Handbook

The risks and consequences of oil pollution in Vietnam & Guidelines on bioremediation of oil spills

Version 1.0

June 2006

Co-funded by the European Commission

within the framework of the Asia Pro Eco Programme

This handbook was produced by the following consortium of eight institutions from Europe and Vietnam, within the framework of the project "Bioremediation of oil spills in Vietnam" (BIOREM):

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June 2006

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Acronyms and Abbreviations

ARC/INFO	Geographic Information System
ASEAN	Association of Southeast Asian Nations
bbl/d	barrels per day
BTEX	Benzol, Toluol, Ethylbenzol, Xylole
CFU	Counting of colony forming units
CSM	Conceptual Site Model
CVM	Contingent Valuation Method
DBMS	Database Management System
DO	Diesel Oil
DoNRE	Department of Natural Resources and Environment
DoSTE	Department of Science, Technology and Environment
DWT	Deadweight Tons
EHWS	Extreme High Water Spring
EIA	Environmental Impact Assessment
ELG	Einsatzleitgruppe der Küstenländer und des Bundes zur Bekämpfung von Meeresverschmutzungen, Germany
ENA	Enhanced Natural Attenuation
EPA	Environmental Protection Agency, USA
ESI	Environmental Sensitivy Index
FO	Fuel Oil
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIS	Geographical Information System
GKSS	Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt mbH, Helmholtz Association of German Research Centres
HCMC	Ho Chi Minh City
HP	Horse-Power
ICEM	International Center for Environmental Management, Australia
ICM	Integrated Coastal Management Plan
IMO	International Maritime Organisation
IPIECA	International Petroleum Industry Environmental Conservation
IRS	Environmental Reference System
ITOPF	International Tanker Owners Pollution Federation
KNOC	Korean National Oil Company
LEP	Law on Environmental Protection
LHK	Llightly Volatile Halogenated Hydrocarbons
LNAPL	Light Non-Aqueous Phase Liquids
LPG	Liquefied Petroleum Gas

MCA	Maritime and Coastguard Agency, UK
MKW	Petroleum-Derived Hydrocarbon
MLA	Marine Laboratory Aberdeen
MNA	Monitored Natural Attenuation
MoNRE	Ministry of Natural Resources and Environment
MoSTE	Ministry of Science, Technology and Environment
NA	Natural Attenuation
NEBA	Net Environmental Benefit Analysis
NOAA	National Oceanic & Atmospheric Administration, USA
OECD	Organisation for Economic Cooperation and Development
OPA	Oil Pollution Act, USA 1990
OPRC	International Convention on Oil Pollution Preparedness, Response and Co-operation, 1990
OSI's	Oil Spill Incidents
PAH	Poly Aromatic Hydrocarbons
PCDD/F	Polychlorierte dioxins and furans
PCU	Pollution Controll Unit
PetroVietnam	Vietnam Oil and Gas Corporation
PXDD/F	Polyhalogenated dioxins and furans
RDCPSE	Research and Development Centre for Petroleum Safety and Environment
REMUS	Remote Environment Monitoring UnitS
SBM, SLM	Sonderstelle der Länder zur Bekämpfung für Meeresverschmutzung, Germany
SEEEC	Sea Empress Environmental Evaluation CVTSommittee
SJWRF	San Jacinto Wetland Research Facility
UEK	Unabhängige Expertenkommission "Havarie Pallas"
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
VNA	Vietnam News Agency
VND	Vietnamese Dong
VOC	Volatile Organic Compounds
WADABA	Wasserstraßendatenbank, Germany
WATiS	Wattemeerinformationssystem, Germany
WTA	Willingness to accept
WTP	Willingness to pay

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1 Introduction

1.1 Funding of this Project

The production of these guidelines and handbook has been co-funded by the European Union, within the framework of the Asia Pro Eco Programme (Contract: ASI/B7-301/2598/18-2004/79067).

The project is co-funded by the Asia Pro Eco Programme of the European Union. The Asia Pro Eco Programme was launched in 2002 as an initiative by the European Union (EU) to strengthen the environmental dialogue between Europe and Asia. This five-year programme, which has a total budget of EUR 31.5 million, aims to provide support to European and Asian organisations to enable them to share strategies, advanced technologies and know-how in addressing Asian environmental issues.

The Asia Pro Eco Programme is a programme dedicated to the improvement of environmental performance in Asian economic sectors through the exchange of environmental policies, technologies and practices, and to promote sustainable investment and trade between the European Union Member States and South Asia, South-East Asia and China.

For further information regarding the Asia Pro Eco Programme and the European Union, please see the following websites:

- Asia Pro Eco Programme website: **http://europa.eu.int/comm/europeaid/projects/Asia_Pro_Eco/index_en.htm**
- European Commission website: **www.europa.eu.int**
- EuropeAid Co-operation Office website: **www.europa.eu.int/comm/europeaid**
- European Commission External Relations website: **www.europa.eu.int/comm/external_relations**
- European Commission DG Development website: **www.europa.eu.int/comm/development**
- European Commission DG Education and Culture website: **http://europa.eu.int/comm/dgs/education_culture/index_en.htm**
- European Union in the World website: **www.europa.eu.int/comm/world**

1.2 The Project "BIOREM"

Vietnam, located in the Southeast Asian region, has about 3,400 km of coastline, over 3,000 islands and more than 1,000,000 km^2 of exclusive economic sea zone. As the country has been identified as a medium priority market for the oil and gas sector, it is highly vulnerable to oil spills caused by exploration and transport. Thus, effective and efficient oil spill response is needed and lead to the project-idea of promoting bioremediation of contaminated shorelines. This handbook represents the major results of the joint applied research project *BIOREM "Bioremediation of oil spills in Vietnam"*. The project was conducted by an international consortium of 8 institutions from Europe and Vietnam, consisting of

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The project started in June 2004 and finished after a duration of 12 month in June 2005.
Further information on BIOREM and all results and publications (downloads) can be obtained from the project´s website: www.bioremediation.hs-bremen.de.

1.3 Objectives of the Project

1.3.1 Specific Objectives

- Development of guidelines:
  The specific objective of the project is to develop practical oriented guidelines, specifically for Vietnam, on decision-making and implementation of exsitu- and insitu bioremediation of contaminated shorelines. The guidelines will integrate all relevant aspects, incl. environmental, technical, economic, socio-cultural and legal framework conditions.
- Workshop and Training course:
  The guidelines will be presented to an interdisciplinary circle of Vietnamese decision-makers and stakeholders who are directly and indirectly involved in response to oil pollution, bioremediation and coastal zone management. The objective is to promote bioremediation as an option for secondary oil spill response and its implementation in contingency planning. A two-day training course will be carried out, to train professionals in understanding the scope and the application options of the guidelines.
- Development of training material:
  The resulting guidelines will be the basis for the development of a practice oriented training module on response to oil pollution and the application of bioremediation to marine oil spills in Vietnam. The results will be integrated into the curricula of the participating universities.
- Dissemination:
  The resulting guidelines and training material will be widely disseminated, e.g. free of charge worldwide via this project web-site: www.bioremediation.hs-bremen.de .

1.3.2 Overall Objectives

- Promotion of environmental awareness and a cleaner Vietnam by contributing to effective and efficient response to oil pollution and contingency planning in Vietnam by providing guidelines and training.
- Contribution to the promotion of bioremediation which is, in many cases, a cost-effective and environmentally sound treatment option for contaminated sand, soils or sediment.
- Contribution to facilitating networking, collaboration and cooperation between stakeholders in Vietnam and at an international level with European experts, by the transfer and exchange of knowledge through networked experience within the field of response to oil pollution and bioremediation.
- Contribution to the promotion of an integrated planning, integrated coastal zone management and integrated waste management by considering specific treatment and utilisation paths for waste (e.g. contaminated sand), as well as socio-economic, environmental and health and safety aspects, when deciding on how to deal with oil pollution waste.
- Contribution to a further integration of international aspects into higher education, in particular in environmental (or related) degree courses. This will contribute to the qualification of young professionals facing an increasing globalisation in terms of markets and careers.

1.4 Target Group

The Guidelines as result of this project are useful for a wide range of professionals involved in response to oil spill fighting, bioremediation and coastal zone management (on high and middle management level), such as:

- decision-makers, stakeholders
- operational units
- administration
- companies

Furthermore, there should be effects on undergraduate and postgraduate students (Subjects of studies: environmental science and engineering, waste management, marine biological sciences, coastal zone management, etc.) who will be the base of knowledge for future oil spill response.

The Guidelines are developed under particular consideration of the framework conditions in Vietnam, providing a wide range of background information for this country. However the major parts of the Guidelines are applicable for oil spill response activities in every country of Southeast Asia.

1.5 Content Overview

The chapters (2-6) of this Handbook for Bioremediation-Guidelines include:

- Introduction to marine oil pollution (Chapter 2)
    - Introduction to oil composition, oil properties, etc.
    - Sources of oil pollution and example incidents from all over the world
    - Impacts of marine oil pollution on the coastal environment and socio-economic consequences
    - State of the art of response options
    - Overview on sensitive mapping and contingency planning

- Introduction to framework conditions of Vietnam (Chapter 3)
    - Information on Vietnam´s marine and coastal environment
    - Information on Vietnam´s marine and coastal economy
    - Overview on oil pollution incidents in Vietnam and risks of occurrences
    - Information on oil spill response and contingency planning in Vietnam

- Information about treatment options of oily sand, soil and sediment (Chapter 4 & 5)
    - Options of non-biological treatment (Chapter 4)
    - Bioremediation of oil spills (Chapter 5)
    - Address list of relevant institutions in Vietnam **(ANNEX A)**
    - Information on oil spill response equipment **(ANNEX A)**

- Implementation guidelines for bioremediation (Chapter 6)
    - Description of the implementation steps (in total 11 steps)
    - e.g. Decision tree flow-chart which guides the user systematically through the decision-making process, step by step, incl. explanatory notes

2 Introduction to Marine Oil Pollution

The following chapter put its scope on the basic knowledge about oil, oil in marine environments and its impacts as well the possible cleaning procedures. In addition to the theoretical discussion of the environmental impact of oil spills, known cases are reviewed.

2.1 Definitions of Oil

Crude oil and petroleum-based products are a mixture of different hydrocarbon-based substances. As each individually compound exhibit a wide range of physical properties, the oil-mixtures behaviour is determined by the properties, ratio and interactions of every oil-part which affects e.g. the way oil spreads and breaks down as well as its influence on the natural or man-made environment. In addition to the oils chemical and physical characteristics the prevailing weather and sea conditions as well as whether the oil remains at sea or comes ashore are of great importance. Therefore informations about the mixtures composition and the environments factors are basically for choosing appropriate response options to combat spilled oil

2.1.1 Chemical Properties of Oil

Crude Oil
Crude oil is comprised of hydrocarbon compounds (50 to 98% of total composition) as well as of non-hydrocarbon compounds (e.g. sulphur, nitrogen, oxygen, various trace metals). It can be divided into four major classes with a wide array of different characteristics. They are listed in order of biodegradability:

Saturated Hydrocarbons - Alkanes
Alkanes are the most abundant constituents in crude oil. They are almost nonpolar compounds with chains from one to over 40 carbons and do not solute in water. Apart from the high flammability of volatile alkanes, they are chemically little reactive. Alkanes with chain lengths from 10 to 26 carbons are considered to be degraded most rapidly, but also the degradation of alkanes with chain lengths up to 44 carbons was proved under laboratory conditions. Branched alkanes are less susceptible for degradation than normal (*n*-) alkanes. As branched alkanes with long C-chains are highly resistant to biodegradation, they are used as an indicator for undegradable compounds during a biological treatment.
The predominant mechanism of *n*-alkanes degradation involves terminal oxidation to the corresponding alcohol, aldehydes, or fatty acid functional group. Methyl branching increases the resistance to microbial attack, but even highly branched isoprenoid alkanes, which were thought to be resistant to biodegradion, have been shown to be readily biodegradable. However, cyloalkanes are particularly resistant to biodegradation.

Aromatic Hydrocarbons
Aromatics are compounds with one or more fused aromatic rings. Examples for monocyclic aromatic hydrocarbons are benzene, toluene, and xylenes, for polycyclic aromatic hydrocarbons with two or more fused aromatic rings are PAHs as naphtalene, anthracene, and phenanthrene. PAHs are of particular environmental concern because they are potential carcinogens or may be transformed into carcinogenes by microbial metabolism.
Light compounds with one or two cycles are quite well and rapidly biodegraded. Monoaromatics are toxic to some microorganisms due to their solvent action on cell membranes, but they are easily biodegradable in low concentrations. Heavy compounds with fife or more cycles are highly resistant to degradation. The degradation of aromatics proceeds most rapid under aerobic conditions. Although the biodegradation usually is a little slower than the alkane´s degradation, there are some low molecular weight aromatics (e.g. naphtalein) that may be oxidised before many saturates.

Resins and Asphaltenes

Little is known about biodegradation of these compounds, because their complex structure is difficult to analyze. Resins and Asphaltenes have been considered to be insusceptible to biodegradation, but some low molecular weight resin fractions may be degraded at low concentrations as well as asphaltenes through co-metabolism.

Refined Oil Products

Refined oil products derive from processed crude oil e.g. due to catalytic cracking and fractional distillation. The chemical and physical properties of these products differ in accordance to the crude oils type and the specific treatment. Beneath unsaturated and aromatic hydrocarbons refined oil products consist of unsaturated hydrocarbons (alkenes or olefines) formed during catalytic cracking operations. The concentration of olefins in gasoline is about 30%, in jet fuel about 1%.

2.1.2 Physical Properties of Oil

There are many physical oil properties that affect its behaviour in the environment and therefore have great impact in choosing appropriate spill cleanup actions:

Density or specific Gravity

Oil density is an important index of oil composition that is frequently used to predict its behaviour in water. As most oils are lighter than water, the oils lie flat on top of it. Due to evaporation of lighter substances the oil-spill's density can increase.

Viscosity

Viscosity is an important index of the spreading rate of a spilled oil. A substance's viscosity describes the liquids resistance to flow and to changes in shape or movement. The lower a fluid's viscosity, the more easily it flows. On the other hand, the higher the viscosity, the greater the tendency to stay in one place. The viscosity of petroleum is related to oil compositions and the ambient temperature.
With increasing temperature the viscosity of the fluid decreases.

Pour Point

The pour point describes the temperature at which a fluid becomes semi-solid or stops flowing. For oils this temperature varies from –57°C to 32°C. The pour point is another important characteristics with respect to oil fate and cleanup strategies.

Solubility in Water

This property is important regarding oil fate, oil toxicity and bioremediation processes. The oil's solubility in water is extremely low and depends on the chemical composition of the petroleum hydrocarbon and the temperature. For a typical crude oil, solubility is around 30 mg/L. The most soluble oil components are the low molecular weight aromatics.

Surface Tension

Surface tension is the measure of attraction between the surface molecules of a liquid. The lower a liquids surface tension, the more easily it will spread even without impacts such as wind or water currents. As surface tension decreases with increasing temperature, oil is more likely to spread in warmer waters than in colder ones.

2.1.3 Specific Properties of Oil Compositions:

As refined oil products are formed for particular purposes they show specific properties. In the following some examples regarding general oil compositions and specific named oils.

2.1.3.1 Very Light Oils (e.g. kerosene, gasoline)

- highly volatile (should evaporate completely within 1–2 days at temperate conditions) and leaves little residue
- highly flammable
- high concentration of toxic (soluble) compounds
- Gasoline: amenable to biodegradation
- Kerosene: relatively persistent in the environment
- spreads on water surfaces and penetrates porous soils quickly
- severe impacts to water column and intertidal resources
- duration of impacts is a function of the resource recovery rate
- no dispersion during cleanup necessary

2.1.3.2 Light Oils (e.g. diesel, No.2 fuel oils, light crudes)

- moderately/non volatile, will leave residue up to 1/3 of spills amount
- spreads quickly and is easily dispersed
- moderate concentrations of toxic (soluble) compounds
- pollutes intertidal resources with long-term contamination potential
- potential for subtidal impacts as dissolution, mixing, sorption onto suspended sediments
- no dispersion during cleanup necessary
- cleanup can be very effective

2.1.3.3 Medium Oils (most crude oils)

- about 1/3 evaporates within 24 hours
- maximum water-soluble fraction is 10 – 100 ppm
- contamination of intertidal resources can be severe/long-term
- impact to waterflow and fur-bearing mammals can be severe
- chemical dispersion is a option within 1-2 days
- cleanup most effective if conducted quickly

2.1.3.4 Heavy Oils (e.g. heavy crude oils, No. 6 fuel, bunker C)

- may be heavier than water
- difficult to pump
- little or no evaporation or dissolution
- water-soluble fraction < 10 ppm
- moderate flash point
- heavy contamination of intertidal areas likely
- severe impacts to waterflow and fur-bearing mammals
- long-term contamination of sediment possible
- weathers very slow
- dispersion seldom effective
- shoreline cleanup difficult under all conditions

2.1.3.5 Heavier refined oil products

- pose a lesser fire
- lesser toxic hazard
- do not spread on water as readily
- more persistent
- may present a greater remediation challenge

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Table 2.1-1: Properties of several oil compositions

	very light oils (e.g. kerosene, gasoline)	**light oils** (e.g. diesel, No.2 fuel oils, light crudes)	**medium oils** (most crude oils)	**heavy oils** (e.g. heavy crude oils, No. 6 fuel, bunker C)	**heavier refined oil products**
Volatility	↑ leaves little residue	↗ leave residue up to 1/3 of spilles amount	→ ↘ ca. 1/3 evaporates within 24 h; up to 50% may evaporate	↓ ↘	↓ ↘
Inflamm-ability	↑	↗	→	↘	↘
Solubility in water	↑	↑	→ max. water-soluble fraction is 10 – 100 ppm	↘ < 10 ppm	↓ ↘
Natural dispersion	↑	↑	→	↘	↘
Toxicity	↑	→	↘ variable	↘ servere impacts to waterflow and fur-bearing mammals	↘
Spreading on water	↑	↑	→	↘	↓ ↘
Soil penetration	↑ penetrates easily	↑ penetrates easily	→	→ long-term contamination of sediment is possible; heavy contamination of intertidal areas likely	↘
Viscosity	↓	↓	↘ →	↗	↑
Cleanup operation	no dispersion during cleanup necessary	-no dispersion during cleanup necessary; -cleanup can be very effective	chemical dispersion is a option within 1-2 days; cleanup most effective if conducted quickly	- dispersion seldom effective; - shoreline cleanup difficult under all conditions	-pretty persistent in the environment; -may present a greater remediation challenge
Further notes		- pollutes intertidal resources with long-term contamination potential; - potential for subtidal impacts as dissolution, mixing, sorption onto suspended sediments	-tend to form stable emulsions under high physical energy conditions -potential for sinking after weathering, particularly in a silt-laden environment	-may be heavier than water -difficult to pump -little or no evaporation	

Symbols: ↑ - very high ↗ - high → - moderate ↘ - little ↓ - very little/none

Refinery products with likewise specifically properties are:

- Gasoline
- Kerosene
- Diesel and bunkering fuel

2.2 Sources of Oil Pollution

The precise contribution of individual contaminants by the shipping industry remains obscure and uncertain, mainly due to the quality of the data and the sources from which they are derived. However, it remains a public misconception that oil spills following collisions or tanker accidents are the biggest cause of marine and port pollution. They account only for 5%, or 0.12 million tons, of the 2.60 million tons of oil which end up quietly in the seas each year, while oil and oily waste entering the marine environment from traditional, both, legal and illegal, routine ship maintenance and other operations are more than four times larger (1996: 0.52 million tons) than amounts from accidental cargo spills:

Table 2.2-1: Sources of oil and oily wastes in seawater

SOURCES OF OIL AND OILY WASTE ENTERING THE SEAS		TONS PER YEAR (millions)	%
DOWN THE DRAIN	• used engine oil • oil runoff and wastes from land-based industrial sources • other land-based sources	1.38	53
ROUTINE SHIP MAINTENANCE AND OPERATION	• bilge and tank cleaning • fuel leakages • oily ballast water • oily and wastes • cargo residues	0.52	20
UP IN SMOKE	• atmospheric deposition of hydrocarbons in the seas through air pollution from vehicles and industry	0.34	13
NATURAL SEEPS	• oil released from the ocean bottom and eroding sedimentary rocks	0.24	9
BIG SPILLS	• tanker accidents • accidents of other types of ships	0.12	5
TOTAL		2.60	100

[Wesnigk, Johanna B.; Universität Bremen; 2005]

Even though the "Big Spills" sum up to only five percent of the total annual discharge, they cause major problems to the affected regions. The concentrated contamination of seawater causes manifold problems for the marine life as well for the marine dependent life's such as fisheries.

The majority of the accidental spills are a combination of actions and circumstances. The analysis below explores the incidence of spills of different sizes in terms of the primary event or operation in progress at the time of the spill. It is evident from this research that the majority of spills from tankers occur as a result of routine actions such as loading, discharging or bunkering and normally occur in or around a port. The majority of these operational incidents are small (91% of these spills result in a spill of less than 7 tons). Accidents that involve collisions or groundings which attract media coverage usually result in much larger spills, almost a fifth result in spills over 700 tons.
The following data is basically taken from the ITOPF Internet Resource (http://www.itopf.com/index2.html) which is considered to be a very reliable source regarding oil pollution and its response.

Table 2.2-2: Incidence of spills by cause between 1970 and 2004

	< 7 tonnes	7-700 tonnes	> 700 tonnes	Total
OPERATIONS				
Loading/discharging	2817	327	30	3174
Bunkering	548	26	0	574
Other operations	1177	55	1	1233
ACCIDENTS				
Collisions	167	283	95	545
Groundings	232	214	117	563
Hull failures	573	88	43	704
Fires & explosions	85	14	30	129
Other/Unknown	2176	144	24	2344
TOTAL	**7775**	**1151**	**340**	**9266**

[Source: http://www.itopf.com/stats.html; 16.04.2006]

The collected data can be visualized as follows.

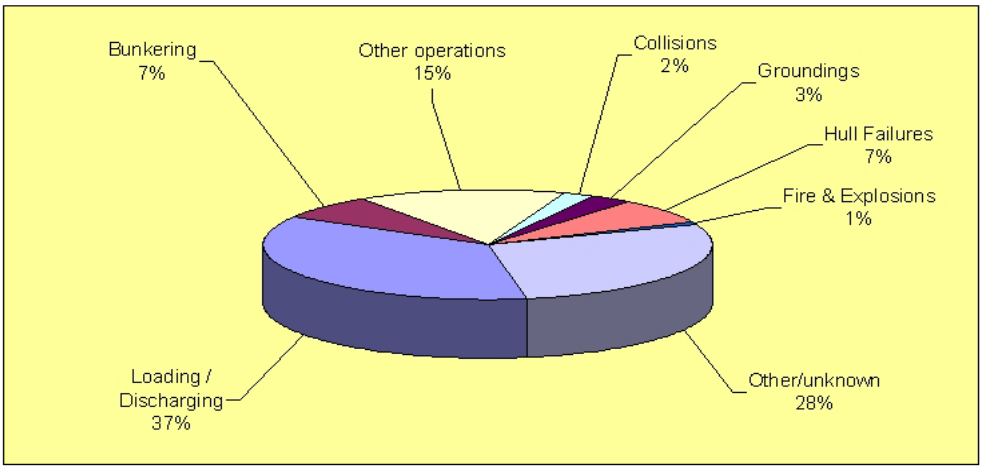

Figure 2-1: Incidence of spills under 7 tons by cause between 1970 and 2004[1]

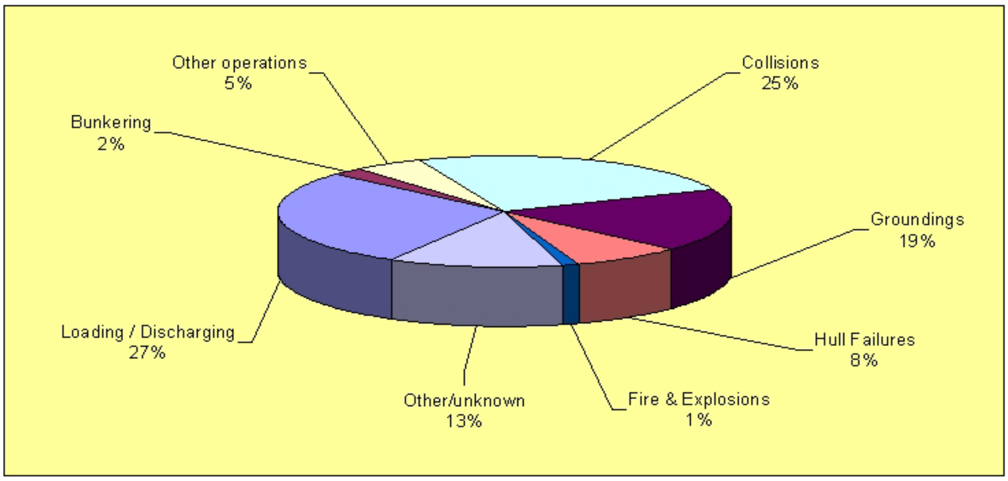

Figure 2-2: Incidence of spills 7-700 tons by cause between 1970 and 2004[1]

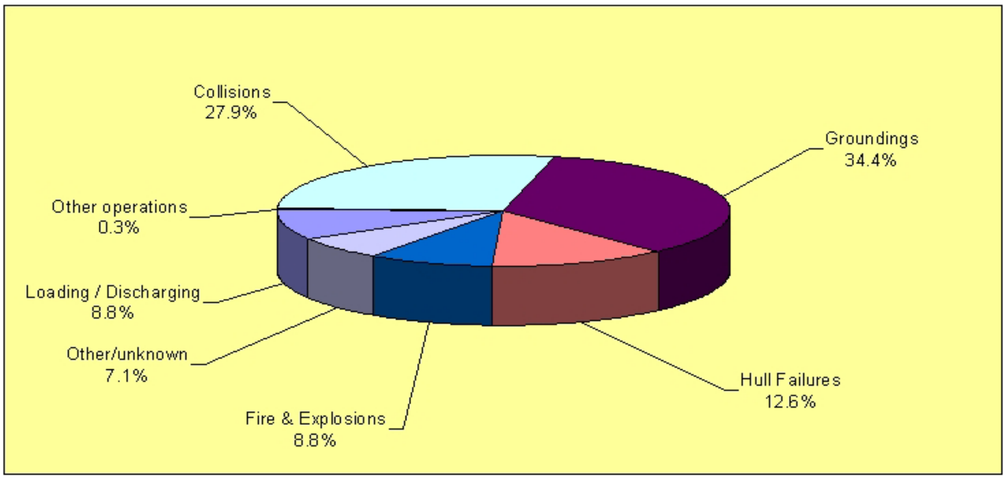

Figure 2-3: Incidence of spills over 700 tons by cause between 1970 and 2004[1]

2.3 Environmental Impacts of Oil Pollution

Oil spills can have a serious economic impact on coastal activities and on fisheries. Often such damage is temporary and is caused by the physical properties of oil creating nuisance and hazardous conditions. The ecological impacts on marine life is compounded by acute and chronic toxicity and tainting effects resulting from the chemical composition of oil as well as from the diversity and variability of biological systems and their sensitivity to oil pollution.

The extent of the damage caused by a spill is not always directly related to the quantity of oil spilt. A little oil in a sensitive area can do considerably more harm than a large quantity on a sandy beach. Therefore three factors are important:

1. Circumstances of the spill
2. Factors modifying the spill behaviour
3. Factors influencing the impact of the spill on marine organisms and amenities.

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[1] Piecharts: http://www.itopf.com/stats.html; 25.09.2005

The effects of oil on marine life can be considered as being caused by
either its physical nature, i.e.

- Physical contamination, i.e. clogging, interference with mobility or feeding
- Smothering, i.e. suffocation, heat stress

or by the chemical components of the oil, leading to:

- Acute toxicity - lethal, sub lethal, immediate effects, e.g. narcotic
- Chronic toxicity - mostly delayed effects
- Bioaccumulation, especially in molluscs like mussels
- Tainting of sea food
- Indirect effects: Marine life can also be affected by starvation or proliferation due to missing food/predators, by the clean-up operation or indirectly through physical damage to the habitats in which they live.

Populations of plants and animals in the sea are subject to considerable natural fluctuations in numbers, due to changes in climatic, hydrographical conditions and the availability of food. Thus the species composition and age structure of the various populations within a particular marine habitat are not constant but in a state of dynamic balance. This makes it difficult to assess the effects of an oil spill in quantitative terms as changes due to the spill and changes caused by natural variability and hard to distinguish.
Due to the strict legislation on environmental liability, the Exxon Valdez accident in Alaska is one of the few oil spills where extensive data was collected during long-term monitoring to do a quantitative assessment of the damage to the biota.
The different life stages of a species may show widely different tolerances and reactions to oil pollution. Usually the eggs, larval and juvenile stages will be more susceptible than the adults. However, many marine species produce very large numbers of eggs and larval stages to overcome natural loss (i.e. being food for other species). Normally 1 in 100.000 eggs will survive to maturity. Therefore localised loss of eggs or larvae through an oil spill are unlikely to have a discernible effect on the size or health of future adult populations.
The ability of animal and plant populations to recover from an oil spill and the time taken for a normal balance in the habitat to be re-established depends upon the severity and duration of the disturbance and the recovery potential of the individual species.

1. Abundant organisms with highly mobile young stages which are produced regularly in large numbers may repopulate a cleaned-up area rapidly.
2. Slowly maturing, long-lived species with low reproductive rates may take many years to recover their numbers and age structure. Examples are: seals, otters, reptiles, whales and dolphins and some cold water fish.
3. In general, the rate of recovery in tropical or Mediterranean regions is faster than in cold environments like the North Atlantic and the Baltic Sea.

Whilst it may be possible to restore the physical characteristics of oiled habitats close its condition before the spill, the extent to which its biological recovery can be enhanced and is severely limited. The cleaning of mangroves and salt marshes including replanting of seedlings may be possible in some situations. The replacement of animals seems to be impossible or at least hard to achieve and has not been tried yet. The replacement of animals can be considered as less effective and inefficient.

2.3.1 Effects on Marine Habitats

The marine habitats are different in their natural burden to pollutants and their ecosystem thus they are served by the same medium: water.
The following chapters put their scope on the different marine habitats and its residents.

2.3.1.1 Open Waters and Seabed

Plankton is a term applied to floating plants and animals carried passively by water currents in the upper layers of the sea. They form the base of the marine food web and include the eggs and young stages of fish, shellfish and many bottom-living animals. Their sensitivity to oil pollution has been demonstrated experimentally. In the open sea, the rapid dilution of some oil, the dispersion, evaporation and the high natural mortality as well as the patchy distribution of plankton make significant effects unlikely.

2.3.1.2 Fish and Mammals

Large swimming animals such as squid, fish, turtles, whales and dolphins are highly mobile and therefore rarely affected in offshore waters. In coastal areas marine mammals, such as seals or otters, and reptiles such as turtles are particularly vulnerable to oil contamination and ingestion because of their need to surface to breathe and to leave the water to breed. Adult fish living in nearshore waters and juvenile fish in shallow water nursery grounds are also at risk from exposure to dispersed or dissolved oil, especially if dispersants are used.

2.3.1.3 Benthos

Plants and animals living on the sea bed also form an important part of the food web. In nearshore waters many of the animals, like shellfish, crabs, shrimps and some seaweed such as kelp are exploited commercially. In shallow waters oil droplets may reach the bottom, particularly during periods of rough weather. Again the use of dispersants greatly increases the exposure of benthos organisms to oil.
Fresh crude oil and light refined products with a high proportion of toxic compounds can cause local damage to seagrass beds and to various animals such as clams, sea urchins and worms. The incorporation of oil components into sediments can lead to residence times of several years in localised areas. This leads to sub-lethal chronic effects and the tainting of bottom living or bottom feeding species used commercially.
Weathered oil may accumulate sediment particles and sink, especially after temporary stranding, thus causing damage to benthic species. Therefore each cleanup should be done fast and thoroughly.

2.3.1.4 Shorelines

They are most exposed to floating oil and its effects. Rocks are most at risk, where they are sheltered or tides and storms have left oil clinging to exposed and rough surfaces. In both cases natural wave action is strongly reduced and exposure times of wildlife prolonged.
Cobble, pebble and shingle beaches oil penetration increases with increasing stone size and the buried oil may persist for some time.
Particle size, water table depth and drainage characteristics determine the oil penetration of sand beaches. Coarse sand beaches enable more penetration of oil, particularly with low viscosity oils. Fine grained sand on flat profile beaches remains mostly wet during the full tidal cycle so that little penetration takes place.
The impact is particularly great where large areas of rock, sand and especially mud are uncovered at low tide. Intertidal animals and plants are able to withstand short term exposure to adverse conditions such as low oxygen or high temperature. However they may be killed by toxic oil components or physically smothered by viscous and weathered oils and emulsions. Animals may become detached from rocks or emerge from burrows, to be killed or washed away.
Recolonisation by dominant biota is possible, usually first the settlement of seaweed to be followed by grazing animals. However, the complete re-establishment of a normal balanced ecosystem may take many years. Many examples from research done after accidents can be found in the IRS index cards, which will be described in the second lecture on sensitivity mapping and can be found completely on the course cd.

2.3.1.5 Wetlands and Salt Marshes

Salt marshes occur in sheltered waters in temperate and cold regions and are characterised by dense low vegetation on mud flats drained by a network of channels. Therefore they are characteristic of low energy environments.
The organic input from the marsh provides the basic source of food for a rich and diverse fauna of worms, snails, clams and crabs which in turn are eaten by birds congregating in large numbers at low tide, especially at certain times of the year.
Marsh vegetation shows greater sensitivity to fresh light crude oil or light refined products than to weathered oils which cause relatively little damage. Oiling of the lower portion of plants and their root systems can be lethal whereas even a severe coating on leaves may be of little consequence, when it is outside the growing season.
More widespread damage can be expected from repeated contamination or if oil penetrates into sediments, e.g. during storms or due to animal burrows and plant root channels, where it can persist for several years. Similarly, if oil reaches the inner portion of marshes during a period of extremely high tides or storms, the residence time may be prolonged, affecting the plants as well as birds that feed and roost there more strongly.
Additional clean-up operations in wetlands are the most complicated ones to perform. Heavy equipment can destroy the plant cover and push oil further into the sediment. The tidal action makes usage of special booms necessary.
→ The example of the German Wadden-Sea[2] will be used to illustrate the sensitivity of tidal mud and sand flats as well as salt marsh areas in a further lecture on sensitivity mapping.
Especially grave are impacts on tropical wetlands containing mangroves. Coral reefs are not as sensitive as mangroves and normally not as exposed to oil but the associated flora and fauna can suffer from chronic effects. These impacts will not be elaborated here as in European waters no mangroves or corals occur.

2.3.1.6 Birds

Birds which congregate in large numbers on the sea or seashore to breed, feed or moult are particularly vulnerable to oil pollution. Examples may be auks, geese and ducks as well as the whole group of palearctic wading birds as well as solitary species such as cormorants and gannets, which dive to feed. Oil ingested by birds during preening of their feathers may be lethal. A common cause for death is from drowning, starvation and loss of body heat due to the damage of the plumage by oil. Feathers and down matted with oil lose the waterproofing and insulating properties. The use of dispersants enhance these effects and make the birds lose their buoyancy.
There are many examples of oil spills having caused large bird mortalities at sea leading to concern for the survival of the population. Many seabirds have long lives, delayed maturity and slow reproduction-rates. These factors taken together can hinder rapid recovery in isolated colonies or already stressed populations. Even a small oil spill close to a seabird breeding colony will have a damaging effect out of proportion to the amount spilt.
The cleaning of oiled birds may save individual birds but causes considerable stress for them. It should be done by trained personnel and makes most sense in the case of endangered species.

2.3.2 Conclusions

Difficult decision will have to be taken during an oil spill in order to mitigate damage and to resolve conflicts of interest. Therefore much can be done at the contingency planning stage to identify sensitive areas and to determine priorities for protection.
Sensitivity mapping can be a useful starting point and will be elaborated in another talk. Detailed consideration should be given to the likely impact that a spill can have on each habitat or activity, taking into account any seasonal variability. Attention is then given to identify areas to be protected and their order of priority. The

[2] geogr.: tideland

value of each resource depends upon the importance given to environmental, recreational, economic and political considerations. A wide range of data may have to be gathered and evaluated. If such an planning exercise is properly conducted, studies of resources at risk in a specific area can also form a basis for quantifying any damage caused by a spill.

If at all possible not only oil spills should be focussed on, but spills of other chemicals, especially when they are transported in bulk to or from nearby ports. Their behaviour and potential for recovery during clean-up should be another option for the contingency plan and the sensitivity maps.

The following points should be remembered:

- Most oil spills result from operational failures on all kinds of ships and oil platforms, not from major tanker accidents. It is estimated that 1.500 illegal discharges take place in the North Sea per year.
- There are around 431 oil platforms with more than 4500 oil wells drilled into the North Sea sediment as well as over 9000 km of seabed pipelines. Average daily production were 3.6 mio. barrels of oil and 9 bio SCDF of gas. It is estimated that 40 t of oil and 270 t of chemicals per day are discharged.
- The following sources for impacts exist: accidental spillage of oil, discharge of production water containing oil, chemicals from produced water, and cuttings from drilling operations. It is estimated that 5000 km² of the seabed are polluted.
- Maritime transport is estimated to contribute 12% to the total burden of pollutants entering the sea.
- The fate of oil at sea is determined by its characteristics and the physical, chemical and biological processes of the sea environment. Some lead to its dilution and removal, some cause it to change into persistent forms.
- The time scale of these changes depends on the oil and on the weather and climatic conditions and they will affect the choice of clean-up techniques as well as the nature of damage.
- Only a small percentage of oil will be biodegraded naturally in a reasonable amount of time.
- Other factors modifying the impact of the oil are: duration and concentration of exposure, the physical state of the oil the pollution history of the site and organisms, other stresses and time of season.
- Persistent oil seriously affects usage of coastal amenity areas and can interfere with the normal working of power stations and other industries requiring clean sea water supplies.
- Marine life can suffer from physical and chemical effects of the oil, especially in low energy environments with prolonged exposure e.g. in tidal mudflats and salt marshes.
- Long-lived species with low reproduction rates are most at risk.
- Oil spills can contaminated fishing and mariculture equipment and facilities and cause loss of market confidence in seafood products.

2.4 Socio-economic Aspects of Oil Pollution

Contamination of coastal amenities is a common feature of many oil spills leading to public disquiet and interference with activities such as swimming, boating, angling and diving. The tourist, trade and industry can also be affected. Because of their visual impact persistent oils and their residues cause the most concern, with the greatest (most public) effect likely to be just before or during the tourist season. The disturbance to coastal areas from a single oil spill is comparatively short lived and any effect on tourism is largely a question of restoring public confidence once clean-up is completed.

2.4.1 Environment-Economy-Interaction

The occurrence of an oil spill, which causes natural damages, always includes impacts on society and economy, too. Economy and environment are interconnected. The economy depends on the environment. Figure 2-4 shows a simplified picture of the economy and the environment interactions. The upper matrix is showing the economy and the way in which component parts of the economy interact. In the lower matrix the environment, consisting of all In-Situ resources, such as energy sources, fisheries, land or the capacity of the environment to assimilate waste products, is shown. Within this matrix there are interactions, too [Pearce; 1990; p. 30].

A change of the environmental quality leads to changes in the flow of environmental services to individuals and economy. Also the way in which individuals and economy use the environment may be modified [Hassan; 1997; p. 287].

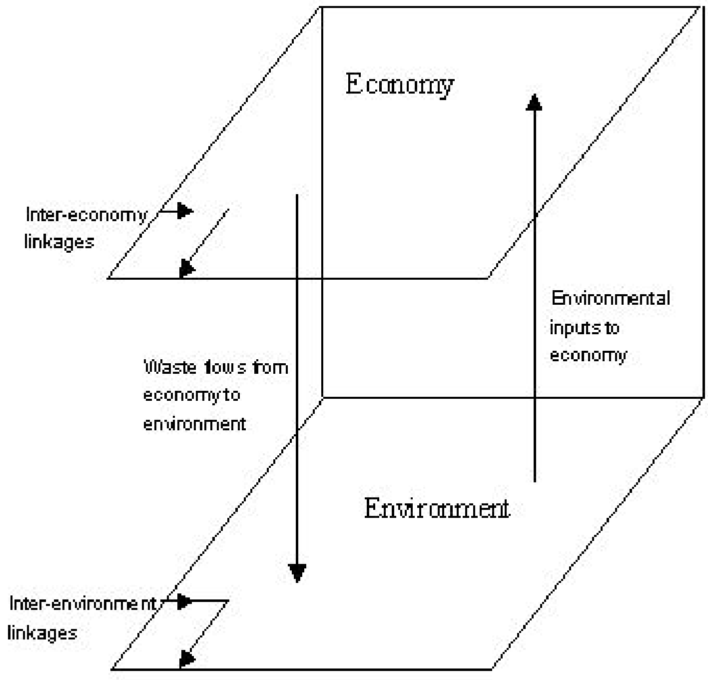

Figure 2-4: General Environment-Economy Interaction [Pearce; 1990; p. 30]

Socioeconomic factors vary between regions and countries. While some marine areas have high national or even international importance for fishing, mariculture, tourism, other industries or conservation, others rank only as locally important. There are also seasonal differences in the sensitivity of marine resources to oil pollution and thus in the impacts of oil spills on the exploitation of natural resources.

In

Table 2.4-1 several ecosystems, which may be in danger in case of an oil spill event, are listed together with their ecological and socioeconomic importance.

Table 2.4-1: Ecological and Socioeconomic Importance of Marine Ecosystems

Open coastal waters	Seabird feeding areas Commercial fishing and shell fishing Sea angling and other recreation
Sandy beaches	Recreation Access to water Shrimp fishing and stake netting for flat fish in some areas
Salt marshes	High biological productivity Export of detritus and nutrients to adjacent coastal waters Nursery areas for commercially important fish species Areas of scientific interest Feeding and roosting areas for shore and seabirds
Mangrove ecosystems	Shelter for many large species of fish, mammals and reptiles Shelter for young stages of commercially important fish and crustaceans Supply of fish, shellfish for coastal people living at subsistence level Supply of wood to coastal people for burning, building and tanning
Coral reefs	Protection to shorelines Supply of fish, shellfish and sea-grass for local populations at the artisan level
Tidal sand flats	General ecological significance Bird feeding areas Flatfish nursery areas Shrimp feeding grounds Bait digging
Subtidal seabed of coastal seas	Support of fish and shellfish stocks that are exploited by trawling Support of coastal mariculture operations
Rocky and boulder shores	Sea angling and shellfish collecting Seaweed harvesting Visual attractiveness Seabird breeding sites Teaching, research and conservation/scientific interest
Estuaries	Fisheries Recreation Transport Industry Waste disposal

[O'Sullivan; 2001]

An oil spill thus can cause serious socioeconomic impacts on local communities and national economies.

2.4.2 Socioeconomic Impacts caused by Oil Spills

Socioeconomic effects of oil spills include the economic losses of people who live directly or indirectly from the affected resources, losses of benefits that cannot be dealt with in terms of market values, such as natural and cultural values provided by the natural heritage [Vazquez.; 2003; p. 30] and social impacts, such as effects on public health.

2.4.2.1 Impacts on Fisheries and Aquaculture

Oil spills have the potential to cause severe long-term environmental impacts resulting in grave economic impacts. The contamination of fisheries and aquaculture provokes losses of income for people who live directly from the exploitation and sale of marine resources as well as for people who depend on the fisheries and aquaculture sector, such as wholesalers and retailers of fish and seafood.

Adult free-swimming fish, squid and wild stocks of other commercially important marine animals and plants in open waters seldom suffer directly from oil spills. The greatest impact is found on shorelines and shallow waters where animals and plants may be physically coated or exposed to toxic components in the oil. Seafood species especially sensitive to smothering and oil toxicity are seaweeds, oysters, mussels and clams. A major concern is the contamination of farmed fish, which, confined in cages, cannot avoid the oil.

Wild-stock Fisheries

Oil pollution may affect fisheries:

- by reducing the availability of fish or shellfish
- by causing tainting of the fish or shellfish
- by fouling fishing gear and boats
- by preventing the use of certain fishing grounds
- by reducing prices and creating difficulties in marketing of fish or shellfish.

Oil spills may result in loss of fishing opportunities by the mortality of free-living or cultivated organisms [IMO; 2002]. Mortalities of adult fish have been observed following a number of spills, especially in cases where the amounts of oil were very large, such as Prestige and Amoco Cadiz [O'Sullivan; 2001].

Tainting means the presence of disagreeable flavours in fish or shellfish. It is a frequent consequence of oil spillages or oily-water discharges. Fish not killed can be tainted by oil and make it unsaleable. The threat of possible or suspected tainting may lead to temporary closure of fishing grounds and shellfisheries. Fishermen may be banned from fishing until the affected zones are declared taint-free. [IMO; 2002]; [O'Sullivan; 2001]

Oil spills include the risk of fouling of boats and fishing and aquaculture gear. Fishing operations can be impeded because gear operated through a slick would be contaminated [IMO; 2002]. The presence of oil slicks on the sea surface leads to fouling of fishing gear and catches. Fishermen have to avoid temporarily certain fishing grounds because of the risk of fouling and suffered losses in their income. Particularly vulnerable to contamination of gear are shallow-water fisheries, especially, those using small-mesh nets, such as the ones used for shrimp, where small traces of oil can taint a complete catch hauled in the net [O'Sullivan; 2001].

Fish or shellfish originating from a locality where an oil spill has occurred may fetch lower prices. Tainting or the public perception that fish comes from an affected area can make it unsaleable. Buyers may turn to other sources [O'Sullivan; 2001] and an area may loose its "good name" and thus get impacted by an oil spill for a long time. The actual or perceived tainting may result in short and long-term loss of markets and reduced prices [IMO; 2002]. It may be difficult to restore the confidence of the market in the catches originating from affected areas. Therefore the fishing communities are in danger to suffer long-term losses in their income although the biological damage may be removed after a shorter period of time [O'Sullivan; 2001].

Marine Aquaculture

Oil spillages may affect marine aquaculture:

- by causing direct mortality of stocks of marketable fish or shellfish
- by causing tainting
- by smothering or contaminating culture racks and gear
- by making harvesting difficult or impossible
- by affecting water supplies or entering ponds through water intakes
- by reducing prices and creating difficulties in marketing.

Cultured species held in cages near the surface or grown on the intertidal part of the shore are at high risk to get directly affected by contact with oil. Particularly vulnerable is the shellfish, which is held in cages close to the surface. Marine aquaculture has been seriously affected by oil spill incidents, such as Amoco Cadic, Erika and Tanio [ITOPF; 2004]. Generally the impact of oil spillages tended had been sublethal and resulted in tainting [O'Sullivan; 2001].

The free living fish and also the cultivated stock may become tainted and acquire a bothering taste. As even a very small quantity of oil may cause serious tainting. Lobsters, mussels, oysters and clams have been tainted following oil spillages, making them unmarketable. [O'Sullivan; 2001]; [IMO; 2002]

Due to the presence of oil slicks on the surface of the sea, harvesting of cultivated species may become impossible or difficult. Flotation equipment, nets, cages and ropes are likely to become contaminated by oil. To remove oil completely from fishing gear, especially from fine-mesh netting and other synthetic materials, is extremely difficult. Often replacement of contaminated material becomes necessary [O'Sullivan; 2001].

Land-based coastal fish farms, which require a continuous supply of clean seawater, pump intakes of seawater to onshore tanks or use ponds connected to the sea by a channel. The presence of oil on the sea surface or dispersed oil droplets may cause contamination of the pipework, tanks or ponds. This may result in losses or tainting of stocks and a shut-down of water supply. A disruption of water supply leads to reduced oxygen levels and increased concentrations of toxic waste products in cultivated stocks [O'Sullivan; 2001].

Shellfish transferred from the source of oil to clean water may cleanse themselves. The taint may disappear after several weeks to a couple of months. But, the confidence of the market may be lost for a much longer period. The impacts of oil spillages on the marketing of cultivated fish or shellfish are even more serious than those on the sale of wild-stock fish due to the greater dependence of aquaculture on a pollution-free image [O'Sullivan; 2001]. The ability of growers to sell their products may severely be affected. Aquaculture facilities may become closed [Donaldson; 1994]. Since many aquaculture operations are heavily concentrated in small areas, even small spills can cause serious damage locally [IMO; 2002].

Case History: The Nakhodka Oil Spill

In 1997 the Nakhodka broke up with an estimated 10.000 tonnes of cargo onboard off the north coast of Japan. It caused heavy contamination of the coastline. Oil stranded at various locations over a distance of more than 1.000 km. The length of contamination posed great problems for the authorities. Around 10.000 people were involved in the shoreline clean-up, where primarily manual methods have been used.

Due to the fact that it was widespread practice to involve the fishing community into the nearshore and shoreline clean-up operations the clean-up secured an alternative source of income in the period when fishing activities were prevented by the presence of oil at the sea. For this reason the income of traditional fishermen was only marginally affected by the incident.

Besides of the fishermen also aquaculture operators suffered financial losses. The oil contamination caused the total loss of the seaweed harvest of one year. Furthermore, the whole stock of an onshore fish farm was lost following persistent oil contamination of sea water supplies [White; 1998].

Figure 2-5: Case History - Nakhodka Oil Spill

Seaweed Harvesting

Oil spillages may affect seaweed harvesting:

- by causing direct mortality of the plants
- by contaminating or tainting the seaweed and destroying its market value
- by replacement of valuable seaweed due to fast-growing of algae.

Following oil spill incidents fertiliser and soil conditioning of seaweed may be damaged. Even a very small concentration of hydrocarbons in water may cause dieback in growing plants. Due to the Amoco Cadiz oil spillage large masses of oil-contaminated algae became detached from their rocky substrate and were washed ashore.

Even if oil pollution does not damage the conditioning of the seaweed, it may destroy its value for alginate extraction. Seaweeds harvested directly for food may become tainted and unsaleable following a minor amount of oil pollution [O'Sullivan; 2001].

The demonstrated damages to wild-stock fisheries, marine aquaculture and seaweed harvesting can have a substantial effect on communities dependent on them. Commercial as well as subsistence activities in these sectors are concerned by oil spillages. Temporary financial losses to fishermen and aquaculture operators may be caused. Artisanal fishermen, especially in developing countries, may also suffer temporary food shortage [Donaldson; 1994]. The extent of socioeconomic impacts caused by an oil spillage may be determined by the time-up to biological re-establishment of the affected coast.

The fishermen and aquaculture operators are often in the frontline of oil spill impacts. But losses may be suffered also by processors, transporters, wholesalers and retailers, who are involved in the process of bringing seafood and fish to the market. The people involved in fishing and aquaculture due to losses in their income suffer from a loss of buying power. This may have an adverse effect on local trade. Furthermore, the advertising costs needed to mitigate the reputation of an affected region have to be taken into account while considering economic impacts of oil pollution on fisheries [IMO; 2002].

Fishing and seafood cultivation are not always pursued throughout the year. Therefore seasonal differences in sensitivity to oil spills may occur. The most seaweed in Asia, for example, is harvested in spring or early summer while the next generation is not planted out until early autumn [IMO; 2002]. So, the extent of socioeconomic damages in the fisheries and aquaculture sector is also determined by the time of the occurrence of the spill.

2.4.2.2 Impacts on Coastal Agriculture

Oil spillages may affect agricultural activities:

- by onshore winds carrying oil droplets or aerosol onto crops
- by entering of oil onto fields with high tides causing damages to paddies
- by causing damage to sheep grazing on intertidal seaweeds.

Whereas in European coastal areas, vegetable and flower cultivation, feeding of cattle and sheep grazing are important agricultural sectors, in Asian coastal areas the cultivation of rice plays a significant role. If the agricultural land is low lying and located close to the sea level oil spillages may affect the agricultural sector.
Following a major incident onshore winds may carry an aerosol of oil droplets onto fields. This may result in defoliating, tainting or other damage of crop (Sullivan, Jacques (1998)). An example is the case of the Castillo de Bellver spillage 1983 in South Africa, where oil droplets fell on wheat growing and sheep grazing lands [ITOPF; 2004].
Oily water also may enter the inland on the direct way on high tides. Paddies grown on low level may be affected heavily thereby. Following oil spillages in Vietnam rice paddies have been contaminated. On the coast of Shetland and Orkney islands oil impacted intertidal seaweeds used as grazing land for sheep. This resulted in the oiling of fleeces of sheep causing a loss of market value of the wool. In a few cases sheep were killed also by grazing on oil-contaminated seaweed [O'Sullivan; 2001].

2.4.2.3 Impacts on Tourism

Oil spillages may affect tourism:

- by contamination of beaches and park areas and reduction of amenity
- by restriction of recreational activities in coastal areas
- by damaging tourist facilities
- by causing a loss of attractiveness of shorelines for tourists and therewith a drop in tourism
- by causing economic losses to people involved in the tourism industry
- by causing a loss of reputation of affected areas
- by creating difficulties in marketing of affected regions.

The contamination of shorelines may cause high costs, especially when attractive coastal beaches and park areas are affected. Oil contamination reduces the amenity of shorelines and therewith the attractiveness for tourists. It may become impossible to conduct recreational activities which serve the tourist trade, such as bathing, boating, recreational fishing and diving for shorter or longer periods of time. Specially sensitive are those protected marine areas, which may be also attractions for tourists [IPIECA; 2000].
Besides coastal amenities such as beaches and park areas tourist facilities are in danger of oil pollution, for example, marinas which provide facilities for pleasure boat use.

Oil may temporarily make such resources unusable by causing damage to such facilities. Boat renters and diving tour operators may suffer significant economic losses and damages to their private property [IPIECA; 2000]. The loss of amenity can harm local communities considerably. Especially when beaches which are heavily used by the public are affected by oil spills, the impact on the local economy may be high. Tourists may cancel their holidays in the affected regions and this may cause a drop in tourism. As a result, hotel and restaurant owners and others who have their income from expenses of tourists, such as retail sellers, transport companies and tour operators, may suffer significant economic losses. These losses of income may have an adverse effect on local trade because, people involved in the tourism industry suffer a loss in their buying power [Maschke; 1998].

Generally, the disturbance to coastal areas and to recreational pursuits from oil spills is short-lived [ITOPF; 2004], [Donaldson; 1994]. But, the consequences from oil pollution for tourism in some cases may hold up longer than the time up to optical re-establishment of the coast. An areas' reputation and tourist bookings can be lost for periods after the spill [IPIECA; 2000]. The effect on tourism is largely a question of restoring the public confidence. High advertising costs may be needed to mitigate the reputation of an affected region. They have to be taken into account while considering economic impacts of oil pollution on tourism [ITOPF; 2004]. An example for long-term damages suffered by the local tourism sector is the Braer spill, which affected the Shetland tourism industries, and deterred many tourists from visiting the island for up to three years [ITOPF; 2004].

2.4.2.4 Impacts on Industries

Oil spillages may affect industries:

- by contamination of piping systems of industrial or desalination plants abstracting sea water
- by causing a shut-down of a plant while cleaning contaminated tubes leading to a decrease in output
- by causing commercial losses to the shipping industries, especially to the vessel owner, charterer and cargo owner of the ship, which caused an oil spillage

Industries may be adversely affected by oil spills if they rely on clean sea water for their normal operations. Many industries are depending on clean water intake. Some industries abstract sea water for cooling or other purposes. In several countries it is common to use desalination plants for production of drinking water. If oil enters the industrial or desalination plants together with abstracted water this can have serious effects [IPIECA; 2000]; [ITOPF; 2004].

Through oil-water intakes the facilities can be negatively affected, especially the piping system and condenser tubes may become contaminated. Due to the fouling it may be necessary to shut down the plant for carrying out the cleaning and leading to a reduction in output [GPA; 2004].

Oil spill incidents also harm the shipping and related industries. The crew of the vessel concerned may loose their jobs, health and even their lives. The vessel owner, the charterer and the cargo owner suffer commercial losses and may gain also under bad reputation [Donaldson; 1994].

2.4.2.5 Effects on Human Health

Besides economic impacts, oil spills may also cause various social impacts, especially human health impacts. The public health is vulnerable to oil spills:

- by evaporation of strong oil vapours causing health impacts to local residents, tourists and personnel engaged in clean-up operations inhaling the toxic hydrocarbon vapour
- by contamination of fishery products consumed by the local population
- by causing a change of consumption patterns resulting in a shift to less healthy diets
- by causing an increase in social injury.

Toxic hydrocarbon vapour may be released into air causing considerable discomfort to local residents, tourists and the personnel engaged in clean-up. The exposure of humans to toxic hydrocarbon vaporise can have serious effects on public health. For instance, due to the Tasman Spirit oil spill in Pakistan in 2003 toxic plume drifted with onshore winds over highly populated areas (see

Table 2.4-1). Nausea, fainting, memory loss and chest pain caused by this plume have been reported later [Zia; 2004].

Another possible human health hazard following oil spills comes from eating of fishery products contaminated by oil spills. Components derived by oil may include low concentrations of carcinogens. Polycyclic aromatic hydrocarbons hereby command greatest attention. According to information of the IMO it is not possible to define a concentration threshold of potential carcinogens in seafood products that represent a risk-free intake for humans. Seafood safety is also affected by other forms of contamination, such as heavy metals. The risk to an individual or community from oil spill derived carcinogens should be assessed in the context of the overall exposure from all potential sources of toxic components in food, also taking into account the various levels of seafood intake in different regions and ethnic groups [IMO; 2002].

Case History: Tasman Spirit Oil Spill

The Tasman Spirit oil spill on the Karachi coast in Pakistan in 2003 caused enormous damage to the environment, marine life and inhabitants of the area. It is estimated that ca. 30.000 tonnes of oil were spilled from the Tasman Spirit. The oil contaminated approximately 2.062 km^2 of marine area and affected 300.000 people. The negative impacts on the socioeconomy, particularly on public health, of the coastal population were serious and prolonged.

As a result of the spill many health effects were documented. Studies estimated that about 12.000 tons of the Tasman Spirit oil evaporated after the spill. The toxic plume with high concentrations of Volatile Organic Compounds (VOC's) drifted with onshore winds over popular recreational beaches and the heavily populated coastal area. Residential areas were badly affected with contaminated air for three weeks. Health impacts like nosebleeds, nausea, fainting, memory loss and chest pain were reported immediately after the spill. The event also caused social injury as increased anxiety disorders, hopelessness and depression appeared.

Coastal fishermen were the group of residents most affected by the spill. The oil affected fish and shellfish and commercial fisheries significantly. Mass mortality among coastal fishes and high concentrations of toxic PAH's in fishes caught from the impacted area have been observed. This resulted in a break-down of small-scale fishery. Fishermen reported a 100 per cent loss of income during the 6 months after the spill. [Zia; 2004]

Figure 2-6: Case History – Tasman Spirit Oil Spill

Due to oil spills fishing grounds may become closed until they are declared taint-free. This may have consequences on the diets of people living in coastal areas, especially for people fishing for sustenance. Seafood diet is inherently nutritious and rich in protein and vitamins. The levels of seafood intake are varying in different regions and ethnic groups. Restrictions on seafood intake following oil spills can cause the change of consumption patterns and a shift to less healthy diets [IMO; 2002].

Due to oil spills the living conditions of inhabitants of affected areas may have colossal change resulting in an increase of social injury. For example, the Exxon Valdez spill had an destabilizing effect on communities depending on harvests of marine resources. Increases in stress disorders, domestic violence, depression and substance abuse had been reported following the spill. Special investigations about groups of Alaskan Natives whose subsistence harvests as well as social and cultural activities were severely disrupted by the Exxon Valdez oil spill report about experienced high levels of depression among Native people after the occurrence of the spill [Picou; 1996].

2.4.2.6 Damage to Wildlife and Amenity

Oil spills affecting shorelines may cause both economic consequences on tradable goods and services connected to the sea as well as economic impacts on goods and services which are not tradable, such as amenity and biodiversity. A loss of tradable goods and services leading to a loss of use of natural resources, such as fish, seaweed, recreation areas or clean sea-water, causes a loss of income and expenses in affected areas. Goods and services which are not tradable, such as the natural heritage, are nevertheless essential for maintaining the economy and the environment. The natural heritage provides values related to the active use of natural areas, such as the enjoyment of the landscape, as well as values of cultural or ecological character that are not related to the active use of natural areas but have intrinsic value [Vazquez; 2003].

Even a small oil spill can cause widespread damage to wildlife. Animals and plants with high risk of impact by an oil spill are those that come into contact with the contaminated sea surface. Major damage to marine wildlife occurs, when oil comes ashore, killing living organisms and causing toxic effects in coastal ecosystems (Donaldson (1994)). A variety of ecosystems, such as mangroves and coral reefs serve as nursery grounds for fish and other marine organisms, thus supporting the fishing industry. Sandy beaches support tourism and recreation [IPIECA; 1997].

As a beautiful coast brings recreational satisfaction to individuals any damage in the quality of the shoreline consequently leads to the degradation of their welfare. The population of an affected area and the tourists visiting the concerned region suffer a loss of enjoyment if oil is destroying the amenity and restricting recreational activities on the shoreline [Bonnieux; 2004].

Also, archaelogical features are vulnerable to oil spills in a number of ways. Marine archaeology, such as wrecks or medieval fish traps, may be contaminated and the surface characteristics of some materials such as wood or peat deposits may be changed [SEEEC; 1998].

Case History: The Funiwa and the Bahia Las Minas Oil Spill

Examples for two tropical oil spills are the Funiwa V 1980 in Nigeria and Bahia Las Minas 1986 in Panama. Both caused widespread damages to the local natural resources. The Nigerian oil spill killed over 320 hectares, the Panama spill killed about 75 hectares of mangrove forest. In both cases the oiling of the mangrove habitat lead to the death or tainting of molluscs and crustaceans, including species which belonged to the subsistence food of local people.

In Panama oil leaching slowly from mangrove sediments damaged also sub-tidal corals. Other coral reef-flat areas were damaged by direct oiling at low tide. It was taken a large mangrove re-planting scheme to speed up the natural generation in Panama. More than 86.000 mangrove seedlings were planted out after one year. The chemical monitoring and pilot transplant experiments accompanying these measures have shown that oil residues in the sediments had weathered after one year and lost most of their toxicity to seedlings [White; 1998]; [IPIECA; 1992]; [IPIECA;1993].

Figure 2-7: Case History – The Funiwa and the Bahia Las Minas Oil Spill

2.4.3 The Costs Caused by Oil Spills

The next chapter will cater to the costs caused by oil spills, including costs of cleanup and oil abatement, compensation costs and costs of measures of restoration and economic losses. The quantification of economic effects is faced with many problems and specialized knowledge about damage costs is still sparely existent [UEK; 2000]. An exception regarding the process of damage assessment represents the Amoco Cadiz incident in 1978, where a group of scientists identified the social and economic impacts of this incident and quantified them as far as possible (see Figure 2-8).

Case History: Amoco Cadiz Oil Spill

On 16th March 1978 the Amoco Cadiz went aground off the coast of Northern Brittany in France. It lost all its cargo, 220.00 tons of oil, and caused a large oil spill contaminating 350 km of coastline [Thebaud; 2003].

The economy of the affected region is dominated by maritime activities and tourism. The sectors marine aquaculture, fisheries and tourism had been seriously affected by the incident in 1978 [Fairhall; 1980]; [Link; 2000]. The decline in fish-production after the pollution reached 21 % for fish and crustaceans. The reduction of tourist visits is estimated to be 11.6 million which means a 17 % drop [Bonnieux; 2004]. The drop in tourism and fishing industry affected the final demand and the consumption in Brittany resulting in a decrease of revenues.

The Bretagne was the second largest tourism market in France in 1978 when the oil spill occurred. Especially German tourists visited this region. Due to the incident it were especially the firms offering accommodation facilities which suffered heavy financial penalties. Many people employed in the tourism sector of the affected region lost their jobs in this year [Fairhall; 1980]; [Link; 2000].

The French government supported the region in a number of ways during 1978. A large advertising campaign had been conducted to support the local tourism sector. Furthermore, 5,08 million Euro compensation had been paid by the government to reimburse losses of wages in the fisheries sector. Private households, organisations and enterprises paid 1,46 million Euro to a central balancing stock for damages caused by the oil pollution. The European Union also supplied funds in the amount of 487.733 Euro for the coverage of costs for cleanup efforts [Fairhall; 1980]; [Link; 2000]. It constituted only a small fraction of the total cleanup costs (see Table below).

An overview of the social costs caused by this accident is given in the table below.

Following the assessment of damages caused by the Amoco the clean up and restoration costs represented the major part of the social costs of the Amoco Cadiz oil spill [Bonnieux; 2004].

Table: Social Costs of the Amoco Cadiz Oil Spill

	Million Euros 2003
Clean up and restoration costs	230,5 (46,2 %)
Marine resources losses	50,6 (10,1 %)
Fishing industry	22,6
Shellfish breeding	28,0
Recreation and amenity losses	51,7 (10,4 %)
Tourism industry losses	85,7 (17,2 %)
Direct losses (value added)	55,4
Indirect losses to the other sectors	30,3
Ecological losses	80,2 (16,1 %)
Total	447,0 (100 %)

[Bonnieux; 2004]

Figure 2-8: Case history - Amoco Cadiz oil spill

2.4.3.1 Costs of Oil Abatement and Cleanup

The costs of cleanup and oil abatement may be divided into the following types of costs:

- the costs of the incident (loss of cargo, loss of the ship, costs for repair of the ship, costs of salvage)
- the costs for technical equipment, oil abatement and container (rental fee for equipment, costs of reparation, oil separator, costs of disposal)
- costs for labourers working in oil abatement (wages, protective clothing, logistics)
- expenses for dispersives
- costs of temporary storage and subsequent cleanup actions of contaminated soil
- costs for fire-fighting
- costs for manual cleanup of polluted beaches/ coastlines
- miscellaneous costs (claims as consequences of accidents at work/ adverse effects to the health of workers, insurance charges for the workers, expenses for public relations)
- expenses for infrastructure management (costs of planning and consultation, communication)
- expenses for authorities, insurances and international organisations [UEK; 2000].

2.4.3.2 Compensation Costs and Costs of Measures of Restoration

The compensation costs and costs of measures of restoration include:
costs for resettlement of wild living animal species
construction costs for centres of salvation and rehabilitation, equipment, veterinary consultation, animal food, monitoring and research programmes
costs of the assessment process of the damages of natural resources (restoration, control, research consultancy, equipment for research, long-term monitoring, publication of research results)

2.4.3.3 Costs of Economic Losses

The economic sectors tourism, fishery and agriculture may be severely affected by an oil spill incident. The causer of an incident may therefore become liable to pay for:

- economic losses
- property damages
- costs for lawyer, court and compensations [UEK; 2000].

Case History: The Exxon Valdez Oil Spill

The Exxon Valdez ran aground on 24th March 1989 in Prince William Sound, Alaska. It released ca. 42 million litres of oil into a ecologically rich coastal zone. The spill occurred at the beginning of the most biologically active season and impacted the ecosystem processes throughout the summer of 1989. The most important damages due to the Exxon Valdez oil spill were the ecological ones as the affected area is one with great natural beauty and rich wild fauna [Bonnieux; 2004].

The US National Oceanic and Atmospheric Administration commissioned a panel of prominent economists chaired by Nobel prize winners Kenneth Arrow and Robert Solow to advise it on the use of contingent valuation for estimations of lost passive and non-use values through the Exxon Valdez oil spill. Contingent valuation is a survey approach designed to create the missing market for public goods by determining what people would be willing to pay (WTP) for changes in the quantity or quality of such goods or what they would be willing to accept (WTA) in compensation for these goods.

The research aimed to develop a valid survey instrument to measure the lost passive use values due to the natural resource injuries caused by the Exxon Valdez oil spill [Carson; 2003]. The lost passive use value, measured by the public’s willingness to pay to prevent another Exxon Valdez oil spill, was determined with 2,8 billion dollars [Carson; 2003] after [Bonnieux; 2004].

This amount executed 54 % of the total costs caused by the Exxon Valdez. It has been used for the restoration of the damaged natural resources, for projects of restoration in Prince William Sound and the support of the fisheries sector [UEK; 2000].

Figure 2-9: Case history – Exxon Valdez oil spill

2.4.3.4 Factors influencing the Height of Costs caused by Oil Spills

To pre-estimate the overall costs of an incident is not possible, because many factors determine the costs of oil spills. The interactions between them are very complex and so make cost predictions not reliable [White; 2003]. So, the costs of measures of oil abatement are not necessarily consummate with the amount of the spilled oil. The type of oil, the location of the incident, the weather conditions and the amount of oil altogether with other factors influence the height of costs caused by an oil spill.
A compendium and analysis of the knowledge of the costs caused by oil spill incidents worldwide is given in the study of Schmidt-Etkin [Schmidt-Etkin; 1998].
Another important source regarding the costs of oil spills and the influencing factors is the study of Grey [Grey; 1999].

2.4.3.5 The Compensation Process following Oil Spills

The compensation paid in cases of oil spill incidents is regulated in the 1969 International Convention on Civil Liability for Oil Pollution Damage and in the 1971 International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage. Both have been amended through the protocols of 1992, especially with the focus onto the extent of payments. The conventions were developed under the auspices of the International Maritime Organisation (IMO).
In 2003 a „Supplementary Fund“ was modelled to address the concerns of those states which consider the 1992 CLC and Fund limits as insufficient to cover all valid claims arising out of a major tanker accident. Its ratification is optional but available to all states that are party to the 1992 Fund Convention.
Some states have their own domestic legislation for compensating those affected by oil spills from tankers within their territory. For example, the USA enacted its own Oil Pollution Act following the Exxon Valdez incident [ITOPF; 2004]. In contrast to the above mentioned international conventions in the Oil Pollution Act of 1990 (OPA) of the USA are damages liable to pay compensation not limited to the costs of restoration of the environmental damages. There the idea of damage is including ecological damages in the broadest sense [UEK; 2000].
Further information may be found under: http://www.itopf.com/clcfund.html. The full texts of the 1992 Civil Liability and Fund Conventions are available under: http://www.iopcfund.org/npdf/engtextoc.pdf. The full text of the Oil Pollution Act 1990 (OPA 90) is available under: http://www.uscg.mil/hq/g-m/nmc/response/opawordp.pdf .
Usually different categories of numbers are discussed in the process of assessing and compensating the damages caused by oil spills: the estimates by experts, the compensation claims and the compensation paid to the claimants. It is difficult to establish one single global estimate of the social costs caused by an oil spill. Within the mentioned three categories always divergences may be observed. The paper of [Thebaud; 2003] tries to explain the divergences between the numbers. Based on an analysis of several major oil spills they find empirical difficulties and damage assessment methodologies, but also the institutional framework and information asymmetries as explanatory factors for the occurrence of different numbers in the discussion and process of damage valuation and compensation.

2.4.4 Damage Assessment

In most cases it is difficult to establish a single global estimate of the social costs caused by oil spills [Thebaud; 2003]. While some types of costs are easy to assess, such as the monetary expenses in salaries, equipment and physical operations for controlling, cleanup and restoration of the affected shoreline, others include difficulties concerning their assessment [White; 2003]. For example, the assessment of loss of working time and earnings for fishermen or lower returns for a hotel or commune is more complicated. The damage suffered by a hotel owner as a result of smaller earnings can not be proved with the help of bills of charge as in the case of the cleanup costs.
While some aspects are easy to assess from an economic standpoint, it is for others not easy to deal with them in monetary terms [OECD; 1982]. Valuing damage to wildlife and amenity in monetary terms presents real problems.

As the sea and the shoreline belong to everyone and are not privately owned there exist no market prices for the judgement of their value. But if only the costs of economic loss and cleanup and repair are used, an important dimension is left out of account [Vazquez; 2003].

2.4.4.1 The Concept of Total Economic Value

The effects of pollution of natural resources can be seen also as a decrease in the flow of services provided by the natural capital. An important point in quantification of damages to the ecosystem is the recoverability in reference to the baseline services [Bonnieux; 2004]. One concept to highlight the economic side of costal changes by environmental pollution is the concept of Total Economic Value (TEV). In figure 7 the concept of TEV with the goods and services provided by coral reefs is presented. Each of these goods and services creates economic value.

Many benefits associated with natural areas are not traded in markets and thus have no market value. If an economic analysis includes only those values for which there are market prices, it provides a distorted measure of benefits. To address this problem the concept of TEV was developed in the mid-1980s by economists as a more comprehensive concept of the economic value of nature. TEV encompasses direct commercial values and non-market-values as well as ecological functions and non-use benefits associated with natural areas.

