4. FATE AND EFFECTS OF SPILLED OIL

This section describes the properties and behavior of spilled oil that are important to a spill response operation, and the potential effects that the spilled oil and associated response operations may have in the various environments encountered in the project area.

4.1. Fate of Spilled Oil

The chemical composition of oil changes due to weathering. Weathering occurs by evaporation, microbial degradation, chemical oxidation, and photochemical reactions. Some oils weather rapidly and undergo extensive changes in character, whereas others remain relatively unchanged over long periods of time. The effects of weathering are generally rapid (1 to 2 days) for hydrocarbons with lower molecular weights as a result of evaporation. Degradation of the higher weight fractions is slower and occurs primarily through microbial degradation and chemical oxidation.

The weathering or *fate* of spilled oil depends on the oil properties and on environmental conditions. It is important to recognize the dynamic nature of spilled oil and the fact that the properties of spilled oil can change over time. During a response operation, it is important to monitor the continuous changes in the properties of the spilled oil, as response strategies may have to be modified.

Oil Properties

Crude or refined oils vary in their physical and chemical characteristics. These characteristics affect their volatility, toxicity, weathering rate and persistence. Table 4-1 shows properties for crude from the various oil fields in the development area.

Table 4-1. Crude Properties (Reservoir Conditions)

	KOMÉ	MIANDOUM	BOLOBO
ºAPI Gravity	18 – 20	24	17 – 22
Pour Point (ºF)	15 – 40	20	13 – 37
GOR (SCF/STB)	15	47	15 – 32
H_2S (ppm)	0	0	0
Viscosity (cp)(+/- 190ºF)	70 – 296	38	72

Important properties from a spill response viewpoint include:

- **specific gravity (density)** — determines if the oil will float on water or sink. The specific gravity of most crude and refined oils lies between 0.78 and 1.00. The U.S. petroleum industry has customarily used the so-called °API (Degrees API Gravity). API gravity is inversely proportional to the true specific gravity and corrects the specific gravity value to 15.5ºC (60ºF), so that on the API scale, freshwater has a specific gravity of 10.00. Light oils with a low specific gravity (<0.8) have high values on the API Scale (>45), whereas heavier oils have low API gravity values. The °API gravity places most oils within a convenient range of 10 – 50 °API. The specific gravity of spilled oil will increase with time, as the more volatile (and less dense) components are lost.

- **pour point** — the lowest temperature at which the oil will flow, below which the oil will act as a semi-solid substance. As ambient air temperatures vary, stranded oil may be alternately fluid or semi-solid. This property is important in evaluating whether oil will penetrate into sediments or move downslope.
- **viscosity** — a measure of the resistance of the oil to flow, or its internal cohesion, that controls the rates of spreading and the degree to which oil can penetrate into sediments. Low viscosity oils are light and fluid whereas high viscosity oils are semi-solid or tarry. Estimated viscosity at 70º F of Chad crude is 400–1000 cp (similar to Bunker C).
- **H_2S** — Unlike other sulphur compounds in crude oils, which tend to accumulate in the distillation residue, hydrogen sulphide is evolved during distillation or other heating processes. During an oil spill, this makes it a safety concern, as hydrogen sulphide is a toxic gas with a time-weighted average (TWA; an 8-hr. exposure limit established by ACGIH) exposure limit of 10 ppm and a short-term exposure limit (STEL) of 15 ppm (ACGIH, 1996).

Other oil properties to be considered during a response include boiling point, flash point, surface tension, adhesion, solubility and aromatic content.

- **boiling point** — determines the temperature at which each hydrocarbon will evaporate. Many of the light (low boiling) fractions ("light ends") evaporate at temperatures less than 20ºC (68ºF). As these light fractions evaporate, the remaining oil is reduced in volume and becomes denser and more viscous.
- **flash point** — the lowest temperature at which the fractions of the oil will ignite when exposed to an ignition source. This is a critical safety parameter; it must be remembered that a serious hazard may exist if air temperatures are above flash points of light fractions in spilled oils. Gasolines and other light fuels can be ignited under most ambient conditions and therefore pose a serious hazard when spilled. Many freshly spilled crude oils also have low flash points until the lighter components have evaporated or dispersed.
- **surface tension** — controls the rate at which the oil will spread. Oils with a low surface tension spread more rapidly, so that a greater surface area is exposed to weathering. Surface tension is partially controlled by ambient temperatures and decreases as temperatures increase.
- **adhesion** — is important in determining whether the oil will stick to sediments or other materials it comes in contact with.
- **solubility** — determines if oil will dissolve in water and become toxic to marine life.
- **aromatic content** — aromatics are more toxic, have a high solubility that may increase toxic effects, and are more volatile than other hydrocarbon components.

Again, it is important to remember that these properties, and the environmental conditions that affect them, change over time and should continuously be monitored. For example, as oil weathers due to evaporation processes after a spill, the specific gravity usually increases, and the evaporation rate increases with increased temperatures and wind speed.

4.1.1. On-land Spills

The pipeline will be buried in order to reduce the risk of leaks and to prevent interference with agricultural lands and wildlife migration routes. Typically, the pipeline will be buried one meter underground. In some areas, like stream and road crossings, the pipeline may be buried even deeper.

Oil movement or flow over the ground surface follows the topography of the land (oil flows downhill). In general, oil will flow until it reaches a surface water body or a depression, or until sorbent effects prevent further movement. Oil flowing over land can infiltrate vegetation cover and soil. The rate of oil movement and depth of penetration are dependent on a variety of factors and are best determined by direct observation.

If ground water becomes contaminated, contaminants generally remain concentrated in plumes. Because ground water moves relatively slowly, contaminants do not mix or spread rapidly. Contaminants from ground water may eventually migrate and appear in surface waters.

