ENVIRONMENTAL ASSESSMENT OF WELL ENGINEERING ASSET - 2002 REVIEW AND UPDATE

PETROLEUM DEVELOPMENT OMAN

SULTANATE OF OMAN

Authorized for release by:

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Date: 12 July 2003

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July 2003

EXECUTIVE SUMMARY

Introduction

This report updates the environmental assessment of Well Engineering asset, which is one of the eight service assets within PDO's concession area in the Sultanate of Oman. The first environmental assessment for Well Engineering asset was carried out in September 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 gas producing wells. Currently, PDO produces 843,490 barrels/day of crude and 44 million Sm^3 of gas on average per day.

Well Engineering asset is one of the service providers in PDO. The areas of operation of the asset cover the entire interior concession area in south and central Oman.

The Well Engineering asset is primarily responsible for the design, construction, in-well maintenance and abandonment of production and exploration wells throughout PDO's concession area. The wells include oil, gas and water wells. Annually, well engineering asset drills about 350 new wells and carries out about 600 well service interventions. The other technical activities of well engineering asset include the development and implementation of new drilling technologies and maintaining well data from drilling and pumping operations throughout the concession area.

The other activities of the asset include providing inputs to field development plans, and managing the drilling sequence planning and agreement process to the production assets well engineering.

Well engineering asset, works under the overall direction of the Exploration Director. At the asset level, it is managed by the Well Engineering Manager. The asset consists of operational departments *viz.*, exploration (TWX), development (TWD), well services (TWS) and support services (TWE), each of which is managed by a departmental head.

Description of Environment

The topographical features of the PDO's concession area show two distinct zones as below:

- Desert plains with very low populations within most of the concession area
- Low to medium altitude hills over the southernmost and northernmost parts

The natural vegetation is composed of desert plants and grasses, and is restricted to the wadi plains only. Among all the assets, Nimr and Marmul assets have relatively denser vegetation.

Most of the concession area falls under central and south-central Oman and is characterised by flat gravel desert plains with occasional rocky outcrops interspersed with a few wadi channels. The altitude in the plains is mostly in the range of 100-150m above the mean sea level. The desert plains are very thinly populated. Hills of low to medium altitude are encountered over the southernmost and northernmost parts of the concession area.

The geology of most of the PDO's concession area comprises of mainly limestone with shale, dolomite and sandstone. The central plains mostly consist of flat limestones of oligocene and miocene ages to mid-tertiary. UeR aquifer is the main prolific aquifer in the area.

The mineral content in UeR water increases as it travels from south to north. Within the entire PDO concession area, only Marmul asset has groundwater that is potable without any pre-treatment. In all other assets the UeR water is very saline.

The mean monthly temperatures range from around 20^{o}C in December/ January to about 35^{o}C in July. The maximum absolute temperature will be as high as 50^{o}C and the minimum absolute temperature will be as low as 5^{o}C.

Rainfall in this region is scanty and is highly variable in time and space with an average of 36 mm per annum. Although the annual average rainfall is very low, flash floods are known to have occurred in the area. Wind speeds vary considerably from calm to strong gusts. The dominant wind direction is from the south with an average wind speed of 8 knots.

The natural flora in most of the concession area is composed of desert plants and grasses, and trees are rarely seen. Several fauna groups including mammals, birds and reptiles are seen. Large mammalian species known to inhabit the area include the Arabian Gazelle (*Gazelle gazelle*), the Rhim Gazelle (*Gazella subgutturosa marica*), the Nubian Ibex (*Capra nubiana*). These animals are currently listed on the IUCN World Red List and the Regional Red List threat categories. The Arabian Oryx is seen in Mukhaizna field in Bahja asset.

The human population density within PDO's concession area (interior areas) is extremely low and is to the order of 26 persons per 100 km^2. The majority are the PDO and contractor staff living in the various accommodation camps located in the assets, and they number about 20,000 currently.

There are no forts, ruins or other archeological declared sites in PDO's concession area. However, abundant marine fossils are present in Jabal Fahud and Natih areas (Fahud asset).

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	▪ The air emissions from DGs are estimated to exceed the permissible concentration limits prescribed in SP-1005 for stationary combustion sources. ▪ The drilling staff will be continuously exposed to DG emissions. ▪ The DG stack emissions may not disperse well in the atmospheric due to short stack heights. ▪ No monitoring data are available demonstrating compliance with either emission standards or air quality standards in rig sites or rig campsites.	▪ SP-1005 may require an amendment since standard designs of DGs are unlikely to meet these emissions standards. ▪ Ambient air quality shall be monitored in rig camps and rig sites to check for compliance. ▪ If ambient air standards are not met, stack heights may need to be raised, DGs shall be retrofitted with air pollution control devices, or better fuels shall be used.
SP-1006: Specification for Aqueous Effluents	▪ The overflow from septic tanks into soak pit contains high concentration of organic matter and may carry pathogenic organism.	▪ Soak pits shall be avoided to the extent possible. ▪ Soak pits shall be placed far away from public places.
SP-1007: Specification for Accidental Releases to Land and Water	▪ Loss of drilling fluid (containing chemicals) into the borehole during drilling occurs. ▪ Soil contamination with oils and chemicals occurs from unlined waste pits.	▪ Loss of drilling fluids shall be minimised during drilling. ▪ Waste pits shall be lined with impervious synthetic liner wherever needed.
SP-1008: Specification for Use of Energy, Materials and Resources	▪ Efficient use of water is not demonstrated. The total quantity of groundwater consumed in drilling quite significant and is about 20% of total groundwater abstraction in PDO. ▪ Efficient use of fuel for the diesel generators is not demonstrated	▪ Flow meter for all water supply wells to be provided and abstraction of water to be reported. ▪ Opportunities for water and fuel conservation shall be explored.
SP-1009: Specification for Waste Management	▪ Not all contaminated soils are removed from the waste pits.	▪ Waste pit soils shall always be analysed for contamination before backfilling.
SP-1010: Specification for Environmental Noise and Vibration	▪ Rig units and DGs used for power generation generate high level noise. ▪ Even though the noise generation in a given site is of short duration, the drilling staff will be continuously exposed. ▪ No monitoring data are available demonstrating compliance with work place or air noise standards in rig sites or rig campsites.	▪ Work place and ambient noise levels shall be monitored to check for compliance with the standards. ▪ If warranted, noise attenuation measures shall be taken.
SP-1011: Specification for Flora and Fauna	▪ None	▪ None
SP-1012: Specification for Land Management	▪ Well abandonment and site restoration is not completed as required in SP-1012 in several places. ▪ Contaminated soils are not remediated in several drilling sites.	▪ SP-1012 shall be implemented at all drilling sites.