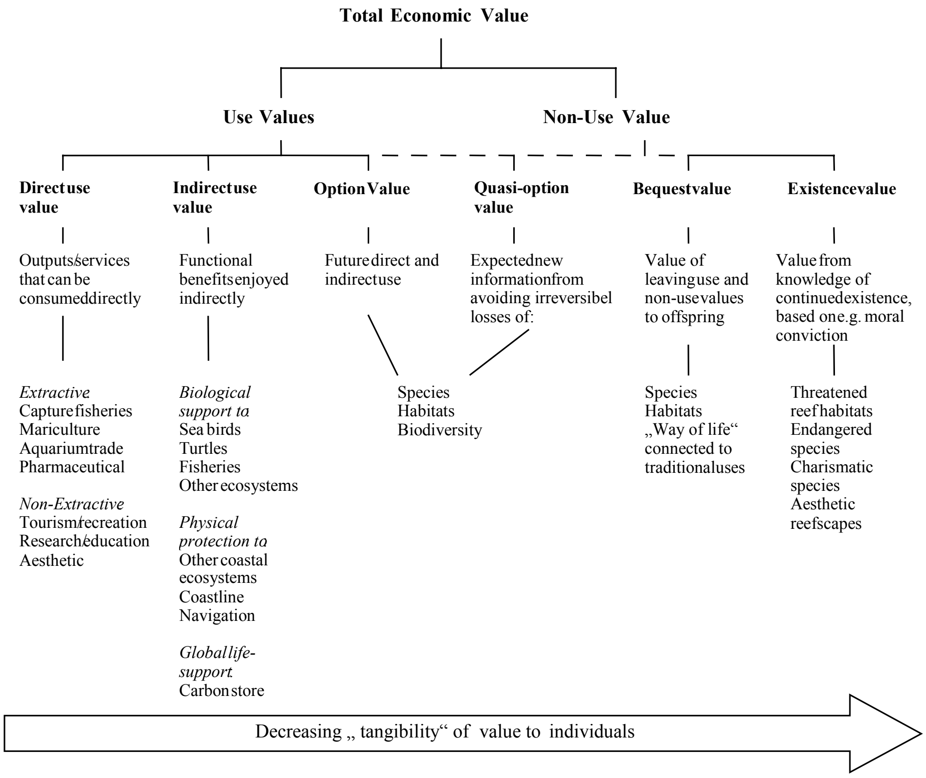

Figure 2-10: Goods and services provided by coral reefs [Pearce; 1990]

2.4.4.2 Valuation Techniques

The goods provided by natural areas include tangible services, such as food and energy, as well as less tangible services (see Figure 2-10). The direct measure of losses of intangible services, such as biodiversity, includes many difficulties. One way to estimate the decrease of its value is to investigate how much people would be willing to pay to prevent future oil spills [Bonnieux; 2004]. This method, also called contingent valuation method (CVM), is often used to estimate amenity losses due to environmental damage in monetary terms. The evaluation of damages caused by the Exxon Valdez incident was a pioneer in estimation of the loss of collective values for damages resulting from an accident. Prior to the Exxon Valdez oil spill, the estimation of collective values was not well known to many economists (see Figure 2-10).

In the relative ratio of intangible values, such as amenity, to tangible values, such as support of fisheries, lies a big difference between developing and developed countries. In contrast to the developed countries in developing countries, among poorer rural communities, environmental services affect the household directly through household production. While the willingness to pay for amenity is supposed to be quite low in poor communities, marketed environmental goods and services, such as fruits and fish are expected to be more important in low income ranges, especially in rural areas.

That's why in poorer communities in developing countries the most important environmental goods, are the least appropriate to popular forms of estimating environmental goods and services in developed countries, such as CVM. In developing countries the main emphasis is on the estimation of the economic value of marketed environmental goods and services.

2.4.5 Conclusion - Socioeconomic Consequences of Oil Spills for Vietnam

Vietnam with its 3.200 km long coastline and rich biodiversity is highly vulnerable to oil spills. The sea-based economy plays a very important role for the whole Vietnamese economic development. The coastal and marine resources and services are used for fisheries, agriculture, tourism, transport and other industries. The coastal regions contribute significantly, namely over 40 %, of the Vietnamese gross domestic product [VNA; 2003]. It is predicted that the population density at the Vietnamese coast will increase in future. The economic sectors will expand. Due to this development the population pressures as well as the economic pressures in the coastal environment will rise over time. The economic development will result in an increased demand for services and products provided by the natural systems, including the marine resources. The Vietnamese economy has developed quickly during the last decade. As a developing country Vietnam aims to keep high GDP growth rates [CIEM; 2004]. Since the economic reforms of doi moi in 1986 all GDP sectors have been growing. Major changes have also occurred in the composition of GDP by sector. The share of the industrial/construction sector is now at approximately 40 percent. The service sector is at 38 percent. The proportion of the agriculture, forestry, and fishery sector is at almost 22 percent. The development of the GDP reflects the development of Vietnam to a more industrialised country as the industry sector increased from 22 percent in 1990 up to 40 percent in 2003. In the same time the agriculture-fisheries-sector declined from 40 percent to 21,8 percent. Although the share of this sector seems to be low in comparison to the share of the industries in the GDP Vietnam is still largely dependent on its natural resources. This also reflected by the fact that 80 % of the population live in rural areas, two-thirds of them dependent on agriculture for living.

The natural damages caused by an oil spill, always include impacts on society and economy. As the economy depends on the environment an oil spill event will always change the extent and also the way in which the economy may use the environment. Firstly, oil spills mean a loss of tradable goods and services, such as fish or seaweed. Thus they cause a loss of income and expenses in affected areas for people who live directly or indirectly from the affected resources. Secondly, oil spills include social impacts, such as effects on public health and the increase of social injury. Thirdly, oil spills affect also goods and services which are not tradable, such as amenity and biodiversity, and thus lead to a loss of values of cultural or ecological character. They are not necessarily related to the active use of natural areas but have an intrinsic value.

The products of the fisheries sub sector, especially those from the aquaculture sector, are a major source of Vietnamese export earnings. Revenues of this were US$ 2.020 million in 2002. Oil spills pose a significant threat to the fishing and aquaculture resources. They may cause tainting and contamination of fish and seafood. Fishing and harvesting restrictions may become necessary. This may result in economic loss from business interruption. The sale of cultivated fish or shellfish is highly dependent on a pollution-free image. A loss of consumer confidence in products of affected areas may have long-term impacts on the local economy. Markets may be lost in long-term perspective. The fishermen and aquaculture operators are often in the frontline of oil spill impacts. But losses may be suffered also by processors, transporters, wholesalers and retailers- thus, the people who are involved in the process of bringing seafood and fish to the market. All these people also suffer from a loss of buying power. This may have an adverse effect on local trade. As aquacultural products are the major source of Vietnamese export earnings a large oil spill may cause a loss of foreign markets.

This may lead to a remarkable decrease of foreign exchange affecting the Vietnamese economy. The damages to fisheries, marine aquaculture and seaweed harvesting can have a substantial effect on communities dependent on them. Commercial as well as subsistence activities in these sectors are concerned by oil spillages. Besides of the temporary financial losses to fishermen and aquaculture operators artisanal fishermen may also suffer temporary food shortage.

Oil spills may also lead to economic losses in the agricultural sector. The cultivation of rice is a common agricultural activity in Vietnamese coastal regions, especially in coastal deltas. Due to multiplier effects an oil spill incident affecting paddies may result in economic impacts on related businesses, too.

Vietnam attracts domestic as well as foreign tourists. In 2000 there were approximately 10,7 million domestic tourists. The total number of visitors from abroad in 2001 was estimated with 2,63 million, 55 percent of them tourists. The tourism is Vietnam's fourth largest foreign-exchange earner. Of the leisure and tourist destinations of Vietnam about 70 percent are located in coastal areas. They attract 80 percent of the total of tourists each year. The contamination of shorelines may cause high costs. It may become impossible to conduct recreational activities which serve the tourist trade, such as bathing and boating. A large oil spill may have a severe impact to the Vietnamese tourism industry. Tourists may cancel their holidays in the affected regions. Due to reduced tourist arrivals from the inland as well as foreign countries the affected regions may suffer a remarkable loss of income. The drop in tourism can have consequences on tourist trade as well as on businesses connected with tourism. Hotel and restaurant owners and others who have their income from expenses of tourists, such as retail sellers, transport companies and tour operators, may suffer significant economic losses. As every economic activity has a multiplier effect, an oil spill incident affecting an important recreational area would cause economic impacts not only on local, but also on provincial and national level. Generally, the disturbance to coastal areas and to recreational pursuits from oil spills is short-lived (in comparison to the biological damages). But, sometimes the consequences from oil pollution for tourism may hold up longer than the time up to optical re-establishment of the coast. An areas' reputation and tourist bookings can be lost for periods after the spill.

Marine areas provide environmental services also to the industry. In Vietnam three major economic zones and almost 30 industrial and export processing zones are located in coastal areas. Furthermore, marine transportation is an important sector for the Vietnamese economy. There is an extensive network of domestic small scale ports. They support the local economies by facilitating the transportation of goods among regions. An oil spill incident affecting an industrial zone can have negative impacts on plants relying on clean sea-water. Industries depending on clean water intake may suffer decreases in output and economic loss due to a shut-down of the plant caused by the contamination of their piping systems. Furthermore, oil spill incidents may cause also damage to the Vietnamese transportation sector. Oil spillages may result in delays of transporting inputs for the industry respectively outputs of the industry. Thus they may cause a reduction of industrial and commercial activities.

Marine resources provide a source of food, income and employment for many people in Vietnam. The damage of natural resources due to spilled oil may cause loss of harvests, job loss and a loss of income. Especially, poor households are highly vulnerable. Because their income level is very low and unstable they are not able to resist a downward-shift in income. Shocks, such as oil spills, may result in great instability in their lives. Fishery is a way of life to many people in Vietnam. More than 4 million people live in tidal areas and about 1 million in swamp and lagoon areas in the island line. 80 % of the coastal communities rely on fisheries.

A big part, approximately 90 percent, of all fishers are artisanal and small-scale. Small scale fishing is a source of food and casual employment. The degradation of fishery resources can have a major negative impact on the lives of such people. Wild fisheries constitutes an important safety net and provides a source of income for landless and displaced people. Near-shore and coastal fishing are main sources of food in coastal areas. The degradation of fisheries resources caused by an oil spill may constrain the already limited opportunities of poor people in rural areas located on the coastline.

It is predicted that the coastal economic activities such as port and maritime activities, oil and gas exploitation, construction, aquaculture and coastal tourism will increase in the next decade. A rapid increase of the population density at the Vietnamese coast is expected. Though the population pressures as well as the economic pressures in the coastal environment and its affected ecosystems will rise over time. The expansion

of economic sectors including the sea-based economy will result in an increased demand for services and products provided by natural systems, including marine resources.
Fisheries, aquaculture and tourism are examples for industries, that are part of the sea-based economy and expected to grow on in future. They are considered as sectors that can push the economic development of Vietnam and may also help to raise incomes especially from low income people [CPRGS; 2003]. A large oil spill could easily contaminate hundreds of kilometres of the Vietnamese shoreline. It would threaten or destroy the marine ecosystems many subsistence and commercial economic activities rely on and would cause grave socioeconomic impacts on shoreline communities and the Vietnamese economy [UNEP; 2001].

2.5 Known Cases and Incidents

Table 2.5-1 gives as brief summary of 20 major oil spills since 1967. Some of these spills caused little environmental damage due to the oil evaporating before it had reached the coastline. The Exxon Valdez is 35th in the all time list but is included in the table due to the extensive environmental damage it caused and subsequent media coverage.

Table 2.5-1: Major oil spills since 1967

Position	Ship Name	Year	Location	Spill Size (tonnes)
1	Atlantic Empress	1979	Off Tobago, West Indies	287,000
2	ABT Summer	1991	700 nautical miles off Angola	260,000
3	Castillo de Bellver	1983	Off Saldanha Bay, South Africa	252,000
4	Amoco Cadiz	1978	Off Brittany, France	223,000
5	Haven	1991	Genoa, Italy	144,000
6	Odyssey	1988	700 nautical miles off Nova Scotia, Canada	132,000
7	Torrey Canyon	1967	Scilly Isles, UK	119,000
8	Sea Star	1972	Gulf of Oman	115,000
9	Irenes Serenade	1980	Navarino Bay, Greece	100,000
10	Urquiola	1976	La Coruna, Spain	100,000
11	Hawaiian Patriot	1977	300 nautical miles off Honolulu	95,000
12	Independenta	1979	Bosphorus, Turkey	95,000
13	Jakob Maersk	1975	Oporto, Portugal	88,000
14	Braer	1993	Shetland Islands, UK	85,000
15	Khark 5	1989	120 nautical miles off Atlantic coast of Morocco	80,000
16	Prestige	2002	Off the Spanish coast	63,000*
17	Aegean Sea	1992	La Coruna, Spain	74,000
18	Sea Empress	1996	Milford Haven, UK	72,000
19	Katina P	1992	Off Maputo, Mozambique	72,000
35	Exxon Valdez	1989	Prince William Sound, Alaska, USA	37,000

[Source: http://www.itopf.com/stats.html; 21.12.2005]

The graph below (Figure 2-11) shows the quantity of oil spilled worldwide from 1970 to 2004. Some of the major spills are highlighted in blue. The graph indicates that in some years the vast majority of the spilled oil came from one major incident. Examples for major oilspills are the Castillio de Bellver (1983; 252,000 tons) and the ABT Summer (1991; 260,000 tons) which ran aground.

Note, that in 2002, the vast majority of oil spilled was due to the Prestige disaster.

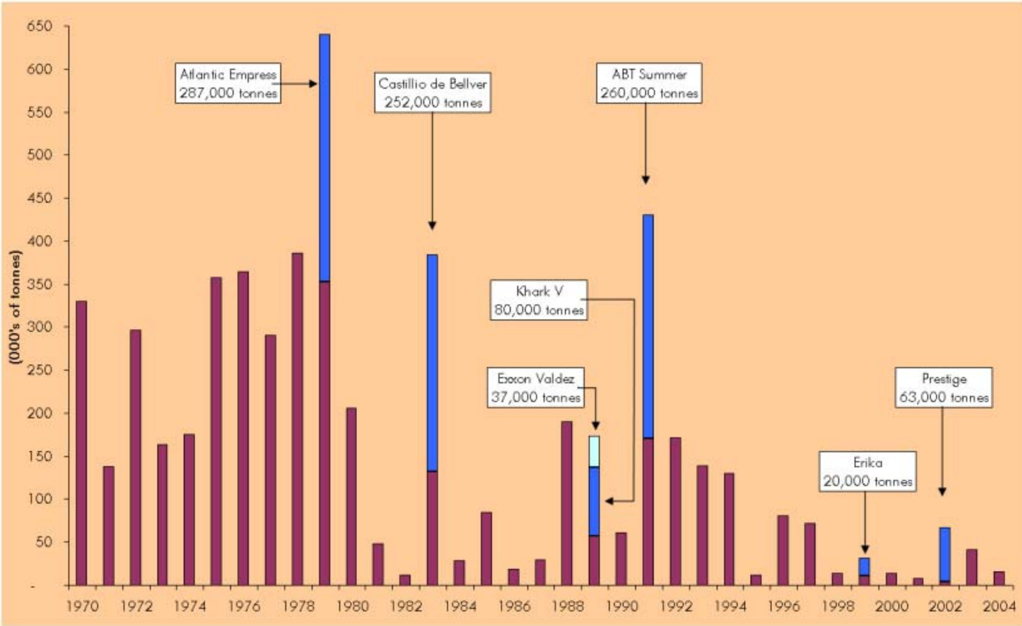

Figure 2-11: Quantities of Oil Spilt [Source: http://www.itopf.com/stats.html; 21.12.2005]

In addition to the information given by Table 2.5-1 and Figure 2-11 the geographical location of selected major oil spills is shown in the map on the next page.

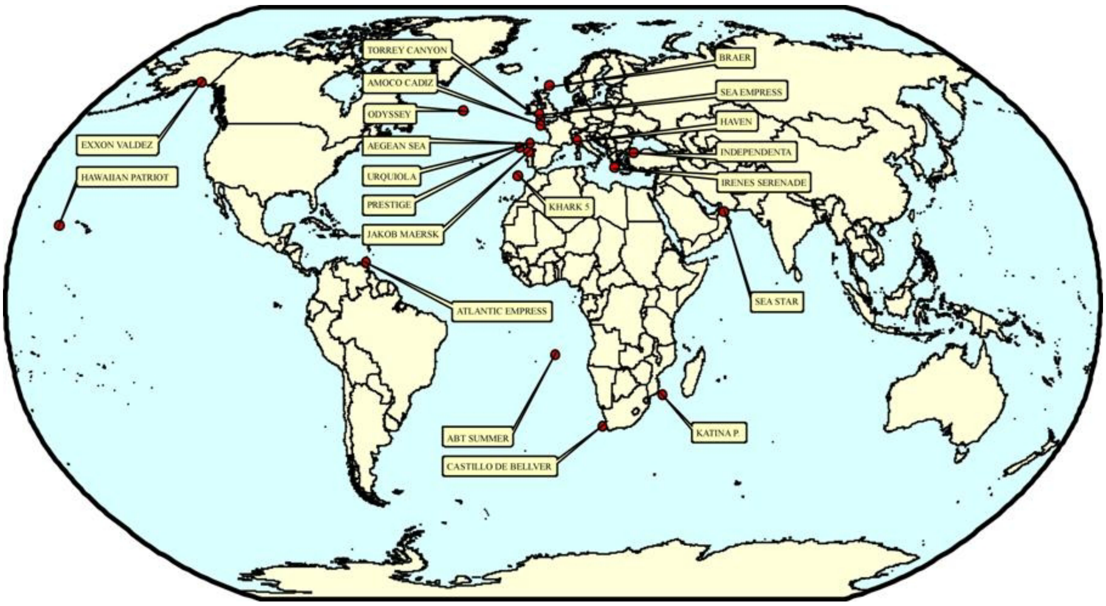

Figure 2-12: Location of Selected Spills [Source: http://www.itopf.com/stats.html; 21.12.2005]

The tables below show the observed annual quantities and the quantities of total decadal spill since 1970.

Table 2.5-2: Quantities 1970's

1970	330,000
1971	138,000
1972	297,000
1973	164,000
1974	175,000
1975	357,000
1976	364,000
1977	291,000
1978	386,000
1979	640,000
1970s	**Total: 3,142,000**

Table 2.5-4: Quantities 1990's

1990	61,000
1991	430,000
1992	172,000
1993	139,000
1994	130,000
1995	12,000
1996	80,000
1997	72,000
1998	13,000
1999	31,000
1990s	**Total: 1,140,000**

Table 2.5-3: Quantities 1980's

1980	206,000
1981	48,000
1982	12,000
1983	384,000
1984	28,000
1985	85,000
1986	19,000
1987	30,000
1988	190,000
1989	174,000
1980s	**Total: 1,176,000**

Table 2.5-5: Quantities 2000-2004

2000	14,000
2001	8,000
2002	67,000
2003	42,000
2004	15,000
2000-2004	**Total: 146,000**

Again, it is worth noting that one individual spill was responsible for a vast increase in the amount spilled in any given year.

For example: note that 1990 and 1992 suffered spills of 61,000 and 172,000 tons respectively whereas 1991, the year of the ABT Summer disaster recorded 430,000 tons of oil spilled. The same is true for 1982 and 1984 (12,000 and 28,000 tons) and 1983, the year of the Castillo de Bellver disaster, 384,000 tons[3].

Besides the major spills caused by accidents there are other sources of seawater contamination by oil.

Following some of the in accidents stated in Table 2.5-1 are discussed. The environmental and socio-economic considerations are taken into account.

2.5.1 "Sea Empress"

The Sea Empress was built in Spain in 1993; she was registered in Liberia and had a gross tonnage of 147,273 [TSO; 2005]. On the 15th of February she ran aground off St Ann's Head off Milford Haven in South West Wales. Over the next week 72,000 tons of Forties Light crude oil and approximately 360 tons of fuel

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[3] Source: http://www.itopf.com/stats.html; 21.12.2005

ware released from the vessel [Swansea; 2005]. When she ran aground, it was widely accepted that huge environmental damage would be caused; the coast of South West Wales is an area of exceptional environmental importance and contains 35 Sites of Special Scientific Interest, two National Nature Reserves, one Marine Nature Reserve and the UK's only coastal National Park.

However, the environmental impacts of the spill were far less than anticipated; this was due to the following reasons:

1) The spill occurred in February, the majority of the areas seabirds had not returned to nest and many marine fish species were in deeper water or were inactive.
2) Winds were blowing from the northerly quadrant for most of the period of the spill when the oil was being released (63,000 tons → 87%). A week later the wind changed and blew the remaining oil on to the beaches of South Pembrokeshire and Carmarthen Bay.
3) Approximately 40% of the light crude oil evaporated and was blown away from the shore.
4) Mechanical recovery of oil was hampered due to high winds (>15 knots) and the application of chemical dispersants by air was very successful and in addition to natural dispersal resulted in approximately 17,000 tons of oil to be removed.
5) Only 3-5% (3,700-5,300 tons) of oil reached the shore and due to an effective coastal clean up program, amenity beaches were visibly clear of oil within 6 weeks of the spill [[Empress; 1998]].

Despite these factors, the environmental impacts of the spill were still widespread and serious. The following paragraphs are a brief overview of the damage caused.

2.5.1.1 Human Health

A preliminary report published soon after the spill suggested that short term conditions within the local community included: nausea, headaches and skin conditions. Dermatological conditions also occurred in workers who did not wear the appropriate protective clothing whilst cleaning beaches. Effects were minimised due to the fact that the volatile hydrocarbons were dispersed seaward.

2.5.1.2 Commercial Fisheries

The area of the spill is under the control of the South Wales Sea Fisheries Committee. The fishing industry is small compared to UK landings but is locally important. Soon after the spill, levels of hydrocarbons were elevated in molluscs, crustaceans and some fin fish. Bans on fishing were lifted after 3 months on all fin fish including salmon and seas trout and on crustaceans, molluscs and whelks after 8 months [Empress; 1998]. Concentrations in mussels remained much higher and a ban on commercial mussel fishing was in place until September 1997 [Empress; 1998]. No mortalities of commercial fin fish, molluscs, or crustaceans that may be attributed to the oil spill were recorded. Furthermore there is no evidence that spawning of these species was damaged in 1996 or subsequent years. Closure orders restricting the crustacean fishery were imposed after the spill; as a result the landings were down for 1996 but were the highest since 1976 the following year [Empress; 1998].

There was no evidence of mass mortalities in commercial fin fish or crustaceans however large numbers of dead or moribund bivalve molluscs, starfish and heart urchins were found in and around the area of the spill and in Carmarthen Bay. The high concentrations of hydrocarbons found in these organisms suggested their deaths had been caused by the spill.

2.5.1.3 Shoreline Impacts

The area affected by the spill is largely dominated by rocky shores although there are several commercially important sandy beaches widely used by tourists. Surveys conducted 6 moths before the spill enabled an accurate depiction of the effects of the oil. Deaths of herbivorous gastropods especially limpets had caused some areas to be dominated by the green algae *Enteromorpha* and some of the brown *Fuchoid* seaweeds. In most areas barnacles survived and high larval settlement in 1996 enabled levels to quickly restore themselves to pre spill densities. Few other rocky shore species were affected adversely [Empress; 1998].

Other species that suffered detrimental effects included: *Laminaria,* amphipods, polychaete worms and brittle stars. Of particular concern to conservationists was *Asterina phylactica,* the cushion star which inhabits West Angle Bay. West Angle was one of the hardest hit areas and only 13 of the 150 cushion stars that existed before the spill survived [Empress; 1998].

2.5.1.4 Birds and Mammals

It is estimated that nearly 7,000 birds were collected on the beaches and an unknown number died at sea. Of the 7,000 collected, over half were still alive and were released after being cleaned. However, evidence suggests that the majority of these birds die soon after release. The most abundant casualty was the common scoter (66% of collections). Detailed studied have indicated that bivalve mollusc populations on which the scoters feed were reduced and other food sources, such as razor shells became more accessible due to oil contamination but probably more toxic.

Numbers of guillemots and razorbills decreased in the affected area by 13% and 7% respectively and some colonies have remained at 50% of pre spill levels. The main nursery areas for cetaceans (the bottlenose dolphin and harbour porpoise) and Atlantic grey seals are to the north west of the affected areas and no change in behaviour or numbers was noted after the spill [Empress; 1998].

2.5.2 "Exxon Valdez"

The Exxon Valdez grounded on Bligh Reef, Prince William Sound on the 24th March 1989. Approximately 37,000 tons of Alaska North Slope Crude Oil spilled into Prince William Sound [ITOPF Exxon; 2005]. On the all time list of spills, the Exxon Valdez was a relatively small one, what made the spill so disastrous was the extremely fragile environment in which it happened.

2.5.2.1 Seabirds

Prince William Sound provides feeding and breeding grounds for a wide variety of seabirds, it is therefore not surprising that over 30,000 birds from 9 species were recovered from the beaches and the water; however it is thought that the total number was several times greater [Piatt; 1990]. One of the unexpected casualties from the oil was the bald eagle; eagles were reported having oiled feathers, presumably from foraging on beaches. Tests showed that it took 2 years for the population to be restored to its previous levels. Over 80% of the seabird casualties were auks. The concern was the auks' ability to restore numbers as they have an extremely low reproductive rate, however tests showed that numbers were restored to pre-spill levels in 2-3 years [Piatt; 1990].

2.5.2.2 Sea Mammals

Evidence from previous spills suggests that the effects of oil on sea mammals are not a particular problem. There is no evidence from the mortality rates of whales and porpoise in the months after the Exxon Valdez spill that any deaths were cause by oil.

Seal and sea lion populations had been in decline in Prince William Sound in the 1970's, the rates of decline post-Exxon Valdez continued as predicted and although there were undoubtedly some cases of oiling the population remained largely unaffected [Valdez; 2005].

Unlike whales and dolphins, sea otters are more vulnerable to oil pollution as they rely on a thick layer of fur to preserve heat rather than a layer of blubber. If this gets oiled they may die from hypothermia or through ingestion of oil trying to clean themselves. However, sea otters have a high reproductive rate and tests conducted after the spill saw sea otter populations restore themselves to pre spill levels very quickly after the spill.

2.5.2.3 Shoreline Communities

Up to 1400 miles of shoreline in the Prince William Sound area was affected by oil. Both the oil and the intensive clean up techniques used had major environmental consequences. The inter-tidal zone supports a wide variety of flora and fauna including inter-tidal organisms, sea otters and sea birds such as Black Oystercatchers and Harlequin Ducks [Exxon Trust; 2005].

Many species of invertebrates and algae were less abundant at oiled sites than unaffected sites. In particular the abundance of the brown algae *Fucus gardneri* was reduced following the spill. Some opportunistic species such as species of barnacle, filamentous brown algae and oligochaete worms colonised areas affected by the oil spill and the clean up. The aim of the shoreline cleaning program was to restore conditions to ones that would have existed had the spill not taken place [Exxon Trust; 2005].

2.5.2.4 Sub-tidal Communities

The shallow waters of Prince William Sound are dominated by kelp forests and eelgrass beds, these ecosystems support such organisms as polychaete worms, clams, snails and other invertebrates. The communities associated with the kelp and eelgrass beds provide food, shelter for a variety of nearshore fishes, birds and marine mammals.

The negative effects of the oil on these communities were felt most by oil sensitive species such as amphipods. There were a reduced number of eelgrass shoots and flowers at oiled sites but this may have been due to boat traffic caused by the clean up operations rather than oiling. Some invertebrates living in the sediment were more abundant at oiled sites; this is due to their higher tolerance to pollution, a lack of competition and a response to the organic enrichment of an environment with the addition of oil. These invertebrates included: 8 families of polychaete worms, 2 families of snails and one family of mussels.

2.5.3 "Tasman Spirit"

The Tasman Spirit grounded in the channel in the Port of Karachi on the 27th of July 2003. Significant spillage didn't occur until the 13th of August and between the 13th and 18th of august she spilled approximately 27,000 tons of Iranian Light crude oil [ReliefWeb; 2005]. The coastal environment in which the Tasman Spirit ran aground is a rich tropical and estuarine ecosystem; it provides a habitat for sea turtles, dolphins, porpoises, and beaked whales. There are also large areas of mangrove swamps.

It is thought that the area initially affected by the oil was around 40km². Extensive tests on the sea water revealed hydrocarbon contamination, the 40km² area was thought to contain around 12,000 tons of oil [ReliefWeb; 2005].

2.5.3.1 Air Pollution

As Iranian Light crude oil is a light oil around 11,000 tons of volatile organic compounds evaporated after the spillage [ReliefWeb; 2005]. A pungent odour was reported to be perceptible at a distance of one kilometre form the beach. One of the medical camps set up on site treated 250 people who reported problems associated with petroleum hydrocarbon exposure. Further epidemiological studies will need to be conducted to determine the long term health implication on the local population.

2.5.3.2 Impact on Productivity

Due to there being a layer of oil on the surface of the water, light penetration was negligible; as a result the photosynthetic activity of phytoplankton was reduced. Tests show that phytoplankton groups usually present in July were either absent or reduced substantially. Further tests carried out showed that some of the affected phytoplankton groups showed slight cell deformities, it has yet to be concluded that there is a correlation between this and the spill.

Determining the loss of phytoplankton and zooplankton is very hard due to there being a lack of base data to refer to. It is made harder due to the short life cycle of these organisms.

2.5.3.3 Fisheries Resources

On August 14th between 500-500kg of dead fish were found on Clifton Beach. The following species were found: mullets, catfish, shellfish and crabs. The gills and other hard body parts of the fish were covered in a thick layer of oil. On August 19th, a further 100 dead fish were collected. These fell into the following categories: 50% grey mullet, 20% sardinella and the other 30% comprised of sea catfish, croakers, scats, eels, tripod and scorpion fish [ReliefWeb; 2005].

2.5.3.4 Impact on Mangroves

The impact of the spill on the mangrove swamps was observed in the form of seedling death in *Avicennia marina* and a fatal effect on the young growths of mangrove species. This has caused a major loss in the mangroves ability to regenerate, the long term effects of this are not yet known.

The acute toxicity of crude oil in mangroves was observed after the Tasman Spirit spill. Seedlings of mangrove plants are highly vulnerable to oil exposure, they cannot survive in oiled sediments after they have used to food reserve therein.

2.5.4 "Torrey Canyon"

The Torrey Canyon was built in the United States in 1959; she was registered in Liberia and had a gross tonnage of 183,000 [Loughborough; 2005]. On the 18th of March 1967, she ran aground on Pollard Rock on the Seven Stones Reef, near Lands End, Cornwall. Over the next 12 days, 119,000 tons of Kuwait crude oil spilled into the sea [ITOPF Torrey; 2005]. With a spill of this magnitude, large scale pollution and environmental damage is inevitable, as a result of this, arrangements were made at the time to coordinate a survey looking at the effects of the oil and detergents used in the clean up operation.

2.5.4.1 Impact and Recovery

The first generation of dispersants in the 1960's were often more toxic to marine life than the oil itself. Laboratory experiments conducted after the Torrey Canyon disaster show that the concentration required to kill 50% of intertidal organisms in 24 hours of exposure is between 5 and 100 ppm (parts-per-million) with limpets in the genus *Patella* being particularly vulnerable. These lethal concentrations are much lower than those needed to disperse oil. As a consequence many algae and almost all animals were killed in areas of the shore that were subject to dispersant spraying [UK Marine; 2005].

2.5.4.2 Patterns of Re-colonisation

The effects on the rocky shores were profound and long lasting. The removal of the limpets had a particular effect as they are the dominant grazers in intertidal environments. Following the death of the grazers, the intertidal zone was subject to a dense flush of green algae, in particular *Ulva, Enteromporpha and Blidingia.*
This was observed for up to one year after the spill. After approximately 6 months, large brown algae began to colonise the shores; in particular the Fuchoids, *Fucus vesiculosus and Fucus serrauts.* The dense canopy of the brown algae prevented any re-colonisation of barnacles due to the long sweeping fronds of the Fuchiods preventing larval settlement. This was enhanced by the presence of the carnivorous Dogwhelk (*Nucella lapillus)* [UK Marine; 2005].

2.5.4.3 Reappearance of Grazers

The first evidence that *Patella* had re-colonised shores was in the early winter of 1967/8. The limpets had begun to re-establish themselves under the dense canopy of the Fuchoids thus preventing further *Fucus* plants establishing themselves. As the plants aged, limpet grazing of their holdfasts weakened them further and between 1971 and 1975, the shores became very bare with less algal coverage than before the spill [UK Marine; 2005].
Following the disappearance of the Fuchoids, the abnormally high density of limpets migrated across the shore. This is unusual behaviour in this species as there normal behaviour involves roaming approximately a metre around the place on the rock they settle or their 'home scar'. Barnacle numbers also increased due to the disappearance of the Fuchoids. Between 1975 and 1980, limpet populations fluctuated but this was attributed to normal spatial and temporal variations.

2.5.4.4 Recovery of Barnacle Populations

After the initial decline in barnacle numbers as a result of the spill, numbers steadily increased at all shore heights. At the shore height equivalent to the mean high water neap level, all counts of barnacle numbers after 1979 stayed within one standard deviation of the pre-spill mean level. Only one value (1990) exceeded the mean. The same irregular pattern for the mid tide level was observed in the months after the spill, with exceptionally high counts just after the bare phase in 1976. In the lower shore area, the fluctuations were much more exaggerated that the other shore heights. This may have been due to the greater influence of biological interactions such as predation with *Nucella lapillus* and competition with the Common Mussel *(Mytulis edulis)* [UK Marine; 2005].

Timescale for Recovery:
Research shows that the estimated timescale for recovery at these sites is around 10 years, if barnacle densities are used as an indicator, 15 years may be more appropriate. These timescales may seem long but they make sense if the life expectancy of these organisms is taken into account: *Fucus* 4-5 years, *Patella* 10 years, *Chthamalus* (barnacle) at least 5 years [UK Marine; 2005].

This timescale is considerably longer than first thought by ecologists at the time. It was wrongly assumed that dense growth of seaweeds was an indication of recovery and some ecologists suggested that the sites had fully recovered in 2 years. However Southward and Southward (1978) dismissed these assumptions and the expected rapid recovery. Evidence shows that some sites heavily treated with dispersants had not returned to normal after 10 years, and in the worst cases it may take 15 years for the sites to recover fully.

2.5.4.5 Seabirds

An estimated 25,000 birds died as a result of the Torrey Canyon grounding. The spill coincided with their northerly migration and the coasts of South England and Brittany are nesting beaches for a wide variety of seabirds including: shags, guillemots, cormorants, razorbills, puffins and great northern divers. Thousands of birds were picked up and cleaned but the survival rate was around 1% due to ingestion of oil, pneumonia and improper cleaning and handling [Greennature II; 2005].

2.5.4.6 The Clean Up

In all, over 10,000 tons of detergents were used, primarily BP1002 which contained 12% non-ionic surfactant and 3% stabiliser which was sprayed onto the surface of the water. As well as detergents, manual removal methods were also deployed on many of the beaches on the north coast of Brittany. Clean up methods included pumping, bailing and bulldozing oil. In all 4,000 tons of oil and oil emulsions were removed from Guernsey and 4,200 tons from French beaches. The technique used by the French to treat floating oil was to disperse 3,000 tons of chalk on the surface of the water. It was believed that the chalk would make the oil sink or disperse. The high density of the oil and the relative calm conditions at sea contributed to the success of this project (source: footnote 12).
After considering the options of towing the vessel ashore or pumping the remaining oil onto another ship were considered, government authorities decided to bomb the vessel in order to burn the remaining oil. The Royal Navy carried out the bombing on the 28th-30th of March. A Navy helicopter dropped napalm, sodium chlorate and aviation fuel to fuel the fire [Greennature II; 2005].

2.5.5 “Braer”

On the 5th February 1993, the Liberian registered tanker, the Braer ran aground following engine failure in severe weather on Garth’s Ness, Shetland. Over a period of 12 days, 84,700 tons of Norwegian Gulfaks crude oil and up to 1500 tons of heavy bunker oil spilled into the sea [ITOPF Braer; 2005]. Severe weather conditions limited mechanical recovery of the oil at sea so 130 tons of chemical dispersant were sprayed onto the slick [ITOPF Braer; 2005].

2.5.5.1 Seabed Ecology

In all areas sampled after the spill, there was an extremely rich benthic fauna recorded. In all 478 species were identified, there was no evidence in species richness, abundance or diversity that the oil from the Braer spill had had any effect [Impact Braer; 1994; P. 74]. This evidence suggested that the impact of the oil had not been serious enough to disrupt trends in community structure however high hydrocarbon readings from some groups of species indicated that there had been a detectable effect. For example, the crustacean order *Amphipoda* was completely absent from the most heavily oiled sites off west Burra but numbers were found to be at their normal levels in Yell Sound which was uncontaminated.

2.5.5.2 Fish and Shellfish

The Shetland Islands have a thriving farm salmon industry, as a result, the MLA (Marine Laboratory Aberdeen) and several other local agencies quickly set up a monitoring program after the spill. The results from the early part of the work show that salmon in the affected areas had very high concentrations of PAH's (polycyclic aromatic hydrocarbons) in their flesh and taste panel analysis showed them to be highly tainted. Elevated levels of benzene were also found, they returned to background levels by the 19th January 1993 [Impact Braer; 1994; P. 82].

Tests showed that one day after the spill, salmon had up to between 12,500 and 15,000 ng/g of PAH's in their blood. It took 190 days for all traces of PAH's to disappear [Impact Braer; 1994; P. 82]. The reduction in PAH's is caused by the process of elimination of substances in the course of metabolism, this occurs in salmon and other fishes.

2.5.5.3 Wild Fish

Wild fish were subject to widespread PAH contamination in and around the zone most affected by the oil. Some of the affected species were: haddock, whiting, plaice, dabs and a variety of shellfish (scallops, edible and velvet crabs). They are not generally as vulnerable as farmed species as they can move away from the contaminated areas; this was reflected in the taint and contamination results from wild fish.

2.5.5.4 Shellfish

As a general rule, shellfish are more vulnerable to an oil spill than fish due to the fact they have a closer association with and exposure to oil contaminated sediments [Impact Braer; 1994; P. 97]. This led to higher levels of contamination in shellfish and longer lasting effects, in particular for scallops, queens and mussels. This is most likely to be due to their filter feeding habits and an inability to degrade and excrete hydrocarbons. This can have a knock on effect on fish populations if they feed on contaminated shellfish. It was not thought to have a serious effect in the case of the Braer due to the limited area affected by the oil.

2.5.5.5 Shoreline and near-Shore Ecology

After extensive tests on a variety of near-shore and shorelines organisms, it would appear that there was very little hydrocarbon contamination from the Braer. The most likely scenario is that after an initial toxic impact, much of the oil that reached the coast was either dispersed or buried in the months following the spill [Impact Braer; 1994; P. 109].

On rocky shores, damage caused by the oil was more evident than on the sediments. The absence of the grazer Common Limpet (*Patella vulgate*) populations and an abundance of the green algae *Enteromorpha* suggests that the oil had a significant effect on the limpet population. Mortality of the barnacle *Semibalanus balanoides* was also observed in the wreck area. No evidence of damage by oil was recorded in exposed sub0tidal rocky substrata.

2.5.5.6 Sea Mammals

Marine mammals are some of the hardest organisms to study. They are very mobile and through hunting have learned to be wary of humans. Otters were one of the species that were feared for due to their dependence on inshore fish. However there is no evidence to suggest that there were any long term impacts on the otter population and generally at the time of the spill, the otter population of the Shetland Islands was on the increase. Some holts in the immediate vicinity of the spill were empty in September 193 and this was probably due to a lack of fish rather than oil contamination.

Of all the marine mammals in the area, the Grey Seal showed the most obvious short term impacts of the spill, results showed ocular and respiratory problems; however there was no evidence of increased mortality in Grey Seals as a result of the spill. Common Seals were even less affected than Grey seals due to their different dietary habits and distribution at the time of the spill.

2.5.5.7 Seabirds

The timing of the Braer disaster could not have been better from a seabird perspective. Many of the seabirds that use the Shetland Islands as a breeding ground move offshore in the winter, as a result, the amount of birds coming into contact with the oil was lower than it would have been if the spill had taken place in the summer breeding season.

In January 1993, 1,542 dead oiled birds and 235 alive oiled birds were recovered. The vast majority (75%) of the shags, black guillemots, long tailed ducks and eider ducks had heavily oiled plumage [Impact Braer; 1994; P. 119].

Detailed research in the years after the spill suggested that there were no major effects on breeding success in the summer of 1993 nor any signs that sub lethal toxic effects had caused any changes in the behaviour of birds returning to breed in subsequent years.

2.5.6 “Prestige”

On the 19th November 2002, the oil tanker Prestige sank about 160km off the coast of North West Spain in waters 3600m deep [Spillcon; 2005]. The single hulled vessel was built in 1976 and was chartered to carry 77,000 tons of heavy fuel from Latvia to Singapore. The vessel had sustained a 50m gash on the starboard side and under tow at the direction of the Spanish authorities, the Prestige broke up in heavy seas and spilled a total of 64,000 tons [WWF; 2005].

2.5.6.1 Coastal Communities

Preliminary studies on the effect of the Prestige’s oil on the shorelines show evidence of substantial damage. The damage extended to areas of the shore above the EHWS (Extreme High Water Spring), especially to lichens.

This is due to oil droplets being carried in onshore winds. In the littoral (intertidal) zone disappearance of the brown alga *Pelvetia canaliculata, Fucus spiralis, Fucus vesiculosus* and *Rhodothamniella floridula* was recorded [WWF; 2005].

Over the 12 months following the spill, benthic macrofaunal species that are known to be sensitive to crude oil declined and were replaced by opportunistic species, usually polychaetes. This decline was followed by a three year slump in species known to be vulnerable to oil. It was only in the fourth year after the spill that pollution sensitive species reappeared on the shore.

2.5.6.2 Marine Birds and Mammals

Records show that 23,428 birds had either been injured or killed by the pollution by May 2003. Of these 75% were found dead and only 10% of the remaining 25% survived being cleaned and released. Overall mortality was expected to be in the region of 250,000 to 300,000 birds (source: footnote 21). The majority of the casualties were made up of Common Guillemots, Puffins, Atlantic Razorbills, Gannets, Shags and various species of Gull. Most of the birds were found in January 2003, 2 months after the disaster, in February there was a significant increase in numbers on the French and Cantabrian coasts as the oil advanced towards these regions. The extent of the damage was such that the survival of certain species was under threat such as *Uria aalge,* the Iberian Guillemot. Before the wreck only 10 nesting couples had been recorded in some of the badly affected areas [WWF; 2005].

In the first month after the disaster, the bodies of 27 cetaceans from 7 different species were found although in only one case was oil the sole cause of death. In addition, 16 turtles were found (13 Loggerhead and 3 Leatherback Sea Turtles) of which 5 were live. It was noted that due to the mobility of these marine mammals, the impact of the oil was not as severe as it could have been.

2.6 Response options

The following response options represent the cleansing and embanking methods to prevent further damage to the environment and its habitants. It has to be divided in embanking and cleaning at sea (Offshore) and the decontamination of Shorelines.

2.6.1 Offshore

The offshore response actions are actions to prevent the contamination of the sensitive shoreline environments. The links below are references to different reports and guidelines referring to offshore cleaning.

2.6.1.1 Booms

The use of booms is often seen as an ideal technique in clean up since if it's effective, it removes the oil from the marine environment while being relatively cheap and causing no environmental damage. Booms are widely used in response worldwide and are often one of the first techniques used in open water to try to contain an oil slick.

The ITOPF website contains a page titled 'Containment and Recovery of Floating Oil' and contains information on the use of both booms and skimmers at sea. To visit the link please click: http://www.itopf.com/containment.html

The US Environmental Protection Agency have provided online information on the use of booms as an option in spill response to visit their website please click: http://www.epa.gov/oilspill/booms.htm. They have also provided a 4 page report on their website on 'Mechanical Containment and Recovery of Oil Following a Spill' which contains more detailed information on the use of booms.

The URL to the report is http://www.epa.gov/oilspill/pdfs/chap2.pdf

www.oil-spill-web.com has provided a web based resource on booms and boom configuration, to visit the resource please click: http://www.oil-spill-web.com/handbook/2.htm

The US Department of the Interior has a page on its website detailing the roles of response techniques including booms. The work has been done as part of the Offshore Minerals Management Technology Assessment and Research program. The information can be found at http://www.mms.gov/tarprojectcategories/mechanic.htm

2.6.1.2 Chemical Dispersants

Use of dispersants is one of the currently accepted responses to an oil spill. Dispersant use is part of the standard 24 hour response programs in European countries. Dispersant use has been associated with having detrimental effects on the environment often which are worse than the effects of the oil. In most European countries, dispersant use is now strictly controlled and regulated and only used as part of a response when appropriate.

For a comprehensive summary of the use of dispersants in oil spill response and how they work, please refer to the link:

http://www.ipieca.org/downloads/oil_spill/oilspill_reports/Vol5_2_summary.pdf. It is a summary of the IPIECA perspective on dispersants and their role in oil spill response.

ITOPF have also provided a section on their website concerning the science behind dispersants, limitations, types of dispersant, application at sea, vessel spraying, aerial spraying, shoreline application and limitations to dispersant use. The URL is: http://www.itopf.com/dispersa.html.

NOAA have developed a 'Dispersant Guided Tour' where the following subject areas are covered in an interactive web based package:

1. What Are Dispersants?
2. Why Use Dispersants?
3. How Do They Work?
4. How Are They Applied?
5. What Constraints Affect Their Use?
6. What Happens to Dispersed Oil?
7. What Are Their Environmental Impacts?
8. How Are Applications Monitored?
9. Where Are Dispersants Being Used?
10. How Is NOAA Involved?
11. What's the Bottom Line?

The US Environmental Protection Agency have a page on their website covering the use of dispersants, to visit the site please click: http://www.epa.gov/oilspill/disperse.htm There is also a 3 page report on their website on 'Alternative Countermeasures for Oil Spills' that includes a section on dispersants, the report can be found at: http://www.epa.gov/oilspill/pdfs/chap3.pdf

2.6.1.3 Sorbents

The US Department of the Interior and Environment Canada have a webpage dedicated to the testing and performance of using sorbents in oil spill response. The page contains details of the project and links to several articles and scientific papers on the following topics:

- Selection Criteria and Laboratory Evaluation of Oil spill Sorbents,
- Testing Protocol and Certification Listing Program,
- Oil Spill Sorbents: Testing Protocol and Certification Listing Program,
- Simple Test Guidelines for Screening Oil Spill Sorbents for Toxicity,
- Sorbent Test Program 1999-2000, Interim Report.

The web address is: http://www.mms.gov/tarprojects/180.htm

The US Environmental Protection Agency (EPA) have a webpage dedicated to sorbent technology, it explains the difference between a*b*sorbents and a*d*sorbents and discusses organic and inorganic sorbents. The US Department of the Interior has a page on its website detailing the roles of response techniques including skimmers.

The work has been done as part of the Offshore Minerals Management Technology Assessment and Research program. The information can be found at: http://www.epa.gov/oilspill/sorbents.htm .

Sorbents are also covered in a 4 page report on the EPA website along with other mechanical containment techniques for dealing with a spill. The website is: http://www.epa.gov/oilspill/pdfs/chap2.pdf

2.6.1.4 Skimmers

Skimmers are another piece of equipment that is often used in part of a standard response program; they are often used in conjunction with booms. Once the slick has been contained with the booms and made thick enough for the skimmers to be used efficiently, they remove the oil from the surface of the water.

The US Environmental Protection Agency (EPA) have provided a web based source of information on skimmers, it covers the three main types of skimmer (Weir, Oleophilic and Suction) and can be found at the following URL:

http://www.epa.gov/oilspill/skimmers.htm. Information on skimmers can also be found in a 4 page report on the EPA's website titled 'Mechanical Containment and Recovery of Oil Following a Spill'. The report can be found at

http://www.epa.gov/oilspill/pdfs/chap2.pdf .

www.oil-spill-web.com has provided a web based resource on skimmers, their principles and performance, to visit the resource please click:

http://www.oil-spill-web.com/handbook/2.htm

The US Department of the Interior has a page on its website detailing the roles of response techniques including skimmers. The work has been done as part of the Offshore Minerals Management Technology Assessment and Research program. The information can be found at http://www.mms.gov/tarprojectcategories/mechanic.htm

2.6.2 Shoreline Clean-Up

There is no definitive set of guidelines available when developing shoreline clean up strategies after an oil spill; however in the vast majority of cases it is a vital part of the clean up and inevitably the one that receives the most media and public scrutiny. The reason why there is no definitive set of measures is that the circumstances surrounding the spill will determine the nature of the shoreline strategy. Factors that need to be considered when developing a shoreline clean up strategy include:

- Weather conditions (wind speed and direction, tidal state),
- Proximity of vessel and spilled oil to shore,
- Type and amount of oil spilled,
- Type of shoreline (rocky, sandy, shingle, pebble, mudflat, estuary),
- Proximity to economic resources and centres of population,
- Proximity to tourist facilities,
- Proximity to sites of environmental importance/sensitivity.

The most effective method of determining an appropriate response is to consider the above factors and use past spills as case studies and examples of poor or best practice. The links in the 'Global Summary' section of this report will provide information on shoreline clean up on a case by case basis.

A generic description of techniques used in shoreline clean up can be found on the ITOPF website, the link to the page is: http://www.itopf.com/shoreline.html.

The page contains details on strategy, mobile oil, sand beaches, rocky shores, salt marshes and mangroves, organisation and the termination of the clean up.

The Global Marine Oil Pollution Information Gateway of the United Nations Environment Programme (http://oils.gpa.unep.org) provides a range of information on different techniques that can be used in shoreline and clean up operations. The actions below are explained on the linked NOAA[4] Websites:

- No action (when a shoreline is very remote or inaccessible, when natural removal rates are fast, or clean-up activities will do more harm than if the oil is left to be removed by natural processes)
- Natural recovery (evaporation, oxidation, and biodegradation can start the clean-up process, but are generally too slow to provide adequate environmental recovery)
- Application of barriers or berms
- Physical http://response.restoration.noaa.gov/shor_aid/cleanup/herd.htmlherding
- Manual oil removal / cleaning
- Mechanical oil removal
- Use of sorbents (passive collection)
- Use of vacuum
- Removal of oily debris
- Sediment reworking/tilling (raking, bulldozing)
- Vegetation cutting/removal
- Shoreline flooding (deluge)
- Ambient low-pressure or high-pressure water washing (pressure washing, flushing)
- Warm-water or hot-water high-pressure washing

To view more details click on the words underlined in blue and you will be linked to the website and further information.

2.6.3 Response Options – An Overview

The following Table 2.6-1 summarizes the different response options with their advantages and disadvantages.

[4] Office of Response and Restoration – NOAA's National Ocean Service; National Oceanic & Atmospheric Administration (NOAA)- Department of Commerce; http://response.restoration.noaa.gov/; 10/2005

Table 2.6-1: Different response options and their advantages and disadvantages

OPTION:	**HYPERLINK**	**METHOD OF APPLICATION**	**ADVANTAGES**	**DISADVANTAGES**
Chemical Dispersants (Offshore)	Oil Spill Responses Summary - chemical dispersants	Work boats for small spills Range of aircraft and helicopters depending on spill size Vehicles such as tractors Adapted back packs for shoreline clean up	Efficient method of cleaning up slicks in open water Natural process of dispersion is accelerated No physical interference with the environment	Seen as adding an additional pollutant to the environment Potential tainting of fish stocks Ineffective on oils with a high viscosity Specialist equipment and logistics needed 1-2 day functional lifetime after application
Booms (Offshore)	Oil Spill Responses Summary - booms	Towing by one or more vessels	Efficient oil containment technique Foam filled booms are light and inexpensive Rubber booms have long shelf lives and offer compact storage They have a high buoyancy to weight ratio and follow wave movements closely	Limited by weather conditions Effectiveness depends on the speed that boom is being towed through the water Light oil spreads quickly, booms need to be applied immediately after a spill Recovery systems typically have a swath of a few metres, they may not have a significant effect on a large spill Towing and manoeuvring booms at sea is difficult
Skimmers (Offshore)	Oil Spill Responses Summary - skimmers There are a wide range of skimmers available, for more information click: http://www.oil-spill-web.com/oilspill/handbook2.htm#Booms	May be free floating, side mounted on a vessel, built into a vessel, built into the apex of a containment boom, held by a crane or held by hand	Offer clean up in a wide range of circumstances Disc skimmers have a high recovery efficiency Brush skimmers have a wide viscosity range Efficient in sheltered water	Prone to difficulties presented by wind, waves and currents Demand for temporary storage for the collected oil Debris in the water can damage skimmers

Table 2.6-2: Different response options and their advantages and disadvantages

OPTION:	HYPERLINK	METHOD OF APPLICATION	ADVANTAGES	DISADVANTAGES
Sorbents (Offshore)	Oil Spill Responses Summary - sorbents	Can be applied manually or mechanically using blowers or fans For use on sea or land	Useful in clean up operations in inaccessible locations Inexpensive and usually available in large quantities Can be used at sea and on land Synthetic absorbents can absorb up to 70 times their own weight in oil	Used sorbents present are a toxic waste hazard and need to be disposed of properly Some absorb water as well as oil and can sink Some lose particles in the water and are hard to collect after use Can be used once only, once absorbed, the oil cannot be released Can be hard to apply in windy conditions
Shoreline clean up	Oil Spill Response Summary - shoreline clean up	Manual or mechanical	Good political strategy Aids recovery of amenity beaches and protected areas of shore	Potential cause of environmental damage Requires extensive communication and logistics Inaccessible areas of shore may be impossible to reach Care must be taken not to remove excessive amounts of substrate Aggressive techniques such as high pressure water jets and sand blasting harm flora and fauns

2.7 Identification and Mapping of sensitive Areas

For the identification it has to be decided in environmentally, culturally and economically sensitive areas. Following areas are covered in this chapter:

- Kinds of habitats and their vulnerability to oil spills,
- Priority list and ESI ranking,
- Comparison to EU Impact reference Systems,
- Facts about sensitivity maps,
- Examples from Vietnam and Southern Ireland,

The major case study of the report is on the environmental sensitivity index for intertidal areas of the German North Sea coast. Within the case study information is included on: marine pollution control in Germany, response organisations, national and international agreements and the general pollution policy. The Wadden Sea is used as a more specific case study and includes thematic mapping of tidal flats, evaluation of benthos, fish and shrimps, bird populations, marine mammals and salt marshes. There is also a section on the Wadden Sea Information System.

2.7.1 Introduction

Human activities can have major effects on the marine and coastal environment. In order to prevent and be prepared for accidents several instruments have been evolved to avoid the worst effects of pollution and other destructive influences.
Examples are:

- Environmental impact assessment (EIA) - used in the planning stage for major installations,
- Environmental management - used during the operation of facilities which can have major effects on the environment,
- Contingency planning - this can be part of environmental management or - as in the case of the protection of coastal state's waters from shipping and offshore accidents - standing alone.

For all these instruments the detailed knowledge of the activity leading to chronic or accidental pollution is important an additionally the detailed knowledge of the resources and habitats potentially affected. In addition to their diversity, ecological and economic functions, especially their sensitivity and potential reactions in regard to pollutants like oil or other agents need to be known. Therefore long-term monitoring and research is done for determination of chronic impacts; and sensitivity mapping is used for prediction and for assessment of damage.

In all cases a thorough description and understanding of the status quo is a prerequisite. If the status quo is not known, identification and prioritisation of sensitive areas will be hard to accomplish and will remain controversial. Data from ecosystem research and EIA’s done for coastal installations can be helpful as a starting point and close contact to coastal environmental scientists and authorities is advisable.
What will be presented in the following paper may sound like a tedious exercise but it is worthwhile to do such a systematic mapping before a major accident takes place. Then uncomfortable decision can be taken on a sound scientific basis. Furthermore compensation claims and claims to recover clean-up costs are substantially facilitated by good background data.
The decisions about priorities to be put on sensitivity maps should be taken in cooperation with relevant bodies, such as nature protection and fisheries departments, tourist boards and conservation groups. It will be hard to achieve consensus, but it is crucial to reach the best possible agreement before a spill has occurred. Later there will be not enough time and public pressure is much higher.

2.7.2 Kinds of Habitats and their Vulnerability to Oil Spills

According to Gundlach & Hayes the following priority list of vulnerability or sensitivity for different coastal habitats against oil was developed. Their concept is based on geomorphological parameters. It was designed for a wide array of different coastal regions, taking into account an array of sedimentological, biological, meteorological and hydrographical factors. Later on it was slightly modified to the ESI - Environmental Sensitivity Index [Michel; 1993].

<u>Priority List and ESI ranking:</u>
1= least sensitive to oil pollution and 10 = most sensitive to oil pollution

1. Exposed rocky headlands, e.g. in Scotland
2. Erosive wave-cut platforms, e-g- in South-West Wales
3. Fine-grained sand beaches, gently sloping
4. Coarse-grained sand beaches, steeply sloping
5. Exposed tidal flats / mixed sand and coarser material (gravel, pebble, boulders) beaches (ESI)
6. Mixed sand and gravel beaches / coarse gravel pebble, boulders beach with high permeability
7. Gravel beaches / exposed (tidal) flats with compact sediment and significant biomass, e.g. mussel banks (without biomass ESI 5 is ok)
8. Sheltered rocky coasts, e.g. around Milford Haven
9. Sheltered tidal flats, e.g. Wadden Sea
10. Salt marshes and mangrove swamps, areas act as sediment and oil traps

This classification can, in cases where not much is known about the biodiversity of a specific stretch of coast line, be used as baseline and.
The underlying parameters are:

1. the potential for dispersion of the oil due to wind and wave action and
2. the potential for introduction into deeper layers of the sediment.
3. Natural oil retention times on the shore.
4. Biodiversity and productivity of the shore habitats and their organisms.

This last point is not well reflected in the first six to seven categories. Furthermore the ESI does not take into account the use of the shore by wildlife and people, as example may serve a bird colony on an exposed rocky shore (ESI 1!?) Therefore wildlife assessment should supplement the ESI ranking and should take precedence in the case of oil spill combating.
In the case of the Wadden Sea this classification is much too general, as only the classes 3, 5/7, 9 and 10 occur. This unique habitat makes it necessary to include a greater number of ecological parameters and therefore to modify this general concept substantially. It has not been possible to develop a general ESI for subtidal flats, because their sensitivity is considerably influenced by the specific circumstances of a spill, by the specific habitat and particular species and their individual sensitivities.

2.7.3 Comparison to EU Impact Reference System (IRS)

A more recent development is the European Impact Reference System. It uses the same basis but goes into more detail in regard to ecosystem values and functions. The overall sensitivity of an ecosystem to oil pollution is determined by:

- The vulnerability of the habitat or physical environment
- The sensitivity of the populations or communities of the organisms living in that environment
- The resilience of the living community as a whole.

The IRS does not include local information of any kind (geographical, hydrographic, socio-economic, political priorities) nor does it provide guidance for counter measures. The IRS approach covers mainly the biological effect of hydrocarbons. Through the use of separate index cards its aim is easy usage for non-biologist in emergency spill situation for evaluation of spill impacts.
The full text is available at:
http://europa.eu.int/comm/environment/civil/pdfdocs/irsfinal_98.pdf.

IRS is grouping ecosystems into five sensitivity groups, but points it out that other local rankings should be kept. The parameters are more or less the same as 1-4 above, but the ease of access and cleaning is integrated.

High	concentrations of mammals and seabirds are added (ESI 9-10)
Medium high	estuaries and ice areas are added (ESI 8)
Medium	sub-tidal seabeds on sheltered coasts are added (ESI 6-7)
Low medium	sub-tidal seabeds on exposed coasts are added (ESI 3-5)
Low	open coastal waters are added (ESI 1-2)

Several examples from the IRS system, i.e. exposed and sheltered rocky shores and shingle and pebble beaches will be presented in detail. It gives a lot of ecological information on vulnerability, sensitivity and recovery, nevertheless the ranking needs to be done as described above.

2.7.3.1 Facts about sensitivity Maps

A sensitivity map has to be easy to use and should be as uniform in layout and legend as possible. Depending on the size of the spill, different scales are necessary, a strategic map covering all areas and their resources (scale 1 : 1 Mio), which a spill might reach, intermediate strategic maps, and detailed operational maps for coastal areas (scale 1 : 10.000). The latter may only be necessary for high risk parts of the coast. All relevant information should be on it, but not too much to clutter the picture. For some resources such a birds, seasonal or even monthly maps may be necessary.

Two types of information are needed:

1. Locations of sensitive resources, i.e. feeding or breeding sites, locations of threatened or endangered species, nature reserves, national parks,
2. Practical information for spill response and shore clean-up.

Two maps or different text sections can be used. In modern approaches photographs and computer databases are used. They can be more easily updated and photographs may make it easier to locate position and features.

Economically important information can be:

- Shallow water fishing areas
- Shellfish beds
- Sea life nursery areas
- Beaches with fishing/angling/trapping activities
- Aquaculture installations
- Seaweed gathering
- River mouths for migratory fish such as salmon
- Boat and recreational facilities
- Industrial facilities
- Sites of cultural, historical or scenic significance, i.e., sunset viewpoints.

Agreed protection priorities should be shown on the map and/or the accompanying guidelines.

A key should be on any map, as need for detail can differ tremendously, e.g. in Norway different fishing methods and facilities are necessary to be represented.

Example 1: Sensitivity Map from Vietnam
To give an example for a simple sensitivity map the Vietnamese Mekong Delta part is shown. About 90 % of the coast has the highest "most sensitive" index, whereas the immediate coastline has the value "high", and only a protected mangrove area in the river leading to former Saigon (HCMC) has "very high" for the coastline. Near shore waters are more diversified, between medium and high in the dry season and between “medium” and “medium high” in the rainy season.
Specially marked are areas like fish, shrimp and cuttlefish habitats, bird sanctuaries and areas of economic importance like beaches, tourist sites and ports. As the Mekong Delta is characterised by a network of brackish water channels and rivulets, the potential influence of oil pollution can reach far inland. Chronic oil pollution is common on the large channels, where extensive use of outboard engines can be seen.

Example 2: Sensitivity Map with detailed Explanation from Southern Ireland
This map is more elaborate as it has a second text page full of details explaining the resources and the combating options.

2.7.3.2 Case study: The environmental sensitivity Index for intertidal Areas of the German North Sea Coast

Marine pollution control in Germany
Firstly the German organisation and area of responsibility for marine pollution control is summarized.
Five coastal states have joint responsibility with the Federal government for counter pollution measures. They cover 1374 km of coastline along the North and Baltic Sea. A joint emergency response group (in German ELG) has to convene after major accidents. They will be advised and assisted by the Federal and State Pollution Control Units (PCU or SBM and SLM in German), which are permanently on duty for offshore and near shore combating activities.

Response organisation in cases of accidental pollution
The response system is installed in tiers, based on the amount of spilled oil and the area concerned. For minor spills the fire brigade is responsible, for moderate ones the local authorities support the PCU and above 50 t or 50.000 m² polluted sea area respective 3 km polluted shore or threatened sensitive area the ELG is responsible. A Coastguard Centre is on duty for 24 h reporting and coordination of all government crafts (water and shipping directorate, waterways police, border police, customs, navy, fishing control).

National and international agreements and contracts
Agreements are made with German tanker owners, tug and salvage companies and disaster management institutions, as well as with the Navy, esp. for surveillance aircraft. The North Sea is protected by the Bonn Agreement, the Baltic Sea by the Helsinki Convention. Additionally there are Denger, Nethger and Sweger-Plans for Mutual Oil Pollution Cooperation with Denmark, the Netherlands and Sweden.

General pollution policy
Prevention of pollution is focussed on by VTS and mandatory pilotage in rivers and estuaries. In combating the highest priority is given to containment and minimisation of spreading and a focus is put on mechanical recovery. Dispersants will not be used at all.
And EDP-aided marine disaster management system has been established. Sophisticated oil slick movement trajectory fore- and hind-casting is one part of it, photographs and sensitivity maps and operational information of the area another. Due to the experience with a small spill (Pallas) the strategy and the system are being refined and streamlined, taking into account experiences with one responsible person as done in the UK.

2.7.3.3 The Wadden Sea - a sensitive Environment

This national park is probably the most sensitive area in regard to oil pollution in Europe. It consists of tidal mud and sand flats, barrier islands, alluvial terrestrial zones and salt marshes. It is about 450 km long and up to 20 km wide, including parts of Denmark, Germany and the Netherlands.

The Wadden Sea is of enormous value as a cleansing site for coastal waters - and major rivers like the Rhine (indirectly), Weser and Elbe add their fill of pollutants. It is a nursery for young fish, as well as feeding and resting ground for nearly all northern species of wading birds and waterfowl.
The proximity of important shipping routes and major ports is a permanent threat. Large quantities of oil, which can be spread over wide areas by tides and winds, threaten the area not only with temporary damage but rather with permanent harm. Oil bound to the sediment will be released very slowly and can repeatedly contaminate the tidal flats, even if they have been cleaned. Low temperatures over most of the year do not enhance natural cleaning processes.

Therefore the following approach was chosen:

- information on the vulnerability of the system was collected for distinct field stations,
- the areas and the seasons during which special protection is required were identified,
- the circumstances were defined, under which control measures and clean-up would do more harm than good.

→ With all this information a plan was developed, which mechanical devices or chemical methods should be employed in the various zones of the region and maps were produced.
The main criteria for assigning different sensitivities were the type of habitat affected and the biotic and abiotic factors at work, i.e. toxicity, (bio)turbation, persistence and their interrelationships.

2.7.3.4 Thematic mapping of tidal flats

The main activity is the map-production as result of an 8000 km² survey, which represents the German Wadden Sea area. Also the development of a comprehensive data base and information system, and the development of an evaluation system for the vulnerability of species and habitats in regard to oil.
A side effect of this approach was the use of existing laboratory data and their integration with new data for easy use by contingency planners, national park authorities and for ecosystem research.

For the thematic mapping, the following abiotic factors were considered:

- Exact position and elevation of the sites (benthos field stations),
- Length of time they remain under water,
- Grain size and shear strength of the sediment.

The following biotic factors or groups were considered

- Diversity and biomass of macro- and meiofauna (large and medium sized animals),
- Diversity and abundance of juvenile fish, microphytobenthos and macrophytes (small and large plants, attached to the sediment),
- Importance of the area as resting, molting, and nesting site for birds,
- Significance as habitat for mammals, like seals, dolphins, small whales.

To deal with the interrelationship among biotic and abiotic factors, a list of ecologically relevant parameters for every benthic species was prepared. This weighted evaluation of the species is based on determination of the species diversity and abundance, and on sediment conditions at each site.
Differences in the vulnerability of the fish and birds in the various areas and of the salt marsh as a very specific habitat were similarly evaluated, both individually and in combination with data for the various sites in the entire region. All of the characteristics recorded were assembled in the data processing system.

Evaluation of findings

The numerical evaluations of the findings were done in a linear way. Indices were assigned to all mentioned groups, which were calculated from their individual numerically assigned values. These values are simplified by the formation of four classes (1 - 4) of increasing vulnerability.

Seasonality: In the period of December until end of March, only the vulnerability class "benthos-sediment" is relevant. As soon as the juvenile fish arrive and the nesting and resting season for several (migratory) bird species begin, the appropriate class values are added, i.e. starting at the beginning of April. Finally at the end of November a scale from 1 to a maximum of 12 is reached.

The vulnerability of the salt marsh is represented as a separate group.
To delimit the habitats, the individual values of the sites (distinct field stations) were assigned to areas with borders set by a protocol, standardised for use by EDP and GIS. Examples will be shown of some of the conditions in the sheltered tidal flats between the island of Spiekeroog and the mainland.

Evaluation of individual categories

Sediments: Sediment classes were defined according to the relative amount of particles less than 0,06 mm and to the water content. In addition light and dark sand flats were separated.

Class 1	light sand flats
Class 2	dark sand flats
Class 3	tidal flats of sand and silt
Class 4	mud flats, these are the most sensitive to oil pollution

Benthos: The following classes were determined on the basis of the following parameters:

- the physiological sensitivity to oil,
- the ecological sensitivity to oil,
- the importance as a food source, based on average weight of total biomass,
- the metabolic importance, i.e. increasing oxygen supply in sediment due to bioturbation, or controlling other populations as substrate or epistrate feeders,
- the capability of dispersal, i.e. actively swimming, having planctonic larval stages or being mainly immobile,
- the duration of the reproductive period, i.e. whole year, or six to four, or one to three months, which slows the recovery more and more.

Within each category each species was assigned a value from 1 to 3, signifying weak, minor or strong effects.
An example is given for macro fauna’s physiological sensitivity:

Class 1	species with little change in abundance after exposure to oil/petroleum
Class 2	significant decline in abundance
Class 3	very great decline in abundance

… and for ecological sensitivity:

Class 1	**endobenthic** sand dwellers, substrate feeders or predators
Class 2	sand flat dwellers feeding on the surface, non-filtering inhabitants of mixed sand and mud flats, animals tolerant of oxygen deficits
Class 3	predators with tentacles, filter feeders, species living on the surface of mud flats

Through some simple calculations arithmetic index values for all species at each station were calculated. They were added and multiplied with the sediment class value to result in a station index for each station. They were placed in four classes numbered with increasing sensitivity as a summary of all benthos factors.
→ Several diagrams and maps will be shown to illustrate this system.

Fish and shrimps
For fish and shrimps and additional factor was the commercial importance of the species. Otherwise the evaluation was done with the same parameters as the benthos. Four classes were then assigned. In order to get the relevant data on fish and shrimp stocks, various transsects during high tide were performed.

Bird Populations: Birds were separated into breeding, non-breeding and molting populations.
Of the about 27 species potentially breeding in the Wadden Sea, 13 proved to be especially vulnerable to oil. To those a minimum breeding pair number is assigned. Furthermore the qualitative difference exists, whether birds are suspected to breed or they have been proven to breed in the area. Other parameters are number of species and rarity. This grading of importance results in another weighed evaluation and finally in four classes.
For the non-breeding populations - about 36 species in total - only the proof of presence or whether they are reaching or exceeding the minimum abundance was considered important.
The molting birds were directly organised in four classes according to their population size.
Then the three class values were combined. The individual class values for each month were added and the sums were assigned new class values from 1 - 4. This procedure is important as only at certain periods of time birds have to stay within a limited area, normally they are mobile with a great radius of activity. If this area is disturbed or destroyed, there is only a small chance for the bird to move, because other suitable habitats are already occupied.

Marine Mammals in the Wadden Sea are mainly represented by the common seal. Its resting places must meet a number of conditions, and so their locations can be exactly determined and documented as a special feature on sensitivity maps. The only factor of importance could be, whether the animals are using the site for resting, only or for reproduction, too.

Salt Marshes
As research was done on the sensitivity of halophytes (salt tolerant plants) to oil and petroleum, special evaluation criteria could be developed. They are based on the following categories for each species:

- Area of contact (scale 1 - 3, small, medium, large)
- Position of the regenerative organs - here position of regenerative organs and location of new shoots after oil contamination were considered, i.e. - underground - high or low above, forming rosettes, small plants (scale 1 - 6);
- Physiological reaction - (scale 1 - 4, little to very strong)
- Regeneration - (scale 1 - 5, very rapid to no regeneration)
- Degree of endangerment - scale 1 - 3, low, medium, high) This is an evaluation of the exposure to harm in case of an accident. The main zone of endangerment is assumed to extend as far as the midtide level or a little beyond.

All values are added and the sum is divided by the number of criteria. This number is assigned to one of eight classes corresponding to special indicator values. If the area is grazed by sheep, the sensitivity index is increased by two points, because contamination is intensified in the absence of protective leaf cover. Thus, a scale from 1 to 10 is created.
To take into account the population density of a species a community vulnerability index uses the ratio to the total settlement density. The value for oil sensitivity of the specific kind of plant association is then placed in one of four classes thus summarising the vulnerability and the contribution to plant coverage.

Overall Evaluation

For the overall evaluation the values for all classes were combined, expect for those for the salt marsh. Thus, the sum can reach a maximum of 12 points. Because of the linear arrangements all evaluations are strictly relative, i.e. inside the Wadden Sea the most and least vulnerable habitats are determined. An enlargement of the area would result in a new arrangement of index values.

By comparing the maps 5,6, and 7 with the summarised information on map 8, the relative contribution by the benthos, fish and birds to the total sensitivity index value can be seen.

2.7.4 The Data Base and the Wadden Sea Information System

The long term data management for the ESI was achieved with the Wadden Sea Information System WATIS. A project oriented data management was used, which allows for new data structures with new projects or tasks. Each project-oriented data structure is encapsulated but on the other hand strictly connected by common meta data and by a common representation of georeferences via a name triplet including project name, position and date of location definition. Through the meta data users are enabled to easily find data of interest. Research can be done by asking for specific locations, time, or theme. The general description of the project, methods used, and all parameters involved and used within the tables can be found.

The database provides for an interface for transfer of all topological data to and from GIS ARC/INFO. The capability and flexibility of the WATIS system enables an integration of data into further computer supported decision systems. One system called REMUS has been developed for the German coastline for oil spill combating. To explain it would need another lecture.

