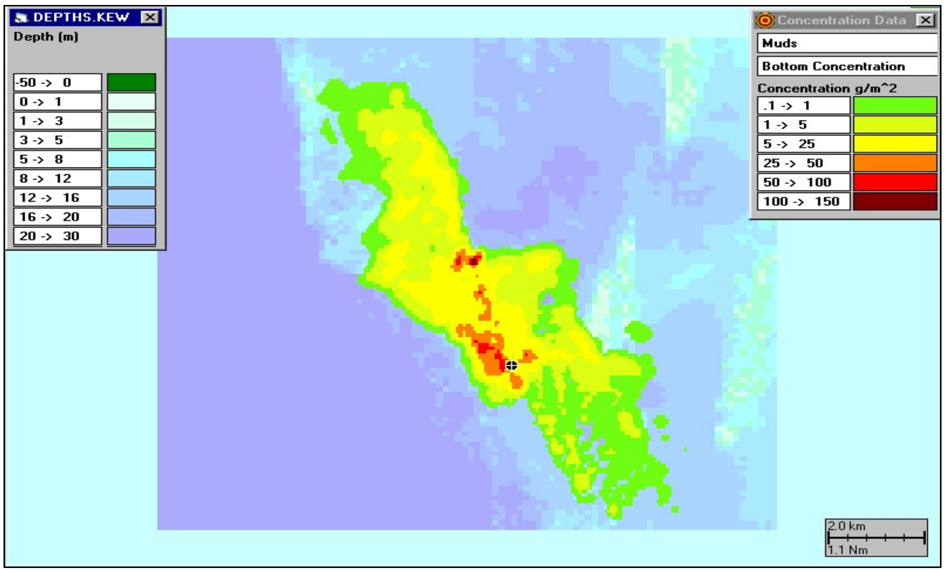


Figure 55. Example MUDMAP bottom concentration output for drilling fluid discharge.

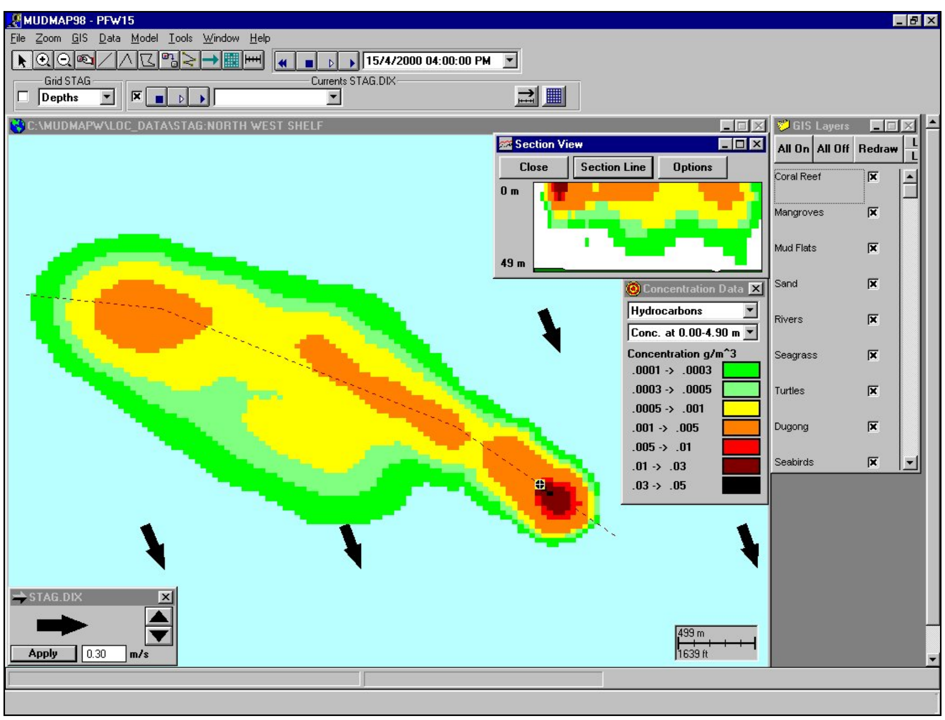


Figure 56. Example MUDMAP water column concentration output for drilling fluid discharge.

MUDMAP uses a color graphics-based user interface and provides an embedded geographic information system, environmental data management tools, and procedures to input data and to animate model output. The system can be readily applied to any location in the world. Application of MUDMAP to predict the transport and deposition of heavy and light drill fluids off Pt. Conception, California and the near-field plume dynamics of a laboratory experiment for a multi-component mud discharged into a uniform flowing, stratified water column are presented in Spaulding et al. (1994). King and McAllister (1997, 1998) present the application and extensive verification of the model for a produced water discharge on Australia's northwest shelf. GEMS (1998) presents the application of the model to assess the dispersion and deposition of drilling cuttings released off the northwest coast of Australia.

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# Appendix E: CORMIX Model Description

CORMIX is a commercially available water quality modelling and decision support system supported by the U.S. EPA. It is designed for environmental impact assessment of mixing zones resulting from wastewater discharges from point sources. CORMIX is a length scale model, so called because the variables used to define the mixing forces occurring in the near-field can be arranged in groups that have length dimension. Results from laboratory experiments have been used to determine empirical relationships between these groups of parameters, and from these relationships the model predicts plume behaviour in the field. The model system has been favourably compared to field and laboratory data (Akar and Jirka, 1991a; Doneker and Jirka, 1990; Jones et al., 2007) and reviewed in multiple journal proceedings (Akar and Jirka, 1991b; Akar and Jirka, 1994; Baumgartner et al., 1994; Doneker et al., 1991, Doneker et al., 1999).

The CORMIX model calculates a series of length scales based on the definition of ambient conditions and the discharge being simulated, and it uses these to determine a flow class. A flow class specifies which type of discharge plume will occur given the ambient and discharge specifications provided by the user. As an example, the discharge may have the characteristics of a jet or a plume, the discharge may be positively or negatively buoyant, or the ambient currents may be weak or strong. CORMIX runs a series of models for the series of flow classes that define the discharge in its various stages and strings the results together. CORMIX model output defines the discharge plume centreline, plume diameter, centreline dilution and average plume concentration from positively, neutrally and negatively buoyant effluent plumes.

CORMIX simulations are done assuming steady state current conditions. The parameters of the simulated discharge are also defined as constants, including the discharge rate, temperature and concentration of any constituents present.

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Annex D2

# Dispersion Modelling of Drilling Discharges: Deepwater Tano Block, offshore Ghana

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# Final Report

# Dispersion Modeling of Drilling Discharges: Deepwater Tano Block, offshore Ghana

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**Project Manager:** Nathan Vinhateiro

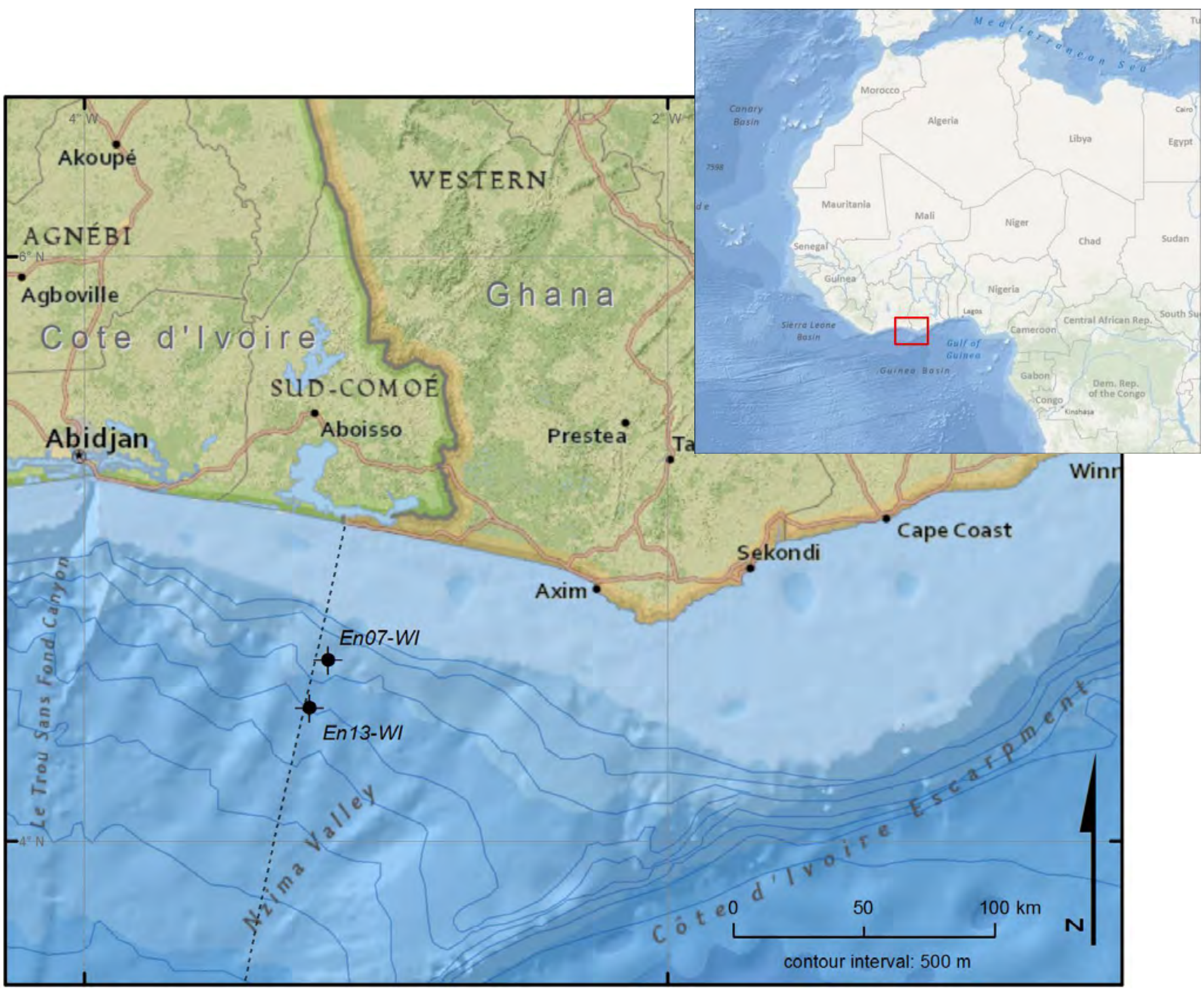
**PROJECT NUMBER:** ASA 13-176

**VERSION:** Final

**DATE:** 17 Feb 2014

**CLIENT:**

John Ward, Mark Irvine
**Environmental Resources Management**, London, UK



# Document Control Form

## Title:

"Dispersion Modeling of Drilling Discharges: Deepwater Tano Block, offshore Ghana."

## Location & Operator:

Enyenra Field, Deepwater Tano License Block. Tullow Ghana Limited (TGL).

## ASA Project Number:

13-176 ERM Ghana Drilling

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| Release | File Name | Date Submitted | Notes |
|---|---|---|---|
| Preliminary | 13-176_ERM_Ghana_Prelim_20Dec2013 | 20 December 2013 | Preliminary model results |
| Draft | 13-176_ERM_Ghana_Draft_17Jan2014 | 17 January 2014 | Complete modeling report (draft) |
| Draft (Rev1) | 13-176_ERM_Ghana_Draft_29Jan2014 | 29 January 2014 | Revised to include ERM comments |
| Final | 13-176_ERM_Ghana_Final_29Jan2014 | 17 February 2014 | Issued final (no comments from TGL) |

## Disclaimer:

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# Executive Summary

Environmental Resources Management (ERM) contracted with Applied Science Associates, Inc. (dba RPS-ASA) to evaluate seabed deposition and suspended sediment concentrations associated with operational discharges within the Deepwater Tano (DWT) license block, offshore Ghana. Two drilling sites within the Enyenra field (En07-WI and En13-WI) were selected for the dispersion modeling to represent different water depths along the continental slope. The sites are located approximately 50-70 km south of the coast at water depths of 1330 m and 1990 m, respectively. The study consisted of simulating the release of drill cuttings and drilling mud at each site for up to four drilling sections, using varying current conditions over a period of 15 consecutive days. Simulations were performed to evaluate seabed deposition and sediment plumes following the discharge of cuttings treated with a thermal desorption unit (TDU).

Discharge simulations were completed using ASA's MUDMAP modeling system. The MUDMAP model predicts the transport of solid releases in the marine environment and the resulting seabed deposition. The model requires information regarding the discharge characteristics (release location, rate of discharge, etc.), the properties of the sediment (particle sizes, density), and environmental characteristics (bathymetry and ocean currents), to predict the transport of solids through the water column.

The general ocean circulation in the DWT block is strongly influenced by the behaviour of the Guinea Current. Modeling and observational studies have noted that this feature exhibits minimum velocities during the autumn months and maximum during the spring/summer. Because drilling in the DWT block is expected to occur throughout the year, MUDMAP simulations were performed for different periods to examine the potential effect of seasonal circulation patterns. Releases were simulated during the months of April and December – which correspond to periods used during previous modeling for the TEN Development (ASA project 11-053). Peak, eastwardly oriented surface currents characterize the flow regime during April, whereas currents during December are less intense and more directionally variable. For each scenario, vertically and time varied currents derived from the HYCOM (HYbrid Coordinate Ocean Model) global simulation were used to reproduce the density and wind-driven circulation in the tropical Atlantic. Currents used as model inputs were obtained at a daily resolution.

The resulting bottom deposition from individual discharge sections was analysed along with the pattern of cumulative deposits for each site and season. All scenarios predict a generally rounded and tight depositional footprint that surrounds each well head. Contours representing very fine thickness intervals (0.1 mm) are slightly more elongate and extend up to 620 m from the release site. The areal extent of deposition above 1 mm is nearly indistinguishable between sites/seasons. The similarities are primarily due to the occurrence of very weak bottom currents at both sites, and the treatment of cuttings returned to the surface. The TDU process results in extremely fine particles that do not contribute significantly to the cumulative mass accumulation on the seabed. Considering all scenarios, thicknesses at or above 1 mm are confined to a distance of 96 m from the discharge sites and occupy a maximum areal extent of 0.02195 $km^2$; thicknesses greater than 10 mm extend up to 48 m with a maximum footprint of 0.00599 $km^2$.

MUDMAP was also used to assess total suspended solid (TSS) concentrations associated with the drilling operation for representative current regimes. A total of eight MUDMAP scenarios (2 sites x 2 seasons x 2 flow regimes) were performed to simulate the water column plume associated with discharge of TDU powder from the Mobile Offshore Drilling Unit (MODU). As with seabed deposition, the excess TSS near the water surface is highly dependent on the hydrodynamic forcing on the day of the cuttings release. Sediment plumes resulting from discharges of TDU powder are predicted to extend between 230 and 360 m from the MODU. In general, the extent of the plumes is greater during strong current conditions, while the maximum TSS concentrations increase during weak current conditions and the plumes persist for longer periods. The maximum predicted concentration of suspended sediments in the water column (corresponding to the weakest current regime) is 896 mg/L. In all cases, the water column is predicted to return to ambient conditions (<10 mg/L) within an hour of the final release.

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# 1. Introduction

Environmental Resources Management (ERM) contracted with Applied Science Associates, Inc. (dba RPS-ASA) to perform model simulations of drilling discharges at two sites within the Deepwater Tano (DWT) license block, offshore Ghana. The objective of the study was to evaluate seafloor deposition and suspended sediments in the water column resulting from the release of drilling mud and cuttings. Two drilling sites within the Enyenra field (En07-WI and En13-WI) were selected for the dispersion modeling to represent locations at a range of water depths along the continental shelf.

Model simulations were performed for different periods (two seasons) in order to evaluate the influence of variability in regional ocean currents. Discharge periods were chosen based on recent literature and on previous analysis of ocean circulation within the TEN Development area (ASA project 11-053). At each site, identical releases were simulated for each discharge period (2) to compare the impacts of drilling during the months of April and December. The discharge schedule for each scenario was based on a drilling plan that consists of four well sections ranging from 36" to 12 ¼" (inches) in diameter.

ASA's MUDMAP model was used to perform the mud and drill cuttings dispersion modeling. MUDMAP predicts the transport, dispersion, and seabed deposition of drilling fluids, produced water, and solid materials released into the marine environment. Inputs necessary for drilling discharge modeling typically include:

- Environmental Conditions
    - Local hydrodynamics

- Physical Characteristics of the Study Area
    - Geographic coordinates of the study area
    - Bathymetry in the vicinity of the discharge sites

- Discharge Program(s)
    - Description of the volumes and types of drilling discharges
    - Schedule of release, discharge duration and/or discharge rate
    - Approximate depth of release for each section

A description of the input data used in the modeling, including the study location and current dataset, are presented in Section 2. The drilling discharge scenarios are presented in Section 3 and model results in Section 4. Report conclusions are given in Section 5. A technical summary of the MUDMAP model is provided in Appendix A.

# 2. Geographic Location and Environmental Data

## 2.1. Study Location

The TEN Development comprises three oil, gas, and condensate fields, Tweneboa, Enyenra, and Ntomme, located within the DWT licence block offshore West Africa. The expected development in the DWT block includes the drilling of 17 new wells in the Tano Basin (Gulf of Guinea) for the purpose of oil and gas production. The proposed En07-WI and En13-WI drilling sites are located within the Enyenra field, offshore Ghana. The sites fall along the continental slope, approximately 50 and 70 km south of the coast, respectively, and between 2 and 4 km east of the maritime boundary with Côte d'Ivoire. The coordinates and water depth at each site are described in Table 1. Figure 1 shows the well locations with respect to regional geography.

Table 1. Location of the discharge sites selected for modeling. Enyenra Field, Ghana.

| Site Name | Block Name | Easting† | Northing† | Water Depth (m) |
|---|---|---|---|---|
| En07-WI | Deepwater Tano | 481894.4 | 510668.2 | 1330 |
| En13-WI | Deepwater Tano | 474942 | 492538 | 1990 |

† *WGS 84 / UTM zone 30N.*

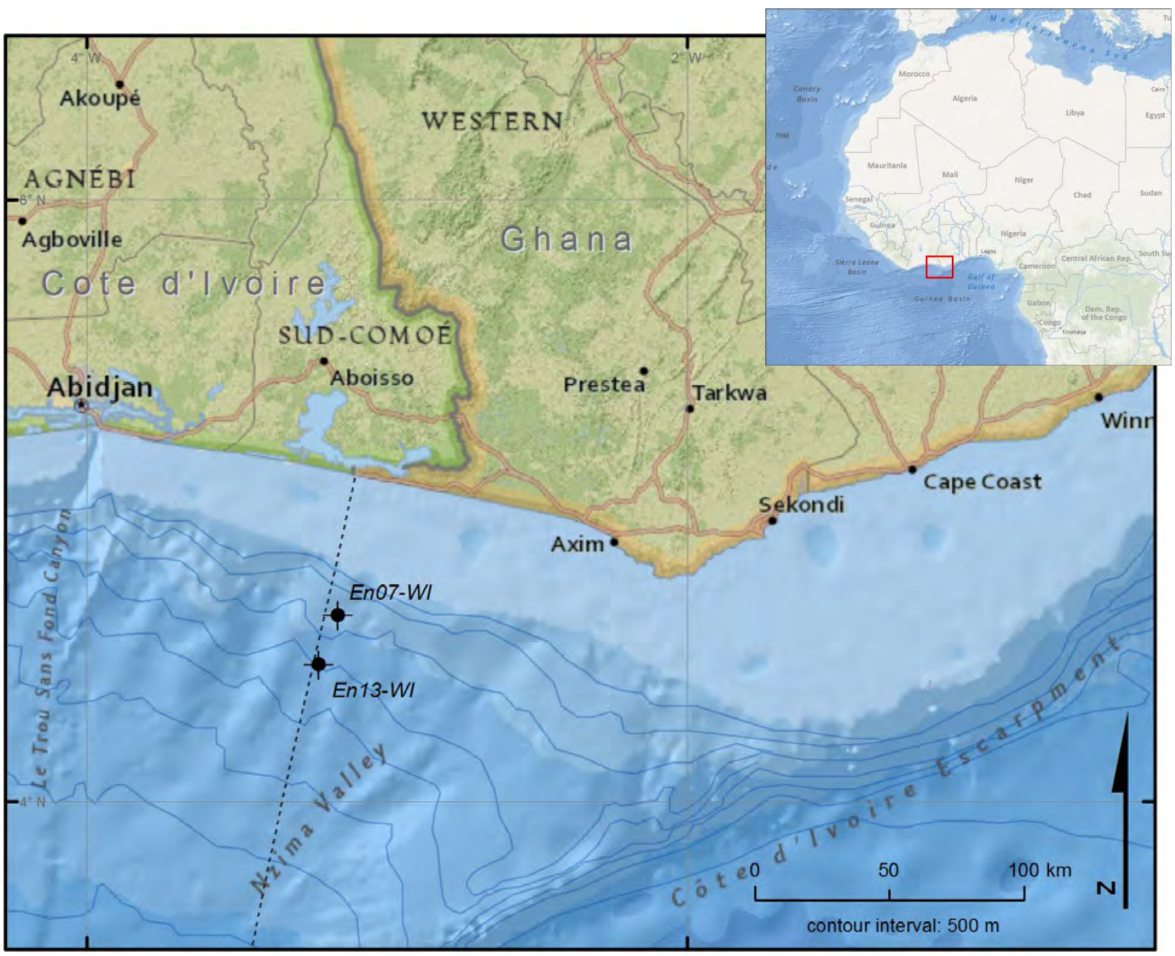



Figure 1. Map of the proposed discharge sites: En13-WI, and En07-WI. Dashed line shows the maritime boundary between Ghana (East) and Côte d'Ivoire (West).

## 2.2. Regional Circulation and Current Datasets

Oceanographic conditions in the Gulf of Guinea are characterized by the Guinea Current at the surface, the Guinea Undercurrent, zones of coastal upwelling, and by the presence of warm, low salinity waters that result from high precipitation and riverine inflow in the eastern Gulf. Offshore Ghana, the primary surface feature is the Guinea Current, which branches eastward from the North Equatorial Counter Current (NECC) as it approaches the African continent (Figure 2; Hardman-Mountford and McGlade, 2003). The current flows eastward at approximately 3°N latitude along the west coast of Africa (Henin et al. 1986), exhibiting relatively strong surface velocities (up to 100 cm/s) in the waters offshore Ghana (Richardson and Reverdin, 1987). Binet and Marchal (1993) report average depths of the Guinea Current of 15 m near the coast and approximately 25 m offshore. In the subsurface, the Guinea Undercurrent flows westward as a return branch of the Equatorial Undercurrent (Binet and Marchal, 1993). The eastward surface flow and westward return via the Guinea Undercurrent give the system a structure of surface and subsurface circulation similar to other eastern ocean boundary upwelling areas (Roy, 1995).

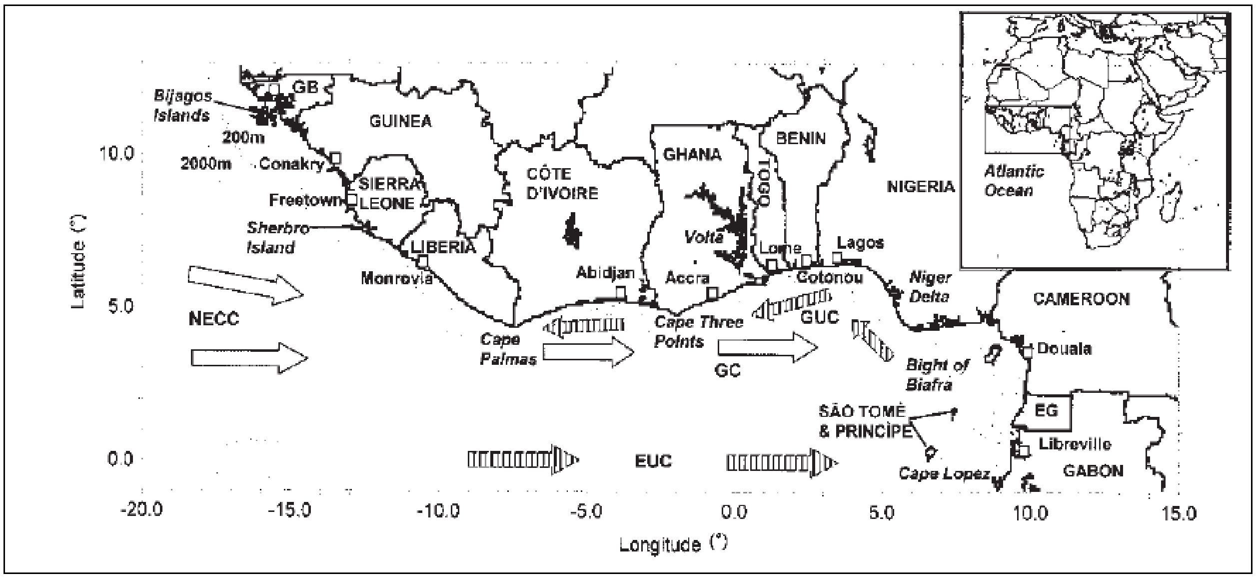



Figure 2. General circulation in the Gulf of Guinea region (Hardman-Mountford and McGlade, 2003). Solid arrows represent surface currents and hatched arrows represent undercurrents: EUC=Equatorial Undercurrent, GC=Guinea Current, GUC=Guinea Undercurrent, NECC=North Equatorial Counter Current.

Like other eastern ocean boundary currents, the Guinea Current is characterized by areas of upwelling and increased biological productivity (Gyory et al., 2005). Coastal upwelling intensifies along the central Gulf of Guinea coast during two (seasonal) periods, with a major upwelling between June and October and again for a brief period between January and February (Hardman-Mountford and McGlade, 2010). Enhanced coastal upwelling during the summer months is related a coincident intensification of the Guinea Current, as stronger current velocities bring the thermocline closer to the surface in the coastal region (Gyory et al., 2005; Philander, 1979). Although surface currents within the region follow similar directional trends throughout the year (predominant easterly transport), several studies have noted that the Guinea Current exhibits minimum velocities during the winter season (Nov-Feb) and maximum during the summer (May-Sep) (Colin, 1988). Additionally, current reversals have been observed at certain times of the year, particularly during the winter season. These reversals in direction are not well understood, but have historically been attributed to the changes in flow of the NECC, the Canary Current, and the Benguela Current (Gyory, 2005). Other oceanographers have proposed that these anomalous periods are due to surfacing of the Ivorian Undercurrent, which transports subsurface currents westward below the Guinea Current, or due to cyclonic eddy systems near the coast (Ingham, 1970).

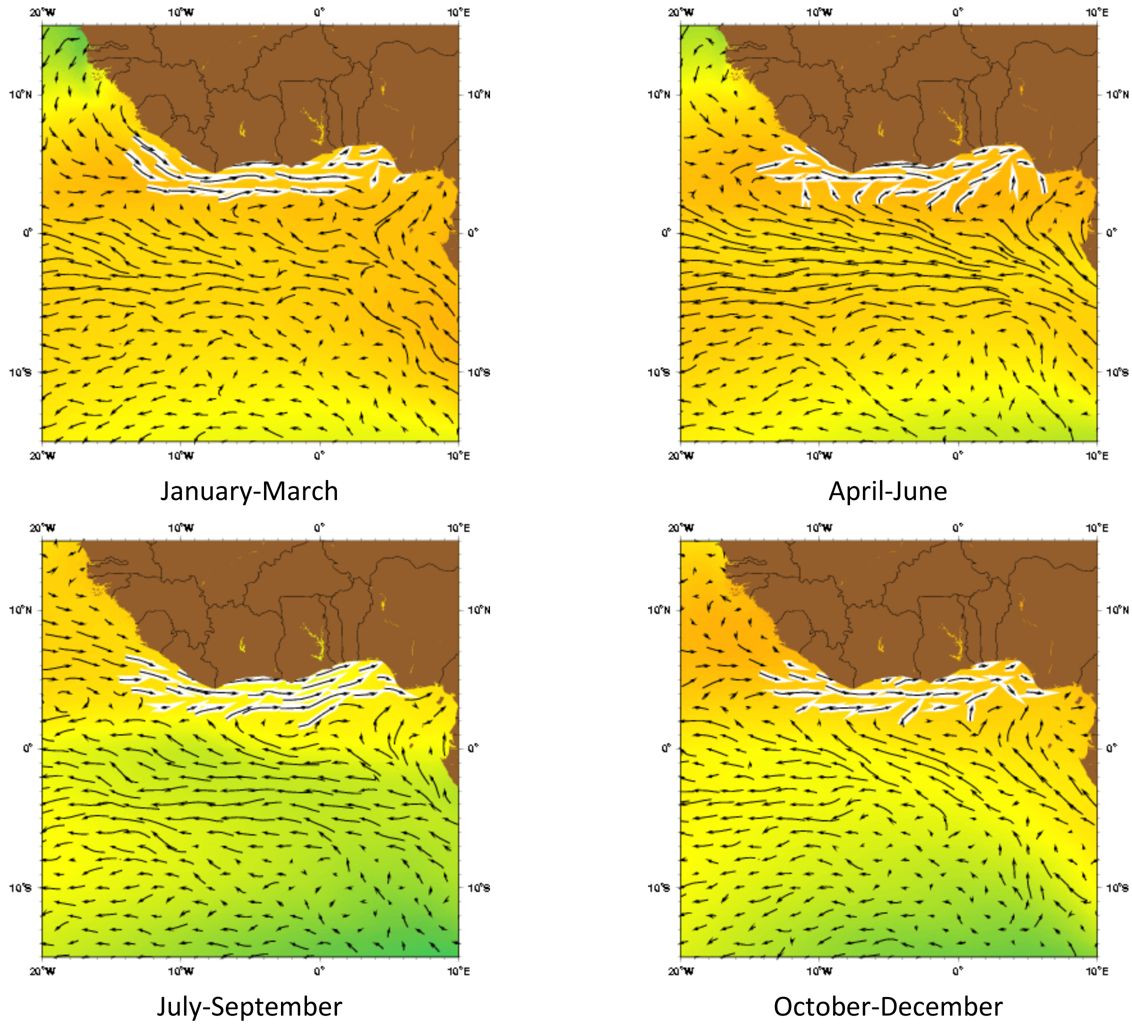



Figure 3. Seasonal trends of the Guinea Current (Source: Gyory et al., 2005). Vectors indicate the average current directionality for each period and the white outlined vectors mark the extent of the Guinea Current.

***Ocean Circulation Dataset – HYCOM Global Simulation***

Currents are the main environmental forcing for the dispersion of drilling muds and cuttings in the water column and therefore strongly influence the fate and transport of discharged sediments. For this study, hydrodynamic data from the HYCOM (HYbrid Coordinate Ocean Model) 1/12 degree global simulation was used to represent oceanic currents for the discharge simulations. The HYCOM model is run by the U.S. Navy to provide a 5-day hydrodynamic forecast (+ 5 day of hindcast as best estimate) and is composed of 3D daily mean temperature, salinity, zonal velocity and meridional velocity fields. Ocean dynamics including geostrophic and wind driven currents are reproduced by the model. The system uses the Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings, 2005) for data assimilation. The model domain has a spatial resolution defined by a 1/12 degree grid in the horizontal direction and a daily temporal resolution, which for this study was obtained for the period from September 2008 to November 2013.

At each well site, daily currents were obtained by interpolating the values from the nearest HYCOM model grid point. At the model cell closest to En13-WI, the water column is represented in 26 discrete vertical layers; at En07-WI, the HYCOM model contains 24 vertical layers. Summary statistics from the hydrodynamic inputs are discussed further below, although at both sites the flow characteristics are quite similar.

Vertical profiles derived from the nearest HYCOM model grid points show the average magnitude of currents with depth at each site (Figure 4 and Figure 5). Surface currents as represented by the model are of moderate speed (30-40 cm/s) although currents greater than 80 cm/s do occur approximately 5% of the time. Currents of this magnitude agree with observations of relatively strong surface velocities (~100 cm/s) in the surface waters offshore Ghana (Richardson and Reverdin, 1987). Current intensity decreases rapidly with depth in the water column and average speeds drop below 10 cm/s by 400 meters depth. Current roses showing the statistical distribution of modeled currents (by depth interval) indicate a cumulative easterly flow for surface currents. Bottom currents are directionally variable and extremely weak (average speeds between 2-3 cm/s).

When viewed as monthly averages, statistics from the HYCOM dataset also reflect the seasonal variability in current speeds as noted above. Surface velocities are approximately 25% stronger during the boreal spring and summer Mar-Sep when compared to the annual average (Figure 6; Figure 7). The fastest surface velocities (>50 cm/s, on average) occur in April and May and the slowest (~25 cm/s) between during the winter months. Monthly current roses (Figure 8 and Figure 9) also indicate strong eastward flow during spring and summer months and weaker more variable currents during the fall/winter. By contrast, subsurface layers reach peak flow velocities during fall/winter months, although the difference in flow speeds is nominal (< 1 cm/s).

Figure 10 and Figure 11 present time series (stick plots) of current vectors for the full HYCOM model period at En13-WI and En07-WI, respectively. The periodic flow reversals, and interannual variability in flow intensity represented in the model emphasize the complex spatial and temporal circulation patterns in the Gulf of Guinea, which are not fully represented in a regional flow schematic (e.g. Figure 2). At both locations, flow becomes more variable with depth and net westerly flow (attributed to the Guinea Undercurrent) is observed in the model at depths below 150 m. In the surface layers, the seasonal variability in currents are regular and repeatable features for all years in the time series and the dataset maintains these oscillations for depths above 50 m. As represented by the HYCOM model, currents have undergone intensification during the most recent calendar year (2013) and the dominant easterly-directed flow pattern is most apparent during this period. Bottom currents at both sites are characterized by generally weak and variable flow that persists year-round.

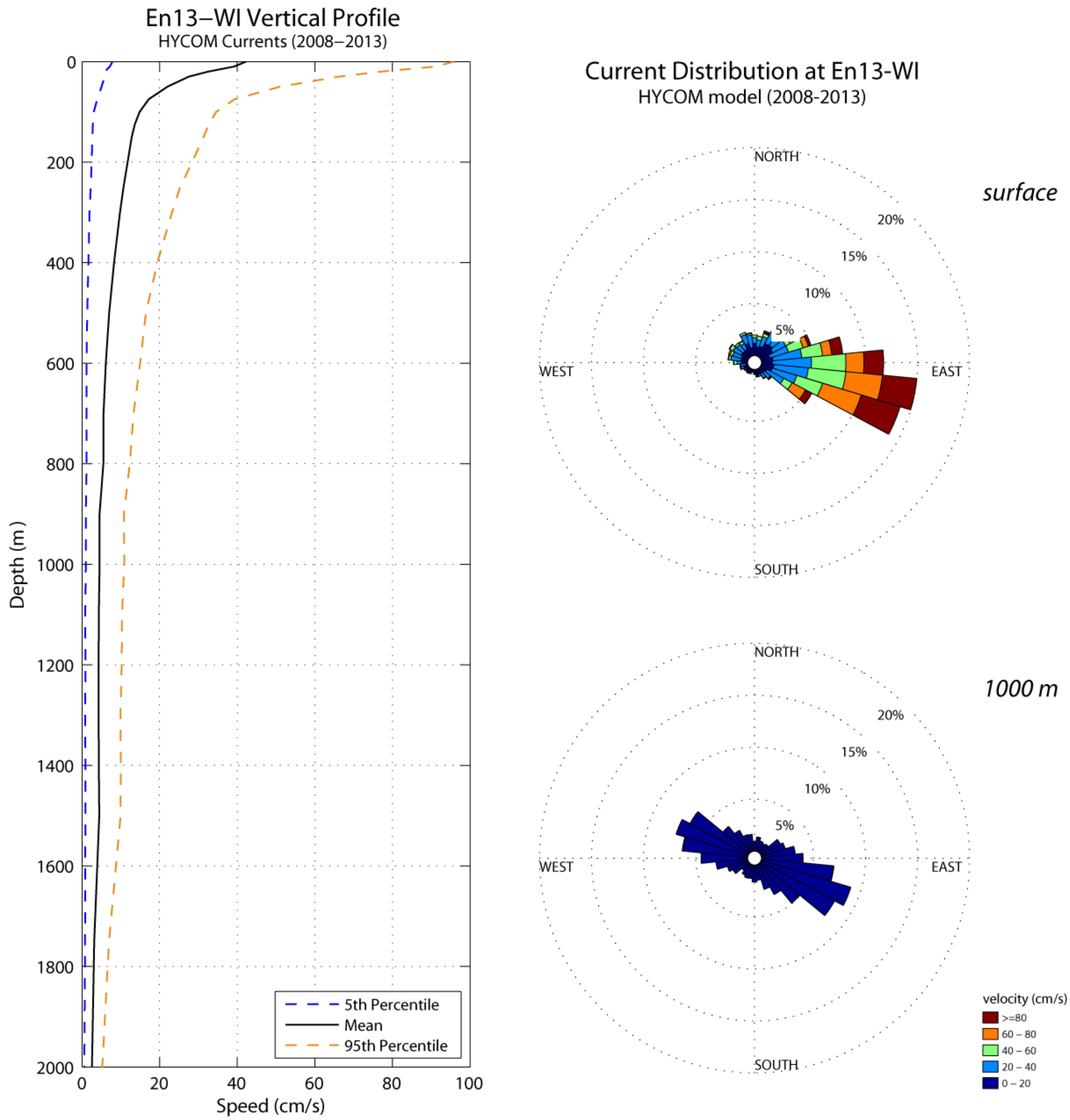



Figure 4. Vertical profile (left) and current roses showing the distribution of current speeds (right) for the En13-WI site, derived from HYCOM model currents between 2008 and 2013.

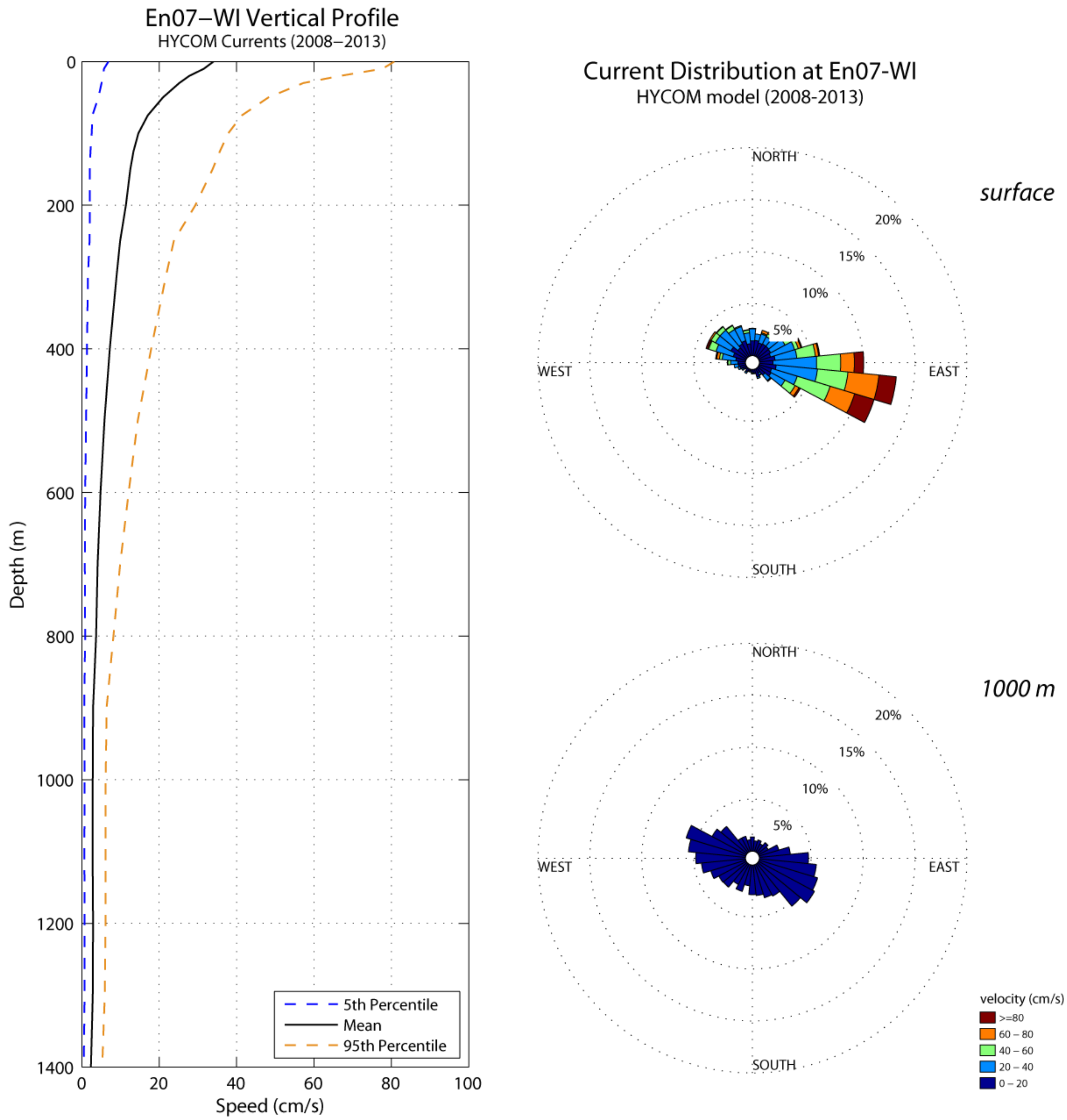



Figure 5. Vertical profile (left) and current roses showing the distribution of current speeds (right) for the En07-WI site, derived from HYCOM model currents between 2008 and 2013.

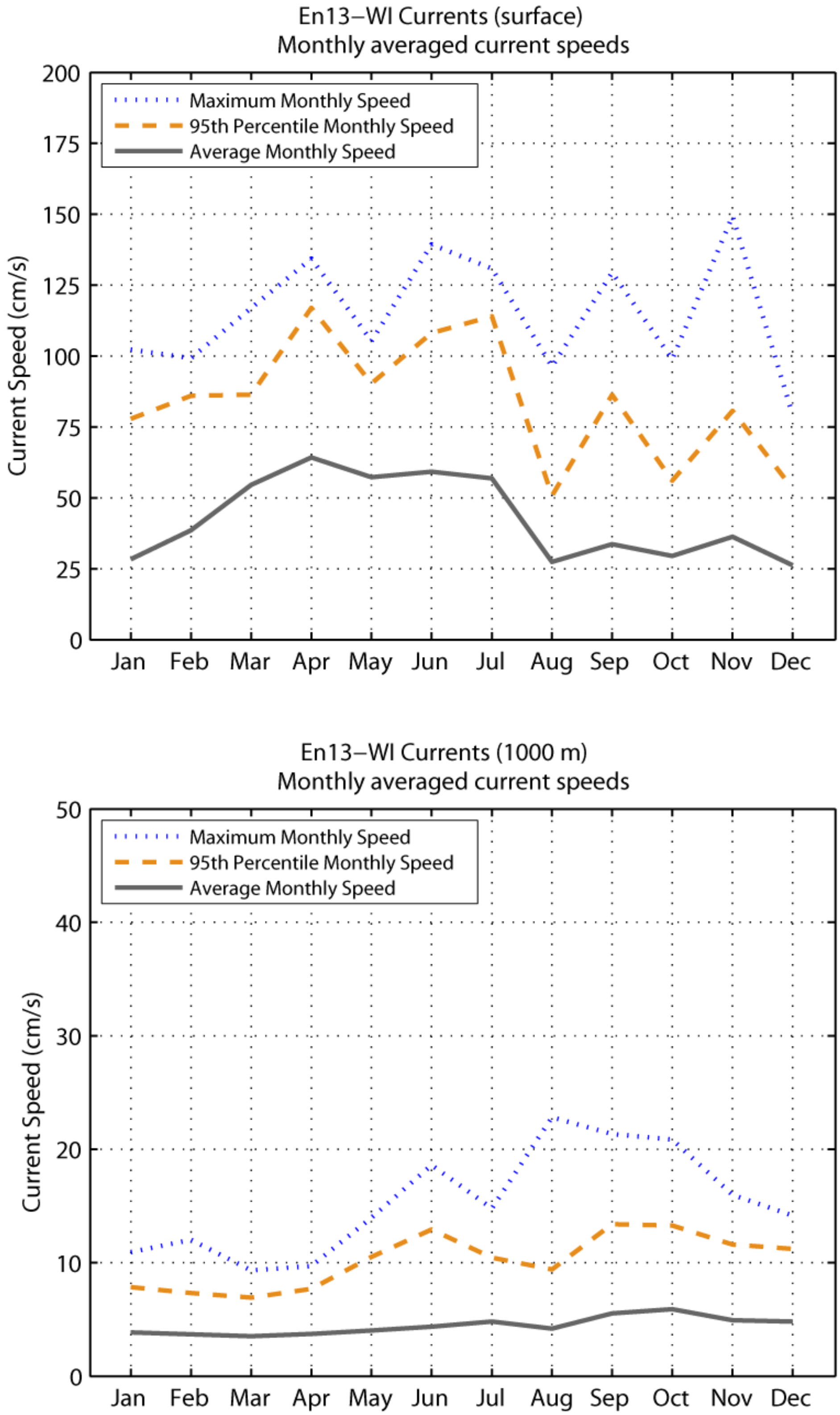
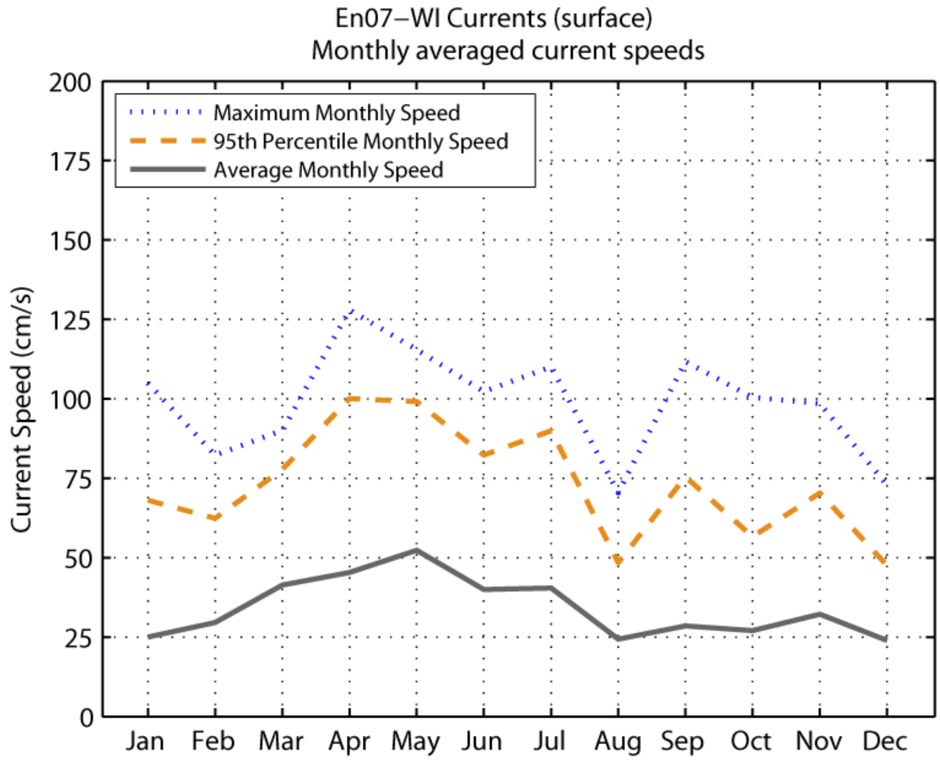



Figure 6. Monthly averaged current speeds at En13-WI derived from the HYCOM global dataset. Average current speeds are shown for the surface (top figure) and 1000 m (bottom figure) water depths.



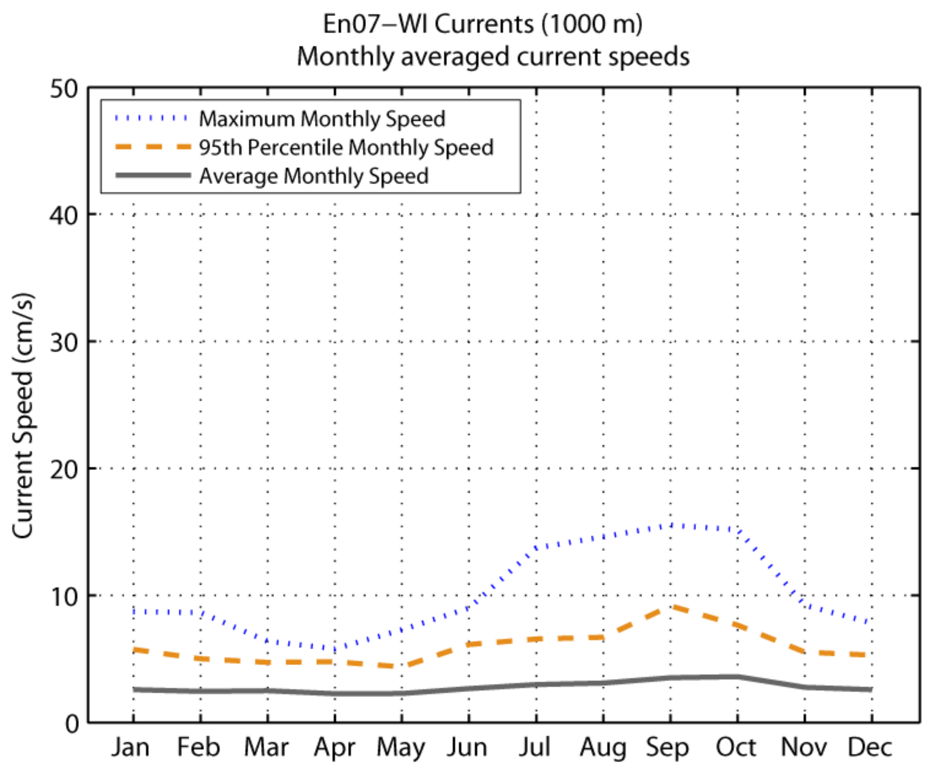




Figure 7. Monthly averaged current speeds at En07-WI derived from the HYCOM global dataset. Average current speeds are shown for the surface (top figure) and 1000 m (bottom figure) water depths.

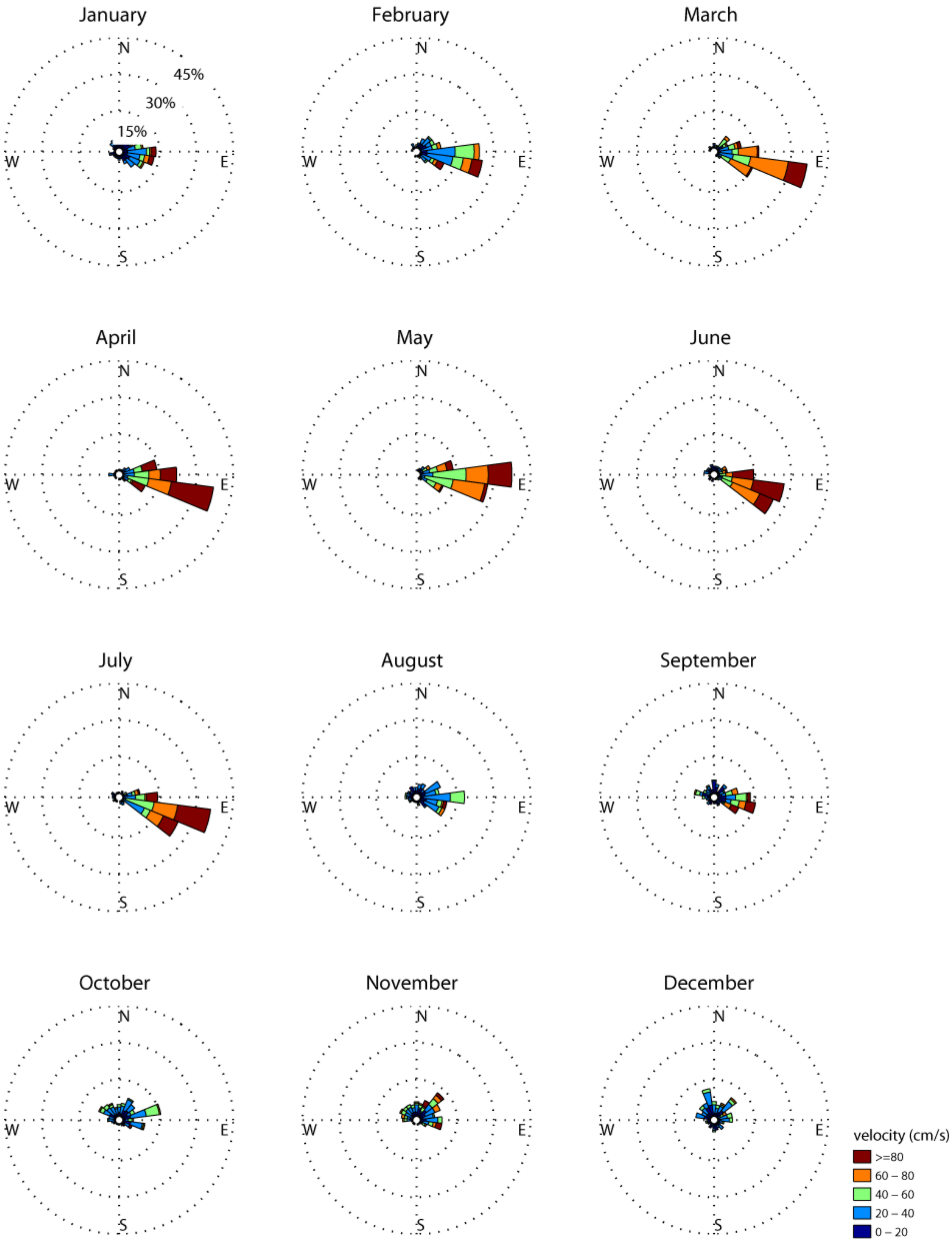



Figure 8. Current roses showing the distribution of surface currents (speed and direction) by month at the En13-WI site, derived from HYCOM model currents between 2008 and 2013.

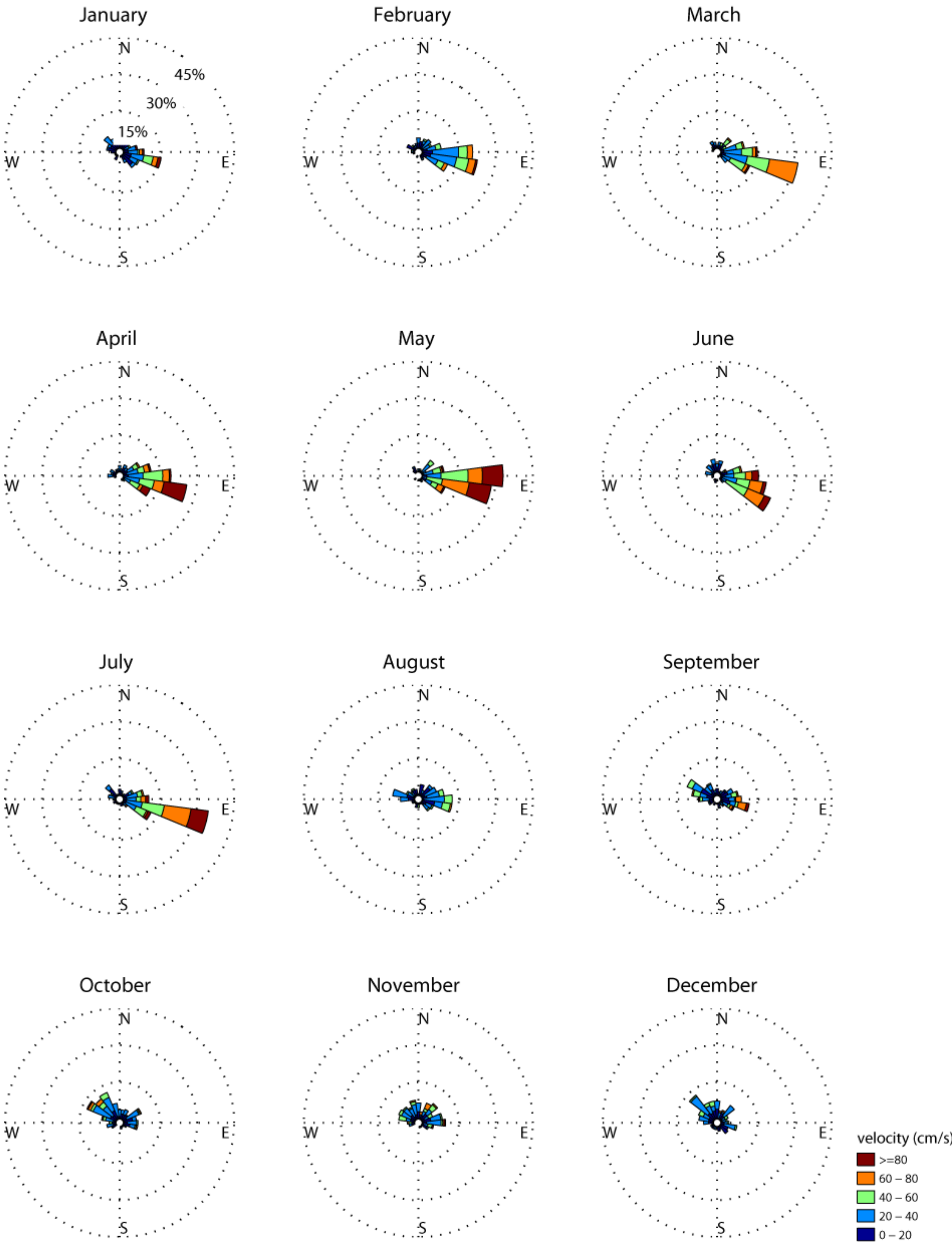



Figure 9. Current roses showing the distribution of surface currents (speed and direction) by month at the En07-WI site, derived from HYCOM model currents between 2008 and 2013.

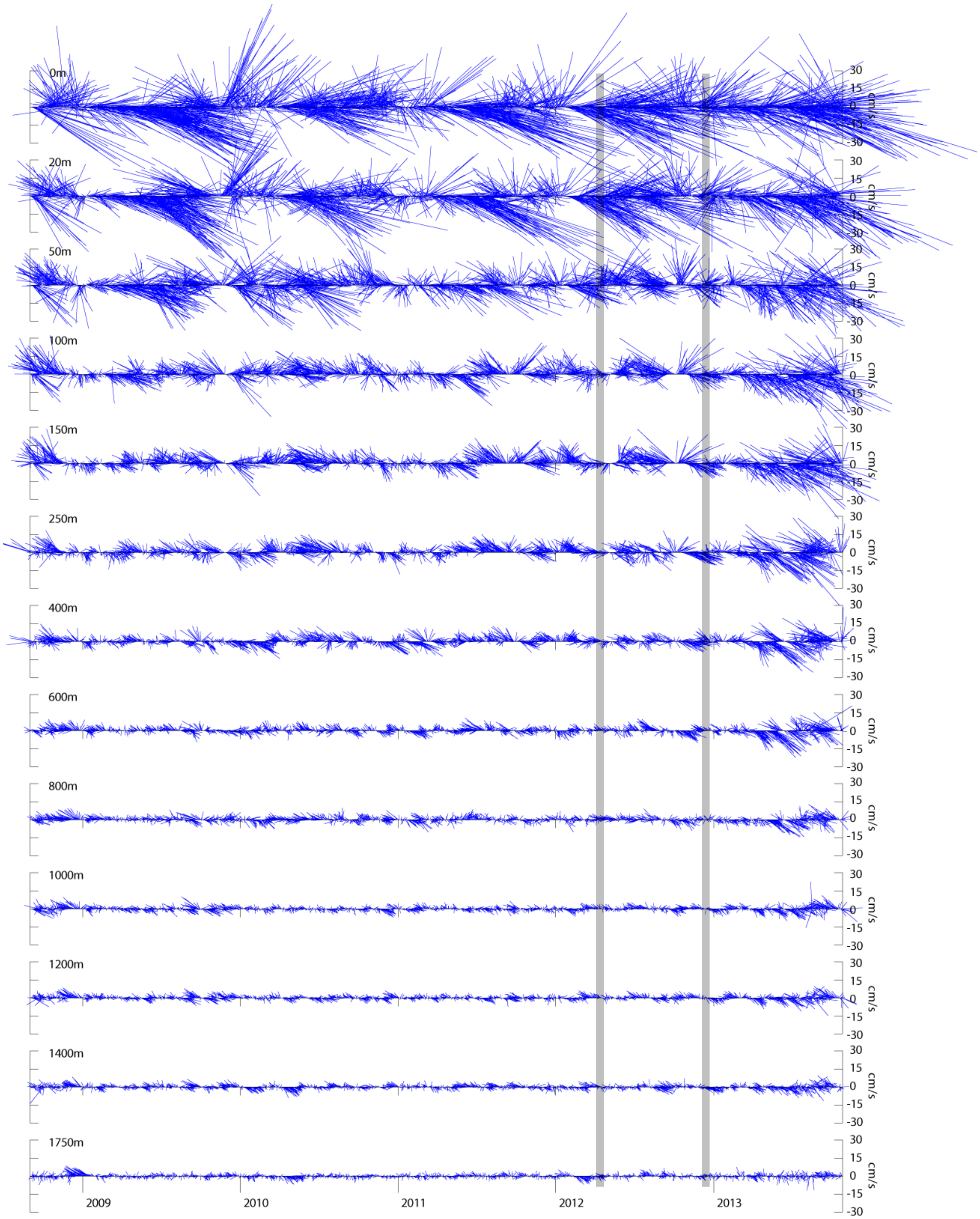



Figure 10. Time series of HYCOM model currents with depth at the En13-WI discharge site. Shading indicates the simulation periods (Apr 1-16 and Dec 1-16, 2012).

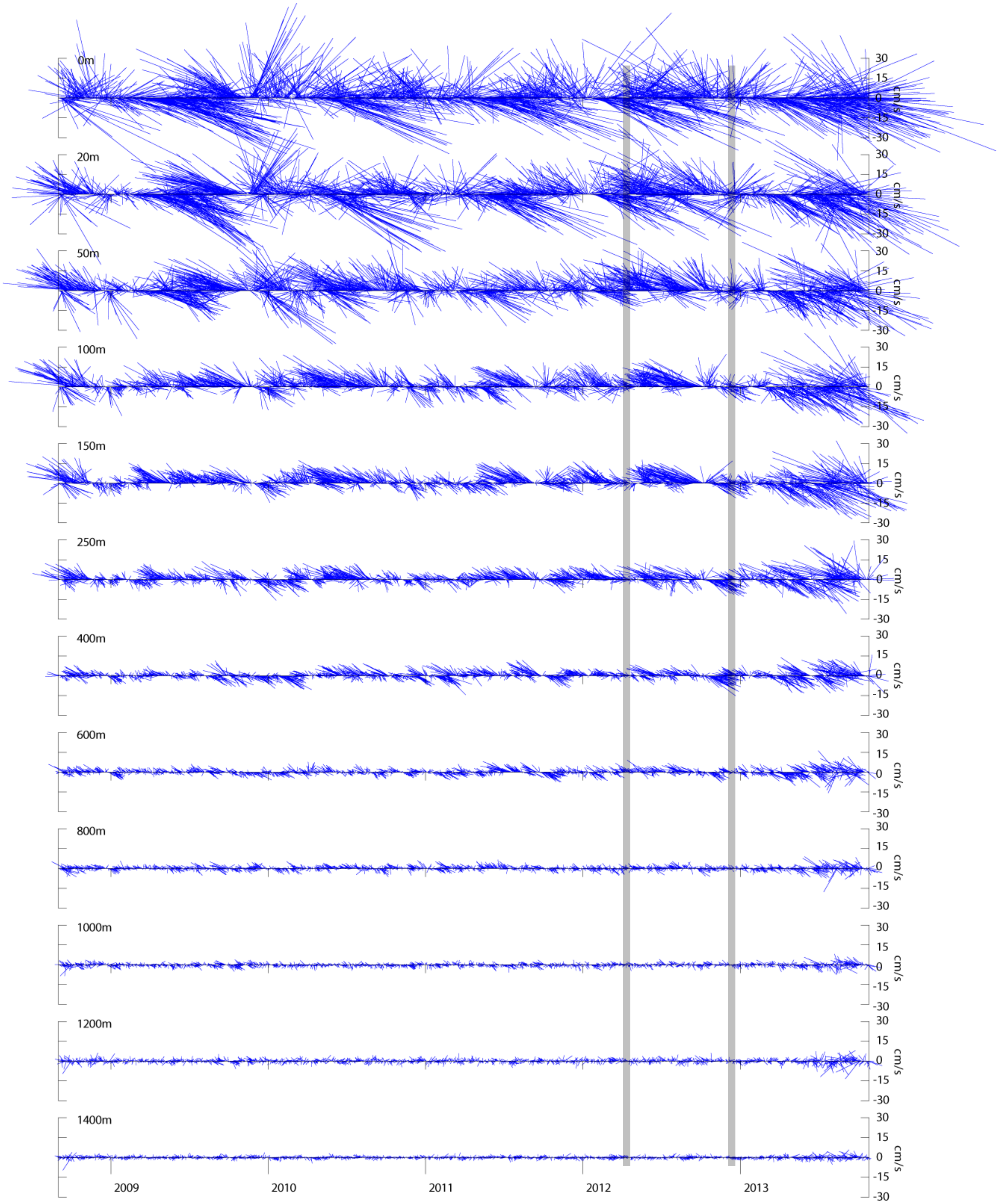



Figure 11. Time series of HYCOM model currents with depth at the En07-WI discharge site. Shading indicates the simulation periods (Apr 1-16 and Dec 1-16, 2012).

# 3. Drilling Discharge Simulations

The following section describes the model used for simulating releases of drilling discharges and the release scenarios. *Drilling discharges* refers to waste materials and by-products of drilling that are often released directly to the marine environment, including drill cuttings and spent drilling muds. Because drilling is typically performed in different intervals (sections) reflecting differences in operations (drilling diameters), the discharge schedule may vary as a function of drilling rate, cuttings and mud volumes, or depth of release in the water column (near-surface or near-seabed typically). The analysis presented here evaluates differences in seabed deposition and sediment plume characteristics for a single discharge program released at two sites and over two different time periods (a total of four model scenarios).

## 3.1. Model Description - MUDMAP

Drilling discharges simulations were completed using ASA's MUDMAP modeling system (Spaulding et al., 1994). MUDMAP is a numerical model developed by ASA to predict the near and far field transport, dispersion, and bottom deposition of drilling mud and cuttings. In MUDMAP, the equations governing conservation of mass, momentum, buoyancy, and solid particle flux are formulated using integral plume theory and then solved using a Runge Kutta numerical integration technique. The model includes three stages: convective descent/ascent, dynamic collapse, and far field dispersion. It allows the transport and dispersion of the release to be modeled through all stages of its movement. The initial dilution and vertical spreading of the release is predicted in the convective descent/ascent process. The far field process predicts the transport and dispersion of the release caused by the ambient current and turbulence fields. In the dynamic collapse process, the release impacts the surface or bottom, or becomes trapped by vertical density gradients in the water column.

The model output consists of definition of the movement and shape of the discharge plume, the concentrations of insoluble (i.e., cuttings and mud) discharge components in the water column, and the accumulation of discharged solids on the seabed. The model predicts the transport of discharged solids from the time of discharge to initial settling on the seabed. MUDMAP does not account for resuspension and transport of previously discharged solids; therefore it provides a conservative estimate of the potential seafloor depositions. The far field and passive diffusion stage is based on a particle based random walk model. More details about MUDMAP are included in Appendix A.

## 3.2. Discharge Scenarios

Dispersion modeling was completed to evaluate seabed deposition and sediment plume extents resulting from discharges at the En13-WI and En07-WI drilling sites. Based on information provided by ERM/TGL, the drilling program at both sites consists of four sections; the first two sections to be drilled with water based mud (WBM) and the lowermost sections drilled using low toxicity oil based mud (LTOBM). The discharge schedule provided by ERM/TGL is shown in Table 2 and consists of the release of 1,643 Metric Tonnes (MT) of cuttings and 1,390 $m^3$ of drilling fluids (WBM) over the course of 15 days.

During the riserless phase of drilling (sections 1 and 2), all cuttings and WBM are expected to be released directly at the seabed (+5 m above the wellhead on the seafloor). Subsequent sections will be drilled with LTOBM and surface returns of cuttings will be processed with a thermal desorption unit (TDU) prior to discharge. The release of TDU powder was simulated from a depth of 15 meters below the sea surface. A continuous discharge rate was specified for the duration of each of the individual drill sections. The release of drilling fluids from sections 3 and 4 was not simulated as it is expected that all LTOBM will be recovered and transported onshore for disposal.

Table 2. Drilling discharges program used for model simulations at En13-WI and En07-WI.

| Section | Diameter (in) | Duration (days) | Cuttings Release Rate (MT/hr) | Mud Release Rate ($m^3$/hr) | Mud Type | Drilling Start Date | | Release Depth[1] |
|---|---|---|---|---|---|---|---|---|
| 1 | 36” | 0.5 | 11.46 | 15.83 | WBM | 1-Apr-12 | 1-Dec-12 | seabed |
| 2 | 26” | 1.5 | 17.01 | 33.33 | WBM | 1-Apr-12 | 1-Dec-12 | seabed |
| 3 | 16” | 6 | 4.8 | — | LTOBM | 3-Apr-12 | 3-Dec-12 | sea surface |
| 4 | 12 ¼” | 7 | 1.2 | — | LTOBM | 9-Apr-12 | 9-Dec-12 | sea surface |
| **Total Discharges** | | | **1,642.68 MT** | **1,389.84 $m^3$** | | | | |

[1] releases simulated at 5 m above the seabed and 15 m below the sea surface

Because currents are the main driving force for the transport and dispersion of discharged drilling muds and cuttings in the water column, seasonal, annual, or interannual variability in currents can strongly influence the fate of discharged material. Analysis of hydrodynamic model data (Section 2.2) suggests that currents in the region are complex and undergo substantial variability both spatially and temporally. Because drilling operations within the DWT Block will occur throughout the year, a modeling strategy was developed to compare the results of different flow conditions that characterize the potential range of release periods. Seasonal differences in the current field were represented by simulating releases during the months of April and December -- periods identified during previous modeling for the TEN Development (ASA project 11-053). Drilling releases were simulated to begin on April 1, a period of peak surface current velocities that are directed primarily toward the east. An additional model of the same duration was run with discharges beginning on December 1, a period characterized by less intense currents in upper water column that are more directionally variable. For both periods, subsurface currents (below 500 m) are relatively weak (<8 cm/s).

In total, four (4) discharge scenarios were performed using the MUDMAP dispersion model representing both discharge programs simulated at different times of the year. For all scenarios, vertically and time varied currents derived from HYCOM for a representative period (2012-2013) were used to drive the advection of the discharged solids. The exact HYCOM currents used for modeling correspond to the dates shown in Table 2.

## 3.3. Discharge sediment characteristics

To assess the fate of drilling discharges in the marine environment it is critical to characterize the components of the released materials. The composition of the drilling mud applied will depend on the characteristics of the formation and this composition determines the density and weight of the discharged fluid, its toxicity, and the settling velocities of the material released in the water column.

Information describing the specific components of the drilling mud expected to be used for operations within the Enyenra field (including the percent water and concentration and type of weighting materials) was not provided with the discharge schedule. For this reason, a representative WBM fluid composition was assumed for modeling. The composition (in weight percent) for the various components of typical drilling muds is presented in Table 3. The bulk density of the drilling fluids used for MUDMAP simulations was 1,192.1 kg/$m^3$. Solid particles occupy 22% of the total mud weight.