Specification	Areas of Non-compliance or Concern	Recommended Additional Mitigation Measures
SP-1170: Specification for Management of Naturally Occurring Radioactive Material	▪ None	▪ None

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)
BOP	Blowout preventer
bpd	barrels per day
Bq	Bequerel, unit for measurement of radioactivity (One nuclear disintegration/second)
^oC	degree centigrade
^oK	degree Kelvin
$CaCO_3$	calcium carbonate
CFC	chloro-fluoro-carbon
d	day
DG	Diesel generator
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)
LCM	Lost circulation materials
LP	low pressure (0.5 – 150 kPa gauge pressure)
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^oC)
NO	nitric dioxide
NO_2	nitrogen dioxide
NO_x	oxides of nitrogen

NORM	naturally occurring radioactive materials
OBM	Oil-based drilling mud
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^oC)
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
WBM	Water-based drilling mud
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 administrative assets 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 (including Rima) and Marmul. The crude oil export facilities and the administrative head quarters are located on the coast in Mina Al Fahal.

Currently PDO operates from about a hundred fields and has 2,454 oil producing wells and 72 gas producing wells. The total production of crude oil currently is about 843,490 barrels per day, and that of associated gas is 44 million Sm^3 per day. 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).

Table 1.1: Description of Production Assets in PDO

Production Asset	Land Area (km^2)	Crude 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**

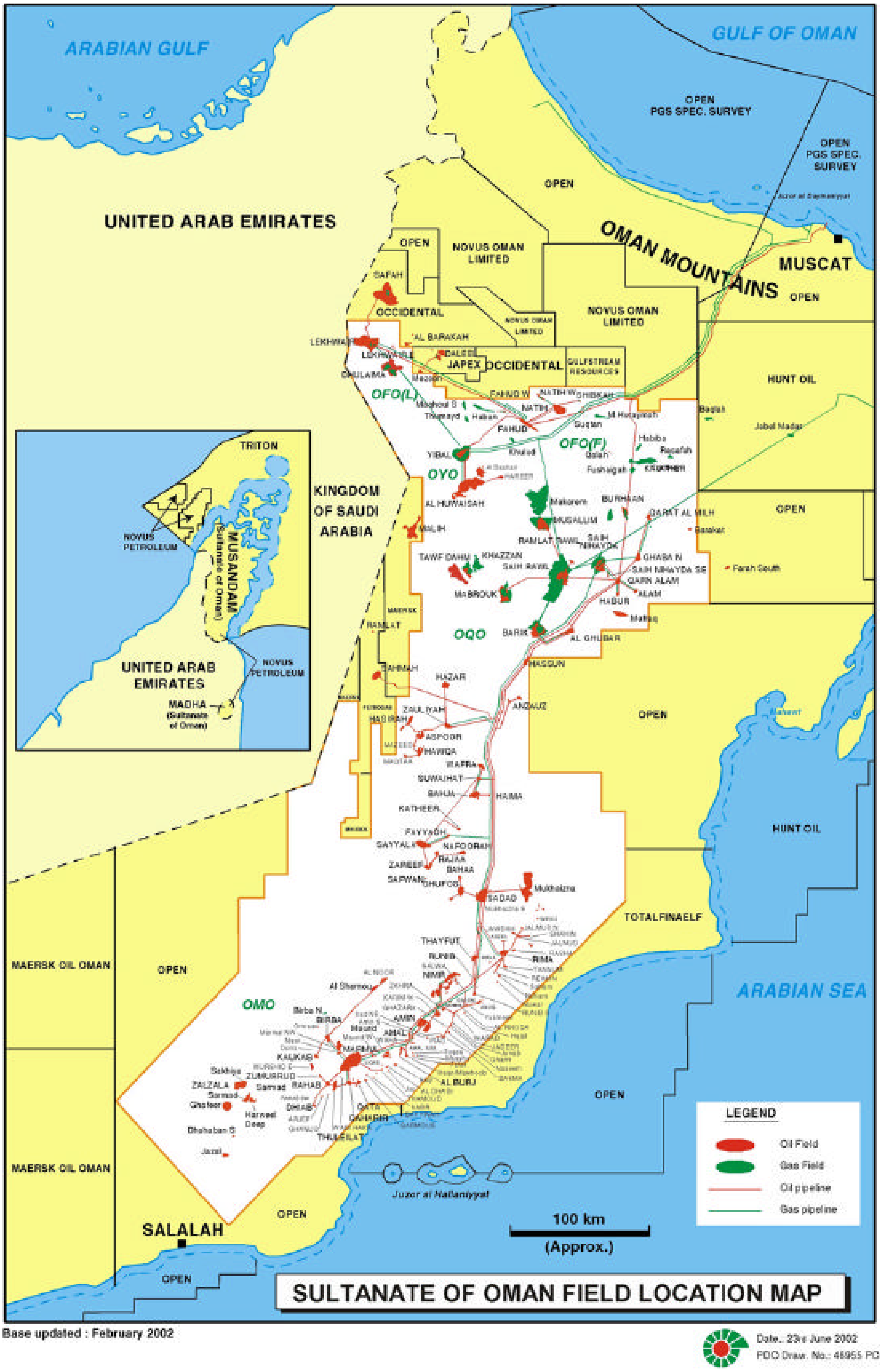


Figure 1.1: Geographical Map of PDO's Concession Area

In addition to the seven production assets, there are eight service assets in PDO, which provide technical, analytical, engineering, supply and transportation support to the production assets. A brief description of the services assets is presented below in Table 1.2.

