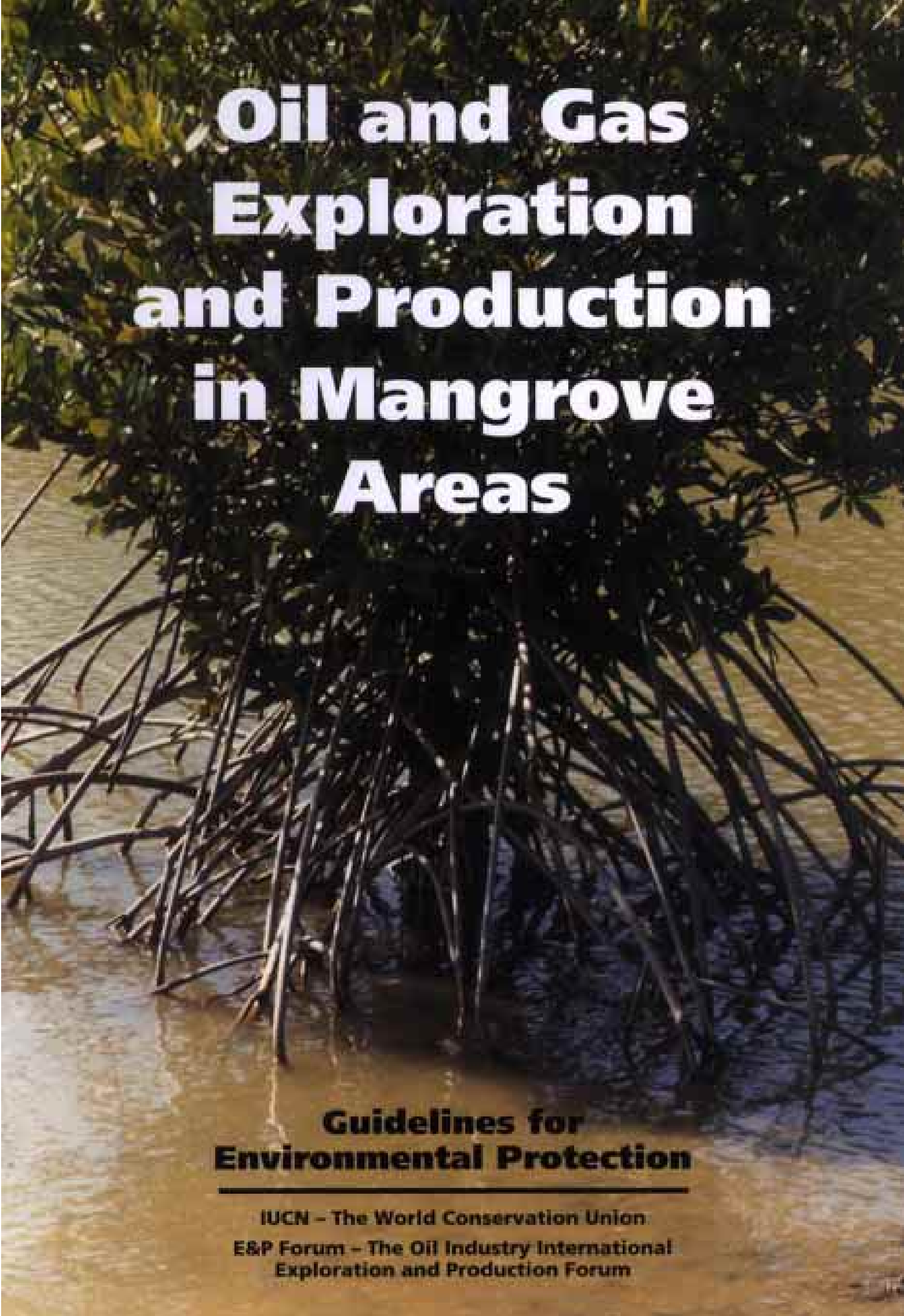

Oil and Gas Exploration and Production in Mangrove Areas

Guidelines for Environmental Protection

IUCN – The World Conservation Union

E&P Forum – The Oil Industry International Exploration and Production Forum

IUCN—The World Conservation Union

Founded in 1948, IUCN—The World Conservation Union—brings together States, government agencies and a diverse range of non-governmental organisations in a unique world partnership: some 720 members in all, spread across 123 countries.

As a Union, IUCN seeks to serve its members—to represent their views on the world stage and to provide them with the concepts, strategies and technical support they need to achieve their goals. Through its six Commissions, IUCN draws together over 5000 expert volunteers in project teams and action groups. A central secretariat coordinates the IUCN Programme and leads initiatives on the conservation and sustainable use of the world's biological diversity and the management of habitats and natural resources, as well as providing a range of services. The Union has helped many countries to prepare National Conservation Strategies, and demonstrates the application of its knowledge through the field projects it supervises. Operations are increasingly decentralised and are carried forward by an expanding network of regional and country offices, located primarily in developing countries.

IUCN seeks above all to work with its members to achieve development that is sustainable and that provides a lasting improvement in the quality of life for people all over the world.

The E&P Forum

The Oil Industry International Exploration and Production Forum (E&P Forum) is an international association of oil companies and petroleum industry organisations formed in 1974. It was established to represent its members' interests at the International Maritime Organisation and other specialist agencies of the United Nations, and to governmental and other international bodies concerned with regulating the exploration and production of oil and gas. While maintaining this activity, the Forum now concerns itself with all aspects of exploration and production operations, with particular emphasis on safety of personnel and protection of the environment.

As of 1992, the Forum has 52 members made up of 38 oil companies and 14 national oil industry associations, operating in 52 different countries.

The work of the Forum covers:

- monitoring the activities of relevant global and regional international inter-governmental organisations;
- developing industry positions on issues;
- advancing the positions on issues under consideration in international organisations, drawing on the collective expertise of its members; and
- disseminating information on good practice through the development of industry guidelines, codes of practice, checklists, etc.

IUCN/E&P Forum Collaboration

IUCN and the E&P Forum have collaborated to produce these Environmental Guidelines for use by industry, authorities and individuals involved with oil and gas exploration and production in mangrove areas. The Guidelines were prepared by a working group of representatives from the Conservation Services Division of IUCN and the E&P Forum. The IUCN team consisted of Jeremy Carew-Reid, Paul Driver, Ron Bisset, David Stone, Claire Santer, Peter Burbridge, Jim Davie and Enrique Lahmann. The Forum formed a task force which was chaired by N. H. Wright (Shell) with the following members: G. H. Norris (Amerada Hess), Ms J. M. Bruney (Exxon), M. T. Stephenson (Texaco), A. Loppinet (Total) and A. D. Read (E&P Forum).

These Guidelines constitute report number 2.54/184 in the list of E&P Forum publications.

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Preface

Mangroves play an important role in sustaining the economic and social welfare of coastal nations. These wetland forest ecosystems generate a diverse range of renewable resources that can be harvested indefinitely if properly managed. Mangroves also play a valuable role in supporting fisheries, and in protecting coastal communities and agricultural land from coastal storms, tsunamis and other natural hazards.

Under the Ramsar Convention (see Appendix II) wetlands, including mangroves, are recognised as being of national and international importance. The 1992 United Nations Conference on Environment and Development (UNCED) stressed the importance of conserving mangrove forests and developing their renewable resources in a wise and sustainable manner. The direct implication of these statements is that the functions of mangroves, in terms of supply of renewable resources, should not be threatened. If national economic imperatives require development in or near mangroves, then such development must be undertaken in a manner which minimises, to the greatest possible extent, damage to the mangrove system(s).

In some coastal regions, oil and gas deposits are found in geological structures underlying mangrove and associated coastal ecosystems. With careful planning and management, oil and gas resources can be developed without causing significant environmental damage to mangroves or imposing negative economic or social impacts on local communities. A working party from the E&P Forum and IUCN—the World Conservation Union—has prepared this guide to assist people from the oil industry, and officials, to plan for and manage the exploration and production of oil and gas resources found in mangrove areas in a manner that minimises potentially adverse environmental impacts. It is hoped that these practical guidelines will serve the international community well in achieving economically and environmentally sound use of oil, gas and mangrove resources.

Chapter 1

Introduction

Purpose of these Guidelines

Oil or gas exploration and production operations have the potential to cause significant effects to the structure and function of mangrove ecosystems. It is both easier and cheaper to avoid such effects through good planning than to try to reverse them once they have happened.

The purpose of these Guidelines is to provide practical direction to achieve conservation of mangroves and enhance protection of marine ecosystems during oil and gas exploration and production activities.

Not all the measures discussed in these guidelines will necessarily be appropriate to all forms of petroleum operations in all regions. Site-specific measures will need to be determined by the nature of the proposed operations and the sensitivity of the mangrove systems.

These guidelines represent internationally acceptable practices for oil and gas operations in mangrove ecosystems. In practice, however, specific requirements and standards for particular areas will have to be determined between the operating company and the appropriate authorities in the host country, taking account of the nature of the proposed operations and the sensitivity of the mangrove systems.

Overview of Mangrove Ecosystems

Mangroves are forest ecosystems specially adapted to saline soil and water conditions. They grow along sheltered coastlines of most tropical and subtropical regions. They may colonise the banks of major rivers up to 100km inland. Some 60 species of trees, many associated plants and thousands of species of mammals, birds, fish and invertebrates have been recorded from different mangrove forests.

Not all mangroves are the same. Species composition and the forest characteristics are dependent upon factors such as:

- climate;
- coastal landform;
- tidal range;
- availability of fresh water; and
- soil type.

In general, mangrove forests in humid tropical areas with relatively flat coastal plains will be large in area, contain a diverse range of species, and form a dense forest cover. In more arid areas (with a greater range of air and water temperatures) and on coastlines with narrow coastal plains and/or on rocky coastlines, the area, diversity, and density will be less. The range of species is also dependent upon the location, with greater species richness in eastern areas (notably South-east Asia) than in West Africa and the Americas.

Mangrove forests are highly productive ecosystems with many important environmental, social and economic functions. More than 70 major uses of mangrove plants have been identified, ranging from timber extraction to the preparation of medicines (see Tables 1 and 2).

Table 1. Products from Mangrove Plants

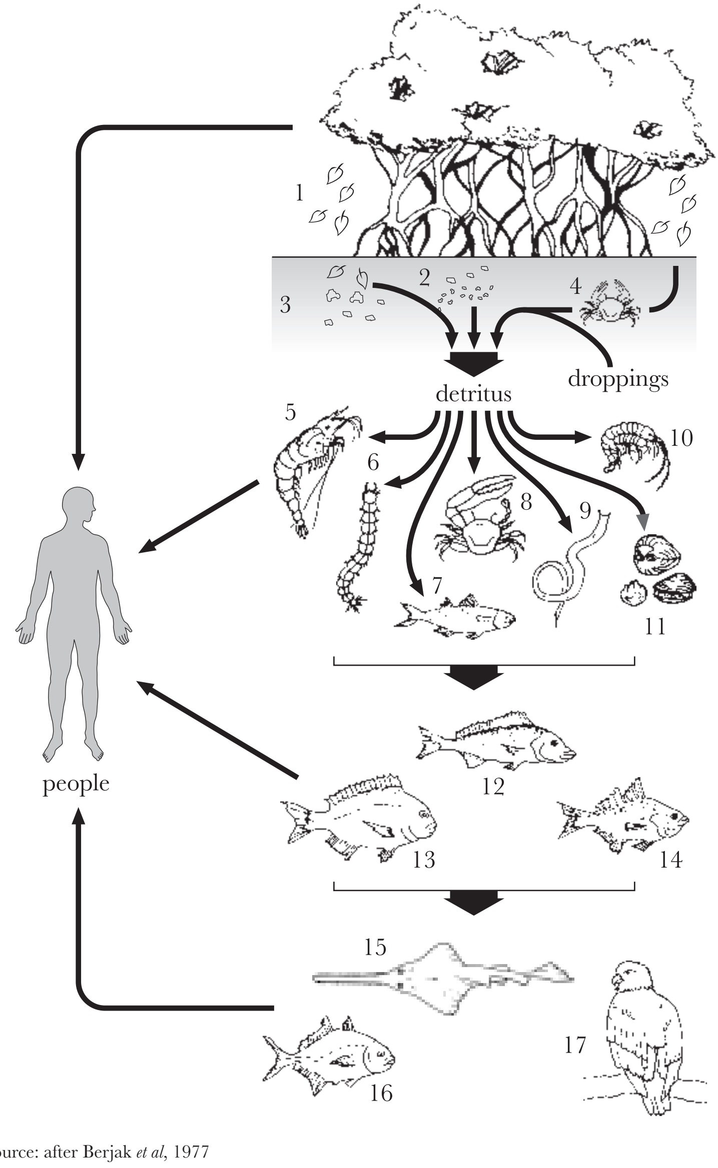
USES	PRODUCTS
Fuel	Firewood for cooking, heating; firewood for smoking fish; firewood for smoking sheet rubber; firewood for burning bricks; firewood for baking bread; firewood for drying rice; charcoal
Construction	Timber for scaffolding; timber for heavy construction (bridges, etc.); railroad ties; mining pit props; deck pilings; beams and poles for buildings; flooring, panelling; boat-building materials; fence posts; water pipes; chipboard; glue
Fishing	Poles for fish traps; fishing floats; fish poison; tannins for net preservation; breeding and nursery grounds
Agriculture	Fodder; compost/mulch
Paper production	Paper of various kinds
Food, drugs and beverages	Sugar; alcohol; cooking oil; tea substitutes; dessert topping; condiments from bark; sweetmeats from propagules; vegetables from propagules, fruit or leaves; cigarette wrappers; medicines from bark, leaves and fruit
Household items	Furniture; glue; hairdressing oil; tool handles; rice mortar; toys; matchsticks; incense
Textiles and leather production	Synthetic fibres; dye for cloth; tannins for leather preservation
Other	Packing boxes

Source: after Saenger *et al*, 1983

Important environmental functions of mangroves include:

- control of coastal erosion;
- stabilisation of sediments;
- protection of adjacent coral reefs from suspended solids;
- protection of coastal land uses from ocean storms; and
- the provision of feeding, nursery and breeding areas for commercially important fish, crustaceans, molluscs and other aquatic wildlife (see Figure 1).

