5 *IMPACT IDENTIFICATION AND ASSESSMENT*

5.1 *ASSESSMENT METHODOLOGY*

5.1.1 *Introduction*

This chapter provides an assessment of potential environmental and social impacts from the Jubilee Field Phase 1 Development project. The assessment methodology used in this EIA is outlined in *Chapter 1* and additional details on how the magnitude and significance of these impacts are assessed, taking into account the sensitivity of the receptors and resources affected, are provided below.

The approach adopted for this EIA process was to identify the impacts that are likely to be significant and those impacts that are not likely to be significant are excluded (scoped out) from the assessment. This process does not take into account the application of mitigation measures, other than those that are built into the design of the project. Where there is uncertainty in this process the potential impacts are included in the assessment, therefore, there will be potential impacts included in the assessment that that are ultimately judged to be not significant.

The chapter also provides details on the additional mitigation measures that Tullow has agreed to implement to avoid, reduce, remediate or compensate for potential negative impacts and the actions to be taken to create or enhance positive benefits of the project. The impacts that remain following application of the mitigation measures (called residual impacts) are then assessed. The key impacts are summarised at the end of this chapter. The mitigation measures and monitoring plans discussed in this chapter are presented in more detail in *Chapter 6* and *Chapter 7,* respectively, and incorporated into the provisional Environmental Management Plan in *Chapter 9*.

Key impacts are assessed under the following headings.

- Project Footprint.
- Operational Discharges.
- Air Emissions.
- Waste Management.
- Oil Spill Risk.
- Socioeconomic and Human Impacts.
- Cumulative Impacts.
- Transboundary Impacts.

5.1.2 *Predicting the Magnitude of Impacts*

The impact assessment describes what will happen by predicting the magnitude of impacts and quantifying these to the extent practicable. The term 'magnitude' covers all the dimensions of the predicted impact to the natural and social environment including:

- the nature of the change (what resource or receptor is affected and how);
- the spatial extent of the area impacted or proportion of the population or community affected;
- its temporal extent (ie duration, frequency, reversibility); and
- where relevant, the probability of the impact occurring as a result of accidental or unplanned events.

Table 5.1 provides definitions for the spatial and temporal dimension of the magnitude of impacts used in this assessment.

Table 5.1 Magnitude Definitions

Impact magnitude – the degree of change brought about in the environment	
Spatial Scale	**On-site** – impacts that are limited to the Jubilee Unit Area or Takoradi Port and surroundings. **Local** – impacts that are limited to the concession blocks or Takoradi. **Regional** – impacts that are experienced at a regional scale eg Western Region. **National** – impacts that are experienced at a national scale **Transboundary/International** – impacts that are experienced at a international scale ie affecting another country or international waters.
Temporal Scale	**Short-term** – impacts that are predicted to last only for the duration of the drilling/installation period (ie 2 years). **Long-term** – impacts that will continue for the life of the project, but ceases when the project stops operating (ie 20 years). **Temporary** – impacts are predicted to be reversible and will return to a previous state when the impact ceases or after a period of recovery. **Permanent** – impacts that cause a permanent change in the affected receptor or resource that endures substantially beyond the project lifetime. **Continuous** – impacts that occur continuously or frequently. **Intermittent –** impacts that are occasional or occur only under specific circumstances

Magnitude therefore describes the actual change that is predicted to occur in the resource or receptor (eg the area and duration over which disturbance of the seabed will occur; the degree of impact on the livelihoods of a local community; the probability (likelihood) and consequences in terms of accidental events). An assessment of the overall magnitude of an impact is therefore provided that takes into account all the dimensions of the impact described above to determine whether an impact is of low, medium or high magnitude. For social impacts, the magnitude considers the perspective of those affected by taking into account the likely perceived importance of the impact and the ability of people to manage and adapt to change. For impacts on ecological resources, the criteria used to assess the magnitude of impacts are presented in *Box 5.1* (based on Duinker and Beanlands, 1986).

Box 5.1 *Magnitude Criteria for Ecological Impacts*

- A **High Magnitude Impact** affects an entire population or species in sufficient magnitude to cause a decline in abundance and/or change in distribution beyond which natural recruitment (reproduction, immigration from unaffected areas) would not return that population or species, or any population or species dependent upon it, to its former level within several generations*. A high magnitude impact may also adversely affect the integrity of a site, habitat or ecosystem.
- A **Moderate Magnitude Impact** affects a portion of a population and may bring about a change in abundance and/or distribution over one or more generations*, but does not threaten the integrity of that population or any population dependent on it. A moderate magnitude impact may also affect the ecological functioning of a site, habitat or ecosystem but without adversely affecting its overall integrity. The area affected is also important.
- A **Low Magnitude Impact** affects a specific group of localised individuals within a population over a short time period (one generation* or less) but does not affect other trophic levels or the population itself.

* These are generations of the animal / plant species under consideration not human generations. It should be noted that the restoration potential of an affected habitat also needs to be considered in applying the above criteria.

5.1.3 *Sensitivity of Resources and Receptors*

The significance of an impact of a given magnitude will depend on the sensitivity of resources and receptors to that impact. For ecological impacts sensitivity can be assigned as low, medium or high based on the conservation importance of habitats and species. For habitats these are based on naturalness, extent, rarity, fragility, diversity and importance as a community resource. For species *Table 5.2* presents the criteria for deciding on the value or sensitivity of individual species[1]. This approach follows the guidelines produced by the Energy and Biodiversity Initiative (EBI)[2].

(1) The above criteria should be applied with a degree of caution. Seasonal variations and species lifecycle stage should be taken into account when considering species sensitivity. For example, a whale population might be deemed as more sensitive during the breeding period and when mothers are accompanied by young calves. Fish species might be deemed more sensitive during their spawning period than at other times of year.
(2) Energy & Biodiversity Initiative, Integrating Biodiversity into Oil & Gas Development, 2003 - A framework formed by several leading oil and gas companies working alongside conservation organisations to form a partnership designed to produce practical guidelines, tools and models to improve the environmental performance of energy operations, minimise harm to biodiversity, and maximise opportunities for conservation wherever oil and gas resources are developed.

Table 5.2 *Species Value / Sensitivity Criteria*

Value / Sensitivity	**Low**	**Medium**	**High**
Criteria	Not protected or listed and common / abundant; or not critical to other ecosystem functions (eg key prey species to other species).	Not protected or listed but: a species common globally but rare in Ghana; important to ecosystem functions; or under threat or population decline.	Specifically protected under Ghanaian legislation and/or international conventions eg CITIES[(1)]. Listed as rare, threatened or endangered eg IUCN[(2)]

For socioeconomic and health impacts sensitivity is based on individuals' ability to adapt to changes and maintain their livelihoods and health (*Table 5.3*).

Table 5.3 *Socioeconomic and Health Sensitivity Criteria*

Sensitivity	**Low**	**Medium**	**High**
Socioeconomic resources / receptors			
Criteria	Those affected able to adapt with relative ease and maintain pre-impact livelihoods	Able to adapt with some difficulty and maintain pre-impact livelihoods but only with a degree of support	Those affected will not be able to adapt to changes and continue to maintain-pre impact livelihoods
Health resources/ receptors			
Criteria	Those affected will be able to adapt to health impacts and maintain pre-impact levels of health	Those affected will be able to adapt to health impacts, but with difficulty and maintain pre-impact levels of health only with support	Those affected will not be able to adapt o to health impacts and continue to maintain pre-impact health levels.

5.1.4 *Evaluation of Significance*

Virtually all human activity imposes some disturbance to aspects of the natural and social environment because of physical impacts on natural systems or due to interactions with other human activities and human systems. To provide information to decision makers and other stakeholders on the importance of different project impacts an evaluation of the significance of each impact is made by the EIA team.

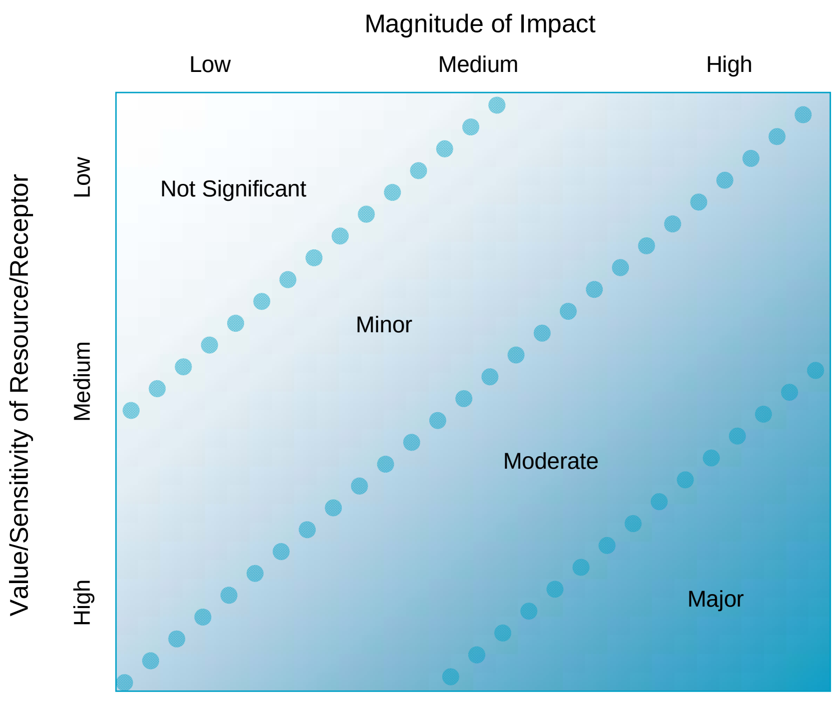
As there is no statutory definition of significance this evaluation of significance is therefore necessarily subjective. Existing industry or national standards (eg water quality standards), combined with the plans and policies of the Jubilee Joint Venture (JV) parties, have, however, informed this judgement. Where standards are either not available or provide insufficient

(1) Convention on International Trade in Endangered Species of Wild Fauna and Flora
(2) The International Union for the Conservation of Nature and Natural Resources

information on their own to allow grading of significance, significance is evaluated taking into account the magnitude of the impact and the value or sensitivity of the affected resource or receptor. The value of a resource is judged by taking into account its quality and its importance as represented, for example; by its local, regional, national or international designation; its importance to the local or wider community; or its economic value. The sensitivity of receptors, for example a household, community or wider social group, will take into account their likely response to the change and their ability to adapt to and manage the effects of the impact. As the evaluation of the significance of social impacts includes individual and community perceptions and attitudes the significance of a given impact may vary according to the individuals or communities involved.

Magnitude and value/sensitivity are looked at in combination to evaluate whether an impact is, or is not, significant and if so its degree of significance (defined in terms of *Minor, Moderate* or *Major).* Impacts classed as *not significant* include those that are slight or transitory, often indistinguishable from the background/natural level of environmental and social change. This principle is illustrated schematically in *Figure 5.1*.

Figure 5.1 Evaluation of Significance



5.1.5 Mitigation Measures

One of the key objectives of an EIA is to identify and define socially, environmentally and technically acceptable and cost effective mitigation measures. These should avoid unnecessary damage to the environment;

safeguard valued or finite resources, natural areas, habitats and ecosystems; and protect humans and their associated social environments.

Mitigation measures are developed to avoid, reduce, remedy or compensate for any negative impacts identified, and to create or enhance positive impacts such as environmental and social benefits. In this context the term mitigation measures includes operational controls as well as management actions. These measures are often established through industry standards and may include:

- changes to the design of the project during the design process (eg changing the development approach);
- engineering controls and other physical measures applied (eg waste water treatment facilities);
- operational plans and procedures (eg waste management plans); and
- the provision of like-for-like replacement, restoration or compensation.

For impacts that are assessed to be of *Major* significance, a change in design is usually required to avoid or reduce these. For impacts assessed to be of *Moderate* significance, specific mitigation measures such as engineering controls are usually required to reduce these impacts to As Low As Reasonably Practicable (ALARP) levels. This approach takes into account the technical and financial feasibility of mitigation measures. Impacts assessed to be of *Minor* significance are usually managed through good industry practice, operational plans and procedures. The focus of mitigation is usually on avoiding or reducing negative environmental and social impacts. Measures to enhance positive impacts, such as economic benefits, are also mitigation measures.

5.1.6 Assessing Residual Impacts

Impact prediction takes into account any mitigation, control and operational management measures that are part of the project design and project plan. A residual impact is the impact that is predicted to remain once mitigation measures have been designed into the intended activity.

5.2 PROJECT FOOTPRINT

5.2.1 Scope of Assessment

This section provides an assessment of the potential impacts from the physical footprint of the Jubilee Phase 1 project and discusses measures to be implemented to mitigate those impacts. The term 'physical footprint' incorporates both the physical presence of the offshore and onshore structures and equipment and the effects of these on the physical environment and associated resources and receptors. Impacts from the physical footprint include impacts from noise and light sources.

The following issues are considered of potential significance with regard to the physical footprint of the project.

- Impacts to benthic fauna communities during the installation and long-term physical presence of subsea infrastructure on the seabed.

- Impacts to marine organisms from underwater sound produced by the project.

- Impacts of FPSO, MODUs and vessels presence on local fish populations.

The following potential impacts are not included in the detailed assessment as they are not considered to be significant.

- **Impacts from FPSO lighting and flaring on Birds.** Many birds chose to migrate at night to take advantage of the more stable weather conditions which benefit migration, and for some species to avoid daytime predators. Artificial lighting, however, may affect nocturnal movement of birds. Previous research has found that migrating birds (especially songbirds, waders and ducks) may circle around offshore lit structures including offshore platforms. The effects are reported to be pronounced during periods of low cloud and fog, when there is poor visibility. Erickson *et al*. (2001) suggested that lighting was a critical attractant, leading to collision of birds with tall structures, and recent research appears to support the role of lighting. On going research in the Dutch sector of the North Sea for NAM (Nederlandse Aardolie Maatschappij) suggests that the red end of the spectrum components of conventional platform lighting affect birds, and that the use of green spectra could significantly reduce the effects on the populations of those species most at risk (Bruinzeel 2009). Birds which are drawn to lit platforms often circle around for prolonged periods resulting in fatigue. They sometimes land on the platforms, or collide with the structures, and if there is little food or water for them on the platform, this can result in their death. There are Important Bird Areas (IBAs) along the coastline of Ghana and the Ivory Coast which support migratory bird species known to use the East Atlantic Flyway. Such species occur along the west coast of Africa, including red knot (*Calidris canutus*) and sanderling (*Calidris alba*). (Boere and Stroud 2006). Detailed information about African bird migration routes is less well understood and is the subject of ongoing research (Birdlife 2009). Whilst there is a risk of migrating birds encountering the platform, many of the effects described above are based on research undertaken in the North Sea, and similar weather conditions in the location of the Jubilee field are not expected. Research in the North Sea also found that in more stable conditions when skies were clear and there was little cloud, few birds responded to lights (NAM 2007). It is also likely that some of the bird species which are migrating through this area will do so during the daytime, and hence should be less affected by lighting. The Jubilee joint venture partners have had drill rigs deployed in the area for over 2 years and have not reported unusual bird attraction or congregation. The risk of impacts on birds from the FPSO lights is considered to be low and *not significant*. As part of the routine reporting from the FPSO the presence of significant bird landings during the year and/or records of any bird deaths will be recorded to inform any future mitigation strategies.

- **Impacts from FPSO lighting and flaring on Turtles.** There is the potential that turtles will be attracted to the FPSO at night where hatchlings could be subject to increased predation by birds and fish that also are attracted to these structures. The FPSO is 60 km from the nearest shore and would not be visible from the shore and any turtle nesting beaches. The risk of any impacts on turtles and turtle hatchlings from the FPSO lights is considered to be low and *not significant.*

- **The impacts to marine mammals and turtles from vessel collision and marine debris**. Collisions have been known to occur worldwide and also in West Africa (Félix and Van Waerebeek, 2005; Van Waerebeek *et al*., 2007) and increased marine vessel traffic between the Jubilee field and Takoradi port will increase the risk of collisions. The increased risk of collision is considered to be low however given the relatively low volume of project related traffic and the speed that they move at (typically moving at less than 12 knots). Marine mammals and marine turtles are most sensitive in areas with fast moving vessels which frequently change direction and are more able to avoid the large, relatively slow moving support vessels associated with the project. Disposal of solid waste to sea will not occur from the FPSO, MODUs or support vessels, with the exception of treated kitchen waste and treated sewerage, which will be macerated. Discharges during the previously permitted well drilling operations, including drill cuttings discharges, are addressed in *Annex B.* The risks to marine mammals and marine turtles from vessels collisions and damage from marine debris associated with the project are considered to be small and are assessed as *not significant*.

- **Impacts from noise.** Activities in the Jubilee field will be located approximately 60 km offshore, away from any sensitive noise receptors. Onshore noise at the port in Takoradi from the project is assessed as *not significant* as activities will be within an existing busy port. Noise on the FPSO will be controlled for occupational exposure reasons so that workers in open areas will not require to wear hearing protection (the WHO standard is 85 dB without hearing protection). A 85 dB noise source (measured at 10 m from source) will have attenuated to 45 dB at 1,000 m. Fishermen and other marine users not associated with the project will be outside the 1,000 m exclusion zone centred on the turret and therefore at least 500 m from the FPSO. The risk of noise exposure above the 85 dB standard is therefore extremely unlikely. Noise from helicopter flights to and from the Air Force base at Takoradi and the Jubilee field has the potential to cause disturbance. Careful flight planning to avoid sensitive areas will avoid significant impacts. This includes a minimum flight height of 2,300 feet (710 m) above the Amansuri Wetland IBA to avoid disturbance to wildlife.

- **Impacts on Cultural Heritage.** There will be no requirement to build new onshore facilities on undisturbed ground as the projects will be using existing onshore facilities (so called brown field sites). The offshore location of the Jubilee field is in water depths of over 1,100 m. Side scan sonar surveys have been undertaken to verify that there are no ship wrecks in the area. There will be no new coastal developments (ie port developments or pipeline landings) as part of the Phase 1 Project therefore there will be no impacts on known marine archaeological sites. For these reasons there will be no direct or indirect impacts on known or unknown marine and terrestrial sites of archaeological or cultural heritage importance. The risk of impacts on cultural heritage from project activities is considered to be very low and is not considered further in this EIA.

5.2.2 *Impacts from Subsea Infrastructure*

Sources of Impact

The Jubilee Field Phase 1 development will have a physical footprint on the seabed through placement of infrastructure during the construction and commissioning of subsea infrastructure and from the permanent presence of some of this infrastructure. This will result in habitat loss or disruption to defined areas of the seabed and impacts to benthos (animals living in or on the seabed) and demersal (bottom-dwelling) fish.

The main impacts are expected to arise from:

- short-term disturbance directly to the seabed (eg from sediment suspension), with secondary impacts on the benthic and demersal community, during installation of subsea infrastructure;
- permanent habitat and associated species loss or damage from coverage of areas of seabed by moorings, well manifolds, well heads, riser bases, flowlines and umbilicals; and
- permanent changes to the habitat arising from the physical presence of subsea infrastructure (eg sediment disturbance and reef effects from marine organisms growing on subsea infrastructure).

Table 5.4 summarises the main infrastructure components, their dimensions, area of seabed disturbance and nature of impacts anticipated from its installation and permanent presence. More details on the purposes of this infrastructure and a schematic of the various subsea infrastructure components are given in *Chapter 3*.

Impact Assessment

As summarised in *Table 5.4*, potential impacts to the seabed and benthic fauna include the following.

Effects from sediment disturbed during infrastructure installation. Sediment may become disturbed and suspended in the water column by project activities undertaken on or near the seabed such as installation of flowlines, moorings, manifolds and riser bases. Suspended sediment could lead to the smothering of sessile species and possible secondary effects such as impacts to the respiration of benthic organisms and demersal fish. The duration of installation activity is relatively short-term and localised, and the water quality and exposed populations are of low sensitivity and are expected to recover relatively quickly. The overall magnitude of the impact is considered to be low.