Table 3. Composition of drilling fluids used for modeling (NRC, 1983; OGP, 2003; Neff, 2005; Neff, 2010).

| Discharged material | Component | Weight % | Specific gravity | Mud bulk density (kg/m³) | Percent solid by weight |
|---|---|---|---|---|---|
| WBM | water | 76 | 1.026 | 1192.1 | 22.0 |
| | barite | 15 | 4.48 | | |
| | bentonite clay | 7 | 2.5 | | |
| | other (salt/additives) | 2 | 0.53 | | |

Particle size data, along with material density, is typically used to calculate settling velocities for MUDMAP simulations. The size distribution of discharged solids varies as a function of the geology, the type of drilling fluid, and the treatment of cuttings. For this study, a representative size distribution (based on published values) was used to characterize the drill cuttings releases from sections 1 and 2 (Table 4). Settling velocities of the WBM used to drill sections 1 and 2 were also based on published values and are described in Table 5. The particle sizes used to represent cuttings treated by the TDU process (sections 3 and 4) were obtained by ERM from a TDU supplier (Table 6). The data were measured by laser diffraction of actual material produced by the TDU. The conversion of particle sizes to settling velocities assumed a specific gravity of 2.5 for the treated cuttings.

Table 4. Drill cuttings settling velocities used for simulations; sections 1 and 2 (Brandsma and Smith, 1999).

| Size Class* | Percent Volume | Settling Velocity | |
|---|---|---|---|
| | | (cm/s) | (m/day) |
| 1 | 8 | 0.0001 | 0.12 |
| 2 | 6 | 0.0017 | 1.49 |
| 3 | 7 | 0.0223 | 19 |
| 4 | 3 | 0.238 | 206 |
| 5 | 2 | 1.48 | 1276 |
| 6 | 18 | 4.07 | 3518 |
| 7 | 16 | 9.90 | 8552 |
| 8 | 15 | 13.65 | 11792 |
| 9 | 25 | 26.21 | 22647 |

*Size classes correspond to particles sizes between approximately 1.5 µm and 4.5 cm (assuming specific gravity of cuttings = 2.5).

Table 5. Drilling mud settling velocities used for simulations; sections 1 and 2 (Brandsma and Smith, 1999).

| Size Class | Percent Volume | Settling Velocity | |
|---|---|---|---|
| | | (cm/s) | (m/day) |
| 1 | 7.00 | 0.0027 | 2.4 |
| 2 | 8.00 | 0.0061 | 5.3 |
| 3 | 5.00 | 0.0148 | 12.8 |
| 4 | 10.00 | 0.0300 | 25.9 |
| 5 | 13.26 | 0.0436 | 37.7 |
| 6 | 13.26 | 0.0512 | 44.2 |
| 7 | 19.24 | 0.0640 | 55.3 |
| 8 | 19.24 | 0.0823 | 71.1 |
| 9 | 4.00 | 0.4267 | 368.7 |
| 10 | 1.00 | 1.1217 | 969.1 |

Table 6. TDU cuttings settling velocities used for simulations; sections 3 and 4 (sourced from TDU supplier).

| Size Class | Percent Volume | Settling Velocity | |
|---|---|---|---|
| | | (cm/s) | (m/day) |
| 1 | 3.46 | 0.000034 | 0.028977 |
| 2 | 4.35 | 0.000042 | 0.036482 |
| 3 | 4.95 | 0.000053 | 0.045989 |
| 4 | 4.86 | 0.000067 | 0.057872 |
| 5 | 4.22 | 0.000084 | 0.072858 |
| 6 | 3.46 | 0.000106 | 0.091748 |
| 7 | 2.82 | 0.000134 | 0.115518 |
| 8 | 2.42 | 0.000168 | 0.145348 |
| 9 | 2.22 | 0.000212 | 0.182976 |
| 10 | 2.20 | 0.000267 | 0.230388 |
| 11 | 2.28 | 0.000336 | 0.289992 |
| 12 | 2.43 | 0.000423 | 0.365146 |
| 13 | 2.60 | 0.000532 | 0.459744 |
| 14 | 2.73 | 0.00067 | 0.578778 |
| 15 | 2.82 | 0.000843 | 0.728321 |
| 16 | 2.86 | 0.001062 | 0.917166 |
| 17 | 2.86 | 0.001336 | 1.154635 |
| 18 | 2.84 | 0.001683 | 1.453683 |
| 19 | 2.81 | 0.002118 | 1.829683 |
| 20 | 2.80 | 0.002666 | 2.303524 |
| 21 | 2.83 | 0.003357 | 2.900284 |
| 22 | 2.87 | 0.004226 | 3.651159 |
| 23 | 2.95 | 0.00532 | 4.596443 |
| 24 | 3.04 | 0.006697 | 5.786267 |
| 25 | 3.10 | 0.008431 | 7.284735 |
| 26 | 3.14 | 0.01061 | 9.17133 |
| 27 | 3.10 | 0.01336 | 11.54536 |
| 28 | 3.00 | 0.01682 | 14.53478 |
| 29 | 2.81 | 0.02118 | 18.29761 |
| 30 | 2.54 | 0.02666 | 23.03698 |
| 31 | 2.19 | 0.03357 | 29.00121 |
| 32 | 1.82 | 0.04226 | 36.51004 |
| 33 | 1.43 | 0.0532 | 45.96408 |
| 34 | 1.80 | 0.08431 | 72.84509 |
| 35 | 1.15 | 0.2118 | 182.9837 |
| 36 | 0.24 | 0.532 | 459.628 |

The extent to which discharged sediments accumulate on the seabed is largely controlled by the particle settling velocities (a function of size and density) and the prevailing currents in the water column. Figure 12 compares settling characteristics for each of the discharged materials used as model input. Given the relatively deep water at both drilling sites (>1,000 m), and the fine particle sizes resulting from the TDU treatment process, releases near the seabed are expected to contribute more substantially to deposition as compared to those occurring at the surface. Not taking into account the advective processes, over 85% of the TDU powder would require at least 10 days in order to settle from the surface to the seabed at En-13.

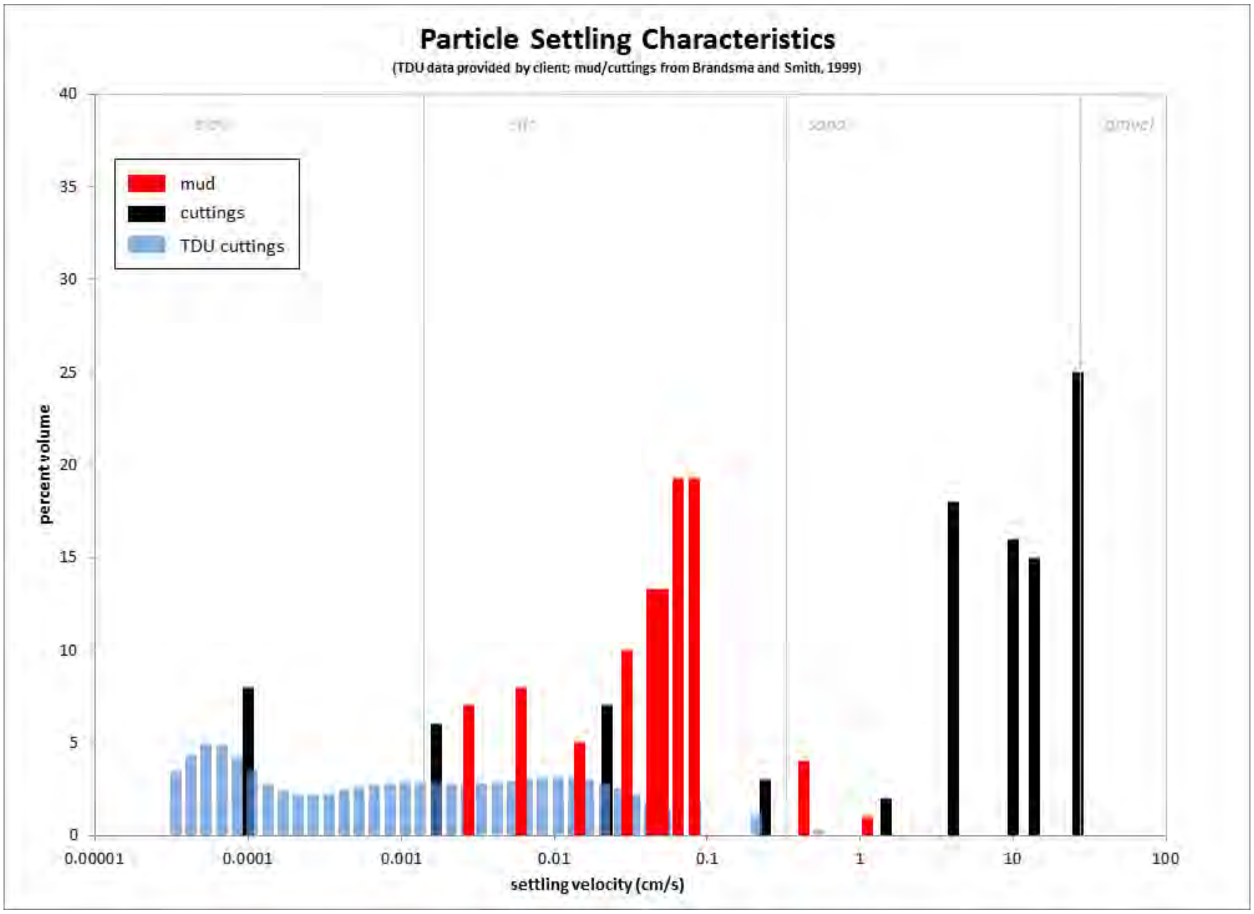



Figure 12. Comparison of settling velocities for solid discharges used in the modeling study. Size class divisions are from Gibbs et al. (1971).

# 4. Results of the Drilling Discharge Simulations

## 4.1. Predicted deposition thickness

Four discharge scenarios were analysed, corresponding to the schedules and release volumes described in Section 3.2. MUDMAP was used to predict the resulting bottom deposition from each discharge along with the pattern of cumulative deposits. Following the simulated release of each section in MUDMAP, the model continued to track the far field dispersion for four additional days, to account for the settling of fine material suspended in the water column. Figure 13 and Figure 14 show the plan view extents of the model-predicted seabed deposition at En13-WI and En07-WI, respectively; Table 7 through Table 10 summarizes the areal impact of each scenario.

As shown in Figure 13 and Figure 14, the extent of deposition between sites and between seasons is nominal. All scenarios result in a generally rounded and tight depositional footprint that surrounds the well head.  Contours representing very fine thickness intervals (0.1 mm) are slightly more elongate and extend between 505 m and 620 m from the release sites. Deposit thicknesses for each scenario are calculated from mass accumulation on the seabed and assume a sediment bulk density of 2,500 kg/m$^3$ and no void ratio (zero porosity). Differences in the extent of deposition between each season are primarily confined to thicknesses below 1 mm. For both sites, the most substantial differences are in the orientation of the very fine deposition defined by the 0.5-0.1 mm contours. Although the areal extent of these intervals remains similar between the discharge periods (Figure 15 and Figure 16), the overall shape is indicative of the flow characteristics at depth during the seabed releases. For all scenarios, the gradient of contours at or above 1 mm is uniform and concentric around the well, which indicates that dispersion processes are nearly as influential as advection from currents due to the settling characteristics of material being released and the water depths.

When drilling occurs in deep water (> 1000 m), which is the case for both the En13-WI and En07-WI well sites, discharges originating from the sea surface may not contribute substantially to the observed deposition at the seafloor. For this study, the extremely fine particle sizes of the TDU powder further contribute to this outcome. At both sites, the TDU powder discharges remain suspended in the upper water column until eventually dispersing below levels detectible by the model. As a consequence, the surface releases do not contribute significantly to the cumulative mass accumulation on the seabed. By contrast, the cuttings discharged directly at the seabed (sections 1 and 2) settle relatively quickly owing to (i) the release depth, (ii) the size distribution, and (iii) the relatively weak currents near the seabed. Seabed releases of WBM are transported further from the discharge site by the prevailing currents resulting in the broad, thin deposition layers.

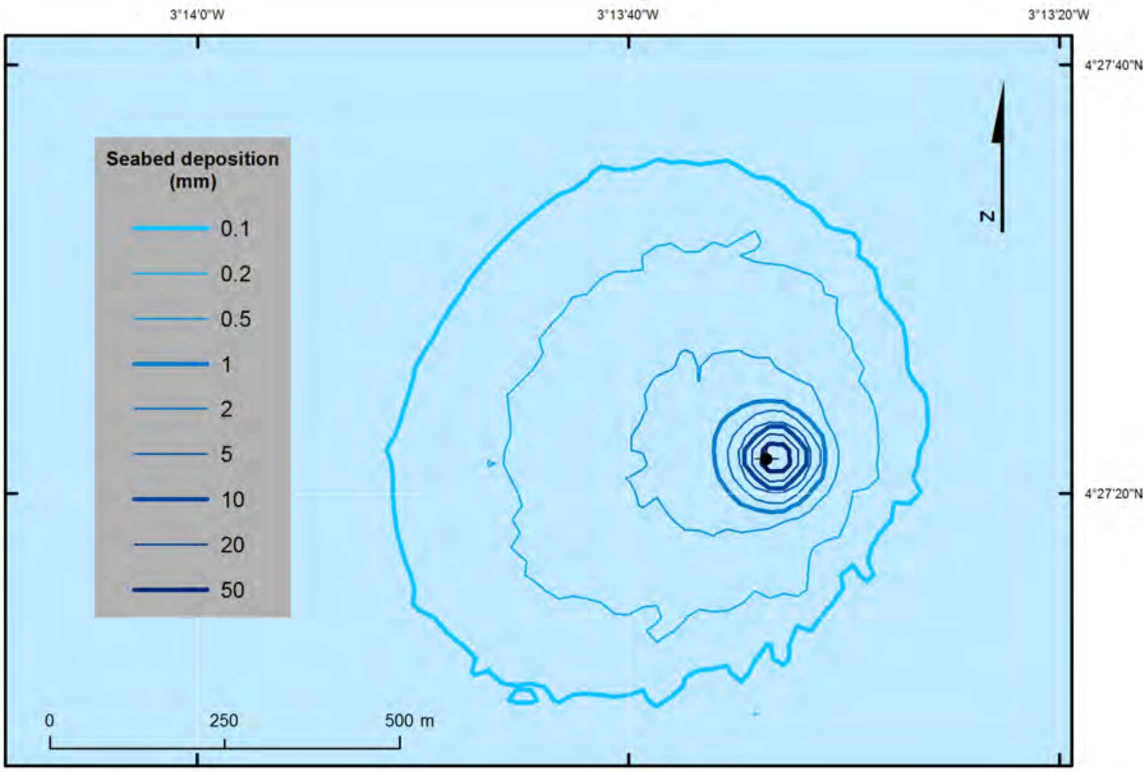
At the En13-WI drilling site, the discharge program results in deposition of 10 mm up to 48 m from the well and an aerial extent of 0.00519 km$^2$; deposition at 1 mm extends a maximum of 95 m and covers an area of 0.01876 km$^2$; and deposition at thickness of 0.1 mm extends a maximum of 600 m and covers 0.44985 km$^2$ of the seabed. At En07-WI, thicknesses of 10 mm or greater are confined to a distance of 47 m from the discharge site and an aerial extent of 0.00599 km$^2$; deposition at 1 mm extends a maximum of 96 m and covers an area of 0.02195 km$^2$; and deposition at thickness of 0.1 mm extends 620 m and covers up to 0.471 km$^2$of the seabed.

Table 7. Areal extent of seabed deposition (by thickness interval) at En13-WI.

| Deposition Thickness (mm) | Cumulative Area Exceeding ($km^2$) | |
|---|---|---|
| | Scenario 1 (April) | Scenario 2 (December) |
| **0.1** | **0.44665** | **0.44985** |
| 0.2 | 0.22233 | 0.22632 |
| 0.5 | 0.05907 | 0.05628 |
| **1** | **0.01876** | **0.01796** |
| 2 | 0.01277 | 0.01237 |
| 5 | 0.00838 | 0.00718 |
| **10** | **0.00479** | **0.00519** |
| 20 | 0.00479 | 0.00439 |
| 50 | 0.0016 | 0.0016 |
| **100** | **—** | **—** |

Table 8. Maximum extent of thickness contours (distance from release site) at En13-WI.

| Deposition Thickness (mm) | Maximum extent from discharge point (m) | |
|---|---|---|
| | Scenario 1 (April) | Scenario 2 (December) |
| 0.1 | 560 | 600 |
| 1 | 92 | 95 |
| 10 | 47 | 48 |
| 100 | — | — |



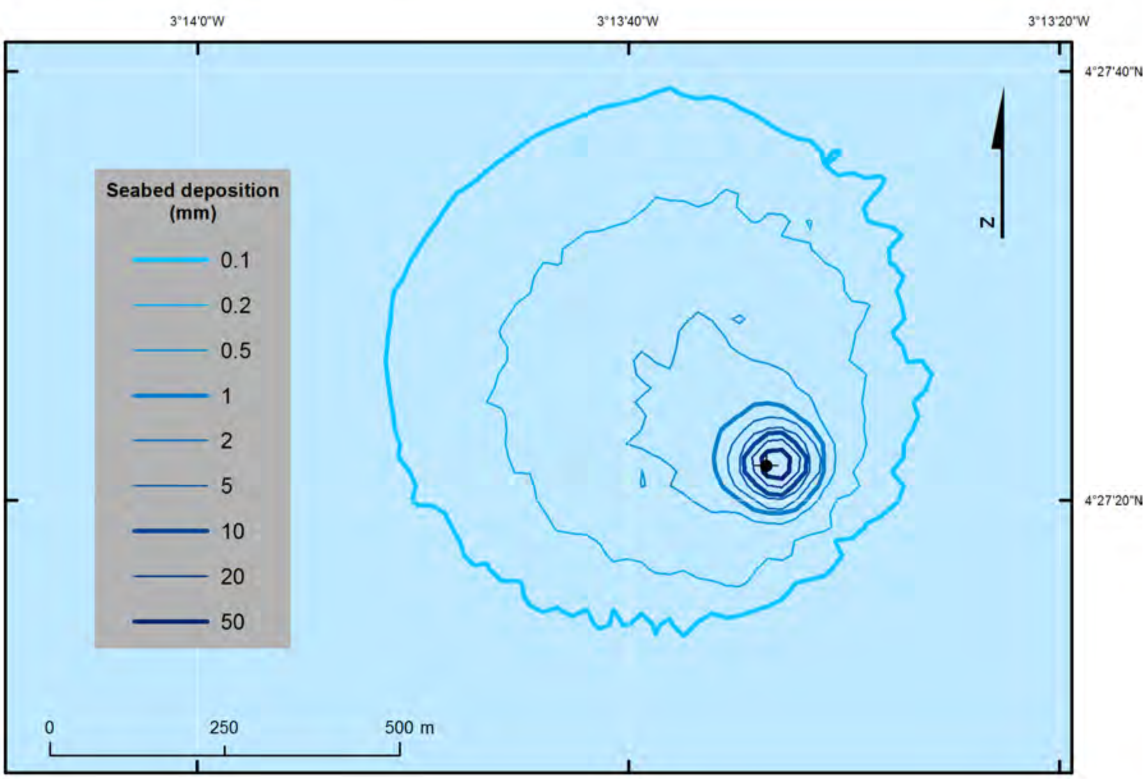




Figure 13. Cumulative deposition thickness (cuttings and mud) at En13-WI using April 2012 (top) and December 2012 (bottom) current conditions.

Table 9. Areal extent of seabed deposition (by thickness interval) at En07-WI.

| Deposition Thickness (mm) | Cumulative Area Exceeding (ha) | |
|---|---|---|
| | Scenario 1 (April) | Scenario 2 (December) |
| **0.1** | **0.471** | **0.44705** |
| 0.2 | 0.25426 | 0.23311 |
| 0.5 | 0.07185 | 0.05987 |
| **1** | **0.02195** | **0.01876** |
| 2 | 0.01317 | 0.01197 |
| 5 | 0.00758 | 0.00798 |
| **10** | **0.00599** | **0.00519** |
| 20 | 0.00319 | 0.00399 |
| 50 | 0.0012 | 0.0016 |
| **100** | **—** | **0.44705** |

Table 10. Maximum extent of thickness contours (distance from release site) at En07-WI.

| Deposition Thickness (mm) | Maximum extent from discharge point (m) | |
|---|---|---|
| | Scenario 1 (April) | Scenario 2 (December) |
| 0.1 | 505 | 620 |
| 1 | 96 | 93 |
| 10 | 47 | 46 |
| 100 | — | — |

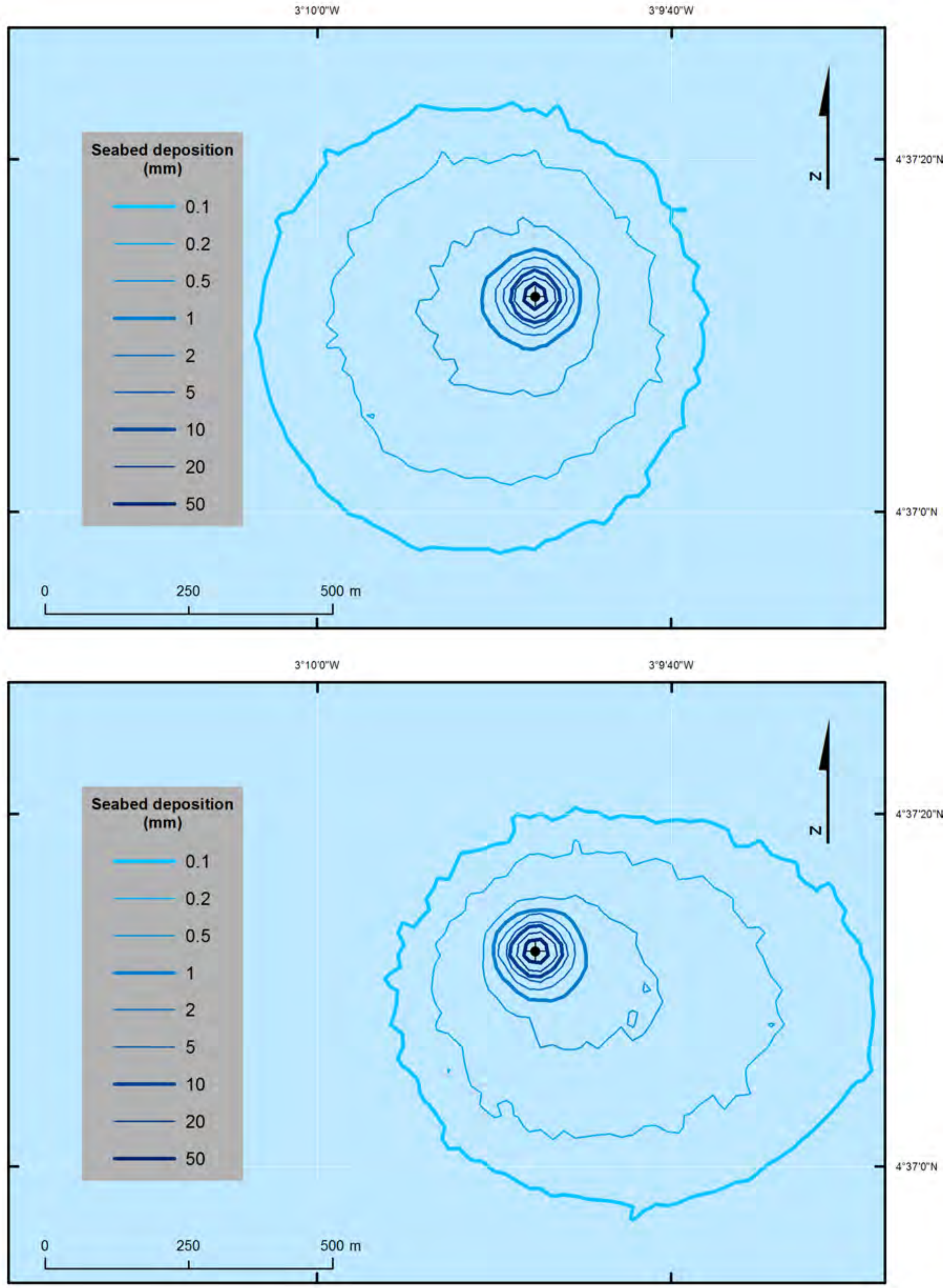



Figure 14. Cumulative deposition thickness (cuttings and mud) at En07-WI using April 2012 (top) and December 2012 (bottom) current conditions.

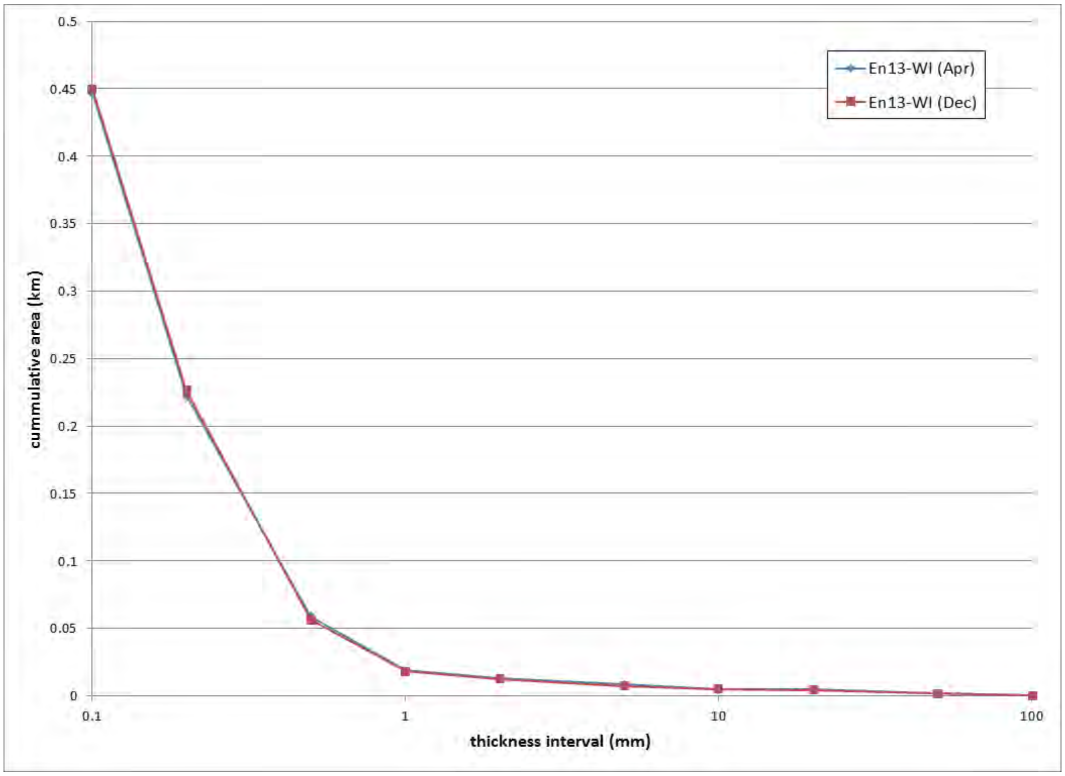



Figure 15. Comparison of seabed deposition (by thickness interval) for cumulative discharges at En13-WI. Blue – April discharge program, Red – December discharge program.

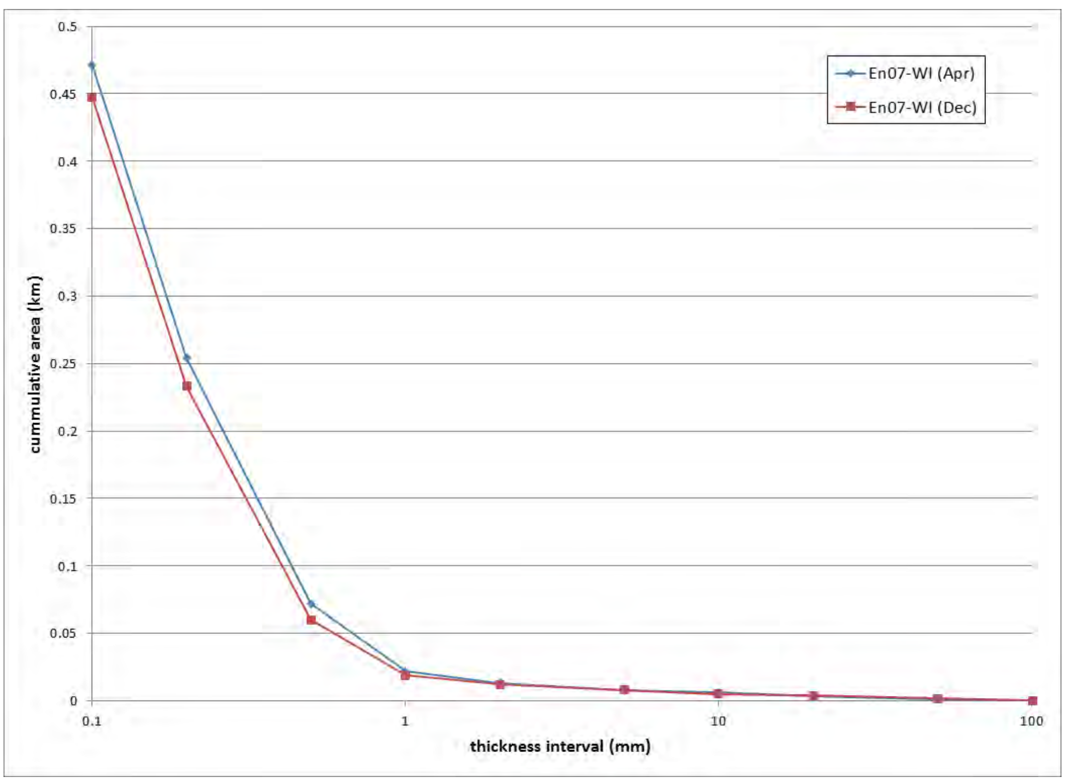



Figure 16. Comparison of seabed deposition (by thickness interval) for cumulative discharges at En07-WI. Blue – April discharge program, Red – December discharge program.

## 4.2. Predicted Water Column Concentrations

MUDMAP was also used to predict concentrations of total suspended solids (TSS) in the water column as a result of discharges at the sea surface. As discussed in section 4.1, a significant portion of TDU powder released from the MODU remains suspended in the water column. Any sustained water column plumes are controlled by currents at the sea surface and by the rate that the TDU powder is released. Thus, to reproduce maximum TSS concentrations, simulations were performed for the drilling interval corresponding to the largest release rate (section 3; Table 2).

Drilling in the Enyenra field is expected to occur throughout the year. Accordingly a total of eight representative MUDMAP scenarios were performed to evaluate the range in extent and trajectory of the sediment plume as a result of variability in currents, seasons, and drilling sites. Table 11 summarizes the inputs for each model run. For each scenario, the release of TDU powder was simulated for approximately four hours, allowing the water column to achieve steady state concentrations of suspended sediments. For each scenario the model then continued to track the transport and dispersion of the plume until its maximum concentrations declined below 10 mg/L. 10 mg/L was selected as a background concentration based on an environmental baseline survey of the adjacent Jubilee field (TDI-Brooks, 2008), which indicates that minimum concentrations of suspended solids in the region are 11.22 mg/L.

Table 11. Date, release rate, and current regime used to calculate the maximum TSS concentrations for each release scenario.

| Name | Scenario | Discharge Date | Drilling Section | Release Rate (MT/hr) |
|---|---|---|---|---|
| Scenario 1 | Maximum current speeds, EN13-WI April 2012 | 8 April 2012 | 3 (16”) | 4.8 |
| Scenario 2 | Minimum current speeds, EN13-WI April 2012 | 27 April 2012 | 3 (16”) | 4.8 |
| Scenario 3 | Maximum current speeds, EN13-WI December 2012 | 14 December 2012 | 3 (16”) | 4.8 |
| Scenario 4 | Minimum current speeds, EN13-WI December 2012 | 4 December 2012 | 3 (16”) | 4.8 |
| Scenario 5 | Maximum current speeds, EN07-WI April 2012 | 9 April 2012 | 3 (16”) | 4.8 |
| Scenario 6 | Minimum current speeds, EN07-WI April 2012 | 30 April 2012 | 3 (16”) | 4.8 |
| Scenario 7 | Maximum current speeds, EN07-WI December 2012 | 16 December 2012 | 3 (16”) | 4.8 |
| Scenario 8 | Minimum current speeds, EN07-WI December 2012 | 28 December 2012 | 3 (16”) | 4.8 |

Figure 17 through Figure 20 show the aggregation of TSS values that occur for the duration each simulation. These figures do not represent any instantaneous snapshot of water column concentrations, but instead show the maximum, time-integrated TSS within the study domain for each modeled release. The maximum predicted concentration of suspended sediments in the water column ranges from a maximum of 896 mg/L as a result of discharges at En07-WI during December (Scenario 8), to 467 mg/L at En13-WI during April (Scenario 1). Due to the small particle sizes that result from the TDU treatment process and the relatively strong current speeds at the surface, most of the suspended sediment remains within the uppermost 30 meters of the water column until dispersing below the 10 mg/L threshold.

Table 12 summarizes the maximum distance of observed excess water column concentrations for each of the eight scenarios. The trends observed in the model-predicted TSS plume are similar to those of the seabed deposition simulations; namely, that the plume trajectory varies as a result of the flow regime occurring on the day of the release. For that reason the results should be considered within the context of all possible current conditions in the DWT block. In general, the extent of the plumes is greater during strong current conditions, while the maximum TSS concentrations increase during weak current conditions and persist for longer in the water column.

For all scenarios, the plume migrates from the release site immediately after drilling discharges cease. The plume travels with ambient currents until dispersion and turbulence cause the TSS concentrations to fall below the 10 mg/L threshold. To this end, a stronger current regime has the effect of clearing the water column more quickly than weaker and more variable flow, although in all cases, the water column returns to ambient conditions (<10 mg/L) within an hour of the final release. Very strong surface currents (such as those that correspond with Scenario 1; >100 cm/s) allow the model domain to achieve background concentrations in less than 10 minutes. The threshold of 10 mg/L reflects a conservative estimate of ambient TSS concentrations based on previous field investigations offshore Ghana (TDI-Brooks, 2008).

Table 12. Maximum distance of excess water column concentrations for each discharge scenario.

| Water Column Concentration (mg/L) | Distance from discharge point (m) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 |
| 10 | 302 | 355 | 312 | 230 | 325 | 360 | 309 | 340 |
| 50 | 99 | 62 | 78 | 55 | 88 | 59 | 72 | 57 |
| 100 | 75 | 41 | 59 | 37 | 62 | 42 | 45 | 41 |
| 500 | — | 8 | 6 | 8 | — | 7 | 7 | 8 |

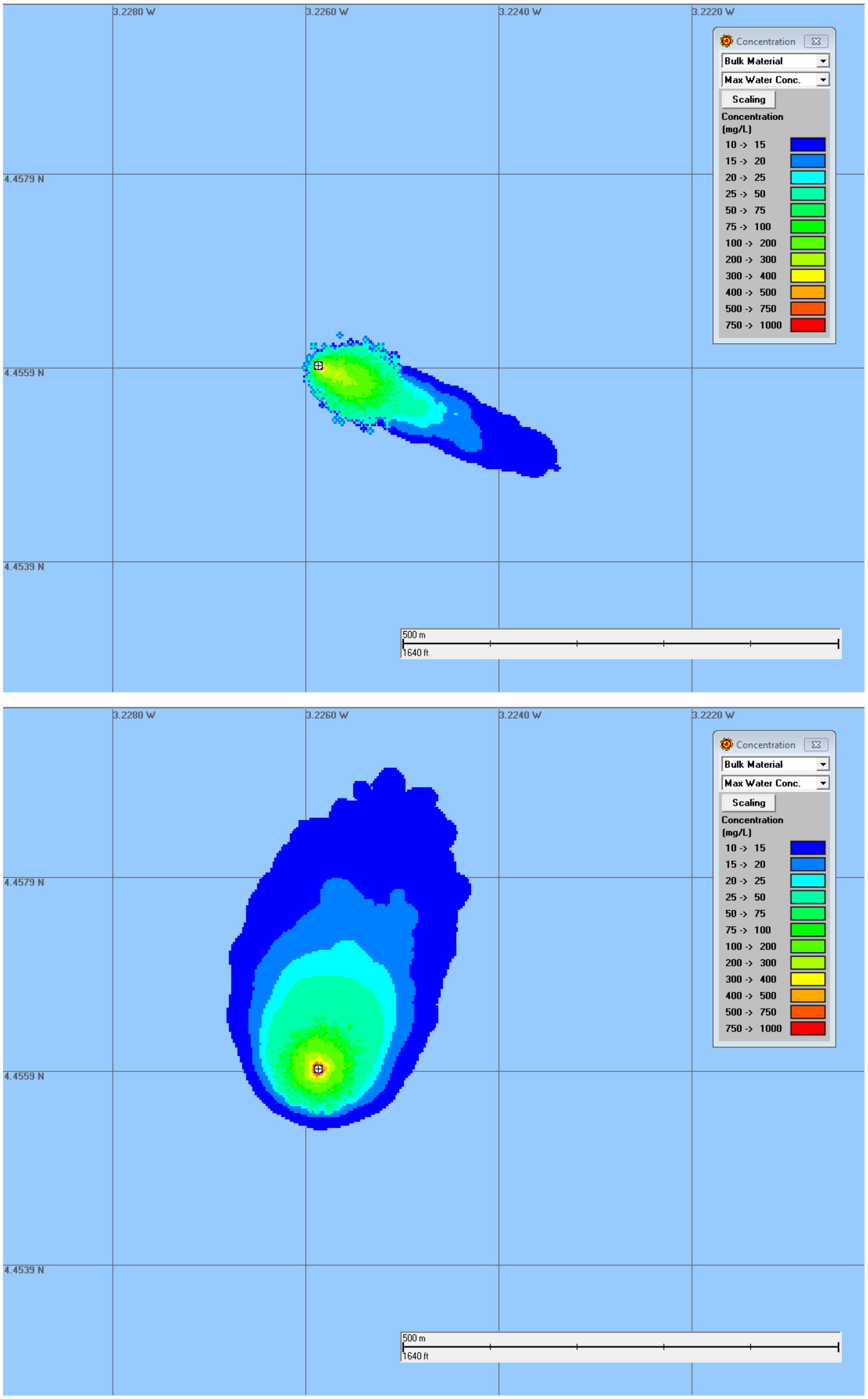



Figure 17. Maximum suspended sediment concentrations (mg/L) resulting from the discharge of TDU powder at EN13-WI during April 2012 maximum (Scenario 1; top) and minimum (Scenario 2; bottom) current conditions.

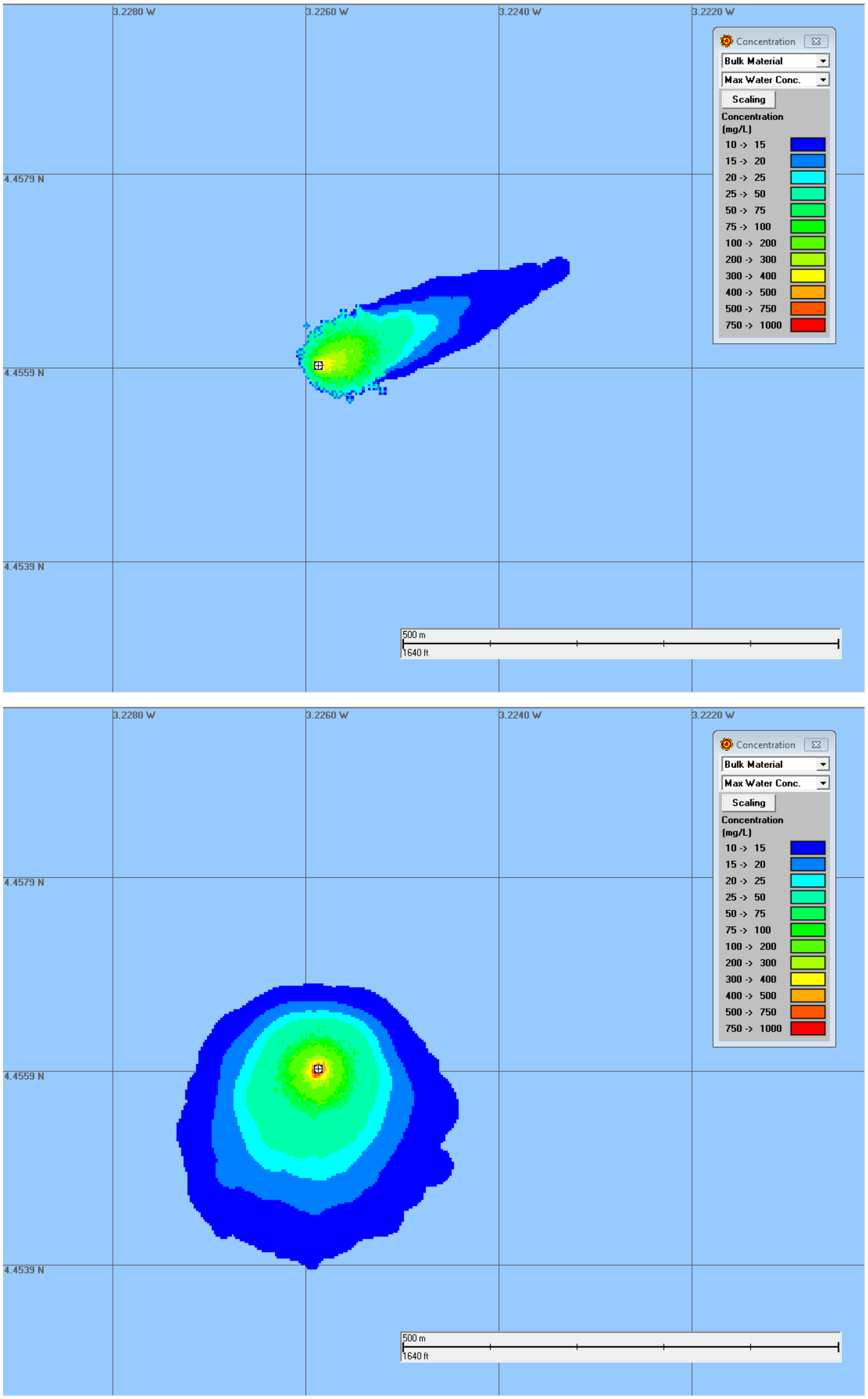



Figure 18. Maximum suspended sediment concentrations (mg/L) resulting from the discharge of TDU powder at EN13-WI during December 2012 maximum (Scenario 3; top) and minimum (Scenario 4; bottom) current conditions.

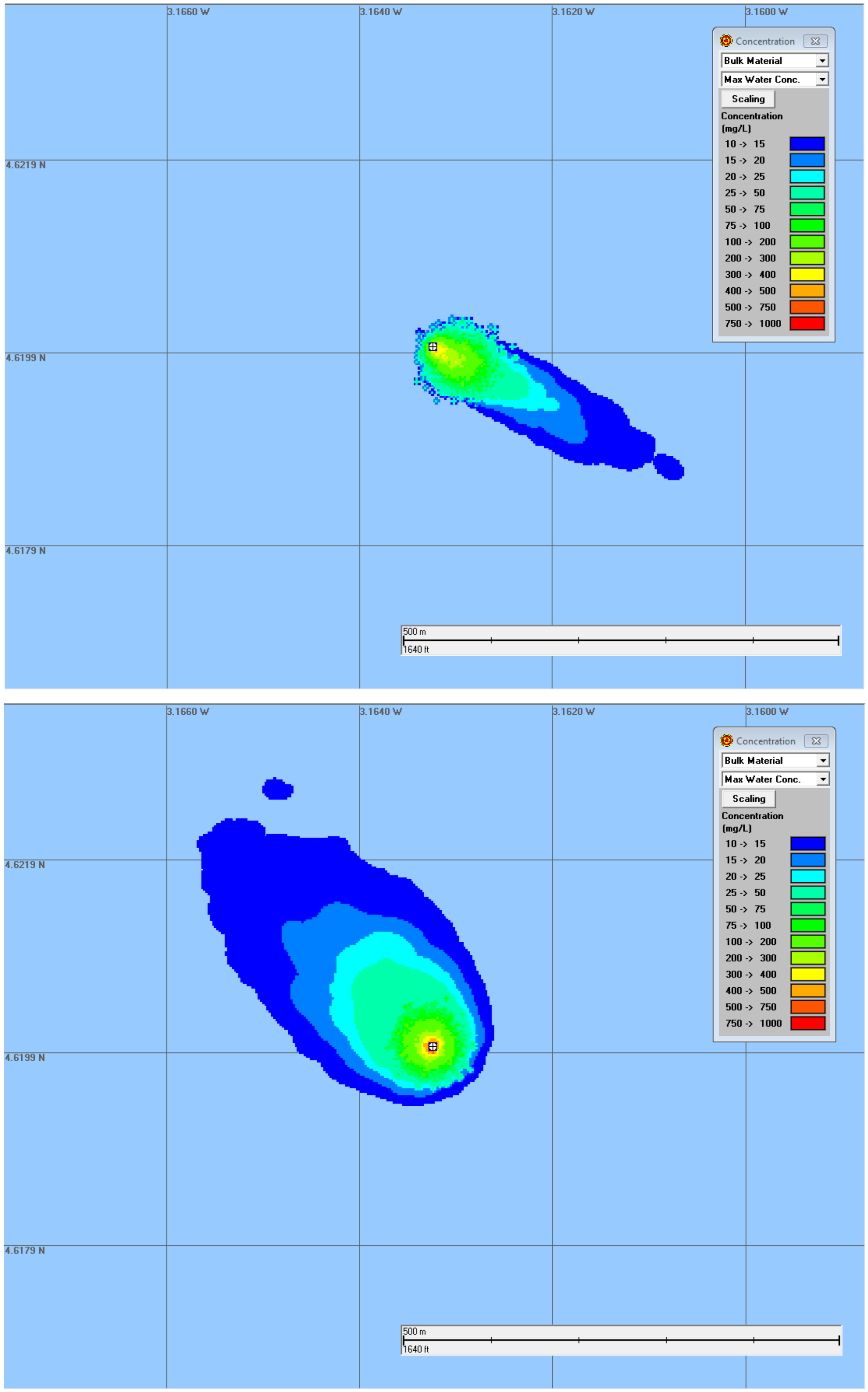



Figure 19. Maximum suspended sediment concentrations (mg/L) resulting from the discharge of TDU powder at EN07-WI during April 2012 maximum (Scenario 5; top) and minimum (Scenario 6; bottom) current conditions.

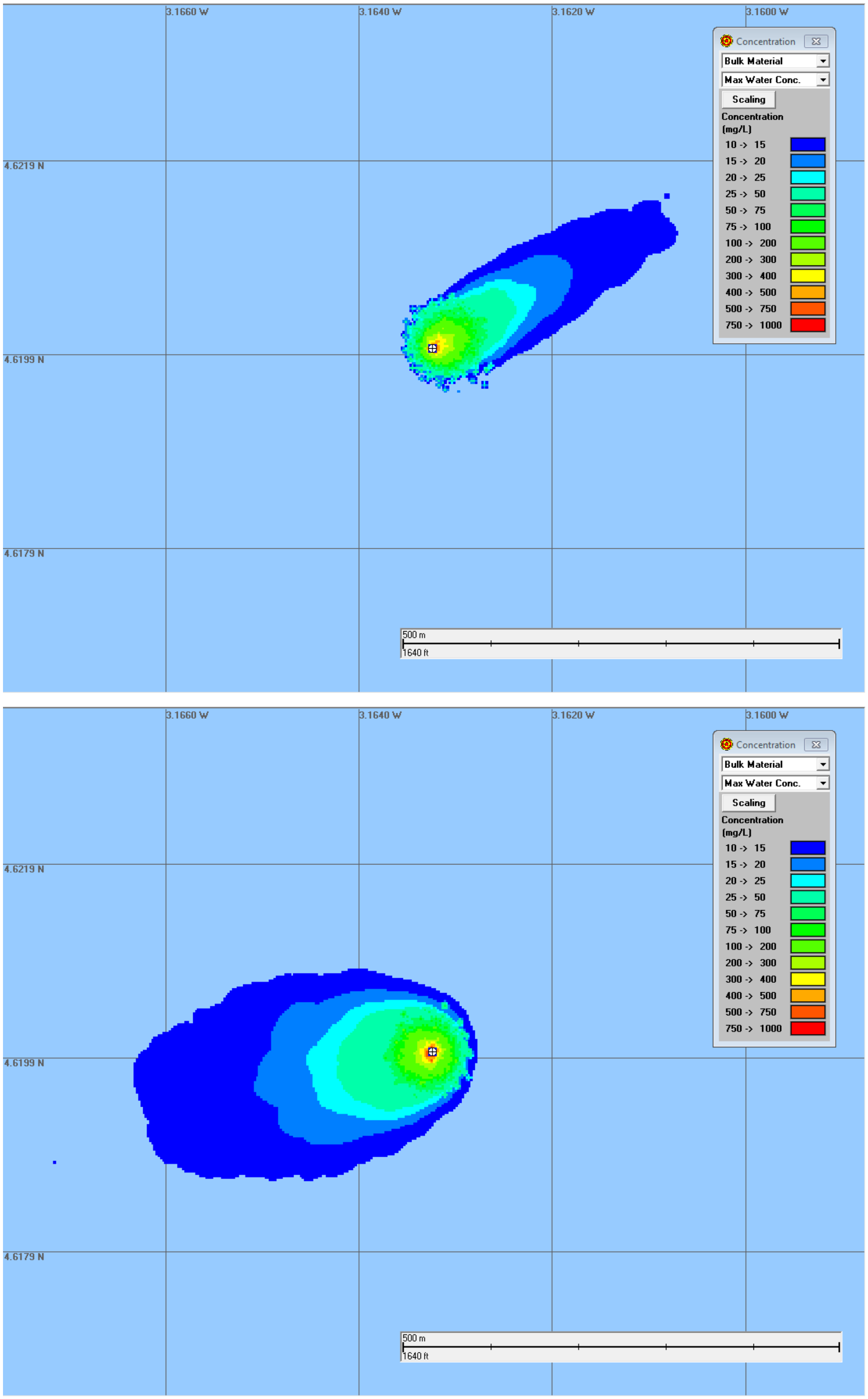



Figure 20. Maximum suspended sediment concentrations (mg/L) resulting from the discharge of TDU powder at EN07-WI during December 2012 maximum (Scenario 7; top) and minimum (Scenario 8; bottom) current conditions.

# 5. Conclusions

This report presents the results of drill cuttings and mud discharge simulations conducted for two locations in the Deepwater Tano Block, in the Gulf of Guinea. The drilling sites (En07-WI and En13-WI) are situated along the continental slope, approximately 50-70 km south of the Ghanaian coastline, and 2-4 km from the maritime boundary with Côte d'Ivoire. Dispersion modeling was completed at both sites in order to evaluate seabed deposition from releases of drilling mud and cuttings and the potential for sediment plumes resulting from the discharge of pulverized cuttings after treatment with a thermal desorption unit.

Simulations of drilling releases were completed using ASA's MUDMAP modeling software. Because drilling operations within the DWT block are expected to occur throughout the year, a modeling strategy was developed to compare the results of different flow conditions that characterize the potential range of release periods. Specifically, releases were simulated during the months of April and December – which were identified as representative periods during previous modeling for the TEN Development. A total of four discharge scenarios were performed to evaluate seabed deposition (2 release periods per location). An additional eight MUDMAP simulations were performed to examine the range in plume characteristics from sea surface discharges (2 sites x 2 periods x 2 current regimes). For each scenario, vertically and time varied currents derived from the HYCOM 1/12 degree global simulation for a representative period (2012-2013) were used to drive the advection of the discharged solids.

The cumulative seabed deposition resulting from each discharge scenario was analysed along with predictions of suspended sediment plumes in the upper water column resulting from the near-instantaneous release of drilling mud. In summary:

- All scenarios result in a generally rounded and tight depositional footprint that surrounds each well head. Contours representing very fine thickness intervals (0.1 mm) are slightly more elongate and extend between 505 m and 620 m from the release sites. The areal extent of deposition above 1 mm is nearly indistinguishable between sites/seasons.
- Because both sites utilize the same discharge schedule, differences in the extent of seabed deposition between sites and seasons is nominal. This is primarily due to the occurrence of very weak bottom currents at both sites, and the treatment of cuttings returned to the MODU. The TDU process results in extremely fine particles that not contribute significantly to the cumulative mass accumulation on the seabed.
- Thicknesses at or above 1 mm are confined to an area within 96 m of the well head and thickness greater than 10 mm are confined to 48 m.
- Sediment plumes resulting from discharges of TDU powder are predicted to extend between 230 and 360 m from the release site; the trajectory varies as a result of the flow regime occurring on the day of the release.
- In general, the extent of the plumes is greater during strong current conditions, while the maximum TSS concentrations increase during weak current conditions and persist for longer in the water column. The maximum predicted concentration of suspended sediments in the water column (corresponding to the weakest current regime) is 896 mg/L.
- In all cases, the water column is predicted to return to ambient conditions (<10 mg/L) within an hour of the final release.

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# Appendix A: MUDMAP Model Description

MUDMAP is a personal computer-based model developed by ASA to predict the near and far-field transport, dispersion, and bottom deposition of drill muds and cuttings and produced water (Spaulding et al; 1994). In MUDMAP, the equations governing conservation of mass, momentum, buoyancy, and solid particle flux are formulated using integral plume theory and then solved using a Runge Kutta numerical integration technique. The model includes three stages:

> Stage 1: **Convective decent/jet stage** – The first stage determines the initial dilution and spreading of the material in the immediate vicinity of the release location. This is calculated from the discharge velocity, momentum, entrainment and drag forces.
>
> Stage 2: **Dynamic collapse stage** – The second stage determines the spread and dilution of the released material as it either hits the sea surface or sea bottom or becomes trapped by a strong density gradient in the water column. Advection, density differences and density gradients drive the transport of the plume.
>
> Stage 3: **Dispersion stage –** In the final stage the model predicts the transport and dispersion of the discharged material by the local currents. Dispersion of the discharged material will be enhanced with increased current speeds and water depth and with greater variation in current direction over time and depth.

MUDMAP is based on the theoretical approach initially developed by Koh and Chang (1973) and refined and extended by Brandsma and Sauer (1983) and Khondaker (2000) for the convective descent/ascent and dynamic collapse stages. The far-field, passive diffusion stage is based on a particle based random walk model. This is the same random walk model used in ASA's OILMAP spill modeling system (ASA, 1999).

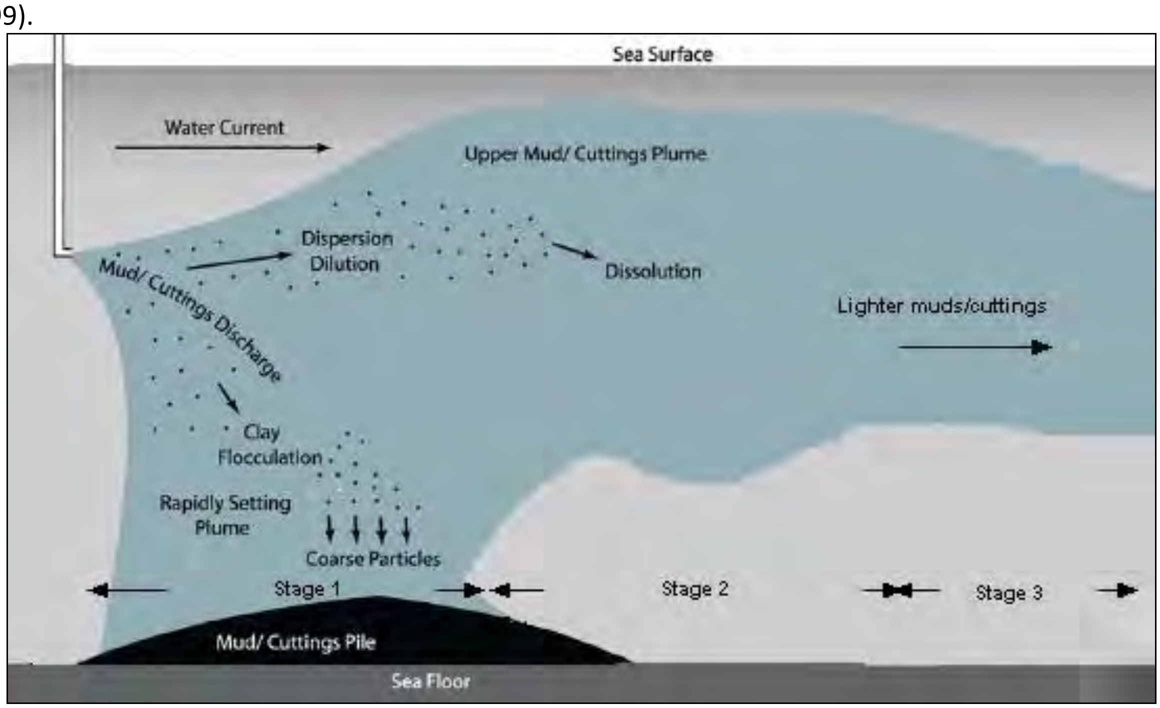


Figure A1. Conceptual diagram showing the general behavior of cuttings and muds following discharge to the ocean and the three distinct discharge phases (after Neff 2005).

The model's output consists of calculations of the movement and shape of the discharge plume, the concentrations of soluble (i.e. oil in produced water) and insoluble (i.e. cuttings and muds) discharge components in the water column, and the accumulation of discharged solids on the seabed. The model predicts the initial fate of discharged solids, from the time of discharge to initial settling on the seabed As MUDMAP does not account for resuspension and transport of previously discharged solids, it provides a conservative estimate of the potential seafloor concentrations (Neff 2005).

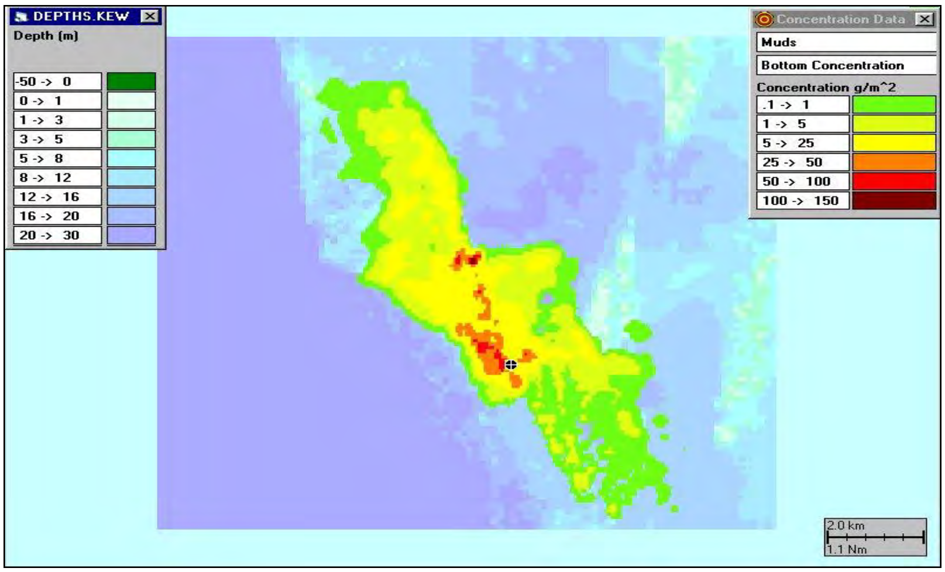


Figure A2 Example MUDMAP bottom concentration output for drilling fluid discharge.

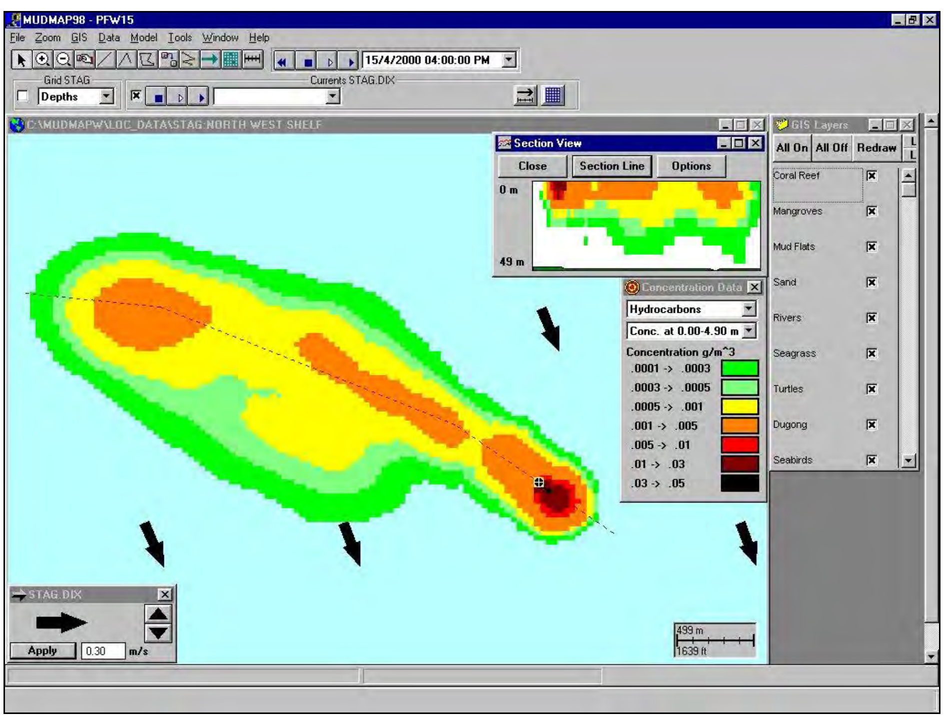


Figure A3. Example MUDMAP water column concentration output for drilling fluid discharge.

MUDMAP uses a color graphics-based user interface and provides an embedded geographic information system, environmental data management tools, and procedures to input data and to animate model output. The system can be readily applied to any location in the world. Application of MUDMAP to predict the transport and deposition of heavy and light drill fluids off Pt. Conception, California and the near-field plume dynamics of a laboratory experiment for a multi-component mud discharged into a uniform flowing, stratified water column are presented in Spaulding et al. (1994). King and McAllister (1997, 1998) present the application and extensive verification of the model for a produced water discharge on Australia's northwest shelf. GEMS (1998) applied the model to assess the dispersion and deposition of drilling cuttings released off the northwest coast of Australia.

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Annex E

# Underwater Noise Survey Report

# MEASUREMENT AND ASSESSMENT OF UNDERWATER NOISE FROM FPSO OPERATION AND OFF-LOADING FOR THE JUBILEE FIELD, GHANA

| | |
|---|---|
| Gardline Project Ref. | 8391 |
| Fieldwork Dates | 8-18th August 2011 |
| Report Status | Final |
| Issue Date | 13th October 2011 |

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# EXECUTIVE SUMMARY

Marine vessels and offshore development platforms such as oil rigs and Floating Production, Storage and Off-loading vessels (FPSO) have the potential to emit noise and vibrations into the surrounding environment. Under the Ghanaian Environmental Assessment Regulations (1999) an Environmental Impact Assessment (EIA) is mandatory for oil and gas field developments. As part of the EIA process, Tullow Ghana Ltd commissioned a theoretical assessment of potential noise sources, their levels and possible impact on marine life in the Jubilee field off Ghana before the commencement of production (Irvine et al. 2009). Following the EIA process, Tullow Ghana Ltd commissioned Gardline Environmental Ltd to undertake *in situ* measurements of underwater sound in order to characterise the sound levels around the FPSO during the operational phase.

The objectives of the underwater sound measurements were:

i) to measure the received sound levels as a function of range and bearing from the FPSO during 'normal operations' and during a 'tanker off-load';
ii) to estimate the sound source levels;
iii) to map the propagated sound field around the FPSO;
iv) to estimate the impact of received sound levels on marine life.

The measured FPSO sound output during a normal operation contained the majority of the acoustic energy in the 25 Hz to 2 kHz frequency range. The peak in the spectral source level occurred between around 100 to 250 Hz and likely results from machinery noise radiating through the hull of the FPSO.

In addition to the lower frequency noise a tonal component with frequency of around 13.5 kHz was also radiated from the FPSO. The source of this tonal component could not be identified but is likely to originate from high speed rotating machinery.

Sound levels measured during the tanker off-load had the majority of the acoustic energy within the frequency range 400 Hz to 16 kHz. This broader frequency range was thought to be due to propeller noise, with possible cavitation, of the handling tug vessel used during the off-load.

The measured and modelled data indicate that none of the underwater sound levels around the FPSO during normal operations or during off-load are sufficient to pose an injury risk to marine mammals.

The predicted sound levels indicate that behavioural disturbance of marine mammals near the surface may occur within a range of 0.5 km of the FPSO during normal operation and within a range of around 1 km of the off-loading vessel. However, deep diving marine mammals such as the sperm whale (*Physeter sp*.) may exhibit behavioural disturbance at larger ranges due to lower acoustic losses at depth compared to the surface. In this case the behavioural disturbance range may extend out to around 5 to 6 km from the source, which may result in changes to their movements and diving patterns and may thus effect their foraging.

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# 1. Introduction

## 1.1 Background

The work presented in this document was undertaken to characterise underwater sound levels around the FPSO Kwame Nkrumah during the production phase at the Jubilee Field production area off the Ghanaian coast. Empirical data collection and analyses was conducted by Gardline Environmental Ltd in collaboration with the National Physical Laboratory and Loughborough University. The aim was to characterize sound levels around the FPSO during a 'normal operation' and during a 'tanker off-load' and describe ambient noise levels in an adjacent area with no constant anthropogenic sound sources.

This section summarises the main environmental parameters described in the Environmental Impact Statement (EIS) (Irvine et al. 2009) that will be relevant in the analyses and assessment of the noise data presented in this report. In addition, an introduction to underwater sound, its propagation and potential impact on marine life is presented in more detail here, including appropriate references to the scientific literature.

## 1.2 Jubilee Field and the Kwame Nkrumah FPSO

The Jubilee field is located in the offshore waters of the Gulf of Guinea, about 60 km from the nearest coast (Figure 1.1).

The development involves a number of wells connected through a network of valves and pipelines to the Kwame Nkrumah FPSO that is permanently moored in the north-eastern part of the Jubilee field. The Kwame Nkrumah is about 330m long and some 50 m wide and has a storage capacity of approximately 1.6 million barrels of oil. It is fixed in place using a mooring system consisting of nine 1,900 m long chains connected to a turret system that is built into the FPSO. The turret system has a universal joint at the bow of the vessel, allowing it to move freely around the vertical axis at the bow and align with the prevailing wind, wave and current direction.

The processed crude oil is stored in the FPSO storage tanks and off-loaded to oil tankers approximately every couple of weeks over a period of about 20 hours for distribution to onshore markets worldwide. The export tanker is manoeuvred into a bow-to-stern position behind the FPSO and secured to the FPSO by a 100 m long mooring hawser. Crude oil is transferred through a single 50 cm wide hose which splits after about 300 m into two 40cm hoses that are connected to the tanker. A holdback tug assists the tanker in maintaining its position. The FPSO is linked to a buoy moored vessel on the stern side. Drilling and completion of wells started in late 2008 and was still underway in August 2011 with two drilling rigs; Eirik Raude and Atwood Hunter, indicated in Figure 1.1 operating in the Jubilee field, south of the FPSO.

Onshore support and provision of service vessels is largely ran from Takoradi, which is the nearest suitable Ghanaian port and airfield. There is a defined shipping lane for Tullow Ghana Ltd (hereafter Tullow) vessels as they transit between Takoradi and the Jubilee field. The approximate location of the lane is indicated in Figure 1.1. Outside the Jubilee Field area of drilling and production other offshore activities frequent the region. For example, the main east-west shipping route along the Ghanaian coast is approximately 8 nm (13.5 km) south of the Jubilee Field.

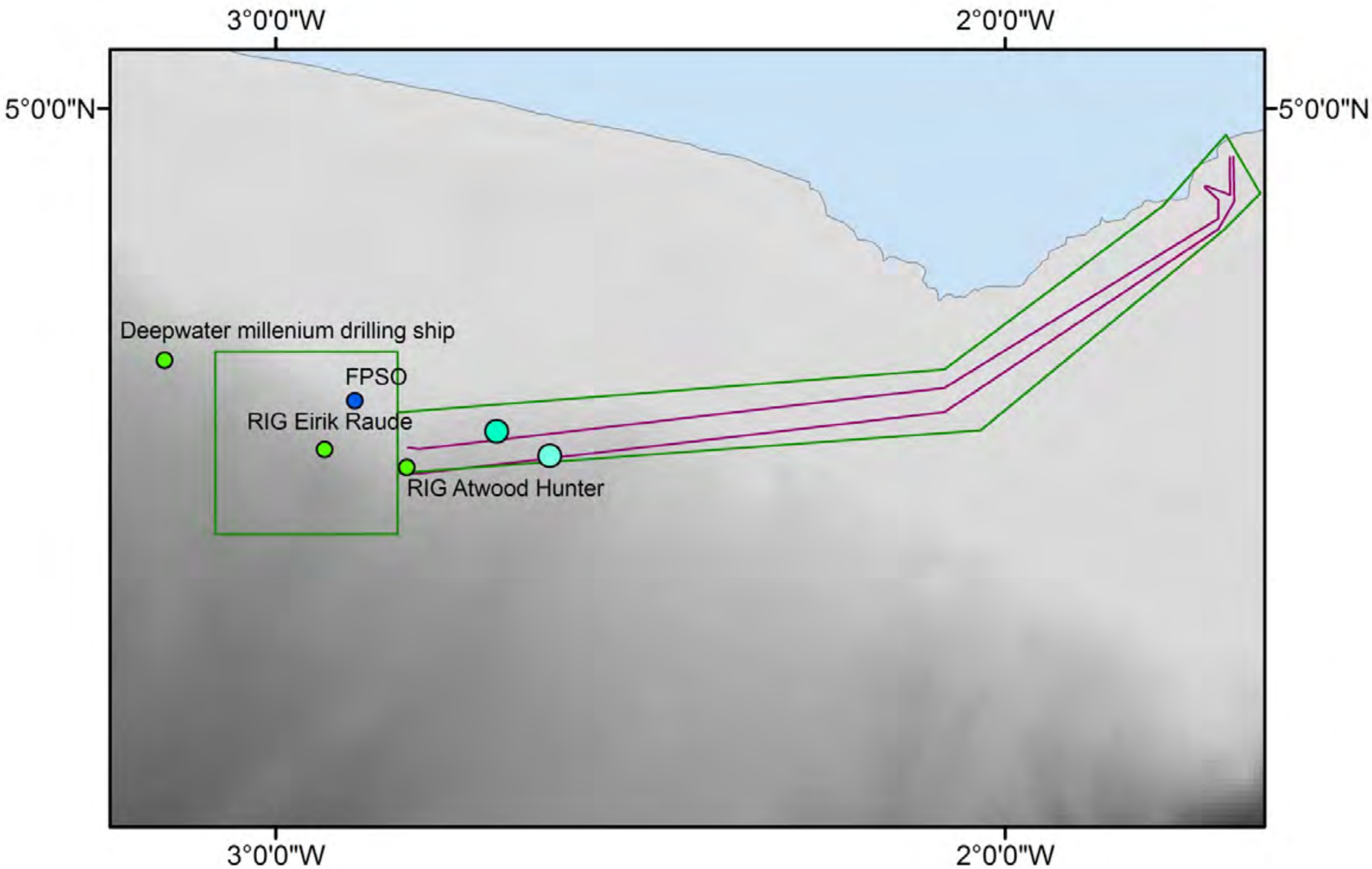


**Figure 1.1 - Map of Ghanaian offshore waters (grey) and the adjacent coast (blue).** The gradient in grey depicts water depth, with lighter shades indicating shallower areas. The Jubilee Field is indicated with a green square and the FPSO (●) lies in the north-eastern sector of the Jubilee Field. The rig positions are more southerly (●) while a drilling ship (●) frequented the area to the north-west during the time underwater noise measurements were undertaken. A specially defined shipping lane for Tullow vessels as they transit between Takoradi and the Jubilee Field is indicated by green lines, linking Jubilee Field to land. Within these two ambient noise measurement locations are shown (●).