The GIS is used for map and topology creating, manipulating and plotting. The resulting sensitivity index maps for the Wadden Sea are accessible via internet under

http://w3g.gkss.de/watis/skoeli/skoeli.html

Task of WATIS

The manifold interdisciplinary research activities result in large amounts of data. The Wadden Sea Information System WATIS is designed to ensure long term and safe storage of these data. Furthermore, it should combine all these different types of data in an overall picture and act as an interface between research and management. Moreover, the system must be very flexible for the integration of additional projects in the future.

Projects

The Wadden Sea with its particularly high biological productivity and its endemic species is highly endangered, by the input of pollutants, oil spill, tourism, and commercial fishing. Only intensive administrative and political efforts based on a sensible management concept can protect the Wadden Sea in the future. For the development of such a concept a good knowledge of the ecosystem is essential.

This results in an extensive need for research in many different disciplines. As a consequence, many research projects have begun in the past.

Technical Concept

The essential concept of WATIS is the central storage of all data and the coordination of the central database WADABA, as a reference system, which at the same time allows to work with data excerpts on local systems.

The central part of the WATIS is a relational database WADABA at the GKSS Research Centre. Connected to the WADABA are local systems at various research institutes and administrations.

It is possible to have access to WATIS using any computer and software product, but we recommend and use at GKSS the following systems:

- A PC or Workstation with any software to write and read data in form of tables in dBase-Format. Files can be transferred via diskette, better is a net-connection, to allow direct retrieval and fast data exchange.

- A Workstation running a Geographical Information System (ARC/INFO, ESRI) and a DBMS (Oracle). Data in form of tables and maps can be handled with this system. The file transfer is handled via Internet.

Data Retrieval

The WADABA contains a very large number of tables and became very complex. Therefore, WATIS provides a tool for data retrieval which is easy to learn and easy to handle by persons not familiar with details of computing techniques. It supports questions concerning the structures, contents and sources of the data. We have developed the piloting systems, LOTSE, McWATIS and LOTSE/p, which allow an easy search and retrieval of the data.

To ensure a long term utilisation of all data, their origin, time ranges and methods are also available. Data exist in the form of tables, maps, stationary time series and in a grid format for example satellite pictures. In the WADABA all coordinates are kept in radians, defined on the European Datum. During a retrieval the coordinates may be converted into the desired coordinate system.

2.7.5 Guidelines on Sensitivity Mapping for Oil Spill Response

This chapter contains a summary of the attached IMO/IPIECA Report Series Volume One (**Annex B**) on Sensitivity Mapping for Oil Spill Response. Below is the chapter-layout of the report and a summary of each chapters' contents along with a link to view the report electronically:

1. **Introduction:** Brief summary and introduction to sensitivity mapping.
2. **Prospective user groups and their needs:** Contains the IPIECA Tiered Response to sensitivity mapping and information on a cost effective approach, the requirement for information on sensitive resources and varying types of maps that may be needed.
3. **Map Requirements:** Basic requirements for an understandable and easily usable map, including:
    - The maps must contain an instant message and not require too much specialist knowledge,
    - They should contain enough information to be of value but not to confuse,
    - They should not unnecessarily bisect natural features,
    - They should use symbols that do not conflict and do not convey the wrong message,
    - They should set a suitable scale,
    - They should clearly mark scale, direction, legend/key, date of production and title,
    - They should include a location map to show the relationship between any sub area and the area as a whole.

    This chapter also contains information on the single and series map approach and advice on the practical handling of the maps.
4. **Types of information that could be included on maps**: This chapter includes information on:
    1. shoreline types,
    2. subtidal habitats (including coral reefs, seagrass beds and kelp beds),
    3. wildlife and protected areas,
    4. fish, fishing activities, shellfish and aquaculture,
    5. socio-economic features,
    6. oil spill response features,
    7. symbols,
    8. seasonal aspects.

5. **Obtaining and agreeing information for sensitivity maps:** A short section containing information on levels of information required, liaising with local people, additional survey work, consultation with relevant bodies and use of the coastal zone.
6. **Geographical Information Systems (GIS):** Information about GIS systems including advantages and disadvantages and how GIS can be integrated into sensitivity mapping.

To view the full 28 page report, please click on:
http://www.ipieca.org/downloads/oil_spill/oilspill_reports/IMO_Vol1.pdf [IMO/IPIECA; 1994]

2.8 Contingency Planning

The section on contingency planning is based on the contingency plans that have been drawn up by ITOPF (International Tanker Owners Pollution Federation) and the IPIECA (International Petroleum Industry Environmental Conservation Association) The reports provide a concise summary of the material that is available online on the ITOPF and IPIECA websites.
The UK is used as a national case study for contingency planning and the MCA (Maritime Coastguard Agency) contingency plan for the UK is also summarised.

2.8.1 The ITOPF Perspective

Contingency Planning should follow the tiered response concept. The majority of oil spills are small and can be dealt with on a local basis (Tier One). If the incident should be beyond the capability of local resources or should it affect a wider geographical area an enhanced but compatible response should be launched, (Tier Two). The foundation of this tiered response is the local plan for a local facility such as a port or oil terminal or for the length of coastline at risk from a spill. The amalgamation of several of these local plans may form the part of a district or national plan. National plans may be integrated into regional response strategies that may involve 2 or more countries.

In general, contingency plans should follow a similar layout if they are local, national or regional. If the plans are compatible they can be easily understood and ensure a smooth transition from one level to the next.
Contingency plans are best divided into two distinct sections. The first should be a descriptive document outlining the overall strategy of the plan while the second should form the operational plan concerned with procedures to be followed in the event of a spill. The strategy part of the plan should define the policy, responsibilities and rationale for the operational plan. The plan should be complete within itself and should not have to include references to other documents.

2.8.1.1 Strategy

The strategy section should cover eight main areas:

1) Introduction,
2) Risk assessment,
3) Resources at risk and priorities for protection,
4) Response strategies,
5) Organisation and management,
6) Equipment, supplies services and manpower,
7) Communications and control,
8) Training, exercises and updating procedures.

The introduction should include the authority or lead agency responsible for the formulation and implementation of the plan and an explanation of the statutory requirements should be defined. The geographical coverage of the plan should also be outlined.

The expected frequency, size and the likely types of oil that may be involved in an incident should be addressed. Historical data may be able to provide quantitative data. The number of calls made by vessels, in particular, tankers is relevant. The probable movement and fate of slicks should also be studied and logged. This data may be able to provide a range of possible spill scenarios. Detailed information on oil types and prevailing meteorological and oceanographic data should be made available.

Areas that may be particularly vulnerable to oil pollution should be identified. These may include: sea water intakes, fisheries, mariculture, seabird nesting sites, and marine mammal communities. Since it may not be possible to offer the same degree of protection to all these resources it is necessary to prioritise. There are some more practical issues that need to be addressed, seasonal variations such as nesting seasons and locations as well as information on the location and sensitivity of resources.

The clean up strategies should be determined in relation to the perceived risk and agreed response strategies. Limitations of the clean up technologies should be flagged and the most appropriate equipment should be chosen according to weather conditions. There should also be a shoreline clean up strategy prepared for the types of shoreline that may be affected. Predetermined waste disposal sites should also be detailed.
The outline and organisation of the response team is important to consider in order to avoid confusion. Central coordination should be under a single organisation and should be in complete control of the implementation of the plan. Should more than one organisation be involved due to a wide geographical area, procedures for coordination between these organisations should be planned. The size of the plan will depend on the size of the area covered. Any relevant government organisations, advisors and expects should be notified.

The siting of response equipment, the procedures for mobilisation and an inventory for available equipment should be made available. Provision for food, clothes, shelter and medical facilities should be made as well as an estimation of manpower needed with an excess incorporated in the case of a large spill.

The establishment of a central control centre should be predetermined as well as regional mobile control centres that can be located close to the scene of operations. Maps, charts, reports and documents should be provided as and when needed and a record of all equipment and materials used kept for future reference and the submission of claims for compensation.

Training programs for all personnel should be developed with regular updates to ensure an appropriate response. Equipment should be tried and tested prior to use for availability and performance. A spill offers the best opportunity to test the plan, as soon as the clean up has been completed events should be reviewed and the plan updated.

2.8.1.2 Operational Plan

The operational procedure can be divided into six main sections during a spill:

1. Notification,
2. Evaluation,
3. Response,
4. Clean-up,
5. Communication,
6. Termination.

The information needed to accurately depict and indicate the seriousness of an incident should be made available, i.e. date, time, position, source, cause, amount, type of oil, type of slick etc. A program to contact relevant personnel should also be included. Methods for trajectory modelling, aerial and terrestrial surveillance, the identification of threatened resources and notifying parties who are likely to be affected should also be included.

The plan should be flexible so that a range of response options could be deployed at any time according to the situation. This should include procedures for placing manpower and equipment on standby.

Procedures for the establishment of a dedicated response centre responsible for mobilising and deploying necessary equipment, organising logistic support, continuing with any aerial or terrestrial surveillance and considering disposal options need to be determined. In addition it is necessary to have a command centre near the site of the incident and appropriate communication between all centres.

Guidelines for the level of clean up necessary at each affected site should be provided as well as sites for temporary storage and procedures for standing down equipment.

A list of information has been devised by ITOPF detailing what will be required to carry out an efficient and effective response:

- Contact directory of response personnel - out of office contact details should be included where appropriate.
- Contact directory of third parties - parties likely to have an interest in an incident e.g. police, media, parties of likely impact and other authorities.
- Primary response equipment - government, private contractor and oil industry equipment.
- Auxiliary response equipment - sources of workboats, tugs, helicopters, aircraft, barges, vacuum trucks, tractors, protective clothing, hand tools, radios etc.
- Logistics suppliers - suppliers of catering, housing, transport, sanitation, laundry etc.
- Manpower sources - contractors, local authorities, military, fire brigades, volunteer organisations and other sources.
- Experts and advisors - personnel with detailed knowledge of oil pollution; of the local coastal environment, particularly of flora and fauna; of safety; and of other areas.
- Maps of sensitive areas - showing detailed information on the location of amenity and ecologically sensitive areas; sea water intakes; fisheries; mariculture; seabirds and marine mammals; and other resources likely to be threatened. Seasonal sensitivity should be highlighted.
- Maps of the coastal region - showing priorities for protection; illustrating strategies and restrictions; access points; waste sites; etc.
- Oil types likely to be encountered - detailing their properties; persistence; likely fate and effects; suitable response techniques; etc.

Ten questions developed by ITOPF designed to assess the adequacy of your contingency plan:

1. Has there been a realistic assessment of the nature and size of the possible threat, and of the resources most at risk, bearing in mind the probable movement of any oil spilled?

2. Have priorities for protection been agreed, taking into account the viability of the various protection and clean-up options?
3. Has a strategy for protecting and cleaning the various areas been agreed and clearly explained?
4. Has the necessary organisation been outlined and the responsibilities of all those involved been clearly stated with no ‘grey areas’ - will all who have a task to perform be aware of what is expected of them?
5. Are the levels of equipment, materials and manpower sufficient to deal with the anticipated size of spill. If not, have back-up resources been identified and, where necessary, have mechanisms for obtaining their release and entry to the country been established?
6. Have temporary storage sites and final disposal routes for collected oil and debris been identified?
7. Are the alerting and initial evaluation procedures fully explained as well as arrangements for continual review of the progress and effectiveness of the clean-up operation?
8. Have the arrangements for ensuring effective communication between shore, sea and air been described?
9. Have all aspects of the plan been tested and nothing significant found lacking?
10. Is the plan compatible with plans for adjacent areas and other activities?

2.8.2 The IPIECA Perspective

In preparing this report, the IPIECA (International Petroleum Industry Environmental Conservation Association) has been guided by a set of principles that encourage every organisation involved in the transportation, handling and storage of oil to consider the following:
It is of paramount importance to concentrate on preventing spills. In practical terms, this requires that operating procedures should stress the high priority senior management gives to preventing spills.
Despite the best efforts of individual organisations, some spills will still occur and will affect the local environment.
Response to spills should seek to minimize the severity of the environmental and socioeconomic damage and to hasten the recovery of any damaged ecosystem.
The response should always seek to complement and make use of natural forces to the fullest extent practicable.

<u>An oil spill contingency plan should be com prised of the following sections:</u>
A strategy section: This should describe the scope of the plan, the geographical coverage, perceived risks, roles and responsibilities of those charged with implementing the plan and the proposed response strategy.
An actions and operations section: This should set out the emergency procedures that will allow rapid assessment of the spill and the proposed response strategy.
A data directory: This should contain all relevant maps, resource lists and data sheets required to support an oil spill response effort and conduct the response according to an agreed strategy.

It is widely accepted that those countries that have a properly developed contingency plan are better prepared to deal with an incident than those who do not.
The preferred industry approach to contingency planning tackles three main issues:

To enable effective escalation of a response to changing circumstances, companies should develop a plan according to the tiered response described in this report.
Maximum credible and most likely case scenarios should be identified based on a risk analysis of the geographic area covered by the plan.
A cooperative approach by all parties involved is essential in ensuring an effective response. When plans are being developed, companies should seek the cooperation of those who share the risk, and those who will participate in the response by integrating their plans with national authorities and industry partners.

2.8.2.1 The Tiered Response

Oil spill risks and the responses they require should be classified according to the size of the spill and the proximity to a company's operating facilities. This has led to the formation of the Tiered Response. A company should be able to develop a response capability in a way that allows it to be escalated as and when required for each incident.

Tier One - Small Local Spills:

This should cover all operations at company owned, operated or shared facilities where events are controlled by the company's operating procedures. Personnel and equipment should be on hand to respond immediately to an on site incident. Such an incident would typically be associated with ship transfer or bunkering operations at a jetty, pier or mooring or around waterside storage tanks.

The Plan should recognise the need for local operators to control events and establish a rapid response aimed at containing and if possible recovering the spill. If this is achieved there will be no need to involve other parties except from meeting legal, reporting or alerting requirements.

Tier Two – Medium spills that may be local or at some distance from operational centres:

This will cover company operations at their own facilities and within public or multi-user facilities where a company has limited control of events and the physical area covered by the spill is larger than the Tier One level.

The risks here would be associated with shipping incidents in ports, harbours, estuaries or fuel pipes. It could also be from pipelines, tank failures or nearshore exploration or production. Other users of the port or facility should recognise they run similar risks and should be encouraged to join in establishing an oil spill plan and response capability. At this level there is a possibility that public services and amenities may be affected so local government may act as the principal coordination and control agency. The contingency plan should carefully define the response capability, the roles and responsibilities of the various parties, the scope of the plan and the procedures for escalating the plan to a Tier Three response level.

Tier Three – Large spills that may exceed national boundaries:

This will cover major incidents, the scale and scope of which is beyond a Tier Two response. Tier Three responses typically cover large oil spills at sea where the operating company may not have the capability to deploy resources immediately and the government would take control. The spill may have an impact on the property operations of the company or occur near a company installation and may be too large for the company to handle alone. Alternatively, it may be very remote from all company installations, owned or operated installations. The likelihood of such incidents is relatively low but the pollution can be considerable and coastlines over a wide area may be at risk.

The contingency plans should aim to access and mobilise local, national and international resources quickly and efficiently. Due to such incidents becoming high profile and politically sensitive, the tier three plan will probably form part of a National Emergency Plan headed by an appropriate national agency or government body. The contingency plan must identify the agreed role for all participants within that National Emergency Plan.

In reality, incidents rarely fall entirely into one of the tiers and the boundaries inevitably become blurred. It is therefore advisable to be able to involve the next highest tier from the earliest opportunities.

International Resources – International or regional capabilities established by industry or government:

Governments have recognised the serious threat posed by tier three incidents and the potential requirement for international assistance to help mitigate the consequences. Mutual support for Tier Three incidents with the associated ability to enhance national capability across political boundaries is a basic tenet of the OPRC Convention.

Against this background, industry has established and funds a network of 'Tier Three Centres'. The use of these Centres is explained in a joint briefing paper prepared by IPIECA and ITOPF (International Tanker

Owners Pollution Federation Ltd). It is important that local industry is aware of these Centres and it incorporates them into their plans. Governments should be aware of the need to facilitate customs and immigrations procedures to allow any international resources to be mobilised effectively.

2.8.2.2 Cooperation with Government Agencies

Government policies on response to oil spills vary from nation to nation.
All governments are encouraged to ratify the OPRC Convention 1990.
It is crucial that industry works with government agencies.
There needs to be clarity between government and industry plans as to who are responsible for which actions under all circumstances. Government agencies must be consulted at an encouraged to participate in all development of contingency plans.
Where feasible, governments and private businesses should be encouraged to purchase oil spill response equipment.

For more details on the role of the OPRC Convention 1990 in contingency planning for marine oil spill response please refer to www.imo.org and
http://www.ipieca.org/downloads/oil_spill/oilspill_reports/English/Vol2_ContPlanning_1050.71KB.pdf [IPIECA Contingency; 2005; p. 8 and 9]

Information gathering and risk assessment:
Historic data, climate, local meteorology and environmental sensitivities are important factors in assessing the risk, fate, behaviour and potential consequences of spilled oil.
Historic data:
Many assessments have been made concerning the amount of oil entering the marine environment and all recognise the relatively small amount arising from tanker spillages.
The goal for any company should be to conduct its operations without spills, inevitably, they will happen and it is the responsibility of the company to respond.

Data provided by ITOPF indicating the causes, spill size and product carried of spills between 1974 and 1998 can be found at
http://www.ipieca.org/downloads/oil_spill/oilspill_reports/English/Vol2_ContPlanning_1050.71KB.pdf [IPIECA Contingency; 2005; p. 10 and 11].

History suggests that major spills from exploration and production are far less common than major spills from oil tanker incidents.
Statistics suggest that major tanker spills are impossible to predict when and where they may occur.
Those responsible for contingency planning will use the information from risk assessment with information about technical, social, economic and political values.

Oil properties:
The base properties of an oil will determine the physical and chemical changes it undergoes when it comes into contact to water and its resulting persistence and toxicity.
It is recommended that a company keeps a list of all oils and their properties it may have dealings with.
Most oils have a tendency to incorporate sea water and form a water in oil emulsion. This can increase the volume of the oil by 3 or 4 times.

Current and wind data:
Apart from spreading which causes the oil to cover a progressively large area, the slick moves at the speed of surface currents and at about 3% of the wind speed.
A spill is likely to spread to an average of 0.1mm, at this point the oil breaks up into strands of varying thickness called windrows that are aligned to the wind direction.

Sea Conditions:

Sea conditions influence the behaviour of spilled oil and determine the effectiveness of responses. A rough sea assists the dispersal of the oil but hampers the mechanical clean up efforts.

Computer trajectory modelling:

Various organisations and companies have developed models for predicting the behaviour of spilled oil. They can provide valuable information for planners and pollution response teams but are not essential for planning and response.

Models can provide information about the likelihood of sensitive habitats being affected and this can influence decisions concerning response strategy.

Operation of models requires trained personnel and it is important that the users of such technology are aware of the associated limitations with such models.

Monitoring is a predictive tool and cannot replace the need to physically trace the movements of a spill.

2.8.2.3 Sensitivity Mapping of the Environment at Risk

Mapping and updating sensitivity maps are key in the planning process.

The maps provide key information to responders showing environmentally sensitive areas.

The making of a sensitivity map involves information on commercial, ecological and recreational resources and deciding what guidelines are used for spill response may be included.

Maps may either be paper based or on a GIS[5].

For a vulnerability index of shores, please refer to http://www.ipieca.org/downloads/oil_spill/oilspill_reports/English/Vol2_ContPlanning_1050.71KB.pdf [IPIECA Contingency; 2005].

2.8.2.4 Strategy Development

Strategies will need to be adaptable to different locations, under different conditions and at varying times of the year. They must be established in consultation with the relevant authorities and stakeholders.

The realities of the situation and the limitations of the equipment should be well understood. This includes the type of oil spilled and the current weather conditions.

Depending on the temperature and sea conditions some light crude oils virtually disappear from the surface through evaporation.

There may be instances where a 'no active response other than monitoring and evaluation' is the best option.

The selection of appropriate clean up techniques may be easier if the spill has occurred at either exploration or production facilities. They have a known position and the flow rate and characteristics of the oil may well be known.

If there are adverse weather conditions at the time of the spill, it may well become impossible to assemble and deploy response equipment quickly enough to influence the fate of the oil.

If shorelines are threatened, the response strategy must become defensive – this may involve protecting critical coastal resources and preparing for clean up operations.

2.8.2.5 Planning and Response Options to minimise Damage

Ecological, recreational and commercial concerns should be carefully balanced and the consequences of not applying a certain strategy should be understood by all parties.

This process has been described as a NEBA (net environmental benefit analysis) and provides a framework for science based planning away from the emotive atmosphere that often surrounds spills.

Through NEBA, all stakeholders should be able to understand the reasons why certain strategies are being used.

NEBA uses natural clean up (i.e. no intervention) as the benchmark against which to judge response actions.

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[5] Geographical Information System

The application of chemical dispersants to shorelines may be regarded as a negative option if viewed in isolation.

With a proper understanding of the action of dispersants and the resultant dilution of dispersed oil, NEBA can flag the use of dispersants as the best option for the environment.

If shorelines become oiled, NEBA can provide a useful framework by which to determine the level and intensity of any clean up.

There is evidence to suggest that if the clean up techniques are too invasive they can damage the environment.

For NEBA to be properly undertaken, reliable information about an area needs o be available – this illustrates the need for sensitivity maps.

2.8.2.6 Equipment and Supplies

The specification of equipment capabilities is not an exact science and much will depend on the local circumstances and the weather conditions on the day.

The time needed to transport and deploy equipment and its effectiveness in different oil spill situations. This can be achieved through field deployments during exercises.

Tier One capability is an essential component of an effective plan. On site personnel must be trained and aware of how this equipment should be deployed and operated.

The equipment, combined with contractors, operators and authorities in the area form the resources to support the Tier Two and Three contingency plans.

For a list of typical response equipment that may be used to carry out on-water and shoreline response activities please refer to:
http://www.ipieca.org/downloads/oil_spill/oilspill_reports/English/Vol2_ContPlanning_1050.71KB.pdf [IPIECA Shoreline; 2005]. An inventory of all spill equipment and supplies that will be available to the response organisation should be made available.

2.8.2.7 Recovered Oil and Debris Management

Recovered oil, debris and contaminated beach material has to be properly disposed of, it may also need to be transported and handled through temporary storage sites.

Suitable vehicles, equipment, temporary storage sites and final disposal methods and locations need to be identified.

The handling and disposal of oil and oily waste can have a major effect on the logistics of the clean up operation. It is best to dispose of the materials as near to the point of pick up as possible.

Processing and disposal of oil must be done according to local regulations; care must be taken not to cause another environmental problem.

2.8.2.8 Management, Training, Exercises and Plan Review

In order to react quickly, response staff should be assigned specific roles and responsibilities, they should be properly trained and rehearsed and available 24 hours a day.

Management:

There are four fundamental elements that make up effective management of an oil spill.

A response organisation: with functional teams to address command, planning, operations, logistics and financial and legal factors.

Clear roles and responsibilities: a 'job description' for each of the identified roles within the organisation.

Effective communications: information flow is a serious challenge and requires both modern technology and disciplined personnel.

Suitable resources: the availability of appropriate equipment and staff

Management needs to be able to function effectively at all three tiers.

An industry organisation must be able to be flexible with existing government organisations, especially at tiers two and three.

Organisations utilising tier three resources must be able to expedite their arrival into the overall response. The key management, advisory and supervisory roles should be representatives of the company or government involved.

For a typical organisation chart for a large oil spill, please refer to: http://www.ipieca.org/downloads/oil_spill/oilspill_reports/English/Vol2_ContPlanning_1050.71KB.pdf [IPIECA Org.; 2005].

Training:
Training should include the appropriate level of tuition in oil spill response theory and equipment deployment. Familiarisation with the relevant contingency plans and procedures will also form part of the training package. The International Maritime Organisation (IMO) has produced syllabuses and material for three Model Oil Spill Training Courses (Senior Manager, Supervisor and Operator levels). A 'train-the-trainer' and advice on specialist courses. Information about these courses is available from the IMO.

Exercises:
Spill simulations are an excellent way to exercise and train personnel in their emergency roles and to test plans and procedures.
Important relationships with external contractors and contractors are made in large scale practise operations. IMO/IPIECA Report Series Volume Two provides guidance on exercise planning.
The IPIECA publication guide can be found by clicking the following link:
http://www.ipieca.org/downloads/PublicationsGuide.pdf [IPIECA Pub; 2005]

Plan Review:
This is not a one off event and plans require periodic review and maintenance.
At the basic level, this will ensure that contact information and equipment lists are kept up to date. It could involve more fundamental changes in the light of experiences from exercises or real spill responses.

2.8.3 PetroVietnam "Oil Spill Contingency Plan" (OSCP)

PetroVietnam's "Oil Spill Contingency Plan" (see Annex A.3) is based on the following regulations:

- The Decree No 38/CP dated may 30th , 1995 of the Government approving PetroVietnam Organisation and Operation Charter;
- The Environmental Protection Regulations in the exploration, field development, production, storage, transportation, petroleum processing and related services issued by the Decision of the Minister of Science, Technology and Environment on April 10th, 1998;
- The Guiding Circular No 2262/TT-MTg dated December 29th, 1995 of the Minister of Science technology and Environment on the oil spill combat;
- The Document No 3054 on June 3rd, 1994 of the Government Office on the coordination of oil spill combat;
- The proposal of the General manager of the Science, Technology and Environment Division.

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3 Frame Conditions in Vietnam

3.1 Overview

Table 3.1-1: Vietnam's national profile

Area	329 560 km^2
Land boundaries	4 639 km
Continental shelf area	approx. 700 000 km^2 (to 200 m)
Length of coastline	3 444 km (excludes islands)
Number of islands	approx. 3 000
Population (July 2004)	82 689 518
Age structure (July 2004) **0-14 years** **15-64 years** **65 years and over**	 29.4% (male 12,524,098; female 11,807,763) 65.0% (male 26,475,156; female 27,239,543) 05.6% (male 1,928,568; female 2,714,390)
Population growth rate (2004)	01.3%
59 Administrative division provinces	An Giang, Bac Giang, Bac Kan, Bac Lieu, Bac Ninh, Ba Ria-Vung Tau, Ben Tre, Binh Dinh, Binh Duong, Binh Phuoc, Binh Thuan, Ca Mau, Cao Bang, Dac Lak, Dac Nong, Dien Bien, Dong Nai, Dong Thap, Gia Lai, Ha Giang, Hai Duong, Ha Nam, Ha Tay, Ha Tinh, Hau Giang, Hoa Binh, Hung Yen, Khanh Hoa, Kien Giang, Kon Tum, Lai Chau, Lam Dong, Lang Son, Lao Cai, Long An, Nam Dinh, Nghe An, Ninh Binh, Ninh Thuan, Phu Tho, Phu Yen, Quang Binh, Quang Nam, Quang Ngai, Quang Ninh, Quang Tri, Soc Trang, Son La, Tay Ninh, Thai Binh, Thai Nguyen, Thanh Hoa, Thua Thien-Hue, Tien Giang, Tra Vinh, Tuyen Quang, Vinh Long, Vinh Phuc, Yen Bai
5 Municipalities	Can Tho, Da Nang, Hai Phong, Ha Noi, Ho Chi Minh City
GDP (2003)	purchasing power parity: 203.7 billion US$
GDP - real growth rate (2003)	7.2%
GDP - per capita (2003)	purchasing power parity: 2,500 US$
GDP - distribution (2003) **agriculture** **industry** **services**	 21.8% 39.7% 38.5%
Investment (gross fixed 2003)	33% of GDP

3.2 Vietnams Marine and Coastal Environment

3.2.1 Geography and Geomorphology

Vietnam, an independent country located in the Southeast Asian region (Figure 3-1), has a total area of 329,560 km^2, bordering China to the North, Laos and Cambodia to the West, the Gulf of Thailand to the South and the Pacific Ocean to the East. The country stretches from latitudes 8°30' to 23°30'N and has about 3,400 km of coastline, over 3,000 islands and more than 1,000,000 km^2 of exclusive economic sea zone, including approximately 700,000 km^2 of shelf area (to 200 m depth under the sea level).

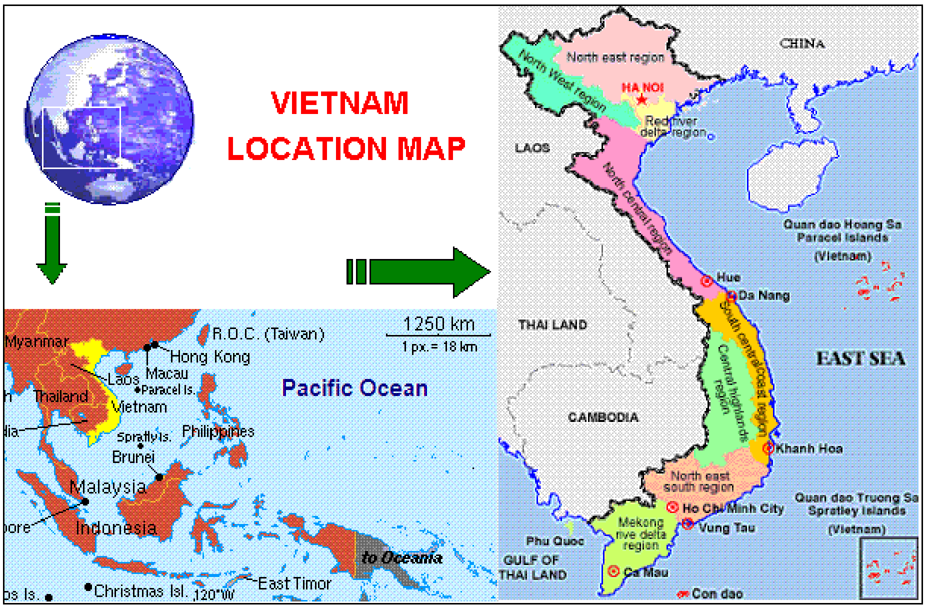


Figure 3-1: Vietnam location map

As shown in Figure 3-1, Vietnam has a 'S'-shape coastline, starting from Mong Cai, Quang Ninh province and ending in Ha Tien, Kien Giang province. Totally, there are 30 provinces having coast and coastal area in Vietnam.

<u>The coastal zone is divided into natural areas as following:</u>
Mong Cai - Do Son, Do Son - Lach Truong, Lach Truong - Mui Ron, Mui Ron - Hai Van, Hai Van - Dai Lanh, Dai Lanh - Vung Tau, Vung Tau - Ca Mau, Tay Nam Bo, and off-shore islands.
In geographical term, the Vietnamese coast can be categorized into two regions: the Northern which routes from Mong Cai to Da Nang (Da Nang city) and the Southern which routes from Da Nang to Ha Tien. Based on characteristics of natural and social conditions, the North Coast and the South Coast are consequently divided into sub-regions as follows.

<u>The Northern coast is divided into three sub-regions:</u>
the North Coast from Mong Cai to Nga Son (Thanh Hoa province)
the North Central Coast from Nga Son to Cau Hai Bay (Hue city)
the Central Coast from Cau Hai Bay to Da Nang

The Southern coast is divided into for sub-regions:
Da Nang - Da Rang Coast from Da Nang to Da Rang (Phu Yen province)
Da Rang - Vung Tau Coast from Da Rang to Vung Tau (Ba Ria - Vung Tau province)
Vung Tau - Ca Mau Coast from Vung Tau to Ca Mau Cape (Ca Mau province)
Ca Mau - Kien Giang Coast from Ca Mau Cape to Vietnam-Cambodia border which belongs to Kien Giang province

In average, each 1 kilometer of Vietnam's coastline has 100 km^2 of inland area and each 1 km^2 of Vietnam's inland area has nearly 4 km^2 of exclusive economic sea zone. On account of having such a long coast, natural characteristics in terms of geography, geomorphology, meteorology and etc. of those coastline and coastal areas are greatly different among the seven sub-regions.

Geographical and topographical characteristics along Vietnam's coast are extremely diversified. The combination of mountain systems, river and canal networks and coastal deltas resulted in a shoreline having highly complex types and configurations. These types and configurations are briefly described in the following category of sub-regions.

3.2.1.1 The North Coast

The North Coast has a length of about 340 kilometers and is separated into two sections:

The section from Mong Cai to Hai Phong (Hai Phong City) has a twisting coastline. Mountains such as the Dong Trieu are very closed to the sea, and the coastal delta is very narrow. These features result in a shoreline with many bays, shores and creeks. Another characteristic is that bays in this shoreline section usually have numerous islands and archipelagos such as Ha Long Bay and Bai Tu Long.

The section from Hai Phong to Nga Son contains the Red River Estuaries and the Red River Delta, which is the second largest delta in Vietnam. Overall, this section has a gradually sloping shoreline, a lot of estuaries and numerous tidal flats.

3.2.1.2 The North Central Coast

The North Central Coast also has a dense river mouths network. However, the overall area of the North Central Coast is very narrow, with mountains closed to the sea in some areas and a higher slope from onshore to offshore. These features result in a narrow coastal delta along the coastline, which is also cut by mountains in some places such as the Hoanh Son. The coastline therefore has many configurations along the North Central Coast, including bays, shores, rocky shores, rocky capes, beaches and rocky platforms, tidal flats, marshes and many small isles and islands such as Son Duong Isle, Mat Isle, Me Isle, etc.

3.2.1.3 The Central Coast

In the Central Coast, there are also a dense network of small rivers, which generate a larger coastal delta in comparison to the North Central Coast. The shoreline is highly twisted together with the coastal delta and the estuariy system to generate a lot of bays (Cau Hai Bay), shores, beaches and tidal flats.

This coast has fewer mountains closed to the sea resulting in fewer rocky capes and rocky shores. Rocky capes in this area include for instance Hai Van Cape and Lay Cape. There are some islands in the offshore area including Con Trau Isle, Rua Isle, etc.

3.2.1.4 The Da Nang – Da Rang Coast

The coastal delta in this coast is narrower and more mountains are closed to the sea in comparison to the Central Coast. The river network is also dense and developed, with major rivers including Thu Bon River and Da Rang River. This network results in numerous estuaries along the coast.

In an overview, the Da Nang – Da Rang Coast is highly complex in term of shoreline configurations and types, and relatively similar to the North Central Coast. Along the Da Nang – Da Rang Coast, the coastline has also many configurations including bays (Dung Quat), shores, rocky shores, rocky capes, beaches and rocky platforms, tidal flats, marshes and many small isles and islands such as Cu Lao Cham Isle, Ly Son Isle, Cu Lao Xanh Isle, etc.

3.2.1.5 The Da Rang – Vung Tau Coast

There are many small rivers such as Cua Lap River, Cai River, Dinh River and Luy River in the Da Rang – Vung Tau Coast. These rivers generate some small deltas in the coastal zone including Phuoc Thanh and Phuoc Tinh and estuaries including Xich Ram and Da Nong.

The coastal delta is much narrower and strongly cut by mountains. There are more mountains closed to the sea, particularly in the northern section of Da Rang – Vung Tau Coast. The shoreline is highly twisted with a dense rocky-cape-system. Bays and shores are also more frequent in the northern section of this coast including Nha Trang Bay and Cam Ranh Bay. Furthermore, a number of islands and isles are present in these bays such as Hon Ba Isle, Hon Chut Isle, Hon Tre Isle, etc. To the south of the region, the seabed’s slope is more gradual, forming a lot of grounds, marshes and tidal flats.

3.2.1.6 The Vung Tau – Ca Mau Coast

This area contains the highest dense river network and estuariy systems in Vietnam, which are formed by the Cuu Long River (Mekong). It is the largest delta in Vietnam. Via two major branches, Cuu Long annually transports up to 187 million tons of materials from the continent to the downstream coastal area. This is a major factor defining geographical and geomorphological characteristics of the area.

Overall, the coast is relatively flat. This feature also results in significant flooding and salinity in the coastal area when being influenced by strong winds, storms and tidal flows. Along the coast, there are many sand bars and soil bars which run in parallel with the shoreline. Offshore area also presents some islands (Con Son Islands). As being strong influenced with saline water by the tide, the Vung Tau – Ca Mau Coast has a dense coastal mangrove system which is especially valuable in terms of bioreserves, ecology and economy. With these values, these mangroves are being protected.
The Ca Mau – Kien Giang Coast

The Ca Mau – Kien Giang Coast is relatively similar to the Vung Tau – Ca Mau Coast. Features include a flat and large coastal delta, a dense river and canal system, and a dense mangrove system along the coast. There are some bays in the area such as Rach Gia Bay and Cay Duong Bay. The islands and archipelagos are highly developed in the area with Phu Quoc Island, Tho Chu Island, Nam Du Island, etc. The Ca Mau – Kien Giang Coast belongs to the Thailand Bay, so there are fewer storms in comparison to other sub-regions in Vietnam.

In short, excluding the Vung Tau – Ca Mau Coast, Ca Mau – Kien Giang Coast and the southern section of the North Coast which are mainly large coastal deltas the most common shorelines are tidal flats, mangroves, marshes, sand and gravel beaches. The combined effect of mountains, rivers and estuaries as well as narrow coastal deltas in the other areas results in highly complexed and diversified structures and configurations along the coastline. It is therefore likely to expect all types of shorelines, from rocky shores and rocky platforms to tidal flats, marshes and beaches with many sediment types in these areas.

Along with rapid economic growth, maritime shipping development and petro-industrialization, Vietnam's coast is being threatened by water pollution due to the over-exploitation of the natural resources. This report will take inventory of some data figures on marine and coastal economic activities and discuss the environmental problems that may be concerned.

3.2.2 Natural Environment

3.2.2.1 Natural Characteristics

Currently, Vietnam territorial waters contain a great wealth of fauna and flora species. It is surveyed and indicated that about 10,837 marine and coastal plants and animal species exist. They are living in more than 20 typical ecological systems and distribute in 9 different marine and coastal biodiversity regions. The higher levels of biodiverse sea zones are recognized as Mong Cai - Do Son, Hai Van - Dai Lanh and Dai Lanh - Vung Tau. Coral reefs exist on rocky islands of Halong Bay, the Paracel Island (Hoang Sa) and Spratly Islands (Truong Sa), that both are rocky promontories of the central coastline. Further coral reefs are located in the surrounding of Con Dao Island and Phu Quoc Island. Vietnam's coast is evaluated as a place having a high bio-productivity and it is estimated that each year marine and coastal capture fishery have brought about a net profit of 60-80 million USD for the nation.

Vietnam has about 252,000 ha of the mangrove swamp forests and tidal mudflats, including estuary and delta systems, numerous small offshore islands, large coastal brackish and saline lagoons, large areas of salt pans and aquaculture ponds, many freshwater lakes and water storage reservoirs, and numerous rivers and streams. The biggest wetland forest is in the Mekong River Delta (191,800 ha) (Figure 3-2). There are about 1,600 species of fauna and flora living under the canopies of these mangrove forests. Although Vietnam could be a very valuable renewable resource and there are many sea protected areas for coastal species, however, it seems difficulty to control the threat of sea pollution and over-exploitation.

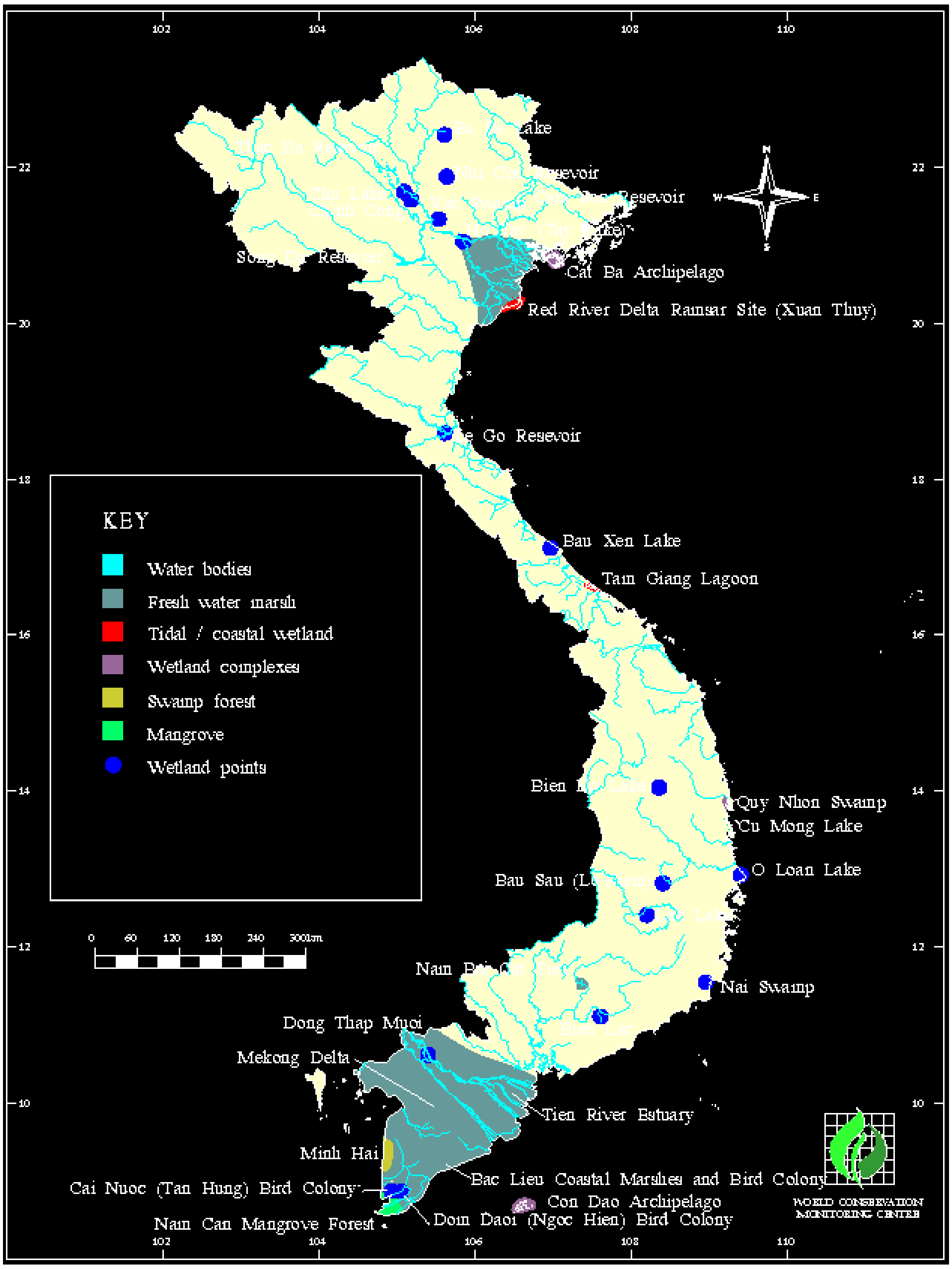


Figure 3-2: Water map of Vietnam [UNEP Monitoring; 1994]

3.2.2.2 Environmental Characteristics

Atmospheric temperature

In a general view, mean atmospheric temperature increases gradually along the coast from the North to the South. Mean atmospheric temperature reaches the lowest of 19.5 $^{\circ}$C in the area from Mong Cai to Hai Phong and the highest of 29.0 $^{\circ}$C in the area of Tra Vinh to Soc Trang. In the North Coast, the North Central Coast and the Central Coast, the mean temperature rise more rapidly. This is a result of relatively long winters in the North and the North Central of Vietnam. For oil spill response, those winters will have some potential inhibitory effects on the bioremediation process since the mean temperature is often below 15 $^{\circ}$C. It is more stable in the area from Hue to Kien Giang, as the mean temperature is in a range of 26-29 $^{\circ}$C, which is more favourable for the bioremediation process of oil.

Radiation and Sunshine Hours

Total radiation and annual sunshine hours in coastal areas are much smaller in the North Coast, the North Central and the Central Coast than in the coastal areas between Da Nang and Ca Mau. The mean annual sunshine in the North is about 1,800-2,000 hours, while it is about 2,200-2,800 hours in the South. The total annual radiation is 55-60 (104 kJ/cm²) for the North and 65-80 (104 kJ/cm²) for the South.

Wind and Waves

Wind and waves also play significant roles that affect the bioremediation process. Waves rework the sediments which have small grain size such as pebble or sand, causing disturbance to oil. While wind speed and occurrence affect the evaporation process.

Along the coast, all sub-regions have two monsoons, the Northeast and the Southwest monsoon. The Northeast monsoon often starts from November and ends in April, while the Southwest monsoon often starts from May and ends in October. However, this pattern is not applied exactly for the whole coastal area as there are some moderate differences in duration and started month of each monsoon among these seven sub-regions. The dominating wind direction of Figure 3-1: Vietnam location map each sub-region is Northeast in January and Southwest in October. The most frequent wind speed is in a range of 1-10 m/s. Higher speeds appear rarely but wind speed is increased significantly during tropical storms and typhoons.

Waves also have the similar pattern, the dominating direction is Southwest in January and Northeast in October. Generally, stronger waves with wave heights of 2 to 4 m present more frequently in the South than that in the North. But in overall the most frequent wave height along Vietnam's coast is in a range of 0.5 to 2 m only.

In combination with other factors, strong wind also causes other consequences in coastal areas. For instance in Cuu Long estuaries in the South, the area from Ho Chi Minh City to Ben Tre is under the influence of surge and saline due to progressing wind.

Tide

When springing, tidal flow causes flooding for intertidal grounds. If oil settles in such these grounds, oil will replace from sediments and float to water surface when grounds are flooded. Hence the bioremediation process of oil at these areas is impacted significantly by the tide.

Again, due to a long coastline, tidal characteristics such as regime, tidal height and flow also vary greatly along the coastline. In an overview, diurnal is the major regime for the Northern Coast while composite patterns (irregular semi-diurnal and irregular diurnal) are much more frequent.

In term of the distribution of size of the mean tide during high tide (approximate) along Vietnam coast, the mean tide has the maximum value of about 3.4 m in the North Coast, then decreases gradually when coming south, reach the minimum value of about 0.5 m at Da Nang, then increases gradually again to about 3.0 m at Con Dao, and finally decreases sharply to about 1.0 m at Tho Chu. Based on this distribution, it shows that the North Coast, the North Central Coast and the area from Vung Tau to Ganh Hao usually have mean tides in the range of 2 to 3.5 m.

Storm

Stronger winds and waves always come together with storms so that storms can affect greatly to the bioremediation process. As a tropical country, there are many storms and typhoons hitting Vietnam's coast every year. Each year, there are more or less 10 sea-typhoons from the Philippines and the East Sea attacking the coastal provinces, special the Central region. Sea-typhoons are considered as one of the natural risks for fishing, shipping, tourist and aquaculture that may be one of the limitating factors to the national developments.

In comparison, there are generally more storms in the North and North Central Coast than in the South. Also, some coastal zones from Hai Phong to Nghe An (including the Red River Estuaries) usually have large surge when being influenced by storms. The southern areas from Da Nang to Phu Yen, Binh Thuan to Ca Mau and Ca Mau to Kien Giang have fewer storms than for instance the areas between Phu Yen and Khanh Hoa.

Rainfall

With the “two monsoon system” as mentioned above, weather along Vietnam’s coast can be separated into distinctive seasons which are the dry season and the rainy season. The dry season comes together with the Northeast monsoon, starting from November and ending in April. In this season, the amount of rainfall decreases significantly. Particularly affected are the areas from Mong Cai to Thanh Hoa in the North and from Ninh Thuan to Bac Lieu in the South. In the dry season, total rainfalls are only between 200 and 400 mm in these two areas but 400 to 1,200 mm in the others.

On the other hand, the rainy season comes together with the Southwest monsoon, starting from May and ending in October. The total rainfall along the coast is between 800 and 2,400 mm. Some areas such as Quang Ninh (North Coast), Dong Hoi and Da Nang (Central Coast) have a total rainfall up to 2,800 mm during the rainy season. Usually, the South has greater rainfall than the North.

3.3 The Potential Socioeconomic Impact of Oil Spills in Vietnam

An oil spill can have serious socioeconomic impacts on the affected regions, local communities, inhabitants and national economies. Vietnam is highly vulnerable to oil spills. In the following sections socioeconomic factors will be determined according to Vietnam’s vulnerability to oil spills.

3.3.1 The Socioeconomic Character of the Vietnamese Shoreline

Vietnam has a 3.200 km long coastline with rich biodiversity. The shoreline is diversified in its geographical and topographical characteristics. All types of shorelines, from rocky shores and rocky platforms to tidal flats, marshes and beaches occur. The Vung Tau–, Ca Mau- and Kien Giang–Coast as well as the south section of the North Coast are large coastal deltas. The most common types of shorelines there are tidal flats, mangroves, marshes, sandy and gravel beaches. The other coastal areas consist of a combination of mountains, rivers and estuaries in a highly complex structure.

On the coast half of all cities and provinces in Vietnam are found. Among them, some provinces have the most important roles in the Vietnamese economy, such as Ho Chi Minh City, Ba Ria–Vung Tau, Hai Phong City and Da Nang City. The sea-based economy constitutes a remarkable proportion of the total Vietnamese economic output. Industry, fisheries, agriculture, forestry, mineral exploitation, shipping and tourism are activities that use and affect coastal and marine environment services and resources.

Coastal regions contribute over 40 % of the Vietnamese gross domestic product, 50 % of the annual national export value and provide jobs for over 10 million people [VNA; 2003]. Many agricultural and fishing communities on the coastline rely on coastal wetlands and coral reefs and also the growing urban populations located on the coast are supported by Vietnam’s shoreline [WorldBank; 2003].

Three major economic zones and almost 30 industrial and export processing zones are located in coastal areas [VNA; 2003].

Due to the high density of ships passing Vietnam’s sea and the recent oil and gas exploitation development the risk of oil pollution on the Vietnamese coastline is high. A large oil spill could easily contaminate hundreds of kilometres of shoreline. It would threaten or destroy the marine ecosystems and cause grave socioeconomic impacts on shoreline communities and the Vietnamese economy [UNEP; 2001].

3.3.2 Economic Structure in Vietnam

GDP Structure

In 1986 economic reforms were implemented in Vietnam. These reforms, known as doi moi (renovation), included market liberalization and decentralization policies. Since then the economic structure of the country has been experiencing positive changes. The transformation of the country is also reflected in the development of Vietnam’s GDP. All GDP sectors have been growing steadily since the beginning of the 1990s. Major changes have also occurred in the composition of GDP by sector.

Industrial production has rapidly developed and occupies a major proportion of the national production level. The service sector has maintained the same level as in previous years.

The shares of the industrial/construction and services sectors are now at approximately 40 and 38 percent (see Figure 3-3), up from shares of 22 and 38 percent in 1990. The proportion of the agriculture, forestry, and fishery sectors continued in a downward trend. The share in GDP of this sector declined from 40 percent in 1990 to a lower, but still substantial, 21,8 percent in 2003. [UNDP; 2003]; [CIEM; 2004]; [GSO; 1999]

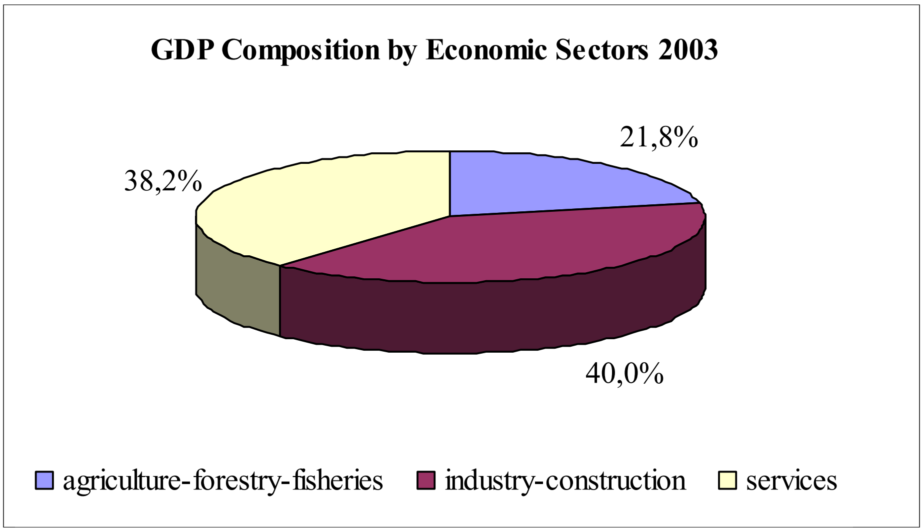


Figure 3-3: GDP Composition by Economic Sectors in 2003 (%) (at current prices) [CIEM; 2004, p. 24]; [GSO; 1999]

Industry/Construction:

The industry and construction sector saw substantial growth rates in recent years. The annual growth rate of the industrial sector in 2003 was 10,3 %. The growth in this sector is primarily responsible for the consistent growth rates that Vietnam has sustained (see Figure 3-5). The major industries in Vietnam include mining, foodstuff processing and the production of chemicals, fertilisers, steel, cement, construction materials, textiles and garments, wood products, and mechanical equipment. [CIEM; 2004]; [GSO; 1999]; [UNDP; 2004]

Services:

The services sector is the second largest contributor to GDP growth. In 2003, the services sector prospered and value added increased by 6,6 percent. Market related business services (like trade, hotels and restaurants, transportation, post, tourism, finance and banking et al.) were the largest contributor to the value-added growth rate of the services sector, attaining 5,1 percentage points, or 77 %. [CIEM; 2004]; [GSO; 1999]

Tourism:

The Vietnamese tourism sector benefits fundamentally from the amenity of the shoreline. Of the leisure and tourist destinations of Vietnam about 70 percent are located in coastal areas. They attract 80 percent of tourists each year [VNAT II; 2001]; [ICEM; 2003]. According to a report of the UNDP the tourism industry of the country has not yet fully utilized the potential advantages such as natural landscapes, cultural values and historical relics [UNDP; 2004]. Another important potential for the further development in this sector is the large number of domestic tourists, which is often lacking in other developing countries [Venard; 2003].

As for many other economic sectors, the tourism industry in Vietnam has been increasing its activities since the middle of the 80’s. It is very difficult to measure the contribution of tourism to the economy. This is basically because the diverse types of businesses selling goods or services to tourists do not constitute an easily separable economic sector.

Mainly the tourism industry can be observed as part of the services sector. Vietnam’s tourism sector is growing fast. In 2003 the share of the group of hotels and restaurants, transportation, post and tourism was accounting for 6,8 % in GDP. [CIEM; 2004]

The country attracts domestic as well as foreign tourists. Domestic tourism has risen sharply due to the fact that incomes and leisure time in Vietnam have increased. In 1995, there were approximately 4,5 million domestic tourists. This number grew up to about 10,7 million domestic tourists in 2000 [ICEM; 2003].
Lot of efforts have been made to attract foreign tourists since 1986, too. The total number of visitors from abroad (including holidaymakers, business people and overseas Vietnamese visiting their family) grew from around 200.000 in 1990 to an estimated 2,63 million foreigners, 55 percent of them tourists, in 2001. [Venard; 2003]; [CPRGS; 2004]. So tourism is also an important supplier of foreign currency [Boye; 2002]. It has become Vietnam's fourth largest foreign-exchange earner [EIU; 2001] after [Venard; 2003].

Figure 3-4: Number of Foreign Tourists in Vietnam per Year [VNA; 2003] after [Venard; 2003, p. 1430]

Agriculture-Forestry-Fisheries:
For the agriculture, forestry, fisheries sector the growth rate in 2003 was only 3,2 %. This was mainly because natural calamities occurring over large areas have impeded economic performance, especially in this sector. The economic composition of the agriculture, forestry, fisheries sector is shifting. The increase in the share of the fishery sub-sector goes together with the decrease in the share of the agriculture and the forestry sub-sector. While the value-added component of agriculture increased by only 2,8 % the value added of the aquatic production sector grew substantially at a rate of 7,1 %. Forestry rose by only 0,7 % in 2003. [CIEM; 2004]; [GSO; 1999]

The Fishery Sub-Sector:
The fishery-sector is playing an important role in the comprehensive poverty reduction and growth strategy in Vietnam. Aquaculture and off-shore seafood exploitation are considered as businesses with significant growth potential. On account of this the government introduces policies to develop aquaculture and offshore fishing for improving the capacity, investment and technical facilities in these sectors [CPRGS; 2003].
The fishery sector is one of the fastest growing in Vietnam. Revenues increased from US$ 850 million in 1998 to US$ 2.020 million in 2002. Vietnam's fisheries products are a major source of export earnings [Kelly; 2001]. In 2003, the aquatic production continued to grow with its value added increasing by 7,1 %. The sector can be divided into the catch of marine products and the aquaculture. The catch of marine products grew in 2003 by 1,4 %. The output of aquaculture increased by 14,4 %. Of that shrimp increased by 20,2 % and fish increased by 17,9 %. The hare of fish farming in the gross output of the fishery sub-sector rose from 33 % in 2000 to nearly 51 % in 2003 [CIEM; 2004]; [ICEM; 2003]. Fish farming grew in accordance with commercial production direction. Many regions expanded the area for large and medium-scale commercial production and increased the number of harvests. This development comprised the participation of many enterprises of all ownership types.

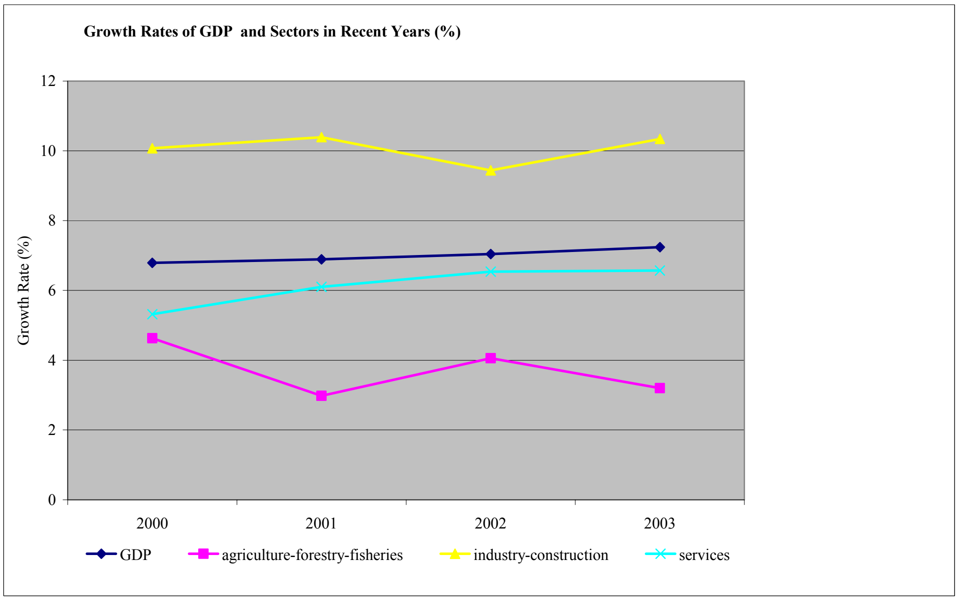


Figure 3-5: Growth Rates of GDP and Sectors in Recent Years (%) [CIEM; 2004, p. 21]; [GSO; 1999]

Oil and gas

Since the early 1970s, oil and gas in the offshore and continental shelf of the Southern Vietnam (the Cuu Long and South Con Son Basin) have been allowed to survey. After 1990, the activities of oil exploration have really expanded parallel with the economical development of the country. Vietnam has been identified as a medium priority market for the oil and gas sector. Vietnam's annual oil and gas production increased rapidly and reached 16.8 millions tons/a respectively 1.6 billion m^3/a. The total petroleum production is over 98 million tons/a of oil and 5.6 billions m^3/a of gas.

Currently, there are six large operating oil fields (Figure 3-1), of which Bach Ho (White Tiger), Rang Dong (Dawn), Hong Ngoc (Ruby) and Dai Hung (Big Bear) are the largest. Crude oil production averaged 352,507 barrels per day (bbl/d) in 2003. Up to now, there about more than 360 oil wells drilled for exploration and production.

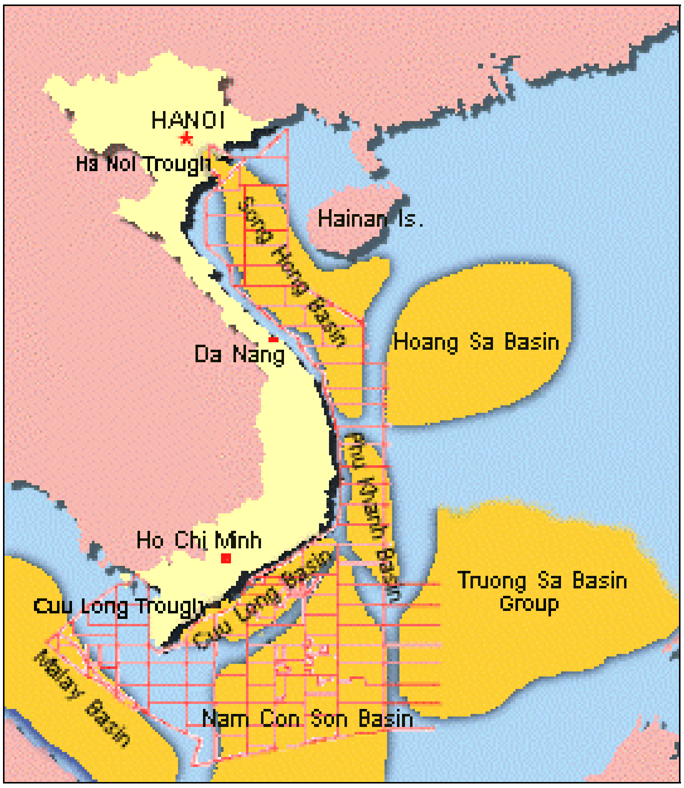
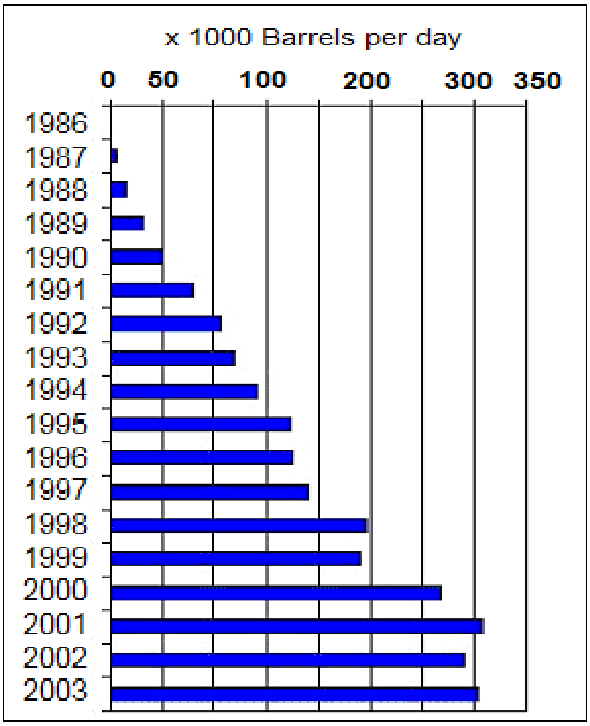


Figure 3-6: Vietnam's Oil and gas exploitation map [PV; 2005]

A large portion of Vietnam's oil production is exported mainly to Japan, Singapore, the United States and South Korea due to there is no operating oil refinery in Vietnam up to now. Up to now, Ba Ria – Vung Tau is the only coastal province with petroleum industry and is developing rapidly due to its offshore oil and gas reserves.

Table 3.3-1: Vietnam's Crude Oil Production



[PV; 2005]

A 140,000 bbl/d Oil Refinery Plant (Dung Quat) is under construction in Quang Ngai province (estimated costs: 1.3 billion US$. Furthermore, a new large oil storage facility with the capacity of 2.68 million barrels is being planned to build in Khanh Hoa province. Oil and natural gas exploration and production industries in Vietnam are now conducted by foreign investors and the government-owned company “PetroVietnam” (Vietnam Oil and Gas Corporation).

Table 3.3-2: Oil and Gas data figures

Proven Oil Reserves (2004)	600 million barrels
Oil Production (2003)	352,507 barrels per day (bbl/d)
Oil Consumption (2003)	202,000 bbl/d
Net Oil Exports (2003)	150,507 bbl/d
Natural Gas Reserves (2004)	6.8 trillion cubic feet (Tcf)
Natural Gas Production (2002)	79.8 billion cubic feet (Bcf)
Natural Gas Consumption (2002)	79.8 Bcf

[PV; 2005]

In Vietnam, natural gas production and consumption are rising quickly. It is estimated that about 70% of urban households using liquefied petroleum gas (LPG) for cooking and other purposes. In 2004, PetroVietnam has taken 202 billion cubic feet from the oil fields Bach Ho, Hong Ngoc and Rang Dong, Lan Tay (Western Orchid), Lan Do (Red Orchid), Ca Ngu Vang (Golden Tuna) and Voi Trang (White Elephant) (Table 3.3-2). Natural gas is exploited and transported from offshore oil fields to Dinh Co Gas Terminal in Ba Ria - Vung Tau onshore for consuming use partly in Phu My electricity power plant. Another complex of a gas-power-nitrogenous-fertiliser plant in Ca Mau was approved with a capacity of approximately 70 billion cubic feet per year and a electricity generation of 720 megawatt. The investigation costs are about 230 million US$.

Oil and petroleum products such as Diesel Oil (DO) and Fuel Oil (FO) for domestic and industrial uses were fully imported. In 2003, 2,410 tons of petroleum products shipments had been transferred and the amount of oil to be transhipped is gradually increasing in the following years.

The Composition of Employment

In 2003, the total labor force in Vietnam was approximately 42.128.300 people. 59 % of the total labor force is in the agriculture-forestry-fishery sector. Most People working in this sector are untrained, unskilled and receive low income. Employment in industry and construction accounted for 16,4 %, and employment in services made up 24,6 %. The national average level of unemployment was 5,8 %. The rate of unemployment of female workers was 7,2 % in 2003.

There are still great differences with regard to professional qualifications between urban and rural workers. While in rural areas workers with professional qualifications accounted for 13,3 % of the regional labor force; the share in urban areas was 45,0 %. The share of workers with the lowest professional qualifications was found in the North West region (10,7 %) and the Mekong River Delta (10,7 %).

At national level, the average monthly salary of a wage earner was 775.000 VND. Among the eight regions, the average monthly salary was highest in the South East region (844.700 VND). The lowest average monthly salary was found in the Red River Delta (712.600 VND). [CIEM; 2004]; [GSO; 1999]

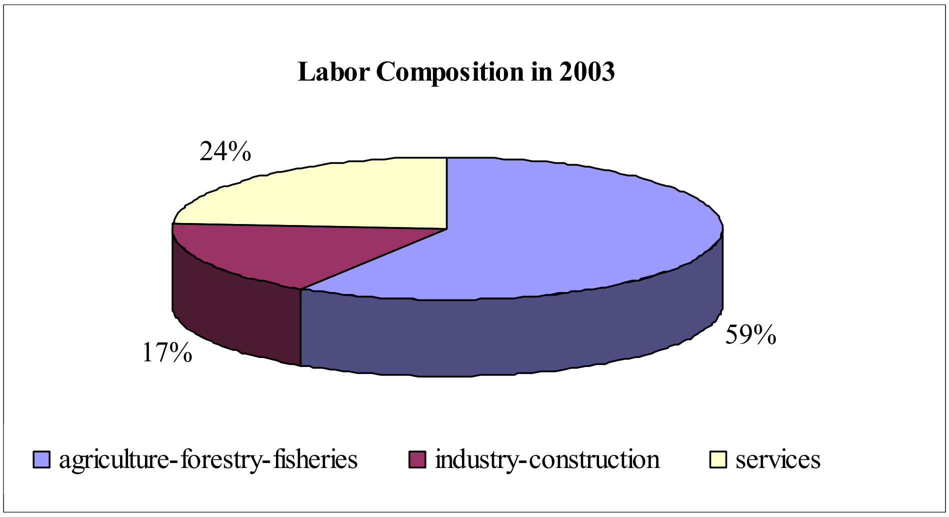


Figure 3-7: Labor Composition in 2003 (%) [CIEM; 2004, p. 21]; [GSO; 1999]

3.3.3 The Sea-based Economy

Agriculture:

The most common agricultural activity in every coastal region is cultivating rice. Usually, rice is cultivated two crops per year. Rice fields make up the largest part of land use in every coastal delta.

Other common agricultural activities are salt production, mangrove forestation and exploitation. However, these activities are focused mainly in the South due to higher radiation and atmospheric temperature characteristics and the scale of coastal mangrove systems.

Fishery and Aquaculture:

Fishery and aquaculture are highly developed and contribute significantly to the Vietnamese economy. In some coastal provinces fishery and aquaculture constitute even the largest part of the gross domestic product. Coastal residents usually conduct both, nearshore and offshore fishing.

Overall, the most common type of industry is the processing industry of fish and aquacultural products in current.

The Vietnamese marine capture fisheries can be divided into coastal fishery, inshore fishery (at a depth of less than 20 m), shallow water offshore fishery (up to approx. 50 m depth) and deep-sea fishery (more than 50 m depth). It is found that in Vietnam's coastal area there are 10,837 species of plants and animals. Out of 1260 marine fish species, Vietnam's water contains approximately 100 commercially viable marine fish species of which 1.3 million tons of the approximately 3.5 million tons are considered renewable. Marine capture fishery and brackish water aquaculture production have developed strongly in Vietnam after economic reform, especially since the 1990s. Fishery have been regarded as one the most important sectors in the Vietnamese economy. In 2000, the fishery and aquaculture export valued up by 35% to 1.3 billion US$ and total output production up by 20% to 1,827,310 tons. Regarding the Vietnam Ministry of Fishery (1997), the potential area for aquaculture development is estimated at 1.82 million ha as distributed in Figure 3-8.

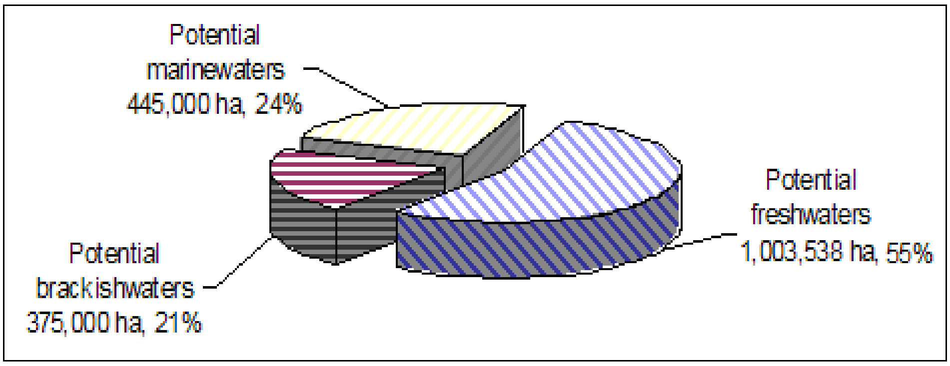


Figure 3-8: Potential fisheries development [Sources: Ministry of Fisheries, 1997]

Each year, Vietnam's sea area can supply nearly 4.2 million tons of marine fishes. Beside marine animals, there are also many high valued natural resources such as *Gracilaria verrucosa*, *Sargassum* can be exploited with a volume of 45,000-50,000 tons. In addition, there are also many precious species such as abalones, sea turtles or sea birds. Fish fin, fish bladder or mother pearl can also be exploited.

Fishery and aquaculture are specially developed in the South. Suitable conditions in terms of climate and other ocean characteristics result in the largest fishing grounds of the Southeast Vietnam Sea and in the Thailand Bay. Coastal residents usually conduct both nearshore and offshore fishing throughout the year. Vietnamese fishers still have used traditional inshore fishing with small and medium wooden boats, simple fishnets and own-experiences applied direct nearby the beaches, estuaries, shallow river mouths. They have captured all kinds and sizes of fish and shellfish species for their daily protein possible.

Figure 3-9: Small-scale fishery along the coastline

Over-fishing capture situation becomes one of the serious pressures on the coastal and seabed animal resources in present. About 8% of the fishers have investigated new big vessels equipped with 400-500 horse-power (HP) engines for deep-sea fishing. Incomes from fishery and aquaculture are even the largest part of the gross production of some coastal provinces. It is estimated that there are 3.4 million labourers working in the fishery sector as fishing, processing and services, of which more than 700,000 are involved in aquaculture.

There are an additional 1.4 million ha of freshwater, brackish water and marine water-surface available for aquaculture purposes, mainly shrimps, smaller mud crabs, lobsters, oysters and seaweed. However, the productivity of aquaculture is rather low (250-300 kg/ha) compared to other countries in the region. Aquacultural products after being processed are the major exporting good of Vietnam.

Figure 3-10: Various delicious seafood from the Vietnamese seabed

Up to now, Vietnam's fishery products have punched in 80 countries and territories. It is expected that the fishery production will score 3.3 million Mt[6] (including 1.94 million MT of capture and 1.36 million MT of aquaculture) and the export will amount to 2.6 billion US$ in 2005 (Ministry of Fishery, 2002). There is a high requirement for upgrading the seafood processing technique according to international standards as coveted export licenses from the European Union, Japan and from the United States of America.