Figure 1. Interdependencies Within the Mangrove Ecosystem



Microbial decomposers and herbivores

1. Leaves
2. Algae
3. Fungi, protozoa, bacteria
4. Sesarmid and grapsid crabs

Detrivores

5. Shrimp
6. Insect larvae
7. Mullet
8. Fiddler crabs
9. Worms
10. Amphipods
11. Bivalve molluscs

Small carnivores

12. Grunters
13. Emperors
14. Pony fishes

Large carnivores

15. Sawfish
16. Trevallies
17. Sea eagle

Source: after Berjak *et al*, 1977

The value of these goods and functions is often underestimated. Owing to the wide range of services provided by mangroves, many different and often diffuse groups depend upon them in some way. Examples include:

- fishermen harvesting fish, crabs, shrimps, and other species which depend upon mangroves for part of their life cycle;
- farmers whose crops are protected from coastal storms by the buffer function of mangroves; and
- shipping and navigation authorities which benefit from mangroves controlling sedimentation and coastal erosion that could otherwise alter navigation channels.

Table 2. Products from Mangrove Ecosystems

SOURCE	PRODUCTS
Finfish (many species)	Food; fertilizer
Crustaceans (prawns, shrimps, crabs)	Food
Molluscs (oysters, mussels, cockles)	Food
Bees	Honey; wax
Birds	Food; feathers; recreation (bird-watching, hunting)
Mammals	Skins; food; recreation
Reptiles	Food; recreation

Many environmental functions are undervalued until they are lost with the destruction of mangroves. The natural control of coastal erosion is, for example, often not appreciated until an engineering solution is sought to combat erosion following the clearance of mangroves. Experience has shown that the construction of coastal defences along former mangrove coastlines can be extremely expensive. Planners and resource managers should plan to avoid environmental damage to mangroves which can result in disruption of the economy and the social welfare of local people.

General Guidelines

Operations should be planned and operated in a manner that avoids or, where unavoidable, minimises direct or indirect adverse impacts on the mangrove environment. Deforestation and disturbance of the mangrove ecosystem should be limited through the following measures:

- minimal use of mangrove forest;
- minimal interruption of freshwater flow to mangroves;
- minimal alteration of tidal water flow to and within mangroves;
- minimal disruption to vegetation;
- minimal disturbance to soils;

- maintenance (where possible) of buffer strips along coastlines, rivers, streams and creeks; and
- control of environmental pollution.

In order to take into account the fragile nature of mangrove ecosystems (discussed in Chapter 2), the operating company should endeavour to reduce the potential impact of oil and gas operations on mangroves by:

- careful planning of seismic surveys, exploratory drilling and the provision of attendant facilities;
- selecting techniques and equipment which will minimise the need for supporting infrastructure inside the mangroves; and
- careful monitoring of activities to identify unexpected impacts at an early stage.

Two of the principal causes of the loss of mangrove are over-exploitation of mangrove timber and the conversion of mangrove areas to aquaculture ponds or agriculture. The operating company should consider access options which minimise the risk of encouraging increased access to mangrove areas, subsequent human colonisation, and land reclamation. The establishment and enforcement of mangrove conservation policies is primarily the responsibility of local government. Coordination with local authorities to minimise ensuing colonisation of mangroves is essential. It is in the interest of the operating companies to encourage relevant authorities to take steps to control pressures on mangroves. It must be recognised, however, that colonisation and commercial activities by the local population cannot be effectively controlled by operating companies alone. Government action should complement measures taken by the operating company to ensure that operations do not result in unnecessary adverse environmental, social, or economic impacts.

Legislation

As a minimum, the petroleum industry must adhere to local and national government rules, regulations, and policies, or apply responsible standards where such regulations do not exist or are not implemented. Some of the regulations will relate to land activities, others to marine. The petroleum industry should encourage public authorities to integrate their policies in line with the principles underlying the 1971 Wetlands (Ramsar) Convention (see Appendices I and II).

Chapter 2

Major Features of Mangrove Forests which can influence the Planning and Implementation of Oil and Gas Operations

Features

Mangrove forests differ from other forest ecosystems in a number of ways that have a direct bearing upon oil and gas operations:

- mangroves are generally located in dynamic environments with major daily and seasonal fluctuations in water levels. Essentially they are wetlands which are subject to constantly changing flows of fresh and salt water. The duration and depth of inundation, a major feature of mangroves, depends upon seasonal variations in rainfall, land-management practices in upstream areas, and tidal range;
- intertidal environments are typically recent and subject to rapid change through erosion, sedimentation or changes in sea level. Before beginning any operation at a mangrove site it is critical that the direction and rate of natural change in the environment is understood and that operations are designed to avoid any significant alteration of these natural processes;
- mangroves can be found on many different forms of soil, ranging from deep peat to poorly consolidated sands, silts and clays. Soil conditions can also vary considerably over short distances and the load-bearing capacity of the soil can be highly unpredictable;
- marine clay soils with a potential to generate acid sulphate are common. Where present, the depth to the acid layer can vary from a few centimetres to more than 1m. If these soils are exposed to the air (as the result of dredging channels, digging holes, or removal of surface materials), sulphuric acid is released and the pH of surrounding waters and soils can fall rapidly to below 2.5. Once the acid is liberated, it is extremely difficult and very expensive to reverse the process. The impact of acid drainage on fisheries, irrigation and other activities can be severe and may cause major economic loss and, in extreme cases, abandonment of lands. The creation of acid conditions increases the maintenance requirement for equipment and hinders site restoration when operations cease;
- it is critical to maintain freshwater flows and normal tidal patterns in mangroves. Significant damage to vegetation (as well as the general ecosystem) and its ability to regenerate can be caused through disruption of water flow or circulation. Although mangroves are salt-tolerant they need fresh water, which is usually provided by sub-soil seepage. Actions such as road construction, diversion of water, dredging and drainage are major threats because they disrupt surface water flows. Dredging can alter intertidal hydrology over a much wider area than the immediate site and is potentially a serious problem;
- the productivity of the mangrove forest system depends on a dynamic balance among water flows, sedimentation, erosion and species composition. A significant change in any one of these factors can create conditions which may result in changes in the vegetation and land form and which may also have a direct effect on adjacent ecosystems and land use activities. For example, dredging can create erosion at the seaward edge of the mangrove forest and within areas adjacent to the dredged channel. Once the fine balance is disrupted by dredging, it can stimulate a series of other changes. Increased rates of erosion will make the water more turbid, reduce primary production in estuaries and increase the rate of siltation of navigation channels or coral reefs; and

- the functional significance of mangrove ecosystems to environmental, economic and social well-being extends far beyond the boundaries of the site. This needs to be carefully considered in assessing the sphere of the impact of planned activities.

Processes and Functions

The following environmental processes should be protected by environmental management measures:
- transportation of fresh water, nutrients, sediments and other materials to mangroves from upstream areas;
- production of propagules (seed sources);
- the balance between sedimentation and erosion of substrate;
- the accumulation and drainage of salt and organic matter in the soil; and
- interchange of inorganic and organic materials, plants and animals between the mangrove system and surrounding tidal creeks, estuaries, lagoons and other water bodies.

These processes are intricately linked to the following functions which should be maintained:
- stabilisation of sediments transported from upstream areas to the coast, as well as those sediments being transported in the littoral environment;
- reduction of suspended solid levels in coastal waters, particularly over corals;
- control of coastal erosion;
- protection of coastal land and waters from storms and consequent tidal surges;
- transformation of dissolved nutrients from terrestrial sources into materials which help sustain coastal and marine food webs;
- removal of polluting substances from the water column by processes such as entrapment of contaminants by sediments;
- feeding, spawning and nursery grounds for riverine, coastal and marine fish, crustaceans and molluscs;
- protection of groundwater resources by reducing salt concentrations in surface water percolating into the ground; and
- dissipation of flood waters and reduction of flood water currents.

Major products of mangroves, their uses, and the main economic sectors involved are given in Tables 1 and 2. These uses are dependent upon the maintenance of the processes referred to above. Although these Guidelines cannot cover all of these in detail, some additional information is provided in the following section on one of the most obvious uses of mangroves—fisheries—and how this relates to current issues. Additional information may be obtained from sources listed in the Bibliography.

Fisheries

Mangroves are of critical importance to local fisheries. Three different forms of fisheries may be found in, or adjacent to mangroves:
- commercial fisheries;
- small-scale fisheries employing non-capital intensive methods; and
- aquaculture, consisting of pens and cages for finfish; rafts and culture beds for mussels; poles, blocks or culture beds for oysters; or ponds for the culture of fish or shrimp.

The main direct impact of oil and gas operations on fisheries is likely to be the disturbance of spawning and nursery activities of finfish. The potential impact from operations on fisheries can be minimised by avoiding disturbance of the mangroves and interference with fishing activities. Fisheries and aquaculture may be affected directly by seismic work (see Chapter 4).

Specific attention should be paid to:

- establishing and mapping the normal level, types and patterns of fishing activity well in advance of operations;
- determining the seasonal patterns of spawning and inshore movement of juveniles of species that depend on the mangroves;
- notifying fishermen's groups and aquaculture operators of the timing of seismic operations; and
- incorporating the needs of fisheries interests into management plans for subsequent production operations.

These will be accomplished through liaison with fisheries or other relevant authorities. Acquired information can form a baseline for subsequent detailed discussions on potential interference with fishing. Where appropriate (for example, where people's livelihood could be jeopardised), important traditional fishing locations should be kept confidential.

Chapter 3

Environmental Management and Planning

Environmental considerations should be taken into account throughout the project planning process, from project conception to project closure, decommissioning, and site restoration. Environmental management is a line management responsibility and appropriate resources should be made available by the operating companies to implement the necessary procedures and ensure that they are effective in minimising impact.

Policy and Principles for Mangrove Areas

All possible steps should be taken to minimise disturbance of mangrove ecosystems by oil and gas operations. Where disturbance is unavoidable, operations should be designed to minimise permanent impact upon major environmental processes. Restoration objectives should first consider the potential for rehabilitating the original condition and functions of the ecosystem. Proposed mitigation procedures should be planned using expert advice. The following steps should be taken in planning for environmental protection during operations.

Environmental Profile

An environmental profile of the proposed site should be produced when considering the acquisition of an exploration concession. The objectives of an environmental profile are to:

- assist planning and control of seismic surveys and exploration drilling activities;
- provide background to consultations with external bodies;
- select sites avoiding areas of high sensitivity;
- schedule activities avoiding sensitive periods;
- modify or select equipment and techniques to minimise adverse impacts; and
- identify specific protection measures.

The environmental profile should provide:

- a review of applicable regulations, land-use patterns and other development proposals likely to affect the area;
- available environmental data, identification of national parks, other protected and environmentally and culturally sensitive areas;
- an identification of sensitive issues;
- an appreciation of existing effects (arising from local knowledge of impending oil and gas related activities in an area) and potential impacts; and
- an assessment of social and economic uses of mangroves in the proposed concession area.

The environmental profile will be the basis for any additional studies.

Preliminary Environmental Impact Assessment (EIA)

A preliminary EIA report should be prepared before beginning any activity on the site. This builds on the findings of the environmental profile and examines the issues in greater detail. Site specific surveys and data gathering will be required, particularly where sensitive issues have been identified. The preliminary EIA will further define and quantify sensitive issues and identify additional environmental, social and cultural issues. The purpose of this exercise is to identify the sensitivities of the area, including the presence of endangered species, water flow and sedimentation patterns, and to recommend environmental control and protection measures. The final document is prepared in consultation with appropriate authorities and organisations, environmental specialists or institutes, indigenous populations and the general public. Acquired data should then be used to modify the plan of operations, if necessary.

In most cases this initial study will indicate the need for a full or comprehensive EIA (see below). In some cases, however, the preliminary EIA will be sufficient.

All contracts should clearly state the environmental protection requirements for all stages of the development, and require contractors to prepare an environmental plan including protection procedures, training of staff, contingency arrangements and regular review of performance (audits).

Environmental Impact Assessment (EIA)

The preparation of a comprehensive EIA report, for all but very limited exploration activities and for all production activities, is a fundamental part of environmental planning and should be viewed as an essential part of the development plan.

The objectives of an EIA are to:

- identify sensitive components of the existing environment within the project area and its environs;
- assist project design and planning by identifying those aspects of location, construction, operations and decommissioning which may cause adverse environmental, social, health and economic effects;
- recommend measures during construction, commissioning and operations to avoid/ameliorate these effects and/or increase beneficial impacts;
- identify the best practicable environmental option. This requires that the environmental implications of all available development options be evaluated. The chosen option should result in the least environmental damage, in balance with other social, health and economic considerations, and be consistent with the prevailing regulations;
- estimate and describe the nature and likelihood of environmentally damaging incidents to provide a basis for contingency plans;
- identify existing and expected environmental regulations that will affect the development and advise on standards, consents and targets;
- identify any environmental issues and concerns which may, in the future, affect the development;
- recommend an environmental management programme for the life of the development, including compliance, monitoring, auditing and contingency planning; and
- provide the basis for support and control documentation and consultation with regulatory and non-regulatory authorities and the public.