## 1.3 Natural environment at the Jubilee field

### 1.3.1 Physical environment in the Jubilee Field

The Jubilee Field lies on a south-westward sloping continental slope in water depths between 1,100 and 1,700 m and covers and area of approximately 110 $km^2$. It is located over clays and silts that form a generally smooth seabed.

The region is characterized by two distinct climatic states: the dry and the wet season. The rainy season peaks between May and July and again between September and October, whereas temperatures and rainfall decline between July and August.

In general, the surface water in the gulf of Guinea is warm (24 to 29°C) with a strong thermocline at 10 to 40 m depth. Surface temperatures are cooled during upwelling, which generally occurs along the Ghanaian coast from July through to September and also to a lesser extent between December and January.

The swell in the area generally reaches heights of about 0.9 to 1.4 m, rarely attaining 2.5 m or more.

### 1.3.2 Marine mammals and Fish in the Jubilee Field

Of the two groups of marine mammals reported to utilise the Ghanaian marine environment, namely cetaceans (Cetacea) and manatees (Sirenia), only cetaceans were considered in this noise impact assessment, as West African manatees present in Ghana do not venture into the deep offshore waters (Irvine et al. 2009).

According to the EIS eighteen cetacean species at least occasionally reside in the Gulf Of Guinea (Table 1.1). This includes one baleen whale (Mysticeti) and seventeen odontocetes (Odontoceti). Of these a sperm whale (*Physeter sp.*) is classed as vulnerable by the International Union for Conservation of Nature (IUCN), while other species, including the only baleen whale in the area, the humpback whale (*Megaptera novaeangliae*), are either not considered to be of concern or there is insufficient data available.

The composition and distribution of fish communities in the Ghanaian waters is influenced by the upwelling, which as described above, is seasonal. Two groups of fish were identified as occurring in the Jubilee Field within the EIS; (i) pelagic fish such as tuna and swordfish species and (ii) deep water species. Tuna and swordfish group includes large pelagic fish that are said to be highly migratory occupying the surface waters (mainly top 100m) of the entire tropical and sub-tropical Atlantic Ocean. Little information exists for the deep water fish. According to the EIS the only IUCN redlisted species likely to occur in the Ghanaian waters are tuna and swordfish.

**Table 1.1 - List of whale and dolphin species of Ghana, IUCN Conservation Status and Species Sensitivities (adopted from the Environmnetal Impact Statement (Irvine et al. 2009)).**

| Species | IUCN Status | Sensitivity |
|---|---|---|
| Delphinidae | | |
| Common bottlenose dolphin (*Tursiops truncatus*) | LC | Low |
| Clymene dolphin (*Stenella clymene*) | DD | Medium |
| Spinner dolphin (*Stenella longirostris*) | DD | Medium |
| Pantropical spotted dolphin (*Stenella attenuate*) | LC | Low |
| Atlantic spotted dolphin (*Stenella frontalis*) (G. Cuvier, 1829) | DD | Medium |
| Long-beaked common dolphin (*Delphinus capensis*) | DD | Medium |
| Fraser's dolphin (*Lagenodelphis hosei*) | LC | Low |
| Rough-toothed dolphin (*Steno bredanensis*) | LC | Low |
| Risso's dolphin (*Grampus griseus*) | LC | Low |
| Melon-headed whale (*Peponocephala electra*) | LC | Low |
| Pygmy killer whale (*Feresa attenuata*) | DD | Medium |
| Short-finned pilot whale (*Globicephala macrorhynchus*) | DD | Medium |
| Killer whale (*Orcinus orca*) | DD | Medium |
| False killer whale (*Pseudorca crassidens*) | DD | Medium |
| Ziphiidae (beaked whales) | | |
| Cuvier's beaked whale (*Ziphius cavirostris*) | LC | Low |
| Kogiidae (pygmy sperm whales) | | |
| Dwarf sperm whale (*Kogia sima*) | DD | Medium |
| Physeteridae (sperm whales) | | |
| Sperm whale (*Physeter macrocephalus* or *Physeter catodon*) | VU | High |
| Balaenopteridae (rorquals) | | |
| Humpback whale (*Megaptera novaeangliae*) | LC | Medium |

*VU = Vulnerable; LC = Least Concern; DD = Data Deficient*

# 2. Description of underwater sound

## 2.1 Types of sound

In simple terms sound can be described as a travelling disturbance of pressure from some equilibrium value.

The sources of such disturbance can be characterized as natural or anthropogenic in origin. Natural sources of sound include biologicals such as marine fauna and nonbiological sources such as seismic activity, waves, currents and weather. Main origins of anthropogenic sounds include naval activity and commercial offshore operations such as shipping, installation, exploration and production.

In terms of occurrence, sounds and sound sources can be described as continuous or transient, depending on whether their contribution is constant or not. For example, the contribution of distant shipping at a given location will be continuous, while the noise contribution of a vessel transiting close to the measurement point will be intermittent over a longer time scale. However, this same noise would be classed as continuous over short measurement intervals (few seconds). An example of a transient sound would be the sound pulses resulting from a seismic survey.

In terms of the FPSO the fixed installation can be viewed as a constant sound source in the area and the associated vessels intermittent sound sources, although the output of a specific source will likely vary as a function of operational mode.

## 2.2 Terminology and Underwater sound propagation

The unit of pressure is the pascal (Pa) or newton per square metre ($Nm^{-2}$), however, by convention sound levels are expressed in decibels (dB) relative to a reference pressure, which is 1 μPa for underwater sound. The sound level is usually described as a source or a received level.

Source level is an idealised acoustic far-field parameter. It may be considered as the sound pressure level that would exist at a range of 1 m from the acoustic centre of an equivalent simple source which radiates the same acoustic power into the medium as the source in question. Source level might be expressed in a number of ways, for example as sound pressure level (dB re 1 μPa·m, often referred to as dB re 1 μPa @ 1 m) or sound exposure level (dB re 1 $\mu Pa^2 \cdot s \cdot m^2$). For a simple source, the pressure is inversely dependent on range. However, it should be noted that for real sources in realistic conditions, the value of the source level is highly unlikely to represent the actual sound pressure level at this range. Indeed, for a large distributed source, a position so close to the source may be in the acoustic near-field (or even inside the source). As the sound moves away from the source it generally decreases in amplitude. This reduction of acoustic field strength as it propagates from the source is called transmission loss.

Transmission loss (TL) is the term used to describe the reduction of the sound level as a function of distance from a sound source. Transmission loss is usually stated as a positive number in terms of dB loss for the total range between the reference distance (1 m for source level) and the receiver location. The mechanisms by which the sound intensity reduces are primarily geometrical spreading, sound absorption in the water and losses into the seabed or other boundaries. Thus the contribution of a specific sound to noise in a given area depends on the sound level at the source and how effectively the sound propagates away from its source. A moderate level source transmitting over an efficient propagation path may produce the same received sound pressure level as a higher level source transmitting through a 'lossy' propagation path. In deep water, variations in water properties can strongly influence the sound propagation. In shallower water, the surface and bottom have strong effects. Often variation in bathymetry (depth) can have significant effects on the transmission of the sound. In general sound energy decreases with increasing distance from the source with lower frequencies experiencing smaller losses compared to higher frequencies as the sound travels through the water column. Sound speed in the ocean is also an important oceanographic variable in underwater sound propagation. It is largely dependent on three main physical factors: temperature, depth (hydrostatic pressure) and salinity, increasing as they increase. A varying vertical sound speed profile may cause upward or downward refraction of the sound as it bends towards the sound speed minimum. In the tropics the depth at which the sound minimum occurs is generally hundreds of metres below the surface, however, upwelling that brings cooler waters up to the surface can result in an additional rapid dip in sound speed speed in the surface layer.

The strength of the acoustic field at a given depth and range relative to the source is termed received level. Estimates of received level generally involve collection of empirical data at multiple points away from the source and numerical modelling that estimates sound levels at any one point from the source.

While solely empirical data could be used in noise impact predictions this approach is only applicable in an isotropic environment (possessing homogenous propagation properties) where propagation is uniform in all directions. The varied bathymetry of the Jubilee field shelf presents a diverse environment and requires use of numerical propagation models to obtain sound field estimates around the source.

The wave equation describing the propagation of an acoustic field is often difficult to solve in real-world situations. A good model describing the propagation of sound in the ocean should take into account:

- the interaction with the sea-surface;
- the interaction with (and transmission through) the seabed;
- the refraction of the sound due to the sound speed gradient;
- absorption of the sound by the sea-water and the seabed;
- the geometrical spreading of the sound away from the source;
- receiver and source depths.

One common approach is to use a method of normal modes, often applied in cases where the sound speed is stratified (changes vertically with depth but not horizontally with range). The normal mode method is useful to calculate the sound field where the water column acts as a waveguide for a limited number of propagating modes. The theory can be expanded to account for different types of seabed (assuming the properties are known), and variations in sound speed gradients. The problem of solving the wave equation for range dependent conditions such as sloping or irregular bottoms and range-varying sound speed profiles has been overcome by an approximation called the parabolic equation. Here, small incremental changes in range and depth are used to accommodate changes in propagation parameters without the occurrence of large errors. The parabolic equation method provides a frequency domain solution for transmission loss and can provide distance and depth dependent transmission loss predictions. However, in deep water with large numbers of modes propagating, the method is computationally demanding (Richardson et al. 1995; Lurton 2003).

In water deep enough for propagation of ten or more modes, ray theory may be used. This requires that the sound speed changes slowly, with little change over a distance of one acoustic wavelength, and is best suited to the higher frequencies (and thus smaller wavelengths). The sound field is calculated by tracing ray paths, starting from the source, at uniformly spaced angular intervals. For each increment in range, the ray direction is determined from the ray equations and the local gradient of sound speed versus depth. This method is useful in deep water, where a small number of rays transmit most of the acoustic energy from source to receiver, where there is a direct path from source to receiver, and where only a limited number of surface and bottom reflections contribute. For shallow water, the large number of reflected paths makes the method somewhat impractical (Richardson et al. 1995; Lurton 2003).

Invariably sophisticated propagation models and site specific propagation environment data are required to obtain accurate estimates of sound levels around the source with which to estimate the impact of noise on marine fauna.

Similarly, regardless of how sophisticated the model, the accuracy of numerical model outputs depends on the accuracy of environmental parameters assumed for the propagation modelling. While there are a number of good theoretical models that estimate transmission loss for given environmental properties, to be successfully used, the acoustic environmental characteristics need to be known (Richardson et al. 1995). These include seafloor topography and sound speed in both the water column and in the seafloor.

The accuracy of any model also depends on accurate representation of the source. The sources in the case of the Jubilee Field FPSO normal operation and off-load include the noise being radiated near the surface during operation from the FPSO hull and the noise from the holdback tug vessel. For all the modelling considered in this report, each prediction is made based on discrete frequencies, chosen to best represent the highest impact sources during both installation and operation.

## 2.3 Metrics used for this assessment

Comment metrics used to report measured sound levels in impact assessment studies include Sound Pressure Level (SPL) and Sound Exposure Level (SEL).

The Sound Pressure Level is expressed in units of dB re 1 μPa, for the root mean square (rms) of pressure, *p*, as shown by the following expression:

$$= 20\log \frac{}{} \quad , \tag{1}$$

where $p_0$ is the reference pressure of 1 μPa. This definition of SPL used throughout this report.

The Sound Exposure Level takes time period into account. The SEL for a specific signal is calculated by integrating the square of the pressure waveform over the duration of the signal.

The calculation is given by:

$$Ls = \int_{t1}^{t2} p^2(t)dt \, . \tag{2}$$

The value is then expressed in dB re 1 $\mu Pa^2 \cdot s$ and is calculated from:

$$= 10 \quad \frac{}{} \tag{3}$$

where $E_0$ is the reference value of 1 $\mu Pa^2 \cdot s$.

For the purposes of this assessment, the *Ls* (or SEL) is integrated over a one second period (i.e. *t*2 – *t*1 = 1). In this case, the SEL dB value and the SPL dB value are equivalent.

The cumulative exposure can also be used to consider the noise dose received during the total exposure duration. For injuries such as TTS and PTS, it is this cumulative exposure that is the important parameter to consider.

## 2.4 Ambient noise in the ocean

Ambient noise is the background noise and originates from a range of noise sources, both natural and anthropogenic. Ambient noise in the ocean spans a large frequency range from below 1 Hz, to well over 100 kHz. Above 100 kHz, the ambient noise is dominated by thermal noise levels. In deep water, the contributions from various sources have been extensively studied and the levels of ambient noise are relatively well defined. The classic text by Urick (1983) and Wenz (1962) summarise deep water ambient noise. These are known as Knudsen spectra from the pioneering work carried by Knudsen et al. (1948) to measure the levels of ambient noise. The ambient noise spectrum will normally be made up from a number of contributing sources and is illustrated in Figure 2.1. This plot has been adapted from the presentation of the ambient noise spectra by Richardson et al. (1995). At the lower frequencies shipping noise will dominate, while at the higher frequencies noise from waves and precipitation will dominate. The frequency at which the change occurs is a complex function of local bathymetry, propagation conditions, shipping levels and weather.

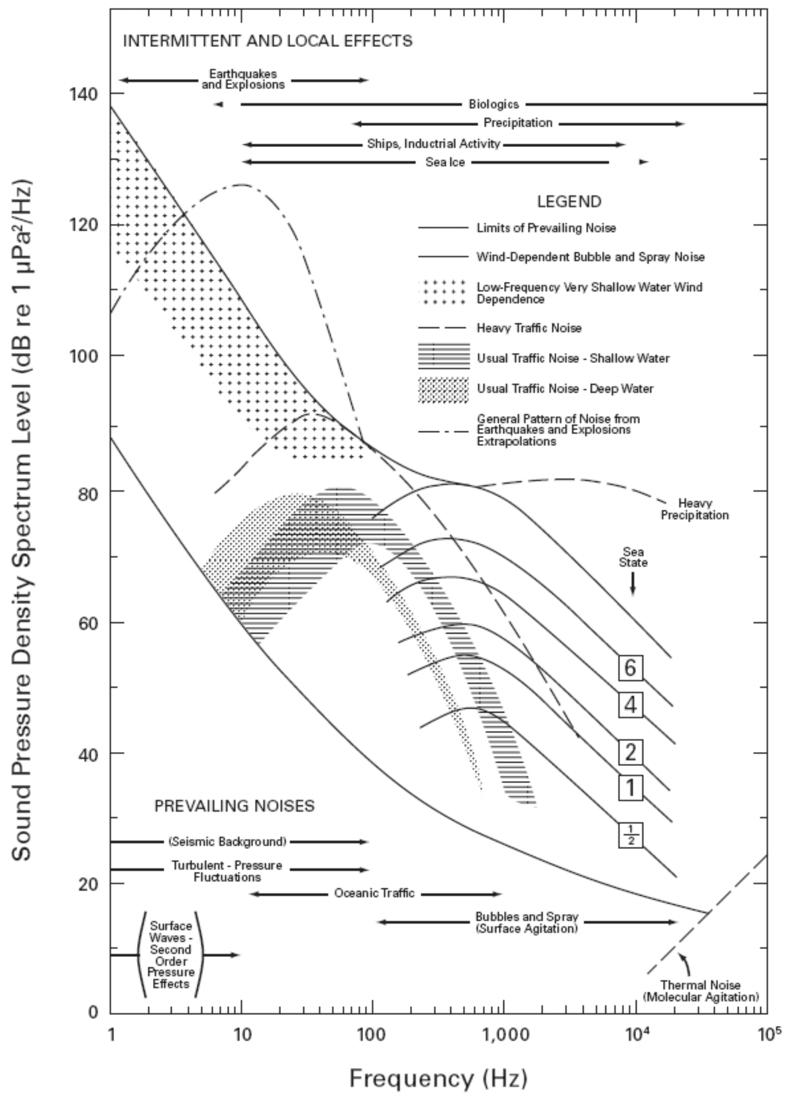


**Figure 2.1 - Typical ambient noise spectra (From Richardson et al. (1995), originally formulated by Wenz (1962)).**

## 2.5 Underwater noise at the Jubilee field

Main anthropogenic sound sources as identified by the EIS include vessel and machinery noise. In general, noise at the Jubilee Field will likely be dominated by anthropogenic noise at lower frequencies, with wave and wind contributing more at higher frequencies and the biologicals potentially vocalizing across this range. The ambient noise in the Jubilee Field may well have ambient noise levels which approximate the Wenz heavy traffic curve (see Figure 2.1) at lower frequencies due to the oil operations in the area. At higher frequencies, the ambient noise will likely depend on sea-state as predicted by Wenz (1962).

As the FPSO is held in its location by a turret mooring, its operational noise will be dominated by machinery noise radiating from the hull, originating from mechanical vibration from generators, gas turbines, pumps and compressors (Irvine et al. 2009). The actual noise generated likely depends on the mechanical equipment operating on board and probably varies with time. There is no propeller, thruster or cavitation noise associated with the operation of a turret moored FPSO other than those of support and off-loading vessels. During the measured oil off-loading period, the only vessel maintaining its position was the holdback tug, and noise radiated from its propellers will likely represent the single noisiest source during an off-load operation.

Proximity of near-by drilling vessels or platforms will also likely contribute to generally elevated sound levels. Whilst holding station, dynamically positioned vessels can radiate significant noise, particularly if they operate with single speed, variable pitch type thrusters.

The EIS which is based on review of relevant published literature estimates source levels of vessels operating in the area will not exceed 190 dB re 1 µPa·m and are likely to have most energy in the lower frequency bands.

# 3. Effect of underwater noise on marine life

The potential effect of noise on marine fauna largely depends on the hearing sensitivity of the receptor and the level of the perceived sound. The four main components that govern the overall potential impact of noise on marine fauna include (i) sound source, (ii) propagation, (iii) receptor and (iv) exposure. Sound sources and propagation have been considered in Section 2 of this report. The receptor and its response to the exposure are considered in this section.

Cetacean and fish sensitivity to noise is based on their dependence on sound for basic functions that affect their reproduction and survival. Cetaceans can use sound for communication and to navigate, catch prey and detect predators, while some fish rely on sound for mating purposes such as to attract mates and mark territory for example.

## 3.1 Audiograms

For an estimate to be made of whether an animal will be affected by an underwater sound, the hearing sensitivity of the animal must be considered. If the sound is composed of frequencies which do not lie within the reception bandwidth of the animal, the impact is likely to be negligible. For example, a sound at an ultrasonic frequency of 50 kHz will not be heard by a human observer (Kinsler et al. 1982).

It is therefore possible to apply weighting to the received sound pressure level according to the sensitivity of the exposed animal. This is most commonly done by making use of audiometric data for the animal of interest. For example, a frequency weighting which incorporates the relative frequency response of the human ear is commonly used to assess the effect of noise on humans. The most widely used metric in this case is the dB A-weighting which incorporates the frequency weighting based on the 40-phon Fletcher-Munson human hearing curves (Burns 1973).

Audiograms are a representation of the hearing sensitivity of a subject as a function of frequency. These are presented as the sound pressure levels required for the subject to just perceive the sound (hearing thresholds) or more commonly to perceive the sound with a certain loudness (e.g. for a loudness of 40 phon).

To determine an audiogram for an animal requires a technique which does not rely on direct cognitive compliance. The animal cannot be asked whether the sound is perceptible. Two principal techniques are commonly used. The first relies on behavioural response and requires the animal to be trained to perform a task in response to an aural stimulus. This can only be used for animals that can be trained. The second method involves measurement of the evoked auditory potential which is the electrical impulse in the auditory nerves that results from the sound being heard by the animal. In this approach, electrodes are attached to the animal to measure the electrical response to the sound directly. Whilst audiograms are useful, there is very limited data of its type, with audiograms for a given species often missing or based on a measurement of an individual animal. Such data may thus not be representative of all subjects, as hearing sensitivity can vary with time and may differ between subjects.

## 3.2 Potential Impact

Underwater sound can potentially have a negative impact on marine mammals and fish from changing their acoustic habitat to scaring them away and even causing physical injury. In general, biological damage as a result of sound is either related to a large pressure change (barotrauma) or to the total quantity of sound energy received by a receptor. Barotrauma injury can result from exposure to a high intensity sound even if the sound is of short duration, such as an explosion. However, when considering injury due to the energy of an exposure, the time of the exposure becomes important. For example, a continuous source operating at a given sound pressure level is more damaging than an intermittent source reaching the same sound pressure level. The harmful effects (impacts) of high-level underwater sound can be summarised as lethal, physical injury and hearing impairment. Other ways in which sound or noise may affect marine mammals and fish is by causing behavioural disturbance and masking.

### 3.2.1 Lethality

High peak pressure sound levels have the potential to cause death, or severe injury leading to death, of marine mammals and fish. Some of these effects may be considered to be barometric pressure effects due to the shock experienced by the animal, rather than acoustic effects per se. There has been considerable research into the levels of incident peak pressure and impulse (integral of the peak pressure over time) that cause lethal injury in species of fish and in human divers. The work of Yelverton et al. (1973; 1975; 1976) on fish highlighted that for a given pressure wave the severity of the injury and likelihood of a lethal effect is related to the duration of the pressure wave- i.e. a pulse of the same peak pressure but with a longer duration would be more likely to cause injury. In the Yelverton model, smaller fish are generally more vulnerable than larger ones. Richardson et al. (1995) converted Yelverton's expressions for fish mortality into those representative of larger marine mammals.

### 3.2.2 Injury and hearing impairment

High exposure levels from underwater sound sources can also cause hearing impairment. This can take the form of a temporary loss in hearing sensitivity, known as a Temporary Threshold Shift (TTS), or a permanent loss of hearing sensitivity known as a Permanent Threshold Shift (PTS). For transient and continuous sounds the potential for injury is not just related to the level of the underwater sound and the hearing bandwidth of the animal, but is also influenced by the duration of exposure.

### 3.2.3 Behavioural response

At levels where the underwater sound wave may not directly injure animals or cause hearing impairment, the underwater sound may have the potential to cause behavioural disturbance. Studies of the behavioural response of marine species to sound describe a variety of different behavioural reactions, and a general consensus for criteria has been slow to emerge. However, there is general agreement that the hearing sensitivity of the animal should be taken into account with a frequency weighting applied to the received levels. Frequency weighting provides a sound level referenced to an animal's hearing ability either for individual species or classes of species, and therefore a measure of the potential of the sound to cause an effect. The measure that is obtained represents the perceived level of the sound for that animal. This is an important consideration because even apparently loud underwater sound may have no effect on an animal if it is at frequencies outside the animal's hearing range.

### 3.2.4 Auditory Masking

Auditory masking occurs when an unwanted sound reduces the audibility of a signal which occurs in the same critical band, even if the signal level is above the absolute hearing threshold. Auditory masking can reduce the ability of an animal to communicate or detect predators. For sonar equipped animals, masking can also reduce their ability to hunt and navigate. However, the largely low frequency (1kHz) and relatively low level noise related to surface vessels will likely be of very limited disruption to odontocete ability to echolocate, as they produce sounds at frequencies of several kHz. Surface vessel related noise may mask some humpback whale vocalizations, as this species vocalise within the 30 to 8000 Hz range (Richardson et al. 1995). However, the measured FPSO noise is unlikely to have an overwhelming effect over other offshore sound sources such as drilling rigs and merchant shipping lanes.

### 3.2.5 Audibility

The audible range is the range over which marine species can hear the noise from a specific source. This will extend to the distance where the sound either falls below the ambient perceived sea noise level or the auditory threshold of the animal. Whether the animal can hear the sound is not usually a consideration used for impact assessment, since impact is usually judged in terms of physical or behavioural effects. There may be no consequence, negative or otherwise, of the animal hearing the sound.

## 3.3 Criteria used in the noise impact assessment

### 3.3.1 Impact of FPSO on marine fauna

This work considers the impact of acoustic noise on marine mammals and fish in accordance with the findings of the EIS. The noise impact assessment within the EIS for this project was delivered as a comprehensive desktop study and postulated that no noise from the project will be high enough to cause instantaneous injury. The EIS also proposed the likelihood of underwater noise impacting marine mammals was low, while fish were deemed as not particularly sensitive to underwater sound (Irvine et al. 2009).

This section describes the impact criteria applied in marine mammal noise impact assessments with a view to estimate the impact ranges based on measured data.

### 3.3.2 Criteria for marine mammals

Various impact criteria for marine mammals have been developed over recent years. Perhaps most widely accepted and used is the work of Southall et al. (2007) of the US Marine Mammal Criteria Group of the NMFS (National Marine Fisheries Service part of NOAA). The Marine Mammal Noise Exposure Criteria were developed through consensus of an expert committee and peer-reviewed. Southall et al. (2007) classify marine mammals into five functional hearing groups: three of which encompass cetaceans. The groups were devised based on current knowledge and interpolation of appropriate marine mammal hearing data and include (i) low-frequency cetaceans, (ii) mid-frequency cetaceans, (iii) high-frequency cetaceans and pinnipeds in (iv) water and (v) in air.

The Marine Mammal Noise Exposure Criteria, consider three sound types which cover the range of sound sources to which marine mammal might be exposed. These are defined as: i) single pulses; ii) multiple pulses; and iii) nonpulses. Non-pulses include any tonal or broadband noise which cannot be defined as a pulse and for the purposes of this report would almost certainly describe any operation noise generated by the FPSO hull, supporting vessels/aircraft and any off-loading vessel propeller/thruster noise.

Southall et al. (2007) consider two types of response: injury and behavioural response. They regard permanent loss of hearing or the PTS-onset to constitute injury, while a severity scaling system was devised from a database of relevant studies in order to derive behavioural response thresholds. This severity scaling system ranks the behavioural response from a zero for 'no response' to a 9 for 'outright panic, flight, stampede, attack of conspecifics or stranding events'. A behavioural response with a severity scale of 6 is considered to represent a disturbance, with animals showing noticeable changes in swimming pattern to minor avoidance reactions.

It should be noted that Southall et al. (2007), suggest dual exposure criteria approach for injury criteria which includes an SEL and a SPL criterion. While the behavioural response criteria are given as an SPL metric only. In the case of the SEL, a series of filters have been developed alongside an approach known as M-weighting: the signal is first weighted (filtered) relative to hearing abilities of species under test and the Sound Exposure Level or accumulated SEL is then calculated (Theobald et al. 2009). This has the advantage that for signals containing multiple frequency components, energy contributions from frequency components outside the hearing band of the species will be reduced or removed from the overall exposure estimate. On the other hand SPL which is considered for a peak level is not subjected to a weighted response.

Southall et al. (2007) estimate that all three cetacean groups experience injury at the same level but give a range of behavioural response thresholds, which can be consulted on circumstantial basis depending on the sound source, the receptor, the severity of the response and the number of relevant studies from which the responses were drawn.

The injury criteria are specified at 230 dB re 1 μPa (unweighted) SPL peak and 215 dB re 1 $\mu Pa^2 \cdot s$ (M weighted) SEL.

The humpback whale, the only baleen whale species reported from the Ghanaian waters, belongs to the low frequency cetacean hearing group. Based on behavioural observations collated as part of the US NMFS criteria, the onset of significant behavioural disturbance (severity scaling 6 and above) in the low-frequency cetaceans may occur over a range of received levels likely above 110 dB re 1 μPa (SPL).

The mid-frequency cetacean hearing group contains the majority of species found in the Gulf of Guinea, and also includes the vulnerable sperm whale. For this group Southall et al. (2007) behavioural criteria also indicate that received levels of 110 dB re 1 μPa (SPL) may elicit a behavioural responses with a possible severity scaling of 6 with a high probability of a behavioural response with a severity scaling of 3.

The severity scale proposed by Southall et al. (2007) indicates that changes in diving patterns might be observed from a severity scaling of 3 and higher. This could be important for odontocetes, such as the sperm whale, that are reliant on deep diving for foraging.

Limited information exists for high-frequency cetacean exposure. There is indication that nonpulsed noise at a received level exceeding 110 dB re 1 μPa (SPL) would elicit a response of 6 on the severity scale (Southall et al. 2007). However, this is based on laboratory experiments with the harbour porpoise and it is not known if the same response can be assigned to other high frequency cetaceans and any nonpulsed sound.

It should be noted that using these criteria does not account for the potential disturbance associated with the prolonged exposure to the sound source, however, it is also thought that animals may generally avoid areas with elevated noise levels.

### 3.3.3. Fish

The hearing capabilities of fish species are often characterised as either a hearing specialist or generalist. The term hearing specialist generally refers to fish species that have a structure linking the swim bladder and ears, whereas hearing generalist would not normally be considered to have this connection (Webb et al. 2008). Hearing generalists generally hear over relatively narrow frequency ranges from 50 Hz or below to 1,000 Hz or 1,500 Hz with a hearing sensitivity which is often not very good, while there is also considerable variation between species. Hearing specialists usually have improved sensitivity over the same range and sensitivity to sound at higher frequencies extending above 3,000 Hz.

Injury to fish has been a concern for the high intensity, usually impulsive, sounds such as underwater blasting, seismic airguns and impact piling. The latter of these has prompted the Fisheries Hydroacoustic Working Group (FHWG) (established by California Department for Transportation in coordination with the US Federal Highways Administration and the departments of transportation in Oregon state and Washington state) to advise use of an interim dual injury criteria based on a peak sound pressure level of 206 dB re 1 μPa for a single pile strike and an accumulated (cumulative) sound exposure level of 187 dB re 1 $\mu Pa^2 \cdot s$ for all fish larger than 2 grams in mass (Carlsen et al. 2007). Although these criteria do not apply to continuous noise sources such as vessel or oil platform noise, it does indicate that fish are predominantly at risk of injury from high intensity sound sources. The sound pressure levels and sound exposure levels that have been measured from in the Jubilee field indicate that injury to fish is unlikely.

Studies on the behavioural response of fish to underwater sound are very limited and currently, no criteria exist for assessing this. There have been some observational studies examining the effect of seismic surveying or airguns on fish demonstrating that fish behaviour is influenced by high intensity sounds (Engås et al. 1996; McCauley et al. 2000; Webb et al. 2008; Løkkeborg et al. 2010). For surface vessels and oil platforms there is likely to be a much less significant effect and in some cases may be attracted to surface vessels holding station (Røstad et al. 2006). There is however evidence that ‘silent research vessels’ used for fisheries studies do cause fish to react and move away from the vessel, although it is thought that the particle motion generated by the moving might be the cause of this (Sand et al. 2008). However, the International Council for the Exploration of the Sea (ICES) has formulated recommendations for maximum radiated underwater noise from research vessels which are approximately 30 dB above the hearing threshold of Atlantic cod (*Gadus morhua*) and herring (*Clupea harengus*) ((ICES:209, 1995), which are shown in Figure 3.1). The implication of this is that vessels operating with source levels of around 110 to 120 dB re 1 µPa·m are not thought to cause any significant movement of fish away from the vessel. Although the FPSO during normal operation and the off-loading will result in source levels above this, the radiated noise level would rapidly decrease within a few hundred metres to levels which are decreasingly likely to cause significant movement of fish away from the vessel or FPSO.

It should be noted that behavioural disturbance will depend on a number of factors such as the type of fish, its sex, age and condition, as well as other stressors to which the fish is or has been exposed. For example, it would be expected that smaller fish might undergo the above behavioural changes at slightly lower levels. In addition to this, the response of the fish will depend on the reasons and drivers for the fish being in the area. Foraging for example, may increase the likelyhood for the fish to remain in the area despite the elevated noise level.

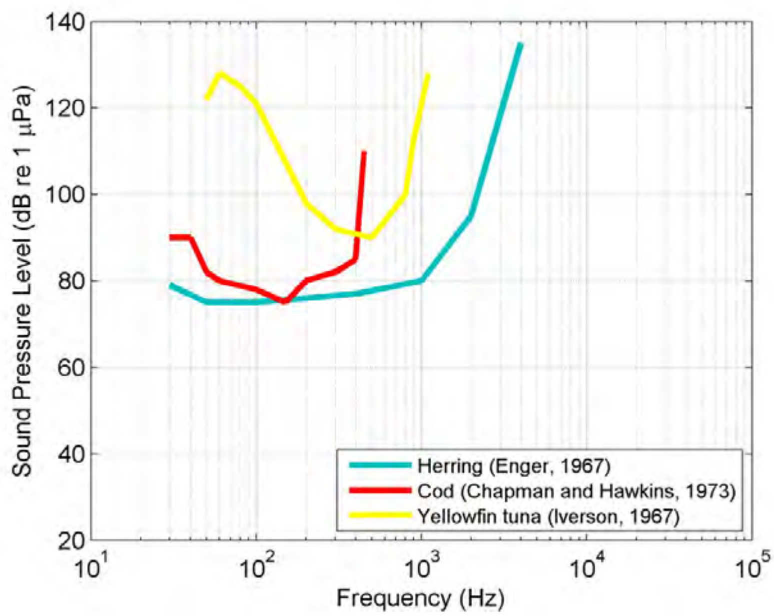


**Figure 3.1 – Hearing threshold data for selected fish species.**

# 4. Underwater noise measurement in the Jubilee Field

The approach was two fold in two ways. Firstly, because two scenarios were considered: Ambient noise and operational FPSO noise (FPSO during a normal operation and during tanker off-load). For all datasets received levels of sound recordings were determined. Secondly, two approaches were adopted, measurement and numerical modelling. In order to estimate impacts of FPSO operational noise on marine fauna measured sound levels were further used to obtain sound field maps. This was done following further two steps: (i) use of received level data to estimate the sound source level (SL) and (ii) propagation of SL values in order to construct the sound field around the FPSO.

## 4.1 Acoustic data sampling

### 4.1.1 Sampling locations

*4.1.1.1 Ambient noise*

In order to characterise ambient sound levels recordings had to be collected from an area adjacent to the Jubilee Field that experiences least offshore activity. Positions of main operations in the area were plotted against the known shipping lanes and vessel traffic monitored via the AIS system. The designated Tullow shipping lane described in the introduction experienced least activity at the time of empirical data collection and was thus chosen for ambient noise measurements.

*4.1.1.2 FPSO*

Underwater sound recordings were collected to characterise sound levels around the FPSO during 'normal operations' and during a 'tanker off-load'.

To achieve this, underwater sound recordings were taken at various ranges and bearings from the FPSO (hereafter referred to as sampling stations) with a separate recording system near the FPSO to record any fluctuations in the output levels (hereafter referred to as a static recorder ). The FPSO is generally described as southward facing and usually does not swing around the turret much. Based on this assumption sampling transects were determined for the given FPSO position (bridge coordinates) and specific sampling location coordinates chosen at various ranges from the FPSO (from 200 m to 10 km) and at different bearings (45 degree increments) so as to best capture sound level changes with distance from the source and inspect for directional variation in the radiated noise. In contrast to the expected, the FPSO swung around the turret considerably during this survey (up to 90 to 180 degrees during a field day) and in an attempt to maintain the general bearing throughout each transect, sampling points were determined based on the visual reference to the FPSO with guesstimates of range. Measurement point positions are indicated in Figure 4.1.

During the off-load four vessels were operational at the FPSO site; the FPSO, the tanker and two tugs. The tugs were holding the FPSO and the tanker apart. One tug was moored to an anchored surface buoy and linked to the FPSO and the other pulling away in the opposite direction on the tanker. This holdback tug was likely the single most apparent source of underwater noise during the measured off-load.

All measurement locations were GPS position fixed and all the data acquisition time stamped against GPS to better than 1 s accuracy. All time stamps were recorded as GMT.


**Figure 4.1a – Map indicating measurement sampling stations (•) during a normal FPSO operation. Guesstimated ranges are provided for each measurement point.**

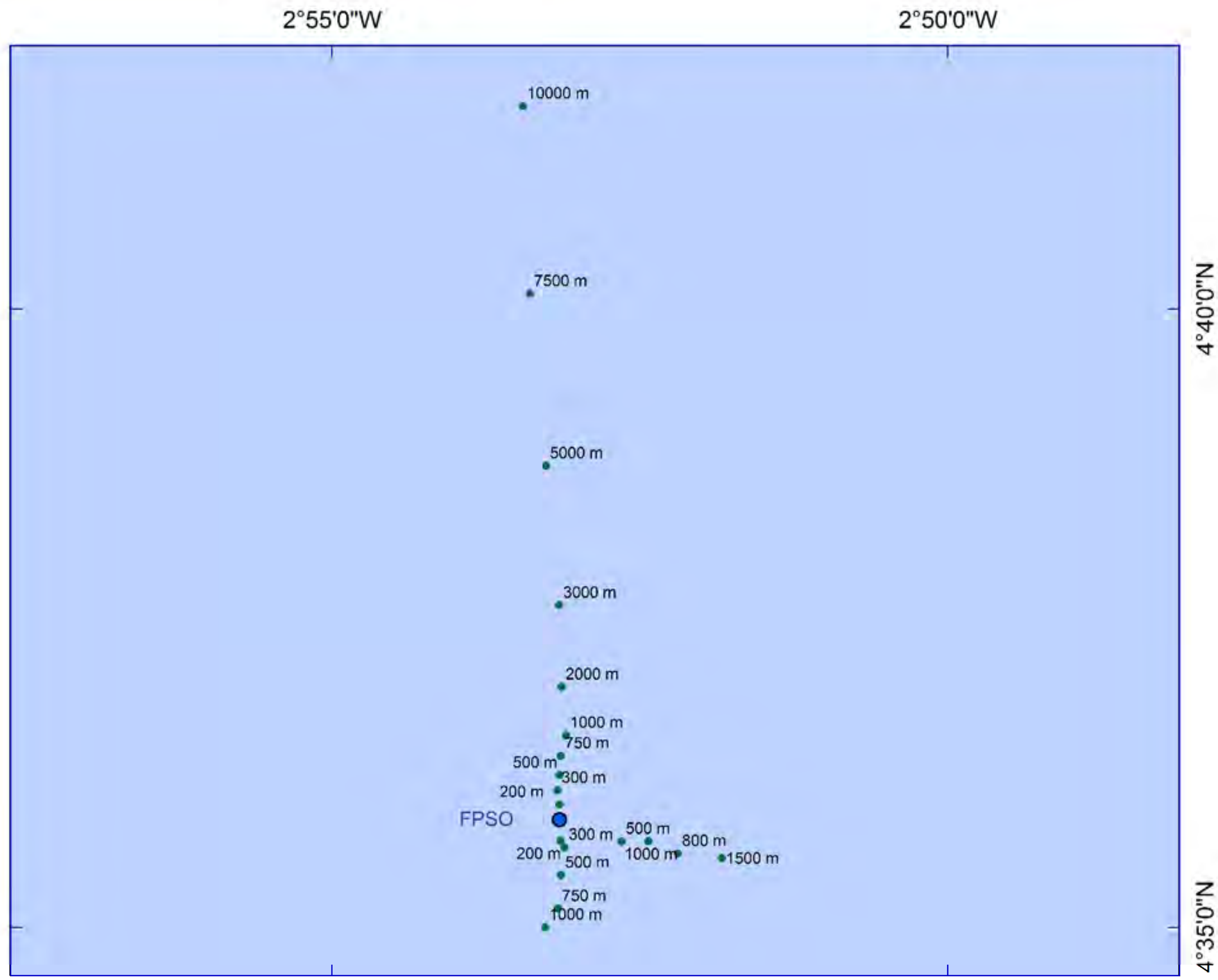


**Figure 4.1b – Map indicating measurement sampling stations (●) during the tanker offload. Guesstimated ranges are provided for each measurement point.**

### 4.1.2 Measurement methodology, equipment and instrumentation

#### *4.1.2.1 Ambient noise and FPSO sampling stations*

Acoustic equipment used to collect underwater acoustic samples as a function of range and bearing from the FPSO was set up on a RHIB which acted as the survey vessel. The data acquisition system was stored in a pelicase providing shelter from sea spray and direct sunlight. Hydrophone cable and hydrophones were stored on the deck and deployed off the side at the beam of the RHIB. During acoustic sampling the engine and all electronic sources of noise, except the hand held GPS, were turned off.

Data acquisition was carried out using a computer-based broadband analysis system with a sampling rate of 360 kS/s. This allowed signals with frequencies up to 180 kHz to be recorded. The data acquisition system is based around a 16-channel DAQ multichannel unit manufactured by National Instruments (NI) operating at 16-bits and capable of sampling at up to 1.25 MS/s. Two channels were used, connected to two hydrophones: a Reson TC4032 and TC4014. Bespoke sound acquisition LabView software was used to obtain recordings and data were saved in an uncompressed format. Both hydrophones were fixed away from the hydrophone cable to avoid contact and thus unwanted noise. The hydrophones were deployed on a 20 m long cable with an anti-heave mechanism to reduce the effect of surface motion. All the measurement equipment was operated from batteries to remove any possible noise from the engine or generator.

Sound speed measurements were obtained on two occasions 4 with a sound velocity probe SV X2 deployed to depths of about 170 m. The instrument is fitted with a pressure sensor for accurate depth readings. Although the instrument is capable of much deeper deployments this could not be realised in the absence of a winch.

#### *4.1.2.2 FPSO Static recorder sampling*

The static, noise monitoring recorder is a self-contained data acquisition unit, with a SRD HS70 hydrophone positioned in the water column. The recorder was deployed on 50 m of rope off the off-load hose at the stern of the FPSO. It sampled underwater sound at 96 kS/s providing a measurement bandwidth of 48 kHz. It recorded at 24-bit resolution and saved data in an uncompressed format.

All hydrophones used were calibrated traceable to UK national standards by NPL over the full frequency range of use.

## 4.2 Analyses of acoustic recordings

The measured underwater ambient noise samples and underwater noise measurements of the FPSO and off-loading operation were first inspected for quality by experienced acousticians who aurally and visually examined the data. Due to swell and chop during the underwater noise measurements, much of the data was contaminated with noise originating from the RHIB (from which the measurements were taken) splashing in the water. Data were selected where this extraneous noise was minimal and to further reduce the effect of this unwanted noise, received levels were obtained using longer time averages. Thirty seconds was deemed sufficiently long to smooth out the contribution of the extraneous transient sounds whilst allowing sufficient time resolution to identify time variant output from the FPSO and off-loading vessels.

The selected data were analysed initially using narrow band to identify any tonal component which might be generated from the FPSO or off-loading vessels. One particularly strong tonal component at around 13.5 kHz was identified which appeared to come from the FPSO (see Section 5.2.1.1). Received levels were then calculated as third octave band data at frequencies consistent with American National Standards Institute standard S1.6-1984 (ANSI, 1984) using Mathworks MatLab 2011a.

For the work presented in this report, the stated received levels are calculated as SPL and SEL as described in Section 2.3.

### 4.3 Propagation modelling

The propagation modelling was undertaken in two parts:

i) to estimate the source level from the measured noise data at different ranges
ii) to propagate the estimated source level to generate sound maps of the area around the FPSO

The propagation modelling approaches are identical except that i) propagates back towards the source and ii) propagates outwards from the source.

This was achieved using two modelling solutions. A parabolic equation solution was used for source level estimates and in outward propagation of frequencies below 2 kHz and ray tracing solution was used for outward propagation at higher frequencies.

A source depth of 20 m was chosen as most of the noise sources associated with the operation of the FPSO have been assumed to be close to the surface, predominantly radiated as 'hull' noise, except for the off-loading where it was assumed that propeller noise would be predominant.

The ray tracing implementation used Bellhop, a solution provided by the Acoustic Toolbox User interface and Post processor (AcTUP V2.2L) and the particular implementation of the PE method used here was the RAM code, a very wide angle PE code based on Pade series expansion (Bamberger et al. 1988; Collins 1989; Collins 1993; Collins 1994), provided in AcTUP V2.2L. The RAM code allows for a varying speed of sound profile and range-dependent bathymetry to be input into the software whilst also considering the seabed composition. All the model solutions were processed in Mathworks MATLAB 2011a.

Sound speed profiles were determined from water temperature and salinity data obtained from the World Ocean Atlas 2005 database (WOA05; http://www.nodc.noaa.gov /OC5/WOA05/pr _woa05.html) and calculated using the Chen-Millero Li equation (Millero and Li 1994). As these are long term averages and sound speed profile may change on a daily basis sound speed profiles were also collected whilst in the field and used in combination with the WOA2005 data for the source level modelling. For impact assessment long term seasonal averages were applied to obtain a more general picture. The summer and winter profiles for the region, obtained from the WOA2005 database, are shown in Figure 4.2. Sound speed profile was also measured in the Jubilee Field during the noise measurement period, and profiles obtained are shown alongside the average sound speed profile from the WOA2005 data for August in Figure 4.3. The measured sound speed shows a strong surface layer effect because of temperature. This may vary substantially on a day to day basis depending on surface environmental conditions. Deeper down, below around 60 m, there is an indication that perhaps the water temperature is above the average for August, resulting in a slightly higher sound speed.

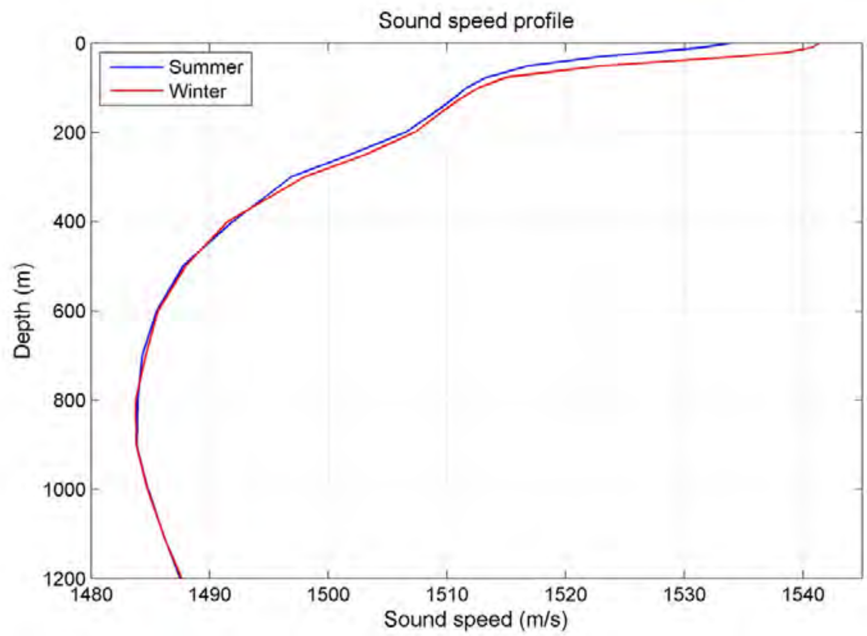


**Figure 4.2 – Average summer and winter sound speed profiles taken from the WOA2005 database.**

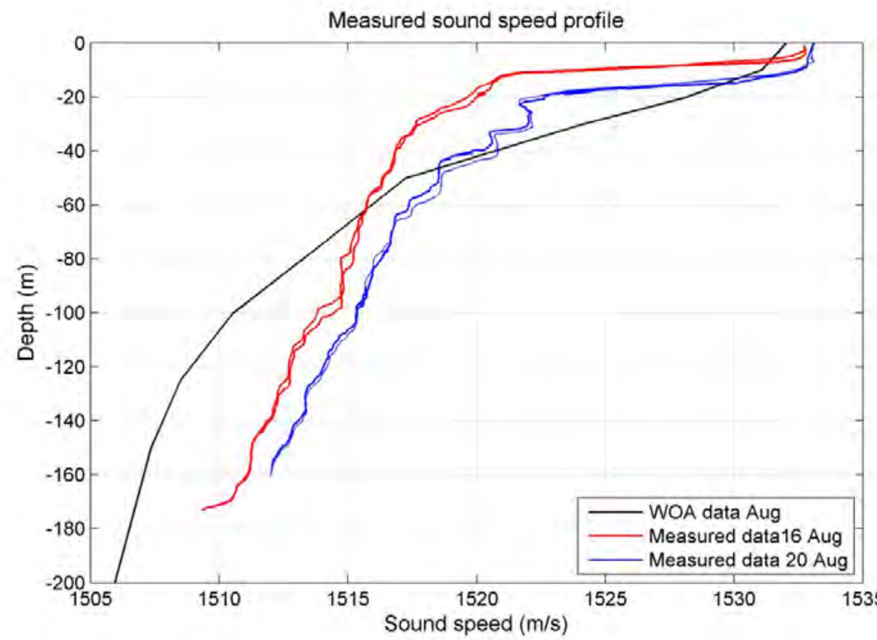


**Figure 4.3 - Two measured sound speed profiles compared with the August average from the WOA2005 database.**

Bathymetry data for the area were obtained from GEBCO digital atlas bathymetry data at one minute resolution, which in the area approximates 1 nautical mile. A sequence of 8 transects radiating from the FPSO out to a 10 km range were selected for modelling. An example is shown in Figure 4.4. As the continental slope off Ghana primarily consists of clays and silts (Irvine et al. 2009) averaged seabed properties given in Hamilton (1980) were adopted for the area with no strong reflection assumed for the seafloor.

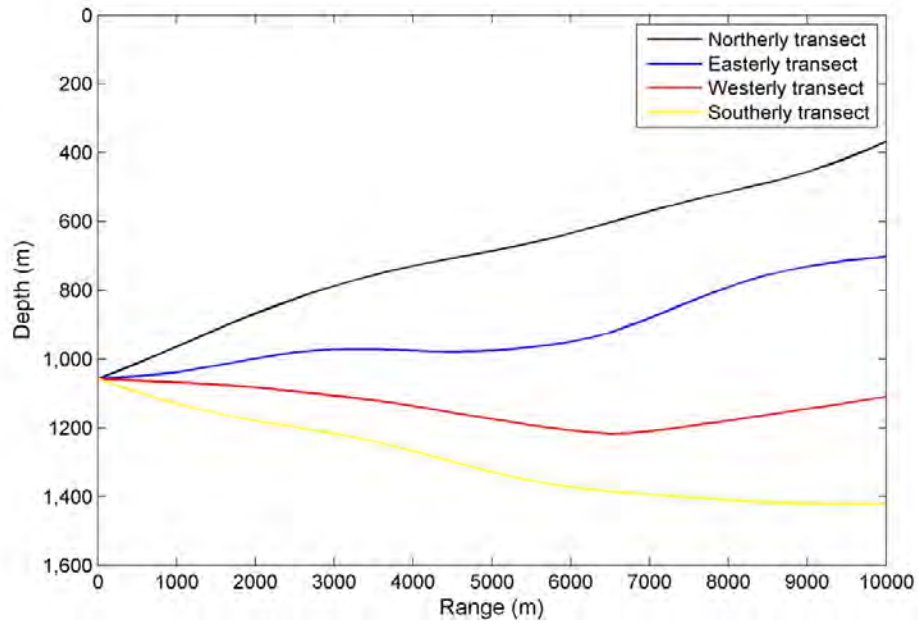


**Figure 4.4 - Bathymetry profiles for representative transects from the FPSO position.**

# 5. Results

## 5.1 Ambient noise

The ambient noise was sampled at two locations in the Jubilee field as described in Section 4.1.1.1 using the methodology outlined in Section 4.1.2.1 and has been analysed as described in Section 4.2 in third-octave bands. These are plotted as power spectral densities in Figure 5.1 and compared with the Wenz curve for sea-state 4 and for different shipping traffic conditions (Wenz 1962). The sea-state during the ambient noise measurements was estimated to be between 3 and 4, tending towards 4. The reference sea-state noise curves from Wenz (1962) are shown in Figure 2.1.

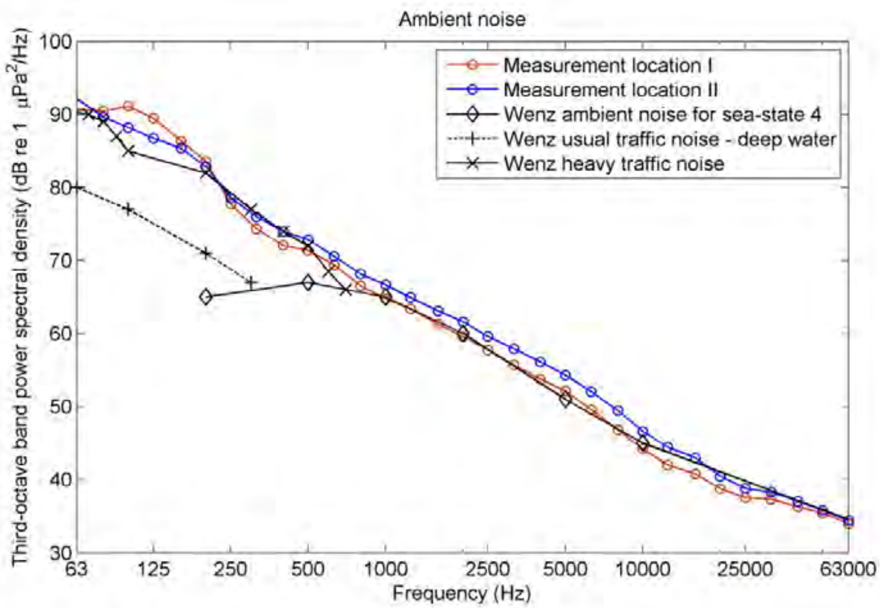


**Figure 5.1 - Plot showing average third-octave band power spectral density obtained from 30 s periods at measurement locations I and II.** A typical ambient noise curve for sea-state 4 and for usual traffic noise obtained from Wenz (1962) are shown for comparison.

Figure 5.1 shows the third-octave band ambient noise levels measured in an area of least offshore activity near the Jubilee Field. When compared to the Wenz curve for sea-state 4, the measured noise levels near the Jubilee Field appear to be consistent with those expected for deep ocean ambient noise. Below around 1000 Hz, the measured data is consistently higher than expected for a sea-state 4 condition and is more consistent with heavy shipping traffic noise. Persistent low frequency noise from merchant shipping, tankers and other surface vessels and dynamically positioned rigs would be expected to contribute to this lower frequency ambient noise. It is also possible that there was noise contamination from the RHIB splash which was likely more predominant below 63 Hz.

Measurements taken at each location show a similar general shape but are typically a few dB lower at location I measured in the morning compared to location II measured in the afternoon. This corresponds to a general increase in sea-state as the day progressed.

As with any ambient noise measurement these data provide a snapshot in time and space and will invariably vary as environmental conditions change.

## 5.2 FPSO noise

### 5.2.1 Source level

The source level for the FPSO during normal operation and for off-loading was obtained using the received level data from ranges of less than 1 km due to the better signal to noise ratio of the measured data. Beyond this range, the signal-to-noise ratio was not sufficiently high to obtain an accurate received level measurement. This was partially due to the extraneous noise generated by the measurement platform (RHIB splash noise) and also because of the propagating nature of the sound near the surface. Because of the rapidly decreasing sound speed measured near the surface (see Figure 4.3), any sound source near the surface will tend to refract away from the surface resulting in an increased transmission loss between the source relatively close to the surface and the hydrophone also relatively close to the surface.

The transmission loss was estimated between the source and receiving hydrophone and then summed with the 30 second averaged received level measured at the hydrophones for each third-octave band at a number of ranges. The source levels shown in Sections 5.2.1.1 and 5.2.1.2 are the averaged source levels obtained from back propagation of received levels from a number of measurement ranges. It should also be noted that these are the point monopole source level positioned below the surface, assumed to be 20 m in this case. Ship noise data reported in the literature is usually stated as the dipole source level (termed “affected” source level by ANSI S12.64) and so this data should be converted before comparisons are made. The conversion between a dipole and monopole Source Level is given by (Ainslie 2010).

*5.2.1.1 FPSO during normal operation*

The estimated source level for the FPSO during normal operation is shown in Figure 5.2 and 5.3. Figure 5.2 shows the frequency range 25 Hz to 2 kHz, which contains the majority of the acoustic energy in the noise generated by the FPSO during normal operation. The peak in the spectral source level occurs between around 100 to 250 Hz and is likely related to machinery noise radiating through the hull of the FPSO. The source level spectrum shown in Figure 5.2 was used to propagate the sound field to ranges of around 10 km to assess its impact on marine mammals in the area.

Figure 5.3 shows an extended frequency range which includes a tonal component of around 13.5 kHz which also occurred in the measurement data for the FPSO and was clearly audible on the close range measurement data. In Figure 5.3, this 13.5 kHz tonal component is captured within the 12.5 kHz third-octave band which was also propagated to assess its impact on marine mammals in the area. The source of this 13.5 kHz tone could not be identified but is most likely to originate from high speed rotating machinery.

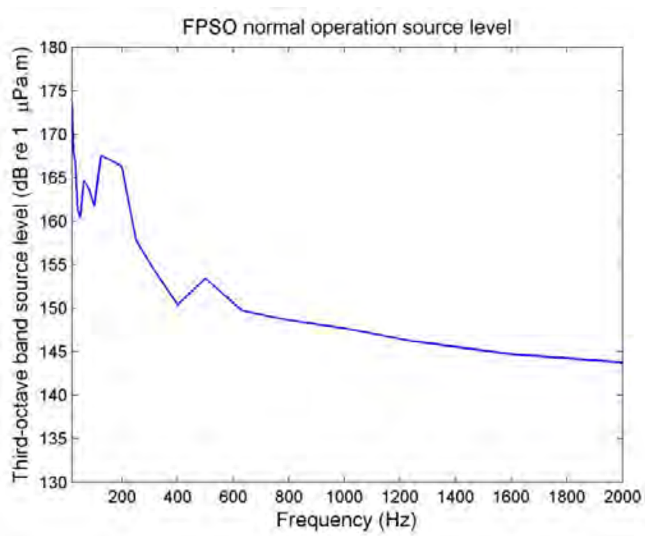


**Figure 5.2 – Third-octave band monopole source level of FPSO during normal operation from 25 Hz to 2 kHz, resulting in a broadband source level of 182 dB re 1 µPa·m.**

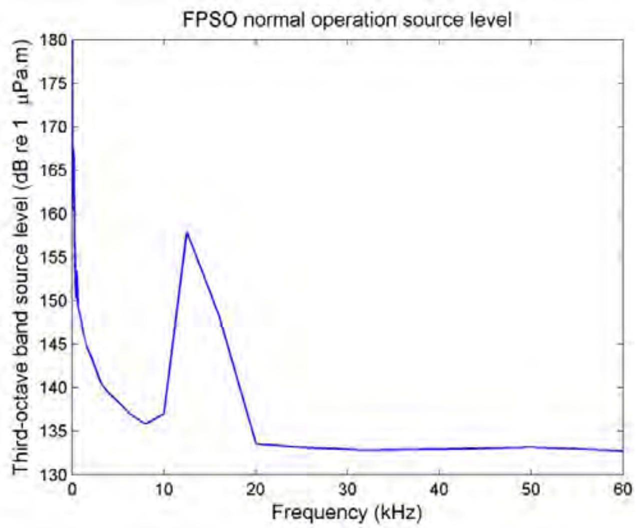


**Figure 5.3 – Third-octave band monopole source level of FPSO during normal operation from 25 Hz to 60 kHz.**

*5.2.1.2 Off-load*

The estimated source level for the off-load is shown in Figure 5.4 obtained from the tug vessel used to maintain the off-loading tanker's position. This tug was confirmed as the only vessel with its propeller operating during this period and the predominant noise source was identified as likely propeller noise with cavitation both audibly and by spectrogram analysis. The frequency range 400 Hz to 16 kHz, shown in Figure 5.4, was used to propagate the sound field out to around 10 km. It should be noted that this source would be present in addition to the noise from the FPSO during normal operation, which would be several hundred metres away.

The broadband source level predicted in the Environmental Impact Statement (Irvine et al. 2009) for the off-loading tanker was 190 dB re 1 µPa·m. As the measured tanker did not use propellers or thrusters to dynamically position, the predominant off-load noise originated from the tug, which as shown in Figure 5.4 has a lower source level than that predicted for the off-loading tanker. It is possible that the off-loading tanker would have resulted in broadband source levels of around 190 dB re 1 µPa·m during its approach and departure only, although it is probable that the tanker would have been travelling at a lower speed within the Jubilee Field to that which the 190 dB re 1 µPa·m would have been based on. Arveson and Vendittis (2000) show correlation between a vessel's speed and its source level, with slower speeds resulting in decreased levels of noise.

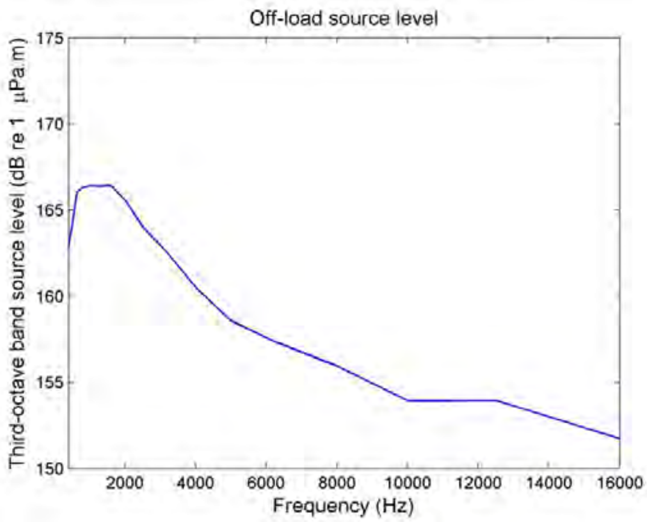


**Figure 5.4 – Third-octave band monopole source level of off-loading from 400 Hz to 16 kHz, resulting in a broadband source level of 176 dB re 1 µPa·m.**

### 5.2.2 Propagated sound field

The source level was propagated in third octave bands using the source levels described in Section 5.2.1. Some examples of the transmission loss used to estimate the third-octave band received levels from the source levels are shown in Figure 5.5. This shows the transmission loss as a function of depth and range for four bearings diverging from the FPSO position, for a summer speed of sound profile. The darker colours indicate a higher loss of the sound for a given point. The regions of high transmission loss at the bottom of the plots, particularly the upper and lower right ones, indicates increased loss into the seabed. The plots also indicate that there is less loss of the sound at greater depths when compared to depths nearer the surface. This could have implications for deep diving cetaceans.

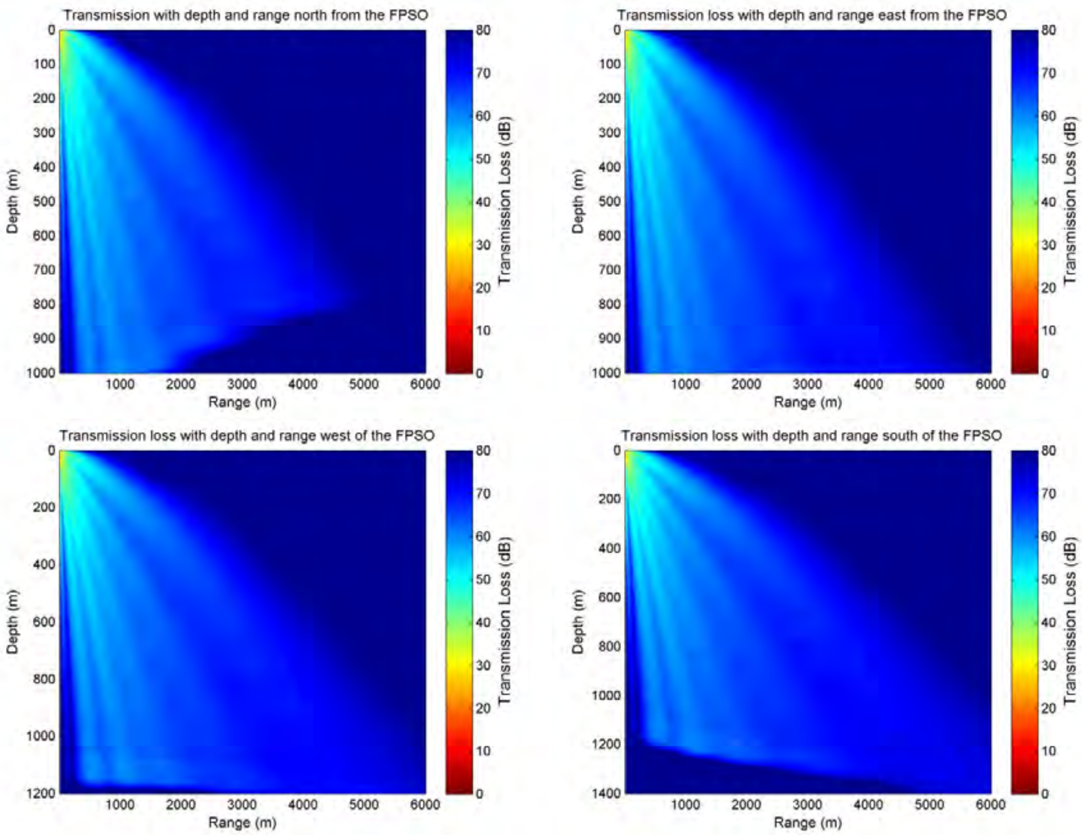


**Figure 5.5 – Transmission loss, for the winter sound speed profile, at 200 Hz with depth and range away from the FPSO for north (upper left), east (upper right), west (lower left) and south (lower right).**

To create a two-dimensional sound map around the FPSO during normal operation and during off-loading, transmission loss was estimated by interpolating 8 modelled transmission loss transects at 10 m depth and applying this propagation to the source level estimates. The results are shown below in Sections 5.2.2.1 and 5.2.2.2 and provide an estimate of the sound field or received level around the FPSO.

Because many cetacean species spend a large proportion of their times close to land and close to the surface and mostly do not dive deeper than 100 metres Perrin et al.(2008) the 10 m depth will regularly be utilised by them. A relevant exception are sperm whales that spend a large proportion of their time diving and have been reported to reach depths of over 1000 m (Watwood et al. 2006). During such dives they would sample different strata of the water column, and therefore potentially be exposed to different sound levels as illustrated in Figure 5.5.

*5.2.2.1 FPSO during normal operation*

The sound maps around the FPSO are plotted in Figures 5.6 and 5.7 for a summer and a winter sound speed profile, respectively. These are shown as one second broadband SELs covering the frequency range from 25 Hz to 2 kHz. As indicted in Figure 5.2, this includes the majority of the acoustic energy that is radiated by the FPSO during normal operation, expect for the tonal component at about 13.5 kHz which is visible in Figure 5.3 in the third-octave band with a centre frequency of 12.5 kHz. The resulting sound map from this third-octave band is shown in Figure 5.8 for summer propagation conditions and in Figure 5.9 for winter propagation conditions.

Prevalent lower frequency bands will potentially propagate more efficiently in the upper portion of the water column during the summer, with levels typically 1 to 2 dB higher than the winter at ranges of a few kilometres and more. However, at ranges of less than 1 kilometre the levels are very similar. Based on the propagation sound maps, it can be determined that the FPSO during normal operation will radiate noise levels near the surface which should decay to around 110 dB re 1 µPa$^2$·s (SEL) at ranges of approximately 0.5 km. Although the sound field propagates less efficiently towards the coast, this effect only influences the sound level near the surface beyond ranges of 5 to 6 km.

Because one second SELs have been used, the SEL received level can be used interchangeably with the SPL root mean square parameter used in the Marine Mammal Noise Exposure Criteria for low and mid frequency cetaceans exposed to nonpulse sounds (Southall et al., 2007).

The Marine Mammal Noise Exposure Criteria indicates that none of the levels generated by the FPSO during normal operation are sufficiently high to pose an injury risk to marine mammals. The predicted sound levels, shown in Figures 5.6 and 5.7, indicate that behavioural disturbance of marine mammals near the surface may occur within a range of 0.5 km of the FPSO during normal operation. For deep diving marine mammals the sound levels to which they are exposed would be expected to increase (see Figure 5.5) when they are within 5 to 6 km of the FPSO. Odontocetes which routinely dive to forage at depth, such as the sperm whale, may therefore exhibit signs of behavioural disturbance at greater ranges which could results in changes to their diving patterns. The range at which this occurs depends on the depth of the dive but could have an influence at ranges up to around 6 km. Non- deep diving cetaceans are much less affected by this propagation phenomenon but may exhibit disturbance behaviour when they dive below the surface at ranges greater than the 0.5 km as indicated above, but this is unlikely to have an influence beyond around 2 to 3 km from the FPSO.

The 13.5 kHz tonal component contributes significantly to the 12.5 kHz third-octave band and would likely be audible above ambient noise out to ranges of 4 km and farther. However, the SPL is sufficiently diminished with range such that it is small compared with the lower frequency bands. Although the tonal component may be an annoyance for marine mammals close to the FPSO it is unlikely to cause a behavioural disturbance beyond the ranges already stated above for the FPSO during normal operation.