Ports and marine transportation:

As Vietnam is a long and narrow country with a complex geomorphology due to a large quantity of mountains and highlands, a dense network of rivers, canals, many bays and shores along the coastline, water transportation is strongly developed. Presently, there is a highly busy marine traffic system on the coastal waters of Vietnam. Shipyards are developed in some coastal provinces.

At present there are 7 big ports at the major routes for goods imported and exported. Furthermore, there are more than 50 small ports working as a network of domestic ports which are located at estuaries and along the coast. Generally, Vietnamese flotilla is still weak with average useful life of 15-20 years. Vietnam's ports are also places for goods and oil transhipment to other countries. Vietnam's sea is also currently waterway for oil transportation from Middle East to the country and other Eastern Asian regions (Figure 3-11).

Waterway dredging is necessary to do regularly for all the ports of Vietnam because sedimentation processes are constantly raising.

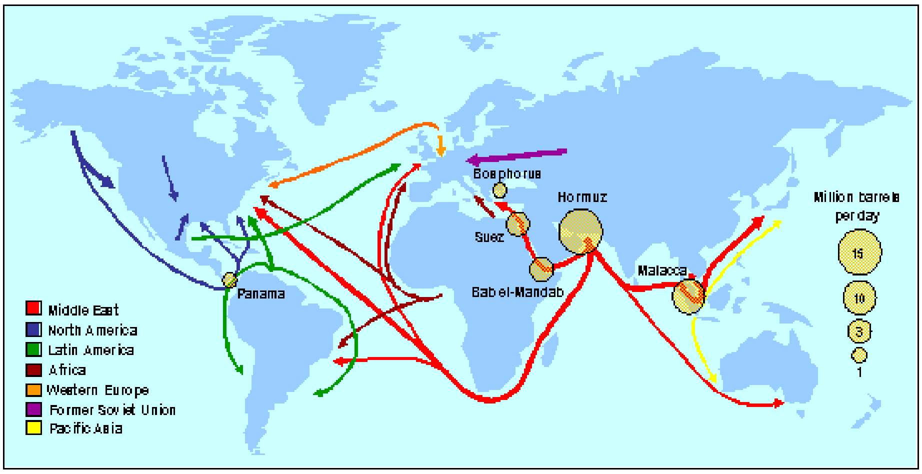


Figure 3-11: Oil shipping ways in the world

6 Mega tonnes

Industry:

The most common type of industry is the processing of fish and aquacultural products. In some coastal provinces shipyards are developed. Due to its offshore oil and gas reserves in Ba Ria – Vung Tau the petroleum industry is developing rapidly. As Vietnam's economy is developing rapidly, supported also by the marine transportation system, it is expected that more industry parks will be constructed in coastal areas in the near future. An example for this trend is the Dung Quat Industry Park in Quang Ngai province.

Tourism:

Vietnam is considered as one of the favourable geographical position for tourism development in the South East Asian region. Recently, tourism is developing sharply to become one of the most important economic figures. Due to a high complex geomorphology combining mountains, land, sea shore, and ecosystem and creating many beautiful landscapes, beaches and ecotourist places along Vietnam's coast are highly valuable for tourism exploitation. Ha Long Bay has been recognised as World's Heritage and there are many more famous beaches in Vung Tau, Da Nang, Nha Trang, etc.

Each year Vietnam Tourism has received more than 2 million international visitors and Vietnamese from overseas.

Tourism contributes considerable for national budget, approximately 10% of the country's GDP. Vietnam Tourism has indicated 7 areas which were given priority to investments in tourism development, 5 of them are coastal and sea areas (Figure 3-12):

1. Ha Noi Capital and the surrounding areas.
2. Ha Long Bay-Cat Ba Island-Do Son Peninsula belonging to Quang Ninh and Hai Phong.
3. The area of Hue-Da Nang-Lao Bao.
4. The areas of Van Phong bay-Nha Trang-Ninh Chu-Da lat.
5. The Vung Tau-Long Hai coastal areas.
6. Ho Chi Minh City and the surrounding areas.
7. Ha Tien-Phu Quoc marine areas.

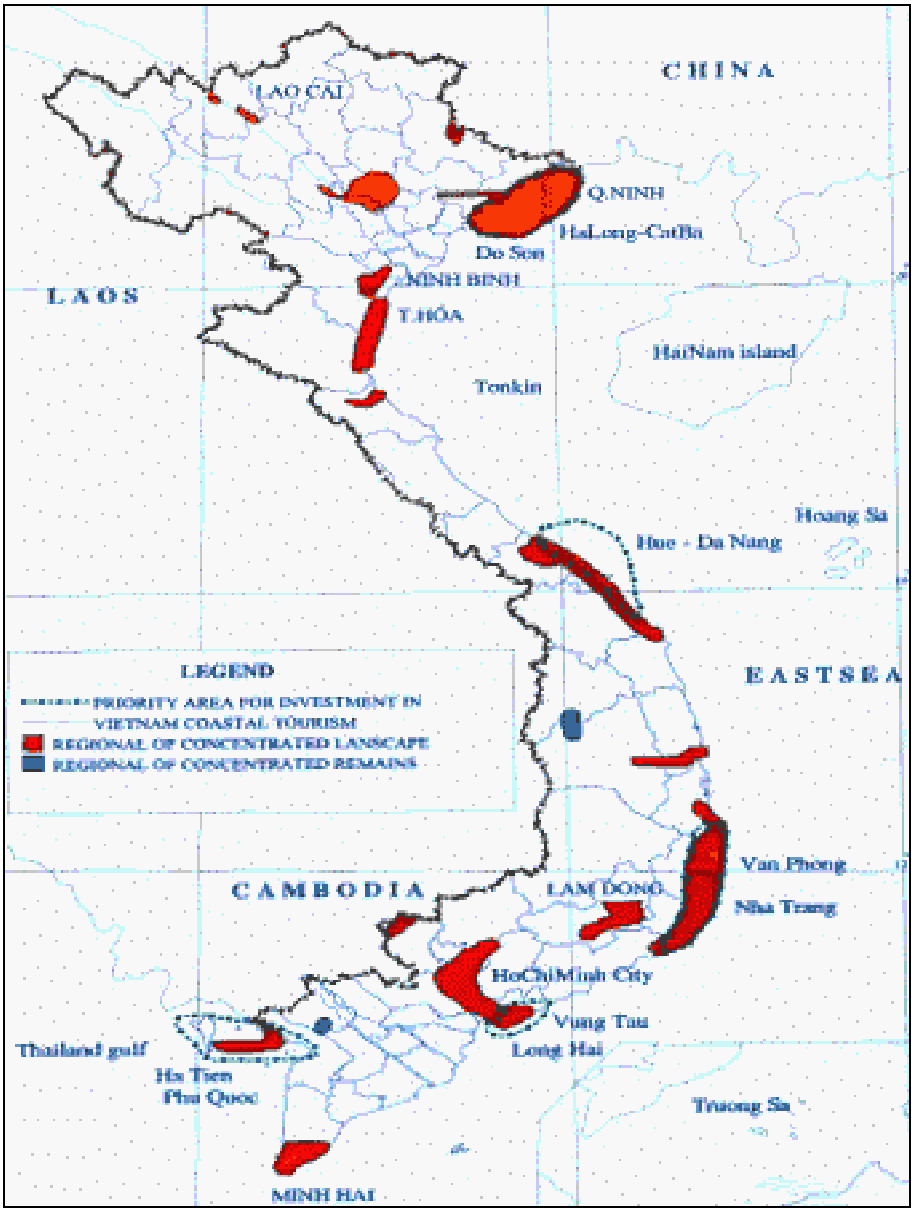


Figure 3-12: Prioritised zones for tourism development in Vietnam [Vietnam National Administration of Tourism, 2000]

3.3.4 Human Impacts on Coastal Changes in Vietnam

Vietnam has been identified as one of the ten most biologically diverse countries of the world. It contains about ten percent of the world's species while covering less than one percent of its land area [WorldBank; 2002]; [ICEM; 2003]. Vietnam's coastline is over 3.200 km in length. The long coast with its wide range of latitude and altitudes has contributed to diverse ecosystems, species and genetic resources. Because of the high productivity of ecosystems such as estuaries, lagoons, mangrove forests, coral reefs, and seagrass beds, the coastal zone is high in biodiversity.

Due to the presence of rich natural resources and other favourable natural conditions, the coast is a zone of active development with high population density. Out of Vietnam's 77 million people, 24 % live in coastal districts.

The long coastline supports growing urban populations together with many agricultural and fishing communities that rely on valuable coastal wetlands and coral reefs. Industrial and urban development, fisheries, agriculture, forestry, mineral exploitation, shipping and tourism are some of the key activities that use and affect coastal and marine environment services and resources [WorldBank; 2001].
Recently, changes in the Vietnamese coastal environment and ecosystems have become obvious. The changes have been caused by natural processes as well as human activities. Activities like upstream deforestation, the destruction of mangrove swamps, agriculture, aquaculture, and industrial and domestic activities in both the coastal zone and the river catchments have influenced the Vietnamese coastal environment. Due to these influences the loading and accumulation of pollutants increased and changed the quality of coastal and marine environments. Pollution and eutrophication resulted in the reduction of biodiversity [Than; 2002].
Human activities threaten the rich and coastal marine ecosystems, and have consequent economic impacts, mainly on the fishery-sub sector. From 1950 to 2000 Vietnam has lost more than 80 percent of its mangrove forests, with shrimp farming being one of the leading causes for this destruction. About 96 percent of Vietnam's coral reefs are threatened by human activities, such as destructive fishing methods, over fishing, and pollution. Of aquatic resources, like shrimp, crab, oyster and many species of fish, over one hundred species of economic value have been identified in Vietnam.
But due to over-fishing and destruction of coral reefs and mangroves the number of threatened species has risen [Kelly; 2001]. The changes in the coastal environment and ecosystems have led to a heavy drop in the fish catch per effort, threatening the sustainability of the marine fisheries sector [WorldBank; 2003].

3.3.5 Marine Protected Areas in Vietnam

The economy in Vietnam developed rapidly over the past 10 years. The increased demand for the services and products provided by natural systems due to this development is threatening the sustainability of Vietnam’s economy in long-term perspective. A further sustainable development can only be secured by the conservation and protection of natural reserves and ecosystems [ICEM; 2003].
As a concept, marine protection is new to Vietnam. The country now has about 2 million ha of natural reserves, representing six percent of its territory. But the number of marine protected areas is small. Only the national parks on Cat Ba and Con Dao islands, the Nha Trang Bay reserve in Khanh Hoa province, and the Cu Lao Cham reserve in Quang Nam province are listed as sea reserves in the country [VOV; 2004]. In order to strengthen the management and protection of the living environment of fisheries species, up to 2010 more marine protected areas will be designated. These include areas along the whole Vietnamese coastline [Thu; 2001].
In the foreground of conservation of marine areas is the protection of landscapes and biodiversity. But Wetlands and marine protected areas provide a number of other benefits, too. For instance, they support fisheries, tourism, scientific research and environmental education as well as the industries. In the Vietnam National Report on Protected Areas and Development of 2003 the relationship of the protected area system with community development and economic sectors such as water resources, energy, agriculture, fisheries, tourism, industry and environment are analysed in following sections [ICEM; 2003].

Fishery:
Marine and wetland protected areas are vital to developing sustainable fisheries and conserving aquatic biodiversity in Vietnam. A growing body of data suggests that there is a close relationship between the management of coastal wetlands and the size of coastal fish yields. Mangroves and coral reefs are particularly important in sustaining fishery production. They are nurseries for larval and juvenile fish and shellfish. Mangroves also make an important contribution to biomass, which fuels fisheries production. Another benefit for fisheries is that, over-exploited fish stocks can recover if their nursery and breeding areas are effectively managed within protected areas.

Tourism:
In many countries, protected areas are famous tourist destinations. Examples in developing countries are the National Parks of East and Southern Africa, and the marine parks of the Philippines and Thailand.
On the Vietnamese shoreline, tourism and nature protection are still two separated things. Although about 70 percent of the leisure and tourist destinations of Vietnam are located in coastal areas, only a small number of the few coastal protected areas serve tourism [ICEM; 2003]; [VNAT I; 2001]. The most people visiting Vietnam's protected areas are domestic tourists. The Tam Dao National Park is one of the most visited protected areas in the country. In 1999 about 50.000 national tourists and 3.000 international tourists visited the park [ICEM; 2003]; [GTZ; 2000]. The revenue potential of protected areas in Vietnam is still low, because tourism facilities (e.g. accommodations, information centres, guides and trails) are limited.
Furthermore the ICEM considers the Vietnamese wildlife as not bountiful enough to animate the „willingness to pay" of international tourists for visiting them.
The Tourism Master Plan, which was developed under a project funded by UNDP and executed by the World Tourism Organisation and Vietnam's National Administration of Tourism in 2001, includes specific guidelines for tourism in national parks and for ecotourism. Therefore in future a higher number of tourists can be expected in marine protected areas, too.

Industry:
Protected areas provide environmental services also to the industry. For instance, they supply raw materials for industrial production (e.g. water) and protect watersheds or river catchments that supply water to industries and provide bio-prospective opportunities for technological development. There exists only a little information about the links between industry and protected areas in Vietnam and more research is needed to better understand the contributions of the protected areas make to the industry better.

Although the ICEM in it's National Report on Protected Areas and Development refers only to protected areas, the points listed above can be seen as benefits natural resources serve for the economy in general. The increasing demand for the services and products provided by natural systems due to the economic development in Vietnam requires the investing in their maintenance [ICEM; 2003].

3.3.6 Social Vulnerability to Unexpected Shocks like Oil Spills

Social Vulnerability and Resource Dependency:
In general, vulnerability is an overall concept to describe how a society copes with the adverse effects of sea-level rise and climate change. Social vulnerability is the exposure of groups or individuals to stress caused by environmental change. Stress, in the social sense, results in disruption to livelihoods and forces adaptation to the changing physical environment. Generally social vulnerability encompasses the disruption to livelihoods and loss of security [Adger; 1999]. The occurrence of an oil spill poses an unexpected threat to the social and economic stability of coastal communities, because oil spills can damage or even destroy the natural resources these communities rely on for their income and employment.
Resource dependency is directly related to the vulnerability to environmental change [Machlis; 1990] after [Adger; 1999]. Coastal communities can be dependent to a greater or lesser degree on coastal resources. The direct dependence of communities on ecosystems influences their ability to cope with shocks, particularly in the context of food security [Adger; 2000]. Studies have shown that those parts of a coastal community directly dependent on fishing experience suffer major impacts from events such as oil spills. If the pollution stress is frequent and severe, the fishing communities have to cope with this event (Dow (1999) after [Adger; 2000].
In Southeast Asia as in Vietnam a high number of people are employed directly in marine capture fisheries. Others earn their living by building boats, by processing, marketing, and distributing fish, or by supplying goods and services needed by the region's fishers. The collection of material from tidal flats, mangrove forests, and coral reefs - for household consumption or for sale - are other economic opportunities for members of fishing communities. Local materials, including grasses and sedges, may be harvested and manufactured into mats, baskets, and other articles. Many communities in South East Asia as in Vietnam can be understood as dependent not on a single resource but on the whole marine ecosystem.

A common solution to problems of vulnerability in resource dependent communities is to promote economic diversification. In case of an oil spill, communities have to cope with the environmental change by looking for alternative employment opportunities. If coastal resources are destroyed land-based activities are the only alternatives, such as animal husbandry, farming and rural industrialisation, for income and employment [Bailey; 1996].

Poverty in Vietnam:

The damage of natural resources due to spilled oil may cause loss of harvests, job loss, loss of income and loss of health. Poor households are highly vulnerable to shocks such as oil spills. Because their income level is very low and unstable they are not able to resist a downward-shift in income due to an oil spill. Because of the fragile economic conditions of poor households in rural areas in Vietnam, these shocks may result in great instability in their lives.

Poverty is a widespread phenomenon in Vietnam. From the Vietnamese Ministry of Labour, Invalids and Social Affairs, the poverty line is measured by a standard of food security. It is defined as below 25 kg rice per capita per month in urban areas, 20 kg in rural households in lowland/midland areas, and 15 kg in highland areas. By this definition, poverty in Vietnam declined from 22 percent in 1994 to 20 percent in 1995 and 17 percent in 2000. The income level of many households is barely above the poverty line. A small decline in their living standards can push them below the poverty line [Tuan; 2003]. According to Vietnamese statistical data, living conditions and rates of poverty greatly vary in different regions (see Table 3.3-3).

Table 3.3-3: Poverty levels in 1998

Regions	**% Total Population**	**% Total Population Under Poverty Level in 1998**
Northwest and Northeast	17,1	28,1
Red River Delta	19,4	15,0
North Central Coast	13,1	17,8
South Central Coast	8,5	10,1
Central Highlands	4,0	5,1
Southeast	16,7	2,6
Mekong River Delta	21,1	21,2

[GSO; 1999, p. 175]

Even though all regions have shown some progress on poverty alleviation, the inequality between regions has persisted. The development of the regional Gini-Coefficients between 1995 and 1998 shows, that the gap between rich and poor people is widening. The Gini-Coefficient here expresses perfect income equity as 1 and absolute inequity as 100 (see Table 3.3-4) [GSO; 1999]; [Tuan; 2003].

Table 3.3-4: Income Gini-Coefficient in Vietnamese Regions

Regions	**1995**	**1999**
Red River Delta	33,0	41,3
Northeast	32,5	38,0
Northwest	36,1	39,4
North Central Coast	34,4	37,8
South Central Coast	34,5	38,5
Central Highlands	45,6	43,4
Southeast	36,9	44,6
Mekong River Delta	38,3	42,0

[GSO; 1999, p. 175]

Over 90 % of the poor in Vietnam live in rural areas. They are highly vulnerable to the daily difficulties and occasional shocks that may strike an individual, a family or a community. They have only low savings capacity and therefore are unlikely to be able to resist unexpected shocks such as oil spills. A small downward shift in income can easily push them below the poverty line [CPRGS; 2003], [WorldBank; 2003]. Poor people tend to be highly dependent on natural resources for their livelihood. They highlight their perception of natural resources as a safety net.

The poverty rate is extremely high among ethnic minority groups [CPRGS; 2003]. Ethnic minority groups comprise approximately 14 percent of the Vietnamese population, but account for 29 percent of the poor [GoV; 2002]; [ICEM; 2003]. Their poverty mainly results from living in remote areas and lack of access to markets and arable land. Therefore, ethnic minority communities are often dependent upon natural resources [ICEM; 2003].

Poverty and Fisheries in Vietnam:

In Vietnam more than 4 million people live in tidal areas and about 1 million in swamp and lagoon areas in the island line. 80 % of the coastal communities rely on fisheries. The sector is a major source of food, employment, income, and way of life in Vietnam. Estimations by the Ministry of Fishery suggest that there are 3,4 million labourers working in the fishery sector, including fishing, aquaculture, processing and services.

A country case study conducted by the UNDP about fisheries in Vietnam determines that in coastal communities the fishers belong to the poorest part of the population. The source of income of fishers is unstable. They are vulnerable to weather, typhoons, and migration of fish species. Big parts, approximately 90 percent, of all fishers are artisanal and small-scale.

Most of them belong to the poorest section of the population, mainly because they have no access to agricultural land. Many fishers don‘t have access to land for agriculture, because in several coastal locations, mangrove forests and agricultural land have been replaced by large, intensive shrimp farming ponds. As they are not able to diversify or to move completely into other productive activities their livelihood is highly vulnerable [Tuan; 2003].

Food Security:

The consumption of different kinds of aquatic products accounts for approximately 50 percent of the Vietnamese consumption of protein-containing food. The per-capita consumption of fish is around 8 kg per year. This is less than the average world consumption of 10 to 30 kg fish. In general Vietnamese families spend more money on meat than on fish. But particularly for poor coastal households fish is the primary source of food.

Many people in shoreline areas do not have access to agricultural land. 80 percent of the population in coastal areas depend on fisheries resources as well as aquacultural resources in marshes and mangrove forests for their livelihood. In the Mekong Delta, for instance, 83 percent of the low-income families catch fish in rice fields, canals and rivers. Studies conducted in the Mekong Delta indicate that there is an annual consume of over 30 kg of fish per person. The fisher’s families even show a higher consumption rate with 50 kg per person annually.

The need for fish as daily food causes pressure on the fishing industry in general. As offshore fishing accounts only 10 to 15 percent of the total fisheries near-shore and coastal fishing are the main sources of food. So the need for fish as daily food causes particularly pressure on coastal and near-shore marine resources [Tuan; 2003].

3.3.7 Socioeconomic Assessment of Pollution Damages

Evaluation of Damage Costs:

The Vietnamese coastal environment is very sensitive. Especially its coral reefs, mangroves, and seagrass beds are particularly vulnerable to forces resulting from human activities [Than; 2002]. Oil creates significant and varied negative impacts and costs to human health, the environment, the economy and cultures. To evaluate these costs is critical. Many different factors influence the magnitude of the damage and a lot of data have to be adducted to evaluate the damage.

For the evaluation of the damage caused by an oil spill it is not sufficient to judge the affected area only after the event. Knowledge about the status quo ante of the strucked region, especially about the environmental and socioeconomic conditions before occurring of the spill, is an important pre-condition for the damage judgement. If such information from the affected region or chosen areas for comparison is missing false conclusions can be drawn. Therefore to preposition an environmental and socioeconomic monitoring is necessary. For reasons of financing not all areas that potentially could be affected by oil spills can be investigated on a continuing basis. Therefore representative areas should be chosen for research, which can be used for the purpose of comparison in case of an oil spill [Maschke; 1989].

Wetland Inventory:

Wetland inventory, which is a tool for identifying the functions and values of wetlands - including ecological, social and cultural values - also provides the basis for measuring future change in wetlands [Finlayson; 1995]. Wetlands are rich ecosystems, capable of providing a range of goods and services of use to human populations. Economic valuation can help to highlight the importance of the services and goods provided by ecosystems. One concept to illustrate the valuation of marine areas is the concept of the Total Economic Value. Within the UNEP/GEF Project: "Reversing Environmental Degradation Trends in the South China Sea and Gulf of Thailand" the Total Economic Value of different wetland areas, especially of mangrove ecosystems, was evaluated [UNEP; 2003].

The goods and services produced by mangrove ecosystems differentiated into their usage on community, national and global level are listed in Table 3.3-5.

Table 3.3-5: Valuation of mangroves

Community level	**National level**	**Global level**
Timber and firewood	Timber production	Conservation
Fodder for animals	Charcoal production	Education
Traditional medicine	Shrimp and crab industires	Preservation of biodiversity
Food	Mangrove silviculture	Indicator of climate change
Local employment	Trade	
Recreation	Ecotourism	
Shell collection	Education	
Erosion control	Water quality management	
Protection from storm damage	Coastal and estuary protection	

[Dahdouh-Guebas; 2000]; [Hamilton; 1984, p. 384]

These goods and services generate economic value. For instance, fishery resources can be harvested and sold, creating value added. Alike preservation and eco-tourism create value. The goods and services need to be quantified and monetized. For goods sold in the market place, this is directly possible by looking at their market price. For ecological services this is not the case. Therefore, complex valuation techniques are used to calculate an economic value of these services. The value of all goods and services combined gives the Total Economic Value for an ecosystem [Pearce; 1990].

Oil spills can impact mangroves dramatically and even destroy them [Ellison; 1996]. When the tide is high they enter mangrove forests and are deposited on the aerial roots and sediment surface as the tide recedes. Because heavy oil is covering the trees breathing pores and also due to the toxicity of substances in the oil mangroves can be killed.

It is very important to distinguish between the concepts of environmental benefits respectively Total Economic Value and the effects of pollution. For the evaluation of damage a reference point has to be chosen against which environmental changes are to be measured [Freeman; 1979].

The costs of pollution are the losses represented by the move from a level of cleanliness to the existing pollution level. So that part of damage costs due to an oil spill corresponding to affected mangrove areas can be seen also as the foregone Total Economic Value of these areas because of pollution.

Socio-economic Assessment of Wetland in Vietnam:

Within the above mentioned UNEP/GEF Project: “Reversing Environmental Degradation Trends in the South China Sea and Gulf of Thailand” the Total Economic Value of various Vietnamese mangrove ecosystems, for example Van Uc Estuary, Kim Son Mudflat, Tam Giang, Cau Hai Lagoon, Thu Bon Estuary, was evaluated. As an example here is demonstrated, how the Total Economic Value of Ba Lat Estuary in Nam Dinh Province was evaluated within the study [UNEP; 2003]. This site is located at the Giao Thuy district and an internationally important wetland area in Vietnam. It is used for shrimp farming as well as for recreational purpose.

Table 3.3-6: Total Economic Value of the Ba Lat Estuary

	Low Value – Estimated Value		High Value – Estimated Value	
	VND	Euro	VND	Euro
Direct value				
Timber	103.620	5,02	108.200	5,25
Fuel wood	82.500	4,00	86.400	4,19
Indirect Value				
Aquaculture	13.500.000	654,54	15.000.000	727,27
Marine product collection *	2.640.000	128	2.860.000	138,67
Honey	112.000	5,43	132.000	6,4
Medicinal plants	14.200	0,69	18.500	0,9
Tourism	12.000	0,58	15.000	0,73
Environmental Value				
Stabilizing micro-climate, improving air quality, water quality, preventing the site from water surge, etc.	15.100.000	732,11	16.400.000	795,14
Total Economic Value (per ha)	31.565.720	1.530,44	34.620.100	1.678,53
Estimated Total Economic Value estimated on the basis of total area	**254.475.574.524**	**12.338.083,42**	**279.099.283.577**	**13.531.948,01**

* unorganised fishing and marine product collection, conducted by household member occasionally or seasonally
Currency exchange rate: Euro 1= VND 20.625,21 [March 2005]

[Birdlife FIPI; 1996]; [Adger; 1999] and [Giao; 2000] after [UNEP; 2003]

The Total Economic Value comprises direct use value, indirect use value, option value, and existence value. The relative importance of the individual components of TEV for a given mangrove area is site specific. In assessing the economic value of mangroves, the UNEP/GEF study emphasizes only the "use value", which comprises direct and indirect use values. The value of biodiversity and non-use value of mangroves are not assessed. The components shown in Table 3.3-6 of Total Economic Value include direct use value of mangroves in terms of local community usage and indirect use value in terms of off-shore fishery linkages and coastal line protection.

3.4 Vietnam's Marine and Coastal Environmental Problems

Vietnam is known as one of the countries having a high biodiversity in the world, including in species composition, landscapes and ecosystems as well. In the last few years, the annual growth rate of industrial production was 10-15% and highly distributed to the percentage of GDP in the whole country, especially in the development zones. However, this growth involves production of wastewater, which is mostly not treated when flowing into the rivers and finally to the coastal zone. Otherwise, Vietnam's biodiversity is being threatened by its modernization and industrialization process (Table 3.4-1). Coral reef conditions in Vietnam are declining (Figure 3-13).

Table 3.4-1: Nationally threatened species in Vietnam (Source: WCMC database, 1994)

Category: Taxa:	endangered	vulnerable	threatened	rare	indeterminate	total
Mammals	30	23	1	24	-	78
Birds	14	6	32	31	-	83
Reptiles/ Amphibians	8	19	16	11	-	54
Fishes	6	24	13	29	3	75
Inverts	10	24	9	29	3	75
Total	68	96	71	124	6	365

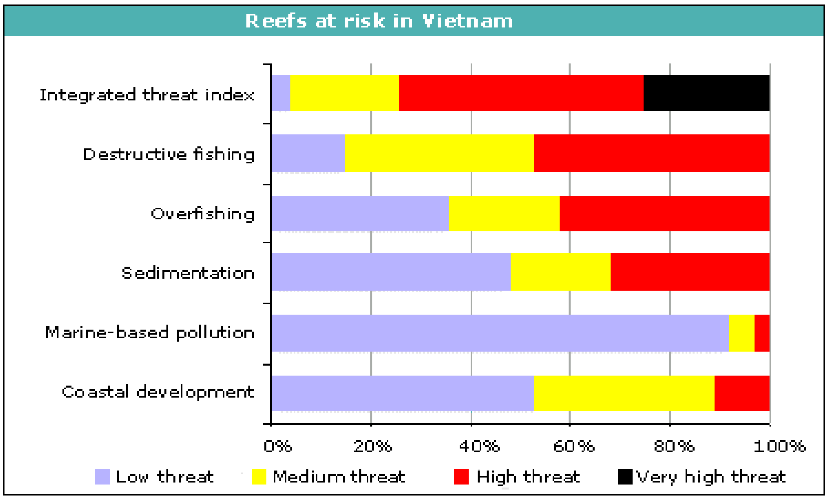


Figure 3-13: Reefs at risk in Vietnam (Source: Vo Si Tuan, 1998)

There are three main reasons that may lead the degradation of environment seriously in Vietnam:

3.4.1 Industrial Pollution

Most of the industrial plants have been constructed closed to the water as coastal areas, estuaries, river banks, reservoirs, lagoons and wetlands. Their untreated wastewater, hazardous wastes and other tailings are highly sources for water pollution. Oil pollution due to shipping activities and accidents occurs in the coastal estuarine waters. Almost 29 coastal provinces of Vietnam are facing oil spill problems and the number of such accidents has grown over the last few years, especially in the Southern Sea. A significant amount of uncollected solid waste from the households also goes into rivers and the sea.

3.4.2 Chemical Pollution

Over-used agricultural fertilisers and pesticides have runoff from the fields to the streams and caused water pollution. A great amount of organic compounds, heavy metals and oil comprises the pollution load of such waste water. Together with the recorded oil spills, attention must also be paid to oil spills from non-identified sources. Untreated wastewater from households have also contributed the degradation of water quality.

3.4.3 Natural over-Exploitation

Increasing population pressure, high poverty and paucity of livelihood opportunities are contributing to the over-exploitation of natural resources, habitat destruction and biodiversity losses. The situation of over-fishing, fishing with poisons and explosives, fishing with fine gill nets, electric fishing, etc. are destroying aqua habitats, too. Coral habitats are threatened by pollution, including siltation from land; over-exploitation of fish and invertebrates, oil spill disasters, coral breaking for the souvenir trade, making cement, etc.

3.5 Oil Spill Occurrences in Vietnam

Recently, Vietnam's economy has maintained its relatively high levels of growth. Together with the development is increase of oil consumption, oil transportation, etc. leading to risk of oil spill incident. Main activities related to oil spills are oil production and transportation.

Oil and oil products are some of the common transported goods. In general, oil shipping is quite high in density in the South of Vietnam. Some ports in this area always load oil and oil products, such as the ports of Vung Tau, Sai Gon and Dong Nai. In the southern area, every year about 10 million tons of oil products are imported into Vietnam and 70% of this amount come through southern ports (Sai Gon, Vung Tau).

This area also locates in the major sea route for oil transportation from Middle East to the eastern parts of Asia and is the most focused zone for petroleum exploration and production activities in Vietnam as mentioned above. Moreover, weather conditions in the area are adverse (waves, wind, currents, etc.) so that risk of oil spill incidents is quite high. Marine or river/canal oil spills are one of the very serious risks which may cause economically significant damage not only immediately but also permanently resulting in a hardly destroyed environment. It will cause a costly recovery which takes a long time to restore. Some nearshore activities like fishing, aquaculture, agriculture, tourist and ecosystem are unrecoverable leading to cause direct effects on local people’s life.

Under statistical data on oil spills, the southern area had the biggest and most of the oil spill incidents in Vietnam such as the NEPTUNE ARIES incident in 1994 (1864 tons), the FORMOSA ONE incident in 2001 (750 tons), oil spill incidents in 2003…etc. According to reported data, there were 28 oil spill incidents occurred in coastal and offshore areas of South Vietnam during 1992-2004. In this period, there were 10 incidents classified in Tier II (under category of the National Oil Spill Response Plan). A list of oil spill incidents in coastal and offshore areas of southeast Vietnam during 1992-2004 is presented in
Table 3.5-1 to
Table 3.5-3 on the next page.

Table 3.5-1: Oil spill incidents in coastal and offshore areas of southeast Vietnam during 1992-2004 (Part 1)

No	Date	Incident / Co-ordinates	Spill volume	Oil type	Damage assessment
01	29/06/ 1992	oil spilled 4 times from *Chi Lang* tanker (Vung Tau)	not reported	Crude oil	Administrative adjudication for the Chi Linh tanker (45,000 US$)
02	26/11/ 1992	flexible pipe from *Chi Linh* tanker to *Ten Ei Maru* tanker (Bach Ho field) was broken	300-700 tons	Crude oil	Administrative adjudication for the Chi Linh tanker (30,000 US$)
03	1993	*Long Son* supply boat collided to platform and caused oil leakage from fuel tank oil spill during loading from *Long Son* supply boat to *Chi Linh* tanker	not reported	-	not reported
04	18/01/ 1993	flexible pipe from *Chi Linh* tanker to *Pacific Spirit* tanker was broken	not reported	Crude oil	not reported
05	01/01/ 1993	flexible pipe from *Chi Linh* tanker to *Chizukawa* tanker was broken	not reported	Crude oil	not reported
06	18/09/ 1993	collision between two tankers at 20 km distance from *Ky Van* cape, Vung Tau (*Pan Havert* tanker was wrecked)	300 tons	Fuel oil + LO + Diesel oil	Damage estimated 640,000 US$
07	Oct. 1993	*Viking Carrier* tanker was wrecked leading to oil spill	380 tons	Not reported	not reported
08	02/02/ 1994	flexible pipe from *Chi Linh* tanker to *Cypress* tanker was broken	not reported	Crude oil	not reported
09	08/05/ 1994	large tanker and small oil tanker collided in the estuary area of Can Gio (HCMC[7])	about 130 tons	Fuel oil	Damage estimated 2 million US$
10	03/10/ 1994	*Neptune Aries* tanker collided to terminal jetty at Cat Lai (HCMC)	1,864 tons	Diesel oil	4.2 million US$ compensatory payment
11	06/01/ 1995	transportation pipe was broken from collision between *Lam Son 01* supply boat and *Pacific Pluto* tanker = oil spilled consequently (Bach Ho field)	not reported	-	not reported

[7] Ho Chi Minh City

Table 3.5-2: Oil spill incidents in coastal and offshore areas of southeast Vietnam during 1992-2004 (Part 2)

No.	Date	Incident/Co-ordinates	Spill volume	Oil type	Damage assessment
12	08/02/ 1995	flexible pipe from tanker to offshore loading buoy was broken – Dai Hung field	14 tons	Crude oil	not reported
13	15/02/ 1995	oil leaked from tanker when high tide in the river (Cai Be)	about. 8 tons	Gas oil	River pollution
14	Oct. 1995	the wreckage of *Gigek Extajo* tanker caused oil spillage	400 tons	-	not reported
15	03/12/19 95	*Maco Arabico* tanker was wrecked at position of 9°49N and 108°05E	not reported	Fuel oil + Diesel oil + LO	not reported
16	18/12/19 95	the dash of two tankers at position of 9°16N and 106°40E (the *Jannifier* tanker was wrecked)	not reported	Fuel oil + Diesel oil + LO	not reported
17	23/12/19 95	the collision between two tankers at co-ordinates of 10°16'13N and 109°41'15E (the *Memed Abashiza* tanker was sank)	500 tons	Fuel oil + Diesel oil + LO	not reported
18	27/01/19 96	oil spillage from *Gemini* tanker (Cat Lai)	70 tons	Diesel oil	400,000 US$ as the compensation
19	15/07/19 96	*Maersk Retriever* supply boat collided to *Batst* platform caused fuel tank broken (Block 04-1)	83m^3	Diesel oil	Administrative adjudication as much as 28,000 US$
20	19/03/19 99	marine accident of *Viva Ocean* caused oil spill (Bai Truoc-Vung Tau)	not reported	-	not reported
21	16/04/19 99	barge collided with tanker (Nha Be river – HCMC)	about 95 tons	Diesel oil	Damage estimated 1.2 billion VND
22	01/07/19 99	the transportation pipe from second Centre Platform to Ba Vi vessel was snapped off (Bach Ho field)	not reported	Crude oil	not reported
23	06/1999	the residual oil in broken pipe on 1st Jun as above was spilled due to transportation of *Sao Mai 3* supply boat	not reported	Crude oil	Administrative adjudication 50 million VND
24	1999	*Sao Mai 3* supply boat collided to platform broke fuel tank	not reported	Diesel oil	not reported
25	03/02/20 00	the transportation pipe was broken (Bach Ho field)	not reported	Crude oil	not reported
26	07/09/20 01	tanker *Formosa One* collided to tanker *Petrolimex 01* (Ganh Rai bay– Vung Tau)	900m^3	Diesel oil	Damage estimated 17.2 million US$

Table 3.5-3: Oil spill incidents in coastal and offshore areas of southeast Vietnam during 1992-2004 (Part 3)

No.	Date	Incident/Co-ordinates	Spill volume	Oil type	Damage assessment
27	12/01/ 2003	collision between vessel *FORTUNE FREIGHTER* and tug boats *AG-7174H* alongside barge *AG-6139H* on Sai Gon river	388 m^3	Diesel oil	Damage estimated 2.1 billion VND
28	20/03/ 2003	tanker *Hong Anh* was sank at position 10°25'73"N and 107°00'723"E near buoy No 7 at Ganh Rai bay, Vung Tau	> 100 tons	Fuel oil	Damage estimated 19.6 billion VND
29	21/01/ 2005	oil spill incident in January 21, 2005: tanker *KASCO MONROVIA* collided to *Saigon Petro* jetty – Ho Chi Minh City	approx. 350 tons	Diesel oil	under assessing

Classification of oil spill size (tons) according to causes is shown in Figure 3-14 below:

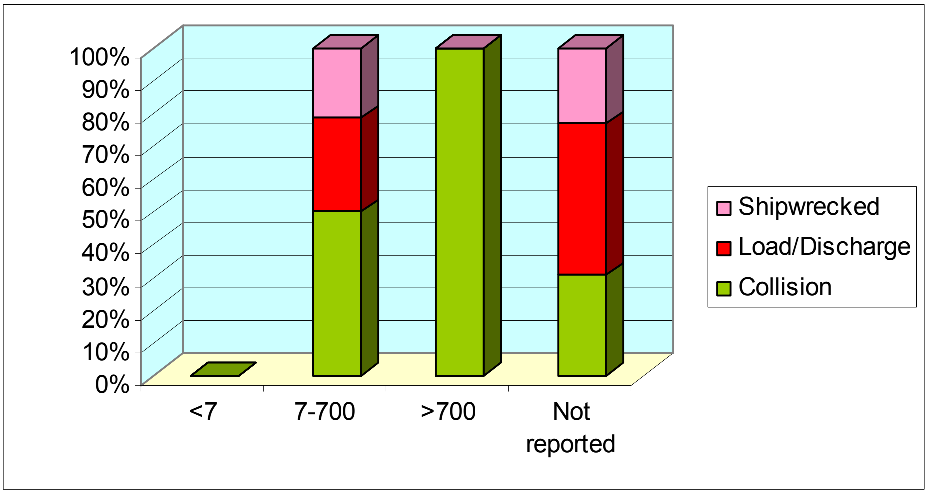


Figure 3-14: Classification (by size; tons) of oil spill incidents in Vietnam from 1992 to 2005

Figure 3-14 shows that oil spill incidents with a size > 700 tons had been caused by collision. There are many spills with amounts of oil spills not reported, however most of these spills are often in minor size and mainly occur in loading/transferring.

In overview, oil spill from collision is the major cause especially for spills over 700 tons. This is explained by condition of waterway traffic in Vietnam including bad status of vessel, tanker, etc. The unsuitable developments of economic and infrastructure is also the reason causing oil spill incidents. Another reasons are weather conditions in Vietnam with complicated regime of wind, currents and tides. In fact, many oil spill incidents occurred due to bad weather, respectively weather makes incidents become even worse. Oil spill occurrence can be clearly seen by some typical spills in recent years. Characteristics as well as response methods of the oil spill incidents are described as follows:

Oil spill incident in March 10th, 1994: Tanker *NEPTUNE ARIES* collided to *CAT LAI* Jetty – Ho Chi Minh City (about 1864 tons Diesel oil was spilled)
Response equipments are deployed but have almost no effectiveness due to river conditions:
Ebb-tide, strong current (pulling oil flow under boom, big vessel difficult moving), the incident occurred in night time. In this case, simple response was effective (local people use every available means in river to collect oil, even used boats to collect oil…)

Oil spill incident in April 16th, 1999 caused by collision of vessel *NHAT THUAN* to *HIEP HOA* oil barge on the Nha Be river. 114 m³ Diesel oil (approx. 95 tons) were spilled. Response equipment of Petrolimex was not effective (ebb-tide, strong current) and not associated in collection but transferred whole oil rest in barge (324 m³) to avoid sinking of barge.

Oil spill incident in September 7th, 2001 in Ganh Rai bay, Ba Ria - Vung Tau province. The incident occurred in night time during spring tide and it was impossible to mobilize response equipment. The spill location is only about 2 km far away from ashore. In the first day all spilled oil had quickly spread and drifted to ashore causing pollution of large area.

Oil spill incident in January 12th, 2003: Collision between vessel *FORTUNE FREIGHTER* and tug boats *AG-7174H* alongside barge *AG-6139H* on the Sai Gon river caused spill about 388 m³ Diesel oil. Cooperated response onsite was quite effective with response equipment on the river.

Oil spill incident in March 20th, 2003: Tanker *HONG ANH* sank at position 10°25'N and 107°00'E closed to buoy No.7 in Ganh Rai bay. More than 100 tons Fuel oil were spilled. Because the incident occurred in the river mouth with strong waves and ebb tide, response measures were almost not effective. Following currents and wind were the reasons for oil slick drifting to the riverside and coastal area.

The overview of oil spill incidents above shows that most of big oil spill incidents are caused by collisions. After spilled, oil often hits to shore causing serious pollution to the shoreline as well as its environment. Cleanup measures are very important factors to minimize effects of oil spill incidents. Actually, such measures are not really effective in Vietnam due to many reasons. The lack of cleanup procedure is the major reason. Response resources for cleanup are always activated from available resources such as local people, nearby activities, etc. which are not trained for cleaning up.

3.6 Danger of Marine Oil Pollution in Vietnam in the Future

3.6.1 General cConditions of Vietnam's Sea

Vietnam is one of the most sea potential economic oriented countries in the world. It is located on critical international marine routes, connecting among the most economic exciting centers in the world. This location is also favorable for building the sea ports, ship building factories and marine services. Besides, Vietnam also plays an important role on sea economic development strategy of the labor countries, which do not have the coasts or geographic conditions for developing the sea economy.

The Vietnamese coastline extends for some 3,444 km through more than 15 degrees of latitude from 8°30'N to 23°S (from Quang Ninh to Kien Giang provinces) and shows a variation in climate and biodiversity along this broad N-S line. The country has more than 3,000 inshore and offshore islands and islets which extend to claims covering the Spratly and Paracel archipelagos. There are broadly five distinct marine areas that differ according to coral diversity (1) western Tonkin gulf, (2) middle central, (3) south central, (4) southeastern and (5) southwestern.

Vietnam's Sea has a good climate for the development of sea creatures with a rich and diversified resource of sea creatures and minerals. There are 26 coastal provinces and cities counting 42% of the area and 45% of the whole country's population with 15.5 million people living near the sea and 160.000 people on the islands.

The General conditions of Vietnam's port and shipping systems

Vietnam's sea ports play a vital role in the country's economic development – and as shipments increase, that role is even getting larger.

Vietnam currently has more than 110 ports and wharves under management of different units, all of them are invested by the State. Among them, there are 4 big ports namely Quang Ninh, Hai Phong, Sai Gon, Da Nang and 3 medium-size ports namely Nghe Tinh, Quy Nhon and Nha Trang.

3.6.2 Development Plans of Water Transports and Shipping in General

3.6.2.1 The National Shipping Team

Basing on the national general statistics, in the year of 2002 there were 610 freight ships operating in the maritime transport with 18,491.8 thousand tons total volume of freight. There were also thousands of craffs, towing vessels, freight ships, motor boats, and barges working on the inland waterways with the freight volume of 52,299.7 thousand tons. The numbers for the year 2003 are 21,807.6 thousand tons for marine transport and 53,188.2 thousand tons for inland waterways, increasing more than 100% in comparison with the year 2002. On the other statistics, according to the Vietnam Maritime Bureau by early October 2004, the Vietnamese shipping fleet had increased to 994 ships with 2.85 million dead weight tons (dwt), ranging 60/150 on the world and 4/10 in the ASEAN member countries.

Transport capacity was mostly concentrated in state shipping enterprises with 1.78 million dwt. Vietnamese export goods have increased rapidly in volume over recent years, growing from 18.7 million tons in 2000 to 29.7 million tons at the end of 2003, of which crude oil accounted for 50%. This was a huge volume of goods to transport and Vietnam National Shipping Lines was only able to carry 12% of the total volume of crude oil exports in 2000, due to the low capacity of their fleet of oil tankers.

The majority (more than 70%) of cargo ships arrived in Ho Chi Minh City, with the remainder being shipped to Hai Phong, destined mainly for Hanoi. The number of ships coming to Hai Phong has been remained relatively constant, while Da Nang is reported to receive more and more container ships each year (see table
Table 3.6-1,
Table 3.6-2 and
Table 3.6-3.

Table 3.6-1: Volume of freight by type of transport (thousand tons)

Year	Total	of which:			
		Railway	Road	Inland waterway	Maritime transport
1995	132576.3	4515.0	92255.5	28466.9	7306.9
2003	255446.9	8284.8	172094.5	53188.2	21807.6

Table 3.6-2: Volume of freight traffic by type of transport (million tons per km)

Year	Total	of which:			
		Rail	Road	Inland waterways	Maritime transport
1995	25328.1	1750.6	5137.5	3015.5	15335.2
2003	57415.0	2703.3	9219.4	5099.9	40215.6

Table 3.6-3: Volume of import&export main cargo across sea ports managed by the central level (thousand tons)

Year	1995	1996	1997	1998	1999	2000	2001
TOTAL	14487.9	15435.0	15032.0	17141.1	17424.7	21902.5	30567.8
Export Cargo:	3737.1	4379.0	4647.6	4788.1	5262.1	5460.9	8530.7

3.6.2.2 National Shipping Plan

The Ministry of Planning and Investment has submitted an ambitious 32,000 billion VND (2 billion US$) plan to the government to develop Vietnam's national transportation by ship. The shipping fleet blueprint details investments up to 2010, as well as broader objectives to 2020, and aims to lift the total freight capacity of Vietnam National Shipping Lines Corporation (Vinalines) to 29 million tons of goods by 2005 and 45 million tons by 2010.

Under the plan, by 2010, the national shipping teams should carry 80% of the domestic cargo, and 30 per cent of the international cargo coming in and out of Vietnam's ports - a huge leap from the current 16 and 15% respectively.

To achieve these goals, the corporation plans to spend 300 million US$ on 10 new oil tankers for servicing the country's first oil refinery in Quang Ngai Province, as well as purchasing 10 more 325,000-tons vessels capable of shifting 2.5 to 3 million tons of cargo a year.

The ministry's suggestions to the government include exempting Vinalines from corporate income tax to release more investment capital; requesting low-interest loans from domestic and overseas banks to fund purchases of vessels and removing 5% import duty on the overseas ships that Vietnam cannot manufacture.

Vinalines' shipping fleet current capacity is 850,000 dead weight tons (dwt) with a goal to reach 1.5 million dwt by 2005, which should see the corporation handling up to 80% domestic and 20% import-export cargo volume.

Petro Vietnam plan for building fleet: Petro Vietnam has planned to invest in five crude oil tankers of the AFRAMAX type by 2005. The plan aims to ensure the transport of sufficient oil from the oilfields to the Dung Quat Oil Refinery on the central coast of Vietnam. The tanker fleet will have 10 oil tankers in 2020, which will be able to supply sufficient oil to Vietnam's two oil refineries and other international oil buyers. The plan aims to form a fleet that is able to carry at least 30% of crude oil exports, guarantee the transport of oil for domestic oil refineries and gradually enter the regional and global crude oil transport market.
Currently, according to shipping statistics, in recent years 99% of the total amount of crude oil exports from Vietnam were carried by foreign shipping fleets while production of crude oil in Vietnam has been about 17 million tons per year. This is the reason for the fleet development plan of the company.
The information and numbers above demonstrate the increasing of cargos being transferred through Vietnam's sea ports in the recent years and how busy marine transporting operation is. Basically, most of goods or cargos had been transported via three major ports in Ho Chi Minh City, Hai Phong and Da Nang. For example, the throughput in Ho Chi Minh City port is an encouraging figure and compares well to the total 73 million tons estimated for this year nationwide. In general, Vietnam's National Shipping Team is facing with the lack of vessels for transferring cargo, especially the crude oil for exporting.
To overcome with the increasing volume of cargo transferring and marine transports, the Vietnam Sea Port Association (VPA) plans to give priority to 30 sea ports to renovate and upgrade wharves, narrow passages, warehouses and unloading equipment until 2010. Besides, the plan of developing and upgrading the national shipping fleets is for both capacity and technology to meet the increasing requirement of the market.

3.6.2.3 Vietnams List and Development Plans of Major Ports

Northern Area: Quang Ninh Port, Cam Pha Port, Hai Phong Port, Cua Cam Port, Vat Cach Port, Doan Xa Port.

Central Area: Thanh Hoa Port, Nghe Tinh Port, Vung Ang Port, Quang Binh Port, Cua Viet Port, Thanh An Port, Chan May Port, Da Nang Port, Nguyen Van Troi Port, Ky Ha Port, Ky Ha Quang Nam Port, Hai Son Port, Song Han 9 Port, Quy Nhon Port, Nha Trang Port, Thi Nai Port, Ba Ngoi Port.

Southern Area: Phu My Port, Dong Nai Port, Sai Gon new Port, Sai Gon Port, Sai Gon Petro Port, Ben Nghe Port, Tan Thuan Dong Port, Rau Qua Port, Cat Lai oil Port, Nha be oil Port, Bo Sen Port, My Tho Port, Dong Thap Port, Vinh Long Port, Can Tho Port, Ben Dam-Con Dao-Vung Tau Port, Vung Tau commercial Port, My Thoi Port.

3.6.2.4 The Vietnamese Plan for Development of Harbours until 2010

Vietnam's harbour system will be divided into 8 groups with 115 harbours: the northern harbours, the northern centre harbours, the Cuu Long dental harbours, Ho Chi Minh and Co Dao harbours. There are three large ports located at Da Nang, Hai Phong, and Ho Chi Minh City. The strategy for Vietnam's port system development was to build a national fleet of container vessels and bulk cargo vessels of large capacity. It should be able to carry about 40% of the total volume of import-export cargo in the whole country. The expansion of the national port system has been planned to coincide with the development of international shipping and the locations of planned or expanded industrial zones along the coast.

<u>*Sai Gon Port*</u>:
It is planned to be relocated into three different locations along rivers in Ho Chi Minh and Ba Ria – Vung Tau province and will be built separate ports for containerized and general cargo. As the plan of the port in Hiep Phuoc shows, it would have a capacity of 20,000-dwt ships. The ports in the Cai Mep and Thi Vai rivers will be suitable for 50,000-80,000 dwt vessels.The planned container terminal covering 48 hectares along the Thi Vai River will have two 600-meter-long piers able to handle 80,000-dwt ships, while the 27-hectare general cargo

port with the two same piers is designed to receive 50,000-dwt ships. The port covering 36 hectares in Hiep Phuoc will have three piers with a total length of 700 meters for 20,000-30,000 dwt ships. The plan has been discussed to move forward for a new container terminal just south of Ho Chi Minh City at Tan Thuan along the Saigon River. The new Vietnam International Container Terminal is designed to accommodate up to two containerships of 1,000 TEU's, or 20,000 deadweight tons (dwt). Most of the container traffic arriving in Ho Chi Minh City is currently handled at the existing facilities at Sai Gon Port, Newport and Ben Nghe. Vung Tau, Thi Vai River Terminals and Chan May, near Hue, are also seen as having potential as a major container facility, possibly as a transshipment centre for Vietnam and other Asian countries. The construction of new bulk wheat unloading and milling facilities are also discussed for the regions south of Ho Chi Minh City on the Thi Vai River.

Cai Lan – Quang Ninh Port:

The Cai Lan deep-water port in the northern province of Quang Ninh had its first phase inaugurated, with three new piers able to receive 30,000-40,000 dwt ships.The port was put into operation in 1995 with only one pier and has since contributed to bolstering the development of Cai Lan Industrial Park, especially the construction of a wheat flour factory and an edible oil plant. Therefore, the Ministry of Communications and Transport had decided to develop Cai Lan into a deep-water port with seven piers. After three years of construction, the project's first phase was completed allowing for port calls by 30,000-40,000 dwt ships. With just four piers, Cai Lan can handle 17 million tons of cargo annually, according to the bureau. Works on the project's second phase will soon begin, raising the total number of piers at the port to seven. The port holds great potential for growth, especially after a new railway linking China's Yunnan and Kunming and from Kunming to Vietnam's Hai Phong is built.

Hai Phong Port:

In Hai Phong, most of the container traffic is handled at two terminals, Berths One, Two, and Three, and at another called Chua Ve terminal. Chua Ve currently has two older berths (300 meters in length) and a new berth with two gantry cranes installed in 1998. Plans for a new terminal closer to the ocean to handle dry and liquid bulk cargoes and general cargoes would allow the existing facilities at Hai Phong to be dedicated solely to container traffic. With regular dredging the port, expects can maintain the capacity to accept 10,000 dwt vessels.

Da Nang Port:

Da Nang port network consists of Tien Sa Sea Port and the Han River Port. The total yard area is 125,350 m^2 and the total warehouse area is 22,764 m^2. The length of berths is 1,647 m^2 and total area of berths is 27,633 m^2. The Port's throughput is 3-4 million tons per year. The plan for Da Nang is to upgrade the Tien Sa Sea Port and Han River Port) and build Lien Chieu Port additionally. The suggestion is receiving large amounts of freight from East-West corridor to serve Lien Chieu, Hoa Khanh and Da Nang Industrial Zones as well as the key economic areas of Central Vietnam and the Western highlands. It is also plan to increase Tien Sa's handling capacity up to 2.2-2.4 million tons per year in 2003 and 3.6-3.9 million tons untill 2010. Furthermore, planners want to facilitate the vessels up to 10,000-30,000 dwt in 2003 in order to become the general import and export port and serve Da Nang, Dien Nam - Dien Ngoc industrial zones (Quang Nam) and international sea travellers. The newly built wharf No 3 is expected to expand its stations to attract more than 70,000 international sea tourists annually.

Nha Trang Port:

This port is located at 12^{o}12'N - 109^{o}13'E with 5 km length and 11.5 meter depth. The Perth can take all the vessels up to 20.000 dwt and passenger ships with 30,000 GRT. Nha Trang port is located in Nha Trang bay and a governmental business of Vietnam. It is a sea line for the areas of Nha Trang - Khanh Hoa province and the south middle centre of Vietnam. Nha Trang port is being upgraded with new technology systems that will lead it to the biggest and the most modern port in Vietnam. Cargo throughput is increasing and comprising 70 to 80% of the total of Nha Trang – Khanh Hoa and the area of South Middle centre of Vietnam.

Quy Nhon Port:

This port has a length of 7 km, located at 13°46'N 109°14'E. The channel depth is approximately 8.5 m which allowes a maximum size of vessels with 28.514 GRT. The plan is to build wharves for 30,000 dwt vessel, building open yards and internal roads, dredging access channel. The total investment capital is like 113 billion VND and it was expected to be completed in the second quarter of 2004. Additionally, there is another investment capital of 45 billion VND for handling equipment such as a tug boat, shore crane and forklift.

3.6.2.5 Oil Drilling and Production Operation in Vietnam

Vietnam has 600 million barrels of proven oil reserves and further discoveries are likely. Crude oil production averaged 352,507 barrels per day (bbl/d) in 2003. The country has six operating oil fields, of which Bach Ho (White Tiger), Rang Dong (Dawn), Hang Ngoc and Dai Hung (Big Bear) are the largest. Most oil exploration and production activities occur offshore in the Cuu Long and Nam Con Son Basin. Export markets include Japan (the main importer of Vietnamese oil), Singapore, the United States, and South Korea. Vietnam had net exports of an estimated 150,507 bbl/d of oil in 2003.

The government has issued around 44 investment licenses for oil and gas exploration since the industry was opened to foreign partners in 1998. More than 30 companies, including American, European, Korean, and Japanese firms, now operate in offshore Vietnam. In May 2003, Zarubezhneft, a Russian oil company, decided to withdraw from the development of the Dai Hung oil field, which was developed in conjunction with PetroVietnam. Zarubezhneft will maintain its interest in the Bach Ho field (block 9-01), which is currently the largest oil-producing field in Vietnam.

In January 2003, PetroVietnam and Petronas Carigali Overseas Company of Malaysia signed a contract to explore and exploit oil and gas in lot 01-02/97, located on Vietnam's continental shelf. First drilling is expected to be carried out in mid-2004. PCVL also has a plan to build up one more platform Ruby B, which is coming into operation by the end of 2005. The total production of both Ruby A and B is 15.000 – 20.000 bbl/d.

Rang Dong platform operated by JVPC (Japan) also has a very stable production of 50.000–55.000 bbl/d.

Some of the new entrants to Vietnam's upstream have made substantial finds. During 2002 and 2003, large oil and gas deposits were discovered in the Ca Ngu Vang (Golden Tuna) and Voi Trang (White Elephant) fields. The Ca Ngu Vang well, drilled by SOCO Vietnam, was the first well to be drilled on Block 9-2. SOCO's estimates state that there could be approx. 250 million barrels of oil in that area. The Voi Trang well, drilled by the Hoang Long Joint Operating Company, was the second well drilled on Block 16-1. Lam Son JOC had the first exploration well at Block 02/97 with the depth of 2,817 m and there was a good sign at the depth of 1800 m. Before that, there were two more JOCs (Hoan Vu and Trong Son) reporting finds in the Ca Ngu Vang (Block 09-02) and Song Doc – 1X (block 46 – 02). Hoan Vu JOC with the find in Block 09 – 02 also reported that they found light oil in the basement and estimated 2.606 bbl/d. Basing on this finding, Hoan Vu has decided to drill two more appraisal wells in the early of 2005.

A major oil find in Block 15-1 of the Cuu Long Basin was announced in October 2000 by a consortium including ConocoPhillips, the Korean National Oil Company (KNOC), SK Corporation of South Korea, and the French firm Geopetrol. After further exploratory drilling in early 2001, KNOC announced that Block 15-1 contained recoverable reserves of around 400 million barrels. Fields located on this block include Su Tu Den (Black Lion), Su Tu Vang (Golden Lion) and Su Tu Trang (White Lion). All of them came online in early 2004. Su Tu Den is currently producing 60,000 bbl/d. The discovery well at Su Tu Trang flowed 8,682 bbl/d and is scheduled to be developed in 2008. The consortium plans to drill appraisal wells in Su Tu Vang during late 2004. Conoco also holds interests in some adjacent blocks, including Block 15-2 which contains the 40,000 bbl/d Ran. Currently, there are more than 90 harbors on the whole country with nearly 24 km of quay and more than 10 ports of transit. There are also some ports specializing on loading containers with modern technology in comparison to other countries in the region.

In April 2003, PetroVietnam discovered a major oil deposit in Dai Hung (Big Bear). The field is located off the southern province of Ba Ria-Vung Tau with a daily capacity of 6,300 bbl/d of oil and 4.32 million cubic feet of gas. Throughout 2003, further exploratory drilling took place in an attempt to assess the total reserve of the oil field. Đại Hung is planned to reproduce by the end of the year 2004. PVEP reported that there would be five more new wells coming into production and estimated 4,000 – 7,000 bbl/d.

In June 2003, PetroVietnam signed a deal with Pertamina of Indonesia and Petronas of Malaysia, to develop an offshore oil and gas block in the South China Sea. The block, SK-305, is located in Malaysian waters closed to Vietnamese and Indonesian maritime territory. In late 2002, the companies agreed to jointly develop two blocks in Vietnam's Nam Con Son Basin, the first three-way cooperation between national oil companies in South-East Asia. Exploration in Block 46/02, which is located adjacent to the Vietnamese-Malaysian PM-3 joint development area, has yielded another oil discovery initially producing 7,300 bbl/d.

Following the commencement of drilling operations in the Su Tu Den (Black Lion) crude field in October 2003, the state-owned Vietnam National Oil and Gas Corporation, known as PetroVietnam, has reported rapidly expanding production volumes. In the first quarter of 2004 PetroVietnam reported that it had exported 496,000 bbl/d of crude oil, a year-on-year increase of 14%. The Su Tu Den operation is owned by a consortium comprising PetroVietnam (with a 50% stake), ConocoPhillips (US), the Korea National Oil Corporation and SK Corp (South Korea). By June 2004 crude oil production at the Su Tu Den oil field is expected to reach 95,000 bbl/d. However, the country's largest oil field Bach Ho (White Tiger) is accounting for around 70% of total production. Despite its crude oil production capacity, Vietnam remains reliant on imports of petroleum products because of its lack of refining capacity.

3.6.3 Summarised Danger of Marine Oil Pollution in Vietnam in the Future

With all above information, we could see how busy are the marine transports and oil drilling and producing operations in Vietnam. Besides all the benefits and advantages that these developments offer, we also find the high risks and dangers that these activities create. Some of them are the oil spills from shipping transports as well as from drilling and producing sections.

The highest risk of oil spills comes from the marine transports, when there is an accident between vessels or vessels with the other structures of the port. It only counts 10% of all the oil spills accidents but the volume of those oil spills is 700 tons/year. According to the Petrol Safe Research Centre, from 1987 to 2001 there were 90 oil spills in Viet Nam, half caused by marine accidents or oil ships. Oil spills equivalent to 7,380 tons occurred in 1992 and in 1995, the number increased to 10,020 tons and in the year 2000 there were even 17,650 tons. On the other statistic, there were 49 oil spills in Vietnam between 1990-2003. And from 1993 to 2003, there were 2,520 tons of oil spills in eight accidents, causing damage like 7 million US$. Most accidents occurred on Sai Gon River as there is a port used specially for transferring oil and also due to the difficulty in the geographical conditions. Thus, it will be a point of attention even in the future.

The other major operations which take a critical part in the oil spill issues are the oil drilling and production activities. The oil exploration and production in Vietnam has been increasing over the years as seen in information above. The oil and gas industry’s development involves two kinds of pollution: permanent pollution and oil spills.

The number of oil spills resulting from the oil and gas industry and marine transportation are increasing. There were 4 big and small oil spills in 1997, which increased to 6 in 1998 and 10 in 1999.

The oil spills caused by drilling operations are rare but they also count ¾ on 50,000 tons of oil spilled from drilling sections, basing on the international statistics. The main reasons for these accidents are normally occurred while the crude oil is transferred from the production unit (such as a production platform or oil tanker) to a ship in rough weather conditions. Sometimes, the Diesel oil is spilled from the supply boat by somehow accidents. As we can see from the drilling section in Vietnam, the main locations are situated in the Cuu Long and Nam Con Son Basins. Currently, there are more than 300 drilling and production wells in Bach Ho, Rong, Dai Hung, Ruby fields and the more the production operations carried out, the higher risk of oil spills in Vietnam is likely occur.

Together with the recorded oil spills, attention must also be paid to oil spills from non-identified sources. Almost all the 29 coastal provinces of Vietnam are facing this problem and the number of such oil spills has grown over the last few years. Although these spills are of moderate volume, 2-3 tons on average, some of them are of bigger scale as the ones in Do Son-Hai Phong (May 1994) and Ba Tri-Ben Tre (May 1995).

To solve this issue of oil spills which is increasing along with the development of marine transports and oil drilling operation, The Government has a 10-year national plan until 2010 that outlines how to combat the effects of oil spills step by step. As a result, a project to build three national rescuing centres in Viet Nam's three regions. The first centre has been opened in the central port city of Da Nang and it will be in charge of responding to oil spills in nine central coastal provinces stretching from Quang Tri to Ninh Thuan in a bid to protect the sea from ecological damage. However, with limited equipment, the centre will only be able to fight spills that occur in rivers or coastal areas. To respond to large-scale oil spills that occur out to sea, the centre will need to have a multi-function oil recovery ship like other regional countries. The other two centres are planned to locate in Hai Phong and Vung Tau, respectively. The other issues that Vietnam is facing with in fighting the increasing threat of oil spills is the lack of modern equipment and competent people for this job. On the whole country, there is not any oil spill response plan, yet usable as a guideline for all levels.

The National response plan is in the process of building. Thus, currently, if there is any oil spill which may have a major impact, the army and local authorities will be involved. There has not been any professional force, yet that was trained and specialized only on the responding of oil spills. These facts have alarmed us and show the need for the solution of oil spills in Vietnam.

3.7 Oil Spill Response and Contingency Planning in Vietnam

Abbreviations:

DoNRE	Department of Natural Resources and Environment
DoSTE	Department of Science, Technology and Environment
MoNRE	Ministry of Natural Resources and Environment
MoSTE	Ministry of Science, Technology and Environment
OSI's	Oil Spill Incidents
PetroVietnam	Vietnam Oil and Gas Corporation
RDCPSE	Research and Development Centre for Petroleum Safety & Environment

3.7.1 Legislation, Regulation

At present in Vietnam, the process of industrialization and modernization has happened strongly. Along with that development, danger of environmental pollution due to oil spills has created many urgent problems, which had to be solved immediately. Marine or on the river/canal oil spills are one of the very serious risks which may cause economically significant damage not only immediately but also permanently. The costly recovery of the destroyed environment will take a long time to restore. Near shore activities like fishery, aquaculture, agriculture and tourism are unrecoverable, leading to cause direct effects on local people's life. Thus, the oil spill becomes an urgent matter that is required to pay attention by the marine economic branches as well as the local authorities.

In view of nationality, Ministry of Science, Technology and Environment (now Ministry of Natural Resources and Environment – MoNRE) has researched and submitted the draft of national oil spill response plan since 1990. According to suggestion of National Searching and Rescue Committee and proposals of ministries, branches, and related agencies, the Prime Minister signed **Decision Nº.129/2001/QĐ-TTg** dated August 29th, 2001 relating to approval of national oil spill response plan in the period of 2001-2010.
Besides this decision, oil spill response is to conform completely to all legislations promulgated by the government as well as state management agencies on the environment as follows:

Table 3.7-1: Overview of oil spill related legislations in Vietnam

Legislation	**Description**
Law on Environmental Protection (LEP)	This Law protects the environment by implementing Vietnam's obligations under various international environmental conventions. (further description below)
National Conservation Strategy (1985)	This Strategy is a national program that addresses the issues of conservation and rational use of natural resources.
Ordinance on the Conservation and Management of Living Aquatic Resources (1989)	This Ordinance provides for the sustainable management of fisheries and deals with such matters as fishing seasons, catch size, prevention of pollution in fisheries grounds and the encouragement of local and international investment of capital and technology.
National Plan for Environment and Sustainable Development 1991-2000	This Pan outlines a national framework for action in the field of environment and sustainable development for Vietnam.
Law on Petroleum (July 6th 1993)	This Law regulates the exploration and production of petroleum resources within the territorial waters, the EEZ and on the Continental Shelf.
Oil and Gas Law (1994)	This Law establishes the process for the grant of initial leases to companies engaged in oil and gas activities. It also imposes env. protection requirements on these companies.
National Law on Environmental Protection (1993)	This Law takes a holistic approach to oceans governance. Its objectives are to create an integrated management structure, increase environ-mental awareness in the general public and safe-guard human and environmental health so as to create an environment for sustainable development.
Vietnam Maritime Code/ Law (1990)	The Maritime Code largely covers ships and crews, it includes provisions on the responsibilities for protecting the marine environment and for dealing with pollution and accidents in the marine environment. This law also prescribes liability for environmental damage.
Biodiversity Action Plan (1995)	This Plan is comprehensive and sets out broad strategies for strengthening institutional capacity in the management of protected areas, wetlands and biological diversity in general. These strategies are consistent with the obligations under the Convention on Biological Diversity.
Integrated Coastal Management Plan (ICM) (1996-2000)	This Plan considers environmental issues as well as the dominant social and economic concerns of Vietnam with regard to Coastal development National Marine and Coastal Zone Development Strategy of Vietnam Under this Strategy, Vietnam has passed a number of legal and policy instruments in order to improve the integration of national marine and coastal management systems.
Fisheries Master Plan for fisheries to the Year 2010	This Plan is focused on improving fisheries management and development.

3.7.1.1 Law on Environmental Protection

Passed by the National Assembly of the S.R.Vietnam on December 27th, 1993 and the Governmental Decree (No. 175/CP dated on 18th October, 1994) in order to provide guidance for implementation of the Law on Environmental Protection. Oil pollution response & prevention as well as environmental pollution are mentioned in chapter II (Preventing and Dealing with the Environmental Depression, Pollution and incidents) due to the items 10, 20 and 21. Chapter III also defines actions need to be done to deal with environmental depression, pollution and incidents. Details of these are described below:

Article 32

The remedy of an environmental incident includes: eliminating the cause of the incident; rescuing people and property; assisting, stabilizing the life of the people; repairing damaged facilities; restoring production; sanitizing the environment, preventing and combating epidemics; investigating, collecting statistics on damages, monitoring changes to the environment; rehabilitating the environment of the affected area.

Article 33

Persons who detect signs of an environmental incident must immediately notify the local People's Committee, the nearest agency or organisation for timely action.

Organisations, individuals at the site of the environmental incident must take appropriate measures to timely remedy it and immediately report to the superior administrative authority, the nearest People's Committee and the State management agency for environmental protection.

Article 34

The chairman of the People's Committee of the locality where the environmental incident occurs is empowered to order an emergency mobilization of man power, materials and other means for remedial actions.

If the environmental incident occurs in an area covering several localities, the Chairmen of the respective local People's Committees shall cooperate to take remedial actions.

In case the incident is beyond local remedy capability, the Minister of Science, Technology and Environment in conjunction with the heads of the agencies concerned shall determine the application of remedial measures and report to the Prime Minister.

Article 35

In case the environmental incident is of special severity, the Prime Minister shall determine the application of urgent remedial measures.

When such incident has been brought under control the Prime Minister shall determine the revocation of the application of the urgent remedial measures.

Article 36

The agencies which are empowered to mobilise manpower, materials, and other means to remedy environmental incidents must reimburse the mobilised organisations, individuals for their expenses according to regulations by the law.

3.7.1.2 Circular No. 2262/TT-MTg

This circular was issued by the Ministry of Science, Technology and Environment (MoSTE) on December 29th, 1995 and shall give providing guidance for oil spill incidents response. The circular is to meet the demand of restoration and timely response oil spill incidents which are increasing in the country in order to accordance with the real situation. Furthermore, it should be a step for preparation of the general national oil spill contingency plan. MoSTE issued this circular to guide response and treatment of oil spill incidents relating to searching, exploring and developing mines and exploiting, transporting and processing oil as well as for distribution and storing oil and oil products.

General Definition:
Oil spill often occurs in Searching, Exploring, Developing mines, Transporting, Processing, Distributing and Storing oil and oil products.

Oil spill with amount of oil more than hundreds of liters can be considered as oil spill incident.

Depending on environmental conditions and weather of each area, each specific time; effects of oil cause different damage to environment. Areas being priority to protect are water sources for living and production, aquacultural area, coastal rice fields, salt march, mangrove forest, wetlands, seaweed sites, coral reef, beaches of tourism area, residents and historical monuments.

Oil spill prevention and restoration are very complicated and difficult requiring promptly organisation and cooperation, and implementation adequate technique.

Oil spill incident often causes serious environmental consequence, especially at rivers, estuaries, bays and coastal areas. Organisations, personnel having riverside activities as catching and aqua-cultivation, tourism, salt march, agriculture, etc. are often directly effected about economic and life.

Compensation on environmental damage due to oil spill incidents is international routine and has been conducted in Vietnam; however this is complicated legal issue so that compensation should be done seriously and promptly.

This circular also defines activities need to be done when oil spills occur:
When oil spill incident occurs at wherever on land, coastal area or at sea belong to sovereignty of the Socialist Republic of Vietnam, works hereinafter will be done promptly:

Report procedure:
Organisations, personnels who observes oil spill incident will notify immediately local authority, Department of Science, Technology and Environment (now is Department of Natural Resources and Environment-DoNRE).
When being notified, local authority, DoNRE will notify relevant agencies such as forces of Fire Fighting, Police, Army in local area in order to cooperate in response and/or receive response guideline.

Agency of MoNRE that directs oil spill incident is National Environmental Agency
In case incident exceeds response ability of local, the Minister of MoNRE will cooperate with leaders of relevant agencies to decide as well as implement response measure and report to Prime Minister.
For offshore oil spill incident with oil spill amount more than 2 tonnes, beside notify agencies as point ‘a’, polluter must report to MoNRE.

Works need to be done:

Firstly, seeking for all methods to rescue victims from dangerous area.