The proposed oil field development area is relatively flat with a total relief of approximately 30 m. The topography along the pipeline transportation system in Chad is relatively flat for the first approximately 35 km to the crossing of the Kagopal-Goré road. Continuing southwest of Kagopal, the route crosses generally rolling topography ranging between approximately 500 m and 550 m in elevation. Near Gadjibian the topography generally ranges between 460 m and 550 m in elevation, with the lower elevations continuing to reflect the bottoms of drainage features. This topography generally continues for the route to the border with Cameroon.

The landscape of the proposed pipeline route through Cameroon generally is rolling to hilly, except for the last 55 km to the coast. The elevation along the Project route increases steadily from 550 m in elevation at the border with Chad to about 800 m near pipeline kilometer 235. The study area then drops back to near 650 m and lies in a broad trough that separates two tablelands, which are parts of the highest portion of the Adamaoua Plateau at more than 1,200 m above mean sea level. The proposed route then traverses two extensive high plains before dropping onto the coastal plain for the last 55 km of the route to the coast.

The primary soils encountered within the project facilities in Chad are sandy and clayey silts, silty sand, clayey sand, lateritic gravel, and hard laterite soils. Topsoil overlies some of the above-mentioned soils to a depth of up to 0.5 m. Much of Cameroon is characterized by geomorphically stable erosion surfaces overlying a thick mantle of weathered bedrock. A soil horizon of varying depths generally made up of clay and silt-sized sediments of weathered granites and gneisses overlies these surfaces. These soils are potentially unstable when the vegetation cover is disturbed. Spilled oil may penetrate the surface topsoil, however, penetration of oil into the sand, clay and silty soils of the project area would be limited to light oils (e.g., a diesel).

Oil-burning heaters will be used to heat the crude oil flowing through PS-2 and PS-3 to approximately 71ºC (160ºF). This process lowers the viscosity of oil and improves its flow through the pump stations. The temperature range for oil in the pipeline is projected to be between 71ºC (160ºF) and 32ºC (90ºF). A leak of heated oil from the pipeline at or near the pump stations would tend to initially flow faster and be more likely to penetrate permeable or porous materials than leaks from cooler (pipeline) temperature areas of the oil transportation system. In the case of a spill, the oil flow speed and ability to penetrate into sediments and soils would decrease as it cooled.

4.1.2. <u>Offshore Spills</u>

The fate of hydrocarbons in the marine environment depends on a number of factors, including air and water temperatures; the type and amount of nutrients and inorganic substances present; winds, tides, and currents; and the amount of sediment suspended in the water.

Movement

Currents and wind are the driving forces for the movement of an offshore oil spill. Ocean currents have three components: the residual current, the tidal current, and the wind-driven surface currents. Currents produced by fresh or brackish water outflow from a river can also deflect oil away from a river mouth or estuary.

Residual currents are produced by the long-range motion of water in the ocean caused by the rotation of the earth, the geometry of the oceans, and temperature differences in the ocean. These rivers of water within the ocean change slowly, although they may have a seasonal variation. More localized residual currents can occur due to geometric effects of the ocean-land boundary. Residual currents generally flow in the same direction for long periods of time. Coastal boundary currents can trap or contain oil close to a shore (Murray and Owens, 1988) or keep oil away from a shore.

Tidally driven ocean currents are produced by changes in water level caused by astronomical effects. These currents change both their magnitude and direction with every tidal cycle. In most cases, the tidal flow is symmetrical with time, particularly in deep water. The net motion of oil due to tidal currents is very low, even for large currents, because tidal currents oscillate. If an oil slick is spread over regions with varying water depths, tidal currents can result in a net advection of the oil. This is due to the fact that the currents are stronger in shallow-water areas and weaker in deep water. Both the direction and magnitude of future tidal currents can be predicted easily, after measurements have been taken during tidal cycles.

The third type of ocean current is a surface current generated by the interaction of the wind with the water surface (see also Section 5.1). The speed of these surface currents is typically 2–4% of the wind speed (Table 4-2), and motion is approximately in the direction of the wind. This is the only effect of the wind on oil motion. Wind-produced waves are oscillatory and do not cause net oil movement in deep water.

Table 4-2. Resultant Surface Current due to Wind

Wind Velocity km/hr	3% of Wind Velocity	=	Meters/Second	=	Knots
25	0.75 km/hr	=	0.21 m/s	=	0.41 kts
50	1.5 km/hr	=	0.42 m/s	=	0.82 kts

Winds are produced by pressure differences in the atmosphere and can change rapidly with time. As a result, there is limited capability to predict winds. In most oceanic areas, reliable forecasts can be produced only for 48 to 72 hours in advance, with an outlook for five days. Forecasts beyond a few days are generally not based on predictive models, but rather on a variety of statistical procedures of weather prediction and are, therefore, not useful for oil spill modeling.

Primary Weathering Processes

When oil is released onto the water surface, its characteristics start to change due to a number of physical-chemical processes. All of the processes are interactive. Weathering rates depend on oil type, physical properties such as viscosity and pour point, chemical properties such as wax content, amount of oil spilled, weather and sea state conditions, and location (whether oil stays at sea or is stranded).

The primary processes affecting the fate of most spilled oil are:

- Spreading
- Evaporation
- Dispersion
- Dissolution
- Emulsification

These processes dominate in the first few days to weeks of a spill, and, except dissolution, these processes may dramatically change the nature of the oil. In addition, a number of longer term processes include the following:

- Biodegradation
- Photo- and auto-oxidation
- Sedimentation

These longer-term processes are less important than the first five for the initial prediction of the fate of spilled oil, and their contribution to the oil fate is typically neglected in models. These are, however, more important in the later stages of weathering and usually determine the ultimate fate of the spilled oil.

