ENVIRONMENTAL ASSESSMENT OF LEKHWAIR ASSET - 2002 REVIEW AND UPDATE

PETROLEUM DEVELOPMENT OMAN

SULTANATE OF OMAN

Authorized for release by:

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EXECUTIVE SUMMARY

Introduction

This report updates the environmental assessment of Lekhwair asset, which is one of the seven production assets within PDO's concession area in the Sultanate of Oman. The first environmental assessment for Lekhwair asset was carried out in July 1999. Since then, several changes with respect to the facilities, processes and procedures have taken place in the asset. In order to review the impacts on the environment due to these changes, the environmental hazards and effects associated with the activities in the asset are reassessed in this study. This study is conducted, on behalf of PDO by HMR Environmental Consultants during the period of June-December 2002.

Overview of Asset Activities and Facilities

PDO operates over 113,550 km^2 of concession area consisting of about a hundred fields, 2,454 oil producing wells and 72 non-associated gas producing wells. Currently, PDO (including gas asset) produces about 843,490 barrels of oil (black oil and condensate) and 44 million Sm^3 of gas (associated and non-associated) on average per day as reported for the year 2002. Lekhwair covers a land area of 3,560 km^2 and consisting of 2 operating fields and 223 producing wells.

This asset currently produces 14,601 m^3/d of oil (black oil and condensate) (10.9% of PDO) and 1550,000 Sm^3/d of associated gas (3.5 % of PDO). The total power generation in the asset is 51.4 MW and the total abstraction of groundwater in the asset is 13,690 m^3/d. The total length of flow lines in the asset is 384 km and the total length of roads in the asset is 158 km.

The asset has one production station (located in Lekhwair), ten remote manifold stations and one gathering station to collect crude from wells. There is one gas fired gas turbine power station located in Lekhwair. There is no booster station or permanent laboratory facility at Lekhwair. There is a water treatment plant based on reverse osmosis (RO) process. There are two permanent accommodation camps, one for PDO staff and the other for contractors. There are two permanent sewage treatment plants (STPs), one for PDO camp and the other for Contractor's camp. There is a central waste management centre in the asset.

The asset releases about 2,339 tpd of CO_2, 4 tpd of NO_x, 4 tpd of CO and <1 tpd of SO_2 and 16 tpa HC into the atmosphere. The liquid effluents generated in the asset include 21,980 m^3/d of produced water and 153 m^3/d of sewage. The total hazardous waste produced is about 279 tpa. The total volume of accidental oil spills and leaks reported in the asset is 8 m^3 per year.

Description of Environment

Lekhwair asset is located in the northwest corner of PDO's concession area, bordering to Saudi Arabian and United Arab Emirates. The asset area is mostly gravel plain, with low sand dunes present on the western and northern sides of the asset. The mean altitude of the asset is about 100 m above the mean sea level. A few shallow wadis (Wadi Bu Mudiq and Wadi al Ayn are the major wadis) flow from the north and drain into the south-east corner of the asset.

The geology of the asset area comprises of mainly composed of limestone, dolomite, shale, clay and anhydrite. Fars aquifer is the shallowest aquifer in the asset and has superior water quality. However, UeR aquifer is the most prolific but the groundwater is quite saline.

The region has an arid climate with mean monthly temperatures ranging from 19 ^oC (January) to 37 ^oC (June). The maximum and minimum absolute temperatures are 51^oC and 6^oC

respectively. The mean annual rainfall in Fahud area is 20 mm, which is highly variable in time and space.

The vegetation is composed of desert plants and grasses, while trees are rarely seen. Wildlife is uncommon in Lekhwair due to extremely arid with high temperatures, very little rain and sparse vegetation. Therefore wildlife is concentrated in the wadis where no large mammals are present except for domestic livestock. The desert hare may be found but rodents and reptiles are the main wildlife in this hyper-arid area. A number of bird species are recorded.

There are no towns or bedouin (nomadic or semi-nomadic) settlements within the Lekhwair asset area. The number of persons currently accommodated in PDO and contractor camps in the asset is about 260. The literature search and a walk-through field survey have shown no evidence of archaeological sites in Lekhwair asset. The cultural resources are limited to a mosque located in PDO's main camp.

Significant Environmental Effects

Based on the existing activities and the current status of the environment in the asset, the environmental hazards and potential effects are identified. The potential environmental effects are assessed based on the HEMP methodology outlined in PDO's document GU-195 "Environmental Assessment Guideline". The effects with a risk rating level of medium or higher are short-listed and the necessary additional mitigation measures are recommended. The following table summarizes the recommended additional mitigation measures against each of the environmental specifications of PDO, *viz.*, SP-1005 to SP-1012 and SP-1170.

Specification	Areas of Non-compliance or Concern	Recommended Additional Mitigation Measures
SP-1005: Specification for Emissions to Atmosphere	• Stationary sources of air emissions are not monitored to check compliance with emission standards. • Ambient air is not monitored to check compliance with air quality standards.	• All continuous air emission sources such as gas turbine and heater stacks shall be monitored for compliance. • Ambient air quality shall be monitored in accommodation camps periodically.
SP-1006: Specification for Aqueous Effluents	• Current STP monitoring frequency and schedule are inadequate. Once a day or once a week monitoring cannot detect if standards are breached during peak load times. • Technical proficiency of STP operators and supervisors is below par.	• STP monitoring frequency and schedule need to be revised to ensure compliance at all times. Monitoring frequency may be increased to 4 times per day for on-site measurements and composite samples may be taken for laboratory analysis. • All STP operators and supervisors shall be provided continuing education and training on STP operation and monitoring.

Specification	Areas of Non-compliance or Concern	Recommended Additional Mitigation Measures
SP-1007: Specification for Accidental Releases to Land and Water	• Oil saver pit at Lekhwair B overflows. • Quantities of contaminated soil transported to landfarm are not reported.	• Oil saver pit shall be provided at Lekhwair Production Station. • Vacuum tanker for oil removal shall be available at Lekhwair. • Oil saver pit capacity and the transfer pump capacity at Lekhwair B shall be increased to contain one tanker capacity. • Records to be maintained for the contaminated sand transported to Fahud.
SP-1008: Specification for Use of Energy, Materials and Resources	• Optimal use of energy and water is not demonstrated as required in the specification.	• Avenues for minimization of water consumption shall be explored. • Monitoring of water wells shall be continued to ensure that there is no depletion of groundwater reserves over a longer term.
SP-1009: Specification for Waste Management	• Waste consignments are not properly estimated. • Waste compaction equipment is inadequate. • Waste recycling is not significant.	• Compliance with waste handling procedures shall be enforced. • Waste operators shall be closely supervised. • Waste recycling avenues shall be explored at corporate level.
SP-1010: Specification for Environmental Noise and Vibration	• Ambient noise levels are not monitored to check compliance with the standards.	• Ambient noise levels shall be monitored in accommodation camps periodically
SP-1011: Specification for Flora and Fauna	• None	• None
SP-1012: Specification for Land Management	• There are several abandoned well sites, which require restoration.	• Site restoration program shall be accelerated.
SP-1170: Specification for Management of Naturally Occurring Radioactive	• NORM survey in the stations is not completed.	• Comprehensive NORM survey to be completed and necessary mitigation measures to be taken, if required.

Conclusion

Based on the present study, it is concluded that no change in PDO's existing HSE management system is required. However, it is necessary to modify the HSE plans and programmes in the asset by incorporating the additional mitigation measures recommended above. This will ensure that the potential environmental risks are minimized, non-compliances are eliminated and the overall environmental performance in the asset is significantly improved.

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ABBREVIATIONS

AP	atmospheric pressure (<0.5 kPa gauge pressure)
API	American Petroleum Institute
bar(g)	unit of gauge pressure (equal to 101.3 kPa gauge)
bbl	barrel (equal to about 159 liters)
bpd	barrels per day
Bq	Bequerel, unit for measurement of radioactivity (One nuclear disintegration/second)
^{o}C	degree centigrade
^{o}K	degree Kelvin
$CaCO_3$	calcium carbonate
CFC	chloro-fluoro-carbon
d	day
DGEA	Directorate General of Environmental Affairs
DLN	dry low NO_x
DWD	deep water disposal
ESP	electrical submersible pump
E&P	exploration & production
EPC	engineering, procurement and construction
EU	European Union
h	hour
ha	hectare
HCFC	hydro-chloro-fluoro-carbon
HFC	hydro-fluoro-carbon
HEMP	hazards and effects management process
HMR Consultants	HMR Environmental Engineering Consultants
HP	high pressure (>150 kPa gauge pressure)
kg	kilogram
km	kilometer
km^2	square kilometer
kPa	kilo Pascal, unit of pressure (1 atm = 101.13 kPa)
LP	low pressure (0.5 – 150 kPa gauge pressure)
LPS	Lekhwair Production Station
LRVC	liquid ring vacuum compressors
m^3	cubic meter
mg	milligram
ml	milliliter
MLPS	main line pumping station
MOL	main oil line
MPN	most probable number
mPa.s	milli-Pascal-second (a unit of viscosity equivalent to 1 centipoise or cp)
MD	ministerial decision
MJ	mega-Joule
NOCS plant	North Oman crude stabilization plant
MW	megawatt
MWh	megawatt-hour
MRME&WR	Ministry of Regional Municipalities, Environment and Water Resources
MSDS	material safety data sheet
NAAQ	national ambient air quality
Nm^3	normal cubic meter (at 1atm and $0^{o}C$)
NO	nitric dioxide
NO_2	nitrogen dioxide
NO_x	oxides of nitrogen
NORM	naturally occurring radioactive materials
PDO	Petroleum Development Oman LLC

ppm	parts per million
ppmv	parts per million, volume based
PM_{10}	particulate matter of <10 µm size
$PM_{2.5}$	particulate matter of <2.5 µm size
RD	royal decree
RMS	remote manifold station
RO	reverse osmosis
SHOC	safe handling of chemicals
Sm^3	standard cubic meter (at 1atm and 20^{o}C)
SOGL	south Oman gas line
STOIIP	stock tank of oil initially in place
t	metric tonne (equal to 1000 kg)
TDS	total dissolved solids
tpa	tonnes per annum (year)
tpd	tonnes per day
tph	tonnes per hour
TSP	total suspended particulates
UeR	Umm er Radhuma
UNEP	United Nations Environmental Program
UNESCO	United Nations Scientific and Cultural Organisation
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation
µg	micro-gram
µm	micro-meter (also known as micron)
µS/cm	micro-Siemens per centimeter (unit of electrical conductivity)

1 INTRODUCTION

1.1 Petroleum Development Oman

Petroleum Development Oman (PDO) is the largest petroleum exploration and production (E&P) company in the Sultanate of Oman, with over 113,550 km^2 of concession area, covering most of the central and southern parts of the Sultanate. The geographical map of PDO's concession area is shown in Figure 1.1. Presently, PDO's concession area is divided into two main directorates viz., North Oman and South Oman. The production assets within North Oman include Fahud, Lekhwair, Yibal and Qarn Alam, and those within South Oman include Bahja, Nimr and Marmul. The crude oil export facilities and the administrative head quarters are located on the coast in Mina Al Fahal. The current asset organisation structure in PDO is shown in Figure 1.2.

Currently PDO (including gas asset) operates from about a hundred fields and has 2,454 oil producing wells and 72 non-associated gas producing wells. The total production of oil (black oil and condensate) currently is about 843,490 barrels per day and that of gas (associated and non-associated) is about 44 million Sm^3 per day as reported for the year 2002. A network of 9,300 km of pipelines, 28 gathering stations and 18 production stations feed the produced crude oil into the main storage facility located at Mina Al Fahal near Muscat (at Muscat coastal area), from where the oil is loaded into tankers moored offshore. The produced gas is partly utilised within the assets and the rest processed in three gas stabilisation stations (located in Yibal, Saih Rawl and Saih Nihayda) and then exported. The asset-wise break-up for land area, crude oil production, gas production and production water is presented in Table 1.1 below for the current year (2002) and their percentages are given in figure 1.3.

Table 1.1: Description of Production Assets in PDO

Production Asset	Land Area (km^2)	Oil Production (m^3/d average)	Gas Production (10^3 x Sm^3/d average)	Produced Water (m^3/d average)
Fahud	11,580	14,670	5,007	11,239
Lekhwair Asset	3,560	14,601	1,550	21,977
Yibal Asset (Including Gas Asset)	5,830	31,134	31,995	154,970
Qarn Alam Asset	18,900	14,462	3,084	67,255
Bahja Asset	30,560	12,347	550	27,050
Nimr Asset (Including Rima and Al Noor)	16,160	35,669	780	313,105
Marmul Asset	26,960	11,221	900	41,937
Total for PDO's Concession Area	**113,550**	**134,104**	**43,866**	**637,533**

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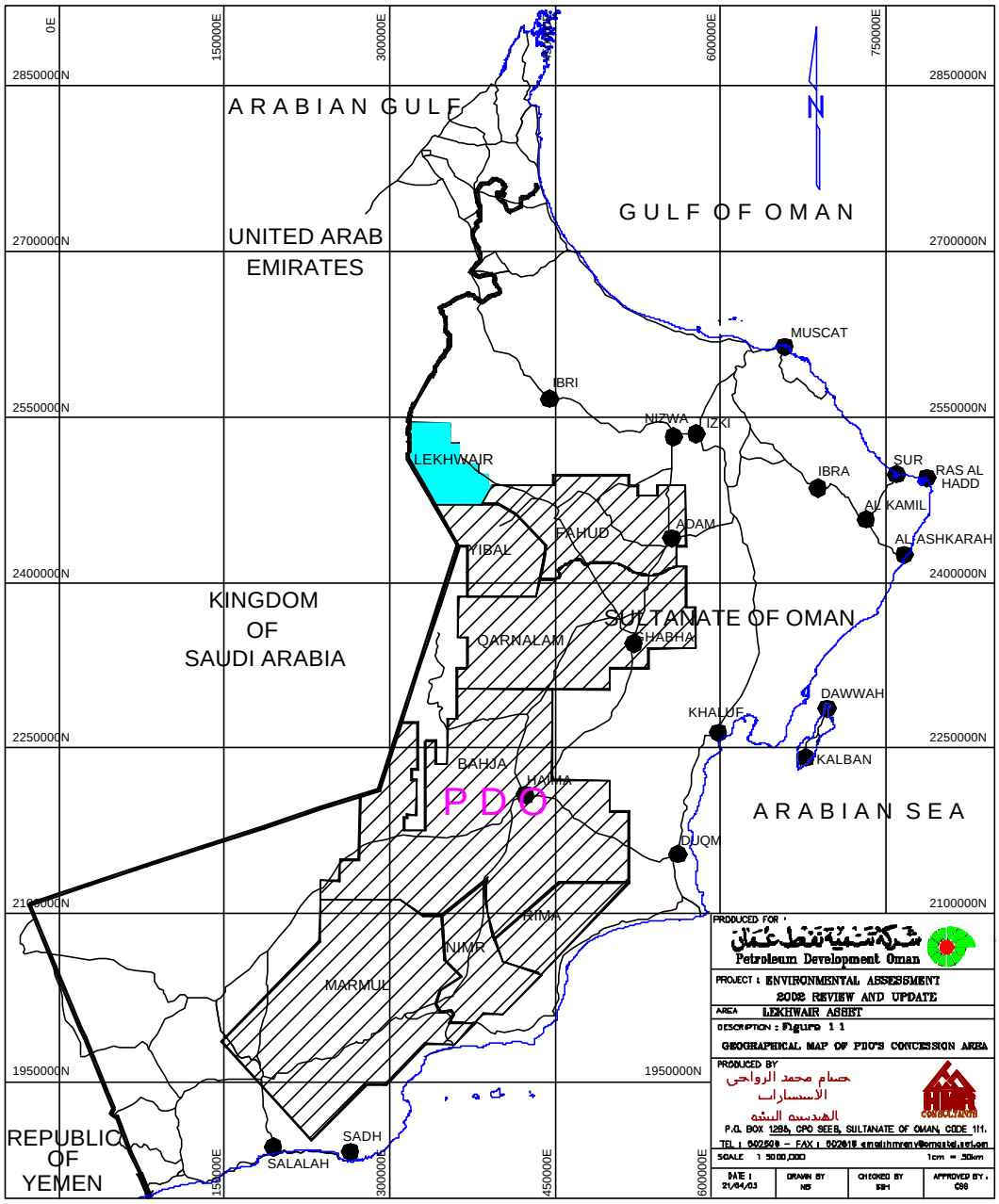

Figure 1.1: Geographical Map of PDO's Concession Area

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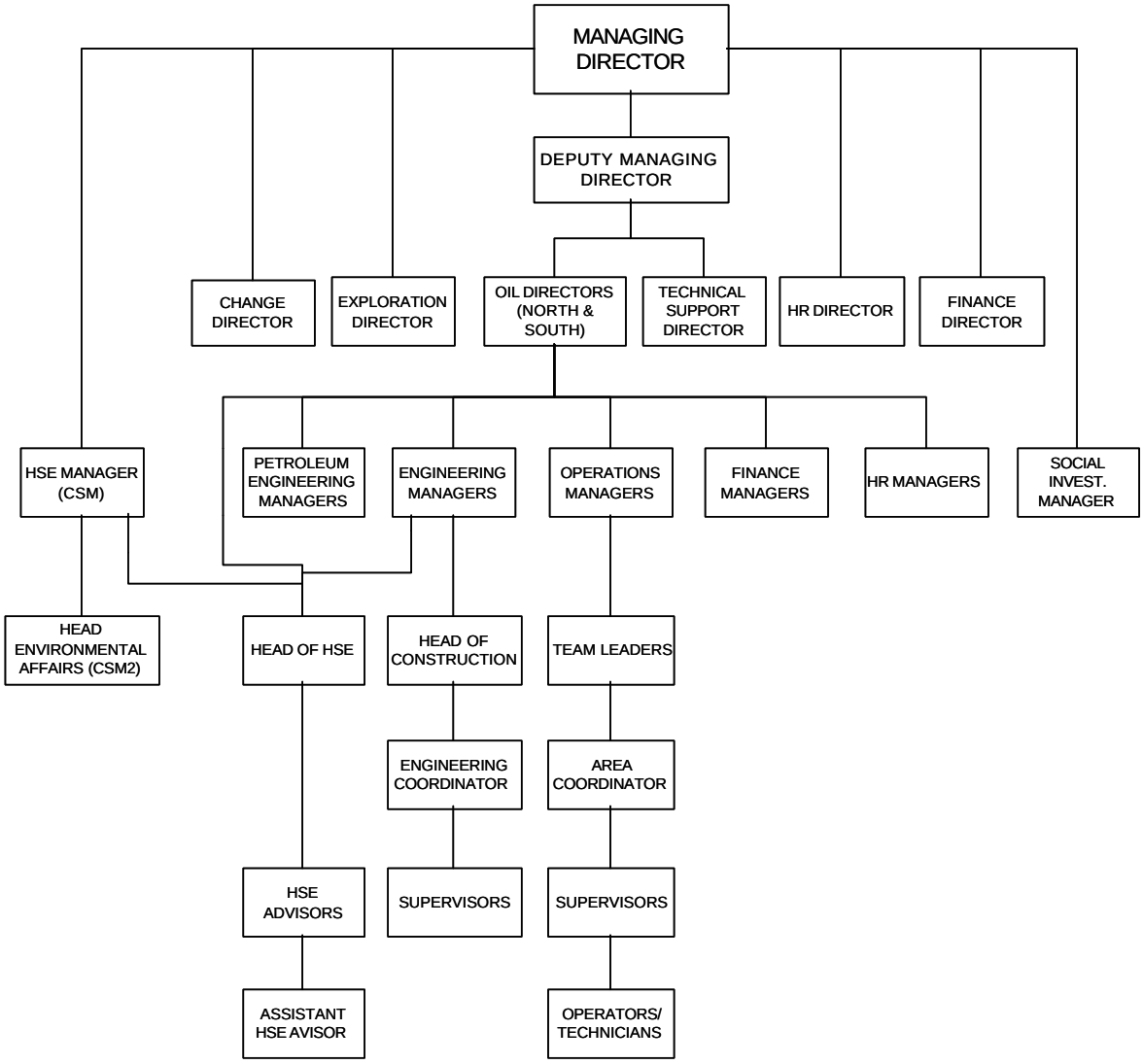

Figure 1.2: Organisation Structure in PDO

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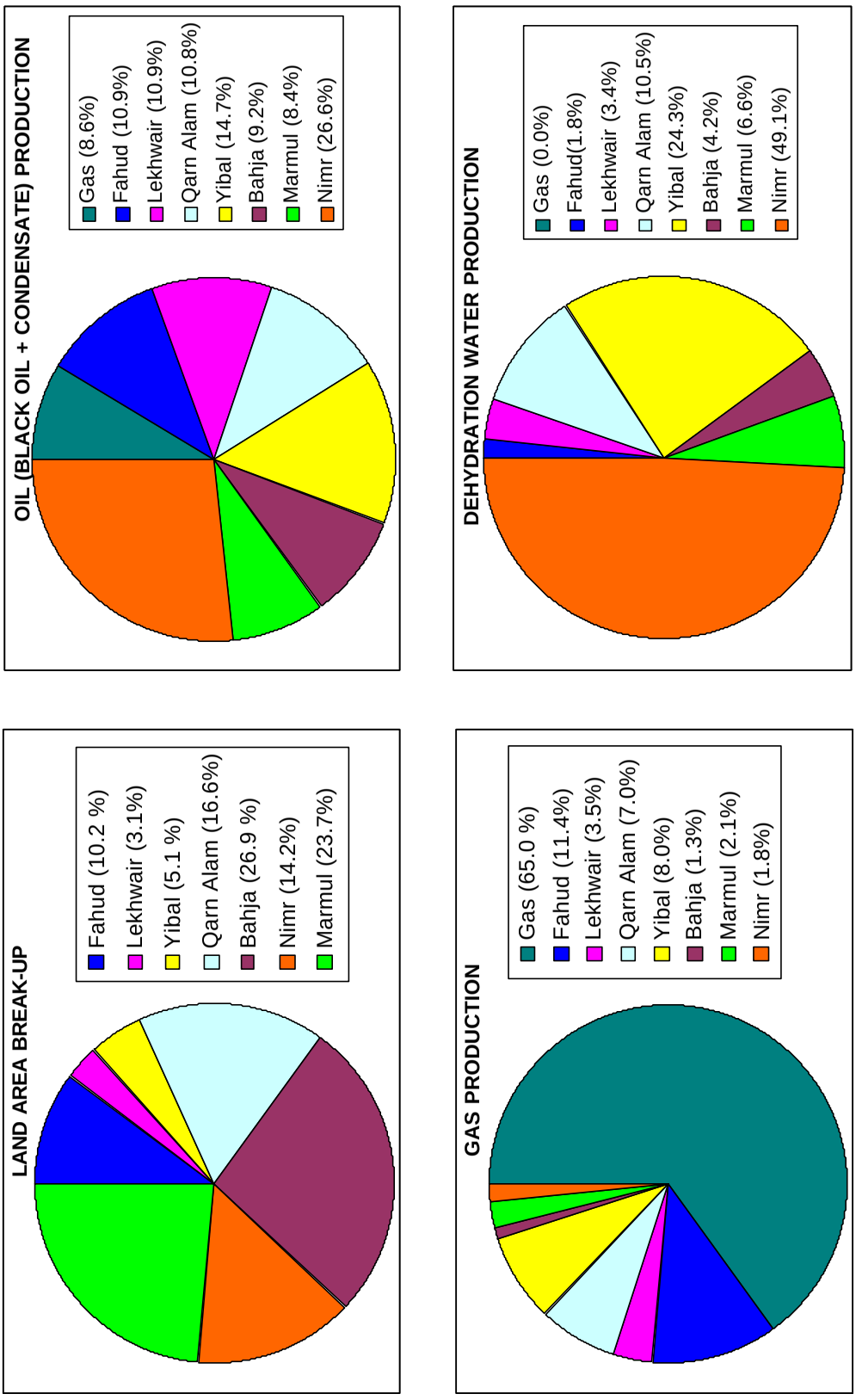

Figure 1.3: Asset-wise Break-up of Land Area, Oil, Gas and Produced Water

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1.2 Environmental Impact Assessment

The environmental impact assessment (EIA) for all the production and service assets was first conducted during the period of 1998–2000, and based on this the environmental management plans and programmes were developed.