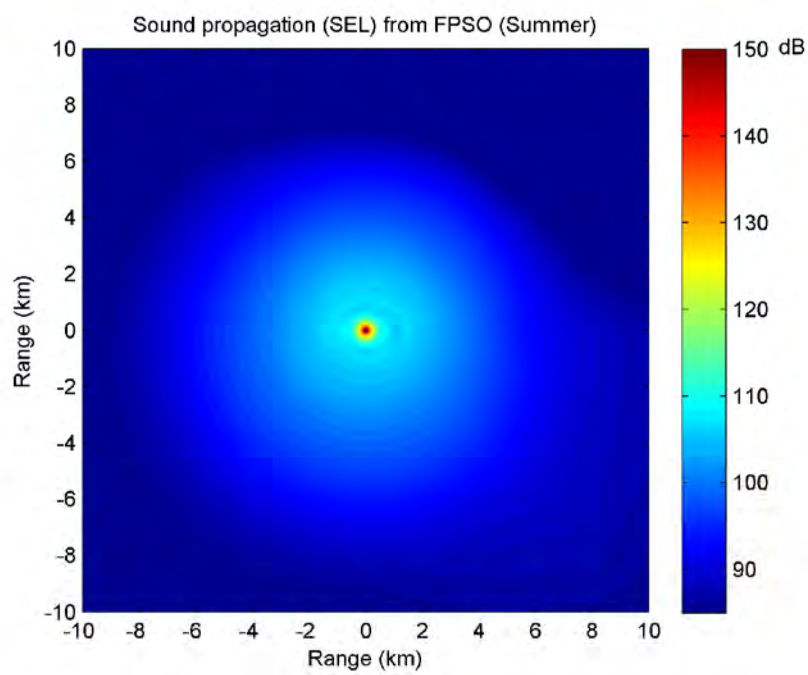


**Figure 5.6 – 25 Hz to 2 kHz broadband SEL received level sound map around the FPSO during normal operation for summer propagation conditions, colour map units are dB re 1 µPa$^2$·s.**

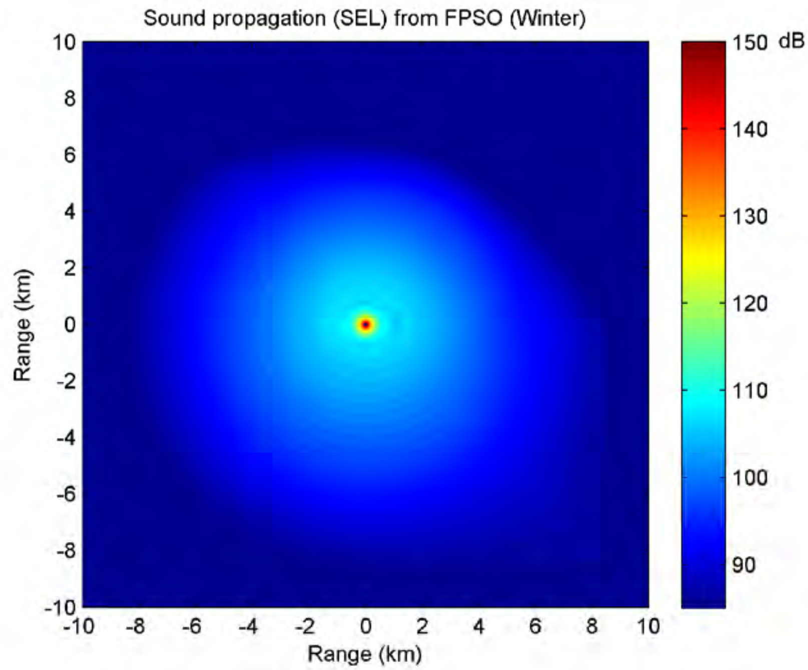


**Figure 5.7 - 25 Hz to 2 kHz broadband SEL received level sound map around the FPSO during normal operation for winter propagation conditions, colour map units are dB re 1 μPa$^2$·s.**

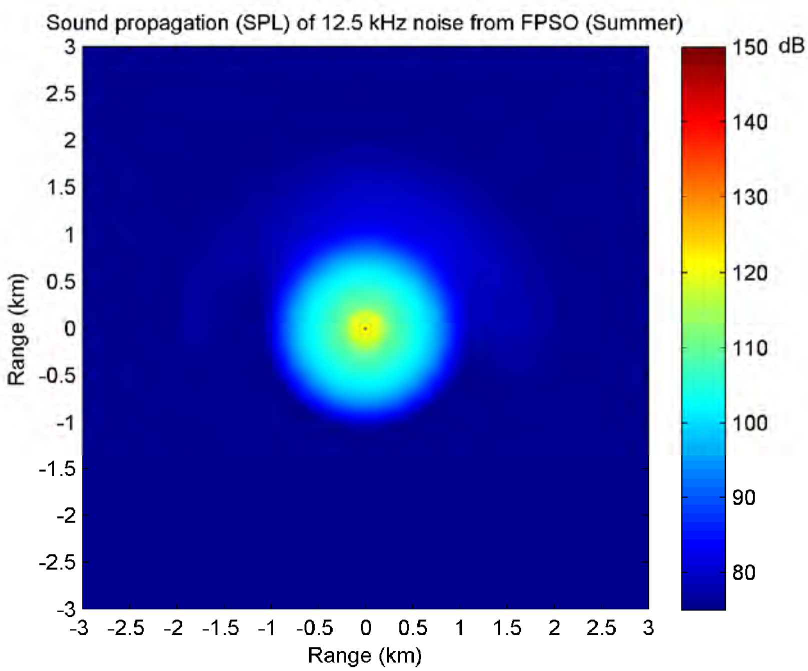


**Figure 5.8 – 12.5 kHz third octave band SPL received level sound map around the FPSO during normal operation for summer propagation conditions, colour map units are dB re 1 μPa.**

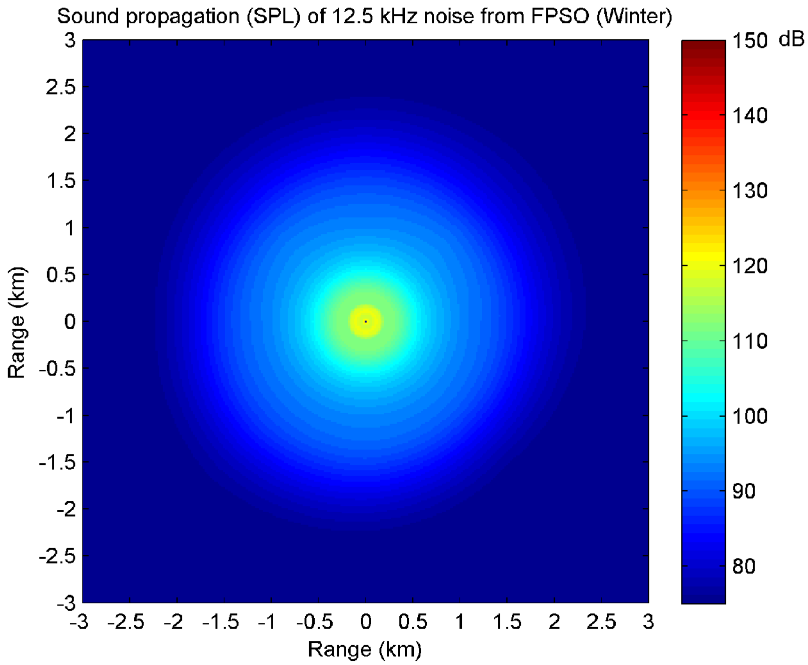


**Figure 5.9 - 12.5 kHz third octave band SPL received level sound map around the FPSO during normal operation for winter propagation conditions, colour map units are dB re 1 µPa.**

*5.2.1.2 Off-load*

The sound map during off-loading has been plotted assuming both a summer and a winter sound speed profile and is shown in Figures 5.10 and 5.11, respectively. These are shown as one second broadband SELs covering the frequency range 400 Hz to 16 kHz. This is substantially broader in frequency range than that used for the FPSO during normal operation due to the off-loading noise being dominated by propeller noise with possible cavitation. As indicted in Figure 5.4, this frequency range includes the majority of the acoustic energy that is radiated during the off-loading operation.

The higher frequency components present in the off-loading noise result in a substantial difference in sound levels near the surface at close range to the off-loading vessel, for the summer and winter conditions, which are not present at greater distances. At ranges of a few kilometres and more, the sound level difference between summer and winter are predicted to be very similar. However at 1 km and closer, the summer conditions result in the sound initially bending away from the surface which does not happen to such an extent during the winter. In the case of the off-loading operation, the winter conditions will result in the larger behavioural disturbance ranges.

Based on the winter propagation sound map, it can be determined that the off-loading operation will radiate noise levels near the surface which should decay to around 110 dB re 1 µPa$^2$·s (SEL) at ranges of approximately 1 km. This would be relatively uniform regardless of the bearing of the FPSO or off-loading vessel as the influences of bathymetry on the sound propagation near the surface only start to have an effect beyond ranges of around 5 to 6 km. As with the FPSO during normal operation the SEL received level can be used interchangeably with the SPL root mean square parameter used in the Marine Mammal Noise Exposure Criteria for low and mid frequency cetaceans exposed to nonpulse sounds (Southall et al., 2007).

The Marine Mammal Noise Exposure Criteria indicates that none of the levels generated during the off-loading operation are sufficiently high to pose an injury risk to marine mammals. The predicted sound levels, shown in Figures 5.10 and 5.11, indicate that behavioural disturbance of marine mammals near the surface may occur within a range of around 1 km of the off-loading vessel. As described in Section 5.2.2.1 for the FPSO during normal operation, odontocetes which routinely dive to forage at depth, such as the sperm whale, may exhibit signs of behavioural disturbance at greater ranges which could results in changes to their diving patterns at ranges up to around 6 km. Non-deep diving cetaceans are much less affected by this propagation phenomenon but may exhibit disturbance behaviour when they dive below the surface at ranges greater than the 0.5 km indicated above, but this is unlikely to have an influence beyond around 2 to 3 km from the off-loading vessel.

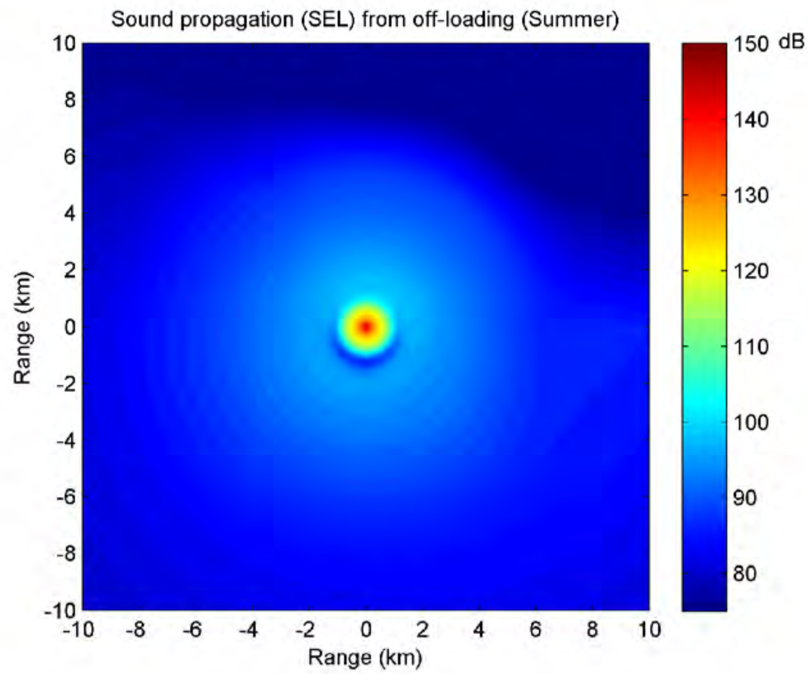


**Figure 5.10- 40 Hz to 16 kHz broadband SEL received level sound map around the off-loading vessel for summer propagation conditions, colour map units are dB re 1 μPa$^2$·s.**

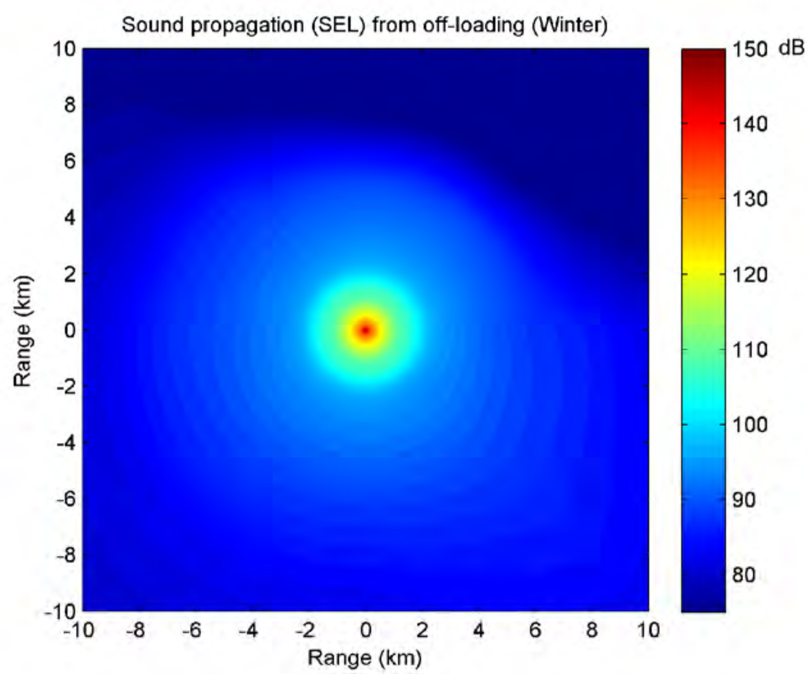


**Figure 5.11- 400 Hz to 16 kHz broadband SEL received level sound map around the off-loading vessel for winter propagation conditions, colour map units are dB re 1 μPa$^2$·s.**

### 5.2.3 Summary of the estimated impact arising from underwater noise from the FPSO

Using the modelled noise levels presented in the previous section and the impact criteria for marine mammals summarised in Section 3, estimates of impact ranges have been derived for the FPSO during normal operation and for the off-loading operation based on a non-dynamically positioned off-load tanker handled with a tug vessel. No internationally agreed criteria exist for fish to assess the impact of noise on them. However, there are indications that the radiated noise level would rapidly decrease within a few hundred metres to levels which are decreasingly likely to cause significant movement of fish away from the FPSO or off-loading vessel and that injury as a result of noise exposure is unlikely for either FPSO during normal operation or off-loading.

Potential impact on marine mammals from the FPSO during normal operation:

i) The noise levels generated by the FPSO during normal operation are unlikely to pose an injury risk to marine mammals likely to be present in the area.

ii) Behavioural disturbance of marine mammals, which are likely to be present in the area, and largely reside near the sea surface may occur within a range of 500 m of the FPSO during normal operation. This range may be farther for cetaceans diving to greater depths.

iii) The deep diving cetaceans, such as the sperm whale, may be experience behavioural disturbance at ranges up 6 km.

Potential impact on marine mammals during off-loading to a tug handled tanker:

i) The noise levels generated during the off-loading operation are unlikely to pose an injury risk to marine mammals likely to be present in the area.

ii) Behavioural disturbance of marine mammals, which are likely to be present in the area, and largely reside near the sea surface may occur within a range of 1 km of the off-loading operation. This range may be farther for cetaceans diving to greater depths.

iii) The deep diving cetaceans, such as the sperm whale, may be experience behavioural disturbance at ranges up 6 km

# 6. Conclusions

Underwater sound measurements were undertaken in the Jubilee Field of the Kwame Nkrumah FPSO during normal operation and off-load to a tanker handled by a tug vessel. This measured data enabled the source level for each activity to be established which was propagated out to produce sound maps of the area surrounding the FPSO. These were used to assess the impact on marine life.

The measured and modelled data indicate that none of the underwater sound levels around the FPSO during normal operation or during off-load are sufficient to pose an injury risk to marine mammals.

The predicted sound levels indicate that behavioural disturbance of marine mammals near the surface may occur within a range of 0.5 km of the FPSO during normal operation and within a range of around 1 km of the off-loading vessel. However, deep diving marine mammals may exhibit behavioural disturbance at larger ranges due to lower acoustic losses at depth compared to the surface. In this case the behavioural disturbance range may extend out to around 5 to 6 km from the source.

Odontocete species that routinely undertake deep water foraging trips, such as the sperm whale, may therefore exhibit signs of behavioural disturbance out to ranges of around 5 to 6 km, which may result in changes to their movements and diving patterns and may thus effect their foraging.

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Annex F

# Drill Cuttings Best Practicable Environmental Option Study

Annex F1

# Main Report: BPEO for the Management of Drilling Discharges from the TEN Project

aquatera
environmental services and products

# Main report: BPEO for the management of drilling discharges from the TEN project

**Report to Tullow Ghana Ltd**

**Issued by Aquatera Ltd**

**P442 July 2012**

www.aquatera.co.uk

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|---|---|---|
| Rev 0 | 24-07-2012 | Draft revised after comments |
| Rev1 | 09-08-2012 | Inclusion of Appendix J to assess single well |
| Rev2 | 21-08-12 | Addressing TGL comments on cuttings drier operations |
| Rev3 | 01-10-12 | Amended to address TGL comments of 17/9/12 |
| Rev4 | 08-10-12 | Amendments in section 7.5.2 to address TGL comments of 5-10-12 |

## Table of Contents

# 1 Introduction

## 1.1 Background to the report

This report and its associated appendices, contained in two volumes, present the findings of a Best Practical Environmental Option (BPEO) study for drilling wastes from the TEN oil development, offshore Ghana. The TEN project is being undertaken by Tullow Oil plc. The BPEO project has been completed by Aquatera Ltd, an international environmental consultancy company based in Scotland, UK, with extensive experience of completing such work.

## 1.2 Hydrocarbon exploration in Ghana

Hydrocarbon exploration in Ghana started as early as 1896, with wells being drilled in the vicinity of Half-Asini as a result of oil seeps found in the onshore Tano Basin, in the Western Region of Ghana. Ghana's offshore oil and gas production began in 1978 with the development of the Saltpond oil field lying 13km offshore.

Over the past eight years, exploration for commercial hydrocarbons in Ghana has intensified with exploration and development of fields in deep water of over 1,000m, with activities undertaken by Tullow, Kosmos, Hess Corporation, Hunt Oil, Afren and Norsk Hydro Oil and Gas among others. Of the greater than 50 exploration wells drilled in Ghana, approximately 75% showed indications of hydrocarbons and ten discoveries have been made. The country currently lists a total of 19 oilfields, gas fields and prospective wells.

## 1.3 About Tullow Ghana

Tullow Oil plc, through its subsidiary, Tullow Ghana Limited, has interests in two exploration blocks in Ghana - Deepwater Tano and West Cape Three Points. Since drilling began in June 2007, with the Mahogany-1 well, over 30 further wells have been drilled, discovering the Jubilee, TEN, Teak, Mahogany and Alaska fields (Figure 1. 1). Tullow is the operator of the Jubilee field, which straddles both blocks, and lies approximately 60 kilometres off the coast of Ghana. 17 wells have been drilled and completed already as part of Jubilee Phase 1, and a further 8 wells are planned for Jubilee Phase 1A. These lie in approx. 1100m water depth.

In March 2009, the Tweneboa-1 exploration well, in the Deep Water Tano licence, 25 km from Jubilee, discovered a light hydrocarbon accumulation. This discovery well was followed up with further exploration, appraisal wells and production testing of the Tweneboa, Enyenra and Ntomme fields, collectively known as TEN Tullow anticipates developing the three accumulations in an integrated subsea cluster development scheme using a single Floating Production and Storage Offshore (FPSO) unit.

The TEN Development Project has made significant progress since the Front End Engineering & Design (FEED) commenced in August 2011. A design competition has commenced with three FPSO contractors and a local project office has been set up in Singapore to support this activity. Subsea FEED is nearing completion and tenders for this work are being prepared.

Tullow expects to submit the TEN Plan of Development (PoD) and a formal declaration of commerciality to the Government of Ghana in the third quarter of 2012. This will incorporate the proposed development plan drawn from the FEED work and the ongoing appraisal programme. The PoD will also include an Environmental Impact Assessment (EIA) of the proposed development, which will include the results of this Best Practicable Environmental Option (BPEO) study. First production from the TEN cluster development is anticipated to be approximately 36 months after government approval of the PoD.

**Figure 1. 1 Tullow Ghana Ltd interests in two exploration blocks in Ghana - Deepwater Tano and West Cape Three Points**

# 2 Best Practicable Environmental Option Process

## 2.1 What is Best Practicable Environmental Option (BPEO)?

The concept of the Best Practicable Environmental Option (BPEO) originates from work in the United Kingdom by the Royal Commission on Environmental Pollution[1]. It is defined as the option that "provides the most benefit or least damage to the environmental as a whole, at an acceptable cost, in the long term as well as the short term". BPEO is not a legal requirement in the UK but it is recognised as a best practice methodology in the UK and across Europe.

## 2.2 Tullow Oil plc requirements for BPEO

In line with Tullow Oil plc, Tullow Ghana Limited aims to conduct its business to the highest industry standards in a way that is ethical, safe and minimises impacts on the environment. Tullow has a long-term perspective to developing the oil business in Ghana in a way that is both profitable and delivers sustainable economic growth into the future.

Tullow Oil PLC has developed internal standards for environmental requirements for new projects, which includes the need to carry out a transparent assessment of the available options through a Best Practicable Environmental Option (BPEO) process:

> *"For all projects, a Best Practicable Environmental Option Assessment (BPEO) shall be carried out during the planning stage of a drilling campaign and continually reviewed to identify the most suitable environmental disposal option based on the waste hierarchy for drilling and completions related discharges"*[2,3] *(See Table 2-1).*

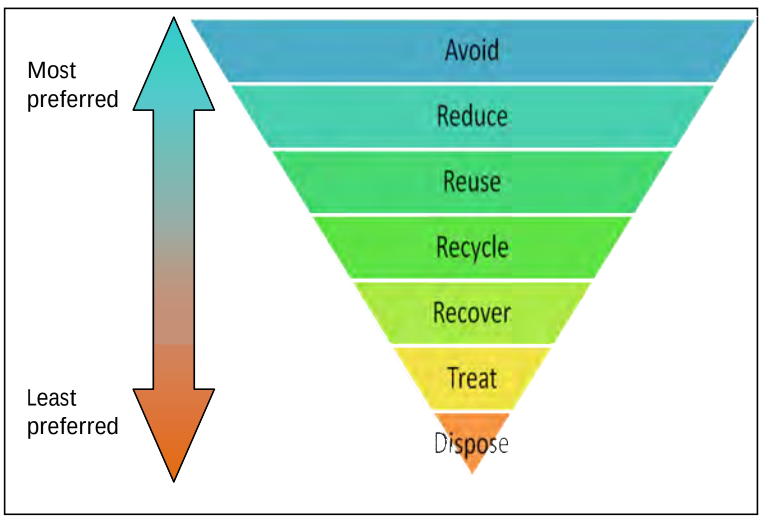


**Table 2-1 Typical waste handling hierarchy**

Tullow Ghana has chosen to commission this BPEO as an independent study to examine all options for handling drill cuttings, compare the advantages and disadvantages of all viable

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[1] Royal Commission on Environmental Pollution, 12th Report (1988). *Best Practicable Environmental Option,* HMSO, London.

[2] Well Engineering : Drill Fluids & Cuttings Disposal Standard (Doc No.: T-WEL-STD-0001)

[3] For information on completing a BPEO refer to the Drill Fluids and Cuttings Disposal Guidelines (T-WEL-GUD-0001)

options and rank the most suitable options in order of preference. The options will be analysed from a number of perspectives including, environmental impact, regulatory requirements, corporate reputation, health & safety and the effects on local economy, infrastructure, culture and jobs.

## 2.3 Objectives of BPEO

The objectives of this BPEO study are to determine the best management practice for handling drilling discharges during Tullow Ghana's TEN drilling campaign.

The aim of BPEO process is to ensure that all relevant issues are taken into account when selecting a preferred option. The BPEO should clearly demonstrate these assessments and the logical pathway towards arriving at a set of recommendations. The cheapest or the best technical option may not necessarily be the most appropriate option to select especially when dealing with sensitive environments and/or endangered species, where there is high potential for public opposition. Likewise there may be circumstances where negative impacts in relation to one or more criteria are tolerated or even accepted due to significant advantages in other criteria..

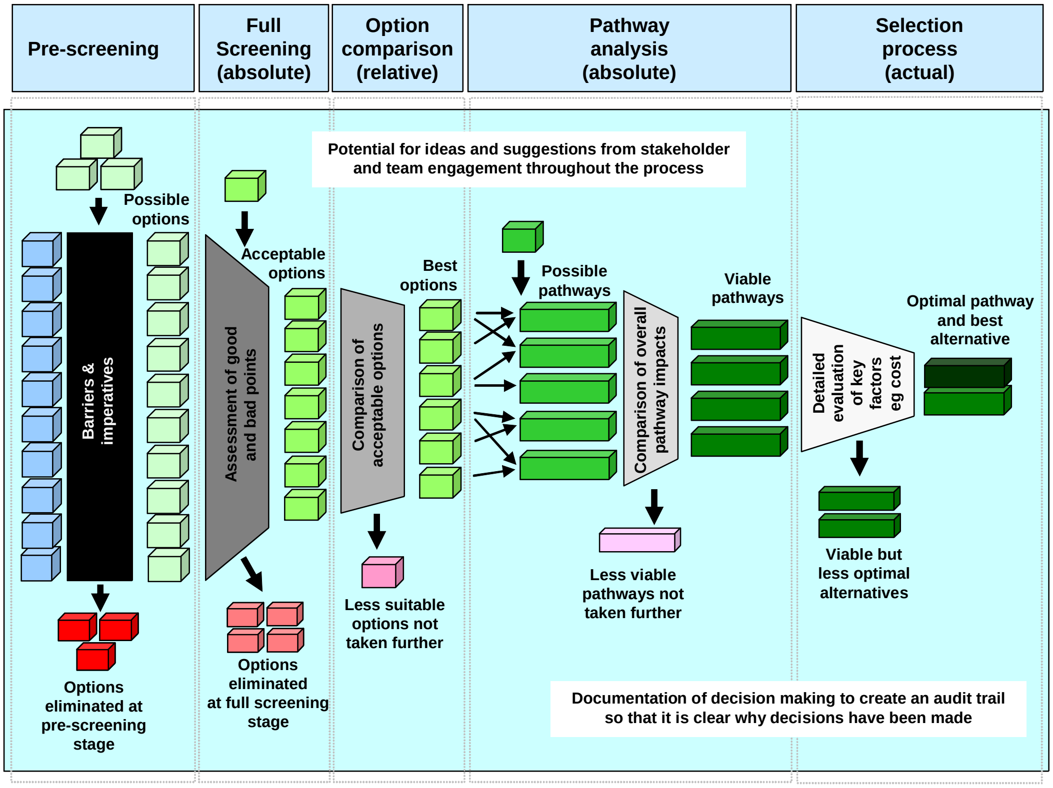
The final selection of the best option will be made by Tullow and then subjected to regulatory approvals. In this way, the BPEO process is comprehensive and provides transparency and accountability in the early decision making process.

## 2.4 Approach taken to completing the BPEO

The BPEO process followed for this study has been established based upon experience gained from a variety of previous projects in various countries and applied to various types of project. It involves the following key activities that are also illustrated in Figure 2-2:

- Identify all possible options throughout the complete drilling process which may impact the quality and quantity of drilling waste created and its handling thereafter through to final disposal;
- Develop and categorise a range of Absolute Assessment Criteria;
- Pre-screen options against these criteria, preferably in consultation with stakeholders, to eliminate any "showstoppers";
- Fully screen the options taken forward using Absolute Assessment Criteria;
- Combine remaining potential options into potential pathways;
- Develop Relative Assessment Criteria, preferably in consultation with stakeholders;
- Review and rank the best options; and
- Recommend the best option(s).

**Figure 2-2 Schematic diagram of the overall BPEO process**




## 2.5 Why is this approach used?

The assessment of the BPEO is designed to be a broad ranging evidence-based process. In essence therefore the priority of BPEO is to be comprehensive rather than deep in its analysis. The evidence that any BPEO process uses can be qualitative or quantitative, measured or judgemental – what is most important is that all evidence and reason used to make a judgement, is referenced and available to the reader. This approach provides a high degree of transparency in relation to how and why a particular conclusion was reached. Although such transparency does not necessarily build universal consensus it does serve to give confidence to all stakeholders that the important issues have been considered equally in any options.

A further aspect is to ensure that there is a strong correlation between the evidence used to make a judgement and the classification of each criteria used. This ensures that the reasoning for a particular judgement can be easily understood. For some issues there may be more than one piece of evidence within particular criteria and these may be cumulative, contradictory, interdependent or independent. Again documenting the various factors relevant to a particular issue and then clearly outlining why a particular classification has been decided upon can help deal with such situations satisfactorily.

Some variance in results is inevitable, whether arising from dissimilar perceptions of stakeholder groups or poor quality cost data. We address this by carrying out a sensitivity analysis to test whether the variation in perception or accuracy of data would actually affect the decision. For instance, in this study additional shipping requirements is a large unknown cost factor and we provide an alternative shipping scenario to see what it would take to make the onshore disposal options cheaper than the offshore options.

## 2.6 BPEO processes and decision making

One final factor to emphasise about BPEO is that it is designed to be a robust exploration of the issues associated with a decision, but not to actually make the decision. The responsibility for decision-making and the accountability for those decisions resides absolutely with the Tullow project management team. A number of decisions influence the final outcome and gate keepers for decision-making within Tullow are presumed to include:

- Tullow Ghana Well Engineering Manager base both in country and in London
- TEN Project Director
- Ghana Development Manager
- Ghana EHS Manager

## 2.7 How does the BPEO fit in with the EIA process?

The Environmental Impact Assessment (EIA) process usually sits alongside the design process and culminates with the production of an Environmental Statement (ES), which is submitted to the relevant authorities as a formal stage in the project permitting process. The ES needs to show:

- alternatives that were identified;
- proposed mitigation measures to reduce the potential impacts;
- a detailed assessment of the selected option that includes;
    - the potential impacts arising from the selected option and;
    - how the project will ensure that these mitigation measures will be adopted.

The BPEO process essentially forms the assessment of alternatives in the overall process. As such it usually takes place earlier in the design process and prior to any specific permitting requirements arising. BPEO in itself is therefore a voluntary process rather than a statutory requirement.

# 3 Sources of information

Various sources of information have informed this BPEO process. The key sources are listed below; within the body of the report text cross-references are made to footnotes for pertinent references throughout the report.

**General information**

Project description

- Project design documents
- Direct communication with Tullow project team specialists
  - Dr Glenn Bestall; Ghana Projects Technical EHS Manager
  - James Gilmour; Senior Drilling Engineer TEN Development project

**Internal BPEO factors**

**Safety**

- OGP publications
- Tullow Well Engineering EHS Incident Records Rev 00

**Technical risk**

- Discharged Oily Cuttings Options and Strategy Report (Tullow Oil document)
- Shale Characterisation and Stability Study (MI Swaco report to Tullow Ghana)
- LDP Cuttings Disposal Options – Risk Assessment (Tullow Uganda Operations document)
- Aquatera team experience
  - Mike Holgate, Reginald Minton, Gill Bishop, Gareth Davies

**Cost data**

- Direct communication with Tullow project team specialists
  - Dr Glenn Bestall; Ghana Projects Technical EHS Manager
  - James Gilmour; Senior Drilling Engineer TEN Development project
- Aquatera team experience
  - Mike Holgate, Reginald Minton

**Policy framework**

- Tullow Oil code of business conduct
- Tullow Oil EHS (Environment, Health and Safety Policy)

**External BPEO factors**

Environmental

- Jubilee Field Phase 1 Environment Impact Statement (ERM report to Tullow Ghana)
- Jubilee Field Drill Cuttings Study (CSA report to Tullow Ghana)
- Aquatera team experience
  - Dave Runciman, Gill Bishop, Gareth Davies

**Economic**

- Direct communication from Tullow project team specialists
  - Glen BestallGhana Projects Technical EHS Manager
  - James Gilmour Senior Drilling Engineer TEN Development project
- Assessment of Waste Treatment and Disposal Options for Priority Waste (ERM report to Tullow Ghana)

**Societal**

- Jubilee Field Phase 1 Environment Impact Statement (ERM report to Tullow Ghana)

**Regulation**

- Drill cuttings and fluid disposal guidelines (Tullow document)
- Jubilee Field Phase 1 Environment Impact Statement (ERM report to Tullow Ghana)

To provide a robust evidence base for the project a list of key questions to Tullow was prepared with a log kept of their replies and sources. A series of comprehensive tables presenting this information are given in the relevant topic based appendices B to I.

In addition to the standard notes and data references there were a number of areas where specialist studies have been carried out previously or where a more detailed analysis was required before conclusions could be drawn. This more expansive information is available in a series of Annexes to this report with the key issues arising presented the relevant Appendix.

The topics covered by these study papers are as follows:

- Waste management options
- Seabed conditions
- Marine mammal recording
- Underwater noise

# 4 Project Description

## 4.1 Introduction

For the purposes of the BPEO process a base case drilling operation needs to be defined. This characterises the aspects of the programme that are fixed and indicates where possible alternatives may be applicable. By establishing this base case the scope of potential options to be screened in Section 5 becomes apparent.

The key stages of the TEN development drilling project are outlined below in Table 4-1.

**Table 4-1 Key stages in the development drilling process which were considered within this project**

| Key project stages | Comments |
|---|---|
| Well Planning | This includes planning the overall drilling programme in terms of well numbers, locations, timing and rigs to be used. This work has already been completed and there is no scope for variation. |
| Top-hole drilling | This is a standard global approach. It involves drilling with sea water and with occasional viscous sweep of mud to clean the hole of drilled cuttings. These materials are discharged to the sea bed at the top of the well as there is no riser or blowout preventer (BOP). At the end of drilling this section the hole is finally filled with thick mud. This allows for safe changing of the bit and installation of the steel casing into the hole. The BOP and riser can then be installed. |
| Bottom-hole drilling | Once the BOP and riser is in place, there is a closed system connecting the well to the rig. With this system in place the mud and cuttings from the lower sections of the well are returned to the rig, where they can be processed. |
| Offshore cuttings treatment | The cuttings are usually cleaned of excess mud and the whole mud and mud removed from the cuttings can be reused. Options for reducing the mud content on cuttings include sieving, centrifugal and thermal separation systems. The cleaned cuttings are then disposed of offshore or contained and shipped ashore. |
| Offshore cuttings disposal | Offshore discharge of cleaned cuttings is via a discharge pipe to below the surface of the sea. After release the cuttings disperse and settle to the seabed. Any residual mud, coating the cuttings, is likely to stay associated with the cuttings. |
| Offshore containment | Storage of cuttings and associated mud in containers before shipment back to shore. |
| Transport to shore | The transfer of containers, if required to a supply vessel and then onward transport back to shore where they are transferred to the quayside by lifting or pumping. |
| Onshore transport | Haulage of cuttings and associated mud from the quayside to the designated treatment or disposal option |
| Onshore cuttings treatment | Measures that reduce the mud associated with cuttings or which bind the mud and cuttings in a more inert state. |
| Onshore cuttings disposal | Approaches which create a final destination for the cuttings. |
| Onshore re-use & recycling | Approaches which take the cuttings and turn them into a useful product. |
| Monitoring | Measuring levels of disturbance or contamination around activity locations. |

The supply lines upstream and downstream of these specific operations have not been considered within the project.

In particular this BPEO study has focussed upon the treatment and disposal of the drilled cuttings. It has not considered the generation and handling of other drill related waste streams not directly linked to the cuttings. For example this study does not consider non aqueous oily: waste arising from:

- interfaces when displacing water based mud with non-aqueous drilling fluids and vice versa
- the drill floor and other sources around the rig
- well testing
- cleaning mud tanks

These wastes which have a high liquid content and may often termed "slops" are handled through a different waste management process.

## 4.2 Drilling programme

The Tweneboa, Enyenra and Ntomme oil fields which make up the TEN development are located in deep water (approximately 1000m – 2000m), about 60km from the nearest coast in western Ghana. The fields lie within the Deepwater Tano licence block, on the edge of Ghana's marine territorial boundary with Cote d'Ivoire; they were discovered by five exploration wells drilled in 2009 and 2010. Three other prospective structures have been identified in the vicinity of the TEN development, while a further prospect and a part of the producing Jubilee field both lie in the eastern sector of Deepwater Tano block some 30 km away.

The planned TEN development currently includes the drilling and completion of 20 wells and completing a further five already drilled[4]. An early diagram depicts a total of 25 planned wells comprising 13 hydrocarbon production wells, 10 water injection and two gas reinjection wells as shown in, Figure 4.1, but this is likely to be superseded by a further document revision. The wells will be connected on the seabed through a series of sub-sea wellheads, manifolds and pipelines to a Floating, Storage and Offloading (FPSO) vessel located on the surface.

## 4.3 Timescales

A total of 20 wells will be drilled and completed with an additional five requiring completion only. For each well, the planned duration for top hole and bottom hole drilling are six days and 29 days respectively, followed by 30 days for running trees and completing (Table 4-2). For the purposes of this study, we have assumed that each well will take a month (30 days) to drill. Drilling is scheduled to start in first quarter 2014 and continue for a three year period until 2017[5].

**Table 4-2 Outline Provisional drilling schedule for the TEN development (data source Tullow; RFI No. 7)**

For the new wells that need to be drilled they will require: tophole drilling (6 days) + bottom hole drilling (29 days) + Run tree & complete for each well (30 days) = total of 65 days

[4] Email from Tullow 23/5/12; RFI NO.8

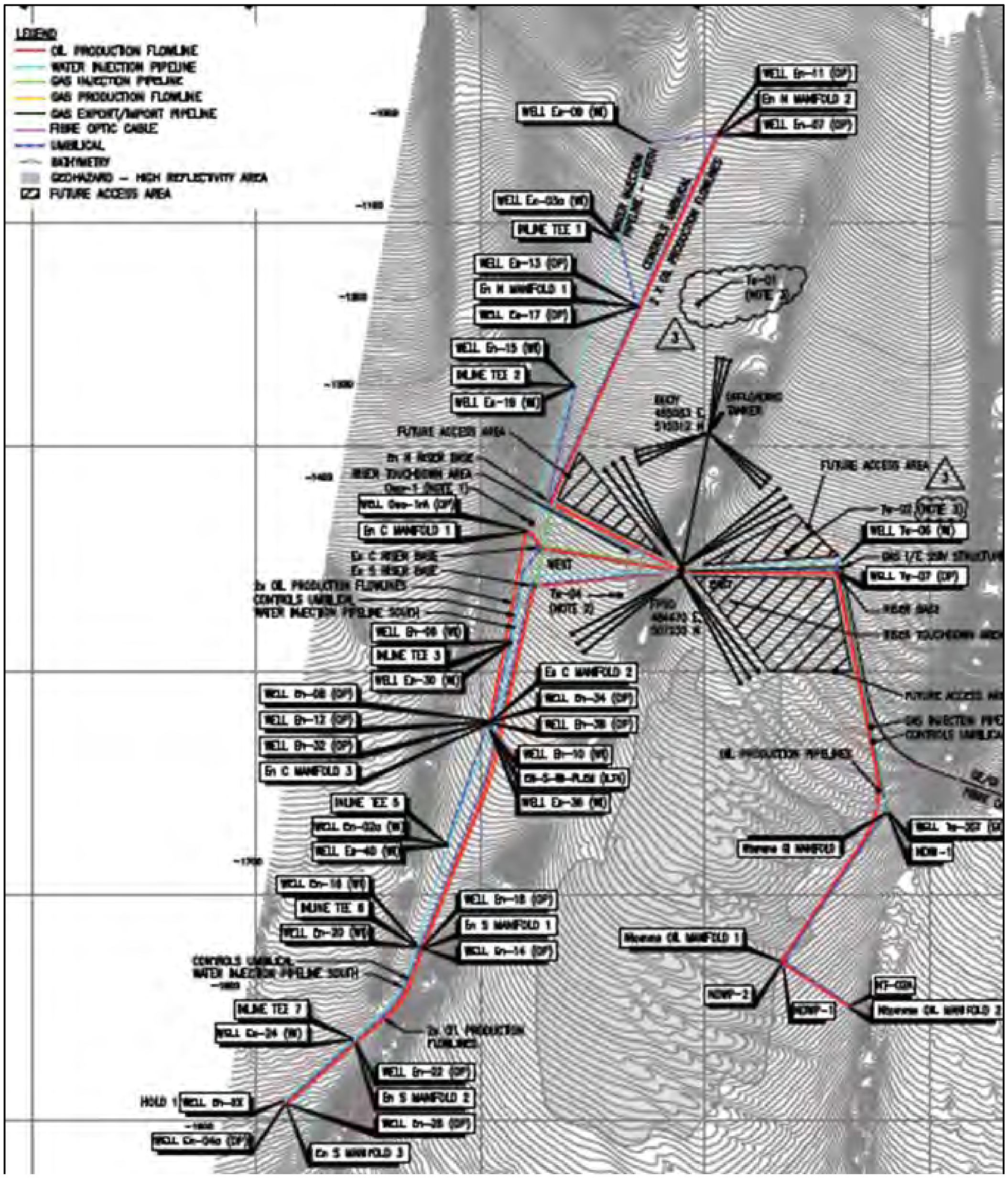
[5] Source Tullow RFI No. 7

| Well Names | Well names | Well Names |
| --- | --- | --- |
| EN E01 Prod A | EN E01 Inj A | EN E02 Prod A |
| EN E01 Prod B | EN E01 Inj B | EN E03/4 Inj A |
| EN E01 Prod C | EN E01 Inj C | NDWP-1 |
| EN E01 Prod D | EN E01 Inj D | NDWP-2 |
| EN E01 Prod E | EN E01 Inj E | NDWI-1 |
| EN E01 Prod F | EN E01 Inj F | Tw 06 |
| | | Tw07 |

For the existing exploration and appraisal wells only final works will be needed: Run tree & complete (30 days) total per well.

| Well Names | Well Names |
| --- | --- |
| Tw-3 ST1 | EN04 A |
| Ntomme-2A | EN02 A |
| Owo-1R | |

**Figure 4-1 Indicative well and infrastructure locations for the TEN development**[6]




[6] **Tullow Oil, T.E.N. field layout Revision 3, 2/5/12**

## 4.4 Drilling Units

Deepwater drilling can be achieved through dynamically positioned drilling rigs or by specialist drilling-ships. Due to the water depths involved at TEN the wells will be drilled using large, modern, dynamically-positioned semi-submersible drilling units. Possible candidate rigs for the works are the Sedco Energy and West Leo.

These rigs are 5th and 6th generation deepwater rigs built in 2001 (Sedco Energy) and 2011 (West Leo); they are designed for deepwater and harsh conditions and fitted with state of the art equipment, which includes Verti-G cuttings driers; there may be sufficient deck space and load capacity for the installation of additional cuttings cleaning equipment if required[7].

## 4.5 Well geology

The geological structure of the TEN development area has been better informed by Tullow's exploration drilling. Figure 4.2 sets out the anticipated geological sequence and the associated drill sections which are outlined in more detail in Appendix C.

This anticipated lithology, or rock sequence, presents a series of drilling challenges which are managed through well profile design, mud selection, the drilling process itself and the monitoring of well conditions during drilling.

## 4.6 Well design

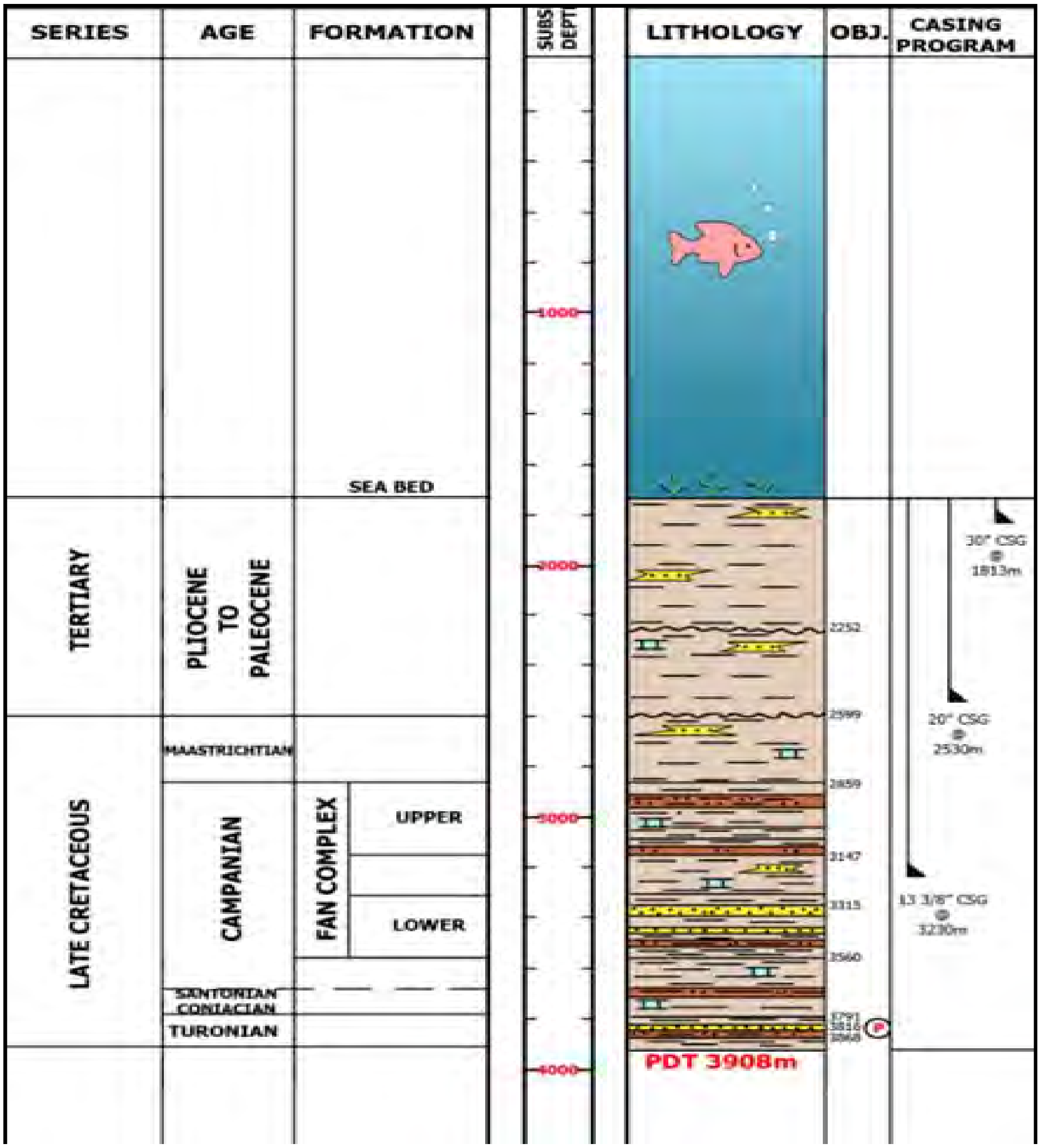
The profile of each well will vary depending upon its function (producer or injector), location, reservoir properties, target depth, offset from vertical and the geology and any anticipated drilling hazards. However for the purposes of the BPEO these differences are unlikely to be significant; therefore a generic well profile (Table 4-3) has been assumed.

**Table 4-3 Generic TEN well profile assumed for this BPEO study**

| Water depth | 1200m |
|---|---|
| 26" hole | Drilled with water based mud (WBM) from 1,200m to 2000m(length 800m) [note: cuttings from 26" hole are not recovered to surface] |
| 16" hole | Drilled with Non Aqueous Drilling Fluid (NADF) from 2,000m to 3,000m (Length 1,000m) [note: cuttings will be recovered to surface since BOP stack now in place for drilling this section] |
| 12¼" hole - | Drilled with Non Aqueous Drilling Fluid (NADF) from 3,000m to 4,500m (Length 1,500m) [note: cuttings will be recovered to surface since BOP stack now in place for drilling this section] |
| Casing sizes | |
| 36" conductor | jetted from 1,200m to 1,280m (80m) |
| 26" hole | 20" casing |
| 16" hole | 13 -3/8" casing, |
| 12¼" hole | 9 -5/8" casing |
| Cuttings generated and cuttings density | |
| 16" | approximately 340 tonnes cuttings (assuming 2.6 SG) |
| 12¼" hole | approximately 300 tonnes cuttings (assuming 2.6 SG) |

[7] Tullow Oil (2012) T.E.N. Development Discharged oil cuttings options and strategy report.

**Figure 4-2 Anticipated rock structure in a typical TEN exploration well**




## 4.7 Drilling Fluid/Mud selection

Drilling mud is pumped from the surface through the hollow drill string, exits through nozzles in the drill bit, and returns to the surface through the annular space between the drill string and the walls of the well. The main purpose of the drilling fluid is to maintain a positive pressure in the well over formation pressure, cool and lubricate the drill bit, remove cuttings and stabilise the well bore.

The 36" and 26" surface sections of the hole are normally drilled with seawater, occasionally pumping slugs of viscous mud around the well to sweep the drilled cuttings out of the hole. At this stage there is no connection between the well head and the rig so the sea water, mud and cuttings are pumped directly into the sea.

The sea water in the well is replaced with viscous mud when the drill string is pulled to run casing. Once the 20" casing has been set, the blowout preventer is installed on the wellhead on the sea bed which is connected to the rig by the riser. This allows the mud to be returned to the surface making a closed loop system which offers much more scope for using more sophisticated muds that can provide greater hole stability.

There are two broad categories of drilling fluids which are used at this stage: Water based fluids/Mud (WBF/WBM) and Non-Aqueous drilling fluids (NADF). WBM has a single water phase with a number of additives such as viscosifiers and shale stabilising agents.

NADF drilling fluids are made up of highly saline water droplets that are emulsified in low toxicity oil. NADFs provide very stable hole conditions with high lubricity for drilling highly deviated wells with less risk of incurring delays arising from borehole instability. The mud selected for the Jubilee field was ESCAID 120 which is a group III[8] NADF (enhanced low toxicity mineral oil). This was selected as it meets the required technical performance characteristics, meets the environmental criteria as a group III NADF and was readily available[9].

## 4.8 Treatment and disposal of drilling muds and cuttings

Drilling wastes can be treated and disposed of in a number of ways. There are typically three possible disposal locations:

- Directly at the seabed
- Discharge to sea from the rig
- Disposal onshore

### *4.8.1 Offshore treatment and disposal of drilling wastes*

There are two basic sources of waste materials, the rock itself and the drilling fluid/mud. These two constituents change depending upon the well section being drilled. For the upper well, the top hole section (26” hole section), the drilling fluids (mainly seawater) and cuttings, which tend to be more granular, are discharged directly onto the surrounding seabed from the drilled hole.

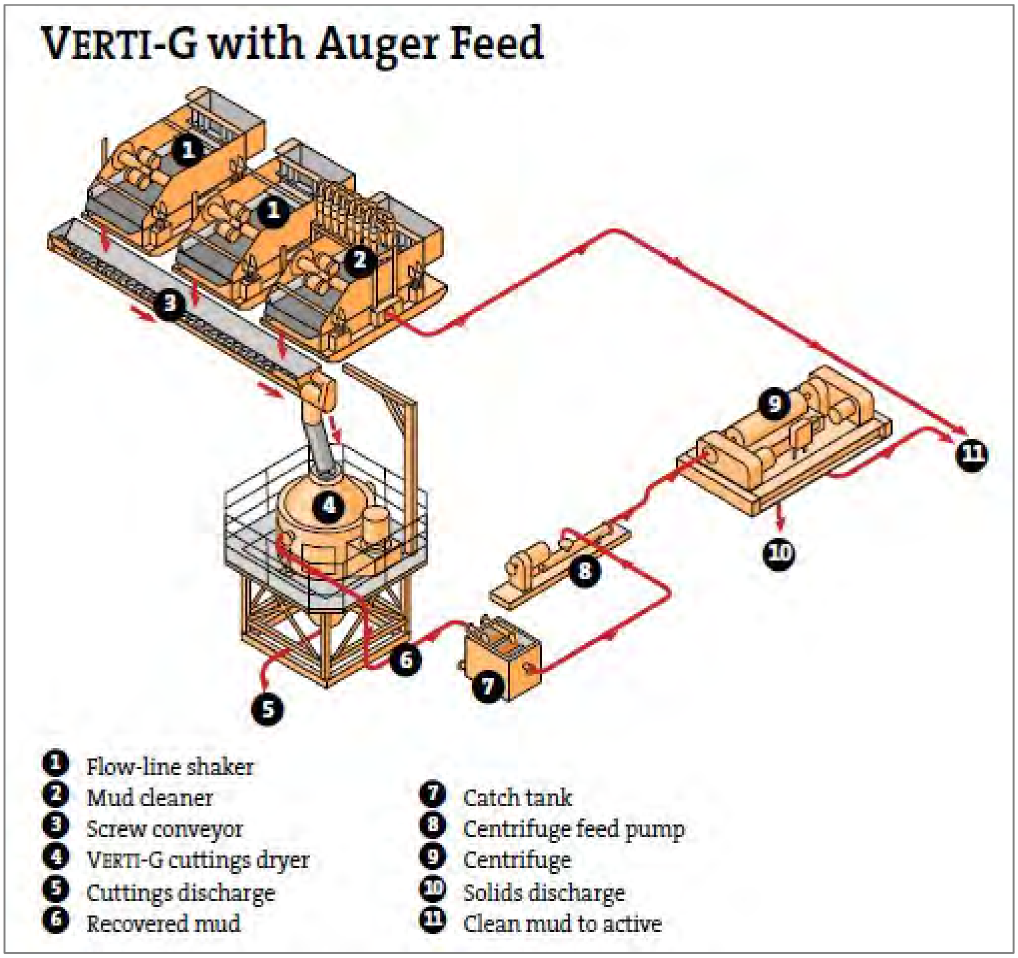
Once the 20” casing is in place and the drilling riser set, the drilling fluid with entrained cuttings can be recovered from the well via the annulus. On the rig, shale shakers form the basic solids control equipment which separate the mud from the cuttings. There is potential for further cuttings treatment to be undertaken at this stage. Centrifugal driers have been used recently in Tullow’s Jubilee field development wells.[10] The cuttings are first dried using a Verti-G cuttings dryer, with cleaned cuttings discharged via a cutting chute at least 15m below the sea surface. The removed mud and suspended fine cuttings are further treated using a centrifuge, the reconditioned mud is then returned to the mud tanks for re-use. The recovered fines, which have been separated from the reconditioned mud are co-mingled with the main drilled cuttings waste stream for disposal via the cuttings chute.

[8] NADF are divided into three groups according to the level of aromatic hydrocarbon content. Group III NADFs have less than 0.5% aromatic content.

[9] Jubilee Field EIA, Annex B

[10] ERM (2009) Ghana Jubilee Field Phase 1 Environmental Impact Statement Appendix B.

**Figure 4-4 Layout of a typical cuttings drying system**




### *4.8.2 Supply links to shore*

Supply boats are used to transport operational materials (bulk fluids, casing materials, chemicals) and waste (hazardous and non-hazardous) between the shore and the rigs. This will include any bulk materials such as drill cuttings destined for onshore treatment and/or disposal. If such a strategy is adopted a method of cuttings storage and transfer to the vessel would need to be established. Most materials transfer takes place through crane lifts for solid materials and containers and by transfer hoses for bulk fluids (liquids and powders). The frequency of supply boat visits varies with operational requirements and inevitably increases if cuttings disposal ashore is practised.

### *4.8.3 Shore side support and disposal of wastes*

Any materials returned to shore need to be securely stored and if appropriate treated and/or disposed of. Waste treatment facilities near to the onshore support base at Takoradi are presently rather limited. A review of waste management options undertaken for Tullow Oil by

ERM[11] found that there are no registered hazardous landfill sites in Ghana, very limited facilities for recycling hazardous waste (including oily sediments and oily solids), no facilities for high temperature incineration of hazardous waste liquid or solid streams. Current Tullow Oil operations in the Jubilee field highlight these issues and a number of other factors which need to be taken into account. The waste management practices and ERM (2010) recommendations for particular hazardous waste streams are outlined in Table 4-4 below:

**Table 4-4 Tullow Hazardous waste streams – management practices and ERM recommendations[12]**

| Waste stream | Current measures/issues | ERM recommendations |
|---|---|---|
| HC residues from vessel clean out activities and sludges which cannot be pumped | Treated at Takoradi thermal power station's oily waste water treatment plant | Engage with waste management companies to facilitate incineration within Ghana; export for incineration in the short term |
| Waste oils | Treated at Takoradi thermal power station's oily waste water treatment plant | Engage with waste management companies to facilitate incineration within Ghana; export for incineration |
| Drums with HC, chemical or paint residues | Oily slops believed to be treated at Takoradi thermal power station's oily waste water treatment plant; steel drums recycled by Western Casings Limited in Ghana. | Engage with waste management companies for facilitate incineration within Ghana; export for incineration recommended |
| Cuttings drier wastes | Used for making bricks for non-construction purposes/ Current end user requirement likely to cease before the end of the project | N/A |
| Dry HC deposits on filters, oily rags, contaminated Personal Protective Equipment (PPE) etc | Stored pending development of appropriate management solution | N/A |
| Produced sand (>1% oil dry wt) | Unknown | Engage with waste management companies to identify any future potential for landfarming, biopiles, or thermal desorption onshore. |

## 4.9 Summary of the base case drilling programme

The base case for the TEN project is therefore for:

- Drilling 20 development wells;
- Completing 25 development wells;
- Drilling to take place 2014 to March 2017;
- Drilling locations spread over the TEN development area;
- Two semi-submersible drilling rigs to be used;
- Top hole materials to be discharged at the seabed;
- Returned cuttings treated with fine mesh shakers and centrifugal drier;
- Separated mud is re-conditioned using a second centrifugal system
- Cleaned cuttings and fines from secondary mud treatment are co-mingled and discharged to sea via a subsurface cuttings chute;
- Supply boats operating from Takoradi on a 2 day cycle basis;

[11] ERM (2010) Assessment of waste treatment and disposal options for priority waste streams;

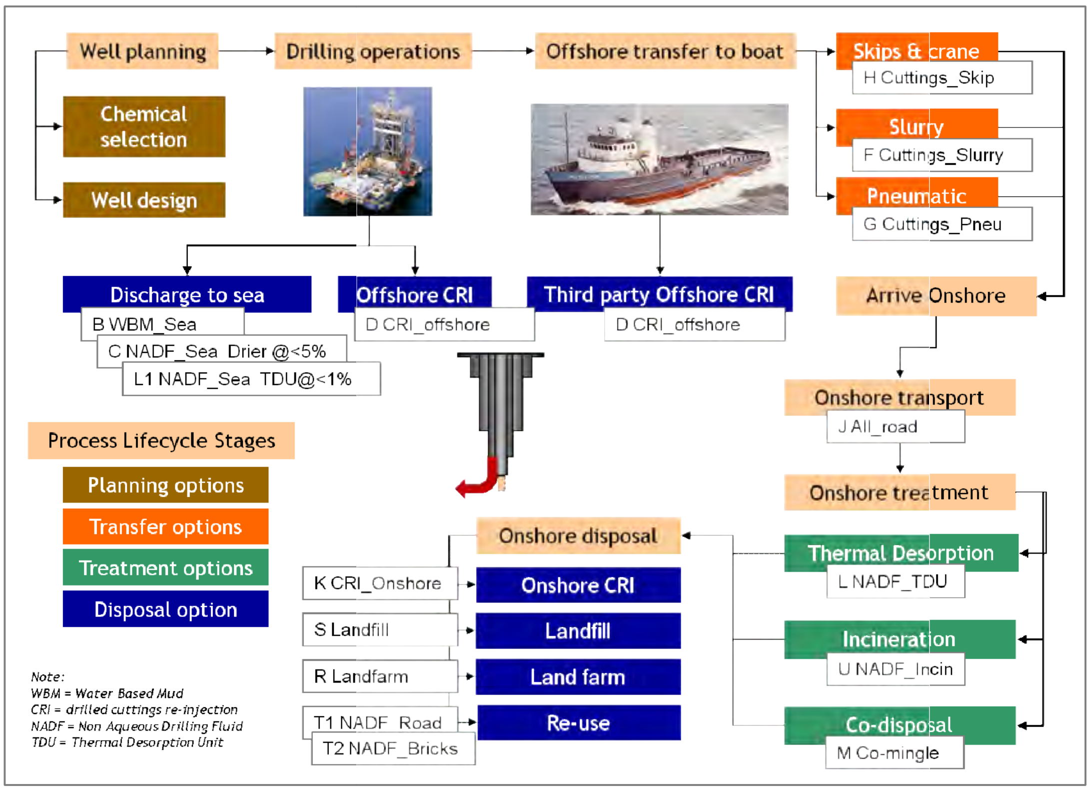
[12] ERM (2010) Assessment of waste treatment and disposal options for priority waste streams

# 5 BPEO phase 1 – option identification

## 5.1 Technical options considered

Drilling waste management begins with well planning and ends with the disposal of residual waste; these and all the interim stages formed part of the option identification process as shown in Figure 5-1. Well planning takes account of both, the design of the well itself, as well as the mud system that is used, and the fluids used for completion and stimulation of the well. The next stage in the lifecycle considers options associated with the drilling rig itself, the support vessels used and the cuttings handling technology used. If the waste is brought back to shore there are a series of logistical steps to get materials from the port to the treatment or disposal site. There are then a set of options for the treatment reuse or ultimate disposal of the wastes. These include both onshore, offshore on-site and offshore off-site options.

**Figure 5-1 Illustration of option identification process**




The options that were initially identified are listed in Table 5.1 and described in more detail in Appendix A.

**Table 5-1 Preliminary options considered in the management of the drilling waste lifecycle**

| PLANNING STAGE | OPTIONS |
|---|---|
| Well Planning | Slim hole options |
| | Rig selection |
| Chemical / Fluid / Mud selection | Water Based Muds (WBM) |
| | Non-Aqueous Drilling Fluids (NADF) |
| Offshore disposal | At seabed |
| | From surface |
| | Simultaneous re-injection |
| | Re-injection off-site at dedicated well owner by 3rd Party |
| | Re-injection off-site at dedicated well owner by Tullow |
| Offshore treatment | Nothing additional to shale shakers |
| | High performance shale shakers |
| | Shakers + cuttings drier |
| | Shakers + cuttings drier + thermal desorption |
| Offshore containment & transfer | Waste skips |
| | Bulk cuttings transfer |
| | Big bags |
| Transport to shore | Supply vessel |
| Onshore transport | Lorry |
| | Rail |
| Onshore treatment | Thermal desorption |
| | Bioremediation |
| | Land farming |
| Onshore disposal | Cutting pit |
| | Onshore cuttings re-injection (CRI) |
| | Incineration |
| Re-use & recycling | Non-structural construction - bricks |
| | Non-structural construction - roads |
| | Landfill cover |

# 6 BPEO stage 2 - Pre-screening of options

During pre-screening each of the options outlined in Section 5 were considered in terms of the base case project requirements outlined at the end of Section 4 and in terms of any foreseeable absolute barriers or imperatives.

Possible barriers could include:

- Safety barriers – excessively high risks of accident or injury
- Technical barriers – significant deterioration over the deliverability of the drilling programme
- Cost barriers – costs or liability levels which compromise the viability of the project
- Regulatory control – explicit banning of options
- Impact barriers – excessive levels of negative impacts

Possible imperatives could include:

- Safety – ways of doing things which are known to avoid high risk occurrences
- Technical imperatives – where industry standard approaches are universally adopted
- Regulatory imperatives – where regulations demand certain actions or approaches
- Impact imperatives – where great benefits can arise or where otherwise certain and severe negative impacts will be avoided

## 6.1 Evaluation of options

The following sub-sections provide justifications for the screening judgements made. They explain why certain options were screened out and why others were screened into the ongoing BPEO evaluation process.

## 6.2 Well Planning

### *6.2.1 Slim-hole Options*

Tullow have drilled several slim-hole wells in Jubilee Phase 1; the slim hole design philosophy completes the well in a relatively large 12¼" hole, to optimise production and minimise the total number of wells that need to be drilled. For the TEN development Tullow have taken the opportunity to reduce the volume of drill cuttings generated[13] by drilling the 13 3/8" casing section with 16" hole in preference to a 17½"; this is then followed by a 12¼" section to complete the well.

### *6.2.2 Rig selection*

The final rig selection has yet to take place. However, all of the rigs being considered are capable of fitting additional cuttings treatment facilities.

## 6.3 Chemical fluid and mud selection

On any drilling operation there is an important choice to be made about the type of drilling mud that is used for bottom hole drilling and its particular formulation. The choice of mud is a decision that has to balance a series of risks, opportunities and costs. A number of exploration and appraisal wells have already been drilled in the TEN development area and

[13] Info from Tullow (RFI No. 8, 34)

therefore the drilling risks and challenges are well understood. On the basis of this experience the Tullow drilling team have chosen a Non Aqueous Drilling Fluid (NADF) as the selected drilling mud. This choice does however give rise to a number of other consequences regards cuttings disposal and discharge standards that need to be met. It was considered appropriate therefore for the BPEO study to consider the overall risks and opportunities associated with the selection of muds to demonstrate the full range of issues that has to be taken into account with both water based mud (WBM) and NADF options for bottom hole drilling.

## 6.4 Offshore Treatment

Shale shakers are designed to separate drilled cuttings from the drilling fluid. High performance shale shakers are able to run very fine mesh screens and are particularly useful with water based muds. With oil based muds there is a disadvantage that the smaller cuttings that are removed have a higher surface area and so the residual oil on cuttings is increased from an average of 9.3% after primary shale shakers to an average of 13.8% from secondary shale shakers according to data from the US Environmental Protection Agency (USEPA)[14]. It is understood that both rigs have high performance shale shakers and so options for this stage in the treatment process are not discussed any further.

However, the Ghanaian regulations require the OOC level to be <3% and further treatment will be required in any case to achieve this standard. The options for this treatment are cuttings driers which operate on a centrifugal separation principle and thermal desorption units which drive off the oil by heat. Both of these options are taken forward in the subsequent analysis.

## 6.5 Offshore disposal

Cuttings reinjection offshore was rejected on technical and high cost grounds. There has been no demand for technology for injection to deep water subsea wellheads and so this is currently unavailable. The high cost of deepwater offshore operations carries a significant likelihood of plugging a well or injection flowlines with cuttings slurry in shallow water operations and the risk of plugging would increase with deepwater flowlines. Loss of a flowline or well would have major consequences in terms of delay, given the operating cost (including deferred oil) of $2 million/day. The cost of drilling a dedicated well (USD 60 million) and associated wellhead and flowlines (USD 40 million) would exceed USD 100 million, without allowing for a risk assessed cost of plugging flowlines or delays arising from designing, constructing and operating an injection wellhead.

The remaining options are therefore related to discharge of cuttings directly to the sea. This can be done above surface, below surface or near the seabed. Given the water depths involved, and the low ambient turbidity of the water subsurface discharge was the only option taken forward.

## 6.6 Offshore containment and transfer

Cuttings can be collected and contained in a number of ways on the drill deck for onward transport ashore via the supply boat. While the options of containment in dedicated skips and tanks and a hybrid system have all been taken forward for further assessment, containment in

[14] Jacques Whitford Stantec Ltd (2009)

big bags has been rejected on technical and safety grounds. The following factors count against the big-bag option: limited weight capacity; the consequent large number of bags required; the integrity of the bags; level of waste and lack of sustainability with 'one use only' bags and the safety implications of numerous crane operations.

## 6.7 Transport to shore

Supply vessels have a 6-8 hour journey from port to the field. Such vessels already regularly supply the rig, but the additional pressures placed upon the service if drilling waste is returned to shore in any quantities may increase the need for vessels, especially when drilling with high penetration rates in the large diameter 17½" hole. Vessels will need good DP station keeping capability in relatively poor weather conditions in order to avoid weather related downtime. This places a restriction on the vessels that may be available at short notice in the spot market, which will in turn have a big influence on cost.

## 6.8 Onshore transport

Road transport has been assumed to be undertaken by trucks. The road system to the port is robust and many trucks are available for spot or contract hire, or purchase.

The use of railways has been discounted on technical grounds. Although the port of Takoradi is served by Ghana's rail system for freight, the county's rail network is not very extensive and the apparent unreliability of the passenger services does not build confidence for smooth running operations. Originally state constructed and renowned in its heyday, the track and rolling stock have become outdated. It is now privately maintained and its current status reflects a long term lack of investment. Both road and rail have benefited from recent new investment (Ghana Ports & Harbours website) and use of the railways may become a viable option in the future if aligned with the destinations where treatment plant and final disposal facilities are available.

**Figure 6.1 Takoradi port, Ghana**

## 6.9 Onshore Treatment

**Thermal desorption** – this process uses heat to drive off the associated oil from the cuttings, then condenses the oil once again so that it can be reused. There are no onshore thermal desorption units in country at present. The big advantage of such treatment is that the material removed from the cuttings by the thermal process can be re-constituted with other mud product. This effectively eliminates the liquid waste stream. The cleaned cuttings are easier to dispose of than un-treated cuttings and the process is less complex than bio-remediation. The disadvantage is the cost and logistics issues and the need for a destination for the dried cuttings – usually produced as a powder after this process.

**Bio-remediation** – there are no established processing facilities of this type in Ghana. A more extensive, low-tech approach is so called landfarming (see later in 6.11).

## 6.10 Onshore disposal

**Cuttings pit** – this is a proven option in all parts of the world for the management of hazardous waste, but no facilities are currently available. The control of the materials within a pit environment is good, but it is more of a storage rather disposal option. The position regarding the ownership of the waste is not clear, but it seems likely that it would follow UK legislation in that the liabilities associated with the waste remains with the waste generator and cannot be passed on to the waste contractor. As such Tullow would retain an open ended liability and responsibility to monitor and maintain the integrity of the cuttings pit. In addition, any new site would need to be permitted. Despite these issues, the proven nature of the option means that this has been taken forward for further evaluation.

**Onshore cuttings re-injection** – this option is technically unavailable to Tullow as the company has no existing or aspirational licences for onshore drilling. With third parties, it is very unlikely that suitable permits for onshore re-injection would be available in time to allow disposal wells to be constructed in time to meet the Tullow development schedule. This option was not taken forward further.

**Incineration** - Oil based mud residues on cuttings have a level of calorific value that makes incineration barely practicable at 3%. Options include co-firing with fuel for power plants, or large scale industrial processes such as cement manufacture. Incineration is a controlled thermal process reaching temperatures of 1000$^o$ Celsius, with clean-up of liquid effluent and stack emissions.

Ghana's power stations include three hydroelectric plants, a diesel plant at Tema and thermal power plants in Takoradi and Aboadze. Oily waste, such as water/waste oil, oily sludge and slop are all acceptable feedstock; waste oil currently recovered from cuttings drying technology on the Jubilee Phase 1 drilling campaign is disposed of via this route. However current development plans for the power plant are for changing feedstock from crude oil/diesel to natural gas which would be imported from Nigeria, and which would effectively eliminate a final re-use/disposal source for these particular Tullow drilling waste products. This option is rejected on grounds of cost and technical uncertainty.

## 6.11 Onshore re-use and recycling

**Non-structural materials** – this involves the binding of sediment rich wastes into stone or sediment based products where structural standards are not critical. Examples of objects that can be produced include kerb stones, security barriers, landscaping features etc. Of the onshore options this is one of the easier methods to establish and some work is already being done with Tullow in the Jubilee area for the waste fines from the offshore centrifugal driers. This option was therefore taken forwards.

**Road construction** – Development of the road infrastructure outside Accra is rudimentary and future development and potential possibilities are currently unknown. Due to residual liability issues this option was rejected at this stage.

**Landfill cover** – again this option has been used in many areas of the world for the disposal of nonhazardous waste. BP has recently conducted tests on the TDU treated cuttings in Azerbaijan which showed that it could be classified as a Non-Hazardous Waste. In their Sustainability report (2010) they state that "About 4,229 tonnes of the treated drill cuttings were used as operational landfill cover at the Tehlukeli Tullantilar LLC non-hazardous landfill site during the year to minimise the potential for wind-blown litter, birds and vermin. Further studies were made on the use of treated cuttings as an infill in quarry restoration. A series of chemical analysis tests was also implemented which confirmed the non-hazardous nature of the ITD-treated drill cuttings".[15] Its application in Ghana is uncertain but it was considered worthy of further consideration.

**Landfarming** – this option has been used in many operating areas; especially the US and Canada. However, it has a significant land take. The cuttings contain up to approximately 1% salt as well as 3% hydrocarbons and the salt content may present problems on land where there are ambient elevated salt levels. In addition, there is an issue in monitoring the degradation of the hydrocarbons and possible liabilities. However, it was considered that there should be good potential for biodegradation with Ghana and this option was evaluated further.

## 6.12 Overview of pre-screening

On the basis of the judgements made above Table 6.1 provides an overview of the pre-screening process. It clearly shows which options are still left in the process and which have been removed from further evaluation. The table also shows the criteria that were used as the main basis for acceptance or rejection at this stage. They demonstrate that the main influencing criteria are internal, namely a mixture of Technical, Health and Safety, Cost and Regulatory factors. Those taken forward to the next stage are discussed in Section 7.