Spreading: Spreading occurs during the early stages of the spill. According to Fay (1971), there are three stages of spreading. These are:

- Phase One—gravity-inertia: This early phase occurs immediately after the oil has been released and is driven by gravity. This is simply due to the fact that oil, being a liquid, will not remain in a pile. The rate at which the oil moves depends on its inertia; that is, the oil needs time, due to its mass, to move. The process occurs for a few minutes to hours and is generally finished by the time a spill response is initiated.
- Phase Two—gravity-viscous: This phase also starts immediately after the oil has been released and is again caused by gravity. In this phase, however, the viscosity retards the rate of oil motion. That is, light oil will spread more rapidly than heavy oil. The time span for this process is from minutes to many hours. As other fate processes act on the oil (for example, evaporation), viscosity increases, and the spreading process slows.
- Phase Three—surface tension-viscous: This is the final phase of spreading and occurs over a time period of many hours to days. The driving force is the surface tension, a force at the molecular level that may make the oil spread on the water. The retarding force is the oil viscosity.

Evaporation: Components of spilled oil evaporate at varying rates and are transported and diluted by atmospheric processes. Evaporation is usually the most important weathering process in the first days immediately following a spill. Evaporation may be responsible for the loss of one-third to two-thirds of an oil spill mass within a few hours or a day (Jordan and Payne, 1980). Rapid initial loss of the more volatile fractions is followed by progressively slower loss of less volatile components. A number of parameters contribute to the rate of evaporation of oil on water.

- *Properties of the oil*: Light oil evaporates more rapidly than heavier oil (Table 4-3).
- *Temperature*: Higher temperatures increase the rate of evaporation.
- *Wind speed*: Oil evaporates more rapidly with increasing wind speed.
- *Area of contact of oil with the atmosphere*: The greater the area, the more rapid the evaporation. Since the rate of spreading depends on the viscosity of the oil, light oils evaporate more rapidly, due both to an increase in exposed area and their higher percentage of lighter components.

Table 4-3. Approximate Evaporation for Various Classes of Oil (ITOPF, 1987)

Oil Type	12-Hour Evaporation*	48-Hour Evaporation	Total Fraction Evaporated
Group 1 (Gasoline)	50 – 100%	100%	100%
Group 2 (Diesel)	10 – 40%	25 – 80%	100%
Group 3 (Medium Crude)	5 – 15%	10 – 25%	35%
Group 4 (Heavy Oils)	1 – 3%	5 – 10%	15%
Group 5 (Low API)	0 – 2%	1 – 5%	10%

(*) Lower limits are for 5ºC and the upper limit for 30ºC and a moderate wind speed of 5 m/sec.

Dispersion: Natural dispersion is the removal of oil from the water surface by its incorporation, in the form of small droplets, into the water column by wave action. The rate of dispersion depends on the amount of wave energy at the sea surface. For low-energy wave conditions, the rate of dispersion is low. For high sea states, dispersion may dominate with the result that most of the oil is removed from the water surface in a few hours.

The more viscous the oil, the slower the rate of dispersion. In the water column, dispersed oil is present as small droplets and, thus, has a much higher surface area in contact with the water. This increases the rate of dissolution and the rate of natural biodegradation. The rates of both evaporation and dispersion increase with increasing wind and decreasing viscosity. They are thus competing processes in the oil mass balance.

Emulsification: Emulsification is the incorporation of water into oil and is the opposite of dispersion. Small drops of water become surrounded by oil. In order to emulsify oil, external energy from wave action is needed. In general, heavier oils emulsify more rapidly than lighter oils. The oil may remain in a slick, which can contain as much as 70% water by weight and can have a viscosity a hundred to a thousand times greater than the original oil. Water-in-oil emulsions often are referred to as “(chocolate) mousse”. Due to its high viscosity, emulsified oil is difficult to remove from the water surface. Emulsion affects the adhesion properties of oil; this dramatically affects the on-water recovery options, and an oil-in-water emulsion likely will not stick to shore zone materials.

Dissolution: Most components of oil have very low solubilities, but a few dissolve readily in water and become part of the water column. This process should be distinguished from dispersion, which produces particles or droplets of oil in the water. The same components of oil that readily dissolve in water also quickly evaporate, and these are therefore competing processes.

Submerged or Sinking Oil

Oil floats as long as it is less dense that the surrounding water. The density of fresh water is taken as 1.0 and the density of seawater usually is 1.025 (i.e., it is more dense). As oil weathers due to evaporation processes after a spill, the specific gravity usually increases. Mixing with sediments also can alter the specific density of oil. This may occur as oil is washed from a beach and incorporated with sediments by wave action.

Oil on the surface may sink if the density of the water changes. This may occur in coastal waters where different water bodies meet, such as at density fronts or at inlets and in estuaries.

Current speed and temperature can affect floatation. The same oil that would sink in calm waters (<0.1 knot) likely will remain on the surface in currents of more than 0.5 knot. In warm or hot climates, as the water in nearshore areas warms and cools each day, oil that has a density close to that of water may sink during the overnight cooling and rise again during the daytime warm period, creating sinking and refloating cycles.

Natural collection sites for sinking oils include trenches, depressions and eddy areas. It is often difficult to obtain information on natural subsurface collection sites.

Projected Weathering Process (Mass Balance) on Water

ADIOS model curves for Bunker B and Bunker C oils are included in Appendix E. These curves project the changes in the properties and effects of weathering over time from the start of a spill scenario based on user-defined spill parameters. Scenarios for the project are based on model curves for Bunker C because it has characteristics that are similar to the Chad crude properties.