It is an internal requirement in PDO to review and update the EIA once every three years, in order to periodically re-assess the environmental impacts and appropriately revise the environmental management plans and programmes. Accordingly, PDO has requested HMR Environmental Engineering Consultants (HMR Consultants) to carry out the first review and update of the EIA for all its assets. This study was conducted over the period of June – December 2002 and presents the review and update of the environmental assessment for the entire Lekhwair asset, which includes Lekhwair and Dhulaima fields. The previous environmental assessment study for Lekhwair asset was completed in July 1999 (*Reference 1*).

1.3 Objectives and Scope of Study

The objectives of this environmental assessment were the following:

- Updating the environmental inventories in the asset, taking into consideration all developments and activities that have taken place since the last environmental assessment conducted in July 1999.
- Reviewing the environmental requirements in the asset, taking into consideration any recent changes in the legislative and corporate regulations and specifications
- Auditing the environmental performance for the current year.
- Updating the environmental baseline data, wherever required.
- Reviewing the significant aspects and re-assessing the environmental impacts, in view of the above.
- Revising the environmental mitigation measures and monitoring plan, wherever required.

The social and health impact assessment components were not included in this study. The quantitative risk analysis was also not included in this study.

1.4 Method of Study

This study was carried out in three stages. In the first stage, the previous EIA report (*Reference 1*) and other available environmental documents were reviewed. Based on this review, detailed and structured checklists were prepared for asset data verification

and environmental performance audit. Subsequently, in the second stage, a site visit was undertaken to check the ground realities and to collect all necessary information. During the site visit, the key operating personnel in the asset including the Area Coordinator and the Area HSE Advisor were interviewed, and a detailed environmental audit of the various facilities in the asset was conducted. In the third stage, all the data collected were analysed and the significant environmental hazards (aspects) were identified. Then the environmental effects (impacts) were reassessed using PDO's "Hazards and Effects Management Procedure (HEMP)" as described in the PDO's document GU-195 "Environmental Assessment Guideline" (*Reference 2*). Following the reassessment, the environmental mitigation measures and the monitoring plans were revised as appropriate.

1.5 Structure of Report

This report is prepared based on the table of contents suggested for environmental assessment report in PDO's "Environmental Assessment Guideline" *(Reference 2)*. A non-technical executive summary is presented at the beginning of the report.

Section 1 overview of PDO activities and description of all the production assets. The scope and objective of the work is presented.

Section 2 presents the regulatory framework and outlines the environmental regulations governing the environmental aspects in the work.

Section 3 details the description of Lekhwair asset along with the consumption of utilities and materials in the asset.

Section 4 describes the various waste products and energies released to the environment from activities performed in Lekhwair asset. Characterisation and quantification of the various waste products released to the environment are presented in this section and their treatment and disposal practices are analysed.

Section 5 presents a detailed description of the environment status within the Lekhwair asset.

Section 6 provides a description of the significant environmental hazards associated with the asset activities identifying the environmental effects. These effects are assed based on the methodology outlined in PDO's document GU-195. The identified potential environmental impacts were rated based on the PDO's environmental risk criteria attached in appendix.

Section 7 summarises the significant environmental effects and mitigation measures in the asset for adverse impacts. Additional mitigation measures aimed at minimizing

the potential environmental risks and improvement of the overall performance were also suggested.

Section 8 lists the references used for this document.

Other useful information not included in the main text is presented in the appendices. The details of the personnel responsible in the preparation and review of the report are presented in Appendix 1.

2 REGULATORY FRAMEWORK

2.1 Omani Regulations

The Omani regulations on environmental protection, control and management are covered under two basic laws *viz*., the "Law for the Conservation of the Environment and Prevention of Pollution" first promulgated in 1982 as Royal Decree (RD) 10/82 and superseded in November 2001 as RD 114/2001 and the "Law on Protection of Sources of Potable Water from Pollution" promulgated in November 2001 as RD 115/2001. The responsibility for the implementation of this law rests with the Ministry of Regional Municipalities, Environment and Water Resources (MRME&WR), which issues regulations, standards and guidelines through "ministerial decisions (MDs)". Within MRME&WR, the authority responsible for environmental permitting, inspection and control in the Sultanate of Oman is the Directorate General of Environmental Affairs (DGEA).

The current Omani environmental laws and regulations are listed below in chronological order.

Table 2.1: Environmental Laws and Regulations in Oman

(Presented in Chronological Order)

Title	Reference Number
Protection of certain species of birds	MD 4/76
Law on the development of water resources and its amendments	RD 76/77, RD 82/88, RD 29/00
Omani drinking water standards	OS8/98
Law on national heritage protection	RD 2/80, RD 6/80
Law for the conservation of the environment and prevention of pollution and its amendments	RD 10/82 (superseded), RD 63/85, MD 5/86, RD 71/89, MD 2/90, RD 31/93, RD 114/2001
Regulations concerning the disposal of liquid effluents to marine environment	MD 7/84
Regulations for the discharge of industrial and commercial effluents	MD 8/84
Regulations for septic tanks and holding tanks	MD 5/86 (superseded), MD 421/98
Regulations for air pollution control from stationary sources	MD 5/86
Regulations for the registrations of existing wells and new well permits	MD 2/90
Regulations for the management of the solid non-hazardous wastes	MD 17/93
Regulation for the management of hazardous wastes	MD 18/93
Regulations for wastewater re-use and discharge	MD 145/93, RD 115/2001
Regulating issuance of environmental permits	MD 300/93
Regulation on the removal of vegetation	MD 128/93
Regulation on hunting, capture or firing at wild animals	MD 207/93
Regulations for noise pollution in public environment	MD 79/94
Regulations for noise pollution in the working environment	MD 80/94
Law on handling and use of chemicals	RD 46/95

Title	Reference Number
Regulations for the handling of toxic substances	MD 248/97
Regulations for control and management of radioactive materials substances	MD 249/97
Regulation on the use of desalination units on wells	MD 342/97
Law on protection of potable water sources from pollution	RD 115/2001

2.2 Shell Group Environmental Guidelines

The Royal Dutch Shell Group has a formulated an extensive HSE management system covering all Shell's activities including hydrocarbon exploration and production. The system includes a series of comprehensive set of guidelines, standards and procedures. These guidelines have been incorporated into PDO's series of specifications where applicable; yet remain as reference documents covering specific operations and activities.

The Shells Group environmental specifications (standards and guidelines) are listed below in Table 2.2.

Table 2.2: Shell Group Environmental Specifications

Reference Number	Title
EP 95-0110	Management of Contractor HSE
EP 95-0120	Competence Assurance for HSE-critical Activities
EP 95-0140	Exploration & Production HSE Strategy and Policy Implementation Guide
EP 95-0220	Concept Selection
EP 95-0300	Overview Hazards and Effects Management Process
EP 95-0330	Drinking Water Guidelines
EP 95-0352	Quantitative Risk Assessment
EP 95-0370	Environmental Assessment
EP 95-0371	Social Impact Assessment Guidelines
EP 95-0375	Environmental Quality Standards - Air
EP 95-0376	Monitoring Air Quality
EP 95-0377	Quantifying Atmospheric Emissions
EP 95-0380	Environmental Quality Standards - Water
EP 95-0381	Monitoring Water Quality
EP 95-0385	Environmental Quality Standards - Soil and Groundwater
EP 95-0386	Monitoring Soil and Groundwater
EP 95-0387	Contaminated Soil and Groundwater
EP 95-0390	Waste Management Guidelines
None	Guide for Risk Based Management of Potentially Contaminated Land

2.3 PDO Corporate Environmental Specifications

PDO has established a comprehensive health, safety and environment (HSE) management system, based on ISO 14001, the international standard for environmental management and EP: 95-0000, the Royal Dutch Shell group guidelines on HSE management. PDO has developed environmental specifications for application throughout its facilities within Oman, based on the Omani regulatory

standards and Shell Group guidelines. PDO's specifications, which are described in the following sections, fully comply with the Omani regulatory standards, and in most cases are more stringent. The list of PDO's environmental specifications SP-1005 to SP-1012 and SP-1170 version dated 7/2002 is presented below in Table 2.3.

Table 2.3: PDO's Environmental Specifications

Reference Number	Title
SP-1005	Specification for Emissions to Atmosphere
SP-1006	Specification for Aqueous Effluents
SP-1007	Specification for Accidental Releases to Land and Water
SP-1008	Specification for the Use of Energy, Materials and Resources
SP-1009	Specification for Waste Management
SP-1010	Specification for Environmental Noise and Vibration
SP-1011	Specification for Flora and Fauna Protection
SP-1012	Specification for Land Management
SP-1170	Specification for Management of Naturally Occurring Radioactive Materials

In the following sections, the various environmental standards given under the above specifications are summarized.

2.4 Environmental Standards

2.4.1 Emissions to Atmosphere

PDO specification SP-1005 on emissions to atmosphere addresses both stationary and mobile sources and is largely based on MD 5/86 “Regulations for Air Pollution Control from Stationary Sources” and Shell Exploration and Production International best practices. These are presented below in Table 2.4.

Table 2.4: Air Emission Standards

Parameter	Maximum Permissible Concentration
Hydrogen chloride	200 mg/Nm^3
Hydrogen fluoride	100 mg/Nm^3
Oxides of nitrogen (as NO_2)	200 mg/Nm^3
Phosphorus as (P_2O_5)	50 mg/Nm^3
Hydrogen sulphide	5 ppmv (7 mg/Nm^3)
Total particulates	100 mg/Nm^3

Note: Nm^3 refers to volume at 0 ^oC and 1atm.

In addition to the above emission limits, PDO has specified the following requirements to minimise air pollution and fugitive emissions:

(a) There shall be no continuous venting of gas in new projects.

(b) Fugitive emissions occurring as a result of leaks from components (such as pipe connections, valves, rotating shafts and other packed components) shall be minimised through enhanced maintenance programs. There shall be no significant visible emissions of fugitive dust.

(c) No smoke emitted shall be as dark or darker than shade 1 on the Ringlemann scale (equivalent to 20% opacity).

(d) No odorous substances shall be emitted to the environment that are recognisable at residences for more than 150 hours per year.

(e) CFCs, HCFCs or HFCs shall not be knowingly vented to the atmosphere. They shall be recovered and re-used during servicing and maintenance. No equipment or product containing CFCs shall be selected for purchase or lease. Further, no equipment or product containing HCFCs shall be selected for purchase or lease, unless no alternatives are available in the market.

(f) There shall be no halon releases to the atmosphere for maintenance, testing or any other purposes. Halon releases are permitted under emergency situations only. No new halon fire fighting systems in new projects shall be purchased, and no virgin halons shall be used for recharging any existing halon fire fighting systems in use.

2.4.2 Ambient Air Quality

Presently, there are no Omani standards for ambient air quality. In their absence, MRME&WR recommends the use of United States Environmental Protection Agency's (USEPA) national ambient air quality (NAAQ) standards. PDO uses World Health Organisation (WHO) - European Union (EU) and Netherlands standards, which are more stringent than USEPA's NAAQ standards. PDO's ambient air quality standards are given as both limit values and guide values. The "limit values" are the maximum permissible concentrations in the ambient air, which if exceeded will result in non-compliance. The "guide values" are the desirable upper limits. PDO's ambient air quality standards are given in Table 2.5 below.

Table 2.5: Ambient Air Quality Standards

Parameter	Averaging Period	Limit Value ($\mu g/m^3$)	Guide Value ($\mu g/m^3$)
Oxides of nitrogen as NO_2	1 hour 4 hour 24 hour 1 year	400 - 150 -	- 95 - 30
Sulphur dioxide	10 minutes 1 hour 24 hours 1 year	500 350 125 50	- - 125 30

Hydrogen sulphide	30 minutes 24 hours	- 150	7 -
Carbon monoxide	1 hour 8 hour	40000 6000	- -
Benzene	1 hour 1 year	- 10	7.5 5
Total suspended particulate matter	1 year	120	-
Particulate products of incomplete combustion	24 hours 1 year	125 50	- -

2.4.3 Aqueous Effluents

PDO specification SP-1006 on aqueous effluent discharge is derived from a number of Ministerial Decisions (in particular, MD 7/84, MD 5/84 and MD145/93). The effluents include production water and other various process waters, sewage and storm water run-off. The specification covers both land and marine discharges. The details are presented below.

- **Production Water:**

The approved PDO Production Water Management Plan, which has been agreed upon with the government consists of five principles. These principles govern the disposal of production water (or other hyper saline brines), and are listed below in the order of preference.

(a) Minimise the volumes of water produced during oil extraction.

(b) Maximise reuse of such produced waters.

(c) Phase out the use of shallow disposal wells and prevent disposal into useable or exploitable aquifers.

(d) Return production water to the producing reservoir.

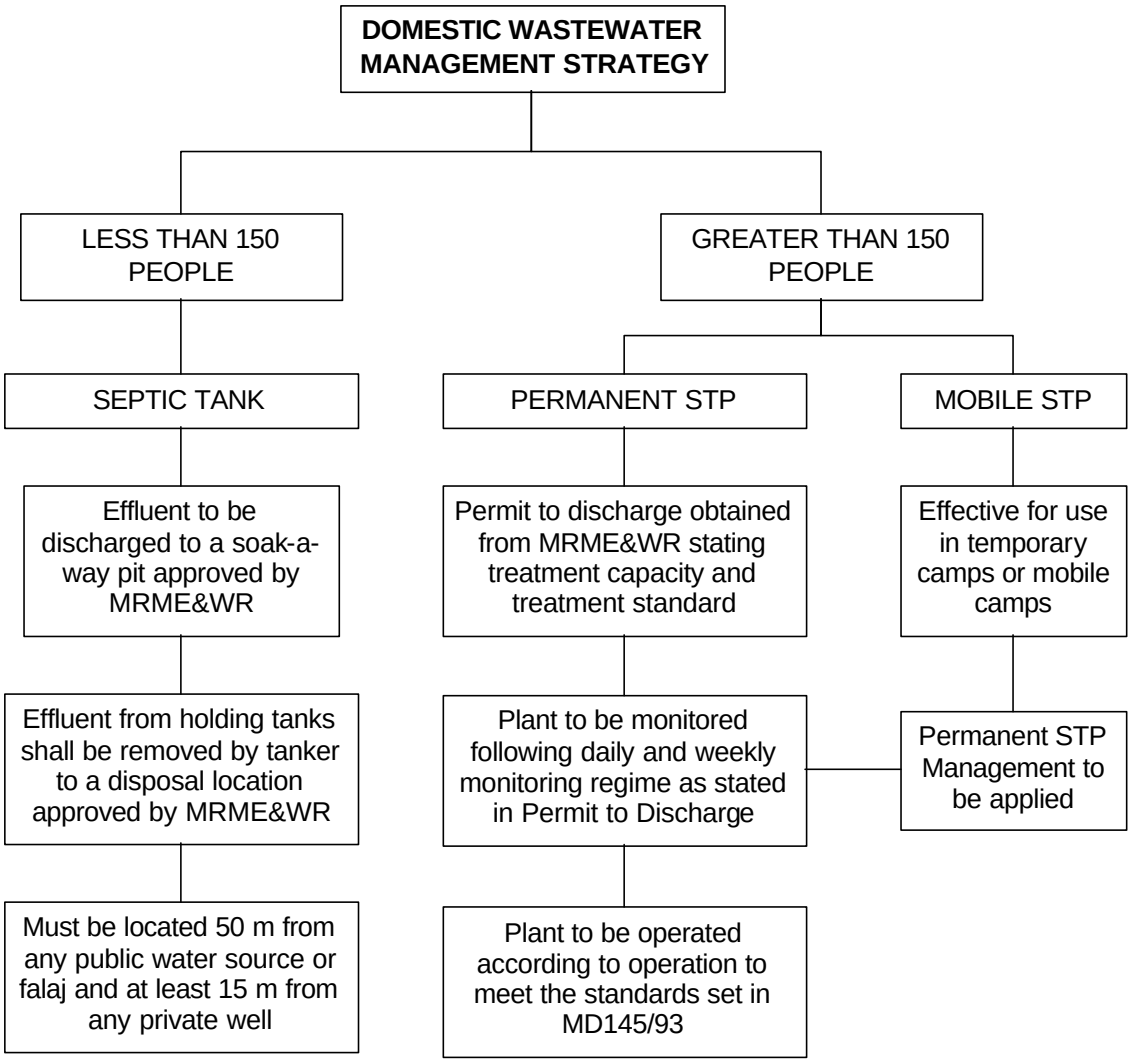
(e) Dispose surplus waters to formations, which have salinity greater than 35,000 mg/L, in conjunction with case-specific monitoring programs.

- **Other Process Effluents:**

The disposal of other process (such as reverse osmosis plants, hydrotest, maintenance etc.) effluents is dependent on the location and degree of the contamination. If the effluent is to be discharged to land then the quality of the water shall satisfy the water quality standards as identified in MD 145/93. Where the water is to be disposed of to the marine environment the effluent shall meet the water quality standards as per MD 7/84. In the event that the water quality standards are not met then the effluent discharge should be segregated and undergo treatment so as not to impact on the receiving environment.

- **Sewage Effluent:**

PDO have developed a strategy to select the wastewater treatment technology for various operations across the company. The strategy uses the population size of each camp as a basis for selecting a wastewater treatment option. This approach is summarised in the flowchart shown in below:



- **Storm Water Runoff:**

There are no legal requirements with respect to the discharge of storm water runoff uncontaminated by hydrocarbons. Potentially hydrocarbon contaminated storm water runoff shall be segregated and treated to the standards specified for on land discharge or marine disposal.

- **On Land Discharge:**

The following are PDO's standards for on land discharge and re-use of treated wastewater, which are the same as Omani standards (MD145/93 and RD 115/2001).

There are two types of standards (Standard A-1 and A-2), which differ from each other based on the intended re-use of treated sewage effluent. They are presented in Table 2.6.

Table 2.6: Classification of Standards A-1 and A-2 for Re-use of Treated Wastewater

Specification	Standard A-1	Standard A-2
Crops	- Vegetables likely to be eaten raw - Fruit likely to be eaten raw and within 2 weeks of any irrigation	- Vegetables to be cooked or processed - Fruit if no irrigation within 2 weeks of cropping - Fodder, cereal and seed crops
Grass and ornamental areas	- Public parks, hotel lawns recreational areas - Areas with public access. - Lakes with public contact (except place which may be used for praying and hand washing)	- Pastures - Areas with no public access

The treated wastewater if discharged on land shall meet the following specifications given In Table 2.7.

Table 2.7: Standards for Treated Wastewater Discharged on Land

Parameter	Units	Standard A-1	Standard A-2
Biochemical oxygen demand (5 days @ 20^0C)	mg/L	15	20
Chemical oxygen demand	mg/L	150	200
Suspended solids	mg/L	15	30
Total dissolved solids	mg/L	1500	2000
Electrical conductivity	µS/cm	2000	2700
Sodium absorption ratio	-	10	10
pH	-	6 - 9	6 -9
Aluminium (as Al)	mg/L	5	5
Arsenic (as As)	mg/L	0.100	0.100
Barium (as Ba)	mg/L	1	2
Beryllium (as Be)	mg/L	0.100	0.300
Boron (as B)	mg/L	0.500	1.000
Cadmium (as Cd)	mg/L	0.010	0.010
Chloride (as Cl)	mg/L	650	650
Chromium (total as Cr)	mg/L	0.050	0.050
Cobalt (as Co)	mg/L	0.050	0.050
Copper (as Cu)	mg/L	0.500	1.000
Cyanide (total as CN)	mg/L	0.050	0.100
Fluoride (as F)	mg/L	1	2
Iron (total as Fe)	mg/L	1	5
Lead (as Pb)	mg/L	0.100	0.200
Lithium (as Li)	mg/L	0.070	0.070
Magnesium (as Mg)	mg/L	150	150
Manganese (as Mn)	mg/L	0.100	0.500
Mercury (as Hg)	mg/L	0.001	0.001
Molybdenum (as Mo)	mg/L	0.010	0.050
Nickel (as Ni)	mg/L	0.100	0.100

Parameter	Units	Standard A-1	Standard A-2
Nitrogen: Ammoniacal (as N) : Nitrate (as NO_3) : Organic (Kjeldahl) (as N)	mg/L	5 50 5	10 50 10
Oil and grease (total extractable)	mg/L	0.500	0.500
Phenols (total)	mg/L	0.001	0.002
Phosphorus (total as P)	mg/L	30	30
Selenium (as Se)	mg/L	0.020	0.020
Silver (as Ag)	mg/L	0.010	0.010
Sodium (as Na)	mg/L	200	300
Sulphate (as SO_4)	mg/L	400	400
Sulphide (total as S)	mg/L	0.100	0.100
Vanadium (as V)	mg/L	0.100	0.100
Zinc (as Zn)	mg/L	5	5
Faecal coliform bacteria	Number per 100 mL	200	1000
Viable nematode ova	Number per L	<1	<1

The sludge generated from the treatment of domestic wastewaters may be applied on land for agricultural use, subject to the conditions set in Table 2.8. After spreading the sludge, there must be at least a three-week period before any grazing or harvesting of forage crops. Sludge application on land prohibited in the following cases:

- On soils while fruits or vegetable crops, other than fruit trees, are growing or being harvested
- For six months preceding the harvesting of fruit or vegetables that are normally eaten raw, and grown in contact with the soil
- On soils with pH less than 7

Table 2.8: Maximum Permissible Metal Concentrations in Sludge

Metal	Maximum Permissible Concentration (mg/kg dry solid)	Maximum Application Rate (kg/ha/yr)	Maximum Permissible Concentration in Soil (mg/kg dry solid)
Cadmium	20	0.150	3
Chromium	1000	10	400
Copper	1000	10	150
Lead	1000	15	30
Mercury	10	0.100	1
Molybdenum	20	0.100	3
Nickel	300	3	75
Selenium	50	0.150	5
Zinc	3000	15	300

Any sludge containing metal concentration above the following prescribed limits shall be disposed in sanitary landfills or to other facilities with approval from MRME&WR.

- **Marine Disposal:**

Any effluent discharged into the marine environment shall meet the specifications given below in Table 2.9, which are same as or more stringent than the discharge limits into the marine environment as per MD 7/84.