Table 1.2: Description of Service Assets in PDO

Service Asset	Main Activities and Areas of Operation
GeoSolutions Asset	- Provide geo-services to frontier exploration and production assets for the identification and development of hydrocarbon reserves within PDO's concession area - The areas of technical service include seismic data acquisition & processing; geological support & laboratory services; geomatics support; sub-surface information management & technology support; services; and reservoir characterisation.
Well Engineering Asset	- Prepare and update preliminary and detailed designs for new oil wells throughout PDO's concession area - Prepare new oil well construction and completion programmes throughout PDO's concession area - Construct new oil wells and modifying any existing wells as required throughout PDO's concession area - Close out non-producing wells and restore abandoned well sites throughout PDO's concession area
Infrastructure Asset	TERMINAL OPERATIONS DEPARTMENT - Operate and maintain the Mina Al Fahal Tank Farm consisting of 10 crude oil storage tanks with a total storage capacity of 5 million barrels - Operate and maintain the offshore oil export facilities in Mina Al Fahal consisting of three single point moorings and two coastal buoy moorings - Operate and maintain the oil export metering systems and offshore oil pollution combating equipment in Mina Al Fahal POWER SYSTEMS DEPARTMENT - Operate and maintain ten power stations consisting of 22 gas turbines throughout PDO's concession area - Operate and maintain twenty-two 132 kV substations throughout PDO's concession area - Operate and maintain 1276 km long 132 kV overhead electrical transmission lines throughout PDO's concession area PIPELINE DEPARTMENT - Operate and maintain 1510 km long main oil line for transportation of liquid hydrocarbons from all production assets to the export terminal in Mina Al Fahal - Operate and maintain 670 km long south Oman gas line for transportation of dry sweet gas hydrocarbons from Saih Nihayda (Qarn Alam Asset) to Marmul asset - Operate and maintain the main oil line booster stations in Hubara (Nimr Asset), Sahma (Bahja Asset) and Nahada (Fahud Asset)
Gas Asset	- Operate and maintain, on behalf of the government, gas treatment facilities (government gas plant, government butane plant and butane storage and loading facility) in Yibal - Operate and maintain, on behalf of the government, liquefied natural gas upstream facilities in Saih Rawl, Barik and Saih Nihayda - Operate and maintain, on behalf of the government, natural gas pipeline system from Yibal to Murayat (296 km long), from Murayat to Al Ghubra (29 km long) and from Murayat to Sohar (225 km long) as well as spur lines - Operate and maintain, on behalf of the government, pressure reducing terminals for natural gas customers throughout Oman

Logistics Asset	Provide dedicated logistics support to all other assets in PDO through sub-contracting for the following services: - Cargo handling and haulage including rig moves - Passenger commuting by land and air - Fleet management - Warehousing including central chemical storage
Estate Services Asset	- Provide and maintain accommodation facilities for PDO staff in Mina Al Fahal - Maintain air-conditioning and refrigeration system within PDO area in Mina Al Fahal - Provide catering and laundry services for PDO staff in Mina Al Fahal - Supply potable water and maintain electrical power distribution systems within PDO area in Mina Al Fahal - Manage sewage treatment plants, treated sewage re-use and solid waste disposal for waste generated within PDO area in Mina Al Fahal - Manage the incinerator located in mina Al Fahal for thermal destruction of clinical wastes generated throughout PDO's concession area
Production Chemistry Asset	- Provide drilling chemistry support including analysis of drilling fluids and cements, technical specifications for drilling fluids and cements, evaluation of new drilling fluid and cement products and technologies for all assets in PDO - Provide process and treatment support including expert advice on all chemical and physical processes related to production, treatment and transportation of gas and oil for all assets in PDO - Provide laboratory support for physico-chemical analysis of well fluids, crude oil, gas, produced water, groundwater, treated water, sewage, raw materials and process chemicals for all assets in PDO

The current organisation structure in PDO is shown in Figure 1.2.

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. The previous environmental assessment study for Well Engineering asset was completed in November 1999 (*Reference 1*). It is an internal requirement in PDO to review and update of the EIA once in every three years, in order to periodically reassess 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 Well Engineering asset.

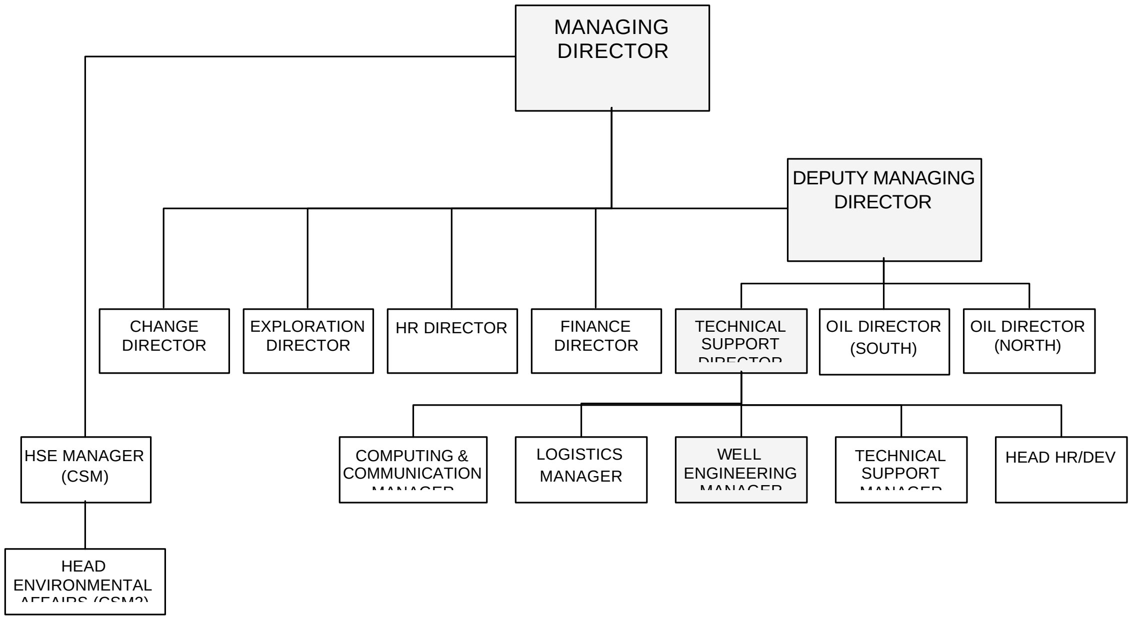


Figure 1.2: Organisation Structure in PDO

1.3 Objectives and Scope of Study

The objectives of the present 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 November 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 reassessing the environmental impacts, in view of the above.
- Revising the environmental mitigation and monitoring plan, wherever required.