Where Oil Strands

- On sheltered coasts with small waves, most of the oil will be deposited as a thin band in the middle to upper intertidal zone (in the zone of wave action).
- If washed ashore during periods of storm-wave activity, oil can be carried farther up a beach and deposited in the supratidal zone (above the limit of most wave action); this oil is stranded and will not be affected by waves until the next period of high water levels.
- On impermeable surfaces (bedrock, solid man-made structures), oil remains on the surface.
- On permeable shores (i.e., shores with sediments), subsurface oil can be present due to burial and/or penetration.
- Oil may penetrate below the surface of a beach, depending on the size of the sediment and the viscosity of the oil. Only light oils (e.g., a diesel) can penetrate a sand or mixed sand-gravel beach, whereas all but the more viscous oils can easily penetrate into a pebble-cobble beach.

Persistence

The persistence of oil stranded on the shoreline is dependent on (Table 4-4):

- the character of the oil,
- the physical character of the shoreline, and

- shoreline processes.

Table 4-4. Persistence of Oil with Varying Characteristics

Characteristic	Low Persistence	High Persistence
Type of Oil	Light, Volitile	Heavy or Tarry
Thickness of Oil on Shore Surface	Thin (<1 cm)	Thick (> 10 cm)
Depth of Oil Penetration	Oil exposed on surface	Buried below surface
Fetch Distance	Long	Short
Prevailing Winds	Onshore	Offshore
Coastal Exposure	Straight (open)	Indented (sheltered)
Wave Energy	High, Exposed coast	Low, Sheltered coast

Stranded oil can be buried or eroded by the normal movement of beach sediments as they are redistributed by the action of waves and winds. Cycles of burial and erosion may develop.

Oil may remain if it is:

- located above water level limits — stranded above the higher high-water mark and so not in contact with water, or
- semi-solid or has a solid/semi-solid (asphalt) “skin” — so that the forces of cohesion are too strong and prevent small particles from breaking away from the oil surface.

4.1.3. River Spills

The weathering processes acting on oil in and along the river are in most cases similar to those described above for offshore spills. The dynamics of a river or stream environment, however, have additional effects on the fate and behavior of spilled oil.

Oil entering rivers and streams will begin to spread as in offshore spills, but the spreading motion will be rapidly overcome by the surface current at which point an elongated slick will form. The oil will flow downstream at the speed of the current generally without wind effects. In general, oil will tend to accumulate in areas of quiet water or eddies at the inside of river bends on a meandering river or stream, or in other pools where velocities are slower. Pools of oil may also accumulate behind log or debris jams.

Water near the center of a stream channel will flow faster than water near the banks or bottom of the channel where the retarding forces of friction with the channel are greater. This difference in current speed and the resulting shearing forces between water layers is typically the major mixing mechanism that spreads a slick out as it moves downstream. The resulting smearing of the oil distribution along the axis of flow controls the plume shape and size, and the distance over which the oil concentration will remain above a particular level of concern. The leading edge of the slick may move as a relatively sharp front (at the current speed in the middle of the channel), however, mixing will continuously exchange water and oil between the slower, near-bank regions and the faster-flowing, center regions of the river. From a practical point of view, this means that although it might be possible to predict the initial arrival of oil at a point along the river, it will be considerably more difficult to estimate when the threat is past, since the areas of slower currents may continue to supply oil to the main stream channel, even after the leading edge is past (Overstreet and Galt, 1995).

Stream flow is unidirectional in a long, straight channel; however, few natural channels are actually straight and uniform for any appreciable distance. As water flows around a bend in a river, or encounters an eddy, centrifugal force tends to pile water up along the outside edge of the turn. This secondary flow slightly deflects the streamlines in the flow as the river moves around bends. More significantly, secondary flow helps move oil particles across the shear boundaries and greatly increases the smearing, or dispersion, of the slick in the downstream direction. Thus pollutants tend to spread more rapidly, decreasing their peak concentrations relative to what would be expected for a straight channel (Overstreet and Galt, 1995).

Many river cross-channel profiles are very irregular, with rapids at one extreme and quiet bays at the other. These features either accelerate or decelerate the average flow down the river. These irregularities contribute to the shear in the current pattern and will significantly increase the along-channel spreading of the oil distribution.

Shear-dominated flows cause another effect that characterizes river spills. Shear in currents along the banks and river bottom are typically the major source of turbulence in rivers, in contrast to surface-wave activity in oceans. Mixing and dispersion caused by the interaction of the shear and the turbulence can move significant amounts of oil below the surface (particularly if it is relatively dense, such as a heavy No. 6 oil; or if it is finely distributed as droplets). The shear-dominated river regimes tend to produce spill distributions having higher subsurface oil concentrations than would be expected in marine spills (Overstreet and Galt, 1995). This turbulence increases with increased velocity of flow and bed roughness.

Most perennial streams in the project area are believed to have significant dispersive, dilution, and assimilative capacity if a project related accidental spill or release of pollutants entered the water.

For any oil that enters a river, irrespective of flow velocities or water levels, some of the oil will end up on the riverbanks. In faster flowing conditions, the geographic spread and the affected area would be greater than under slower flow conditions, although local concentrations of oil may be greater for slower streams. The rate of movement of the leading edge of oil spilled into a river would be virtually the same as the maximum surface current in the river. No current speed data are available at this time but it is reasonable to assume minimum flow rates of 0.1 m/s (0.36 km/hour) during the dry season and flow rates of greater than 0.5 to 1m/s (1.8 to 3.6 km/hour) would be common during higher discharge conditions and where streams or rivers may pass through a constricted channel.

Seasonal or Episodic Stream Flow

Seasonal or episodic changes in runoff and rainfall cause increases in river current speed. These runoff variations also change the water level and may strand oil on the shoreline at different levels. For example, falling water levels may strand oil so that it will not refloat, which removes it as a secondary source for remobilization but may leave a persistent shoreline cleanup problem.