Table 2.9: Standards for Treated Wastewater Discharged into Marine Environment

Parameter	Discharge limit
Arsenic	0.05 mg/L
Cadmium	0.05 mg/L
Chromium	0.50mg/L
Copper	0.50 mg/L
Cyanide	0.10 mg/L
Iron	2.00 mg/L
Lead	0.10 mg/L
Mercury	0.001 mg/L
Nickel	0.10 mg/L
Selenium	0.02 mg/L
Silver	0.005 mg/L
Zinc	0.10 mg/L
Chlorine (salt)	2.50 mg/L (minimum)
Hydrogen ions	6-9 units
Sulfide salts	0.10 mg/L
Sticking solid particles	30.0 mg/L
Sludge	75.0 Jackson sight unit
BOD	30.0 mg/L
Oil & grease	5.0 mg/L
Carbolic acids (phenols)	0.10 mg/L
Ammonium nitrates	40.0 mg/L
Phosphates	0.10 mg/L
Faecal coliforms	100 MPN/100 mL (80% samples)
Faecal streptococci	100 MPN/100 mL
Salmonella	Zero MPN/L

2.4.4 Accidental Releases to Land and Water

PDO specification SP-1007 on accidental releases to land and water focuses on minimising the effect on groundwater, and soil. The requirements are outlined below:

- Equipment, processes, pipelines etc. containing material harmful to the environment shall be designed, maintained, operated and abandoned to prevent accidental releases to the environment
- In case of a loss of containment to the environment, the contamination shall be assessed and the soil and groundwater shall be cleaned to a level compatible with the environmental quality standard of the receiving environment (available EP 95-0385)

2.4.5 Use of Energy, Materials and Resources

PDO specification SP-1008 on the use of energy, materials and resources attempts on the efficient use of natural resources. The requirements under this specification are outlined in Table 2.10.

Table 2.10: Applicable Requirements for the Use of Energy, Materials and Resources

Indicators	Requirement
Energy	- Efficient use of energy at all times shall be demonstrated
Water Resources	- RD 82/88 controls the exploitation of groundwater in the interest of agricultural and development plans - MD 2/90 requires all wells used for the detection or extraction of groundwater be registered with MRME&WR - Efficient water use shall be demonstrated for hydrocarbon production
Land Use	- Under PDO's concession agreement, land no longer necessary for operations shall be handed back to the government
Use of Chemicals	- The manufacture, import, storage, handling and use of any chemical substance shall comply with RD 46/95 - Under RD/248/97, the manufacture, export, transport, storage, handling use, and disposal of any chemical substance will require a permit from MRME&WR - Chemicals shall only be bought with valid Safe Handling of chemicals (SHOC) card. The chemicals shall be stored with the SHOC card visible

2.4.6 Waste Management

PDO specification SP-1009 on waste management defines what are hazardous and non-hazardous wastes, and outlines the waste management strategy in PDO. This specification complies with Omani regulations MD 17/93 and MD 18/93 dealing with non-hazardous and hazardous waste management. The classification of non-hazardous and hazardous wastes is specified under SP 1009 as below in Table 2.11.

Table 2.11: Classifications of Hazardous and Non-Hazardous Wastes

Hazardous Wastes	Non-Hazardous Wastes
Hazardous empty drums	Kitchen refuse
Waste lubricants	Domestic waste
Pigging sludge	Tree/grass cuttings
Tyres	Water-based drilling mud and cuttings
Batteries	Office waste
Clinical waste	Non-hazardous waste chemicals
Naturally occurring radioactive material	Non-hazardous empty drums
Sewage sludge	Scrap metal
Oil-based drilling mud and cuttings	
Hazardous waste chemicals and lab waste chemicals	
Oily sand /soil	
Oily sludge	

PDO's waste management hierarchy is as below:

- Pollution prevention: elimination, change or reduction of operating practices, which result in wastes
- Source reduction: generation of less wastes through more efficient processes
- Re-use: the use of materials or products that are reusable in their original form
- Recycling/recovery: the conversion of waste into usable materials, or the extraction of energy or materials from the waste
- Treatment: the destruction, detoxification and/or neutralisation of residues
- Responsible disposal: depositing wastes using appropriate methods for a given situation

Based on the above hierarchy, the detailed waste handling and disposal procedures are given in the specification SP-1009. The procedures for the handling and disposal of NORM wastes are given under the specification SP-1170. These are discussed in Section 2.4.10 in this chapter.

2.4.7 Environmental Noise and Vibration

PDO specification SP-1010 on environmental noise and vibration is based on Omani standards MD 79/94 and MD 80/94. PDO standards on ambient noise, which are the same as Omani standards (MD 79/94) are summarized in Table 2.12 below.

Table 2.12: Ambient Noise Standards

Type of District	Maximum Permissible Noise Level [as L_{eq} in dB (A)]		
	Workdays – Day time (7am –6pm)	Workdays – Evening (6pm –11pm)	Workdays Night time (11pm- 7am) and Holidays
Rural, residential, recreational	45	40	35
Suburban residential	50	45	40
Urban residential	55	50	45
Urban residential with some workshops or business	60	55	50
Industrial and commercial	70	70	70

2.4.8 Flora and Fauna

PDO specification SP-1011 on protection of wildlife is developed in response to several Omani royal decrees and ministerial decisions on environmental protection.

The specification outlines specific ecological zones and based on their importance, defines specific requirements for carrying out projects. These are summarized in Table 2.13 below.

Table 2.13: Classification of Environmentally Sensitive Areas

Ecological Zone	Description	Requirements
Zone 1: Areas of Concern	National reserves or sanctuaries	Activities shall be restricted
	Areas that provide habitat to particularly sensitive wildlife	
	Areas containing high proportions of endemic flora or fauna	
	Woodlands	
	Areas of exceptional natural beauty	
Zone 2: Areas of Interest	Areas having significant natural features and beauty	Activities shall be restricted for those not compatible with the protection of the area
	Areas showing features of geological or climatic history	
	Artificially created areas to attract wildlife and migratory birds	
Arabian Oryx Sanctuary	Area defined by RD 9/94	Case-specific approval from MRME&WR

2.4.9 Land Management

There is currently no specific Omani legislation on land management (site preparation, abandonment and restoration). PDO's policy on abandonment requires that redundant assets shall be removed where appropriate and the environment restored to, or as near as reasonably practicable, to its original state. PDO specification SP-1012 on land management is summarized below in Table 2.14.

Table 2.14: Land Management Requirements

Project Stage	Requirements
Site Selection	- Selection of a site shall be carried out in accordance with PDO's procedure on HEMP and environmental assessment guideline
Site Preparation	- Earthmoving shall be conducted to minimize environmental effects - Trees shall not be felled or removed - Borrow pits shall not be excavated more than 2m in depth - Borrow pits shall not be excavated in wadis, in areas used by grazing livestock or in areas which would cause nuisance to local inhabitants - A 20m wide right-of-way shall be provided for all pipelines (10m each side) - Where pipelines or roads cross wadis, earthmoving shall be carried out to minimize flow or characteristics of shallow aquifers

Project Stage	Requirements
Site Abandonment and Restoration	- Restored land shall be visually similar to the surrounding landscape - All waste materials shall be removed - Hydrocarbon shall be removed from site if concentrations greater than 1% weight - Areas having less than 1% weight hydrocarbon contamination shall be covered with 0.6m of clean sand within 6 months of abandonment - All pipelines, process equipment and instrumentation shall be removed - All camp facilities shall be removed and site re-graded. Any soak pits shall be backfilled - Borrow pits shall be filled with 0.3m of clean sand and graded to match the surrounding contours

2.4.10 NORM Waste Disposal

Oil sludges, pigging wastes, tubulars and water/well accessories from reservoir locations are known to contain NORM materials. The monitoring, handling, transport, storage, treatment and disposal of NORM wastes are specified under SP-1170 "Specification for Management of Naturally Occurring Radioactive Materials". This specification conforms to MD 249/97, " Regulations for the Control and Management of Radioactive Materials". Any waste having radioactivity greater than 100 Bq/g (for solids) and 100 kBq/L (for liquids) is classified as radioactive waste. Such waste shall be sent to PDO's dedicated storage facility in Zauliyah as soon as possible. Normal transport vehicles can be used. However, the waste shall be packaged as per the detailed procedures given in the specification. Any recyclable items shall be released only after they are decontaminated by an authorised contractor at the designated site, such that the radioactivity level is reduced to <100 Bq/g. If decontamination is not possible, the wastes shall be retained at the storage site until the radioactivity level drops to <100 Bq/g.

3 ASSET DESCRIPTION

3.1 Asset Organisation

Geographically, Lekhwair asset is located in the northwest corner of PDO's concession area, bordering to Saudi Arabian and United Arab Emirates. It covers a total land area of 3,560 km^2 (3.1% of PDO's total concession area) and consists of 2 operating oil fields and 223 producing wells. Lekhwair field was discovered in 1968 and initially brought on stream in 1976. The Lekhwair Production Station (LPS) was built in 1991. The asset organisation structure is shown in Figure 3.1. The asset management structure including the health, safety and environment (HSE) management structure is shown in Figure 3.2.

This asset produces 14,601 m^3/d of oil (black oil + condensate) (10.9 % of PDO's total crude oil production) and 1,550,000 Sm^3/d of associated gas (3.5% of PDO's total gas production) as reported for the year 2002. The asset also produces 21,977 m^3/d of produced water. The total power generation in the asset is 51.4 MW and the total abstraction of groundwater in the asset is 13,690 m^3/d excluding water used by rigs. The total length of roads in the asset is 158 km and the total length of flow lines is 384 km.

The facilities currently available in the asset are listed in Table 3.1 below.

Table 3.1: List of Facilities in Lekhwair Asset

Name of Facility	Number of Units
Production stations	1
Gathering stations	1
Power stations	1
Water treatment plant (RO plant)	1
Booster stations	None
Produced water injection / disposal plants	Part of the production station
Permanent PDO camps	1
Contractor camps	1
Permanent sewage treatment plants	2
Mobile sewage treatment plants	None
Central chemical stores	None
Waste management centre	1
Drilling rigs	None

The production station (main station) is located in Lekhwair, approximately 130 km from Fahud. The unique SulFerox plant to treat associated gas for removal of H_2S is located at Lekhwair. There are ten remote manifold stations and one gathering station to collect crude from wells. There is one gas fired gas turbine power station located in Lekhwair. There is no booster station or permanent laboratory facility at Lekhwair. There is a water treatment plant based on reverse osmosis (RO) process.

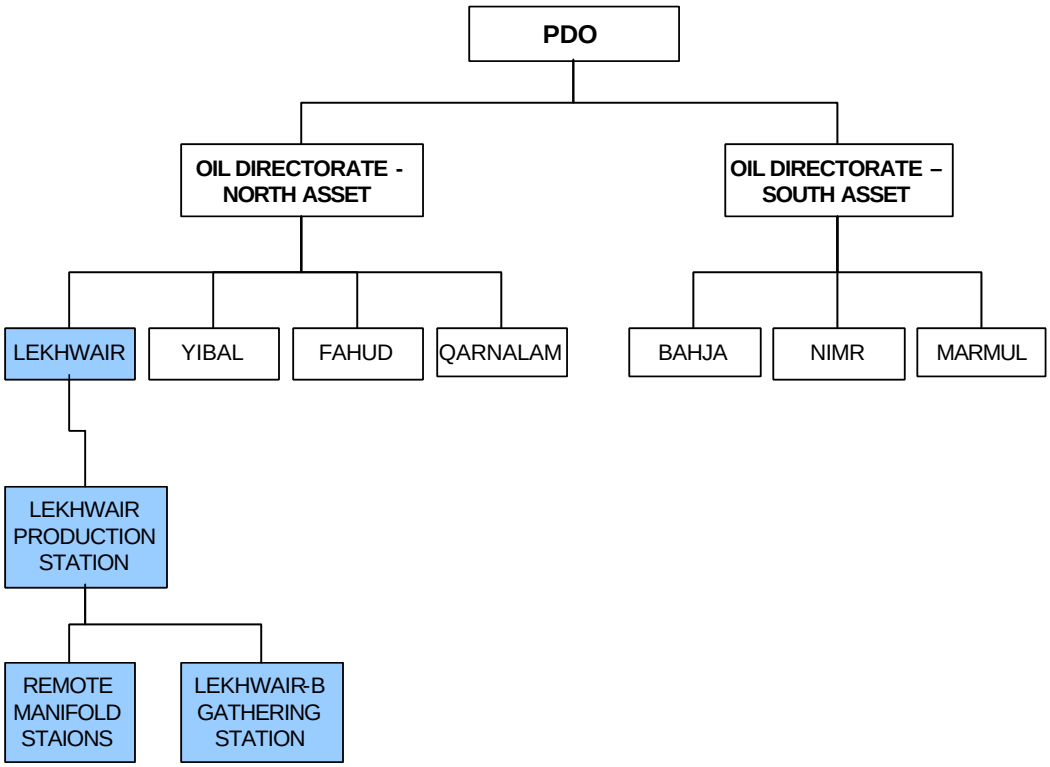


Figure 3.1: Asset Organization Structure for Lekhwair

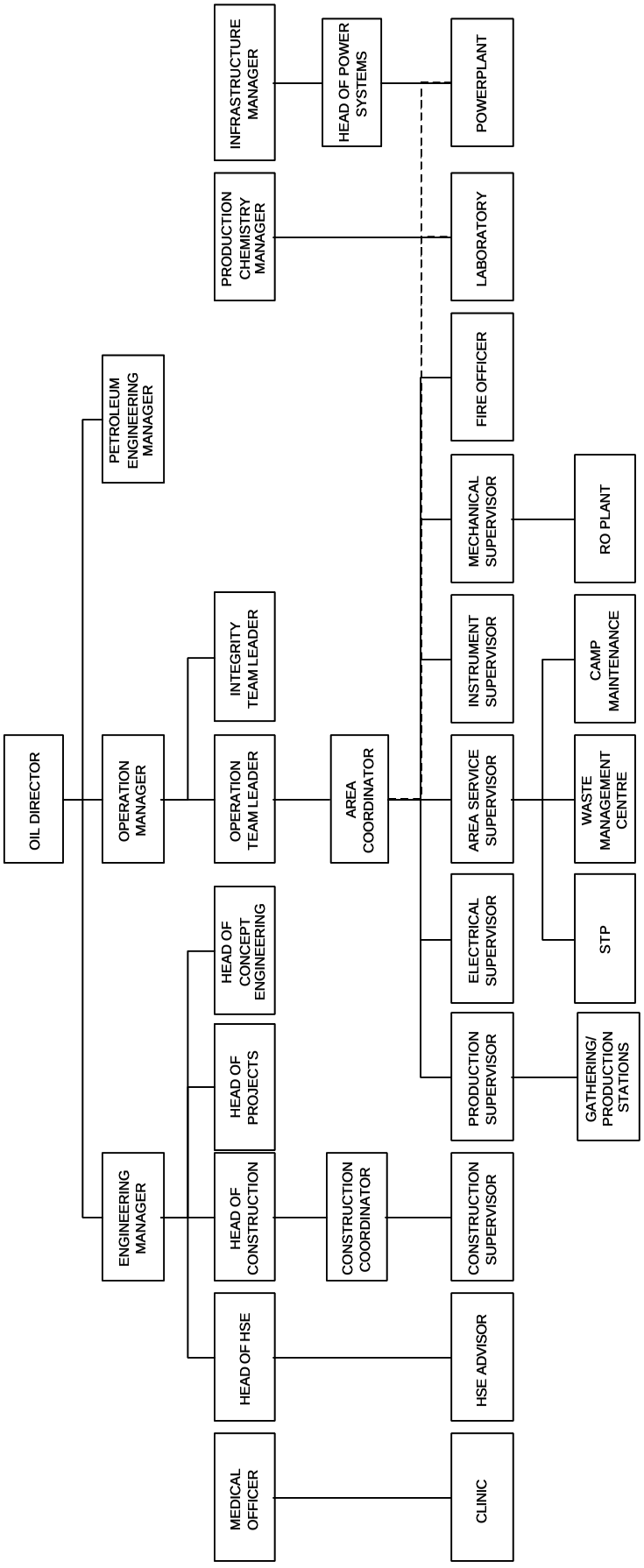


Figure 3.2: Asset Management Structure for Lekhwair

There are two permanent accommodation camps, one for PDO staff and the other for contractors. There are two permanent sewage treatment plants (STPs), one for PDO camp and the other for Contractor's camp. There is a central waste management centre in the asset.

3.2 Activity Description

The major production related and associated activities performed in the asset may be summarised as below:

- Extraction of reservoir fluid from oil fields and transporting it to production station either through remote manifold stations or via gathering station.
- Separation of associated gas from the reservoir fluid in the gathering station or production station.
- Separation of produced water and crude oil at the production station
- Exporting of crude to the crude stabilisation plant at Fahud.
- Desulphurisation of associated gas in SulFerox plant and the export of treated gas to Fahud and Yibal.
- Abstraction of groundwater and desalination
- Generation of power using gas fired gas turbines
- Disposal of produced water by injection into deep aquifers
- Treatment of liquid effluents
- Disposal of solid waste
- Flaring of unutilised associated gas

In addition to the above production activities, the following developmental and construction activities are also performed at some location or the other within the asset throughout the year:

- Seismic survey
- Drilling
- Well construction
- Pipeline construction and maintenance
- Road construction and maintenance
- Power line construction and maintenance

- Well closure and site restoration

A schematic diagram illustrating the major production related and associated activities performed in the asset is shown in Figure 3.3. A brief description of the major facilities and activities in the asset are discussed in the following sections.

3.3 Remote Manifold Stations

Crude oil from Lekhwair-A field is extracted from approximately 192 gas lifted wells and transported to remote manifold station. There are ten remote manifold stations (RMS), each comprising a bulk manifold, a test manifold and a gas lift manifold. The bulk crude lines from the RMS are connected to one of three bulk separators in LPS. Well performance is determined regularly by lining up each well separately to flow through the test line at an RMS to its associated test separator at LPS. Compressed gas is supplied from the Lekhwair production station to RMS via gas lift manifold.

3.4 Gathering Station

Crude oil from Lekhwair-B field is pumped from the reservoir using gas lift pumps, electrical submersible pumps (ESP) and beam pumps. The extracted fluid is transported through flow lines to Lekhwair-B gathering station. In the gathering station, the extracted fluid is degassed in a bulk separator. This separated gas is compressed and sent to LPS through a gas line. The degassed liquid is sent to LPS via a separate pipeline for dehydration.

3.5 Production Station

LPS is the only production station in Lekhwair asset. In this production station, the reservoir fluid from different remote manifold stations and degassed crude from Lekhwair-B gathering station is processed. A brief description is presented below.

The reservoir fluid from the remote manifold stations enters LPS through bulk manifolds. From there, it flows into three identical bulk separators, where the gas is separated from the liquid. The separated gas flows to four gas lift compression trains operating in parallel. Each compression train consists of 4 stages driven by a single electric motor. The gas is compressed from 118 kPa to 7400 kPa. Part of the compressed gas is then sent to the remote manifold stations and Lekhwair-B station for use in the gas lift wells. The excess gas is exported to Fahud and Yibal. However it is first desulphurised in the SulFerox plant, since the gas produced in the asset contains high concentration of hydrogen sulphide (H_2S).

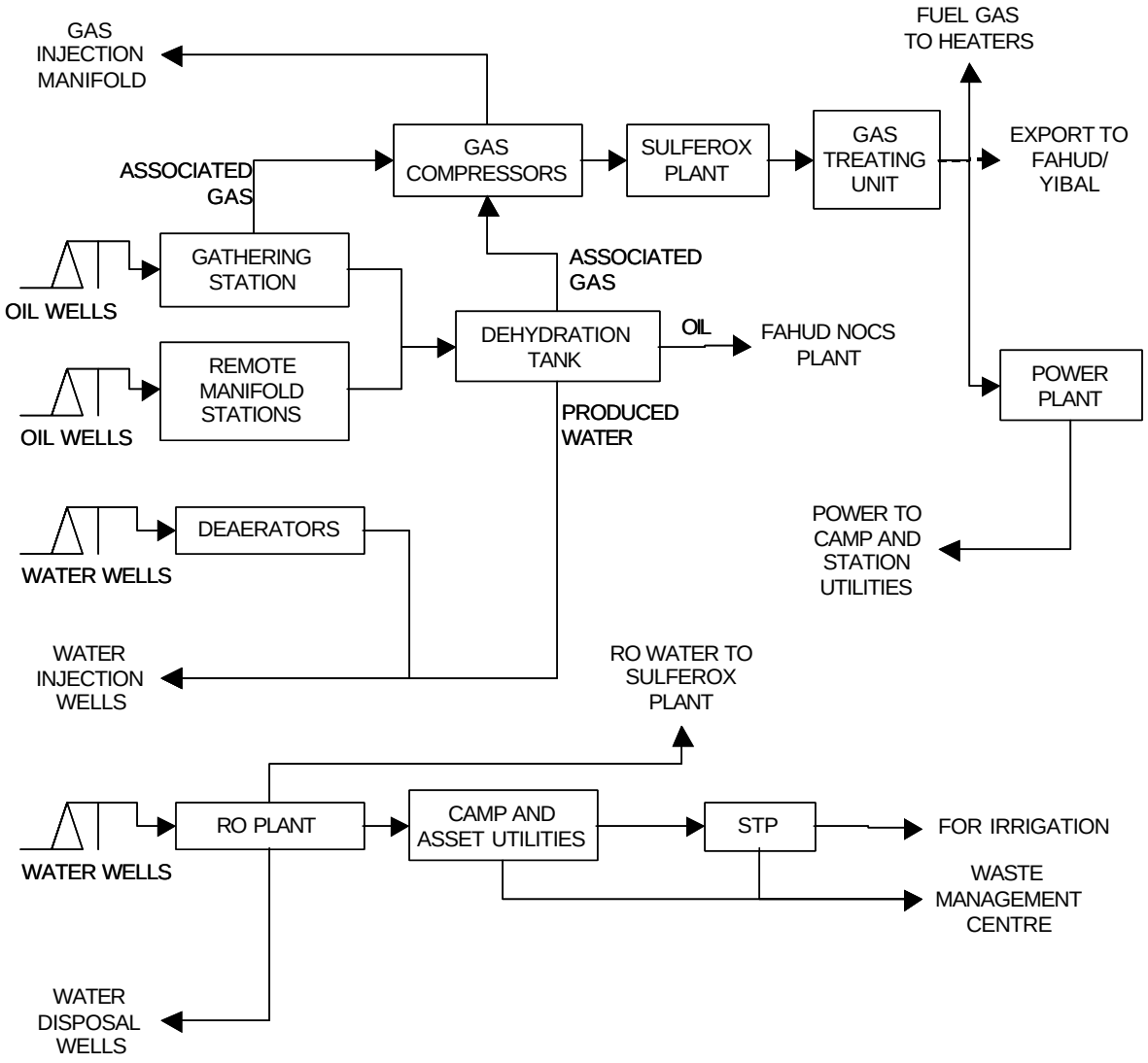


Figure 3.3 Schematic Diagram of Production and Associated Processes in Lekwair Asset

After degassing, the reservoir fluid is sent to dehydration tanks, where the produced water is removed from the crude. There are two dehydration tanks in which the water phase is separated from the oil phase by gravity settling. The separated production water is then re-injected into the reservoir. The dehydrated crude oil is sent to the crude storage tanks for export to MAF.

3.6 SulFerox Plant

SulFerox is a proprietary sweetening (desulphurising) process designed to reduce the H_2S concentration to 5 ppm in the associated gas. In this process, the sour (high H_2S content) gas is heated to about 10-15 ^oC above the dew point (to prevent hydrocarbon liquid condensing) and reacted with SulFerox liquid (aqueous solution containing about 1% Fe^{++} and Fe^{+++}) in two packed bed counter-current gas-liquid contactor columns. In the contactors, H_2S in the sour gas chemically reacts with SulFerox liquid to form elemental suphur as a precipitate. The gas-liquid-solid mixture from the contactors is passed through a flash separator to separate the sweet gas and then to a SulFerox regeneration vessel. In the regeneration vessel, air is injected for SulFerox regeneration and the regenerated liquid is recycled to the contactors. The solid slurry from the regeneration vessel is sent to a vacuum drum filter where sulphur cake is recovered.