The EIA report should include the following:

- description of the nature, quality and dynamics of the existing environment;
- project description, including alternative proposals;
- description of the regulatory regime;
- identification of the significant potential impacts of the development and its alternatives;
- prediction and characterisation of each predicted impact for all alternatives;
- recommended alternative actions or mitigative measures to minimise adverse impacts and enhance any environmental benefits;
- assessment and evaluation of unavoidable impacts;

- environmental management strategy and plan;
- decommissioning, reclamation and restoration plan; and
- proposed monitoring programme.

The EIA should evaluate the existing environment and the field exploration or development plan, identify potential adverse impacts, and recommend mitigation actions to avoid or minimise them. They should include a decommissioning plan to be implemented upon completion of the project. The findings of the EIA can, at each stage, be incorporated into the next phase of the project design. Any changes in project specification should be re-evaluated within the EIA. The end product will be a comprehensive and detailed environmental management plan, which will include recommendations for monitoring and auditing. An essential part of this process will be the development of an oil spill contingency plan. When more than one operator is involved in an area, joint plans should be formulated, whenever possible, to avoid omission, duplication of effort and cumulative impacts and to provide for cooperative oil spill response.

Environmental Management

There may be a need for environmental advice from specialists on exploration, construction, production, and decommissioning, depending on the scale of the project. Such advice will assist line management in ensuring that the environmental management plan is formulated and implemented and that appropriate liaison is maintained with both statutory and local authority agencies and with local communities.

Environmental Monitoring

The objective of an environmental monitoring programme is to identify the actual impacts arising from the project so that remedial measures can be taken as soon as possible. The elements to be monitored include:

- air quality;
- water quality;
- maintenance of environmental resources;
- land-use and clearance;
- hydrological integrity;
- erosion and sedimentation associated with dredging; and
- immigration.

The objectives of monitoring programmes may vary, depending on the activity and operations in progress, but will include some or all of the following elements to:

- check the overall effectiveness of design and operational procedures in protecting the environment;
- comply with regulations, standards, planning consents and compliance programmes;
- identify sudden or long-term environmental changes;
- measure physical disturbance and subsequent recovery following rehabilitation;
- study impact and recovery following accidents and incidents;
- confirm that environmental protection equipment and procedures are effective; and
- compare actual impacts with those predicted in the EIA.

Environmental performance can be monitored by:

- measuring and recording quantitative source information (amounts and concentrations of emissions, effluents and wastes against consents and standards);
- measuring and recording environmental quality in the vicinity of a site (ecological/biological, physical and chemical analyses);
- measuring and recording qualitative information (implementation of environmental

management measures, local liaison activities, provision of new equipment or process modifications to reduce environmental impact);

- impact monitoring—assessment of the extent and severity of any impacts, demonstration of relationships between observed and predicted impacts (from the EIA), demonstration of relationship between observed impacts and operational activities;
- measuring and assessing re-instatement and recovery success, and the effectiveness of any mitigation measures; and
- documentation—project reports, records and photographs.

To verify the effectiveness of control measures, appropriate environmental monitoring and recording should take place during exploration, construction, and operation of oil production facilities. There may be legal requirements for appropriate monitoring to be performed.

The final and essential element of any monitoring programme is feedback and action. Any indication that conditions are abnormal should be reported, action taken to discover the cause, and adequate solutions implemented.

Environmental Audit

Environmental auditing should be conducted by the operator to ensure that applicable environmental standards are being maintained and that company policies and the environmental management plan are being followed. Enforcement of company policy, procedures and standards is a line management responsibility. Environmental audits should be undertaken periodically at each operation.

The environmental audit process provides an assessment of environmental performance during all phases of project development, but particularly of the operational phase. It acts as an internal control process to ensure that environmental protection and management procedures are being enforced rigorously. Each environmental audit will:

- evaluate line management systems, operations, monitoring practices and data, procedures and plans;
- check the accuracy of the EIA predictions and ensure that mitigation and monitoring recommendations are being implemented;
- identify current and potential environmental problems;
- recommend improvements to the management of the operation;
- evaluate compliance with regulatory requirements; and
- evaluate company policies.

Chapter 4

Environmental Management of Field Operations in Mangrove Areas

At each stage in the development of an oil and gas exploration and production project there are specific management procedures and actions which can be implemented to prevent potential harm to mangroves and minimise unavoidable impact. By following these guidelines mangrove ecosystem functions can be maintained or restored (see Table 3).

Exploration Surveys

Exploration surveys are designed to collect geological information about subterranean rock formations to determine the most likely location of hydrocarbon reserves. The existence of exploration concessions which include mangrove areas, does not necessarily mean that exploration activities will conflict with the conservation of these areas. Exploration is usually conducted in two ways: remote operations and local seismic surveys.

Remote Operations

Oil and gas exploration using satellite remote sensing and aerial geomagnetic survey techniques is unlikely to conflict with conservation of mangroves. Data collected using remote sensing may provide useful information about geological structures in both protected and unprotected areas and indicate where more extensive on-the-ground exploration may be possible. Such data can contribute to optimal planning of any subsequent ground operations.

High resolution satellite photographs or radar surveys can be particularly valuable for updating topographic maps, especially for the paths of rivers and the coverage and types of vegetation. Photographs, with appropriate ground site correlations, also provide information on seasonal vegetation cover and primary drainage patterns, which must be maintained. Time series photographs permit an assessment to be made of existing changes in the condition and extent of mangroves. Limited fieldwork may be necessary to calibrate and assist the interpretation of satellite imagery.

Low level flights should be scheduled so that disturbance of breeding, migration, or growth patterns of sensitive species is minimised. In some countries, legislation exists controlling low level overflights in protected and sensitive regions.

Local Seismic Surveys

As part of the planning process seismic activities in mangrove areas should be minimised. Remote sensing techniques can be used, in the early stages, to adjust locations and to minimise both the extent and the impacts of seismic activity, especially on modifications to drainage patterns.

During initial investigations, prior to any concession award, an Environmental Profile should be prepared as discussed above. If the geological structures show economic promise, a Preliminary EIA report should be prepared to define environmental constraints. If a concession is obtained, exploration planning will continue and will address environmental controls and methods to be used during seismic operations. These controls and methods will be derived from the environmental concerns identified in the Preliminary EIA and may form part of the EIA, if required.

Table 3. Summary of the Exploration and Production Process

PROCESS	POSSIBLE EQUIPMENT	SOURCES OF IMPACT
AERIAL SURVEY Favourable landscape features?	Satellite for remote sensing Aircraft for aerial photography and geomagnetic surveys	Low-level flights
SEISMIC SURVEY Reservoir geology present? (Potential trap?)	Vibroseis equipment, air guns or explosives Base camps	Access methods Line cutting Shot-hole drilling Effects of explosions Influx of labourers Waste disposal Changes in surface hydrology Erosion
EXPLORATORY DRILLING Hydrocarbon bearing formation?	Drill rig and equipment Drilling fluid system Base camp	Access methods Clearing for drill sites Influx of labourers Drilling fluid disposal Other waste disposal Accidental spills Changes in surface hydrology Erosion
APPRAISAL Field economical to develop?	Well-test equipment	Well-test fluid disposal
DEVELOPMENT AND PRODUCTION Reservoir exploitation with eventual decline; continued production becomes uneconomic	Drilling rig and equipment Drilling fluid system Larger base camp Well heads Equipment for artificial lift Separators and treaters Gas production plant Flowlines and pipelines Workover rigs Storage facilities Flares Re-injection equipment	Access methods Clearings for well sites 'Permanent' labour force Clearings for pipelines Drilling fluid disposal Produced water disposal Workover fluid disposal Other waste disposal Accidental spills Flare emissions Changes in surface hydrology Erosion
DECOMMISIONING	Equipment to plug wells Equipment to remove facilities	Physical disturbance from removal techniques Waste disposal Residual contamination

In either case, it may be possible to take advantage of the access obtained during seismic operations to gather site-specific environmental data. This may then be used in planning any subsequent exploratory drilling or field development.

The primary sources of impact from local seismic operations are:
- access methods;
- line cutting;
- base camps;
- influx of a large number of labourers;
- waste disposal;
- shot-hole drilling;
- explosions;
- noise;
- human immigration and settlement along access roads;
- erosion; and
- changes to drainage patterns.

The EIA should review potential impacts on aquatic and terrestrial life. The EIA process requires the ranking of environmental risks which incorporates both probability and significance. It is the goal of the operator to conduct the necessary seismic operations in a manner which prevents or minimises damage to the major environmental processes in mangrove areas.

Various seismic survey techniques exist for terrestrial and aquatic areas. In water, seismic surveys are usually conducted with acoustic energy sources such as air or water guns. On land, surveys may be conducted using either explosive sources or Vibroseis. This method requires the input of mechanical energy at specified points along a relatively straight line. This energy produces acoustic waves that are reflected by changes in the subsurface geological strata. The reflected waves are detected by sensors arranged along several kilometres of survey line (over several square kilometres in 3-D surveys) and recorded. In some mangrove areas, 3-D seismic surveys are conducted requiring lines spaced only a few hundred metres apart. Additional planning of minimum access is necessary in this type of survey.

Vibroseis techniques involve the use of heavy vehicles that require an access route approximately 4m wide and a solid base to support the vehicles. Vibroseis may be used in areas immediately adjacent to mangrove areas. The weight and size of Vibroseis equipment, however, will generally make it inappropriate for use in mangrove systems. Water techniques, such as air guns and water guns, usually require water depths of more than 2–3m and a large amount of ancillary equipment such as compressors. These techniques are typically employed using ships outfitted for this purpose, but can involve shallow draught barges. Water techniques are, therefore, not usually a viable option in shallow, complex, coastal systems such as mangroves. Thus, explosive techniques are most likely to be used in mangroves.

When using explosive techniques, consideration should be given to the amount of explosive and to the depth of the charge. In the soft, wet mangrove environment, it is likely that greater hole depth will be required to prevent surface cratering. It is more cost effective to drill holes (and load and tamp explosives) below the venting depth than it is to backfill craters afterwards, particularly because fill material may have to be imported. Shot holes should be plugged to prevent erosion, maintain surface hydrology and decrease the surface hazard to humans and wildlife.

Environmental considerations should also be applied to the planning of seismic lines. Seismic lines have proceeded, in the past, along a specific compass bearing. Where survey lines are used, the area cleared should be as narrow as practical—1.5–2m width is recommended as a maximum. Current practice is to deviate or 'dog-leg' the line where practical to reduce disturbance to vegetation and soils, to avoid destruction of large mangrove trees or threatened species, to reduce hydrological impacts and to screen the seismic line from access routes (which also reduces visual impact). Developments in seismic data processing allow a limited degree of flexibility in the precise siting and orientation of seismic lines which may potentially be exploited to minimise impact on mangroves. All route markers and other debris should be removed for proper disposal. The orientation of seismic lines along the direction of the flood tide may lead to excessive mangrove erosion. Such orientation should therefore be avoided. Where this is not possible, a mangrove buffer of 100m should be maintained at the seaward edge.

Access for Seismic Surveys

In remote coastal areas such as mangroves, access for seismic teams is usually either on foot or by small skiffs, airboats, or pontoons. The equipment is hand portable but may require helicopter logistical support. Safety considerations of helicopter use are of primary importance in the selection of access and transport modes in order to minimise risk exposure in the whole operation. The construction of helipads and drop zones along seismic lines may be necessary to meet safety and operational needs. The size and number of helipads and drop zones should be as small as possible, while maintaining safety standards. Consideration should be given to locating helipads and drop zones in natural clearings. They should be constructed with the goals of maintaining hydrology, controlling erosion and ensuring safety. Flight access routes and schedules should be selected to minimise noise impacts in sensitive areas, such as breeding sites.

Gaining access by vehicle to survey areas is likely to result in much more significant impacts, and vehicular access should therefore be minimised. Environmental impacts will result directly from the clearance of access tracks; where vehicular access is required for the transport of equipment, the access route should be made as narrow as possible. Clearing for shot hole drilling simply requires sufficient access for hand portable or larger types of shot hole drill rigs. Roads should not significantly alter the natural hydrology of the mangrove system and should maintain the features and functional characteristics of mangroves. Indirect impacts of roads may occur because of the increased accessibility of the mangrove system to local people. The advice and cooperation of any authorities responsible for local land-use should be sought.

Base Camps

Camp sites should be chosen with a view to use in subsequent operations. The preferred option in mangroves is a camp based on a barge which is self contained and moveable within the operational area. Where conditions are not suitable for a barge camp, a dry location should be chosen at which environmental impact will be acceptably low. Whenever possible, an existing clearing should be used for the dry camp. If a bulldozer or other heavy equipment were required to construct the camp, a construction plan of the site should be prepared, together with a restoration plan to be implemented once the project is completed. The use of heavy machinery should be strictly controlled and supervised.

Hunting, fishing, trapping and gathering of food resources by workers, when on- and off-duty, should be strictly prohibited. This prohibition should extend to the purchase of these items from the indigenous population by workers.

Advanced planning is essential in remote areas since all waste must be properly managed on-site. Provision should be made for mechanical sanitary systems for barge operations and portable septic tank systems for land-based operations. Discharges from such systems should be consistent with local regulations, if available. If not, World Health Organization or equivalent guidelines or standards should be adopted. Aqueous effluents should be disposed of properly. In the absence of specific regulations, the following recommendations should be observed:

- for over-water locations that are regularly flushed by tidal flows, the final effluent should be diluted with an equal volume of water, and discharged at least 1m below the surface during the ebb tide;
- there should be no chlorination of effluent discharges, unless this is required to protect public health; and
- for land locations, the final effluents should be disposed of through a soakaway system at least 150m from any surface water.