Rising water levels may wash off beached oil and reintroduce floating oil or may cover up or bury oil that is adhered to sediment or vegetation. High water levels may lead to greater oil contact with shore bank vegetation and may strand oil in small pools and eddies along the bank. Most streams in the project area are perennial, and watersheds generate significant volumes of surface runoff, suggesting significant potential for scour and degradation during major storms.

Floods are perhaps the most extreme form of water level change and can introduce a whole new set of considerations. Some waterways do not even appear to be in the same area as they were before flood stage. Numerous side lakes may develop during flooding and oil entering these areas with floodwaters may become trapped. Oil may be carried into flood plains during overbank flood stages, leaving potentially extensive areas of oiled vegetation and soils. Only light oils (e.g., a diesel) would penetrate the extensive flat sandbanks along the rivers in southern Chad. Stranded crude oil would remain on the sand surface and could be remobilized by higher water flow levels, or buried by sediments deposited by floodwaters. Peak flows and flood depths and elevations for the Pendé and Loulé Rivers in the vicinity of Komé Field and OC are listed in Table 4-5. Additional information on seasonal rainfall can be found in the EA documents.

Seasonal flow rate data for rivers in the project area are included in the Tables 4-6 (Cameroon) and 4-7 (Chad). No streamflow records are available for the Loulé and Nya; low-flow estimates based on cross section surveys of the two streams are 17–21 and 18–24 m^3/s, respectively. It is considered that the low-flow estimates understate actual discharges, particularly for the Nya (ANTEA, 1995).

Table 4-5. Flood Data for the Pendé and Loulé Rivers in the Vicinity of Komé Field and OC (Dames and Moore, 1996)

Return Period	Peak Flow (m^3/s)	Flood Depth (m)	Flood Elevation (m)
Pendé River			
10 year	1,039 – 1,298	4.2 – 4.4	387.2 – 387.4
50 year	1,467 – 1,638	4.5 – 4.6	387.5 – 387.6
100 year	1,633 – 1,780	4.6 – 4.7	387.6 – 387.7
1,000 year	2,129 – 2,295	4.9 – 5.0	387.7 – 388.0
Loulé River			
10 year	289	3.2 – 3.7	384.1 – 389.6
50 year	329 – 406	3.4 – 3.9	384.3 – 389.8
100 year	338 – 451	3.5 – 4.0	384.4 – 389.9
1,000 year	355 – 589	3.7 – 4.3	384.6 – 390.2

Table 4-6. Mean Monthly Stream Flows for Selected Rivers (derived from Cameroon EA)

Month	Stream Flow (m^3/sec)				
	Mbéré River at Mbéré, border of Chad, Cameroon and African Republic	Lom River at Bétaré Oya	Nyong River 271 km from mouth	Nyong River at Kaya 233 km from mouth	Lokoundjé River at Lolodorf
January	30.9	77.1	123.0	137.0	9.0
February	19.4	45.0	82.2	74.9	7.8
March	15.6	22.9	80.5	91.6	16.2
April	26.8	72.9	129.0	151.0	27.1
May	44.2	112.0	190.0	236.0	33.6
June	83.2	216.0	137.0	270.0	37.2
July	155.0	243.0	166.0	188.0	17.6
August	264.0	278.0	129.0	167.0	13.0
September	316.0	471.0	239.0	278.0	33.8
October	231.0	559.0	469.0	516.0	68.4
November	83.1	251.0	507.0	552.0	62.9
December	45.5	122.0	274.0	303.0	23.8
Annual Mean	108.0	206.0	205.0	252.0	29.8

Table 4-7. Stream Flow Data at Selected Gauges (Chad; adapted from Chad EA)

	Logone River at Moundou	Pendé River at Goré	Pendé River at Doba
	Lat. 8º32'2"N Long. 16º4'6"E	Lat. 7º57'N Long. 16º37'E	Lat. 8º39'N Long. 16º50'E
Drainage Area (km^3)	33,970	12,020	14,300
Average annual rainfall (mm)	1,393	1,492	1,448
Observed/Estimated Discharge (m^3/s)			
Max. daily	2,650	983	1,090
Mean annual	347	90.8	86.8
Min. daily	7.96	0.01	0.11
10-year daily peak	2,384	918	993
10-year daily low	11.4	0.061	0.315
100-year daily peak	2,966	1,158	1.559
100-year daily low	6.95	0.0001	0.068

4.2. Potential Effects of Spilled Oil

This section discusses the potential effects of an oil spill, including general impacts of response activities. In addition to spills on land and in offshore and river environments, special attention is given to critical habitats and areas of special concern within the project area (Section 4.2.4). Much of the following sensitivity information was derived from the Project EAs prepared by Dames and Moore.

4.2.1. <u>On-land Spills</u>

It is recognized that despite best management practices the potential exists for accidental releases of vehicle and equipment fluids and oil to occur. The potential for a spill to occur during operations allows for the possibility that areas near the pipeline could be affected.

Spills of diesel, gasoline, hydraulic, brake, transmission, and other equipment fluids, as well as other chemicals, could have an impact on vegetation, animals, and local land use activities. They could also impact water supplies and aquatic resources if they were to enter surface waters or groundwater aquifers (see Section 4.2.4, Critical Habitats, discussion of shallow aquifers). Spills of this nature may tend to be isolated and generally occur on access roads, maintenance facilities, and other areas where vehicular traffic is common. These impacts would be reduced by control measures. Any incidents that occur would be small, localized, and intermittent.

Crude oil spills could occur in the Oil Field Development Area and along the PTS during the operational life of the Project. On land impacts would include infiltration of oil into surrounding vegetation cover and soils. Animals and birds could ingest contaminated vegetation. Disruption of migration routes and local activities, such as hunting and agriculture, could also occur, especially during response activities. Attention should be paid to the considerable numbers of animals that move through the area regularly on their way to livestock markets. The primary concern of a spill on land would be to prevent it from impacting surface water channels or groundwater aquifers.