15 http://www.bp.com/liveassets/bp_internet/bp_caspian/bp_caspian_en/STAGING/local_assets/downloads_pdfs/s/BP_sustainability_Report_2010_final_dec_2011.pdf

**Table 6-1 Results of pre-screening for drilling waste handling options**

| Key | Option taken forward | Option rejected | Decision already made or not applicable |
|---|---|---|---|

| Lifecycle phase | Option | Outcome | Key screening criteria | Comments |
|---|---|---|---|---|
| Well Planning | Slim hole options | N/A | Technical | Well profiles are already optimised |
| | Rig selection | N/A | Technical & cost | Rigs have already been selected, they are large enough to take thermal desorption equipment if required |
| Drilling Fluid | Use of water Based Muds | ✓ | Technical | In the right geological conditions and for the right kind of wells WBM can provide the optimal fluids |
| | Use of non-aqueous drilling fluid | ✓ | Technical and cost | in most geological conditions and for most wells NADF can provide an optimal fluid |
| Offshore Treatment | Standard shale shakers | N/A | Technical | Both rigs fitted with high performance shakers so not applicable to this study |
| | High performance shale shakers | N/A | Technical | Both rigs fitted with high performance shakers so not applicable to this study |
| | Cuttings drier | ✓ | Regulation & reputation | Discharge 3-5% mud on cuttings |
| | Thermal desorption | ✓ | Cost, reputation & regulation | Discharge <1% mud on cuttings |
| Offshore disposal | Disposal at seabed onsite | N/A | Technical | Top-hole returns always this route |
| | Disposal near surface | N/A | Technical | Standard practise when risks from cuttings discharge are deemed acceptable |
| | Disposal in deep water | × | Cost and ecology | Helps to reduce impacts in surface waters if critical |
| | Simultaneous re-injection | × | Technical | High cost and technology inadequate for injection to deep water subsea wellheads |
| | Re-injection off-site at 3rd Party well | × | Technical / Cost | No 3rd party wells available |
| | Re-injection off-site at Tullow well | × | Technical / Cost | No existing unused wells available. High cost of drilling a dedicated well |
| Offshore containment & transfer | Skip and ship | ✓ | Cost and safety | Widely used technique |
| | Bulk cuttings transfer | ✓ | Cost and safety | New but successful technique |
| | Hybrid transfer | ✓ | Cost, technical & safety | New but successful technique |
| | Big bags | × | Health and Safety | Additional crane lifts, monitoring & assessing integrity of bags, otherwise one time use of bags only |
| Transport to shore | Supply vessel | ✓ | Cost | Standard approach but costly if more boats are required |
| Onshore transport | Lorry | ✓ | Cost and safety | Standard approach to moving goods around |
| | Rail | × | Technical | Rail system is not very extensive or reliable |
| Onshore treatment | Thermal desorption | ✓ | Cost & technical | Widespread use in sector |
| | Bioremediation | × | Technical | Lack of competent contractor |
| Onshore disposal | Cutting pit | ✓ | Regulation and reputation | Concerns over liabilities |
| | Onshore CRI | × | Technical | No facilities. permitting & schedule risks |
| | Incineration | × | Technical, | Facilities due to be phased out |
| Re-use & recycling | Non-structural bricks | ✓ | Technical & reputation | Concerns over acceptance & liabilities |
| | Non-structural construction - Roads | × | Technical and reputation | Concerns over liabilities |
| | Landfill cover | ✓ | Technical & reputation | Only for TDU cuttings. Concerns over liabilities |
| | Land farming | ✓ | Technical & reputation | Concerns with technical competence and liabilities. |

On the basis of this analysis the following options, in Tables 6.1 and 6.2 were taken forward or rejected.

**Table 6.2 Options taken forward**

| Drill Cuttings Lifecycle phase | Option |
|---|---|
| Bottom hole drilling fluid | Water Based Mud |
| Bottom hole drilling fluid | NADF |
| Offshore treatment | Cuttings drier |
| Offshore treatment | Thermal desorption |
| Offshore disposal | Disposal at sea onsite - WBM |
| Offshore disposal | Disposal at sea onsite - NADF |
| Containment & transport to shore | Bulk Cuttings Transfer using pneumatic or similar system |
| Containment & transport to shore | Skip transfer |
| Containment & transport to shore | Hybrid bulk transfer |
| Onshore transport | Lorry |
| Onshore treatment | Thermal desorption onshore |
| Onshore treatment & disposal | Land farming |
| Onshore disposal | Cutting pit |
| Re-use & recycling | Non-structural construction – Bricks |
| Re-use & recycling | Landfill cover |

**Table 6.3 Options that were not taken forward**

| Lifecycle phase | Option |
|---|---|
| Well Planning | Slim hole options |
| Well Planning | Rig selection |
| Top hole fluids | Water Based Mud, Materials to seabed |
| Top hole materials | Return to surface via flexi riser |
| Offshore Treatment | Standard shale shakers |
| Offshore Treatment | High performance shale shakers |
| Offshore disposal | Simultaneous re-injection |
| Offshore disposal | Re-injection off-site at dedicated well owner by 3rd Party |
| Offshore disposal | Re-injection off-site at dedicated well owner by Tullow |
| Containment & Transport to shore | Big bags |
| Onshore transport | Rail |
| Onshore treatment | Bioremediation |
| Onshore disposal | Onshore CRI |
| Onshore disposal | Incineration |
| Re-use & recycling | Non-structural construction – Roads |

# 7 Full screening of options: Absolute Assessment

## 7.1 Absolute assessment of components

Stage 2 screening ensures that the options taken forward into the comparative phase of the BPEO are practical to implement as well as being generally acceptable in terms of the various evaluation criteria applied in the study. Table 7-1 summarises the scoring assessment and is followed by detailed justifications broken down into the eight screening criteria.

Ideally there might be options presenting no negative effects, which could be taken forward. These could be considered as “no impact” options. Unfortunately none of the options available here falls into this category and therefore the aim must be to select the more optimal options. There are no strict rules for deciding which options to take forward. The focus is necessarily on the highest positive and negative scores. Bearing in mind that the assessment matrix is a log scale and all the criteria (such as reputation, cost etc.) have been designed to have an equal weighting. The -5 and -4 scores provide a good basis for identifying candidates for elimination based on all criteria apart from cost. High positive scores will also suggest definite inclusion of options in the latter stages of the assessment. For reference the absolute assessment criteria are included below in **Table 7-1**, **Table 7-2**, and **Table 7-4**. Further, more detailed analysis is provided in the Appendices B to I.

**Table 7-1 Details of the expanded assessment criteria used within each criteria**

| Criteria | Assessment factors |
|---|---|
| H&S | Accidents – taking account severity and frequency<br>Possible exposure to materials harmful to human health such as dust, vapours etc; taking account of the availability of appropriate mitigation measures.<br>Other occupational health & hygiene issues, manual handling, exposure to chemical etc |
| Technical risk | State of maturity – proven or novel<br>Success rate – ability to meet performance specifications<br>Reliability of technology – breakdown, lifetime<br>Schedule risk – potential delays arising from use of a technology, delivery, installation, permitting, operational delays |
| Cost | Capital – purchase, delivery and installation cost of differential item<br>Operational – operations and maintenance costs of differential item<br>Liabilities – potential exposure to legal or legacy costs<br>Cost risk – quality of cost estimate, risk based costs taking account of likelihood and severity (total cost of a possible event) |
| Reputation | Company policy alignment – is approach in line, or out of line with company policy<br>Media profile – could the issue become a media focus<br>Shareholder perception – is approach seen positively or negatively by government, public or NGOs? |
| Ecological | Deviation from natural variability taking account of:<br>Disturbance - loss or addition of habitat or changes to factors supporting habitat, noise, visual or other effects on species<br>Conservation value – level of protection for species of habitats affected<br>Area affected<br>Toxicity – chemical contamination by toxic materials<br>Persistence – length of time agents will remain in ecosystem<br>Recovery – time taken for habitats and species may adapt and/or re-colonise<br>Cumulative effects of impacts |
| Economic | Local content – proportion of costs spent on jobs & local services/facilities<br>Growth – potential to grow local businesses and supply chain capacity<br>Improvements in infrastructure<br>Inflation, impact on gap between “have’s” and “have not’s”<br>Taxes & royalties – any value to government or agencies from activity |
| Social | Disturbance – noise, visual, smell or other physical nuisance to local population<br>Disruption – changes to access, infrastructure, transport links etc<br>Facilities – changes to the availability, quality of community-based utilities<br>Culture – influences upon local traditions and ways of life |
| Regulation | Compliance – degree of compliance with applicable regulations<br>Local policy alignment – degree of alignment with international standards and best practice<br>Degree of future proofing - against change in regulation within project lifetime<br>Penalties – level of fines etc levied for non-compliance |

**Table 7-2 Absolute assessment matrix - screening of internal factors**

| Topic | Negative | | | | | | Positive | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
| | Severe | Major | Moderate | Minor | Negligible | None | Negligible | Minor | Moderate | Major | Severe |
| Health and safety | One incident with multiple fatalities (>10) or >10 fatal accidents | One incident with multiple fatalities (<10) or up to10 fatal accidents | Single fatality and/or multiple serious injuries / chronic health problems | Associated with serious injury and/or multiple LTI*s. Managed exposure to harmful materials | Risk of LTI*s or minor injuries is similar to normal activities | Basic levels of risk experienced by the public during normal activities | Avoiding LTI* and minor injuries, making things better than normal | Reducing serious injuries & multiple LTI*s below normal risk levels. Reducing existing exposure to harmful materials | Avoids single fatality | Avoids multiple fatality | Avoids number of multiple fatality incident |
| Scale of accidents | Numerous fatalities | Multiple fatalities | Single fatality | Serious injury | Minor injury | No significant injury | Avoiding minor injury | Avoiding serious injury | Avoiding fatality | Avoiding multiple fatality | Avoiding numerous fatalities |
| Likelihood of accidents | Per millennium | Per century | Per decade | Per yr | Number per year | No potential for accidents | Avoids minor injury | Avoids serious injury | Avoids fatality | Avoids multiple fatality | Avoids numerous fatalities |
| Technical risk | Jeopardises project objectives Relies upon blue sky research or design from scratch | Leads to serious risk of lost time and or opportunities Uses novel technology untested in the field | Risk of delays: <10 days / project, <1 days / well New technology with > 3 years field experience, Some flexibility | Risk of delays: <1 days / project, <5 hours / well Emerging technologies, (< 3 years experience), Limited flexibility | Leads to minor delays Less well established technology Could affect flexibility | Normal levels of reliability and flexibility, using established technologies | Enhanced reliability over base case | Shortened duration of <1day per project | Shortened duration of <10days per project | Leads to major time (months) and risk saving on project | Guarantees project success, leads to extreme time saving (years) and risk saving on project |
| Maturity | Never tried before, need development before ready | Ready to use but unproven | Novel and little tested | Proven from limited applications | Tested and proven but unreliable | Tested and proven and reliable | Planned for use locally | Already used locally | Widely used locally | Proven and reliable locally | Particularly suitable to local conditions |
| Performance | None compliant no adaptation potential | None compliance but adaption possible | Varies wildly in relation to standards | Gets close to standards reliably | Generally meets standards | Meets existing local standards | Generally meets standards | Reliable performance near to standards | | | Guaranteed compliance |
| Schedule risk | Decades | Years | Months | Weeks | Lost time risks of days | None | Time scales firmed up over days | Weeks | Months | Years | Decades |

- LTI = Lost time injury

**Table 7-3 Absolute assessment matrix - screening of internal factors (continued)**

| Topic | Negative | | | | | | Positive | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
| | Severe | Major | Moderate | Minor | Negligible | None | Negligible | Minor | Moderate | Major | Severe |
| Cost | Billions | 100 millions | 10 millions | millions | Hundred thousands | Less than 10 thousands | Hundred thousands | Millions | 10 millions | 100 millions | Billions |
| Capital & operational | >100million over project, or 25 MM per well | < $100million over project, or $2.5 MM per well | < $10million over project, or $250,000 per well | < $1million over project, or $25,000 per well | < $100,000 over project, $2,500 per well | No costs or cost savings over base case | Cost reductions from standard costs of <$100k over project | Cost reductions of <$1M over project | Cost reductions of <$10M over project | Cost reductions of <$100M over project | Cost reductions of >$100M over project |
| Liabilities or residual value | Liability of $billions | Liability of $100 millions | Liability of $10 millions | Liability of $millions | Liability of $sub millions | No residual liabilities or values | Residual value of $sub millions | Residual value of $millions | Residual value of $10 millions | Residual value of $100 millions | Residual value of $billions |
| Reputation | International focus | National focus | Regional focus | Local focus. | Individual focus | No reputation issues | Individual focus | Local focus. | Regional focus | National focus. | International focus |
| Publicity | International media | National media | Regional media Sector media | Local media | No media coverage | No issues | No media coverage | Local media | Regional media Sector media | National media | International media |
| Public reaction | Extensive direct action, civil disobedience with broad public support. | Some direct action, significant support base in population | Widespread campaigning & concern by single issue groups. Occasional peaceful protest | Specific concerns or local concerns about specific aspects of development. | An awareness and some concerns in few individuals | No issues | Awareness of possible value but no specific benefits | Awareness of general value but no specific benefits | Widespread agreement of benefits across a number of issues and interests | National recognition of benefits created | International recognition of benefits created |

### Table 7-4 Absolute assessment matrix - screening of external factors

| Topic | Negative | | | | | | Positive | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
| | Severe | Major | Moderate | Minor | Negligible | None | Negligible | Minor | Moderate | Major | Severe |
| Environmental | Total change to ecosystem and no recovery | Major impact. High toxicity or poor recovery potential | Change beyond natural variability but eventual recovery | Similar to natural variability and good recovery potential | Within scope of natural variability | No effects or effects not detectable | Improvements to local ecosystems, but with scope of natural variation | Measurable improvements to local ecosystems, similar to f natural variability which are robust over time | Marked improvement to local ecosystems beyond scope of natural change and which is robust to reversal | improvements to individual ecosystems over a wide area, robust over time | Permanent improvements to overall ecosystems, |
| Change in existing GHG emission levels MT | >1 Million MT $CO_2$ equivalent GHG | <l Million MT $CO_2$ equivalent GHG | <100,000 MT $CO_2$ equivalent GHG | <10,000 MT$CO_2$ equivalent GHG | Increase <1,000 MT $CO_2$ equivalent GHG | No green house gas emissions | Decrease in existing emissions <1,000 MT $CO_2$ | Decrease in <10,000t of $CO_2$ equivalent GHG | Decrease in <100,000t of $CO_2$ equivalent GHG | Decrease in <1 Million MT of $CO_2$ equivalent GHG | Decrease in <10 Million MT of $CO_2$ equivalent GHG |
| Toxicity of materials (LC50) and quantity | Hours over 100km | Days of 10km | Months over 1km | Years over 100m | Decades over 10m | No toxic releases | Averts existing inputs of mild toxicants | Averts existing inputs of slight toxicants | Averts existing inputs of moderate toxicants | Averts existing inputs of major toxicants | Averts existing inputs of severe toxicants |
| Persistence of harmful materials (not inert) | Century | Decade | Year | Month | Day | No harmful materials | Averts existing release with persistence over a day | Averts existing release with persistence over a month | Averts existing release with persistence over a year | Averts existing release with persistence over a decade | Averts existing release with persistence over a century |
| Duration of effect | Negative effect for a century | Negative effect for a decade | Negative effect for a year | Negative effect for a month | Negative effect for a day | No effect | Positive effect for a day | Positive effect for a month | Positive effect for a year | Positive effect for a decade | Positive effect for a century |
| Range of effect | Negative effect over 1000km | Negative effect over 100km | Negative effect over 10km | Negative effect over 1km | Negative effect over 100m | No effect | Positive effect over 100m | Positive effect over 1km | Positive effect over 10km | Positive effect over 100km | Positive effect over 1000km |
| Economic | Loss of– business > $10 MM Inflation ≤1000% | Loss of– business >$1 MM Inflation <100% | Loss of– business >$100,000 Inflation <10% | Loss of– business >$10,00 Inflation <1% | Loss of– business >$1,000 Inflation <0.1% | No change to jobs or business opportunities | Generates business >$1,000 | Generates business >$10,000 | Generates business >$100,000 | Generates business >$1 MM | Generates business ≤$10 MM |
| Jobs | 10,000 | 1000 | 100 | 10 | 1 job lost | No change in jobs | 1 new job | 10 | 100 | 1000 | 10,000 |
| Local content – loss or gain of local income | >$10M | >$1M | >$100k | >$10k | Loss of >$1k | Change less than $1,000 | Gain of >£1k | >$10k | >$100k | >$1M | >$10M |
| Affects on business | Global | International | National | Regional | Local | No effects | Local | Regional | National | International | Global |
| Taxes/royalties | $100M | $10M | $1M | $100k | $10k | No taxes or royalties | $10k | $100k | $1M | $10M | $100M |

**Table 7-5 Absolute assessment matrix - screening of external factors (continued)**

| Topic | Negative | | | | | | Positive | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
| | Severe | Major | Moderate | Minor | Negligible | None | Negligible | Minor | Moderate | Major | Severe |
| Social | Massive social changes, affecting majority of population negatively | Social changes, affecting major part of population negatively | Social changes affecting a minor section of the community negatively | Changes to localised community or limited organisational structures negatively | Changes affecting a few individuals negatively | Effects known but not detectable | Positive changes affecting a few individuals | Positive changes to localised community or limited organisational structures | Positive social changes affecting a minor section of the community | Positive social changes, affecting major part of population | Massive social changes, positively affecting majority of population |
| Nuisance | Regional | Multi- community | Community | Street | Household | No disturbance or benefit | Better conditions for household(s) | Better conditions for streets | Better conditions for community | Better conditions for multi-community | Better conditions for region |
| Facilities | Loss of regional facilities | Loss of multi-community facilities | Loss of community facilities | Loss of street facilities | Loss of household facilities | No change in facilities | Improved household facilities | Improved street facilities | Improved community facilities | Improved multi-community facilities | Improved regional facilities |
| Culture | Lost, no recovery | Poor recovery | Beyond existing change | Similar to existing change | Within existing change | No change to culture | Enhanced or secured within existing range of activities | Enhanced or secured similar to existing range of activities | Enhanced or secured beyond existing range of activities | Long term security of cultural assets | Perpetual security and enhancement of cultural assets |
| Regulation | Regulatory outrage | Unlikely to get approval | Difficulties in gaining approvals | Possible regulatory challenge | Regulatory comment | Match regulations | Noted as good performance | Seen as being proactive, generates goodwill | Welcomed and commented on publically by regulators | Generates active support from regulators | Exemplar for regulators |
| Compliance | In conflict with principles of regulation | Out of line with regulation | Explicitly limited or controlled by regulation | Limited of controlled by spirit of regulations | Noted by regulations but not restricted | Meet current regulations | Noted positively in regulations, but within normal expectations | Specific measures to go beyond regulation | Meets all international guidelines – top quartile performer | Exceeds all regulations | Best in class performance finding new solutions |
| Future proofing | Return to proven problem areas | Return to old rejected standards | Always failing to meet standards | Often not meeting standards | Sometimes not meeting standards | Meet current standards | Sometimes performing better than required | Mostly performing better than required | Always exceeding standards | Some future proofing | Fully future proofed concepts |
| Penalties | $100M | $10M | $1M | $100k | Fine of $10k | None | Dividend of $10k | $100k | $1M | $10M | $100M |

## 7.2 Absolute evaluation of possible options

Based upon the criteria definitions presented above; each option which made it through the pre-screening process was evaluated against each of the BPEO evaluation criteria. Judgements were made, based upon available evidence and, where necessary, experience about the level of BPEO score that is applicable. The detailed justifications for the scores presented here are contained in Appendices B to I as outlined below:

**Listing of topics contained in the Appendices**

| Appendix | Topic |
|---|---|
| Appendix B | Health and safety issues |
| Appendix C | Technical risk issues |
| Appendix D | Cost issues |
| Appendix E | Reputation issues |
| Appendix F | Environmental issues |
| Appendix G | Economic issues |
| Appendix H | Social issues |
| Appendix I | Regulatory issues |

The scores taken into the evaluation are outlined below in Table 7-6. It can be seen that there was a wide range of scores allocated including positive and negative aspects. It should be noted that no -5 or +5 scores were awarded and this is to be expected since any scores at this level should have triggered the pre-screening process completed earlier. Any unacceptable options have been left out and if an option had been judged as imperative then that option would have been taken forward.

There are certain patterns that can be discerned from the summary results:

- There are a number of the offshore options that have little or no interaction with the onshore sensitivities
- Onshore activities generally have more interactions than offshore activities
- Onshore options generally interact with all onshore sensitivities except ecological issues, due to the predominant use of urban and brownfield sites for activities
- The key benefits are economic and to a lesser extent social
- The key negative aspects relate to cost, technical, reputation and regulatory issues

**Table 7-6 Summary of absolute assessment scores**

| Key | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extreme negative | Major negative | Moderate negative | Minor negative | Negligible negative | Neutral | Negligible positive | Minor positive | Moderate positive | Major positive | Extreme positive |

| Drill Cuttings Lifecycle phase | Option | HS | Technical | Cost | Reputation | Ecological | Economic | Societal | Regulatory |
|---|---|---|---|---|---|---|---|---|---|
| Bottom hole drilling fluid | Water Based Mud (WBM) | -2 | -4 | -3 | +1 | -1 | +2 | 0 | 0 |
| Bottom hole drilling fluid | Non aqueous drilling fluid (NADF) | -2 | 0 | -3 | -1 | -2 | +3 | 0 | 0 |
| | | | | | | | | | |
| Offshore Treatment | Cuttings drier | -2 | -1 | -2 | 0 | -1 | +2 | 0 | 0 |
| Offshore Treatment | Thermal desorption | -2 | -2 | -4 | +3 | -2 | +3 | 0 | 0 |
| | | | | | | | | | |
| Offshore disposal | Disposal at sea onsite - WBM | 0 | 0 | -1 | -2 | -2 | 0 | 0 | +1 |
| Offshore disposal | Disposal at sea onsite - NADF 3% | 0 | -2 | -2 | -3 | -3 | +2 | 0 | -3 |
| Offshore disposal | Disposal at sea onsite - NADF 1% | 0 | -1 | 0 | -2 | -1 | +1 | 0 | -1 |
| | | | | | | | | | |
| Containment | Bulk transfer & transport | -1 | -1 | -4 | -1 | -3 | +3 | -1 | 0 |
| Containment | Hybrid & transport | -2 | -1 | -4 | -1 | -3 | +3 | -1 | 0 |
| Containment | Skip and ship & transport | -3 | -3 | -4 | -2 | -3 | +3 | -1 | 0 |
| | | | | | | | | | |
| Onshore transport | Lorry – for Skip & ship | -2 | 0 | -3 | -1 | -1 | +3 | -2 | 0 |
| | | | | | | | | | |
| Onshore treatment | Thermal desorption | -1 | -2 | -3 | 0 | -1 | +3 | -2 | -1 |
| Onshore disposal | Cutting pit | -1 | -3 | -3 | -2 | -4 | +3 | 0 | -3 |
| Re-use & recycling | NSCM – Bricks from skip & ship ops | -1 | -2 | -3 | +1 | -2 | +3 | +1 | -1 |
| Re-use & recycling | Landfill cover | -1 | -3 | -2 | 0 | 0 | +2 | -2 | -3 |
| Re-use & recycling | Land farming | -1 | -3 | -4 | -2 | -3 | +3 | -3 | -3 |

## 7.3 Absolute assessment of treatment and disposal pathways

The next stage of the absolute assessment process involves revisiting the individual options that appear acceptable and combining them into fully functional cuttings handling pathways. In this way the implications of every stage in the process from materials selection to ultimate re-use, or disposal can be taken into account. At this stage further consideration is also given to where the key decision points are for each pathway, as well as the quality and preciseness of the information upon which judgements have been made. This helps to substantiate the suitability and accuracy of the data underpinning the selection process. This process may also indicate where further work or discussion needs to focus, in order to firm up on recommendations, or alternatively it may suggest that sufficient information is already available in order to come to a robust decision on the optimal way forward. The results of this process are shown in Table 7-7

**Table 7-7 Summary of treatment & disposal pathways taken forward**

| Pathway | Drilling Fluid | Transport | Disposal |
|---|---|---|---|
| A | WBM throughout well | - | Discharge at sea on-site |
| B | NADF bottom hole | - | Discharge at sea on-site |
| C | NADF bottom hole | Bulk cuttings containment & ship | 5 Onshore options |
| D | NADF bottom hole | Skip and ship | 5 Onshore options |
| E | NADF bottom hole | Hybrid (hose and ship) | 5 Onshore options |

Using the scoring from the absolute assessment results presented above, the integrated pathways are now evaluated individually, then comparatively.

## 7.4 Evaluation of integrated pathways

### *7.4.1 Offshore disposal options*

**Pathway A – WBM well with offshore disposal**

| Drill Cuttings Lifecycle phase | Option | HS | Technical | Cost | Reputation | Ecological | Economic | Societal | Regulatory |
|---|---|---|---|---|---|---|---|---|---|
| Bottom hole drilling fluid | Water Based Mud | -2 | -4 | -3 | +1 | -1 | +2 | 0 | 0 |
| Offshore disposal | Disposal at sea onsite - WBM | 0 | 0 | -1 | -2 | -2 | 0 | 0 | +1 |

| Performance | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 1 | 3 | 2 | 6 | 2 | 1 | 0 | 0 | 0 |

**Pathway B1 – NADF well with cuttings drying and offshore disposal;**

| Drill Cuttings Lifecycle phase | Option | HS | Technical | Cost | Reputation | Ecological | Economic | Societal | Regulatory |
|---|---|---|---|---|---|---|---|---|---|
| Bottom hole drilling fluid | NADF | -2 | 0 | -3 | -1 | -2 | +3 | 0 | 0 |
| Offshore Treatment | Cuttings drier | -2 | -1 | -2 | 0 | -1 | +2 | 0 | 0 |
| Offshore disposal | Disposal at sea onsite - NADF 3% | 0 | -2 | -2 | -3 | -3 | +2 | 0 | -3 |

| Performance | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0 | 4 | 6 | 3 | 8 | 0 | 2 | 1 | 0 | 0 |

**Pathway B2 – NADF well with thermal desorption and offshore disposal**

| Drill Cuttings Lifecycle phase | Option | HS | Technical | Cost | Reputation | Ecological | Economic | Societal | Regulatory |
|---|---|---|---|---|---|---|---|---|---|
| Bottom hole drilling fluid | NADF | -2 | 0 | -3 | -1 | -2 | +3 | 0 | 0 |
| Offshore Treatment | Thermal desorption | -2 | -2 | -4 | +3 | -2 | +3 | 0 | 0 |
| Offshore disposal | Disposal at sea onsite - NADF >1% | 0 | -1 | 0 | -2 | -1 | +1 | 0 | -1 |

| Performance | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 1 | 6 | 4 | 8 | 1 | 0 | 3 | 0 | 0 |

### *7.4.2 Onshore pathway options*

For the onshore pathways the best offshore containment and onshore disposal options were selected first. This was achieved by ranking the options as shown below:

**Offshore containment and transport options**

| Drill Cuttings Lifecycle phase | Option | HS | Technical | Cost | Reputation | Ecological | Economic | Societal | Regulatory |
|---|---|---|---|---|---|---|---|---|---|
| Containment | Bulk transfer & transport | -1 | -1 | -4 | -1 | -3 | +3 | -1 | 0 |
| Containment | Hybrid transport | -2 | -1 | -4 | -1 | -3 | +3 | -1 | 0 |
| Containment | Skip and ship & transport | -3 | -3 | -4 | -2 | -4 | +3 | -1 | 0 |

Looking at the cuttings handling issues, without taking account of the air emissions from the additional supply vessels, it can be seen that there is little to choose between the bulk handling system and the hybrid system, the bulk system was, however, used for the further pathway assessment, due to its overall better performance. Taking the containment and shipping of the cuttings as a whole, the air emissions from the supply vessels are the major contributor to the environmental impact. Much will depend upon the options available to exploit the spot market, but taking the TGL premise that the project would need dedicated supply vessels, the additional emissions would be of the order of 90,000 MT of $CO_2$, which ranks as being on the high side of a moderate impact (-3).

**Onshore treatment and disposal options**

| Drill Cuttings Lifecycle phase | Option | HS | Technical | Cost | Reputation | Ecological | Economic | Societal | Regulatory |
|---|---|---|---|---|---|---|---|---|---|
| Re-use & recycling | Non-structural construction - Bricks | -1 | -2 | -3 | +1 | -2 | +3 | +1 | -1 |
| Onshore treatment | Thermal desorption | -1 | -2 | -3 | 0 | -2 | +3 | -2 | -1 |
| Re-use & recycling | Landfill cover | -1 | -3 | -2 | 0 | 0 | +2 | -2 | -3 |
| Onshore disposal | Cutting pit | -1 | -3 | -3 | -2 | -4 | +3 | 0 | -3 |
| Re-use & recycling | Land farming | -1 | -3 | -4 | -2 | -3 | +3 | -3 | -3 |

It can be seen from this quick assessment that the option of mixing drilling wastes into non-structural building materials provided the best of the onshore options as it provides an opportunity to produce something of value from the waste like paving stones or kerbstones. Landfarming is a possibility but the salt content is a potential issue as well as the time and supervision required to ensure a responsible outcome. There are also potential legacy and liability issues. Disposal via a cuttings pit is not attractive as it presents substantial legacy and liability issues through storing the waste rather than finding an final disposal route.

Having established that the stabilisation/non-structural building materials (NSBM) option was the best onshore treatment and disposal option, it was then combined with the best containment and transport options needed to bring the materials ashore, to give an overall pathway performance evaluation.

**Pathway C1 – Onshore disposal of NADF for use as Non Structural Building Material (NSBM)**

| Drill Cuttings Lifecycle phase | Option | HS | Technical | Cost | Reputation | Ecological | Economic | Societal | Regulatory |
|---|---|---|---|---|---|---|---|---|---|
| Bottom hole drilling fluid | NADF | -2 | 0 | -3 | -1 | -2 | +3 | 0 | 0 |
| Offshore Treatment | Cuttings drier | -2 | -1 | -2 | 0 | -1 | +2 | 0 | 0 |
| Containment | Bulk transfer & transport | -1 | -1 | -4 | -1 | -3 | +3 | -1 | 0 |
| Onshore transport | Lorry | -2 | 0 | -3 | -1 | -1 | +3 | -2 | 0 |
| Re-use & recycling | Non-structural construction - Bricks | -1 | -2 | -3 | +1 | -2 | +3 | +1 | -1 |

| Performance | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 4 | 8 | 11 | 9 | 2 | 1 | 4 | 0 | 0 |

## 7.5 Comparison of options

### *7.5.1 Numerical comparison*

Having evaluated the options the final part of this stage in the process is to compare the options against each other. This can be achieved visually or through the application of a simple scoring system where orders of magnitude points are given corresponding to the score awarded (e.g. 3 scores of -3 = 3,000; 2 scores of +2 = 200; 1 score of -1 = -10). The latter approach is shown below, followed by the visual approach overleaf:

**Pathway A – WBM with offshore disposal**

| Performance | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|
| | 1 | 1 | 3 | 2 | 6 | 2 | 1 | 0 |

| Total –ve points | Total +ve points | Total scoring cells |
|---|---|---|
| 11,320 | 120 | 16 |

**Pathway B1 – NADF with cuttings drying only and offshore disposal**

| Performance | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|
| | 0 | 4 | 6 | 3 | 8 | 0 | 2 | 1 |

| Total –ve points | Total +ve points | Total scoring cells |
|---|---|---|
| 4,630 | 1,200 | 24 |

**Pathway B2 – NADF with thermal desorption and offshore disposal**

| Performance | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|
| | 1 | 1 | 6 | 4 | 8 | 1 | 0 | 3 |

| Total –ve points | Total +ve points | Total scoring cells |
|---|---|---|
| 11,640 | 3,010 | 24 |

**Pathway C1 – NADF, shipping to shore with onshore disposal as NSBM**

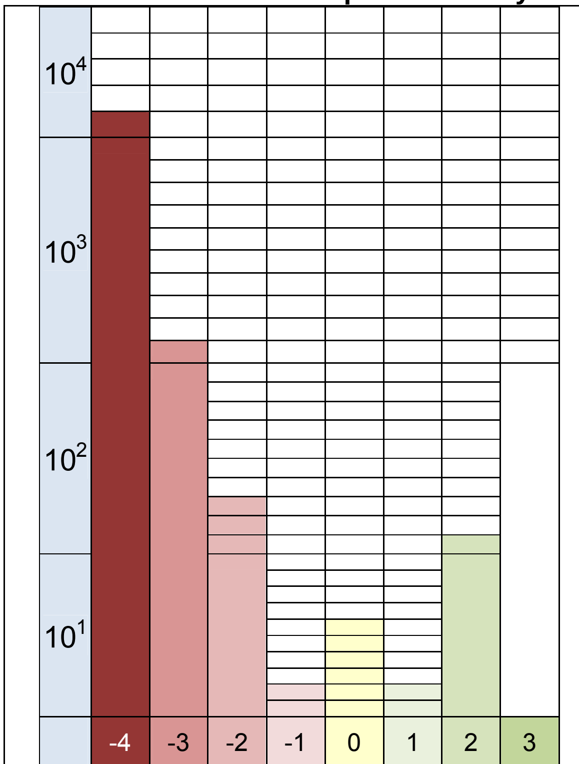
| Performance | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|
| | 1 | 4 | 8 | 11 | 9 | 2 | 1 | 4 |

| Total –ve points | Total +ve points | Total scoring cells |
|---|---|---|
| 14,910 | 4,120 | 40 |

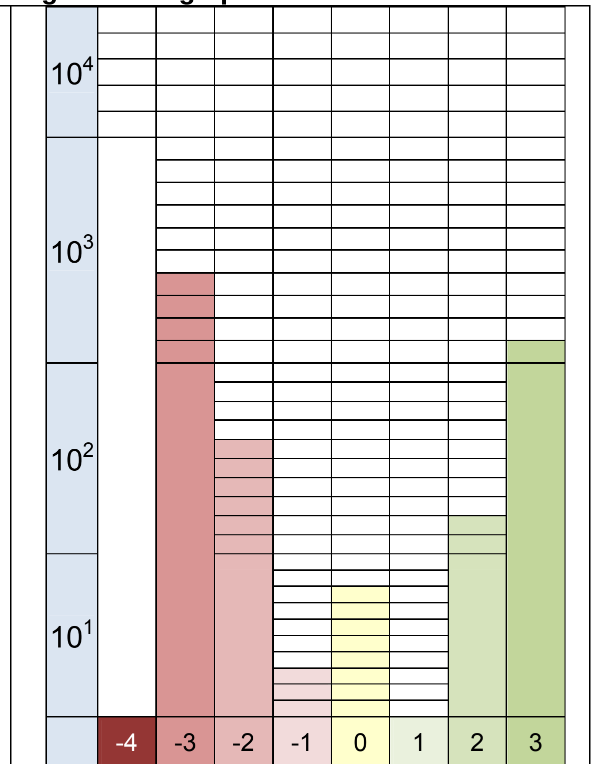
### *7.5.2 Visual comparison of scores*

The following set of tables provides a visual or “dashboard” analysis, showing the distribution of the number of occurrences. Again it is important to bear in mind that a score of 4 is 10 times greater than a score of 3 and 100x greater than a score of 2.

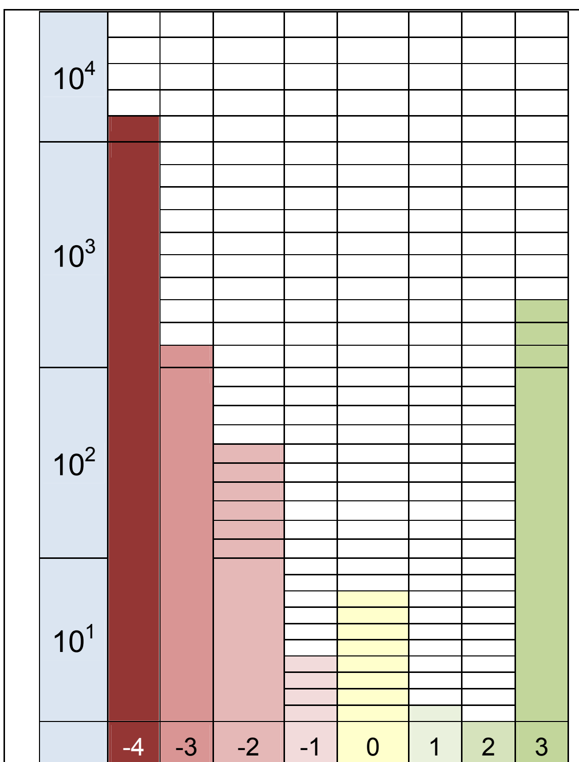
**Table 7-8 Visual comparison of key cuttings handling options**



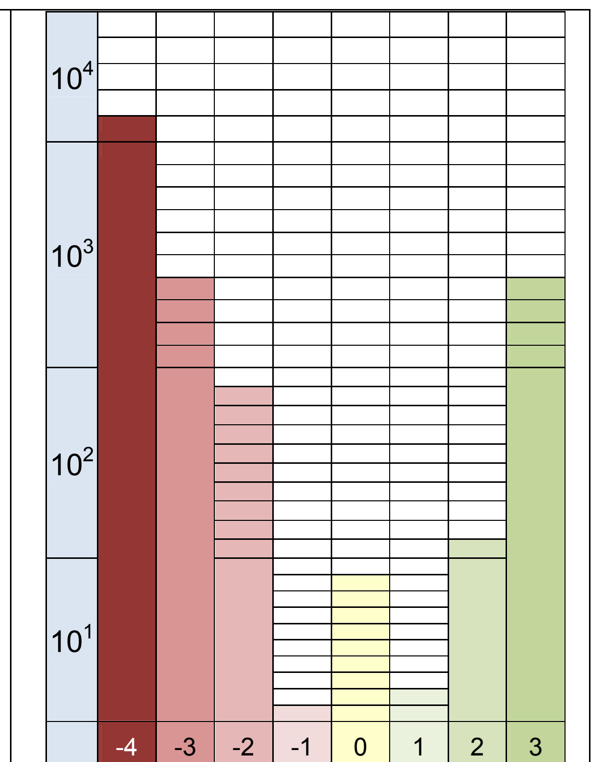

Pathway A1- Use & offshore disposal of WBM




Pathway B1 - Use & offshore disposal of NADF @ 3-5%




Pathway B2 - Use & offshore disposal of NADF @ 1%




Pathway C1 - Use of NADF with onshore treatment & disposal

**Negative scores**

It can be seen from this comparison that the current practice of disposal of NADF offshore after centrifugal drying has the lowest overall score. However, it does have a number of significant impacts associated with it – indicated by the four issues scored at -3 (cost, reputation, environment and regulatory). The option with the next best negative score is B2 (using a TDU offshore) which has a single -3 score and a single -4 score, both of which are cost related.

If the extra cost for the thermal desorption unit in the B2 and C1 options are accepted by Tullow, then pathway B2 with offshore disposal becomes the optimal approach. What is also apparent is that there are far more impacts and issues associated with the onshore treatment and disposal option than for the offshore options. This reflects the multiple locations affected by bringing materials to shore and the high air emissions from having additional dedicated supply vessels (90,000 MT $CO_2$). Although the 3,000 MT of $CO_2$ from the TDU are six times higher than the driers, they are still relatively low and rank as having a minor impact.

**Positive scores**

The offshore thermal treatment pathway B2 and the onshore pathway C1 give the most significant benefits, reflecting the policy and regulatory benefits of the former, and the more intense economic benefits of the latter.

### *7.5.3 Screening of pathways options by absolute assessment*

**WBM bottom hole drilling – shakers – discharge at sea on-site**

This option is characterised by risk and uncertainty. The root cause of the uncertainty is the lack of information that is available from offset wells in the area that have been drilled with WBM. The limited evidence from the shale analysis and geology indicate that drilling exploration wells with WBM are probably technically feasible. However there is a high likelihood of incurring some additional Non Productive Time (NPT) during routine operations, with reasonable likelihood of incurring more serious and expensive delays from an unplanned event like sticking the pipe or casing in the hole. The only way that this level of uncertainty can be reduced is to get direct evidence by drilling a well with WBM. Given that the cost of delays for production wells is always going to be much higher than for exploration wells due to the associated cost of deferred oil; along with the tendency to greater complexity, the best opportunity for trialling WBM would be in an exploration well.

When planning a 20 well drilling program for production, the risk profile is therefore very biased towards incurring very high additional costs through unplanned events. Aquatera estimates of costs arising from delays have been cautious, adding one additional bit trip in 50% of the wells for routine operations and allowing to have a side track in one of the 19 planned wells. Even this level of risk incurs additional risk assessed costs of over $60 million. These costs could easily get much higher but are unlikely to be much lower than the $15-20 million cost of continuing to use NADF and installing a TDU offshore. In view of the current level of uncertainty, the WBM risk profile and the need to plan with confidence:

***This option was not therefore taken forward for relative assessment***

**NADF bottom hole drilling – shaker and cuttings drier – discharge at sea on-site**

This process is assumed to yield cuttings with 3% OOC as currently attained at Jubilee. The combined hydrocarbon content of the dried cuttings centrifuge fines routinely meets Tullow's 3% OOC goal (checked by retort analysis), which enables it to be diverted into the cuttings drier overboard discharge route[16]. The co-mingling of wastes always provides greater opportunities for one waste stream to upset the standards reached overall with another. In this case the volume and size of the fines generated in any well may have an effect upon the level of associated mud that is changed. It is foreseeable that the separated fines could lead to overall discharge standards being exceeded. There is a surcharge mechanism in place, in Ghana, to deal with this situation should it arise. There is therefore an additional level of regulatory and reputational risk with this option[17].

***This option is used as the base case for the relative assessment***

**NADF bottom hole drilling – shaker and thermal desorption unit – discharge at sea on-site**

This process yields a cuttings product which is normally virtually hydrocarbon free with less than 1% oil on cuttings (normally around 0.1%), 1% salt (Calcium Chloride) and with the cuttings reduced to a fine powder. The discharge of low levels of salt into the marine environment is much better than disposal on land, whilst the reduction of the cuttings to a fine powder will facilitate good dispersion in the water column and reduce seabed impacts compared to previous drilling activities.

***This option was therefore compared against the base case in the relative assessment***

**Bulk containment (e.g. HCB tanks)**

This containment system scores a high negative (-3) on cost and is considered to be a long term CAPEX investment in process. It would seem that very similar H&S gains could be made at a much lower cost by using a hybrid modal system where skips on ships are filled pneumatically from containment immediately post-shakers or post-drier.

**Skip and ship**

Skip and ship has high negative scores for technical and cost. Its H&S score is also a concern as TGL's experience and perception of the risks to personnel are higher than in more mature operating areas and lifting incidents make up a significant proportion of all incidents (>10%).

**Cuttings Pits**

Cuttings pits have high negative scores for cost, ecological impact and regulation. This option is best suited for storage of material for further processing and is not a credible disposal option as it carries an open ended commitment to manage the waste in perpetuity.

**Making non-structural building materials**

This is the least difficult of the onshore options and has the best overall performance. There are however still real concerns about the quality of the product and any potential for leaching of harmful

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[16] Info from TEN project team (email 2/8/12)

[17] Drilling slops make up a separate waste stream amounting to $\leq$10 tonnes per well are currently shipped ashore as part of routine supply ship backloads and are being used for the construction of NSCM bricks. However, despite planning agreements that the bricks will not be used for structural purposes due to the origin of the materials, it is apparent that their use is less controlled than would be desired. This situation appears to be very difficult to manage and the resultant potential liability which remains with TGL is likely to be unacceptable to the company, especially for the quantities of brick feedstock which will arise from the 19-35 TEN wells. This waste stream is not considered further within this BPEO study.

chemical residues and the uses to which the product is put. Drill cuttings are generally much softer than aggregate and are not suitable for construction.

**Onshore treatment with TDU**

This option was not taken forward as it is possible to treat the cuttings offshore saving shipping costs, which more than covers the cost of having to have a backup unit on the rig that is due to do the completions.

**Landfill cover**

Landfill cover is only appropriate for the disposal of non-hazardous waste – in this case the output from the onshore TDU – which is not being taken forward (see above).

**Landfarming**

Landfarming would require the cooperation and training of a local contractor, together with regulatory approval. Both these aspects carry a high degree of schedule risk. Care would need to be taken to find a suitable site which is relatively salt-tolerant to minimise the environmental impact. By comparison, Non Structural Building Materials (NSBM) are considered to be the best option for onshore treatment and disposal as it offers the opportunity to turn a waste into a resource, with minimal environmental impact. There are risks associated with the NSBM option, but these need to be addressed for the disposal of the fines recovered from the cuttings driers.

***Only the best of the onshore disposal pathways was taken forward for relative assessment. This comprised hybrid containment and transport offshore and the incorporation of cuttings materials into non-structural items onshore.***

# 8 Option Comparison - Relative Assessment

## 8.1 Introduction

Having established which options are good performers in terms of the defined criteria, and selected the best performing options for further analysis, this next stage provides for a more detailed comparative evaluation. The first stage is to select one of the pathways as a base case. Usually this is the simplest process or the one that is considered closest to standard practice. In this project the base case is considered to be drilling with NADF and the offshore discharge of cuttings and recovered fines with <3% OOC. Two alternative pathways have been brought forward to be compared against the base case:

- an option involving upgrading the offshore treatment of cuttings to <1%oil on cuttings using a thermal desorption unit (TDU); and
- an option ship to shore with a hybrid bulk transfer system stabilisation as non-structural building materials (NSBM).

## 8.2 Relative assessment criteria

The relative assessment criteria used that are used to score these options against the base case are outlined below in Tables 8-1 and 8-2.

**Table 8-1 Relative assessment matrix (internal factors)**

| | Health & Safety | Technical risk | Cost | Reputation |
|---|---|---|---|---|
| Factors considered. likelihood >10% | Risks arising from accidents and exposure to chemicals and agents | Lost time due to schedule risk, reduced flexibility, novel technology | CAPEX, OPEX & risk assessed costs from liabilities | Perceptions of external stakeholders |
| Category | | | | |
| - - -<br>Much worse | Extensive increase in LTIs, likely to have more than one additional fatality.<br>Widespread decrease in chronic illnesses from exposure to chemicals. | Increases lost time due to reduced flexibility, lack of spares / resources, deliverability, novel technology: >20 days over project, >1 day /well | Additional >$10 million over project >$250,000 per well | Provokes widespread campaigning by NGOs, national media coverage.<br>Not aligned with policy |
| - -<br>Moderately worse | Significant increase in LTIs, Likely to have a fatality in exploration programme.<br>Increase in chronic illnesses from exposure to chemicals. | Increases project delays >1 day over the project, >5 hours / well | Additional >$1 million over project $25,000 per well | Provokes local concern, possible campaign and media coverage. |
| -<br>Slightly worse | Probable increase LTIs, possible increase in fatality.<br>Slight increase exposure to harmful chemicals / agents. | Increases delays >1 day over the project >1 hour per well | Additional >$100,000 over project $2,500 per well | Provokes local concerns and erosion of goodwill, but little media coverage concerns |
| No change +/- | Little or no change over the base case | | | |
| +<br>Slightly better | Probable decrease LTIs, slight decrease exposure to harmful chemicals / agents. | Reduces lost time due to improved flexibility, spares / resources, deliverability, technology: >1 day over the project, > 1 hour / well | Savings >$100,000 over project $2,500 per well | Generates awareness of possible benefits, little media coverage. |
| ++<br>Moderately better | Significant decrease in LTIs, Likely to avoid a fatality in exploration programme.<br>Decrease in chronic illnesses from exposure to chemicals. | Reduces project delays days over the project or >5 hours / well | Savings >$1 million over project $25,000 per well | Generates local support with some positive local media coverage. |
| +++<br>Much better | Extensive decrease in LTIs, , avoids more than one fatality.<br>Widespread decrease in chronic illnesses from exposure to chemicals. | Reduces delays >20 days over project or >1 day / well | Savings >$10 million over project, $250,000 per well | Generates widespread support and positive, national media coverage, awards etc. |

**Table 8-2 Relative assessment matrix (external factors)**

| | Ecological | Economic | Social | Regulation |
|---|---|---|---|---|
| Factors considered. Assumes likelihood >10% | Impacts arising from pollution, land take, access, cultural or archaeological impacts | Impacts from investment, inflation, jobs, current businesses | Impacts from social inequality, cultural influence, skills, STDs. | Compliance with external regulation and internal corporate policy |
| Category | | | | |
| - - - Much worse | Additional impact is beyond natural variability with slow recovery or widespread lesser impacts | Loss of– business >$1 MM. | Major negative changes from inflation, increased inequality, cultural influence, skills, STDs. | Much less likely to get regulatory approval |
| - - Moderately worse | Additional impact is beyond natural variability but eventual recovery | Loss of– business >$100,000 | Moderate negative changes from inflation, increased inequality, cultural influence, skills, STDs. | Less likely to get regulatory approval |
| - Slightly worse | Additional impact is similar to natural variability with good recovery potential, or limited to small areas | Loss of– business >$10,000 | Minor negative changes from inflation, increased inequality, cultural influence, skills, STDs. | Increased challenge from regulator |
| No change +/- | Little or no change over the base case | | | |
| + Slightly better | Marginal improvements to local ecosystems | Generates business >$10,000 | Minor positive changes from inflation, increased inequality, cultural influence, skills, STDs. | Reduced challenge from regulator |
| ++ Moderately better | Measurable improvements to local ecosystems | Generates business >$100,000 | Moderate positive changes from inflation, increased inequality, cultural influence, skills, STDs. | More likely to get regulatory approval |
| +++ Much better | Marked improvement to local ecosystems | Generates business >$1 MM | Major positive changes from inflation, increased inequality, cultural influence, skills, STDs. | Much more likely to get regulatory approval |

## 8.3 Comparison of Pathway B2 (offshore thermal desorption treatment and discharge) with the base case

This first comparison takes the offshore thermal treatment pathway and compares that with the cuttings drier and centrifugal treatment. Two key areas that require quantification relate to the anticipated cost of this option and the possible local economic benefit (See Table 8.3 & 8.4).

The following analysis is based on the results of the preliminary engineering studies that have been carried out by the TEN team (TEN 2012c), which found that the installation of a TDU on 5$^{th}$ or 6$^{th}$ generation semi-submersible rigs is technically feasible and that there will be no delays to drilling operations during installation of the unit. For operations, the TDU is a more complex piece of equipment than the cuttings driers and appropriate provision for buffer storage capacity needs to be included to cope with minor breakdowns. It is also assumed in the cost calculations that the cuttings driers will be removed as the TDU requires a relatively wet feed and the drier units would be redundant apart from acting as a contingency option.

**Table 8-3 Difference in capital and operating costs**

| Offshore TDU | Offshore treatment | Containment | Lorry+ dock crane | Stabilisation | Total cost | Total cost difference |
|---|---|---|---|---|---|---|
| Base case[1] | $5,900,000 | None | 0 | 0 | $5,900,000 | N/A |
| 2 Offshore units | $27,000,000 | 0 | 0 | 0 | $27,000,000 | $21,022,219 |
| 1 Offshore unit | $20,000,000 | 0 | 0 | 0 | $20,000,000 | $14,022,219 |

[1] Including monitoring costs

**Table 8-4 Difference in local economic benefit**

| Offshore TDU | Offshore treatment | Containment | Lorry+ dock crane | Stabilisation | Total local value |
|---|---|---|---|---|---|
| Base case B1 | $278,000 | 0 | 0 | 0 | $278,000 |
| Pathway B2 | $189,000 | 0 | 0 | 0 | $189,000 |
| Difference in local value | -$89,000 | 0 | 0 | 0 | -$89,000 |

It can be seen from these summary tables that in absolute cost terms the offshore TDU option is between $14 million and $21 million more expensive than the offshore centrifugal treatment system, currently in place. There is potential for substantial cost escalation if there are any delays to drilling operations during the installation or operation of the TDU unit.

Regarding economic benefit, most of this cost difference is taken up with goods and services that have been imported into Ghana, consequently the difference in local content is only just over $200,000 in favour of the base case. Despite being more expensive, offshore TDU is less labour intensive than shipping to shore, as it avoids setting up an onshore waste treatment pathway.

On the environmental side, the calculated air emissions are shown in Table 8-5. These are based on the tonnage of cuttings processed and are not corrected for the additional base oil recovered by TDU[18]. Whilst the TDU atmospheric emissions are shown as being six times higher than from the cuttings driers, these are still assessed as being negligible. One way of assessing the relative importance of an impact is to value it as a monetary figure. The UK government has generated a range of carbon values based on the global cost of the full damage that $CO_2$ imposes over the whole of its time in the atmosphere. We have taken a mid range value of $100/MT, which gives a value of around $300,000. This is a minor impact and has not been judged as being significant when undertaking the relative assessment of the environmental benefit of the TDU.

[18] The additional base oil (approx 2.9%) that is recovered from the TDU over the cuttings driers will depend upon the Oil/Water ratio of the drilling mud, but would probably reduce the difference in emissions by 20-30%.

**Table 8-5 Air emissions from Base case and TDU (B2)**

| Sources | Working Time | No. Vessels or Fuel | Power | Emissions | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $CO_2$ | CO | NOx | $SO_2$ | VOC | CO2 |
| | days | *(tonnes)* | (kW) | *(tonnes)* | *(tonnes)* | *(tonnes)* | *(tonnes)* | *(tonnes)* | % |
| Drilling Rig | 665 | - | 18000 | 189,605 | 459.6 | 3447.4 | 313.7 | 143.6 | 0.0 |
| Drier(s) | 665 | 1 | 40 | 421 | 1.0 | 7.7 | 0.7 | 0.3 | 0.2% |
| TDU | - | 843 | 1 | 2,783 | 15.2 | 3.1 | 4.4 | 21.1 | 1.5% |

Drilling rig power is nominally rated at 50% of installed capacity (36 MW)

Taking these factors into account along with the justification given in the absolute assessment Table 8-6 the assessment then goes on to evaluate and compare the two offshore treatment options across the range of evaluation factors based upon the scoring system outlined in Table 8-2.

**Table 8-6 Relative comparison of offshore TDU with cuttings drier base case**

| | Offshore treatment | Containment | Lorry + dock crane | Stabilisation |
|---|---|---|---|---|
| Health & safety | +/- | | | |
| | No particular differences | Not applicable | Not applicable | Not applicable |
| Technical risk | - | | | |
| | Driers more reliable than TDU | Not applicable | Not applicable | Not applicable |
| Cost | - - - | | | |
| | Significant added cost of TDU over driers ($14-21 MM) | Not applicable | Not applicable | Not applicable |
| Reputation | + + | | | |
| | Enhanced treatment capacity viewed positively by stakeholders | Not applicable | Not applicable | Not applicable |
| Environmental | + + + | | | |
| | Enhanced treatment capacity reduces seabed impacts | Not applicable | Not applicable | Not applicable |
| Economic | +/- | | | |
| | No significant difference | Not applicable | Not applicable | Not applicable |
| Social | +/- | | | |
| | No particular differences | Not applicable | Not applicable | Not applicable |
| Regulation | + + + | | | |
| | Meets required and future standards and viewed positively | Not applicable | Not applicable | Not applicable |

| Performance | - - - (-100) | - - (-10) | - (-1) | +/- | + (+1) | ++ (+10) | +++ (+100) |
|---|---|---|---|---|---|---|---|
| | 1 | 0 | 1 | 3 | 0 | 1 | 2 |

| Total–ve points | Total +ve points | Total scoring cells |
|---|---|---|
| 101 | 210 | 8 |

The main areas of differences and areas for further consideration are associated with cost, regulation and environmental impact, for example:

- Cost of the TDU technology
- Improved environmental performance of the TDU with reduced impact at the sea bed from 0.1 – 1.0% hydrocarbons and better dispersion in the water column
- Extent to which the current discharges at 3% OOC methods meet regulatory expectations and degree of future proofing
- Extent to which cuttings can be relied on to always meet 3% OOC

On balance there are more advantages than disadvantages to using offshore thermal treatment compared to offshore centrifugal treatment, assuming that the TDU can be installed without incurring delays during installation or operation. The overall summary comparison (see Table 8-7) shows this in its balance of scores.

**Table 8-7 Comparison of offshore thermal treatment (B2) with base case, cuttings drier (B1)**

| Pathway B2 – Offshore TDU | Relative score | Comments |
|---|---|---|
| Health & safety | +/- | No transfer of waste onshore in either case |
| Technical risk | - | Driers likely to be more reliable than TDU |
| Cost | - - - | Equipment offshore much more costly |
| Reputation | + + | TDU discharges generally viewed positively and seen as proactive |
| Environmental | + + + | Seabed impacts will be reduced. TDU air emissions will be higher but are not significant enough to reduce the overall environmental benefit. |
| Economic | +/- | No material difference |
| Social | +/- | No material difference |
| Regulation | + + + | TDU option support by regulator, generates goodwill |

## 8.4 Comparison of Pathway C1 (onshore stabilisation as non-structural building materials) with base case

Pathway C1 was developed to assess the issues associated with shipping cuttings ashore for treatment and disposal. As before, these first two Table 8-8 & Table 8-9 present details of the overall costs, and the local content associated with the base case and the onshore treatment alternatives.

**Table 8-8 Total costs of options**

| Ship to shore and NS BM | Offshore treatment | Containment | Lorry+ dock crane | Stabilisation | Total cost | Total cost difference |
|---|---|---|---|---|---|---|
| Base case B1 | $5,320,000 | None | None | None | $5,320,000 | N/A |
| Pathway C1 - High vessel cost estimate | $5,320,000 | $55,182,200 | $225,863 | $1,806,900 | $62,534,963 | $56,634,963 |
| Pathway C1 - Low vessel cost estimate | $5,320,000 | $15,000,000 | $225,863 | $1,806,900 | $22,353,763 | $17,032,763 |

**Table 8-9 Economic value of options**

| Ship to shore and NSBM | Offshore treatment | Containment | Lorry+ dock crane | Stabilisation | Total local value |
|---|---|---|---|---|---|
| Base case B1 | $316,000 | $0 | 0 | 0 | $316,000 |
| Pathway C1 | $266,000 | $498,750 | $225,863 | $451,725 | $1,442,338 |
| Difference in economic value | -$50,000 | $498,750 | $225,863 | $451,725 | $1,126,338 |

It can be seen that the level of vessel costs dominate the economics of the onshore pathway. The estimate for the shipping costs used in the high value, came from the TEN project team and was based on needing the equivalent of 1.5 additional vessels throughout drilling operations. A low estimate has been included to test the sensitivity of a decision to ship to shore to shipping costs. This scenario assumes that suitable vessels would be available as a spot charter for 9 days per well, whilst drilling the 17½" hole section, where cuttings generation is fastest and includes an allowance for mobilisation and demobilisation of the vessel. The cost spread between the two estimates is $45 million. As before the level of economic benefits to be affected is much less that the overall cost. This is because of the limited local content in the various technology pathways, with a number of imported facilities and expertise.

The air emissions (see Table 8-10) show the importance of the air emissions from the additional support vessel requirements. These effectively counter-balance the reduced impacts to the seabed by taking the cuttings ashore.

**Table 8-10 Comparison of air emissions**

| Activity | Time (days) | No. | Fuel (t/d) | Power (kW) | $CO_2$ *(tonnes)* | CO *(tonnes)* | NOx *(tonnes)* | $SO_2$ *(tonnes)* | VOC *(tonnes)* | PM *(tonnes)* | $CO_2$ *% drill rig $CO_2$* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Drilling Rig | 665 | 1 | | 18000 | 189,605 | 459.6 | 3447.4 | 313.7 | 143.6 | 57.5 | 0.0 |
| Supply boat | 665 | 1.5 | | 5000 | 91,642 | 222.2 | 1666.2 | 151.6 | 69.4 | 27.8 | 48% |
| Supply boat | 171 | 1 | | 5000 | 15,710 | 38.1 | 285.6 | 26.0 | 11.9 | 4.8 | 8% |
| Cuttings drier | 665 | 1 | | 40 | 421 | 1.0 | 7.7 | 0.7 | 0.3 | 0.1 | 0.2% |
| Trucks | Total | | 26 | - | 86 | 0.5 | 0.1 | 0.1 | 0.7 | | 0.05% |
| Trucks (fines) | Total | | 3 | - | 9 | 0.0 | 0.0 | 0.0 | 0.1 | | 0.00% |

Drilling rig (36 MW) & supply vessel (10 MW) power is nominally rated at 50% of installed capacity to average out time in port / idling or operating at low fuel demand.

The overall comparison of the offshore cuttings cleaning and the onshore stabilisation of cuttings wastes are shown in Table 8-11.

**Table 8-11 Relative comparison with of shipping cuttings ashore for stabilisation**

| Pathway C1 Non structural building materials | Offshore treatment | Containment | Lorry+ dock crane | Stabilisation |
|---|---|---|---|---|
| Health & safety | +/- | - | - | - |
| | No material differences | Increased potential for lifting related accidents but no likely fatalities | Increased potential for road traffic accidents | Larger scale operation will have greater H&S related risks |
| Technical risk | +/- | - | +/- | - - |
| | No material differences | Slight schedule risk from weather delays from extra volume | No material differences | Increased volume of material: higher schedule risks |
| Cost | +/- | - - - | - | - - |
| | No material differences | Extra cost from containers and shipping costs ($17-60MM) | Extra transport costs | Extra stabilisation costs |
| Reputation | + | +/- | +/- | + |
| | Avoids discharges to sea which are not viewed positively by stakeholders | No material differences | No material differences | Setting up a larger onshore disposal pathway may be viewed as beneficial by certain regulatory agencies |
| Environmental | + + | - - | +/- | - |
| | Seabed effects are reduced, but still top hole impacts | Shipping emissions are higher <100,000t in worst case | No material differences | Some footprint related impacts |
| Economic | - | + + | + + | ++ |
| | Less work offshore – no cuttings monitoring surveys | Vessel crews ($500K) | Onshore transport ($200K) | Stabilisation ($1 MM) |
| Social | +/- | +/- | - | +/- |
| | No material differences | No material differences | Less nuisance from road traffic | No material differences |
| Regulation | + + | +/- | +/- | - |
| | Base case does not meet regulatory expectations | No material differences | No material differences | Approval of onshore disposal pathways may be difficult |

| Performance | - - - (-100) | - - (-10) | - (-1) | +/- | + (+1) | ++ (+10) | +++ (+100) |
|---|---|---|---|---|---|---|---|
| | 1 | 3 | 9 | 12 | 2 | 5 | 0 |

| Total–ve points | Total +ve points | Total scoring cells |
|---|---|---|
| 139 | 52 | 32 |

The level of additional supply vessels that will be required is both a key variable and a source of uncertainty for cost and air emissions. There are also a significant number of less advantageous, negative issues where performance is worse.

The results show that the key areas of concern and interest area are:

- Establishing the right product and market for the NSBM – ideally it should be a product like paving slabs or kerbstones, rather than bricks which, in the wrong hands, can easily be used inappropriately for building;

- Product leaching studies will have to be undertaken to clearly demonstrate that the hydrocarbons are permanently stabilised in order to get a permit;
- Permitting aspects could present a significant risk and the concept needs to be tested with the regulator;
- The benefits of reduce offshore impacts on the seabed are broadly balanced by the additional emissions from additional shipping requirements.

The overall performance of the onshore treatment option is shown in Table 8-12, where cost is seen to be the key factor.

**Table 8-12 Overall performance of onshore treatment**

| Pathway C1 NSBM | Overall | Comments |
|---|---|---|
| Health & safety | - | Additional crane and transport activity increase the likelihood of accidents. The likelihood of fatality is low enough to score as a single – ve. |
| Technical risk | - - | There are a number of onshore permitting and processing capacity issues to be resolved. |
| Cost | - - - | Very dependent on shipping costs ($17-60MM) but onshore treatment is always more expensive |
| Reputation | + | Creation of a useful product likely to be viewed more positively than offshore discharge or perceived "dumping at sea" |
| Environmental | +/- | Offshore impacts are balanced by additional air emissions from shipping |
| Economic | + + | Onshore pathway will create jobs and local content |
| Social | +/- | No material difference |
| Regulation | +/- | Offshore benefits welcomed, but residual issues with setting up larger scale onshore process |

# 9 Selection of preferred option

The conclusions below are based upon the following assumptions:

- There is very little information about the performance of Water Based Drilling fluids in the area. WBM was screened out of the relative assessment because the use of WBM can easily lead to schedule delays, which can quickly become extremely expensive when drilling production wells in a deep water environment. Given the lack of any offset well information, it is difficult to justify the planning of an extensive development program with such a high degree of risk exposure. If relevant well information were to become available from offset exploration wells with similar geological profiles that showed minimal drilling problems and no Non Productive Time, then WBM could become an attractive option.
- We have assumed that the installation of a TDU on $5^{th}$ or $6^{th}$ generation semi-submersible rigs is technically feasible and that there will be no delays to drilling operations during installation of the unit. For operations, we have also assumed that there will be no logistical constraints and that it will be possible to provide sufficient buffer storage capacity for the cuttings to avoid drilling delays arising from minor breakdowns.
- It has not been possible to get a clear understanding of local constraints associated with the stabilisation of cuttings into Non Structural Building Materials. These include potential products such as paving slabs, the market for such products, the potential liabilities associated with misuse of the product and the likely attitude of the regulator towards such products.
- The additional shipping requirements are an important variable. Aquatera has provided a sensitivity analysis based on benchmarks with other projects.

A summary of the outcome of the relative assessment is presented in Table 9.1.

**Table 9-1 Comparison of the relative performance of offshore thermal and onshore treatment options against the base case of offshore cuttings driers**

| Comments Offshore TDU (B1) over base case and Ship to onshore and stabilisation to NSBM (C1) | Pathway B2 Offshore TDU | Criteria | Pathway C1 Onshore NSBM |
|---|---|---|---|
| No material differences (B2); increased handling and crane operations (C1) | +/- | Health & safety | - |
| No material differences (B2); potential permitting and misuse of product from resale (C1) | +/- | Technical risk | - - |
| Additional $14-20MM cost (B2); $17-55MM (C1) | - - - | Cost | - - - |
| Perceived advantage through being seen to invest in green solutions to meet regulatory aspirations | + + | Reputation | + |
| Minimal hydrocarbons, better dispersion in water column (B2), high air emissions from ships (C1) | + + + | Environmental | +/- |
| No material differences (B2), more local content from shipping and processing onshore (C1) | +/- | Economic | + + |
| No material differences | +/- | Social | +/- |
| Meets regulators aspirations (B2), no issues with permitting of NSBM materials (C1) | + + + | Regulation | +/- |

Onshore treatment emerges as the most expensive option and the low cost shipping scenario is needed to make it competitive with Offshore TDU. Even with this low cost shipping scenario costs are not significantly low enough to change the decision due to the issues arising from:

- Additional shipping, which is a major source of air emissions as well as increased safety risks;
- Establishing the product and market for NSBM that avoids any potential liabilities arising from misuse or sale to others in the supply chain;
- Permitting and schedule risks arising from permitting of NSBM to general use, leaching tests to establish quality of stabilisation of hydrocarbons;

Onshore treatment does offer good potential for increased local content from vessel crews and the stabilisation process but this is not sufficient to outweigh disadvantages listed above.

Treating cuttings with the TDU offshore and discharging the cleaned cuttings to sea has the following advantages over the base case:

- It meets regulatory aspirations;
- There is less environmental impact – practically zero hydrocarbons to sea, good dispersion, no chemical discharges from NADF sections, some additional air emissions over base case but not significant;
- It is likely to be seen positively as a green investment initiative when compared with a perception of dumping oily waste at sea.

The disadvantage is the high cost of approximately $20 million which is around 2% of the total well cost.

It should be noted that these conclusions could change if the assumptions upon which they are based were to change, with the receipt of different, more recent or better information.

**Additional consideration of single well drilling scenario**

One such circumstance, in this regard, is the possibility that the drilling programme could require the support of the third drilling rig to drill one or two wells if the main rig was falling behind schedule. In such a situation the rig would be on hire for a relatively short period, perhaps amounting to a few months, and a key question is what kind of cuttings handling would be considered optimal. The previous analysis for the full drilling programme showed that the BPEO was to use an offshore TDU, with the associated heavy capital cost spread over perhaps 19 wells. In this single well scenario any works and costs associated with tooling up or fitting out the rig would likely only be required for the single Tullow well. However, the possible impacts arising from a single well are likely to be less significant, whether they are beneficial, or detrimental.

An analysis of the situation as presented in Appendix J shows that the anticipated costs for installing an offshore TDU for a short well programme are prohibitive and that the levels of ecological impact for one well are relatively small and insignificant. In summary, the BPEO for one well, or a small number of wells, would be to use offshore cuttings driers with overboard discharge of <3% OOC.

This conclusion, for a single well, differs from that derived for a longer term well programme where the offshore TDU is the BPEO.

Annex F2

# Appendices to: BPEO for the Management of Drilling Discharges from the TEN Project

# Appendices to : BPEO for the management of drilling discharges from the TEN project

**Report to Tullow Ghana Ltd**

**Issued by Aquatera Ltd**

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| | | |
| | | |

# Table of Contents

# Appendix A . Description of Technical Options

This Appendix provides a general introduction to the drill process and the various options for handling drilling wastes. It is designed to help readers who are unfamiliar with the process and the technology to better understand the background context for this BPEO study. The Appendix firstly outlines how drilling wastes arise and then outlines the various options for managing and handling them.

## A1. Generation of Drilling Wastes

### A1.1. Sources of drilling wastes

The wastes from the drilling process arise from the sediments and rocks drilled out of the hole and the drilling mud that is circulated through the hole to clear out the drilled cuttings.

In the upper sections of the well, before the blowout preventer (BOP) and the riser are put in place the drilled cutting and excess mud flow out from the top of the hole at the seabed and disperse and settle, nearby.

In the lower sections of the well after the BOP and riser are in place the drilling mud is pumped from the surface through the hollow drill string, exits through nozzles in the drill bit, and returns to the rig through the annular space between the drill string and the walls of the hole and then through the riser between the seafloor and the drill rig.

As the drill bit grinds rocks into drill cuttings, the cuttings are flushed away from the bit and carried to the surface by the mud flow. The cuttings are then separated from the mud so that mud can be re-used. The drilling mud is also used to control subsurface pressures, lubricate the drill bit and stabilise the well bore, among other functions.