All waste materials from field operations should be brought back to the base camp for proper disposal. Disposal options include incineration, compaction and removal from site, and burial (especially for biodegradable materials), or any combination of these.

A safety data sheet should be maintained for all potentially hazardous materials, as well as supporting documentation for the transport, use and disposal of such materials. Used motor oil and filters from vehicles and generators should be removed from the area for proper disposal. Used motor oil should not be used for dust suppression on access roads. Disposal of chemicals and motor oil should be documented, including quantities involved and the disposal locations.

A plan should be prepared to prevent and contain accidental oil discharges or fuel spillages. All equipment should be fitted with drip trays. Stationary fuel storage facilities should have secondary containment. A barge camp should have sufficient oil containment booms and oil absorbent materials available on-site for use in case of a spill during fuel transfer operations. Consultation with the local authorities and local representatives will form an essential part of the development of contingency arrangements.

Final Audit and Restoration

Prior to the cessation of operations, the environmental impact of the seismic programme should be measured and recorded in order to evaluate the need for possible re-instatement or post-operation controls by authorities. A series of position-fixed photographs of seismic lines, camp sites and access routes provides a permanent time-fixed record of impact, which will assist in the re-examination of specific sites to measure recovery. Upon completion of a seismic programme, the agreed restoration plan (as specified in contracts) should be implemented. Before any restoration work is implemented, consideration should be given to further use of infrastructure by subsequent construction or drilling operations. Any access routes that will not be used during exploratory drilling or field development should be closed. This may require the introduction of physical barriers, removal of bridges, or replanting of cleared areas, in consultation with the authorities. Similarly, all camp sites not subject to further use should be restored. All disposal sites should be properly closed and a full disposal record maintained for each location. Non-biodegradable wastes should not be buried in mangroves because of the likelihood of their re-exposure in this dynamic environment. Consideration should be given to making the provision of a full record of post-operational impact—covering waste disposal and site inspections—a requirement in seismic contracts.

Exploratory Drilling Operations

Once seismic data have been processed and a prospect identified, exploratory drilling is conducted. To achieve minimum impact from exploration drilling, environmental planning must be applied from the conceptual to decommissioning stages. Decisions made at the conceptual stage will affect the characteristics of the operation and its associated impacts (Table 3). Once operations begin, strict environmental management and quality checks must be applied.

In order to determine the presence of economically recoverable hydrocarbons in the target formation, exploratory drilling of one or more wells is performed. Drilling should be planned and implemented in a manner that will minimise the overall impact and promote the restoration of the site. The time between identifying a prospect and drilling can vary from a few months to a year or more, depending upon the logistics and access requirements of the site.

Conceptual Stage

Planning access for drilling operations cannot be separated from site selection since there may be trade-offs with other aspects of the operation that will minimise the overall environmental impact. Likewise, waste disposal requires proper planning from the conceptual to decommissioning stages.

For most exploratory drilling operations in mangroves, the provision of access by causeways or by dredging ‘drill slots’ is the greatest cause of environmental impact. Direct impacts may result from mangrove clearance, drainage disruption, soil erosion, and general habitat instability. Indirect impacts may result from increased mangrove access for local populations. For these reasons, slim hole drilling, or directional drilling, from outside mangrove areas should be considered as an option. It should be recognised, however, that directional drilling cannot be universally applied.

Site Selection

A primary source of environmental impact in mangrove operations will be the preparation of the drill site and associated access. A plan for the post-operational re-instatement of the site should be prepared at the time the site is designed.

The precise location of a drill site is dependent upon the characteristics of the underlying geological formations. If the formations permit, there may be several possible site options to drill, thereby allowing a degree of flexibility in the choice of the site. In many cases, however, the area from which the prospect can be drilled is restricted to an area of less than 500m diameter. Directional drilling should be considered as one of a number of options to avoid or minimise damage to the mangroves. This may allow the location of the drill site to be displaced by up to 1km, depending upon the reservoir and geological characteristics. The relative costs of directional drilling set against the cumulative costs of dredging, hydrological controls, re-instatement and overall impact should be evaluated.

It should be recognised that the most appropriate exploration well site need not necessarily dictate the location of a future appraisal/production well site, should a discovery be made. Once it appears likely that production will follow, however, sites should be selected with a view towards their eventual use as production well sites in order to minimise overall impact (see ‘Drilling Operations’).

In an extensive mangrove area, it may be possible to locate the well site in a natural clearing or previously disturbed site. Excavation within the mangroves should be avoided to reduce the risk of erosion and interference with tidal flushing.

Access for Drilling Activities

Many of the same considerations relevant to seismic surveys (see 'Access for Seismic Surveys') will apply in the larger scale exploratory drilling phase. Construction of access routes to site locations and camps must be completed before drilling rig mobilisation. The average time for site construction is 2–4 months.

Seasonal environmental factors have an important bearing upon the type and timing of access construction. Factors that must be taken into account include monsoons, rainfall, storm surges, the navigability of rivers, minimum water depths, maximum water levels, currents, sand banks and tidal influences.

The existing infrastructure and the availability of road and water transport will affect the degree of additional construction required for the operation. When a series of wells is to be drilled in, or adjacent to, mangrove areas, significant reductions in construction, cost and impact can be achieved by incorporating flexibility into access schemes.

Water Access

Access has to be prepared not only for the drilling rig but also for supply and accommodation modules. The fragility of the environment necessitates advanced planning to ensure that suitable drilling and accommodation barges are available to minimise access requirements. This should include consideration of narrow gauge barges that reduce the need for dredging and that can negotiate difficult waterways more easily. Several types of drilling barge operations are shown in Table 4.

Dredging

If other forms of operation, such as directional drilling, are not feasible, dredging may be required. Any dredging operation must be carefully planned to minimise disturbance to mangroves and avoid consequent problems of erosion. Planning should be conducted in such a way as to facilitate subsequent rehabilitation of the site.

Table 4. Access Requirements for Drilling Operations in Mangroves (These are listed in order of increasing scale of access requirements)

DRILLING BARGE	ACCESS	CAMP/ACCOMMODATION
Small drill barge (minimum facilities)	Water	Land camp site
Small drilling barge (minimum facilities)	Helicopter	Land camp site
Small barges	Water/dredge	Camp/accommodation on separate barge
Drilling barge (deep draught)	Water/dredge	Barge with accommodation

Drilling operations in mangroves may involve the construction of a dredged 'slot' and an access channel. The drill barge may be a floating unit or a jack-up unit. If the latter is used, soil investigations must be conducted to ensure the load-bearing capacity of the soil is sufficient for the expected use.

Dredging involves deepening/widening an existing channel or cutting a new access channel. The dimensions of the channel are determined by the size of the barge used. During dredging operations, existing creeks are surveyed, widened and deepened where necessary. Sharp bends in access creeks are usually removed.

The depth of access channels and the drilling slot will depend on the water levels expected during dredging and drilling as well as clearance requirements for the draught of barges and boats. The use of shallow draught jet-barges can reduce the scale and cost of dredging activities, especially in areas where currents are fast and there are unpredictable changes in water levels.

Tree stumps are removed by drag line to a depth of 1–2m and spoil is usually deposited on the banks to form bund walls. Sediment is removed by cutter/suction dredger and deposited in mounds directly adjacent to the dredge channel. Disposal of dredge spoil at sea should only be considered if environmental resources such as coral reefs will not be impaired. This requires careful evaluation of the disposal location, the currents and the proximity of vulnerable resources. Spoil banks may extend more than 30m beyond the edge of the channel. The spreading of liquid spoil and the formation of bunds which prevent spoil from flowing back into the canal should be carefully controlled. The lateral spread landward of dredge spoil should also be controlled. The slopes of the canal banks should be set to prevent canal caving and the subsequent need for re-excavation.

Dredge channels will disrupt the natural hydrology of mangrove areas and may make them vulnerable to erosion. Compaction of the spoil by additional excavations can further damage the area. Deposited dredge spoil may destroy mangroves through direct burial (by smothering the pneumatophores), or by forming a barrier to water transport.

Disturbance of the soil may lead to changes in the pH of the soil and water that could lead to chronic deterioration of the quality of the mangroves (see Chapter 2). The soil characteristics should be surveyed in advance to ensure that the best engineering solution in environmental terms is selected, avoiding costly re-instatement.

Roads and Causeways

Access to the drill site may require the building of a road from land out into the mangroves. This can cause both direct and indirect impacts. Drainage disruption and soil erosion are primary considerations, because proper functioning of these systems depends on a dynamic flux of water, changing salinity, and movement of organic materials. Modification or impairment of the natural processes can cause both acute and chronic impacts.

Road construction is normally undertaken using local materials and occasionally using geotextiles (for example, polyethylene sheeting) and gravel. However, mangrove soil is usually unsuitable for road construction material. Causeway construction will require the excavation of borrow pits or the use of other suitable road-bed material which will have to be transported to the construction site from other areas. The siting of borrow pits and the manner of their excavation and subsequent re-instatement or use should be considered in the EIA. Excavation within the mangroves should be avoided.

The length of road/causeway constructed within the mangroves should be minimised. Proper engineering of road construction should avoid interference with natural flushing of the mangroves. Road construction should incorporate drainage for runoff water, including culverts and bridges, as required by local land and water conditions. The use of bulldozers or other track-laying vehicles on unconsolidated soils should be avoided. Low ground pressure construction vehicles should be used in their place.

Without a weather proofing surface, roads will rapidly become pitted, eroded, and degraded. Suitable surfacing materials should be applied in a manner that minimises erosion. It may be necessary to line the surface of the road with geotextiles to prevent erosion. Laterite (if locally available) could be used as a surface layer.

Timbered-surfaces are often used on soft and shallow embankments in swamp mangrove areas. Timbered roads consume large quantities of wood, however, and strict controls are required on the authorised source of suitable material. Where possible, the use of local timber should be minimised. Surrounding areas should not be cleared of timber. Instead, this should be purchased from an approved supplier or authorised forestry source in agreement with the authorities. The amount of timber to be used per square metre of road together with an estimate of the total amount of timber required for road construction should be specified in the environmental and civil engineering plans for the operation. These should be repeatedly checked during the operation. Recycling of timber matting will reduce the overall amount of timber required.

It should be recognised that once built, roads could remain as a means of access for many years. Highly engineered, strengthened roads would provide an access route for a longer period of time than simple compacted soil roads. At the end of operations, roads constructed for access to drilling sites should therefore be removed, blocked, or treated in a manner that is consistent with plans for the future use of the site, as agreed in the concession permit.

Aerial Roadways and Piled Roads

Roads on piles or aerial roadways may be used in some circumstances, providing that suitable soil conditions are available. Soil surveys are often required in mangrove areas to ensure appropriate piling. These types of roads allow transport of a land rig to the drill site while avoiding disruption of the local hydrology.

Airstrips and Helipads

Safety considerations of helicopter transportation for men and equipment will always be of paramount importance. In some instances helicopters may cause the least environmental impact, compared to road building or dredging. Flyways for helicopters will, however, still have to be cleared. Other disadvantages of helicopters include higher costs for transportation, and safety risks in flight operations. In all cases, the total amount of clearance necessary for the use of helicopters should be carefully mapped and rigorously compared with corresponding clearance for alternative access routes.

Drilling Options

Drilling in mangroves may involve the use of a land rig or helirig on a constructed land site, a jack-up rig floated into the site, or a drilling barge. Each type of operation has a different type and intensity of impact resulting from different access requirements. To avoid/reduce impacts on the mangroves, it may be possible to employ directional drilling techniques. Slim hole drilling offers the opportunity, not only of reducing the scale of equipment and transport costs, but also reducing the volume of drilling waste. In all cases, drilling contracts should specify environmental requirements and include preparation of an environmental plan identifying environmental protection, waste management control, monitoring, recording and auditing.

Directional Drilling

This allows the drilling rig to be located outside the mangrove while permitting underlying rock formations to be drilled. The use of this specialised technique needs to be considered during the conceptual stage. Rock formations, horizontal and vertical distances between the rig and the potential oil bearing structure, all have to be evaluated in terms of their suitability.

Drilling Barge Operations

Drilling barges are towed to the location. These consist of a specially designed drilling unit mounted on a floating barge anchored at the drill site, often with associated equipment and storage for materials. Accommodation may be located on separate barges. Alternatively, larger drilling barges, such as swamp barges may include personnel accommodation and other facilities.

In some cases, it may be possible to use a slim hole land rig temporarily mounted on a barge, to reduce the size and scale of access impact. It may also be possible to temporarily mount a mini land drilling rig on a barge as another means to minimise impact.

Jack-Up Rig

A jack-up rig is a floating unit that can be towed to a given location. The supporting legs are then jacked down into the substrate, elevating the drilling platform and facilities above the water level.