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

1.4 Method of Study

The present study was carried out in three stages. In the first stage, the previous EIA reports (*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, 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 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 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 activities performed by Well Engineering 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 by Well Engineering 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 of the areas within which the Well Engineering asset operates.

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
Regulations for the handling of toxic substances	MD 248/97

Title	Reference Number
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-1005on 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 ^{o}C 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	400	-
	4 hour	-	95
	24 hour	150	-
	1 year	-	30
Sulphur dioxide	10 minutes	500	-
	1 hour	350	-
	24 hours	125	125
	1 year	50	30
Hydrogen sulphide	30 minutes	-	7
	24 hours	150	-
Carbon monoxide	1 hour	40000	-
	8 hour	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.

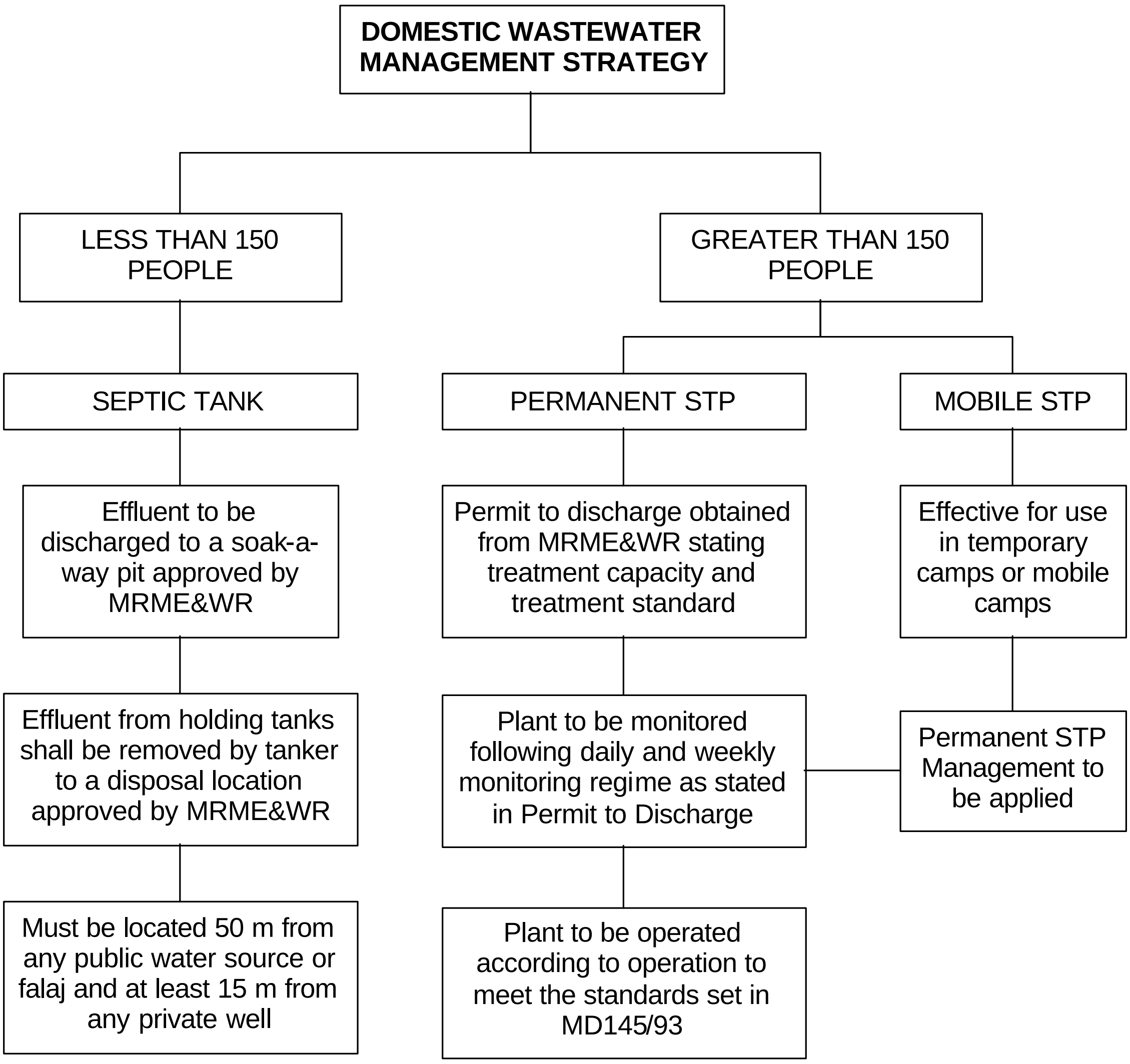
(e) Dispose surplus waters to formations, which have salinity greater than 35,000 mg/L, in conjunction with case-specific monitoring programs.

- **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 Introduction

Well engineering asset is one of the eight technical service providers in PDO, whose areas of operation cover the entire concession area in south and central Oman. Well engineering asset is primarily responsible for the design, construction, in-well maintenance and abandonment of production and exploration wells throughout PDO's concession area. The wells include oil, gas and water wells. Annually, well engineering asset drills about 350 new wells and carries out about 600 well service interventions. The other technical activities of well engineering asset include the development and implementation of new drilling technologies and maintaining well data from drilling and pumping operations throughout the concession area.

The other activities of the asset include providing inputs to field development plans, and managing the drilling sequence planning and agreement process to the production assets well engineering.

Well engineering asset, works under the overall direction of the technical Support Director. At the asset level, it is managed by the Well Engineering Manager. The asset consists of operational departments *viz.*, exploration (TWX), development (TWD), well services (TWS) and support services (TWE), each of which is managed by a departmental head. The asset management structure of the asset including the health, safety and environment (HSE) management structure is shown in Figure 3.1.

3.2 Description of Facilities

Most of the field activities of the well engineering asset are carried out through contracting. Thus, all the equipment used by the well engineering asset for drilling and well maintenance are owned and operated by the contractors approved PDO. The major equipment presently used by the asset for its field activities include following:

- Thirty-two rigs for drilling new wells
- Five well test units for analysing the well fluids
- Fifteen hoists for in-well maintenance service
- One frac unit for assistance in drilling through difficult sub-surface structure

These units are not stationed permanently at a particular site. Instead they are deployed throughout the concession area based on the field development plans and programmes of each production asset.