The hot sweet gas from the flash separator is pre-cooled by heat exchange with the inlet sour gas and then chilled to its dew point (5 ^oC) in a propane chiller. The condensate is removed in a cold separator and the dry gas is reheated to ambient temperature. This treated gas is then exported to Fahud and Yibal via pipeline.

3.7 Power Station

The electrical power is required in the asset for production activities, auxiliary activities and accommodation facilities. The total electrical power requirement in the asset is presently 53 MW. Most of the required power is generated internally in the power plant located near LPS, with very little import from the PDO grid. The Lekhwair power plant is a gas turbine based plant and runs on associated gas produced within the asset. The power plant is operated on open cycle, with no waste heat recovery. The details of the power plant are given below in Table 3.2.

Table 3.2: Details of Power Plants In Lekhwair Asset

Specifications	Power Plant at Lekhwair
Total generating capacity	60 MW
No. of gas turbines	2
Make and model of gas turbines	Frame 6
Fuel used	Associated gas (100%)

Specifications	Power Plant at Lekhwair
Fuel consumed per day	357,000 m^3
Emission control system used	Standard combustion system with no low NO_x control
Number of stacks	2
Stack height	15 m (approximately)
Stack exit diameter	4.3m
Stack gas exit temperature	595^oC

3.8 Water Treatment Plant

The groundwater in the asset is saline and therefore it needs to be desalinated for process and domestic use. The total treated water requirement is presently 240 m^3/d. The desalination is done by reverse osmosis (RO). The net feed water to the RO plant is currently 576 m^3/d. Groundwater is abstracted from Fars aquifer at a depth of 93 m to 110 m using borewells. The details of the existing water treatment plant are given in Table 3.3 below.

Table 3.3: Details of Water Treatment Plant in Lekhwair

Specifications	Value / Description
Total freshwater production capacity	240 m^3/d
TDS of treated water	300-800 mg/L
Type of desalination	Reverse osmosis
No. of units	Three
Make and model	Supplier: Kennicot England
Total flow rate of inlet stream	576 m^3/d
TDS of feed water	8500 mg/L
Total flow rate of reject stream	336 m^3/d
TDS of reject stream	22200 mg/L

3.9 Auxiliary Facilities

3.9.1 Overview

The major auxiliary facilities in the asset include the following:

- Water injection system
- Sewage treatment plants
- Waste management centre
- Production chemistry laboratory
- Maintenance workshop
- Accommodation facilities
- Miscellaneous facilities

A brief description of these facilities is presented below.

3.9.2 Water Injection System

Water is injected into the producing reservoir to maintain sufficient pressure. The rate of water injection is equal to the rate of extraction of reservoir fluid. Currently, the volume of produced water separated from the extracted fluid in the production station is 20,765 m^3/d. To this, 13,276 m^3/d of groundwater extracted from Fars aquifer is added for injection into the reservoir. Before injection, the groundwater is de-aerated.

The water (produced water + Fars water) before injection is pressurised to about 11,000 kPa. Currently, 105 water injection wells are used in the asset.

3.9.3 Sewage Treatment Plants

There are two sewage treatment plants in the asset. One plant of 150 m^3/d capacity is dedicated for the treatment of sewage generated from the PDO camp. The second plant of 220 m^3/d capacity is dedicated for the treatment of sewage generated from the Contractor camps. The details of these facilities are presented in Chapter 4.

3.9.4 Waste Management Centre

Lekhwair asset has a centralised waste management centre for the disposal of both non-hazardous and hazardous wastes. Lekhwair asset has separate landfills for hazardous wastes, non-hazardous waste and sanitary waste. It also has a sulfur dumping yard and SulFerox evaporation ponds. This facility does not handle NORM wastes clinical wastes. NORM wastes are sent to a dedicated storage /disposal site in Zauliyah and the clinical wastes are sent to an incinerator in MAF. The details of the waste management centre are presented in Chapter 4.

3.9.5 Production Chemistry Laboratory

Lekhwair asset has a laboratory facility located within the administrative area for the analysis of oil and gas quality, produced water analysis and effluent analysis. The necessary laboratory equipment required for chemical, thermo-physical and biological analysis are available in the facility. However, there are no resident analytical staff in this asset. This facility is intermittently operated by Fahud Production Chemistry staff.

3.9.6 Workshops

A general maintenance workshop and an automotive maintenance workshop are located within the asset. In addition, there are also several small workshop units at work sites. Oily wastes from these workshops are collected separately and sent to the waste management centre.

3.9.7 Accommodation Facilities

There are two permanent accommodation camps located within the asset. The PDO main camp is exclusive for the accommodation of PDO staff and their visitors. The other camp is for the contractor staff and their visitors. Both the accommodation camps have catering and laundry facilities, and all the rooms are fully furnished and air-conditioned. The details of accommodation facilities are summarised below in Table 3.4.

Table 3.4: Accommodation Facilities in Lekhwair Asset

Item	Description
Total number of permanent camps	One PDO Main Camp and one Contractors camp (motel)
Total number of mobile camps	Depends on how many drilling rigs are operating. Presently, there are no rigs operating in the asset.
Total number of housing units and total number of PDO staff (and visitors) accommodated at any time in PDO main camp	Rooms : 120 Occupancy : 100
Total number of housing units and total number of contractor staff (and visitor) accommodated at any time in contractors camp	Rooms : 118 Occupancy : 160
Typical number of staff accommodated at any time in each mobile camp	Presently there are no mobile camps in the asset.
Total number of canteens in the permanent camps	PDO camp – 2 (one for PDO staff and one for catering staff) Contractor camps – 2 (Senior mess and Junior mess)
Total number of laundries in the permanent camps	2 laundries
Recreation facilities available in PDO main camp	Playing area (tennis, volleyball etc.) Swimming pool Gymnasium and Indoor games area Auditorium, conference rooms, TV room and reading room Mosque

3.9.8 Miscellaneous Facilities

The administrative offices are located in a large building called 'The Camp Main Office'. Other facilities available within the asset include a medical clinic, shops, ROP station, fire station, airstrip, vehicles for transportation etc.

3.10 Developmental and Construction Activities

3.10.1 Overview

Developmental and construction activities are carried out in the asset throughout the year, at some location or the other. At a site, these activities are of short duration ranging from a few days to a few weeks. These activities include seismic survey, drilling and well completion, pipeline construction and maintenance, road construction and maintenance, power line construction and maintenance, well closure and site restoration. The detailed description of these activities is presented in the individual EIA report for each of the service assets. A brief description is provided below.

3.10.2 Seismic Survey

Seismic survey is carried out for locating the new oil fields. This survey is carried out by the Exploration Asset Team. The seismic survey involves the mobilization and operation of survey equipment such as vibrator trucks and geophones, any site preparation work and management of on-site accommodation camps (mobile camps). Typically, the survey activity at a site lasts for 4-12 weeks.

3.10.3 Drilling and Well Completion

Drilling of exploration and production wells is a major construction activity with significant environmental aspects. Contractors under the supervision of the Exploration Asset Team carry out exploration drilling, while contractors under the supervision of the Well Engineering Asset Team carry out the drilling of producing wells. Drilling and well completion process involves the following sub-processes.

- Well pad preparation, which included site levelling, construction of access road for the rigs, construction of water and waste pits etc.
- Mobilization of drilling rig by road using over 20 trucks

- Setting up of rotary drilling rig on well pad with ancillary facilities (power generation unit, fuel storage, waste oil storage, drilling mud / chemical storage, accommodation / office and sewage treatment / handling)
- Preparation of water based or oil based muds for well drilling
- Continuous drilling, with drill string casing and cementing for protection of shallow aquifer
- Discharge of drilling mud and drill cuttings into a dedicated, fenced waste pit at each well pad
- Well completion and installation of wellhead (Xmas tree)

Typically, well pad preparation takes 4-7 days, rig mobilization up to 10 days, drilling about 2 weeks and well completion about 1-2 days. The drilling team stays on-site in mobile camps. Up to 150 personnel may be involved in the drilling team.

3.10.4 Pipeline, Road and Power Line Construction and Maintenance

The laying of new pipelines and the repair / replacement of defective pipelines is undertaken by the Infrastructure Asset Team. Laying of new pipelines may involve site preparation including removal of vegetation, to lay out the pipes as well as to provide access roads. For a new pipeline, hydrotesting is carried out prior to commissioning.

Road laying and maintenance involve the use of construction equipment such as bulldozers, road rollers etc. and may require importing to site construction materials such as gravel, stone aggregates, asphalt etc. This process also requires significant quantity of water for wetting and dust suppression.

Laying of new power lines and the maintenance of existing power lines is supervised by the Infrastructure Electrical Team. This activity normally does not involve major site preparation since the power lines are normally laid along the pipeline access roads.

3.10.5 Well Closure and Site Restoration

As wells dry out over a period of time, well closure is also a continuing activity in the assets and is also carried out by the Well Engineering Asset.

Well closure involves the removal of both surface and sub-surface structures from the well site. The surface structures include the production and auxiliary equipment, flow

lines, storage tanks, above ground steelwork and concrete. The sub-surface structures include the foundations, well casings, etc.

The site restoration first involves the removal of any soil found to be contaminated oils or chemicals, and sending these soils for remediation or disposal. After the removal of structure and the equipment from the site, all efforts will be made to restore the landscape of the site, so that it integrates well with the surroundings. Where possible, the site will be restored to a level so that it can be put to a useful purpose.

3.11 Materials and Utilities

The production of oil does not require any raw materials. However, a large number of process chemicals are used in drilling, dehydration of crude, water treatment, scale control, corrosion control and wastewater treatment. The various process chemical used in the asset are grouped together based on their application and the quantities consumed in the year (2001) are given in Table 3.5 below.

Table 3.5: Consumption of Process Chemicals in Lekhwair Asset

Name of Process Chemical	Physical State and Chemical Nature	Purpose	Quantity Consumed per Year
Water based muds		For drilling	Quantity unknown
Oil based muds		For drilling	Quantity unknown
Demulsifier	Liquid; mixture of aliphatic and aromatic hydrocarbons; surface active agents	Used in dehydration of crude and deoiling of production water	225 L/d
Defoaming agents	Liquid; mixture of aliphatic and aromatic hydrocarbons; surface active agents	Used in dehydration of crude and deoiling of production water	100 L/week
Scale inhibitors	Liquid; mostly organic phosphates	Used in RO plant for scale control	15 L/d
Corrosion inhibitors	Liquid; surface active agents in alcohols	Used in RO plant pipelines for corrosion control	270 L/d
Oxygen scavengers	Liquid; surface active agents in alcohols	Used in pipelines for corrosion control	None currently used
Acids, alkalis and chelating agents	Liquid or solid; reactive and corrosive	Used in RO plant for membrane cleaning	Acid: 10 kg/month Alkali: 25 kg/month
Chlorine or hypochlorite solution	Liquid or tablets; strong oxidant	Used in RO plant and STPs for disinfection	75 kg/month

Name of Process Chemical	Physical State and Chemical Nature	Purpose	Quantity Consumed per Year
Biocides	Liquid	Used in pipeline during pigging for control of fungal growth	1100 L/week
Speciality chemicals	Liquid and powder	Used in SulFerox plant for sulphur separation	Chemical IC110 – 3000 kg/month Chemical IC211– 1500 kg/month Chemical CA100 – 1500 kg/month Chemical CA2202 – 600 mL/d Chemical CA299 – 200 mL/d
Flammable gases in cylinders	Pressurised gas, flammable	Cooking gas	1900 kg/month
Inflammable gases in cylinders	Pressurised gas	Welding gas	Quantity unknown
Solvents	Liquid	Painting	Quantity unknown

Note: All these chemicals are transported by road in trucks

The quantities of electrical power, fuels and freshwater (year 2002) consumed in the asset for the year 2002 are given below in Table 3.6.

Table 3.6: Consumption of Power, Fuels and Freshwater in Lekhwair Asset

Utility	Consumer	Quantity Consumed per Year
Electrical power (average power consumption per day)	Oil fields, gathering stations, manifolds, water injection plant, sulferox plant and accommodation and auxiliary facilities	1270 MWh /day
Associated gas	Lekhwair power plant (gas turbines)	97.59x 10^6 Sm^3 (For Jan to Sept 2002)
	Production station (heaters)	1.38x 10^6 Sm^3 (For Jan to Sept 2002)
	Total	**98.97 x 10^6 Sm^3 (For Jan to Sept 2002)**
Freshwater (desalinated)	Production station and other processes	50 m^3/ d
	Domestic use	190 m^3/ d
	Total	**240 m^3/ d**

Note: The fuel gas analysis is shown in Appendix 3.

4 RELEASES TO ENVIRONMENT

4.1 Introduction

In this section, the various waste products and energies released into the environment from the various activities performed within the Lekhwair asset are discussed. The activities in the asset may be classified into the following groups, based on their nature:

- Activities related to production
- Activities related to generation of utilities
- Activities related to support services
- Activities related to construction, maintenance and decommissioning

The ***production related activities*** include all the activities performed in the oil fields, remote manifold stations, gathering station, production stations and pipelines. The ***activities related to utilities*** include the activities performed in the power stations, sewage treatment plants and water treatment plants. The ***activities related to support services*** include catering, laundry, air conditioning etc. performed within the PDO and contractor camps; waste handling, treatment and disposal activities; and other activities such as transportation and workshops. All the activities are more or less continuous in nature and are site-specific.

The ***activities related to construction, maintenance and decommissioning*** include seismic survey, drilling, well construction, laying and repairing the pipelines, laying and repairing the roads, well closure etc. These activities are carried out almost throughout the year at some site or the other within the asset. However, at a particular site, these activities are essentially temporary (short duration) in nature and of very localized impact. Therefore, any wastes generated from these activities are not discussed here unless they have a long resident time (ex: drilling wastes). However, a detailed analysis of wastes arising for these wastes are considered separately under the relevant EIA study for the service asset.

The wastes released into the environment from all the above activities might be classified into the following groups, based on their physical state as well as nature:

- Air emissions
- Liquid effluents
- Solid wastes
- Noise
- Accidental leaks and spills

In order to quantify and characterize these releases, the currently available database is used. In cases where data are not available or insufficient, an attempt is made to estimate the quantities and characteristics using theoretical or empirical equations. Where estimates based on theoretical or empirical equations are considered not reasonably accurate, recommendations are made for direct measurement.

4.2 Air Emissions

4.2.1 Overview

The air emissions in the asset for the purpose of this report are classified into the following categories:

- Stack emissions
- Flare / vent emissions
- Area source emissions
- Mobile source emissions

While most of these emissions are continuous and long term, there are other several temporary sources from which the emissions are intermittent and of short duration. These sources, such as the equipment used for exploration, drilling, construction or maintenance purposes are operated for a short duration at any given site. As stated earlier (refer Section 4.1), the emissions from the temporary sources are discussed elsewhere and are not included in this report. The discussion on the various emission sources in the asset, their quantification, characterization and emission control is presented in the following sections.

4.2.2 Stack Emissions

Stack emissions are the most dominant air emissions in any asset by virtue of their number and the quantity of emissions. The sources of stack emissions include the gas turbines (used in power stations for power generation and in booster stations for mechanical drive), heaters used in the production stations and the standby diesel generators used for emergency power supply. The emissions from standby diesel generators are very infrequent and hence of no significance. Hence, they are not considered further in this report.

The inventory of stacks in the asset is presented below in Table 4.1.

Table 4.1: Inventory of Stacks in Lekhwair Asset

Location	Gas Turbine Stacks	Heater Stacks	Total Number of Stacks
Lekhwair Production Station	0	3 (Furnace stacks)	3
Lekhwair-B Gathering Station	0	0	0
Lekhwair Power Station	2 (GT1 and GT2)	0	2
Asset total	2	3	5

Note: Minor stacks such as standby diesel generator stacks are not included, since emissions from these stacks are very infrequent and emissions loads are relatively insignificant

The fuel burned in all the above systems is the associated gas produced in the asset. The detailed analysis of the fuel gas used in the asset is shown in *Appendix 2*. The emissions are the products of combustion. The pollutants of concern in these emissions are sulphur dioxide (SO_2), oxides of nitrogen (NO_X), carbon monoxide (CO) and particulate matter (PM), which is primarily due to unburnt hydrocarbons (HC), which are released as fine particulates of <10µm size (PM_{10}) with a significant fraction under 2.5µm size ($PM_{2.5}$). Further, the emissions also contain significant quantity of carbon dioxide (CO_2), which is a greenhouse gas.

The detailed information on the stack design specifications, exit temperature, exit velocity, total gas flow rate, heat emission rate and the emission rates of individual pollutants for each stack is presented in *Appendix 3*. It may be noted that the stack emissions are not regularly monitored in the asset. Instead, the emission rates are estimated based on empirical emission factors, as described in *Appendix 3*. The emission inventories for all the assets are summarized in Table 4.2 below.

Table 4.2: Emission Loads from Stacks in Lekhwair Asset

Area	Fuel consumed in 1000 Sm^3/d	Quantity of Emissions					
		Heat (10^6 MJ/d)	CO_2 (tpd)	SO_2 (tpd)	NO_X as NO_2 (tpd)	CO (tpd)	PM_{10} including HC (tpd)
Lekhwair Production Station	5.06	NA	15.2	0.00	0.0	0.0	0.0
Lekhwair Power Station	357.46	NA	1494.2	0.00	3.6	1.5	0.3
Asset total from all stacks	362.52	NA	1509.4	0.00	3.7	1.5	0.3

Note: For the cells marked NA, data are not available and not reported.

Particulate emissions are not significant for gas fired systems. Particulate emission controls are required only for fuels such as solid fuels and heavy petroleum residues

with significant ash content. The HC emissions along with CO emissions are minimised due to high combustion efficiency of the fired systems, and therefore do not need any specific control systems.

SO_2 emissions depend on the sulphur content (or the hydrogen sulphide concentration) in the fuel gas. In Lekhwair asset, the hydrogen sulphide concentration in the associated gas is quite high and is up to 500 ppm. Therefore the gas is desulphurised in SulFerox plant (refer Section 3.6) such that the treated sweet gas will have <5 ppm H_2S. There is no Omani regulatory standard or PDO specification for maximum permissible SO_2 concentration in the stack emissions. However, PDO specification SP-1005 requires that SO_2 emission load be such that the ambient air quality standards (refer Table 2.5 in Chapter 2) are not breached.

NO_x emissions from standard combustion systems in the gas turbines can be quite significant. While there are no Omani specifications presently, PDO specification SP-1005 requires that NO_x emission concentration shall not exceed 200 mg/Nm^3. No data are available on NO_x concentrations in the stack emissions and no NO_x emission control systems are provided for any of the combustion systems.

4.2.3 Flare / Vent Emissions

Flares and vents are installed in the asset to release into the atmosphere any associated gas that cannot be utilised or re-injected into the reservoir. PDO has a “no continuous venting” policy, which requires that gases are flared (combusted at the flare tip) such that no unburned hydrocarbons are released into the atmosphere. Venting is permitted only under abnormal conditions such as insufficient gas pressure or quantity to support the flame. In PDO’s terminology, vent is an unlit (cold) flare and as such, there is no physical difference between a vent and a flare. Three types of flares / vents exist in PDO, *viz.*, high pressure (HP) flare / vent, low pressure (LP) flare / vent and atmospheric pressure (AP) flare / vent. The principal difference is that the gas pressure is greater than 150 kPa(g) for HP flare / vent, 0.5 to 150 kPa(g) for LP flare / vent and 0 to 0.5kPa(g)for AP flare / vent.

The constituents in the flare emissions are not different from those of stacks, except for their composition. Generally, the emission factors (tonnes emission per tonne of gas flared) for CO and HC from the flares are substantially higher than those for stacks. The SO_2 emissions depend on the sulphur content in the gas flared. NO_x emissions will be slightly higher than that from a gas turbine fitted with DLN burner. The emission factors for flares in PDO are estimated based on Tier 3 emission factors

given in the Shell group specification EP 95-0377 on "Quantifying Atmospheric Emissions" (*Reference 3*), as below:

CO_2	: 27.5 x E kg per tonne of gas flared
CO	: 8.7 kg per tonne of gas flared
NO_x as NO_2	: 1.5 kg per tonne of gas flared
SO_2	: 20 x S kg per tonne of gas flared
HC	: 3 x (100 - E) kg per tonne of gas flared
Smoke index	: Ringlemann 1

where E is the flare efficiency (assumed to be 95%) as percentage and S is the mass percentage of sulphur in the fuel gas. In the case where the flare is unlit (cold vent), the emissions have the characteristics as the vented gas.

The concentrations of pollutants, mainly HC, CO and NO_x in the flare emissions are controlled by proper design of the flare tip. The basic principle is to ensure near complete combustion through good entrainment of air for combustion, good fuel-air mixing and flame stability. All the flares are currently designed such that the smoke index, which a measure of combustion efficiency is Ringlemann 1 or lower.

The details of flares / vents in the asset are presented below in Table 4.3.

Table 4.3: Inventory of Emissions from Flares / Vents in Lekhwair Asset

Area	Number of Flares / Vents	Quantity of Gas Flared / Vented (10^3 Sm^3/d)	No. of Hours Vented per Year	Heat Emission Rate (10^5 MJ/d)	CO_2 Emission Rate (tpd)
Lekhwair Production Station	3 (1 HP + 1 LP +1 AP)	0	129.74	745.69	748.7
Lekhwair -B Gathering Station	2 (1 LP + 1 AP)	19.11	0	9.43	75.9
Asset total	5 (1 HP + 2 LP + 2 AP)	163.24	0	67.96	824.6

4.2.4 Area Source Emissions

The area sources for air emissions in the asset include bulk storage tanks, waste disposal sites, sewage treatment plant (STP) sites, wastewater lagoons and excavation sites.

For area sources, ***bulk storage tanks*** account for most of the air emissions. The air emissions from bulk storage tanks are basically the hydrocarbon vapour losses into the atmosphere due to evaporative pressure build-up in the tanks and their purging during tank fillings. Among the bulk storage tanks, only the crude oil and associated gas storage tanks are considered as significant area sources, while the storage tanks of small capacities for petroleum products are disregarded.

The ***waste disposal sites*** include the dump sites / landfill sites, land farms for contaminated soils and drilling waste pits. The emissions from these sites may include hydrocarbon vapours (due to surface evaporation), dust (due to wind dispersal) and other noxious gases (due to waste decomposition). The ***emissions from STP sites*** and the wastewater lagoons are basically the odorous vapours such as sulphides and amines. They are released only under septic conditions, which rarely exist in the asset. The ***excavation sites*** are basically associated with well pad construction. The emissions are basically dust risings and temporary in nature. Hence they are not considered in this report.

Only hydrocarbon emissions are considered significant in quantity from area sources in PDO. The hydrocarbon vapour emissions from all significant area sources are estimated based on Tier 3 emission factors given in the Shell group specification EP 95-0377 on "Quantifying Atmospheric Emissions" (*Reference 3*):

Fixed roof tank	: 131.765 grams per tonne of throughput
Internal floating roof tank	: 0.235 grams per tonne of throughput
External floating roof tank	: 1.000 grams per tonne of throughput

The above emission factors are based on USEPA's AP-42 methods. It is assumed in PDO that 15% of the total hydrocarbons emissions are methane and the remaining 85% are non-methanes.

Crude oil storage tanks are identified as the principal area sources of air emissions, and the emissions from these sources are hydrocarbon vapours. The details of the crude oil storage tanks in the asset and the estimated hydrocarbon vapour emissions from these sources are presented in Table 4.4 below.