Use any measures to avoid oil continue spreading to around area.

Seeking all measures to contain spilled oil, avoid oil larger spreading especially to priority protection (as mentioned in point I.3).

In case collision of tankers or broken down of oil storage, it is necessary to transfer and transport oil to safety area.

In case incidents caused by floating facilities contain oil, it is necessary to move the facilities to safety anchor location.

In case oil spill offshore far from the shore, it can be consider to use dispersant to avoid oil drift and pollute shoreline because of sensitivity shoreline that need to be protected. All case using dispersant must be allowed by MoNRE. It is strictly prohibited when use dispersant in rivers, estuaries, bays and coastal shallow water.

When oil spread and drifted to shore, it is necessary to promptly use any measures, means, from simple (such as showel, bucket, basin…) to modern equipment (such as absorb vehicle, oil pump, bulldozer, truck...) to collect oil slick, oil sludge.

Conduct shoreline cleaning-up after collecting oil as mention in point g. Treatment and cleaning-up technique for specific type of shoreline need to be discussed and conducted under guideline of environmental agencies of central government and local.

It is necessary to collect transport oil slick, oil sludge and oily materials (soil, sand, branch, oily waste, etc.) to separated place to avoid oil penetrating to environment and then such materials will be treated by instruction of specialized agencies.

Implementation:

Organisation, personnel observed oil spill incident will immediately notify as mentioned in point II.1.

Oil spill incident caused from facilities or occur in area of which organisation/personnel (platforms of Vietnam and oversea Petroleum companies; ships of Vietnam and oversea; petrochemical areas; ports; oil storages; oil pipeline …) the organisation/personnel is responsible for response immediately and alert local authority, relevant agencies which have response equipment (such as oil port, fire fighting & prevention, port authority...) and being allowed local and police, army forces locating in the area in order to cooperate and treat consequence.

For oil spill incident occur in activities of PetroVietnam, response will be conducted under plan of PetroVietnam according to Document No. 3054/DK dated June 03, 1994 of government office.

Oil spill incident occurs in which local area, People’s Committee of this area will conduct response activities. Local authority need to activate all local forces, forces of army, police, fire fighting & prevention and central agencies locating in this area to join in response incident. DoNRE will be clue to support President of Provincial People’s Committee at local area in response oil spill incident.

In case oil spill exceed response ability of province, city, the Minister of MoNRE will cooperate with leaders of relevant agencies to decide and implement response measure and report to Prime Minister.

In case oil spill in large size with level and extent of region, province, MoNRE will cooperate relevant branches in asking Prime Minister to request international response resources coming Vietnam to support oil spill response.

Prevention measure:

With principle “prevention is better than cure”, all local areas, organisations having activities which can cause oil spill should have prevention measure and focus on below contents:

Establish oil spill response plans in their own extent that adequating with real situation, at the highest risk area as port, ship lane, petroleum exploration, developing mines and storage, petrol tanker…in order to actively cope with spill situations. Annually, such plans should be approved by MoNRE to cooperate and activate if required.

Establish organisations with suitable equipments in coping with oil spill incident occuring in their own area. Such organisations and equipments are built accordance with approved plan, this is primary base at the area in order to join into general response plan of the whole country.
Annually, it is necessary to organise training and drill to test, adjust and improve response ability of basic response, accordance with real situation.
Regularly checking technology, production process, improve safety level in activities can cause oil spill.

3.7.1.3 Decision No. 395/1998 QD-KHCN&MT

"Regulation for environmental protection in searching, exploring and developing mines and exploiting, storing, transporting and processing oil and related services"

Chapter II (Solutions to environmental pollution, degradation and accidents) of the decision has specific description on oil spill response. Detailed contents are showed below:

During the implementation of a Petroleum Project, a Petroleum Organisation shall maintain adequate staff, equipment and contact with related bodies including local authorities and foreign organisations in order to manage and minimize environmental damage(s) that may arise from an environmental incident.

Petroleum Organisations conducting offshore petroleum productions must ensure:
the availability of response equipment for oil spillage up to 15 tons on every producing platform, oil receipt and delivery terminal;
the ability to launch to sea response equipment for oil spillage up to 500 tons within 24 hours.

Article 37
In the event of a major incident causing substantial damage to the environment due to blow-out or spillages from an oil floating storage unit, leakage of toxic gas or explosion, the Petroleum Organisation involved shall promptly take all necessary measures to respond and, at the same time, immediately inform the Provincial People's Committee of the province(s) where the incident occurs, MoSTE and other related bodies in conformity with the approved oil spill contingency plan.
PetroVietnam is held responsible for making a general oil spill contingency plan for all operations by its subsidiaries, contractors, joint-ventures with its contributed capital for coordinating actions among Petroleum Organisations, related bodies as well as the People's Committee of the localities where the incident occurs, and foreign response organisations to ensure the most expedient and efficient response.

Article 38
On an occurrence of an oil spill with a volume of over 2 metric tons, the Petroleum Organisation involved shall immediately notify MoSTE and the Provincial People's Committee of the province(s) where the incident occurs. A full report on such oil spill shall be filed and submitted to MoSTE and the Provincial People's Committee of the province(s) where the incident occurs within 15 days after the incident has been remedied.

Article 39
The use of dispersants to treat spilled oil shall comply with the procedures set forth in the approved oil spill contingency plan, and shall meet the following requirements.
Dispersants can only be used to treat the spilled oil after all other measures to recover such oil have proved to be inappropriate.
Only those dispersants registered with and approved by MoSTE can be employed. Cautions must be taken to avoid excessive use of dispersants.
It is prohibited to use dispersants in rivers, estuaries, coastal waters with a depth of less than 20 meters or less than 2 km off coast, and other ecologically sensitive areas.
The use of dispersants must be approved by MoSTE. In case of emergency when the spilled oil may present a serious threat to the safety of human life, properties, natural resources, the Petroleum Organisation involved may use those dispersants registered in its oil spill contingency plan which has been approved by MoSTE.

After using dispersants, the Petroleum Organisation involved shall report in detail to MoSTE on the incident, the use of dispersants and its consequence.
Thus, in Vietnam at present has current legislation and regulation on oil spill response as mentioned. Some detailed regulation, legislation as well as guideline for oil spill response have been developed. Based on specific condition, such regulations are more and more detail and effective through real oil spill incidents. The considerable development of legal aspect of oil spill response is the National Oil Spill Response Plan which is presented below.

3.7.2 National Strategy, Contingency Planning

The **Decision No.129** above also presents the National Plan on coping strategies for oil spill incidents in the period of 2001-2010. A summarized plan is described below:

3.7.2.1 Objectives of the Plan

a/ Objectives to be achieved by 2010:
- Being ready to cope promptly and effectively with all cases of OSI’s, so as to minimize damage caused to the environment as well as their adverse impacts on the economic sectors and the people's life.

- The perfection of the system of mechanisms, policies and organisations from the central to grassroots levels, the building of the professional force to act as the core in OSI coping activities.

b/ Objectives to be achieved by 2005:
The readiness for effectively coping with OSI’s in a number of OSI’s-prone regions, where great damage may be entailed, such as the sea area of Ba Ria-Vung Tau province, Sai Gon-Dong Nai rivers, Central Vietnam's sea area from Da Nang to Nha Trang city, coastal and river areas in Hai Phong City and Ha Long Bay.

3.7.2.2 Scope of Implementation of the National Plan

a/ Scope of implementation of the national plan on coping with OSI’s
The national plan on coping with OSI’s shall be implemented in all mainland regions, offshore islands and marine zones (the internal waters, territorial water, contiguous zones, exclusive economic zones and continental shelf of Vietnam) defied on May 12th, 1977. Declaration of the Government of the Socialist Republic of Vietnam on the territorial waters, contiguous zones, exclusive economic zones and continental shelf of Vietnam.

Coping with OSI’s shall be carried out in all cases of oil spilling caused by any domestic or foreign organisations and/or individual for any reasons.

b/ Regions of coping with OSI’s
- *The Northern region*, covering all the northern provinces and cities southward to the end of Quang Binh province; the entire sea area in Tonkin Gulf within the scope of coping with OSI’s stretching to parallel 17^{o}10' North.

- *The Central region*, covering all the provinces and cities of the Central Vietnam from Quang Tri province to Binh Thuan province's southernmost point; the entire sea area within the scope of coping with OSI’s from parallel 17^{o}10' North to 11^{o}20' North.

- *The Southern region*, covering all the southern provinces and cities from Ninh Thuan province to Ca Mau and Kien Giang provinces' southernmost points; the entire sea area from parallel 11°20' North, stretching southward, to the southern limit of this national plan's scope of coping with OSI's.

c/ Classification of OSI degrees
Activities of coping with OSI's shall be carried out depending on OSI degrees, which are classified from degree I to degree III according to the volume of oil spilled into the environment.

Degree I:	under 100 tons.
Degree II:	between 100 and 2,000 tons
Degree III:	over 2,000 tons

3.7.2.3 The System and Operation Mechanism of the OSI - Coping Levels

The activities of coping with OSI's shall be carried out at 3 levels: grassroots, regional and national.

a/ Grassroots level:
- Socio-economic establishments and defense-security establishments (hereinafter collectively referred to as establishments), which are likely to cause OSI's, shall have to work out coping plans by themselves, invest in facilities and equipment and organise forces to ensure the prompt and effective OSI prevention and coping corresponding to the possibility of oil spilling caused by themselves, and be ready to take part in common activities of coping with OSI's under unified mobilization and/or command of the competent agencies.

- In cases where an establishment's potential and capability are limited, it shall have to enter into contracts with other establishments in the same locality or with the regional OSI-coping center for supports in coping with OSI when it occurs at its place.

b/ Regional level:
In each OSI-coping region, a regional OSI-coping center (hereinafter referred to as regional center for short) shall be organised.

- The regional center shall be organised and operate under the statute of public utility State enterprises, have professional forces acting as core units fully qualified and ready to perform the task of coping with OSI's of degree II or higher within their assigned regions.

- On the basis of general evaluation of the practical situation and the demands for manpower, facilities, equipment and supplies for OSI-coping activities in each region, the State shall additionally invest in the regional centers, in order to make them capable of performing the task of coping with OSI's within their assigned regions.

- The regional centers shall submit to the State management by the managing ministries and branches. The National Committee for Search and Rescue shall directly instruct the regional centers in the domain of coping with OSI's.

From now till 2004, to concentrate efforts on building and putting into operation two centers in the Central and Southern regions. On the basis of experience drawn from operation of these two centers, the National Committee for Search and Rescue shall propose plan for building the Northern Centre, thus ensuring that by 2010, the whole country shall have three regional OSI-coping centers in operation.

c/ National level

- In cases where an OSI occurs beyond the coping capacity of a regional center, the National Committee for Search and Rescue shall mobilize forces of other regional centers, the ministries, branches, localities, organisations and individuals for coordinated OSI-coping activities.

- In cases where an OSI occurs beyond the coping capacity of domestic forces, the National Committee for Search and Rescue shall propose the Prime Minister to ask for help from foreign OSI-coping forces. The National Committee for Search and Rescue shall assume the prime responsibility and coordinate with various forces in these OSI - coping activities.

3.7.3 Competences / Responsibilities / Key Players

Competences, responsibilities and organisation of implementation of the national plan on coping with OSI's are described in the Article 2 of Decision No. 129 and presented as follow:

3.7.3.1 The National Committee for Search and Rescue

Shall act as the agency taking the prime charge, command and organising the implementation of the National Plan on coping with OSI's.

a) Elaborate the regulation on OSI-coping activities nation-wide and build the organising system for implementation, thus ensuring that from 2002/2003 the OSI-coping activities shall be administered under the regulation by a uniformly organised system throughout the country.
b) Assume the prime responsibility for community-based propagation and education, raising of citizens' sense of responsibility, mobilization and organisation of people to participate in activities of preventing and coping with OSI's with a view to socializing the task of preventing and coping with OSI's.
c) Direct, mobilize, command and coordinate forces taking part in coping with OSI's.
d) Assume the prime responsibility and coordinate with the Ministry of Science, Technology and Environment and the concerned ministries and branches in synthesizing and submitting to the Prime Minister annual plans and five-year plans, first of all the plan on coping with OSI's in 2001-2005 period, organise the implementation thereof as soon as such plans are approved at the regions, ministries, branches, provinces and centrally-run cities, and regularly guide, urge and supervise the implementation of the plans according to the current regulations.
e) Direct the investigation and verification of big OSI's, propose to the Prime Minister and the concerned agencies measures to prevent and/or minimize the damage cause by OSI's.
f) Organise and direct annual drills in coping with OSI's, provide professional training courses to the force engaged in coping with OSI's.
g) Act as a national coordinator for Vietnam's participation in international co-operation activities in the domain of coping with OSI's; coordinate with the countries having contiguous zones with Vietnam in conducting joint activities of coping with OSI's upon their occurrence in such zones.
h) Draw up the list of documents on international relations in coping with OSI's, then propose it to the concerned State Management agencies for promulgation according to their competence, thus ensuring that by 2003 our country shall have sufficient legal documents to serve as legal bases for OSI-coping organisations at home and abroad to coordinate with one another in coping with OSI's in Vietnam.

3.7.3.2 The Ministry of Science, Technology and Environment

a) Propose to the Government and the Prime Minister for promulgation or promulgate according to its own competence policies and legal documents in the domain of overcoming OSI consequences caused to the environment; elaborate and organise the implementation of the 2001-2005 five-year plan on the promulgation of these documents.

b) Guild the ministries, branches and localities in evaluating and determining damage and overcoming consequence being the environment degradation caused by OSI’s.

c) Organise and support the National Committee for Search and Rescue in conducting scientific research in the domain of coping with OSI’s.

d) Inspect, examine and handle violations, settle disputes, complains and denunciations according to its competence.

3.7.3.3 The Ministry of Defense

a) Elaborate and organise the implementation of plans on fast deployment of the army's forces and means to take part in the coordinated OSI-coping activities at the request of the National Committee for Search and Rescue.

b) Establish the OSI-coping centre of the Central Vietnam in the rescue system of the Ministry of Defense. The Ministry of Defense shall assume the prime responsibility and coordinate with the National Committee for Search and Rescue, the Ministry of Planning and Investment, the Ministry of Finance and other concerned agencies in prescribing the OSI-coping task of Central Vietnam's Centre, furnishing facilities and equipment, and training primary necessary personnel of the center, so that the center can be ready for its task in 2002-2004 period.

3.7.3.4 PetroVietnam

a) Elaborate and organise the implementation of plans on fast deployment of the oil and gas sector's forces and means to take part in the coordinated coping of OSI’s at the request of the National Committee for Search and Rescue.

b) Establish the OSI-coping center of the Southern region in the emergency system under the Vietnam Oil and Gas Corporation. The Vietnam Oil and Gas Corporation shall assume the prime responsibility and coordinate with National Committee for Search and Rescue, the Ministry of Planning and Investment, the Ministry of Finance and other concerned agencies in prescribing the OSI-coping task of the Southern region's center, furnishing facilities and equipment, and training primary necessary personnel of the center, so that the center can be ready for its task in 2002-2004 period.

3.7.3.5 The concerned Ministries and Branches

a) Direct and inspect organisation and production and business establishments under their respective management, which are likely to cause OSI’s, in working out plans and organising the coping of OSI’s according to the provisions of this Decision.

b) Mobilize forces and means under their respective management for the coping of OSI’s at the request of the National Committee for Search and Rescue.

3.7.3.6 The People's Committee of the Provinces and centrally-run Cities

a) Provinces and centrally-run cities, with establishments likely to cause OSI’s shall have to elaborate and organise the implementation of their own plans on coping with OSI’s on the basis of mobilizing forces, means, facilities and equipment for coping with OSI’s from establishments attached to the State agencies, organisations and individuals located in the localities under their respective management.

b) Direct and inspect organisations and production and business establishments under their respective management, which are likely to cause OSI’s, in working out plans on coping with OSI’s and organising the implementation thereof according to the provisions of this Decision.

c) Create conditions for and coordinate with the forces of the ministries, branches and other localities in monitoring and supervising OSI's, and at the same time, direct the coping activities when OSI's occur in their localities.

Table 3.7-2: Reference list of key players and agencies relating to oil spill response

No	Organisations	Tel	Fax
01	**Government Office** 1 Hoang Hoa Tham, Hanoi	04-8458241	08-044130 08-044940
02	**Government, Petroleum Department** 1 Hoang Hoa Tham, Hanoi	08-043136	08-044130
03	**Ministry of Natural Resources and Environment** 83 Nguyen Chi Thanh, Hanoi	04-8343911 04- 8343309	04-8359221 04-8352191
04	**Environment Department** 67 Nguyen Du, Hanoi	04-8256581	04-8223189
05	**Emergency Standing Office of PetroVietnam** 22 Ngo Quyen, Dist. Hoan Kiem, Ha noi	04-9344515/ 252526 ext 152	04-9344514
06	**Ministry of Defense** 1A Hoang Dieu, Hanoi	04-8468101 04-8455812	
07	**Navy Commander** 38 Dien Bien Phu, Hai Phong	031-841327	031-842844
08	**Border Guard Commander** 4 Dinh Cong Trang, Hanoi	04-8268191	
09	**Air force Commander** 171 Truong Chinh, Hanoi	04-8522878 04-8522871	
10	**Ministry of Interior** 15 Tran Binh Trong, Hanoi	04-8268131	
11	**Marine Police Department** 276 Da Nang, Hai Phong	031-760457	031-761921
12	**Fire Fighting &Prevention Department** 2 Dinh Le, Hanoi	04-8254659	04-9340806
13	**Ministry of Transport &Communication** 80 Tran Hung Dao, Hanoi	04-8254012	04-8267366
14	**Vietnam Maritime Bureau** 7A Lang Ha, Hanoi **Marine Searching - Rescue Centre** 8 Pham Hung, Cau Giay-Hanoi	04-8562284 04-7683050	04-8560729 04-7683048
15	**Ministry of public Health** 138A Giang Vo, Hanoi	04-8443039	04-8460701
16	**Ministry of Fishery** 10 Nguyen Cong Hoan, Hanoi	04-8246137 04-8326714	04-8326702
17	**Ministry of Labour, War Invalid and Social Affairs** 12 Ngo Quyen, Hanoi	04-8246137	04-8253969
18	**Vietnam Civil Aviation Administration** Gia Lam airport, Hanoi	04-8720199 04-8271513	04-8732762 04-8271933
19	**Standing Searching-Rescue Committee of Vietnam Civil Aviation Administration** Gia Lam Airport, Hanoi	04-8720199 04-8271513/ 252	04-8274194
20	**National Weather PrognOSI's Centre** 4 Dang Thai Than, Hanoi	04-8254278	04-8254278
21	**Central Flood -Typhoon Prevention Department** 2 Ngoc Ha, Hanoi	04-7335697 04-7335696 04-7335693	04-7335701
22	**National Searching - Rescue Committee (NSRC)** 26 Hoang Dieu, Hanoi	069-553775 069-552313 069-553614 069-553612 04-7333664	04-7333845
23	**Standing Office Flood-Typhoon Prevention & Searching – Rescue of Province Ba Ria–Vung Tau**	064-828999	064-828999 064-829891
24	**Ministry of Industry** 54 Hai Ba Trung, Hanoi (Management Board of Flood-Typhoon Prevention)	04-8253407	04-8258210

3.7.4 Equipment and intended Oil Spill Response Centres

Facilities for oil spill response are also assigned in the Decision No. 129 for levels of response resources.

a/ At establishments:
The establishments shall furnish themselves with means, facilities and equipment so as to be able to cope with OSI's of a certain degree, which may occur at their establishments under the provisions of this plan.

b/ At the regional centres:
The regional centres must have the following essential facilities, equipment, means and supplies:

- Technical and information and communication facilities and equipment in service of administration of the centres' operations.
- Special-use ship fleets, speedboats, buoys of all kinds, dispersers and devices and equipment for containing oil, pumping, sucking and spraying dispersers and gathering oil; system of treating oil dregs...
- Protective equipment, devices and outfits for persons engaged in coping activities.

c/ At the steering and administering agencies:
The National Committee for Search and Rescue, the Ministry of Science, Technology and Environment and other concerned agencies shall be furnished with information and communication equipment and other facilities and equipment suitable to their assigned responsibilities as prescribed in Article 2 of this Decision.

Presently, Vietnam has not many stockpiles for oil spill response. Beside regional response resources being established, Vietnam now has some stockpiles such as Xuan Thu company (in Da Nang province), VIETSOVPETRO and PV Drilling in Ba Ria Vung Tau province, Dai Minh Pte. in Ho Chi Minh City, etc.. The major stockpiles are located in the south of Vietnam due to specific characteristics of petroleum activities and transportation of oil products that are mainly focused in this area. Present response resources that can provide a response level for oil spill amounts is about 1000 tons.
Lists of equipment of VIETSOVPETRO and PV Drilling are presented in **Annex A2** .

3.7.4.1 Vietnams Response Centres

In the future, Vietnam will build three oil spill response centres in three regions:

1. The Vietnam People's Navy has been tasked with overseeing an oil spill response centre in the north.
2. In the southern region, the National Committee for Search and Rescue will coordinate with the Government and PetroVietnam to develop a plan for a regional centre.
3. The National Committee for Search and Rescue currently oversees the oil spill centre in the central region. This centre was opened in the port of Da Nang City to respond to spills in nine central coastal provinces stretching from Quang Tri to Ninh Thuan. This is the first pilot centre for the purpose building the next two centres in the southern and northern regions. The centre belongs to Song Thu Company (Head Department of National Defence Industry). After opening this centre, Song Thu Company will continue to construct response bases at sea areas of Khanh Hoa and Dung Quat (Quang Ngai province). It is equipped with 2,000 m of containment buoys, two skimmer machines, a helicopter spraying system, three large tanks to hold recovered oil, one ship to carry oil, trucks and other specialized facilities. However, with current equipment the centre can support for response in river or coastal area only. To response an oil spill in larger size, the centre needs to be equipped with multipurpose skimmer as well as other equipment.

Facilities and technique of the three centres will have ability to cover oil spill response in the whole Vietnam and can be combined in coping with large spill.

3.7.5 Current Activities, Programs

Before the *National Oil Spill Response Contingency Plan* is issued, the local authorities and branches based on their own specific requirements prepared their oil spill response plans for the locality and purchased equipment. Such plans are established for local authorities as well as branches which have activities with high risk of oil spills such as oil exploration & production, oil transportation, etc. At present, oil spill response in petroleum offshore has been conducted by contractors. At coastal areas, the real status oil spill incident of some provinces and cities required to have effective plans to deploy when oil spills occur. RDCPSE has established oil spill response plans for these local authorities and branches (Ho Chi Minh City, Ba Ria-Vung Tau province, etc.) as well as for contractors operating on petroleum and relevant activities (port, oil storage, etc.). Others provinces and cities are also researching to prepare oil spill response plans in order to timely response as well as become a part of the national oil spill response plan in the future. In these plans, the most important, of course, is the efficiency of the plan. Its factors such as deploying time, ability of response resources, experience, etc. are prerequisite issues.

Annually, branches and relevant agencies conduct or associatively conduct training programs in order to check and review their oil spill response plans. Recent years, response resources are bringing into play which is proven by real oil spill incidents. Also, the cooperation between resources and relevant agencies is effective; this will assure the effectiveness in larger scale when the national oil spill response plan is implemented.

Currently, Vietnam is deploying the national oil spill contingency plan. Being a part of the national plan for responding to oil spills from 2001 to 2010, the three oil spill response centres will be built shortly in three separate regions of Vietnam as mentioned above. With the development of the national oil spill response plan as well as the establishment of three oil spill response centres, Vietnam will have sufficient abilities to response oil spill incidents in particular and protect environment in general.

3.8 Treatment Capability of oily contaminated Solid Waste in Vietnam

Until now, petroleum products are integral material and fuel resources for the society development. However, oil sludge and oily contaminated wastes from petroleum industry activities (exploration, exploitation, transportation, refining, storage, application …) are pollution resources. Particularly, some additives in petroleum products are of difficult biodegradable and are extremly hazardous to ecological system and public health.
In Vietnam, together with the economic growth and the strong development of petroleum and other industry, oily contaminated wastes are causing negative influence on the environment. Meanwile, the deficiency of treatment technology and control system cause non-effective prevention and mitigation of oil contaminated wastes.

3.8.1 Sources of oily contaminated Wastes in Vietnam

3.8.1.1 From Petroleum Industry Activities (Exploration, Exploitation, Transportation…)

In Vietnam, the exploration and exploitation are operated mainly in South East and West East Sea. The solid waste from the above activities include cuttings, drilling mud, oil sludge and domestic waste. The cuttings and dilling muds are mainly waste from the oil exploration and exploitation. According to Petrovietnam, upon the well design the volume of the cuttings and drilling mud are approximately 300 – 600 m^3/well. Naturally the cuttings are the mixture including mineral soil, drilling mud, oil, gas and well-water.

Table 3.8-1: The concentration of oil and metals in the cuttings of Rang Dong field's well (depth 2500 m, using water based drilling mud)

No.	Parameter	Unit	Value
1	Ba	ppm	4.752,16
2	Cu	ppm	15,49
3	Pb	ppm	15,74
4	Zn	ppm	17,2
5	Hg	ppm	0,06
6	Total organic compound	ppm	406,50

[Source: JVPC, 4/2002]

The discharging drilling mud, what is non-recycled for reuse, include bentonit, barit, crude oil and petroleum product, additives, etc.

According to recent common regulation, for the offshore drilling operation, the cuttings are permited to discharge into the sea (excluding the cuttings containing mineral and synthetic oil based drilling mud, what is required to be treated to 10 g/kg oil cuttings limit before discharging into the sea). For the inshore drilling operation, all of the cuttings and mud are required specially collected, managed and treated like hazadous wastes.

3.8.2 From Petroleum Ports and Storages

Oily contaminated waste from petroleum ports and storages occurs mainly from cleaning tanks. According to Vietnam Petrolimex Coporation, each 5,000 m^3 tank produces averagely 50 kg sludge / month.

Table 3.8-2: The content of sludge from petroleum tanks of III Branch Petrolimex Corp.

No.	Parameter	Unit	Value
1	Pb	ppm	5,2
2	Zn	ppm	102,7
3	Cd	ppm	1,26
4	Cu	ppm	72,6
5	Mn	ppm	7,6
6	Fe	ppm	137.10^3
7	pH		6,23
8	Total organic compounds	%	23

[Source: B12 Petrolimex Company, 8/ 1998]

3.8.3 From Oil Tanker Sanitation

During the last years, oil tanker sanitation service has increasingly developed in Vietnam. However, due to the lack of management procedure on hazadous waste, until 2005 the environmental authority gave the permission to carry out the sanitation services of Vietnamese tankers. In this time, four tankers of VIETSOVPETRO (tonnage: 150,000) were cleaned once a year with discharging 3,000 tons of sludge. Normally, the content of sludge is depended on the oils characteristics; the pre-treatment and exploitation process; the sanitation methods, etc.

Table 3.8-3: The properties of oil sludge in Bach Ho field

No.	Parameter	Unit	Sample 1	Sample 2	Sample 3
1	Status		solid	thick	viscous
2	Sulfur	% mass	0,09	0,38	0,53
3	Water	% mass	2,22	4,88	11,73
4	Mechanical impurities	% mass	50,58	0,67	0,89
5	Paraffine	% mass	31,60	55,74	24,73
6	Oil	% mass	10,08	32,71	57,70
7	Bitumen	% mass	5,14	4,93	4,40
8	Asphalten	% mass	0,59	1,07	0,57
9	Heat-production	kcal/kg	10860	10750	10800

[Source: Vung Tau Shipyard and Petroservices Company, 4/2002]

3.8.4 From Oil Spill Accidents

During the last three decades, oil spill accidents have become more and more in Vietnam. The responses and the collection of spilt oil occur almost unprompted using only simple mechanical facilities. Therefore, polluted areas are not treated and restored actively, yet. Up to now, they are cleaned up only naturally with the time.

3.9 The Management and Treatment Status of oily Waste in Vietnam

3.9.1 Legislation and Policy on Hazardous (including oily) Waste management

There are several legislations for dealing with hazardous waste including oily waste. Following, there is a list showing the most important legislations, such as:

- Law of Environmental Protection, 1993
- The Governmental Decree No 175-CP of October 18, 1994, detailing the implementation of the Law on Environmental Protection
- Direction No. 256/2003/QD-TTg on April 2, 2003, of the Prime Minister approving the National Strategy on Environmental Protection up to year 2010 and Vision to 2020
- Decision No. 152/1999/QD-TTg on July 10, 1999 of the Prime Minister approving the National Strategy for Solid Waste Management in Industrial and Urban Areas until 2020
- Decision No. 155/1999/QD-TTg on July 16, 1999, of the Prime Minister promulgating the regulations on hazardous waste management

- Decision of MOSTE No. 395/1998/QD-BKHCNMT on 10 April 1998 on issuing regulation on environment protection in searching, exploring, and developing oilfield; exploiting, storing, transporting, processing oil and gas and supplying related services.

3.9.2 Treatment Status of oily contaminated Waste in Vietnam

3.9.2.1 In the Storages of Vietnam Petrolimex Corp.:

Oily sludges from petroleum ports and storages are collected and treated onsite by simple or industrial furnaces. Recently, in some large storages (for example, in the storages of B12 Petrolimex Company) the bioremediation of oily sludge is in experimental stage.

3.9.2.2 In the Off-Shore Petroleum Activities:

According to recent common regulation, for the offshore drilling operation the cuttings are permitted disposal into the sea (excluding the cuttings containing mineral and synthetic oil based drilling mud that are required to be treated to the 10 g/kg oil cuttings limit before dumping into the sea). The oil sludge, the non-reused petroleum products and the other oily contaminated solid wastes are required to be collected and transported to the treatment areas inland.

Recently, all of the solid waste from South East offshore fields are transported to the Vung Tau port and followed to the Nui Dinh petroleum landfill. The incinerator for oily contaminated waste has been recently invested by VIETSOVPETRO in order to replace the overloaded Nui Dinh landfill.

3.9.2.3 In the Oil Tanker Sanitation Service:

Oil sludge is collected and sent to the treatment areas inland. At Song Thu Company in Da Nang City oily contaminated waste is burned in the incinerator, and at II Transportation Mechanic Company in Ho Chi Minh City the residue is moulded in form of bricks using for brick-tile industry is produced from the oily sludge from tankers.

3.9.2.4 In the Oil Spill Clean-Up:

As aforesaid, in Vietnam the responses and the collection oil spilt occur almost unpromptedly using only simple mechanical measures. However, some oil spill bioremediation were carried out, like as the treatment of diesel contaminated sand by the bioproduct Enretech in oil spill accident at Ganh Rai bay and the treatment of oily contaminated soil by Enretech at Vung Tau petroleum service port.

3.9.3 Assessment of Capability of the Authorities and Service enterprises for Management and Treatment of oily contaminated Wastes

Advantages

The government of Vietnam already issued some legislations and policy documents on the management and treatment of hazardous waste. For the implementation, technical assistance from international organisations is most welcome.

Besides, the application of research and development of treatment technologies for oily contaminated waste takes place.

Difficulties

- Most oily contaminated and industrial waste is collected together with common waste
- Deficiency of technical guidelines on oily waste treatment
- Deficiency of Vietnamese standards related to oily contaminated waste collection and treatment
- The limited capability of service enterprises for the oily contaminated waste treatment can lead to a secondary pollution
- Governmental inspection on the hazardous waste management is insufficient
- Public awareness on oily waste management and treatment is limited

3.9.4 Recommendations on the Oil Waste Management and Treatment

- Promulgation of standards on oily contaminated waste management and treatment
- Promulgation of technical guidelines on oily contaminated waste management and treatment
- Planning and establishing service centers using proper technology for hazardous wastes in accordance with industrial zones
- Improvement of institutional effectiveness, of monitoring and enforcement of hazardous waste management and treatment
- Creation of incentives for oily contaminated waste treatment and recycling
- Improvement of public awareness, perception and technical skills on the collection, seperation, treatment and recycling of oily contaminated waste

3.10 References of Chapter 3

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4 Non-Biological Treatment of oily Sand, Soil and Sediment

4.1 Introduction

Freshwater and marine ecosystems are crucial for global ecology. Deliberate as well as accidental oil spills frequently have catastrophic short-term effects on local to regional scale. Especially coastal ecosystems are, in most cases, heavily impacted. Severe risks for human health, drinking water supply etc. occur. Since coasts are areas of dense population, economy is mainly sea-based and at least in part depends on transportation, fisheries, tourism related to splendiferous coastal ecosystem etc. In case of an oil disaster the economic development is slowed down or even thrown back for years or decades. Vietnam has experienced several oil spills of different dimension in the past [MG; 2005].

When an oil spill occurs, then immediate, well-coordinated, effective and efficient response measures are required. Those must include the treatment of soil and other materials contaminated with oil (waste). Whereas bioremediation is in many cases a cost-effective and environmentally sound treatment of soils polluted with oil a practice-oriented guidance for emergency situations has also to consider that more rapid measures might be required. Thus, promoting an adequate response to oil spills must include physicochemical as well thermal treatment options even though those are, in most cases, more expensive. In addition, especially the thermal treatment of oil-polluted soil may reach significantly lower concentrations of residuals than bioremediation technologies.

Limiting factors for the application of the different non-biological treatment technologies are the acceptable duration of the respective measure and the availability of financial resources, technical equipment and well-trained personnel. Taking into account the length of Vietnam’s coastline of about 3,000 km a decentralised or a multi-centre approach should be employed.

Non-biological treatment of soil can be carried out *In-Situ* or *Ex-Situ*, the latter either on-site or off-site. *In-Situ* means that the soil is not excavated before treatment. *Ex-Situ* treatment requires excavation and can take place on site or at another place, e.g. at an central stationary waste treatment facility. Thus, on-site treatment includes at least excavation, treatment of soil and disposal of residues such as fly ash or flocculation sludge but off-site treatment requires transportation and additional storage.

In any case, depending on the type of both oil and pollution path, hazard of explosion, inhalation toxicity, hazard of toxic depositions in the surrounding area and hazard of self-ignition must be considered. Especially in the case of stripping or thermal treatment, encapsulation of aggregates, designation of black and white zones, protective clothing, inhalation protection, fire and explosion prevention measures are required [Kowa; 1993]; [Lissner; 1993].

Oil Recycling

Oil recycling may be carried out if highly concentrated and less polluted waste oil e.g. originating from oil processing, oil separators etc. has to be disposed. Depending on the type of oil it can be re-refined, processed to methanol, directly used in construction (bitumen) or purified to be gasified or combusted (referred to section 4.3).

In the case of an oil spill, material recycling of oil skimmed from the sea surface, oil manually removed from rock surfaces etc. is theoretically possible. However, since those might be neither applicable nor appropriate the main objective of pre-treatment is the improvement of the gasification or combustion properties of this waste.

In any case, oversized inert solids like gravel, stones etc. have to be separated by means of rusts, screens, filters, separation tanks etc. In tanks, water and oil should largely separate simultaneously. Phase separation can be enhanced by addition of demulsifiers, warming to 120 – 150 °C, low pressure and subsequent condensation of the water. Additives and metal compounds may be removed from processed oil in advance in order to reduce hazardous emissions of physicochemical or thermal treatment. However, both physicochemical and thermal treatment include wastewater as well as flue gas or exhaust air treatment. Recycled oil of medium quality can be used in blast furnaces where it simultaneously acts as fuel, reducer and additive. Less purified oil, i.e. oily waste with high content of fine particles, can be processed (incinerated) in cement works or production of clinkers. Then the oil acts as fuel and the inert particles are included into the product [Möller; 2004].

In-Situ

Contaminated coasts may be treated In-Situ by means of water steam under high or low pressure, possibly including the addition of surfactants and/or nutrients. However, no acceleration of ecological regeneration of rocky coasts was observed after such treatments. Moreover, reduced and/or retarded re-colonisation, at least temporarily for 1-2 years, was observed at rocky coasts in some cases. Oil was dislocated towards sub-littoral zones [Bernem; 1997].

Ex-Situ

The preparation of oil-contaminated coast includes the mechanical removal of the surface oil layer from rocks as well as the excavation of contaminated surface soil and sediment. A rule of thumb is that excavation is immediately necessary in order to prevent groundwater pollution if the oil content of the soil excesses 30 g/kg. Excavation is usually carried out by means of heavy machines, e.g. dredgers, bulldozers etc. A precondition is that sufficient capacities for the temporary storage of the excavated soil are available. The use of heavy machines may lead to compaction, aggregation, enhanced erosion and/or retarded re-colonisation of the coast [Bernem; 1997]; [Zeschmann I; 1993].

4.2 Physicochemical Treatment (Soil-Washing)

Physicochemical soil treatment can easily achieve residual oil concentrations below 500 mg/kg [Zeschmann II; 1993]. The separation of persistent organic compounds, heavy metal compounds etc. is also possible. Physicochemical treatment can take place on-site as well as off-site, both in mobile and stationary installations. In the case of off-site treatment, additional transport and storage capacities are required. Contaminated soil is usually transported on the road by lorries, tractors etc. or by wagon train, bulk cargo ship etc.. Dust emissions must be prevented during transport. The main advantages of off-site treatment are the rapid decontamination of the polluted property, the possible secure temporarily storage in prepared repositories and the possible treatment in stationary facilities with continuous operation [Kuyumcu I; 1995]; [Lissner; 1993]; [Zeschmann II; 1993].

4.2.1 Introduction

The main objective of physicochemical treatment of oil-contaminated soil is the separation of oil from soil particles through application of mechanical energy. This is achieved by means of a combination of several wet classing and sorting steps (“soil-washing”). The efficiency of soil-washing cab be substantially enhanced through the application of surfactants or other additives. Soil-washing is generally applicable to slightly to moderately contaminated material such as soil, sediment or certain waste. Through soil-washing, the oil is concentrated in the low-weight fractions separated from gravel and sand, in the silt fractions and in the washing water/solution. Sometimes, physicochemical treatment of soil is differentiated into “washing” (with pure water) and “extraction” (with solvents or water and additives). Here, the use of the term “soil-washing” comprises both variants.

After excavation and, if necessary, transport and temporal storage of the soil (1) five general components can be combined in a soil-washing process – repeatedly, in different order and in different realisation (Figure 4-1):

- preparation of the soil (metal separation etc., initial classing, crushing) (2)
- disintegration (water, energy, surfactants) (3)
- classing (4)
- sorting (5)
- separation of solids from liquor (6)

After this actual soil-washing procedure, the waste of the process has to be disposed:

- wastewater treatment (7)
- exhaust/waste air treatment (8)
- treatment of highly contaminated and separated fractions (sand, silt, light-weight material) (9)

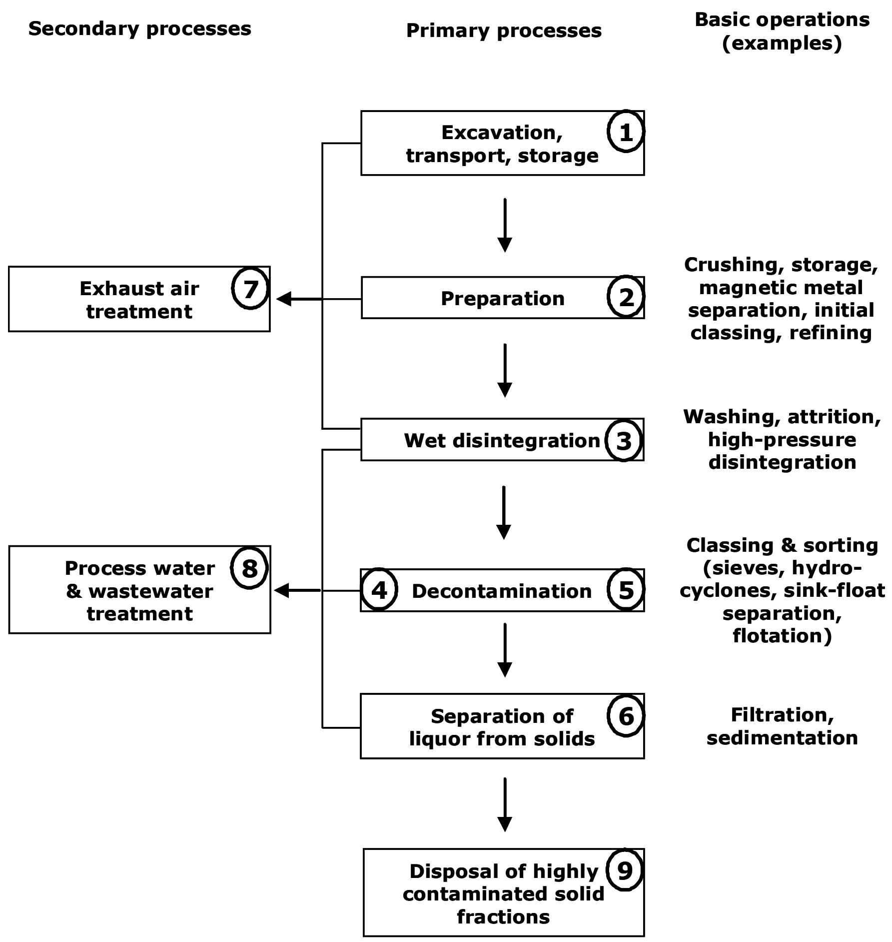


Figure 4-1: Basic processes of soil-washing (Modified according to [GUR; 1993])

One possible example for a soil-washing operation is presented in Figure 4-2. Please, note that the light-weight fractions, metals, etc. separated through soil preparation are not depicted. These fractions have to be disposed as well, of course.

The preferred method for the disposal of the fine soil material highly contaminated with hydrocarbon compounds is thermal treatment (see section 4.3).

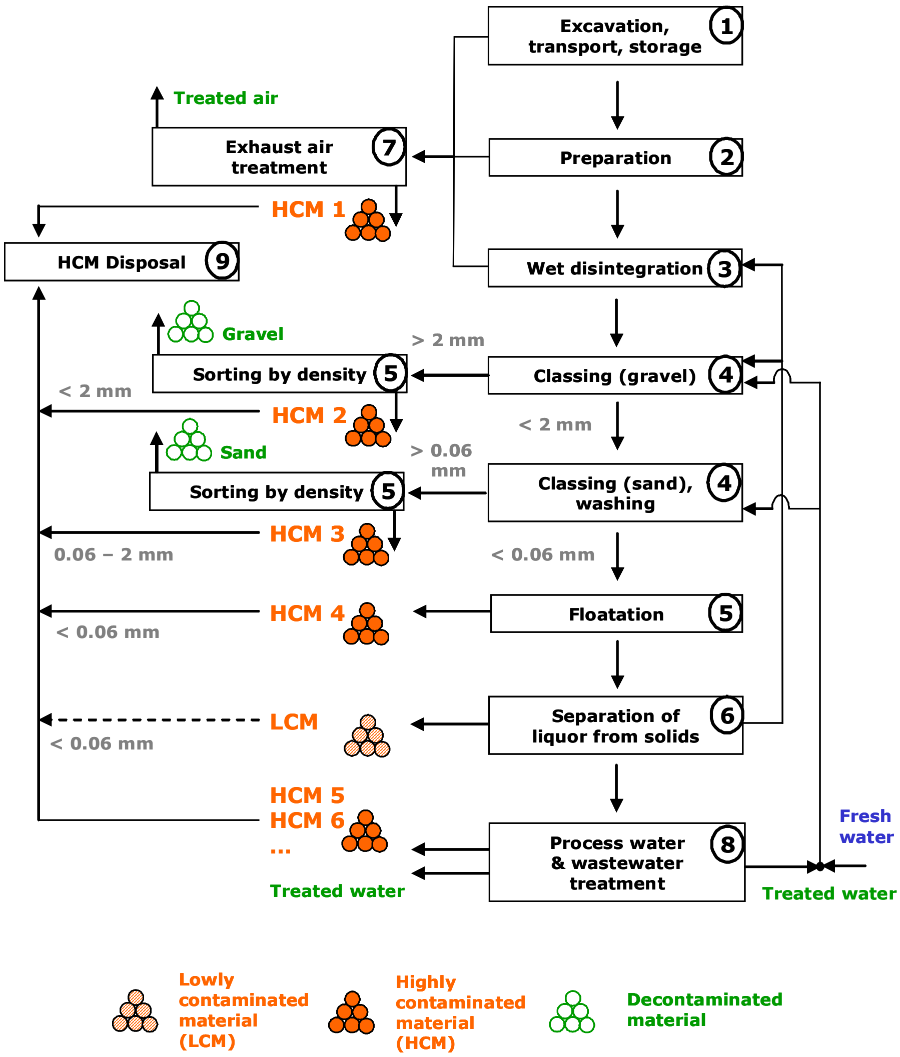


Figure 4-2: Soil-washing operation (Modified according to [GUR; 1993])

The general applicability of a soil-washing technology depends critically on the properties of the contaminant (the oil) and its distribution over the different soil particle fractions. In Figure 4-3 a decision scheme on the applicability of a soil-washing procedure is depicted schematically.

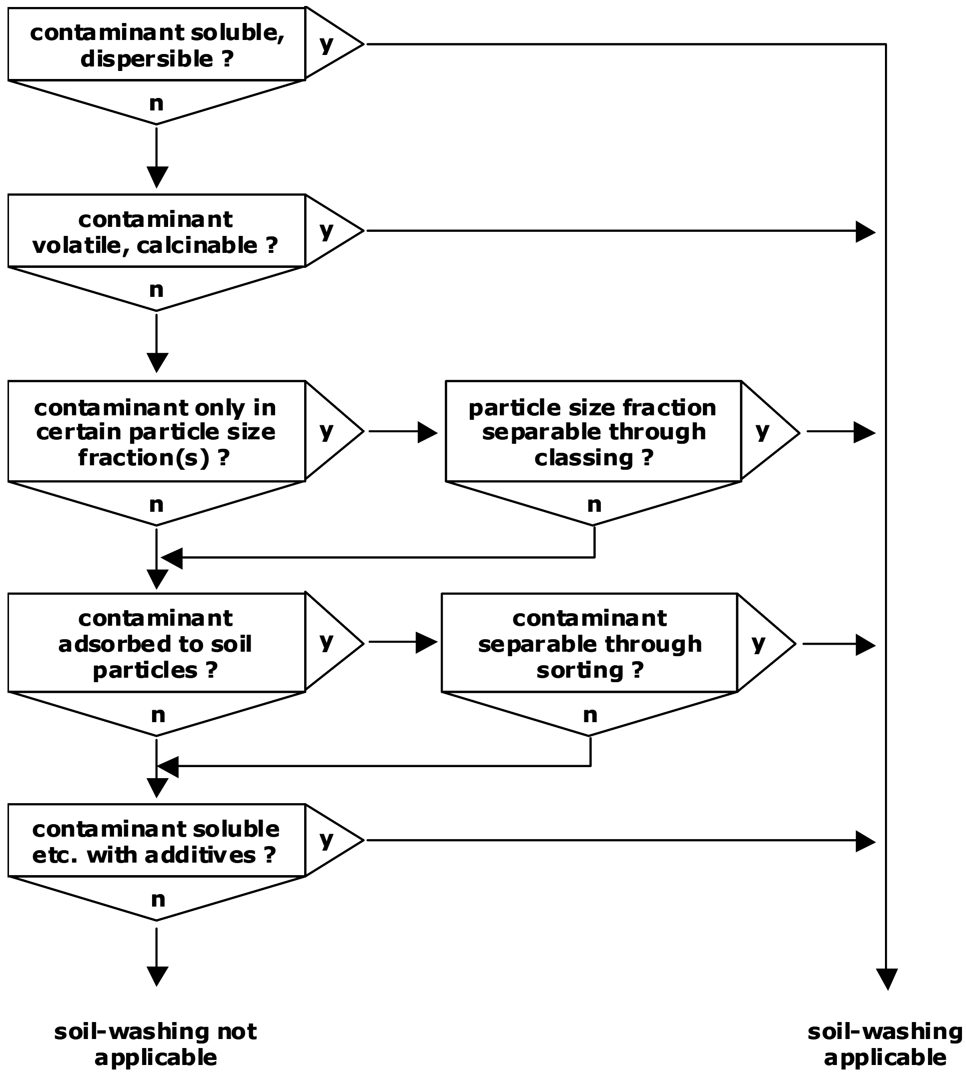


Figure 4-3: Decision scheme on applicability of soil-washing (Modified according to [Kuyumcu I; 1995])

4.2.2 Preparation of Soil

After excavation, transport and temporary storage the soil must be pre-treated and its most important properties must be determined before it can be supplied to a soil-washing installation. Pre-treatment in most cases includes at least initial sorting steps (separation of metals, large plastic foils, bulk wood etc.), initial classing (rusts, screens) and crushing of oversized material. The grain size distribution of the soil, the oil mass per grain size fraction and basic soil characteristics like pH-value have to be determined. The density allocation is determined by means of sink-float separation, decontamination characteristics are determined and soil-washing experiments are carried out at laboratory scale.
Crushing of bulky material is carried out by means of hammer crushers, jay crushers, impact crushers etc.

4.2.3 Disintegration

The disintegration aims at releasing of the oil, oily particles or oily phases from agglomerations with other soil phases. The actual separation of oil from soil particles (gravel, sand) has top priority. If this is not achievable the separation of oily particles or phases is aimed.

Disintegration usually consists of two stages: dispersing and classing. At first, the soil is mixed or treated with water in drum washers, hutch washers, attrition cells, vibrating screw washers, centrifugal baffle aggregates, high pressure water jets etc. The separation of oil from gravel and sand is started. The oil is suspended in the water or dislocated to the silt fraction. Silt particles are dispersed in the water. Most of these aggregates simultaneously class the soil (see below) by separating gravel and, in part, sand from the dispersion. In most applications, soil disintegration, i.e. if it was a combination of particle size reduction, classing and oil separation, is a multi-stage process. In order to minimise efforts and environmental impact it is usually carried out without addition of surfactants.

After contamination of porous material such as sandstone the oil also permeates into the pores. In this case, further size reduction (crushing, milling) is required to releasing the embedded oil.

4.2.4 Classing

Classing means the separation of poly-disperse mixtures based on grain size. There are two basic classing principles: screening and flow classing. Classing results in (at least) two particle fractions which have a different particle size but the same physicochemical properties. If the physicochemical properties of the two particle size fractions are different then classing was accompanied by sorting. Classing based only on grain size is conducted by means of screens and rusts, with effective separation sizes > 1 mm . Classing based on vertical velocity (sinking, falling) is carried out by means of up-current classifiers, screw separators, hydro-cyclones or hydro-separators with parallel flow or counter flow. In the case of soil-washing, initial classing of the oversized material and classing by means of hydro-cyclones have also sorting effects.

Screening is applied for:

1. separation of bulky material (wood, rocks, etc.) from contaminated soil,
2. separation of treated gravel or sand from fines,
3. washing and dewatering of oversized material of hydro-cyclones or up-current classifiers,
4. dewatering of the products of jiggers,
5. separation of freely floating material in wet disintegration aggregates or gravity separators

A major advantage of screening is that several technological requirements are met simultaneously, such as

1. separation of the main proportion of fine material with washing flow,
2. treatment of oversize particles (gravel, sand), i.e. in case of simultaneous spraying of fresh water,
3. dewatering of oversize particles (gravel, sand) on the last screen.

In **hydro-cyclones** the particles are separated based on grain size in a field of centrifugal force. Hydro-cyclones are very simple, robust and effective apparatuses, are worn slowly, require little space and can be part of stationary as well as mobile operations. In most soil-washing operations, several hydro-cyclones delivering different (decreasing) effective separation sizes are operated in series and several of these lines are operated in parallel. One-stage or sole hydro-cyclone classing does mostly not achieve the required separation success. Hydro-cyclones with nominal diameters of 40–250 mm are used. Classing by means of hydro-cyclones can achieve an effective separation size of 5–300 µm. Depending on the properties of the soil supplied to the washing process, operating parameters and/or type, size or sequence of the hydro-cyclones have to and easily can be varied.

In soil-washing, **up-current classifiers** are operated for post-treatment of oversized material of hydro-cyclones in order to separate fine (and highly contaminated) particles carried due to incomplete separation or for separating low-density material such as wood, peat or plant residues. Thus, up-current classifiers are in fact sorting aggregates at the same time. With minor changes of fluidic, measuring and controlling internals any up-current classifier can modified into a sorting aggregate.
Classing/sorting by means of up-current classifiers is based on the different sink velocities of particles in a fluid.

The specific sink velocity depends on:

1. the velocity of the fluid,
2. the density, size and shape of the grain.

Only if the particles had equal density and shape, the classing effects of screens and up-current classifiers are similar. In the case of up-current classifiers, the particles are separated into classes of equal falling. This can be achieved through current or counter current flow.

4.2.5 High Pressure Soil-Washing

High pressure soil-washing (water velocity ≤ 900 km/h) is a technically mature technology but appropriate only for large soil masses > 10’000 Mg. It can be operated very economically in case of high throughput stationary operations but requires high technical efforts and specific costs in case of mobile operations. The treated soil lacks the fine particle fraction (silt).
High pressure water jets can be applied at two treatment stages (Klöckner-Oecotoc technology):

1. initial disintegration of soil aggregates (see above)
2. separation of oil from soil particles.

Thus, high pressure soil-washing is combined classing, sorting and decontamination. The decontamination process also comprises impact chambers and attrition mills (see below) [Gebhardt; 1993]; [GUR; 1993].

4.2.6 Stripping

The stripping technology can be operated economically already in case of small soil masses > 150 Mg of less contaminated soil. Soils with low silt < 10 % (m/m) can be decontaminated to residual oil concentration of < 100 mg/kg. Soils with higher silt usually contain 300 – 900 mg/kg residual oil and have to be landfilled at controlled sites or treated through advanced treatment before reuse. The overall efforts increase with increasing silt fraction.
In this technology, the excavated and prepared soil is filled into a basin or vat and mixed with the water/washing solution. Then, air is jetted in from injectors at the bottom and oil as well as silt particles and oil-silt agglomerates are stripped to the water surface. The wastewater/washing solution as well as the produced oily sludge are highly contaminated and have to be treated and disposed separately. Again, stripping is a combination of classing, sorting and decontamination [Gebhardt; 1993].

4.2.7 Sorting

Sorting is the separation of particle mixtures based on material properties, e.g. density, wettability, magnetism or colour. In almost all soil-washing processes, it is based on density: jiggers, separation in film flow (trough washers, washing tables), sink-float separation, up-current sorters. If I) the supplied material (soil) was inhomogeneous, II) the particle size distribution was rather wide and III) the particle shape is significantly varying, then sorting can also depend on grain size. Flotation is based on the varying wettability of different materials.

Jiggers have to realise two functions:

1. layering and, subsequently
2. separation of the layers.

Jiggers are applied in order to separate moderately to highly contaminated low-weight (< 1.8 cm^3/g) and high-weight (> 1.8 cm^3/g) particles of medium to large particle size. Porous particles which still could carry oil permeated into pores should also be separated. The coarse grained fraction of the soil is supplied in a water flow to a jiggled tank with sloping bottom plate. The particles form a stratified layer depending on their density, the fraction of lowest density being the uppermost. The layering is forced through a periodic upward water flow passing through the soil. The jigging process is determined by the soil properties, the upward water flow (velocity, volume, frequency, etc.), the transport water flow, the height of the formed bed, the throughput.

A special variant of jigging is the **heavy-media sink and float separation**. In this case, the soil is supplied to a liquor whose density is lower than that of the high-weight fraction and higher than that of the low-weight fraction, respectively. So the particles of low density float and the specifically heavy particles sink. Even though the selectivity of the heavy-media sink and float separation is higher, this technology is rarely integrated into soil-washing operations because the specific costs are significantly higher than those of standard jiggers.
Sorting (and classing) can also be carried out in a film flow on a sloping plate. The two realisations applied for soil-washing are spiral through washers and vibrating washing tables. These apparatuses, depending on their specification, can be used for differentiating particles with grain size of approximately 0.03 – 5 mm.

Spiral through washers are applied to separating particles of low and high density both usually being highly contaminated. The soil suspension with 10 – 40 % solid matter (m/m), e.g. the undersized effluent of hydro-cyclones, is supplied to an open, spiral, u-shaped steel plate from the top and moves down by gravity. Three major flows are formed: spirally downwards on the bottom of the spiral, inward on the bottom of the steel plate and outwards on the surface of the downwards moving sludge. The particles are separated into three fractions of low, medium and high specific gravity that move downwards forming carpets from the outer to the inner region of the channel. Particles with low specific gravity, such as wood, coal or plant residues, are forming the outmost carpet. Particles with a high specific gravity are transported towards the spiral axis and downwards on the bottom and along the inner side of the channel. Finally, the carpets are split by means of longitudinal plates and collected separately. Spiral through washers (or spiral concentrators) are combined to batteries of up to 40 spirals. Each spiral has a capacity of up to 4 – 5 Mg/h.

Major advantages of spiral through washers are:

1. lack of mechanically moved components
2. long lifespan (slow wearing)
3. little energy consumption
4. lightweight construction (composite materials)
5. supply of additional washing water not required
6. low investment costs
7. high throughput

Disadvantages are:

1. lower selectivity compared to washing tables
2. high pumping efforts in case of multi-stage operations
3. control of discharge of high-density material not possible. Optimal selectivity is only achievable if pre-classing was carried out.

In the case of **washing tables**, the soil is supplied to a vibrating sloping fluted steel plate from the top. The flutes have a very high ratio of length to diameter, and a water flow crosses the direction of the flutes. Particles move slowly along the flutes and a combination of different forces (gravity, inertia, friction) causes sorting. Since the height of the sides of the flutes decreases with length, particles successively run over the sides, are selectively separated into carpets and are discharged by the cross-flowing water.

Major disadvantages of washing tables are:

1. low specific throughput and the resulting high specific area requirement
2. high water consumption
3. required narrow particle size distribution (0.03 – 2 mm)

The specific throughput can be increased through construction of multiple-layer tables. Nevertheless, the specific throughput is 10 – 40 times lower than in the case of spiral through washers. Therefore, washing tables are only used in particular cases, if the high selectivity is required and flotation (see below) is not applicable.

Flotation is a mechanical separation process in a three-phase system (water/additives, air, particles), based on wettability of particles.
It aims at:

1. separation of dispersed fine particles (silt, very fine sand) into lowly/not contaminated fraction and contaminant concentrate
2. the complete separation of dispersed particles and, depending on the respective problem
3. the removal of dissolved contaminants

Subsequently, the dispersion is fed into the flotation cell, additives decrease the wettability of the dispersed particles, air is jetted into the stirred dispersion, air bubbles form aggregates (heterocoagulates) with hydrophobic particles, aggregates float to the water surface and the foam layer is skimmed.

The additives are divided into three groups:

1. <u>collectors:</u> non-specifically selective hydrophobising reagents,
2. <u>controllers:</u> reagents changing the adsorptive properties of collectors, either decreasing (depressants) or increasing (activators) adsorption, strongly depending on pH value,
3. <u>foamers:</u> surface active reagents to producing foam layers with defined properties.

The use of these kinds of additives for flotation of soil fractions contaminated with oil should not be necessary if one took the natural differences in hydrophobicity of soil grains and oil into account. In the case of very fine dispersed particles or emulsified drops, the effective surface has to be increased prior to flotation in order to improve the floatability. Flocculation (grains), coalescence (drops) or adsorption (both) to larger particles can achieve this. Analogously, dissolved pollutants have to be flocculated, precipitated or adsorbed to particles by at first. Waiving the use of additives, flotation is applicable for grain size of 25 – 300 µm (ore, soil), 25 – 750 µm (coal).

The main criteria for categorising flotation apparatuses is the method of air bubble generation used.
Types of flotation cells appropriate for soil-washing operations are:

1. <u>stirred flotation cells:</u> high selectivity, very robust, insensitive to change of throughput,
2. <u>pneumatic flotation cells:</u> high selectivity, high specific throughput, less robust, more sensitive to change of throughput,
3. <u>flash flotation cells</u> (for treatment of process water and wastewater): non-selective, high efficiency, for complex dispersions.

Flotation can be applied for

1. separation of contaminated solids, i.e. particles with low density, hydrocarbon containing particles (0.02 – 2 mm particle size),
2. separation of oily phases, de-emulsifying, treatment of oil sludge,
3. process water treatment (usually < 0.063 mm particle size; pre-treatment necessary: precipitation, de-emulsifying)
4. wastewater treatment (pre-treatment necessary: flocculation, precipitation)

Flotation cells are usually operated in series as well as in parallel and always in combination with other classing and sorting apparatuses (see chapter Classing, section on hydro-cyclones).

Up-current classifiers/sorters have already been introduced in chapter Classing (see above).

4.2.8 Separation of Solids from Liquor

Soil-washing produces three solid mass fluxes that have to be dewatered: gravel (particle size > 2 mm), sand (0.06 – 2 mm) and silt sludge (< 0.06 mm).

Gravel and sand are usually sufficiently dewatered by means of screw apparatuses or vibrating/oscillating screens (see chapter “Classing”). The sludge mainly consisting of silt particles is dewatered by means of flocculation followed by sedimentation/thickening or filtration. Flocculation is achieved through addition of organic polymers and/or iron or aluminium salts or as coagulation through addition of electrolytes. Compression thickener, baffle plate thickener and circular thickener are aggregates frequently used for sedimentation/thickening. Due to the small particle size, filtration has to be carried out under pressure. Dewatering of the filter cake can be forced by additional heating. Chamber filter press, wire press and belt filter press can be used [GUR; 1993].

4.2.9 Waste Disposal

Wastewater, waste air, separated lightweight material and gravel, sand and sludge have to be disposed.

Wastewater (and process water) treatment is identical with separation of fine particles, dissolved pollutants and emulsified substances (see above). In the case of soil contaminated with oil it can be estimated that the effluent can be discharged to the sewer system and co-treated in sewage treatment works.

Air exhausted from enclosed aggregates and soil repositories is treated by means of standard technologies. A detailed description is out of the scope of this report.

Gravel and sand should have been sufficiently cleaned for use in construction, re-cultivation measures etc. Lowly contaminated silt or sludge can be subjected to bioremediation (see respective chapters). Highly contaminated silt or sludge as well as lightweight fractions are usually thermally treated (see below).

4.3 Thermal Treatment

The chapter "Thermal Treatment" is mainly based on Bilitewski et al. (1997), Gebhardt (1993), Kuyumcu I (1995), Matig (1993), Möller (2004). Additional references are indicated within the respective section.

4.3.1 *In-Situ*-Incineration

In-Situ-incineration of contaminated sites is not recommendable because

- high temperatures result from the high heat value of oil
- toxic residues are formed
- toxic emissions occur
- plants and animals are killed
- permeability of soil increases.

Thus, only excavation and *Ex-Situ*-treatment are acceptable.

4.3.2 *Ex-Situ*-Incineration

The main advantage of *Ex-Situ* thermal soil treatment is that it is a very rapid treatment independent on both the type of soil and the type of the oil. In addition, co-treatment with oil skimmed from sea surface, refuse-derived fuel, sewage sludge etc. is possible.

Disadvantages are:

1. it is expensive, because effective exhaust gas treatment is required
2. the costs dramatically increase with decreasing oil mass portion (high energy expenditure)
3. the disposal of slag and ash is subsequently necessary
4. the treated soils are biologically inactive (dead)

Basic operations of thermal soil treatment are, analogous to thermal treatment of municipal waste, preparation of soil, thermal treatment, post-combustion (afterburning) of flue gas, fly ash separation and flue gas treatment.

4.3.3 Definitions and Processes

Thermal treatment comprises or may mean different processes:

- incineration: thermal disposal of fuel, waste, soil, etc.
- drying: volatilisation through primary air flux and heat radiation from combustion chamber, optionally through return flux of hot flue gas (65–75°C)
- degasification: volatilisation of volatile compounds, initial transformation of solids to gases (75–250°C, depending on heat supplied), under presence of oxygen self-ignition at > 250°C
- pyrolysis: airtight thermal transformation of organically fixed carbon to gases (500–600°C), promotion through water vapour and oxygen supply
- combustion: thermal transformation of fuel under air/oxygen supply, products are CO_2, H_2O, SO_2, ash, slag and trace gases (1'200°C highest theoretically achievable mean temperature in combustion chamber)
- complete combustion: gaseous products consist of CO_2, H_2O, SO_2, trace gases only, solids do not burn or release gas (any longer)
- incomplete combustion: gaseous products contain relevant amounts of combustible compounds as CO, H_2, hydrocarbons, solids may still release gas or burn
- gasification: thermal, non-burning transformation of fuel under air/oxygen supply
- sintering: fusion of ash particles due to partial and local smelting of ash, i.e. promoted through presence of iron, formation of slag with highly varying properties

4.3.4 Soil Preparation

Contaminated soil has to be excavated, if necessary transported to the central, stationary treatment facility, stored, initially sorted and, if necessary, classed (rusts), crushed and/or homogenised. If necessary, initial/additional dewatering has to be done (see above). Final drying of fuel occurs in the drying zone as part of the incinerators.

4.3.5 Co-Incineration

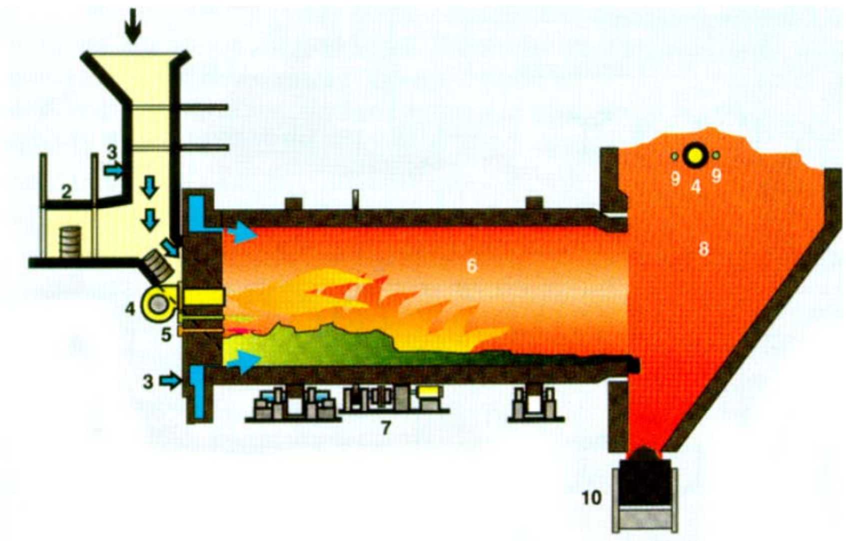
In most cases, if the soil either contains negligible amounts of oversized material or was adequately pre-treated, it can be co-incinerated in cement works, clinker production facilities and waste incinerators. In the first two cases, the soil acts simultaneously as fuel and raw material.

4.3.6 Mono-Incineration

Soil mono-incineration usually consists of low-temperature vaporisation and gasification (400–700°C) followed by gas combustion (< 1'400°C). In order to prevent the formation of polyhalogenated dioxins and furans (PXDD/F), post-combustion of waste gas must be conducted at least 1'100–1'200°C. The treated gas has to be quenched rapidly in order do prevent *de novo*-synthesis of PXDD/F. Direct incineration is only appropriate if the proportion of the oil (m/m) is high in relation to non-combustible soil particles.
The three most important technologies for thermal soil treatment are rotary kiln, grate firing and fluidised bed incineration. Low-temperature incineration, Thermoselect technology and Noell-conversion-technology are other options but not yet mature or applicable only in certain cases.

4.3.6.1 Rotary Kiln

Bulky or lumpy fuel, i.e. inhomogeneous material, is supplied into a rotating drum with a length of 8 – 12 m, in some cases < 20 m, and a diameter of 1 – 5 m (Figure 4.6-1). The combustion temperature is 800 – 900 °C but operation at 400 C is also possible. In the so-called afterburning chamber gases out of the main combustion chamber (drum) and of the liquid fuel burner is mixed with secondary (tertiary) air. So the entire flue gas has an equal temperature of 950 °C for 5 s in the upper part of the chamber (afterburning).



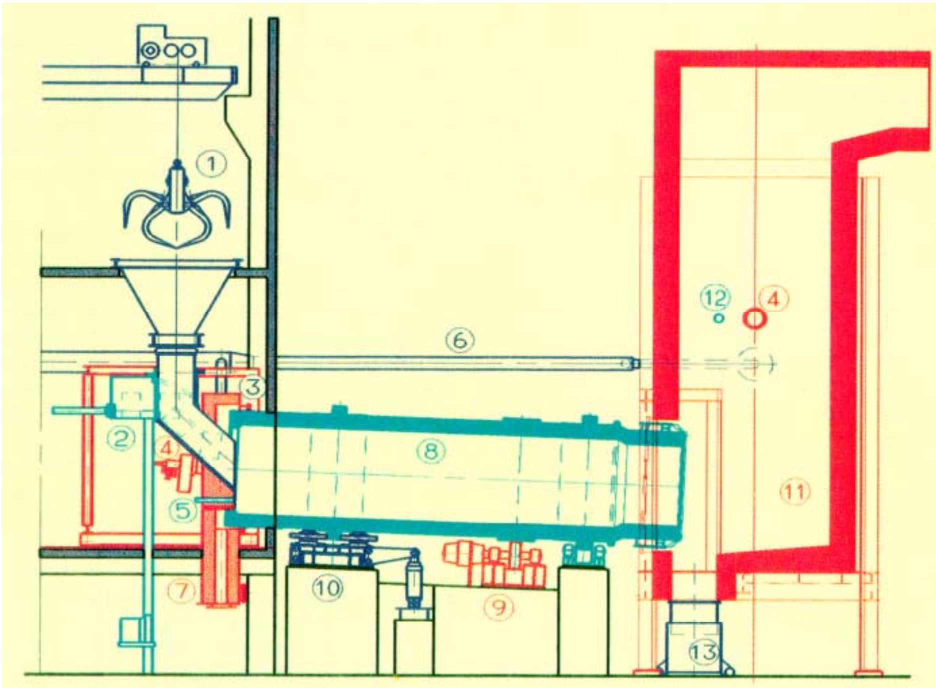
1 bulk fuel supply. 2 barrel supply. 3 primary air supply. 4 burner for liquid fuel. 5 blowpipe for liquid and paste-like fuel. 6 combustion chamber (rotating tube). 7 drive mechanism. 8 afterburning chamber. 9 water injection. 10 slag discharge.

Figure 4-4: Rotary Kiln (Adopted from [Igelbüscher; 2005])

Table 4.3-1: Application range of selected incineration technologies for treatment of oily waste, modified [Möller; 2004]

	rotary kiln	grate firing	fluidised bed incineration
solid material	+++	+++	+
soil	+++	-	-
gravel	+	-	-
bitumen	+++	+	-
oily municipal solid waste	+++	+	-
oil , 30 – 100 % (m/m)	-	+	+
oil , 5 – 30 % (m/m) *, e.g. sedimentation sludge	+	+	+++
oil , 0 – 5 % (m/m), e.g. flocculation sludge	+	+++	+++

Symbols: * depending on viscosity
+++ well applicable
+ partly applicable
- not applicable



1 crane/bulk fuel supply. 2 barrel supply. 3 primary air supply. 4 burner for liquid fuel. 5 blowpipe for liquid and paste-like fuel. 6 secondary air supply. 7 rotating tube front wall. 8 rotating tube. 9 drive mechanism. 10 track. 11 afterburning chamber. 12 wastewater injection. 13 slag discharge.

Figure 4-5: Rotary Kiln (Adopted from [Igelbüscher; 2005])

The rotary kiln technology has some significant advantages:

1. very flexibly applicable
2. efficient disintegration of conglomerates and aggregates
3. particle size reduction and homogenisation
4. efficient heat transfer within soil and from tube cladding to soil
5. high and constant temperature
6. low energy costs
7. simple construction
8. sintering of residuals.

Mobile rotary kiln installations have operational capacities of 5 – 15 Mg/h depending on proportion of clay and water content [Matig; 1993]. In general, a single kiln has a capacity of 0.1 – 20 Mg/h.

Disadvantages are

1. low turbidity of gas
2. high corrosion of the cladding
3. insufficient retention time of flue gas which makes afterburning necessary
4. highest flue gas production of the existing technologies.

Rotary kilns are not applied for incineration of hazardous waste because a retention time of the flue gas in the afterburning chamber of > 2 s at > 1'200°C is due in this case. Rotary kilns can be operated either with current flow or with counter current flow. Current flow means that fuel and air both are supplied at the cold end of the drum. Ash and gas leave the drum at the hot end. Current flow is applicable for lumpy, pasty or liquid fuel, i.e. for the combustion of materials with high heat values. A major disadvantage is that the ignition zone is dislocated towards the outlet if fuel with low heat value is combusted. In some cases, e.g. in the case of soil with low organic mass fraction or low contamination with oil, additional firing might be necessary.

If air was applied at the hot end of the drum, this is called counter current flow. This operational method is applied in case of fuels with low heat value.