In terms of the extent of the activities and environmental effects, rigs are the major equipment used in well engineering activities. To operate a rig, several on-site facilities need to be established at the rig site. The main on-site facilities include the following:

- Drilling material and chemical storage units
- Drilling fluid preparation and pumping units
- Power generation units
- Nitrogen generation units
- Fuel storage tanks
- Water storage tanks
- Drilling waste and wastewater storage pits
- Accommodation facilities

The electrical power required to support the drilling and associated activities is supplied by diesel generators (DGs) located on-site. Typically, the total power requirement at a rig site is about – MW. Compressed nitrogen gas is used in under-balanced drilling to counter balance the excess reservoir pressure. Nitrogen is generated at site by using nitrogen generation units, which consists of air compressors, nitrogen generators and nitrogen compressors.

Except for well cementing, fresh water is not required in drilling. Either production water from a nearby production station or untreated groundwater from a nearby water well is supplied to the site in tankers or pipeline and stored.

For the field personnel involved in drilling operations, on-site or near-site accommodation facilities are provided throughout the period of drilling process, which typically lasts 10 days to 4 weeks. Typically, 60-100 personnel (working in two shifts) are involved in each rig site operations. Out of these up to ten personnel live on-site in portacabins. The remaining personnel are accommodated in the rig camp, which is located typically within 5 km from the drilling site. The rig camp consists of 10-15 portacabins with a canteen, laundry and limited recreation facilities. Power for the camp is supplied by the DGs operating on-site. Water is supplied in tankers from the nearby PDO main camp and stored in storage tanks. For sewage treatment, typically septic tanks with soak pits are provided. Where possible, sewage is diverted to the nearby sewage treatment plant.

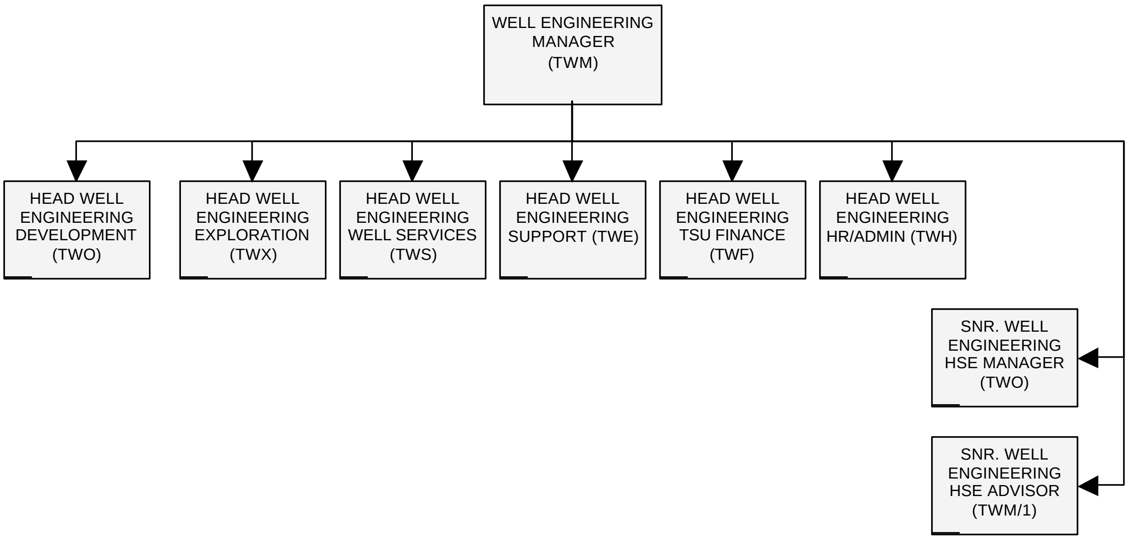


Figure 3.1: Management Structure for Well Engineering Asset

3.3 Activity Description

3.3.1 Overview

For oil and gas production, there are two types of drilling: exploration and development. Exploratory drilling is the drilling of new wells at potential sites to determine the potential for hydrocarbon reserves. Development drilling is the drilling of new wells at sites of proven hydrocarbon reserves to continuously extract the reservoir fluids. In some cases, an exploratory well may be converted into a producing well. Basically, there is no difference in the drilling process for exploration or development. The drilling activity consists of a series of sub-activities starting from rig site preparation to well completion.

The major sub-activities of drilling and well completion are listed below:

- Well site preparation
- Rig mobilisation
- Drilling
- Well completion
- Well testing
- Well site restoration

Once the rig moves out of the site, the well site will be ready for connecting the pump and flow lines to the well. Once the pump is energised, the well starts producing.

Apart from drilling and well completion, the other field activities of the well engineering asset are well intervention and well closure. Well intervention refers to in-well maintenance service for under-performing wells. Well closure refers to the activities associated with closing the non-producing wells at the end of their life cycle and restoring the well site for alternate use. These activities are discussed briefly in the following sections.

3.3.2 Well Site Preparation

The sites for drilling new wells are identified by the exploration asset based on seismic surveys. Environmental aspects are also considered along with the technical aspects while determining the exact well site. An area of about 1 ha is required for well site operations. The area required for the temporary rig camp is also about 1 ha. Rig camp is located typically within 5 km of the well site, based on logistic and environmental considerations. The preparation of well pad and rig campsite is carried out by the concerned asset and handed over to well engineering asset for drilling.

The well site consists of a well pad, a water pit and a waste pit. The well pad size is typically 127 m by 81 m or 102 m by 76 m. The rig and all the auxiliary equipment used in drilling are located on the well pad. The water pit is a compacted earthen pit of 30 m by 50 m with 1.2 m depth and the waste pit is also another compacted earthen pit of 30 m by 40 m with 1.2 m depth. Expect in environmentally sensitive areas (such as areas where shallow groundwater is encountered), the water and waste pits are not lined with any impermeable liners such as plastic films.

The following sequence of activities is associated with well site preparation:

- Survey of the well site for any pipelines, buried services and environmental aspects including ecological and archaeological sensitivity
- Removal of vegetation (if any) and grading
- Watering and compacting
- Elevation of well pad by 1m using soil excavated from borrow pits
- Excavation of water and waste pits
- Laying of access paths to the well pad

The site preparation of rig camp involves all the above activities except site elevation and the construction of water and waste pits. The well site and rig campsite preparation lasts for about 15-20 days.