Impact of Response Activities

When soils are moved and compacted by heavy equipment, the particle size and porosity can be altered, important soil components such as mycorrhiza and seeds can be destroyed, and a loss of soil nutrients by leaching can occur. Mycorrhiza associated with the root systems of many tropical plants influence nutrient cycling and germination processes. Response activities utilizing heavy equipment for oil containment or excavating of oiled soil materials (see Section 8) may cause a mixing of soil layers and movement of organic materials. Once mixing occurs, essential nutrients could be leached from topsoil by underlying substrates. This impact would be short-term and limited to the response area.

If soil structure and fertility are degraded by repeated disturbance, re-establishment of the native vegetation may be greatly retarded. An alternate, and less desirable, successional sequence also could occur, resulting in the rapid establishment of introduced plant species or undesirable weeds. When this occurs, the normal successional sequence halts or is dramatically slowed and the regenerative capacity of savanna or forest habitat could be impaired. Weedy shrubs and woody pioneer species readily re-establish themselves, but re-establishment of the normal successional habitat is less assured. This results from lack of seed input from tree species, whose seeds tend to be large, relatively short-lived, and dependent upon animal dispersal. A secondary successional habitat could become established, but the process may take longer.

4.2.2. Offshore Spills

Despite best management practices the potential exists for accidental releases of oil to occur from offshore facilities. The potential for an offshore spill to occur during operations, coupled with the proximity of the FSO to the shoreline, allows for the possibility that the Cameroon coastline in the vicinity of the FSO could be affected.

The coastal characteristics information presented in the Cameroon EA, Appendix C, was used to help develop an environmental sensitivity index (ESI) classification system for the Cameroon coastline between the Cameroon/Equatorial Guinea border at the mouth of the Ntem River to Point Souelaba at the mouth of the Cameroon Estuary. The classifications are shown on maps included in Appendix A of this GOSRP.

Marine Biota

The effects of an oil spill on marine organisms would depend on the organisms exposed, the conditions of the exposure, the volume of oil spilled, and other variables at the time of the spill. Response activities may also affect organisms. Sediment suspension due to disturbance during response activities could impact the near-shore biota; however, the marine organisms in the FSO area are well adapted to turbid waters.

An oil spill could have potential effects on marine mammals. Sublethal effects such as changes in normal migration routes and in behavior could also occur; however, there is a general lack of marine mammal populations in the study area (none were observed during marine field investigations).

Fish could be susceptible to effects of spilled oil. While juvenile and adult fish would be able to avoid oily areas, the near-surface eggs and larvae of many species would not be able to do so due to their lack of mobility. Therefore, these early life stages generally are more susceptible to oil spill impacts. Fish can be affected indirectly by spilled oil due to death of prey species, or through an effect on reproduction. Because of the widespread geographic distribution and large reproductive potential of most fish species, however, recovery from potential impacts as a result of an oil spill is expected to be rapid. Fishing is a primary economic activity in the proposed project area. Commercial and/or subsistence fishing could be temporarily halted to avoid harvesting organisms potentially tainted with oil, or to avoid contamination of boats and gear with oil.

Deaths of birds could result from oil coating their plumage and possibly from the toxic effects of ingesting oil. Certain birds would be particularly susceptible because they float on the water and dive for food. Sublethal effects from exposure to spilled oil may also contribute to increased mortality rates under certain environmental conditions.

Although some reduction of phytoplankton productivity could occur as a result of an oil spill, the impact on phytoplankton populations is expected to be less than significant because of the widespread distribution and large reproductive potentials of phytoplankton. Zooplankton could also be affected directly by increased mortality or indirectly through a decrease in food supply and changes in behavior, respiration, and reproduction.

Benthos

The largest impact of an oil spill on the benthic biota probably would result if the oil sank and coated the bottom. The more toxic, lightweight components probably would have evaporated or dissolved into the water before the oil reached the bottom. A direct effect would be mortality from smothering, although some mobile organisms would probably be able to move through this material. However, for most oil spills, coating of benthic biota has not been observed.

Sandy Intertidal Habitat

The physical effects of spilled oil probably would be more significant than chemical toxicity to the sandy beach biota. By the time the oil reached the shoreline, the more toxic fractions would likely have evaporated or dissolved. Because of the high-energy nature of sandy beaches, the residence time of oil is usually short, about one to two tidal cycles. Sandy beaches in the study area generally have few species, and these species characteristically have a high turnover and wide geographic distribution. Under these conditions, biotic recovery to pre-spill conditions would likely occur within one to two years.

Rocky Intertidal Habitat

Rocky intertidal habitats in the study area generally support a greater biomass and variety of plants and animals than do sandy beach habitats. As in the sandy beach habitats, physical effects of oil would be more likely to cause harmful impacts than would chemical toxicity.

Both direct and indirect effects of spilled oil on rocky habitat organisms could occur. Direct effects include mortality due to smothering; indirect effects include behavioral changes due to the coating of the substrate. Although local, short-term impacts could be significant long-term impacts are typically rare for these habitats. The high-energy nature of the environment generally leads to a relatively rapid recovery of available habitat and recolonization by most species. Recovery to pre-spill conditions would likely occur within one to three years.

Tourism/Recreational Beach Use

An oil spill that reaches the beaches could halt the tourism/recreational use of beaches until cleanup had been completed.. While a decline in tourism might be felt by local population centers most affected by a spill, the overall level of tourism in the event of a large spill in the region would be expected to remain relatively stable. Thus, the short-term impacts of an oil spill on tourism/recreation beach use could be significant in the areas affected by the spill; however, the longer-term impacts would be mitigated by the cleanup.