Table 5.4 Potential Seafloor Disturbance

Component	Total Seafloor Area Affected (ha)	Potential Impact
FPSO Facility		• Loss of, or damage to, habitats and communities beneath the equipment during placement. • Smothering and secondary effects from sediment disturbed during equipment installation. • Changes to sediment structure and composition. • Creation of new substrate and potential habitat. • Creation of a barrier precluding movement / migration of benthic organisms.
Mooring Suction piles (9)	0.0162	
Production Wells (9)		
Manifolds (5)	0.028	
Wellhead Trees (9)	0.017	
Water Injection Wells (5)		
Manifolds (2)	0.0074	
Wellhead Trees (5)	0.001	
Gas Injection Wells (3)		
Manifolds (1)	0.004	
Wellhead Trees (3)	0.006	
Riser Bases and SDUs		
Riser Bases (2)	0.72	
Subsea Distribution Unit	0.03	
Flowlines / Umbilicals		
Production Flowlines	0.75	
Water Injection Lines	0.27	
Gas Injection Lines	0.06	
Umbilicals	0.40	
TOTAL	**2.3096** ha	

1 hectare (ha) =10,000 m^2

Loss of or damage to marine habitats. The positioning of subsea infrastructure, in particular flowlines, will result in the loss of or damage to seabed habitats and associated communities. The total area of seabed that will be directly affected by the physical presence of subsea infrastructure is relatively small at approximately 2.3096 ha (23,096 m^2). For comparison, the Jubilee Field Unit Area covers 110 km^2 (and the area within which the subsea infrastructure is located covers approximately 34 km^2), therefore installation of the subsea infrastructure will directly impact less than 0.1% of the seafloor in the Jubilee Field Unit Area. The mortality of most organisms beneath installed infrastructure is predicted, particularly for sessile species (which typify the benthic communities) where avoidance and vertical migration is generally not possible. The impact on seabed habitats and species will be very localised, with the area affected being a small percentage of the total area of similar habitats in this offshore, deepwater location and consequently the loss of areas of muddy/silty habitat is considered to be low magnitude at a community ecology level.

Loss of fish prey organisms. The loss of or damage to seabed habitats and associated communities will reduce prey availability to demersal deep water fish species in the area that rely on benthic food sources. The impacts to benthic organisms are considered to be very localised and the total loss will represent a small fraction of the food sources available to fish predators. In addition, the fish species impacted are highly mobile, travel large distances for food and will be able to source prey from other locations. The magnitude of these changes will be low.

Changes to sediment structure and composition. Changes to sediments may occur from a variety of processes, eg from compaction or changes to water current flow caused by the presence of the infrastructure. Any change to habitat conditions is anticipated to be small and expected to only slightly alter the conditions and dependant community structure.

Barriers precluding movement / migration of benthic organisms. Flowlines of significant linear length have the potential to create a physical barrier to mobile benthic organisms such as crustaceans. However, the height of the flowlines (25 cm diameter) is not expected to create a significant barrier, especially as flowlines are likely to settle into the soft sediments by approximately 30 to 50% of their diameter.

Creation of new substrate and potential habitat. The placement of seabed equipment, in an otherwise uniform and relatively featureless habitat, could also provide some positive benefits by providing a stable substratum and increased habitat complexity which could be colonised over time. This 'reef effect' will be at a small scale and localised but nevertheless can add to local biodiversity.

The conservation evaluation criteria presented in *Table 5.2* have been applied to the known benthic habitats and seabed conditions in the Jubilee Unit Area. The habitat has been assessed as low sensitivity given the generally featureless benthic habitat and homogeneous benthic fauna. Permanent impacts from the physical footprint of the offshore infrastructure will be localised and are assessed as being of *Minor* significance.

Mitigation Measures

The following measures are aimed at mitigating potential impacts on the seabed from the installation and long-term presence of subsea infrastructure.

- The layout of the subsea infrastructure will be designed to avoid seabed features considered to be geo-hazards. This will also protect areas with potentially more diverse habitats and species.

- Pre installation sidescan sonar and ROV surveys will determine if there are significant seabed features that should be avoided where possible, such as channels

- Most subsea flowlines will be laid directly on the seabed and flowline burial using methods such as dredging and jetting will be avoided.

Residual Impact

The installation and presence of structures on the seabed constitutes a low magnitude impact to habitats and species which are assessed as being of low conservation value and sensitivity. The negative impacts of seabed structures on benthic communities are assessed as being of *Minor* significance. The positive impacts from the small scale introduction of new substrates for colonisation by benthic organisms are also assessed as being of *Minor* significance.

5.2.3 Interaction between Underwater Sounds and Marine Ecology

Sources of Noise

Sounds in the marine environment can be categorised as either naturally occurring or anthropogenic (human produced) in origin. Natural sources of sound include marine mammal vocalisations; and sounds from other marine life, wind, rain, and waves. Anthropogenic sounds come from shipping, fishing, dredging, exploration and production activity, sonar (navigation, fishing, and defence), seismic survey sources and construction (eg percussive piling). Most noise sources are intermittent in a given area, eg vessel movements (other than in busy shipping lanes where they are near continuous). For offshore operations the fixed installation will produce continuous or near continuous noise as well as intermittent noise from visiting vessel movements.

The main sources of underwater sound associated with the project can be categorised into the following.

- **Propeller and Thrusters.** Noise from vessel propellers and thrusters is predominately caused by cavitation around the blades whilst transiting at speed or operating thrusters under load in order to maintain a vessel's position (ie dynamic positioning). Noise produced is typically broadband noise, with some low tonal peaks.

- **Machinery Noise.** The source of this type of noise is from large machinery, such as large power generation units (eg diesel engines or gas turbines), compressors and fluid pumps. The nature of sound is dependant on a number of variables, such as number and size of machinery operating and coupling between machinery and the deck. Machinery noise is often of low frequency and tonal in nature.

- **Equipment in Water.** Noise is produced from equipment such as flowlines and subsea valves.

Noise produced by the project will be generally of a low frequency with the strongest tones at about 100 kHz. Details are provided in *Table 5.5* which are derived from Richardson *et al* (1995). The propagation of sound through water is affected by spreading (distance) losses and attenuation (absorption) losses with sound energy decreasing with increasing distance from the source. The losses are also influenced by factors such as water depth, temperature and pressure (McCauley *et al*, 2000). The potential for noise produced by the Phase 1 Jubilee project to impact marine species will therefore be influenced to a large extent by the distance between the noise source and the marine species, and the sensitivity of these species to noise.

Table 5.5 Indication of Sounds that may be Produced by Project Activities

Project Activity	Approximate Highest Sound Levels (dB re 1 μPa @ 1m)*	Peak Frequency Band – Indicative Ranges (Hz)**
Tug	170 dB	50 -1,000
Pipelay vessel	180 dB	1,000-100,000
Supply vessel	180 dB	10-1,000
Export Tanker	190 dB	10-100
Subsea choke valve	120 dB	1,000-100,000
FPSO	160 dB	1,000-100,000
MODU	174 to 185 dB	10-10,000

*Sound pressure is expressed on a decibel scale (dB) and referenced to 1 micro Pascal at 1 m from the source. [dB re 1 μPa @ 1m]
** Sound frequency is expressed in Hertz. Only the approximate range of peak frequencies is presented, frequencies outside this range are likely to exist but be lower in sound level.

Sound Power Level (SPL) which measures the sound energy is the metric that has most often been measured or estimated during disturbance studies, however, it is recognised that the Sound Exposure Level (SEL) which takes into account the duration of exposure also influences behavioural changes.

Sensitive Receptors

Localised noise sources, if sufficiently loud, may be detrimental to certain marine species under some circumstances and may result in physical harm or behavioural changes. The sources and effects of anthropogenic underwater noise have been reviewed by Richardson *et al.* (1995). Of particular concern are the impacts of underwater sound on some species of marine mammals due to their known reliance on sound for activities such as communication and navigation. Turtles are less reliant on sound and are considered less sensitive to sound from marine activities such as seismic surveys (Weir 2007) and are unlikely to be affected by sound levels expected from the Jubilee Phase 1 project. West African manatees are also present in Ghana almost exclusively in continental waters and do not occur in deep offshore waters. Available information on marine fish, shellfish and birds indicates that they are not particularly sensitive to underwater sound. Although fish are likely to be attracted to the FPSO, MODUs and support vessels while stationary (see *Section 5.2.4* regarding Fish Aggregating Devices), the energy and nature (generally continuous) of operational noise are unlikely to result in startle reactions to fish. Fish may be attracted by the noise of operational vessels (Røstad *et al* 2006) but are likely to avoid areas where noise levels are at level to cause disturbance. Physical damage to fish is possible at high noise levels in the range 180 to 220 dB (Evan and Nice 1996) which would only exist very close (a few metres) to the source and noises at these levels are likely to be avoided by fish.

As discussed in *Chapter 4*, although current knowledge of the distribution and ecology of marine mammals (whales and dolphins) in the Gulf of Guinea is limited, there is evidence derived from bycatches and strandings that show that the variety of marine mammals in Ghanaian waters is moderately diverse. The available data indicated that there are 18 species belonging to 5 families comprising one species of baleen whale (humpback whale) and 17 species of odontocetes (toothed whales and dolphins). Of the odontocetes, one species, the sperm whale, is categorised as vulnerable by the IUCN. Against the sensitivity criteria in *Table 5.2*, this species is considered to be of high value, due to the IUCN categorisation. Nominal species sensitivities for the purposes of this impact assessment are shown in *Table 5.6*.

Table 5.6 Whales and Dolphins of Ghana, IUCN Conservation Status and Species Sensitivities

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

Marine mammals rely on sound for echolocation, detection of predators and prey and communication within or between social groups. Auditory damage can be caused by sudden pressure changes and ranges from minor damage with temporary (minutes to days) hearing loss, to severe damage with permanent hearing loss and damage. Repeated or continual exposure to high level sound can cause shifts of hearing thresholds (ie hearing impairment) in some species (Richardson *et al* 1995). However, marine mammals are unlikely to intentionally approach operations producing continuous or semi-continuous sounds that are powerful enough to lead to auditory damage. At lower sound levels there may be behavioural changes such as changes to diving patterns and avoidance behaviour, particularly when the noise source is intermittent. Continued exposure often results in habituation to the sound, followed by a recommencement of normal behaviour.

McCauley (1994) suggested that auditory injury of marine mammals could occur around 220 dB and injury is expected to become more severe with an increase in sound levels. The work of Southall *et al* (2007) of the Marine Mammal Criteria Group suggests that, in order to cause instantaneous injury to marine mammals resulting in a permanent loss in hearing ability that is referred to as permanent threshold shift (PTS), the sound level must exceed 230 deciBells (dB) re 1 micro Pascal (peak) (such as may be experienced from a seismic survey).

The Southall *et al* (2007) reviews data for activities involving multiple noise pulses (such as seismic survey noise sources) separately from more continuous, non-pulsed, noise (such as from vessel engine noise). The document defines broad groups of marine mammals that are expected to have similar sensitivity to noise. The groups are divided into low, medium and high frequency cetaceans.

The low frequency cetacean hearing group includes the baleen whales (such as humpback, fin, blue and sei whale) which appear to avoid sounds of received levels greater than 150 to 180 dB, exhibit significant behavioural responses at 140 to 160 dB and subtle behavioural responses at levels above 120 dB (McCauley 1994, 2000, Malme *et al* 1985, Southall *et al* 2007). Studies on the effects of low frequency seismic sound on odontocetes (toothed whales) suggest that these marine mammals appear to have greater tolerances to high level sounds (Rankin and Evans, 1998; Davis *et al* 1990 and Madsen *et al* 2002).

The majority of species found in Ghanaian waters are in the mid-frequency cetacean hearing group (delphinidae, ziphiidae and physeteridae). The combined data for this group do not indicate a clear tendency for increasing reaction with noise level. However, studies by Madsen *et al* (2002) showed no observable reaction by sperm whales to an air gun array at noise levels of 120 to 140 dB (re 1 micro Pascal).

The high frequency cetacean hearing group includes the dwarf sperm whale and a criterion of 140 dB is suggested for behavioural responses (Southall *et al* 2007).

A conservative threshold of 120 dB represents a level at which behavioural responses (such as avoidance) may occur for continuous noise sources by sensitive species. The sound characteristics such as amplitude, frequency and duration are also important. This sound threshold level and sensitivity to sound characteristics will differ between marine mammal species and within individuals depending on age, sex and activity (eg feeding, migration). In general, the sound frequencies to which a particular marine mammal is most sensitive tends to coincide with those frequencies it uses for echolocation, navigation and communication as these can be masked by anthropogenic sounds. In general, it is believed that whales will avoid areas in which significant masking occurs, or they may increase sound pressure levels of calls in order to overcome masking effects.

Impact Assessment

None of the noise sources from the project are capable of causing instantaneous injury because the source levels are not high enough, even at very short ranges. For the purposes of this assessment the 120 dB sound level has been used as an indicative minimum where responses to disturbance such as avoidance of the area may be seen by some individuals of the sensitive species such as humpback whales. Noise levels above this level are likely from a number of project activities (see *Table 5.5*). As most noise sources from the offshore operations are continuous or near continuous it is considered very unlikely that marine mammals would approach the source of noise to reach a point where auditory damage could occur (ie more than 180 to 200 dB).

The loudest noises are likely to be generated by the export tankers (due to propeller cavitation) with noise levels up to approximately 190 dB at source. The noise levels will decrease with distance and is expected to be less than 180 dB within 10 m from source (see *Table 5.7).*

It is expected that the noise from the Jubilee field installation and operational activities will result in avoidance behaviour for some species of marine mammals, particularly where noise levels exceed 120dB. *Table 5.7* provides an estimate of the noise transmission loss distances for a number of source levels. It is noted that actual noise decay levels will vary depending on factors such as water depth, temperature and pressure as discussed above. For the highest noise levels (export tankers) noise sources could take up to a 3 to 5 km radius to decay to a level of 120 dB. It is noted that export tankers will generate this level of noise while steaming. The tankers will be in the Jubilee field approximately every 5 to 7 days and the noise levels when connected to the FPSO (and held in position using the holdback tug) will be much less.

Other vessels, such as support and pipe-lay vessels, associated with the project have sound levels of up to approximately 180 dB. It is expected that these sound levels would decay to a level of 120 dB within a 1 km radius of the source. Therefore, it is expected that the sphere of influence, ie where some marine mammals may be predicted to exhibit avoidance reactions to the FPSO and other larger project vessels, will be approximately 1 to 3 km radius (recognising that more than one vessel may be operating in an area). However, the supply or support vessels may have a greater ability to disturb in relation to their sound level, due to the fact they regularly move between Takoradi port and the Jubilee field.

Table 5.7 *Estimated Transmission Loss Distances for Various Noise Source Levels*

Source level at 1 m (dB re 1 μPA)	**Target levlel at receptor (dB re 1 μPa)**	**Distance required for sound to decay to target level (m)**
210	120	31,600
200	120	10,000
190	120	3,162
180	120	1,000
170	120	316
160	120	100
150	120	32
140	120	10
130	120	3

Note: Assumes free-field spherical radiation from point source, with no bottom reflection effects or linear absorption.. Decay distances calculated using Spherical Spreading Law Lr = Ls - 20 log R, where Lr is the level received, Ls is the source level and R is the range.

The MODUs could also generate relatively high sound levels of up to 174 to 185 dB, although at relatively low frequencies. Richardson *et al.* (1995) reported that broadband levels did not exceed ambient levels beyond 1 km from a well drilling operation, although weak tones were received at approximately 18 km away. Generally noise from MODU activities is at a similar level to noise from shipping activities, although MODUs are generating these noises when stationery.

Marine mammals in the general area of drilling and production activities will already be exposed to noise from shipping activity in the area. The main east-west shipping route along the Ghana coast is approximately 8 nm (13.5 km) south of the Jubilee field (see *Section 5.7.8*). Marine mammals occupying or passing through the area will be accustomed to a degree of marine noise from this shipping activity.

The potential impacts on the 18 marine mammal species understood to occur in Ghanaian waters can be summarised as follows.

- **Balaenopteridae (rorquals).** The hearing frequency sensitivity of the humpback whale is likely to coincide with the low frequency noise levels produced by vessel propellers and thrusters and therefore it is considered the most likely sensitive receptor to noise. The area in which behavioural changes may be anticipated is likely to be small (1 to 5 km radius from Jubilee field activities). Humpback whales may tolerate low levels of continuous or nearly continuous sounds, such as those associated with this project and are expected to avoid areas where continuous or nearly continuous sounds levels may cause disturbance. Given the sound levels from project activities and the continuous nature of the sound, humpback whales are expected to avoid the immediate area around the Jubilee field during installation and operational activities. Humpback whales are classified as Least Concern by the IUCN, however, they are sensitive to the low frequency noises produced by the project and are likely to avoid being closers than a few kilometres from the sound sources. The impact of this behavioural response is assessed as being of *Minor* significance.

- **Delphinidae, Ziphiidae (beaked whales) and Physeteridae (sperm whales).** The hearing frequency sensitivity of these whales and dolphins is not likely to coincide with the frequency range containing most of the sound energy from vessels or other operations. Sperm whales, which are classed as Vulnerable by the IUCN and dive in deep waters, are expected to avoid areas (less than 5 km radius from project activities) where sounds may cause disturbance. Given the scale of the area affected by noise in an open sea location the impacts of relatively low frequency underwater sound on these whales and dolphins is assessed as being of *Minor* significance.

- **Kogiidae (pygmy sperm whales).** The dwarf sperm whale is classified by IUNC as Data Deficient and is considered sensitive to high frequency sounds. Most noise from the project will be in the low frequency range and impacts on this species are assessed as being *not significant.*

Mitigation Measures

The following mitigation measures will be adopted to minimise the potential for disturbing marine animals and to obtain further information on marine mammal presence in the area in an effort to reduce the potential adverse impacts of the project and future activities on marine mammals.

- Tullow will develop and enforce a specific policy and procedures to ensure that traffic and operations of drilling vessels, support vessels and helicopters will minimise disturbance to marine mammals. For example, vessels will not be allowed to intentionally approach marine mammals and, where safe to do so, will alter course or reduce speed to further limit the potential for disturbance or collision.

- A programme for training vessel operators in marine mammal and turtle observation and monitoring at and in the vicinity of the proposed Jubilee field development will be developed and implemented to obtain additional information on marine mammal distribution in the area.

Residual Impacts

Phase 1 Jubilee development activities are unlikely to generate sound levels which could cause auditory damage to marine mammals, even in the unlikely event that marine mammals approach the sound sources at very close proximity (ie within 10 metres). It is likely that sound levels from activities (for example the FPSO or other large vessels) will reach levels that could result in avoidance behaviour of some marine mammals (ie more than 120 dB). These sound levels are likely to be limited to a 1 to 3 km radius around the project facilities. Oil tankers may have a more significant sound level, which may increase this radius to approximately 5 km. However, tankers represent temporary noise sources with a single 24 hour offloading event every 5 to 7 days and tankers will not have engines running at full power when in the project area or connected to the FPSO. The area within the Jubilee field that will have noise levels over 120 db will vary depending on project activities and on the location of MODUs and support vessels but in most cases will be within a 10 km radius of the centre of the field. It is noted that the noise levels will decrease after the installation phase as there will be few vessels operating in the area.

Humpback whales are considered to be the most sensitive marine mammals in the area due to their hearing frequency sensitivity. Most other marine mammal species (eg sperm, beaked whales and dolphins) are less likely to be disturbed if exposed to noise as their hearing frequency ranges overlap less significantly with that expected to be produced by the project. Overall the residual impacts are anticipated to be of *Minor* significance taking into account the nature of the activities, the type of marine mammals present in the area, and the small size of the area where sound levels are at a level that could lead to avoidance.

5.2.4 Impacts of FPSO Presence on Local Fish Populations

Sources of Impact

Large pelagic fish species (ie tuna and billfish) and deep water (demersal) fish species will be present in the Jubilee field area. Pelagic species which inhabit the surface layers of the water column are likely to be impacted by the presence of the FPSO, MODUs and support vessels as many pelagic fish species are known to readily associate with floating objects (known as Fish Aggregating Devices (FAD)) (Røstad, *et al* 2006). The deep water fish communities are likely to be affected by the installation and presence of subsea infrastructure.