Table 4.4: Air Emissions from Area Sources in Lekhwair Asset

Description of Source	Tank Type	Tank Capacity (m^3)	Throughput Rate (Tonnes per Year)	Total Hydrocarbon Emission Rate (Tonnes per Year)
Crude oil storage tanks in Lekhwair Production Station	Fixed roof	2 tanks of 6,830 m^3 each	4,165	0 (See Note 1)
Crude oil storage tank – 2 in Lekhwair –B Gathering	Fixed roof	2 tanks of 398 m^3	Not available	0

Description of Source	Tank Type	Tank Capacity (m^3)	Throughput Rate (Tonnes per Year)	Total Hydrocarbon Emission Rate (Tonnes per Year)
station		each		(See Note 1)
All sources	-	-	4,165	0 (See Note 1)

Note 1: All fixed roof ranks are provided with vents for collection of vapours and these vapours are routed to the flare. Hence there will be no direct emissions to air from fixed roof tanks

4.2.5 Mobile Source Emissions

Motor vehicles used within the asset for the transportation of materials and men constitute mobile air emission sources. The types of motor vehicles used may be classified as light duty petrol vehicles (cars and 4-wheel drives), medium duty diesel vehicles (buses and vans) and heavy duty diesel vehicles (trucks). The significant pollutants present in these emissions are NO_x, CO and PM_{10}, which includes the unburnt HC. The emission factors (mass of pollutants emitted per running kilometre) depend on the type of the motor vehicle, type of the fuel, running speed, load conditions and environmental conditions.

In PDO, the air emissions from mobile sources are estimated based on Tier 3 emission factors given in the Shell group specification EP 95-0377 on "Quantifying Atmospheric Emissions" (*Reference 3*). These are based on USEPA's AP-42 methods. However, for the sake of simplicity, EP 95-0377 specification uses common emission factors for all categories of land transport vehicles, as shown below:

CO_2	: 3200 kg per tonne of fuel consumed
CO	: 27 kg per tonne of fuel consumed
NO_x as NO_2	: 38 kg per tonne of fuel consumed
SO_2	: 8 kg per tonne of fuel consumed
HC	: 5.6 kg per tonne of fuel consumed

In the above estimates, it is assumed that all vehicles are diesel driven, moderately aged and the sulphur content in the fuel is 0.4% by mass.

The estimated total emissions from mobile sources in the asset are as given in Table 4.5 below.

Table 4.5: Air Emissions from Mobile Sources in Lekhwair Asset

Parameter	Quantity
Total number of land vehicles operating in the asset (PDO and Contractors)	Not available
Total quantity of fuel consumed – petrol	41.69 tpa
Total quantity of fuel consumed – diesel	575.08 tpa
Total quantity of fuel consumed – all fuels	616.77 tpa

Parameter	Quantity
Total emission of CO_2	1,973.65 tpa
Total emission of CO	16.65 tpa
Total emission of NO_x	23.44 tpa
Total emission of SO_2	4.94 tpa
Total emission of HC	3.45 tpa

4.3 Liquid Effluents

4.3.1 Overview

The liquid effluents in the asset may be classified into three groups *viz.*, continuous, intermittent and accidental. The different effluent streams in each group include the following:

- Produced water (continuous)
- Water treatment plant rejects (continuous)
- Sewage (continuous)
- Vessel washings (intermittent)
- Hydrotest water (intermittent)
- Drilling wastewater (intermittent)
- Leaks and spills of oils and chemicals (accidental)

Quantity-wise, the most significant streams are produced water, water treatment plant rejects and sewage, which are continuously generated. ***Produced water*** refers to the water separated from the crude and then disposed. ***Water treatment plant effluents*** refer to the concentrated brine rejects from reverse osmosis (RO) plants and the backwash of softening plants. ***Sewage*** refers to the domestic effluents generated from accommodation facilities, canteens, laundries and the wastewater generated from the various washrooms and toilets in administrative areas. Sewage generated from mobile camps used by the seismic survey and drilling teams are not considered here, since these camps stay at a site for typically 1-2 weeks only and they are handled separately.

With respect to the intermittent effluents, the ***vessel washings*** refer to the occasional washings from process tanks and vessels. ***Hydrotest water*** refers to the wastewater that is finally disposed after hydrotesting of pipelines. ***Drilling wastewater*** refers to the wastewater that is finally disposed after the completion of oil well drilling.

The ***oil and chemical leaks and spills*** occur only accidentally due to pipeline failure, storage tank failure and road accidents. The leaks and spills usually result in the contamination of soils. They are discussed separately under Section 4.6. The leaks and spills involving water or treated sewage are not considered as waste streams, and hence not discussed in this section.

4.3.2 Quantification and Characterisation of Liquid Effluent

The quantities of the various liquid effluent streams generated in the asset are presented in Table 4.6 below, along with a brief description of their nature.

Table 4.6: Liquid Effluents Generated in Lekhwair Asset

Liquid Effluent	Source of Generation	Streams	Quantity Generated (m^3/d)	Typical Nature and Characteristics of Raw Effluent
Produced water (Continuous)	Production station	Deep disposal Shallow disposal Total	21,977 0 21,977	Water content in the reservoir fluid with high dissolved inorganic salts, traces of oil and virtually free of organic matter
Water treatment effluents (Continuous)	RO plants and softening plants	RO plant rejects + back wash Total	336 336	Backwash with high dissolved inorganic salts and virtually free of organic matter
Sewage (Continuous)	Accommodation facilities, canteens, laundries, toilets and wash basins	PDO STP Contractor STP Total	62 91 153 (See Note 1)	Wastewater from domestic activities with mostly biodegradable nutrients as suspended and dissolved matter
Vessel washings (Intermittent)	Process tanks and vessels	All	Negligible	Occasional washings with traces of oil and detergents, and virtually free of organic matter
Hydrotest water (Intermittent)	Pipeline under testing	All sources in the asset	Negligible	Wastewater after hydrotesting with traces of oil and virtually free of organic matter
Drilling wastewater (Intermittent)	New drilling sites	All sources in the asset	Not available	Wastewater from drilling activities with traces of oil, heavy metals and virtually free of organic matter

Note: Sewage generated from mobile camps are not included, since mobile camps do not stay for more than 1-2 weeks at a site and the effluents are separately handled

4.3.3 Effluent Treatment

- **Overview**

The produced water is re-injected back into the reservoir system without any treatment. The RO plant rejects and backwash are collected in the wastewater pit and then disposed into a shallow aquifer. Sewage is treated by biological oxidation in STPs based on activated sludge process for removal of organic nutrients. With respect to the intermittent streams, they are either mixed with other compatible effluents or appropriately disposed as discussed in the following sections.

- **Produced Water**

Produced water is separated from the crude in the dehydration tanks in the production station. It is then disposed off by re-injecting into Kharaib and lower Shuaiba formations using deep injection wells. No deoiling is done before disposal. The residual oil content in the produced water will be in the order of 150 mg/L.

- **RO Plant Rejects and Backwash**

RO plant rejects and backwash are collected in a wastewater pit. This wastewater is characterised by high content of total dissolved solids (TDS), but virtually free of organic matter. From the wastewater pit, the wastewater is pumped out and disposed into shallow aquifer (Dammam formation).

- **Sewage**

Sewage is treated in two STPs, which are based on activated sludge process. The detailed treatment process description is presented in the environmental audit report of the STPs in PDO (*Reference 4*). A brief description is provided below.

Raw sewage from the various points of generation is pumped to STP lifting station. Then the raw sewage from the lifting station is pumped to the aeration tanks, and then passes through bar screens to trap large objects. In the aeration tank, the oxygen necessary for oxidation is supplied by submerged air diffusers. The sewage in the aeration tanks is internally re-circulated to ensure good mixing and to eliminate the settling of solids in the aeration tank. From the aeration tank, the effluent is transferred to a settling tank for the removal of sludge (excess biomass generated due to biological oxidation of the nutrients) by gravity settling. The sludge settled in the bottom of the settling tank is returned to the aeration tank to maintain a healthy biomass concentration (about 4000 mg/L) in the aeration tank. Excess sludge generated in the system is removed periodically from the settling tank to the sludge drying bed.

The clarified effluent from the settling tank is passed through a sand filter to remove any remaining fine suspended particles. The sand filter is periodically backwashed with treated sewage to remove the filtered particles, and the backwash is then pumped back to the aeration tank. The filtrate from the sand filter is then disinfected before it is pumped to the storage tank. The sludge removed from the settling tank is dried in sludge drying before it is sent to the waste management centre.

There are two STPs in the asset. The first (STP/LKH-1) of 130 m^3/d design capacity is dedicated for the sewage from PDO's camp, the second (STP/LKH-2) of 220 m^3/d design capacity is dedicated for sewage from Contractor's camp. The design details of the STPs in Lekhwair are presented below in Table 4.7.

Table 4.7: Design Specification of STPs in Lekhwair

Design Specifications	STP/LKH-1 (PDO Camp)	STP/LKH-2 (Contractor Camp)
Hydraulic flow rate (m^3/d)	130	220
Loading rate (kg/d) - TSS	Data not available	Data not available
Loading rate (kg/d) - BOD	21	36
Raw sewage holding tank capacity (m^3)	None	101
Aeration tank volume (m^3)	161	254
Type of aeration mechanism in aeration tank	Submerged air diffusers	Submerged air diffusers
DO maintained in aeration tank (mg/L)	1-2 mg/L	1-2 mg/L
MLSS maintained in aeration tank (mg/L)	3500-4000	3500-4000
Sludge settling tank volume (m^3)	80	325
Balancing tank (m^3)	14	28
Sand filter diameter (m) and height (m)	2 units of 0.95 m diameter	2 units of 0.95 m diameter
Type of chlorination provided	Sodium hypochlorite and chlorine tablets (sodium isocyanuric acid)	Sodium hypochlorite and chlorine tablets (sodium isocyanuric acid)
Treated sewage tank volume (m^3)	150	440
Size of sludge drying beds (m x m x m)	5 beds each of 7.2 m x 5.00 m common for both STPs	

- **Intermittent Effluents**

The major intermittent effluents include the hydrotest water and the drilling wastewater. Hydrotesting is performed only for the new pipelines. Since no new pipelines are laid out in the asset recently, no effluent is generated from hydrotesting in the asset. The standard practice in PDO for the disposal of hydrotest water states that if the hydrotest water quality meets the discharge standards (refer Table 2.7), it will be drained into the desert. If not, it will be sent to the production station for disposal along with the produced water.

The total quantity of wastewater generated from drilling activities in the asset depends on the frequency and duration of drilling. The standard practice in PDO for the disposal of drilling wastewater is to collect the wastewater in a waste pit and allow it to slowly evaporate by solar radiation. The sludge generated after drying will be disposed of as oily sludge or contaminated soil.

4.3.4 Effluent Disposal

- **Quality of Treated Effluents**

The typical characteristics of the treated effluent streams are presented in Table 4.8 below. The characteristics of production water and water treatment plant effluents are based on the analysis of periodic samples collected and analysed by PDO during the year 2002. The characteristics of sewage are based on the analysis of periodic samples collected and analysed by the STP operator during the year 2002. The intermittent effluent streams are not routinely analysed. Hence their characteristics presented below are based on limited analysis. The detailed analytical results of the continuous effluent streams are presented in the environmental audit reports for 2003 (*Reference 5*).

Table 4.8: Typical Characteristics of Treated Effluent Streams

Parameter	Units	Typical Characteristics		
		Produced Water	RO Plant Rejects + Back Wash	Sewage
pH	No units	-	7.8	4.6-7.9
Total suspended solids (TSS)	mg/L	4	-	3-42
Total dissolved solids (TDS)	mg/L	122277	20994	-
Total salinity	mg/L	-	19116	-
Total hardness as $CaCO_3$		-	5621	-
Total chloride as Cl	mg/L	75294	9086	-
Oil and grease (O&G)	mg/L	140	-	-
Biochemical oxygen demand (BOD)	mg/L	Negligible	Negligible	1-24
Chemical oxygen demand (COD)	mg/L	Negligible	Negligible	3-65
Total ammoniacal nitrogen	mg/L	Negligible	Negligible	0-5
Faecal coliform count	per 100 mL	Negligible	Negligible	0-1

Note: "-" indicates that data are not available.

- **Disposal of Produced Water and RO Plant Rejects + Backwash**

The Omani regulations (RD 115/2001, MD 145/93, MD 7/84) as well as PDO's specifications (SP-1006) do not permit the discharge of these effluents into either marine waters or onto the land, principally due to the high TDS content. Therefore, SP-1006 recommends their disposal into the deep aquifers where the salinity is above 35,000 mg/L. The specification also requires that shallow disposal (where salinity is <35000 mg/L) to cease by year 2000. The details of produced water and RO plant rejects + backwash are as below in Table 4.9.

Table 4.9: Details of Disposal of Produced Water and RO Plant Rejects + Backwash

Parameter	Description
Re-Injection (produced water)	
Nature of formation:	Kharaib and Lower Shuaiba
Salinity of aquifer:	Same as oil bearing reservoir
Number of injection pumps:	3
Total volume injected per day (2002):	21970 m^3/day
Shallow Disposal (RO rejects + backwash)	
Nature of formation:	Dammam
Depth from ground level:	About 550 m
Salinity of aquifer:	>60,000 mg/L
Number of disposal pumps:	1
Total volume disposed per day (2002):	336 m^3/day

- **Disposal of Treated Sewage**

Land application of treated sewage is practised throughout PDO. The SP-1006 as well as RD 155/2001 (also MD 145/93) permit land irrigation provides the following conditions:

- In areas with no public access: pH is 6-9, O&G O.5 mg/L, TSS 30 mg/L, TDS 2000 mg/L, BOD 20 mg/L, COD 200 mg/L and faecal coliform count 1000 per 100 mL
- In areas with public access: pH is 6-9, O&G O.5 mg/L, TSS 15 mg/L, TDS 1500 mg/L, BOD 15 mg/L, COD 150 mg/L and faecal coliform count 200 per 100 mL.

In Lekhwair asset, the treated sewage after filtration and chlorination is used for the irrigation of lawns and trees using a network of PVC pipes and sprinklers, some with timing devices.

The characteristics of the treated effluent from the STPs as monitored during the year 2002 are summarised in Table 4.10:

Table 4.10: Treated Sewage Characteristics

Parameter	Units	LKHSTP-PDO	LKHSTP-Contr.1
Volume of sewage treated	m^3/d	Average: 62 Max: -	Average: 91 Max: -
Biological oxygen demand	mg/L	Range: 4-24 Average: 10 XN: 3/51	Range: 1-20 Average: 8 XN: 0/51
Chemical oxygen demand	mg/L	Range: 6-65 Average: 26 XN: 0/51	Range: 3-71 Average: 20 XN: 0/51
Total suspended solids	mg/L	Range: 3-42 Average: 13 XN: 2/51	Range: 3-40 Average: 10 XN: 1/51
pH	None	Range: 6-7.9 Average: 7 XN: 0/51	Range: 5-8.6 Average: 7 XN: 1/51
Faecal coliforms	Nos./ 100 ml	Range: 0-1 Average: 0 XN: 0/51	Range: 0 Average: 0 XN: 0/51
Ammoniacal nitrogen	mg/L	Range: 0-7 Average: 1 XN: 0/51	Range: 0-1 Average: 0 XN: 0/51

Notes: XN = Number times regulatory standards exceeded per total number of times monitored.
- = Data not available

4.4 Solid Wastes

4.4.1 Overview

Several types of solid wastes are generated in the asset. Based on the sources of generation, they may be classified as industrial, domestic and construction wastes. Some of these wastes are non-hazardous while some are hazardous.

The non-hazardous wastes include the following groups:

- Domestic and office waste
- Water based drilling mud and cuttings
- Non-hazardous industrial waste

The hazardous wastes include the following groups:

- Oil based mud and cuttings
- Sewage sludge
- Waste lubricants
- Oily sludges

- Oily sand
- Pigging sludge
- Non-recyclable batteries
- Recyclable hazardous batteries
- Transformers and transformer cooling fluids
- Clinical wastes
- NORM wastes
- Chemical wastes (including miscellaneous hazardous wastes)

The quantities of the waste generated in the asset during 2001-2002 and their disposal are discussed in the following sections.

4.4.2 Waste Generation

The quantities of the various solid wastes generated in the asset currently (2002) are given in Table 4.11 below.

Table 4.11: Solid Waste Generated in Lekhwair Asset

Waste Group	Classification	Units	Quantity Generated in 2002 (Jan-Sep).
Domestic and office waste	Non-hazardous	Tonnes	8,626
Water based drilling mud and cuttings	Non-hazardous	Tonnes	0
Non-hazardous industrial waste	Non-hazardous	Tonnes	58,020
Total non-hazardous wastes			66,646
Oil based mud and cuttings	Hazardous	Tonnes	Data not available
Sewage sludge	Hazardous	Tonnes	<1 (not reported)
Waste lubricants	Hazardous	Tonnes	0.025
Oily sludges	Hazardous	Tonnes	120
Oily sand	Hazardous	Tonnes	32
Pigging sludge	Hazardous	Tonnes	0
Non-recyclable batteries	Hazardous	Pieces	94
Recyclable hazardous batteries	Hazardous	Pieces	0
Transformers and transformer cooling fluids	Hazardous	Tonnes	0
Clinical wastes	Hazardous	Tonnes	Data not available
NORM wastes	Hazardous	Tonnes	0
Chemical wastes (including miscellaneous hazardous wastes)	Hazardous	Tonnes	33
Total hazardous wastes		Tonnes	279

Among the solid waste, the clinical wastes and NORM wastes are of prime importance. Clinical wastes generated in PDO clinic comprises used syringes, cotton / dressing containing blood and other body fluids, human tissue etc. This waste requires special handling and disposal due to their nature and presence of pathogens. NORM wastes are the wastes containing naturally occurring radioactive materials (NORM), which are commonly encountered during well services operations. Some oil sludges, pigging wastes, tubulars and water/well accessories from reservoir locations may contain NORM. Any waste having radioactivity greater than 100 Bq/g (for solids) and 100 kBq/L (for liquids) is classified as radioactive waste.

4.4.3 Waste Disposal

The above wastes are disposed according to the requirements of SP-1009. The waste disposal practice in the asset is described in Table 4.12 below:

Table 4.12: Solid Waste Disposal Practice in Lekhwair Asset

Waste Group	Waste Disposal Practice
Domestic and office waste	- Kitchen waste is packed in black bins / plastic bags and send to the sanitary landfill in the asset. Green waste is also sent to the sanitary landfill. - Recyclable domestic and office waste (paper, plastic, cans etc) is segregated at source, packed in yellow bins / plastic bags and sent to an external recycling facility. - Non-recyclable waste is sent to the sanitary landfill.
Water based drilling mud and cuttings	- Unless total petroleum hydrocarbon content is >10 g/kg, they are disposed in a dedicated landfill in the Lekhwair waste management centre. - Otherwise, they are treated as oily sand
Non-hazardous industrial waste	- Iron scrap, electrical cable, wood, paper, metal/plastic drums are segregated at source and sent to sent to an external recycling facility. - Metal / plastic containers of non-hazardous chemicals are punctured, crushed and sent to an external recycling facility. - Non-recyclable waste is sent to the sanitary landfill.
Oil based mud and cuttings	- Presently no such waste.
Sewage sludge	- Sewage from septic tanks is sent to STPs for drying along with STP sludge. - Dry sludge is applied on land if it meets the specifications (SP-1006), otherwise sent to for landfilling as hazardous waste in the waste management centre.
Waste lubricants	- Sent to the oil saver pits for recycle into crude oil system.
Oily sludges	- Liquid fraction is sent to an external facility for recycling. - Solid fraction stored at waste management centre for transporting to Fahud land farm.
Oily sand	- Sent to Fahud land farm.
Pigging sludge	- Sent to Fahud landfarm, if it is not a NORM waste. - Otherwise, sent to NORM waste management centre in Zauliyah for storage and disposal.
Non-recyclable batteries	- They are packaged in refuse bags and disposed in the landfill with domestic waste.

Waste Group	Waste Disposal Practice
Recyclable hazardous batteries	- The terminal are taped, electrolytes are drained and then sent to an external facility for recycling.
Transformers and transformer cooling fluids	- If they are PCB free (<50ppm), cooling fluids are drained and recycled to the crude oil system and the container is disposed as non-hazardous waste. - Otherwise, they are segregated and stored in the waste management centre for final disposal by a specialist
Clinical wastes	- All wastes are packaged in special yellow bags or cartons and sent to the incinerator in MAF for treatment.
NORM wastes	- All NORM waste is sent to the waste management centre in Zauliyah for storage and disposal.
Chemical wastes (including sludge from sulferox plant)	- Unused chemicals, if possible sent back to the supplier - Containers of hazardous chemicals are decontaminated, punctured / crushed and sent for recycling at an external facility - Sulferox waste is disposed in a dedicated landfill in the waste management centre.

4.4.4 Waste Management Centre

Lekhwair has a centralised waste management centre for the disposal of both non-hazardous and hazardous wastes. Further, only Lekhwair has a dedicated sulfur disposal facility. This facility does not handle NORM wastes, which are sent to a dedicated storage / disposal site in Zauliyah. Similarly, any clinical wastes generated in the asset are sent to MAF for incineration. The complete details of the waste management centre are presented in the environmental audit report on PDO's waste management centres (*Reference 5*). They are summarized below in Table 4.13.

Table 4.13: Details of Lekhwair Waste Management Centre

Item	Description
Types of waste handled	Non-hazardous and hazardous waste including chemical wastes (suphur from SulFerox plant)
Total site area (m^2)	Approximately 16 ha
Facilities available	Dozers available for burying waste
Storage (holding) area for non-hazardous wastes	Open space is available for non-hazardous wastes.
Storage (holding) tank for waste oils and oil sludges	A waste oil pit is available, which appears to be under-sized.
Storage (holding) area for chemical wastes	Four concrete pits for solar evaporation of waste SulFerox solution .
Storage (holding) area for other miscellaneous hazardous wastes	A separate hazardous waste storage area is provided with drainage facility for any leaks and spills.
Sanitary landfill	Unlined 50m x 4m x 3m trenches for kitchen wastes.
Hazardous waste landfill	Unlined 50 m x 4.5 m x 3 m trenches for sulphur waste
Land farm	There is no land farm in Lekhwair. Contaminated soil is transported to Fahud for land farming.

4.5 Noise

4.5.1 Sources of Generation

The noise sources in the asset may be classified into the following categories:

- Continuous sources
- Intermittent sources
- Mobile sources

The major noise generating sources are present mainly in the production station, gathering stations, power stations, booster stations, RO plants, production water disposal sites and STPs. Both continuous and intermittent sources are present. The continuous sources include rotary pumps, compressors, electrical motors, burners, stacks, flares and other rotating equipment. All these sources are outdoor, stationary point sources. The intermittent sources include the pressure relief valves, standby diesel generators and some intermittently operated pumps and motors.

There are no significant noise sources in the oil fields. In all other areas such as accommodation facilities, administrative building, waste management centres, workshops etc., there are only intermittent noise sources.

The mobile sources include the normal transportation vehicles such as cars, vans, buses and trucks and construction equipment such as earth moving machines (excavators, dumpers, bulldozers etc.), rotary drilling rigs, lifting equipment (cranes and hoists), concrete mixers etc.

4.5.2 Noise Levels

Due to the presence of a large number of noise generating sources in process areas (particularly Production Station and Power Stations), it is not possible to measure the noise level at the source point for each equipment. Therefore, instead of considering all the individual sources as distinct point sources, a group of them may be treated as an area source.