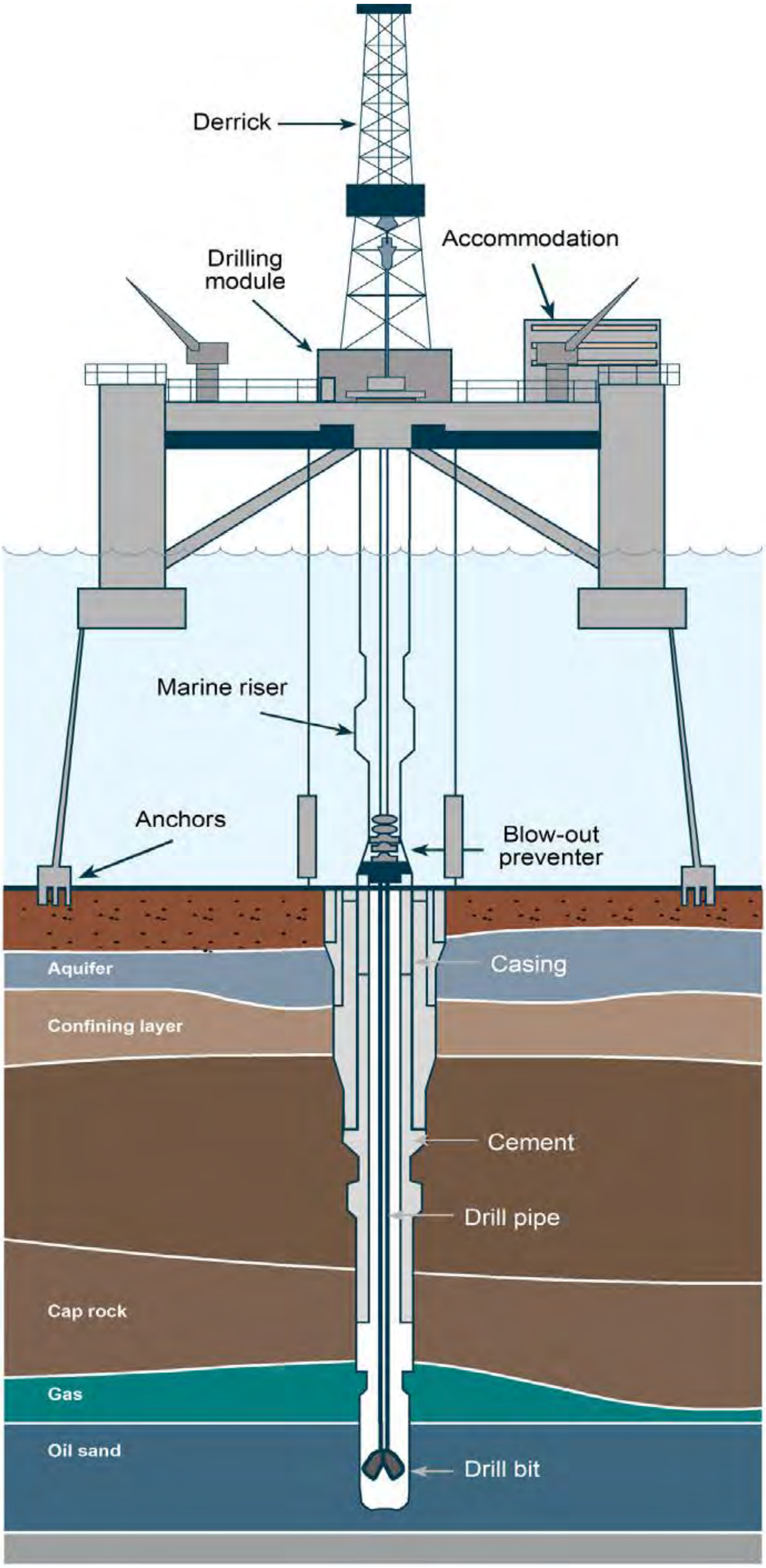
### A1.2. Solids Control

The first step in separating the cuttings from the mud involves circulating the mixture of mud and cuttings over vibrating screens called shale shakers.

The liquid mud passes through the screens and is re-circulated back to the mud tanks ready to be pumped back down the hole. The mud properties may be adjusted by chemical treatment at this time, together with additional mechanical processes to remove fine solids. The drill cuttings remain on top of the shale shaker screens where they can be collected and stored in a tank or pit for further treatment or disposal. In general, the separated drill cuttings are coated with a large quantity of drilling mud roughly equal in volume to the cuttings.

Additional mechanical processing on the separated mud, using hydrocyclones and centrifuges is often used to further remove as many fine solids as possible. Any build-up of these particles will thicken the drill mud and eventually make it unusable, requiring disposal. The solid waste that is removed is combined with the solid waste from the shale shakers for treatment and / or disposal.

**Figure A-1**



Derrick
Drilling
module
Accommodation
Marine riser
Anchors
Blow-out
preventer
Aquifer
Casing
Confining layer
Cement
Drill pipe
Cap rock
Gas
Oil sand
Drill bit

### A1.3. Mud Recycling

Most water-phase muds are disposed of at the end of a well due to the high drilled solids content. With low density muds containing low concentrations of weighting agents, it is possible to remove the weighting agents by centrifugation and then treat the remaining fluids with coagulants and flocculants to aggregate the fine solids, so that they too can be removed by centrifugation.

With oil based muds, the solids are not softened by coming into contact with water and are more easily removed by the solids control equipment. The reduced accumulation of drilled solids generally allows the mud to be recycled, although some chemical treatment is usually required to adjust the mud properties to meet the specifications for the new well.

There are also many relatively simple processes that can be used on drilling rigs to capture clean mud, that would otherwise be discarded, and return it to use. Examples include pipe wipers, mud buckets, and vacuuming of spills on the rig floor. Recovery of mud during tank cleaning may also allow the mud to be reused. Solids control equipment, like centrifuges, can be used to remove solids from the re-circulating mud stream.

### A1.4. Management of Drilling Wastes

The management technologies and practices described in the next sections follow the waste management hierarchy outlined below:

1. Can the level of waste be avoided or reduced? If not,
2. Can it be re-used? If not,
3. Can it be recycled? If not,
4. It must be disposed of in such a way that the impacts to the environment are acceptable.

This hierarchy is often simplified to reduce – reuse – recycle.

## A2. Minimizing Waste at Source

This section outlines some of the best practices that have been developed within the industry to minimise the amount of waste that is generated at source.

### A2.1. Reducing the Number of Wells

The total number of wells required can be reduced by getting better geological information from seismic information. This applies to both finding oil in the first place (exploration wells) and working out the best way to extract the oil (appraisal wells).

### A2.2. Drilling Smaller Diameter Holes

The amount of drill cuttings generated is directly related to the diameter of the hole that is drilled. Smaller holes generate less waste. However, there are technical limits to the smallest size of hole that can be drilled whilst obtaining the geological or production information that is required. Therefore reducing hole size increases the risk of not meeting the well objectives.

On the other hand, drilling smaller holes could halve the amount of drilling waste generated and reduce the overall well cost. Drilling wells where good geological information exists is unlikely to present major technical risks.

## A3. Selection of Drilling Muds

Drilling muds can be broadly separated into oil based mud (emulsions containing >50% oil or oil substitutes) and water based mud (contains water, no oil).

### A3.1. Water Based Muds

When using water based drilling mud, younger type rocks tend to become soft with prolonged contact, causing the hole to destabilize and fragments of rock to break away from the wellbore. The softening action of water on the rock can create delays to the drilling programme by making it difficult to move pipe in and out of the hole when changing the bit or running casing. In some geological areas of the world, it is not uncommon for the borehole to collapse and trap the drilling equipment in the well.

Softening the rock also causes the drilled cuttings to break up allowing fine solids to disperse into the mud. The build-up of solids in the mud eventually increases the viscosity of the drilling mud to a point at which it becomes unusable. This creates another large waste stream for the disposal of “spent” mud with an unacceptably high content of drilled solids.

### A3.2. Oil Based Muds

Oil based muds are designed to limit the action of water within the mud by creating an emulsion of oil and water. The water phase has a high salinity and ionic strength. This prevents the water from being sucked into the rock thus creating much more stable borehole conditions.

The drilled solids are also easier to remove and there is much less build-up of solids with little or no generation of “spent” mud.

The oil provides much greater lubricity than with water based muds making it possible to drill very long, extended reach wells from a single well site during development drilling, many of which cannot be drilled with water based mud.

### A3.3. Selection of Drilling Mud Chemicals

The first major decision is to choose whether to use water based mud or oil based mud. Regulations in most parts of the world normally allow the discharge of water based mud and cuttings directly into the sea, providing the chemical constituents meet the regulatory requirements. Thus in offshore situations, it is usually cheaper and more convenient to use water based mud unless the rock is especially sensitive to water or there are other technical challenges. Where water based muds are not allowed to be discharged the optimal solution may be quite different.

The disposal of waste with a high chloride content on land can create more environmental impact than the disposal of oil, as the chlorides are very long lived and do not bio-degrade in the soil. The suitability of water and oil based muds for a variety of treatment and reuse options may vary considerably. The greater operational efficiencies achievable when drilling with oil based muds are often a significant factor when assessing mud options.

Even when the basis for the mud has been selected there are important decisions to be taken in relation to the chemical additives that are used. These chemicals may be compared in terms of:

- **Functional reliability**
- **Cost**
- **Influence of later treatments and processes**
- **Toxicity**
- **Persistence**
- **Potential for accumulation**
- **Health & safety issues.**

Examples of some of the functions fulfilled by various chemical additives are provided in the Table A-1.

**Table A-1 Description of the functions of certain drilling mud additives**

Weighting agents

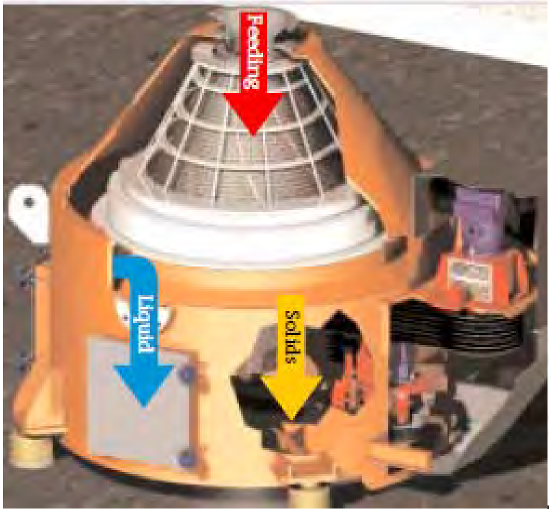
| Mud function | General chemical additive(s) |
|---|---|
| Control subsurface pressures by making the pressure generated by the mud column greater than the formation pressure | Barite (Barium sulphate), hematite ($Fe_2O_3$) and calcium carbonate ($CaCO_3$) |

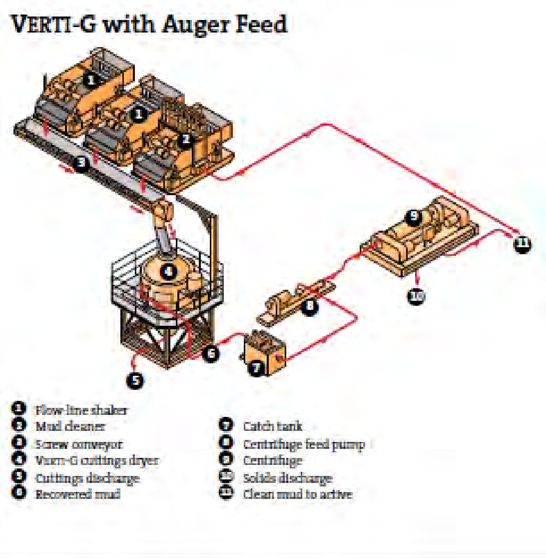
Other agents

| Mud function | Water based chemical additive(s) | Oil based chemical additive(s) |
|---|---|---|
| Cool and lubricate the bit | Water | Low toxicity oils, synthetic oils |
| Remove drilled cuttings away from the bit | Viscosifiers: xanthum gums, cellulose based polymers (also used as food additives), Bentonite clays (used for clarifying beer) | Bentonite clays modified with quaternary amines |
| Stabilise the borehole | Potassium chloride, complex aluminium salts, silicates, glycols, lime, “salt free” bio-degradable alternatives | Calcium chloride, biodegradable alternatives – nitrates, sulphates, glycols |
| Prevent the sticking of the drilling equipment (emulsion stability in OBM) | Starch, cellulose based polymers, Bentonite clays | Chemical emulsifiers |

## A4. Cuttings drier

Cuttings driers are based on centrifuge technology in which cuttings from the shale shakers are feed into the unit. The cleaned cuttings are discharged into the sea via a cutting chute at least 15m below the sea surface. The recovered drilling mud and suspended fine cuttings which are generated in the drying process are then further treated using a standard drilling mud centrifuge. The reconditioned mud is then returned through to the mud tanks for re-use. The recovered fines which have been separated from the mud are re-combined with the main drilled cuttings stream for disposal via the cuttings chute.




## A5. Thermal desorption

See description below in Section A9.5

## A6. Cuttings Transport Offshore

If the drilled cuttings generated offshore cannot be disposed of at the drill site, they have to be transported from the drilling rig to a boat so that they can be transported to a suitable disposal site.

There are three approaches to be considered:

- Skip and ship
- Slurrification and bulk transport
- Drying, pneumatic transfer and bulk transport

Each of these options is now described.

### A6.1. Skips

This is based on loading cuttings into a skip then lifting the skip onto a supply boat for shipment to shore. The operation is technically simple but is limited by weather, increased risk of accidents and ties up the rig cranes for long periods.

**Figure A-2** Skips used to transport cuttings

## A6.2. Slurrification

In this method the drilled cuttings are transferred from the shale shakers to a central holding tank(s), where oil (for oil based mud) or water (for water based mud) is added to agitate the cuttings. The cuttings are then transformed into a slurry by continuous circulation with a modified pump before being transferred to a storage tank on the supply boat through a hose connection. On arrival at the port, the process would be reversed and the slurry would be pumped from the boat to the quayside for storage.

### A6.3. Pneumatic Transport

In this case the drilled cuttings are collected from the shale shakers and blown into special holding tanks using compressed air, using the same principles that are used to transfer dry powders like cement or barite.

The same method is then used to transfer the cuttings to the supply boat and subsequently from the supply boat to the shore.

**Figure A-3 Hose transfer of cuttings to bulk tanks on supply vessel**

## A7. Port Transfer

The transfer of the cuttings from the supply boat to the port facility is essentially the reverse of how the cuttings arrived on the boat in the first place. Depending upon the capacity of onward treatment and disposal options, the offloaded cutting may need temporary storage at the port. If they are in sealed containers this need not be under cover, otherwise it should be under cover. Storage of cuttings over any extended period will lead to consolidation within the holding container and emptying such materials at a later date may be much more difficult. Oil based muds, in particular, may release oil type odours if they heat up during storage.

**Figure A-4 Takoradi harbour**

# A8. Cuttings Transport

## A8.1. Road

The most common form of onshore transport is by road. For cuttings delivered by skips normal haulage lorries will be sufficient. For cuttings contained in more specialised containers, more specialised lorries may be needed.

One factor related to the scale of cuttings handling operations during exploration is that activity may be sporadic over time, but can be intense when it occurs.

If port storage is not required for the cuttings brought ashore they can be directly loaded from the boat to the lorry by crane or forklift truck.

Safety is a primary concern at each stage of the cuttings handling process but considerable extra care has to be taken to minimize the risks of road transport. This can include extensive training for drivers, inspection of the vehicles themselves and the creation of journey management procedures. The reason for this focus is that road transport is responsible for 25% of fatalities[1] within the oil & gas sector.

## A8.2. Other options

The cuttings slurry can be pumped along a pipeline from the supply boat to an onshore storage facility or perhaps to a nearby treatment/disposal site. Another option is to move the cuttings to a treatment or disposal site by rail.

[1] OGP Safety performance indicators 2004

**Figure A-5 Road haulage of cuttings**

# A9. Cuttings Treatment

## A9.1. Bioremediation

Bioremediation (also known as biological treatment or bio-treatment) uses micro-organisms (bacteria and fungi), to biologically degrade hydrocarbon-contaminated waste into a non-toxic residue, which can then be applied to land or some other appropriate end use.

Bioremediation can for example create a drier, more stable material for land filling, thereby reducing the potential of hydrocarbons to leach into water courses. Bioremediation can be a slow process and may require many months or years to reach the desired result. The speed of bioremediation depends on the composition of the hydrocarbon components, the environment, and the type of treatment utilised.

Typically, land farming is used to treat large quantities of oil-impacted materials, if surface space is not a limitation. Bio-piles and composting are used to accelerate remediation of smaller quantities of more recalcitrant wastes streams.

Although bioremediation is primarily targeted at petroleum hydrocarbons, inorganic compounds can also be beneficially affected. Metals may be incorporated into the soil matrix (through chelation, exchange reactions, or covalent bonding). Metals may also become less soluble through oxidation, precipitation, and pH variations. Unlike hydrocarbons, salt is unaffected by the bio-treatment processes and may accumulate in soils which have a limited capacity to accept salts. If salt levels become too high, the bioremediation potential of the soils may be damaged and treatment of hydrocarbons can be inhibited. However, being soluble in water, the levels of salts in the soil can be managed.

A more detailed description of the different bioremediation options is provided below:

## A9.2. Land Farming

In this relatively simple treatment method, hydrocarbon contaminated cuttings are placed and treated in a bermed and sometimes lined, treatment area.

From a best practice standpoint, lined cells are generally recommended. The contaminated cuttings are tilled and mixed in with virgin soil so the cuttings depth does not exceed approximately 14 inches.

After the initial mixing of cuttings, the land farm area is mixed with a plough on a daily basis to mix air into the waste. Moisture and nutrients are controlled to enhance bioremediation.

The length of time for bioremediation to occur will be longer if nutrients, oxygen or temperature are not properly controlled. When the desired level of treatment is achieved, the treated cuttings soil mix is removed and another layer of cuttings is ploughed into the treatment area.

The exploration and production industry has used land farming to treat oil based drilling fluid wastes for many years, using micro-organisms in the soil to naturally biodegrade hydrocarbon constituents, dilute and attenuate metals and transform and assimilate waste constituents. The degradation process tends to be relatively slow and is controlled by the inherent biodegradation properties of the waste constituents, soil temperature, soil-water content and contact between the micro-organisms and the wastes.

Land farming can be a relatively low-cost drilling waste management approach. Some studies indicate that land farming does not adversely affect soils and can enhance certain sandy soils by increasing their water-retaining capacity, hence reducing fertilizer losses. Inorganic compounds and metals are diluted in the soil, and may be incorporated into the matrix (through chelation, exchange reactions, covalent bonding, or other processes), or may become less soluble through oxidation, precipitation, and pH effects. The attenuation of heavy metals (or the taking up of metals by plants) can depend on the clay content and cation-exchange capacity of the soil.

**Figure A-6 Typical landfarming activity**

## A9.3. Land Spreading

Land spreading (also known as land treatment) is a process similar to land farming, however, in land spreading, a one-time application of waste is made to the treatment area. In addition, land spreading areas are not lined. The objective of land spreading is to dispose of the waste in a manner that preserves the subsoil's chemical, biological, and physical properties by limiting the accumulation of contaminants and protecting the quality of surface and groundwater.

The land spreading area is determined on the basis of a calculated loading rate that considers the absolute salt concentration, hydrocarbon concentration, metals concentration, and pH level after mixing with the soil. The drilling waste is spread on the land and incorporated into the upper soil zone (typically upper 6-8 inches of soil). Periodic tillage of the mixture (to increase aeration) and the addition of water and nutrients to the waste soil mixture can enhance aerobic biodegradation of hydrocarbons. Because land spreading sites receive only a single application of waste, the potential for accumulation of waste components in the soil is reduced (as compared with land farming, where waste is applied repeatedly).

## A9.4. Composting

This is a controlled biological process, in which contaminated OBM cuttings are mixed with co-composting organic wastes and bulking agents to make it easier to deliver the optimum levels of nutrients, air and water to the micro-organisms.

Typically, thermophilic conditions (54 to 65 °C) are maintained to properly compost the waste. The increased temperatures result from heat produced by micro-organisms during the degradation of the organic material in the waste. The cuttings are mixed with bulking agents and organic amendments, such as wood chips or animal/vegetative wastes, to enhance the porosity of the mixture to be decomposed. Maximum degradation efficiency is achieved through maintaining oxygenation (e.g. windrow turning), providing irrigation as necessary and closely monitoring the moisture content and temperature of the windrow.

Three common designs of composting are:

1. Static Pile Composting - Compost is formed into piles (bio-piles) several metres high on an impermeable pad and aerated with blowers or vacuum pumps.
2. Mechanically Agitated In-Vessel Composting - A bio-pile approximately 1.6 m in height is placed in a treatment vessel where it is mixed and aerated with purpose built equipment.
3. Biobed or Windrow Composting - Compost is placed in long piles of approximately 0.6 m in height, known as windrows or bio-beds and periodically mixed by conventional tractors or similar equipment.

## A9.5. Thermal Processes

Thermal technologies use high temperatures to reclaim or destroy the hydrocarbon-components of oil-based mud and cuttings. Additional treatment may be necessary for metals and salts, depending on the final fate of the wastes. Thermal treatment can be an interim process to reduce toxicity and volume and prepare a waste stream for further treatment or disposal (e.g., landfill, land farming, land spreading). Thermal treatment technology is generally set up in a fixed land-based installation, but smaller units have recently been developed that would be suitable for installation on an offshore production platform.

**Figure A-7 Typical onshore thermal desorption plant**

### *Thermal Desorption*

With thermal desorption heat is applied directly or indirectly to the wastes, to vaporize volatile and semi-volatile components without incinerating the soil or damaging the hydrocarbons. The hydrocarbon vapours are normally condensed so that the valuable recovered oil can be recycled. There are many technical options for thermal desorption including indirect rotary kilns, hot oil processors, thermal phase separation, thermal distillation, thermal plasma volatilization and modular thermal processors.

Thermal desorption depends on volatilisation and the treatment efficiency is related to the volatility of the components of the waste stream. Thermal desorption easily removes light hydrocarbons, aromatics and other volatile organics at 250$^{o}$C to 350$^{o}$C. Higher temperatures are needed to remove heavier compounds such as polycyclic aromatic hydrocarbons.

For the purposes of this BPEO, we will assume the use of modern oil based mud formulations that only contain light hydrocarbons in the base fluid and the bulk of the emulsifier packages. Some heavier emulsifiers and oil wetting agents may be present in low concentrations, which may be difficult to remove at the lower temperatures. Normally the final hydrocarbon content is <0.5% by dry weight of cuttings.

The main potential pollutant issue arises from chlorides, which may be present in concentrations of up to 10,000 mg/l after distillation (10% by weight). The chlorides can be eliminated by substitution of calcium chloride with nitrates, sulphates or glycol in the original mud formulation.

### *Incineration*

Incineration is typically used to destroy organic wastes that are highly toxic, highly flammable, and resistant to biological breakdown, or pose high levels of risk to human health and the environment. In this case, the oil based mud does not need to be broken down because it will not contain harmful or persistent pollutants.

Incineration is considered because of the potential to use the oily cuttings as a fuel source for either cement manufacture or coal fired electricity generation.

## A9.6. Stabilisation/Solidification

Stabilisation/solidification (S/S) is a means by which the mobility of contaminants in a waste stream can be reduced – effectively reducing or eliminating the "pathway" by which a contaminant reaches the environment.

The terms "Stabilisation" and "Solidification" are often used as generic terms covering a wide range of physical / chemical processes, including:

- **"Stabilisation"** – Process which reduces the mobility of the contaminants through the addition of binders which produce more chemically stable constituents. The "stabilised" waste is generally still a crumbly solid rather than a monolithic solid;

- **"Solidification"** – Process utilises encapsulation of the waste to reduce exposure. Solidification involves the addition of binders to impart physical modifications to contain contaminants and reduce mobilisation;

- **"Encapsulation"** – Process similar to solidification where the objective is to physically encapsulate (rather than chemically bond) waste within a solid material.

Stabilisation/solidification is a low cost technology applied widely in developing countries to reduce the hazard of waste prior to landfill. Stabilisation is a simple, low capital and operating cost process, and equally suited to use at source or at centralised facilities. It is particularly useful in ensuring waste meets acceptance criteria for landfill.

Stabilisation/solidification is most effective for waste streams impacted by heavy metals. It is also effective for concentrations of some lower-end petroleum hydrocarbons, provided the oil content is not too high.

There is some evidence that stabilisation agents exist for chloride and other salts, but field examples have not been identified.

Oily exploration wastes and metals associated with drilling mud can be stabilised by the addition of a variety of stabilizing agents. Heavy metals which are often present in drill cuttings can present the greatest risk of all constituents present, and therefore stabilisation can be an effective tool for neutralizing this waste stream.

Commonly used additives include the pozzolans: cement, fly ash, lime and cement kiln wastes. Cuttings can be mixed with additives and moisture-conditioned using field equipment similar to biologic land farming or mixed in-place for use as a road sub-base material. Once the cuttings are stabilised they can be reused as a road stabilizing material, as a cover for berms or treatment areas, or can be disposed of in landfills (see below). Tests for leaching are typically performed prior to beneficial reuse of the stabilised materials.

## A10. Cuttings Recycling

There are opportunities to recycle drill cuttings and associated mud, provided that the hydrocarbon content, moisture content, salinity and clay content of the cuttings are suitable for the intended use of the material and meet or exceed all regulatory requirements.

### A10.1. Construction Material

After primary separation on shale shakers, cuttings are still coated with mud and may not therefore be suitable for recycling as construction materials. Additional treatment steps can be employed to render the cuttings more benign, e.g. the cuttings can be thermally treated to remove the hydrocarbon fractions, leaving behind a relatively clean solid material. Alternatively, the cuttings may be screened or filtered to physically remove most of the attached liquid mud. If cuttings contain too much liquid, they can be stabilized by adding fly ash, cement or, other pozzolanic materials to improve their ease of handling before they are converted into a final product such as:

- Bricks for construction
- Aggregate or filler in concrete, concrete blocks or concrete pads
- Paving slabs
- Fill material or daily cover material at landfills.

Other possible construction applications include use in pavements, encapsulation in bitumen for use as a road surfacing material, or use in cement manufacture. The economics of a given option is rarely based on the value of the finished product, but rather on its cost in comparison to alternative disposal options. Whatever disposal or reuse option is eventually chosen, legal liability will always stay with the company who produced the waste initially.

### A10.2. Road Spreading

**Figure A-8 Typical road spreading operation**

One use of cuttings is to stabilize surfaces that are subject to erosion, such as roads or drilling pads. Oily cuttings can serve the same function as traditional tar-and-chip road surfacing. This can be achieved by either hot or cold asphalting processes and would involve encapsulating the cuttings in Bitumen. There is some doubt over the structural integrity of rock cuttings drilled with water based muds; in addition not all regulatory agencies allow road spreading.

Where it is permitted, operators must obtain permission from the regulatory agency and the landowner before spreading cuttings.

Some jurisdictions limit road spreading to dirt roads within the operational area, while others may allow cuttings to be spread on public dirt roads.

Operators should make sure that cuttings are not spread close to stream crossings or on steep slopes. Application rates need be controlled so that no free oil appears on the road surface.

### A10.3. Restoration of Wetlands Using Cuttings

Another new application for drilling wastes involves using them as a substrate for restoring coastal wetlands. The US Department of Energy funded several projects to test the feasibility of treating cuttings and using them to help restore damaged wetlands.

The first phase of work involved greenhouse mesocosm experiments, in which several species of wetlands plants were grown in treated cuttings, topsoil, and dredged sediments (the typical substrate used in wetlands restoration operations). The results indicated that properly treated cuttings grew wetlands vegetation as well as the dredged material. No full scale field demonstrations of this promising waste management approach have been tried to date, but it is likely that the approach will be tested somewhere over the next decade.

## A11. Disposal Options

The options for the final disposal of drilling waste are essentially above ground, underground, or into the sea. In all cases, appropriate monitoring programmes are needed to ensure there is no deterioration of the surrounding environment.

### A11.1. Disposal on Land: Landfill

**Figure A-9 Typical landfill operation**

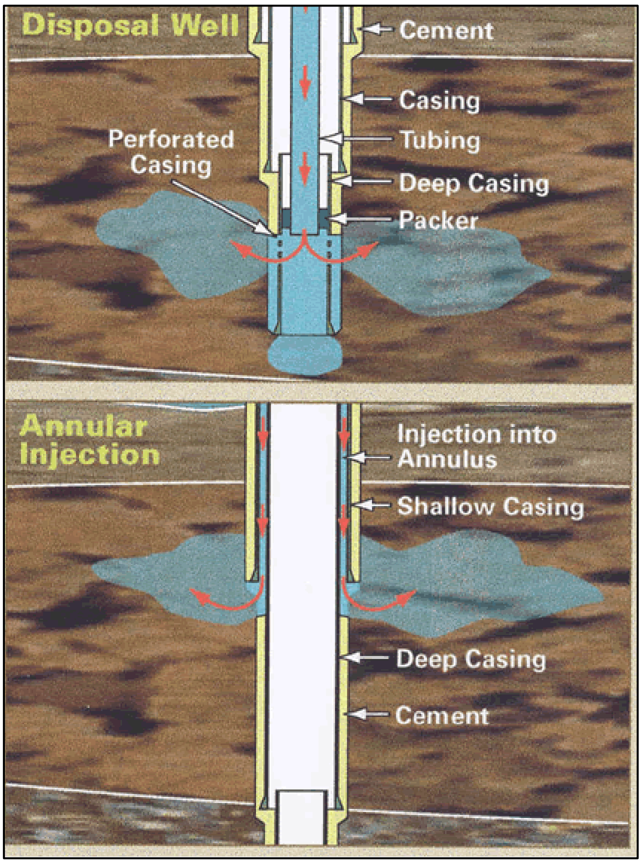
Landfill sites are specifically designated areas for the long term storage of waste. These sites are often sealed to prevent the waste from contaminating the wider environment, using clays or geo-membranes.

Normally, the quality of the seal is proportional to the hazard posed by the waste. Monitoring holes are placed around the facility so that it is easy to monitor the condition of the surrounding ground water.

A further development of this option given the low levels of hazard associated with cuttings may be to use some cuttings material to help make up the final landfill cover material. This would of course need to be accepted by the authorities and to pass any relevant environmental standards.

## A11.2. Disposal Underground: Onshore Cuttings Re-injection

**Figure A-10 Examples of injection processes**




This practice involves injecting drilling waste into underground formations for permanent disposal. The drill cuttings are ground into small particles and then mixed with water, or some other liquid, to make a slurry. The slurry is then injected into an underground formation at pressures high enough to fracture the rock.

There are two common forms of slurry injection: annular injection and tubing injection into a dedicated disposal well. Annular injection introduces the waste slurry through the space between two casing strings (known as the annulus). At the lower end of the outermost casing string, the slurry enters the formation.

Tubing injection into a dedicated disposal well involves either injection into a section of the open hole that is below all casing strings, or injection into a section of the casing that has been perforated with a series of holes at the depth of an injection formation.

Many annular injection programmes are designed to receive wastes from just one well. On multi-well platforms or onshore well pads, the first well drilled may receive the waste from the second well. For each successive well, the drilling wastes are injected into previously drilled wells. In this mode, no single injection well is used for more than a few weeks or months. Other injection programs, particularly those with a dedicated disposal well, may inject into the same well for months or years.

Different types of rocks have different permeability characteristics. Although rocks appear solid, they are made up of many grains or particles that are bound together by chemical and physical forces. Under the high pressure found at depths of several thousand feet, water and other fluids are able to move through the pores between particles. Some types of rock, such as clays and shale, consist of very small grains and the pore spaces between the grains are so tiny that fluids do not move through them very readily. In contrast, sandstone is made up of cemented sand grains and the relatively large pore spaces allow fluids to move through them much more easily.

Slurry injection relies on fracturing. When the slurry is no longer able to move through the pore spaces and the injection pressure continues to be applied, the rocks will crack or fracture. Continuous injection typically creates a large fracture that moves outward and upward from the point of injection. Using intermittent injection, it is possible to generate a zone of smaller fractures around the injection point.

Most annular injection programmes inject into shale or other low-permeability formations, while most dedicated injection wells inject into high-permeability sand layers. Regardless of the type of rock selected for the injection formation, preferred sites will have formations with the opposite permeability characteristics (high vs. low).

Locations with alternating sequences of sand and shale are the best candidates to contain fracture growth. The overlying low-permeability layers serve as fracture containment barriers, while the high-permeability layers serve as zones where liquids can rapidly leak off.

It is therefore essential to carefully select an injection site that has the right geology. Fracture propagation models are then used to predict fracture growth and optimal injection pressures. Injection pressures are then carefully monitored during the injection programme to ensure that the fractures do not breach the natural containment barriers in the rock or the manmade barriers provided by the casing and cement.

### A11.3. Offshore Re-injection of Drilling Wastes

The principles of re-injection offshore are essentially the same as for onshore. However, with exploration wells, usually only one well is drilled at any given location hence injection involves the following two storage and disposal scenarios:

- For tubing injection there needs to be sufficient storage space on the rig to store all the drilling waste generated from the entire well before it can be re-injected.
- For annular injection there needs to be sufficient storage space on the rig to store all the drilling waste generated until the well is deep enough for a suitable annulus to become available for injection.

A particular added difficulty with exploration drilling in deeper water is that the well head equipment is located on the seabed. This is because a floating rig is used which moves to some extent with waves and tides. The well head therefore needs to be secure during such movements and when, in particularly bad weather, the rig may need to decouple from the well. In shallower waters where jack-up rigs can be used for exploration drilling the wellhead can be located at deck level making re-injection of cuttings more feasible.

### A11.4. Disposal to Sea

In early offshore oil and gas developments, drilling wastes were generally discharged from the platforms directly to the ocean, using mainly water based muds. The use of oil based fluids started to become more widespread to meet the demands of ever more challenging well profiles (especially for offshore developments) and to reduce the risks involved when drilling water sensitive formations, especially in deep high pressure wells. However, there was increasing evidence that the consequence of discharging oil based muds was much greater than for water based muds.

#### *Oil Based Mud*

During the 1970s and 1980s, the results of sea bed monitoring programmes in the North Sea and Gulf of Mexico indicated that oil based mud cuttings could have undesirable long term effects on local ecology, especially when there was a high concentration of drilling sites. The cuttings piles created marked ecological impact zones within a 100m radius around the drilling sites, significant effects out to a 500m radius from the well and subtle effects out to around 1500m. The effects of the oil based mud cuttings piles on the local ecosystem arose from three mechanisms:

- Directly smothering organisms;
- Direct toxic effects;
- Indirect effects from the creation of anoxic (oxygen deprived) conditions by microbial;
- Degradation of the organic components in the waste.

During the 1990's, considerable research was carried out to develop:

- Less toxic mineral oils by the removal of aromatic chemicals
- Synthetic oils (e.g. Paraffin or olefins) that were often by-products from other refining activities
- Custom made products like esters that were especially designed to be more biodegradable.

These initiatives have only had limited success in reducing the environmental impact. Consequently, the discharge of oil based mud cuttings has either been phased out or is strictly controlled in most parts of the world.

The other approach that has been applied more recently is to clean the cuttings before discharge. Small offshore thermal desorption units have been developed that will, for example, meet the UK North Sea discharge limits of < 1% oil on cuttings, which is currently perceived to be a "safe" residual hydrocarbon level by the UK regulatory authorities.

### *Water Based Mud*

Cuttings generated with water based muds are more fragile than those generated with oil based muds. When discharged, WBM cuttings tend to disperse more readily in the water column and on the seabed than OBM cuttings. Any whole mud released into the sea also disperses more easily. This dispersion does lead to a greater distribution of fine materials in the water column, but in contrast leads to much less smothering of the benthos around the wellhead.

With water based muds, the conventional view is that the discharges of whole mud and cuttings are not generally environmentally harmful except in certain specific and highly sensitive areas. Such sensitive area may include coral reefs, areas with a high level of suspension feeding organisms present and other areas known to be sensitive to increased turbidity. This view is supported by a number of seabed surveys, primarily in the North Sea, the United States and in Western Australia.

Concerns have also been raised about the possible effects of fine materials in the water column interfering with filtration systems of plankton and other sea animals. This may be important at high suspended solids concentrations, but the effects are likely to be localised.

Water based muds themselves generally have a relatively low toxicity but care still needs to be taken with any additives to ensure that they are not too harmful.

# Appendix B . Health and Safety Issues

This appendix provides all of the relevant background information about how health and safety issues have been handled within the BPEO study process.

## B1. Sources of Information

Information was obtained from published sources, including information from the web together with information provided specifically by the project team and information from Aquatera's team experience.

### B1.1. Published Sources and Existing Reports

The following published sources have been used:

**UK Health & Safety Executive:**

Garvie (2004) Lifting Incident Review 1998-2003; HSE Research Report 183.

- Lifting incident data broken down into drilling handling, mechanical handling, equipment failure and human factors; looks for any evidence of decrease in number of incidents with introduction of industry safety initiatives.

HSE (2011) UK HSE Safety Bulletin. www.hse.gov.uk/offshore/statistics/stat0910.htm

- A detailed analysis of industry safety incident statistics broken down into operational groupings such as deck operations and drilling; successfully isolates the figures for lifting activities.

**Tullow Oil:**

TGL (2012) TGL Well engineering EHS incident reports for 2008-2011.

- Excel spreadsheet provides brief incident records by drilling unit and by incident type on a monthly basis over a 4 year period.

Tullow Uganda Operations (PTY) Ltd ( 2009) LDP Cuttings Disposal Options - Risk Assessment, Internal Report.

- This study was carried out for working in a remote African inland lake location. The paper breaks down each of six cuttings disposal options into their component tasks and risk assesses each task. Four of the disposal options are for full containment; they are divided into containment by bulk or by skip and ship, and by dewatering offshore on onshore.

Tullow Oil (2011) Environmental Managements System Public Statement for 2010 Operations Rev 0.

- Reporting of environmental performance indicators for operations in the UKCS, which include a skip and ship operation in the southern North Sea.

**International Association of Oil and Gas Producers (OGP) Publications:**

OGP (2002) Safety Performance of the Global E&P Industry 2001. OGP Publications, Report NO. 6.59/330.

OGP (2007) Safety Performance Indicators 2006 data. OGP Publications, Report NO. 391.

OGP (2012) Safety Performance Indicators 2011 data. OGP Publications, Report No. 2011S.

- All annual OGP publications above provide worldwide data on Fatal Accident Rate, Total Recordable Incident Rate, Lost Time Injuries, together with analysis of causal factors.

OGP (2010) Risk Assessment Data Directory, Land transport accident statistics. OGP Publications, Report NO. 434-9.

- Provision of land transport (including road and rail) accident statistics for a wide range of countries in Europe, Africa, Asia, Middle East and Oceania for given years; (Ghana data for 2001).

Kirkness, A. & Garrick (2008) Treatment of Nonaqueous-Fluid-Contaminated Drill Cuttings - Raising Environmental and Safety Standards SPE Report; IADC/SPE 112727.

- This paper presents a strong argument for cleaning cuttings offshore with a Rotomill thermal desorption process, however it is noted that the authors are from a commercial rather than an academic institution, hence bias is inevitable.

### B1.2. Requested Data, Derived Data and Assumptions

The following additional data requirements were explored.

**Table B-1 Information needs and sources used from non-pulished information**

| Data requirements | Response from Client | Reference / Data Source |
|---|---|---|
| Is there a significant safety risk associated with ship to shore? | Yes! TGL believes that given the current lack of experience (offshore/onshore) of this waste mgt. route a significant increase in all risk profiles (safety, logistics, environmental, economic, carbon footprint et al) would ensue with the adoption of this method of disposal! | TGL HSE team |
| Comparative safety risk of different options | TGL safety statistics show that lifting is responsible for around 10% of incidents – about 4-5 per year | TGL HSE team; See Tullow (2012) safety statistics document above |

## B2. Key Input Data

### B2.1. Skip and Ship Safety Issues

Regardless of the choice of technology to move cuttings from the shakers to skips or big bags on the rig deck, the 'skip and ship' option involves numerous handling operations. Crane manoeuvres are required to load full skips/bags onto supply vessels and to unload empty skips to the deck. Typical well generating 1000 tonnes cuttings would require 200 skips for containment. A number of hazards are associated with the entire cuttings containment operation (Table B-2)

**Table B-2 Risk profile of some key tasks and hazards associated with full containment of cuttings (taken from Tullow 2009).**

| Task | Hazards |
|---|---|
| Installation of equipment on the rig | People injuries (caught between, struck by equipment, working at height, tools & equipment, manual handling, slips, trips & falls; isolation/LOTO, electrocution), fire risk, confined space, permit to work, |
| Cuttings collection on the rig | People injuries – Caught between rotating equipment, Caught between, Struck by equipment; Equipment damage – blocked lines; Environmental spills; Choked conveyers; Noise induced deafness, |
| Transfer of cuttings from the rig to the transportation barge | People Injuries (Caught between, Struck by Equipment); working at height, tools & equipment; Manual handling, Slips, Trips & Falls, Drowning |
| Collection of fluids on the rig and transfer of fluids to the barge | People Injuries (Manual handling, Slips Trips & Falls); Environment (Loss of containment) |
| Rig down equipment on the rig at the end of the project | People Injuries (Caught Between, Struck by, working at height, tools and equipment, manual handling, slips trips & falls, Drowning. |

### B2.2. UK Experience of Lifting Operations and Safety

Zero discharge of OPF cuttings was introduced in the North Sea on 16 January 2001 under OSPAR Decision 2000/3[2] that effectively eliminates the discharge of NADFs. The UKCS, HSE figures show that in the lead up to and immediately following this recommendation, lifting incidents accounted for 18.6% of total incidents during the 6 year period 1998-2003[3] ( Figure B-1). Of these, approximately 58% was attributed to mechanical handling i.e. crane operations; thus 10.8% of total incidents were attributed to lifting with cranes.

**Figure B-1 Frequency of lifting incidents in the North Sea UKCS (from Garvie 2004)**

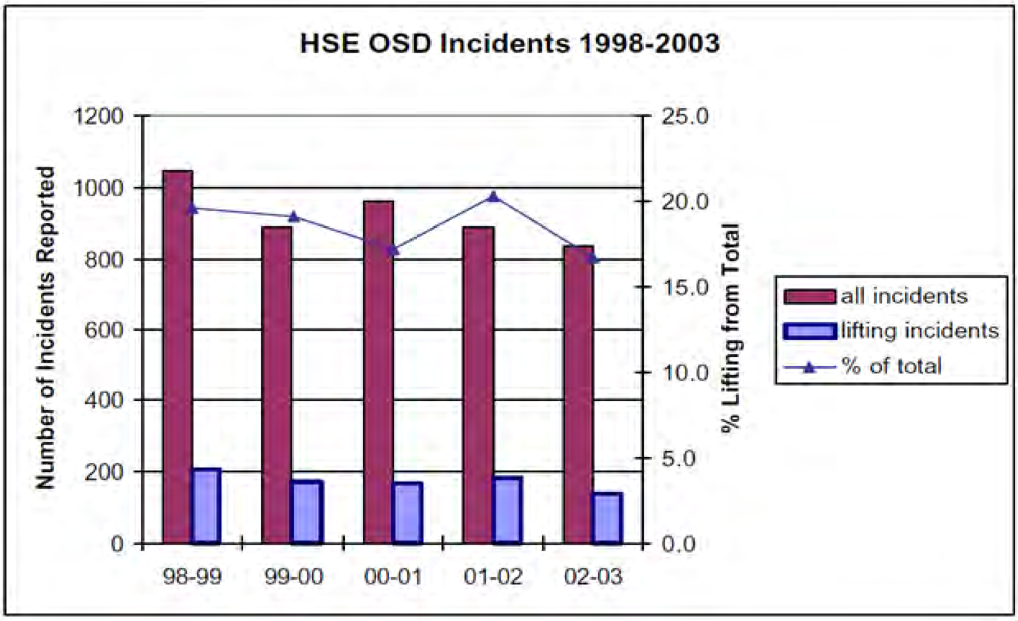
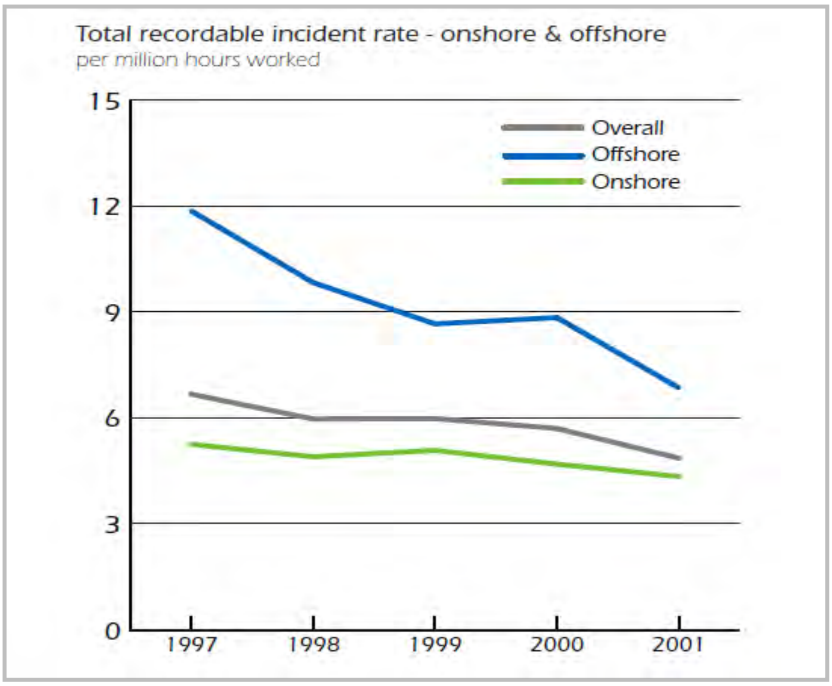



**Figure B-2 Total Recordable Incident Rate 1997-2001 (from OGP 2002)**

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[2] OSPAR Decision 2000/3 on the Use of Organic-Phase Drilling Fluids (OPF) and the discharge of OPF-Contaminated Cuttings.

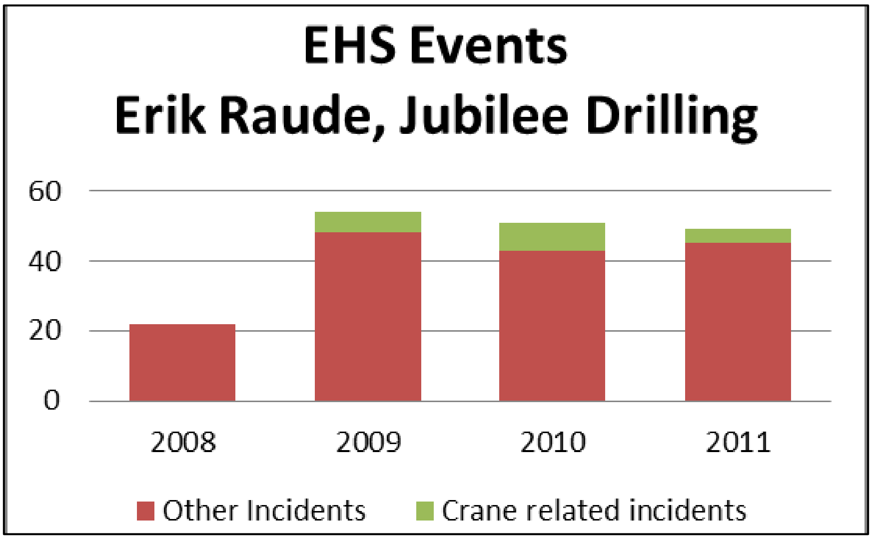
[3] Garvie (2004) Lifting Incident Review 1998-2003; HSE Research Report 183.

The root cause of 59% of the total lifting incidents was ascribed to human factors and 33% to equipment failure (the remaining 8% unattributed). A significant decrease (32%) in the number of incidents per year occurred over this 5 year period which coincides not only with the introduction of the Lifting Operations and Lifting Equipment Regulations (LOLER) and the OG industry's Step Change in Safety campaign, but also an increase in skip and ship operations in the North Sea leading up to and through the 2001 change in regulations which brought in the reduction to 1% o.o.c permitted discharge. No OBM cuttings have been discharged in the UKCS since 1996; and no discharge of OBF cuttings since 2002[4]. A general decrease in incidents was also seen through 1997 – 2001 (Figure B-2).

### B2.3. Ghanaian Safety Performance

TGL's own safety statistics for the Jubilee drilling campaign[5] show a small number of crane related incidents over this 3.25 year period; the number varied between 8% and 12% of the total EHS incidents each year, which is similar to the UKCS percentage of 10.8%.

**Figure B-3 TGL accident statistics; source Tullow 2009.**




### B2.4. Total Recordable Incident Rate (TRIR)

Global safety performance indicators (Figure B-4) show that Africa's 5 year rolling TRIR per million hours worked for drilling (company personnel only) rates fifth highest out of seven regions and decreased very slightly in 2011 to just below the global average of 1.58. The highest recorded figures are from Europe where comparable numbers are approximately 1.9 for the 4 year average 2006-2010 rising to 2.1 in 2011. Contractor figures tend to be higher throughout all countries, with Africa still rating fifth out of the seven regions for the rolling four year average, but rising to fourth in 2011 as figures in the Middle East improved dramatically.

In summary, whilst there is no direct evidence from North Sea operations that indicates there will be a significant increase in accident frequencies, it is clear that eliminating the hazard of additional crane lifts will make the operation safer; what is not clear is by how much.

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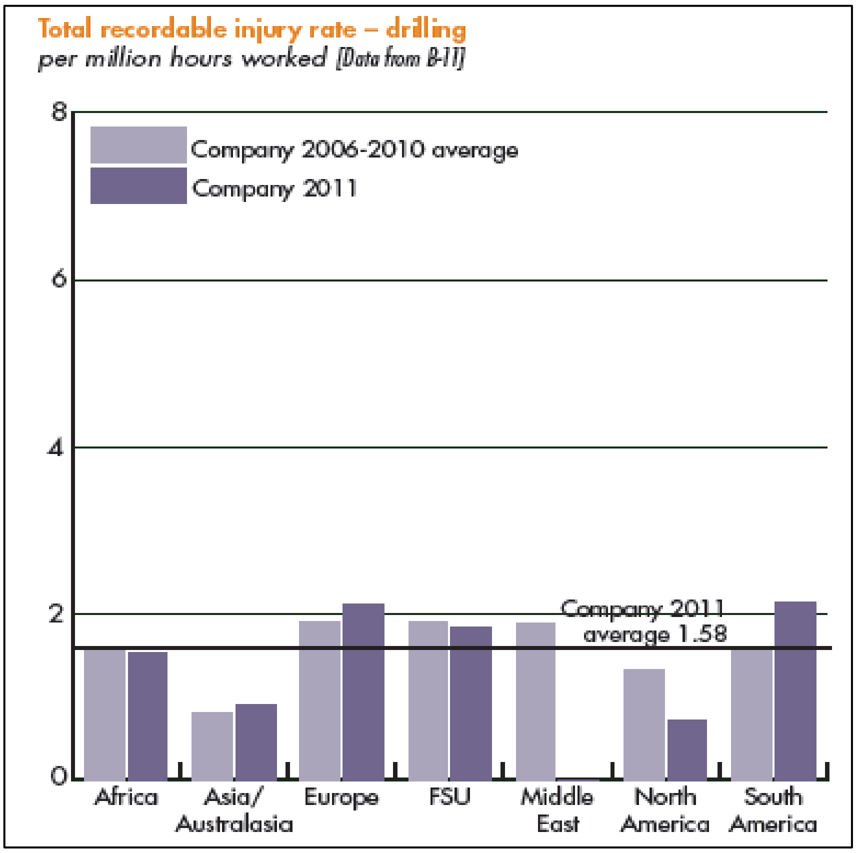
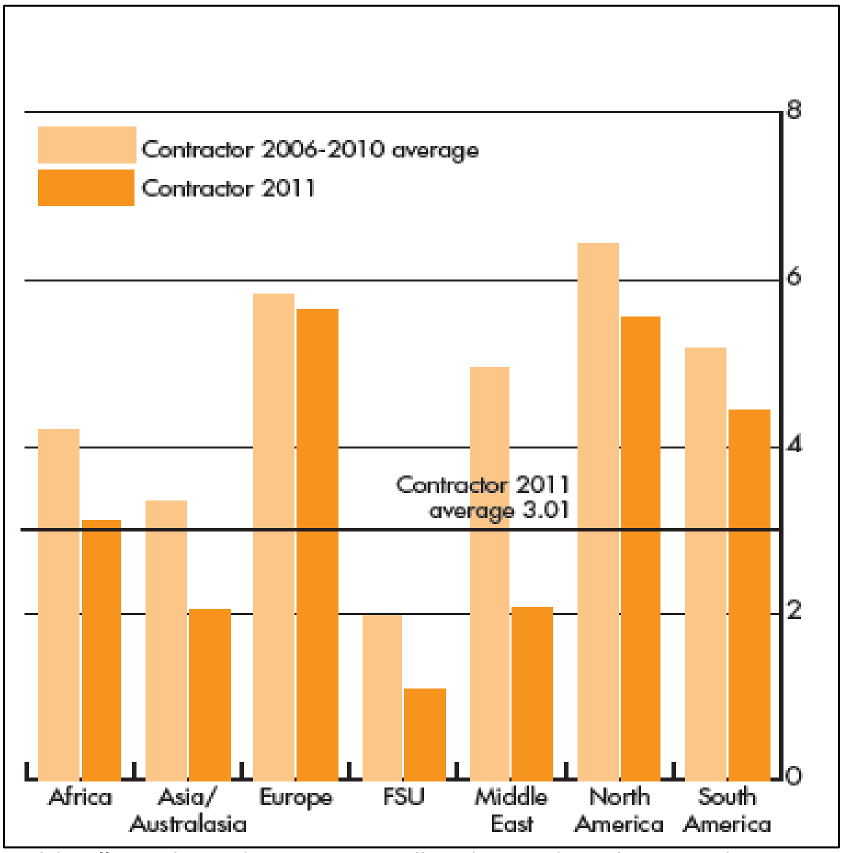
[4] OSPAR 2007 Summary Record OSPAR 2006.

[5] TGL Drilling EHS Incidents, Jubilee, 2008-2011

**Figure B-4 Total Recordable Injury Rate (TRIR) – drilling. [Taken from OGP 2012]**



## B3. Evaluation of Absolute Scores

The following table details the justification and scores relating to health and safety issues for all of the options.

**Table B-3 Scores and justification relating to health & safety issues for all options**

| Option | Score | Comment |
|---|---|---|
| Water Based Muds | -2 | Minor first aid type injuries quite common from contact with potassium or sodium hydroxide which are used extensively and can cause alkali burns if in contact with skin or eyes. This can occur during mixing and treatment of drilling fluid. There are also health risks associated with exposure to chemical dust. Tullow operations policies recognise these risks (ref). It has therefore been assumed that exposure is properly managed by the use of personal protective equipment (gloves, eye protection, aprons), the appropriate ventilation of mud mixing areas and the use of dust masks. Accidental spills, over-spilling of WBM on the drill floor can occur regularly and any spillages are directed into drains and over the side of the rig. |
| NADF | -2 | NADF drilling fluids will be frequently spilled on the drill floor whilst tripping (making up or dismantling drill pipe. This in turn leads to mud soiled overalls and skin contact. Chemical components of NADF are less benign than WBMs, though group III NADF fluids present fewer occupational health hazards, through removal of potential carcinogens, than group II low toxicity oil based muds. Exposure to vapours in an enclosed, often humid, warm atmosphere could present some respiratory problems after extended exposure. There is a low likelihood of injuries or accidents involving people. Score assumes effective ventilation systems are in place on the modern rigs being used by Tullow, considered essential for protecting persons at risk. PPE and training in chemical handling are assumed throughout to counter the inherent potential risk to lungs, eyes, nose, and throat and skin. Overall NADF is more hazardous than WBM but not enough to merit -3 if adequate ventilation is in place. |
| Cuttings Drier | -2 | Cuttings driers are in routine use within Tullow Ghana operations; hence crews are trained in their maintenance and use, a factor which reduces risk of injury. Cuttings driers are simple items of equipment normally operated by one crew member. Therefore such machinery has an inherently low likelihood of injuries or accidents involving people. However crews may be subject to long periods working in the mud processing area with associated exposure to organic vapours as above. |
| Thermal Desorption | -2 | The main source of accidental events is most likely to be during the installation and decommissioning, but it is not thought that the risk of an accident is going to be appreciably higher than normal. Score due to working in potentially hazardous atmosphere with good HVAC ventilation and appropriate training. |
| Disposal At Sea Onsite - WBM | 0 | WBM discharge to sea takes place during riserless drilling of the top hole sections There is no contact with any offshore workers. Opening dump valve to discharge to sea does not involve additional hazards. |
| Disposal At Sea Onsite - NADF @<5% | 0 | Discharge to sea does not involve additional health and safety hazards. |
| Disposal At Sea Onsite - NADF <1% | 0 | Discharge to sea does not involve additional health and safety hazards. |
| Bulk Cuttings Transfer | -1 | Normal or only slightly elevated level of risk over normal operations in an offshore environment. No additional risk to normal lifting and handling operations as this system which greatly reduces crane operations. They are restricted to installation of the high capacity tank/frame system and lifting of the tank when full. Safety statistics are likely to compare very well with normal operations given the estimated 800 crane operations[6] per well when using a skip & ship system for cuttings containment. As the system contains the cuttings as they leave the shakers, there is very little further exposure to toxic chemical vapours from NADF fluids. |
| Hybrid Cuttings Transfer | -2 | Hose transfer offshore reduces and simplifies crane movements at sea which are more hazardous than dockside crane operations. Risk levels increased slightly due to number of hose connection operations. |

[6] Based on 1000 tonnes cuttings per well, 4 crane operations per skip.

| Option | Score | Comment |
|---|---|---|
| Skip And Ship | -3 | See section B2.2 for full details. There can be as many as 15 crane lifts to move a skip full of cuttings from the rig to the supply boat, to shore and onto the processing site[7]. Per well lifts can therefore be in the order of 800 and additional crane lifts for the whole TEN programme could be of the order of 15,000 lifts (assuming 15 lifts per skip). Lifting accounts for around 10% of accidents offshore of 5 incidents a year. Although accident statistics from the UK offshore sector show that lifting incidents actually fell over recent years the trends for Ghana are less clear. An additional 15,000 lifts could add perhaps 10% to the total number of lifts at present, adding proportionately 0.5 to 1 incident per year to local accident rates. |
| Road Transport | -2 | In every society that has roads there is a tolerated level of risk in for commercial drivers, private cars and in terms of public exposure to road traffic accidents. The levels of ambient risk in Ghana are higher than in the UK, for example. Traffic volume on Ghana's roads is low compared to UK, but frequency of accidents is 2.5 times as high and the fatality rate is 12 times as high[8] .<br>Assuming 10 tonnes of cuttings could be transported per truck over 50 km round trip from the dock to the treatment/disposal site, using OGP statistics (below), there will be 8% chance if an accident resulting in an injury and a 1% chance of a fatality over the planned operation. These accident rates do not include an incidents associated with onshore lifting during loading and unloading. No figures are available for this activity but there will be further risks from these activities. Taken as a whole the process is scored as -2, though it could be argued that this it should be -1. |
| Onshore Thermal Desorption | -1 | This technology is associated with general processing hazards; leading to a risk of injury from using heat and some health risks from exposure to concentrated volatile compounds given off as vapours. All hazards require good plant management and training of personnel to provide a safe working environment. There is a low likelihood of injuries or accidents involving people. |
| Cutting Pit | -1 | Generally a low risk operation; input of cuttings materials carried risks associated with normal digging and earth moving operations; considerable manoeuvring of vehicles within site. Risks similar to slurry pits on farms. Additional risk of exposure to vapours. |
| Non-Structural building materials | -1 | Low likelihood of injuries or accidents involving people. Generally a low risk operation, but there is risk to health from fumes if equipment not maintained; There is the potential for manhandling of drilling wastes, for which gloves and appropriate PPE should be worn. The inherent risks to lungs, eyes, nose, throat and skin from NADF coated cuttings will present the same occupational health hazards as the virgin NADF. |
| Landfill Cover | -1 | Low likelihood of injuries or accidents involving people. Landfill sites in particular may have residual contamination issues that constitute a health hazard. Operations themselves should be low risk, comprising vehicle manoeuvring, tipping and spreading. Some risk from residual vapours. |
| Land Farming | -1 | Low likelihood of injuries or accidents involving people. Risks similar to those experienced by farmers as machinery would be used to spread the cuttings and occasionally till the soil. |

[7] KIrkness & Garrick, Treatment of Nonaqueous Fluid contaminated drill cuttings – Raising Environmental and Safety standards SPE 112727 (2008)

[8] OGP (2010) Risk Assessment Data Directory, Land Transport Accident Statistics. OGP Report No. 434-9.

# Appendix C . Technical Issues

This appendix provides all of the relevant background information about how technical issues have been handled within the BPEO study process.

## C1. Sources of Information

Information was obtained from published sources, including information from the web, together with information provided specifically by the project team and from Aquatera's team experience.

### C1.1. Published Sources and Existing Reports

The following published sources have been used:

**General Review**

Jacques Whitford Stantec Ltd (2009) Cuttings Treatment Technology Evaluation. Environmental Studies Research Funds, Report No. 166.

- Review of solids control systems and their performance efficiency from two Canadian operations; Indications that the legal OOC limits (for synthetic oils) are seldom achieved throughout the whole well, although achieved in certain sections; overall performance of less than 10% of the total treated mass of cuttings in the 15 wells studied achieving the required 6.9%. Cuttings dryers and thermal desorption are the two most common secondary solids control systems in use on the east coast of Canada.

**Options for cuttings waste stream:**

Bagit (2012) http://bagIt.co.uk

- Commercial data presented on specification and advantage of using Chubby Bag.

Schlumberger 2012 www.slb.com/services/miswaco/services/drilling_waste_managment/cuttings

Drilling Waste Management Information System (2012) http://web.ead.anl.gov/dwm/techdesc/

- Various pages with descriptions and technical specifications for a number of the drilling waste management options proposed in this BPEO report.

ERM (2010) Assessment of Waste Treatment and Disposal Options for Priority Waste. Report to Tullow Ghana Ltd.; 0119372/01/03.

- Information on local and regional ability to handle drilling waste streams including cuttings; recommendations for short, medium and long term management in the light of anticipated Ghanaian infrastructure and technical plant development.

OGP (2009) Guidelines for Waste Management with Special Focus on Areas with Limited Infrastructure; Rev 1. OGP Report No. 413.

Specifications and behaviours of drilling fluids:

Exxon Mobil (2012) Escaid 120 MSDS

- Mud specification and attributes

Galate, J.W. & Mitchell, R.F (1986) Behaviour of oil muds during drilling operations. SPE Drilling Engineering Vol 1 (2), 97-106.

M I SWACO (2006) Environmental sensitive Ultradril water-base mud used to access targets offshore Cameroon. M I Swaco website.

**Selection of Drilling Fluids:**

M I Swaco (2012) Tullow Ghana Core J-16 GI; Shale Characterization and Stability Study. Report to Tullow Ghana Ltd.; FES12-03.

- Evaluation of cores from the adjacent Jubilee field to help assess the extent of any scope for using WBM fluids in deeper formations.

Schlumberger 2012
www.slb.com/services/miswaco/services/drilling_fluid/df_systems/water_base

Simpson, J.P., WALKER, T.O., O'Brien-Goins-Simpson & Assocs.Inc and G.Z. Jiang (1995) Environmentally acceptable water-based mud can prevent shale hydration and maintain borehole stability. SPE Drilling and Completion Vol 10 (4), 242-249.

Tullow Oil (2012) TEN Development Discharged Oily Cuttings Options and Strategy Report, Rev 3. Internal Report 000002-TLW-WE-RPT-0004.

Tullow Oil (2012) Drill Cuttings and Fluids Disposal Guidelines Rev 0. T-WEL-GUD-0002

## C1.2. Requested Data, Derived Data and Assumption

The following additional data requirements were explored:

**Table C-1 Additional data sought for the study**

| Data requirements | Response from Client | Reference/ Data Source |
|---|---|---|
| Drilling fluids: What NADF/OPM mud specification will be selected for this current project? Will it be the same or similar to the Jubilee wells? What % of wells with 8 1/2" hole using WBM? | All phase 1A wells have similar mud to Jubilee phase 1. Only new mud will be a WBM which will be used in the reservoir section of the horizontal well (J-19) and may be used in the reservoir sections of other production wells. TEN to be similar. No 81/2" holes to be drilled on any TEN well. | TGL project team |
| Current operations - need to clarify what happens to the non-cuttings waste stream - sludge (10% of total volume with c40% oil v/v - is this discharged to sea? | Centrifuge fines are co-mingled with drier cuttings discharge and discharged overboard meeting 3% OOC; remaining centrifuge sludge is cleaned at end of well and backloaded to shore as part of routine oily waste for hazardous waste disposal. | TGL project team |
| Onshore Cuttings Reception - facilities at deep water ports Takoradi or Tema would be required to handle cuttings as they are special (hazardous) waste. Do any of these handling facilities exist? Facilities need to be able to offload and store a ship load of cuttings - transfer to WDF. Location of proposed cuttings treatment? | Yes facilities are available on a limited scale - current facilities are only capable of handling small volumes of cuttings and are not designed or suited to treat cuttings from an entire well. | |
| Performance targets: As per EPA stretch target applied to Jubilee, has Tullow investigated how to achieve <1% oil on cuttings using offshore treatments such as Rotomill? | Yes, offshore Hammermill have been investigated | 00002-TLW-WE-RPT-0004 Discharged Oily Cuttings Options and Strategy Report Rev 3.pdf |

| Data requirements | Response from Client | Reference/ Data Source |
|---|---|---|
| Supply vessel availability - are there any constraints beyond cost e.g. quay space? | Tullow has 1 dedicated berth in Takoradi harbour | |
| Waste Management Facilities: Do any other operators in Ghana have any plans for long term waste management facilities? | Basic facilities do exist for all non-hazardous and some hazardous (H/C based) waste streams. Incineration and/or TDU facilities are being planned by 2 companies but, are still at a very early stage. | Ghana National Waste Strategy Report - TGL/ERM 2011 |
| Cuttings discharge: What drilling systems would need to be in place to ensure no discharge of cuttings contaminated with reservoir oil | Transfer to ship | |
| Drilling fluids: Will WBM be used to drill the upper sections (36" and 26") of TEN wells currently being planned? What types of mud are planned? Constituents (broad description and toxicity data) Are the newer well profiles and geology similar to Jubilee wells? | WBM is seawater with Guar Gum and Pre-hydrated gel sweeps. Constituents:<br>Seawater Soda Ash<br>Barite Duovis<br>Bentonite Polypac<br>Caustic soda CaCl2 | Jubilee EIA - Appendix B<br><br>MI mud programmes and MSDS |
| Details of NADF muds that are being used – what is the OGP classification and composition of base oil (olephin type, paraffin, mineral oil etc.) | NADF is the same as in Jubilee phase 1 i.e. ESCAID 120.<br><br>ESCAID 120 is a de-aromatised mineral oil. Widely used within the region. Substitution with purely synthetic, slightly more biodegradable base oil. (LAO or internal olefin) is commercially difficult because of shared facilities with other operators. Could consider long term phase in of alternatives. Cost benefit TBA | Jubilee EIA Annex B;<br><br>TGL Project Team telecom 080512. |
| Drilling fluids: What is the justification for using NADF fluids on mid 17.5" and lower 12.5" well sections as opposed to continuing with WBM? Are newly planned wells to be drilled in a similar manner to Jubilee wells? | NADF has many advantages over WBM;-<br>1) low reactivity with claystones<br>2) Less stuck drillstrings<br>3) lower torque and drag<br>4) less corrosion<br>5) less casing wear<br>6) less hole collapse<br>7) lower drilling risk<br>8) fewer lost hole sections<br><br>New wells will be drilled with 16" hole instead of 17-1/2" hole to reduce the volume of cuttings generated. | Well documented in numerous SPE papers |
| Well design - Slim-hole designs - to what extent have slim hole designs been considered? Clarify & provide brief history of slim hole well design and associated risk. | We have drilled several slim hole wells in Jubilee phase 1, however, the risk of insufficient structural support for the well is higher with the slim-hole well design. Current view is that the risks associated with the slim-hole design are not acceptable.<br>16" hole is being drilled instead of 17-1/2". | Risk is a generally accepted fact; TGL project team |

| Data requirements | Response from Client | Reference/ Data Source |
|---|---|---|
| Well profiles - details of drilling programme for typical well, Hole sizes, casing depths, lithology column | The well profiles for phase TEN are not finalised yet; the most common casing sizes used likely to be:<br>36" conductor jetted from 1,200m to 1,280m (80m)<br>26" hole = 20" casing<br>16" hole = 13-3/8" casing<br>12-1/4" hole = 9-5/8" casing<br>8-1/2" hole = 7" liner or screens | Geological Programme and Drilling Programme |
| As for well profiles for Phase 1A, but adding additional well profiles if they can be grouped (typical, vertical, sidetrack, horizontal etc.) | Assume 25 wells for TEN in total | Jubilee Phase 1A Development plan |
| CRI - is this a feasible offshore option? Broad overview of offshore storage options for cuttings - availability of cuttings reinjection wells? | CRI is not an option with current deepwater wellhead technology; reviewing cost estimates | Dril-Quip: Email from Allan Gibson CRI Offshore 080512 |
| CRI: Cuttings Reinjection at dedicated offshore disposal well remote from platform - this requires skip and ship and injection via a dedicated buoy and riser system. Are any cuttings disposal wells available? Was the drilling of dedicated cuttings reinjection wells considered during well planning and design for Jubilee? Will it be considered for further wells in West field? | CRI in deepwater would be technically challenging and has never been attempted. | Industry knowledge |
| CRI: Cuttings Reinjection at dedicated disposal well owned by 3rd party. Are any other operators on Ghana CS considering/planning to reinject cuttings? Would use of a 3rd party well be a practical option or indeed a legal option? | No operators are reinjecting cuttings in Ghana. | Industry knowledge |
| Cuttings collection on platform and ship to shore for processing: are there any constraints that lead to choosing a particular approach e.g. skip and ship over say vacuum transfer | Either option to transfer the cuttings would be possible. Also pneumatic transfer is possible. | MI cleancut pneumatic cuttings transfer system. |
| CRI at a dedicated Tullow location with dedicated injection well- is this an available or potential option onshore? Would it be acceptable to regulators? | The option to ship the cuttings to an onshore cuttings disposal well is not available. Tullow does not own any onshore licenses and therefore is not allowed to drill onshore. | fact |

| Data requirements | Response from Client | Reference/ Data Source |
|---|---|---|
| Onshore cuttings treatment - thermal desorption: Is the thermal desorption process available onshore anywhere? Could it be brought in to the region from elsewhere with trained operators? | This treatment option is thus far not available in Ghana although it is being considered for implementation by at least one Ghanaian waste management company? It is thought that the nearest TDU is stationed in Nigeria. There are (also) no methodologies currently available for handling/dealing with the residues arising post TDU treatment. TGL still firmly believes that should skip n ship be forced on the current oil/gas operators, people WILL be hurt. | TGL project team<br><br>ERM (2010) waste study |
| Onshore cuttings treatment - bioremediation. This requires a dedicated site where compostables are mixed with the cuttings waste and inoculated with special bacteria; monitoring would be required. | TGL is currently considering this treatment mode as a standby alternative for remediating any hydrocarbon soiled beach material post offshore Tier 2 or 3 spill. Not considered an option for drill cuttings though as it would mean purchasing/leasing local land for this purpose? | TGL Project Team<br><br>ERM (2010) waste study |
| Onshore cuttings disposal - Landfarming of cleaned cuttings - is there any precedent onshore in Ghana for this operation? | This treatment option is thus far not available in Ghana although it is being considered for implementation by at least one Ghanaian waste management company? It is thought that the nearest TDU is stationed in Nigerian. There are (also) no methodologies currently available for handling/dealing with the residues arising post TDU treatment? TGL still firmly believes that should skip n ship be forced on the current oil/gas operators, people WILL be hurt. | TGL Project Team<br><br>ERM (2010) waste study |
| Onshore cuttings disposal: Hazardous landfill sites - are there any sites currently available onshore? | This is definitely not an option. TGL have neither the resources or will to plan, implement and maintain a 'best practice' municipal land-fill site (not CORE business). It is known that the appropriate Ghana metropolitan authority is also not planning a project of this type. | TGL Project team<br><br>ERM (2010) waste study |
| Onshore cuttings treatment - fixation: This requires a dedicated site; waste is mixed with chemical fixative - lime/cement - or encapsulated to prevent leaching; disposal to secure landfill; monitoring required. | This treatment option is thus far not available in Ghana although it is being considered for implementation by at least one Ghanaian waste management company? It is thought that the nearest TDU is stationed in Nigeria? There are (also) no methodologies currently available for handling/dealing with the residues arising post TDU treatment? TGL still firmly believes that should skip n ship be forced on the current oil/gas operators, people WILL be hurt. | TGL Project team<br><br>ERM(2010) waste study |
| Onshore cuttings disposal: Road construction companies onshore Ghana - are there currently any Ghanaian companies who could be approached about potential for using OBM cuttings as base material for roads? | This would be a very tortuous process from start to finish! Outside Accra, there is only a very rudimentary road infrastructure and also, future requirements for road surfacing materials are a big 'unknown'? | TGL project team<br><br>Fact; |

| Data requirements | Response from Client | Reference/ Data Source |
|---|---|---|
| Onshore disposal - Brickworks - is there currently any sites onshore which would accept OBM cuttings as material to incorporate into brickmaking? | This would be a very tortuous process from start to finish! Outside Accra, there is only a very rudimentary road infrastructure and also, future requirements for road surfacing materials are a big 'unknown'? | TGL project team;<br><br>Fact; |
| Onshore cuttings disposal - Incineration- is this an available or potential option? | This treatment option is thus far not available in Ghana although it is being considered for implementation by at least one Ghanaian waste management company. There are (also) no methodologies currently available/known for handling/dealing with the residues arising post TDU treatment? TGL still firmly believes that should skip n ship be forced on the current oil/gas operators, people WILL be hurt. | TGL Project team<br><br>ERM(2010) waste study; |

## C2. Key Input Data

### C2.1. Technical Risk Arising from Use of Water Based Muds

Water based mud is a well proven technology. However using WBM to drill rock formations that contain a high proportion of water montmorillonite or bentonite clays can result in extensive technical problems and delays. Contact with the drilling fluid causes the clay to swell which can cause a number of adverse borehole conditions and non-productive time (NPT), depending upon the montmorillonite content of the shales. These include:

- Tight hole when tripping as the hole swells around the bit and larger diameter drill collars. This requires the drill string to be worked through the tight section or washed/reamed using the mud pumps, all of which adds considerable time.
- Additional "wiper trips" where the drill string is pulled out of the open hole and run back to bottom to assess the condition of the hole before running logs or casing. Accumulation of drilled cuttings in the annulus causing a blockage or "packing-off". The drill string has to be worked up and down to try and break up the cuttings and release the blockage. This exercise can often lead to the drill string becoming stuck. If the drill string becomes stuck, the well normally has to be side tracked.
- Wellbore wash outs as the unstable shales collapse. This can give rise to ledges in deviated holes which can cause problems running casing and poor cementation of the casing, which can compromise well integrity.
- Higher risk of bit balling with reduced drilling performance or having to change the bit

In this deepwater environment there are additional issues arising from being unable to land the casing in the wellhead because of hole collapse or poor hole conditions. It is very easy to stick the casing under these conditions, especially in highly deviated holes. The first option would be to pull the casing back out of the hole, then to go back in with the bit to try and improve the condition of the well bore. This scenario carries a risk of getting stuck on the way out. Finding remedy for stuck casing would be complex and time consuming and extremely expensive, whilst drilling in deep water can be very costly. Tullow Oil suffered a $300MM NPT cost in a recent deep water well drilled by TGL in French Guyana; the majority of NPT here was attributed to wellbore instability due to running WBM. Costs included the loss of more than 3 Bottom Hole Assemblies and the drilling of a mechanical sidetrack taking almost one year.