Impact Assessment

The pelagic species found in offshore deep-water locations in the Gulf of Guinea are mainly highly migratory and will not become permanent residents under the FPSO. The total number of fish that will congregate under the FPSO is not known, however, evidence suggests that the number of fish that shelter beneath a floating object is not necessarily determined by the size of floating object (Nelson 2009). Generally, FADs work for only a relatively short period of time as fish shoals (ie large congregations of fish) moving around the east Atlantic Ocean and will only be present for a number of days or weeks (Itano *et al* 2004) until they move on. Although commercially exploited species associated with the FPSO, deep sea buoys, MODUs and support vessels and their exclusions zones will be afforded some protection from fishing activity, the benefit to fish ecology is considered to be of *Minor* significance due to the temporary nature of the residency of fish near the FPSO, deep sea buoys, MODUs and support vessels.

Light is an important stimulus for many fish species and they are attracted to the surface waters when the moon is full (due to the vertical migration of zooplankton and other prey species). Fish aggregations around the FPSO, MODUs and vessels may also be influenced by the artificial light at night as zooplankton and their fish predators are drawn towards the light generated by project facilities. The increased availability of prey species to pelagic fish may result in a benefit to a proportion of these pelagic fish populations, however, the scale of this impact will be small in the context of the area over which these species range and the positive impact will be *not significant.* In addition, most species are only associated with FADs during daylight hours (Castro *et al* 2002) and will disperse during the night to forage in open waters.

Deep water fish are also known to aggregate around seabed structures, such as wrecks, as they provide variety of habitats and areas of shelter for fish. The addition of the project seabed infrastructure is likely to attract deep water fish, however, the impacts of this is not considered to be significant in terms of population ecology. Negative impacts due to disturbance during installation may occur, eg from suspended sediments, however this will be short-lived and impacts on mobile fish species that can avoid areas of suspended sediment is assessed as being *not significant.*

Mitigation Measures

No mitigation measures are proposed.

Residual Impacts

The positive and negative residual impacts of the presence of the offshore infrastructure and vessels on fish population is assessed as being not significant.

5.3 OPERATIONAL DISCHARGES

5.3.1 Scope of Assessment

This section provides an assessment of the potential impacts from the operational discharges associated with the Phase 1 Jubilee project. Operational discharges are defined here as any liquid or solid discharges to sea that may occur during the development and operation of the project. For completeness, the discharges during the previously permitted well drilling operations, including drill cuttings discharges, are addressed in *Annex B.* This section addresses the well completion and production phase discharges. Emissions to air and waste management are addressed in *Section 5.4* and *Section 5.5* respectively.

Impacts are assessed from routine operational discharges that are likely to continue throughout the project lifespan (20 years) and from non-routine or one-off discharges that are mainly associated with the project commissioning phase or maintenance works. Accidental events that could lead to discharges of crude oil or diesel into the marine environment are addressed in *Section 5.6.*

The following project vessels and installations will contribute to operational discharges.

- MODUs operating offshore during well completions or well workover activities and associated support or supply vessels.

- Installation vessels such as pipe-lay vessels, umbilical vessels and associated support and supply vessels during installation, and commissioning of the offshore project infrastructure.

- The FPSO once it is installed offshore and its support and supply vessels (eg tugs, crew change vessels) during operation of the project.

- Visiting export tankers.

The majority of discharges will originate from the MODUs and FPSO and the main sources and volumes of these discharges are outlined in *Chapter 3: Section 3.8*. In addition, discharges from the onshore logistics bases via spillage and run-off from storage areas could affect soils and enter ground waters and surface waters.

The main receptors and resources that could be affected by offshore discharges are the receiving waters (ie direct impacts on water quality) and the biological resources that depend on them (ie secondary impacts on marine ecology). The following key types of discharges are addressed in the subsequent sections.

Routine Discharges:
- black water, grey water and food waste (from FPSO, MODUs, construction and support / support vessels);
- deck drainage and bilge water possibly contaminated with traces of hydrocarbons (from FPSO, MODUs, supply and support vessels); and
- produced water (from FPSO).

Non-routine Discharges:
- completion fluids and occasional discharge of workover fluids (from MODUs);
- chemically treated hydrotest waters and pre-commissioning and line flushing fluids from the subsea infrastructure during installation and commissioning;
- hydraulic fluid from subsea valve activation; and
- occasional discharge of ballast waters (from export tankers and other vessels).

The following discharges that are not considered likely to result in significant impacts are discussed below and are not assessed further.

Cooling water. Internal combustion engines on the FPSO and other newer vessels will be cooled in a closed loop freshwater management system with no thermal discharge to sea. There may be small volumes of cooling water discharged from older vessels such as support vessels with a once-through seawater cooling system. In these cases cooling water will be treated through an oil-water separation system before discharge to sea. Surface waters in the Gulf of Guinea are in the range 24 to 29 ˚C and cooling water is typically discharged at mean temperatures of 55˚C (maximum 60˚C). Good industry practice (IFC 2007a) for thermal discharges indicated that there should be no more than a 3˚C increase within 100 m of the discharge. Elevated temperatures will be experienced in the immediate vicinity of any discharges, however, given the high dispersion capacity of open sea, any cooling water discharges from vessels are expected to be within 3˚C of the seawater temperature well within this distance and impacts are assessed as *not significant.* This conclusion is based on previous industry experience of a similar project offshore Angola.

Desalination brine. Hypersaline brine will be produced during freshwater generation on the FPSO and discharged to sea at an approximate rate of 35 to 50 m^3 per day. The salinity of the discharged brine will be approximately 70 parts per thousand. Given the high dilution capacity of a discharge of this limited volume into the open sea, impacts are assessed as *not significant*.

Sulphate removal. The seawater to be used for injection to maintain reservoir pressure will be treated to reduce the concentration of sulphate in the water to reduce the potential of barium and strontium sulphate scales which can build up in wells and on flowlines and valves reducing their efficiency and occasionally causing blockages. Using low sulphate sea water for injection into the reservoir also reduces the potential for the reservoir to be 'soured' over the longer term by the production of hydrogen sulphide which is a by-product of sulphate reducing bacterial (SRB) activity using sulphate for respiration under anaerobic conditions. Seawater typically has a sulphate concentration of 2.9 g/l and on the FPSO injection water is passed through a Sulphate Removal Unit containing fine filters and membranes to reduce this concentration to approximately 0.02g/l. The reject water stream will have sulphate concentrations at approximately 11.8 g/l and will be discharged to sea at an approximate rate of 11,000 to 16,000 m^3 (70,000 to 100,000 barrels) per day during period when water injection is required. In addition, the filters and membranes will be backwashed daily to clean them. The reject water stream will also contain biocides and residual oxygen scavenger at concentrations of up to 200 ppm and 1 ppm respectively.

Sulphate does not have an important role as a nutrient (unlike nitrate and other nutrients) in the marine biogeochemical cycle and consequently has no effect on plankton productivity. The discharge stream will be rapidly diluted and dispersed and impacts on water quality and marine organisms from residual concentrations of biocide and oxygen scavenger are likely to be localised and short term and are assessed as being *not significant*.

Produced sand. Sand from the formation can be transported with the crude oil from the wells through the flowline system and deposited in the separation process on the FPSO. The well completions include the installation of a series of downhole sand control systems (eg mechanical sieves) to significantly reduce the potential volume of medium and coarse sand particles produced. Finer sediments such as fine sands, silts and clay in the reservoir formation can pass through the sand control systems and will remain suspended in the oil and water streams and will be deposited in the oil cargo tanks (where it has to be manually dug out during annual FPSO shutdowns) or more likely be removed with the produced water and discharged to sea. The geological information from the wells drilled to date indicates that produced sand is not expected to be a significant issue for the Jubilee field, particularly with the downhole sand control systems installed during the well completions. Any sand that is produced will form a waste that is either shipped to shore for treatment and disposal (if the residual oil content is more than 1% dry weight) or mixed with seawater and discharged to sea through the produced water system if the oil content is less than 1% dry weight. Discharged produced sand is expected to settle on the seabed in a similar way to fine drill cuttings (see *Annex B* and *Annex D*). Impacts from the generation of small quantities of produced sand are assessed as *not significant.*

5.3.2 Assessment Methodology

The assessment of impacts from marine discharges considers the nature of the discharges and the sensitivity of the receiving environment. The nature of the discharges is defined as a combination of the magnitude of the discharges (ie the volume and frequency) and the composition of discharges (ie chemical make up and toxicity). The sensitivity of the receiving environment includes the scale and nature of likely effects on habitats and species and the conservation importance of these habitats and species.

In deep water offshore areas such as the Jubilee field the main environmental receptors are the waters in the vicinity of the discharges and the marine organisms that occupy these waters (ie plankton, larger invertebrates, fish and their predators). The sensitivity of these environmental receptors is discussed below.

- The results of the Environmental Baseline Survey showed that waters in the Jubilee field are of good quality, as would be expected in an offshore, deep water area. The water depth, distance offshore and hydrography provides a high level of dilution and dispersion for any discharges. Taking the existing good water quality and the dispersive nature of the open water area the overall sensitivity of the area is considered to be medium.

- In the event that significant impacts on water quality occurred, there could be secondary impacts on plankton, larger invertebrates (eg squid), fish and their predators such as marine mammals. Plankton have limited mobility and can be sensitive to impacts on water quality. Mobile species such as larger invertebrates, fish, turtles and mammals will be exposed to discharges but are considered less sensitive as they would be present in the areas of high discharge concentrations for limited periods.

The key mitigation measure is the control of the concentration of pollutants in discharged waters, and thereby allowing natural dispersion and dilution in the open water areas to reduce the concentration to harmless levels beyond the point of discharge. Dispersion modelling was undertaken for the produced water discharge (see *Section 5.3.5* below and *Annex D*), with an oil in water concentration of 42 mg/l to provide information on the dispersive characteristics of the offshore receiving waters. The 42 mg/l is the maximum level that will be permitted for discharge and is based on IFC (2007a) EHS guidelines, however, the actual produced water treatment system is designed to achieve performance at levels significantly lower oil-in-water levels than this. The modelling studies are therefore conservative with discharge concentrations above those expected to be achieved. Although not specifically modelled, the discharges of effluents with lower oil in water concentrations and in lower quantities will be dispersed within shorter distances from the discharge point.

5.3.3 Black Water, Grey Water and Food Waste

Potential Impacts

Discharges from the Phase 1 Jubilee project will include liquid and solid wastes from the FPSO living quarters and similar wastes from the other marine vessels operating as part of the project eg MODUs, installation vessels and support or supply vessels. These will include the following.

- Black water (treated sewage) will be discharged from MODUs (including installation and support vessels) during the well completion and installation phases and from the FPSO (including support vessels and export tankers) during the operational phase. During well completions and installations when the maximum number of personnel will be working offshore the average rate will be approximately 41 m^3 per day and during the operation phase the average rates will be approximately 16 m^3 per day.

- Grey water (domestic wastewater) will be discharged from MODUs, (including installation and support vessels) during the well completion and installation phases and from the FPSO (including support vessels and export tankers) during the operational phase average rates of approximately 69 m^3 per day and 34 m^3 per day respectively.

- The predicted volumes of macerated food waste from the FPSO and MODUs amounts to approximately 96 tonnes per year. The volumes discharged from support / supply vessels and possibly installation vessels will be much smaller as the crew numbers are much less (approximately 10 tonnes per year).

The discharge of organic food waste and raw sewage to sea can create a health hazard while it remains in coastal areas. Organic material and sewage can also lead to oxygen depletion and visual pollution. However, only the support / supply vessels are likely to be operating regularly in coastal waters. With regard to the FPSO and MODUs, the discharge of sewage, domestic wastewater and macerated food wastes will cause a localised increase in the Biological Oxygen Demand in the receiving surface waters.

The discharge of these waste streams will introduce relatively small amounts of nutrients and organic material to well-mixed, well-oxygenated surface ocean waters resulting in a minor contribution to local marine productivity and possibly attracting some opportunist feeders. The sewage and domestic wastewater discharge may contain a low level of residual chlorine from the sewage treatment facility on the FPSO or MODU, but this will not be significant taking into account the relatively low total discharge, ie 16 to 41 m^3 per day.

Impacts from discharges of sewage, grey water and food waste to the marine environment is assessed to be of *Minor* significance given the medium sensitivity of the receiving waters, relatively small discharge volumes and high dilution factor in the offshore marine environment.

Mitigation Measures

The discharge of black water and food waste from the FPSO, MODUs, installation/construction vessels and support and supply vessels will be carried out in accordance with the following MARPOL 73/78 Annex IV and Annex V requirements and good industry practice.

- Black water will be treated prior to discharge to sea. Approved sanitation units onboard will achieve no floating solids, no discolouration of surrounding water and a residual chlorine content of less than 1 mg/l. There will be no discharges from vessels within 12 nautical miles of the nearest land.

- Organic food wastes generated will be macerated to pass through a 25 mm mesh and discharged more than 12 nm from land with no floating solids or foam.

Residual Impacts

The introduction of organic materials is likely to result in localised increase in marine productivity in the surface waters around the FPSO and other vessels.

Residual concentrations of hypochlorite in discharge waters will be set at 1 mg/l, and with rapid dilution and dispersion no significant impacts on water quality are predicted. The residual impacts of the discharge of black water, grey water and macerated food waste from the FPSO, MODUs and other vessels will likely be of *Minor* significance.

5.3.4 Deck Drainage and Bilge Water

Potential Impacts

Water that accumulates in the drains and bilges of the FPSO, MODUs and other support vessels is likely to become contaminated with low levels of hydrocarbons and other chemicals. Unmanaged discharge of this water to the sea represents a potential impact on local water quality and marine organisms. The total volumes of drainage water produced by the FPSO, MODUs and support vessels as part of the Phase 1 Jubilee project will, to a degree, be dependent upon weather conditions (ie rainfall) and deck cleaning and other activities that create run-off. The most significant discharges are likely to be from the FPSO and MODUs, because of the nature of activities being carried out and their greater surface area, rather than from the support vessels. Potential impacts from these sources are assessed as being of *Minor* significance.

Mitigation Measures

Although the amount of discharge from the drains and bilges of the FPSO and other vessels are not expected to be significant, there are some key mitigation measures that will be implemented to ensure the impact on water quality and marine organisms are reduced. These include the following.

- The FPSO and MODU deck and drainage system will include coamings around the main decks to contain leaks, spills and contaminated wash-down water to minimise the potential for uncontrolled overboard release. The open drain system will collect oily rainwater drainage from drip pans and drain boxes throughout the topsides, rainwater on FPSO decks, and deluge water from the modules. A closed drain system will collect hazardous fluids from process equipment in hydrocarbon service. If the deck becomes contaminated, oily deck drainage will be contained by absorbents or collected by a pollution pan for recycling and/or disposal.

- The FPSO, MODUs and marine vessels will treat oily water (eg from open and closed drain systems, bilges and slop tank water) in accordance with the MARPOL Annex I requirements (15 ppm oil and grease as a maximum limit) and discharge to sea.

- Oil discharge monitors are used to ensure oil in water content targets are not exceeded. Records will be maintained of all discharges and oil content to verify controls in place are working effectively.

Residual Impacts

The volume and nature of discharge from drains and bilges will be small scale given the limited volumes discharged, the depth of water offshore and the capacity for dilution and dispersion. This will mean that only very localised and temporary effects on water quality around the point of discharge will occur. With the suitable drainage and treatment systems described above, the residual impacts on water quality and marine organisms associated with discharge of drainage water will likely be of *Minor* significance.

5.3.5 Produced Water

Potential Impacts

Produced water is a by-product of oil and gas hydrocarbons from under-ground reservoirs. Water is naturally present in these reservoirs as a portion of the produced oil and gas is water (either as a liquid with the oil or as a vapour in hydrocarbon gas). Produced water will be separated from the hydrocarbons on the FPSO in the separation train and transferred to the produced water treatment system where it is filtered, cleaned and cooled prior to discharge to sea. The proportion of produced water varies through the life of the reservoir (see *Chapter 3: Section 3.8.2* for a produced water profile based on indicative production rates). Low volumes of produced water are expected in the early stages of Jubilee field production. Based on production forecasts from the Phase 1 field plan of development, an average produced water discharge rate of 6 Mbbl/d is expected over the project lifetime with a peak discharge rate of 18.4 Mbbl/d. There is uncertainty in the forecast of produced water volumes and the FPSO has been designed to process up to 80 Mbbl/d.

Once the exact composition of the produced water is understood it may be possible to mix the produced water with the sea water being used for water injection back to the Jubilee reservoir formation. This is called Produced Water Re-Injection (PWRI) and is commonly practiced in the oil and gas industry to reduce the volume of produced water discharged into the sea. The design of a PWRI system will require analysis of the produced water characteristics and a pilot trial to determine if this approach will be successful in the Jubilee field. PWRI can cause blockage in the water injection wells due to scale formation due to the mixing of produced water and seawater and fine sediment particles in the produced water being carried through into the reinjection water. If the analysis of the produced water characteristics and the pilot trail demonstrate that PWRI is feasible for the Jubilee field then a full PWRI process will be installed which will substantially reduce the volumes of produced water discharged. As it is not known at this stage if PWRI will be possible it has been assumed for the purposes of the EIA that al the produced water will be discharged to sea.

Methanol is used by the oil and gas industry worldwide as antifreeze to inhibit the formation of gas hydrates (ice) within the subsea infrastructure.

The methanol, being water miscible, returns to the FPSO in the produced water and will therefore be discharged to sea with the produced water. During planned system shutdowns up to 200 to 400 bbls of methanol will be used and returned with the produced water and therefore discharged to sea mixed with the discharged produced water. Methanol is readily biodegradable (half life of 6 days), has a low toxicity to marine organisms is graded by OSPAR as a chemical that Poses Little or No Risk to the Environment (PLONAR) and is permitted discharge to sea in the OSPAR countries.

Given the possibility of a continuous discharge of relatively large volume of produced water, this was considered the principal effluent discharge from the Phase 1 Jubilee project. To provide quantitative information to aid the assessment of the potential impact to the marine environment, the dispersion of produced water discharges was modelled using current data input obtained from the Jubilee field (see *Annex D* for details of the modelling work).

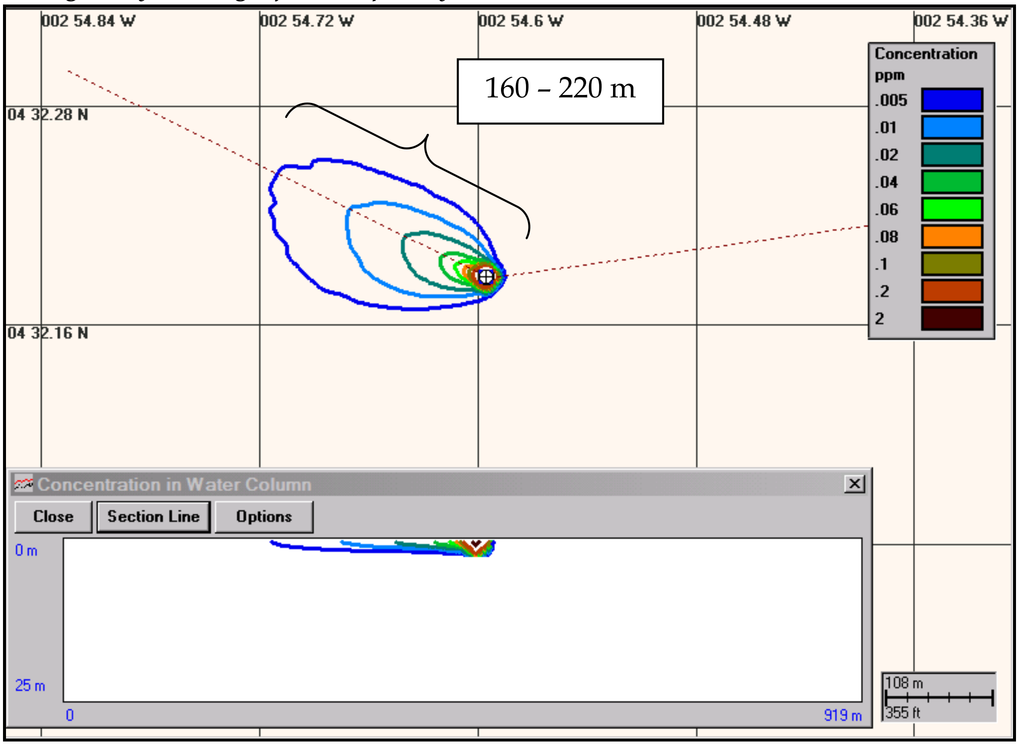
Two discharge rates were modelled to represent the average (6.0 MMbbl/d) and maximum likely (18.4 MMbbl/d) produced water discharge rates. In addition, the maximum discharge rate possible from the design of the process equipment on the FPSO (80 MMbbl/d) was modelled as a worst case. Produced water was assumed to be discharged at the surface with a conservative hydrocarbon concentration of 42 mg/l, which represents the maximum daily discharge rate following IFC (2007a) EHS guidance for produced water discharges (see *Chapter 2: Section 2.6).* From the point of discharge, produced water will disperse to lower hydrocarbon concentrations further away from the discharge point under local oceanographic conditions.