3.3.3 Rig Mobilisation

Rig mobilisation includes the deployment of the rig and all the auxiliaries to the site by road. Rig mobilisation typically takes about 5 days. Considering that the equipment involved are quite wide and heavy, logistics become important. As a part of rig mobilisation, on-site storage facilities for materials, chemicals, fuels and water are also established. The accommodation facilities including catering, laundry and sewage treatment facilities are also established. Chemicals, diesel/crude, tubings, tools and tackles are stored on the well pad. Drilling rig and a few portacabins for on-site accommodation of the key staff are also located on the well pad. A septic tank with soak pit is provided for disposal of sewage. Waste skips for storage of waste material are provided inside the fence. Parking area for the vehicles is located outside the fence.

DGs are provided to supply power for the drilling rig and for other facilities on-site. The DGs are designed to operate on diesel and other light oils. Presently, all the rig DGs use centrifuged crude oil. Centrifuged crude is supplied from Fahud for the rigs in the northern fields and from Sayyala for the rigs in southern fields. The supplied crude is once again centrifuged at site to remove wax, water and bottom sediments.

Except for well cementing, either produced water or untreated well water is transported to the rig site by tankers. However, if the water supply source is within 12 km of the rig site, water is transported by a pipeline.

3.3.4 Drilling

- **Overview**

The actual drilling process starts with the erection of derrick, a steel structure that supports the drilling pipe. A drill bit attached to the end of a drill pipe, referred to as the "drill string," is rotated to make a hole in the ground and conductor casing is inserted. This process of inserting the pipe into the initial part of the well is referred as "spudding". Once the well is spudded and the conductor casing is in place, the drill string is lowered through the inside of the casing to the bottom of the hole. The bit rotates and is slowly lowered as the hole is formed. As the hole deepens, the walls of the hole tend to cave in and widen, so periodically the drill string is lifted out of the hole and the casing is placed into the newly formed portion of the hole to protect the wellbore. This process of drilling and adding sections of casing is continued until final well depth is reached. Typically, the vertical well depth will be in the order of 1100 m below the ground level. The actual well length will however be much longer depending on the well configuration. For a horizontal well, the total well length may be in the order of 1800 m.

During the process of drilling, drilling fluid (also called drilling mud) is circulated in the borehole for the following reasons:

- To balance the reservoir pressure such that the reservoir fluids are not released from the borehole during drilling
- To remove the drilling cutting (rock cuttings) out of the borehole
- To cool the drill bit during drilling

While the top hole is being drilled, water is used as the drilling fluid since total fluid loss is encounter in this section. For subsequent hole sections, drilling mud is used. Drilling mud is pumped into the borehole through the drill string and recirculated to the surface through the annular space between the drill string and the casing. On the surface, the drill cuttings, silt, sand and any gases are separated from the drilling mud before recirculation, using shale shaker, desilter, and desander, and sometimes centrifuge. Separated drill cuttings and solids are discharged into the waste pit.

During the drilling process, the annular space between the casing and the borehole is filled, section by section, with cementing materials. Cementing of the borehole supports the casing and the bore wall, prevents fluid migration between permeable zones and offers corrosion protection to the casing.

After the bore is drilled to the required depth, the well is acid washed if necessary to remove the deposits of calcium carbonate, which is a constituent of the drilling mud. Hydrochloric acid and hydrofluoric acid are used for acid washing. Acid is premixed to the specified dilution and transported to the rig site by dedicated tankers for pumping. No mixing or dilution is done at rig site. Spent acid is disposed off into the waste pit after neutralizing with soda ash or calcium carbonate.

The end stage of drilling is work-over. Work-over refers to clearing the borehole off drilling mud. For this, brine is injected into the borehole and the well.

- **Drilling Techniques**

In conventional drilling, the pressure exerted by the drilling mud in the borehole balances the reservoir pressure. This technique costs less. However, it lowers the well yield due to the build up of drilling solids in the formation being drilled due to high fluid pressure. Under-balanced drilling is a relatively new drilling technique in which the drilling fluid pressure is maintained lower than the reservoir pressure. Under-balanced drilling maximizes the hydrocarbon recovery from the well and also minimizes the drilling problems. Excess pressure reservoir in under-balanced drilling is counter-balanced by injection of pressurized nitrogen. Compressed nitrogen gas is generated at site by using nitrogen generation units, which consists of air compressors, nitrogen generators and nitrogen compressors.

Currently, both conventional and under-balanced drilling techniques are used in PDO. As time goes, it is expected that under-balanced drilling will almost totally replace conventional drilling in PDO.

- **Drilling Muds**

Drilling mud is a liquid mixture of special clays, inorganic salts and chemicals, which is continuously re-circulated in the borehole being drilled. The purpose of the re-circulation is to balance the reservoir pressure, to remove the drill cutting from the borehole and to cool the drill bit. Drilling muds are either water based or oil based.

Predominantly, water-based drilling muds (WBM) are used in PDO. However, for certain drilling situations such as drilling in reactive shales and high angle directional drilling, oil-based drilling muds (OBM) are used. OBMs use light crude oil, diesel oil or mineral oil as the base fluid.

Bentonite and dextrid are the main ingredients of water based drilling muds. Bentonite particles, together with water, will give yield to the mud and prevent water loss, while dextrid is a second important water loss reducer. Inorganic salts such as sodium chloride are used to adjust the density of the drilling mud. Polymers such as CMC-HV and XV are used to increase the viscosity of the drilling mud and ligno-sulphonates are used for thinning the mud.

Since the formation pressure varies at different depths, the density of the drilling fluid must be constantly monitored and adjusted to the borehole conditions during each phase of drilling. Other properties of the drilling fluid, such as lubricity, gel strength, and viscosity, must also be controlled to satisfy changing drilling conditions. During drilling, some amount of water is lost and "watering back" is done to keep constant water content in the mud.