Currently, no data are available on the noise levels for either point sources or area sources. It is however noticed during the site visits that at several places the noise levels are greater than 85 dB(A), which is the permissible workplace noise level.

4.5.3 Noise Control

All the major noise generating equipment such as pumps, motors, compressors, burners etc. are provided with standard noise control systems such sound insulation, vibration control and acoustic packages where necessary.

4.6 Accidental Leaks and Spills

In PDO, all accidental leaks and spills shall be promptly reported. There are three categories of accidental leaks and spills, as below:

- Oil leaks and spills
- Chemical leaks and spills
- Water leaks and spills
- Release of ozone depleting substances (ODS)

While water leaks and spills do not lead to any environmental consequences, they are reported as a matter of water conservation issue. ODS include CFCs, halons, HFCs and HCFCs. The use of these substances is currently phased out in PDO due to their high ozone depletion potential. Some inventories of such substances may still be found in some air-conditioners and portable fire extinguishers According to PDO's specification SP-1005, these substances are not permitted to be released into the atmosphere except in uncontrollable situations or emergencies.

For the current year (2002), the leaks and spills reported in Lekhwair asset are summarized in Table 4.14.

Table 4.14: Accidental Leaks and Spills in Lekhwair Asset

Description	Incidents Reported in 2002			
	Oil Leaks and Spills	Chemical Leaks and Spills	Water Leaks and Spills	Releases of ODS (CFCs and Halons)
Total number of incidents	12	0	41	Unknown
Number of spills into wadis	0	0	0	-
Total volume leaked / spilled (m^3)	7.6	0	64.5	321 kg
Total land area impacted (m^2)	30	0	79	-
Total quantity of soil contaminated (t)	Data not available	0	Not applicable	-

While water leaks and spills do not lead to any environmental consequences, they are reported as a matter of water conservation issue.

5 ENVIRONMENTAL SETTING

5.1 General

In this chapter, the existing environmental conditions in Lekhwair asset is described and analysed. The description is largely based on the information provided in the previous EIA report (*Reference 1*). Additional information is sourced from site reconnaissance surveys conducted as apart of the present environmental assessment study (refer Section 1.3). A brief description and analysis of the environmental aspects are presented in this chapter, due to the nature of activities in the asset, which resulted in very little change from the previous environmental assessment. Detailed description and analysis are limited to the environmental aspects that are likely to have undergone a noticeable change since the last environmental assessment. The areas where specific data are required but not available are identified.

The environmental aspects likely to have undergone noticeable change due to the asset activities include the following:

- Groundwater resources and groundwater quality
- Ambient air quality and noise
- Land use and human settlements

5.2 Location and Topography

Lekhwair asset is located in northwest corner of PDO's concession area, bordering Saudi Arabian and United Arab Emirates. It covers a total land area of 3,560 km^2, which is 3.1% of total PDO concession area. The asset comprises 223 producing wells, two operating oil fields, 10 remote manifold stations, one gathering station and a production station in the asset. Lekhwair production station is located at 2525780 N and 327745 E, and is about 130 km from Fahud by road. The topographical map of the asset is shown in Figure 5.1. The asset boundary co-ordinates are given in Table 5.1 below:

Table 5.1: Lekhwair Asset Boundary Coordinates

Site Boundaries	Clarke 1880 System (Easting or Northing (m))
Northern limit	2471406 N
Eastern limit	392211 E
Southern limit	2544417 N
Western limit	315688 E

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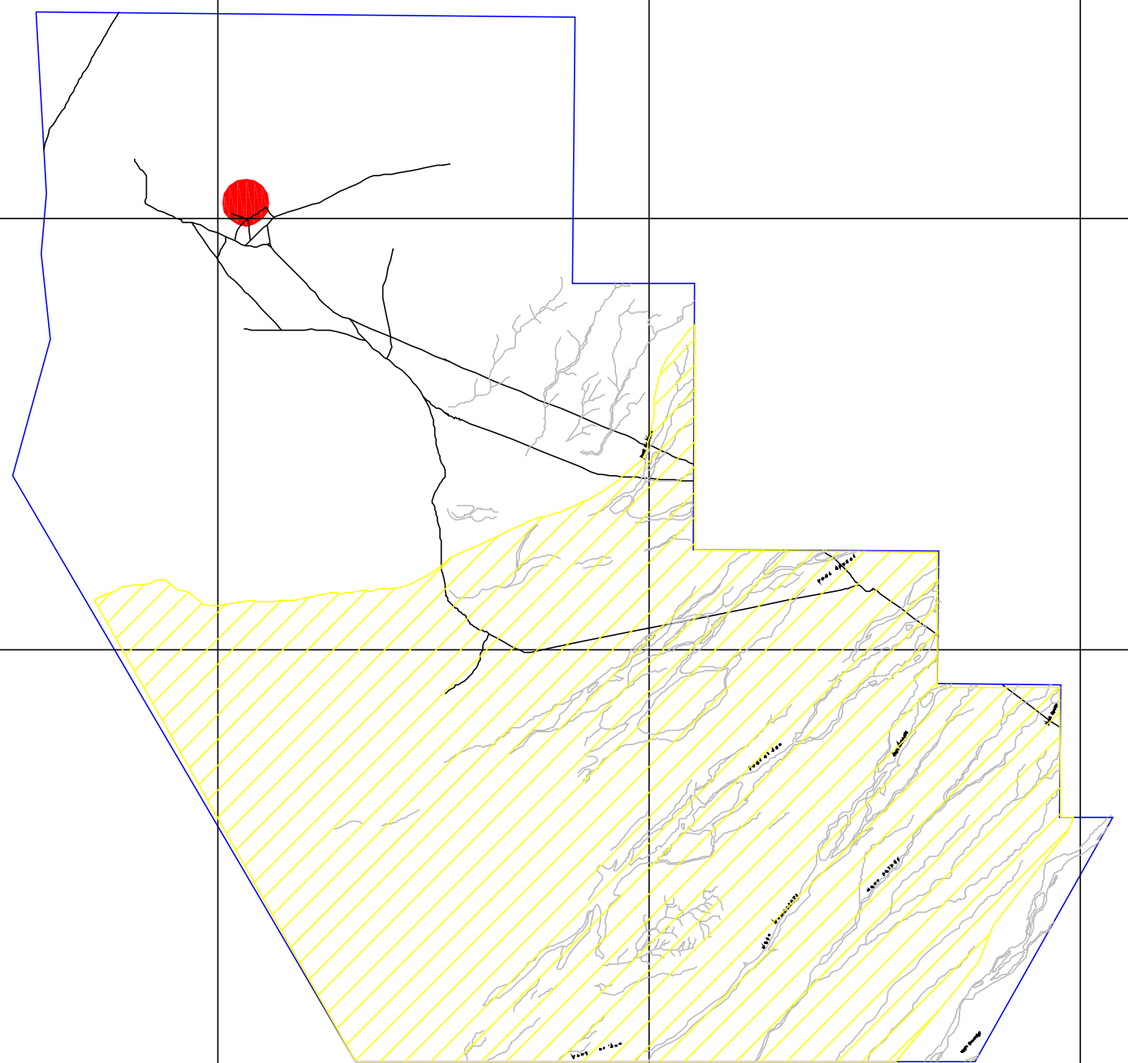
300000E
330000E
360000E
390000E
2530000N
2500000N
2470000N



N
W
E
S

LEGEND

- Permanent Human Settlements
- Bedouin Areas
- Groundwater Protection Site (YELLOW ZONE)
- Richly Vegetated Sites
- Archealogical Sites
- Cultural Sites (Cemetary)
- Recreational Sites
- PDO Camp
- Road
- Wadi

PRODUCED FOR :

شركة تنمية نفط عمان

Petroleum Development Oman

PROJECT : EIA UPDATE FOR PDO

AREA : LEKHWAIR ASSET

DESCRIPTION : Figure 5.1

Topographical Map of Lekhwair Asset

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SCALE : 1:500,000 1cm = 5km

DATE :	DRAWN BY:	CHECKED BY :	APPROVED BY :
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The topography and landscape of most of the asset area is very similar to many other areas of central Oman, characterised by flat plains interspersed with small drainage channels and occasional rocky outcrops. The elevation with reference to the mean sea level ranges from about 100 m.

The asset area is mostly gravel plain, with low sand dunes (i.e., up to a height of 100 m) present on the western and northern sides of the asset. A few shallow wadis flow from the north and drain into the south-east corner of the asset. Wadi Bu Mudiq and Wadi al Ayn are the major wadis, which are relatively vegetated. The natural vegetation is composed of desert plants and grass, and there are no major trees in the asset except in those places irrigated by PDO using treated wastewater.

5.3 Geology and Soil

Most of the exposed surface formations in the asset are tertiary deposits composed of limestone, dolomite, shale, clay and anhydrite. The tertiary formations in Lekhwair area are approximately 1,200 m thick and lie on top of the Cretaceous Shuaiba Formation. They consist of the Fars, Dammam, Rus and UeR formations. The geological cross section in the asset is shown in Figure 5.2.

The Fars formation is approximately 500 m thick. It is composed predominantly of carbonates, which range from limestone and dolomites to marls, gypsum and calcareous shales. The underlying Dammam formation is about 220 m thick and is composed of massive limestone. Thin calcareous shale beds are also present and may be laterally pervasive. An increased proportion of shale characterises the base of the Dammam formation. The Rus formation is approximately 100 m thick and composed mainly of gypsum and dolomite beds. This formation is very likely sealing due to the thickness of the gypsum layers (5–30 m).

The UeR formation is split into upper, middle and lower sections. The upper UeR is about 100 m thick and is characterized in the top 30-m thin interbeds of dolomite and gypsum. Below this limestone beds predominate, but are broken by thin layers of calcareous shale. The middle UeR is some 210–250 m thick and dominated by limestone. The lower UeR (Shammar shale) is about 10 m thick and composed of calcareous shale. It is impermeable and recognised as the likely seal for hydrocarbons in the underlying Shuaiba formation.

No site-specific data are available on the soil quality. Generally, the soils in the asset are classified as unsuitable for agricultural purposes, as per the Ministry of Agriculture and Fisheries “General Soil Map of Oman". The soil map of PDO’s concession area is shown in Figure 5.3.

5.4 Hydrogeology and Groundwater Quality

Groundwater exists in Fars, Dammam and UeR formations. The water table in the Fars aquifer is at 22 m below ground level, while it is 820 m below ground level for UeR aquifer. Fars water in the Lekhwair area is characterised by low salinity (8,000 to 10,000 mg/L chlorides). On the other, UeR water is highly saline (50,000 to 150,000 mg/L chlorides). The isosalinity map of fars and UeR water are shown in Figure 5.4 and Figure 5.5 respectively.

The UeR is the main prolific aquifer in the area. The formation is a highly porous calcareous dolomite. The groundwater in the UeR aquifer flows in the direction of the Umm as Samim, a basin like depression where discharge of water is caused by upward capillary percolation and subsequent evaporation. The piezometric level in the UeR is invariably below ground level in the Lekhwair area, although it approaches close to surface level in the low-lying northwestern tip of the field.

The well yield and water quality data for different locations within the asset are summarised below in Table 5.2. The change in water level and water quality over the past 5 years has also been shown.

Table 5.2: Well Yield and Water Quality Data in Lekhwair Asset

Location	Representative Water Well	Name of Aquifer	Water level		Total Dissolved Solids		Yield	
			(m)	Date	(g/L)	Date	(m3/h)	Date
Dhulaima	Dhulaima WSW-1	Fars	11.8 11.81	Jul'87 May99	12.843 14.549	July'83 Feb'91	36.0	Jul'96
Lekhwair	Lekhwair WSW-10	Fars	23.8 24.94	Mar'80 May'99	17.678 30.044	Mar'80 Jun'84	22.0	Mar'80

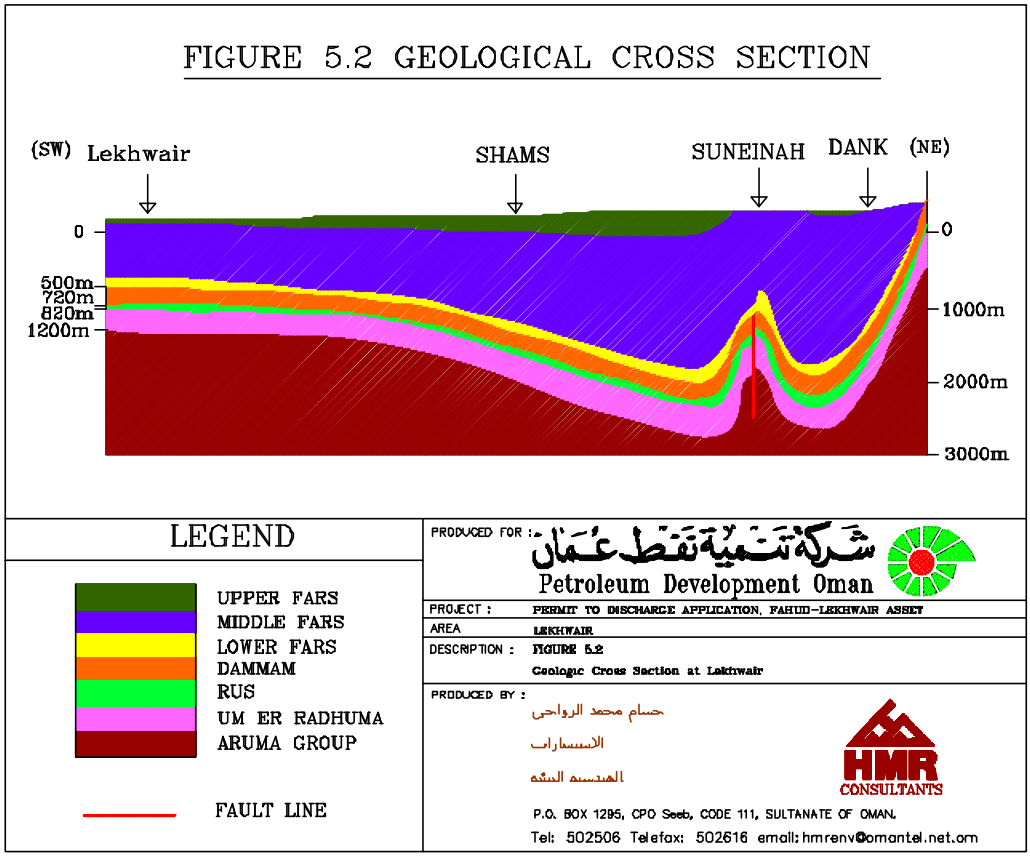

Figure 5.2: Geographical Cross Section in Lekhwair

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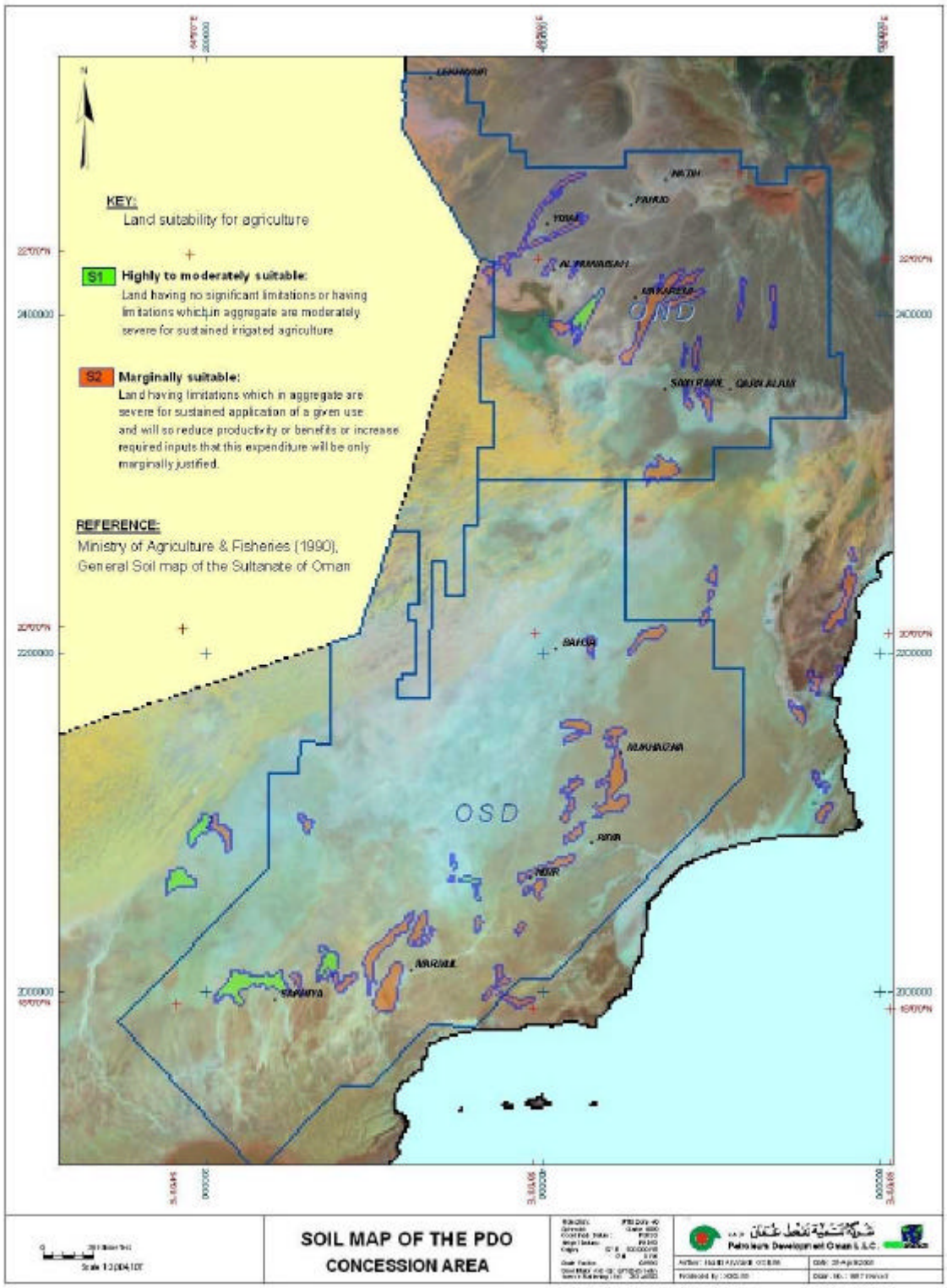

Figure 5.3: Soil Map of PDO's Concession Area

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5.5 Climate

Meteorological data are not available for the Lekhwair asset. The nearest meteorological station is located at Fahud. Considering the proximity of Fahud to Lekhwair, the climatic conditions in both assets will be similar. Meteorological data were recorded in Fahud asset for the year 2002. Based on these data, the mean annual temperature is 29.3°C. The mean monthly temperatures range from 19.7°C in January (with mean minimum of 5.6°C and mean maximum of 34°C) to 37°C in July (with mean minimum of 24°C and mean maximum of 50°C). The maximum and minimum absolute temperatures are 51°C and 6°C respectively.

However, the climate at Lekhwair is considered to be more extreme with local reports of maximum temperatures in the summer regularly exceeding 51°C and with temperatures perhaps lowers than 5.6 °C in winter. The relative lack of vegetation indicates that rainfall in Lekhwair may be somewhat lower than Fahud.

The mean annual rainfall in Fahud area is 20 mm. There is very little inter-annual variation in temperature, but the annual rainfall is exceptionally variable between years with little indication of seasonality. Rain has been known to fall in nearly all months of the year, although the mean monthly rainfall was the highest during February and April, with a secondary peak in August.

Tropical storms and cyclones have been known to enter the Gulf of Oman bringing torrential rain to the coast, but are rarely so widespread to reach as far west into central Oman. Storms or cyclones are practically unknown at the height of the monsoon during the summer months of July to September. However, one rare tropical storm affected much of central Oman during the last week of July 1995 bringing 200 mm of rain to the Hajar mountains and flooding its alluvial plains. Similar rains were experienced in central Oman during the winter months of 1998. The climatic charts are presented in Figure 5.6.

5.6 Ambient Air Quality

Very limited air quality studies have been conducted anywhere in PDO concession area since PDO's exploration and production activities started. For the Lekhwair asset, no data are available on the ambient air quality from the previous EIA report (*Reference 1*). It is generally believed that ambient air quality within PDO concession area is of no significance due to two reasons. Firstly, there are no human settlements close to any operational facilities in the entire PDO concession area. Secondly, there are not many air emissions sources in PDO and the emission loads are not considered very significant.

However, in the absence of any measurements, the significance of ambient air quality cannot be established. Based on the uneven distribution of the emission sources, relatively shorter stack heights and atmospheric inversion conditions expected during winter nights, the concentration of some pollutants in ground level air may be elevated in certain locations and in PDO camps at sometimes. Therefore, it is necessary that air quality surveys be undertaken at periodic intervals at selected locations to determine whether the air quality in the asset is within the permissible limits.

5.7 Ambient Noise

No data are available on the ambient noise levels within the asset. It is believed that the ambient noise levels in this region are of no significance due to the fact that there are no human settlements close to any operational facilities. The high noise generating sources in the facilities such as production station, power stations, gathering stations, and RO plant are unlikely to have any impact on the human settlements. However, they may have an impact on the noise levels in the PDO and contractor camps.

Therefore, it is necessary that noise surveys be undertaken at periodic intervals at selected locations to determine whether the noise levels in the accommodation areas are within the permissible limits.

5.8 Flora and Fauna

With rainfall being very scanty and erratic, the fog moisture largely influences the vegetation in this region. The native vegetation is composed of desert plants and grasses, and trees are rarely seen. The distribution pattern of vegetation is dependent on the water drainage pattern and the presence of adequate sand or fissures in the bedrock for plant establishment.

In the Lekhwair area the gravel plains are nearly bare of vegetation. Sparse vegetation is present in wadis and a few trees can be seen at the base of some sand dunes. *Prosopis cineraria* (“ghaf”), *Acacia ehrenbergiana* (“salam”) and *Acacia tortilis* (“samra”) are the main woody vegetation and *Rhazya, Tephrosia, Fagonia, Dipterygium* and *Zygophyllum* the main subshrubs. The vegetation of Lekhwair asset area can be broadly classified as *Acacia- Zygophyllum-Heliotropium* and *Prosopis-Calligonum.* The first type is the typical vegetation of the hyper-arid areas of Oman where vegetation is confined to depressions and wadis. The second type is the typical vegetation of the sandy deserts in the east and west of Oman.