The hydrographic model inputs show that the regional water circulation is characterised by two periods, namely westward and eastward surface flows. Depending on the direction of the prevailing surface flows during the discharge periods, produced water will disperse in a north-west or south-east direction. In each modelling simulation, produced water was discharged continuously for 30 days, a period sufficiently long to capture variations of current speed and direction.

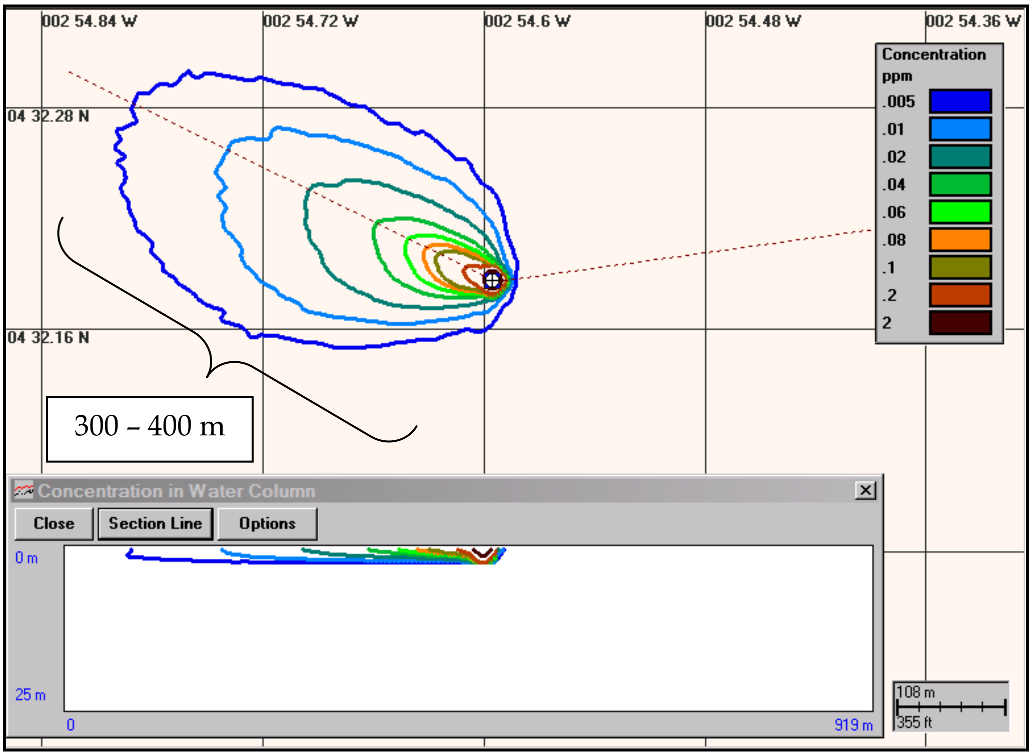
The modelling results showed that hydrocarbons will rapidly disperse within a short distance and the effluent plume will be limited to a water depth of less than 5 m. Dispersion is shown as contours of hydrocarbon concentration from the point of discharge. *Figure 5.2* shows modelling results for maximum and average produced water discharge rates in response to westward currents (the results of the eastwards currents are similar). The outermost concentration contour on the figures represents a hydrocarbon concentration of 0.005 ppm.

Figure 5.2 Simulated Hydrocarbon Distribution in Westward flow

Average daily discharge of 6 Mbbl per day



Maximum likely daily discharge of 18.4 Mbbl per day



The 0.005 ppm contour represents a conservative estimate of the threshold for toxic effects of hydrocarbons to sensitive organisms (French-McKay, 2002). The maximum distance from the discharge point to the 0.005 ppm contour is 300 to 400 m for the 6.0 MMbbl/d discharge and 600 to 700 m for the 18.4

MMbbl/d discharge. The contours in the model scale linearly with concentration, therefore, if the produced water hydrocarbon concentration is 30 ppm, the contours are 71% of the values shown for 42 ppm; and for 20 ppm the contours are 48% of the values shown.

The maximum possible discharge rate from the FPSO (80 MMbbl/d) was also modelled (see *Annex D*). The results showed that the vertical extent of the effluent is 7 to 8 m and the contour representing 0.005 ppm concentration is 2,000-2,200 m from the source of the discharge at its maximum extent.

There would be the potential for impacts on water quality (as a consequence of entrained hydrocarbons and other components such as heavy metals) in the vicinity of the FPSO as a result of produced water discharges. There would also be possible secondary effects on marine organisms (eg plankton, larger invertebrates and fish). Phytoplankton and zooplankton communities seasonally present in the vicinity of the FPSO are likely to be the most sensitive group to impacts from produced water discharges (Gamble *et al* 1987) due to the elevated levels of hydrocarbons in the discharge.

Although fish will be present under and around the FPSO they are unlikely to be exposed to any significant impact as they are mobile and the residence time within the discharge plume will be short. The model results show that the area of impact from the plume to the 0.005 ppm contour is approximately 0.15 to 4 km^2 and to a depth of approximately 5 m, for the average and likely maximum predicted discharge volumes. To provide context this is a maximum of approximately 0.14 to 3.6% of the area of the Jubilee Unit Area.

At the maximum possible discharge rate from the FPSO design the area of potential impact is predicted to be 15 km^2 which is approximately 15% of the area of the Jubilee Unit Area, however, discharges at this rate are not planned and are considered to be very unlikely and if they did occur would be for a short period.

Toxicity studies on produced water discharges have shown that the concentrations of toxic chemicals in most produced waters are well below the test species 96 hour LC50 (lethal concentration for 50% of the individuals tested over a 96 hour period) indicating that acute toxicity is unlikely beyond the immediate vicinity of the discharge (GESAMP 1993).

The waters in the Jubilee field are considered to be of medium sensitivity and the discharges of low toxicity effluents into the highly dispersive offshore waters is assessed of being of *Minor* significance.

Mitigation Measures

Mitigation measures for produced water include the following.

- The FPSOs produced water treatment system will include a three stage process of a water skim vessel, followed by hydrocyclones and ending with a flotation cell prior to discharge to sea. Dispersion of discharges will be increased using diffusers on the discharge pipe.

- Produced water will be continually monitored and if oil in water exceeds 42 mg/l, the water will be routed to the off-specification tank for further treatment prior to any discharge. Operations staff will be alerted to any rising trends by alarms at less than 42 mg/l in various stages.

- Discharge into the sea would be monitored such that the 30 day average will not exceed 29 mg/l.

Discharge of produced water is planned at this stage as there is insufficient information to determine, particularly surrounding produced water composition, if later reinjection of produced water will be possible. Once the FPSO is operational and sufficient produced water has been generated to provide reliable information on the water quality (eg solids contents, level and bacteria). Tullow will undertake a feasibility study for produced water re-injection. This is expected within two years of the start of production if the rate of produced water is close to the current forecast at that time. Sufficient quantity of produced water is required to characterise and engineer the required solution and ensure disposal success to the reservoir. The produced water process pipework on the FPSO has been designed to allow future water re-injection if it proves to be feasible.

Residual Impacts

The dispersion modelling has shown that the treatment of produced water to 42 mg/l maximum oil concentration and discharge into the dispersive open water conditions in the Jubilee field will lead to a localised and short-lived impact to water quality. Marine organisms such as plankton within the mixing zone will be impacted, however, given the area of water affected the impact is assessed as being of *Minor* significance. No significant impacts on larger invertebrates, fish and predators such as turtles and marine mammals are expected.

5.3.6 Completion and Workover Fluids

Potential Impacts

Completion and well workover fluids will include weighted brines or acids, methanol and glycols and other chemical systems. As described in *Chapter 3*, these fluids are used to clean the wellbore and stimulate the flow of hydrocarbons, or to maintain downhole pressure. Once used these fluids may contain contaminants including solid material, oil and chemical additives.

The completion of the Phase 1 Jubilee wells will be a one-off activity and the average time required to complete each of the wells will be approximately 25 days. The Phase 1 wells have been designed for a 20 year lifetime with no planned interventions. Unplanned interventions or workovers are occasionally required, however, this is not expected to be more than once a year across the whole field, with each operation expected to take no more than 30 days.

Most of the chemicals used during completion and workovers will be re-used, remain downhole or will be injected into the formation. Some completion chemicals such as upper completion chemicals and flowback fluid chemical will be flared off after use. Other completion fluids, such as wellbore cleanup fluids, will be discharged overboard. These will include:

- Completion brine (calcium chloride), 845 tonnes per well;
- Diatomaceous Earth Filter Aid (Celite 545), 5.3 tonnes per well;
- Surfactant (Tetraclean-105), 5.9 tonnes per well; and
- Surfactant Booster (Tetraclean-106), 3.3 tonnes per well.

The above chemicals are essentially non-toxic to the marine environment according to the Offshore Chemical Notification Scheme (OCNS Category E – PLONOR / CHARM Gold), meaning that these chemicals are of low toxicity, readily biodegradable and are non-bioaccumulative. Direct impacts on water quality and indirect impacts on marine organisms as assessed as being of *Minor* significance given the toxicity of the discharges, the area affected and the duration of the impacts.

Mitigation Measures

Proposed mitigation measures to reduce the potential impacts associated with the disposal of used completion and workover fluids include the following.

- Selection and use of chemicals will be managed taking into account its concentration, toxicity, bioavailability and bioaccumulation potential, with selection based on the least environmental potential hazard.
- Where possible, used fluids will be injected into the formation, flared, or collected in a closed system and shipped to shore for recycling or treatment and disposal.

- Used wellbore cleanup fluids will be discharged to sea after treatment to achieve a maximum one day oil and grease content of 42 mg/l and 30 day average not exceed 29 mg/l.

- Any acidic completion and workover fluids that are used and are returned to the MODUs with well fluids will be neutralised by mixing in soda ash, or similar, to attain a pH of 5 to 7 before disposal to sea.

Residual Impacts

The residual impacts on water quality and marine organisms associated with the disposal of used completion and workover fluids on the marine environment are predicted to be of *Minor* significance, given the low quantity and toxicity of the treated discharges and the rapid dilution in open waters.

5.3.7 *Pre-commissioning and Line Flushing Fluids*

Potential Impacts

Pre-commissioning operations will involve subsea pipeline inspection, hydro-testing and leak testing operations. Pre-commission of the flowlines and other components is necessary to prove integrity prior to production. These operations will involve filling the flowlines with seawater and added chemicals. The chemicals to be added will comprise the following:

- biocide;
- oxygen scavenger;
- corrosion inhibitor; and
- tracer dye.

The chemical that Tullow is planning to use is TROS 655 supplied by Clariant (or similar). Under the Offshore Chemical Notification Scheme, TROS 655 is classified into a Silver band (Hazard Quotient less than 30 - see *Chapter 3: Section 3.7.3*). During pre-commissioning, the total volume of pre-commissioning fluid that may be discharged to sea is 5 m^3 combined at 1,000 ppm with raw seawater (giving a total volume of approximately 5,000 m^3).

During FPSO leak testing and flowline dewatering operations a total volume of approximately 5 m^3 of the pre-commissioning fluid (diluted to 1,000 ppm in seawater giving a total volume of 5,000 m^3) will be discharged from the FPSO at the sea surface.

For the protection of umbilical tubing during storage and transport Tullow is planning to use SST5007 umbilical storage fluid (or similar). This is mainly Monoethylene Glycol (MEG) and the volume (15m^3) within the umbilicals will be discharged to sea when the umbilicals are being commissioned. The umbilicals will then be flushed using methanol (approximately 4 m^3) and this will be discharged to sea at the drill centres. MEG and methanol are in Category E in the OCNS.

Prior to injecting into the water injection wells, the water treatment facilities will be commissioned. During this process approximately 30,000 m^3 of deoxygenated sea water will be discharged overboard.

When the gas injection flowlines and risers are dewatered (ie the water is pumped out) MEG will be pumped through the pipelines to remove any remaining water. Typically 50-100 m^3 of MEG will be discharged to sea.

These releases will be at the seabed or the sea surface, depending on the equipment being tested and will temporarily expose seabed and sea surface dwelling organisms to the chemicals contained in the hydrotest waters. Typically oxygen scavengers react with water to consume oxygen and produce sulphates. This is a one-off reaction with no harmful by-products. In addition, a substantial proportion of the original scavenger dose is expected to be consumed inside the flow lines prior to release. In common with the oxygen scavenger, a proportion of the biocide chemical is also likely to be consumed/degrade in the flow lines depending on how long it resides there. Tracer dyes are typically poorly biodegradable but are water soluble and will rapidly disperse in the marine environment.

The impacts on water quality and marine organisms for these short term activities is expected to be localised and are assessed as being of *Minor* significance.

Mitigation Measures

Proposed mitigation measures to reduce the potential impacts associated with the discharge of pre-commissioning chemicals include the following.

- A pre-commissioning disposal plan will be developed to control the rate of discharge, chemical use and dispersion. Dispersion will be improved by optimising the discharge rate, pressure and direction of the discharge at the release point. These procedures will be ready for pre-commissioning work in third quarter (Q3) of 2010.

- The volume of pre-commissioning water required will be reduced by testing equipment onshore where possible, before it is loaded onto offshore facilities.

Residual Impacts

The discharges of these volumes of relatively low toxicity effluent will disperse rapidly in the receiving environment. The larger volumes discharged during pipeline inspection may lead at most to temporary minor localised effects to benthic communities on the basis of a horizontal discharge and little likely contact with the plume before it is greatly diluted. These effects are likely to be limited to a few tens of metres from the discharge point and will primarily relate to the nature and residual concentrations of the biocide and oxygen scavenger that are used; noting that these chemicals will be partially consumed while residing in the flowlines. Overall effects will likely be of *Minor* significance on the basis that it will be a localised one-off discharge, impacts will be short-lived and regeneration will be rapid. Secondary impacts higher in the food chain will be *not significant*.

5.3.8 Hydraulic Discharges from Subsea Equipment

Potential Impacts

Subsea hydraulic production control systems are used to control valves. In deep water facilities open loop systems are the industry standard due to their reliability and low maintenance requirements. With this system there is a release of small volumes of hydraulic control fluid into the marine environment each time the valve is activated.

Valves on the production manifolds and trees are required to be tested by actuating them at least once every 3 to 6 months. Manifolds have 10 valves and trees have 4 valves each. This would result in 14 valves activated four times a year. This will result in the discharge of approximately 45 l of hydraulic fluid per year (based on 56 valves releases each discharging an average of 0.8 l). Valves on water and gas injection manifolds are ROV actuated, so they will not release any fluid.

The small volume and intermittent discharges of fluid from the open loop system will be rapidly diluted and dispersed in the receiving water column. It has the potential to cause localised impacts on the water column and marine organisms around the manifold when a discharge occurs. The potential impact is of *Minor* significance.

Mitigation Measures

The hydraulic fluids used will be a water based glycol fluid such as Oceanic HW443 control fluid which has a low toxicity and bioaccumulation potential and is readily biodegradable (OCNS Group D rating).

Residual Impacts

The residual impact of the discharge of hydraulic fluids from the subsea infrastructure is deemed to be of *not significant* given the small scale, localised and intermittent nature of the impact and the low toxicity and rapidly biodegradable fluid used.

5.3.9 Ballast Water

Potential Impacts

As part of the operations of the FPSO, MODUs, supply/support and installation vessels and export tankers whilst on site, sea water will be pumped into designated ballast tanks and released to sea as required in order to maintain the respective vessel at its proper flotation/trim level. This water is known as ballast water and if not managed appropriately can have a potential impact on the marine environment. The main potential impacts associated with ballast water include:

- discharge of ballast water that contains oil or other potential polluting chemicals; and
- the possibility that foreign (alien) species and pathogens may be introduced into Ghanaian waters that can adversely affect native marine biodiversity.

The export tankers that will arrive at the Jubilee Field approximately every 5 to 7 days for cargo transfer will have come from different parts of the world and could potentially introduce invasive species if ballast taken elsewhere in the world is discharged into Ghanaian waters during cargo transfer. There is the potential for impacts of *Minor* significance given the offshore location.

Mitigation Measures

The Phase 1 Jubilee project will implement the following mitigation measures in relation to ballast water management.

- The FPSO is equipped with segregated ballast tanks from other process systems. The primary means of maintaining an even keel, stability and trim on the FPSO will be through management of the distribution of crude oil within the storage tanks, therefore the requirement for ballast water intake and discharge will be minimal.

- Tullow will require that marine vessels are operated in accordance with the applicable MARPOL 73/78 requirements with regards to ballasting operations. MARPOL 73/78, Annex I, requires that discharges into seawater outside of special areas contain no more than 15 ppm oil or grease.

- Visiting export tankers and other vessels discharging ballast water will be required to undertake ballast water management measures in accordance with the requirements of the *International Convention for the Control and Management of Ships Ballast Water & Sediments*. This includes requirements for a ballast water management plan on each vessel and ballast water exchange at least 200 nautical miles from the nearest land and in water at least 200 m deep to minimise the transfer of organisms. Exceptionally, discharges are permitted 50 nautical miles from land in water depths of 200 m. The tanker vetting procedures will include demonstration of compliance with ballast water management requirements (see *Section 3.4.13*).

Residual Impacts

The design of the FPSO and support vessels with separate ballast tanks means that there is no risk of ballast water becoming significantly contaminated with oil. With ballast water management plans in place the risk of introduction of alien species through ballast water discharge is likely to be negligible. In the event that ballast water was exchanged in the Jubilee field, potential impacts are assessed as *not significant* given the distance from shore and water depths in the Jubilee Field.

5.3.10 Onshore Bases

Potential Impacts

The marine support base at Takoradi port will be used throughout the project lifespan for dock space to serve as a loading/offloading point for equipment and machinery. It will also provide quayside facilities for dispatching fuel, chemicals and equipment and allow for temporary storage of spares, production chemicals, fuel and other supplies. On occasion if the Takoradi port is full, the Naval port at Sekondi may be used. The Air Force base will be used as a helicopter support base.

The storage and handling of liquid production chemicals and fuel creates the potential for accidental releases from tanks, pipes, hoses and pumps, including during loading and unloading from the bases to the supply vessels. Discharges from these activities could impact soil, groundwater and surface water quality. The two main causes of impacts are expected to arise from the following.

- Discharges directly into water courses, or via drainage channels, resulting from spills of chemicals or fuel oils.

- Leaks and spillages of chemicals from inappropriate storage and disposal of solid and liquid wastes leading to soil contamination and subsequent groundwater and/or surface water contamination due to rainwater run-off.

The type and volume of contaminated wastes discharged will depend on the type of chemicals being handled and the site drainage, containment and management systems and the degree of rainfall and site run-off area. Without appropriate management, such discharges could result in degradation of surface or groundwater quality. The onshore bases are located away from (more than 1 km) the nearest freshwater resources, however, discharges to coastal waters is possible from activities at the port. Potential impacts from discharges from shore based operations are considered to be of *Minor* significance given the scale of the project operations and the nature of materials being handled.