Advantages then are:

1. pre-heating of air
2. direct leading of vapours from drying zone into the afterburning chamber, firing process is not additionally burdened with water steam etc.
3. self-ignition of fuel occurs earlier
4. reduced length of drum

Disadvantages are that this method of operation is only applicable

1. for fuels with heat values > 8'000 kJ/kg
2. if complete combustion is taking place

The latter means that no utilisable of pyrolysis-gas is formed.

Figure 4-6 schematically visualises the **Deutsche Asphalt** thermal soil treatment operation which is a mobile operation installed on site.

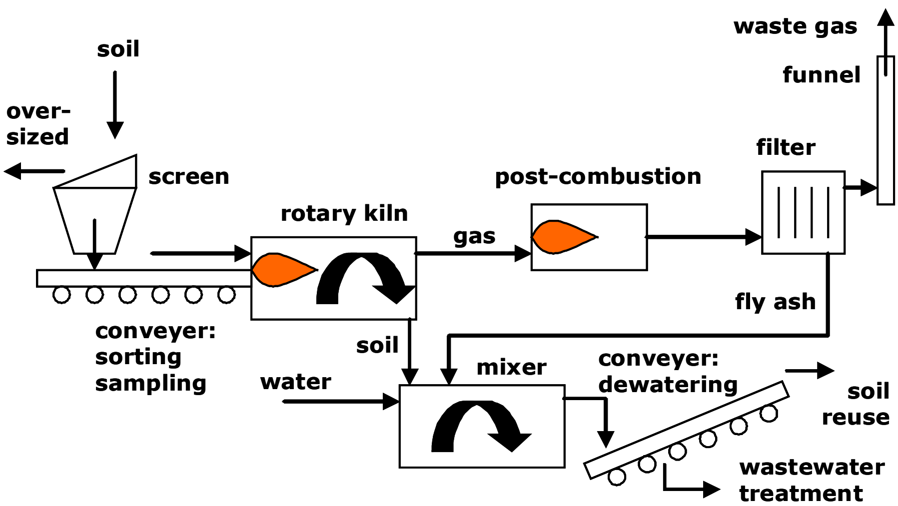


Figure 4-6: Deutsche Asphalt mobile thermal soil treatment operation (Modified according to [Matig; 1993])

The soil is fed via a coarse meshed screen, and the undersized fraction is combusted in a rotary kiln at 400°C. Post-combustion of the gas is carried out at 1000°C. Exhaust gas treatment, washing/cooling of soil and fly ash with water, separation of solids from liquor and wastewater treatment are part of the operation. The residual concentration of oil amounts to 20 – 70 mg/kg. Therefore, the soil can be reused. In Germany specific costs incur of approximately 150 EUR/Mg soil.
In the so-called low-temperature incineration (**Siemens smouldering-incineration technology**) pyrolysis and high-temperature combustion are combined. Pyrolysis (smouldering) of the soil is carried out in a rotating drum at 450°C. Gas flows in counter current flow. Metals and inert solids > 5 mm are separated from the conversion coke. Then, the pyrolysis gas and the pulverised fine fraction of the coke are co-combusted at high temperature (> 1’300°C). The smelter is processed to vitrified granulate through water quenching.

The major and very important advantage of this technology is that only the residuals of the flue gas treatment have to be disposed. The granulated inert smelter can be used in construction.

Disadvantages are:

1. initial crushing of the feed to a maximum grain size of < 200 mm is necessary, e.g. in the case of municipal waste
2. to date no full-scale installation with continuous operation was realised

4.3.7 Grate Firing Systems

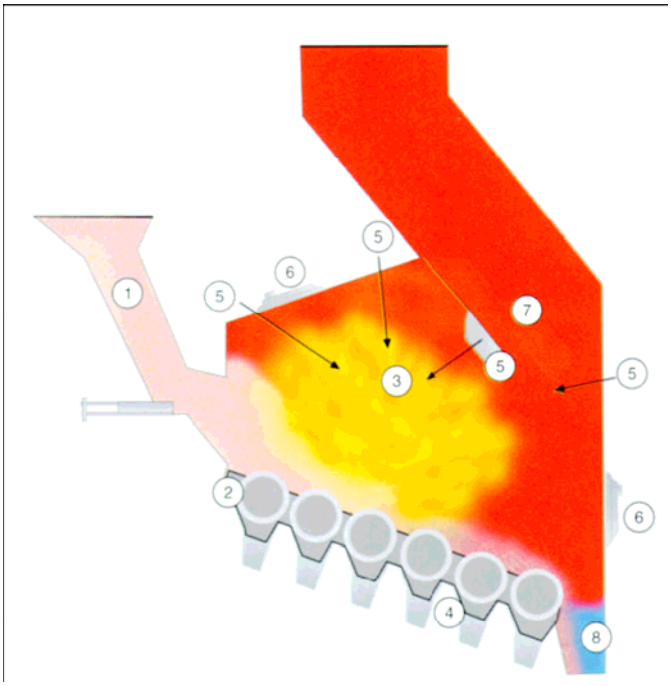
Grate firing systems have abroad spectrum of applications, e.g. for combustion of mixed domestic waste or contaminated soil. Initial size reduction is only necessary in the case of bulky waste. Lumpy or granulated fuel, in this case soil, is poured in bulk on a static or moving grate. The grate fulfils several functions: transport, mixing and spreading of the soil and, if necessary, additional fuel and air supply. Grate and soil are passed through by air/pure oxygen bottom-up.

Subsequently, drying, pyrolysis, combustion, gasification and afterburning (post-combustion) of gas take place:

- drying: in the upper section of the grate, through thermal radiation or convection, warming to > 100°C,
- pyrolysis: further heating during transport on grate, > 250°C, reduced atmospheric pressure, purging of residual moisture and volatile compounds,
- combustion: final incineration, remaining ignition loss of slag < 0.5 %,
- gasification: in the upper part of the combustion chamber, oxidisation of pyrolysis gas with molecular oxygen, > 1 000°C,
- afterburning: minimisation of concentration of incompletely oxidised products and unburned compounds, > 850°C, > 2 s, return of scrubbed flue gas

A variety of specifications of grate firing systems exists, e.g. travelling grates, reciprocating grates, rotating drum grates. In all cases these are slow-motion systems. The operational capacity amounts to 3 – 40 Mg/h domestic waste per line.

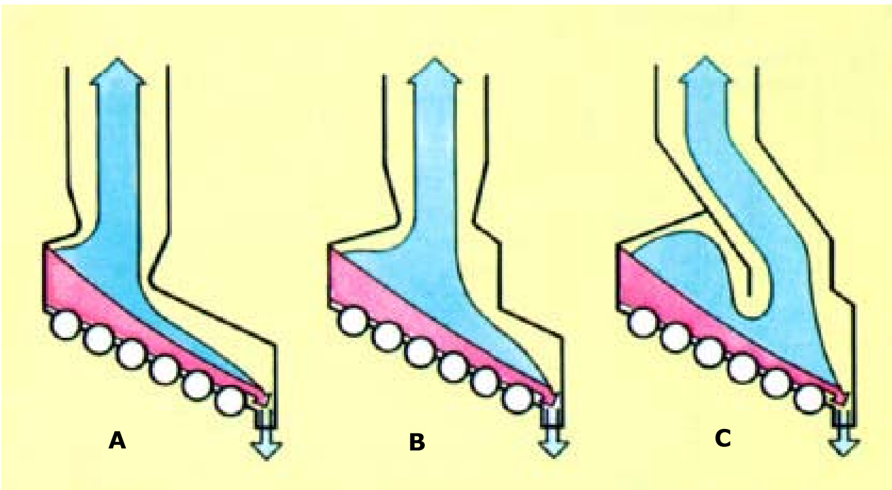
Rotating drum grates (Figure 4.6-5) are frequently applied for soil treatment. Several (six) drums, each 1.5 m in diameter, are placed side-by-side with a total slope of 30 ° the to discharger. The rotation of the drums causes a rolling motion of the soil and, thus, to the effective homogenisation of the soil and an optimal heat transfer.



1 feed. 2 grate rolls. 3 combustion chamber. 4,5 air supply. 6 burner. 7 after-burning zone. 8 bottom slag/ash discharge.

Figure 4-7: Rotating drum grate (Adopted from [Igelbüscher; 2005])

Three major types of air circulation are used in rotating drum grate combustion: current flow, counter current flow, central current flow (Figure 4.6-7):



A) counter current flow. B) central current flow. C) current flow.

Figure 4-8: Critical gas flow path in rotating drum grates (Adopted from [Igelbüscher; 2005])

- current (or direct) flow (A): Fuel/soil and flue gas flow in the same direction and sense of direction. This limits the heat transfer between gas and fuel. Current flow is best suited for dry, rapidly igniting material with high heat values and should prevent excessive heat formation. The gas flows directly through the zone of highest temperature and exhaustive combustion of pyrolysis/ gasification products takes place.

  Disadvantages are:

  I) The highest temperature of the gas is reached at the end of grate. Therefore, re-circulation of the flue gas is necessary for pre-heating of the soil, i.e. if damp material should be incinerated.

II) The formation of gas strands is possible causing an incomplete combustion of the pyrolysis/ gasification products and potentially to an overload of the afterburning zone.

- central current flow (B): is the compromise between current (or direct) flow (C) and counter flow (C).

- counter current flow (C): Fuel/soil and flue gas flow with an opposite sense of direction, the hot flue gas is returned from the ignition to the drying zone (from the lower to the upper end of the grate).

  The main advantage of counter flow operation is that the effective heat transfer and short drying period make this mode of operation appropriate for damp material and material with low heat value.

  Disadvantages are:

  III) the potentially insufficient pre-heating which is a problem, i.e. if odour-forming compounds are formed

  IV) the potential formation of gas strands with an incomplete combustion of the pyrolysis/gasification products and possibly an overload of the afterburning zone.

Fluidised Bed Incineration (Figure 4.6-9) is a special variant that requires a small particle size and a homogeneous particle size distribution of the fuel. Thus, it is only applicable for the incineration of fine granular material, collected fly ash, the silt fraction of soils, flocculation sludge and sewage sludge.

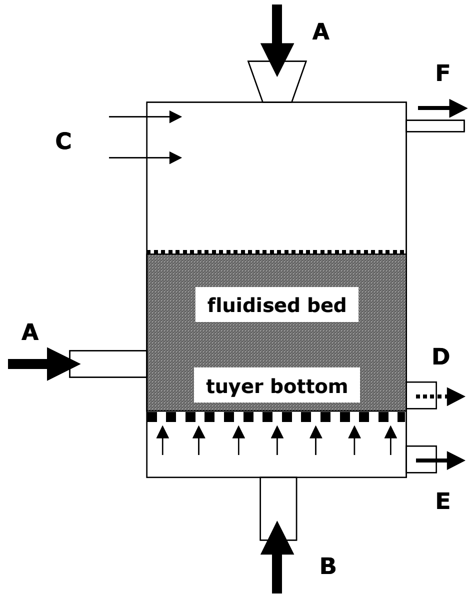
The bottom of the reactor is a tuyer iron equipped with air nozzles and covered by a sand bed. The incineration temperature amounts to < 900°C. Sand bed and fuel are passed through by air bottom-up. This forces the particles into unspecific motion and the subsequent formation of an intensively mixed loose layer that exhibits physical properties similar to boiling fluid. Increase in air velocity further reduces the difference between pressure loss in the sand bed and the counter pressure of the fuel mass. Medium high air velocity leads to an equilibrium and a stationary bed or a bed with a macroscopically static surface. A very high air velocity, in combination with an inclined upper wall (deflector), produces a rotating bed.

Advantages of the fluidised bed technology are:

1. the broad spectrum of tolerable heat values
2. the very homogeneous combustion conditions independent on the properties of the fuel
3. that no moving components implemented into the combustion chamber
4. the clean (odourless) burn
5. the low air consumption and flue gas formation
6. that heat exchange is possible at the bed level
7. the potentially reduced formation of hazardous gases through application of additives (lime)

Disadvantages are:

1. pre-sorting of the fuel is necessary to separating non-combustible components
2. a very homogeneous and small particle size is required
3. an uneven horizontal fuel distribution can occur if the bed has a large diameter
4. the maximum temperature is limited due to the softening of the bed sand
5. it is only applicable for the incineration of less polluted fuel because the retention of heavy metals in the ash is limited
6. fine particles are extensively discharged with flue gas (uncontrolled entrainment), fly ash has to be separated by means of cyclones and return in a loop
7. temperatures > 900°C are achieved only in the afterburning chambers and only with additional firing
8. intensive abrasion of components of the main and afterburning chambers occur



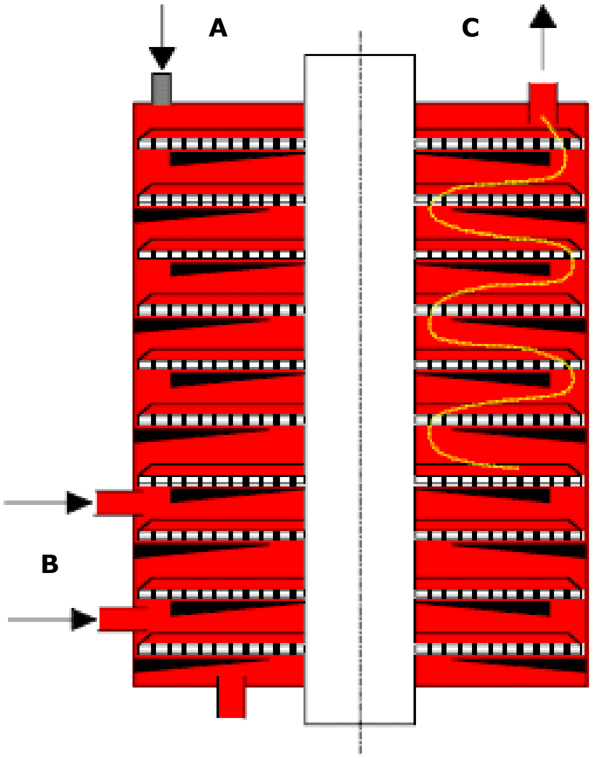
A) fuel supply. B) air supply. C) secondary air supply. D) discharge of coarse material. E) ash removal. F) flue gas discharge.

Figure 4-9: Fluidised bed incineration (According to [Bilitewski; 1997]; [Igelbüscher; 2005])

In the **Volund incineration system**, a combination of a stoker and travelling grates (drying, initial incineration) is coupled to a rotary kiln (final combustion).

4.3.8 Multiple Hearth Furnace

Multiple hearth furnaces (Figure 4.6-11) are applied especially for the simultaneous incineration of lumpy material with homogeneous particle size and sludge or pastures. In most cases, fuel is supplied top-down under counter current air flow. Incinerations goes on at < 850°C. Both current flow and combinations of counter current and current flow are possible as well.



A fuel supply. B air supply. C flue gas discharge.

Figure 4-10: Multiple hearth furnace (Adopted from [Igelbüscher; 2005])

Multiple hearth furnaces realise a very efficient heat transition from ash to air. Therefore, the final ash temperature does not exceed 80 – 90°C.

Disadvantages are:

1. pre-treatment of fuel is necessary, i.e. classing, crushing, homogenisation
2. the differential regulation of the air supply is difficult
3. additional firing at lower levels is necessary if dumpy fuel is incinerated
4. too rapid heating > 400°C can occur with formation of incrustations through additional heating
5. i.e. in the case of counter current air flow formation of gas strands can occur
6. incomplete combustion and odour formation can occur
7. self-ignition of highly volatile compounds in lowest levels can occur
8. temperatures can increase to > 1 000°C causing sintering of the ash
9. afterburning of the flue gas is necessary
10.

4.3.9 Thermoselect Technology

The principle of the Thermoselect technology is the combination of pyrolysis and gasification. The fuel is pressed to a compact block (10 % of the initial volume) and dried in a batch furnace. Subsequently, degasification and optionally pyrolysis of the fuel are carried out. At the end of the degasifier, the solids fall into a chamber equipped with additional gas and air lances. The temperature in this chamber increase to up to 2’000 °C and high-temperature gasification, pyrolysis and partial oxidation occur. The mixed synthesis gas of degasification, pyrolysis and gasification consists of CO, CO_2, H_2, H_2O, fly ash and trace gases, is extensively purified and can be used e.g. for power or heat generation. The inert constituents of the fuel are smelting in the high-temperature reactor. They slip into the homogenisation reactor, are metallurgically conditioned and processed to an oxidised slag carrying a metallic molten phase. The slag is re-solidified in a water quench and granulated. This technology produces a very small volume of flue gas (1/8 of grate firing) but has not yet been realised at full-scale level with continuous operation.

4.3.10 Noell Conversion Technology (Jaeger & Mayer, 2000)

The core of the Noell conversion technology is the combination of pyrolysis and pressurised high-temperature gasification. The technology basically comprises

1. if necessary classing and crushing of the fuel < 50 mm
2. initial drying (water content 10 %)
3. pyrolysis at 550°C
4. processing of pyrolysis coke, separation of pyrolysis oil and water from gas, of metals from coke
5. separate quenching of pyrolysis gas and pyrolysis coke
6. milling of coke
7. joint pressurised (25 bar) high-temperature (1500°C) gasification of pyrolysis gas, pyrolysis oil, powdered coke.

The product of this process is a synthesis gas free of hydrocarbons. After extensive gas purification is used for power generation.

There are two major disadvantages of this technology:

1. inert solids except of metals are not separated from the fuel
2. to date no full-scale installation with continuous operation was realised

4.3.11 Treatment of Waste Gas

Natural oil and especially processed oil do not exclusively consist of substances formed by hydrogen, oxygen and carbon atoms. In addition, the oil polluting the environment due to an oil spill might already have been spiked with additives. Therefore, in order to reducing the emissions of nitrogen oxides, carbon oxides, sulphur dioxide, chlorine compounds, PCDD/Fs, heavy metal compounds, PAH's, carbon black etc., treatment of waste gas and/or exhaust air is a part of every soil incineration operation [Möller; 2004].
Small amounts of volatile hydrocarbons in waste air from soil deposits etc. are sorbed by activated carbon or degraded in biofilters. After vaporisation and gasification steps, combustion of the gas is carried out. After any treatment including an incineration stage, catalytic post-combustion of the waste gas is necessary. The post-combustion is mostly an integrated part of the incineration.

The actual waste gas treatment must include particle collection and gas treatment:

- particle collection: The type of the collector mainly depends on the particle size distribution of the fly ash. Mostly, a cascade of different collectors is operated e.g. cyclones, washers, electrostatic filters, Cottrell-filters, fabric filters. In the case of used oil, the grain size of 80 % of the particles (m/m) is < 1 µm. It is surely and permanently possible to keep the German threshold value of 30 mg/m^3 fly ash remaining in the effluent gas flow. In the case of washers, water treatment is necessary.

- gas treatment: Gaseous products of oil combustion beside of H_2O and CO_2 are mainly SO_2, HCl and NO_X. Wet, spray and dry sorption are applied.

  I) Wet sorption is in most cases a two-step alkaline and acidic measure. Vaporisation of water and crystallisation of salts take place either subsequently or through return into the gas stream before the particle filter.
  II) Spray sorption is conducted before the dust collector. The sorbent is sprayed into the gas stream, water is vaporised, reaction products (salts) are formed, crystallise immediately and are separated in the collector stage. The efficiency is lower than that of wet sorption and the consumption of sorbent is higher.

III) For dry sorption is a dry alkaline sorbents ($Ca(OH)_2$) sprayed into the gas flow. The sorbent reacts with acidic gas components, reaction products (salts) are formed and crystallised immediately and subsequently separated in the collector stage.

The efficiency of dry sorption mainly depends on the water steam content and the temperature of the gas. If necessary, of water must be added. The efficiency is again lower than in the case of wet sorption, and the consumption of sorbent is higher.

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5 Bioremediation of oily Soil, Sand and Sediments

There are several influencing processes that lead to a reduction of oil spill impacts. This chapter supplies an overview of all these processes. The reader gets to know that the most important process -regarding to this handbook- is just a sub-process that needs to be combined with a couple of other processes.

5.1 Influence of Microorganisms and Weathering

5.1.1 Influence of Microorganisms on Oil

A special biological reaction to spilt oil is biodegradation. Sea water and sediment contain a range of marine bacteria, moulds and yeasts. Some of these microorganisms can utilise oil as a source of carbon and energy. They are widely distributed in the sea and more abundant in chronically polluted waters.

The main factors affecting the rate of biodegradation are:

- Temperature
- Availability of oxygen, and
- Availability of nutrients, mainly nitrogen and phosphorus

Each type of microorganism tends to degrade a specific group of hydrocarbons that a wide variety of compounds can be degraded by a range of bacteria. However, some components are resistant to attack (e.g. high molecular PAH with more than four rings like Benzo(a)pyrene). The microorganisms are regularly not present in sufficient numbers to degrade substantial amounts of spilt oil. With the right conditions they multiply rapidly at the oil/water interface until the process becomes limited by nutrient or oxygen deficiency.

Oil can be degraded at this interface only, as the bacteria live in the water. The creation of oil droplets, either through wave and wind action, or through naturally produced or added chemical dispersants, increases the oil droplets' surface which enhances biodegradation. It has been observed that a majority of degrading microorganisms are present in marine sediments, where the not water-soluble oil components tend to concentrate. Sediments with chronic exposure to pollution have been found to harbour microbial communities with the highest potential for hydrocarbon biodegradation. Half-lives for single PAH compounds got observed from 2.2 to 14 weeks. The half-live of four-ring PAHs got asserted with 34 to 87 weeks. In the absence of oxygen no biodegradation was found.

The variety of factors influencing biodegradation makes it difficult to predict the rate of oil removal. In temperate waters, daily rates of between 0.001 and 0.03 grams per tonne of seawater have been reported. The rates may reach 0.5 to 60 grams per tonne in chronically polluted areas. Once oil becomes incorporated to sediments, degradation rates get significantly reduced due to a lack of oxygen and nutrients as well as often due to low temperature.

Because of this it is more efficient and controllable to use degrading bacteria on shore to clean-up oil/water residues after as much oil as possible has been taken out of the water. Only the remaining small percentage will degrade naturally over time at sea. Under controlled conditions in a process called "bioremediation", temperature, oxygen and nutrient content can be influenced for optimum degradation rate and extent.

Around 30 % of crude oil components are resistant to microbial degradation, in heavy fuel oil this percentage is increased.

The following text summarises the impact that oil spills can have on selected marine habitats.

5.1.1.1 Principles of Microbial Megradation of Oil

Bioremediation describes an active used biological technique for reducing negative consequences on the environment due to an oil spill. This process is run by microorganisms, mainly bacteria, which break down a wide range of organic contaminant, such as oil. The great advantage of the bioremediation is the contaminant's removal by the enhancement of the natural biodegradation process of converting these potentially toxic compounds into water and carbon dioxide.

There are several methods to increase the natural biodegradation process: bio stimulation means the addition of nutrients to the spill if the prevailing environmental conditions are insufficient for the required biodegradation process (fertilisation). Bio augmentation is the to resettlement of microorganisms if needed microorganisms are not abundant or their number is inadequate. Phytoremediation is a process utilizing plant growth to accelerate the rate of oil biodegradation and/or habitat recovery.

As the spill-sites vary as well as the respective oils there is no single response technique to be named that suits all spill operations. Therefore it is important to get to know all factors regarding the environment and the oil spill and to set up contingency plans including all current clean-up methods.

5.1.1.2 Microorganisms and susceptible Contaminants

Nearly every environment accommodates microorganisms, which are able to degrade hydrocarbon-based compounds. More than 200 species of bacteria, yeasts and fungi have been shown to degrade hydrocarbons and they are ubiquitous in marine, freshwater, and soil environments. Bacteria are the predominant hydrocarbon-degraders in marine environments, yeast and fungi are also important in freshwater environments. A list of oil-degrading bacteria and fungi is presented in Table 5.1-1.

Table 5.1-1: General oil-degrading bacteria and fungi

bacteria	
Achrornobacter	Lactobaoillus
Acinetobacter	Leumthrix
Actinomyces	Moraxella
Aeromonas	Nocardia
Alcaligenes	Peptococcus
Arthrobacter	Pseudomonas
Bacillus	Sarcina
Beneckea	Spherotilus
Brevebacterium	Spirillum
Coryneforms	Streptomyces
Erwinia	Vibrio
Flavobacterium	Xanthomyces
Klebsiella	

fungi	
Allescheria	Oidiodendrum
Aspergillus	Paecylomyces
Aureobasidium	Phialophora
Botrytis	Penicillium
Candida	Rhodosporidium
Cephalosporium	Rhodotorula
Cladosporium	Saccharomyces
Cunninghamella	Saccharomycopisis
Debaromyces	Scopulariopsis
Fusarium	Sporobolomyces
Gonytrichum	Torulopsis
Hansenula	Trichoderma
Helminthosporium	Trichosporon
Mucor	

Organic contaminants may be degraded by a single type of microorganisms, but more likely, by complex mixed cultures, the components of which may require special environmental conditions. Simple low molecular (light) hydrocarbons will be degraded most rapidly. Here are some compounds susceptible for biodegradation:

- oils (e.g. petroleum, diesel, heating oil, crude oil, lubricants and some fuel oils)
- polycyclic aromatic hydrocarbons (PAH's)
- oxygenated hydrocarbons (e.g. glycols, surfactants, detergents)
- pesticides
- BTEX components (benzene, toluene, ethyl benzene, xylene)
- solvents
- chlorinated solvents
- amines
- anilines
- some explosives

5.1.2 Influence of Weathering

Oil introduced into the environment immediately goes through a variety of physical, chemical and biological processes that changes the oil composition and its properties: normally it will break up and dissipates or scatters into the marine environment over time. These processes are known as weathering. Depending on the oil properties oils weather in different ways.

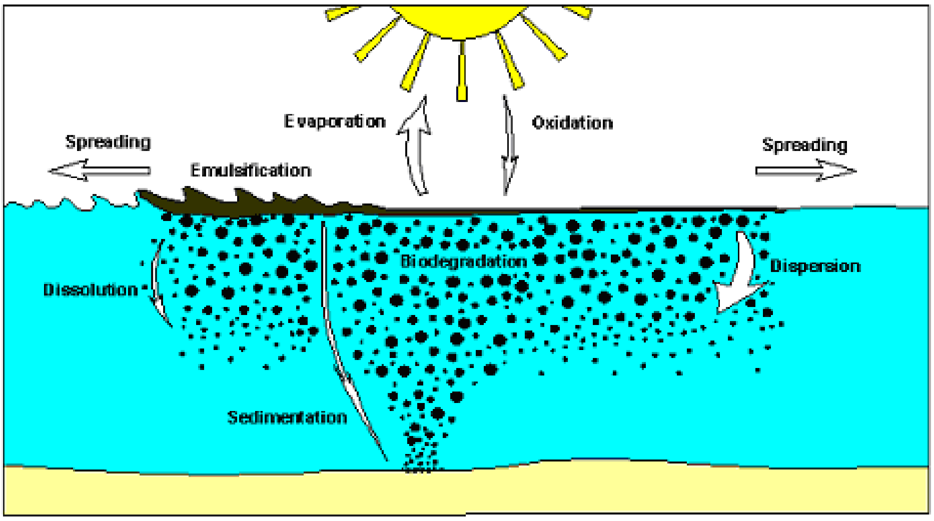

Figure 5-1: Fate of oil spilled at sea showing the main weathering processes [ITOPF F&E; 2005]

5.1.2.1 Evaporation

In terms of environmental impacts, evaporation is the most important weathering process during the early stages of an oil spill. It is responsible for the removal of a large fraction of the oil including the more toxic, lower molecular weight components. This process changes the remaining oil's physical properties significantly due to increased density and viscosity.

The amount of evaporation and the speed at which it occurs depend upon the volatility of the oil: the more light and volatile compounds an oil contains, the more oil evaporates to the atmosphere. In general, in temperate conditions, those oil components with a boiling point under 200°C tend to evaporate within the first 24 hours. Evaporation may increase as the oil spreads, due to the increased surface area. Also a rougher sea, high wind speeds and high temperatures tend to increase the rate of evaporation and the proportion of an oil lost by this process. However, these volatile components may be more persistent when oil is stranded in sediments.

The volatile components make up 20-50% of most crude oils, about 75% of No. 2 fuel oils, and about 100% of gasoline and kerosene.

Evaporation of volatile oil components may benefit microorganisms by removing more toxic low molecular weight compounds such as benzene and smaller normal (*n*-)alkenes.

5.1.2.2 Spreading

Oil spilled on water soon starts to spread out over the sea surface, initially as a single slick. The principal forces influencing the spreading include gravity, inertia, friction, viscosity and surface transfer via evaporation, dissolution, and later biodegradation. The speed at which the spreading takes place depends upon the viscosity of the oil: fluid: low viscosity oils spread more quickly than those with a high viscosity. The thickness of the oil layer varies. After few hours the slick will begin to break up and due to winds, wave action and water turbulence will form narrow bands or windrows parallel to the wind direction.

Other factors influencing the rate of the spreading and breaking up are the prevailing conditions such as temperature, water currents, tidal streams and wind speeds. The more severe those conditions, the more rapid the spreading and breaking up.

5.1.2.3 Dispersion

The oil slick can, if forced by waves and turbulences at the sea surface, break up into fragments and droplets of varying sizes which become mixed into the upper levels of the water column. Whereas the larger droplets will tent to rise to the surface to coalesce with other droplets to reform a slick or to spread out to form a very thin film, the smaller ones remain suspended in the water column. This suspended oil has an increased surface area now which encourages other natural processes such as dissolution, biodegradation and sedimentation to occur.
The natural dispersion can be accelerated by the addition of chemical dispersants.

5.1.2.4 Emulsification (chocolate mousse)

An emulsion is formed when two liquids combine, with one ending up suspended in the other. This process involves a change of state from an oil-water slick or dispersion to a water-in-oil emulsion, occurred by physical mixing promoted by turbulence at the sea surface. Thus formed emulsion may contain up to 80% water, is usually very viscous, and is commonly called “chocolate mousse”.

Oil that forms emulsions with water is more difficult to degrade than weathered unemulsified oil. The emulsion causes the oil volume to increase up to three and four times. This slows and delays other processes which would allow the oil to dissipate.

5.1.2.5 Dissolution

The dissolution of hydrocarbons is important due to their potential influence on the success of bioremediation and the effect toxicity on biological systems. The extent of dissolution is influenced by photochemical and biological processes and depends on the solubility of the spilled oil, weather conditions, and the characteristics of the spill site. The low molecular weight aromatics (e.g. benzene and toluene) are the most soluble oil components, and they are also the most toxic components in crude and refined oils. However, these compounds are also those first to be lost through evaporation, a process which is 10-100 times faster than dissolution. That’s why dissolution is of less importance regarding mass loss during an oil spill.

5.1.2.6 Oxidation

Oxidation is a weathering process that may have important biological consequences. In combination with oxygen, sunlight may be strong enough to transform complex petroleum compounds (e.g. high molecular weight aromatics and polar compounds) into more simple compounds with increased solubility in water, due to the formation of polar compounds. This process may be associated with the formation of toxic compounds.
On the other hand oil reacts with oxygen in forming persistent compounds called tar. The expected extent of tar production (thin films break down at no more than 0.1% per day) depends on the oil type and the extent of the oil exposed to sunlight. The tar formation is caused by the oxidation of thick layers of high viscosity oils or emulsions. Typical examples of this process are tar balls, to be found on shorelines, which have a solid outer crust surrounding a softer, less weathered interior.

5.2 Natural Attenuation (NA)

5.2.1 Definition and Principles of Natural Attenuation

If a chemical compound is spilled into natural biosphere following a human activity or an accident, a lot of processes in the nature can help to avoid a further spreading of this compound. Some of these processes can significantly reduce the amount of the chemicals and can lead to a diminishing of danger that emanates from it. In the practice of contaminated site treatment these processes were summarized under the expression "Natural Attenuation".

One of the regular definitions is given by the US-American *Environmental Protection Agency (EPA)* as following:

Natural Attenuation means:

> *Naturally occurring processes in soil and ground water that act without human intervention to reduce the mass, toxicity, mobility, volume or concentrations of contaminants. [OSWER 1999]*

A typical example caused by NA is the reduction of a pollutant's concentration over the time:

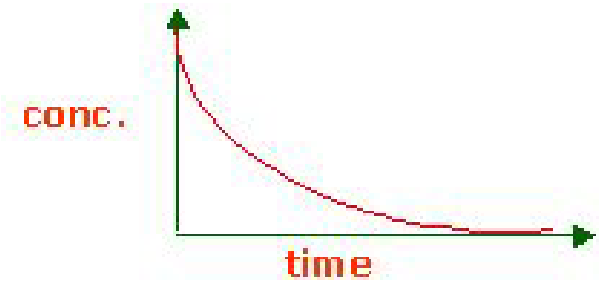

Figure 5-2: Reduced compound concentration by NA [Khan; 2003]

Figure 5-3 shows the typical distribution of a pollutant (with less dense than water, Light Non-Aqueous Phase Liquids = LNAPL) in the subsurface:

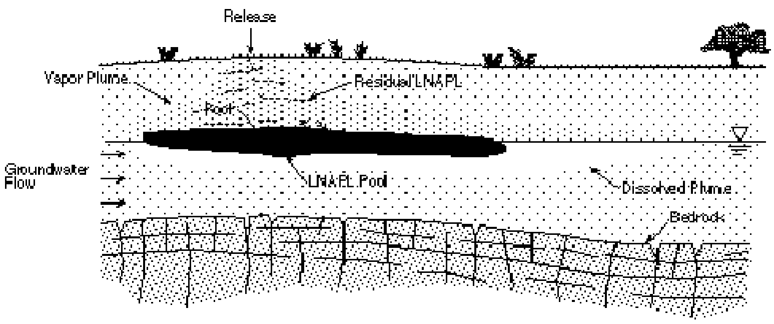

Figure 5-3: Spill of a pollutant into soil and groundwater [CLU-IN; 2005]

Immediately after the spill, the following processes governing the fate:

- Dilution
- Dispersion
- Adsorption
- Volatilisation
- Abiotic Transformation
- Biodegradation

5.2.2 Singular Processes of Natural Attenuation

5.2.2.1 Adsorption

Adsorption is the partitioning of contaminants between aqueous phase and solid aquifer matrix. It decreases the dissolved contaminant concentration until a steady state is reached.

Adsorption itself doesn't lead to net loss of contaminant's mass!

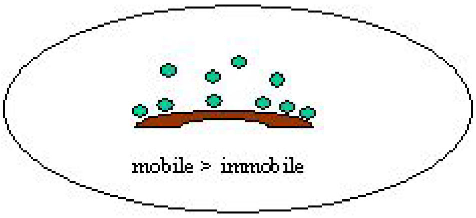

Figure 5-4: Adsorption on a solid surface

5.2.2.2 Dilution, Dissolution

The contaminant becomes transferred and solutes to aqueous phase. Dilution is the most significant physical process what controls the extent of pollutants plume. The Plume becomes stable or expanding (with decreasing pollutant concentrations) if residual (source) contaminants have been removed. No net loss of contaminant mass !

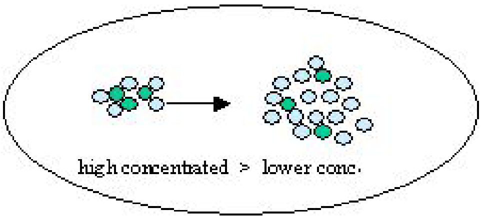

Figure 5-5: Drawing of dilution principle

5.2.2.3 Dispersion

Dispersion is caused by a mechanical and hydraulic mixing of the pollutant and the surrounding soil water or groundwater during the flow trough porous soil matrix. It will decrease contaminant concentrations in centre of plume and increase the concentration on edges. There is also no net loss of contaminant mass!

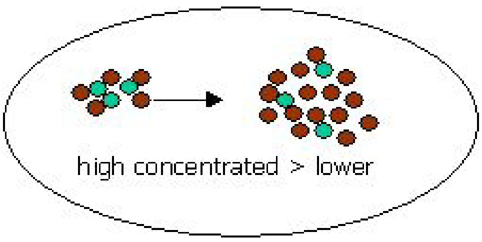

Figure 5-6: Drawing of dispersion by flow through solid porous matrix (brown coloured)

5.2.2.4 **Volatilisation** (Evaporation)

The contaminants move from liquid phase to vapour phase (in to the air or ground air). Volatilisation can result in a net loss of contaminants mass from the aquifer. Rarely a significant attenuation mechanism in the aquifer, except in capillary zone.

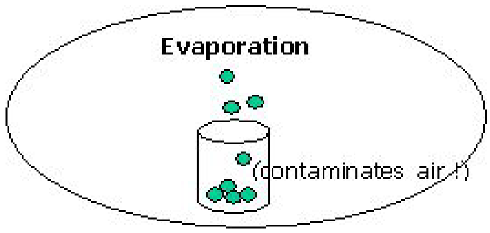

Figure 5-7: Principle of evaporation from aqueous phase

5.2.2.5 **Abiotic Transformations**

The contaminants react and form into other compounds ore break down products. Responsible reactions are for instance hydrolysis, dehalogenation, photo oxidation. These Transformation lead to a reduction of contaminant mass and reduces the aqueous concentrations !

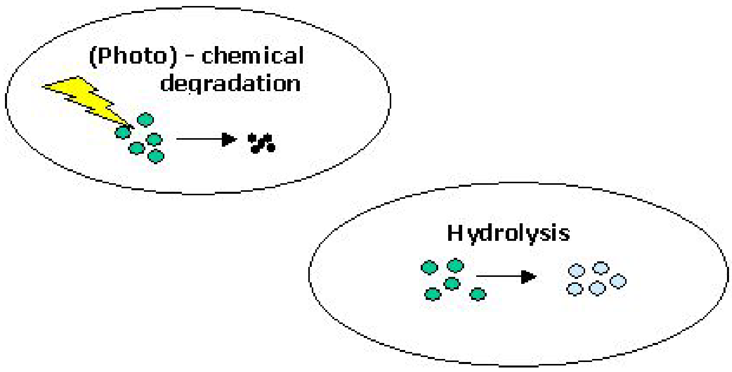

Figure 5-8: Examples of abiotic transformation processes

5.2.2.6 **Biodegradation** (Biotic Transformation)

Organisms include the contaminants in their metabolic process, for instance as source of energy. They transferred the origin compound into other products like carbon dioxide. Contaminants mass will be reduced due this transformation and lead to decreasing aqueous concentrations. It is the most significant process resulting in reduction of contaminant mass in a natural system.

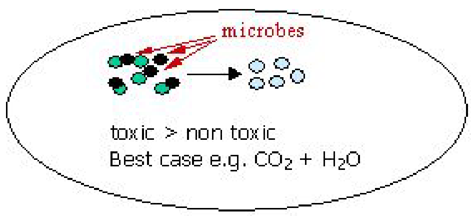

Figure 5-9: Biodegradation - Examples of a pollutant

5.2.3 Combined Processes of Natural Attenuation

In natural systems like a soil or water body non of the processes mentioned above happens singular. They mostly occur parallel and overlapped. The combination of all these NA- processes can significantly decelerate the movement of a pollutant plume and reduce its extent. In a wider time scale Natural Attenuation can lead to a complete clean up of the polluted area and the vanishing of the contaminant.

Combination of various NA-processes and consequences on plume's movement and shape shall be explained in:

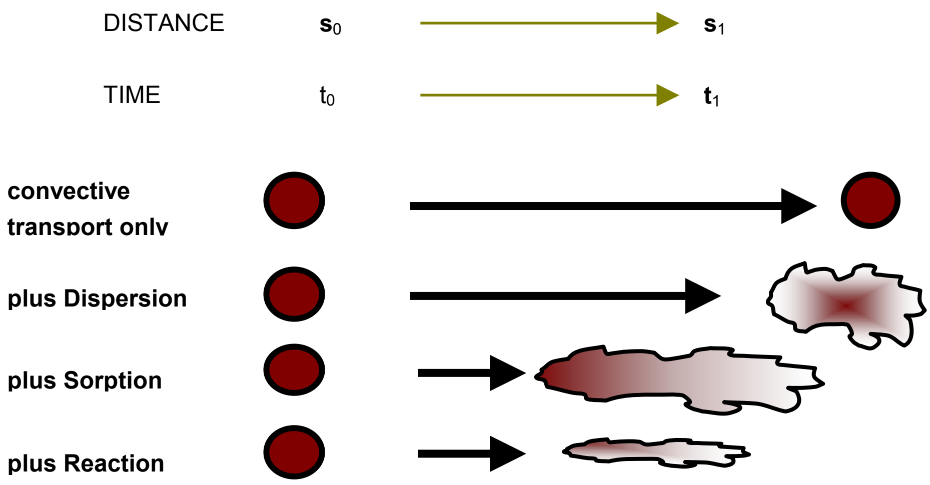

Figure 5-10: Influence of NA-processes on contaminant's plume movement and extent

5.2.4 Summarised Aspects of Natural Attenuation

The including of NA as remediation strategy has to guaranty, that transformation to less hazardous forms and immobilisation of the origin pollutant successfully occur, such as:

ORGANIC COMPOUNDS	to	non hazardous end products and
INORGANIC COMPOUNDS	to	chemical or biological stabilisation

? WHY should NATURAL ATTENUATION be considered as an option for remediation of sites?

- BECAUSE NA HAPPENS ANYWAY
- BECAUSE NA CAN BE A NON – DESTRUCTIVE TECHNIQUE
- BECAUSE NA HAPPENS IN – SITU
- BECAUSE NA IS COST EFFECTIVE
- BECAUSE NA CAN BE A GOOD REMEDY
- BECAUSE NA IS AN IMPORTANT PART OF A TREATMENT TRAIN

? Which parameters are necessary for evaluating a contamination?

There is a need for quantitative assessment of a contaminations behaviour – primarily its amount, extent, and rate of travel, as well as long-term evidence of attenuation.

? Is Natural Attenuation a "Do-Nothing Approach"?

N A = No Action ? WRONG !

Examples of Natural Attenuation – Requirements are a reliable site assessments (which require the site's data about hydrogeology, geochemistry, microbiology, etc.) and high tech approaches, too. Furthermore, suitable samplings as well as analytical and model-ling techniques are included.
The combination of both points enables the decision makers to predict contaminants plume / deposits behaviour. The control of sources / hot spot areas is recommended as the containment of undissolved plume sections. A risk management strategy follows directly to the first site assessment.

5.2.5 NA-Processes of Oil

5.2.5.1 Behaviour on Shorelines

In fact, oil is a very complex mixture made up of hundreds of compounds, mostly hydrocarbons. Lighter portions of the oil, though more toxic than crude oil, are more likely to evaporate or otherwise dissipate before they can reach the sensitive shoreline habitat. Laboratory studies have shown that evaporation can reduce the volume of even a crude oil slick by 20-40%. Heavier oil that does not evaporate, although not as toxic as refined oil, can wash onto rocky and sandy shores where it can cause serious short-term harm to shellfish and plant life.

Hydrocarbon utilising bacteria very quickly become attached to the insoluble oil droplets. They appear on the surface of the slick and in the presence of oxygen microorganisms can oxidise the oil to harmless carbon dioxide. The naturally occurring bioremediation process can possibly be speeded up through increasing the activity of such microbes by providing them with additional nutrients such as Nitrogen or Carbon.

By doing this, the microbe population increases rapidly as they have an additional food-source. This means that a greater area of the oil spill will be covered by microbes, which, in turn, means the breakdown process can be substantially speeded up.

Another problem is oil becoming trapped in sediment - this also increases the duration the oil remains [Barnbrock; 2001].

5.2.5.2 Spill of a Pollutant at the Sea

The oil starts to spread over the sea surface, soon after it is spilled. The speed at which this takes place depends to a great extent on the viscosity of the oil and the volume spilled. Fluid, low viscosity oils spread more quickly than those with a high viscosity. Liquid oils initially spread as a coherent slick but quickly begin to break up.

Solid or highly viscous oils fragment rather spread to thin layers. At temperatures below their pour point, oils rapidly solidify and hardly spread at all but may remain many centimetres thick. Winds, wave action and water turbulences tend to cause oil to form narrow bands or 'windrows' parallel to the wind direction.

The specific properties of the oil become less important at this stage in determining slick movement. The rate at which oil spreads or fragments is also affected by tidal streams and currents - the stronger the combined forces, the faster the process. There are many examples of spills spreading over several square kilometres in just a few hours and over several hundreds of square kilometres within a few days, thus seriously limiting the possibility of effective clean-up at sea.

Processes which dominate oil movement and fate at the sea are dissolution, emulsification, dispersion, volatilisation (evaporation), abiotic transformation (oxidations and other chemical reactions) and biodegradation.

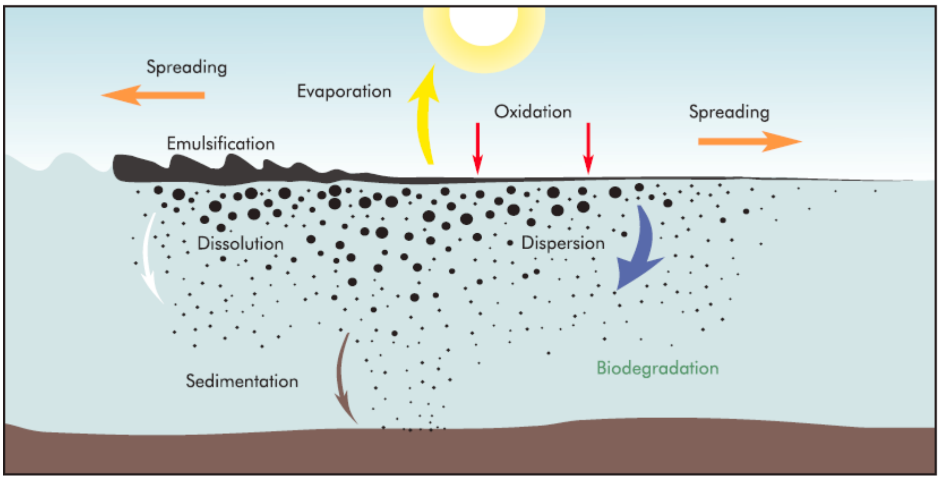

Figure 5-11: Processes which act on spilled oil in open seawater [ITOPF; 2005]

5.2.5.3 Oil on Shorelines

Oil phases in soil move typically in the capillary fringe (border line) between unsaturated and saturated zones. Only higher pressures of oil phases cause an infiltration of petroleum derived hydrocarbons in water-saturated layers (groundwater).

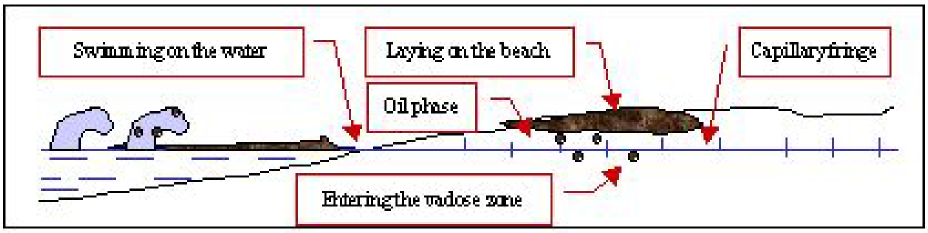

Figure 5-12: Spilled oil on shore [Khan; 2003]

Volatile components of petroleum hydrocarbons like BTEX-compounds vaporize partially at the soil surface and in unsaturated soil layers. In water dissolved oil components only slight adsorb at mineral surfaces in the aquifer. But with increasing amounts of organic carbon content in the soil the adsorption rates grow. It becomes to an important and significant reason of prevention of movement and further spreading of this components known as immobilisation.

Problem: Emulsification

Most oils will take up water droplets and form water-in-oil emulsions under the turbulent action of waves on the sea surface. Very viscous oils tend to take up water more slowly than more liquid oils. Stable emulsions may contain as much as 70%-80% water, are often semi-solid and have a strong red/brown, orange or yellow colour. They are highly persistent and may remain emulsified for a long time.

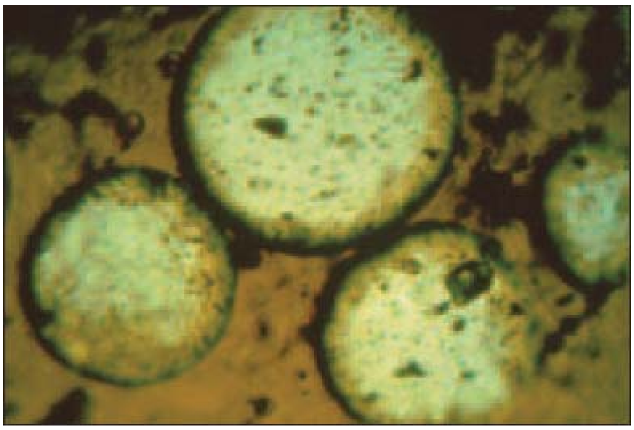

Figure 5-13: A greatly magnified image (x 1,000) of a water-in-oil emulsion showing individual water droplets surrounded by oil [ITOPF; 2005]

Figure 5.2-13: The dissipation of many oils is slowed by the formation of highly viscous water-in-oil emulsions [ITOPF; 2005]

Less stable emulsions may separate out into oil and water if heated by sunlight under calm conditions or when stranded on shorelines. The formation of water-in-oil emulsion reduces the rate of other weathering processes. Formation of solid fragments starts if temperatures reach values below the pour point of the oils. Such oils are highly persistent and have the potential to travel great distances.

Figure 5-14: Nile Blend crude (pour point +33°C) in sea water of 28°C [ITOPF; 2005]

Figure 5-15: Water-in-oil emulsions often accumulate on shores in thick layers [ITOPF; 2005]

Figure 5-16: Solid oil disposal on sandy beach [ITOPF; 2005]

5.2.5.4 Oil in Soils and Groundwater

Petroleum hydrocarbons are general not miscible with water. They are much lighter than water, because of their lower density. But petroleum hydrocarbons are mixtures of compounds with different water solubilities. Several components can diffuse in to the soil water and groundwater. Such a water contaminated with dissolved oil components can easily merge with fresh and non-contaminated water due to the hydrodynamic dispersion. Thus, a progressive dilution occurs, which is transversal and lateral to the water flow direction.

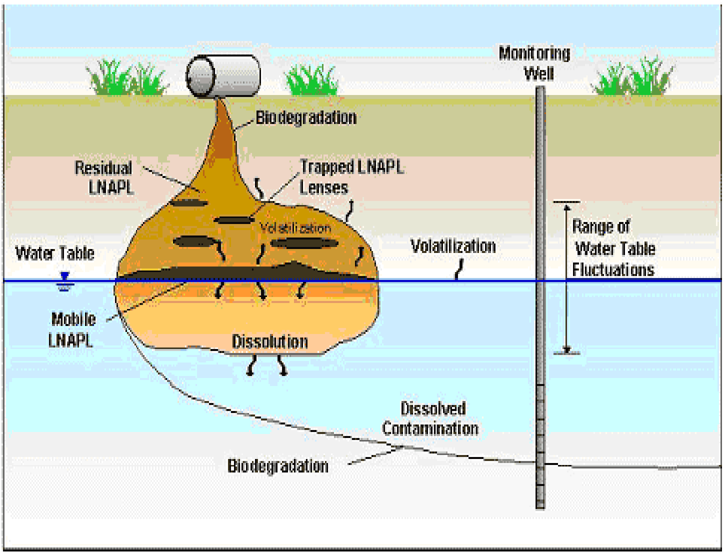

Figure 5-17: Fate of spilled petroleum hydrocarbon in soil and groundwater [Khan; 2003]

The movement of oil phases in soil happens typically in the border zone between unsaturated and saturated (water) areas. Only a higher pressure of the oil phase can cause an infiltration of petroleum derived hydrocarbons in water-saturated layers (groundwater).

Volatile components of petroleum hydrocarbons like BTEX-compounds vaporize partially. These volatilisation occurs both at the soil surface and in the unsaturated soil layers. Due to this transition to the soil air and atmospheric air, the concentration of these components in the oil and water phase decreases [LfU; 1991].

Oil components, dissolved in water, do only slight adsorb at mineral surfaces in the aquifer. But with increasing amounts of organic carbon content in the soil, the adsorption rates grow. It becomes to an important and significant reason that prevents further movement and spreading of this components (immobilisation).

5.2.6 Monitored Natural Attenuation (MNA)

Surveillance of contaminants fate leads to Monitored Natural Attenuation. MNA is reliance on Natural Attenuation processes to achieve site-specific remedial objectives in a time frame that is reasonable compared to other methods. It’s appropriated only when demonstrated capable of meeting objectives in an acceptable timeframe.

Footprints of Natural Attenuation are:

- end products (Carbon Dioxide, Methane, Ethane, Chloride)
- metabolite formation (DCE[8], VC[9])
- associated chemical changes (Sulphate, Nitrate, etc.)
- Oxygen loss, Sulphide, Ferric (II) and Manganese (II) production

None of the above mentioned footprints are really useful for an assessment of on shore oil requirements for Natural Attenuation!

Monitoring challenges have to be sensitive, precise, reliable, reproducible, and easy to handle. They require typically:

- on-site and at the place installation
- continuous control
- process Relation
- quick results
- cost efficiency (but not just “cheap”)
- data obtained serve as base for the decision making process

5.2.7 Enhanced Natural Attenuation (ENA)

If the conditions in the subsurface are not optimal for natural ongoing of biodegradation, it is possible to enhance the Natural Attenuation processes.

In case of Bioremediation we support and maintain the ongoing Biodegradation.

(Bio-)**Remediation** = **enhancement** of
the natural attenuation process “**biodegradation**” !

? Why to enhance natural biodegradation?

[8] Dichlorethane
[9] Vinyl Chloride

At the contaminated site are many processes available for bioremediation, but most of them need support. Typical factors that affect significant biodegradation processes of spilled contaminants at the sites are:

- dissolved oxygen concentration is too high or too low
- low nutrient concentration (Phosphorus, Nitrogen, etc.)
- too much contaminant mass for Natural Attenuation

Short available time frames for NA or MNA clean up decisions due to special site requirements (socio-economic utilisation aspects) can lead to ENA applications.

5.2.8 Decision about Applicability of NA on Oil contaminated Shorelines

Decisions about NA application as treatment option for shorelines require basic knowledge about advantages and disadvantages of oil – NA. Examples are mentioned below:

Time scale is a general disadvantage !

NA-processes take much more time than direct technical remove of the contaminants.

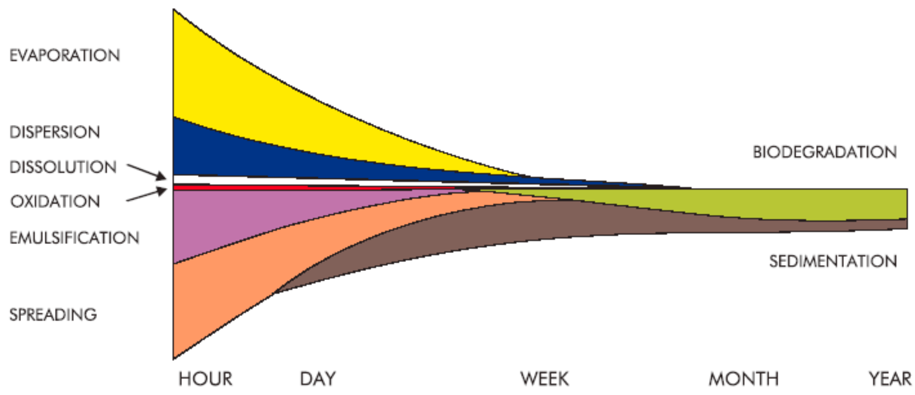

Figure 5-18: Time scale - fate of a crude oil spill showing changes in the relative importance of NA-processes with time [ITOPF; 2005]

Cost benefits are general advantages !

The use of NA for site treatment saves costs for big technical interventions, but this fact depends on the kind of site use and has to pay integration in attention to all socio-economic aspects (habitat functions, areas utilisation, etc.).

Reliable decisions for NA as treatment option demand an integrated Risk Assessment concretised on the contaminated site.

A very important role within a risk assessment takes the Exposure Assessment. The following aspects should be included and considered in each case:

- Release mechanism (volatilisation)
  - Transport mechanism (air convection)
    - Transfer mechanism (volatilisation)
      - Transformation mechanism (chemical reaction)
- Exposure point (air)
- Receptors (population)
- Exposure route (inhalation, ingestion)

Possible exposure pathways are shown in Figure 5-19:

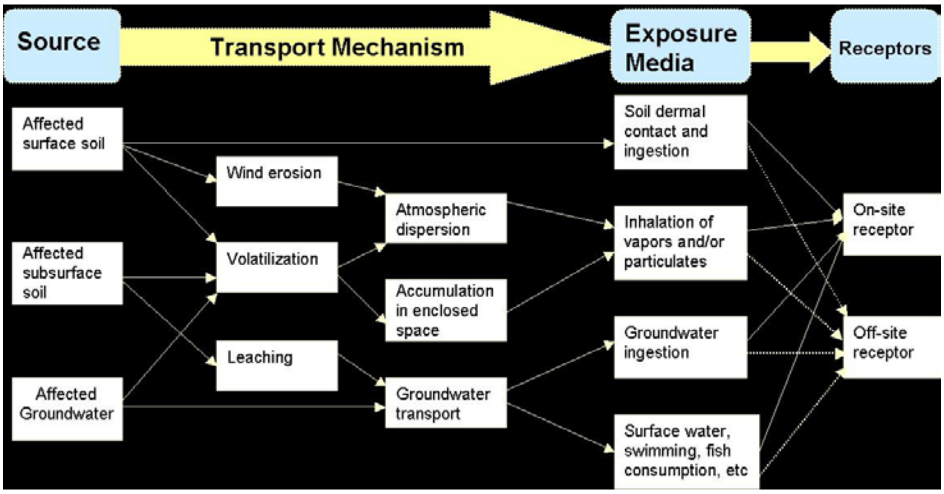

Figure 5-19: exposure pathways from source to receptors [Khan, 2003]

A risk assessment time scale could lead to the following scheme [Khan, 2003]:

Step 1: Review of data and risk characterization

- Screening of data
- Risk Characterization
  - Using Risk Based Screening Level
  - Using Site-Specific Target Levels

Steps 2 and 3: Development of conceptual model and subsequent refinement

- Defining extent of contamination / plume
- Defining physical process effective at the site
- Defining chemical process effective at the site
- Defining biological transformation process effective at the site

Step 4: Modelling of natural attenuation

- Fate and transport modelling of contaminant in vadose zone
- Fate and transport modelling of contaminant in saturated zone
- Modelling of natural attenuation processes

Step 5: Exposure pathway analysis

- Identification of various plausible exposure routes for
  - Onsite receptors
  - Offsite receptors
- Quantification of
  - Onsite risk
  - Offsite risk

Step 6: Long term monitoring plan

- Identification of location of long term monitoring points
- Frequency of sampling and analysis
- Performance evaluation criteria
- Contingency planning

Step 7: Applying for site closure

- Documentation of results
- Demonstration of natural attenuation efficacy of site remediation through
  - Analysis of past historical data
  - Results of analytical/numerical modelling

5.3 Factors and Principles of Bioremediation Techniques

5.3.1 Principles, General Properties

Bioremediation is the active use of techniques to mitigate the consequences of a spill using biological processes in order to stimulate pollutant biodegradation and/or enhanced ecosystem recovery. Biodegradation by naturally occurring or added microorganisms is aimed to break down hazardous substances into less toxic or non toxic substances.

The microorganisms are generally bacteria (but also fungi) and they use organic compounds as source of energy and carbon. Microorganisms require also growth factors (nutrients) and an electron acceptor. The electron acceptor is usually oxygen but others are accepted too (Nitrate, etc.). Nitrogen and Phosphorus are necessary nutrients, although iron, magnesium and sulphur are also needed.

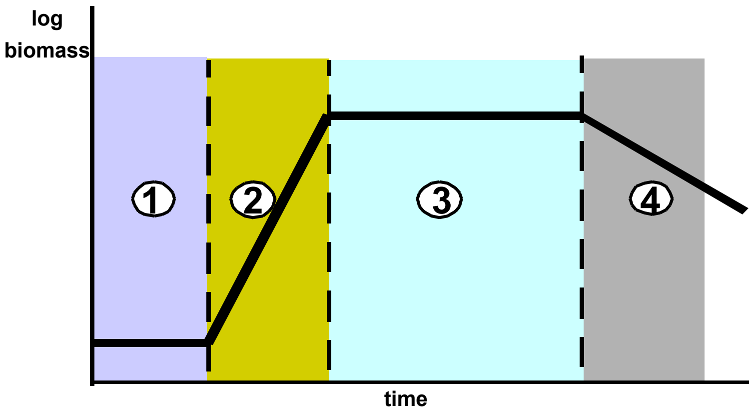

Figure 5-20: Microbial growth during biodegradation

- **Region 1: Lag phase** microbes are adjusting to the new substrate
- **Region 2: Exponential growth phase**, microbes have acclimated to the conditions
- **Region 3: Stationary phase**, limiting substrate or electron acceptor limits the growth rate
- **Region 4: Decay phase**, cells die – death rate exceeds the growth

5.3.2 Factors governing the Biodegradation Processes

Compound specific:

- physical - chemical properties
- biodegradability
- toxicity
- concentrations/ratios

Site specific:

- redox-conditions
- pH value
- availability of nutrients/supplements
- (bio-) availability of contaminants

"Bio" specific:

- interactions
- inhibitors
- induction
- competition
- co-metabolism

5.3.3 Factors Affecting the Efficiency of Bioremediation

Bioremediation is founded on the premise that the natural rate at which biodegradation occurs can be enhanced. The success or failure at which biodegradation works rests on our ability to optimise biological, physical, and engineering parameters at a specific site to achieve the targeted cleanup standards.

It is not easy to evaluate how effective a bioremediation technology is which is caused by several factors:

- In a site contaminated with compounds from a marine oil spill, bioremediation is only one of the processes involved in removal of petroleum from environment. Understanding the effect of this process on the removal of oil we need to understand the other processes involved, too.
- Petroleum is not just a simple pollutant – it contains many contaminants and some of them are easily biodegraded but others are very resistant to microbial degradation.
- There are many different pathways to degrade oil which depend on the type and number of bacterial cultures present in the contaminated area. Therefore, an exact identification of existent microorganisms is required.

Despite bacterial activity and oil characteristics, the rate and effectiveness of bioremediation can be greatly influenced by several environmental conditions. This is an important fact because variables as oxygen or nutrient availability can often be manipulated at spill sites to enhance natural biodegradation. Other variables, such as salinity, are not usually controllable. Insufficient knowledge about the influence of environmental parameters to biodegradation rates may also influence effectiveness of the entire process.

5.3.3.1 Water Content

A soil's water content has great impact on its physical properties such as its tendency to be aerated, compressed, agglomerate, as well as its resistance, and viscosity. A soils ability to be remediated depends on these properties. Furthermore the microorganisms need to be surrounded by water because water is the universal solvent and biochemical reactions depend on this medium to occur. Water is used as medium for transporting nutrients, organic substances and degradation products.

5.3.3.2 Oxygen

is one of the most important requirements for microbial degradation of hydrocarbons. However, its availability is rarely a rate-limiting factor in the biodegradation of marine oil spills. Anaerobic degradation of certain hydrocarbons also occurs, but usually at negligible rates.

Anaerobic degradation of certain hydrocarbons also occurs, but usually at negligible rates. Such degradation follows different chemical paths, and its ecological significance is generally considered minor. Requirements of oxygen can be substantial: 3 to 4 parts of dissolved oxygen are necessary to completely oxidize 1 part of hydrocarbon into carbon dioxide and water.

Oxygen is generally plentiful on and just below the surface of beaches where wave and tide action constantly assist aeration. When oxygen is less available, however, the rates of biodegradation decrease. Thus, oil that has been covered by sediment takes much longer to degrade. Oxygen availability there is determined by depth in the sediment, and height of the water column. Low-energy beaches and fine-grained sediments may also be depleted in oxygen; thus, the rate of biodegradation may be limited in these areas. Pools of oil are a problem because oxygen is less available below their surfaces. Thus, it may be preferable to remove large pools of oil on beaches before attempting bioremediation.

5.3.3.3 Nutrients

such as nitrogen, phosphorus, and iron play a much more critical role than oxygen in limiting the rate of biodegradation in marine waters. Several studies have shown that an inadequate supply of these nutrients may result in a slow rate of biodegradation. Although petroleum is rich in the carbon required by microorganisms, it is deficient in the mineral nutrients necessary to support microbial growth. Marine and other ecosystems are often deficient in these substances because non-oil degrading microorganisms (including phytoplankton) consume them in competition with the oil degrading species. Also, phosphorus precipitates as calcium phosphate at the pH of seawater. Lack of nitrogen and phosphorus is most likely to limit biodegradation, but lack of iron or other trace minerals may sometimes be important. Iron, for instance, is more limited in clear offshore waters than in sediment-rich coastal waters.

5.3.3.4 Temperature

of most seawater is between -2 and 35 °C. Biodegradation has been observed in this entire temperature range since most bacteria are mesophilic and are most active between 5 and 40 °C. Optimal activity can vary but generally occurs at 35 °C. The rates of biodegradation are fastest at the higher end of this range and usually decrease – sometimes dramatically in very cold climates-with decreasing temperature. At low temperature, the rate of hydrocarbon metabolism by microorganisms decreases. Also, lighter fractions of petroleum become less volatile, thereby leaving the petroleum constituents that are toxic to microbes in the water for a longer time and depressing microbial activity. Petroleum also becomes more viscous at low temperature. Hence, less spreading occurs and less surface area is available for colonization by microorganisms. In temperate regions, seasonal changes in water temperature affect the rate of biodegradation, but the process continues year-round.

5.3.3.5 pH - Value

The optimal pH for microbial activity is usually between 5.5 and 8.5 but extremes in pH affect the microbe's ability to degrade hydrocarbons. Although pH does not fluctuate much in the ocean (it remains between 7.6 and 8.1), biodegradation at some sites with extreme pH values may occur as a result of the activity of unique microorganisms which grow in very acidic or alkaline environments. However, pH seems to not have a very important effect on biodegradation rates in most marine environments. In salt marshes, however, the pH may be as low as 5.0 and thus may slow the rate of biodegradation in these habitats.

5.3.3.6 Salinity

Microorganisms are typically well adapted to cope with the range of salinities common in the world's oceans. Estuaries may present a special case because salinity values, as well as oxygen and nutrient levels, are quite different from those in coastal or ocean areas. However, there is little evidence to suggest that microorganisms are adversely affected by other than hyper saline environments.

5.3.3.7 Type of Contaminants

The structure and complexity of a compound determine its potential for aerobic or anaerobic degradation. Generally, hydrocarbons are degraded under aerobic conditions, with simple hydrocarbons being biodegraded faster than complex hydrocarbons. The transformation under anaerobic conditions is very low and not very important on polluted marine environments.

5.3.3.8 Toxic Substances

As showed before some oils have adverse impact on the microorganisms´ existence. The optimal range of this limiting parameters are:

Table 5.3-1: Limiting parameters on microorganisms [Hoffmann et al. 1998]

PDH[1]	2,000 to 20,000 mg/kg
PAH[2]	70 to 300 mg/l
Phenols	< 50 mg/kg
Aromatics	< 200 mg/kg

[1] Petroleum derived hydrocarbons
[2] Polycyclic aromatic hydrocarbons

5.4 In-Situ Bioremediation

5.4.1 Addition of Oxygen

5.4.1.1 Operation Principles

One of the major requirements for microbial degradation of hydrocarbons is oxygen. During biodegradation processes microorganisms consume organic carbon parts of spilled oil and metabolize them under yield of energy. In their growth phase they need the organic carbon for buildup own cell material.

The energy-supplying metabolism of organic carbon to other compounds, in the best case carbon dioxide (complete mineralization), needs electron acceptors oxidation (respiration) of the organic carbon. Energetically oxygen is the most effective electron acceptor and enables the aerobic respiration. Other electron acceptors could be nitrate, sulfate, iron-III; they can be used during anaerobic respiration. But under anaerobic conditions the microbial degradation-rates of oil within sediments are very slow [Atlas et al., 1992; Lee et al., 1991].

The oxygen content in the sediment is typically decreasing by sediments depth and the height of the water column above. With the aim of an effective bioremediation of oil by autochthonous microbes (which already live in sites sediment) the oxygen-supply to these sediment-zones has to be provided. If the microbes get in contact with the oil (here: organic carbon contains the energy source) and the electron acceptor oxygen, they can efficiently metabolize and degrade the oil residues by increasing their own population. The greater the amount of microbes and the area of the oil spill, the greater the velocity and success of the bioremediation breakdown-processes.

Naturally, waves and tidal action constantly assist aeration of the beach sediments, but in many cases the amount of available oxygen is not sufficient. In this case biodegradation of oil takes much longer due to the lack of oxygen available. Here additional supply of oxygen is required and recommended. Methods like sediment tilling have proven themselves as effective techniques increasing the penetration depth of oxygen [Lee et al., 1999].

5.4.1.2 Application

Oxygen Sufficiency

The contaminated sediment needs to be oxygenated sufficiently for maintaining optimum biodegradation rates. Fine sediments (e.g. clay, mud, muddy sand) have a low permeability and are often anoxic. The presence of petroleum in fine-grained sediment often reduces permeability by clogging spaces between sediment particles (polluted sand can thus become impermeable). Oxygen deficiency gets also aggravated by presence of organic matter such as plants, detritus or oil itself. However, its availability is a limiting factor for biodegradation-rates of marine oil spills.

Requirements can be substantial: up to 3 - 4 parts of dissolved oxygen are necessary for complete oxidisation of one part of hydrocarbon to carbon dioxide and water. An ideal-ratio is considered to be 2.6.

Table 5.4-1: Assessment of oxygen sufficiency [IMO, 2001]

Assessment of oxygen content	Criteria for estimating oxygen limitation
Visual and olfactory observation	Black sediment with putrid odor
Measurement of oxidation-reduction potential (redox)	Eh <-50 mV
Measurement of dissolved oxygen in the interstitial water	DO < 1 mg/l

The criteria above offer an exact evaluation of oxygen sufficiency. Nevertheless, a general assessment of the actual oxygen content may be obtained from the shoreline type:

- oxygen is generally plentiful on and just below the surface of beaches. This is due to permanent intake by waves and tidal action;
- on polluted areas where the oil layer was covered by sediments a lower can be expected – availability of oxygen is determined by depth in the sediment, height of the water column, and turbulence;
- low-energy beaches and fine-grained sediments may be also depleted in oxygen;
- oil-pools are problematic, because oxygen is hardly available below – it is strongly recommended to remove the free oil before attempting bioremediation.

At high oil concentrations (more than 5 g/kg of soil) the biodegradation processes will be limited by the availability of oxygen or/and nutrients.

Oxygen Supply

According to the assessment of oxygen-sufficiency, it can be supplied additionally in order to adjust the concentration to the optimum required by oil degrading bacteria. Additional oxygen-supply may be suitable for all sand, gravel and mudflat environments, but the following shoreline-types may particularly require additional oxygen-supply:

- sand to gravel beaches with subsurface oil, where removal is not feasible;
- lightly oiled shorelines, where other techniques are not effective;
- sand beaches with sediment lightly oiled.

A supply of oxygen is not suitable on locations with very sensitive habitats, which may stronglybe affected by a sudden increase in oxygen concentration.

Factors limiting the applicability and effectiveness of oxygen supply (aeration):

- amount of oil penetrated into the sediment layers
- sediment-permeability in order to allow the oxygen penetration from air
- produced impacts
- tidal range
- oxygen concentration

Attention should be paid for limited disturbance of natural shape of shorelines and local habitats on choosing the aeration-technique. The feasibility of mechanical techniques depends on the availability of equipment, the accessibility of the contaminated site and finally on the sediment type. Incorrect set-up may cause deep penetration of oil into anaerobic sediments. If aeration is not feasible then other remediation strategies should be considered.

5.4.1.3 System Design - Methods for Aeration

Aeration of oil contaminated shorelines must be performed with special care. It is important not to bury the pollutant even deeper in sediments. Additionally, the disturbance of natural shape of shorelines and local habitats has to be taken into account when supplying the oxygen.

The methods used on large-scale aeration are mixing or agitating of the contaminated soil, to aerate the oil from the deeper levels with atmospheric oxygen. The majority are regular agricultural methods like raking, ploughing, tilling/harrowing or using a rotovator.

Tilling is a physical method to accelerate natural oil removal by exposing oiled sediments and making them available to higher biochemical degradation. This technique is also an effective tool of aeration for surface layer of sediments. Traditional tilling machines, such as disk harrows and rototillers, can aerate surface soils to a depth of 15-60 cm. A harrow is a heavy frame with sharp teeth, able to aerate the soil for a depth of 15-20 cm. A disk harrow is a harrow equipped with a series of sharp metal disks set on edge or at an angle on one or more axes. Sediments deeper than 60 cm can be aerated by using construction equipment, such as a backhoe.

Figure 5-21:Rototilling (http://www.saukvilletractor.com/html/implements.html)

Currently, tilling is deemed to be a physical method to accelerate natural weathering processes of oil in sandy or coarse-sediment beaches. However, this technique may have some potential in enhancing oil biodegradation in some fine-sediment beaches where oxygen is limited available. Tilling is also considered a low-cost technology among the available aeration methods.