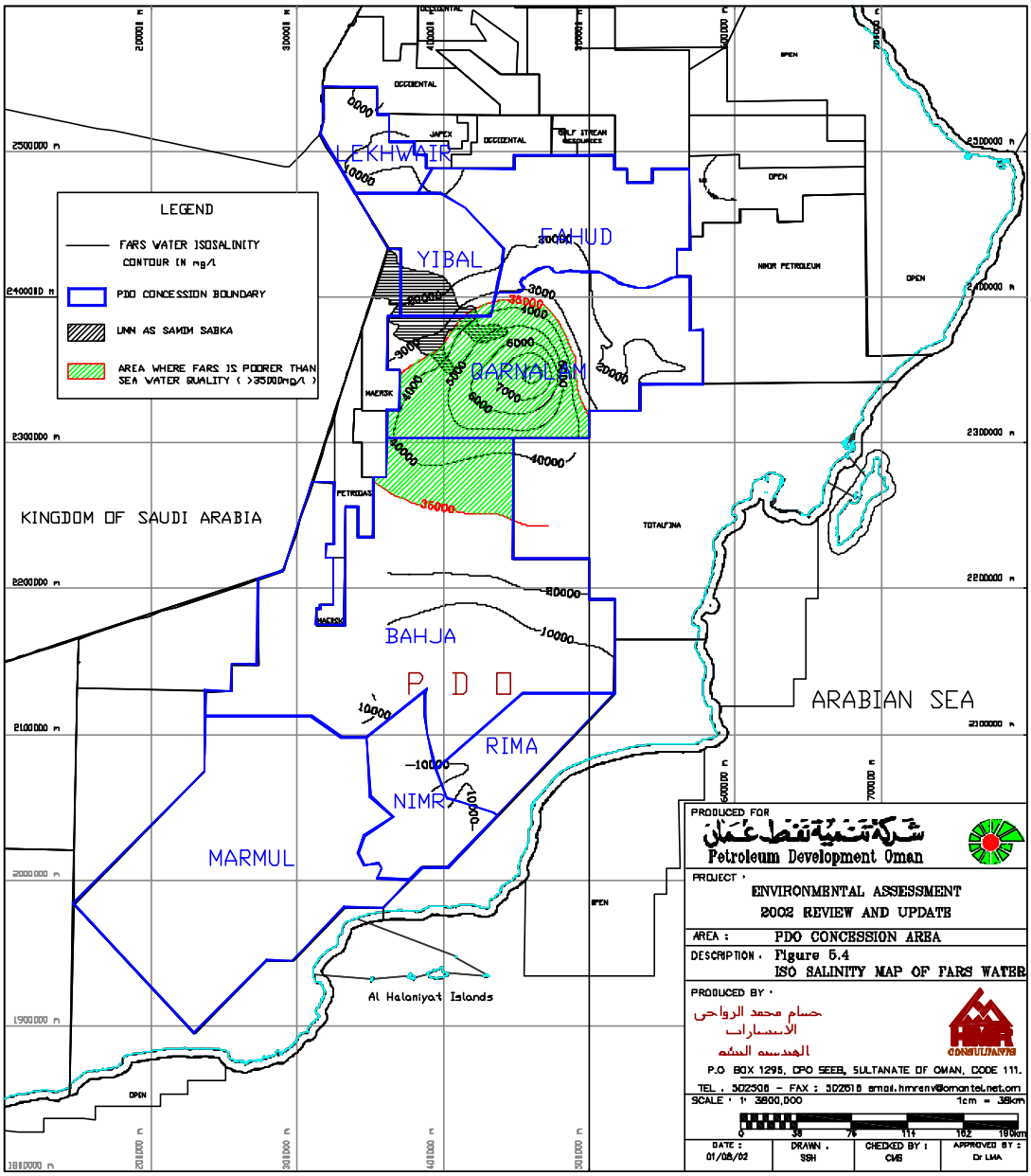

Figure 5.4: Isosalinity Map of Fars Water

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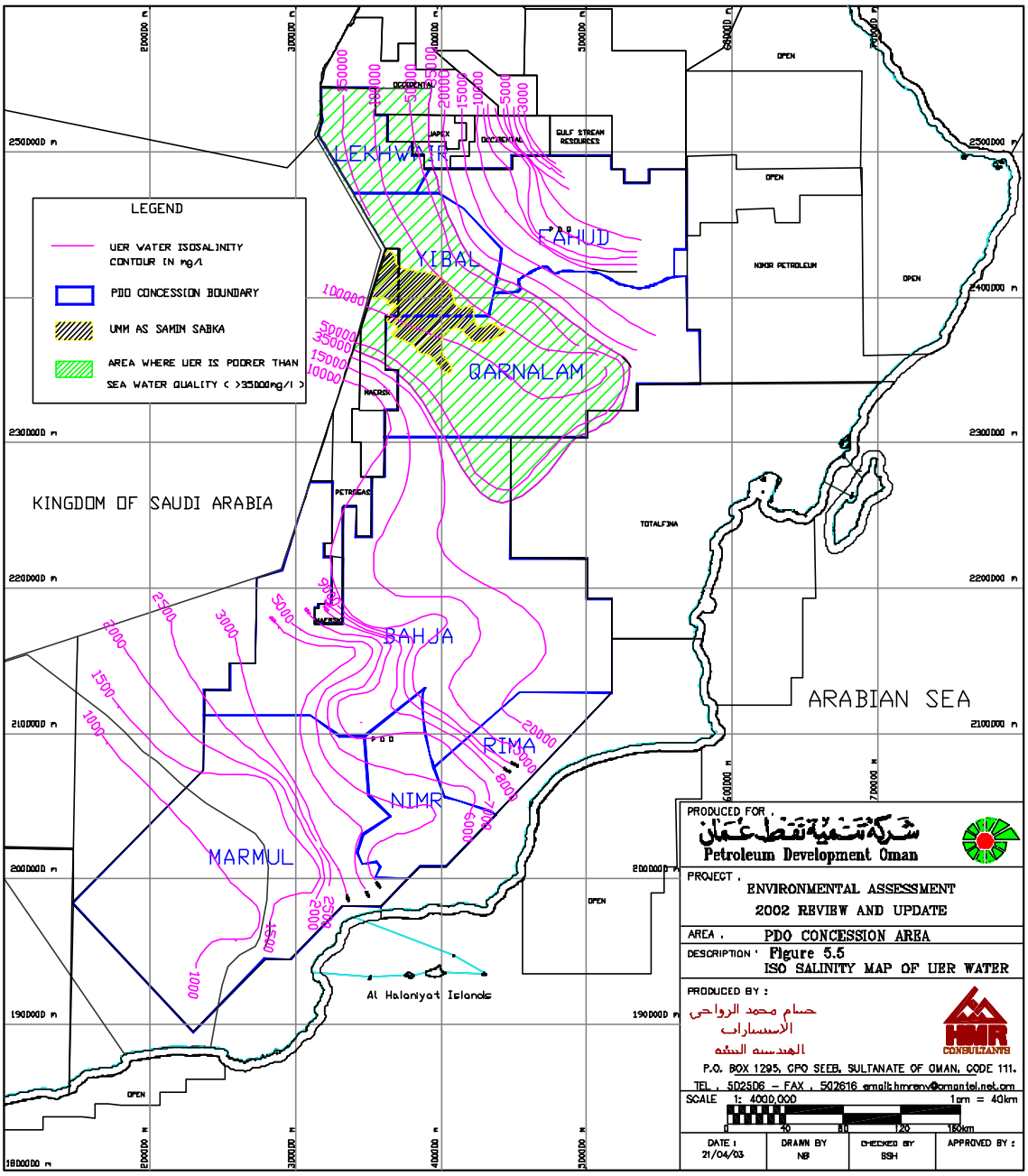

Figure 5.5: Isosalinity Map of Uer Water

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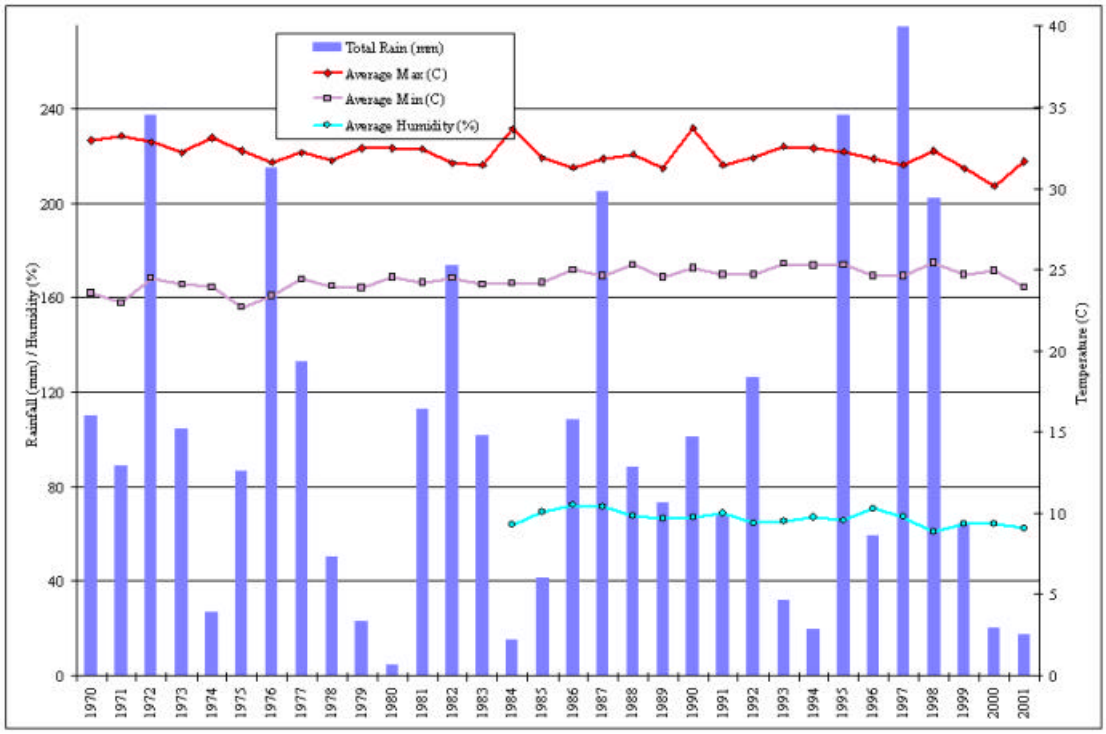
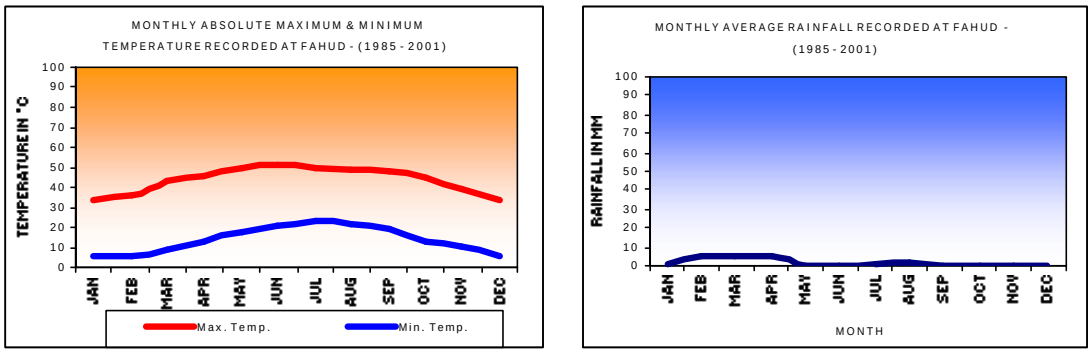


Climatic Variation in Oman
(Recorded at Muscat)



Monthly Variations
(*Recorded at Fahud)*

Figure 5.6: Climatic Charts for Lekhwair Asset

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There are no endemic or rare species in the asset area. The trees and palatable shrubs are browsed and all species show browse lines. Wildlife is uncommon in Lekhwair due to extremely arid with high temperatures, very little rain and sparse vegetation. Therefore wildlife is concentrated in the wadis. There are no large mammals present except for domestic livestock. The desert hare may be found but rodents and reptiles are the main wildlife in this hyper-arid area. A number of bird species are recorded.

5.9 Human Settlements

There are no towns or bedouin (nomadic or semi-nomadic) settlements within the Lekhwair asset area. Livestock, mainly camels graze and browse in Wadi Al Ayn (also called Wadi Badishan). No water troughs are provided for the camels. The details of the settlements located within Lekhwair asset area, population break-up and occupations are summarised in Table 5.3 below.

Table 5.3: Human Settlements in Lekhwair Asset

Village / Camp	Location and Total Land Area	Current Total Population	Total Number of Housing Units	Main Occupations
PDO camp	Main Camp	100	120 rooms	PDO staff
Contractor camp	Outside main camp	160	118	Contractor staff
Towns	None	None	None	None
Villages	None	None	None	None
Bedouin population	Not reported	None	None	None

5.10 Land Use

The land use in this region had undergone significant change due to PDO's exploration and production activities and facilities. Large areas of barren desert land are converted into industrial areas and significant extent of land area is not vegetated.

There is no subsistence farming or date orchards within the Lekhwair asset area. Wadi Al Ayn and Wadi Muwaythil in the southeastern corner of the asset, which have *Acacia* and *Prosopis* trees and relatively rich shrubby vegetation, are utilized by livestock for graze and browse. The details of land area developed by PDO for locating the production and associated facilities are summarised below in Table 5.4.

Table 5.4: Land Use in Lekhwair Asset

Facility	Total Area
Total asset area	3,560 km^2
Production station	160,490 m^2
Gathering stations	1,287 m^2
Power station	17,600 m^2

5.11 Social Infrastructure and Public Services

Like most of the areas in central Oman, Lekhwair asset is very thinly populated area and therefore has limited social infrastructure. The recent developments associated with the oil industry have assisted in providing access to the necessary civic services.

- **Water and Electricity**

Groundwater is the only water resources in the region. All of the potable water for the population in Lekhwair asset, including the PDO and contractor camps is supplied with demineralised water from PDO's RO plants.

Oil exploration and production camps are constructed to be self-sufficient with respect to electrical power. Currently, the entire power is generated from a 60 MW capacity power station located near Lekahwair production station.

- **Roads and Communications**

Lekhwair is connected to Fahud by a graded road. No major road passes through the Lekhwair asset. PDO maintains an extensive network of graded roads, which are open to local population. PDO also maintains an airstrip at Lekhwair, with regular flights. However, these flights are restricted to only PDO staff and its contractors. PDO maintains a network of telephone lines and radio transmitters in the concession area. The region is also covered by GSM telephone service.

- **Education**

There are no towns and villages located in the concession area of Lekhwair asset. Bedouin population are also not reported. Therefore there are no education facilities in the asset area.

- **Health Services**

There are no government health care facilities in Lekhwair asset. Private health-care facilities (clinic and ambulance services) are available within PDO's residential camps. These facilities are generally made available to any outsiders, if the need arises.

5.12 Archaeological Cultural and Recreational Resources

The literature search and a walk-through field survey have shown no evidence of archaeological sites in Lekhwair asset. The cultural resources are limited to a mosque located in PDO's main camp. There are also no recreational facilities, other than those located within PDO's main camp.

6 ENVIRONMENTAL IMPACTS

6.1 Methodology

In this chapter, the significant environmental hazards and effects present in the asset are identified and assessed based on the methodology outlined in PDO's document GU-195 "Environmental Assessment Guideline" (*Reference 2*). In PDO's terminology, the term "environmental hazard" is used for the sources (causes) of potential environmental effects, and term “effect” is used for the impact.

The environmental effects may include all those that are beneficial or adverse, short or long term (acute or chronic), temporary or permanent, direct or indirect, and local or strategic. The adverse effects may include all those leading to, harm to living resources, damage to human health, hindrance to other activities, impairment of quality for use, reduction of amenities, damage to cultural and heritage resources, and damage to physical structures.

For each identified potential environmental effect, the associated environmental risk is assessed based on its likelihood and significance. The likelihood (frequency) of occurrence of an effect, the significance of its consequence and the potential risk level are evaluated qualitatively as described below:

- Rating of likelihood (frequency) of occurrence of an effect:

  A (very low), B (low), C (medium), D (high), E (very high)

- Rating of significance of its consequence:

  slight, minor, localized, major and massive

- Rating of potential environmental risk level:

  l*ow, medium, high and extreme*

The criteria used for rating the environmental risk are discussed in detail in *Appendix 4.*

6.2 Potential Environmental Hazards and Effects

The potential environmental hazards and effects associated with the various activities performed in the asset are presented in *Appendix 5*. These are presented in the form of matrices. In the following sections, the impacts identified are qualitatively assessed according to the methodology presented in Section 6.1.

6.3 Beneficial Impacts

Several beneficial environmental impacts accrue from the asset activities. They include socio-economic, socio-cultural and ecological benefits. These beneficial impacts outweigh the adverse impacts, which are discussed in the subsequent sections. The beneficial impacts from the asset are on the economy, employment, local amenities and ecology. These impacts are discussed below. They are however not rated or ranked as per the methodology discussed in Section 6.1 since PDO's rating criteria apply for adverse impacts only. Therefore, only descriptive treatment is given for the magnitude and significance of the beneficial impacts.

- Economy

In Oman, the national economy is significantly dependent on crude oil production, with petroleum sector contributing about 40% to the gross domestic product. More significantly however, nearly 75% of the government revenue is from oil exports. Thus, there is ever-increasing need for more production of crude oil to sustain the current economic (gross domestic product) growth rate of 10.8%. The total crude oil production in Oman is presently about 330 million barrels annually, out of which about 90% exported. While PDO accounts for over 90% of the total crude oil produced in Oman, Lekhwair asset accounts for about 10.3% of the total PDO oil production. Thus the economic benefits from the asset are quite significant.

- Employment

The total number of permanent staff directly employed by PDO for Lekhwair asset is about 200. The number of permanent staff employed by PDO’s contractors in Lekhwair asset is about 300. In addition, a large number of persons, including local population are also provided indirect employment to provide a number of supporting services. Providing service to PDO is the only alternative employment for the communities in the region, whose main occupation is farming and animal husbandry. Therefore, the beneficial impact on employment is also significant.

- Ecology

While some adverse impacts on ecology may be expected from the asset activities, a few direct beneficial impacts on the ecology also exist. The most significant is the greening of the desert by re-using treated sewage effluents. The land within the PDO main camp and the contractor camps is significantly vegetated with trees, shrubs and

lawns. The significant vegetal cover developed in the asset has provided a habitat for the native fauna, most importantly birds and terrestrial invertebrates.

6.4 Impacts on Natural Resources

The potential environmental effects on the natural resources and the associated environmental hazards are listed below:

Environmental Hazards
- Consumption of mineral resources
- Consumption of groundwater
- Consumption of construction and road building materials
- Land take

Potential Environmental Effects
- Depletion of natural mineral resources
- Depletion of groundwater resources
- Claim of local assets

- **Depletion of Mineral Resources**

Large quantities of crude oil (14,601 m^3/d) and associated gas (1,550,000 Sm^3/d) continuously extracted will result in the depletion of petroleum reserves in the asset. However, the environmental impact and risk resulting from this activity is not discussed here since this forms the core activity of the asset.

Almost all the construction materials are imported and not sourced from any local natural resources. For road building, stone aggregates and soil are used. Soil is sourced locally from borrow pits. Considering that their requirement is very low compared to their availability, this is not expected to have any significant adverse impact.

Based on the above discussion, the overall impact on natural mineral resources is rated as below:

Impact Rating	**Depletion of Mineral Resources**
Nature of impact (beneficial / adverse)	Adverse
Duration of impact (short term / long term)	Long term
Likelihood of occurrence (very low / low / medium / high / very high)	Low
Significance of impact (slight / minor / localized / major / massive)	Slight
Potential risk level (low, medium, high and extreme)	Low

- **Depletion of Groundwater Resources**

About 14,000 m^3/d of groundwater on average is abstracted continuously from Fars formations (shallow aquifer). Over 95% of the groundwater abstracted in this asset is for injection into the producing reservoir to maintain the reservoir pressure. Less than

5% is used for process, construction and domestic use. The total volume of groundwater abstracted is significant and has the potential to cause adverse impact on the groundwater resources. The magnitude of the impact depends on the groundwater balance. Currently, sufficient information is not available on the groundwater recharge rate and on long term fluctuations in the water well yields and water levels. Nevertheless, based on the information available from the other assets, it may be considered that likelihood of adverse impact is low to medium.

Based on the above discussion, the overall impact on groundwater resources is rated as below:

Impact Rating	**Depletion of Ground Water Resources**
Nature of impact (beneficial / adverse)	Adverse
Duration of impact (short term / long term)	Long term
Likelihood of occurrence (very low / low / medium / high / very high)	Low to medium
Significance of impact (slight / minor / localized / major / massive)	Localized
Potential risk level (low, medium, high and extreme)	Medium

- **Claim on Local Assets**

There are virtually no local population within the asset at present and therefore there are no other claimants on local assets.

6.5 Impacts on Air Environment

The potential environmental effects on the air environment and the associated environmental hazards are listed below:

Environmental Hazards
- Release of dust from construction activities and road traffic
- Release of gaseous emissions from stationary sources
- Release of gaseous emissions from mobile sources
- Generation of noise from stationary sources
- Generation of noise from mobile sources

Potential Environmental Effects
- Global warming
- Air pollution
- Noise pollution

- **Global Warming**

CO_2 and methane emissions from the asset have a potential to contribute to global warming. Since there is virtually no venting in the asset, methane emissions are negligible. CO_2 emissions from stacks, flares and vehicles are of the order of 2,340 tpd. This total quantity of $C0_2$ emissions from the asset is not large enough to contribute significantly to global warming, when compared to the land area covered

by the asset. Based on the above discussion, the overall impact on global warming is rated as below:

Impact Rating	Global Warming
Nature of impact (beneficial / adverse)	Adverse
Duration of impact (short term / long term)	Short term
Likelihood of occurrence (very low / low / medium / high / very high)	Very low
Significance of impact (slight / minor / localized / major / massive)	Slight
Potential risk level (low, medium, high and extreme)	Low

- **Air Pollution**

Dust emissions from construction activities, road traffic, and gaseous emissions from stationary and mobile sources can have potential adverse impacts on ambient air quality.

Significant dust emissions may be expected due to the site being dry gravel plain with little vegetation. However, dust emissions are not continuous and highly localized. Further, only the respirable particulates (PM_{10}), which are expected to be 35-50% by mass in the dust have significant health hazard.

There are several stationary (point and non-point) and mobile sources of air emissions in the asset. However, point sources (stacks and vents) account for most of the emission loads in the asset. These emissions release pollutants such as NO_x, CO, SO_2 and unburnt hydrocarbons into air. The total emission loads of these pollutants from all sources in the asset are estimated to be 4, 4, 0.1 and 16 tpd respectively. These quantities are not considered significant of each pollutant is permitted for release into the airshed with no significant degradation of air quality. Further, most of the asset areas are uninhabited.

It is reasonable to assume that the impact on ambient air quality in the asset will be very low. However, in the absence sufficient data on ambient air quality and atmospheric dispersion modeling, the likelihood of degradation of ambient air quality in the asset shall have to be considered medium. Based on the above discussion, the overall impact on air pollution is rated as below:

Impact Rating	Air Pollution
Nature of impact (beneficial / adverse)	Adverse
Duration of impact (short term / long term)	Long term
Likelihood of occurrence (very low / low / medium / high / very high)	Medium
Significance of impact (slight / minor / localized / major / massive)	Minor
Potential risk level (low, medium, high and extreme)	Medium

- **Noise Pollution**

Both stationary and mobile noise generating sources can adversely affect the ambient noise levels. Since the noise from mobile sources is intermittent as well as transient,

most of the potential impacts are due to the continuous and stationary sources such as gas turbines, heaters, air compressors, flares, pumps, motors and other rotating equipment. While sufficient data on source noise levels are not available, it is reasonable to expect that their impacts will be highly localized and limited to less than 1 km distance. There are no human settlements in the asset areas except for PDO and contractors camps. It is however likely that some areas in these camps may be subjected to elevated noise levels. No data are currently available to check whether there is any breach of regulatory standards

Based on the above discussion, the impact on ambient noise is assessed as below:

Impact Rating	**Noise Pollution**
Nature of impact (beneficial / adverse)	Adverse
Duration of impact (short term / long term)	Long term
Likelihood of occurrence (very low / low / medium / high / very high)	Low
Significance of impact (slight / minor / localized / major / massive)	Minor
Potential risk level (low, medium, high and extreme)	Medium

6.6 Impacts on Water Environment

The potential environmental effects on the water environment and the associated environmental hazards are listed below:

Environmental Hazards
- Injection of produced water and RO plant rejects + backwash into aquifers
- Land discharge of treated sewage effluent
- Accidental spillage of hazardous liquids
- Release of leachates from landfill sites

Potential Environmental Effects
- Groundwater contamination

The injection of highly saline production water and RO plant rejects + backwash can result in groundwater contamination if injected into an exploitable aquifer. However, in the asset, the produced water re-injected into the producing oil reservoir and only RO rejects are injected into shallow aquifer. The quantity of RO rejects + backwash disposed into the shallow aquifer is about 370 m^3/d.