Mitigation Measures

The following mitigation measures will be adopted to reduce potential impacts from shore based activities.

- Chemical and fuel storage areas will have appropriate secondary containment (bunds), and procedures for managing the containment systems. Secondary containment design will depend on the type of tanks and nature and volume of the materials being stored.

- Impervious concrete surfaces will be in place at all areas of potential chemical and fuel leaks and spills, including below gauges, pumps, sumps and loading /unloading areas.

- Storage tanks and components will meet international standards, such as those of the American Petroleum Institute, for structural design and integrity.

- Storage tanks and components will undergo periodic inspection for corrosion and integrity and will be subject to regular maintenance of components such as pipes, seals, connectors and valves.

- Fuelling equipment will be inspected daily to ensure all components are in satisfactory condition.

- For chemical and fuel storage, handling and transfer areas, Tullow will install stormwater channels with subsequent treatment through oil-water separators.

- Loading and unloading activities will be conducted by properly trained personnel according to formal procedures to prevent accidental releases and fire and explosion hazards.

- Spill control and response plans will be developed in coordination with the landowners (ie GPHA Takoradi and Takoradi Air Force base).

Residual Impacts

At the onshore logistics bases it is anticipated that Tullow will have a close working and contractual relationship with the base operator (Ghana Ports and Harbours Authority and the Air Force) and thus can anticipate a high level of control in relation to management and mitigation measures. Impacts on water and soil quality from effluent discharges and spills at the onshore logistics bases are assessed to be *not significant* provided that the mitigation measures outlined above are implemented.

5.4 EMISSIONS TO AIR

5.4.1 Scope of Assessment

This section addresses the potential for gaseous emissions from the Jubilee Phase 1 Development project to impact air quality. The following issues are considered of potential significance.

- **Atmospheric Pollutants.** Project activities will emit varying amounts of primary atmospheric pollutants with the potential to impact air quality. These pollutants include carbon monoxide (CO), oxides of nitrogen (NOx), oxides of sulphur (SOx), volatile organic compounds (VOCs) and particulate matter (PM).

- **Greenhouse Gas Emissions.** Project activities will also emit varying amounts of Greenhouse Gases (GHGs) (eg carbon dioxide (CO_2) and methane (CH_4)), believed to contribute to global climate change.

The majority of gaseous emissions from the project will occur offshore within the Jubilee field. Limited gaseous emissions will occur from onshore activities.

Potential impacts to personnel working offshore on the MODU, vessels and FPSO are controlled through health and safety procedures and are not discussed in the EIA. Downstream refining, combustion and other uses of the crude oil produced from the project will result in gaseous emissions and potential air quality impacts. This is not discussed in the EIA.

5.4.2 *Assessment Methodology*

The assessment of the significance of impacts from emission to air has been undertaken by comparing the predicted project emissions to Ghana's national totals for various pollutants and GHG emissions. Contribution is then expressed as a percentage of the total. Air emissions modelling such as that which would determine concentrations of pollutants at increasing distances from a release source has not been undertaken given the relatively low volumes of emissions and the distance of the project offshore. Such modelling studies are appropriate for industrial process located close to sensitive receptors (such as communities) and not warranted in this case.

5.4.3 *Atmospheric Pollutants*

Sources of Emissions

Emissions to atmosphere from the project will result primarily from combustion of fossil fuels (natural gas and diesel) for energy generation; emissions from intermittent flaring during commissioning and non-routine operations (during upset and maintenance conditions); venting of hydrocarbons; and fugitive emissions during cargo transfer. Sources of air emissions will be from the following activities:

- MODU operations for well completions (power generation exhaust emissions);
- FPSO operations (power generation exhaust emissions and non-routine flaring);
- marine support vessels and helicopters (power generation exhaust emissions);
- filling, offloading and operation of export tankers (exhaust and fugitive emissions); and
- dust and exhaust emissions from increased traffic and dry handling of dry goods.

These emissions, except dust emissions, have been quantified and summarised in *Chapter 2*, *Section 2.8.1.* Air emission calculations from fuel uses are presented in *Annex E*. The total estimated annual emissions for various project activities, including support vessel activity, is summarised in *Table 5.8*. The well completions undertaken by MODUs, and the installation and commissioning of the FPSO are estimated to be undertaken over a period of 18 months.

There is limited data available on national emissions. Data from WRI for 1995 is also presented in *Table 5.8*. It is considered that current emission estimates for Ghana would be significantly higher than the 1995 estimates which do not include the significant emissions from sources such as biomass burning, wet soils, lightning and shipping (see below).

Table 5.8 *Estimated Annual Atmospheric Emissions (Tonnes)*

Project Stage	SOx	NOx	VOC	CO
A. Completions, Installation and commissioning				
Completion (Erik Raude)	5,269	7,417	214	1,502
Flowline/injector/umbilical installation	3,275	4,650	113	621
FPSO installation	930	1,235	36	196
Commissioning (flare)	0	93	1	8
Total	9,474	13,395	364	2,327
B. Annual Production				
Operations	1,887	2,319	72	444
Inert gas system (average)	0	0	15,170	0
Abnormal Event flaring**	0	367	3	31
Total Operations (Annual)	1,887	2,686	15,245	475
National Emissions (1995)	32,000	113,000	219,000	2,320,000

* Source: WRI (http://earthtrends.wri.org/pdf_library/country_profiles/cli_cou_288.pdf)

Impact Assessment

The national levels of emissions are relatively low compared to countries with higher levels of industrial activity, therefore the air emissions as percentages of total national emissions appear relatively high for some pollutants, notably SOx (from combustion sources) and VOC (emissions from fugitive releases during crude offloading operations). SOx emissions estimates are based on high sulphur (2% sulphur) fuel and these values are also conservative. It should be noted that low sulphur fuel (less than 0.1% sulphur) has been used for the wells drilled to date and is likely to be used for future operations therefore the actual emissions are likely to be significantly lower than calculated.

The highest SOx emissions will be temporary over the approximate 14 months required where well completions are taking place at the same time as FPSO and seabed infrastructure installation and commissioning due to the volume of fuel oil used in construction and support vessels. During operations the emissions will decrease to approximately half this volume.

Emissions from the offshore activities are unlikely to have significant direct impacts given the absence of sensitive receptors and the highly dispersive nature of the environment of the offshore location. Offshore receptors such as fishing vessels and commercial shipping are unlikely to be exposed to poor quality air other than for very short durations, for example if sailing very close and downwind of the FPSO during flaring.

The potential indirect environmental impacts of these key atmospheric pollutants include:

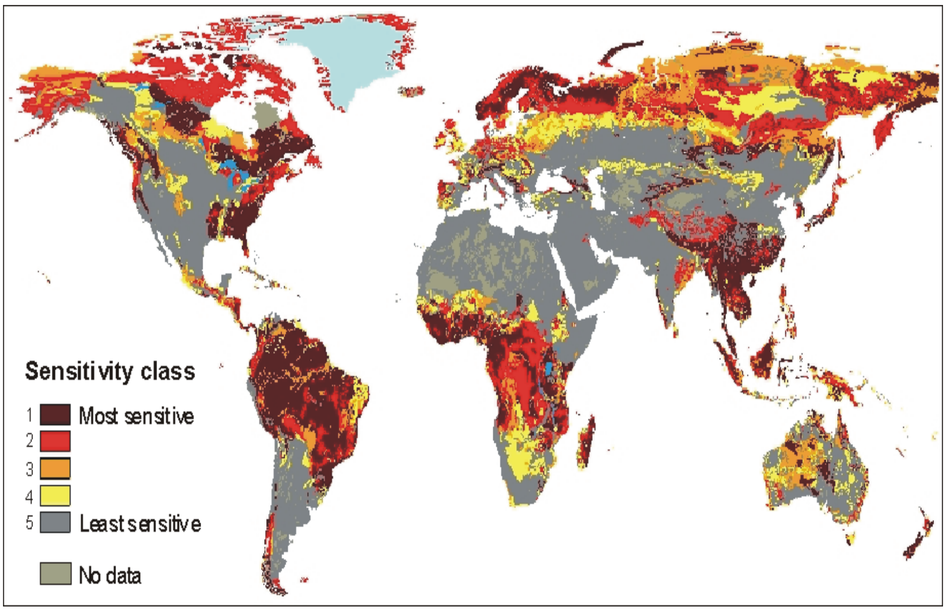
- NOx and SOx contribute to acid deposition which can have an effect on terrestrial and aquatic ecosystems; and
- NOx and VOCs act as precursor to low level ozone formation.

Currently Ghana has few offshore emissions other than from commercial and fishing vessels so the development of the Jubilee field will be a new source of pollutants. The increase in the volume of air emissions is of medium magnitude but due to the absence of sensitive receptors the impact is of *Minor* significance. Increased air quality impacts from daily vessel visits to the port are also of *Minor* significance.

Generation of dust from project traffic on unmade ground and dry handling of dry goods (eg cement) at the shore base could cause local impacts on air quality through increased PM levels. Controls would be in place to protect personnel health and safety during dry goods handling which will prevent significant impacts from dust at the shore base. Potential impacts from dust to neighbouring residential properties from the project are considered to be *not significant*. No major onshore construction activities are planed for the Phase 1 project so the likelihood of significant vehicle movements on unmade ground is low and therefore is assessed as *not significant.*

Emissions of NO_x from large combustion sources in West Africa will contribute to generation of tropospheric ozone and to the deposition of acidic compounds through the transformation in the atmosphere of the original emission of nitric oxide (NO) to nitrate and ultimately as nitric acid (HNO_3) in cloud water. A map of global soil sensitivity is presented in *Figure 5.3* which shows that West Africa has relatively high sensitivity to acid deposition.

Figure 5.3 Global Soil Sensitivity to Acidic Deposition



Source: Kuylenstierna *et al* (2001)

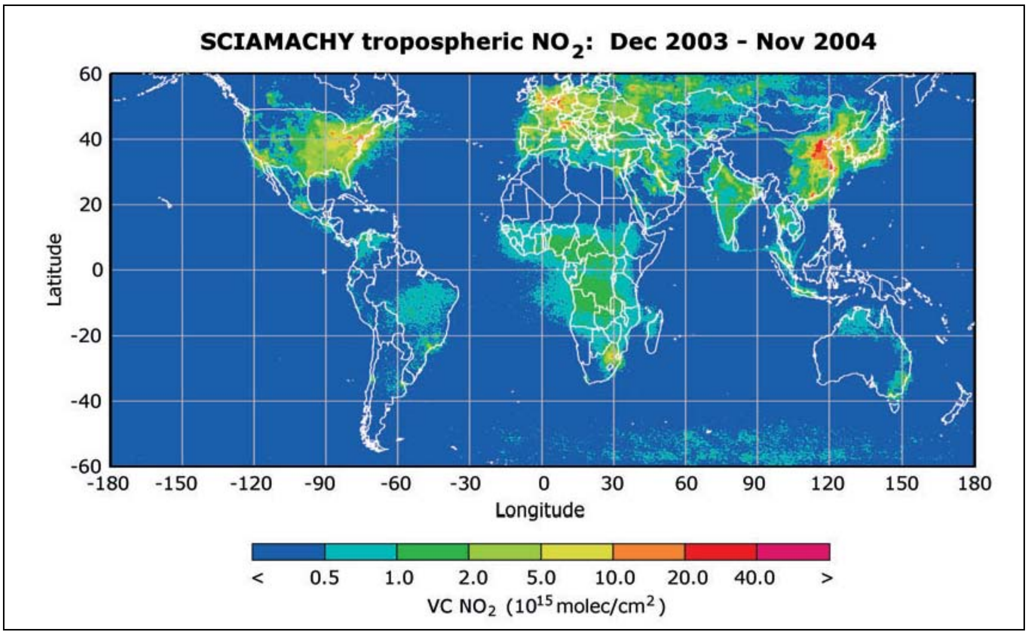
In many other arts of the world deposition of acidic compounds is less of a problem as the alkaline soils act as a very effective buffer. West Africa has not been as extensively researched as North America and Europe, and it is not known whether or by how much the critical loads for soil in the region are being exceeded.

The issue of ozone generation in the region has been the subject of part of an extensive EU research project in recent years (AMMA – African Monsoon Multidisciplinary Analyses). From this and other work, it is evident that the largest contributions to NO_x emissions derive from biomass burning and the wetting of soils following the dry season in the Sahel areas. It is thought that dormant and water stressed microbes are activated by the first rain and metabolise accumulated ammonium and nitrate ions, releasing NO as a by product (Stuart *et al* 2008). For a period of time after the rains, the surface NO_x concentration has been estimated as 0.8 – 1.4 ppb, compared with 0- 0.2 ppb over dry soils. This requires a flux of 5 – 11 ng N m^{-2} s^{-1}.

Using satellite data, other researchers have estimated that soils contribute 3.3 ± 1.8 million tonnes N/year, similar to the biomass burning source (3.8 ± 2.1 million tonnes N/year), and thus account for 40% of surface NO_x emissions over Africa (Jaegle *et al* 2004). Both of these sources contribute to the NO_2 in the atmosphere, as observed by satellite remote sensing techniques. This is illustrated below on a global scale in *Figure 5.4.*

Another large source of NO_X emissions for West Africa is shipping. It is difficult to quantify the emissions from this particular source, but the contribution to air emissions from the vessel associated with the Jubilee field will be small in relation to emissions from the large number of ships that use the shipping lanes to the south of the Jubilee field (see *Figure 5.17*).

Figure 5.4 ***Trophospheric NOx***



Source: http://atmos.caf.dlr.de/projects/scops/

Quantifying the impact of the NO_x and SO_2 emissions from the project in terms of the eventual deposition of H+ ions at the ground for a given receptor location would have to account for the long range transport of the pollutant species and their subsequent chemical transformation in the atmosphere. The impact at any individual location would be extremely small and almost unquantifiable and is considered to be *not significant.*

Mitigation Measures

The following specific mitigation measures will be implemented to minimise the impact of the Phase 1 Jubilee development on air quality.

- The MODU, FPSO, construction/installation and support/supply vessels will comply with MARPOL 73/78 Annex VI standards with regards to air emissions (see *Chapter 2: Section 2.4*). Annex VI sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and diesel engines and prohibits deliberate emissions of ozone-depleting substances including halons and chlorofluorocarbons. In addition incineration of certain products on board such as contaminated packaging materials will be prohibited.

- The vessel fleet to be used during construction and the longer term operational phase will be new or have had a recent refit. Routine preventative maintenance will be undertaken to ensure engine efficiency is maintained.

- Vessels visiting the port will depart at partial power, achieving full power only after leaving the port area and avoiding or limiting the practice of blowing soot from tubes or flues on steam boilers while in port or during unfavourable atmospheric conditions. Where possible onshore power sources will be used for vessels when in port to reduce shipboard power use during loading / unloading activities and vessels will shut down engines when docked.

- Two deep water buoys will be installed in the Jubilee Field during the production phase so that vessels can moor up and cut their main engines when not required for field operations.

- IFC General EHS guidelines for small combustion facilities emissions will be followed for the management of small combustion sources, including exhaust emissions using liquid fuels and gas. The guidelines provide limits for PM, SOx and NOx. Low-sulphur diesel fuel (less than 0.1% sulphur) will be used where possible.

- Methods for controlling and reducing leaks and fugitive emissions will be implemented in the design, operation and maintenance of the offshore facilities. Relief valves on process vessels and pipework will be subject to inspection and maintenance/replacement to reduce leakage. Process gas detection systems will be installed to detect releases for both safety and fault detection reasons.

- Routine flaring will be avoided and non routine flaring will be kept to minimum to maintain safe conditions or during short-duration activities such as start-up, re-start and maintenance activities.

- Routine inspection and maintenance of vehicles, engines, generators, and other equipment will be carried out to maximise equipment fuel efficiency and minimise excess air emissions.

- A Vapour Recovery Unit (VRU) will be installed to collect the vapours from the gas treatment system's TEG dehydration reboiler unit to mitigate the venting of aromatic hydrocarbon compounds that can be released by these units.

- An inert gas system will be used to maintain a slight positive pressure in the storage tanks to reduce emissions of VOCs.

Residual Impacts

The emission inventory for the project has been compiled using worst case assumptions and provide estimated annual emissions of NO_x of approximately 2,686 tonnes and of SO_2 of approximately 1,887 tonnes. In comparison with the known sources in the region, ie biomass burning, wet soils and lightning, the additional emissions from the project are not significant. Overall the impact to local air quality from emissions of atmospheric pollutants is of *Minor* significance at most considering the nature and extent of the emissions and the absence of local receptors in the offshore project area.

5.4.4 *Greenhouse Gas Emissions*

GHG Emission Volumes

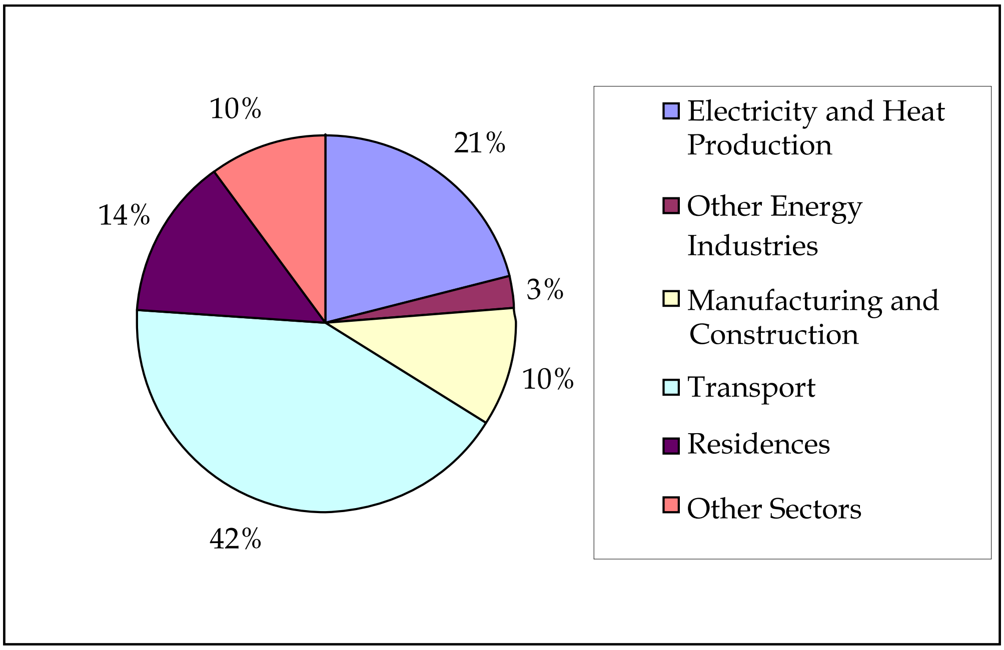
The standards for reporting GHG emissions and country targets are managed by the United Nations Framework Convention on Climate Change (UNFCCC) which was ratified by Ghana in 1995. Ghana prepared an Initial National Communication(1) in 2000 which provides official estimates of total greenhouses gas emissions from Ghana. Ghana GHG emission estimates reported by the World Resource Institute (WRI)(2) in 2003 provides annual CO_2 emission estimates of 4.4 million tonnes in 1998 which is an increase of 23% since the previously reported data in 1990. This is considerably less than the 1998 estimate for Nigeria of 78.45 million tonnes and the 1998 estimate for Sub-Saharan Africa of approximately 515 million tonnes.

(1) Ghana Ministry of Environment Science and Technology, 2001. UNFCCC First national communication. USEPA, Accra
(2) WRI was launched June 3, 1982 as a centre for policy research and analysis addressed to global resource and environmental issues.

The breakdown of emissions for 1999 (WRI 2003) indicates that the main sectors producing CO_2 were transport, electricity and heat production, and residential. The energy industry[(1)] contributes a relatively small source of emissions (3%) (see *Figure 5.5*).

It is likely that the overall GHG emissions from Ghana will have risen considerably since 1998. If a similar rate of increase has taken place as was experienced between 1990 and 1998, expected emissions would now be approximately 5.4 million tonnes.