Helirig

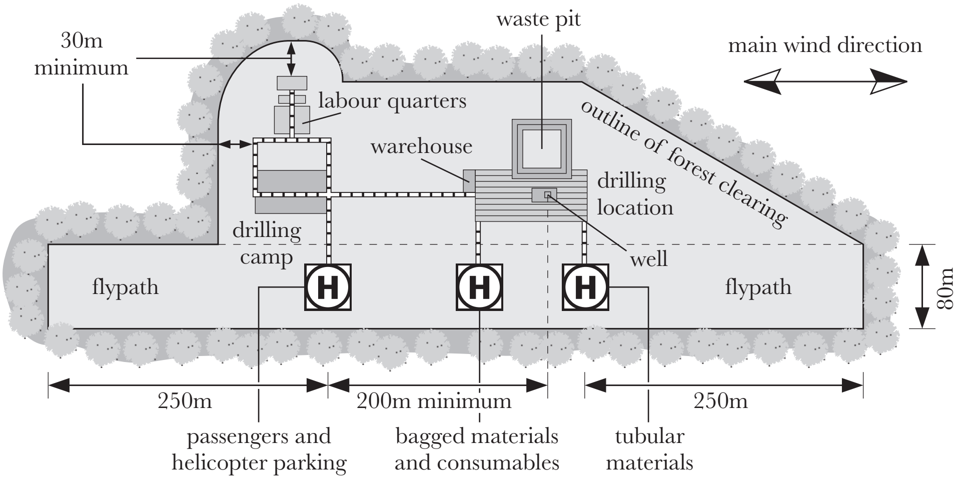
A helirig is a land rig that can be disassembled into packages light enough to allow transportation by helicopter. This type of rig can be used in otherwise inaccessible locations. Helirig locations in mangrove areas may be supported by piled foundations with timber decks or corduroy platforms formed by laying logs on the ground surface. The benefits of using helirigs could include: less tree and ground clearance (resulting in reduced environmental impact, although a higher localised impact); and reduced access to the site by local people so that the extent and duration of impacts are limited.

Access to drill sites using helirigs is an environmentally attractive solution. The total impact of helirig operations must, however, take into account:

- clearings for flight paths;
- emergency landing pads;
- staging areas; and
- fuel storage and transfer.

These impacts should always be considered and minimised. The costs of helirig operations are high in all cases and existing road access to the nearest point to the helirig location will always be a major consideration. Slim hole helirigs could reduce both impact and costs by requiring smaller aircraft. The disadvantages of helirigs include higher costs for transportation and safety risks of flight operations. Twin helicopters with separated landing areas are often required. In many areas, especially remote locations, helicopter support and landing areas are required for emergency evacuation. Figure 2 illustrates the principal requirements for a helirig location.

Figure 2. Typical Layout of Helirig Location



Land Drilling

Drilling locations for land rigs are sized to accommodate a drilling rig, associated equipment, materials and consumable materials. The size of the location will vary with the type of rig and may cover an area from 50 x 50m for slim hole rigs, to more than 120 x 150m, depending on the specific drilling needs.

Supervision of construction activities together with training of staff is vital to avoid actions that may lead to serious environmental impacts. For all construction operations there should be detailed instructions on the controls to be adopted to prevent unnecessary impacts, particularly in areas where local contractors are used. Exposed soil should be contoured to facilitate natural revegetation or replanting with indigenous species.

Well Site Preparation

Drill site preparation will often determine the success of environmental management and subsequent restoration. Drill site locations constructed in mangroves must be above the maximum water level to prevent inundation.

Various types of foundation are prepared for drill sites (corduroy, piled rig or concrete bases), according to the terrain. In the preparation of impermeable foundation surfaces, perimeter drains around the rig subsurface are necessary to allow water runoff. The rig site should slope towards the perimeter drains. Alternatively, re-usable steel platforms could be used.

In the case of corduroy platforms, advanced surveys of timber stocks in and adjacent to the mangroves, together with an agreed plan for timber use are crucial in preventing unnecessary impacts in neighbouring forests. Environmental controls and inspection of timber extraction are essential to ensure minimum impact.

In conclusion, drilling operations should always consider the following:

- drill sites should be designed to occupy the minimum space necessary. This will reduce physical disturbance and the area to be restored. Clearance of vegetation should be kept to a minimum;

- any cleared vegetation should not be automatically burnt or removed. These materials can sometimes be used for foundations and structures or in soil conservation measures;
- well sites should be prepared with drainage and contaminant capture requirements in mind. Where possible, contaminants should be captured separately from rain water to minimise the volume of fluid requiring special disposal. The well site location, together with off-site drainage channels, should prevent water flow across the site. These channels may require lining (for example, with gravel) to prevent erosion. All exposed slopes should be covered, and revegetation with indigenous species should be considered if natural colonization would not otherwise occur quickly enough to prevent erosion;
- a combination of bunds and cut-off drains, along with catch pits for oil/water separation may be required to prevent any loss of oil fuels or grease from the drill site to the mangrove environment;
- all fuel and chemical storage areas should be sealed and bunded to contain spillage and facilitate clean-up. Good housekeeping is essential in the storage, handling and use of fuel and chemicals;
- mud pits should be lined with impermeable materials, such as bentonite. Steel mud tanks may be considered as an alternative; and
- water supplies required for domestic use, drill camp use, mixing with drill mud and emergency well control should be chosen according to local hydrology. The procurement of fresh water from the local mangrove environment must be done with great care. The removal of large amounts of water from the mangroves can cause irreversible damage. Likewise, the abstraction of water from shallow subterranean aquifers can significantly lower the water table, causing either drying out or salt water intrusion.

Base Camps

A base camp is required to accommodate personnel and to store equipment. Its location is normally selected to coincide with access and delivery routes. In some cases, base camps will be used for only a few months to support a single exploratory operation. At other times they may be used for many years, as in the case of a phased drilling programme.

Camp sites should always be selected with decommissioning and restoration in mind. The base camp should be self-contained and may provide workforce accommodation, canteen facilities, a radio room, handling facilities for surplus and scrap material, vehicle maintenance and parking areas, boat maintenance and mooring areas, a helipad and bunded areas for the storage and handling of fuels, a warehouse for spare parts, small equipment and a yard for pipes and heavy equipment. In addition, there should be on-site provision for the collection, treatment and disposal of aqueous effluents and for the collection and incineration of refuse.

Base camp facilities should be outside the mangrove area, either on moored barges or on land. There are a number of different options for a base camp, which can involve a combination of land and barge camps. The most suitable approach will depend upon access routes and operational requirements.

Moored Barges

Base camps can be on barges moored within an estuary or on a tributary within the mangroves. Alternatively, accommodation may be contained within a multi-functional drilling barge unit. Since barge facilities are self-contained, all waste disposal can be carefully controlled.

Land Camps

The location of land camps is normally chosen with easy access and delivery routes in mind. In vegetated areas, the area of clearance should always be kept to a minimum, consistent with operational and safety requirements. Removal of topsoil and vegetation should be avoided, as far as possible, in order to minimise future erosion.

Camp Waste Management

The generation of waste within camps should be kept to a minimum. Provision for waste collection and disposal should be planned at the camp site design stage. All sites should observe relevant local regulations governing solid and liquid waste disposal. Consent or permits may be required for waste disposal. Solid and hydrocarbon wastes should be incinerated and the residue removed off-site for final disposal, unless there are recycling or other disposal options which offer better environmental protection. The use of open fires should be avoided.

Regulations and guidelines may exist which set water quality standards for discharges into surrounding waterways. Liquid wastes that could damage the environment should never be released or allowed to drain directly into a watercourse. All camp sites should have either septic tanks with soakaway pits, or closed sewage systems.

Any fuel spillage should be cleaned up and recorded. Unusable or contaminated fuel should be disposed of in accordance with suitable waste disposal procedures, that is incinerated, recycled, or re-used elsewhere.

Drilling Waste Management

The principal industrial wastes arising from drilling operations are used drilling mud and cuttings. Typical wastes generated in drilling operations are shown in Table 5. In most cases waste disposal facilities will not be available and drilling mud disposal must be managed on-site.

If the quantity and toxicity of drilling waste can be reduced, the impact and cost of environmentally acceptable disposal will be reduced. Some options to reduce the quantity of drilling waste are to:

- consider slim-hole drilling operations;
- use best-available solids recovery equipment;
- recycle mud and chemicals;
- minimise water use through recycling; and
- monitor and record mud quantity, chemical use and waste generation.

Several actions may also be taken to reduce the toxicity of drilling waste:

- consider reduced toxicity mud components and additives;
- segregate waste types;
- minimise the use of biocides; and
- encourage the use of water-based mud.

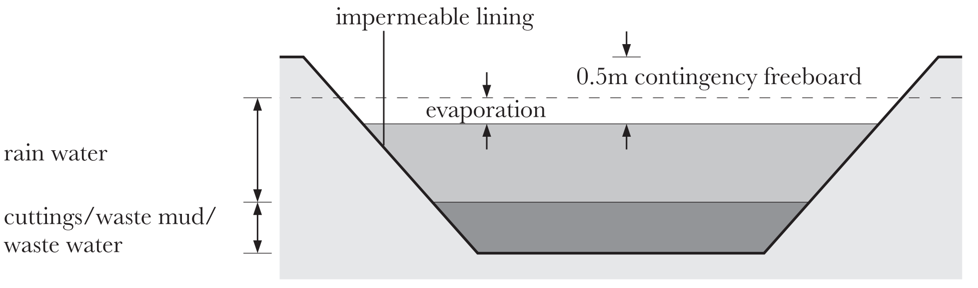
Where more than one exploration site is to be drilled, a coordinated plan of drilling mud and chemical use and recycling will reduce the total volume of waste for disposal.

Mud Pits

Mud pits should be designed (Figure 3) to contain both the anticipated volume of drill cuttings, waste mud and wash water, and a contingency volume for rain (expressed as 0.5m of freeboard—more in high rainfall areas).

The mud pit should be surrounded by a raised bund which prevents entry of run-off water from the well site and adjacent areas. Mud and waste pits should be constructed from an impermeable

Figure 3. Scheme for Sizing of Mud Pit



membrane and soil materials. Construction should be assessed on a site-by-site basis to determine the most appropriate method of lining the pit to prevent seepage of fluids. Seepage of drilling mud fluids must not be allowed in mangrove areas. Steel tanks, as an alternative to waste pits, should be considered, especially in high rainfall areas.

The mud pit should never be used for disposal of oily wastes, sewage effluents or other associated wastes. Should oil enter the mud pit, it should be skimmed off and disposed of in an environmentally acceptable manner.

Waste Oil

Crude oil from well testing should be stored in temporary tanks and/or burned in flare facilities specially designed with respect to the volume and characteristics of the oil. All piping and manifolds should be oil tight. Under no circumstances should oil be intentionally spilled or discharged on-site, dumped in the mud pits or stored in un-lined pits. Lined pits include those pits with clay or synthetic lining as well as those dug in naturally impermeable soil (clay based).

Waste from Well Testing

Once a well has been drilled, it may be necessary to conduct well tests. The purpose of well tests is to establish reservoir pressure and the overall size of oil and/or gas reserves. Well testing involves the production of hydrocarbons to the surface, where oil, gas and water are separated using a test separator.

The volumes of produced reservoir fluids will vary according to the requirements of the well test. A plan for the collection, storage and disposal of all oily materials and the burning of produced gas should be prepared with the design of the well test programme, together with any additional contingency planning requirements. The flaring of gas should be kept to the minimum necessary to meet safety and well testing requirements. The amounts of oily wastes and gas generated during well testing should be recorded, together with their disposal method and location.

Separated oil and water should be collected in steel storage tanks. Oil should be burned on-site through a high efficiency flare or, alternatively, transported outside of mangrove areas for further processing or recycling.

To avoid impairment of environmental resources, separated water may require further treatment and settlement time to allow additional removal of dispersed oil prior to discharge. Separators should be selected during the planning phase of the operation to meet the required discharge standards.

Table 5. Wastes from Exploratory Drilling Operations		
Type of Waste	**Main Component**	**Potential Environmentally Significant Constituents**
Drainage	Rainwater	Hydrocarbons, chemicals, mud particulates
Process water	Engine cooling water, wash water	Hydrocarbons, detergents
Gases	Vent gases, flare gases	Hydrocarbons, dust, well fluids, H_2S
Fire-fighting agents	Halons, treated water	Halons, treatment chemicals
Domestic sewage	Biodegradable organic matter	Solids, detergent, coliform bacteria
Domestic refuse	Garbage, packing materials, kitchen waste	Plastic, organic waste, batteries
Spent bulk chemicals	Cement, bentonite, barite, thinners, fluid loss reducers	Heavy metals, hydrocarbons, organics, solids, alkalis
Spent speciality products	Defoamers, tracers	Hydrocarbons, radio-active materials
Industrial waste	Scrap metal, cleaning materials, packing, thread protectors	Heavy metals, plastic
Industrial waste	Batteries	Acid, heavy metals
Chemicals		Toxic chemicals, acid
Chemical drums (empty)		Toxic chemicals, acid
Waste lubricants	Lube oil, grease	Metals, organic compounds
Spacers	Detergent, surfactants	Hydrocarbons, alcohol, surfactants
Cement slurries Cement mix water	Weighting materials, salts, thinners, viscosifiers	Heavy metals, high pH salts
Spent water-based mud and brine	Whole mud, biodegradable matter, mineral oil	Metals, inorganic salts, pH biocides, hydrocarbons, solids, biological oxygen demand (BOD), organics
Oil-based mud	Oil, chemicals, biocides, bentonite	Heavy metals, oil chemicals, surfactants, biocides
Water-based mud cuttings	Formation solids, water-based mud, mineral oil	Heavy metals, inorganic salts, solids, BOD, organics, surfactants, biocides

Gas from the test separator is usually burnt in a flare designed for this purpose. In the case of a land well site adjacent to mangroves, gas may be piped to a low profile ground flare sited within a fenced, impermeably lined pit (to prevent percolation of unburnt hydrocarbons into groundwater and soil) where it may be ignited and burned at a safe distance from the rig site. Steel tanks may also be used instead of lined pits. Re-instatement of flare pits prior to abandonment should include the removal of residual oil-contaminated material for disposal outside of the mangroves.