Potential Impacts due to Response

Commercial and/or subsistence fishing could be interrupted as a result of fishing vessels being confined to port by oil containment booms.

4.2.3. <u>River Spills</u>

Spills during construction or resulting from pipeline releases at river corssing may lead to oil impacts on rivers in Chad or Cameroon. (Major river crossings are listed in Table 7-1, see Section 7). In marine oil spills, it is very unusual to consider the water itself as a resource to be protected. Spilled oil may move over or through the water, but the water itself is not usually thought to be damaged. For inland spills this is not true. In many cases, the water is used as a primary resource (potable water) and threats to the water supply are a public health problem, immediately escalating the level of concern in river spills. If spills are allowed to enter surface waters, the decrease in water quality following such an event could also adversely affect botanical, wildlife, and other aquatic resources.

Crude oil is generally lighter than water and floats on the surface, potentially coating or causing impact to animals and plants that it may contact. While these impacts could be significant, their likelihood of occurrence would be minimized by the implementation of oil spill response countermeasures (Section 7) and associated safety and environmental protection measures.

Streams and rivers in the project area appear to support relatively small populations of fish, invertebrates, and other organisms. In the Nanga Eboko area fishing is mostly on the Sanaga and in small streams. Fishing is less important in streams and rivers elsewhere in the project area.

As in marine spills, the nature of the shoreline will determine the amount of potential damage that a spill could cause. The flat gradients of the rivers in southern Chad allow development of extensive sandbanks that attract winter migrant wading birds as well as local black-crowned cranes (*Balearica pavonina*), Maribou storks (*Leptoptilus crumeniferus*), herons, egrets, and plovers. The vertical, sandy banks are well suited for nesting colonies of Carmine bee eaters (*Merops nubicus*) and red-throated bee eaters (*M. bulockii*).

Flooding can strand pollution at high levels and threaten larger areas than might otherwise be expected. During a flood event, high water could transport oil into overbank habitats and impact large areas of the floodplains. Agricultural crops and grazing lands may be affected during these situations. Floodplains also are recognized as being important historically as fish nursery sites in Benech and Leveque (in Burgis and Symoens, 1987). The impacts of spill response activities to these areas would be similar to those for on-land spills.

Effects of response operations on botanical resources could include direct disturbance to, or loss of, individuals or populations of plant species. Temporary and permanent loss of riverine (gallery) vegetation could occur during disruptive response operations on the Nya, Loulé and Pendé river floodplains. Erosion and sediment transport would be minimized during response by the use of prudent erosion control practices.

4.2.4. <u>Critical Habitats</u>

Pipeline routing and facility siting has been undertaken to avoid various biologically important locations near the project area, including:

- Important wildlife habitats in the Faro Reserve — Benoué National Park — Bouba Ndjida National Park area
- The Pangar-Djerem Fauna Reserve and the proposed Mbam and Djerem National Park
- The Nyong River wetlands
- The Campo Reserve
- The Timbéri Forest Reserve (88,200 ha), south of Timbéri (see Figure A-1, Appendix A). This reserve is approximately 22 km southeast of the pipeline route.

- The Laramanay Wildlife Reserve; a proposed hunting reserve approximately 7 km north of the proposed pipeline route, east of Bam and Bégangber (see Figure A-1, Appendix A), which is reported to contain important habitat for elephants that may migrate between Chad and Cameroon.
- The Logone floodplain is a wetland area that contains valuable gallery forest and marsh habitat that supports relatively diverse bird and mammal populations and provides important grazing habitat for resident and transhuman livestock.
- A large contiguous stand of African bamboo (*Oxyanthera abyssinica*) northeast of Bessao contains important timber and fuelwood resources for local residents and also provides important elephant habitat. This is not currently an official reserve, though it is a recognized area of value to local residents.

Shallow Aquifers

Shallow aquifers of the Doba Basin provide almost all of the water supplies for the population of the area. The most common domestic water supply source is through wells or occasional hand pumps. Some of the traditional hand dug wells have little protection against surface runoff, and spilled oil flowing on the ground surface in their vicinity could infiltrate these wells. Some of these wells are located in the floodplains of nearby streams, are only 5 to 8 m deep, and presumably capture water of the same or similar quality as that contributing base flows to the streams in the area.

The groundwater gradient follows the topographic slopes. A groundwater contour map for the upper shallow zones of the aquifer is included as Figure 6.4-3 in the Chad EA. The data indicate that the direction of shallow groundwater flow in the vicinity of the Komé and Bolobo well fields is toward the north and northeast, i.e., toward the Nya River, and toward the east in the vicinity of the Miandoum well field.

The clay and silty surface soils within the project area should form a barrier to the aquifers from above.

Endangered and Sensitive Species

The only significant biological habitats remaining in the vicinity of the oil field development area and pipeline in Chad consist mainly of remnant gallery forest and herbaceous wetland vegetation in the alluvial floodplains of major watercourses, and occasional stands of African bamboo (*Oxyanthera abyssinica*) in the region around Bessao and Baibokoum. The pipeline has been routed to avoid large stands of bamboo.

The Mbéré Rift Valley supports a great variety of animals, including large mammals. A large portion of the Mbéré Rift Valley in Cameroon (comprising approximately 60 km of the 320 km pipeline route) is unique in its relative lack of disturbance. It has a high diversity and abundance of wildlife, including elephant, hippopotamus, bongo, and eland, and little-disturbed diverse vegetation including wooded savanna and gallery forest.

Response activities are expected to have little impact on those wildlife resources that remain in the area. Agricultural activity has long since displaced most of the natural habitats and associated wildlife of the region.