Figure 5.5 ***CO_2 Emissions by Sector, Ghana, 1999***



Source: WRI (http://earthtrends.wri.org/pdf_library/country_profiles/cli_cou_288.pdf)

Sources of Project GHG Emissions

The GHGs of particular relevance to the Phase 1 Jubilee project are CO_2 and CH_4. The principal sources of GHGs from the project will include the following.

- Main power generation systems on the FPSO which are used to generate electricity for gas compression and water injection including gas turbine generators and the deck boiler.

- Other less significant combustion sources such as back up generators; shuttle tanker engines; MODU power generation during well completions; and installation/construction vessels and supply/support vessels.

(1) WRI definition: The sum of emissions from combustion of all fossil fuel types used by energy industries. This includes fuel combusted in petroleum refineries, for the manufacture of solid fuels, coal mining, oil and gas exploration and other energy-producing industries.

- No continuous flaring of hydrocarbon gases during normal operations is planned. During normal operations there will only be a pilot light so that the flare will be available in the event of an emergency shutdown. During commissioning and due to upset, maintenance and emergency condition there will be flaring of gas for safety reasons.

- Purging oxygen from the high and low pressure flaring for safety purposes.

Emissions of other gases with GHG potential eg halocarbons will not be released in significant amounts as the FPSO conversion will not use halocarbons, with the possible exception of air conditioning and other domestic appliances.

Predicted Project Emissions

GHG emissions will be highest during the 14 month period required for the main well completion phase as well as the installation and commissioning phase when there will be MODU and construction related vessels operating. During commissioning there will be flaring activity when the FPSO produces first oil and as the plant and process stabilises. Thereafter flaring will be intermittent, for example, occurring when the FPSO compression system is unavailable or during start-ups and operational upsets. Flaring equipment will have pilot burners at the flare tip, capable of igniting the flare gas and sustaining stable combustion.

Releases of GHG to atmosphere from the Phase 1 Jubilee project once operational will predominantly constitute emissions from the FPSO (power generation and non-routine flaring). Routine emissions from support vessel engines will continue as well as occasional emissions during well interventions and workover operations from MODUs.

The concept of a Global Warming Potential (GWP) is used to enable different GHG emissions to be compared to each other and expressed in terms of CO_2-e (carbon dioxide equivalents). Emissions of GHGs are thus given by using the GWP as weighting factors for the emissions of CO_2 (with a weighting factor of 1) and CH_4 (with a weighting factor of 23).

- CO_2-e = 1 (CO_2) + 23 (CH_4).

The estimated GHG emissions from the Phase1 Jubilee project are summarised in *Table 5.9*.

Table 5.9 Estimated Greenhouse Gas Emissions for the Jubilee Phase 1 Development

Activity	Duration	Estimated Emissions (tonnes)		
		CO_2	CH_4	CO_2 equivalent
Completion (Erik Raude) including well cleanup flaring	400 d	425,263	83.75	427,189
Well flowback flaring (17 wells)	24-48 hrs	3,304	0.9	3,325
Flowline/injector/umbilical installation	190 d	263,970	2.3	264,022
FPSO installation	120 d	74,669	0.7	74,685
Commissioning (flare)	180 d	670,374*	988.6	693,111
Abnormal Event flaring	Monthly	92,821*	136.9	95,969
Production	Annual	148,252	17	148,648

* Includes amount of CO_2 that will be contained in the pre-combustion gas that will also be released unchanged into the atmosphere

It should be noted that over 75% of the emissions during the production phase are from the support vessels and the export tankers. During operations the CO_2 emissions from the FPSO will be 31,780 tonnes per year. CO_2 emissions from individual installations for the United Kingdom offshore oil and gas industry are similar. In 2006 emissions were 16,000,000 tonnes for 444 installations which averages approximately 36,000 tonnes per installation (OSPAR 2008). Emissions from the Jubilee field are considered to be of *Minor* significance.

Mitigation Measures

The mitigation measures aimed at reducing GHG emissions to as low as reasonably practicable are generally built into the design of the FPSO and focus predominantly on:

- efficiency of power generation;
- optimisation of overall energy efficiency;
- reduction in flaring; and
- reduction in venting.

To ensure the maximum energy efficiency on the FPSO and reduce the emissions associated with combustion (ie fuel use and flaring), the following measures will be implemented.

- To ensure efficient energy use, the FPSO will be designed with centralised electrical power generation, provided by high efficiency gas turbines, sized and configured to life-of-field power demand.

- The FPSO will be designed to minimise process electricity demand through optimal sizing, configuration and selection of energy efficient equipment, in particular, compressors and pumps.

- Flaring during the commissioning stage of gas handling and in particular gas compression systems will be minimised through pre-commissioning testing of the FPSO process systems in the supply factories and the Singapore dockyard prior to the FPSO sailing to Ghana.

- The project design avoids the need for continuous flaring and significantly reduces direct venting (including from cargo tanks). Tullow will establish a targeted maximum abnormal flaring rate of only 2.5% of the monthly average total gas production. The operations of the FPSO are incentivised for low flare volumes through contractual mechanisms.

In compliance with IFC (2007a) EHS guidance and to monitor the effectiveness of measures to reduce the levels of emissions, Tullow will quantify annually total GHG emission from production and flaring activities as an aggregate in accordance with internationally recognised methodologies and reporting procedures (WRI Greenhouse Gas Protocol's Corporate Accounting and Reporting Standards and Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories 2006).

Residual GHG Emissions

Despite the relatively high volume of GHG emissions from the Phase 1 Jubilee project in relation to national emissions, the impact of GHG emissions is assessed to be of *Minor* significance. However, measures will be implemented to manage GHG emissions to keep these to the minimum required for the safe operations of the project.

5.5 *WASTE MANAGEMENT*

5.5.1 *Scope of Assessment*

The project will generate both non-hazardous wastes (such as paper, kitchen waste and scrap metal) and hazardous wastes (such as used oils and small volumes of process chemicals). These wastes will need to be disposed in a manner protective of the environment. This section discusses the potential environmental and social impacts of waste associated with the project throughout the following three stages of the waste management process.

- Storage and segregation eg on the FPSO, MODUs, supply vessels or onshore supply base.

- Transport of waste from offshore activities to onshore base and onshore base to final disposal location.

- The management and disposal of wastes onshore.

For each of these three stages the potential impacts, mitigation measures and residual impacts are discussed. Note that the effluents and discharges that will come from the project, which may include treated wastes, are discussed in *Section 5.3.*

5.5.2 *Storage and Segregation*

Potential Impacts

The main sources of potential environmental impact resulting from storage, segregation and containment of wastes include the following.

- Inappropriate storage and containment of wastes on offshore facilities or vessels that may result in accidental discharge or spillage of wastes to the marine environment leading to an adverse impact on localised water quality, for example:
  - from the spillage of liquid hazardous wastes such as oil and chemicals, and impacts on the offshore marine biodiversity; and
  - from the release of plastics or other solid wastes that can be ingested by seabirds, turtles or other marine species, or litter coastal areas.

- Inappropriate storage and containment of wastes at the onshore supply base may result in accidental discharge and/or spillage of liquid wastes to soils and water resources. This could result in contamination of local soils, surface water, groundwater, harbour or coastal waters and communities may be adversely impacted if contaminated water or soil resources are then used for drinking, washing, fishing or growing crops.

- Inappropriate and insecure storage of wastes having detrimental impacts on local communities such as degrading the visual appearance of the area, release of odours, and exposure of local communities to health and safety risks.

- Proper segregation of waste streams facilitates recycling and reuse (which may allow for value recovery from the waste stream) leading to positive impacts on waste handling practices and facilities in the area.

Storage of waste arisings from the project has the potential to have impacts of *Minor* significance given the limited in-country storage facilities.

Mitigation Measures

Mitigation of potential impacts related to storage and segregation of waste are by operational controls. The key procedures for controlling wastes are contained in the project Waste Management Plan (WMP). The WMP will require that facilities operated or controlled by Tullow (eg contractors based within Tullow's shore base facilities) will adopt specific procedures for the management of wastes in accordance with legal requirements and in a manner that minimises the potential for environmental damage as far as reasonably practicable.

The WMP will cover offshore and onshore project facilities. The offshore facilities include the FPSO, marine support vessels, and the MODU during well completions and workovers. The onshore facilities include the onshore supply base, offices and the helicopter facilities within the Air Force base.

The aim of the WMP is to ensure that wastes generated by the project are subject to appropriate:

- identification and classification; and
- collection, storage and segregation onboard the FPSO and associated vessels and facilities.

To mitigate the potential impacts on the environment and human heath, Tullow will also construct a secure waste reception and temporary storage facility at the Takoradi shore base. This facility will be constructed on concrete hard standing with fully contained surface water drainage to prevent surface and groundwater contamination. It will also be located within a secure fenced area topped with razor wire for security.

Wastes will be stored in designated areas using appropriate containers for the type of waste until acceptable treatment solutions are available. Tullow will continue to work with local companies in developing waste treatment options.

Residual Impacts

Assuming that the mitigation measures are implemented as defined in the appropriate plans and procedures (specifically the WMP), the risk of significant accidental discharge or spillage of waste to the receiving environment will have been minimised through good waste management practices including safe and secure segregation, storage and containment. The residual impacts from waste storage and segregation are anticipated to be of *Minor* significance. A monitoring plan will be in place to verify this.

5.5.3 Transport of Waste

Potential Impacts

Wastes from project facilities will need to be transported to waste disposal areas. The main sources of potential environmental impact that could result from the transport of wastes include the following.

- Inappropriate handling and containment of wastes during transport on supply vessels (ie taking waste from the FPSO onshore) may result in accidental discharge or spillage of wastes to the marine environment.

- Inappropriate management and control of vehicles and vessels transporting wastes up to and including the approved disposal site may result in potential impacts on both the environment (eg soils and groundwater) and local communities, for example due to littering, spillage of potentially hazardous wastes during transport, and poor security of waste.

Transport of wastes has the potential for impacts of *Minor* significance given the types and quantities of wastes produced.

Mitigation Measures

Mitigation of potential impacts of waste transport will be by the way of operational controls. These are contained in the project WMP. Transport of waste will follow these basic requirements.

- Transported in a safe manner, in accordance with the associated Material Safety Data Sheet information for spent chemicals and other industry packaging and transport advice.

- Use secure containers for liquid wastes.

- Use appropriate waste container for the type of waste and do not overfill.

- Wastes will be transported using properly maintained, legally compliant and suitable vehicles or vessels, with appropriate documentation (including Waste Transfer Notes) and driven/crewed by appropriately trained operators.

- Only vehicles or vessels, which meet the appropriate Tullow safety standards, will be used for the transport of wastes.

Residual Impacts

The risk of any significant accidental discharge or spillage of waste to the receiving environment will have been minimised through good waste transport and tracking practices and use of approved waste transporting contractors. The residual impacts from waste transport are anticipated to be *not significant.*

5.5.4 Waste Management and Waste Disposal

Potential Impacts

Project generated waste will need to be disposed in a manner that avoids significant environmental impacts. The main sources of potential environmental impact that could result from the disposal of wastes from project operations include the following.

- Disposal of wastes at dump sites (non-engineered landfills) that are not designed and operated to the appropriate standards and potentially contaminating adjacent soils, groundwater and surface waters, and/or releasing vapour emissions with the potential to adversely affect air quality or cause a health risk to local communities.
- Sites with inadequate security potentially impacting on local communities due to littering and health and safety risks associated with uncontrolled public access to wastes.

- Open burning of wastes can impact on local air quality and increase health risks.
- Illegal dumping ('fly-tipping') of hazardous wastes (solid or liquid) can contaminate soils, and surface or groundwater, potentially impacting on human health or ecosystems.
- Incineration of wastes has the potential for adverse impact on air quality and secondary impacts on the health of local communities if combustion emissions are not treated to appropriate standards.

Waste arisings from the project have the potential to have impacts of *Moderate* significance given the limited in-country disposal facilities.

Mitigation Measures

Mitigations for potential impacts associated with waste disposal include:
- selection of a suitable disposal facility(s)/method, such as managed landfill, incineration or liquid waste treatment;
- measures to ensure proper continuous operation and monitoring of the disposal facility; and
- operational controls to manage disposal of project waste streams.

Table 5.10 identifies the interim waste management practices that will be used in the early stages of the project, and the options that Tullow will work towards implementing over the first few years of the project.

In the short-term, the project will rely on disposing of its general domestic waste at the existing Sofokrom landfill site located on the outskirts of Takoradi. Tullow is working with existing local waste management contractors to minimise the quantities sent to Sofokrom landfill and to develop waste disposal solutions that will minimise the project's reliance on this facility. Tullow will also engage with waste management contractors from outside of the region (ie Tema and Accra) to review potential options for improving services in the region and introduce additional management options (eg incinerator).

No hazardous wastes will be sent to the Sofokrom landfill. Hazardous wastes will either be sent to approved contractors for recycling/treatment or stored by Tullow in a dedicated waste storage area (see *Section 5.5.2*) until such time as a suitable management option is identified (*Table 5.10*).

Waste oils such as lubricating oils from machinery maintenance and servicing will normally be disposed of by mixing with the production crude stream. If this is not possible then it will be transported ashore in secure containers for disposal to the waste oil process as per the Waste Management Plan.

Tullow have adopted the principles of the 'waste hierarchy' to ensure that waste generation is minimised and reuse and recycling is maximised. Tullow will regularly review the types of waste produced to assess ways to reduce the quantity of waste generated.

This may be achieved through:

- substituting a product containing hazardous materials with one that contains no or less hazardous materials;
- using products with a longer life;
- using products/materials that are more suited to reuse/recycling; and
- management of warehoused products to reduce need for disposing of materials once they have exceeded their shelf life.

Tullow is working with local waste management contractors to identify metal, oil and lead-acid battery recycling facilities in Ghana. Tullow will continue to work with contractors to identify opportunities for further recycling of wastes such as paper and plastic to reduce quantities that are sent to landfill and will regularly review the waste management options available.

Tullow has assessed the available waste management options in Ghana with the aim of identifying the suitability and adequacy of these facilities to receive its project wastes. The results of these visits to existing facilities and a discussion of the potential waste management options are presented in *Annex F*. A few companies are investigating establishing integrated waste management facilities to deal with MARPOL Annex I oily wastes, inorganic wastes, chemical treatment, hazardous waste incineration and physical treatment systems including washing, shredding and container crushing. Tullow is working with these companies to support the establishment of these facilities.

The facilities and activities of waste disposal contractors currently contracted to receive Tullow waste have been audited internally and will be audited periodically throughout the life of the project. The waste disposal and treatment facilities potentially accepting wastes and recycling materials will be kept under review to identify appropriate waste management contractors, and will be reflected in updates of the WMP.

Tullow will audit waste contractors prior to agreeing to any formal contracts and Tullow will ensure that facilities that receive wastes from the project operate at appropriate standards (in accordance with IFC guidelines[(1)]). Tullow will work with selected waste disposal contractors to help them to meet the project's requirements. Given the stage of development of the waste disposal capacity to suitable standards currently in Ghana (*Annex F*), Tullow will work with service providers in Ghana to achieve the long-term management options identified in *Table 5.10* as soon as practicable.
The WMP will be managed through the project Environment, Health and Safety Management System (EHSMS) (see *Chapter 9)*.

(1) International Finance Corporation (2007) *Environmental, Health and Safety Guidelines for Waste Management Facilities*, December 10, 2007

Residual Impacts

The project will generate both hazardous and non-hazardous wastes and, despite the mitigation measures put in place, given the current limited range and standard of available waste treatment and disposal facilities in Ghana the residual impacts associated with the onshore disposal of waste from the project are of *Moderate* significance. However, assuming wastes generated by the project are disposed of as planned in the medium to longer term at waste treatment facilities that are designed and operated according to good practice standards then the residual impacts should be limited to ALARP levels. Tullow will work with contractors to facilitate the upgrading of facilities through time to meet these goals. Hazardous wastes that cannot be disposed of locally until facilities are available will be stored onshore at a safe holding site at the Takoradi shore base or exported (in accordance with the relevant conventions) if required.

Table 5.10 Typical Waste Segregation and Disposal Methods

Category	Type	State	Source/Description	Interim Management	Long-term Management Options
Non-hazardous	Glass	Solid	Bottles and jars etc	• Landfill • Return to supplier (e.g. drink bottles)	• Crush (to reduce volume) and send to landfill • Return to supplier (e.g. drink bottles) • Send to glass recycling facility
	Grease	Sludge	Used cooking oil and galley grease from oil separators	• Add microbes /enzymes to grease traps (source reduction) • Landfill	• Incineration • Waste to energy • Bio-diesel • Bioremediation (compost or land farm)
	Metals	Solid	Ferrous and non-ferrous, including drinks cans (steel and aluminium)	• Reclaim/re-use • Recycle	• Reclaim/re-use • Recycle
	Paper and card	Solid	Papers, magazines, office paper etc.	• Landfill	• Incinerate/waste to energy • Recycling • Landfill
	Plastic	Solid	Bottles and mixed plastics	• Landfill	• Incinerate/waste to energy • Recycling • Landfill
	Residual mixed waste	Solid	Domestic types, food from galley, packaging, bin waste etc	• Landfill	• Incinerate • Landfill • Recycle after materials separation
	Wood	Solid	Pallets, crates, furniture	• Recycle, re-use • Landfill	• Incinerate/waste to energy • Recycle, re-use • Landfill

Category	Type	State	Source/Description	Interim Management	Long-term Management Options
Hazardous	Batteries	Solid	Lead acid, lithium ion, etc	• Storage	• Recycle (eg Pagrik Ghana)
	Chemicals, various	Liquid	Solvents or contaminated chemicals	• Return to supplier • Re-use Inventory management to prevent expiry	• Incinerate (liquid incinerator)
	Medical/clinical	Solid	Swabs, dressings, old medicine etc	• Medical grade incinerator	• Medical grade incinerator
	Oil contaminated materials	Solid	Filters, oily rags	• Storage	• Incinerate/waste to energy
	Oil, used	Liquid	If cannot be mixed with crude export stream	• Treated in oily waste water treatment plant. • Sent to production stream on FPSO	• Treated in oily waste water treatment plant. • Sent to production oil on FPSO
	Tank bottom sludge	Sludge	Tank clean out and un-pumpable sludges	• Treated in oily waste water treatment plant.	• Treated in oily waste water treatment plant.
	Various types	Solid	Fluorescent tubes & bulbs, Glycol filters, paints, solvents, cleaners	• Storage of liquid wastes • Metals recycled	• Incinerate/waste to energy • Metals recycled
	Water, slops	Liquid	Oil contaminated etc	• Treated in oily waste water treatment plant.	• Treated in oily waste water treatment plant.

5.6 *OIL SPILL IMPACT ASSESSMENT*

5.6.1 *Introduction*

The risk of an oil spill (including crude oil and fuel oil) into the marine environment is inherent in all offshore oil developments. The likelihood (probability) of significant oil spills, ie those that can reach the coastline or other sensitive areas from FPSO operations is very low with most oil spills associated with offshore installations being very small and having only limited environmental effects.

The industry approach to dealing with potential oil spills is to develop technology and operational procedures to reduce the likelihood of oil spills occurring whist at the same time planning appropriate responses to oil spills to reduce the severity of impacts in the event of a spill. The response procedures form part of the Oil Spill Contingency Plan (OSCP) which is one part of Tullow's overall Emergency Response Plan for the project (see *Chapter 9*).

This assessment addresses potential oil spills and leaks from the subsea installations, FPSO and the vessels operating close to the FPSO. It also addresses spills from shuttle tankers during offloading operations. Risks of spills from tankers once they are no longer under control of the FPSO Tanker Cargo Transfer Procedures are outside the scope of this EIA. Spills at the shorebase are addressed in the OSCP.

5.6.2 *Assessment Methodology*

The assessment of the potential impacts of an oil spill to the marine and coastal environment requires consideration of the likelihood of various types of spill occurring and the consequences of these spills.

As part of the Safety Case for the project a Quantified Risk Assessment (QRA) was undertaken that examined the frequency of accident events that could result in oil spills of various types and sizes from the project activities. A series of oil spill scenarios were then defined for subsequent modelling.