Major concerns regarding this technique include disturbance the natural shape of shorelines and local habitats as well as the potential of releasing oil and oiled sediment into adjacent locations. The tilling of surface soil may cause oil penetration deeply into the shoreline sediments and may reduce the overall oil biodegradation rates, if the oil penetrates into anaerobic sediments.

5.4.1.4 Advantages and Disadvantages of Oxygen Addition

Advantages of Oxygen Addition

- intensifying the aerobic degradation of oil by increasing the oxygen content in deeper sediment layers;
- advanced contact of spilled oil and oil degrading bacteria (due to sediment mixing effects);
- low-cost technologies;
- easy to apply using available farming machines.

Disadvantages of Oxygen Addition

- potential disturbance the natural shape of shorelines and local habitats;
- high increase in oxygen concentration may affect sensitive habitats;
- incorrect use may cause deep penetration of oil into anaerobic sediments;
- not generally applicable on marshlands and wetlands (danger of damaging the existing vegetation).

5.4.2 Addition of Nutrients

5.4.2.1 Operation Principles

The addition of nutrients to the contaminated shorelines will increase the consumption of oil by the indigene bacteria at faster rates than without [NOAA, 1992]. The mechanism behind this process can be explained as follows:

The added oil stimulates the growth of indigenous microbes by providing high amounts of carbon, which is the food source for the microbes. This new food source is not immediately available for consumption. Shortly after the spill the oil is considered to be toxic for the microbes [Lee et al., 1991]. After this lag period, when the most toxic elements for the microbial organisms are weathered (from several days to several weeks), the microorganisms start degrading the spilled oil and thus their population increases dramatically. This sudden increase depletes the existing amounts of nutrients available, nutrients needed by microbes in addition to carbon. By adding the needed nutrients, the microbes' population continues to grow and thus they degrade larger amounts of spilled oil and at faster rates than without supplementation of nutrients [NOAA, 1992].

The nutrient-addition requires supplementing the contaminated areas with compounds like nitrogen and/or phosphorus. Inadequate nutrient-supply (C:N:P-ratio) may result in a slow rate of biodegradation. Marine and other ecosystems are often deficient in these substances also because non-oil degrading microorganisms (including phytoplankton) which consume them in competition with the oil degrading species. Therefore a nutrient-adjustment by adding nitrogen- and phosphorus-rich fertilisers is necessary to stimulate biodegradation of petroleum hydrocarbons (process known as fertilisation).

5.4.2.2 Application

The need of nutrients required for an optimal growth of oil degrading bacteria is obtained from the following equation [ETRG, 2002]:

$$1\ \text{kg HC} + 2.6\ \text{kg } O_2 + 0.07\ \text{kg N} + 0.007\ \text{kg P} \rightarrow 1.6\ \text{kg } CO_2 + 1\ \text{kg } H_2O + 1\ \text{kg biomass}$$ [10]

The equation above shows an optimal-ratio of Nitrogen / Hydrocarbon = 0.07 and
Phosphorus / Hydrocarbon = 0.007

As general rule, the concentration of nitrogen measured in the contaminated soil has to be around 2 mg/l in order to assure favourable conditions for microbial degradation of hydrocarbons [ETRG, 2002]. Typical ratios of nutrients required to support microbial degradation of carbon (from petroleum hydrocarbons), nitrogen, and phosphate are:

- C:N:P = 100:5:1 respectively, as low as
- C:N:P = 300:10:0.05 [ETRG, 2002]
- Optimal C:N:P ratio is considered to be 100:10:1

For initial application, 10% nitrogen relative to the mean oil content in the contaminated soil was recommended by the Environmental Technologies Research Group of Cádiz University of Spain. Nutrients should be re-applied when the concentration returns to background levels (approx. 2 weeks for water fertilisers and 2 months for slow released fertilisation) [ETRG, 2002].

5.4.2.3 System Design

When deciding what technique to be used for the fertilisation of a contaminated shoreline, it has to be ascertained if the addition of nutrients is technically possible and environmentally acceptable. The nutrient-supply will be performed on moderately to heavily polluted shorelines (in continuation of other techniques) and on lightly polluted shorelines where other techniques failed. Fertilisation is not suitable for shallow waters where it may cause eutrophication or toxicity is an important concern. Fertiliser-application can be accomplished in various methods and techniques depending on the contaminated area’s climatic conditions, the type and concentration of spilled oil and finally the availability and price of the fertilisers selected for application.

Due to their high availability, the commonly used fertilisers are products adopted from agricultural or domestic use. Additionally, commercial products have been developed exclusively for use on shorelines contaminated by oil spills. As the contaminated area is usually highly exposed to climatic conditions (especially tidal actions), these products are classified as water soluble fertilisers, slow-release fertilisers and oleophilic fertilisers.

Water soluble Fertilisers

These products include mineral nutrient salts as KNO_3, $NaNO_3$, NH_4NO_3, K_2HPO_4, $MgNH_4PO_4$ and many commercial inorganic fertilisers [EPA, 2001]. The advantage of water soluble fertilisers is their high availability (most of them are common agricultural fertilisers), they are inexpensive and it is easy to prepare them in order to assure the C:N:P-ratios required. The products can be formulated with a site-specific nitrogen and phosphorous content and thus another advantage is that their composition is usually well known. The main disadvantage is that they easily get washed away by tide and waves because of their water solubility. However, this effect is less acute on low-energy shorelines with little turbulences. Studies have shown that even the water soluble fertilisers are able to remain on contaminated shorelines for several weeks before being washed out [EPA, 2001].

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[10] HC represents the mass of hydrocarbons

The application of water soluble fertilisers to shorelines can be done via spraying nutrient-solutions or by spreading the dry granules. This can be carried out by using unqualified labour (by hand) or using commonly used farming machines. If the soil needs additional oxygen supply (aeration, see chapter "Addition of oxygen"), the distribution of grained fertilisers is recommended and effective to be done during aeration (tilling, ploughing etc.).

Figure 5-22: Addition of nutrients to a contaminated beach [VIT, 2003]

Slow-release Fertilisers

These fertilisers are designed to resist water and avoid the wash-out problems caused by tide and waves. They are available in solid form and consist of inorganic nutrients coated with hydrophobic materials like paraffin, vegetable oils or organic nutrients encapsulated by controlled-rate degradable surface coatings [EPA, 2001]. The slow-release fertilisers can be available in granules or pellets and provide a continuous supply with nutrients to the affected area and generally they may be cheaper than water soluble fertilisers due to their frequency of application.

The advantage of using slow-release fertilisers is that they stay longer on-site. Nevertheless, they also can be washed out and moved from the initial application place by high tide and strong waves. The disadvantage of using nutrients in solid form is that they could accumulate in one location and create punctual high concentrations that can be toxic to aquatic life [NOAA, 1992].

The application of slow-release fertilisers on contaminated shorelines can be done by spreading the granules on the affected area. Cheap labour can be used or available agricultural techniques.

Oleophilic Fertilisers

These products are created to eliminate the problem of fertilisers being washed out from contaminated beaches completely. They are designed to remain at oil-water interfaces by adhering to oil on rocks or other substrates [NOAA, 1992].

Nevertheless, contradictory discussions are elaborated about using such fertilisers on contaminated beaches. Some of them (e.g. Inipol EAP 22) got investigated in monitoring studies and the sentiments are diverse. The divergences are mostly related to the fact that most of the oleophilic compounds contain an extra source of carbon for microbial feeding and this carbon could be degraded preferentially on disfavour of carbon from the oil-spill.

Another important aspect is the compounds' potential toxicology to humans and other organism [NOAA, 1992]. Special safety precautions (wearing protective clothing and respirators) are required to be taken into account when handling products such as Inipol.

Due to their higher costs and the not exactly determined efficiency, oleophilic fertilisers are not recommended for large-scale use on contaminated shorelines. They may be an alternative to water soluble and slow-release fertilisers on high-energy, coarse-grained environments but only after considering the other options.

The summarizing Table 5.4-2 shows the advantages and disadvantages of the major fertiliser types commonly used in oil bioremediation:

Table 5.4-2: Major fertiliser types used in oil bioremediation [adapted from EPA, 2001]

Type of fertilisers	Advantages	Disadvantages
Water soluble	○ Readily available ○ Easy to manipulate for target nutrient concentrations ○ No complicated effect of organic matter	○ Rapidly washed out by wave and tide ○ Labor-intensive and physical intrusive applications ○ Potential toxic effect
Slow release	○ Provide continuous sources of nutrients and may be more cost effective than other types of nutrients	○ Maintaining optimal nutrient release rates could be a challenge
Oleophilic	○ Able to adhere to oil and provide nutrients at the oil-water interface	○ Expensive ○ Effectiveness is variable ○ Containing organic carbon, which may compete with oil degradation and result in undesirable anoxic conditions

5.4.2.4 Advantages and Disadvantages of Nutrient-Addition

Advantages of Nutrient-Addition

- increase of indigenous microbial population and thus accelerated oil consumption rate
- supply of the necessary N and P to ecosystems where the nutrients are consumed by non-oil degrading microorganisms
- easy to apply using cheap manual labour or available farming equipment
- **can be combined with addition of oxygen in a single process** for a better contact of bacteria-nutrients

Disadvantages of Nutrient-Addition

- water soluble fertilisers are easily washed out by tide and waves leading to repeated and numerous addition.
- slow-release fertilisers can accumulate in one location in high concentrations
- oleophilic fertilisers are expensive and are preferentially consumed by indigenous bacteria in disfavor of the spilled oil

5.4.3 Other Techniques

5.4.3.1 Addition of dispersants

Dispersants used on oil spills are substances that contain molecules with a water-compatible ("hydrophilic") end and an oil-compatible ("lipophilic") end. At adequate concentration and mixing energy, these molecules attach to the oil and act similar to detergents used to clean grease from objects. The principle is the reduction of the interfacial tension between oil and water and breaking up the oil slick [NOAA, 1992]. The droplets resulting are more accessible to oil-degrading bacteria due to their increased total surface area.

Great concern has always been about the toxicity of dispersants. The case of the “Torrey Canyon” oil-spill (England, 1967) is an important negative example for the use of large amounts of very toxic degreasers to oiled rocky shores, marshes, and sandy beaches. Since then, a very cautious attitude towards dispersants evolved and the toxicity of dispersants got intensively studied. Laboratory studies suggested that the toxicity of dispersants is correlated with efficiency: the more efficient a product, the greater its toxicity to organisms [NOAA, 1992].

Therefore, the addition of dispersants should be avoided on oil-contaminated shorelines, if possible. This is due to the insufficiently known effects on local ecosystems.

5.4.3.2 Bioaugmentation

Bioaugmentation is the addition of oil-degrading bacteria in order to supplement the existing indigenous microbial populations [IMO, 2001].

The first impression is that supplementing the bacteria population and increasing their number may increase the efficiency of oil biodegradation. In reality, the population of existing oil-consuming bacteria grows during the process of oil degradation. Field studies confirmed that there was no significant increase of oil biodegradation by addition of commercially available microorganisms [IMO, 2001]. Therefore, bioaugmentation is not considered to be an efficient bioremediation method for contaminated shorelines.

5.4.3.3 Phytoremediation

Generally, phytoremediation is a treatment option where plants remove, destroy (degrade) or immobilize hazardous compounds. In terms of oil-contaminated shorelines, phytoremediation can be considered in form of enhanced rhizosphere biodegradation. Here the plant roots provide an aeration of the rhizosphere soil layer and their release of exudates and enzymes enhance the microbial activity in respective zone. Growth stimulation of oil-tolerant plants or re-planting might be an option for bioremediation.

Some authors mentioned phytoremediation as suitable bioremediation method in very sensitive habitats like freshwater wetlands and salt marshes and mangroves where other techniques may cause more damage than the spilled oil itself [Lee et al., 1999; IMO, 2001]. Nevertheless, the effectiveness of phytoremediation is considered to be highly site-specific and does not promise to be an effective clean-up method of contaminated shorelines [EPA, 2004].

5.4.4 Overview of In-Situ Techniques

5.4.4.1 Advantages and disadvantages

Advantages of In-Situ Bioremediation

- minimal impact on site - especially on beaches where other available cleanup technologies (i.e. physical or chemical procedures) may cause additional and irreparable damage;
- no negative effects when used correctly;
- quick removal of some petroleum compounds, faster than evaporation (i.e. low-molecular-weight aromatic hydrocarbons)
- simple and easy to handle solution (i.e. in comparison with hot water spraying);
- simple equipment and no sophisticated technology required, leading to lower costs than for other techniques;

Disadvantages of In-Situ Bioremediation

- significant short-term results cannot be expected: bioremediation is probably not appropriate as an initial and defensive method when high amounts of oil are present;
- tailored approach for each polluted site: bioremediation technologies cannot be used with equal effectiveness in every location;
- data required for optimization: optimization requires substantial information about spill-site and oil characteristics;
- prediction is difficult and not precise: a reliable data base and modeling is required

5.5 Ex-Situ bioremediation

5.5.1 General principles of Ex-Situ bioremediation

In contrast to In-Situ methods, Ex-Situ bioremediation involves the extraction of the contaminated soil or sediment from the subsurface for treatment.

The treatment can either be done **on-site**, i.e. at the location of the pollution incident, using mobile treatment plants, or **off-site** in case of scarcity of space. Here soil treatment plants and landfarming are widely used options. Generally, other permit requirements are applied for off-site methods (i.e. transportation of hazardous waste). Also, treatment processes and equipment are usually more optimised than on-site.

Four main Ex-Situ treatment types can be categorized as follows and will be explained in the following subchapters:

- Landfarming
- Treatment in piles/ windrows (dynamic/static)
- Treatment in reactors
- Treatment in soil treatment centres

All these treatment methods follow an excavation of contaminated material, such as soil, beach or sediments that should be treated microbially.

Figure 5-23: Excavation of contaminated soil [BUAS]

After excavation the contaminated soil is applied to a shredder to hackle and aerate the material. This measure accelerate the whole biochemical process (Figure 5-24).

Figure 5-24: Bulking of conterminaded soil [BUAS]

Most soils already possess sufficient quantities of microorganisms (Figure 5-25). The microbial groups with the most biochemical activity are bacteria which prefer low oxygen levels. They need a carbon source for their cell growth and sustaining their metabolic functions as well as they need nitrogen and phosphorous. Due to varying qualities and quantities of all these compounds, the efficiency of biodegradation changes even among neighbouring microorganisms (Figure 5-26).

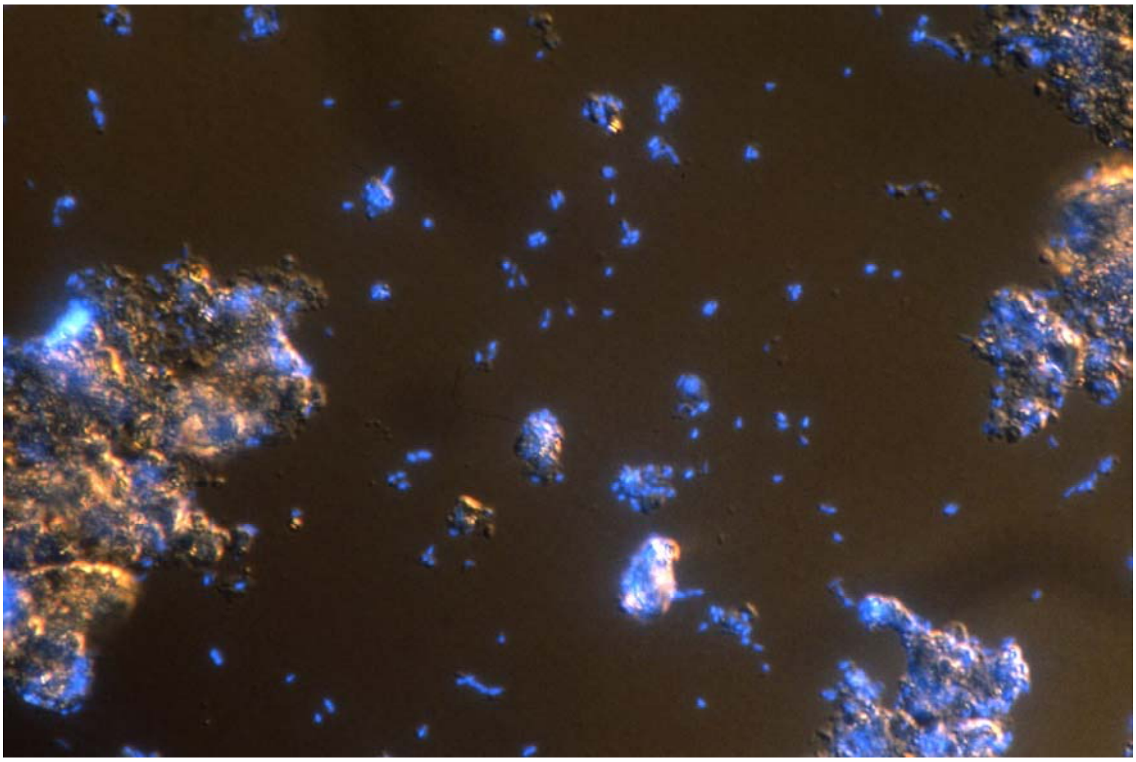

Figure 5-25: Microorganisms coloured with „dapi“ can be seen by fluorescence microscopes [BUAS]

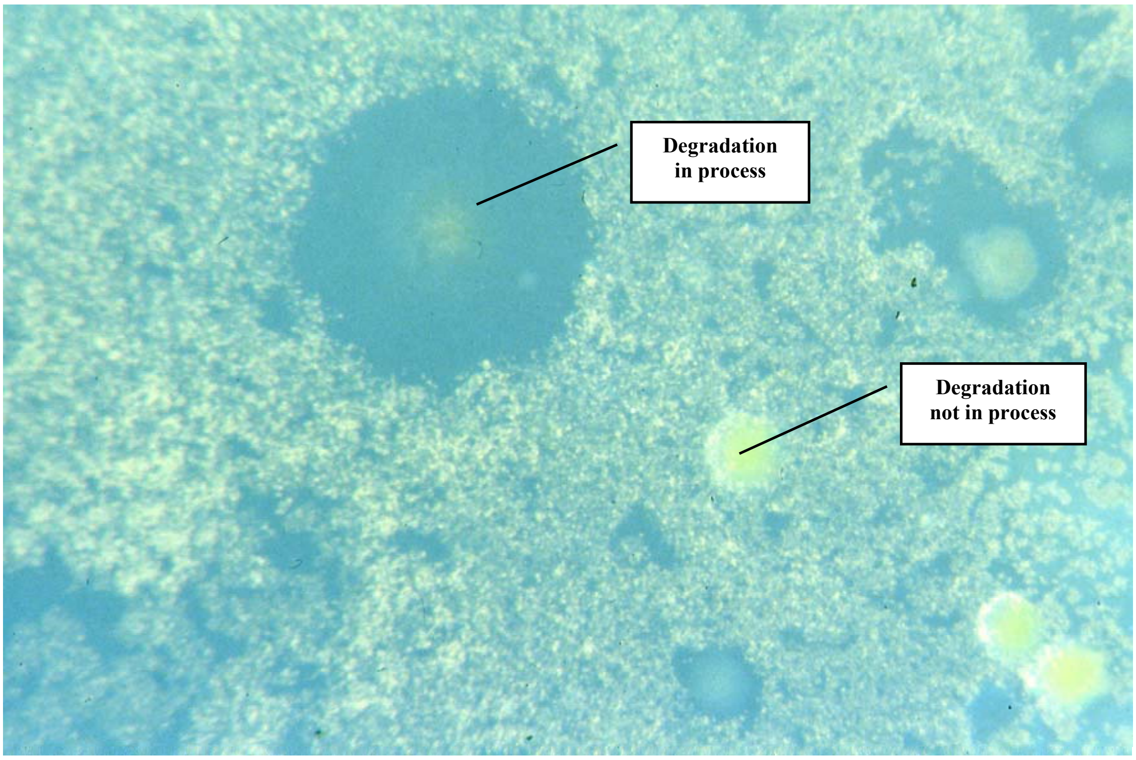

Figure 5-26: Micro organisms degrading PAHs at an agar plate [BUAS]

5.5.2 Landfarming

The term “Landfarming” stands for the traditional treatment methods, also known as land treatment or land application. This ex-situ ground remediation technology is an above ground treatment reducing oil-concentrations via biodegradation.

For this technology the excavated contaminated soil gets spread in a thin layer on uncontaminated soil. The aerobic microbial activity in the soil gets increased by aeration and addition (e.g. turning) of minerals. The enhanced microbial activity results in degradation of the oil constituents (microbial respiration).

Besides, this ex-situ treatment option can be applied in-situ on shallow contaminated soils (less than 1 meter below surface). Here it may be possible to activate microbial activity without excavation, whereas in depths of more than 1.5 m excavation and land application should be considered as general option.

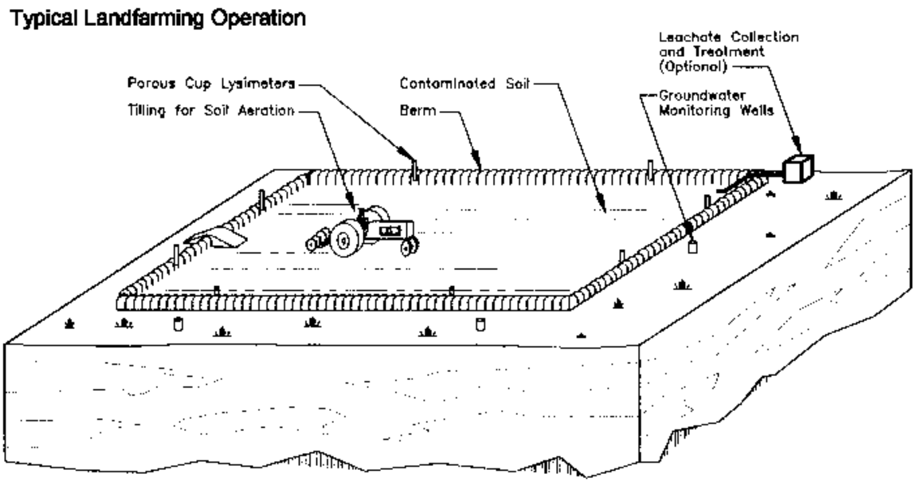

Figure 5-27: Typical Landfarming Operation [http://www.nmenv.state.nm.us/ust/images/remed-4.gif]

5.5.2.1 Application

Landfarming is most effective for volatile petroleum constituents. Oil generally contains more than hundred constituents with a wide range of volatility which thus are able to evaporate in case of a big surface offered by breaking up the soil structure, i.e. by tilling or ploughing as shown in . Additionally, the oxygen supply can be improved and leads to an increasing microbial breakdown.

Figure 5-28: Landfarming in Angola: tilling tractor [Institute for Microbiology, Braunschweig/Germany]

In order to comply with the Kyoto-Protocol, the VOC[11]-emissions occurring during large scale landfarming have to be taken into account.
The mid-range hydrocarbon products (e.g. diesel fuel, kerosene) contain lower percentages of lighter (more volatile) constituents than gasoline. For these petroleum products biodegradation is more significant than evaporation. The heavier (non-volatile) petroleum products (e.g. heating oil, lubricating oils) hardly evaporate during landfarm aeration. The dominant mechanism is biodegradation which breaks down these petroleum products.
However, higher molecular weight petroleum constituents such as those found in heating and lubricating oils, and -to a less extent- in diesel fuel and kerosene, require a longer period of time to degrade than the constituents in gasoline.

5.5.2.2 Operation Principles

Well drained soils are most appropriate for landfarming activities because the large numbers of microorganisms such as bacteria, algae, fungi, protozoa and actinomycetes are generally aerobic.

Additionally, the soil may be blended with cultured microorganisms or animal manure (e.g. from chickens or cows). The incorporation of manure serves to the augmentation of the microbial population and provides additional nutrients.

The effectiveness of landfarming depends on parameters that may be grouped into three categories:

1. soil characteristics
2. constituent characteristics
3. climatic conditions

The texture of oily soil, sand or sediments affects the permeability, moisture content and bulk density of the contaminated material. To ensure that oxygen addition (by tilling or ploughing), nutrient distribution and moisture content of the soils can be maintained within effective ranges, the texture has to be considered. The aeration of soils which tend to clump together (such as clays) is more difficult and results in lower oxygen concentrations than in loose drained soils. There are additional difficulties with the distribution of nutrients throughout these clay soils. Furthermore, they retain water for extended periods following a precipitation event. Fortunally, clays are rare at coastal zones.
As stated before, the volatility of contaminants is important because volatile constituents tend to evaporate from the landfarm, particularly during tilling or ploughing operations, rather than being biodegraded by bacteria.

Typical landfarms are uncovered and are, depending on the climatic zone, exposed to climatic factors including rainfall, snow and wind, as well as ambient temperatures. Rainwater that falls directly on the landfarming site or runs onto, will increase the moisture content of the soil and cause erosion or contaminated runoff-water.
It is important to note that during and following a significant precipitation event, the moisture content of the soils may be temporarily in excess of that required for effective bacterial activity. For good conditions the soil should be

[11] Volatile Organic Compounds

moist but not wet or dripping wet[12]. Contrarily, moisture content may be below the effective range during periods of drought when additional moisture may need to be added. Generally erosion of landfarm soils can occur during windy periods and particularly during loosen the soil by tilling or plowing operations. Wind erosion can be limited by plowing soils into windrows and applying moisture periodically (spray irrigation).

5.5.2.3 System Design

The System design of Landfarming is generally based on traditionally landfarming techniques and thus known farming equipment such as tractors and ploughs are needed.

The Set-Up of a landfarming construction includes additionally for the environmental security:

1. site preparation (grubbing, clearing and grading);
2. berms; liners (if necessary);
3. leachate collection and treatment systems;
4. soil pre-treatment methods (e.g. shredding, blending and amendments for fluffing, pH control);
5. enclosures and appropriate vapor treatment facilities (where needed).

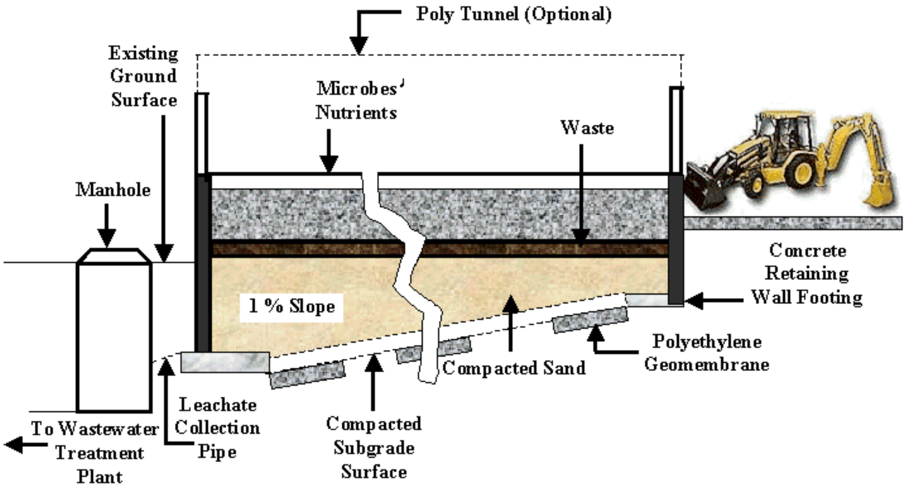

Figure 5-28: System Design of an ideal Landfarming-site [http://www.frtr.gov/matrix2/section4/D01-4-12.html]

The pH of treated soil should be within the range of 6 to 8. The value of about 7 (neutral) is optimal to support bacterial growth. In case of pH values outside this range pH adjustment operations will be required prior to and during landfarming. The pH adjustment can be done by adding lime (raising pH) or elemental sulphur (lowering pH).

Besides the appropriate pH, soil microorganisms require moisture for proper growth. Excessive soil moisture restricts aeration abilities of the subsurface thereby reducing the availability of oxygen which is significant for aerobic bacterial metabolic processes. To prevent drying due to evaporation moisture needs to be added periodically or kept by a protective covering. If the site is located in an area subject to annual rainfall of more than 9.1 meters during the landfarming season, a rain shield (such as a tarp, plastic tunnel or greenhouse structure)

[12] Ideal soil moisture 40 - 85 % of the water-holding capacity (field capacity) of the soil or about 12 percent to 30 percent by weight.

should be considered. Additionally, the rainfall runon and runoff from the landfarm should be controlled using berms at the perimeter of the landfarm leading to a leachate collection system at the bottom of the landfarm and a leachate treatment system to prevent groundwater contamination.

Moisture accumulations in areas with high precipitation or poor drainage may occur and should be considered in the landfarm design. Therefore, Water Management Systems are necessary to control the runon and runoff as well as to avoid saturation of the treatment area or washout of the soils in the landfarm.

Microorganisms require inorganic nutrients such as nitrogen and phosphorus to support cell growth and sustain biodegradation processes. In some cases sufficient quantities of nutrients may be available but, more likely, nutrients need to be added to landfarm soils to maintain bacterial operations. However, excessive amounts of certain nutrients (i.e. phosphate and sulphate) can repress microbial metabolism. The nutrient supply and the pH adjustment are usually done by periodic application of solid fertilisers, lime and/or sulphur while disking to blend soils with the solid amendments or applying liquid nutrients using a sprayer. The concentrations depend on the soil's or sediment's conditions, origin and on the milieu-conditions.

In case of air quality regulations Air Emission Controls (e.g. covers or structural enclosures) may be required if volatile constituents are present. VOC emissions should be estimated based on initial concentrations and the petroleum residues remaining.

It is important that system operation and monitoring plans will be developed for the landfarming operation. The regular monitoring is necessary to ensure optimisation of biodegradation rates, to track constituent concentration reductions and to monitor vapor emissions, migration of constituents into soils beneath the landfarm (if unlined) and groundwater quality.

5.5.2.4 Advantages and Disadvantages

The following table shows the major Advantages and Disadvantages of landfarming in regard to remediation of petroleum residues in soil.

Table 5.5-1: Advantages and Disadvantages of Landfarming:

Advantages	Disadvantages
Relatively simple to design and implement	Concentration reductions greater than 95% and constituent concentrations less than 0.1 ppm are very difficult to achieve
Short treatment times (usually 6 months to 2 years under optimal conditions)	May not be effective for high constituent concentrations (greater than 50,000 ppm total petroleum hydrocarbons)
Cost competitive: $30-60/ton of contaminated soil (USA)	Presence of significant heavy metal concentrations (greater than 2,500 ppm) may inhibit microbial growth
Effective on organic constituents with slow biodegradation rates	Volatile constituents tend to evaporate rather than biodegrade during treatment
	Requires a large land area for treatment → only thin layers applicable
	Dust and vapor generation during landfarm aeration may pose air quality concerns
	May require bottom liner if leaching from the landfarm is a concern
	Limited process control

5.5.3 Windrows (Dynamic / Static) – Piles – Composting

Soil erosion control from wind or water generally includes terracing the (oily) soils into windrows, constructing water management systems and spraying to minimise dust. Windrow-techniques use the principle of composting for the biological degradation of hazardous substances. Depending on regional preferences piles are used alternatively. Piles need less space than rows, but the windrow technique has its advantages in better aeration and in better handling. In Europe windrows are the major technique for ex-situ bioremediation.

5.5.3.1 Application

The windrow set up is determined by the machine- and aeration-technique applied. Depending on the windrow's form it needs to be differentiated between slab- (rectangle) windrows, trapezium and pyramid shaped windrows. The windrows are set up parallel with a usual height up to 3 meters, depending on the machine technology and the ration of space available. Windrows provide better aeration and need less space than Landfarming, but special Equipment for turning and in case of active aeration is needed.

5.5.3.2 Operation Principles

The process engineering of windrow-use is comparable with composting, whereby the soil activity is significantly lower than in composting.

The biological breakdown of pollutants in soil gets basically achieved by abolishing limiting factors (i.e. nutrient, moisture and oxygen supply for microorganisms) and stimulation of biological activity in soil. During the treatment, the soil pollutants get homogenised and thus they are more accessible for microorganisms. Fungi and bacteria are responsible for the degradation. Usually, they still persist in the soil. In case of complete degradation organic pollutants get reduced to mineral end products (CO_2, H_2O, Chloride etc.) and biomass. Also, incomplete degradation can be used for the treatment of contaminated soils, if the pollutants get fixed by humification or metabolised to harmless intermediate products.

Windrows are realized indoor, such as in halls, tents etc. and outdoor, such as on compacted and sealed soil. The different aeration systems are shown in Figure 5-29 below.

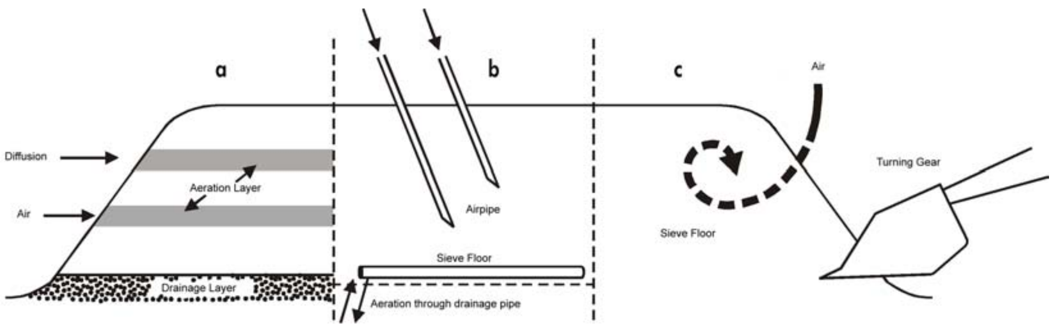

Figure 5-29: Structure of windrows, with passive aeration (a), forced aeration (b) and dynamic aeration (c) [UFZ]

5.5.3.3 System Design

Besides the Windrow-Shape, the system-design is determined by several other factors such as aeration, irrigation, bioaugmentation, structure, aggregates and nutrients. A general set-up scheme for windrow use is displayed in Figure 5-30 below:

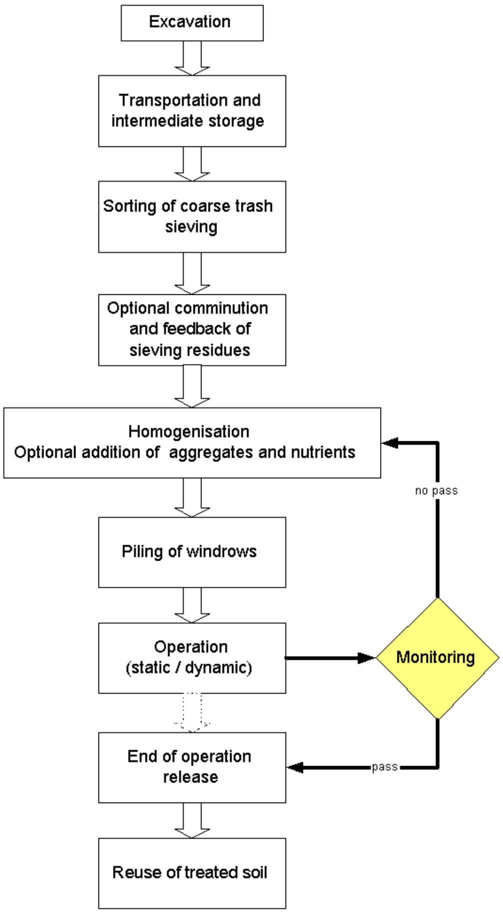

Figure 5-30: General process scheme for windrow use in bioremediation

Aeration

Windrow-techniques are basically aerobic processes which need oxygen for pollutant removal. Generally, it has to be distinguished between active and passive aeration.

Passive aeration can be achieved with a layered windrow construction (Figure 5-29; a) with an alternating configuration of soil- and aeration-layers. For the aeration layers basically coarse structured matter is used as preferably wood chips. This system leads to passive diffusion and gets increased by biological activity within the windrow-body (heat → chimney effect).

The **active aeration** methods are the forced aeration and the dynamic aeration. Forced aeration injects air by internals, such as pipes (see Figure 5-29; b).

Drain pipes, sieve floors and air pipes are widely used for this application. Depending on the blower set up it has to be differentiated between ventilated and sucking aeration. In case of highly volatile PAH's the suction bears advantages, because of the emission prevention and the possibility of downstream filtering.

A third kind of aeration is the **dynamic aeration** which gets accomplished by continuous turning of the windrows (see Figure 5-29; c). This technique is predominantly in practice, because only turning equipment is needed and the aeration results from ambient air while turning.

The aeration technique applied determines significantly the operational procedures and the actual costs during remediation.

<u>Irrigation</u>

Crucial for biological activity in soils is a sufficient moisture content. According to the irrigation technique used, the system has to be considered as dry-row or wet-row.

During set up of **dry-rows** the moisture content gets adjusted equal to the naturally occurring moisture content: For prevention of drying-up the moisture content gets checked regularly and adjusted, if needed (usually while turning).

The irrigation of **wet-rows** takes place during the degradation process. Hereby, the surplus process-water gets drained, collected and cleaned (if necessary and required). The cleaned water can be reused for irrigation in a process water loop. Due to the internals such as drain pipes etc., wet-rows have to be considered as static systems (Figure 5-31).

Figure 5-31: Internals for Water Management and Aeration of Windrows [Institute for Microbiology, Braunschweig/Germany]

In order to create constant conditions for an optimal biological degradation, changes in evaporation, erosion and rainwater leakage can be avoided by using covers from plastic foils as shown in Figure 5-32.

Figure 5-32: Cover of foil on a windrow protected against rain, erosion and evaporation

Bioaugmentation

As a matter of principle, windrows could be inoculated with microbial cultures. Reasons for the process called Bioaugmentation are:

1. The soil-source is lacking on microorganisms or has low activity which does not increase after abolishing the limiting factors.
2. There are persistent pollutants which can only be degraded by special cultures.

In those cases, there can either be used microorganisms extracted on site and reproduced, or under consideration of certain aspects alien microorganisms. Before adding microorganisms, it has to be considered that they have to be established in the new environment and sustain in the concurring micro flora and -fauna. The use of genetically modified microorganisms is still controversial.

Structure and aggregates

The structure improving matter and aggregates are added during the system's set up and provide a better soil structure and increased aeration. Widely used are bark products which also increase the content of organics and thus the biological activity.
If there is no "dilution permit" limiting values can also be achieved by adding less contaminated matter.

Nutrients

The main limiting factor in bioremediation is the lack of nutrients in the soils to be treated. Therefore, knowledge about the amount of nutrients being persistent in the contaminated soil, sand or sediment is important. Most important are organic and inorganic Carbon, Nitrogen and Phosphorus compounds. For best results there need to be sufficient nutrients in a favourable ration. The **C:N:P-Ratio** for bioremediation is considered to be optimal between 100:15:2 and 100:10:1, but may vary individually. Nutrients may be added in liquid or solid form.

5.5.3.4 Advantages and Disadvantages

The following table shows the major advantages and disadvantages of windrows in regard to remediation of petroleum residues in soil.

Table 5.5-2: Advantages and Disadvantages of Windrows:

Advantages	Disadvantages
Very good handling	special Equipment for turning and in case of active aeration is needed.
Exelent aeration	
Need less space than landfarming	

5.5.4 Bioreactors

Bioreactors are technologies which use closed systems for soil treatment leading to pollutant degradation. Depending on the moisture content, they can be classified as solid and liquid matter reactors. Bioreactors need permanent process monitoring and have relatively high operating costs, compared to landfarming and windrow composting.

5.5.4.1 Application

Reactor treatment is basically used stationary on-site but preferably off-site in designated soil treatment centres. In case of good infrastructure and sufficient possibilities of transportation (railway etc.), the reactors can be operated in soil treatment centres economically.

5.5.4.2 Operation Principles

The bioremediation of pollutants in bioreactors could be carried out by overriding the limiting factors for decomposition of organic compounds contaminating soil, sand or sediments after oil spill occurrences. In regard to this, bioreactors are more effective and faster than windrows because of their high grade of mixing soil and additives. Additionally, a closed system can be controlled more effectively.
The existing limiting factors and the options for overriding in bioreactors are displayed in Table 5.5-3.

Table 5.5-3: Techniques for overriding limiting factors in bioreactors

Limiting Factor	Option of Override
Lack of oxygen	Increase of the oxygen partial pressure via intensive aeration, optimised gassing and respectively use of technical oxygen
Lack of nutrients	Addition of nutrient compounds and adjustment of nutrient deficiencies via mixer
Factors of physical milieu	Conditioning and adjustment of pH, moisture and temperature
Availability of pollutants	Increase of mass transfer in the liquid phase due to increase of the water content and continuous mixing
Lack of decomposing microorganisms	Inoculation with reared cultures

5.5.4.3 System Design

Bioreactors for the treatment of contaminated soils can be set up variously. Apart from diverse set-up options there are some basic elements:

- Reactor tank for contaminated soil
- Mixing unit for homogenisation of soil and distribution of nutrients
- Gassing unit for the supply with oxygen and inert gas
- Filter for the cleaning of discharged air
- Metering unit for addition of additives (nutrients, electron acceptors and donators, pH-active substances, redox-active substances)
- Tempering unit for generation and control of desired temperatures

Due to the closed design and the increased degree of homogenisation of the soils for treatment, relevant parameters can be gathered well. Data collection can be accomplished via individual or continuous via online-measurements. Is the reactor endued with process control units, the parameters can be adjusted on setpoints and thus the decomposition rate will be optimised.

The bioreactors can be divided into solid and suspension reactors.
Bioreactors with **solid** matter basically treat earth-moist soils without any effluent of leachate or process water. The moisture content is between 50-70% of the max. water-holding capacity of the treated soils.
The **suspension** or **slurry reactors** are fed with solid matter and water or aqueous soil-sludge. As a result, the max. water-holding capacity gets exceeded by far. Suspension reactors get operated with a solid fraction between 30-50% proportional mass. Suspended soils in higher fractions are difficult to handle and lower fractions are considered as uneconomic.

The advantages of soil suspensions are the increased homogenisation and their treatment being easier to control. Besides that, all kinds of soil can be treated in liquid phase (fine-grained, cohesive and impermeable soils). Disadvantageous is the increased technical effort for producing soil-suspensions and the water removal after treatment.

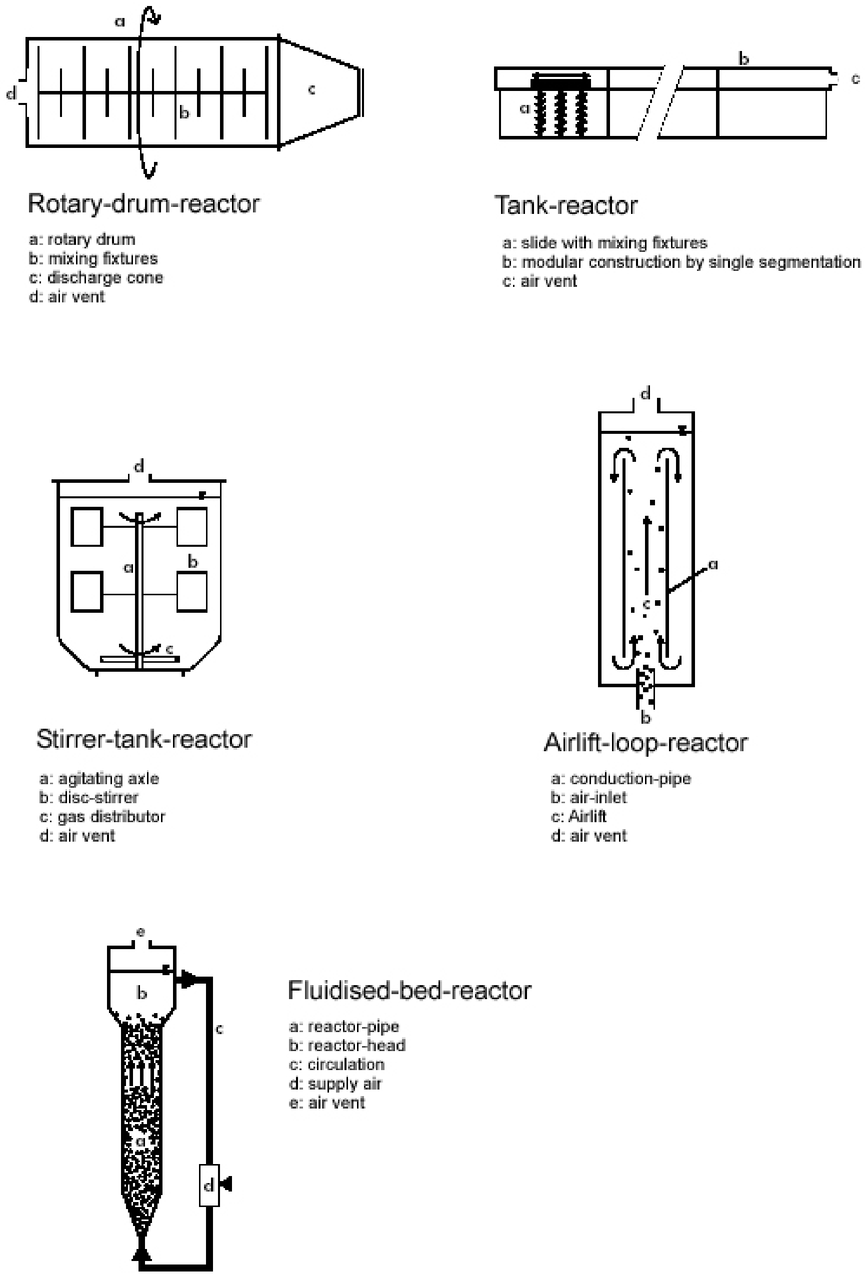

Figure 5-33: solid and suspension reactors

5.5.4.4 Advantages and Disadvantages

The following table shows the major advantages and disadvantages of bioreactors in regard to remediation of petroleum residues in soil.

Table 5.5-4: Advantages and Disadvantages of Bioreactors:

Advantages	Disadvantages

Because of its complexity and increased demand on process engineering this technique may not be suitable for the use in developing countries such as Vietnam.

5.5.5 Soil Treatment Centres

Soil Treatment Centres are basically centralised soil treatment units consisting of the various treatment methods applied depending on the grade of contamination. These specialised treatment facilities minimise the effort on highly specialised personnel needed for decentralised treatment facilities. Besides that, the contaminated matter can be separated by contamination and be applied to the technique most suitable. Soil Treatment Centres can be established if sufficient infrastructure is available and the contaminated soil can be transported adequately.
The use of mobile treatment centres for Vietnam may be considered as uneconomically.

5.5.5.1 Advantages and Disadvantages

The following table shows the major advantages and disadvantages of Soil Treatment Centres in regard to remediation of petroleum residues in soil.

Table 5.5-5: Advantages and Disadvantages of soil treatment centres:

Advantages	Disadvantages

5.5.6 Overview of Ex-Situ Techniques

	Landfarming	Dynamic Windrows	Static Windrows	Treatment in Soil Treatment Centres
Treatment type	Ex-situ	Ex-situ	Ex-situ	Ex-situ
	Off-site option only (generally on-site not enough space)	Off-site or on-site option	Off-site or on-site option	Off-site
	Dynamic treatment	Dynamic treatment	Static treatment	Dynamic or Static treatment in windrows or reactors
Principle	treatment in 50-100 cm material bed, applied onto the soil surface; periodically turning or tilling, to aerate the material, to homogenise the material and break up agglomerates	treatment in up to 3 m windrows periodically turning, to aerate the material, to homogenise the material and break up agglomerates	Pre-treatment of contaminated material (treatment in up to 3 m windrows Installation of active aeration system, Drainage system	Treatment using dynamic or static windrows or reactors, mainly in treatment halls;
Process enhancement	Aeration → turning, tilling, addition of bulking agents (…..)	Aeration → turning, addition of bulking agents (…..)	Aeration → active aeration by blower or vacuum pumps	see dynamic or static treatment
	Moisture content → irrigation, spraying	Moisture content → spraying	Moisture content →spraying, recirculation of leachate water	see dynamic or static treatment
	pH buffer addition→ limestone, agricultural lime	pH buffer addition→ limestone, agricultural lime	pH buffer addition→ limestone, agricultural lime	see dynamic or static treatment
	nutrients → addition of nutrients (…)	nutrients → addition of nutrients (…)	nutrients → addition of nutrients (…)	see dynamic or static treatment
Technical requirements	Agricultural machinery	Front loader, dredger Ground sealing, e.g. HDPE (optional)	front loader or dredger blower or vacuum pumps Ground sealing, e.g. HDPE (optional) Covering by foil, treatment hall/ tent, etc.	see dynamic or static treatment
Other requirements	very high space demand, ca. xx/m³, xx/ t	high space demand, ca. xx/m³, xx/ t	less space demand than dynamic windrows, ca. xx/m³, xx/ t	Soil treatment centre available
	low value, impermeable soil to reduce leaching of contaminants into the ground	optional: HDPE foil, for cover windrows (to prevent from rain)		
	Excavation of contaminated soil (Access, equipment, costs)	Excavation of contaminated soil (Access, equipment, costs)		
	Transportation to off-site location	Transportation (if off-site treatment)		
		optional: gas collection (to prevent volatile contaminants emissions)		
		Disposal /Utilisation of treated material		
Limitations	Uncontrolled factors, like temperature, rain reduce efficiency			high transport distance

	Volatile contaminants cannot be collected (consider national legal requirements)			large quantities of contaminated material (costs!)
	Possible legal restrictions regarding landfarming			
Costs	high operating costs (regular turning, tilling)	High operating costs (regular turning)	low operating costs	market prices, are subject to wide fluctuations
	low installation costs	low-medium installation costs	high installation costs	
	U.S.$ 30-60/ton (USA)	€ xxx	€ xxx	€
Experiences with oil contamination	Standard process, Wide range of experiences, e.g. in USA (petro industry)	Standard process, Wide range of experiences, e.g. in Germany (and many other countries) for treatment of oil-contaminated soil	Standard process, Wide range of experiences, e.g. in Germany (and many other countries) for treatment of oil-contaminated soil	see dynamic or static treatment
	No application in Germany			
Scientific level	low	low	high	
Summary	if not legal restrictions: cheap, low tech, ex-situ (off-site) treatment option, when low value land is sufficiently available	cheap and simple process for ex-situ treatment; flexible operation to respond to process requirements		Treatment by third party with know-how and infrastructure; Potentially cheap option, particularly for smaller quantities of waste

5.5.7 Summary

The choice of the right treatment option depends on various factors and has to be carefully decided in order to avoid inadequate handling following unnecessary efforts of organisation, materials, manpower, etc. resulting in a waste of money. As a matter of fact, the right Ex-Situ treatment option might be always chosen AFTER checking that the amount of sand, soil or sediment spilled with oil can be collected, transported and stored.

5.5.8 Literature

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5.6 Experiences (full scale demonstration)

Several field studies on the performance of oil bioremediation have been carried out in recent years. These have provided more convincing demonstrations of the effectiveness of oil bioremediation since laboratory studies may not consider many real world conditions such as spatial heterogeneity, biological interactions and mass transfer limitations.

5.6.1 Nova Scotia, Canada (1989)

First time when bioremediation was used for decontamination of an oil polluted salt marsh was in Nova Scotia, Canada. Lee and Levy tried for the first time to enhance biodegradation by adding periodically water-soluble granules (ammonium nitrate and triple super phosphate) [Lee et al. 1991]. Two levels of oil concentration were used and the study showed that the effectiveness of nutrient addition was directly related to oil concentration. The case of the highest concentration presents a lower efficiency of nutrients addition, which was explained by penetration of the oil at higher concentrations into the soil layers where little degradation is expected. The conclusion of this study is that bioremediation can be mostly used for cleaning the coastal areas lightly contaminated with oil.

5.6.2 Exxon Valdez, Alaska/USA (1989)

One of the largest successful bioremediation projects in marine environments is exemplified by the cleanup of Alaskan beaches in March 1989. Observing a slow biodegradation rate due to a limited presence of available nutrients, U.S. Environmental Protection Agency examined and tested the effects of adding nitrogen- and phosphorous-based nutrients to enhance the degradation of oil on contaminated beaches. In the first phase, different fertilisers were selected for three particular application strategies and 2-3 weeks after their application a visible reduction in the oil content could be observed on the cobblestone surfaces. In the second series of experiments, a combination of oleophilic and slow release fertiliser was tested along with a water-soluble fertiliser treatment.

5.6.3 San Jacinto Wetland Research Facility (SJWRF), Texas/USA (1994-1997)

A research group from Texas A&M University carried out o series of field experiments in a Texas coastal wetland in order to evaluate the effectiveness of various bioremediation options. The study had three phases, as described below:

Phase I – intrinsic bioremediation were evaluated before and after the oil spill
Phase II – effect of bio augmentation was investigated by using di-ammonium phosphate and di-ammonium phosphate plus nitrate
Phase III – in this phase two commercial bio augmentation products were used plus a repeated di-ammonium phosphate treatment

From phases two and three it was noticed that bioremediation rate was significantly enhanced by use of di-ammonium phosphate but remained constant by addition of microbial products.

5.6.4 Sea Empress Incident, Wales/UK (February 15th, 1996)

The Sea Empress ran aground in Milford Haven on February 1996, releasing 72 000 tonnes of crude oil and 480 tonnes of heavy fuel oil over the next 7 days. A wide range of clean-up techniques were used to treat shorelines oiled after the incident and for the first time after an oil spill in western Europe, a survey was conducted to determine whether any of the contaminated shorelines could be treated with bioremediation. Concentrations of residual hydrocarbons showed that after two months the oil was significantly more biodegraded in the treated plots than in the controls. Thus, the results showed that bioremediation can be used to treat a mixture of crude and heavy fuel oil. In particular, the data suggest that the application of a slow-release fertiliser alone may be a cost-effective method of treating low-energy, contaminated shorelines after a spill accident.

5.6.5 Nakhodka Accident, Japan (January 2nd, 1997)

The Nakhodka oil spill accident was the most serious ever in Japan. To study the application of bioremediation in cleaning up the Nakhodka oil spill, the components of the spilled oil were determined and their biodegradability was analysed. The effects of the spilled oil on the microbial population of the beach sediments were also evaluated. Samples of beach sediments from two coastal areas near the spill were collected and extracted with the aid of hexane. Microbial studies were conducted over a 1-year period on the sediments of one of the polluted beaches. Both the number of bacteria and the diversity index were high soon after the accident. It appears that the spilled oil was a carbon source for the oil-degrading bacteria in the beach sediments.

5.6.6 Terrebonne Parish, Louisiana/USA (1998)

Another important field study was conducted in Louisiana in order to investigate the limiting factors in oil biodegradation in oil coastal wetland. Nutrient amendment and oxygen demand were analysed on forty field plots. Four treatments were performed for evaluating the influence of nutrients addition:

- unoiled control;
- oil control;
- oil plus ammonium nitrate
- oil plus a slow release fertiliser

Overall, the study showed that oil biodegradation rate was not significantly increased by nutrients amendments, which might be explained by the high nutrients availability at the site. On the other side, in those cases where the surface of the contaminated area was exposed to air, the rate of oil biodegradation was higher. In conclusion, oxygen availability is the main factor influencing the oil biodegradation in this case.

5.6.7 Gladstone, Australia (1997-1998)

The field study conducted at Gladstone, Australia, evaluated the effect of pumping air beneath sediment, supplemented with a slow release fertiliser (Osmocote^{TM} Tropical fertiliser) for the mangrove sites, and the addition of nutrient alone for the salt marsh sites. The remediation strategy did not significantly enhance the degradation of none of the two oils used in the experiment. Due to limitations of the experimental design, the study could also not distinguish whether the microbial growth was stimulated by nutrients or by aeration.

5.7 Pros and Cons of Bioremediation

Bioremediation shows as a biological process a number of benefits in cleaning up oil contaminated areas. Nevertheless, there are some negative aspects that have to be considered. A list of advantages and disadvantages is shown in Table 5.7-1 below.

Table 5.7-1: Pros (☑) & Cons (☒) of bioremediation (acc. implementation of the OPRC convention)

Locations of application	☑	oil degrading microorganisms are ubiquitous, therefore bioremediation can be used on a range of shoreline type
	☒	will not work in open water due to the dilution
Degree of contamination	☑	relatively non-intrusive method for final polishing
	☒	impracticable on heavily contaminated beaches – free contaminant has been removed
	☒	dependant on environmental conditions and the oil's nature (i.e. limitations on heavy fuel oil)
Waste and hazards	☑	does not generate waste products
	☒	potential adverse health effects are associated with the release of bioremediation agents (particularly bio augmentation products) and those resulting from the metabolic by-products of biodegradation
Duration, labour & costs	☑	generally not labour intensive and can be cost effective
	☒	takes longer than other physical and/or chemical techniques
	☒	requires thorough planning and detailed monitoring
Public response	☑	has received a positive public response as a natural process
	☑	is more acceptable to public than more invasive chemical or physical procedures
	☒	concerns exist regarding potentials adverse health effects associated with release of bioremediation agents particularly bio augmentation products, and those resulting from the metabolic by-products of biodegradation

5.8 Literature (Kontrolle und hinter an Chapter 5 mach ich noch)

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6 Guidelines for the Implementation of Bioremediation of Marine Oil Spills

In case of an oil spill, immediate response is necessary. Action plans have to be made in advance, because there is no time in case of contingency. Quick response-action is based on guidelines for its implementation including a step-by-step decision support system. This chapter gives systematic decision support in adequate time. It is based on data compiled by the BIOREM-Project.

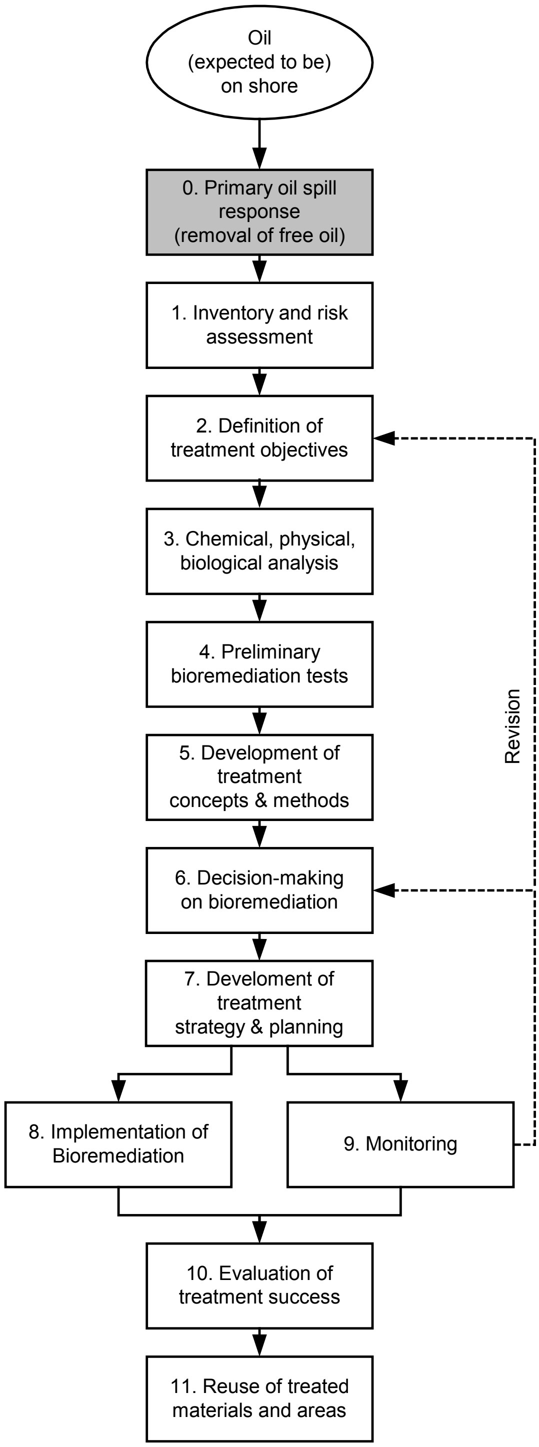

Figure 6-1: Overview over main implementation steps

6.1 Inventory and Risk Assessment

After identification of an oil spill, the primary response will be fast collection and removal of so called “free oil” before reaching the coastline. All the oil collected in advance, reduces the damaging influence of the spill on the coastline with its ecosystems where removal is more difficult.
Coevally primary actions as setting up action plans, inventory checks and other planning actions have to be made and introduced to decision makers.
The first step leading to response-decision-making is the ***Inventory*** *and* ***Risk Assessment*** which is further divided into 3 subcategories as follows:

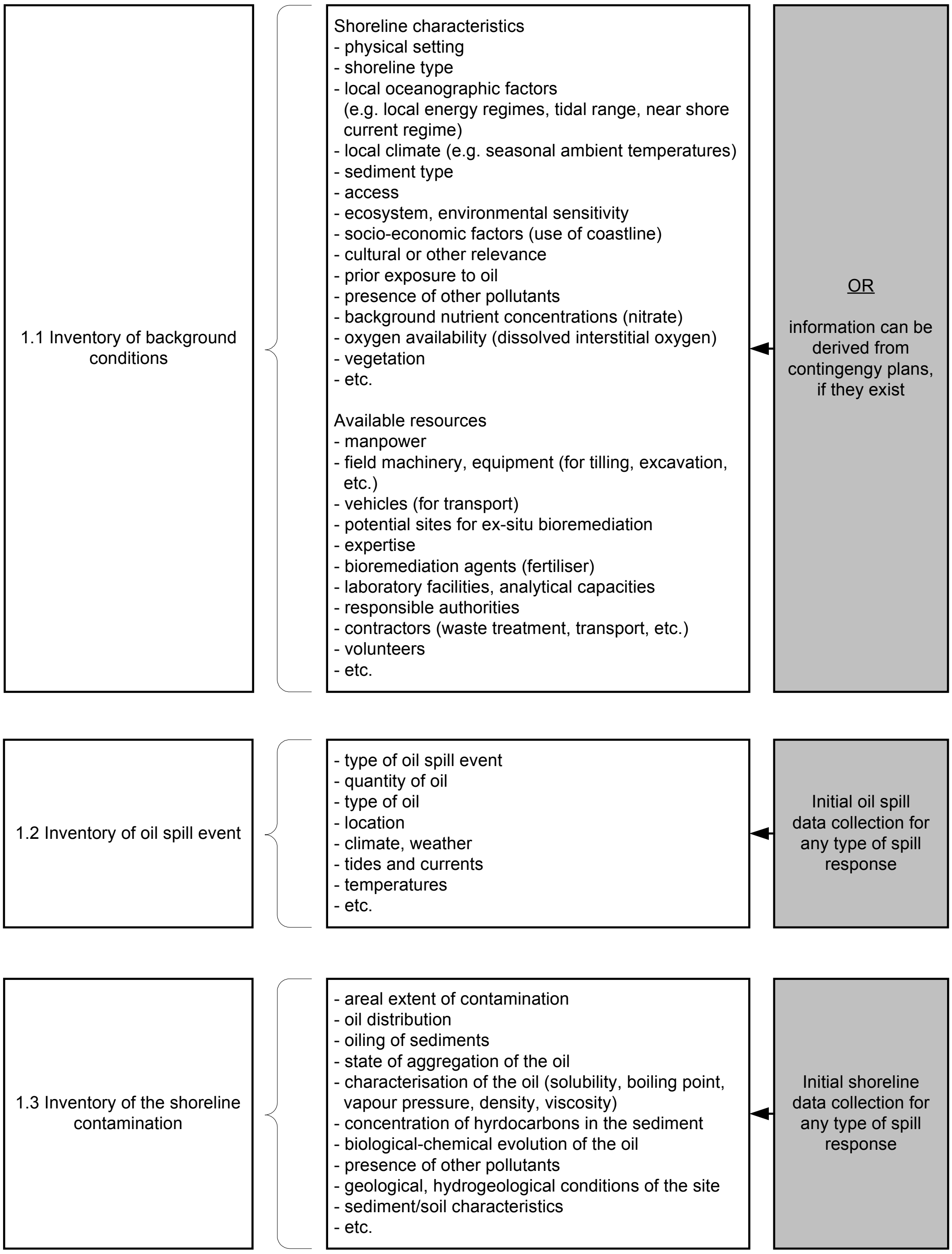

Figure 6-2: Main aspects of the inventory

As shown in Figure 6-2, the inventory is based on a first data collection for general background information according to the spilled area and the oil character as well as its caused contamination.

6.1.1 Inventory of Background Conditions

Marine and coastal oil pollution is known as one of the ecological worst case scenarios. There are different levels of influence due to the interaction of the ecosystem and the depending socio-economy.

There are two major conditions that need to be known for a further planning of response-actions. On the one hand, there are specific shoreline characteristics of the area polluted. On the other hand, there are technical and human resources that could be used for oil spill response. Both need to be identified for a first inventory.

6.1.1.1 Shoreline Characteristics

Geographical and physical characteristics define the type of shoreline and are two of the limiting factors concerning to the way of fighting against oil pollution. It includes the regime of near shore currents and tidal range. Additionally wind energy has a crucial effect on oil broadening.

Along with geographical characteristics, climatic conditions influence the behaviour of oil, especially its consistency. Due to the north-south-extent of Vietnam's coastline, these characteristics present a certain range.

In case of coastal pollution, the type of sediment is a factor influencing the process of removing oil and cleaning soil, sand, stones or rocks. Furthermore it limits the use of collecting/cleaning equipment due to varying access to the waterfront.

In regard to the possibility of bioremediation the concentrations of naturally occurring nutrients (such as Nitrogen) and available Oxygen (chemical reactions) need to be evaluated.

6.1.1.2 Available Resources

One of the crucial resources in fighting oil on shorelines is manpower. The population density determines the manpower available for oil spill response. It differs along Vietnam's coastline depending on the coastline's characteristics. Locals possess better knowledge about the affected environment and have geographical knowledge of the affected areas, which may be crucial in some cases. Furthermore, its in their own interest to sustain their environment and thus their livelihood. Additionally, problems like boarding and lodging get minimized and transports can be distributed to local haulage contractors. Same pertains to the technical support, such as vehicles, machinery and other equipment. Special equipment might be more available in urban regions, whereas useful equipment for oil spill response (tilling, scooping, etc.) will most likely be present in rural areas.

In regard to deal with excavated oily sediments the availability of sites for Ex-Situ bioremediation is important. Coevally, there is a need of expertise and the support with agents needed for remediation should ensured.

The availability of laboratories or other analytical capacities will ease the monitoring throughout the remediation process.

Specific problems for Vietnam are deficiencies with transport and communication on long distances. These deficiencies take important time that organisers and decision-makers may not have in case of an oil spill.

Besides that the responsible authorities need to be known and informed (according to their ranking) as well as the decision about the contact persons. They need to be identified and stand by. An action committee including local and technical experts needs to be established for further organising. It also needs to be decided about the utilisation of manpower and equipment as well as the mobilisation and employment of volunteers and contractors for waste transport and treatment.

Besides all these technical problems security and public relations should be addressed.

The establishment of these background-conditions will take some time which can be reduced or even saved by Contingency Plans. They evaluate and provide necessary background information in advance. It may also be a helpful tool for training courses that inform decision-makers before a spill takes place and define responsibilities for several tasks connected with oil spill response.

6.1.2 Inventory of Oil Spill Event

Each spill is different in type, size and behaviour. Therefore, an initial data collection is needed. Right after detection of an oil spill, the oil-type needs to be identified and its quantity must be appraised. The oil spills location and distance to the coastline must be ascertained as detailed as possible in order to estimate the scale of operations and how much time is left to organise a reaction before oil reaches the coastline. In doing so, the oil's movement and extent due to wind and currents has to be considered attentively.
The actual weather conditions including temperature, wind and rain as well as their expected changes need to be considered when assessing the spill's behaviour.

6.1.3 Inventory of Frame Conditions of the Shoreline Contamination

This part of inventory actions is focused on the results of an oil spill, such as its distribution on and in the water or the shoreline. It is very similar to the above mentioned "Inventory of oil spill event". In order to estimate the extend of an oil spill on the coastline, it is necessary to evaluate as much information as possible. Quick-tests or onsite-tests may be useful to determine the oil.

If the oil is onshore already, the contamination of sediment needs to be examined and its load has to be assessed. In general, the physical character of sediment is limiting for response options even as biological and chemical features and evolutional changing of the oil. Considerations about bio-chemical response-options require knowledge about the presence of other pollutants and nutrients and its concentrations. Furthermore, the geological and hydro geological conditions are important to estimate the potential influence on groundwater.

This summarising assessment of the contamination situation enables decision-makers to figure out the risks for environment, economic and humans. Considering facts as mentioned above, the next chapter will help to define treatment objectives.

6.2 Definition of Treatment Objectives

After or besides immediate response activities but before further implementation steps, decision-making treatment objectives have to be established in co-operation with local stakeholders and decision-makers. Such objectives are settled on different levels as shown in Figure 6-3.

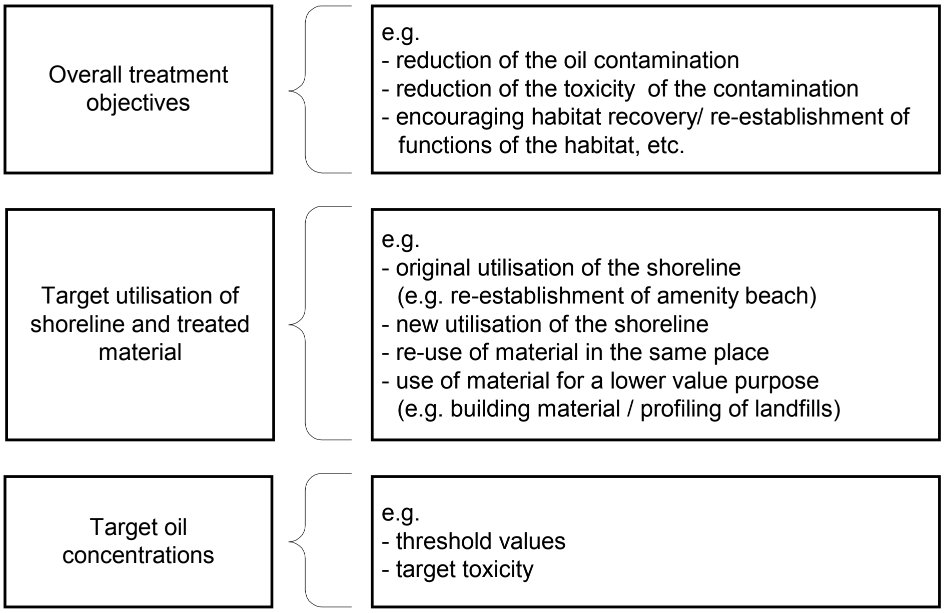

Figure 6-3: Definition of treatment objectives

6.2.1 Overall Treatment Objectives

Major objective of the people affected by the oil spill and the response actions is to restore the environment's initial state as soon as possible.

Irrespectively of the contaminant and the decontamination techniques applied the overall objective is the reduction of the contamination with its subsequent toxicity. Thus following, the habitat's recovery can be focused.Recovery means, that all functions of natural and anthropogenic lifecycle will be re-established in the affected habitat, step by step.

6.2.2 Target Utilisation of Shoreline and Treated Material

As already stated in the inventory, the former utilisation of the affected area is known. Depending on the intensity of an oil spill, the former utilization can be recovered. As a matter of fact, it takes variably more time to recover than to pollute and destroy. Restoring coastlines with copying its old state is often ineffective and hard to achieve. Changing conditions might lead to another way of utilisation by other biota or other socio-economic utilisation, which are not necessarily worse.

Food-production (sea-food) should be avoided for a longer period, as well as other disturbing activities, such as loud water sports. They might be possible after re-establishing a working eco system.

The polluted sediment might be useful after cleaning. It can be left on site in case of In-Situ-treatment or replaced after an Ex-Situ-treatment. The treated soil also could be used for lower value purposes, such as construction material, landfill profiling, etc.

6.2.3 Target Oil Concentrations

The target oil concentrations should reflect overall treatment objectives and the target utilisation of shoreline as mentioned above. Both aim towards a reduction of oil concentration in general.
In comparison, there are special values necessary to reach a case-specific reduction, such as:

Threshold Value:

- The definition of thresholds of concentrations of contaminations which are harmless in the long term for humans and/or environment is discussed by experts extensively. There is no final knowledge on real risk-potential, yet.
- Threshold lists from regulations (e.g. for material recycling) should be used as orientation only.

Table 6.2-1: Threshold values for oil contaminated soil

		Threshold value				
Parameter	**Unit**	**z 0**	**z 1**	**z 2**	**z 3**	
MKW (petroleum-derived hydrocarbon)	mg/kg	100	300	500	1000	**extract from: German classification values for soil, suitable for utilisation [LAGA, Technische Regeln Verwertung]**
BTEX (Benzol, Toluol, Ethylbenzol, Xylole=volatile organic compounds)	mg/kg	<1	1	3	5	
LHKW (lightly volatile halogenated hydrocarbons)	mg/kg	<1	1	3	5	
PAK (polycyclic aromatic hydrocarbon)	mg/kg	1	5 *	15**	20	

* values for Naphthalin and Benzo-(a)-Pyren smaller than 0,5 [Niederländische Liste, 1994]

** values for Naphthalin and Benzo-(a)-Pyren smaller than 1,0

Target Toxicity:

- Reflection of the actual toxicity which can be emitted over water (elution) or air path (instead of concentrations in the solid material).