The land discharge of treated sewage effluents, accidental spillages of oils and chemicals and the release of leachates from the landfill sites can affect the groundwater quality provided they can percolate into the groundwater table. Since groundwater table is 30-160 m below the ground level and arid weather conditions prevail in the asset, there is no possibility for such occurrence.

Based on the above discussion, the impact on the groundwater contamination is assessed as below:

Impact Rating	Groundwater Contamination
Nature of impact (beneficial / adverse)	Adverse
Duration of impact (short term / long term)	Long term
Likelihood of occurrence (very low / low / medium / high / very high)	High
Significance of impact (slight / minor / localized / major / massive)	Localized
Potential risk level (low, medium, high and extreme)	High

6.7 Impacts on Land Environment

The potential environmental effects on the land environment and the associated environmental hazards are listed below:

Environmental Hazards
- Land take
- Land discharge of treated sewage effluent
- Accidental spillage of hazardous liquids
- Landfilling of solid wastes

Potential Environmental Effects
- Alteration of land use
- Loss of vegetation
- Land contamination

- **Alteration of Land Use**

Land take for the installation of project facilities; construction of accommodation camps; drilling of oil wells; laying of pipelines, power lines and access roads; and constructing storage and disposal sites for construction materials and waste materials can have adverse impacts on land use. The land taken for these purposes is barren and has no utility. The extent of permanent land take is marginal compared to the total available land in the asset. Majority of the land take is temporary, for the purpose of drilling of oil wells and laying of pipelines, power lines and access roads. This land is restored nearly to its natural condition after completion of the construction activities.

Based on the above discussion, the impact on land use is rated as below:

Impact Rating	Alteration of Land Use
Nature of impact (beneficial / adverse)	Adverse
Duration of impact (short term / long term)	Short term (mostly)
Likelihood of occurrence (very low / low / medium / high / very high)	Low
Significance of impact (slight / minor / localized / major / massive)	Minor
Potential risk level (low, medium, high and extreme)	Low

- **Loss of Vegetation**

Loss of vegetation is directly related to land take, and therefore the impacts are similar. In addition, the land irrigation of treated sewage effluents compensates any

loss of vegetation elsewhere. The increase is vegetal cover in PDO and contractor camps is significant.

Based on the above discussion, the impact on vegetation is rated as below:

Impact Rating	Loss of Vegetation
Nature of impact (beneficial / adverse)	Adverse
Duration of impact (short term / long term)	Short term (mostly)
Likelihood of occurrence (very low / low / medium / high / very high)	Low
Significance of impact (slight / minor / localized / major / massive)	Minor
Potential risk level (low, medium, high and extreme)	Low

- **Land Contamination**

The discharge of treated sewage effluents on land, accidental spillage of hazardous liquids and landfilling of solid wastes can potentially contaminate the soil. The quality of treated sewage in the asset has been consistently within the regulatory standards except for rare breaches. The landfill sites have been judiciously chosen and scientifically designed to minimize any land contamination. There is no hazardous waste landfill is the asset. Hence, they are not expected to contribute significantly to soil contamination.

The accident spillage of crude oil, mainly due to pipeline and flowline leaks leads to soil contamination. About 10 incidents of oil spills were reported in the year 2001. The total volume of the oil spill was reported as about 9 m^3 and the total land area contaminated were reported as 129 m^2. Thus it is concluded that the extent of soil contamination is negligible compared to the total land area of the asset. It is however likely that the oil leak and spill incidents are under-reported or under-estimated.

A matter of concern in the asset is the absence of an oil saver pit in LPS and the non-availability of a vacuum truck to transfer waste oil collected in drums to the waste management centre. Even the oil saver pit in the waste management centre is undersized, which has often leads waste oil to overflow. Because of these two concerns, the frequency of occurrence is rated as very high.

Oil sludge and tank bottoms are presently treated in the land farming facility. It is likely that these wastes may contain some naturally occurring radioactive materials and therefore the land farm may show low-level radioactivity. In the absence of comprehensive radioactivity monitoring, the potential risk is assumed to exist.

Based on the above discussion, the impact on land contamination is assessed as below:

Impact Rating	Land Contamination
Nature of impact (beneficial / adverse)	Adverse
Duration of impact (short term / long term)	Long term
Likelihood of occurrence (very low / low / medium / high / very high)	High
Significance of impact (slight / minor / localized / major / massive)	Localised
Potential risk level (low, medium, high and extreme)	High

6.8 Impact on Ecology and Wildlife

The potential environmental effects on the ecology and wildlife and the associated environmental hazards are listed below:

Environmental Hazards
- Land take
- Road transport of hazardous substances
- Road travel

Potential Environmental Effects
- Loss of endangered flora
- Loss of endangered fauna
- Threat to wildlife habitats

There are no endangered flora and wildlife habitats in the asset. The population of fauna are very limited. The road traffic for transportation of materials and people is not high but significant. Few road accidents with casualties of common fauna (mostly camels) were ever reported.

Overall, the impact on ecology is considered negligible.

6.9 Impact on Social Environment

Under social environment, employment, agriculture, animal husbandry, native lifestyle, cultural heritage, public health and safety, landscape and aesthetics are considered. Most of the impacts on social environment are beneficial, which are discussed in Section 6.2. There are also a few adverse impacts on the social environment.

There are no human settlements in the asset area except for PDO and contractor camps. Therefore, the significance and magnitude of adverse impacts on social environment are very limited. The only direct adverse impact on social environment that may need to be considered is the public safety and health of the transient population across the asset.

The hazards associated with potential impact on public safety and health are listed below:

Environmental Hazards
- Bulk storage of hazardous substances
- Road transport of hazardous substances
- Accidental release of toxic gases and vapours
- Deployment of large number of migrant workers

Potential Environmental Effects
- Public safety and health

Storage and transportation of hazardous substances, such as combustible liquids, combustible gases and chemicals have the potential to cause damage to public health and safety in the event of significant release into the environment following structural failure and loss of containment. This may lead to fire, explosion, reactivity or toxicity hazard. Bulk storage facilities are located within the production areas and therefore general public are not exposed to any consequences from storage facilities.

However, general public are exposed to road accidents involving hazardous substances. Fortunately, the major substances, crude oil and gas are transported by pipelines and not by road. With respect to accidental leaks of toxic gases and vapours, there are no such substances handled in bulk in the asset.

The deployment of a large number of migrant workers can pose a threat to public health, if they carry communicable diseases or if they are carriers of parasitic diseases. Large scale deployment of migrant workers is not expected in the asset, since no major developmental activity is envisaged. Further, there are no major habitations near the project site.

As noted earlier, some of the waste transported to the disposal or treatment facilities may be hazardous, particularly NORM wastes. However, there radioactivity level is not significant to pose any public health risk.

Based on the above discussion, the impacts on public health and safety are assessed as below:

Impact Rating	**Public Health and Safety**
Nature of impact (beneficial / adverse)	Adverse
Duration of impact (short term / long term)	Short term
Likelihood of occurrence (very low / low / medium / high / very high)	Low
Significance of impact (slight / minor / localized / major / massive)	Minor
Potential risk level (low, medium, high and extreme)	Low

7 SUMMARY OF SIGNIFICANT ENVIRONMENTAL EFFECTS AND MITIGATION MEASURES

The identification and assessment of environmental hazards and effects in the asset are discussed in Chapter 6. All adverse environmental effects with medium to extreme risk are considered as significant environmental effects. In this chapter, the additional mitigation measures required for minimizing the environmental consequences from these effects are developed. It may be noted that PDO has a comprehensive environmental management plan as a part of the HSE management system (refer Chapter 2), which is implemented in the asset. No change in the existing environmental management system is required. However, certain additional mitigation measures will reduce the potential environmental risk and improve the overall environmental performance.

The significant environmental effects are listed below along with explanatory notes.

Environmental Effect	Impact Rating	Potential Risk Level	Comments
Land contamination	• Adverse • Long term • High occurrence • Localised significance	• High risk	• The heightened risk level is due to the absence of oil saver pit in the Production Station, the non-availability of vacuum trucks to remove oil and insufficient capacity of oil saver pit at waste management centre. • Further, frequent overflowing of the oil saver pit at Lekhwair B occurs due to insufficient capacity. • NORM survey not completed to ensure that the tank bottoms and sludges are free of NORM. • Some potential risk may also exist due to suspected occasional exceedence of land discharge standards for treated sewage effluents.
Groundwater contamination	• Adverse • Long term • High occurrence • Localized significance	• High risk	• For the RO plant rejects + backwash, to shallow aquifer is still in practice.
Groundwater depletion	• Adverse • Long term • Low occurrence • Localized significance	• Medium risk	• Large quantities of groundwater is abstracted not only for process + domestic use but also for injection into the producing reservoir. • In the absence of comprehensive long term data on groundwater balance and water well monitoring in the asset, the potential risk on the depletion of groundwater shall be considered to exist.

Environmental Effect	Impact Rating	Potential Risk Level	Comments
Air pollution	• Adverse • Long term • Medium occurrence • Minor significance	• Medium risk	• The currently available information on air quality and air emissions is insufficient to conclude that there is no breach of ambient air quality standards, particularly in the accommodation camps. Hence, the potential risk shall be considered to exist.
Noise pollution	• Adverse • Long term • Low occurrence • Minor significance	• Medium risk	• The currently available information is insufficient to conclude that there is no breach of ambient noise standards, particularly in the accommodation camps. Hence, the potential risk shall be considered to exist

The recommended additional mitigation measures for reducing the environmental risk levels and improving the environmental performance are listed below against each of the environmental specifications of PDO, *viz.*, SP-1005 to SP-1012.

Specification	Areas of Non-compliance or Concern	Recommended Additional Mitigation Measures
SP-1005: Specification for Emissions to Atmosphere	• Stationary sources of air emissions are not monitored to check compliance with emission standards. • Ambient air is not monitored to check compliance with air quality standards.	• All continuous air emission sources such as gas turbine and heater stacks shall be monitored for compliance. • Ambient air quality shall be monitored in accommodation camps periodically.
SP-1006: Specification for Aqueous Effluents	• Current STP monitoring frequency and schedule are inadequate. Once a day or once a week monitoring cannot detect if standards are breached during peak load times. • Technical proficiency of STP operators and supervisors is below par.	• STP monitoring frequency and schedule need to be revised to ensure compliance at all times. Monitoring frequency may be increased to 4 times per day for on-site measurements and composite samples may be taken for laboratory analysis. • All STP operators and supervisors shall be provided continuing education and training on STP operation and monitoring.
SP-1007: Specification for Accidental Releases to Land and Water	• Oil saver pit at Lekhwair B overflows. • Quantities of contaminated soil transported to landfarm are not reported.	• Oil saver pit shall be provided at Lekhwair Production Station. • Vacuum tanker for oil removal shall be available at Lekhwair. • Oil saver pit capacity and the transfer pump capacity at Lekhwair B shall be increased to contain one tanker capacity. • Records to be maintained for the contaminated sand transported to Fahud.

Specification	Areas of Non-compliance or Concern	Recommended Additional Mitigation Measures
SP-1008: Specification for Use of Energy, Materials and Resources	• Optimal use of energy and water is not demonstrated as required in the specification.	• Avenues for minimization of water consumption shall be explored. • Monitoring of water wells shall be continued to ensure that there is no depletion of groundwater reserves over a longer term.
SP-1009: Specification for Waste Management	• Waste consignments are not properly estimated. • Waste compaction equipment is inadequate. • Waste recycling is not significant.	• Compliance with waste handling procedures shall be enforced. • Waste operators shall be closely supervised. • Waste recycling avenues shall be explored at corporate level.
SP-1010: Specification for Environmental Noise and Vibration	• Ambient noise levels are not monitored to check compliance with the standards.	• Ambient noise levels shall be monitored in accommodation camps periodically
SP-1011: Specification for Flora and Fauna	• None	• None
SP-1012: Specification for Land Management	• There are several abandoned well sites, which require restoration.	• Site restoration program shall be accelerated.
SP-1170: Specification for Management of Naturally Occurring Radioactive	• NORM survey in the stations is not completed.	• Comprehensive NORM survey to be completed and necessary mitigation measures to be taken, if required.

8 REFERENCES

1. WS/Atkins, *Fahud/Lekhwair assets area Environmental Assessment Report*, PDO, July 1999

2. PDO, *HEALTH, SAFETY AND ENVIRONMENT GUIDELINE - Environmental Assessment* GU 195, July 2002

3. SIEP, EP 95-0377 *Quantifying Atmospheric Emissions*, September 1995

4. HMR, *Environmental Audit Report of Sewage Treatment Plants in PDO*, April 2003

5. HMR, *Environmental Audit Report of Waste Management Centres in PDO*, April 2003

APPENDIX 1: DETAILS OF PERSONNEL RESPONSIBLE FOR PREPARATION AND REVIEW OF THE REPORT

HMR Environmental Engineering Consultants, Oman are responsible for the preparation of this report on environmental assessment for Lekhwair asset of PDO's concession area. HMR is the leading environmental engineering consultancy in Oman. HMR specializes in the fields of environmental management, water resources management, environmental assessment, environmental auditing, environmental monitoring, pollution control and environmental training.

HMR has a large pool of environmental engineers and scientists, who have work experience throughout the world and the Arabian Gulf. HMR also has technical collaborations and associations with a number of international engineering consulting companies. HMR is registered with the World Bank as well as with the Ministry of Regional Municipalities and Environment, Sultanate of Oman.

The following HMR Staff are responsible for the technical component of this report.

Name of EIA Team Member	**Position in HMR**	**Position in EIA Team**	**Role in Project Execution**
Dr. Laks M. Akella	Senior Consultant	Team Leader and Project Manager	Project management, data analysis and editorial review
C. S. Shaji	Consultant	EIA Expert	Data collection, site audit and report preparation
Robert Spence	Senior Consultant	EIA Expert	Data collection and site audit
C. M. Sushanth	Consultant	EIA Expert	Data collection and site audit
Babu Krishanan	Consultant	EIA Expert	Data collection and site audit
Krishnasamy	Consultant	EIA Expert	Data collection and site audit
Vinod Gopinath	Environmental Technician	EIA Expert	Data collection and site audit
Shubha Srinivas	IT Consultant	Cartographer	Cartography
Randa Mounir	Consultant	Team Member	Editing

On behalf of the client, Petroleum Development Oman, the following individuals are responsible for the review of the EIA report at all stages of the study.

Position in PDO	Name of Reviewer	Role in Project Development
CSM/22	Dr. Muralee R. Thumarukudy	Senior Corporate Environmental Advisor
CSM/25	Ahmed Al Sabahi	Environmental Advisor
ONS	Devendra Upadhyay	HSE Team Leader – North
		Area Coordinator – Lekhwair

APPENDIX 2: FUEL GAS ANALYSIS

Parameter	Lekhwair Production Station	Lekhwair B Station	Lekhwair Power Station
Methane, in % v/v	67.98	46.55	83.25
Ethane, in % v/v	12.72	11.28	6.31
Propane, in % v/v	10.27	14.79	3.80
i-Butane, in % v/v	2.32	5.58	1.14
n-Butane, in % v/v	3.26	9.24	2.09
i-Pentane, in % v/v	1.05	3.42	0.82
n-Pentane, in % v/v	0.72	2.65	0.94
Hexane + , in % v/v	0.30	2.47	0.00
Nitrogen, in % v/v	0.68	1.14	0.33
Carbon Dioxide in % v/v	0.70	2.89	100
Hydrogen Sulphide in ppm	0	800	83.25

APPENDIX 3: DETAILS OF STACKS

Source Description	Number of identical stacks	Stack Height (above ground level)	Stack Internal Diameter (at exit)	Stack Gas Temp (at exit)	Fuel Gas Mass Flow Rate	CO2 Mass Emission Rate	SO2 Mass Emission Rate	NOx Mass Emission Rate	CO Mass Emission Rate	HC Mass Emission Rate
		(m)	(m)	(C)	(kg/h)	(kg/h)	(kg/h)	(kg/h)	(kg/h)	(kg/h)
Lekhwair Production Station: Heater Stacks	3	26	1	171	230	660.0	0.0	0.8	0.0	0.0
Lekhwair Power Station: Gas Turbine	2	15	4.3	480	12,809	46,639.0	0.0	108.3	43.8	6.7
Total					13,039	47,299	-	109	44	7

APPENDIX 4: PDO'S ENVIRONMENTAL RISK EVALUATION CRITERIA

Rating of Consequence of Effect on Environment	**Rating of Frequency of Occurrence**				
	A. Very low: Not heard of but could occur	**B. Low:** Has occurred in other industry	**C. Medium** Has occurred in oil and gas industry	**D. High:** Occurs several times a year in oil and gas industry	**E. Very high:** Occurs several times a year in PDO
Slight effect: Local environmental damage. Within the fence and within systems. Negligible financial consequences	**LOW RISK**				
Minor effect: Contamination. Damage sufficiently large to attack the environment. Single exceedence of statutory or prescribed criterion. Single complaint. No permanent effect on the environment.		**MEDIUM RISK**			
Localized effect: Limited loss of discharges of known toxicity. Repeated exceedence of statutory or prescribed limit. Affecting neighborhood.					
Major effect: Severe environmental damage. The company is required to take extensive measures to restore the contaminated environment to its original state. Extended exceedence of statutory limits		**HIGH RISK**			
Massive effect: Persistent severe environmental damage or severe nuisance or nature conservancy extending over a large area. In terms of commercial or recreational use, a major economic loss for the company. Constant, high exceedence of statutory or prescribed limits				**EXTREME RISK**	

APPENDIX 5: ENVIRONMENTAL HAZARDS AND EFFECTS IDENTIFICATION MATRIX: LEKHWAIR ASSET

Environmental Hazards	**Environmental Sensitivities**																				
	Natural Resources			**Air Environment**			**Water Environment**			**Land Environment**			**Ecology and Wildlife**			**Social Environment**					
	Mineral Resources	Groundwater Resources	Claim on Local Assets	Climate (Global Warming)	Ambient Air Quality	Ambient Noise	Surface Hydrology & Water Quality	Hydrogeology & Ground Water Quality	Marine Water Quality	Land Use	Loss of Vegetation	Soil Quality	Flora	Fauna	Wildlife Habitats	Employment	Agriculture & Animal Husbandry	Native Lifestyle	Cultural Heritage	Public Health & Safety	Landscape & Aesthetics
Land take																					
For installation of project facilities										**X**	X										
For construction of accommodation facilities										**X**	X										
For drilling of oil wells										**X**	X		**X**	X	X						
For laying oil/gas pipelines			X							**X**	X		**X**	X	X						
For laying power lines			X							**X**	X		**X**	X	X						
For laying access roads			X							**X**	X		**X**	X	X						
For land irrigation of treated wastewater										**X**	X										
For storage of construction materials										**X**	X		**X**	X	X						
For storage and disposal of waste materials			**X**							**X**	X		**X**	X	X						

Environmental Hazards	Environmental Sensitivities																				
	Natural Resources			**Air Environment**			**Water Environment**			**Land Environment**			**Ecology and Wildlife**			**Social Environment**					
	Mineral Resources	Groundwater Resources	Claim on Local Assets	Climate (Global Warming)	Ambient Air Quality	Ambient Noise	Surface Hydrology & Water Quality	Hydrogeology & Ground Water Quality	Marine Water Quality	Land Use	Loss of Vegetation	Soil Quality	Flora	Fauna	Wildlife Habitats	Employment	Agriculture & Animal Husbandry	Native Lifestyle	Cultural Heritage	Public Health & Safety	Landscape & Aesthetics
Utilization of Mineral Resources																					
For production of oil and gas	**X**																				
For construction materials	**X**																				
For road building materials	**X**		**X**																		
Utilization of Groundwater Resources																					
For construction water		**X**						**X**													
For process water		**X**						**X**													
For potable water		**X**	**X**					**X**													
Utilization of Human Resources																					
Employment of migrant construction workers																				**X**	
Employment of permanent workers																					

Environmental Hazards	Environmental Sensitivities																				
	Natural Resources			**Air Environment**			**Water Environment**			**Land Environment**			**Ecology and Wildlife**			**Social Environment**					
	Mineral Resources	Groundwater Resources	Claim on Local Assets	Climate (Global Warming)	Ambient Air Quality	Ambient Noise	Surface Hydrology & Water Quality	Hydrogeology & Ground Water Quality	Marine Water Quality	Land Use	Loss of Vegetation	Soil Quality	Flora	Fauna	Wildlife Habitats	Employment	Agriculture & Animal Husbandry	Native Lifestyle	Cultural Heritage	Public Health & Safety	Landscape & Aesthetics
Release of Air Pollutants																					
Dust from construction activities and road traffic					**X**																
Gaseous emissions from stationary sources				**X**	**X**																
Gaseous emissions from mobile sources				**X**	**X**																
Accidental release of toxic gases and vapours																				**X**	
Release of Energy into Atmosphere																					
Hot gases from flares and stacks																					
High level noise from stationary sources						**X**															
High level noise from mobile sources						**X**															

Environmental Sensitivities	**Social Environment**	Landscape & Aesthetics									
		Public Health & Safety									
		Cultural Heritage									
		Native Lifestyle									
		Agriculture & Animal Husbandry									
		Employment									
	Ecology and Wildlife	Wildlife Habitats									
		Fauna									
		Flora									
	Land Environment	Soil Quality			X	X				X	X
		Loss of Vegetation									
		Land Use									
	Water Environment	Marine Water Quality									
		Hydrogeology & Ground Water Quality		X	X	X					
		Surface Hydrology & Water Quality									
	Air Environment	Ambient Noise									
		Ambient Air Quality									
		Climate (Global Warming)									
	Natural Resources	Claim on Local Assets									
		Groundwater Resources									
		Mineral Resources									
Environmental Hazards			**Discharges of Liquid Effluents**	Injection of production water and process effluents into aquifers	Land discharge of treated sewage effluent	Accidental spillage of hazardous liquids	Release of leachates from landfill sites	**Disposal of Solid Wastes**	Handling and transport of hazardous wastes	Landfilling of domestic and non-hazardous industrial wastes	Landfilling of hazardous wastes

Environmental Hazards	Environmental Sensitivities																				
	Natural Resources			**Air Environment**			**Water Environment**			**Land Environment**			**Ecology and Wildlife**			**Social Environment**					
	Mineral Resources	Groundwater Resources	Claim on Local Assets	Climate (Global Warming)	Ambient Air Quality	Ambient Noise	Surface Hydrology & Water Quality	Hydrogeology & Ground Water Quality	Marine Water Quality	Land Use	Loss of Vegetation	Soil Quality	Flora	Fauna	Wildlife Habitats	Employment	Agriculture & Animal Husbandry	Native Lifestyle	Cultural Heritage	Public Health & Safety	Landscape & Aesthetics
Functional Activities																					
Pipeline transport of oil and gas																					
Road transport of hazardous substances														**X**						**X**	
Bulk storage of hazardous substances																				**X**	
Road travel														**X**							
Air travel																					

Note: Filled-in cells indicate potential interaction and blank cells indicate no or negligible interaction.