The oil spill model was developed using meteorological (wind and temperature) and hydrographic data (waves and currents). For the spill scenarios selected, model input data included:

- information on the characteristics of the crude oil and fuel oil;
- varying volumes of oil that could be spilled; and
- weather conditions that could influence the behaviour of oil in the marine environment.

The model was used to give an indication of the likely trajectories and fate of oil spills were they to occur and also to give an indication of the likelihood of a particular area of sea or coast being affected in the event of a spill.

The risk analysis of the various incident scenarios modelled by International Risk Consultants (IRC) is provided in *Annex C.* The results of the oil spill modelling work undertaken by Applied Science Associates (ASA) are summarised in this section and the full report is included in *Annex D*.

Impact Significance

For impacts associated with accidental events it is necessary to consider the risk of an event occurring in assessing impact significance, since if the event does not occur there will be no impact. Risk is defined here as the combination of the likelihood of an event occurring and the consequences of that event. Assessing the significance of residual impacts from accidental events such as oil spills requires consideration of:

- the likelihood that an oil spill event might occur;
- the probability of an oil spill affecting a particular area;
- the sensitivity of the marine / coastal resources that may be affected; and
- the oil spill prevention and response measures that will be implemented.

In this assessment the potential impacts on sensitive resources and receptors are described, followed by an analysis of the likelihood of spills occurring that might affect these resources and receptors.

5.6.3 *Oil Spill Risk Assessment*

Introduction

The QRA was used to provide an assessment of probabilities of potential accident events that could result in an oil spill. A series of accident event scenarios were derived from an environmental hazard identification process (known as HAZID[(1)]) that was undertaken by the project engineering design team and was based on experience for similar projects from around the world. The identified potential oil spill events and their associated likelihoods were categorised by potential oil release volumes. From this information a series of oil spill scenarios combining potential likelihood of spill events and spill sizes were derived for the oil spill trajectory modelling.

Risk Assessment Methodology

The risk assessment considered a number of oil spill scenarios derived from the HAZID study; these are summarised below. Each of these activities has the potential for releasing fuel or crude oil. In the majority of cases it will be in relatively small quantities and although the potential for larger releases exists, these occur far less frequently.

- *Turret Leak.* This scenario considers a range of release sizes from the production header (manifold) located at the FPSO turret. In addition, the

(1) The Jubilee Field Project Environmental HAZID was conducted on 12-May 2009.

scenario considers the potential to release the additional inventory of one flexible riser due to a failure of isolation at the riser boarding valve but with the isolation valve at the riser base closing.

- *Riser Leak.* This scenario considers a range of release sizes from the flexible riser between the isolation valve at the riser base and the riser boarding valve. In addition, the scenario considers the potential to release the inventory of a production flowline due to a failure of isolation at the riser base.

- *Wellhead / Manifold Leak / Flowline Leak.* This scenario considers a range of release sizes from the wellhead, manifold and production flowlines between the wellhead and the isolation valve at the riser base. In addition, the scenario considers the potential to release the inventory of a flexible riser due to a failure of isolation at the riser base. However, isolation failure at the wellhead is considered a very low frequency event with three isolation valves at the wellhead including the surface controlled sub-sea safety valve (SCSSV).

- *Ship Collisions.* This scenario considers ship collisions from merchant vessels (cargo carriers, tanker carriers and Very Large Cargo Carriers (VLCC)), support vessels, fishing vessels and a collision between the FPSO and the export tanker during offloading operations. However, while merchant vessels and support vessels pose a credible risk to the FPSO, local fishing vessels and the export tanker do not; as fishing vessels will be relatively small and the export tanker will always approach the FPSO from the downwind / down current position, making it impossible for environmental conditions to push the export tanker towards the FPSO. A ship collision study undertaken for the Safety Case showed that collisions with large vessels will be very rare events and that that there was no significant advantage of a double hull over a single hull.

- *Transfer Hose Release.* This scenario considers a release from the transfer between the FPSO and the export tanker hose during offloading operations. During cargo offloading, crude oil is transferred from the FPSO to the export tanker through a floating high integrity hose. The sizes of oil spills are based on the quantity of oil in the transfer hose, the transfer rate, the safeguards in place and the likely failure modes that would lead to a release.

- *Bunkering Release.* This scenario considers a release of marine diesel during transfer operations between the Offshore Support Vessel (OSV) and the FPSO. The release may be a small leak due to minor hose damage or a large release due to rupture of the transfer hose.

- *Blowouts.* This scenario considers a reservoir blowout at the wellhead. Blowouts may occur during drilling, completion, production or workovers and last from only a few minutes to several days.

- *FPSO Hull Damage.* This scenario considers releases due to damage to the hull of the FPSO, excluding ship collision. Examining historical data of FPSO releases, the causes of these type of releases from FPSOs have been from foundering and ballast tank explosions.

- *Cargo Tank Explosion*: This scenario considers releases due to an explosion in one of the cargo tanks. Examining historical data of FPSO releases, the causes of these type of releases from FPSOs have been from foundering and ballast tank explosions.

The assumptions and methodology for calculating the size and frequency of release is different for each scenario and is presented in full in *Annex C.*

Results

Oil spills can be categorised in terms of their frequency of occurrence and their magnitude or severity (ie size of spill). These two factors are typically combined to give a measure of risk.

The likelihood or frequency categories are typically presented as the expected number of spill occurrences over a period of years; for example 1E-02 equates to a likely spill every 100 years of operation and 2E-06 equates to two spills every million years. The severity of an oil spill may be categorised according to the quantity spilled. For the purpose of this assessment, the severity has been expressed only in terms of the oil released in barrels of oil to the sea rather than the impact of such spills on sensitive receptors.

Given the spill scenarios examined in the risk assessment *Table 5.11* presents the range of spill sizes, the weighted average of the spill sizes and the predicted frequency of these spills sizes. These have been derived from studies in the Gulf of Mexico and the North Sea (see *Annex C*).

Table 5.11 Weighted Average of Release Sizes and Frequencies

Spill Size Ranges (bbls)	Weighted Avg Volume (bbls)	Weighted Avg Frequency
>1,000,000	1,527,249	2.32E-06
100,000 - 1,000,000	451,511	2.63E-05
10,000 - 100,000	34,654	1.19E-04
1,000 - 10,000	1,519	9.68E-04
100 - 1,000	734	1.01E-02
10 - 100	49	1.42E-02

Note: E-1 equates to 10 years / E-2 equates to 100 years etc. Therefore to use 10E-2 as an example – this equates to a likelihood of 10 spills every 100 years i.e. there is possible likelihood of 1 spill every 10 years.

Figure 5.6 illustrates the results on a graph and clearly shows that relatively small spills (ie approximately 10 bbls) are the most likely to occur (approximately once every 10 years) whereas progressively larger spills become increasingly unlikely to occur (ie a spill between 100 and 1,000 bbl is only predicted to occur every 100 years).

Figure 5.6 *Release Frequencies by Size*

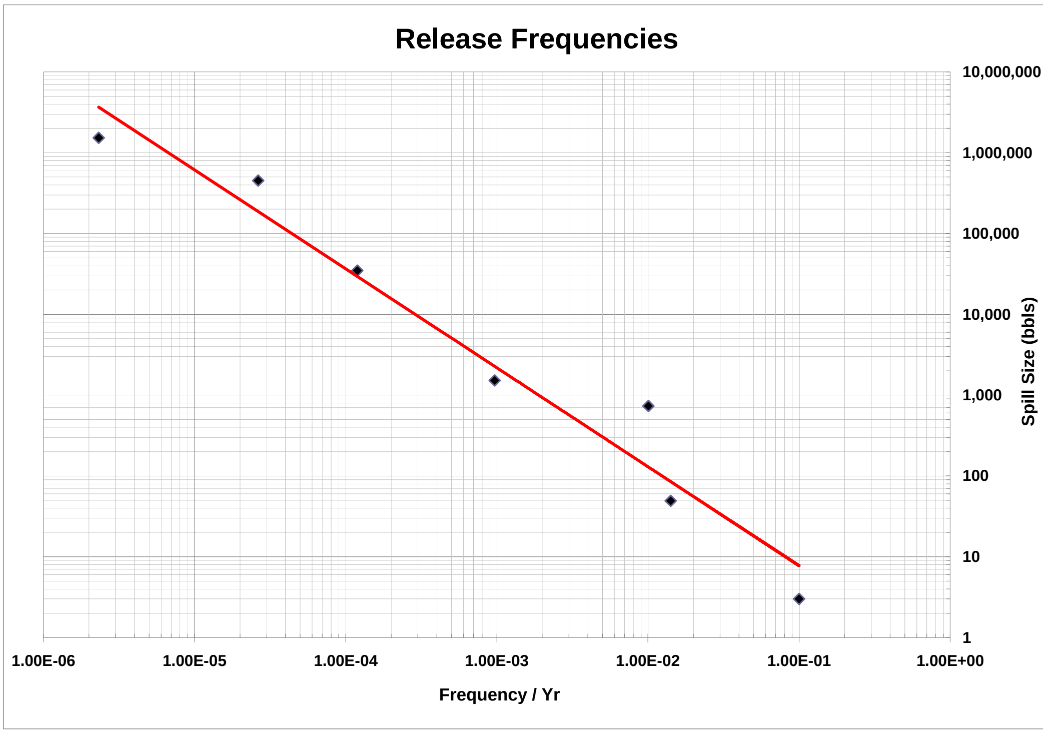
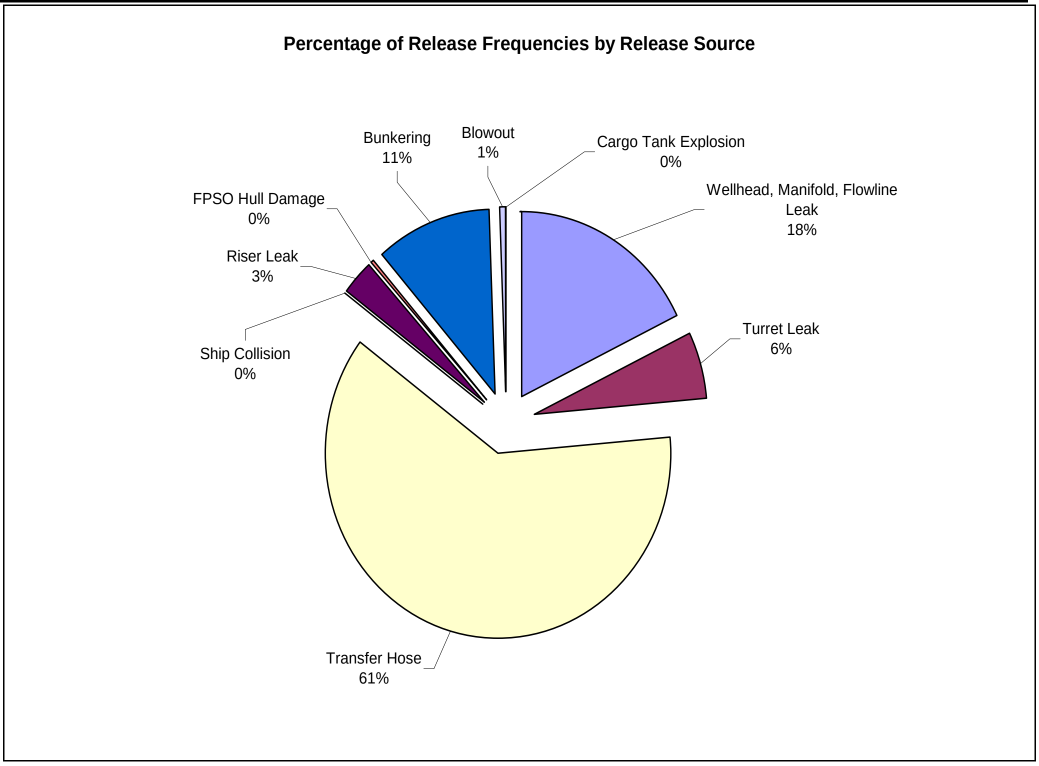


Table 5.12 presents the frequency of spills that can be expected from each of the scenarios examined in the study. This is also illustrated in *Figure 5.7* below which shows that of the spill scenarios examined the most likely source of a spill is from the transfer hose during oil unloading from the FPSO. This is predicted to occur approximately twice every 10 years (2.00E-01). However, this would most likely be a small spill of less than 10 bbls.

Table 5.12 *Release Frequencies by Spill Scenario*

Release Source	**Frequency**
Wellhead, Manifold, Flowline Leak	5.81E-02
Turret Leak	1.86E-02
Transfer Hose	2.00E-01
Ship Collision	1.02E-04
Riser Leak	1.06E-02
FPSO Hull Damage	1.33E-04
Bunkering	3.54E-02
Blowout	1.90E-03
Cargo Tank Explosion	8.30E-05

Figure 5.7 Release Frequencies by Spill Scenario



The major spill events, such as from a ship collision, FPSO hull damage, blowouts and cargo tank explosions are so unlikely to happen they are not registered on *Figure 5.5.* For example spills from a ship collision would be expected once every 10,000 years (ie 1.02E-04).

Based on the conclusions of the oil spill risk assessment, a representative range of credible (albeit in most cases highly unlikely) oil spill scenarios have been identified to inform the oil spill modelling studies. These range (as shown in *Table 5.13)* from relatively small spill sizes of 10 tonnes (approximately 73 bbls) up to very large spills of 28,000 tones (approximately 212,000 bbls). Spill sizes greater than this have been excluded from the modelling as they were identified as being so unlikely to occur they are not considered credible spill scenarios.

5.6.4 Oil Spill Modelling

Introduction

Oil spill modelling was used to predict the consequences of the various oil spill scenarios in the event that a spill was to occur. This required information on the nature of the oil spilled, the location and duration of the spill, the behaviour of the oil in the marine environment, and its transport from the spill site to other marine and coastal areas. The information used in the model allows the likely fate of various oil spills in the marine environment to be assessed and illustrated. This aids the assessment of potential environmental impacts of an oil spill on sensitive receptors (eg coastal habitats).

Table 5.13 Surface Spill Modelling Scenarios

Scenario	Location	Oil Type	Release Duration	Spill Amount (Tonnes)
1	Well M1	Crude	Instantaneous	10
2	FPSO	Marine Gasoil	Instantaneous	10
3	Well M1	Crude	Instantaneous	100
3a	FPSO	Crude	Instantaneous	100
4	FPSO	Marine Gasoil	Instantaneous	100
5	Well M1	Crude	48 hrs	1000
5a	FPSO	Crude	2 hrs	1000
6	Well M1	Crude	48 hrs	5000
7	Well M1	Crude	168 hrs	20000
8	Well M1	Crude	48 hrs	28000
8a	FPSO	Crude	2 hrs	28000

The computer model used was ASA's OILMAP, a software package developed specifically for this purpose. Oil spill models are based on a set of hypothetical values and therefore represent the types of outcome that could arise from a theoretical spill. They cannot, therefore, definitively predict the actual outcome of any given oil spill. The OILMAP model can be used in deterministic mode (predicts the fate of spilled oil over time) and stochastic mode (predicts the probability of various oil spill trajectories). The key assumptions used in the model are outlined in *Box 5.2*.

Oil Weathering Information

The probability of oil being present on the sea surface or reaching a particular location is a function of its persistence (evaporation / dispersibility versus emulsification) in the sea plus the degree to which it is transported by winds and currents. The weathering processes, ie the changes in the chemical and physical properties of a crude oil when it is spilled onto the sea surface, are illustrated in *Figure 5.8.*

Evaporation is the primary cause of rapid volume reduction of spilled oil. The loss of the 'lighter' fractions of oil by evaporation causes an increase in the viscosity and density of the oil residue that remains. Evaporative loss can also cause more subtle changes in the oil properties such as the precipitation of wax and asphaltenes that will alter the flow properties of the residue and help to stabilise water-in-oil emulsions. Evaporation and weathering will be more rapid in warmer marine areas such as the Jubilee field compared to more temperate areas of the world. *Box 5.3* summarises the main processes that cause an oil spill to weather.

Box 5.2 *Assumptions used in the Modelling*

Oil type

The oil types used in the model were based on the crude oil from the exploratory drilling (test drilling reported a light oil) and on a typical marine gasoil (marine diesel). Their evaporation characteristics were assumed based on known behaviour of oils with similar density and viscosity. As different oil types behave in different ways in the marine environment, slight variations in rates of evaporation and degradation may occur between the modelled oils and actual oil spilled.

Spill volumes

The modelling scenarios were run using worst case volumes with the assumption that no oil spill response measures have been taken (eg no skimmers or booms deployed to contain the oil to prevent is spreading, or use of dispersants to aid evaporation of oil) and that no actions have been taken at the point of spillage (eg pumping out of ruptured oil tanks).

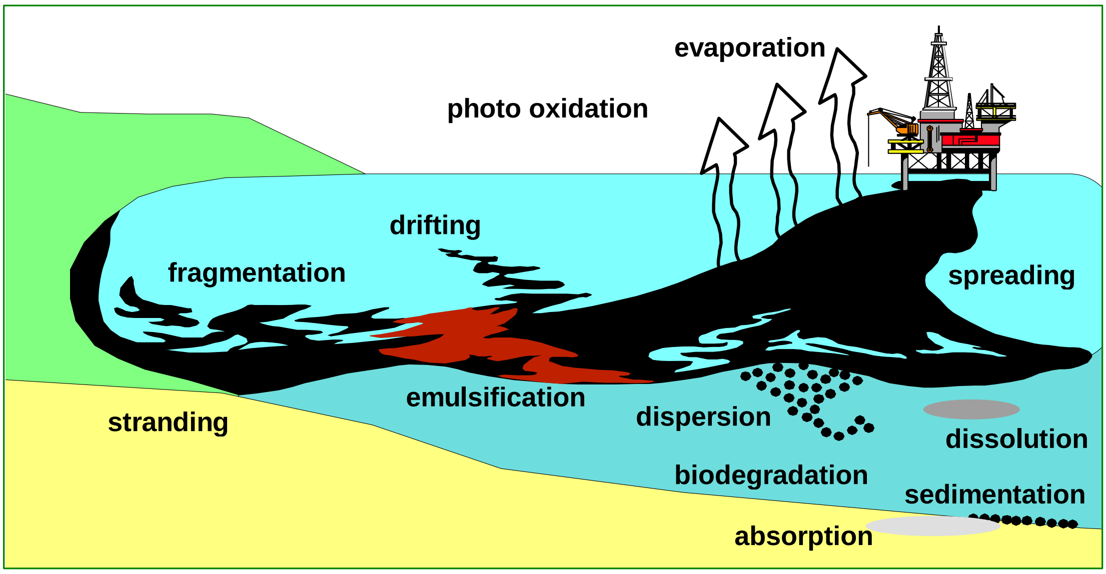
Weather and current conditions

The modelling study examined the fate of oil released during a typical 'season' which was considered to represent the worst-case scenario, ie the currents and wind conditions most likely to result in oil beaching. However, different wind and current conditions may prevail in the event of an actual spill which could result in the oil behaving differently.

Interpretation of modelling outputs

The deterministic model displays the model output for one representative weather scenario and different outputs will occur with different weather scenarios. Deterministic modelling also assumes that weather conditions remain constant over the duration of the simulation rather than changing over the period of the modelled scenario. For modelling purposes a worst case approach is taken with the weather conditions that lead to the shortest time for spilled oil to reach the coast.

Figure 5.8 *Weathering Processes for Oil at Sea*



Source: Tullow Oil: Ghana Oil Spill Contingency Plan (Dec. 2008)

Box 5.3 Summary of Main Weathering Processes of Oil at Sea

Spreading: As soon as oil is spilled, it starts to spread out over the sea surface, initially as a single slick. The speed at which this takes place depends to a great extent upon the viscosity of the oil. As part of the spreading of a slick it is not uncommon for drifting and fragmentation of the oil slick to occur.

Dispersion: Waves and turbulence at the sea surface can cause all or part of a slick to break up into fragments and droplets of varying sizes. These become mixed into the upper levels of the water column. Some of the smaller droplets will remain suspended in the sea water while the larger ones will tend to rise back to the surface, where they may either coalesce with other droplets to reform a slick or spread out to form a very thin film.