Response options target to reach these values. Only by achieving all target values the response options can be considered successful and the activities can be stopped.

6.3 Chemical, Physical and Biological Analysis

Microorganisms are present almost everywhere and very efficient-not only according to remediation of oil pollution. They cause bioremediation which is a sensitive process depending on several biotic and abiotic factors. Therefore it is essential to carry out biological and chemical/ physical analysis to get an initial indication whether the prevailing framework conditions of the contamination are suitable for treatment with bioremediation or not. To safe time and expenses, step by step investigation of the pollutant's biodegradability is important. For this chemical, physical and biological analysis represent the first step which should be followed by concrete bioremediation tests. In case of positive results a potential successful applicability of bioremediation may be possible.

The following three types of analysis have to be carried out, using original soil-samples with typical characteristics in regard to structure and contamination:

1. Analysis of the quantity of present microorganisms
2. Analysis of the quantity of present oil-degrading microorganisms
3. Analysis of the physical and chemical conditions of the contaminated soil/ sediment.

6.3.1 Quantity of Microorganisms

The following two types of analysis should be applied:

- Counting of colony forming units (CFU) of aerobic heterotrophic bacteria
- Respiration rate.

Oil contaminations are degraded under aerobic conditions (under the presence of oxygen). Therefore, it is important to quantify aerobic heterotrophic bacteria who are potentially capable. The respiration rate is measured as CO_2-production. This end-product of bacterial metabolism and is a useful indication of bacterial activity in the contaminated soil or sediment.

Table 6.3-1 and Table 6.3-2 give indications regarding the potential success of bioremediation on the basis of bacteria quantity and respiration-rate. If the tests show a reduced quantity of aerobic heterotrophic bacteria or a reduced activity (measured as CO_2– respiration-rate), the chances for successful bioremediation are limited. The prevailing conditions have limiting or toxic effects to bacteria and thus their number and/or activity will be reduced. Those test can give first indication if bioremediation represents a viable option. However it has to be noted, that bioremediation could also be considered for certain treatment objectives, even though the potential success is limited.

Table 6.3-1: Coarse indication regarding the potential success of bioremediation on the basis of the quantity of aerobic heterotrophic bacteria of the original contaminated soil/sediment [Hoffmann and Viedt, 1998]

Number of aerob heterotrophic bacteria [per g soil as dry substance]	**Potential success of bioremediation**
10^1- 10^3	-
10^4	(+)
10^5	+
10^{6-9}	++

++ = very good, + = good, (+) = limited good, (-) = limited, - = bad

Table 6.3-2: Coarse indication regarding the potential success of bioremediation on the basis of the respiration rate of the original contaminated soil/sediment [Hoffmann and Viedt, 1998]

Respiration rate [CO_2/ kg dry substance * h]	**Potential success of bioremediation**
< 1	-
1-2	+
2-5	++

++ = very good, + = good, (+) = limited good, (-) = limited, - = bad

6.3.2 Quantity of Oil-Degrading Bacteria

The quantity of oil degrading bacteria should be identified using the “CFU Count Method” (count all colony forming units) with a specific oil containing growth media. It is also suitable to measure the degradation of oil. Thus, it is possible to get an indication about the presence of oil-degrading bacteria and their activity under optimised conditions.

6.3.3 Chemical/ Physical Characterisation of contaminated Soil and Sediment

Finally, it is of utmost importance to characterise the contaminated soil/sediment chemically and physically to identify factors which will limit the biodegradation. Most parameters should be analysed in representative soil/sediment samples, others should be analysed onsite under original conditions.

The following analysis should be carried out with representative soil/sediment samples:

- particle size distribution
- water holding capacity
- water content
- pH-value
- salinity, conductivity
- organic content
- nutrients (ammonia, nitrate, nitrite, phosphorus)
- concentration of contaminants
- cation exchange capacity
- redox potential (measured in the field)
- oxygen content (measured in the field)

Analysis that should be carried out especially for In-Situ treatment:

- buffer capacity for organic contaminants
- sequence of soil/sediment layers, lenses, inclusions
- accumulation capacity of inorganic contaminants
- capillary water rising height
- hydrological situation
- ground water level
- height of ground water level
- ground water flow direction
- ground water flow velocity

6.4 Preliminary Bioremediation Tests

Parameters that have to be known for the assessment of a biological remediation are such as particle size, particle density, porosity and permeability as well as aggregation. Before deciding for or against bioremediation as a further response for an oil spill, its general suitability should be clarified. Three different test-scales can be used to find it out. Please, consider:

The smaller the scale, the more specific is the result.

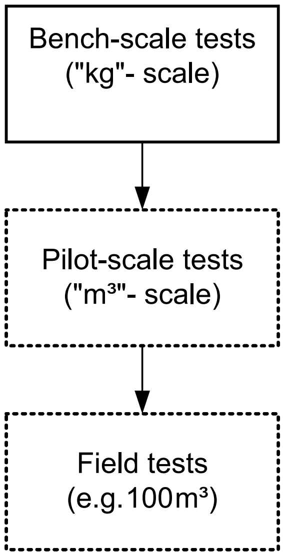

Figure 6-4: Preliminary bioremediation tests

6.4.1 Bench-Scale Tests

The bench-scale test is a small scale test that is mostly carried out in a laboratory. Hereby, a (composite) sample of the spilled oil is taken and analysed in the laboratory. This is usually used to pre-analyse the type of oil and its sourrounding microorganisms. It helps to define the features of the oil and gives information about the microorganisms that are present and wheather the conditions are well enough for bioremediation. It is advisable to run different tests in order to carry out the best method of bioremediation and -if necessary- to change the treatment in case of varying conditions.
Within optimal conditions in a laboratory, the degradation performance is expected to run at a maximum. If this test does not have the expected degradation performance, the result is probably even worse under natural conditions on site.

6.4.2 Pilot-Scale Tests

These tests are carried out to demonstrate the results of small scale tests mentioned above in a larger scale. The interactions between oil, microorganisms and surrounding atmosphere are closed to real conditions, more than in the Bench-scale test. However, it is a good possibility to monitor a defined and manageable amount of material, its additional input and the causing output. If possible, Pilot-scale tests should also run in different tests for the same reasons as mentioned above.

6.4.3 Pilot-Scale Tests

In a pilot-scale test, the amount of material observed is large enough to be seen as a test under real conditions – a so called “full-scale test”. Thus, the results of such a test are absolutely meaningful. It is the best option to investigate conditions and szenarios as they occur in reality. Mostly, these tests are carried out directly “In-Situ” as the amount of material would cause too much trouble and costs for transport. Furthermore, it is ensured to know and evaluate the influences (e.g. weather, sediment, nutrients, etc.) on the surrounding oil. Thus, the influence on the material of the pilot-scale test is well known.

These tests have to carry out several parameters mentioned in Chapter 6.3.3 considering the circumstances of the treatment’s sourrounding, such as temperature, pH-value, etc.

As a matter of fact, local, financial and temporal circumstances are decisive factors for the choice of one of these tests. In case that bioremediation can be recommended due to the results, the next step can follow which develops concepts and methods.

6.5 Development of Treatment Concepts and Methods

6.5.1 Decision-Making for or against Bioremediation

The following scheme shows the decision-making process until the question about In-Situ, Ex-Situ treatment or Monitored Natural Attenuation (MNA). The questions leading to the final decision about the favourable method or the most promising combination of methods are commented and discussed in this chapter.
In practice, the different methods often get combined. They get applied where the estimated success is most promising in combination with the applicability. The choice of the different cleansing methods depends also on the load they can handle and if the removal of the contamination can be managed in an adequate period of time.

Generally the remediation methods can be classified as follows:

Ex-Situ Treatment:	*high loads; depending on the quantities contaminated (excavation, storage, transportation)*
In-Situ Treatment:	medium loads; depending on natural factors such as soil conditions, nutrients available and their accessibility
Monitored Natural Attenuation:	medium to low levels of contamination; depending on limiting and target values
Thermal Treatment:	small loads, depending on kiln capacities
Chemical/Physical Treatment	use of dispersants (wide spread high loads offshore); Physical methods (e.g. encapsulation) on high to medium loads

Each marine oil spill has its unique circumstances depending on the different marine areas and environments (Offshore, Shoreline; Onshore). The load will be distributed differently and thus an assessment for each case and area is needed. For best results (technically and economically) a combination of all actions is recommended.

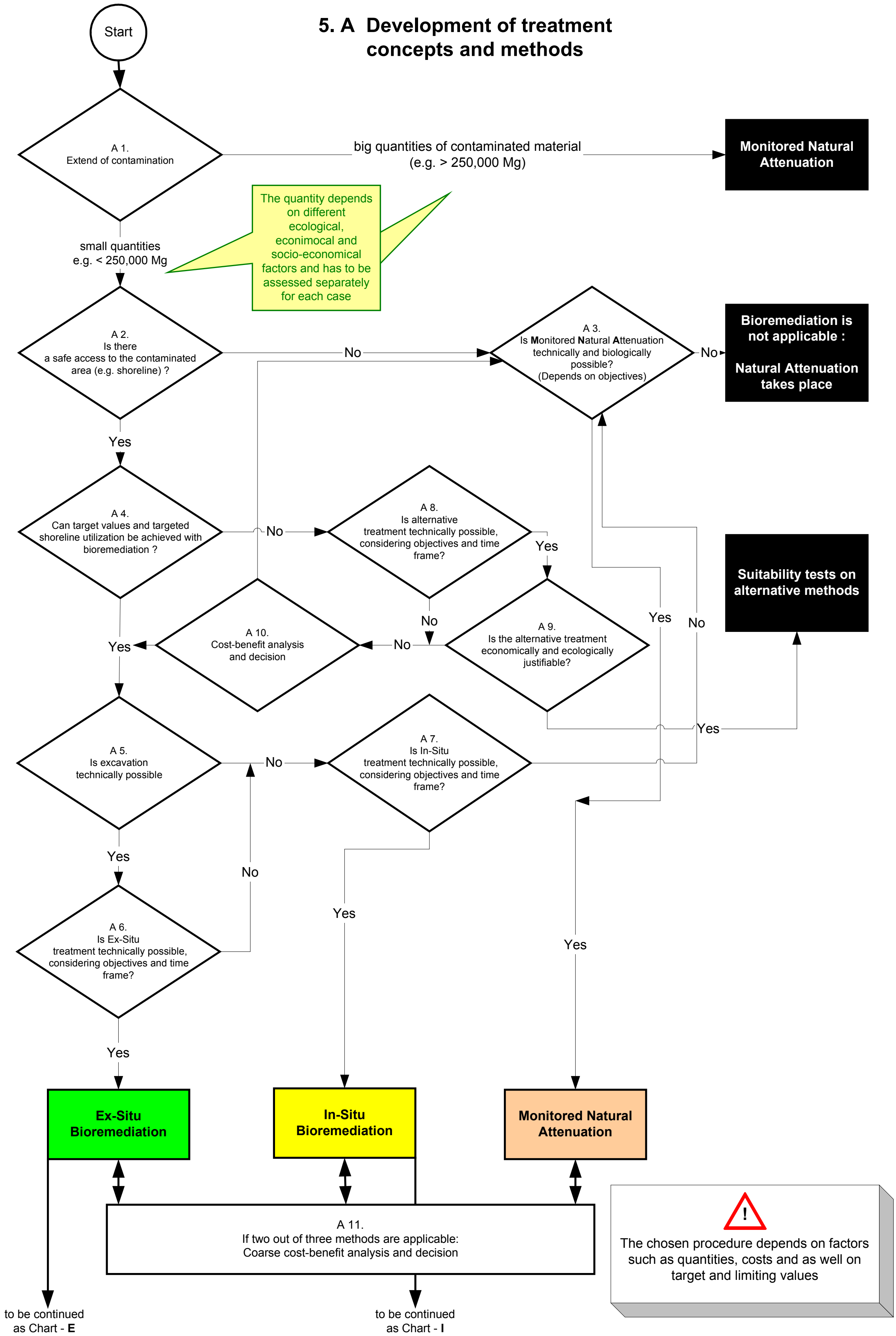

Figure 6-5: Decision-making process (Chart A)

A 1 Extend of Contamination

The extend of the contamination or the contaminated area is a crucial factor for the applicability of the different techniques. Ex-Situ and In-Situ Bioremediation as well as thermically and chemically treatment can handle only certain amounts of contamination. If the maximum loads get exceeded the applicability of the technique can be excluded or combinations have to be considered. Besides the different techniques and the quantities to manage ecological, economical and socio-economical factors have to be taken into account. Possible questions may be:

- How does the oil spill or technique applied affect the environment and live?
- Is the technique applied accepted by publicity? (e.g. use of chemical on minor spills)
- Are livelihoods in danger?
- …

Therefore the extend and impact of the contaminations has to be accessed each time they occur for the specific case.
If there is no application of “active” remediation-techniques possible, Monitored Natural Attenuation (MNA) is the technique of choice.

A 2 Is there a Save Access to the Contaminated Area?

For application of the “active” remediation-techniques a safe access to the contaminated shorelines is needed for the team and equipment involved in planning or implementation of bioremediation and other techniques. Particularly for Ex-Situ bioremediation, the need for excavation and transport has to be considered (e.g. difficult access to wave-cut platforms and rocky exposed cliffs).
If there is access possible further treatment can be planned. If not it has to be assessed if Monitored Natural Attenuation (MNA) is possible.

A 3 Is Monitored Natural Attenuation technically and biologically possible?

In case of no possible “active” remediation the options for monitoring the Natural Attenuation have to be assessed. Monitoring is important to document and prove environments improvement over time. It is also important for the adherence to the limiting values and thus the innocuousness of sea-reutilization for sustaining the local livelihoods.

Natural attenuation (self-cleaning) will involve the following processes:

- Oil can be washed away by wave activity, in high energy coasts. However it has to be noted, this will only remove the oil from the shore and will dilute in the water column. serious effects on the marine flora and fauna can be the consequence.
- Volatile constituents of the oil will volatilize, so that the overall quantity of oil on the shoreline will be reduced. This process is mainly relevant for diesel, kerosene or petrol, which contain relevant quantities of volatile components.
- On the shoreline biodegradation of the oil will occur usually only to a certain extent. Biodegradation is often limited by the lack of nutrients and oxygen.

The following Table 6.5-1 summarizses estimations on the potential duration of natural cleaning for different shoreline types.

Table 6.5-1: Shoreline types and estimations on potential natural cleaning type for oil contaminations [IMO, 2004]

Exposure	Type of coast	Typical time required for natural cleaning
High energy	wave-cut cliffs, seawalls, piers	weeks
	wave-cut rock platforms	weeks - months
	pebble beaches	months - years
	mixed sand and gravel beaches	months - years
	coarse-grained sand beaches	years
	fine-grained sand beaches	years
	coral reefs	years
Low energy	cliffs, seawalls, piers	months
	rock platforms	months
	pebble beaches	months - years
	mixed sand and gravel beaches	months - years
	coarse-grained sand beaches	months - years
	fine-grained sand beaches	years
	tidal mudflats	years
	salt marsh and freshwater marsh	years
	mangroves	years

In cases where even monitoring can not be achieved Natural Attenuation has to take place unobserved.

A 4 Can the Target Values and targeted Shoreline Utilization be achieved with Bioremediation?

Generally, all types of oil are susceptible to microbial degradation and thus target values should be able to be achieved theoretically. However the extent and degradation rate of different types of oils and petroleum products vary greatly, depending on the oil components, concentration as well as the framework conditions, like sediment/soil types, nutrient availability, etc.
There are optimum concentration ranges for biodegradation. With concentrations below those ranges, bioremediation may not be stimulated. Concentrations above may have toxic effects on microorganisms with inhibition degradation processes as consequence.

Oil is subject to weathering processes, which are able to change its characteristics significantly and therewith its biodegradability. An example is that evaporation leads to removal of the more toxic, lower weight components, so that biodegradation is enhanced. On the other hand, the formation of water-in-oil emulsions may increase mass transfer limitations for oxygen and nutrients, and decrease the oil biodegradation rate. Interactions between oil and shoreline-substrate may also play an important role. Finally, oil which has been subject to substantial degradation might not be amendable to bioremediation due to the accumulation of polar components which are more difficult to degrade.

Biodegradability of different Petroleum-oil based Products:
Contamination with petroleum-oil based products, like kerosene, petrol, diesel, heavy fuel oil, etc. represents a mixed contamination with a variety of different constituents. Table 6.5-2 shows a course indication of the biodegradability of the major chemical components, which are present in crude oil and/or refined oil products.

Table 6.5-2: Biodegradability and occurrences of the four major groups of petroleum, components of crude oil and refined oil products

Contaminant	Definition	Bio-Degradability	Occurrence
Saturated hydrocarbons	short chain alkanes (n-alkanes)	high	in crude oil and refined oil products (fuel oil, wax, lubrication oil, petrol, diesel, kerosene, heating oil) concentration in example crude oils *: 67,6 % (Prudhoe Bay) 72,8 % (South Louisiana) 54,3 % (Kuwait) possible range crude oils ** n- or iso alkanes: 10-70% cyclic alkanes: 30-80% concentration in petrol *** 100% saturated alkanes with chains of 5-12 atoms
	long chain alkanes (n-alkanes) or branched alkanes (iso-alkanes)	low	
	cyclic alkanes	low-middle (depends on molecule structure and polarity)	
Aromatic hydrocarbons **a) Monocyclic aromatic carbohydrates** **b) Polycyclic aromatic carbohydrates**	a) BTEX (Benzol, Toluol, Ethylbenzol, Xylole) Phenole Cresole Catechole	high high low high	a) in refined oil products, especially in petrol (over 40%), diesel b) in crude oil, coal concentration in example crude oils* 44,9% (Prudhoe Bay) 18,6 % (South Louisiana) 23,8 % (Kuwait) possible range crude oils ** aromatic hydrocarbons: 20-30%
	b) 2-4 ring PAH (e.g. Naphtalin) 4-6 ring PAH (e.g Benzo(a)pyren)	high low	
Resins	include polar compounds containing nitrogen, sulfur, oxygen (e.g. Pyridines, thiophenes) (NSO)	not	crude oil, residual oils, asphalt concentration in example crude oils*: 4,1% (Prudhoe Bay) 8,6 % (South Louisiana) 21,4 % (Kuwait)
Asphaltenes	poorly characterised high molecular weight compounds (Hydrocarbons, NSO); associated with metals like nickel, vanadium, iron	not	
Unsaturated hydrocarbons	Alkenes Cycloalkenes	low low	only present in refined oil products: petrol, kerosene, heating oil, diesel

* Clarck and Brown, 1997, quoted in EPA 2001
** DECHEMA
*** http://mac.samd.ch/G5/oc/Benzin.ppt

The general susceptibility of mineral-oil-hydrocarbons to microbial degradation proceeds in following order:

1. n-alkanes
2. branched alkanes
3. low-molecular-weight aromatics
4. cyclic alkanes
5. high molecular-weight aromatics

The biodegradability of saturated hydrocarbons can be generally summarized as follows [Hoffmann and Viedt, 1998]:

- Many types of microorganisms can biodegrade aliphatic carbohydrates
- Long-chained n-alkanes are better biodegradable than short-chained, however the longer the chains the smaller the degradability (best degradability with C_9- C_{20}).
- Short chained n-alkanes seem to have more toxic effects on microorganisms due to their the better solubility in water.

- Saturated alkanes are better degradable than unsaturated
- Unbranched alkanes are better degradable than branched.
- Microbial degradation of alkanes is mainly an aerobic process
- The biodegradation of cyclic-alkanes is slow. It depends on the complexity of the structure and the substituted groups.
- The biodegradation of cyclic-alkanes is an aerobic process.

The following main aspects can be summarised regarding the biodegradability of BTEX:

- BETX [ref. to Table 6.5-2] are biodegradable under aerobic conditions and anaerobic conditions (nitrate- and sulphate-respiration, methanogenic conditions).
- Bacteria and fungi are able to degrade BETX compounds.
- Generally BETX are well degradable.

Table 6.5-3 gives an indication on the possible reduction of different oil contaminations, showing the ratio of residual concentrations (R) after a certain time of treatment. The reduction is not only due to biological activities (biodegradation B) but also due to vitalisation of volatile components (V). Depending on the type of oil, a certain fraction is volatile. The highest fraction of volatile components can be found in petrol. As a consequence stripping can be utilised on purpose to reduce volatile components. Apart from the removal of contaminations, this can be useful to reduce inhibiting or toxic components to microorganisms.

Table 6.5-3: Examples of treatment results of oil contaminations: ratio of Volatilisation (V) to biodegradation (B) to residual concentration (R) [various authors, quoted in: DECHEMA]

	V:B:R [%]	**Treatment-period** [weeks]	**Contamination** [g/kg TS]	**Treatment Type**	
Petrol (lead free)	83:11:06	0,5	47	column trials	clay
Kerosene	60:12:28	3	50	column trials	clay
Kerosene	58:39:03	3	4	windrows (treatment halls)	sand & clay
Petroleum derived hydrocarbons (Diesel)	34:42:24	2	4	airlift reactor	
Diesel	37:18:45	4,5	100	column trials	clay
Fuel oil	25:50:25	4,5	140	column trials	
Oil residues	15:48:37	6,5	23,5	digester, liquid	
Bunker C oil*	02:12:86	12	50		

* ca. 90% heavy fuel oil: 53% higher alkanes, 35% aromatics, 12% heterocyclics

In case of contaminations with readily biodegradable hydrocarbons and if the contamination only five to ten times higher than the limiting value and the biological, chemical and physical conditions are additionally good, the remediation target will be achieved quickly.

Beneficial conditions are:

- active biocenosis with potential for reduction of contaminants
- optimised supply of nutrients
- optimised water-content in firm media such as soil

In case of a contamination with persistent substances (e.g. PAH) the degradation processes may be much slower than desired and push the achievement of limiting values in adequate time into question.

Over time the degradation rate will slow down until insignificant further reductions, which is because of:

- easy degradable components have been degraded, only hardly degradable connections are left
- the bio-availability is reduced by chemical bonds
- the bio-availability is reduced by pores and diffusion barriers.

As consequence, high initial concentrations of hardly degradable contaminations are often found to be not suitable for bioremediation processes, when strict remediation threshold values shall be achieved.
Basically it can be concluded that with increasing polarity and molecular size and thus the increasing interconnected water-solubility and bio-availability will slow down biological degradation and conversion.
Besides the kind of contamination itself with its defining factors another great importance is attached to the definition of remediation targets based on the concentration and quantity of pollutants.

A 5 Is Excavation technically possible?

The question about the possibility of excavation and thus accessibility decides between whether to treat In-Situ or Ex-Situ.
Ideal conditions for excavation exists, if the contamination can be located and spotted, its distribution is limited and of capital importance if the site is accessible by machinery.

The excavation requires generally:

- Organisation (site-coordination, action plan)
- Earth moving machinery
- On- and offsite transportation
- Access for vehicles and equipment
- Measures for health and safety
- …

Besides the accessibility the excavation gets also affected if subsurface facilities such as tanks, piping, canal-systems etc. exist within the contaminated area.
In case of inadequate access for the heavy equipment needed for excavation In-Situ treatment has to be considered.

A 6 Is Ex-Situ Treatment technically possible, considering Objectives and Time-Frame?

In Ex-Situ it has to be basically decided which technique will be used. It has to be decided between the main techniques with its slightly different requirements:

- Landfarming-method
- Composting-method
- Reactor-method

Landfarming:

Composting (in Windrows)**:**
If enough space is available, the refilling of the contaminated soil after decontamination is desired and the quantities are adequate, the treatment will occur most likely onsite. The site itself should be incropped, excavateable (accessible) and without any or little subsurface buildings. The contamination is desired to get localized well and focused with little spread.
If the quantities and/or the available space on site are insufficient for onsite treatment it has to accomplished offsite. Offsite treatment plants are mostly stationary.

Fundamental soil-conditions are:

- Optimum water content (max. 30% w/w)
- Grading
- Organic contingent
- Proctor density
- pH (6-8)

Inhibiting factors are:

- Bio availability
- Toxic concentration of contaminants
- Inhomogeneous allocation of contaminants
- Co-contaminants (additional contaminations)

Besides the technical parameters the cost-relevant parameters as accessibility, quantity and transport of the contaminated matter, the assembly and maintenance of the windrows, the duration of the process, the windrow-heights and needed machinery, the demand on nutrients and aggregates have to be considered.

Reactor:

The alternative reactor-method deals with contamination in closed bioreactors. The different modes are to treat solid or in suspension.

Basically the reactor-technique underlies the same limiting factors than the windrow-technique. However, the advantage of reactors is, that limiting factors can be achieved more quickly and effective. The advantage is because of the excessive rate of soil and additive dilution. Besides that are they are controllable and can better be steered. Generally, bioreactors can be used on- or offsite.

Determining criteria are:

- Already existing stationary systems
- Need for mobile systems
- Space available
- Quantity of contaminated soil
- Infrastructure and personnel for supervision

Even though the reactors may compensate the disadvantages of the windrow technique by advanced monitoring and regulation, the contaminated charge needs pre-treatment such as:

- Fractioning (grading)
- Separation of foreign matter (plastics, metals etc.)
- Conditioning of materials (e.g. adjusting of water content, pH and nutrients)
- Sometimes inoculation with activated sludge

Besides the technical parameters the cost-relevant parameters as accessibility and quantity of the contaminated matter as well its transport, complexity, assembly and maintenance of the reactor, the duration of the process, the of the contaminated matter, the required space, the demand on additives and the dehydration have to be considered [Michels, Jochen et.al., 2004].

A 7 Is In-Situ treatment technically possible, considering objectives and time-frame?

After the identification of inadequate conditions for Ex-Situ treatment, the conditions for effective In-Situ treatment have to be assessed and evaluated.

In the traditional In-Situ treatment of contaminated soil several basic criteria evolved. They can be divided in “site- and soil-conditions” and in the conditions of the contaminant itself. The different In-Situ remediation determining criteria are listed below:

Site- and soil-conditions:

- Soil-structure (Pores etc.)
- Soil-texture (Grain-size and distribution)
- Porosity / Compactness of the packing
- Content of water
- Content of organics
- Horizontal and vertical layer progression
- Hydraulic permeabilities
- Groundwater-flow
- Geo- and hydro-chemical conditions
- Potential sorbents (clay, organics)

The criteria on the contaminant are dependent on the oil and its state:

- Vapour-pressure
- Saturation concentration
- Water-solubility and mobility
- Equilibrium of distribution in water and gas phase
- Possibility of formation of explosive gas-compounds

In case of very limited accessibility and insufficient completion of the criteria above the decision will tend towards Monitored Natural Attenuation.

In-Situ techniques gained interest in bioremediation over the last years. In future the trend may tend from complex and expensive techniques towards less expensive techniques like phytoremediation. Besides the economical benefits, these techniques often offer ecological benefits which can be measured with eco-balances. However, the long remediation periods have to be taken into account [Michels, Jochen et.al., 2004].

A 8 Is Alternative Treatment technically possible, considering Objectives and Time-Frame?

The classical soil remediation techniques are elutions with water and other dispersants and suction cleaning of soil-air.

Whereas elimination predominantly gets accomplished by biological remediation immobilisation results from buffering (adsorption or precipitation past reaction with soil related substances). Immobilisation gets amplified by addition of adsorbent materials and precipitants. Adsorption and precipitation are dependent on the pH.

Dilution (reduction of concentration) appears by mixing contaminated with uncontaminated soil (e.g. deep ploughing, insertion of foreign soils).

Besides the techniques already mentioned are others like:

- Use of Micro-emulsions (http://www.internationales-buero.de/de/2152.php) (chemically)
- Use of dispersants (chemically)
- Excavation and thermal treatment (physically)
- Vacuum pumps and oil mist separators (http://www.asca-aachen.com/pages/index_referenzen.html) (physically)

However it has to be noted that these alternative, conventional techniques may achieve the targets in less time but many of these techniques will damage or even destroy the soil structure and its microorganisms.

A 9. Is the Alternative Treatment economically and ecologically Justifiable?

The economic justification of alternative remediation techniques is due to the relatively short treatment periods and established techniques. Additionally the capacities in combination with the conditions have to be assessed.

The ecological justification depends on the potential of the expected environmental damage and destruction occurring from treatment (e.g. dispersants) proportional to the environmental damage caused by the contamination itself. Due to the fact that these alternative techniques get applied where bioremediation techniques are ineffective and a quick effort is needed (e.g. protection of surrounding environments), their ecological consequences get hazarded.

However, the contaminations will be removed, but at the same time the former environments (e.g. soil structure) and micro fauna will be destroyed or changed permanently.

In case of justification the “alternative methods” have suitability to be assessed concerning its cost/benefit-proportion and its estimated outcome.

If the outcome economic or ecologic is not justifiable, a suitability-test with re-evaluated limiting values on the bioremediation-methods or monitored natural attenuation has to be done.

A 10. Cost-Benefit Analysis and Decision, if Alternative Treatment is not possible

If the “alternative-treatment” is not applicable a cost-benefit analysis regarding the new remediation targets with the decision whether to use bioremediation or abandon the site for monitored natural attenuation without further treatment actions or partial treatment within a new action plan.

A 11. If two out of three Methods are applicable: Coarse Cost-Benefit Analysis and Decision

In practice most likely more than one technique is applicable. Even though the remediation of contaminated sites is a combination of the different techniques sometimes there will be more than one technique be suitable for a specific site.

As the name “cost-benefit analysis” suggests, the technique simply adds up the value of the benefits of a course of action, and subtracts the costs associated with it. It is commonly used in all economic decisions and even in private life.

Costs are either one, off, or may be ongoing. Benefits are most often get received over time. This effect can be built into the analysis by calculating a payback period. The payback period is the time it takes for the benefits of a change to repay its costs.

An example for a simple cost-benefit analysis is using only financial costs and financial benefits. It may be the analysis of the cost building a road, and subtract this from the economic benefit of improving transport links. It would not measure either the cost of environmental damage or the benefit of quicker and easier travel to work.

In regard of remediation this consideration is too simple. Here, a more sophisticated approach to cost-benefit analysis is needed. A financial value is needed to put on these intangible costs and benefits. The value can be highly subjective, such like “Is a historic water meadow worth $25,000, or is it worth $500,000 because of its environmental importance?“

Excavation

If the above mentioned tests do not lead to the result that remediation is possible on site (In-Situ), the contaminated soil and sediment has to be removed by excavation and transported to a disposal place or fields that are suitable for the implementation of bioremediation.

Problems like the excavation itself, transportation, storage, equipment, etc. have to be solved before. While remediating, further utilisation paths of the recontaminated soil and sediment can be discussed and decided. Therefore, similar questions according to transportations, interim storage and equipment need to be answered.

6.6 Decision-Making on Bioremediation

The decision-making depends on certain fundamental questions about the “where and how”. The answers of the different questions about circumstances will lead to the applicable treatment method.
Before the decision about the actual treatment method it has to be decided whether to decontaminate In-Situ or Ex-Situ and thus following the decision between on- or off-site treatment. These decisions are crucial for the applicability of the different cleansing methods and the occurring costs.

Depending on remediation-facilities and objectives, sufficient descriptions are needed to find a decision. In general, there are different aspects that can be compared according to three methods of bioremediation as shown in the following Table 6.6-1 .

Table 6.6-1: Overview on different decision-making aspects for bioremediation methods

	Monitored Natural Attenuation	**In-Situ**	**Ex-Situ**
Monitoring of bioremediation results	**+**	**-** (more difficult due to inhomogenous soil, requires more measures)	
Environmental Impact	**+** (No destruction of …)	**+** (No destruction of …)	
Recycling / Disposal of treatment soil	no need for soil disposal/ utilisation	no need for soil disposal/ utilisation	Utilisation or disposal of treated soil/sediment (waste)
Treatment time	Very long	long	Medium
Time for site restoration	**-** (very long, reflecting treatment time under natural conditions)	**-** (long, reflecting treatment time under optimised conditions)	**+** Short
Investment costs			Treatment plant
Operation Cost	Mainly for monitoring	Mainly for monitoring	
			Transport (if off-site treatment) to treatment plant, transport of treated soil
			costs for soil/ sediment excavation
Biological constraints			
Applicable to shoreline types			
Applicable to habitat type			
Waste generation			
Legal implications			Soil becomes waste, after extraction (accordingly EU-law)

Summarising this table and its contents, decision-making depends on technical, economic and time aspects. All possible influences need to be considered as shown in the following chapters of the “Guidelines for the implementation of bioremediation”

6.6.1 Decision-Making for Ex-Situ Bioremediation Techniques

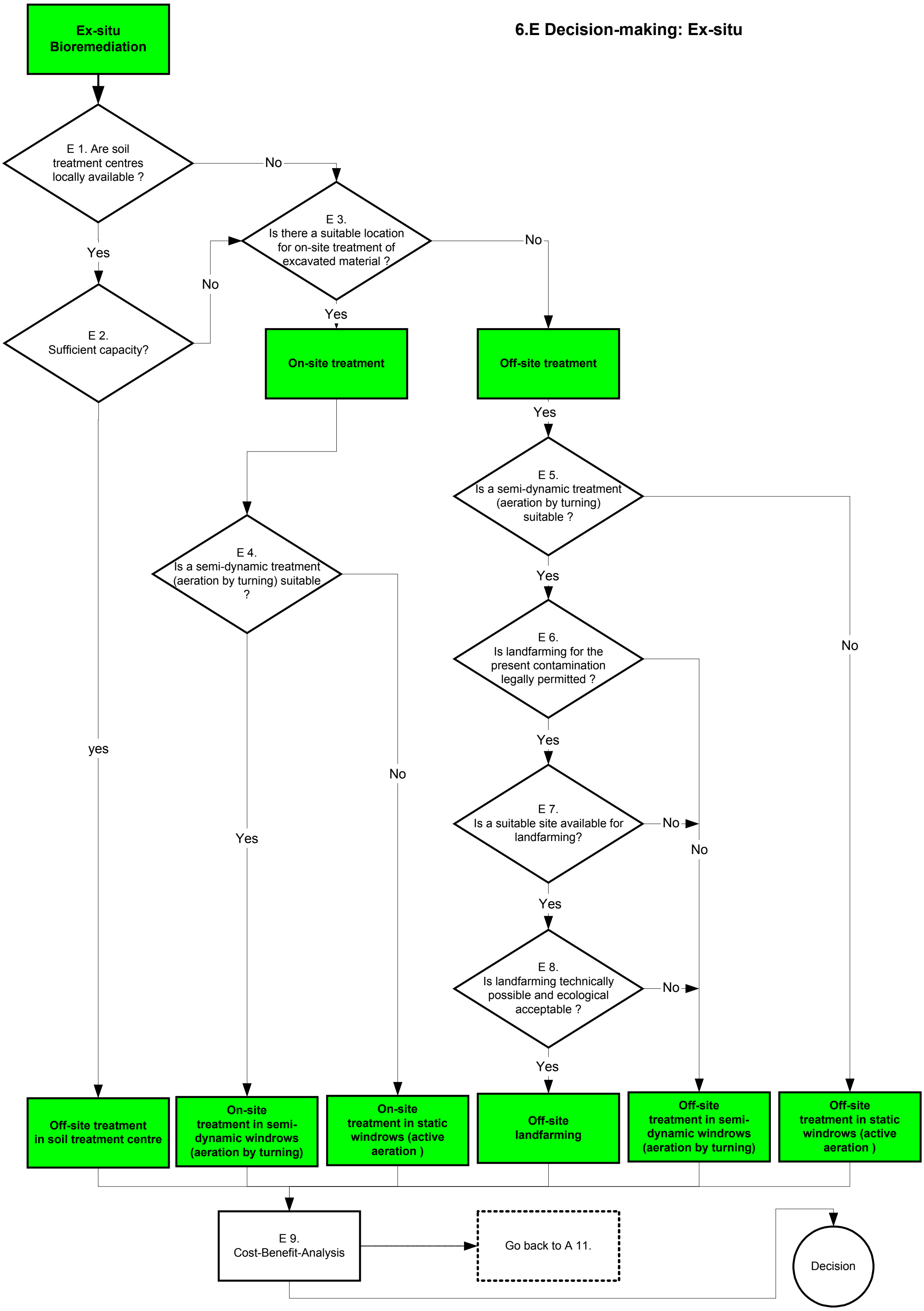

Figure 6-6: Decision-making process for Ex-Situ bioremediation techniques (Chart E)

E 1 Are Soil Treatment Centres locally available?

Soil treatment centres are stationary treatment plants, which provide treatment of contaminated soils / sediments / sands in treatment halls, applying windrow technology or treatment in reactors.

The major advantages are:

- Better infrastructure and equipment
- no installation of mobile facilities, no associated time loss
- no space requirements on site; no need for finding a suitable location for offsite temporary treatment (windrows)
- transferral of the property of the contaminated soil to the bioremediation centre
- cost-efficient treatment, due to repeated use of infrastructure und equipment, also for small quantities of contaminated material.

The prices for the treatment in soil treatment centres are related to the quantities, the treatment technology applied, the type of soil and contamination and the environmental standards. Other influencing factors are political objectives, the number of competitors, costs for disposal and treatment alternatives, and local aspects (e.g. labour costs, etc.).
In addition to the general treatment costs the transport has to be considered as one of the major economic factors. Because of that the distances have to be seen as a crucial point in the decision whether or not to treat the contaminated soils in a stationary plant or close to the contamination.

For Example in Germany wide ranging soil remediation activities started in the 1980's. Therefore soil treatment centres exists all over the country. Today most contaminated materials are treated in soil treatment centres. Only large quantities are dealt with onsite.

E 2 Do the Soil Treatment Centres have sufficient Capacity?

Besides the transport the capacities of the available soil treatment centres are important for further consideration.
If there is insufficient capacity it has to be decided if the quantity of contaminated soil can be distributed to different facilities or if a fractional treatment (e.g. different levels of contamination) is beneficial for the application of other techniques. If soil treatment centres do not state an advantageous solution or if no centres are available other Ex-Situ techniques have to be considered for remediation.

E 3 Is there a suitable Location for Onsite Treatment of excavated Material?

After excluding the total or partial treatment in existing stationary treatment centres, it is to evaluate if there are any suitable sites nearby the contamination for onsite treatment.
If there is only limited space and no further action is possible onsite other sites have to be found close-by (offsite).

Onsite treatment involves the treatment of the excavated sediment on the same site of the contamination. Thus relevant cost factors, costs for transport and temporary storage can be neglected.

Onsite treatment is not always possible. There are several factors influencing feasibility:

Physical site conditions such as:

- Sufficient space for the treatment of the total quantity of contaminated material (usually windrow systems, height max. 3 m)
- Limited slope of the ground
- Suitable soil type of the ground (impermeable)
- Groundwater
- Medium term access for machinery and vehicles.

Environmental aspects such as:

- Environmental sensitivity
- Health and safety for public, neighbours
- Limited / no use of area for public, neighbours
- Impact by transportation, noise.

Legal aspects such as:

- Permits for onsite remediation activities
- Ownership aspects of the site.

E 4 Is a Semi-Dynamic Treatment (Aeration by Turning) suitable On Site?

In case of a suitable site with adequate space, onsite treatment most likely occurs via windrows. For the windrow treatment it has to be evaluated if semi-dynamic treatment is possible. The semi-dynamic treatment is based on aeration by turning and needs no permanent aeration, but more space.

If the aeration by turning is not possible, static windrows have to be used. These get aerated by blowers and a pipe-network. The active aeration has its advantage in the saving of space. Disadvantageous is that the capacities and the aeration-network have to be planned in advance.

E 5 Is a Semi-Dynamic Treatment (Aeration by Turning) suitable Off Site?

The space-criteria is for offsite treatment just as important than for onsite treatment. If there is not enough space for landfarming or dynamic windrows available offsite static windrows with active aeration have to be used.

If there is enough space for dynamic windrows or even landfarming the adherence to the restrictions for landfarming have to be assessed.

E 6 Is Landfarming for the Present Contamination legally Permitted?

The legally permission of landfarming relies on national laws with its limiting values. It has to be established if it is generally allowed and possible to insert contaminated soil and dilute the contamination.

Further considerations are if landfarming is still possible within the limiting values even after insertion and with it dilution of the contaminated soil.

If the limiting values are not obtainable via dilution by mixing and hence landfarming has to be excluded soil has to be treated with semi-dynamic windrows.

E 7 Is a suitable Site available for Landfarming?

After determination of the adherence to the limiting values a suitable site for landfarming needs to be found. For considering landfarming as a treatment option, it is vital to find a suitable site.

Generally, landfarming requires plenty of space. The material usually gets spread up to 40 cm, so that diffusion of air is enhanced. Compared to windrows (up to 3 m) considerably more space is required.

The land is desired to have low economic and agricultural value and needs to be distal to drinking water supplies and other waters (open waters and groundwater). Additionally groundwater needs to be protected by impermeable layers e.g. clay. Because of water-conservation a soil expertise is crucial.

The following list summarises the main aspects which have to be considered, to identify a suitable site:

- low value of the site
- limited slope of the ground
- impermeable layer above groundwater (e.g. clay) to guarantee prevention of ground water pollution
- access for machinery and vehicles
- no high environmental sensitivity
- distance to housing (health and safety, odour)
- permits
- ownership

In case of non-compliance of one or more aspects offsite treatment with semi-dynamic windrows has to be considered.

E 8 Is Landfarming technically possible and ecological Acceptable?

Generally landfarming needs less effort than the use of windrows. Problematic is the vast amount of space and the need for dilution for high loads. In case of high loads large amounts of less contaminated or uncontaminated soil for dilution is needed. With its limited height of applicable soil (ca. 40cm) the quantity determines the space.

Determining factors are:

- adequate site (size, soil conditions, etc.)
- medium contamination
- manageable quantities
- material for dilution available
- machinery available (e.g. ploughs)
- little restrictions

For the ecological acceptance it is important to work within manageable limits on sites where monitoring is possible. Also there should be restricted access to the landfarming sites to prevent accidental harm to people.

If landfarming can be considered as technically and ecologically reasonable alternative, it can be considered as offsite treatment technique for contaminated soils.
However, if landfarming is not suitable semi-dynamic windrows have to be considered alternatively.

E 9. Cost-benefit Analysis

As recognised in Chart A before, most likely more than one technical option will be suitable for Ex-Situ remediation. If more than one technique is suitable a cost-benefit analysis will help to decide which technique or which combination is best to achieve the goals of remediation.

6.6.2 Decision-Making for In-Situ Bioremediation Techniques

During the last years the use of In-Situ bioremediation increased. Besides its economical these techniques also offer ecological advantages which can be displayed with eco-balancing. However, extended remediation periods have to be taken into account.
In-Situ techniques rely on physical, chemical and biological processes. Whereas physical and chemical processes lead to elimination, conversion or immobilization biological processes are not only able to immobilize contamination but also initiate and support physical and chemical processes. Biological catabolism’s will occur contrariwise as secondary effects.
In-Situ techniques do not require expensive excavation of the contaminated soil. Subsequently they may be less expensive, create less dust and thus release less contaminants. However, besides the advantages it is to note that In-Situ techniques are slower than Ex-Situ because of the exacerbated supply with nutrients and CO_2. They also may be more difficult to manage but are most effective at sites with permeable soil (e.g. sands or incompacted soil).

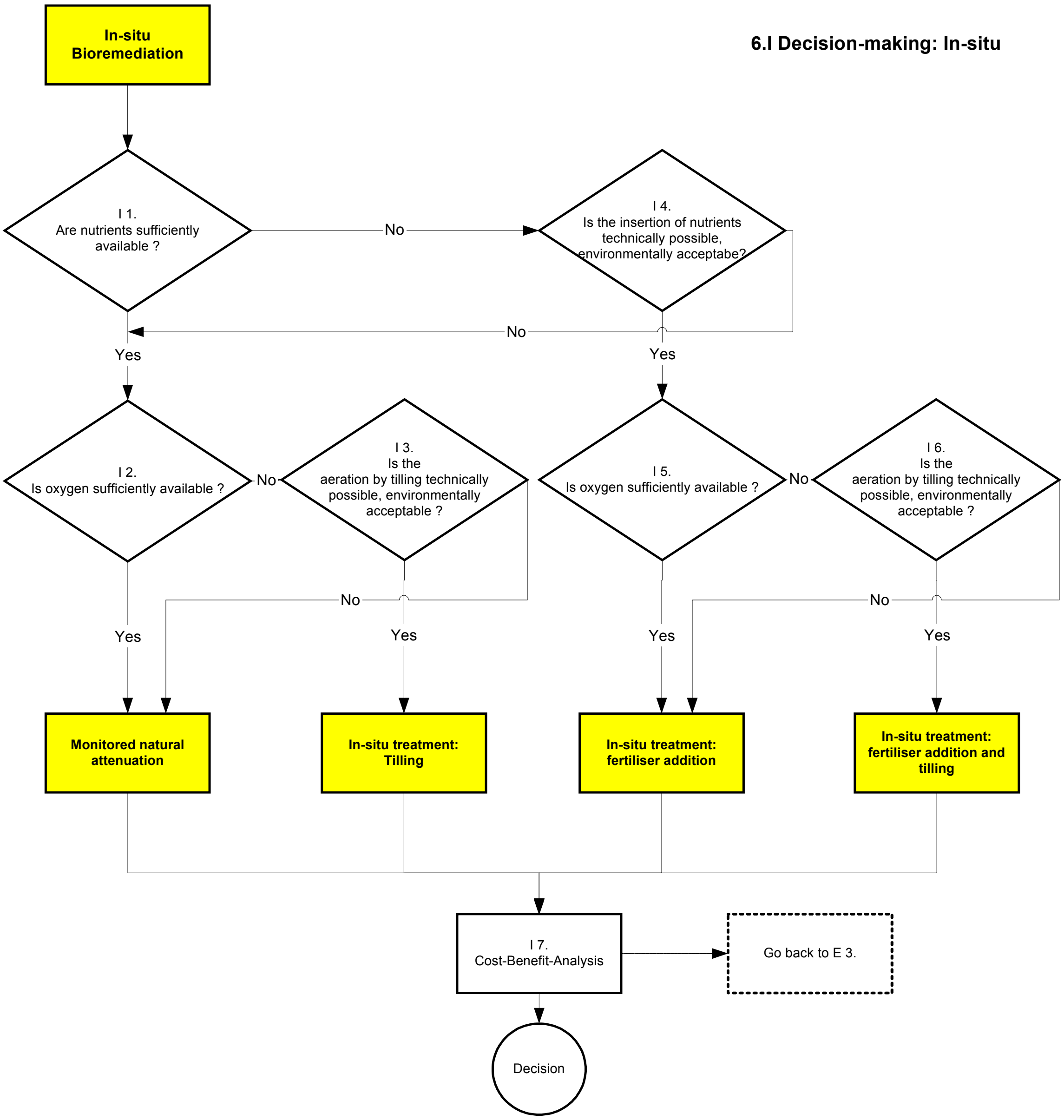

Figure 6-7: Decision-making process for In-Situ bioremediation techniques (Chart I)

I 1 Are Nutrients sufficiently available?

The availability of nutrients in the remediation area (surface - unsaturated soil zone – saturated soil zone) is vital for the biological activity and thus In-Situ remediation. In case of insufficient amount of nutrients they have to be inserted externally. However, if nutrients are sufficiently available other the supply of oxygen has to be ascertained.

I 2 Is Oxygen sufficiently available?

Besides nutrients is oxygen a significant factor for successful In-Situ bioremediation. If nutrients and oxygen are sufficient available the site is suitable for Monitored natural attenuation and no further action is needed.

I 3 Is the Aeration by Tilling technically possible and environmentally acceptable?

In case of lacking oxygen it has to be assessed if an aeration by tilling is possible. Inhibiting factors may be the environment (e.g. Mangroves and overgrown shorelines) where tilling would destroy the complete ecosystem. Just as rocky coastlines may prevent tilling actions for further aeration.
Is tilling neither technically possible nor environmentally acceptable monitored natural attenuation needs to be accomplished.

I 4 Is the Insertion of Nutrients technically possible and environmentally acceptable?

For soils with insufficient nutrients for In-Situ bioremediation it has to be assessed if nutrient-insertion is technically possible. The insertion of nutrients is limited by similar circumstances than aeration. So may nutrification by external fertiliser application (e.g. spraying) be an option for the surface and unsaturated zones in permeable soils, but on rocky shores or overgrown coastlines it will be unlikely harder.
For the environmentally acceptance may be interesting how far the intake of nutrients may affect the algae growth and what the consequences may be. Besides that possible lethal effects on flora and fauna caused by nutrification may be monitored hardly because of the predominantly oil intoxication of the ecosystem.
If an adequate nutrification is not possible it has to be assessed if sufficient oxygen is available for at least monitored natural attenuation.

I 5 Is Oxygen sufficiently available?

As already stated above oxygen is besides nutrients a significant factor for successful In-Situ bioremediation. If oxygen is sufficient available and the site is suitable for fertiliser insertion fertiliser can be applied and no further action is needed.

I 6 Is the Aeration by tilling technically possible and environmentally acceptable?

In case of lacking oxygen it has to be assessed if an aeration by tilling is possible. Inhibiting factors may be the environment (e.g. Mangroves and overgrown shorelines) where tilling would destroy the complete ecosystem or even severely damage it. Just as rocky coastlines may prevent tilling actions for further aeration.
Is tilling neither technically possible nor environmentally acceptable only fertilising without additional aeration needs to be accomplished.
For sites where tilling and nutrification is possible nutrients can be applied while tilling or ploughing for better distribution.

I 7 Cost-Benefit Analysis

Likewise the cost-benefit analysis in Chapter A and E, most likely more than one of the four selected techniques will be suitable for In-Situ remediation. If more than one technique is suitable a cost-benefit analysis will help to decide whether to use which technique or which combination is best to achieve the goals of remediation.

6.7 Development of Treatment Strategy for Bioremediation

Additional to the decision making processes leading to the techniques most suitable for remediation a treatment strategy for bioremediation needs to be developed.
The chapters shown in Figure 6-8 below represent the needful steps for strategy development. It is the execution-plan for the selected techniques.

7.7.1 Determination of priority locations	- sensitivity of areas - levels of contamination - levels of human exposure - possibility of spread (e.g. groundwater access)
7.7.2 Permit requirements	- laws - decrees - authorities involved (coast + shore)
7.7.3 Determination of time schedule	- start of treatment - termination of treatment
7.7.4 Plan for excavation, temporary storage, logistics (Ex-Situ)	- legal requirements - health and safety - environmental requirements - technical requirements
7.7.5 Process design	- determination of quantities (extend of contamination) - determination of floor plan of treatment area (required space) - determination of limiting values which have to be achieved - determination of physical treatment factors (e.g. shape/ height of windrows) - determination of equipment (e.g. for turning) - determination of products (e.g. nutrients NPK fertiliser) - determination of biodegradation enhancement factors (bulking agents, nutrients, agents for ph-value adjustment, tilling/ turning) - determination of technical implementation (e.g. application of additives)
7.7.6 Development of monitoring plan	- sampling strategy (frequency, locations, number of samples) - analysis (chemical/ physical/ biological parameters) - documentation
7.7.7 Development of utilisation / disposal concept for residual soil	- potential utilization pathways - potential disposal pathways - transportation, logistic requirements
7.7.8 Identification of costs and finances	- salary - resources (equipment, machinery, vehicles, bioremediation agents, etc.) - chemical / physical / biological analytics - transport (fuel)
7.7.9 Organization of resources	- human resources - equipment / machinery - vehicles - temporary storage facilities - bioremediation agents - field equipment
7.7.10 Health and safety plan	- oil contamination - bioremediation agents - machinery and equipment - public access

Figure 6-8: Development of treatment strategy for bioremediation

6.7.1 Determination of Priority Locations

Before decision making whether to use which technique priority areas have to be localized. The prioritisation is important to highlight certain aspects of the region affected.

The prioritisation is in regard to coastal oil spills determined by factors such as:

- ecological importance
- ecological sensitivity
- levels of contamination
- levels of human exposure
- cultural importance
- etc.

6.7.2 Permit Requirements

Besides the priorities stated above with its administrative discretion, permits and laws give a hard frame to deal with. Some techniques will drop out even before economical questions are considered.
So it may be that certain treatment-methods are promising for oil removal in the specific case, but they have no permit because of their ecological precariousness.
Equally, some techniques may be ineffective and not be able to reach the limiting values in an adequate period of time, because of the extend of contamination.

6.7.3 Determinations of Time Schedule

The time schedule relies on the prioritisation of site and contamination and in addition to its environmental damaging effects over time. Basically, the start of the remediation and its termination after time and target-achievement are set. Besides that, intermediate remediation targets need to be set and the progress has to be monitored consequently. Just as the remediation targets surrounding actions like preparation of new sites for offsite remediation, supply etc. need to be held within the time schedule to allow undelayed remediation.

6.7.4 Plan for Excavation, temporary Storage, Logistics (Ex-Situ)

If Ex-Situ treatment is the desired option and a suitable treatment site is found excavation and its surrounding actions such as temporary storage and logistics needs to be planned.
First of all legal requirements for excavation and limiting values for soil contaminations have to be assessed. Information about disposition of contaminated excavated earth will be given in relevant legislation about land-use and mining.
Site-access and soil-conditions are crucial for the decision about the equipment to be used (tech. requirements) and the amount of man-power needed for excavation. Besides that occurring hazards for workers and environment needs to be evaluated and health and safety requirements need to be assessed.

6.7.5 Process Design

Ensuing the decision about the applicable techniques the process needs to be designed.
As shown in Figure 6-8 collected criteria are necessary to be known:

- determination of quantities (extend of contamination)
- determination of floor plan of treatment area (required space)
- determination of limiting values which have to be achieved
- determination of physical treatment factors (e.g. shape/ height of windrows)
- determination of equipment (e.g. for turning)
- determination of products (e.g. nutrients NPK fertiliser)
- determination of biodegradation enhancement factors (bulking agents, nutrients, agents for ph-value adjustment, tilling/ turning)
- determination of technical implementation (e.g. application of additives)

After determination of the influencing outline-values the process can be configured according to effectiveness and specific modifications of the techniques selected while decision-making.

6.7.6 Development of Monitoring Plan

The monitoring concept has to be planned and configured for each case specifically. For expense-minimization of analytics in regard to cost-control pilot surveys are helpful.
In many cases the analysis of the contaminant's guiding parameters and the measurable characteristics for bioremediation progress such as nutrient supply, temperature, amount of water and oxygen are sufficient for monitoring.
The time-frame for monitoring depends on experiences and thus only basic expectations can be made. The time-frame basically depends on the correlation between limiting-values and the monitoring results.
Besides that a sampling strategy needs to set up. An overview of tools and methods available for sampling are provided by the U.S. Federal Remediation Technologies Roundtable (FRTR) [http://www.frtr.gov/site/].
Guidance for Site-Characterization and Monitoring-Technologies are given at http://www.frtr.gov/charmonstudies.htm and "Leitfaden - Biologische Verfahren zur Bodensanierung" at http://www.ufz.de/index.php?de=2551.
Information for long term monitoring are provided by the USEPA Clean-up Information in "Subsurface Remediation: Improving Long-Term Monitoring and Remedial Systems Performance Conference Proceedings, April 2000" available at http://clu-in.org/download/misc/subsurf_proceed.pdf.
Besides the sampling strategy and the determination of guiding parameters and characteristics, the documentation and visualization is from particular importance.
For visualisation geographical information systems (GIS) or programs as "Monitoring and Remediation Optimization System" (MAROS) [http://www.gsi-net.com/software/Maros.htm] for groundwater monitoring may be used.

6.7.7 Development of Utilisation / Disposal Concept for Residual Soil

In regard to remediation-aftercare a concept for utilization and disposal of treated, untreated and partially treated soils is of special importance.
Reasonable possibilities for reutilization such as application on unused land, the disposal on landfills or even in construction of landfills with immobilized contaminants.
Besides reutilization and disposal the effort for transportation with its logistic requirements has to be evaluated and adjusted.

6.7.8 Identification of Costs and Finances

Apart from technical requirements the budget and the costs need to be monitored permanently. The previous cost-benefit analyses of "decision-making" have to be included in the overall financial set-up.

Important factors are:

- resources (e.g. equipment and machinery, vehicles for transportation, bioremediation agents, etc.)
- machinery and maintenance materials (e.g. fuels, power)
- infrastructure (e.g. site-access for machinery and transport)
- analytics (chemical / physical / biological)
- salary
- consequential costs (e.g. unsuitable sites)

6.7.9 Organisation of Resources

Even though the financing is assured the availability of human resources, equipment and material is important for the eventual success, likewise.

Important resources are:

- human resources
- equipment and machinery
- vehicles for transportation
- bioremediation agents
- temporary storage facilities
- field equipment

6.7.10 Health and Safety-Plan

For workers, handling waste, and locals a health and safety plan will ease every day live, help to prevent accidents and give decision support in case of accidents.

Health and safety plans have to be set up for:

- oil contamination
- bioremediation agents
- machinery and equipment
- public access

6.8 Implementation of Remediation

According to the techniques assessed as suitable before, treatment will be implemented. Depending on site and conditions it is possible, that different treatment techniques will be applied for sites with varying conditions.

Bioremediation and alternative techniques may be used abreast (e.g. the use of kilns for high excavateable concentrations and bioremediation techniques for medium to low concentrations).

Important for implementation is the adequate planning of procedures and scheduling of supplies. Monitoring is used for the assessment of problems and action planning proximately.

6.9 Monitoring

Long term monitoring programs are founded on the current understanding of site conditions. It is conducted to validate (or refute) the hypotheses regarding site-conditions that are contained in the current conceptual site model (CSM). This CSM is a mental construct of means and experiences of which contaminants were introduced into the environment. Also the fate and the movement of the contaminants in liquid, dissolved, vapour or solid phases from the release points at which the contaminants are extracted and people or ecological receptors are exposed will get incorporated in the decision-making process.

The monitoring results are used to improve the CSM and the remediation techniques through time. All activities undertaken in the monitoring program serve as basis for management decisions. Figure 6-9 shows on the next page the steps leading to the final decisions by revising the data provided by monitoring.

M 1 Initiation of Remediation-Project and Identification of Monitoring-Program Objectives

Besides the decision about the remediation technique applied a set of sampling sites, suite of analytics, and a sampling schedule based upon one ore more program objectives need to be set up. For successful monitoring objectives of the monitoring needs to be developed and clearly articulated prior to initiating and during the processes of the actual monitoring-programme. Site conditions most likely change through time and with remediation progress, thus objectives of monitoring-programs should be revisited and refined as necessary during the course of the program.

M 2 Development of Monitoring Plan Hypothesis

For monitoring planning intermediate objects which can be expected need to be set. The hypothetic objects are important for progress planning and progress monitoring regarding the schedule.

M 3 Definition of Guiding Parameters

The parameters which have to be achieved rely on the particular legislation. The overall achievement and the time needed relies on the remediation-techniques applied. The limiting values will represent the goal of remediation.

9. Monitoring

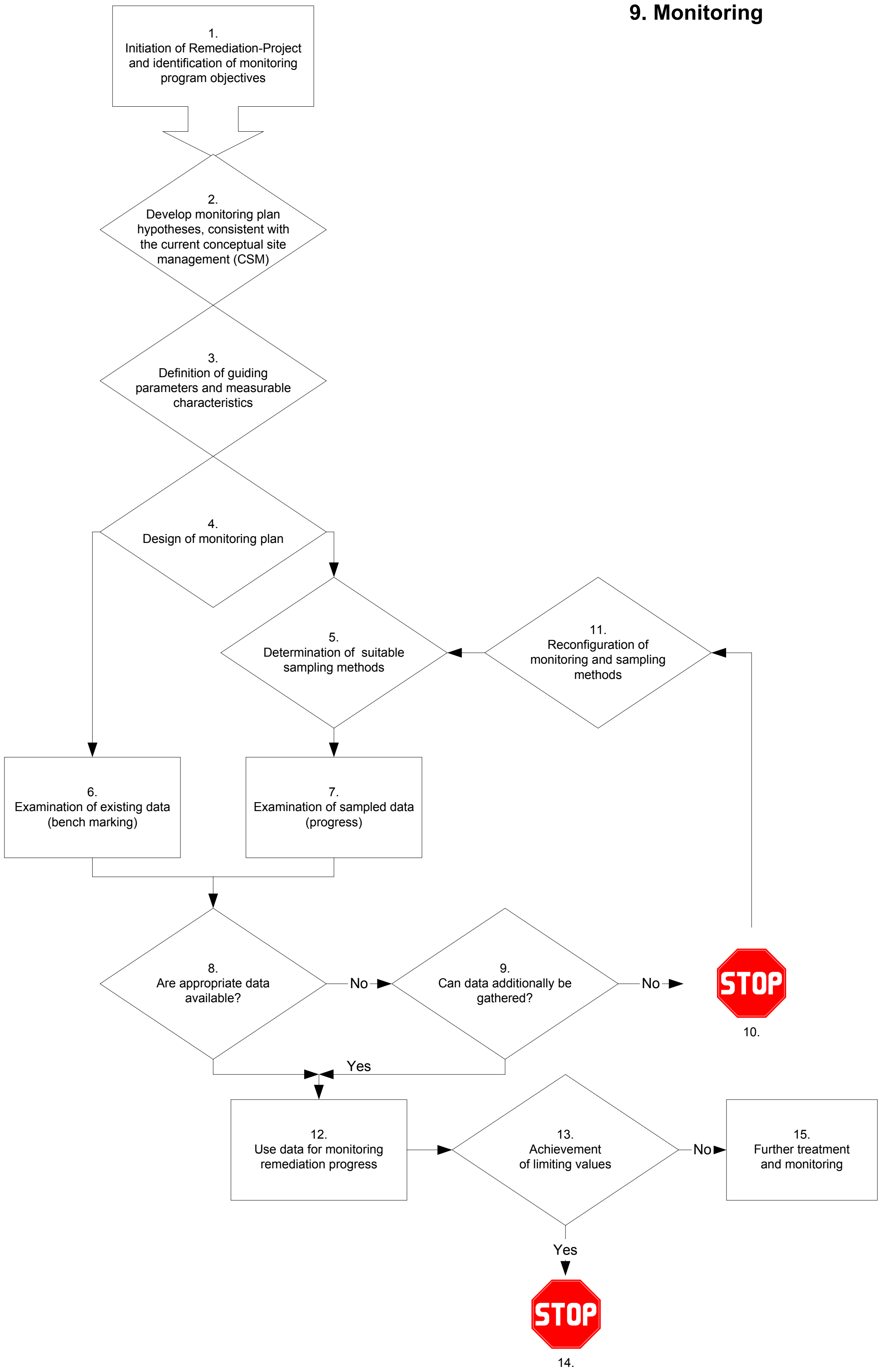

Figure 6-9: Monitoring and resulting decisions

M 4 Design of Monitoring Plan

Combining the site, soil-conditions, the objectives, hypothesises and guiding parameters a suitable monitoring plan can be set up. The monitoring plan includes sampling sites and frequencies as well as the definition of the data required.

M 5 Determination of suitable Sampling Methods

After set up of the monitoring plan, suitable sampling methods need to be found for monitoring. The sampling methods rely on the kind of material and on the substance as well on the sampling-frequency (permanent or by time) required.

M 6 Examination of existing Data

The examination of already sampled existing data gives information about baseline data on the remediation's starting point and the load of contaminants to deal with. The baseline data helps to define estimations about remediation-times for different treatment-methods.

M 7 Examination of sampled Data

The data due to progress-monitoring provided by the previously defined sampling methods gives information about the current state of remediation and the techniques efficiency. Misadjustments and scarcities of e.g. oxygen will be monitored and the operator may respond to reconfigure the process.

M 8 Are appropriate Data available?

The examination of the data provided leads to the qualitative analysis. The data-suitability needs to be questioned permanently in regard to supervision of the analysing techniques. Clues will be given by previous experiences and the progress expectations in combination with validation measures.

M 9 Can data additionally be gathered?

If the gathered data is inappropriate additional data needs to be gathered and analysed. For additional data sampling and verification the operation a second set sampling devices recommended.
If the sampled shapes up inappropriate the monitoring plan needs to be readjusted.

M 10 STOP → Termination and Troubleshooting

In case that no additional data can be gathered monitoring needs to be terminated. If that means that the process can not be controlled further the remediation process needs to be terminated. Problems need to be investigated and solutions developed.

M 11 Reconfiguration and Monitoring of sampling Methods

If the problems and solutions leading to termination of monitoring are found the reconfiguration of the monitoring objectives and sampling methods needs to be done.
The process starts again at the determination of suitable sampling methods, but considering other requisitions.

M 12 Use data for Monitoring Remediation Progress

Is the data according to the collected and evaluated data of step eight and nine suitable, the data can be approved and used for monitoring and display of remediation progress.

M 13 Achievement of Limiting Values

The achievement of limiting values represents the achievement of legal requirements. However, project goals may be much tighter, depending on e.g. local environmental awareness or specially assigned regional ecological value.

M 14 STOP → End of Process

If limiting values are achieved and additional requirements got fulfilled remediation can be stopped.

M 15 Further Treatment and Monitoring

Further treatment is needed if neither monitoring nor secondary monitoring gives indication about achieving the limiting values. In this case treatment has to be executed further on until they get achieved during permanent monitoring.

6.9.1 Evaluation of Treatment Success

Treatment success gets evaluated by constant monitoring and progress documentation. The treatment procedure outcome can be determined as successful if the limiting values are achieved within desired time.

6.10 Reuse of treated Material and Areas

The reuse of treated materials depends on the level of contaminations remaining.

Different factors influencing decisions about reuse are:

- actual legislation
- limiting values for land-use
- possibilities of further dilution with untreated, uncontaminated soil
- possibilities of further natural attenuation and its expectations

The actual reutilisation can be manifold, such as reuse in similar conditions with equal functions or landscaping. Materials which are after treatment still expected to be harmful for the environment can be used in landfill construction where leaching and drift can be prevented.

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ANNEX

Annex A

Annex B

LIST OF EQUIPMENT

No.	Description	Specification	Quantity	Country/ Year of manufacture
1. Containment Boom				
1.1	RO-BOOM 2000 System	Total height: 2 m Length of set: 250 m	02 sets	Denmark 1995
1.2	Vikoma Hi-Sprint Boom System	Total height: 2 m Length of set: 250 m	02 sets	UK 1999
1.3	RO-BOOM 1000 System	Total height: 1m Length of set: 250 m	01 set	Denmark 2002
1.4	Crucial Response Boom System	Total height: 0.75 m Length of set: 250 m	03 sets	USA 1999
1.5	Elastec Maximax I Boom System	Total height: 0.75 m Length of set: 200 m	02 sets	USA 1999
1.6	RO-BOOM 1800 System	Total height: 1.8 m Length: 250m	01 set	Denmark 2004
1.7	Sentinel Boom System	Total height: 1m Length: 300 m	01 set	UK 2004
2. Skimming System				
2.1	Foilex TSD 250 Skimmer	Capacity: 140 m^3/hr	01 set	Sweden 1999
2.2	Crucial ORD 50 Disc Skimmer	Capacity: 50 m^3/hr	01 set	USA 1999
2.3	Sea-Mop 4090 Skimmer	Capacity: 35 m^3/hr	01 set	Denmark 1995
2.4	Ro-Skim 2000 Skimmer	Capacity:100 m^3/hr	01 set	Denmark 1995
2.5	4300-SH Skim-Pak Skimmer	Capacity: 15 Mg/hr	01 set	USA 1999
2.6	Ro-Mop Skimmer	Capacity:12 m^3/hr Single oil sticky rope	01 set	PV Drilling 1999
2.7	Disc Skimmer	Capacity: 20 m^3/hr	01 set	PV Drilling 2002
2.8	Belt/Brush Skimmer	Capacity: 45 m^3/hr	01 set	Denmark 2004
3. Temporary Storage Tank				
3.1	Vikoma Floating storage Tank	Capacity: 25 m^3	02 sets	UK 1999
3.2	Ro-clean Floating storage Tank	Capacity: 25 m^3	02 sets	Denmark 1995
3.2	Ro-clean Floating storage Tank	Capacity: 10 m^3	01 set	Denmark 2002
3.3	Elastec Towable Blader Tank	Capacity: 5 m^3	02 sets	USA 1999
3.4	Ro-clean Open-top Tank	Capacity: 4 m^3	01 set	Denmark 2002

No.	Description	Specification	Quantity	Country/ Year of manufacture
4. Dispersant Spray Set				
4.1	TC3 spray set	Capacity: 910 litres	01 set	UK 1999
4.2	Arm spray set	Capacity: 90 l/min Side width: 6 m 02 units	02 sets	PV Drilling 2001
5. Oil Dispersant				
5.1	Superdispersant-25	Contained in 200 litres drum	50 drums	UK 2001
6. Waste Treating Equipment				
6.1	Incinerator Type 399	Capacity: 500 kg/time	01 set	Denmark 2002
7. Shoreline Clean-up & Launching Equipment				
7.1	Aquila High Pressure Cleaner TD302	Working pres: 300 Pa Water temp.: 95^0C	01 set	Denmark 2002
7.2	Mobile lighting system	Generator: 12 kW Halogen lamp		Japan 2003
7.3	Tons Hiab Crane	5 ton capacity	01 set	Japan 1999
8. Sorbent				
8.1	Oil Sorbent Boom	Dim.: 8'' * 10' 40'/bale	60 bales	Netherlands 2002
8.2	Oil Sorbent Pad	Dim.: 17*19*3/8" 100 pads/bale	100 bales	Netherlands 2002
8.3	Chemical Sorbent Boom	Dim.: 8'' * 10' 40'/bale	30 bales	Netherlands 2002
8.4	Chemical Sorbent Pad	Dim.: 17*19*3/8" 100 pads/bale	30 bales	Netherlands 2002
9. Canoe & Vessel				
9.1	High Speed Response Canoe	Engine: 150 HP Max speed: 60 km/h	01 canoe	VietNam 2004
9.2	Offshore deploying vessel		6 vessels	
9.3	Offshore tow vessel		8 vessels	
9.4	Inshore vessel		12 vessels	

IN-USED RATE

No.	Item	Daily Rate (USD)	Notice
1. Containment Boom			
1.1	RO-BOOM 2000 System	1100/set	
1.2	Vikoma Hi-Sprint Boom System	1200/set	
1.3	RO-BOOM 1000 System	650/set	
1.4	Crucial Response Boom System	570/set	
1.5	Elastec Maximax I Boom System	500/set	
1.6	RO-BOOM 1800 System	1200/set	
1.7	Sentinel Boom System	700/set	
2. Skimming System			
2.1	Foilex TSD 250 Skimmer	635/set	
2.2	Crucial ORD 50 Disc Skimmer	450/set	
2.3	Sea-Mop 4090 Skimmer	250/set	
2.4	Ro-Skim 2000 Skimmer	350/set	
2.5	4300-SH Skim-Pak Skimmer	250/set	
2.6	Ro-Mop Skimmer	185/set	
2.7	Disc Skimmer	295/set	
2.8	Belt/Brush Skimmer	430/set	
3. Temporary Storage Tank			
3.1	Vikoma Floating storage Tank - 25tons	140/set	
3.2	Ro-clean Floating storage Tank - 25tons	140/set	
3.3	Ro-clean Floating storage Tank - 10tons	65/set	
3.4	Elastec Towable Blader Tank - 5tons	45/set	
3.5	Ro-clean Open-top Tank - 4tons	40/set	
4. Dispersant Spray Set			
4.1	TC3 spray set	160/set	
4.2	Arm spray set	95/set	
5. Oil Dispersant			
5.1	Superdispersant-25	900/drum	
6. Waste Treating Equipment			
6.1	Incinerator Type 399	815/set	
7. Shoreline Clean-up Equipment			
7.1	Aquila High Pressure Cleaner TD302	285/set	
8. Sorbent			
8.1	Oil Sorbent Boom	155/bale	
8.2	Oil Sorbent Pad	85/bale	
8.3	Chemical Sorbent Boom	175/bale	
8.4	Chemical Sorbent Pad	115/bale	
9. Canoe & Vessel			
9.1	High Speed Response Canoe	220/canoe	
9.2	Offshore deploying vessel	-	
9.3	Offshore tow vessel	-	
9.4	Inshore vessel	-	

No.	Item	Daily Rate (USD)	Notice
10. Personnel			
10.1	Supervisor (team leader)	300/person	
10.2	Assitant	200/person	
10.3	Marine Engineer	150/person	
10.4	Mechanic	150/person	
10.5	Operator	100/person	

LIST OF PERSONNEL

No.	Position	Quantity	Notice
01	Supervisor (team leader)	4	
02	Assitant	4	
03	Marine Engineer	2	
04	Mechanic	4	
05	Operator	16	