Disposal of Drilling Wastes

The underlying principle for waste disposal is that environmental resources should not be damaged, nor should their sustainable use be jeopardised. Waste disposal requires proper planning from the conceptual stage to decommissioning. Drilling waste disposal plans should be prepared in advance of the drilling operation. The plan should identify how to minimise and control wastes and ultimate disposal routes that will not impair environmental resources. Disposal at sea should be considered only if environmental resources (e.g. coral reefs) will not be impaired.

In all cases, disposal methods of mud and cuttings must be based on a careful assessment of the mud to be used and the environmental conditions in the area being considered for their disposal. The environmental impact of drilling mud disposal is determined in part by the mud type used. Where water-based muds are employed in exploration, the use of additives containing bio-available heavy metals should be avoided. Mangroves are not only vulnerable to oil and chemicals, but also to sedimentation. Under no circumstances therefore should harmful drilling mud fluid be discharged directly into a watercourse within the mangroves, or pumped over the ground surface. It may be necessary to collect all drilling wastes in a barge and transport them out of the mangroves for disposal. Consideration should be given to disposing of water, mud and ground cuttings by injecting these fluids into suitable deep strata, if underground water in such strata is not used for human consumption.

In the rare event that oil-based mud has to be used for specific geological reasons, stringent precautions should be taken to prevent spills. Oil-based mud and cuttings must not be discharged in mangrove areas but disposed of in a purpose-designed facility. If oil-based mud is used, steel tanks or other provisions for mud and cuttings collection should be used to facilitate transport to disposal locations outside the mangroves.

Spill Contingency Plans

Mangroves rely upon their pneumatophores for respiration; once coated with oil, pneumatophores become sealed and the mangroves will eventually suffocate. Furthermore, oil can cause damage to root membranes, leading to the failure of salt control, and influx of salt into the plant tissue. The aquatic ecosystem in mangrove areas is also sensitive to oil and chemicals. This sensitivity is especially acute in areas of low tidal flushing.

Drilling well sites should be designed to prevent spills. Catchment systems should be included in all designs to minimise spill damage. Throughout the drilling operation, from construction to final decommissioning, there should be an appropriate oil spill contingency plan.

Contingency plans should be based upon the location and volume of potential spills. The possibility of a blowout should be addressed in the drilling emergency plans along with a record of testing the blowout preventer. The contingency plan should include the type of spill response equipment and manpower required to respond to accidental spills, both large and small. It should also address the identification and protection of vulnerable and sensitive areas should a spill occur. The plan should clearly identify the actions necessary in the event of an oil spill including the communications network, the individual responsibilities of key emergency personnel and the procedures for reporting to the authorities, and arranging the transportation and housing of extra labour for clean-up work. Finally, the plan should also address the disposal of contaminated wastes generated by a spill. The plan for these short duration activities should be regularly updated and tested through trial runs.

At each stage of the operation, an inventory of hydrocarbon and chemical sources should be kept up-to-date and include fuel tankers, fixed fuel dumps and their locations. During construction, large quantities of fuel are required for vehicles, boats and possibly helicopters, all of which must be transported and stored. There is always a risk of fuel leakage either as the result of an accident, failure to close valves or failure of equipment or materials. Personnel should be made aware of the need for oil spill prevention and should be briefed on how to stop further loss, isolate the source, contain the spread of contamination, clean up spills, and file an incident report.

Oil Spill Clean-up and Rehabilitation

Clean-up efforts can decrease or increase damage from spills. Various biological concerns must be considered in determining the clean-up action that may be least damaging. Mangroves are vulnerable to oil spill dispersants and strict guidelines should be planned for their use near mangrove shorelines. Dispersants may break up floating oil and so reduce exposure to birds, mammals, reptiles and plants, but could lead to the dispersed oil entering the water column. In shallow waters, this may increase the threat to plankton, fish, eggs and larvae. For this reason, dispersants must be prohibited within mangrove areas unless shown to be the least environmentally damaging option.

Recovery and clean-up of oil in mangrove areas should be restricted to cool-water jetting, since most forms of mechanical recovery and chemical usage are likely to cause further environmental damage. If large quantities of oil are spilled, the best environmental option may be not to try and recover the oil, but to leave the area to recover naturally or use methods which exploit natural recovery processes. Such scenarios should be discussed in detail with any relevant authorities in advance of any drilling operation so that all parties respond in a coordinated manner. As always, prevention is the best approach, thus re-emphasising the need for ample bunding and loss prevention in mangrove areas.

Well-Site Decommissioning and Restoration

Authorities should be consulted on methods of decommissioning. A restoration plan should be prepared and agreed upon before drilling site construction takes place. In advance of restoration activities, further confirmation of the plan should be sought from the authorities. After work is completed, confirmation of acceptability should be sought.

All equipment and debris should be removed from the mangroves. An inspection of the well site by a company representative should take place after restoration to establish whether any further action is necessary before the site is vacated. The site should be photographed to establish a permanent record of events.

Land Sites

Wells that are not to be used in the future should be properly plugged downhole to positively isolate subsurface zones and protect usable surface waters. The well head, casing and concrete cellars should be removed to a depth sufficient to ensure no impairment of surface use. Any holes should be filled and the surface contoured to original levels, in accordance with the restoration plan.

The well site should be examined by a company representative and, if necessary, additional drainage courses should be prepared to restore the site's natural hydrology. Transplant programmes can re-establish some key species within mangrove areas to accelerate natural restoration processes.

Mud, incineration and waste pits in elevated drilling sites should be filled and restored to form a stable surface without displacing the contents. Alternatively, they could be excavated and restored, depending on the waste type. The use of high void volume material may be required where large volumes of liquids are present. It is preferable, however, for excess quantities of potentially harmful liquids to be taken away by tanker for proper disposal, or re-injected below the level of usable water systems outside mangrove areas. The finished surface of the mud pit should be contoured and restored, consistent with the rest of the well site.

Well sites that are to be used for hydrocarbon production and that may have to be temporarily shut-in, should be restored to an acceptable standard consistent with future use.

Closure of Access

Where roads and causeways have been constructed to facilitate drilling operations, decommissioning may consist of:

- re-instatement to as-near-the-original state as reasonably possible. This may include removing the road surface and sub-base, levelling any embankments, re-instating drainage systems, reseeding vegetation and tree planting. Removal of causeways is, however, difficult in many cases and may cause additional cumulative damage. In all cases, future erosion should be minimised;
- blocking access roads at strategic points, removal of bridges, dams and culverts and excavation of artificial channels, ditches and mounds of earth; and
- leaving access roads if, in agreement with the authorities, they provide benefit to local communities and will not lead to future adverse environmental impact.

Closure of Submerged Drilling Sites

The drilling location should be cleared of all debris, structures and drill cuttings that would pose a hazard to local fishing or navigation. The withdrawal of the legs of a jack-up rig will leave holes in the sediment, but these will refill in time without causing environmental damage.

Closure of Dredged Channels

A degree of re-instatement of dredged channels may be possible after the operation. The entry point of the access route can be closed by dredging or dumping, or by allowing the access channel to progressively fill and close these spaces. Although it may be possible to partially fill the dredged channel using dredge soil, in most cases this is likely to be impractical and may lead to further environmental impact and disturbance.

Development Drilling/Production

The development phase of an oil and gas extraction project involves a substantial investment to develop the necessary infrastructure. This phase will involve the drilling of many development wells and the construction of a pipeline system to connect the wells, perform the preliminary processing of the product and support the operation. Development may last for a period of between 10 and 30 years, depending upon the size of the hydrocarbon reservoir, the nature of the hydrocarbon and the number of wells drilled. The oil and gas production system will include well sites, centralised processing facilities and the piping necessary to connect the wells to the processing facilities and to move the hydrocarbon to the market. This operational system will be supported by facilities including: a base camp; waste handling; and a transportation network. The extent of these systems will depend upon the size of the hydrocarbon reservoir.

The impact of this infrastructure and its operations upon the mangrove ecosystem will depend upon the location of the reservoir with respect to the mangroves and the way in which development and production are managed. Different development options should be compared at the conceptual stage in terms of the overall environmental impact.

Clearings

Clearings will be made for well drilling sites, centralised petroleum processing facilities and, possibly, accommodation for workers. Cleared locations should be kept to a minimum by locating operational and support facilities outside the mangrove ecosystem, wherever possible. An attempt should be made, consistent with safe and efficient operations, to minimise the size of the site if this must be within the mangrove ecosystem. Clearing design should incorporate rain water drainage in a way that minimises erosion and contamination of existing streams.

Drilling Operations

Reservoir development plans should employ directional drilling techniques wherever practicable. The preferred option would be to locate all well sites outside the mangroves and directionally drill to reach any reservoir beneath them. In the event that a location within the mangroves is necessary, multiple wells should be clustered on one site to minimise the number of well sites and access routes that have to be cleared. This will serve to reduce the overall area cleared, minimise habitat fragmentation and, in some cases, enhance field economics by reducing the number of clearings, roads and infrastructure.

Steel tanks should be considered as the alternative to lined earthen pits for storage and processing of mud, cuttings and other fluids. Every attempt should be made to re-use mud in order to minimise disposal needs. Oil-based mud should not, if possible, be used within the mangrove ecosystem. If the use of an oil-based mud system is necessary for specific geological reasons, the oil-contaminated cuttings should be removed from the mangrove ecosystem. No discharge of oily cuttings or whole oil-based mud should occur within the mangroves.

Construction

Construction of facilities, roads, camps and pipelines should be kept to the minimum necessary for operations. As previously mentioned, the consolidation of several functions at a single site will reduce the number of required sites. While one large site may make a significant impact on the area of mangroves affected, the total area impacted will usually be less than that for several smaller sites, particularly when access is considered. Site design should provide for minimum erosion and subsequent abandonment. In any case, the site design should prevent damage to the major environmental processes outlined in Chapter 2.

The possible presence of acid sulphate soils at a potential site should be investigated carefully by taking soil cores to a depth of about 2m. Any site where acid sulphate soils are present must be developed carefully. Exposing this soil can have damaging effects on both the mangrove ecosystem and structures.

Procurement of fresh water from the local mangrove environment should be done with great care. The removal of large amounts of water from the mangroves can cause irreversible damage to local hydrology. The abstraction of water from shallow subterranean aquifers can significantly lower the water table, causing either drying out or salt water intrusion.

When considering the construction of filled, compacted sites within the mangrove ecosystem, thought must be given to the source of aggregate and its transport route into the mangroves. Aggregate materials are unlikely to be found within mangrove areas and must therefore be transported from elsewhere. The siting of aggregate borrow pits and the extraction methods to be employed should be considered in the EIA.

Central Processing Facilities

Central processing facilities should, if possible, be located outside the mangrove ecosystem. Both the seaward and landward sides should be considered. Since most mangrove areas are limited in extent this should be feasible in most cases. If it is necessary to locate these facilities inside the mangroves, they should be placed on a pier, small platform or other appropriate structure. Where it is not possible to locate facilities on such a structure, then a properly filled and compacted site should be built.

Discharge streams and waste management should also be considered when selecting a site for central processing facilities. These facilities should have provisions for spill minimisation and sumps at all drains.

Flowlines

The number of clearance corridors for flowlines/pipelines should be kept to a minimum and existing access routes should be used in order to minimise damage to mangroves and simplify access for inspection and maintenance. Maximum use should be made of satellite production facilities to minimise the number of individual flowlines. Clustered well sites simplify the use of this technique. Above-surface flowlines are necessary because of the possible damage from burying flowlines in acid sulphate soils. Where any flowline is laid on the surface it should not impede the flow of surface water. Regular inspection of flowlines is necessary because of the dynamic nature of the mangrove environment.

Pipelines

From the design stage, special consideration should be given to the commissioning of the line. The number of pipelines should be kept to the absolute minimum required to move the product out of the area. Clearance width for pipelines will vary according to the size of pipeline, proximity to flowlines and presence of trees which could fall and damage the pipe.

Integrated planning of processing facilities together with flowlines and pipelines is essential to minimise the length of pipelines required, but to also strictly minimise overall clearance requirements. Pipelines should follow existing access routes and cleared areas rather than cutting across undisturbed vegetation.

Where possible, pipelines should be above ground or engineered in such a way that they do not prevent natural surface and groundwater flow, or the natural movement or migration of wildlife. Construction methods employed in pipeline installation should not compact sub-soils, forming a barrier to water flow. Where pipelines cross streams, creeks or other channels, adequate physical support must be provided, bearing in mind the dynamic nature of the substrate. Regional as well as local effects of pipeline clearance and access for inspection and maintenance should be taken into account.

When commissioning the pipeline, consideration should be given to the chemical composition, toxicity and ultimate fate of the hydrotest fluids. Hydrotest liquids should be of minimum toxicity, avoiding the use of heavy metals whenever possible. It should be recognised that the volume of chemically treated water to complete commissioning of lines may be several times the volume of the pipeline. A disposal plan for hydrotest liquids should be prepared as an integral part of selecting the hydrotest programme, identifying points of discharge, predicted dilution and potential impacts. Treatment or processing of hydrotest water prior to discharge to remove toxic components should be considered.

The options for discharge sites, corresponding to predicted dilutions and potential impacts should be carefully considered by management prior to deciding on any discharge. Monitoring of the discharge concentration and subsequent dilution rates may be required by authorities.

Base Camps

The preferred location for accommodation camps is outside the mangrove ecosystem, either on the seaward or landward side. The next least damaging location would be within the mangrove swamp on a platform structure. The last choice for a housing camp would be a filled, compacted site. Accommodation camps within the mangrove ecosystem should be kept to a minimum by housing only the workers. Workers should be transported to and from communities established for family habitation that are located outside the mangroves. Access routes to operational facilities, the presence of acid sulphate soils, the source of water for camp use, and waste management should be considered when selecting the location for an accommodation camp.