Loss of drilling mud into the formations during drilling, referred to as "lost circulation" is a common problem. In PDO, such losses are encountered especially in the tertiary formations (Fars, Damman, UeR etc.) Lost circulation occurs due to highly porous and permeable nature of the formations, breakdown of the formations by the high pressure exerted by the drilling fluids and the fracturing of formation during formation strength test. Lost circulation is classified as seepage losses, partial losses, severe losses and complete losses based on the loss rate. Sealing materials, known lost circulation materials (LCM) are added to the mud to prevent lost circulation. The commonly used LCMs include fibrous materials (such as wood, cellulose fibers, mineral wool, glass fiber and straw), laminar or flake materials (such as mica, cellophane and shredded paper) and granular materials (such as ground nut shells, seed grains, ground limestone, asphalt and diatomaceous earth).

After continuous use, sometimes the mud may get contaminated and need treatment. Soda ash or caustic soda is used to treat the mud. The fluid must be replaced if the drilling fluid cannot be adjusted to meet the borehole drilling conditions. This is referred to as a "changeover."

- **Cementing Materials**

During the progress of drilling, the annular space between the casing and the borehole is cemented section by section. Cementing while providing support to the casing minimizes the fluid migration and provide corrosion resistance to the casing. Cement is mixed with water and additives batch-wise and pumped down the borehole. Water used for cementing is tested for chloride, calcium and magnesium prior to mixing. The additives used include de-foamers, salts, LCMs, dispersants, retarders and surfactants.

- **Completion Fluids**

Completion fluids are used at the end stage of drilling, to replace the drilling mud in the borehole. Completion fluids shall cause minimum formation impairment by solids. Brines are used as completion fluids. Brines are prepared with sodium chloride or calcium chloride. Zinc bromide and calcium bromide is used where higher weight is required in the brine solution. Additives such as starch and HEC and XC polymer are used to improve the viscosity of the brine. Brine is filtered to remove any solid particles, which may damage the formation. Potassium chloride is added to avoid the swelling of the reservoir clay. Brine mixing, filtration and storage facilities provided at the rig site.

- **Well Data Gathering**

During drilling, core samples are taken to determine the petro-physical parameters in hydrocarbon and water bearing formations. Different sizes of core barrels are used for drilling cores, depending on the hole diameter. Cores are sent to PDO’s exploration laboratory in MAF for analysis.

Well logging is another aspect of well data gathering. Mud logging is done during drilling to determine the lithology that gives an indication of hydrocarbon presence. Open hole logging and cased hole logging consist of the measurement of the electrical, nuclear and acoustical properties of the formations. Wireline logging is performed with a sonde or a probe lowered into the borehole or well, usually after the drill string has been withdrawn. Different types of sonde are available for measuring different parameters. Electrical sonde is used for measuring resistivity of the formation.

Nuclear logs record radioactivity that may be either naturally emitted or induced by particle bombardment. A radioactive source is pressed onto the borehole wall by a pad. Radioactive sources are stored in shielded storage compartments that are fitted to wireline logging trucks. When sources are removed from the logging truck and temporarily stored on the wellsite, a 4m by 4 m area is cordoned off around the source and clearly visible radiation warning signs are posted. If the radioactive material lost in the hole, then the well is abandoned and separate program is initiated to prevent further radiation outside the hole. PDO’s specification, SP-1218 for Drilling

Specification – Radioactive Materials, gives the activities to be done in case of radioactive material lost in the well hole.

3.3.5 Well Completion

As described earlier, after the completion of drilling, the borehole is acid washed if needed to remove any carbonate deposits. Then the borehole is cleared of drilling mud and filled with well completion fluid, basically brine solution. The next stage in well completion is fixing the blowout preventer. Blowout is a condition when the reservoir fluids are ejected uncontrollably from the well due to subsurface reservoir pressure. To prevent well blowout, a blowout preventer (BOP) is attached at the top of the well. The final stage of well completion is fixing the necessary well head connectors (known as Christmas tree), which will allow the well pump and flow lines to be connected to the well.

After the Christmas tree is fixed, the pump and flow lines are connected and the pump is energized. With this, the well is ready for production.

3.3.6 Well Testing

Prior to commercial production, on-site well testing is carried out to determine the reservoir fluids flow characteristics and the physical and chemical characteristics. Well testing is carried out typically in 2-4 days. The gas released during well testing is flared off using ground flares. The crude oil is collected in a tank and transferred to a production station, if possible. If not, open burn pits are provided at the rig site to burn off the oil.

3.3.7 Well Site Restoration

After the drilling is completed, the rig along with the auxiliary facilities including the rig camp is moved from the well site to the new site. The drilling staff is responsible for site restoration. Site restoration requires that all the waste materials generated during drilling are transported and disposed of in accordance with PDO specification SP-1009 (Waste Management) and the site is cleared in accordance with the PDO specification SP-1012 (Land Management).

Site restoration requirements include the following:

- Restored land shall be visually similar to the surrounding landscape.
- All waste materials shall be removed.

- Hydrocarbon shall be removed from site if concentrations are greater than 1%.
- Areas having less than 1% hydrocarbon contamination shall be covered with 0.6m of clean sand within 6 months of abandonment.
- 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.

3.3.8 Well Abandonment

In the case of non-performing wells, the well abandonment requires the following actions:

- All the production and auxiliary equipment are dismantled.
- All surface structures including the pipelines, storage tanks, above ground steelwork and concrete are entirely removed from the site.
- The foundations are excavated to the level of the surrounding land, and back-filled with clean desert sand.
- In the case of any other underground structures such as well casings that cannot be removed, necessary precautions and measures are taken to ensure that these will not cause any environmental consequences in future.

Then the well site is restored according to SP-1012 requirements. Post-closure monitoring is carried out, where necessary before transferring the land to the government or the next owner, to demonstrate the fitness of the land for the intended future use.

3.4 Materials and Utilities

The majority of the materials used in the well engineering asset are consumed during the drilling activity. The list and quantities of major drilling materials and chemicals consumed in the asset during the year 2002 are shown below in Table 3.1.