There is only a very limited amount of information available to estimate the length and type of NPT that could be encountered. One approach is to look at the amount of montmorillonite in cores using X ray diffraction. Analysis of a core section from a Jubilee well (J16 GI) at 3183m in the late cretaceous revealed around only 15% montmorillonite content – about the same as the illite content, with large amounts of quartz present[9]. Swelling tests indicated that the clays from this section were only moderately active. This moderate activity of the clays is consistent with the age of the formation.

Table C-2 shows that the tertiary sediments, where clays are normally the most active, are above the 20" casing. The 16" and 12 ¼" sections are in the Cretaceous and only become slightly overpressured to 1.3SG equivalent below the 13 $^{3}/_{8}$" casing shoe. As the clays get older, the montmorillonite gets converted to illite as the water gets squeezed out through digenesis; thus the clays become less reactive. They only remain active if the water does not get squeezed out and starts to support the overburden, resulting in them becoming overpressured. So for the shales to be highly reactive, one would expect higher pore pressures throughout entire 16" and 12 ¼" hole sections.

It would therefore appear that the shales are only moderately reactive, with relatively short hole sections of 1000-1500m. The period during which the bore-hole is open and exposed to the drilling fluid is relatively short and unlikely to exceed the 10 days, at which problems might start to appear. The moderate reactivity of the shales coupled with the relatively short drilling times would indicate that the sections could be drilled successfully with WBM.

Unfortunately, it is not possible to test this with direct evidence of potential Non Productive Time (NPT) from using WBM in the area, as all, or nearly all the deepwater wells in Ghana have been drilled with NADFs and so there are no comparisons available.

A case for replacing NADF with WBM could be made on the basis that the if the shales are only moderately reactive, with relatively short hole sections of 1000-1500m. The period during which the bore-hole is open and exposed to the drilling fluid is relatively short and unlikely to exceed the 10 days, at which problems might start to appear.

**Table C-2 Details of anticipated geological sequence and associated drilling risks**

| Horizon | MD BRT (m) | Lithology | Related issues |
|---|---|---|---|
| *Mean sea level* | 24 | | |
| *Sea Bed* | 1755 | | |
| **Tertiary**<br>Miocene Unconformity | 2277 | Claystones with occasional sandstone beds | Above 20" casing: geological time where clays are normally most reactive<br>**20" Casing 2530m** |
| **Base Tertiary** | 2624 | Claystones with occasional sandstone beds | Low pore pressure consistent with digenesis and conversion of highly reactive montmorillonite to much less reactive illite |
| **Late Cretaceous**<br>Top U Campanian Fan | 2884 | Sandstone some massive with sand/shale interbeds | |
| Base U Campanian Fan | 3172 | | |

[9] MI Swaco (2012) TULLOW GHANA Core J -16 GI Shale Characterization and Stability Study

| Horizon | MD BRT (m) | Lithology | Related issues |
|---|---|---|---|
| Top Lower Campanian Fan | 3340 | Occasional sandstones, some massive, with sand/shale interbeds | **13 $^{3}/_{8}$” casing 3230m** |
| Base Lower Campanian Fan | 3585 | | Pore pressure starts to increase 1.3 S.G. – slight overpressure – |
| Top Tweneboa Fan | 3816 | Interbedded silt and shale | No clays should be stable |
| Top Reservoir | 3841 | Massive sandstone unit | |
| Base Reservoir | 3865 | | |
| Base Tweneboa Fan unit | 3893 | Claystones, with minor thin sandstone interbeds, | Possibility of more reactive clays |
| Base Turonian Fan | 3977 | Claystones, with minor thin sandstone interbeds | |
| Probable Total Depth | 4010 | As above | |

On the other hand, it is easy to envisage a number of scenarios that could incur NPT per well even with only moderately active clays. The scenarios and associated costs are presented in Section D4.1. The time arising from the delay is calculated and costed using the day rate in Table D-8.

There were different views on some of the aspects of possible NPT between the drilling experts within the TEN Project team and the Aquatera team[10]. One important area of consensus was the TEN project team’s estimate of incurring 1½ days NPT either from having to change the bit due to bit balling (TEN Project team) or additional “wiper trips” (Aquatera), where the drill string is pulled back to the casing shoe and then run back to the bottom of the hole to assess the quality of the borehole for running wireline logs or casing. The total cost of 1.6 days additional NPT for 19 wells comes to $29 million.

Costs have also been estimated for a mechanical side track (cost $24 million) and having to retrieve the casing and condition the hole before re-running it (cost $10 million). The TEN project team suggested that over 19 wells, one might expect 2 sidetracks and two occurrences of having to re-run the casing. The Aquatera team, while agreeing with the suggested scenarios, have made a more cautious estimate of additional costs, in view of the moderate reactivity of the shale, and have allowed for one mechanical sidetrack and one retrieval of a casing string which gives an overall cost of $63 million. This estimate is felt to be conservative and also excludes more serious incidents, such as the casing becoming stuck in the hole before it has been landed in the wellhead, which is a very real possibility and would take at least a week and possibly weeks to rectify at a cost of $14 million per week.

It has been established that there are inherent risks of time delays with using WBM in these wells. It is also clear that the operating costs associated with deep water operations are expensive (approximately $1 million / day) and carry additional penalties associated with delays in oil production (also approximately $1 million/day). Aquatera’s conclusion is that in view of these very high operating costs and risk of delays, the WBM option carries too much potential downside risk to be viable in comparison with other options to current practice, such as the use of an offshore TDU.

[10] Members of the Aquatera team collectively have over forty years’ experience with drilling fluids including designing WBM systems to replace NADF and estimation of the cost penalties that can be incurred with in water sensitive shales (see publications in Section XX of main report.

## C3. Evaluation of Absolute Scores for Technical Factors

**Table C-3**

| Option | Absolute score | Comment |
|---|---|---|
| Water Based Muds | -4 | Water based mud is a well proven technology. However using WBM to drill rock formations that contain a high proportion of water sensitive clays can result in extensive technical problems and delays relating to swelling of rock, and instability of well walls. A detailed discussion of the technical issues and delays are presented in Section C2.1. Estimates of associated costs are provided in Table D-8 AND Table D-9. The risk assessed cost of delays due to additional Non Productive Time is estimated to be $61 million (see Section D4.1D4.1). |
| NADF | 0 | The toxicity of NADFs have been reduced significantly since 1975 moving from diesel oil based muds (OBM), through so called low toxicity oil based muds (LTOBM), to synthetic oil based muds (SBM) and more recently to the current combination classified as non-aqueous drilling fluids (NADF), which are virtually free of carcinogens. Likewise, the toxicity of the additives, such as emulsifiers, has been significantly reduced in NADF muds. The fluid proposed by TGL is a well proven Group III NADF, and able to meet performance specifications.<br>Oil based muds are generally considered to de-risk the drilling process by avoiding possible complications due to well bore reactivity (see above comments on WBM). NADF also provides better lubricity in high angle wells, thermal stability in deep high temperature wells and reduction of formation of gas hydrates – a particular issue for deep water wells. They do, however, have disadvantages which include the potential to mask subtle hydrocarbon signatures in reservoir rock and they are more difficult to manage in the event of incurring high rates of mud losses downhole. These issues should be manageable especially where previous drilling has taken place nearby as is the case with these wells. No technical problems are anticipated therefore. |
| Cuttings drier | -1 | Cuttings driers are now considered to be mature technology and are accepted routine practice within Tullow Ghana operations, where it has a proven good performance record. Any failure in the unit is managed by storing cuttings for processing until the unit is repaired. There is also a risk of exceeding the 5% limit, especially when the centrifuge fines are included with the discharged cuttings. This is scored under reputation and regulation, rather than in this technology assessment. |
| Offshore Thermal desorption | -2 | The Hammermill system is proven for offshore use in regions where environmental standards demand cleaner discharges. The units have programmable logic control (PLC) and are run and maintained by a specialist crew. However there are no backup units and some downtime is inevitable. This risk can normally be managed through cuttings storage, but some residual risk of delays remains. Preliminary studies by the TEN Project team indicate that installation is feasible, whilst some delays during initial operations after commissioning can be expected.<br>Schedule impact from late delivery presents an additional risk. The current claimed lead times for the units vary from 4 to 8 months depending upon supplier. There may also be some second hand units available more quickly. The key issues for the installation are storage capacity / deck space, which may differ between suppliers and therefore be a key driver given they are to be installed on existing rigs. The compatibility for hook-up to the Rig Emergency shut-down systems may also be a key factor. It has been assumed that a 28 day installation period will be required after the supply of the units. Due to the tight timeline and chance of teething problems, this option is scored as -2. |
| Disposal at sea onsite - WBM | 0 | This is very practical, well tried and tested approach; used throughout industry.<br>Tophole cuttings are discharged directly to the marine environment as the section is drilled riserless with no returns to rig. All remaining hole sections are returned through the riser to the deck. Where "WBM is used the returns are passed over the shale shakers as a minimum before any discharge.<br>Spent WBM is also usually discharged overboard through a valve as required. These options present no technical risk. |

| Option | Absolute score | Comment |
|---|---|---|
| Disposal at sea onsite - NADF <5% | -2 | This is a proven approach undertaken whenever residual oil on cuttings is compliant with local regulations. It is routinely applied with NADF cuttings in the US and Brazil at <6.9% Oil on Cuttings (OOC) and Ghana, where regulations (EPA draft guidelines) stipulate <3% Oil On Cuttings (OOC) and permits stipulate 1% (Jubilee Phase 1) or 2% (Jubilee phase 1A) but allow for exceeding this target through of a financial penalty system. In the event of equipment failure cuttings have to be stored on site until they can be processed, In the worst case, drilling has to be stopped and so there is some potential for delays but this is not common and is therefore scored as -2. |
| Disposal at sea onsite - NADF <1% | -1 | The discharge of these cuttings with a lower mud on cuttings concentration should have low delay and technical risks |
| Bulk Cuttings Transfer | -1 | A relatively new system of cuttings handling, used globally for less than 5 years. The system requires considerably less deck space than a skip collection system, since each tank has a 40-50 tonne capacity compared with the 5 tonne capacity of a conventional skip. Offshore trials in operational conditions demonstrated successful pneumatic transfer of cuttings from the rig based tank to a ship based tank with no complications[11] . |
| Hybrid cuttings transfer | -1 | The offshore elements of this option are similar to bulk cuttings transfer. Hose transfer offshore reduces crane movements at sea. |
| Skip and ship | -3 | 'Skip and ship' is a proven technology with a number of companies offering skip management and cuttings processing services onshore. Problems have been encountered with meeting operational performance standards usually due to the weather. High seas and high winds can prevent the offload of full skips and upload of empty skips. This has been a particular problem in areas where total containment is required and during the drilling of the upper hole sections where skips may be being filled every 10 minutes and deck space rapidly becomes a problem.<br>However, once in the lower sections of any well, the rate at which skips are filled drops off rapidly and space and supply vessel availability become less critical issues. Skips designed for cuttings are not currently available in Ghana and would have to be imported, but this should be possible, if required, without delaying the project. The extent to which delays can be managed is proportional to the deck space that is available on the drilling rig. This is not possible to quantify with the current level of information. Some weather related downtime can be expected over the drilling program and, in view of the high daily cost of supply vessels at $60,000 per day, the risk is scored as -3. |
| Road transport | 0 | Lorry based transport is very practical, using existing technology with flexible capacity. While the extent of Ghana's roads is limited, and despite current World Bank funded improvements, there is no discernible technical risk from transportation. However there is currently no suitable destination for cuttings waste. |
| Thermal desorption onshore | -2 | The technical risks associated with the operation of the unit is essentially the same as for offshore (see previous comments). However an onshore disposal site also needs to be agreed for the cleaned cuttings powder that is generated by the TDU. |
| Cutting pit | -3* | As a proven technology, provision and filling of a cuttings pit presents little technical risk; however this solution more usually applied within an exploration programme in remote regions or as a contingency for oiled beach material in the event of a spill. Significant schedule risks associated with permitting (see Appendix I ) and construction to be ready in time for 3Q 2013. As a result of construction risk this option is scored at -3 but this could be optimistic. If this option is taken forward it requires more detailed investigation with regards to the schedule, as time constraints could become a showstopper. |
| Non-structural building - materials | -2 | This is largely based on applying proven technology, to an unproven application and market, for making non-structural materials from cuttings. Use of such materials in public spaces is likely to be subject to regulation and may require extensive testing or provision of evidence re leaching. There is also a risk arising from unauthorised re-sale or re-use of NSBM resulting in use |

[11]www.offshore-mag.com/articles/print/volume-66/issue-9/drilling-completion

| Option | Absolute score | Comment |
|---|---|---|
| Landfill cover | -3 | The basic concept is well established and well proven as a technology, but disposal of treated cuttings is likely to require a permit – which carries an associated schedule risk (see Appendix I ). Early clarification of likelihood of a permit or clear disposal route is essential in order to be able to plan with confidence. The acceptability of covering landfill sites still needs to be verified. Setting up necessary operations in time, after permitting, could be challenging |
| Land farming | -3 | Landfarming is a reasonably well proven method (used in the USA & Canada) for certain hydrocarbon contaminated materials; detailed chemical specification of the materials input together with active 'farming' and monitoring of soils are part of the controlled management process. The land does need to be actively "farmed" and needs to be kept well watered. High ambient temperatures would be optimal for this application.<br>Potentially high schedule risk arising from sourcing waste disposal contractor with appropriate skills / training in these techniques plus potential delays with land acquisition, permitting etc. Provisionally scored at -3 |

# Appendix D . Cost Factors

This appendix provides all of the relevant background information about how cost issues have been handled within the BPEO study process.

## D1. Sources of Information

Information was obtained from published sources, including information from the web, together with information provided specifically by the project team and information from Aquatera's team experience.

### D1.1. Published Sources and Existing Reports

Veil, J.A (1997) Costs for offshore disposal of non-hazardous oil field waste: salt caverns versus other disposal methods. Pub. DOE-National Petroleum Technology Office as DOE/BC/W-31-109-ENG-38-3, DE97008692.

Veil, J.A. (1998) Data summary of offshore drilling waste disposal practices. Prepared for US Environmental Protections Agency, Engineering and Analysis Division and US Dept. of Energy, Office of Fossil Energy.
http://www.ead.anl.gov/project/documents/fs20/EPA_DATA.pdf

- These two papers by Veil give a range of costs for non-hazardous disposal of solid and oily waste and for water based drilling wastes across a number of US states. Final disposal options include land spreading, disposal pits and landfill cover; land spreading operations are viewed as having a significant share of the commercial disposal market. Figures quoted are for 1996/1997 in $US and have been increased accordingly by Aquatera.

Tullow Oil (2012c) 00002-TLW-WE-RPT-0004 Discharged Oily Cuttings Options & strategy report

- Tullow provide preliminary rates for two commercial offshore thermal desorption units (Hammermill and Rotomill) which, although presented in the context of a different offshore Ghana drilling campaign, have been useful in this TEN cost estimate.

http://nexus.umn.edu/papers/truckoperatingcosts.pdf

- This gives US rental costs from which Ghanaian costs have been interpolated.

## D1.2. Requested Data, Derived Data and Assumptions

The following additional data requirements were explored:

**Table D-1 Additional data sought for the study**

| Data requirements | Response from Client | Reference / Data Source |
|---|---|---|
| Average well cost [$] and duration [days] | Drilling US$25m / 25 days; Completion US$35 / 25 days; For TEN development, assume 25 wells with same characteristics as those of Phase 1A. | Jubilee Phase 1A Development Plan |
| Cost of construction of lined hazardous waste disposal site | Focus for TGL drilling is deep offshore and, therefore, development of onshore waste disposal would be commercially driven i.e. not TGL core business? There are no lined waste disposal facilities currently in Ghana. | Ghana National Waste Strategy Report - TGL/ERM 2011 |
| Cost of delays due to cuttings cleaning/handling: deferred oil and cost of operations | US$1.2m per day per rig. The average spread day rate for deepwater drilling rig includes day rate for rig and all associated services. | TGL Project team |
| Currency of choice USD / GBP | USD | |
| Details of drilling units to be used | West Leo and Sedco Energy | These 2 rigs are contracted for Phase 1A Jubilee development wells. Typically the West Leo drills the wells and the Sedco Energy completes the wells, however, this can change. |
| Drilling Schedule, well durations and timing | Drilling schedule is attached.<br>For well durations see line 1 above in this table; | TGL TEN Drilling Schedule |
| Estimation of additional boats required to handle ship to shore | Average 1.5 additional boats per rig US$ 60K per day; this assumption is based on 3 additional vessels required split between the two rigs - rig split on batch drilling and completions not always true. | Estimated by MI<br>Conference telecom TGL/AQ 080512 |
| Technical justification for using WBM rather than OPM and estimated cost penalties arising | WBM is more reactive than OBM in claystone formations. WBM causes claystones to swell, which can cause the drillstring to become stuck. Freeing the drillstring can take anything from hours to weeks = additional cost. | CSA (2011) (Jubilee Drill Cuttings Study. Report to TGL; TGL have supplied Lith column XRD of montmorillonite content of shales Justification of OBM |
| Well numbers and well design, e.g. hole sizes and depths etc. | TEN consists of 25 wells; case means 25 wells to complete but only 19 to drill (6 wells re-used)<br>Each well has the following typical hole sizes / depths (section length)<br>Water depth 1,200m<br>26" hole from 1,200m to 2000m (800m) NB: cuttings from 26" hole are not recovered to surface.<br>16" from 2,000m to 3,000m (1,000m)<br>12-1/4" from 3,000m to 4,500m (1,500m)<br>8-1/2" sections are drilled on some wells (depends on completion type) - if an 8-1/2" section is drilled it will typically be 400m length. | TGL Project Team |

| Data requirements | Response from Client | Reference / Data Source |
|---|---|---|
| What percentage wells drilling 8 1/2" hole? | The completions selected for TEN cannot be run inside 7" liner hence 8 1/2" hole is not planned to be drilled in any development well. They will all reach total depth in 12 1/4" based on the current plan. Some Jubilee phase 1A wells plan on having an open hole gravel pack sand face completion which would require 8 1/2" to be drilled with a water based drill-in fluid. TEN wells will be drilled to TD in 12 1/4" hole with LTOBM. | TGL Project Team |
| What is the cost of converting the rig for ship to shore option or onboard thermal desorption to get cuttings less than 1% e.g. TWMA Rotomill | TWMA Rotomill uses thermal, mill and cyclones to clean and separate into powder, oil and water streams, which are sampled, analysed and ready for discharge overboard at OOC < 1%. Cost Est. $10 MM<br>MI Swaco offshore Hammermill OOC < 1%. | 00002-TLW-WE-RPT-0004 Discharged Oily Cuttings Options and Strategy Report Rev 3.pdf |
| What is the current level of cuttings cleaning technology - (high G shakers, cuttings driers, cuttings wash etc.) and expected oil on cuttings levels for OPM sections? Options and cost and benefits (OOC %) of upgrading to higher specifications (cuttings driers & cuttings wash) | Shakers<br>Dryers<br>Centrifuges.<br><br>Jubilee achieving OOC < 3% | Jubilee EIA Appendix B; TGL project team emails |

# D2. Key Input Data

## D2.1. Rig Operations and Deferred Oil Costs

The two largest costs associated with the operations are the cost of the rig operations and the cost of project delays.

Rig operations costs include the direct hire costs of the rig and associated crew and the costs of any dedicated support operations.

Deferred oil costs arises from the gap between the upfront cost of financing the development - the drilling of the wells, installation of manifolds, pipelines, risers and Floating production and storage offloading facility (FPSO) and the revenue arising from production, export and sales. The revenue stream starts from first oil but only becomes optimal once the field is producing at its maximum design capacity. Therefore any additional delays to first oil and plateau production are cost and have to be taken into account in the economic analysis: this is described here as deferred oil.

A breakdown of these estimated costs is presented in to Table D-6.

**Table D-2 Breakdown of operating costs** (Source: TEN Project team)

| Cost per day | Drilling (USD) | Completions USD) |
|---|---|---|
| Rig rate | 650,000 | 650,000 |
| Support costs | 430,000 | 217,000 |
| Deferred oil | 833,333 | 833,333 |
| **Totals** | **1,913,333** | **1,700,333** |

**Table D-3 Costs associated with various aspects of drilling and cuttings handling**

| Direct cost inputs | Values | Units | Source & comments |
|---|---|---|---|
| Well cost | $60,000,000 | per well | TEN Project team |
| Project duration | 570 | days | TEN Project team |
| One well | 634 | MT | TEN Project team |
| Total wells | 19 | wells | TEN Project team |
| 19 wells | 12,046 | MT | TEN Project team |
| Time to drill a well | 30 | days | TEN Project team |
| Drier costs | $4,000 | per day | Aquatera estimate |
| 8 tonne/truck | 1,506 | journeys | Aquatera: Assume 50 km round trip |
| Distance travelled | 75,288 | km | Aquatera: Assume 2 skips per truck |
| Frequency of trucks | 2.6 | journeys per day | Calculated |
| Cost non-hazardous disposal | $20 | per MT | Veil (1997) |
| Fines from regulator | $20,000 | per well | Jubilee EIA ( for out of spec overboard discharge) |
| Road transport | $1 | per Km | http://nexus.umn.edu/papers/truckoperatingcosts.pdf |
| Crane use | $10 | per lift | Aquatera estimate |
| Landfarming onshore | $100 | per MT | Aquatera assumption based on $37/MT OGP (2003), $20-95 Veil (1998) |
| Manufacture of NSBM | $150 | per MT | Aquatera estimate based on $120 / tonne high density readimix |
| Environmental monitoring | $200,000 | for project | Assume locally based vessel, Non Ghanaian surveyors. 4 surveys |

**Table D-4 Costs associated with thermal treatment offshore**

| TDU offshore | One rig cost | Two rigs cost | Source |
|---|---|---|---|
| Hammermill | $16,150,000 | - | Operational & standby costs TEN Project team |
| Mob, engineering and installation | $3,000,000 | $3,000,000 | TEN Project team |
| Demob costs: $800 k / rig | $800,000 | $800,000 | TEN Project team |
| Standby costs of TDU on completions rig | - | $3,400,000 | TEN Project team |
| **TOTALS** | **$19,950,000** | **$7,200,000** | |

**Table D-5 Costs associated with thermal treatment onshore**

| TDU onshore | Cost | Source |
|---|---|---|
| 1x TDU unit onshore | $21,250,000 | TEN Project team |
| Mobilisation and installation onshore | $1,000,000 | Aquatera estimate |
| Cost of site, final disposal etc. | $240,920 | Assumes $20 per tonne for non-hazardous disposal |
| **TOTALS** | **$22,490,920** | |

**Table D-6 Summary of Costs**

| Outputs | Project costs | | Source |
|---|---|---|---|
| **Offshore treatment** | **Drilling** | **Completion** | |
| Offshore TDU 19 wells | $19,950,000 | $7,200,000 | Table D-4 |
| Total two rigs 25 wells (drill & complete) | $27,150,000 | | Above |
| Cuttings drier(s) | $4,560,000 | | Assumes 2 rigs, completions very low solids but still need processing |
| Financial penalties from regulator for 19 wells overboard discharge out of spec | $380,000 | | Table D-3 |
| **Onshore transport & processing** | | | |
| Onshore crane operations | $150,575 | | |
| Onshore TDU | $22,490,920 | | Table D-5 |
| Landfill disposal of TDU waste | $240,920 | | |
| Truck cuttings to treatment centre | $75,288 | | |
| Landfarming onshore | $1,204,600 | | |
| NSBM stabilisation | $1,806,900 | | |

## D3. Evaluation of Absolute Scores for Costs

**Table D-7**

| Option | Absolute score | Comment |
|---|---|---|
| Use of Water Based Muds | -3 | Basic costs of buying and maintaining muds are assumed to be fairly similar for WBM and NADF (within the +/- 50% level of cost estimation) and are estimated to be between $500,000 and $1,000,000 per well. Total WBM costs for the drilling campaign are therefore in the order of $10-20 million. |
| Use of NADF | -3 | OBM costs are assumed to be in the order between $500,000 and $1,000,000 per well, 10-20 million for the project. |
| Cuttings drier | -2 | Cost of the cuttings drier is estimated to be $4000 / day (Aquatera estimate) giving a project cost of $4.5 million for the two rigs. |
| Thermal desorption | -4 | Costs detailed in Table D-4 estimate TDU costs at $ 27 million (TEN Project team study)[12] This assumes that the cuttings driers will be removed from the rig as the TDU requires a relatively wet feed. |
| Disposal at sea onsite - WBM | -1 | Actual discharge of WBM cuttings from the rig has no CAPEX or OPEX costs. On the assumption that the TEN Environmental Permit will be the same as the Jubilee Phase 1 permit, no associated environmental monitoring costs likely to be imposed by Ghana EPA Environmental permit are anticipated. |
| Disposal at sea onsite - NADF <5% | -2 | Overboard discharge of NADF cuttings will attract zero Capex. Where relatively high oil on cuttings levels are achieved (>~5%) offshore monitoring requirements may be imposed which may cost perhaps $50k for each benthic survey or $200,000 for the project, (Aquatera estimate). Where reduced oil on cuttings levels are achieved <~1%, no monitoring is likely to be required.<br><br>Penalty surcharges when less rigorous cleaning is applied for failing to comply with oil concentration on cuttings thresholds should be factored in at $20,000 per well or $400,000 over the project. Total cost estimated at $1.5 million. This pushes the score to -3. Due to the uncertainty -2 has been retained as the score. |
| Disposal at sea onsite - NADF <1% | 0 | This improved level of performance in terms of discharged materials may lead to the requirements for seabed surveys being waived |
| Bulk Cuttings Transfer | -4 | Estimated equipment costs are $5.5 million. Cost of the additional 1.5 vessels required estimated by the project team is $50 million. Less expensive vessel options may be available in which case costs may reduce significantly to around $15 for the vessel transport. See detailed discussion for details. |
| Hybrid | -4 | Estimated equipment costs are $3.8 million. Cost of the additional 1.5 vessels required estimated by the project team is $50 million Less expensive vessel options may be available in which case costs may reduce significantly to around $15 for the vessel transport. See detailed discussion for details. |
| Skip and ship | -4 | Estimated equipment costs are $3.2 million. Cost of the additional 1.5 vessels required estimated by the project team is $50 million. Less expensive vessel options may be available in which case costs may reduce significantly to around $15 for the vessel transport. See detailed discussion for details. |
| Road transport | -3 | Cost of haulage operation estimated to be around $1 per km[13], which is $75,000 for the project assuming a round trip of 50 km from the docks to the processing site. |
| Thermal desorption | -3 | Costs detailed in Section D2.1; estimate TDU costs at $ 27 million (TEN Project team study)[14] Additional charges for disposal at a landfill, using the dried cuttings as a surface dressing is given under Landfill Cover. |

[12] Tullow Oil (2012c) 00002-TLW-WE-RPT-0004 Discharged Oily Cuttings Options & strategy report, modified by J Gilmour email

[13] Based on US operating cost of $0,65/km, rental in Ghana assumed to be $1/km http://nexus.umn.edu/papers/truckoperatingcosts.pdf

[14] TEN Project team (2012) 00002-TLW-WE-RPT-0004 Discharged Oily Cuttings Options & strategy report, modified by J Gilmour email

| Option | Absolute score | Comment |
|---|---|---|
| Cutting pit | -3 | Estimated cost for the programme – $7-13 million based upon costs elsewhere around the world. This does not include any potential residual liability and is based on construction costs only. Maintenance (operational monitoring) would be borne by a 3rd party in control of the facility. Liability costs are a potential associated with leakage from, or catastrophic breakdown of the cuttings pit liner resulting in terrestrial pollution and pollution clean-up costs.<br><br>There is a legacy risk of having to dispose of the contents of the pit at a later date (e.g. this is known to have occurred in Columbia and Thailand). There are also schedule risks associated with permitting and construction |
| Non-structural construction – Bricks | -3 | Basic cementing costs are estimated at $1.25-$2.5MM, excluding reforming equipment and transport. On-going maintenance costs are not applicable. Liability costs are a potential associated with the eventual use of the stabilised materials, but have not been estimated here. http://www.scomigroup.com.my/core/dwm/pdf/treatmentdisposal/drill_cuttings_solidification_1208.pdf |
| Landfill cover | -2 | Source Waste Management World [15]Cost of landfill disposal is very variable, It is not known how cleaned cuttings will be classified. In the UK it is classified as hazardous in Scotland and non-hazardous in England.<br><br>The Jubilee EIA (Chapter 3) mentions two landfill sites at Sofokrom that are suitable for general non-hazardous waste and Takoradi in the Waste Management Plan (Annex F 8.6) Cost for this is very variable but estimated at $20/tonne taking a mid-range estimate, to include local taxes that might apply. Cost of disposal of cleaned cuttings estimated at $250,000. |
| Land farming | -4 | The cost of land farming is given as $37 by OGP[16] but this is based on US data where land farming is already established. Veil (1998) reports cost for land spreading facilities mainly in the region of $20 but as high as $95/ton in the US. In Ghana, we have assumed $100 / tonne to allow for contractor training, land acquisition by contractor and further landfill and disposal taxes. Total cost is the order of just over $1 million.<br><br>A $2 million provision has been made for residual liabilities. Chevron[17] are currently in the middle of counter-suing a settlement of $18.2 billion that was recently made by a court in Ecuador over groundwater pollution arising from cuttings pits and production wastes. This is a unique and complex case, but the damages awarded provide a cautionary tale on the management of potential liabilities. It would only take a 1 in 10,000 chance to incur a risk assessed cost of $2 million |

# D4. Discussion of Key Output Issues

## D4.1. Technical Risk from WBM Cost of Delays

As discussed WBM can cause some technical issues; this scenario looks at an additional bit trip. Another very likely scenario would be that additional "wiper trips" would be needed. A wiper trip requires pulling the drill string out of the open hole section back to the previous casing shoe, then running it back in to check / improve the condition of the hole before running casing or wireline logs. The time arising from the delay is costed using the day rate calculated in Table D-8. It is highly likely that at least one of these scenarios would occur on 50% wells at a total cost of $29 million.

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15 http://www.waste-management-world.com/index/display/article-display/304406/articles/waste-management-world/volume-8/issue-4/features/msw-management-in-europe.html

16 OGP (2003) Environmental Aspects of the use and disposal of non-aqueous drilling fluids associated with offshore oil and gas operations. OGP Report No. 342.

17 http://www.chevron.com/ecuador/?utm_campaign=Ecuador_Mitigation&utm_medium=cpc&utm_source=Google&utm_term=texaco_ecuador&gclid=CM3cnrT7jrECFUcKtAodcGrW9A

Costs have also been estimated for a mechanical side track (cost $22 million; Table) and having to retrieve the casing and condition the hole before re-running it (cost $10 million; Table D-10). The total cost of these three scenarios represents the cost of WBM sourced delays and is estimated to be $61 million.

**Table D-8 Estimated cost of additional trips**

| Bit trip on 50% of wells due to non-optimised PDC design: | | Units |
|---|---|---|
| *(drill to top reservoir, trip out bit, change to 8 bladed PDC, RIH)* | | |
| Circulate Clean | 3.0 | Hrs. |
| POOH at 250 m / hr. | 13.4 | Hrs. |
| Rack BHA | 4.0 | Hrs. |
| Change Bit / Run BHA | 4.0 | Hrs. |
| RIH at 250 m / hr. | 13.4 | Hrs. |
| Wash down | 1.0 | Hrs. |
| **Total** | **38.8** | **Hrs.** |
| **Total** | **1.6** | **Days** |
| **50% 19 wells** | **9.5** | **Wells** |
| **9.5 wells @ 1.6 days bit trip per well** | **15.2** | **days** |
| **Cost (15.2 days @ $1,913,333 per well)** | **$29** | **MM** |

**Table D-9 Estimated cost of a mechanical side track**

| Mechanical side track | | Units |
|---|---|---|
| *(POOH, M/up side track BHA, side track)* | | |
| POOH at 250 m / hr. | 13.4 | Hrs. |
| RIH, set cement plug, POOH | 36.0 | Hrs. |
| M/up BHA | 4.0 | Hrs. |
| RIH at 250 m / hr. | 13.4 | Hrs. |
| Time drill | 12.0 | Hrs. |
| Re-drill section at 10 m/hr. | 200.0 | Hrs. |
| **Total** | 278.8 | **Hrs.** |
| **Total** | **11.6** | **Days** |
| **Wells** | 1.0 | **Wells** |
| **Cost** | **$22** | **MM** |

**Table D-10 estimated cost of tripping a casing string**

| Tripping out casing string | | Units |
|---|---|---|
| *(POOH with 9 5/8" in high angle well, condition hole, re-run)* | | |
| Attempt to work to bottom | 6.0 | Hrs. |
| POOH casing on DP (150 m / hr.) | 10.0 | Hrs. |
| POOH casing wet (5 joints / hr.) | 41.7 | Hrs. |
| Round trip to condition hole | 38.8 | Hrs. |
| RIH Casing (10 joints / hr.) | 20.8 | Hrs. |
| RIH Casing on DP (150 m / hr.) | 10.0 | Hrs. |
| **Total** | 127.3 | **Hrs.** |
| **Total** | **5.3** | **Days** |
| **Wells** | 1.0 | **Wells** |
| **Cost** | **10.1** | **MM** |

## D4.2. Cost of Offshore Thermal Desorption Unit

TEN Project team estimates of the cost of installing a Hammermill Thermal desorption unit offshore are shown in Table D-11. This is based on having a unit on both the drilling rig and the completions rig in order to maintain maximum operational flexibility.

**Table D-11 Cost of offshore TDU**

| Offshore processing | One rig (US$) | Two rigs (US$) |
|---|---|---|
| Hammermill Operational and standby costs: $850 k / well x 19 wells | 16,150,000 | |
| Mob, engineering and installation costs: $3 MM / rig x 2 rigs | 3,000,000 | 3,000,000 |
| Demob costs: $800 k / rig | 800,000 | 800,000 |

| | | |
|---|---|---|
| Standby costs of second Hammermill on completions rig | - | 3,400,000 |
| **Total each rig** | **19,950,000** | **7,200,000** |
| Total two rigs 25 wells | - | **27,150,000** |

### D4.3. Cost of Shipping Cuttings to Shore

The TEN Project team estimate that an additional 1.5 additional supply vessels would be required if cuttings were to be shipped ashore. Assuming an additional 1.5 vessels for the duration of the project (570 drilling days) at $60,000 per vessel per day gives a total project cost of $50 million. This could be an over estimate as the vessel requirement would likely be satisfied by one additional vessel making a larger number of passages. As a cost sensitivity check, it is assumed that an additional vessel is available on spot charter and that two days are allowed for rigging up and rigging down the equipment. Allowing for one boat at nine days per well would reduce this cost to $10 million.

The cost of the transportation equipment is relatively small in comparison to the vessel hire costs. The following cost estimates of shipping cuttings to shore are based on Gulf of Mexico estimates from the Aquatera team and are shown in Table D-12. There is little difference between the vacuum system and the hybrid transfer system; however the bulk transfer option is almost 50% higher in cost than the hybrid system.

**Table D-12 Estimates of skip & ship option costs**

| **Vac skip & ship** | **Per day** | **Days /well** | **No wells** | **Project cost** |
|---|---|---|---|---|
| Equipment Personnel | $5,500 | 30 | 19 | $3,135,000 |
| Extra rig crew | $93 | | | $53,200 |
| Cleaning skips | $10,000 | | | $10,000 |
| **Total** | | | | **$3,198,200** |
| **Hybrid transfer** | **Per day** | **Days /well** | **No wells** | **Project cost** |
| Equipment Personnel | $6,700 | 30 | 19 | $3,819,000 |
| Extra rig crew | $93 | | | $53,200 |
| Cleaning skips | $10,000 | | | $10,000 |
| **Total** | | | | **$3,882,200** |
| **Bulk transfer** | **Per day** | **Days /well** | **No wells** | **Project cost** |
| Equipment Personnel | $9,600 | 30 | 19 | $5,472,000 |
| Extra rig crew | $93 | | | $53,200 |
| Cleaning skips | $10,000 | | | $10,000 |
| **Total** | | | | **$5,535,200** |

# Appendix E. Reputational Issues

This appendix provides all of the relevant background information about how reputation issues have been handled within the BPEO study process.

## E1. Sources of Information

Information was obtained from published sources, including information from the web, together with information provided specifically by the project team and information from Aquatera's team experience.

### E1.1. Published Sources and Existing Reports

Evidence of Tullow's commitment to environmental care is presented in a number of Tullow documents made available to Aquatera.

Tullow Oil (2007) EHS Policy. Doc No.TO-EHS-POL-001-REV7.

- Applicable to all Tullow business units and stating Tullow's overarching EHS goals, together with a number of EHS management statements.

Tullow Oil (2011) Environmental Managements System Public Statement for 2010 Operations Rev 0.

- Reporting of environmental performance indicators for operations in the UKCS, which demonstrates the successful application of Tullow's companywide EHS Management system.

Tullow Oil (2012) Drill Fluids & Cuttings Disposal Standard. Doc No.: T-WEL-STD-0001

- Disposal of drill fluids and cuttings throughout Tullow business worldwide in an environmentally responsible manner; it outlines responsibilities within the organisation and how to evaluate disposal options.

While Ghana's rapidly developing oil and gas industry is welcomed in the region for its contribution to the Ghanaian economy, there will inevitably be difficulties for individual companies and the industry as a whole, in response to any spills or accidental discharges.

Ghana Oil Online (2010) http://ghanaoilonline.org/2010/07/u-s-oil-company-may-pay-a-huge-fine-for-oil-spillage-off-ghana-coast/website

- This news report focuses on two LTOBM spills from two Kosmos drilling rigs on the Jubilee field; it draws attention to the importance of spill prevention throughout the industry and states that the government will set 'perimeters' to prevent coastal pollution. This demonstrates the importance of public perception and emotions in response to impacts from the oil and gas industry on other industries and potential income sources such as fishermen and tourism. It also shows that each company actively contributes to the reputation of the entire oil industry.

http://pulitzercenter.org/articles

http://pulitzercenter.org/reporting/ghana-oil-offshore-drilling-boom-industry-environmental-safety-spill-disaster-plan-jubilee-west-africa-gulf-of-guinea

- Various news articles reported through Pulitzer demonstrate the other side of the rapid pace of oil industry development in Ghana i.e. community nervousness with respect to the country's ability to respond to and manage spills and environmental protection.

## E1.2. Requested Data, Derived Data and Assumptions

The following additional data requirements were explored:

**Table E-1 Details of additional reputation related information requested**

| Data requirements | Response from Client | Reference / Data Source |
|---|---|---|
| Company commitment: Is there a company commitment to drill as many well sections as possible with WBM? | Yes; however technical limitations and uncertainty still a major factor however – see Technical and Cost appendices | TGL drilling team |
| Company commitment: Is there a company commitment to use benign drilling fluid components wherever possible? | Yes | Jubilee EIA Section 2-29,Box 2.1, clause 8 |

# E2. Key Inputs

Tullow Oil has robust documentation in place which demonstrates the company's commitment to responsible chemical selection and management throughout its lifecycle. It has set standards and guidelines for drill fluids and cuttings disposal; these cover the whole suite of drilling waste management options and choices from mud choices through cuttings cleaning to selecting optimal cuttings disposal routes.

# E3. Evaluation of Absolute Scores

**Table E-2**

| Option | Absolute score | Comment |
|---|---|---|
| Water Based Muds | +1 | Aligned with company policy[18] as long as chemicals management process has been followed on the selection of least hazardous chemicals. Low likelihood of media coverage. Use of WBM instead of NADF could be seen as a positive. |
| Use of NADF | -1 | Tullow internal guidance[19] recommends the use of best available techniques (BAT) to reduce OOC, the adoption of a 5% OOC limit on cuttings discharges in conjunction with appropriate toxicity testing and environmental monitoring of drilling locations, and re-evaluation of set limits on a 5-year cycle. Therefore the use and discharge of NADF meets Tullow internal requirements. Ghanaian EPA has asked TGL to explore ways of meeting 1% OOC with new treatment technologies.<br><br>IFC guidance is to not discharge cuttings with OOC >1% but higher values can be justified with EIA. IFC observation was that cuttings and drilling fluids were being managed to ALARP. Spillages totalling 598 barrels NADF (LTOBM) around two Kosmos rigs in the West Cape Three Points area created a negative press response[20]. The threat of oil spills and not meeting EPA aspirational target of 1% OOC have also sparked off some public concerns as there has been some media coverage about the disposal of muds and concern from local fishing communities[21]. Scored overall as -1 on the basis of IFC awareness but no major concerns. |
| Cuttings drier | 0 | Scored 0 as impacts are associated with the disposal of drill cuttings and are discussed in section on disposal of muds. |

[18] Tullow Oil (2012) Drill Fluids & Cuttings Disposal Standard, Well Engineering internal document : T-WEL-STD-0001

[19] Tullow Oil (2012) Drill Cuttings and Fluids Disposal Guidelines Rev 0, Well Engineering internal document T-WEL-GUD-0002

[20] http://ghanaoilonline.org/2010/07/u-s-oil-company-may-pay-a-huge-fine-for-oil-spillage-off-ghana-coast/

[21] http://pulitzercenter.org/reporting

| Option | Absolute score | Comment |
|---|---|---|
| Thermal desorption | +3 | Meets corporate guidance on use of BAT to reduce OOC, but exceeds BAT required to meet 5% OOC.<br>Likely to be viewed positively by IFC and public as an example of a positive proactive initiative on the part of TGL |
| Disposal onsite - WBM | -2 | See above WBM |
| Disposal onsite - NADF <5% | -3 | Disposal of cuttings in the 3-5% or partially cleaned state will be viewed as not meeting best practice. Perception of dumping of oily waste at sea. |
| Disposal at sea onsite - NADF <1% | -2 | Cleaned cutting achieving the 1% oil on cuttings standard is likely to be viewed as best in class performance by investing in green technology as a green investment initiative |
| Bulk Cuttings Transfer | -1 | Avoids extensive use of cranes and eliminates hazards arising from crane operations. Likely to be viewed in a positive light by other stakeholders as an example of best practice for shipping ashore |
| Hybrid transfer | -1 | Likely to be viewed in a positive light by other stakeholders as an example of best practice for shipping ashore |
| Skip and ship | -2 | Corporate guidelines cite this option as a major safety risk with a big increase in crane activity and is perceived to be inherently risky both to the crews on the rig and those on the supply vessels. Possibility of negative reaction from workforce. At the same time skip and ship is widely used in other regions of the world. Whilst there is no direct evidence from North Sea operations indicating that there will be a significant increase in accident frequencies (see Section B2.1), it is clear that eliminating the hazard of additional crane lifts will make the operation safer: what is not clear is by how much. |
| Road transport | -1 | Average increase in truck movements are estimated to be 2.6 journeys per day with 8% chance of an accident resulting in an injury and 1% chance of a fatality. Corporate policy would be to eliminate the hazard if possible, but the risk is relatively low. Some possible increase in public support is possible through the creation of jobs, but marginal. |
| Thermal desorption | 0 | Potential for odours and causing public nuisance, both of which need to be controlled. The facility may be viewed negatively by the local community if care is not taken to site it in a suitable industrial site, with appropriate controls on emissions of waste gases. |
| Cutting pit | -2 | Corporate guidelines recommend that this option should be avoided if possible This option is generally unpopular with stakeholders due to significant land foot print over a long time scale and the perceived risk of leaching of contaminants. Any residual liability for the maintenance of the cuttings pit would need to be established. Since there may be specific concerns but probably only on a local scale this has been scored -2. |
| Non-structural construction – Bricks | +1 | This option may be viewed positively as it makes use of a waste product and supplies the raw materials for manufacture of non-structural materials such as kerbstones or roof tiles. However, the product, manufacturing process and potential for leaching of hydrocarbons has yet to be established. Assurance on these issues will be key factors in forming public opinion. Scope for a positive PR story potentially +2 or +1. |
| Landfill cover | 0 | Only appropriate for treated waste from onshore thermal desorption. May be viewed positively if it makes covering of landfill easier and avoids trucking in material from elsewhere. However, liability issues need to be carefully considered & are the dominant factor, especially as the availability, status and operational standards of the landfills in the area are difficult to confirm. |
| Land farming | -2 | No clear corporate position. The main concerns with land farming are potentially large land requirements and the potential environmental implications (see section on ecology for land farming). Optimal siting of land farming facilities should include site topography, site hydrology, neighbouring land use, and the physical and chemical composition of the waste and the resulting waste-soil mixture. Therefore, if not carried out to the highest standards there may be significant public resistance and damage to Tullow's reputation. Quite likely to be seen as a risk for ground water contamination, with oil companies taking the cheapest option for remediation. Potential for stakeholder concerns to be raised publically. |

# Appendix F . Environmental Issues

This appendix provides all of the relevant background information about how environmental issues have been handled within the BPEO study process.

## F1. Sources of Information

### F1.1. Published Sources and Existing Reports

The key sources of information used in the environmental assessment are outlined below.

Jubilee EIA document (ERM 2009):

- Coastline habitats generally comprise sandy beaches (70% of coastline), intersected by some 10 rivers discharging into the sea. Coastal lagoons on the rivers, behind the beach front are also common. Nearshore habitats range from muds through sands to stone and bedrock. The continental shelf seabed comprises finer sands and muds. On the continental slope these give way to muds and clays crossed by actively eroding canyons. Two slope fans exist at the western and eastern margins of the Ghanaian slope, with steeper gradients between. Most of the current hydrocarbon prospects lie under the western fan, adjacent to the Jubilee and TEN developments.
- Water circulation is dominated by an oceanic gyre current that flows eastwards along the shelf edge, the Equatorial Counter Current. Thermocline can form at 10-40m water depth, with upwelling seasons from July to December, and less in December and January.
- The offshore seabed is generally clean, with a typical infaunal community of worms and bivalve molluscs.
- Plankton standing stocks are not particularly high and this indicates that Ghanaian waters are not especially productive as an offshore ecosystem.
- Fish stocks are dominated by pelagic species that are supported by a pelagic food chain reliant on the seasonal upwelling processes. The species include sardines, anchovy, mackerel, tuna and billfish. Commercially exploited demersal fish stocks are found along the nearshore areas. Deepwater fish stocks are typical of such habitats in tropical areas and do not have particular commercial value.
- A diverse group of cetaceans are found in Ghanaian waters and there is an important calving area for humpback whales. Five species of turtle have been recorded in Ghanaian waters all of which are internationally recognised as under threat and are therefore protected.
- Ghanaian waters do not hold particularly important offshore seabird populations. The area is used by migrating species moving along the West African coast. Birds are more abundant along the coastal lagoon systems.

Marine mammal and turtle observations (Gardline 2012):

- Over a nine month observation period there were 99 sightings of marine mammals, turtles and large fish. 75% of observations were of dolphins, 8% were of whales, 15% were of turtles and one probable sighting each of manta ray and hammerhead shark. 13 species of cetacean were recorded.

Offshore noise measurements and assessment for the Jubilee field (Gardline 2011):

- Noise measurements were made around the working FPSO and offtake vessel at the Jubilee field
- Measurements indicated possible disruption to noise sensitive species out to 0.5 km range and for ultra-sensitive species such as sperm whales out to 6 km.
- The noise signature from drilling may be similar to or slightly greater than that generated by the FPSO.

Environmental Impacts:
CSA (2011) Jubilee Field Drill Cuttings Study. Report to Tullow Ghana Ltd.

- Assessment of the impact of drill cuttings discharges on the marine environment in the Jubilee field and verification of the discharge modelling completed for the Jubilee EIA. Data collected on the hydrography (depth, salinity, temperature), water column suspended solids, metals, hydrocarbons), sediments (particle size analysis, hydrocarbon, metal and total organic carbon concentrations) and macrofauna. This short term study found benthic impacts up to 500m from the well site.

Jacques Whitford Stantec Ltd (2009) Cuttings Treatment Technology Evaluation. Environmental Studies Research Funds, Report No. 166.

- This report contains a useful summary of recent mud and cuttings offshore discharge environmental effects monitoring studies American and Asian locations; similarity of findings reinforce the findings that ester based fluids have a benthic impact up to 200m from the discharge point, compared to the 1200m dispersion range of WBM cuttings.

MMS (2000) Environmental Impacts of Synthetic Based drilling Fluids. OCS Study 2000-064.

- This is a good summary of the composition, profile, drilling characteristics, toxicity and environmental impact of generic synthetic based drilling fluids. It discusses biodegradation and bioaccumulation properties, the lack of biotoxicity to water column organisms and biological effects in benthic organisms at concentration levels of >1000mg/kg.

Neff, Jerry M. (2005) Composition, Environmental Fates and Biological Effect of Water Based Drilling Muds and Cuttings Discharged to the Marine Environment: A synthesis and annotated bibliography prepared for Petroleum Environmental Research Forum (PERF) and American Petroleum Institute.

- Discharge of WBM cuttings in the USA has to meet Effluent Limit Guidelines; majority of WBM components are nontoxic, the most toxic are the deflocculents chrome- or ferrochrome lignosulfonates. Effects primarily caused by physical smothering and low sediment oxygenation; recovery fairly rapid.

Neff, Jerry M. (2010) Fates and Effects of water based drilling muds and cuttings in cold-water environments. Review prepared for Shell E&P Co. Houston, Texas .

OGP (2003) Environmental aspects of the use and disposal of non-aqueous drilling fluids associated with offshore oil and gas operations. OGP Report No. 342.

- A comprehensive review of drill cuttings treatment and NADF cuttings disposal focusing on the fate and effects of the discharge. Field data from the North Sea, Australia, Gulf of Mexico, Eastern Canada. Compilation of various worldwide regulations and practices included.

UKOOA (2005) UKOOA JIP 2004 Drill Cuttings Initiative Phase III: Final report. Report to DTI Report No. 20132900

- Data on hydrocarbon concentrations in sediments around platforms where NADF have been discharged. Drilling histories, together with the extent of cuttings piles and sediment contamination are summarised for a large number of operators in the North Sea.

Environmental Performance:
DECC (2012) Oil and Chemical Spills data 2005-2011 http://og.decc.gov.uk/en

- Statistics on spill frequency, spill type and spill quantities from a UK perspective.

OGP (2011) Environmental performance in the E&P Industry, 2010 data. OGP Report No. 466.

- Voluntary provision of annual worldwide data on emissions and discharges to the environment, including NADF discharged on cuttings. This is broken down into Group II and Group III fluids and reported per country.

Pertra ASA (2007) Environmental risk and oil spill contingency analysis. ST-PERT-S-1008

OSPAR (2006) Summary records OSPAR 2006.

- Areas of seabed where oil concentration is >50mg/kg shoud be monitored to track and assess persistence. The figure of 50mg/kg is held to be the threshold concentration associated with significant biological effects.

## F1.2. Requested Data, Derived Data and Assumptions

**Table F-1 Additional information requested about environmental information**

| Data requirements | Response from Client | Reference / Data Source |
|---|---|---|
| Cuttings and drilling fluids - what are the estimated volumes of drill cuttings and fluids? Are figures available for all planned wells? | Assume 25 wells for TEN And ignore Jubilee wells. Use Jubilee well data | Jubilee EIA Annex B |
| Cuttings modelling - has modelling been undertaken to assess likely cutting plume and deposition pattern? How good is the hydro graphic data which the modelling relies upon? | Cuttings deposition and dispersion modelling has been previously performed within the Jubilee field and is currently underway for the TEN Development project. Follow up studies (in Jubilee) have proven the model results on the sea-bed; analysis of cuttings piles and ecologic significance on-going | ASA modelling - within Jubilee EIA; using model described by Brandsma, M.G. and J.P.Smith (1999)[22]. |
| Cuttings settlement threshold for smothering - has this been estimated? | This issue is discussed within the modelling report. Effects of cuttings sea-bed deposition are thought to be localised and short lived i.e. short regeneration times. | ASA modelling - within Jubilee EIA |
| Jubilee baseline survey - does the scope of this survey include the new well locations currently being planned? If not, what plans are there to gather appropriate data? | New wells currently being drilled as part of the JP1A (infill) campaign are within the study footprint of the previous Jubilee baseline and EIA. Further work is also underway in the adjacent DwT block for the TEN Development project. | Jubilee EIA |

[22] Brandsma, M.G. and J.P. Smith (1999) OOC Mud and Produced Water Discharge Model. Exxon

| Data requirements | Response from Client | Reference / Data Source |
|---|---|---|
| Seabed geophysical survey - has any survey additional to Jubilee field been undertaken? | A water column quality and benthic study has been performed (2008?) by a Norwegian group in collaboration with the Ghana EPA. TEN is not flat featureless topography; there are 3 significant seabed trenches in the vicinity of the TEN development area | Gardline Survey Inc. (2008) Geohazard Assessment, Offshore Ghana, Block West Cape Three Points, Mahogany-2 prospect. Vol 1:3D geohazard study. Project ref 7374; report for Kosmos Energy August 2007; . See bathymetry marked on Tullow email 12/5/12 |

# F2. Discussion of Key Inputs

## F2.1. Environmental Impact of Drilled Cuttings

### *F2.1.1. Assessment Approach*

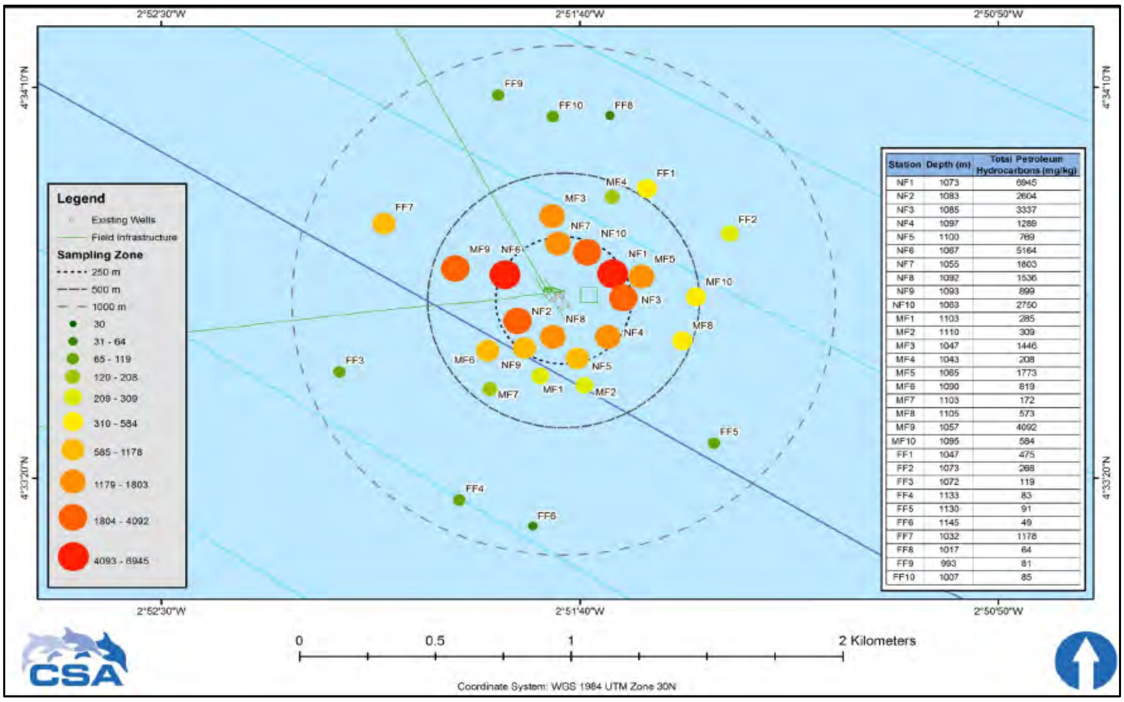
Discharged drill cuttings settle on the seabed around the drilling location. The environmental impact of this material depends upon a number of factors including; cuttings particle size, chemical composition (e.g. water based mud or oil based mud drilling systems), water depth and seabed conditions. At present there is limited environmental data available for drilling sites located in the deepwater Ghana offshore area. Therefore this assessment is primarily based on the environmental survey data reported for the GI-1 drill site located in the nearby Jubilee development (CSA, 2011) along with information presented in the Jubilee field EIA and knowledge of the impacts recorded in the North Sea where cuttings have been discharged.

### *F2.1.2. Impact Footprint Data*

Summary of Jubilee GI-1 drill site survey data:

- A total of thirty sediment samples were collected from the seabed located approximately 150- 750 m from the GI-1 drill site.
- Figures presented in the report indicate that a total of seven wells had been drilled at the centre prior to the survey – no information was provided regarding the timing of the survey with respect to the drilling programme.
- Non Aqueous Drilling fluid (NADF – in this case *Escaid 120*) based mud cuttings were discharged during the drilling operations –the total quantities discharged (both concentration of NADF on cuttings, and total quality of material discharged) are not stated in the report.
- Sediment hydrocarbon concentrations ranging from approximately 100-7,000 $mg.kg^{-1}$ were recorded within 1 km of the drill centre (see report Figure 18 below).
- The highest sediment hydrocarbon concentrations appeared to be present to the north west of the drill site.
- Hydrocarbon concentrations in this range would be expected to have an impact on benthic communities (a general threshold of 50 $mg.kg^{-1}$ total sediment hydrocarbons is used to assess potential seabed impacts by OSPAR [OSPAR, 2006]).
- Based on sediment core data presented in the report, the cuttings deposition depth 150-250 m from the centre appears to be in the order of 3 cm.

**Figure F-1 Total petroleum hydrocarbons concentrations (mg/kg) from near-field, midfield and far-field stations, Jubilee Field (source CSA 2011).**



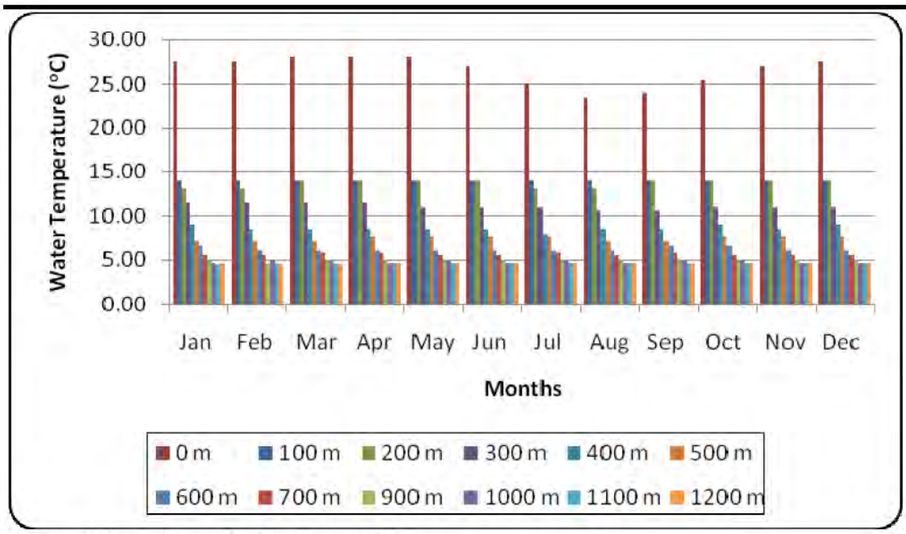

Comparison with North Sea data:

- Hydrocarbon concentrations recorded around major North Sea installations where NADF were discharged (i.e. Miller, Brent A, data from UKOOA cuttings JIP, 2004) were higher or similar to the GI-1 well centre at stations located within approximately 250 m. Concentrations recorded between 500 and 1000 m from the centre were higher for the GI-1 site compared with North Sea sites.
- As expected, this indicates that the cuttings deposited at GI-1 are spread over a wider area due to increased dispersion related to the deep water column present in the area.
- This suggests that the initial cuttings impact footprint will be expected to be larger in the deepwater Ghana area compared with North Sea sites. However this increased dispersion will mean that the size of any physical pile of material (depth in the 10's of cm – where anaerobic conditions could occur, suppressing natural biodegradation processes and significantly reducing the overall recovery rate) is likely to be smaller than North Sea cases.

NADF degradation/seabed recovery expectations:

- The actual rate of degradation/recovery is not known for the area, it will primarily depend on the exact composition of the drill cuttings discharged and the depth of deposition on the seabed. Initiation of a regular programme of seabed surveys at local drilling sites where NADF have been discharged (e.g. Jubilee GI-1) will help define the expected recovery rate for this geographical area.
- Natural degradation rates are influenced by temperature, although Ghana offshore area is located in a hot, tropical region, the water temperature at the seabed is broadly similar to North Sea conditions (around 5 °C) therefore the use of North Sea data is considered as being appropriate. (See Figure 4.9 below, taken from the Jubilee field EIA Chapter 4).

**Figure F-2 Water temperature with depth throughout the year**




Source: Adapted from Noble-Denton, 2008

- Half-life values ranging from 0.4 to 3.2 years for sediment total hydrocarbons (i.e. NADF components) have been reported in a recent Norwegian study (Schaanning and Bakke, 2006) for stations located between 250 to 1,000 m from Norwegian North Sea installations.

## F3. Evaluation of Absolute Scores

**Table F-2**

| Option | Absolute score | Comment |
|---|---|---|
| Use of Water Based Muds | -1 | WBMs typically comprise around 75% water, but also include around 20 chemical ingredients with different functions such as weighting materials (e.g. barite), viscosifiers (e.g. bentonite, carboxymethyl cellulose) and lubricants (e.g. graphite, glycols, glycerine). Shale control materials include salts which may be soluble calcium and potassium salts and other inorganic salts and organics such as glycols. Potassium chloride brines are preferred to calcium brines for their superior shale activity suppression. Although the majority of chemical components are classified as Pose Little or No Risk to the Environment (PLONOR), WBM fluid can be shipped ashore for centrifugation, re-conditioning and re-use, so reducing discharges to the marine environment. This option is assessing use of WBM, not discharge, hence environmental impacts are associated with accidental discharge (uncommon occurrence; see HSE section within this table).<br><br>All WBM chemical components have been assessed for environmental hazards (bioaccumulation, biodegradation, toxicity to test species) and TGL aims to use mostly 'gold' or category E components which are the best possible environmental classifications i.e. least harmful to the environment. WBM fluids are relatively benign if accidentally released into the marine environment; low salt formulation and substitution of barite with calcium carbonate would further reduce any benthic impact potential.<br><br>Changes observed in the benthic fauna after WBM drilling operations are generally accepted as being within the scope of natural variability[23]. |
| Use of NADF | -2 | NADF spillages occur in larger numbers, but not necessarily with greater volumes spilled than WBM spillages. In a single year (2009), the UKCS recorded 23 accidental discharge totalling 21.7 tonnes, with a mean of 0.9 tonnes spilt.<br><br>This option is assessing the use of NADF rather than its discharge, hence potential environmental impacts are only associated with accidental discharge.<br><br>Ecological impacts associated with the disposal of NADF coated drill cuttings are discussed later in row 5 of this table. NADFs comprise both synthetic mud systems and low toxicity oil based mud systems. Synthetic mud systems normally degrade more readily than mineral oil bases, have a lower toxicity in the water column than OBMs and solid phase toxicity tests also shows low toxicity[24]. NADFs are generally not bioavailable and so will not bioaccummulate in benthic fauna.<br><br>Oil based muds can have more widespread and persistent effects than WBM if spilled. Their primary effect is caused by organic enrichment of the sediments, leading to de-oxygenation as the spilled fluids are biologically degraded. Direct chemical toxic effects are not likely to be significant. The deep water TEN environment mitigates potential benthic impacts by increasing dispersion of any spilled fluids, hence decreasing or even avoiding the accumulation of contaminants at the seabed. Nevertheless, world-wide OG monitoring surveys demonstrate that the benthic communities within a 500m radius of spilled fluids can be impacted; the scale of impact is dependent on the water depth. Volume spilled and grade of seabed sediments at the point of impact. Any rig origin spills will enter a reasonably well defined marine environment[25], as compared to spills from supply vessels en route between the port and rig location. |
| Cuttings drier | -1 | Shakers and cuttings driers are powered by electric motors and form part of the cumulative $CO_2$ emissions from the drilling rig turbines.<br><br>Impacts to benthic fauna are associated with disposal of cuttings directly from the shakers and dryers and are discussed below in this table under discharge. |
| Thermal desorption | -2 | Assessing the relative importance of environmental impacts and trying to make comparisons between different types of impact, such as 1 tonne of base oil to sea vs 1 tonne of CO2 has vexed environmental practitioners for some time. |

[23] Neff (2005) Composition, Environmental fates and biological effect of water based drilling muds and cuttings discharged to the marine environment: a synthesis and annotated bibliography. Report to PERF and API.

[24] MMS(2000) Environmental Impacts of Synthetic Based Drilling Fluids

[25] Jubilee EIA

| Option | Absolute score | Comment |
| --- | --- | --- |
| | | One approach to making such comparisons is to convert the environmental impact into a monetary value, which can also act as a common environmental currency.<br><br>The UK government use a form of shadow carbon price to value carbon for policy development which is approximately $100 / MT of CO2. This value is based on the full global cost today of an incremental unit of carbon (or equivalent amount of other greenhouse gases) emitted now, summing the full global cost of the damage it imposes over the whole of its time in the atmosphere.<br><br>The 2,783 tonnes of CO2 that we have calculated for the TDU emissions is a conservative estimate is it does not take account of the recovered base oil. The additional base oil (approx 2.9%) that is recovered from the TDU over the cuttings driers will depend upon the Oil/Water ratio of the drilling mud and could reduce the difference in emissions by 20-30%. The carbon values of $100 / MT of CO2 have a monetary value of $300,000 over the life of the project which gives a score of -2. |
| Disposal at sea onsite - WBM | -2 | Changes beyond natural variability up 250m from platform are predicted, but the fauna will recover quickly through re-colonisation and immigration and be well advanced within a year. Contamination of sediments may extend further but no detectable changes in habitats or species are likely. Effects to species are primarily due to burial and low sediment oxygen concentrations caused by organic enrichment; full recovery may be delayed until surface sediments are re-oxygenated by the microbial degradation of organic contaminants. |
| Disposal at sea onsite - NADF <5% | -3 | Measurable disturbance to habitats and species out to 500 m – 1000 m is expected with discharge of NADF coated cuttings, with the added potential for detectable contamination further out, but unlikely to be accompanied by detectable impacts.<br><br>Work to date at the Jubilee development[26].[27] suggests that deposition of cuttings particles within a 150-250m radius of the drill centre is only 3cm, hence a cuttings pile may not be accumulating; this is likely to be due to water depth allowing greater time for dispersion prior to settlement on sea bed. However, hydrocarbon concentrations within 750m of the drill site are significantly elevated above the accepted OSPAR biological effects threshold of 50mg.kg$^{-1}$; hence community disturbance and ecological impact would be equally probable as a result of OBM cuttings discharge during the TEN campaigns. Rate of recovery of biological communities is dependent on the drilling fluid chemistry and the depth of deposition; extrapolating from Norwegian data[28] contaminated sediments around Jubilee may take between 2 and 17 years to degrade to background levels of 50mg.kg$^{-1}$. The effects of elevated hydrocarbon levels include reduced species richness and high numbers of opportunistic detritus-feeding polychaetes. |
| Disposal at sea onsite - NADF <1% | -1 | With additional cleaning to a level of 1% oil on cuttings or better, the level of seabed contaminant would be expected to be significantly less. In addition the product that comes out of the offshore TDU cleaning process is akin to a relatively dry powder. This material will disperse more easily in the water column and will therefore form a more diffuse plume on the seabed. This will also contribute to a reduced seabed footprint. Greater dispersal in the water column needs to be addressed, but if the discharge is sufficiently below the surface, no adverse effects should arise. |
| Bulk Cuttings Transfer | -1 | Environmental impacts are associated with potential spillage en route and the final disposal of the tank contents. Bulk tank storage significantly reduces the chances of spilling oil-contaminated drill cuttings during transport, though the entire inventory is of course an environmental hazard. In the unlikely event of a shipping incident; there are potentially significant consequences, however the probability of such an incident is low, hence the likely disturbance to the benthic environment is very small.<br><br>Atmospheric emissions, related to the number of supply ships required per well, form part of the cumulative CO2 footprint of the well and will increase it in comparison to cuttings discharge offshore. |

[26] Jubilee EIA;.