Roads

Roads should be planned to minimise length, but not to the detriment of sensitive areas, nor at the risk of potential significant erosion or safety. While some interconnecting roads may be necessary, these should be kept to a minimum.

During road construction, arrangements should be made to minimise erosion and to facilitate natural surface drainage and subsequent revegetation. The source of aggregate (borrow pits, for example) and its route into the mangroves must be considered. Road causeways should be constructed with sufficient culverts to allow the free movement of water. A preferable alternative to a filled, compacted causeway with culverts might be to build all or part of the road on piles.

Roads may be surfaced with properly processed tank- and vessel-bottom material to minimise the effect of vehicle dust, reduce erosion and to maintain the roads in passable condition in wet weather. Correct processing of tank- and vessel-bottom waste for this purpose includes mixing the waste with a suitably absorbent soil or other material (such as lime) at each application. This is intended to prevent leaching or runoff of oil from the road. Alternatively, laterite could be used, if available. The application of surfacing materials should be conducted only in dry weather.

Canals

The number and width of dredged canals for drilling and workover barge access can be minimised by using existing channels, whenever possible. The use of clustered well sites and the smallest possible rigs for the depth of well to be drilled will also reduce the amount of dredging required. Once the drilling phase has been completed there should be no need to dredge new canals. It is necessary to maintain canals during the production phase for daily or weekly inspection of wells.

Canals should be dredged so that there is minimal disruption to surface hydrology and vegetation. Canal width and depth should be no greater than the limits necessary to safely accommodate the drilling barges. Canals should be constructed to maintain existing natural surface drainage patterns and salinity regimes. The possible presence of acid sulphate soils should be investigated. All dredge disposal options should be investigated to reduce the amount of clearance within the mangroves. The speed of all boat traffic should be reduced to minimise bank erosion caused by the wash.

Airstrips/Helipads

Airstrips should be located outside the mangrove ecosystem. They should be adjacent to camps, taking into account safety considerations and the need to minimise clearance of mangroves. Airstrips should be kept to the minimum size necessary by using either short take off and landing (STOL) aircraft, or helicopters. In swamp operations, consideration should be given to locating helipads on top of existing structures in order to avoid additional clearing (without compromising safety). If sufficient open water is available, the use of seaplanes should be considered.

Production Operations

Production operations include those actions necessary to maintain the condition of the wells, the equipment and the producing formation. Many of these operations require fresh water. Care must be taken to ensure that salt water intrusion will not occur as a result of removing large quantities of water from surface waters or ground water.

Well Maintenance Activities

Well maintenance activities (for example acidising, fracturing, solvent stimulation) should use proper containment (such as steel tanks) for the collection of spent treatment fluids. These fluids should be disposed of properly. Some options to be considered include:

- injection into non-usable water zones below deep casings;
- reclamation;
- chemical neutralisation and combination with produced fluids;
- incineration; and
- disposal in other ways that do not involve direct discharge to the environment, or subsequent release of contaminants through leaching.

Maintenance of Facilities and Equipment

Provision should be made to prevent the escape of produced fluids onto soil or into waterways during vessel and flowline maintenance activities. Spill containment equipment should be on-site during such operations. Personnel should be trained in its effective use.

Leaks caused by corrosion in oil storage tanks should be prevented to the maximum extent possible with coatings and cathodic protection (both interior and exterior). A monitoring system should be employed for early detection of leaks.

Chemical Usage

Chemical application should be centralised whenever operations permit, allowing the use of bulk chemical storage tanks and reducing the number of drums on the site (see also ‘Chemical Waste’). Cluster well sites and satellite production facilities are ideal places for such centralisation. The number of chemical products used should be minimised and products should be selected to meet technical requirements while causing least health, safety and environmental impact.

Waste Management

Each site should have an appropriate waste minimisation and disposal plan, using existing infrastructure. Each operation should consider reduction, re-use, reclamation and recycling of materials. Proper records of waste disposal and monitoring should be maintained for inspection at all times.

Produced Water
Produced water is water that is produced from the formation together with oil or gas. It is usually the largest volume of waste arising from production operations. The amount of produced water per barrel of oil produced increases with time.

Produced water will contain mineral salts, oil and other organic and inorganic components and, therefore, must not be discharged into the environment without prior treatment. One disposal option is re-injection into deep geological structures that do not contain usable water. Alternatively, it may be re-injected into the formation to maintain pressure. If re-injection is not adopted, the selected method of treatment will be dependent on the oil and chemical composition of the water and the nature of the receiving environment.

The final effluent should be discharged below the surface of the nearest water body giving the greatest dilution factor, even if this involves piping the water for some distance. Effluent limits should be set to provide adequate protection for those organisms sensitive to low concentrations of oil, heavy metals and elevated water temperature.

Drilling Pit Waste
The use of cluster well sites will confine drilling activities and permit better control of wastes. Steel tanks may be used to contain fluids, minimise spills and provide storage for subsequent disposal.

Drilling fluids and cuttings should either be reclaimed, solidified, encapsulated in an impermeable layer to prevent leaching, landfarmed at a location outside the mangrove ecosystem (depending on the composition of the waste) or hauled to an approved purpose-designed disposal site. Monitoring of groundwater adjacent to disposal sites may be necessary to ensure no contamination or leaching. Consideration may be given to injecting these fluids into non-usable water zones below deep casing strings, if permitted.

Atmospheric Emissions
Safety requirements necessitate a limited amount of flaring and venting. All activities should be designed and operated with controls and policies to minimise atmospheric emissions.

Emissions to the atmosphere should be minimised by equipment selection, appropriate control methods, and inspection and maintenance of equipment. Consideration should be given to dispersion of gases resulting from combustion, and to possible emissions of SO_2, H_2S and any other harmful gases or particulates. Dispersion modelling of H_2S and SO_2 may be required to assess the potential risk and impact on human health and flora/fauna.

Flaring of gas should be kept to a minimum. Venting of unburned gas should be avoided. Where the volume of gas produced is far more than field operational requirements, an assessment of possible markets for the gas should be made. Consideration should be given to other options including the re-injection of significant quantities of excess gas, either for disposal or as temporary storage for subsequent use.

Oil Leaks and Drainage Systems
A leak minimisation strategy should form an integral part of facility design and maintenance procedures. Oil sumps should be provided for all drains to prevent contamination of rain water drainage. Drip pans should be used where needed. There should be separate drainage systems for rain water and oil-contaminated zones. All fuel storage facilities should be bunded to safely contain the full volume of fuel stored. Suitable absorbent material should be immediately

available to clean up surface spillage. Main fuel tanks should have lockable valves and all fuel usage should be logged. Oil spillage or leakage should be reported through incident reporting procedures.

Tank- and Vessel-Bottom Waste

Tank- and vessel-bottom waste may be processed for use as road surfacing material, may be incinerated, or taken off site for proper disposal. The application of suitable non-hazardous wastes as road surfacing material requires the mixing of these wastes with absorbent soil or other material. This practice is necessary to prevent seepage and runoff of oil from the road. Such materials must be applied to roads only in dry weather.

Flares should be designed and operated for maximum burning efficiency. Unburned hydrocarbon fallout should be contained and flare pits should be appropriately lined.

Rain Water Drainage

The design of each site must allow for drainage into natural streams in a way that minimises erosion. This requirement may entail the installation of culverts to channel the rain water, and the use of oil interceptors or sumps in such channels.

Drum Disposal

The accumulation and disposal of drums can present a problem. The use of drums can be minimised by using bulk storage for high volume chemicals and lubricants. Where drums are necessary they should be returned, whenever possible, to the original vendor for re-use. Where this is not possible drums should be cleaned, crushed and taken out of the mangroves for disposal at a selected disposal site. A record of drum disposal should be maintained for each disposal site to allow proper tracking and auditing of waste. Contracts for construction, or with service companies, should include drum removal by the contractor along with controls on drum cleaning prior to any public use. Precautions should be taken to prevent the unauthorised removal of any empty receptacles from the production site or base camp which could lead to a risk of chemical exposure to people.

Chemical Waste

Certain production chemicals, such as descalers (acids or converters), biocides and fungicides will require special disposal techniques. These special techniques include chemical neutralisation, incineration and other approved methods. Chemicals for future use should be properly stored. As part of waste reduction, policy should be to purchase only the chemicals for which there is planned use. Other unused chemicals should be returned to the supplier for resale or proper disposal.

Combustible Waste

Paper, wood, oily rags, oil filters, absorbent pads, plastic wraps and kitchen wastes should be disposed of by burning in a properly designed facility. Incineration during construction and production will almost eliminate the need for on-site landfill operations, particularly if the incinerator residue is compacted before being used as landfill outside the mangroves.

Sanitary Waste

Full treatment septic systems to process all sewage should be installed for all construction, drilling and production facilities, and camps on land. Consideration may be given to marine sewage systems for barge or platform operations. These wastes may need to be monitored. In particular, chlorination should be strictly controlled and oxygenation should be used, where necessary, to prevent damage to aquatic life. For barge or platform operations, sewage can be treated in a packaged treatment plant with final effluent discharged as described in Chapter 4 ('Base Camps').

Spill Contingency Plans

Oil and chemical spill contingency plans should be prepared. Oil and salt water handling facilities, flowlines and pipelines should be designed to prevent spills. Catchment systems should be included in all facility designs to minimise spill damage. Fuel handling operations should have appropriate equipment on site to contain fuel spills. Fuel stores, production sites and treatment facilities should be bunded. Contingency plans should be prepared based upon the risk, location, volume and type of potential spills.

The contingency plan should clearly identify the actions necessary in the event of a spill, the equipment needed, the communications network and the individual responsibilities of key emergency response personnel, together with the reporting procedure to the authorities. In addition, it should address the identification and protection of vulnerable and sensitive areas. The plan will also address the disposal of contaminated waste generated by a spill, and the transportation and housing of extra labour for clean-up work. Dispersants should not be used to combat spills within mangroves. Finally, the plan should be exercised and tested regularly, and updated accordingly.

Decommissioning and Aftercare

Prior to the time when commercial hydrocarbon extraction is no longer possible, the complete decommissioning plan should be finalised and reviewed with authorities. In developing this plan, contact should be made with local residents, communities and host government authorities. The social/community aspects will be taken into account in the decommissioning plan for the entire oil field. Recipients of facilities or infrastructure to be left for other uses should be properly instructed in safe operating methods as well as appropriate care and maintenance. Wells will be plugged downhole and just below the surface, equipment removed and abandonment procedures followed in accordance with industry standards. A summary of environmental protection measures is given in Table 6.

Before any structures or roads are removed, consideration should be given to the possibility that some rehabilitation measures may be damaging to the mangrove ecosystem. If appropriate, all cement, steel or wood installations should be removed to ground level. Roads, well sites or facility sites designated to be decommissioned should have all paving and man-made structures removed to ground level to allow revegetation. The surface should be contoured for drainage and control of erosion and the soil prepared for revegetation. If replanting is undertaken, indigenous species should be selected, compatible with the surrounding habitat.

The aim of decommissioning and aftercare is to maintain or re-establish as far as is practicable, the ecosystem functions (see Chapter 2) that will promote gradual recovery. Dynamic processes within the mangroves such as drainage and erosion must be maintained in order to sustain the mangroves in the long term. In most cases it will not be possible to return sites to their original state.

It may be necessary to identify test revegetation areas, where alternative revegetation treatment can be tried in order to develop the optimal approach for individual sites.

In order to ensure adequate re-instatement:

- the most suitable season for re-instatement should be identified at an early stage;
- the most effective recovery measures should be identified at an early date;

Table 6. Summary of Environmental Protection Measures	
SEISMIC EXPLORATION TO IDENTIFY RESERVES	■ Shot hole method preferable/use sufficient hole depth ■ Minimise length and width of lines and consider 'dog-legged' lines ■ Avoid road construction/minimise clearing and construction ■ Site base camps outside mangroves on barge or land site ■ Re-use materials, minimise wastes, control waste disposal ■ Oil spill contingency plans ■ Maintain seaward mangrove buffer to prevent erosion
EXPLORATORY DRILLING	**Access and Location** ■ Helicopters or piled roads preferable to canals or surface roads ■ Minimise the total area of canals and roads ■ Reduce impacts of dredging—use narrow gauge barges, maintain natural hydrology, proper spoil disposal ■ Avoid dredging in acid sulphate soils ■ Use road construction methods that maintain drainage and reduce erosion ■ Block or remove access routes after use, if appropriate ■ Pile supported location preferable to dredged or filled location ■ Design drill site to occupy minimum space, consider barge-mounted land rig ■ Slim hole drilling **Base Camp and Waste Management** ■ Plan base camp for future use and eventual decommissioning ■ Minimise clearance and land use ■ Use septic tanks with soakaways or closed sewage systems ■ Reduce quantity and toxicity of drilling waste ■ No discharge of oily wastes, including oil-based mud and cuttings ■ Waste minimisation techniques and proper disposal methods ■ Contingency plans for spills
PRODUCTION WELL SITE AND FACILITY	■ Plan sites to minimise impacts on natural resources, conservation interests, settlements, and use by indigenous peoples ■ Where appropriate, design and construct roads, bridges, water supplies, buildings and facilities for subsequent use by local communities in consultation with authorities ■ Plan subsequent decommissioning and restoration at site selection ■ If possible, select a site that is previously cleared, disturbed or of lower ecological value ■ Apply ecological expertise in site selection
DEVELOPMENT DRILLING	■ Consider measures including directional drilling and multiple well heads to reduce the amount of clearing for drill sites within mangroves ■ Plan drilling to optimise use of existing access routes and natural clearings ■ Use drill clusters, slim-hole drilling, where feasible