Temporarily disturbed areas could be recolonized and repopulated by the same species, but probably not by the same individuals, depending on the degree and extent of disturbance. Such differences could affect the ability of certain species to return and persist in remaining natural habitat fragments. Consequently, a limited number of individuals could be affected during response operations.

The following regionally sensitive mammal species have the potential to occur in the study area (see EAs for details).

- Giant eland (*Tragelaphus derbianus gigas*) — formerly occurred in SW Chad in the wooded savanna zone. It may be completely absent from Chad today.
- Red-flanked duiker (*Cephalophus rufilatus*) — This small antelope species was restricted to gallery forests in the wooded savanna zone of Logone Oriental and Moyen Chari prefectures. The population, if it exists, does not appear to be large.
- Grey duiker (*Sylvicapra grimmia*) — This small antelope species was, until recently, widespread throughout the savanna zone of southern Chad. Its total population today is not thought to be abundant overall.
- Bushbuck (*Tragelaphus scriptus*) — This species normally is confined to areas with sufficient cover near permanent water (i.e., gallery forest). Once locally common, total numbers today are unknown.
- Buffon's or western kob (*Kobus kob*) — This species occurs along permanent watercourses within the savanna zone. It may still possibly occur on isolated floodplains in less populated areas.
- Roan (*Hippotragus equinus*) — This species exists in moderate numbers throughout most of the savanna zone of southern Chad, but has been eliminated from densely populated regions.
- Oribi (*Ourebia ourebi*) — This species was once widespread in the southern savannas of Chad, south of latitude 11º north.
- African elephant (*Loxodontia africana*) — Some elephant habitat exists within the Laramanay Reserve, and there may be some use of this area by seasonally migrating elephants. Elephants occur in the Mbéré Rift Valley, the forest in the region east of the Sanaga River, and in the vicinity of the Campo Reserve in Cameroon.
- African linsang (*Poiana richardsonii*) — This species appears to be very rare in the Cameroon Atlantic littoral evergreen forest and are threatened by continued hunting pressure.
- Gorillas — while uncommon, can be observed in the Semideciduous Forest off the road between Deng Deng and Bélabo.

The following sensitive bird species have the potential to occur in the study area:

- River prinia (*Prinia fluviatilis*) — This bird species was known only from waterside vegetation in a few localities in southern Chad (Chappuis, 1974). It prefers marshy floodplain vegetation for nesting and foraging.
- The Mbéré Rift Valley is not exceptionally rich in bird species, but it is possible to find several species of eagle. The rare Abyssinian calao might be present in the zone, as well as the big bustard.

In addition to the above, there are wildlife species whose status in Chad is thought to be reasonably secure at present, either within or outside existing parks. These species are partially protected under Article 25 of Chadian Wildlife Legislation. They include:

- Antbear, Aardvark (*Orycteropus afer*) — The status of this species is uncertain. It is a nocturnal animal relatively widespread in savanna areas where termite species occur.
- Serval (*Leptailurus serval*) — This felid is a hardy survivor in floodplains and near rivers.

- All vultures (*Gyps* and related genera) — All species currently appear to be stable, but the white-headed vulture (*Gypohierax angolensis*) is the least common.
- Cattle egret (*Bubulcus ibis*), little egret (*Egretta garzetta*), yellow-billed egret (*Egretta intermedia*), and great white egret (*Casmerodius alba*) — These species are widespread to occasional along rivers.
- Marabou stork (*Leptoptilus crumenifer*) — This species is common near water.
- Saddlebill stork (*Ephippiorhynchus senegalensis*) — This species is occasionally found along rivers, lakes, and open flooded areas.
- *Borassus aethiopum* — a threatened endangered tree.

Some species are still numerous in the Semideciduous Forest areas of Cameroon, but are beginning to decline in numbers. These include the bongo (*Boocercus euryceros*), blue duiker, chevrotain, water chevrotain, several monkey species (e.g., potto, galago, colobus, and chimpanzee), African ground squirrel (*Euxerus erythopus*), caracal, serval (Felis serval) and golden cat (*Felis aurata*). This decline is due to hunting pressure and loss of habitat from human activity. The warthog is not seen frequently and lion, leopard, and spotted hyena, though once present, apparently have disappeared from the region.

Archaeological and Sacred Sites

Sacred sites would pose a problem because they are not identified easily by outsiders. On the other hand, local people state that they would be more than willing to identify such sites to contractors in advance of response work crews and to move sacred objects to new sites whenever possible.

There is a strong prohibition against the disturbance of physical remains (buried in household compounds; in most villages, cemeteries are reserved for the burial of “strangers”). If absolutely necessary, ancestral remains may be moved to another site. This, however, has to be carried out in close consultation with the owners of the remains and be accompanied by certain rituals that should be performed by the descendants themselves.

Another issue involves local religious beliefs. Many areas are considered to merit “special handling”. In a fishing village in the peri-urban area of Kribi, for example, a water spirit is believed to exist that needs regular appeasement. In other areas, forest spirits frighten people from certain areas and cast their curses on individuals who might try to dare the spirits. The appeasement of spirits involves certain essential rituals that are performed by the local “notables”. In most of the “spirit culture” areas, locals believe that if projects do not do “what is necessary” they are doomed to fail. An implication of this sort of belief is that if these rituals are not performed in the manner considered adequate by the local knowhow, project-related accidents, no matter how minor, are likely to be attributed to spirits that are “taking revenge” on those who showed them disrespect. It is estimated that half of the labor force may refuse to work if accidents are attributed to the violation of certain rituals, especially if they feel physically or spiritually threatened.

It is essential to note that most sacred areas are neither clearly marked nor easily identifiable. In fact, they might be known only to the very small groups that perform their rituals there; it is therefore important to verify the presence of such places in each area when making response operations decisions.