Emulsification: Emulsification of crude oils refers to the process whereby sea water droplets become suspended in the oil. This occurs by physical mixing promoted by turbulence at the sea surface. The emulsion thus formed is usually very viscous and more persistent than the original oil.

Dissolution: Water soluble compounds in an oil may dissolve into the surrounding water. This depends on the composition and state of the oil, and occurs most quickly when the oil is finely dispersed in the water column. Components that are most soluble in sea water are the light aromatic hydrocarbon compounds.

Photo Oxidation: Oils react chemically with oxygen either breaking down into soluble products or forming persistent compounds called tars. This process is promoted by sunlight and the extent to which it occurs depends on the type of oil and the form in which it is exposed to sunlight. However, this process is very slow and even in strong sunlight, thin films of oil break down at no more than 0.1% per day.

Stranding: A term used for when an oil slick reaches the coastline. Also referred to as *beaching*.

Sedimentation: Oil stranded on sandy shorelines often becomes mixed with sand and other sediments. If this mixture is subsequently washed off the beach back into the sea it may then sink. In addition, if the oil catches fire after it has been spilled, the residues that sometimes form can be sufficiently dense to sink.

Biodegredation: Sea water contains a range of micro-organisms that can partially or completely degrade oil to water soluble compounds and eventually to carbon dioxide and water. Many types of micro-organisms exist and each tends to degrade a particular group of compounds in crude oil. However, some compounds in oil are very resistant to attack and may not degrade.

Spill Scenarios Modelled

Following the HAZID process discussed in *Section 5.6.3* 11 representative oil spill scenarios covering two oil types (crude oil and marine gasoil) and six oil spill volumes were selected for modelling. Instantaneous releases assume all the oil is spilled at the same time. For the other release durations (48 hours and 168 hours) it is assumed that the volume of oil modelled is spilled at a constant rate over the spill period. A period of 14 days from release was simulated.

Model Simulations

Each of the eleven spill scenarios were modelled using OILMAP's deterministic and stochastic modes. These are described in more detail below.

- In the *stochastic* mode, estimates are made of the likelihood of particular trajectories of the oil spill. Stochastic modelling uses varied wind and surface current data to evaluate the probable distribution of oil in the event of a spill. The multiple trajectories are then used to produce contour maps showing the probability of surface and shoreline oiling. The results illustrate the probability of a spill reaching specific locations at sea and along the coast, as a consequence of variation in predominantly meteorological and oceanographic conditions.

- In the trajectory and fate mode the model predicts the transport and weathering of oil from instantaneous or continuous spills. In this *deterministic* mode, modelling is undertaken for an oil spill release under specific meteorological conditions (ie one particular wind direction and strength). Predictions then show the location and concentration of the surface oil versus time. The model estimates the change in the oil's areal coverage, thickness and viscosity over time. The model also predicts the amount of oil on the sea surface, in the water column, evaporated, and on the shore, over time (ie how the original volume of oil spilled behaves – how much evaporates, is dispersed, is beached etc). The fate processes in the model include spreading, evaporation, natural dispersion and emulsification.

Environmental Conditions

It is necessary to select appropriate environmental conditions (ie current and meteorological conditions) to use in the model as this has a major influence on the results of the oil spill modelling. Wind data were obtained for the Ghana offshore region from NOAA's NCEP[(1)] atmospheric model reanalysis, and WANE (West Africa (Met-Ocean) Normals and Extremes) predicted winds. Both datasets illustrate that the wind direction and speed is fairly consistent all year; winds are primarily from the south-west quadrant with maximum non-squall observed wind speed of 10 ms^{-1}. Since wind conditions remain very consistent year-round, only one season was considered for selecting the start times of individual model simulations.

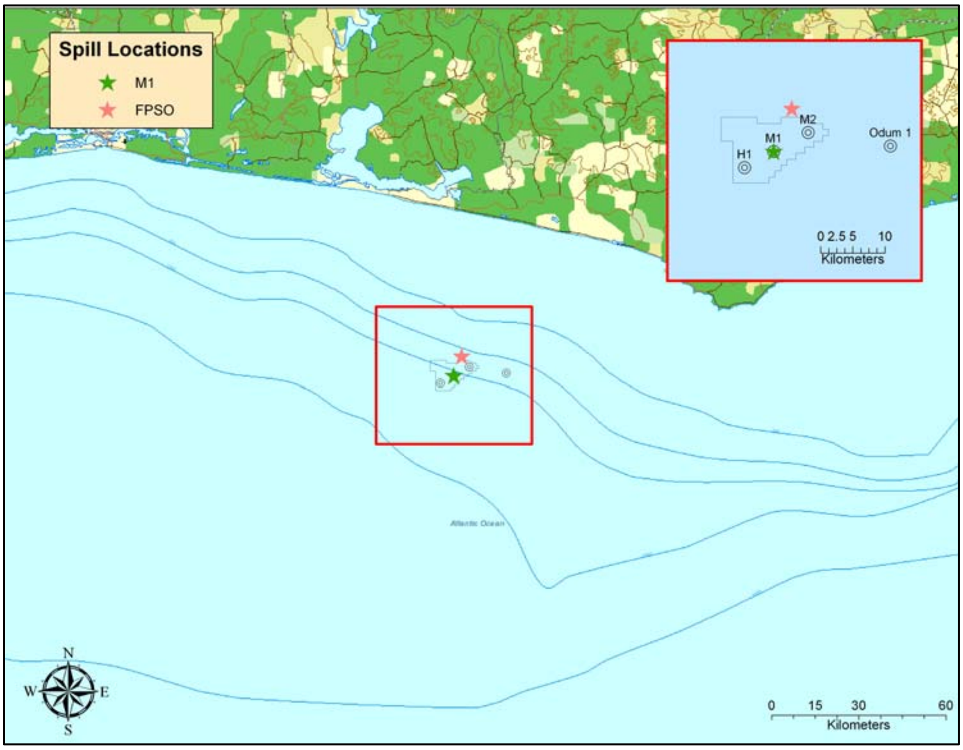
Regional currents were assessed from ADCP (Acoustic Doppler Current Profiler) collected data and WANE predicted currents. Based on the directional trends of the surface currents, the ADCP current data are considered to represent periods of both eastward and westward flow.

(1) US National Oceanic and Atmospheric Association (NOAA): National Centre for Environmental prediction (NCEP)

Location of Spills

For the oil spill scenarios the modelling study assumed potential spills from the Mahogany 1 (M1) well and the FPSO locations, as shown in *Figure 5.*

Figure 5.9 Study Area Showing Location of M1 and FPSO in the Jubilee Field



Oil Type

The characteristics of the oils used in the model simulations are given in *Table 5.14*. These are based on the crude oil (a relatively light oil with an API(1) of 37) expected from the Jubilee field and the type of marine gasoil (diesel) likely to be used. Evaporation characteristics were assumed based on representative oils with a similar density and viscosity at standard test temperatures.

Table 5.14 Oil Characterisation Summary

Oil Type	Density (g/cm^3)	Viscosity (cP)(2)
Crude	0.8783	33
Marine Gasoil (Diesel)	0.8564	4.8

(1) Based on American Petroleum Institute standards for defining oil types.
(2) Centipoise (cP). - Water at 20 °C has a viscosity of 1.0 cP.

5.6.5 *Modelling Results*

The results of the modelling present a worst case that could result from a particular oil spill and assuming that no oil spill response measures eg use of dispersants, skimmers, booming were implemented and that no actions were taken at the point of spillage eg pumping out of ruptured oil tanks. The remainder of this section summarises the results of the different spill scenarios that have been modelled (see *Annex D* for the full report of the study).

Stochastic Modelling Results

The OILMAP stochastic model was applied to predict the probability of sea surface oiling due to potential oil spills during drilling, production and transfer activities at Jubilee Field Well M1 and the FPSO location. The stochastic simulations indicate the probable behaviour of potential oil spills under the specific metocean conditions expected to occur in the study area. Two types of statistics are generated:

- sea surface areas that might be oiled and the associated probability of oiling; and
- the shortest time required for oil to reach any point in the areas predicted to be oiled.

The stochastic model was applied to the 11 spill scenarios. The stochastic analysis is based on 500 independent simulations, each with a different start time within the typical annual wind conditions for the region. It should be noted that the model outputs do not imply that the entire coloured surface presented (see *Figure 5.8* and *Figure 5.9* below) would be oiled in the event of a spill. Rather they define the area in which sea surface oiling could occur and the probability of oil reaching the area, based on the range of potential trajectories derived from the 500 simulations run for each scenario.

The key model results were as follows.

- All the stochastic model simulations for the 11 spill scenarios show the predominant transport of spilled oil is to the east which would impact the Ghanaian coastline near Cape Three Points. This eastward transport of the oil is due to the influence of consistent winds from the south-west quadrant and the currents with a strong easterly component. The footprint for the area of potential impact varies with spill size, with the maximum length of the footprint ranging from 40 km for a marine gasoil spill of 10 Tonnes to more than 600 km for crude oil spills of 1000 Tonnes or more. Shoreline oiling is possible for all scenarios except the marine gasoil spill of 10 tonnes.

- The model simulations show that the minimum time in which spilled oil could reach the Ghana shoreline is 1 to 1.25 days although the average time to reach shore is 2.5 to 4.5 days. Approximately 200 to 300 km of shoreline would be at risk from oiling with the very large spill sizes (ie

20,000 and 28,000 tonnes). The shoreline with the highest probability (40 to 50%) of being oiled is the stretch of coastline approximately 100 km west of Cape Three Points. East of Cape Three Points, a longer reach of shoreline could potentially be oiled, but the probability of oiling is generally less than 10 %. The shoreline east of Cape Three Points has the highest probability of oiling due to a 168-hour release of 20,000 tonnes of crude oil from Well M1. For this scenario some areas have up to a 15 % probability of being oiled.

Table 5.15 summaries the results of the eleven stochastic scenarios in terms of shoreline impacts. The table shows that 45-82 percent of the 500 simulations run for each scenario resulted in oil reaching shore by the end of the simulation. For those simulations with oil reaching shore, the table also indicates the minimum and average time for oil to reach shore, the maximum and average mass of oil that reaches shore, and the length of shoreline that has greater than a 10 percent probability of being oiled.

Table 5.15 Summary of Shoreline Statistics for Stochastic Simulations

Scenario	Volume (Tonnes)	% of Model Runs Reaching Shore	Minimum Time to Reach Shore (Hours)	Average Time to Reach Shore (Hours)	Maximum Amount of Oil Ashore (Tonnes)	Average Amount of Oil Ashore (Tonnes)	Length of coast with >10% probability of oiling (km)
1:	10	45	31	73	7	6	40
2:	10	0	0	0	0	0	NA
3:	100	64	28	96	66	60	60
3a:	100	69	24	90	66	60	65
4:	100	72	25	85	64	58	55
5:	1000	66	31	102	684	559	115
5a:	1000	73	22	84	689	583	70
6:	5000	74	28	97	3530	2746	110
7:	20,000	82	29	109	14,817	9341	170
8:	28,000	72	27	99	21,053	16,372	100
8a:	28,000	70	21	88	21,193	18,849	55

The following figures (*Figure 5.10* and *Figure 5.11)* depict water surface probabilities of oiling for a small spill of 10 tonnes and a large spill of 20,000 tonnes as these represent the two extremes of the modelling scenarios.

Figure 5.10 illustrates that for a spill of 10 tonnes there is a low probability of oil reaching the coastline. *Figure 5.11* illustrates that for a very large spill (ie 20,000 tonne spill) there is a significantly higher probability that oil would reach coastal waters (60 to 70%) and that oil would beach on the stretch of coastline (40 to 50%) approximately 100 km west of Cape Three Points. Although the analysis shows that it is possible that a larger area of coastline east of Cape Three Points would be exposed to oil beaching it is noted that in the event of a spill of this size the probability of this area being affected is in the range 1 to 10%.

Figure 5.10 Probabilities of Water Surface Oiling from Crude Spill of 10 Tonnes at M1

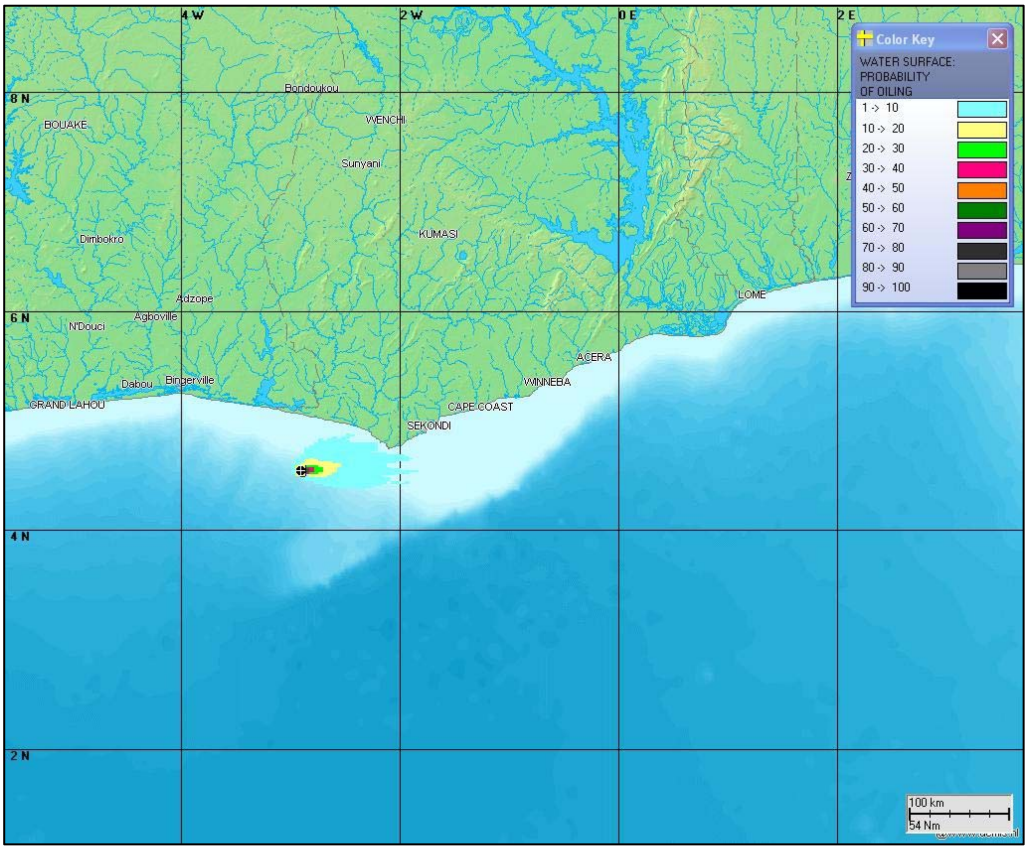
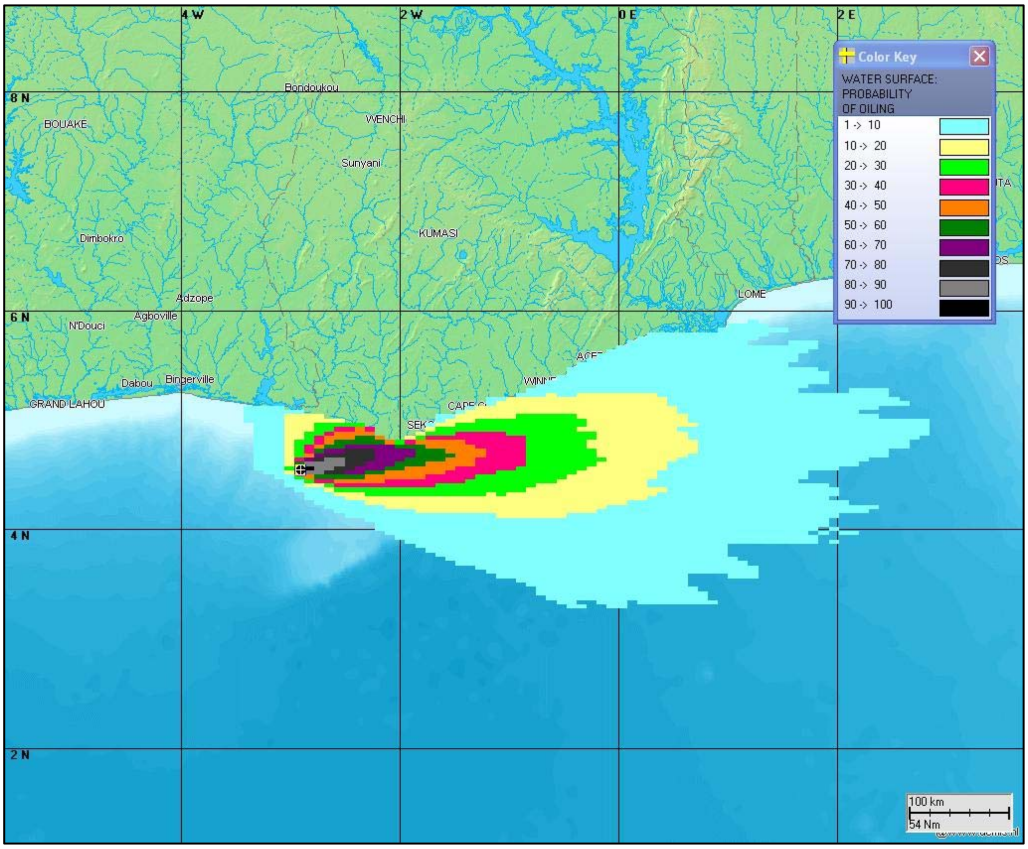


Figure 5.11 Probabilities of Water Surface Oiling from Crude Spill of 20,000 Tonnes at M1



Deterministic Modelling Results

The deterministic (trajectory/fate) modelling simulations represent the fate of an oil spill release under specific meteorological conditions (ie one particular wind direction and strength). In this case a deterministic model simulation was performed for the *worst case* simulation identified in each stochastic analysis for the various spill scenarios. Typically, the worst case is defined as the simulation that predicts the shortest time for oil to reach shore. Due to the consistency of the wind record in the study area and the similarity of the stochastic predictions for the eleven scenarios considered, a single start time when winds are primarily from the south was selected for all the trajectory/fate simulations. However, in the event of an actual spill, the fate of the oil and the location and amount of oil reaching the coast will vary according to the prevailing weather conditions at the time of the spill and whilst the oil is on the sea surface.

These deterministic model simulations provide a time history of oil weathering over the duration of the simulation, expressed as the percentage of spilled oil on the water surface, on the shore, evaporated, and naturally dispersed in the water column. The model outputs show the predicted footprint of the spilled oil (in gray) and the shoreline impacted (in red). The key model results were as follows.

- The model results showed that for the small (10 tonnes) instantaneous diesel spill scenario there is no beaching of oil and therefore no shoreline impact. The other spill scenarios did show potential for shoreline impacts due to oil reaching the coastline.

- The trajectory and footprint of the instantaneous spill of 100 tonnes crude is shown in *Figure 5.12.* The output predicts a shoreline impact to the north and west of the release site along an area of approximately 15 km. The footprint is almost exactly the same for the diesel spills with the same shoreline area being affected. However, due to the much lower evaporation rate of the crude, almost 75% of the spilled oil is still on the water surface when the oil reaches the coast whilst due to evaporation only approximately 40% of the spilled diesel is still on the water surface when it reaches to coast. This same pattern was observed in the other spill scenarios involving both crude and diesel. Similarly the footprint for the 2-hour duration crude oil spills of 1,000 and 28,000 tonnes are nearly identical to those of the 100 tonne spills (*Figure 5.12*).

- The 48 hour duration spills of 1,000, 5,000 and 28,000 tonnes have similar footprints and extent of shoreline oiling. The effect of the 48 hour spill, compared to the instantaneous spill, is to spread the oil over a wider area due to the winds shifting while the oil is being released. For these scenarios approximately 75 km of shoreline to the north, north-east and north-west of the release site are oiled (*Figure 5.13).* For all these scenarios approximately 80% of the oil is still on the water surface when the oil first