Table 6. Summary of Environmental Protection Measures (continued)	
PRODUCTION FACILITIES	■ Locate central processing facilities outside the mangrove system ■ Consolidate functions at a single site to minimise construction of facilities, access routes and camps and minimise site area ■ Locate facilities on piled structures where possible ■ Design clearings to maintain hydrology, reduce erosion and minimise contamination of streams and waterways ■ Investigate for presence of acid sulphate soils ■ Use existing access routes for pipelines and flowlines ■ Consider maximising use of satellite production facilities and cluster well sites ■ Use existing access routes and minimise the construction of new access routes ■ Consider soil conditions, hydrology and erosion control in any route construction ■ Use corrosion prevention techniques in tanks and lines
BASE CAMPS	■ Location of base camp outside mangrove system; a barge or land-based camp, is the preferred option ■ Accommodate only workers at any camp within the mangrove system
WASTE MANAGEMENT	■ Prepare a waste management plan to achieve reduction, re-use, reclamation and recycling of materials ■ Steel tanks preferable to earthen pits for mud systems ■ Line mud pits and design them with contingency capacity ■ No discharge of oil-based muds, oily cuttings, or other oily waste ■ Collect spent fluid from well maintenance activities in steel tanks for proper disposal (e.g. re-injected, incinerated, neutralised) ■ Re-injection of produced water is the preferred disposal option ■ Monitor produced waters that are discharged at the surface ■ Minimise flaring and venting of gas ■ Bund fuel and chemical storage areas, provide oil sumps at drains and use drip pans where needed ■ Prepare and test spill contingency plans and equipment ■ Install septic systems or marine sewage systems at camps ■ Incineration or removal from the site are preferred disposal options for other wastes (depending on the waste type)
DECOMMISSIONING AND RESTORATION	■ Remove or block access routes, where subsequent use by local communities is not appropriate ■ Plug wells downhole and near the surface and remove surface structures ■ Contour site surface, restore natural drainage and stabilise site ■ Revegetate site with indigenous vegetation ■ Monitor and document site recovery

- civil engineering and drilling contracts should ensure that adequate equipment is available to achieve the re-instatement plan;
- phased payment of contract costs can be used to promote satisfactory completion of re-instatement work;
- re-instated sites should be revisited regularly to verify that no unforeseen impact has occurred, and that recovery is progressing; and
- consideration should be given to recording site recovery, including a time series of photographs.

Glossary of Terms

acidising	The addition of acids (hydrochloric, hydrofluoric, acetic, formic, citric) to well fluids to maintain or increase permeability of a rock stratum by dissolving pore blockage due to fine particles from the reservoir stratum, precipitated materials or corrosion products, so improving productivity or injectivity (see 'injection') of a well.
aquifers	Rock strata which contain, and are permeable to, water. The water may be fresh or saline, and either potable or non-potable.
barite	Barium sulphate ($BaSO_4$)—a highly insoluble dense solid—a natural mineral used as a weighting agent in drilling muds.
bentonite	A finely divided clay material added to drilling muds to increase viscosity and gel strength of the mud.
bio-available	Pertaining to substances which are present in a form which can be taken up by plants or animals and which may be incorporated into their tissues.
biocides	Materials which can be added to muds principally for the purpose of prevention or limitation of growth of sulphate-reducing bacteria in the mud or in the oil-reservoir rock.
biodegradable	Susceptible to breakdown, into simpler (often soluble and/or gaseous) compounds, by micro-organisms in the soil, water and atmosphere. Bio-degradation often converts toxic compounds into non- or less-toxic substances.
blowout	Uncontrolled gas, oil or water escape from a well.
blowout preventer	Hydraulically operated device fitted to the top of wells to allow the well to be sealed off should a blowout situation develop.
BOD (biochemical oxygen demand)	Measure of the quantity of dissolved oxygen (expressed in parts per million) used in the decomposition of organic matter by biochemical action.
borrow pits	Pits resulting from the excavation of materials generally used as a fill material for construction purposes (including road surfaces, causeways, bunds).
brine	When added to drilling muds, brine (usually calcium chloride; $CaCl_2$) has three functions: it minimises the reaction between mud and soluble salts in the strata being drilled; it increases mud weight; and it increases mud viscosity.
bund	An impermeable dam or dyke constructed to contain spilled liquids.
casing	Steel tube cemented into wells to prevent both the collapse of the well and unwanted leakage into or from the surrounding strata, or at the surface.
causeway	An elevated section of roadway, which may be built up using wood, steel, concrete, soil, borrow pit material or any combination of these.
cellar	A (concrete) lined space under the working floor of a drilling rig.
chlorination	The addition of hypochlorite to seawater or drinking water in the minimum concentrations required to ensure that growth of marine and bacterial organisms is inhibited, to prevent problems in the use of such water in production activities.

cluster well sites	A single site from which two or more wells have been drilled.
cuttings	The small rock chippings generated by the drilling activities and retrieved from the well by the mud circulation.
decommissioning	The final plugging of wells and the removal of all surface structures.
deforestation	The felling of trees as a result of human activities.
descalers	Substances added to prevent and, to a lesser extent, remove solids such as calcium carbonates and sulphates on the drill pipe and casing. Pitting corrosion of metal can occur under scale deposits.
development wells	Wells for extracting oil and/or gas from the reservoir rocks. They may be either production or injection wells.
directional drilling	Also called deviated drilling. Controlled progressive deviation of a well away from the vertical to reach a different part of a reservoir from a single drilling site.
downhole	Down a well or borehole.
drilling mud	Drilling fluid consisting of a suspension of minerals such as bentonite and barites in a water, or low toxicity base oil. Other chemicals (e.g. biocides, defoamers, corrosion inhibitors, etc.) may also be present. It lubricates the system, removes cuttings and controls pressure.
drilling fluids	(See 'drilling mud').
drill slot	Location which has been dredged to accommodate a drill barge.
flaring	Controlled burning of unwanted hydrocarbons (mostly methane gas) and other non-hydrocarbon substances.
flowline	A small pipeline used to transport fluids from a well to the processing facility.
fracturing	The process of cracking open the rock formation around a well bore to increase productivity.
freeboard	That additional depth of a container which is in excess of the depth required for the normal amount of liquid to be contained.
fungicides	Substances which kill fungi.
geomagnetic survey	A survey which uses sensitive equipment to measure and record variations in the Earth's magnetic field. The pattern of variation gives an indication of subsurface rock structures which, in turn, may indicate possible oil-bearing formations.
helirig	Drilling rig transportable by helicopter.
hydrogen sulphide	A pungent, corrosive, toxic gas occurring naturally in oil and gas (and elsewhere), generated by the normal metabolism of certain types of bacteria.
hydrotest	The checking of the integrity of a container (for example, a tank or pipe) by filling it with water under pressure and checking for any loss of pressure.
injection	The injection (for disposal, storage, or to maintain reservoir pressure) of water, gas or other fluids into a suitably receptive formation via an 'injection well'.
jack-up rig	Self-elevating mobile offshore drilling unit.
landfarming	The controlled and repeated application of waste on a soil surface in order to biodegrade hydrocarbon constituents by using micro-organisms naturally present in the soil.

oil-based mud	Drilling mud which has low-toxicity oil as the base fluid in which other substances are dissolved or suspended (see 'drilling mud').
produced water	Water present in the natural oil reservoir and separated from the stream of produced oil before storage or onward transportation.
prospect	Area contained by a geological structure which is anticipated to contain oil or gas.
plug	To seal a well, or part of a well, with cement.
re-injection	(See 'injection').
remote sensing	The use of sophisticated and sensitive physical and chemical techniques to obtain information at a distance from the subject being examined, usually from above. Such measurements can be made 'remotely' using satellite or airborne equipment.
rig	A collective term used to describe the equipment, including the vessel or structure on which the equipment is installed, required to drill a well.
seismic survey	A survey conducted to map the depths and contours of rock strata by timing the reflections of sound waves released from the surface or from down a borehole (shot hole).
shot hole	A hole drilled for the purpose of placing explosive charges which, on detonation, act as the source of sound waves for seismic survey work.
slim hole drilling	Drilling of a narrower-than-normal well to decrease drilling time, drilling costs, amount of rock cuttings generated, drilling mud requirements and waste mud for disposal, the quantity of chemicals used, and the cost of drilling and well completion tubing.
solvent stimulation	The use of solvents to maintain or increase production of oil from an existing well by increasing the fluidity of the oil.
spawning	The release of eggs by fish and other aquatic species in preparation for fertilisation.
tracers	Materials added to a fluid to assist in the location of that fluid in an enclosed system. Tracers are usually mildly radioactive and are located by sensitive radiation detection equipment.
vent gases	Those gases which are released, unburnt to the atmosphere. Venting may be deliberate (for operational reasons) or accidental.
Vibroseis	A heavy, vehicle-mounted, vibration system used onshore for the generation of shock (sound) waves into the ground during seismic surveys.
void volume	That part of the total volume of a solid which consists of cavities. Void volume generally refers to the spaces left as a results of the irregularity of touching grains of soil or rock.
water-based mud	Drilling mud which has water as the base fluid in which other substances are dissolved or suspended (see 'drilling mud'; 'oil based mud').
well head	Those engineered structures which form the junction of the subsurface well with the surface system of flow control valves ('Christmas Tree') or with the blow out preventer (BOP) of the drilling rig.
workover	A process by which a completed production well is subsequently re-entered and any necessary cleaning, repair and maintenance work done.

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Appendix I

International Environmental Conventions and Agreements

The following conventions and agreements may include provisions relevant to oil and gas operations in mangrove areas:

Convention Relative to the Preservation of Fauna and Flora in their Natural State. 1933.

Convention on Nature Protection and Wild Life Preservation in the Western Hemisphere. 1940.

African Convention on the Conservation of Nature and Natural Resources. 1968.

Convention on Wetlands of International Importance especially as Waterfowl Habitat. 1971. Amended 1982, 1987.

Convention concerning the Protection of the World Cultural and Natural Heritage. 1972.

Convention on Conservation of Nature in the South Pacific. 1976.

Convention on the Conservation of Migratory Species of Wild Animals. 1979. Amended 1988.

Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region. 1983.

Protocol concerning Specially Protected Areas and Wildlife to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region. 1990.

Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region. 1985.

Protocol concerning Protected Areas and Wild Fauna and Flora in the Eastern African Region. 1985.

Protocol for the Conservation and Management of Protected Marine and Coastal Areas of the South-East Pacific. 1989.

Convention on Biological Diversity. 1992.

ASEAN agreement on the Conservation of Nature and Natural Resources. 1985.

Convention concerning the Conservation of the Biodiversity and the Protection of Priority Forestry Areas of Central America. 1992.

Further information can be obtained from the IUCN Environmental Law Information Service, Environmental Law Centre, Adenauerallee 214, D-5300 BONN 1, Germany.

Appendix II

Organizations of Relevance to Mangrove Conservation and Management

Founded in 1948, **IUCN—The World Conservation Union**—is a membership organisation comprising governments, NGOs, research institutions and government agencies in 123 countries. This network supports the work of six Commissions (including threatened species and protected areas) and several thematic programmes, including a Wetlands Programme and a Coastal and Marine Programme. These re-inforce activities of the Union concerned with the management of wetland ecosystems, focusing upon the conservation of ecological and hydrological processes, in particular by developing, testing and promoting means of sustainable utilisation of wetlands. This work is carried out in collaboration with members and partners, in particular the international institutions with a specific wetland mandate, especially the Ramsar Convention Bureau, and the International Waterfowl and Wetlands Research Bureau. For further information, please write to: IUCN, 28 Rue Mauverney, CH-1196 Gland, Switzerland.

The International Waterfowl and Wetlands Research Bureau (IWRB) is an independent non-governmental organisation founded in 1954 to coordinate waterfowl and wetland activities worldwide. Its Waterfowl Division formulates management plans for waterfowl populations and recovery plans for threatened species, while its Wetland Division coordinates activities through a Wetland Management Group. Activities undertaken by this group include the compilation of regional inventories, the preparation of management plans, the publication of wetland management handbooks and the organisation of workshops. For further information, please write to: IWRB, Slimbridge, Gloucester GL2 7BX, UK.

The Convention on Wetlands of International Importance especially as Waterfowl Habitat, also known as the **Ramsar Convention**, is an intergovernmental treaty which provides the framework for international cooperation for the conservation of wetlands habitats. Obligations for Contracting Parties include the designation of wetlands to the 'List of Wetlands of International Importance', the provision of wetland considerations within their national land-use planning, and the creation of natural reserves. The Ramsar Convention Bureau is independent but receives administrative, scientific and technical support from IUCN and IWRB. For further information, please write to: Ramsar Convention Bureau, 28 Rue Mauverney, CH-1196 Gland, Switzerland.

The Regional Seas Programme of the United Nations Environment Programme (UNEP) was initiated in 1974 to promote a regional approach to the control of marine pollution and the management of marine and coastal resources. The programme now covers 11 regions with the participation of over 120 States. For further information on the Regional Seas Programme, contact the Ocean and Coastal Areas Programme Activity Centre, UNEP, P.O. Box 30522, Nairobi, Kenya.

The International Maritime Organization (IMO), a United Nations Organisation of 144 State members, was established in 1948 to provide a means for technical, legal and scientific co-operation among governments to protect the marine environment from pollution by shipping and to promote safety at sea. The activities of the IMO have included the adoption of a number of Conventions concerned with marine pollution and the production of strategies and technical publications. For further information, contact IMO, 4 Albert Embankment, London SE1 7SR, UK.

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