[27] CSA (2011) Jubilee Field Drill Cuttings Study. Report to Tullow Ghana Ltd

[28] Schaanning and Bakke 2006 Remediation of sediments contaminated with drilled cuttings http://www.sintef.no/project/ERMS/Reports/ERMS%20report%20no%2022_Remediation%20of%20sediments_NIVA.pdf

<table>
<tr><th>Option</th><th>Absolute score</th><th>Comment</th></tr>
<tr><td>Skip and ship</td><td>-2</td><td>Ecological effects will arise in the event of spillage and may also be associated with the final fate of the shipped cuttings.<br><br>Accidental discharge overboard from either the rig or the supply boat is likely to effect physical smothering of the benthic fauna and short term organic enrichment of the sediments. Total hydrocarbon concentrations of >50$mgkg^{-1}$ would be likely in the near field, decreasing with distance from the spill. An in-transit spillage of one or more skips is considered unlikely; similar effects would be predicted within a 500m radius of the discharge point.</td></tr>
<tr><td>Sea transport</td><td>-3</td><td>The air emissions from the supply vessel are the major contributor to the environmental impact, though much will depend upon the options available to exploit the spot market. Taking the TGL premise that the project would need a full time dedicated supply vessel, the additional emissions would be of the order of 90,000 MT of $CO_2$, which ranks as being on the high side of a moderate impact (-3).</td></tr>
<tr><td>Road transport</td><td>-1</td><td>Calculations using estimated rates and volumes of cuttings production suggest that lorry requirements might average out at one lorry every day. However, skips are more likely to arrive in batches; therefore traffic volumes may be impacted.<br><br>
<table>
<tr><th>Cuttings quantity per well</th><th>588 tonnes</th></tr>
<tr><td>Total cuttings quantity for 19 wells (oil only)</td><td>11,172 tonnes</td></tr>
<tr><td>Total cuttings quantity for 35 wells (oil + water injection)</td><td>20,580 tonnes</td></tr>
<tr><td>Skip capacity</td><td>5 tonnes</td></tr>
<tr><td>Total duration of drilling campaign (19 wells)</td><td>475 days (19 wells *25 days each)</td></tr>
<tr><td>Total number of skips required</td><td>11,172 / 5 = 2,234.4</td></tr>
<tr><td>Number of skips per lorry</td><td>5 (guess)</td></tr>
<tr><td>Number of lorries</td><td>2234.4/5 = 446.88</td></tr>
<tr><td>Number of lorries per day over duration of drilling campaign</td><td>447 / 475 = 0.94</td></tr>
<tr><td>Frequency of lorries on road</td><td>one per day</td></tr>
</table>
Environmental impacts arising from routine operations would include exhaust emissions which contribute to the cumulative $CO_2$ footprint of the TEN programme and disposal of contaminated water from washing down of trucks. Impacts from unplanned events would include road kills of wildlife and contamination of verges in the event of accidents.</td></tr>
<tr><td>Thermal desorption</td><td>-1</td><td>As this onshore treatment technology does not currently exist in Ghana, the total environmental impacts of developing such a plant would include the land take required for building of the treatment plant.<br><br>Environmental impacts are associated primarily with disposal of end products rather than treatment.<br><br>With suitable design and effective routine maintenance, ecological impacts would be from atmospheric emissions only which have not been calculated at this scoping stage.</td></tr>
<tr><td>Cutting pit</td><td>-4</td><td>The table inset below shows that in order to maintain an optimal depth of 2m, th required pit dimensions to hold cuttings from 19 wells would be approximately 65m x 65m. This area represents a significant land foot print over a long time scale; good design should avoid any off-site contamination. There is a possibility of structural pit damage from earthquakes which might lead to leaks from the structural envelope, but the frequency/likelihood has not been investigated in this study.</td></tr>
</table>

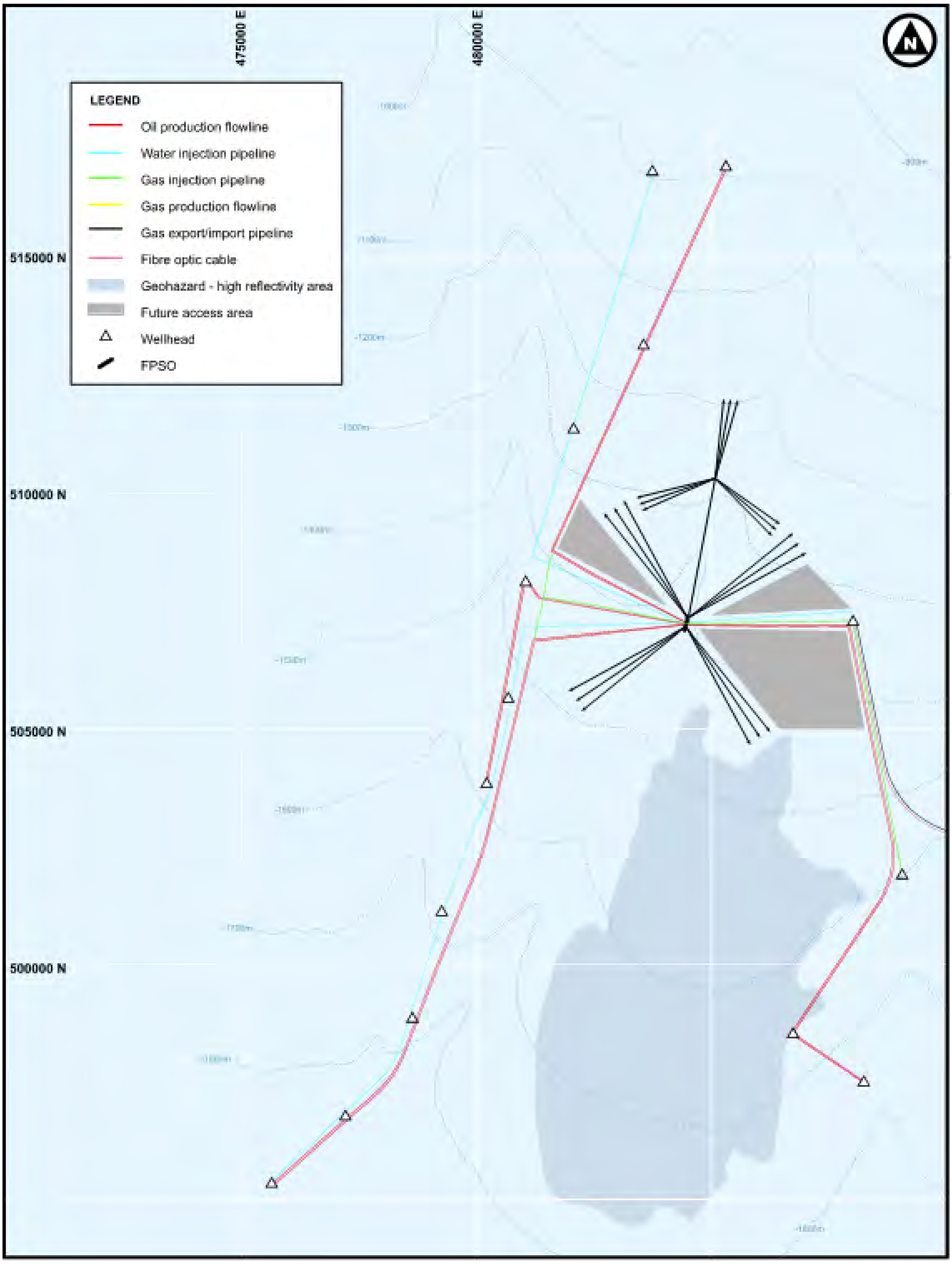
<table>
<tr><th>Option</th><th>Absolute score</th><th>Comment</th></tr>
<tr><td></td><td></td><td><table>
<tr><th>Calculation of cuttings pit dimensions</th><th>One well</th><th>19 wells</th></tr>
<tr><td>Cuttings, tonnes</td><td>588</td><td>11,172</td></tr>
<tr><td>Volume (sg = 2.6), $m^3$</td><td>226</td><td>4296</td></tr>
<tr><td>Area of pit @ 2m depth</td><td>10.6m x 10.6m</td><td>65.5m x 65.5m</td></tr>
</table></td></tr>
<tr><td>Non Structural Building Materials</td><td>-2</td><td>Negligible environmental impact during brick manufacture. Impacts mainly arise from combustion plant required for the process which add to the CO2 emissions of the total cuttings fate and effects pathway; no impact from handmade artisan brick making, which is common in developing countries.</td></tr>
<tr><td>Landfill cover</td><td>0</td><td>There should be no ecological footprint beyond that already created by the quarry or landfill, the visual impacts from these existing facilities should be reduced by the operation</td></tr>
<tr><td>Land farming</td><td>-3</td><td>Some studies indicate that land farming does not adversely affect soils and may even benefit certain sandy soils by increasing their water-retaining capacity and reducing fertilizer losses. However, care must be taken to balance the additions of waste against a soil's capacity to assimilate the waste constituents without destroying soil integrity, creating subsurface soil contamination problems, or causing other adverse environmental impacts, caused by:<br><br>Wastes that contain large amounts of oil and various additives may have diverse effects on parts of the food chain. Higher molecular-weight compounds biodegrade more slowly and may accumulate; therefore elevated concentrations of hydrocarbons in drilling wastes can limit the application rate of a waste on a site<br><br>Wastes containing salt must also be carefully applied to soil since salts cannot biodegrade but may accumulate in soil. If salt levels become too high, the soils may be damaged and treatment of hydrocarbons can be inhibited. Changes to the soils may include pH, nitrogen balance and electrical conductivity; also the accumulation of other contaminants such as major soluble ions (Ca, Mg, Na, Cl), total metals, extractable organic halogens, etc.<br><br>Landfarming also requires the frequent application of water to maintain moisture content of 10-15%; the prudence of using a limited resource for this technology and end point might be debatable at a local and regional level, and discussion may escalate to a broader group of stakeholders in the context of increasing water shortage and water valuation for international sustainability.</td></tr>
</table>

# F4. Discussion of Key Output Issues

## F4.1. TEN Development Drilling Programme

Based on Tullow Oil's current expectations, a total of 36 wells will be drilled in the TEN development area over the next four years. The location of the various drill sites and associated infrastructure are shown below (Figure F-3).

**Figure F-3 TEN Development Project - Potential drill centres (based on Intec Sea 2011 Field Layout Diagram)**




The main drilling locations identified at present are listed in the table below:

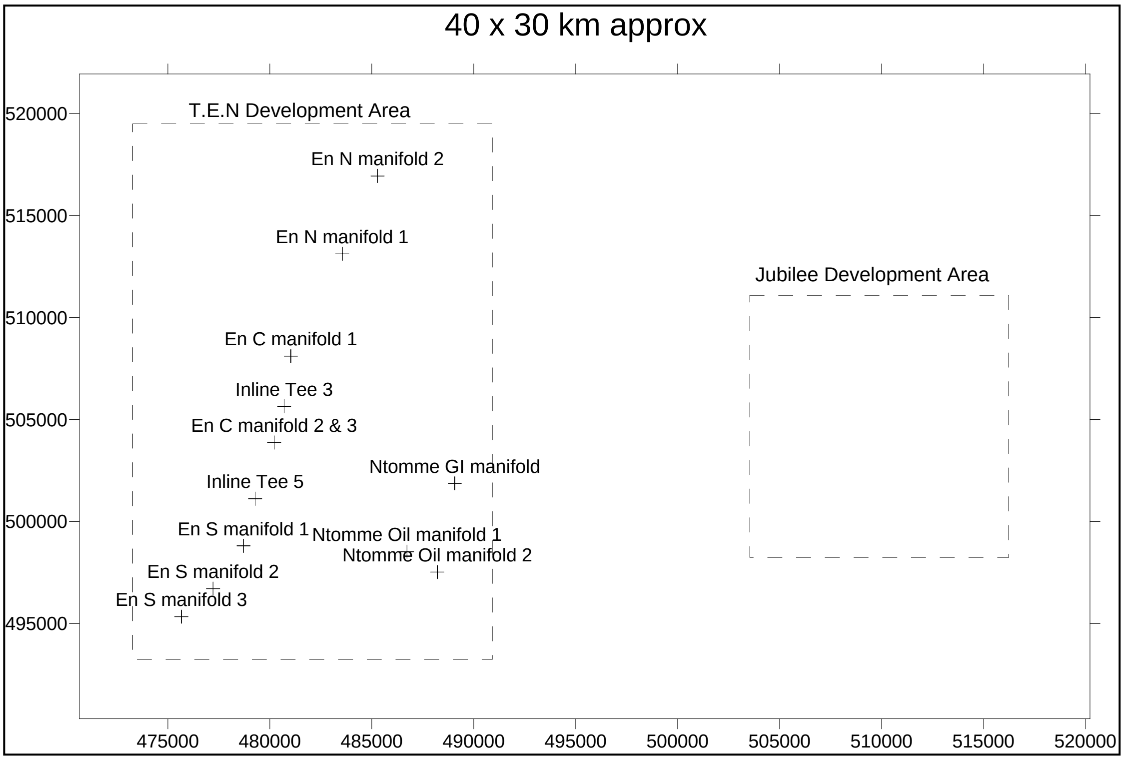
**Table F-3** Main TEN drilling locations

| Installation | Easting | Northing | Number of wells |
|---|---|---|---|
| En N manifold 1 | 483552 | 513119 | 2 |
| En N manifold 2 | 485284 | 516934 | 3 |
| En C manifold 1 | 481031 | 508108 | 1 |
| En C manifolds 2 & 3 | 480213 | 503874 | 8 |
| En S manifold 1 | 478712 | 498812 | 4 |
| En S manifold 2 | 477216 | 496712 | 3 |

| | | | |
|---|---|---|---|
| En S manifold 3 | 475663 | 495339 | 3 |
| Ntomme Oil manifold 1 | 486728 | 498522 | 1 |
| Ntomme Oil manifold 2 | 488215 | 497526 | 2 |
| Ntomme GI manifold | 489072 | 501876 | 2 |
| Inline Tee 3 | 480702 | 505650 | 2 |
| Inline Tee 5 | 479281 | 501120 | 2 |

The location of the TEN field in relation to the Jubilee area is provided below:

**Figure F-4** Outline sketch showing TEN and Jubilee field proximities




## F4.2. Potential Impact Footprint of NADF Discharges from Development Activities

In the absence of detailed information regarding drilling operations and specific environmental data the information relating to the Jubilee GI-1 centre is used to **estimate** the potential impacts arising from the development drilling programme.

Sediments containing <100 mg.kg$^{-1}$ total hydrocarbons were recorded up to approximately 750 m from the GI-1 drill centre therefore – based on existing offshore oil and gas environmental survey data, the benthic communities within this area may be impacted to some extent by the discharged cuttings. The total area of potential impact is therefore 0.75 km x 0.75 km x 3.14 = 1.77 km$^2$ per drill centre.

It is believed that a total of seven wells were drilled at the GI-1 centre however the exact details of the drilling programme are not known (e.g. volumes of WBM and NADF cuttings discharged and concentrations of NADF on discharged cuttings). Assuming the application of a similar drilling strategy at the TEN drill sites it would be reasonable to assume that the likely footprint of impact for the majority of the locations would be smaller (between one to four wells being drilled at each location with the exception of the En C manifolds 2 & 3 where a total of eight wells are planned). Therefore the footprint values provided below can be considered as being highly cautious over-estimations.

**Table F-4**

| **Installation** | **Number of wells** | **Maximum expected impact footprint km²** |
|---|---|---|
| En N manifold 1 | 2 | 1.77 |
| En N manifold 2 | 3 | 1.77 |
| En C manifold 1 | 1 | 1.77 |
| En C manifold 2 & 3 | 8 | 1.77 |
| En S manifold 1 | 4 | 1.77 |
| En S manifold 2 | 3 | 1.77 |
| En S manifold 3 | 3 | 1.77 |
| Ntomme Oil manifold 1 | 1 | 1.77 |
| Ntomme Oil manifold 2 | 2 | 1.77 |
| Ntomme GI manifold | 2 | 1.77 |
| Inline Tee 3 | 2 | 1.77 |
| Inline Tee 5 | 2 | 1.77 |
| **Total** | | **21.24** |

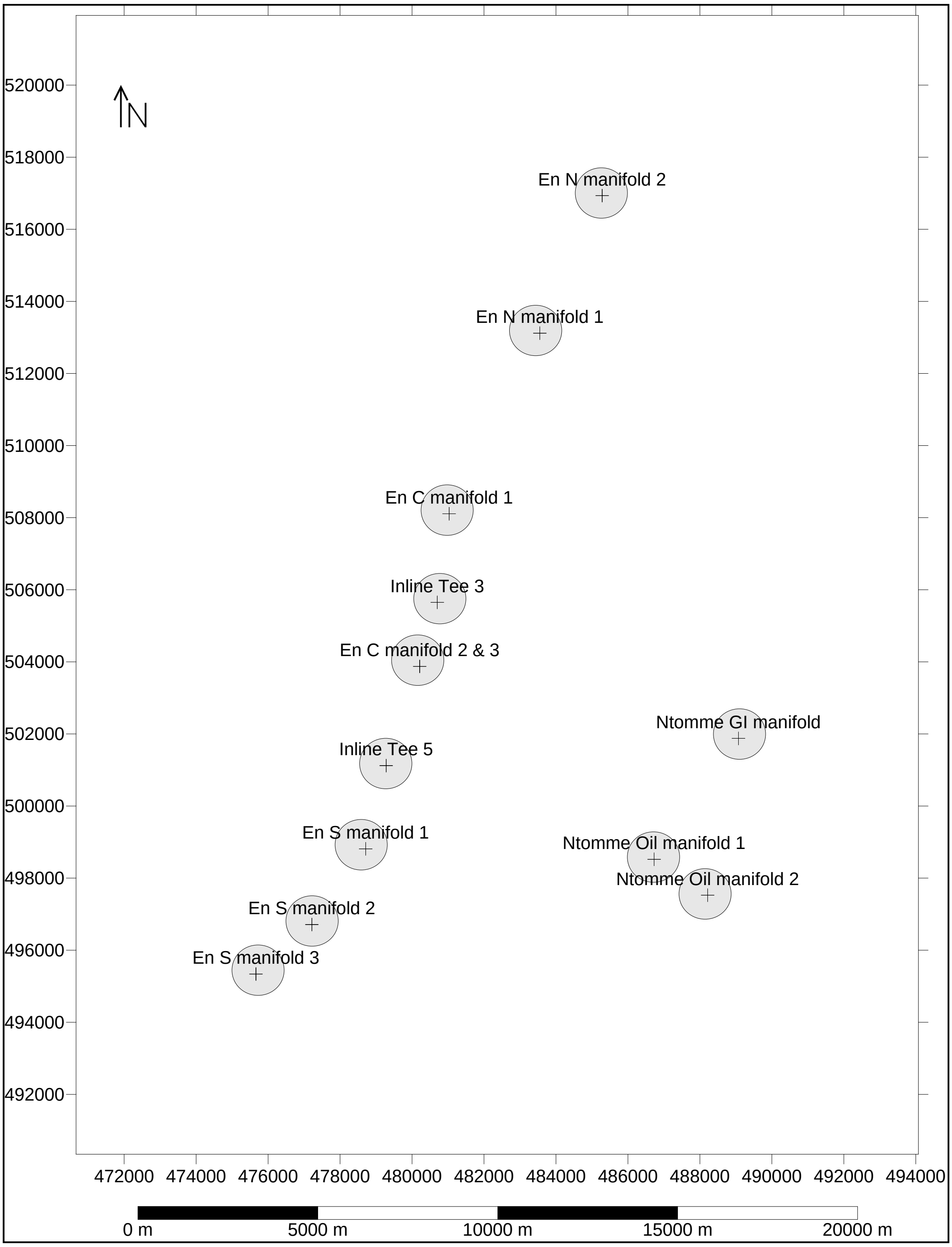
A graphical representation of the **maximum** potential impact areas with respect to the TEN development area as a whole is provided in Figure F-5.

As outlined in Section F2.1.2F2.1.2 the NADF hydrocarbons will degrade naturally over time thus allowing the recovery of seabed conditions. The following calculation (using the half-life values reported by Schaanning and Bakke (2006) and cautious estimations of potential impact areas) was used to provide an indication of how the impact footprint may change with time.

The maximum sediment hydrocarbon concentration recorded outside a 250 m radius (an area of 0.2 $km^2$) of the GI-1 centre was 4,000 $mg.kg^{-1}$ – This would take between 2.5 (best case) and 20 (worst case) years to reach 50 $mg.kg^{-1}$ (typical of background concentrations recorded for the area and the same as the threshold value used by OSPAR to define areas of seabed likely to be impacted by NADF cuttings).

Therefore, based on the **worst case** half-life value of 3.2 years, the **maximum** extent of the expected impact footprint after 20 years would be 0.2 $km^2$ per drill centre, or 2.4 $km^2$ for the TEN area as a whole. Using the **best case** degradation half-life value of 0.4 years the decrease in **maximum** total impact footprint to 2.4 $km^2$ would occur within 3 years.

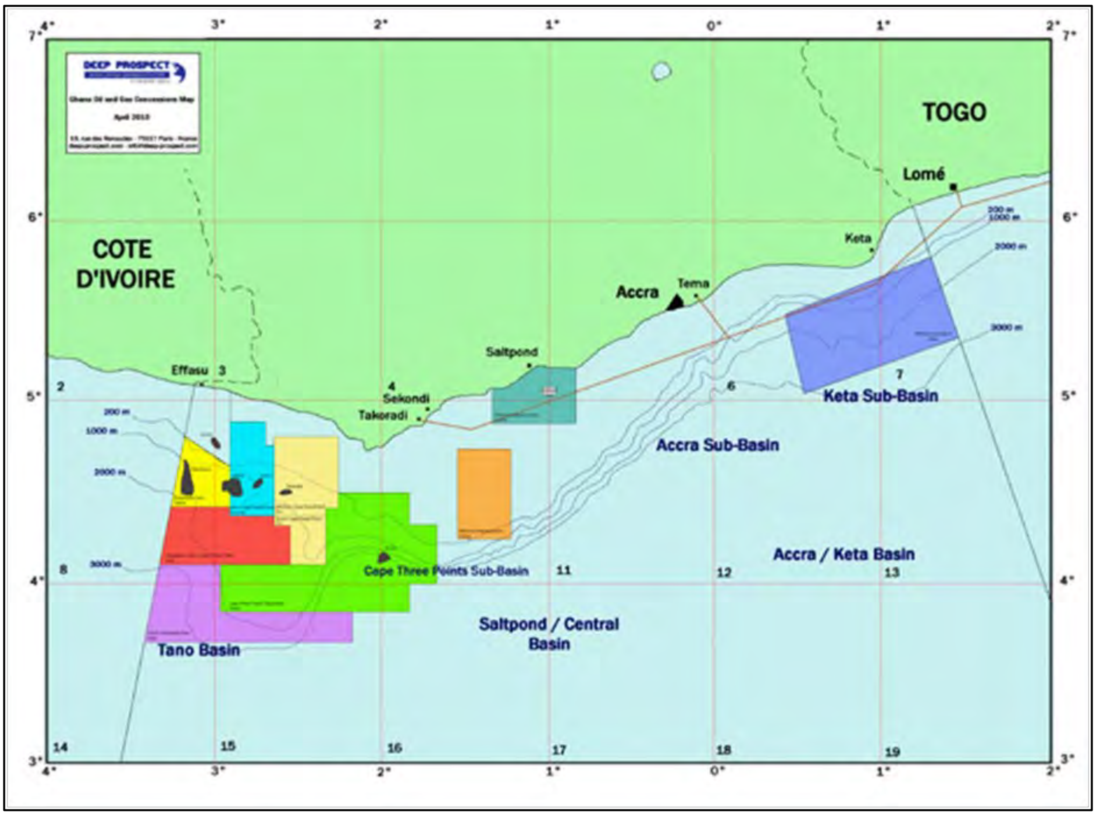
**Figure F-5** Potential maximum impact areas from the TEN development



## F4.3. Overall Continental Shelf Cumulative Impacts

The wider context of development for the whole of the Ghanaian shelf and slope seas can be seen in Figure F-6. This shows that although exploration and production are focused at present in western waters, there is potential for activity to spread to the more central and eastern areas. However, even with such a spread of activity the likely footprint from cuttings discharge would be relatively small and would not influence the distribution or abundance of species over a wider area.

**Figure F-6** Ghana offshore licence blocks and current development



# Appendix G . Economic Issues

This appendix provides all of the relevant background information about how economic issues have been handled within the BPEO study process.

## G1. Sources of Information

### G1.1. Published Sources and Existing Report

Jubilee project EIA (ERM 2009):

- Ghana's economy is based upon agriculture and fishing, accounting for 45-50% of GDP and 55% of employment. Other major sources of employment are mining and quarrying, which employ 15% and manufacturing which employs 11%.
- In the Sekondi-Takoradi Metropolis the port is a major economic driver with secondary industrial and commercial trading activity widespread. Fisheries and tourism are also important.
- Economic migration towards the commercial and mining towns in the Sekondi-Takoradi Metropolis is well established leading to the high proportion of people of working age in the local population.
- Despite the growing economy levels of unemployment and poverty are comparatively high related to the fast growing population.
- Fisheries activity has been in decline recently, whilst the tourism sector is growing; tourism places considerable importance on Ghana's pristine tropical beaches.
- Salt production is carried out in coastal lagoons.

US Central Intelligence Agency – Facts on Ghana (updated 2012)
(https://www.cia.gov/library/publications/the-world-factbook/geos/gh.html)
Some variation apparent in the information from this CIA site as compared to the Jubilee EIA source; however the importance of the emerging oil and gas industry to economic development and foreign exchange is clear.

- Ghana's economy has been strengthened by a quarter century of relatively sound management, a competitive business environment, and sustained reductions in poverty levels.
- Ghana is well endowed with natural resources and agriculture accounts for roughly one-quarter of GDP and employs more than half of the workforce, mainly small landholders. The services sector accounts for 50% of GDP.
- Gold and cocoa production and individual remittances are major sources of foreign exchange. Oil production at Ghana's offshore Jubilee field began in mid-December, 2010, and is expected to boost economic growth. Estimates of 120,000 barrels per day were made for 2011 with the generation of accumulated revenue of US$20 billion between 2012 and 2030 predicted. Estimated oil reserves have jumped to almost 700 million barrels.
- Ghana signed a Millennium Challenge Corporation (MCC) Compact in 2006, which aims to assist in transforming Ghana's agricultural sector. Ghana opted for debt relief under the Heavily Indebted Poor Country (HIPC) program in 2002, and is also benefiting from the Multilateral Debt Relief Initiative that took effect in 2006.
- In 2009 Ghana signed a three-year Poverty Reduction and Growth Facility with the IMF to improve macroeconomic stability, private sector competitiveness, human resource development, and good governance and civic responsibility. Sound macro-

economic management along with high prices for gold and cocoa helped sustain GDP growth in 2008-11.

- Employment figures from GLSS (2008) for the whole country show that the dominant occupation is traditional agriculture & fishing (35%), followed by waged employment (29%) and self-employment (25%); this suggests that unemployment stands at 11%. Other breakdowns within the report show that 70% of 15-64 year olds are economically active, with 55% in agriculture/fishing, 15.% in trading and 11% in manufacturing; the unemployment figure is stated as 3.6%.
- Incomes vary throughout the country, with an average annual income of 7,813.3 cedis (£2558; $4005) reported in Ghana's Western Region. This compares with the highest average Ghanaian salary of 10,871.2 cedis in the Greater Accra region, and the lowest, 2,354.4 cedis in Upper West.
- The Ghana Statistical Service (2008) quotes much lower figures as representative of the whole country, with 1217 cedis (£397; $623) as the average annual household income and 400 cedis (£130; $204) for the average per capita income.

## G1.2. Requested Data, Derived Data and Assumptions

None requested.

## G1.3. Input Data

The following economic assumptions were made:

**Table G-1**

| Socio-economic | Values | Project value | Assumptions & sources |
|---|---|---|---|
| **Inputs** | | | |
| Average annual urban wage | $1,500 | per annum | http://www.statsghana.gov.gh/docfiles/glss5_report.pdf |
| Average daily wage | $4 | per day | Calculated over 365 days |
| Average wage skilled onshore | $25 | per day | Aquatera assumption based on national averages |
| Average wage skilled offshore | $50 | per day | Aquatera assumption based on national averages |

These input factors were used to derive the following output parameters

**Table G-2**

| Outputs | No people | | Assumptions |
|---|---|---|---|
| WBM | 5 | £71,250.00 | 5 local staff: chemicals warehouse, manage bulk chemicals, accounts |
| OBM (mud plant) | 8 | $114,000 | 6 local staff: chemicals warehouse, mud plant, accounts |
| Cuttings driers | 8 | $228,000 | 1 person per shift with rotation of time offshore; 2 rigs |
| TDU installation/decom (60 days) | 6 | $18,000 | Local welders, pipefitters, electrician & labourers |
| TDU operation | 6 | $171,000 | 1 non-Ghanaian supervisor and 0.5 lead, 1.5 Ghanaian support per shift |
| Supply boats (1.5) | 15 | $427,500 | Non Ghanaian Captain, Mates, Engineer. Ghanaian deckhands |
| Dock crane | 100% | $150,575 | All Ghanaian |
| TDU onshore | 8 | $114,000 | 1 non-Ghanaian supervisor and 2 Ghanaian support per shift |
| Lorry | 1 | $14,250 | Assumes that vehicle and fuel costs are made |

| | | | |
|---|---|---|---|
| Landfarming onshore | 75% | $903,450 | 75% Ghanaian content |
| Manufacture of NSBM | 50% | $903,450 | 50% Ghanaian content |
| Environmental monitoring | 25% | $50,000 | 50% Ghanaian content: foreign vessel, mainly Ghanaian crew |

## G2. Evaluation of Absolute Scores

**Table G-3**

| Option | Absolute score | Comment |
|---|---|---|
| Water Based Muds | +2 | Limited local content as nearly all materials are imported. Estimate 5 local jobs associated with chemical storage and office base for mud company (estimate value $75K) plus some infrastructure from office, warehousing etc.*. In time (5-10 years of operation) higher value jobs from mud engineering offshore but will take time and training. |
| NADF | +3 | Limited local content as nearly all materials are imported. Estimate 9 local jobs associated with chemical storage, operation of NADF mud plant and office base for mud company (estimate value $120K) plus some infrastructure from office, warehousing, mud plant etc.* |
| Cuttings drier | +2 | As the machinery is either bought or leased from company outside Ghana there would be little benefit to local companies except storage and handling at a local port if the equipment does not arrive on the rig. Cuttings driers are simple items of equipment normally operated by two crew members; this could create jobs for 4 local Ghanaians if suitably qualified people were available. Assuming crew of 1 ex-pat and 3 Ghanaians, value is $85K |
| Thermal desorption | +3 | As the machinery is either bought or leased from company outside Ghana there would be little benefit to local companies apart from installation work. The units would be run and maintained by a specialist crew of 4 operators and 1 supervisor. Assume two Ghanaian crew – going up to four after training (three average, six in total as back to back) - Value $200K with installation and decommissioning. |
| Disposal at sea onsite - WBM | 0 | No economic impact from this activity |
| Disposal at sea onsite - NADF <5% | +2 | Potential economic benefits resulting from benthic survey if local Ghanaian companies are used, however it is currently unknown if such services exist in country. Some support possible from Ghanaians on surveys; estimated value $25K. |
| Disposal at sea onsite - NADF <1% | +1 | Few economic benefits, possibly some survey needs. |
| Bulk Cuttings Transfer | +3 | Assumes skipper, mate, engineer are not local, but they are supported by a local crew of 5 deckhands / catering (total 10 with back-up crew). The operation may require an additional 1.5 boats. Total local value estimated at $470K. |
| Hybrid bulk transfer | +3 | Assumes skipper, mate, engineer are not local, but they are supported by a local crew of 5 deckhands / catering (total 10 with back-up crew). The operation may require an additional 1.5 boats. Total value estimated at $470K. Additional crane operations onshore at $10/lift which amounts to an additional $150K. Total local value $620K |
| Skip and ship | +3 | As for hybrid transfers. Possibility of using some extra labour during busy times, but unlikely to be substantial |
| Road transport | +3 | Cost of haulage operation estimated to be less than but approaching $1 per km[29], which is $70,000 for the project assuming a round trip of 50 km from the docks to the processing site. |

[29] Based on US operating cost of $0.65/km, rental in Ghana assumed to be $1/km http://nexus.umn.edu/papers/truckoperatingcosts.pdf

| | | |
|---|---|---|
| Thermal desorption | +3 | As the machinery is either bought or leased from company outside Ghana there would be little benefit to local companies apart from installation work. The units would be run and maintained by a specialist crew of 4 operators and 1 supervisor. Assume 2 Ghanaian crew – going up to 4 after training (3 average, 6 in total as back to back). Some additional income from site maintenance and arranging for disposal. |
| Cutting pit | +3 | The average drilling waste burial costs are estimated at $7 to $8 per barrel (Bansal and Sugiarto 1999). Similarly the cost for solid and oil wastes in the US vary from $12-150 per ton. Assuming $81 per ton[30] then the economic benefit is likely to be in the region of several hundred thousand dollars over the course of the project. |
| Non Structural Building Materials | +3 | Good prospects for using local skills and resources – high local labour content but probably between $100k and £1MM |
| Landfill cover | +2 | High level of local content but work not that complex or labour intensive, estimate $25K |
| Land farming | +3 | The cost of land farming is given as $37in OGP (2003) but this is based on US data where land farming is already established. Veil (1998) reports cost for land spreading facilities mainly in the region of $20/ton but as high as $95/ton in the US. In Ghana, we have assumed $100 / tonne to allow for contractor training, land acquisition by contractor and further landfill and disposal taxes. Total cost is the order of just over $1 million. |

[30] Costs For Off-Site Disposal Of Non-hazardous Oil Field Wastes: Salt Caverns Versus Other Disposal Methods, Argonne National Laboratory, 1997

# Appendix H . Social Issues

This appendix provides all of the relevant background information about how social issues have been handled within the BPEO study process

## H1. Sources of Information

The following published sources have been used.

### H1.1. Published Sources and Existing Reports

Ghana Statistical Service (September 2008) Ghana living standards survey. Report of the fifth round (GLSS 5).

- Statistics from this publication have been used to verify or enhance the comprehensive information available in the Jubilee EIA.

Jubilee Project EIA (ERM 2009):

- The administrative structures comprise a mix of relatively new and modern national governmental structures, local authority governance and traditional leaders of groups of people.
- The Western Region of Ghana where the Tullow offshore developments are serviced from has experienced rapid growth over recent years and at 2.5 million accounts for approximately 11% of the total Ghana population.
- The population of the Sekondi-Takoradi Metropolis was 370,000 in 2000, but will be significantly greater now.
- The population is relatively young, with 43% under the age of 15 and a median age of 21 years.
- Increased economic activity e.g. the mining and cocoa booms of 1984-2000, has an influence on population numbers in a country where internal migration in search of work is common. The current oil and gas industry boom is likewise stimulating rapid economic growth and a rise in population numbers in the urban coastal areas of the Western Region. Other, more traditional, migrations take place regularly between the interior and coastal seasonal work demands of farming and fishing. Coupled with high levels of unemployment, the housing demand of migrant workers mean that standards of living are often low.
- Education is free and compulsory up to the age of 15, thereafter junior high, secondary and tertiary education being much less available to all. Only 53% of the population aged 15 years or more is literate, with many children (20%) dropping out of education after primary school; and almost half the Ghanaian population has no schooling. The lack of schools and lack of rural infrastructure are held to be prime reasons for this.
- Poverty is comparatively high in Ghana's Western Region (18.4%) although it has halved since 1991/1992.
- Ghana is focussing on improving health care and health education as evidenced by the overall declining infant mortality rates and increasing life expectancy. Health expenditure is 10.6% GDP, which compares favourably with many developed countries in Europe. However a number of widespread diseases and lack of access to good quality drinking water are still major factors affecting quality of life and significant numbers of children under the age of six (2.6%) have had no vaccinations against the six childhood killer diseases.
- Social infrastructure is based on schools, hospitals and clinics, all of which exist under both public and private ownership. International mining companies have traditionally offered healthcare to employees.

- Water, sanitation and waste management systems tend to be poorly developed and are strongly linked to the quality of life. Piped water is available throughout larger urban areas, but to less than 10% of rural households who rely on rivers, wells, streams and dugouts. Sanitation is poor in many districts with >40% of households in the Western Region having either no toilet at all or just access to a public toilet. There is widespread indiscriminate disposal of waste of all types, with unauthorised dumping being rife. Although 60% of Ghanaians use a specified dump site, 29% are known to use unauthorised sites.
- Energy production and distribution are key to economic development and 99% of urban households now have electricity. Ghana's rural electrification programme is increasing the number of rural households with access to electricity, though many still use kerosene lamps. Cooking is predominantly with wood and charcoal.
- Ghana's power stations include three hydroelectric plants, a diesel plant at Tema and thermal power plants in Takoradi and Aboadze. The thermal power plants, which can currently use oily waste as feedstock, are the subject of development plans for transfer to natural gas feed to be imported from Nigeria.
- Corporate responsibility policy

**EPA (2005)** Ghana State of Environment Report 2004. Accra Ghana; ISBN 9988-557-11-6.
**Worldbank (2008)** World Bank Supports Transport Improvements in West African States. http://web.worldbank.org; Press release NO. 2008/AFR/388.
**Worldbank (2011)** Africa Development Indicators 2011. http://web.worldbank.org

Corporate Responsibility
www.westernghanachamber.org
www.tullowoil.com

- Tullow Ghana Ltd is a corporate sponsor of **Sekondi-Takoradi Regional Chamber of Commerce & Industry CSR Awards**. The company also received two STRCCI CSR awards in 2011**.**
- Tullow Ghana Limited and the Jubilee Partners were announced as the winners of two prestigious awards, recognising efforts to make a positive socio-economic impact in Ghana's Western Region.
- The company was also was commended for its on-going efforts to improve the living conditions for local communities in the areas surrounding its operations. Activities and events included sports related community engagements, a beach clean-up and sponsorship of a popular interschool sporting activity, the Osagyefo cup.
- Jubilee Community support : Tullow acted on the findings from its Jubilee ESIA discussions to identify the most appropriate Social Enterprise and social investment projects for the area which would help to alleviate the most pressing needs of the six coastal communities of the Western Region. The drilling of water wells in the region, and Tullow's support for a programme to eradicate river blindness, were the first direct outcomes of the process. Tullow Ghana has also developed a Social Enterprise strategy and management framework.

### H1.2. Requested Data, Derived Data and Assumptions

None requested.

## H2. Evaluation of Absolute Scores for Social Issues

**Table H-1**

| Option | Absolute score | Comment |
|---|---|---|
| Use of Water Based Muds | 0 | No social impacts |
| Use of NADF | 0 | No social impacts |
| Cuttings drier | 0 | No social impacts |
| Offshore Thermal desorption | 0 | No social impacts |
| Disposal at sea onsite - WBM | 0 | No social impacts |
| Disposal at sea onsite - NADF@ <5% | 0 | No social impacts |
| Disposal at sea onsite - NADF@<1% | 0 | No social impacts |
| Bulk Cuttings Transfer | -1 | Additional unloading of skips in port has potential for some disruption of shipping, depending upon berths /activity levels. |
| Hybrid transfer | -1 | Additional unloading of skips in port has potential for some disruption of shipping, depending upon berths /activity levels |
| Skip and ship | -1 | Additional unloading of skips in port has potential for some disruption of shipping, depending upon berths /activity levels. |
| Road transport | -2 | 2-3 average of additional truck journeys per day, though these might be more frequent at peak times. Minimal overall disruption at port or roads |
| Thermal desorption | --2 | Waste gases from TDU have been known to produce odours and are a potential source of nuisance |
| Cutting pit | 0 | No significant impacts |
| Non Structural Building Materials | +1 | Some uses for such materials could involve common good utilisation or applications |
| Landfill cover | -2 | This will add security to the cover of landfill sites, increasing wider security against nuisance and disease, but some people may also rely upon access to the site for subsistence living |
| Land farming | -3 | Potential issues with land-take and contamination of surface water if not well planned and executed. |

# Appendix I. Regulatory and Policy Issues

This appendix provides all of the relevant background information about how regulatory and policy issues have been handled within the BPEO study process

## I1. Sources of Information

The following published sources have been used:

### I1.1. Published Sources and Existing Reports

Jubilee EIA (ERM 2009)

- The Jubilee EIA presents a comprehensive description of the Ghanaian administrative framework and national legislation governing the developing oil and gas industry. Primary legislation includes the Environmental Protection Act (Act 490 of 1994) which establishes and mandates the Ghana Environmental Protection Agency (EPA); the EIA Regulations (1994), the Environmental Assessment Regulations 1999 (LI 1652) and a number of environmental guidelines apply to all projects likely to have an adverse effect on the environment.
- Oil and gas industry regulations centre on the Ghana National Petroleum Corporation Act and the Petroleum (Exploration & Production) Law (Act 84 of 1984); their demands include submission of an operator's EHS manual to the GNPC prior to commencement of operations.
- Ghana is a signatory to MARPOL Annex I and II which provide regulations for ship drainage water, accidental oil discharge, FPSO hull configuration and bulked chemicals; its draft Marine Pollution Bill will be the enacting legislation for Annexes III,IV,V and VI which cover sewage discharge, garbage, food waste and atmospheric emissions. All Jubilee effluent limits for drilling operations discharges were based on MARPOL requirements.
- A number of worldwide industry standards, guidelines and guidance exist and have been adopted by Tullow; these include the IFC Performance Standards (including PS3 - Pollution Prevention and Abatement), the IFC Environmental Health and Safety Guidelines, various OGP guidelines and principles, and IPIECA guidance on spill response and contingency planning.

**EPA (2010)** Guidelines for Environmental Assessment and Management in the Offshore Oil and Gas Development; an Overview of Ghanaian Environmental Assessment procedure, oil and gas development issues and management approaches.

- These draft guidelines describe the Preliminary Environmental Assessment requirement prior to drilling an exploration well and the issuance of an Environmental Permit after successful review of the PEA.
- It defines OSPAR as the policy/regulation application to the physical impacts from drilling including noise, the discharge of drilling cuttings and the discharge of drilling fluids.
- Effluent guidelines are given for drill cuttings with NADF and with WBM. For NADF, there is to be no discharge to sea of the fluid alone; NADF cuttings may be discharged provided they meet the following conditions:
    - Hg – max 1 mg/kg dry weight in stock barite
    - Cd - max 3 mg/kg dry weight in stock barite
    - Discharge via a caisson at least 15 m below sea surface
    - Oil concentration by weight on dry cuttings:
    - Water depth 0 – <500m No discharge
    - Water depth >500m 3% maximum

**EPA (2012)** Environmental Permit for Development of the Jubilee Field (Jubilee Phase 1A Development). Permit No. CE18280366.

- Environmental conditions of the permit include maintaining a 500m safety zone, establishing a Fisheries Liaison organisation, obtaining chemical permits from the EPA for all drilling chemicals, submitting a solids waste management plan and adopting various best practices;
- Discharge to sea of NADF cuttings must not exceed oil on cuttings concentration of 2% by weight. This is more stringent that the 3% outlined in the draft Environmental Guidelines (EPA 2010) described above.

Environmental Assessment Regulations (LI652,1999) as amended 2002

- This legislation enacts the EIA process.
- All activities likely to have an adverse effect on the environment must be subject to EA and issuance of a permit.
- Many of the possible onshore options for cuttings disposal are likely to require an EIA and certainly will require to be screened by the EPA for environmental approval.
- An EIA would be required for the establishment of a waste disposal site or of facilities for the collection or disposal of hazardous wastes.

## I1.2. Requested Data, Derived Data and Assumptions

**Table I-1**

| Data requirements | Response from Client | Reference / Data Source |
|---|---|---|
| Ghana Environmental Legislation - has all relevant legislation been consulted with respect to cuttings disposal options? | There is no current 'legislation' governing this type of waste stream. The Ghana EPA tends to enact their requirements via the issued 'Permit' schedule. However, oil/gas sector guidelines are about to be published which, reinforce the 1% OOC discharge limit (with financial surcharges applied on a sliding scale). A review of West African legislation (and wider) on this issue has been performed and submitted to the EPA. | TGL/ERM comparative report of drill cuttings discharge legislation |
| Ghana waste regulations - do these include a detailed waste classification system? | Not as yet and see above cell. | None |
| Has Tullow become involved in any discussions with the EPA about the fine structure associated with more than 1% Oil on cuttings discharge? If so what are the financial implications on the project? | Frequent discussions have taken place and will be on-going into the future. The current thinking is that any discharge surcharge is worth paying to prevent the adverse effects (increased risk profiles) of the skip n ship route! | Jubilee Field Drill Cuttings Study (table 1, page 10) |
| OPM - Is there any regulatory resistance to use of oil phase mud (OPM)? | Not as yet. Proposed oil/gas sector environmental guidelines are also not clear on this matter? | None |

## I1.3. Regulation of Discharge of NADF Cuttings

Despite the current guidelines[31], there is pressure from regulator (Ghana EPA) to reduce all discharge of NADF cuttings to below 1% dry weight OOC. This aligns with regulation in some parts of the world such as the UK, Norway and Denmark (OSPAR countries). The draft guidelines state that discharge must not exceed maximum oil on cuttings concentration of 3% in water depths of greater than 500m where there is no reasonable alternative and provided certain conditions are met as outlined below:

**Table I-2**

| *Drilled cuttings – re-inject or ship-to-shore, no discharge to sea except:* |
|---|
| • *Hg – max 1 mg/kg dry weight in stock barite* |
| • *Cd - max 3 mg/kg dry weight in stock barite* |
| • *Discharge via a caisson at least 15 m below sea surface* |
| • *Oil concentration by weight on dry cuttings:* |
| • *Water depth 0 – <500m No discharge* |
| • *Water depth >500m 3% maximum* |

For the Jubilee field (Phase 1) development wells, Tullow proposed to discharge NADF cuttings to sea following treatment to reduce oil on cuttings to less than 5% [32]. In reviewing this EIA, the EPA Environmental Permit for Jubilee Phase 1 stated that Tullow investigated options for further cuttings cleaning improvement to reduce NADF on cuttings to 1% in the longer term. During the Environmental Permit review Tullow requested a revision of the permit conditions and the Ghana EPA responded by stipulating that review of the current 1% OOC discharge limit will require sufficient and adequate baseline data for the Ghana offshore environment to provide scientific evidence that discharge levels could be modified without compromising environmental integrity. TGL completed the Jubilee Field Drill Cuttings Study[33] to address these points. The report makes a formal recommendation to the EPA to increase discharge guidelines from the current 3% to 5% OOC.

Offshore treatment of cuttings using standard cuttings dryer technology (MI Swaco Verti-G or Brandt Vortex) which reduces ROC to < 3%, as is currently being used on the Jubilee field, is in compliance with the levels set out in the Draft Guidelines released by the Ghana EPA[34] draft guideline but not the levels set out in the Environmental Permit granted for the Jubilee Field Phase 1a which state that "oil concentration lower than 2% by weight on dry cuttings" can be deposited at sea or the most stringent international standards which limit ROC to <1%. This option in Table I-3 therefore scored -3, since disposal of cuttings at 3% could be detrimental to Tullow Ghana's reputation within the industry and may be out of line with EPA guidelines if the figure of 2% is adopted.

[31] Ghana EPA (2010) Draft Guidelines for Environmental Assessment and Management in the Offshore Oil and Gas Industry

[32] Jubilee Field EIA- Annex B

[33] CSA (2011) Jubilee Field Drill Cuttings Study

[34] Guidelines for Environmental Assessment and Management in the Offshore Oil and Gas Development

## I2. Evaluation of Absolute Scores for Regulation

**Table I-3**

| Option | Absolute score | Comment |
|---|---|---|
| Use of Water Based Muds | 0 | Not applicable see below disposal at sea |
| Use of NADF | 0 | Not applicable see below disposal at sea |
| Cuttings drier | 0 | Not applicable see below disposal at sea |
| Thermal desorption | 0 | Likely to be seen as proactive by regulator and consistent with best practice amongst top quartile of other operators. High degree of future proofing |
| Disposal at sea onsite - WBM | +1 | Good compliance and possibly seen as proactive by regulator. Aligned with best practice and regulation in most parts of the world, though WBM discharges are banned in certain parts of the world, especially Russia / Sakhalin, but regulation unlikely to change within life of project. In line with the World Bank Standards for disposal of Water-Based Muds. The selected WBM would have to meet and adhere to the conditions outlined in the Environmental Permit. The limits set for the Jubilee Phase 1A development were:<br>*"WBDF – re-inject or ship-to-shore, no discharge to sea except: In compliance with 96 hr. LC-50 of SPP-3% vol. toxicity test first for drilling fluids or alternatively testing based on standard toxicity assessment species (preferably site-specific species); WBDF, fluids and cuttings– re-inject or ship-to-shore, no discharge to sea except meeting: Hg – 1 mg/kg dry weight in stock barite; Cd - 3 mg/kg dry weight in stock barite; Maximum chloride concentration must be less than four times ambient concentration of fresh or brackish receiving water; Discharge via a caisson at least 15 m below sea surface"*<br>These limits are the same as those outlined in the draft guidelines document 'Guidelines for Environmental Assessment and Management in the Offshore Oil and Gas Development' released by the Ghana EPA. |
| Disposal at sea onsite - NADF <5% | -3 | This would be outside regulatory aspirations; however the EPA-defined financial penalties for excessive discharges indicate that the likelihood of developments not meeting requirements has been envisaged. |
| Disposal at sea onsite - NADF <1% | -1 | Some regulatory pressure to meet 1% OOC, therefore risk associated with regulatory approval See I1.3 |
| Bulk Cuttings Transfer | 0 | Not applicable |
| Skip and ship | 0 | Not applicable |
| Road transport | 0 | Not applicable |
| Thermal desorption | -1 | Under Ghana's *Environmental Assessment Regulations* (LI 652, 1999) as amended (2002) all activities likely to have an adverse effect on the environment must be subject to environmental assessment and issuance of a permit. A facility such as this is may well fall under these regulations. |
| Cutting pit | -3 | May require permits or other approvals from regulatory agencies. Under Ghana's Environmental Assessment Regulations (LI 652, 1999) as amended (2002) all activities likely to have an adverse effect on the environment must be subject to environmental assessment and issuance of a permit. A facility such as this is likely to fall under these regulations. Potential issues with residual liability and poor level of future proofing. |
| Non Structural Building Materials | -1 | Under Ghana's Environmental Assessment Regulations (LI 652, 1999) as amended (2002) all activities likely to have an adverse effect on the environment must be subject to environmental assessment and issuance of a permit. It is not clear if this option would require an EIA as this type of project is not specifically listed in the EIA mandatory list, but unlikely. |
| Landfill cover | -3 | This approach has been used previously but waste classification of cuttings may be important. There may be restrictions due to contaminants classification of cuttings wastes. In the event that landfill sites in Ghana are not licensed/permitted, then liability would become a key factor. |
| **Option** | **Absolute score** | **Comment** |

| | | |
|---|---|---|
| Land farming | -3 | Ghanaian position on permitting unknown. This option may require permits or other approvals from regulatory agencies. Under Ghana's Environmental Assessment Regulations (LI 652, 1999) as amended (2002) all activities likely to have an adverse effect on the environment must be subject to environmental assessment and issuance of a permit. It is likely that the use of drill cuttings on greenfield sites would require an EIA as "Land for agriculture of > 40 hectares or affecting 20 families/irrigation" landfill facilities are listed in the EIA mandatory list. Landfarming is practised in US and Canada for IFC. <br>http://www1.ifc.org/wps/wcm/connect/4504dd0048855253ab44fb6a6515bb18/Final%2B-%2BOnshore%2BOil%2Band%2BGas%2BDevelopment.pdf?MOD=AJPERES&id=1323153172270 |

# Appendix J . Single Well Analysis

An additional analysis has been performed based on the possibility of Tullow having to hire a third drilling rig for the drilling of a single well. This situation may arise in the event that one of the TEN long term hire rigs, with installed TDUs, experience operational problems and excessive downtime.

The analysis considers how a one well scenario would affect the scoring presented earlier in:

- Absolute Assessment (Table F1) of selected (relevant) options;
- Evaluation of integrated pathways B2 and C1 (Tables F2,3,4)
- Relative Assessment (Table F6) which compares pathway B2 with the base case (C1);

## Pathways examined

### Base Case: Cuttings drier

Offshore discharge of cutting and separated fines with NADF@<3%,. Slops brought ashore for stabilisation as non-structural building materials.

### Pathway B2: Offshore TDU

Offshore discharge of cleaned cuttings with NADF@<1%,. No associated waste streams to shore.

### Pathway C1: Containment and treatment ashore

Ship to shore with hybrid transfer of cuttings, followed by onshore stabilisation as non structural building materials.

## J-1 Absolute Assessment

Absolute scores for a single well have been evaluated using the same eight criteria (Table J1) and compared to those from the 19 well TEN campaign. The comments give clarification as to which factors are relevant to or dominate the scoring.

### Table J-1 Evaluation of Absolute Scores for a single well – Justifications - factors influencing criteria judgements

Legend

| | |
|---|---|
| | Rows where the score for a single well is better than for the entire campaign (a lower negative score or a higher positive) are highlighted in green. |
| | Rows where the score for a single well is worse than for the entire campaign (a higher negative score or a lower positive score) are highlighted in pink. |

| Criteria | Single Well Score | Option | Comment | TEN Campaign Score |
|---|---|---|---|---|
| H&S | -1 | Cuttings drier | <60 offshore lifts associated with handling 15-30 tonnes waste fines per well (NADF well sections total duration 25 days); likelihood of normal number incidents (LTI) | -2 |
| | -1 | TDU | Score dominated by managed exposure to harmful materials | -2 |
| | 0 | NADF@5% | No crew interaction at discharge point with 5% discharge scenario | 0 |
| | 0 | NADF@1% | No crew interaction at discharge point with 1% discharge | 0 |
| | -1 | skip & ship | 800 lifts might be 0 responsible for 0.026 to 0.05 incidents per year | -3 |
| | -1 | Lorry | risk of RTA's similar to normal | -2 |
| | -1 | NSCM bricks | risk of injury similar to normal ops | -1 |
| Technical | -2 | Cuttings Drier | Risk of delay through equipment failure of <5 hours / well | -3 |
| | -4 | TDU | Risk of delay through equipment failure >1day / well [35] | -2 |
| | -2 | NADF@5% | Risk of delay reasoning identical to total TEN campaign | -2 |
| | -4 | NADF@1% | Score reflects risk of TDU equipment failure | -1 |
| | -3 | skip & ship | one day's well delay quite likely due to weather | -3 |
| | 0 | lorry | normal risk of lorries breaking down; | 0 |

[35] Score for total TEN campaign should also increase to -4, to take account of JG comments that an equipment failure would take longer than 1 day to complete.

| Criteria | Single Well Score | Option | Comment | TEN Campaign Score |
|---|---|---|---|---|
| | -1 | NSCM bricks | less risk of delays; quality believed to be ok; but not permitted wider use | -2 |
| Cost | -2 | Cuttings Drier | $120,000 per well | -2 |
| | -5 | TDU | $19.9million per well | -4 |
| | -2 | NADF@5% | $20,000/well includes potential financial penalty for being >3%ooc; uncertainty reduces score from -3 to -2; | -2 |
| | 0 | NADF@1% | High probability of requirement for post-drilling benthic monitoring being waived | 0 |
| | -3 | skip & ship | cost of $270,000 based on 1.5 ships per well; 30 days@60k | -4 |
| | -2 | lorry | based on $4000 transport costs per well | -3 |
| | -2 | NSCM bricks | $65,790 per well estimate | -3 |
| Reputation | 0 | Cuttings Drier | No awareness out with industry | 0 |
| | +3 | TDU | Best practice and exceeding regulatory requirement | +3 |
| | -3 | NADF@5% | Not meeting best practice | -3 |
| | +2 | NADF@1% | Local media interest likely; valued by fishing community | -2[36] |
| | -2 | skip & ship | local concerns due to Tullow stated bias against S&S | -2 |
| | 0 | lorry | no issues | -1 |
| | -1 | NSCM bricks | scope for positive publicity and setting local protocol for re-use | +1 |
| Environment | -1 | Cuttings Drier | Low CO2 emissions; | -3[37] |
| | -2 | TDU | CO2 emissions from use on one well 118 tonnes | -1 |
| | -1 | NADF@5% | Single well effect out to 200m; no cumulative effect | -3 |
| | -1 | NADF@1% | Single well effect out to 200m; good dispersion of cuttings particles; no cumulative effect | -1 |
| | -1 | skip & ship | based on $CO_2$ emissions from ships | -2 |
| | -1 | lorry | based on $CO_2$ emissions from lorries; 1 lorry /day | -1 |
| | -1 | NSCM bricks | negligible $CO_2$ emissions above normal ops | -2 |
| Economic | +1 | Cuttings Drier | Single well could generate $2300 wages; however use of local labour for a single well is unlikely | +2 |
| | +1 | TDU | Single well likely to generate <5479; however use of local labour for a single well is unlikely | +3 |
| | -3 | NADF@5% | smaller probability of survey requirement for single well discharges | +2 |
| | -1 | NADF@1% | slim probability of survey requirement for single well; (less than 19) | +1 |
| | +1 | skip & ship | Local business gain – short lived – 30 day | +3 |
| | +1 | lorry | Local business gain – short lived – 30 days | +3 |
| | +1 | NSCM bricks | Local business gain – short lived – 30 days | +3 |
| Social | 0 | Cuttings Drier | No social impacts | 0 |
| | 0 | TDU | No social impacts | 0 |
| | 0 | NADF@5% | No social impacts | 0 |
| | 0 | NADF@1% | No social impacts | 0 |
| | 0 | skip & ship | No disturbance / change /effect; normal business | -1 |
| | 0 | lorry | No disturbance / change / effect; normal business | -2 |
| | +1 | NSCM bricks | Small amount of local income generated | +1 |
| Regulatory | 0 | Cuttings Drier | Not applicable | 0 |
| | 0 | TDU | Not applicable | 0 |
| | -1 | NADF@5% | Outside regulatory aspirations and attracting financial penalty $20,000 during 'period of exploration'; unclear whether the penalty applies to a one-off penalty for the duration of a single well, or whether it is cumulative number of consecutive days when the OOC is out of spec. | -3 |
| | -1 | NADF@1% | Same risk wrt regulatory approval and pressure to meet 1% | -1 |
| | 0 | skip & ship | Would meet current standards | 0 |
| | 0 | lorry | Would meet current standards | 0 |
| | -1 | NSCM bricks | Not restricted by regs; cradle to grave potential liability | -1 |

[36] I query this negative score… would prefer to place it at +2

[37] I query such a high score for TEN campaign; evaluation is based on CO2 emissions only i.e. benthic impact not assessed in this category; same applies to both cuttings drier and TDU

The following summary points arise from this assessment:

- For a single well, Health and Safety scores are either the same or improved. There is less cumulative exposure to harmful vapours (NADF and hydrocarbons), and fewer crane lifts.
- Economics – a single well generates less positive benefit to the local economy; mainly a factor of reduction of scale of operation.
- Technical – TDU worse for one well because risk of delays in a single well have more impact; there is less time available to make alternative gains.
- Cost – TDU higher costs as total mob and demob costs are born by a single well rather than 1/19$^{th}$ of these costs. Costs are less for onshore pathways components, based on reduction of scale.
- Environmental – improvements in four out of seven categories; based on fewer CO2 emissions and smaller discharge quantities to sea as compared to 19 wells.

Collating these results into a more graphical format Table J-2 clearly shows where the more significant impacts arise and also the relatively low level of impact associated with a much reduced level of discharge and onshore waste management activities.

**Table J2 Single well – Absolute Assessment Summary of relevant options**

| Drill Cuttings Lifecycle phase | Option | HS | Technical | Cost | Reputation | Ecological | Economic | Societal | Regulatory |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| Offshore Treatment | Cuttings drier | -1 | -2 | -2 | 0 | -1 | +1 | 0 | 0 |
| Offshore Treatment | Thermal desorption | -1 | -4 | -5 | +3 | -2 | +1 | 0 | 0 |
| | | | | | | | | | |
| Offshore disposal | Disposal at sea onsite - NADF <5% | 0 | -2 | -2 | -3 | -1 | +1 | 0 | -1 |
| Offshore disposal | Disposal at sea onsite - NADF <1% | 0 | -4 | 0 | +2 | -1 | 0 | 0 | -1 |
| | | | | | | | | | |
| Containment | Skip and ship & transport | -1 | -3 | -3 | -2 | -1 | +1 | 0 | 0 |
| | | | | | | | | | |
| Onshore transport | Lorry | -1 | 0 | -2 | 0 | -1 | +1 | 0 | 0 |
| | | | | | | | | | |
| Re-use & recycling | Non Structural Building Materials | -1 | -1 | -2 | +1 | -1 | +1 | +1 | -1 |

## J-2 Evaluation of Integrated Pathways

This analysis takes each of the lifecycle phases applicable to a particular pathway and considers them as an aggregated set. It can be seen that the absence of any onshore waste stream for both the Offshore TDU option (Pathway B2) and the use of a centrifugal cuttings drier (Pathway B1) make both pathways very simple.

## Table J3 Pathway B2 –For a single well - NADF well with thermal desorption and offshore disposal

| Drill Cuttings Lifecycle phase | Option | HS | Technical | Cost | Reputation | Ecological | Economic | Societal | Regulatory |
|---|---|---|---|---|---|---|---|---|---|
| Bottom hole drilling fluid | NADF | -2 | 0 | -3 | -1 | -3 | +3 | 0 | 0 |
| Offshore Treatment | Thermal desorption | -1 | -4 | -5 | +3 | -2 | +1 | 0 | 0 |
| Offshore disposal | Disposal at sea onsite - NADF >1% | 0 | -4 | 0 | +2 | -1 | 0 | 0 | -1 |

## Table J4 Pathway B1 NADF bottom hole with cuttings drying only and offshore disposal

| Drill Cuttings Lifecycle phase | Option | HS | Technical | Cost | Reputation | Ecological | Economic | Societal | Regulatory |
|---|---|---|---|---|---|---|---|---|---|
| Bottom hole drilling fluid | NADF | -2 | 0 | -2 | -1 | -3 | +3 | 0 | 0 |
| Offshore Treatment | Cuttings drier | -1 | -2 | -2 | 0 | -1 | +1 | 0 | 0 |
| Offshore disposal | Disposal at sea onsite – NADF 3% | 0 | -1 | -1 | -2 | -2 | +1 | 0 | -2 |

## J-3 Comparison of Pathways

A comparison of the numerical scores of the two pathways (Table J5) shows visually that for a single well, pathway B2 results in a far greater frequency of both high negative scores and high positive scores, whereas pathway C1 is more tightly balanced around the lower positive and negative scores. Zero scores are higher in B2 than in C1. Figure J1 shows the distribution of scores normalised as scoring cell percentages.

## Table J-5 Numerical comparison of options

| Category | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | Total -ve | Total +ve | Total scoring cells |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Performance B2 | 1 | 2 | 2 | 2 | 4 | 9 | 1 | 1 | 2 | 0 | 0 | 122,240 | 2,110 | 24 |
| Performance B1 | 0 | 0 | 1 | 7 | 5 | 8 | 2 | 0 | 1 | 0 | 0 | 1,750 | 1,020 | 24 |

**Pathway B2**

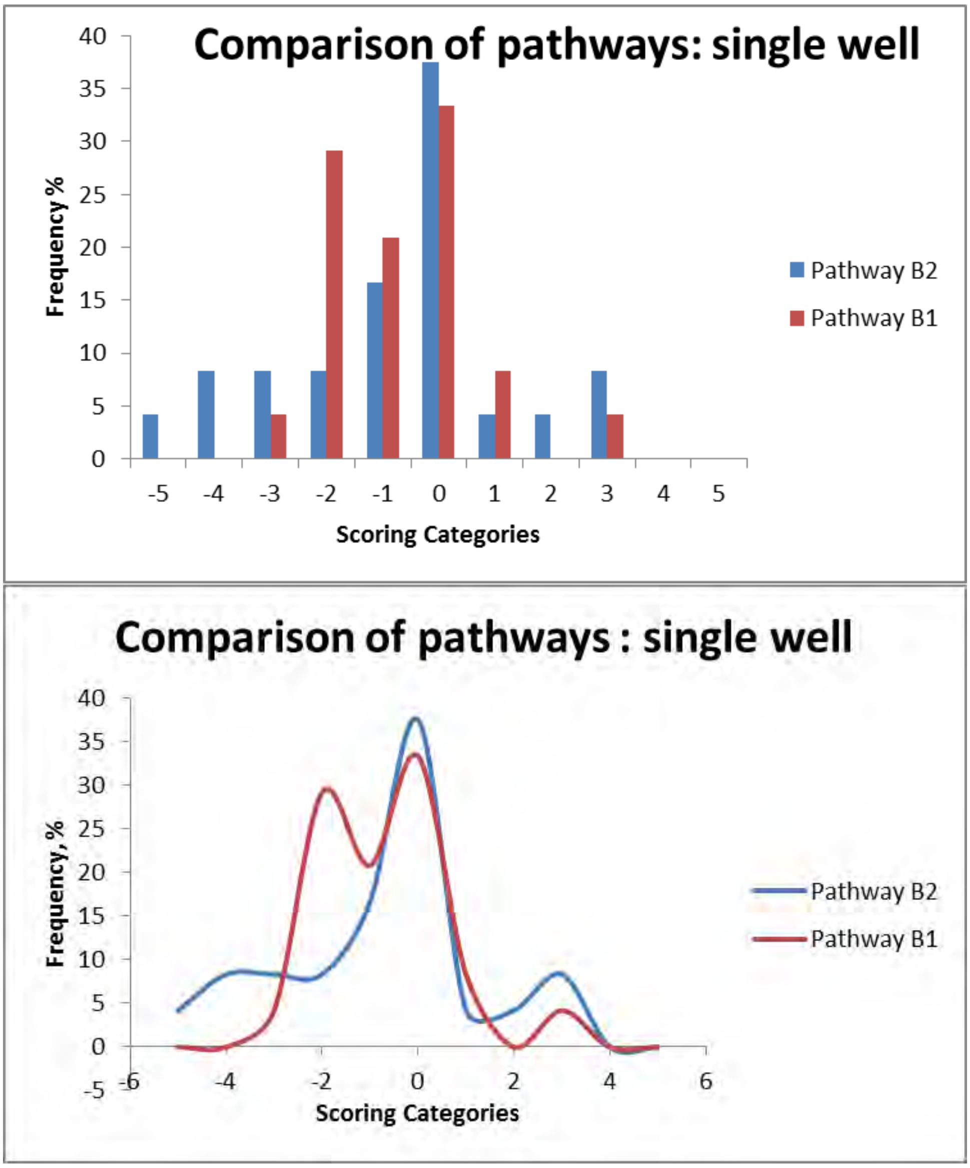
- Scores of -4 and -5 are likely to be 'showstoppers' which would likely have resulted in this B2 pathway being screened out at the pre-screening stage had it been undertaken for a single well. These high negative scores arise in the costing and technical risk criteria, which are fundamental to the viability of the well planning.

- Positive scores can be balanced against this, but the number of positives accounts for only a small percentage (16.7%) of total scores as compared to 45.8% negative scores.

**Pathway B1**

- Positive scores account for only 12.5% of the total scored cells, with 54.2% negative scores; the relatively large proportion of zero scores indicates that this pathway for a single well is very close to the 'norm' for drilling and falls within the impact envelope of routine drilling operations.

**Figure J-1 Graphical comparison of alternative cuttings handling pathways**




## J-4 Option Comparison – Relative Assessment

Having considered the absolute comparison of options a follow-up relative comparison of options has been undertaken. The results are presented in Table J-7.

### Table J7 Single well: Relative comparison of offshore TDU with cuttings drier base case

| Criteria | Offshore treatment | Discharge overboard |
|---|---|---|
| **Health & safety** | +/- | +/- |
| | No particular differences | No particular differences |
| **Technical risk** | - | - |
| | TDU less reliable than driers; repairs more complex and longer duration in event of failure | Higher risk related to contingency planning for TDU equipment failure |
| **Cost** | - - - - | ++ |
| | Significant added cost of TDU over driers ($14-21 MM); all mob and demob cost to be borne by one well | Low probability of financial penalty due to out of spec (>2%OOC) discharge; High probability of reduced monitoring requirement |
| **Reputation** | + + + | + |
| | Enhanced treatment capacity viewed positively by stakeholders; especially for a single well | Limited awareness of improvements to discharge |
| **Environmental** | + | ++ |
| | Enhanced treatment capacity reduces seabed impacts | Measurable improvements to benthic communities |
| **Economic** | +/- | - |
| | Slightly less opportunity (<$10,000) for local contracting (no lorries or NSCM) | Loss of revenue to Ghana EPA from out of spec. cuttings discharges |
| **Social** | +/- | +/- |
| | No particular differences | No particular differences |
| **Regulation** | +/- | ++ |
| | Not applicable to running either pieces of equipment | Meets required and future standards and viewed positively; regulatory challenge less likely over a single well. |

Differences between the single well relative comparison and the total TEN campaign relative comparison can be summarised as:

- Health and Safety - no material differences;
- Technical Risk – TDU more complex and is more prone to equipment failure – sufficient cuttings storage capacity is required to prevent this;
- Cost – the cost of the TDU for one well is significantly higher than for a multi-well campaign as the cost cannot be spread;
- Reputation – there is likely to be an even greater boost to the company's reputation if the TDU is used for a single well ;
- Environment – the decreased environmental impact from using a TDU will be less measurable on a single well than on a 19 well programme;
- Economic – fewer contracting opportunities and loss of revenue to the Ghana EPA from potential financial penalties of out of spec. overboard cuttings discharges;
- Social – no perceivable decrease, during a single well, since no onshore pathways;
- Regulation – excellent overboard discharge quality likely to be viewed very positively by regulator during planning for a single well.

**Table J8 Summary Comparison of offshore Thermal Desorption Unit (offshore discharge of <1%ooc) with base case (cuttings drier and centrifugal and offshore discharge <5%ooc)**

| Pathway B2 – Offshore TDU | Relative score | Comments |
|---|---|---|
| **Health & safety** | +/- | No transfer of waste onshore in either case. |
| **Technical risk** | - | TDU less reliable than driers with longer delays in event of EF. |
| **Cost** | - - - | Extremely high cost of equipment outweighs financial penalty savings. |
| **Reputation** | + + + | TDU discharges generally viewed positively and proactive. |
| **Environmental** | + + | Seabed impacts will be reduced. TDU air emissions will be higher but <5% of the emissions from the rig & balanced by recovery of base oil. |
| **Economic** | - | Small potential loss of revenue to the Ghana EPA from potential financial penalties of out of spec. overboard cuttings discharges |
| **Social** | +/- | No material difference. |
| **Regulation** | + + + | Support of TDU option by regulator generates goodwill and eliminates possible excursions of whenever OOC rises above 3% in drier/centrifuge treatment combination. |

## J-5 Conclusions

Mobilising a TDU to a rig for a single well would, in comparison to a multi-well project,

- Result in no overall difference in H&S criteria, slightly higher potential for equipment failure which can be mitigated if space is available;
- Be much more costly, as the mobilisation and demobilisation costs are focussed to the single well budget;
- Deliver a larger positive reputational message by increasing capex on the project for a relatively smaller environmental benefit;
- Give less environmental benefit as cuttings dispersion on seabed and impact to benthic communities will have only a small contribution to cumulative impacts from the total TEN campaign drilling;
- Effects no change to economic, social or regulatory criteria.

It therefore appears that the increased cost and the less significant environmental benefit are overriding factors which both support the adoption of the existing base case (using a cuttings drier and centrifuge) in the event that an ad hoc rig has to be hired for an individual TEN well.

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