Table 3.1: Major Drilling Materials and Chemicals Consumed by Well Engineering Asset

Item	Purpose	Typical Quantity Consumed per Well Site
Clays	For water loss reduction in WBM	10 t
Crude oil	For preparation of OBM	
Salts (Chlorides of sodium, calcium and potassium and bromides of calcium and zinc)	For density adjustment of drilling muds and completion fluids	20 t
CMC-HV and XV polymers	For viscosity increase of drilling muds and completion fluid	<1 t
Lignosulfonates	For thinning of drilling muds	<1 t
Soda ash / caustic soda	For acid neutralisation	1 t
Hydrochloric or hydrofluoric acid	For acid washing of borehole	
LCMs (fibrous / laminar / granular materials)	For reducing loss of circulating fluids during drilling	5 t
Cements	For well cementing	1 t
De-foamers / dispersants / retarders / surfactants	Cement additives	50 kg

The list and quantities of fuels, power and water consumed in the asset are shown in Table 3.2.

Table 3.2: Fuels, Power and Water Consumed by Well Engineering Asset

Item	Purpose	Typical Quantity Consumed per Well Site
Fuels		
Crude oil	For DGs on rig sites and rig camp sites	53,668 m^3
Diesel oil	For DGs, engines and vehicles on site sites and rig camp sites	10,425 m^3
Power		
In rig site	For drilling equipment and on-site accommodation facilities	4,000 kW
In camp site	For accommodation facilities	1,000 kW
Water		
Produced water / raw well water in rig site	Mud preparation	10,000 m^3
Potable water in rig site	For domestic use	1,000 m^3
Potable water in rig camp site	For domestic use	300 m^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 by the well engineering asset are discussed. The contributions from those activities that are directly handled by the production assets on behalf of well engineering asset are not included here, since they are included in their EIA reports. However, the contributions from all those activities that are performed by contractors under direct contract with the well engineering asset are included here.

The field activities performed by the well engineering asset may be classified under the following headings:

- Well site preparation
- Rig mobilisation
- Drilling
- Well completion
- Well testing
- Well site restoration
- Well intervention
- Well abandonment

In addition, the following support activities may also generate some waste streams:

- Provision of accommodation facilities on and near rig site
- Transportation of materials and chemicals to rig site
- Extraction and transportation of water to rig site

It may be noted that these operations at a site are of short duration ranging from 10 days to 4 weeks. Therefore, the waste generation from these activities is also of short duration.

The wastes released into the environment from all the activities discussed above may 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 released from the activities of well engineering asset are of short duration (typically 10 days to 4 weeks) at a given site. For the purpose of this report, the air emissions released from the asset activities are classified into the following categories:

- Stack emissions
- Flare and burn pit emissions
- Vent and fugitive emissions
- Mobile source emissions

The discussion on the emission sources, quantities, characteristics and emission controls is presented in the following sections.

4.2.2 Stack Emissions

Stack emissions are the most dominant air emissions for well engineering asset by virtue of their number and the quantity of emissions. The sources of stack emissions are the DGs, which are used in the rig site and rig campsite for the power generation. These generators are operated continuously throughout the drilling period at given well site.

The fuel burned in the DGs is mostly the centrifuged crude oil, though diesel fuel is also used sometimes. Crude oil is centrifuged at the rig site to remove the bottom sediments, wax and water before it is fired. The detailed analysis of the centrifuged crude is not available. It is assumed that the sulphur content in the diesel and clean crude is in the order of 0.5% by mass. 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), unburnt hydrocarbons (HC) and particulate matter (PM). The particulate matter is mostly of <10µm size (PM_{10}) and includes the unburnt HC, which is released as finer particles under 2.5µm size ($PM_{2.5}$). Further, the DG emissions also contain significant quantity of carbon dioxide (CO_2), which is a greenhouse gas.

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 are not currently available. The stack emissions are not monitored. Instead, the emission rates are estimated based on Tier 3 emission factors given in the Shell group specification EP 95-0377 on "Quantifying Atmospheric Emissions" (*Reference 3)*. The emission factors for DGs are as given below:

CO_2	: 3200 kg per tonne of fuel burned
CO	: 19 kg per tonne of fuel burned
NO_x as NO_2	: 70 kg per tonne of fuel burned
SO_2	: 20 x S kg per tonne of fuel burned, where S = %wt of sulphur in fuel (default value S = 0.5%)
HC	: 2.04 kg per tonne of fuel burned

Emission factor for PM is not given in EP-0377. It is however known that the ash (mineral matter) present in the fuel along with the unburnt HC particles make up for the total particulate matter in the stack emissions. Therefore, the emission factor for PM is (2.04 + 10 x M) kg per tonne of fuel burned, where M is the ash content in the fuel. It is expected that the value of M will be in the order of 1-2% by mass. A default value of 2% is assumed here.

The average emission loads from DGs are calculated based on the above emission factors. It is noted that the number of DGs and the number of days the DGs are used in a rig site or a rig campsite will vary from site to site. Therefore, based on the annual fuel consumption data (for year 2002) for the well engineering asset as a whole, the average daily emissions for a rig site or a campsite are estimated as shown below in Table 4.1. While calculating the daily averages, only the active days the DGs are used are considered.

Table 4.1: Average Emission Loads from DG Stacks In Rig Sites

Area	Average Fuel Consumed per Site (tpd)	Quantity of Emissions					
		CO_2 (tpd)	SO_2 (tpd)	NO_X as NO_2 (tpd)	CO (tpd)	HC (tpd)	PM (tpd)
Rig site (average)	4.8	15.2	<0.1	0.3	0.1	<0.1	<0.1
Rig camp (average)	1.0	3.1	<0.1	0.1	<0.1	<0.1	<0.1

Note: While calculating average daily fuel consumption, only the active days of DG use are considered.

DGs are not provided with any specific emission control systems. Currently, there are no Omani standards for emissions from DGs. However, PDO's specification on air emissions (SP-1005) requires that NO_x concentration shall not exceed 200 mg/Nm^3 and PM concentrations shall not exceed 100 mg/Nm^3 in the emissions from stationary combustion sources. The specification also requires that SO_2 emission loads be such that the ambient air quality standards (refer Table 2.5 in Chapter 2) are not breached.

Currently, no stack emission monitoring data are available to check whether the concentration of the various pollutants comply with the applicable standards. However, based on past experience with similar systems, the emission concentrations are expected to be as below:

CO	: 1360 mg/Nm^3
NO_x as NO_2	: 5000 mg/Nm^3
SO_2	: 715 mg/Nm^3 (max)
HC	: 145 mg/Nm^3
PM	: 1575 mg/Nm^3 (max)

In these estimations, it is assumed that about 14 Nm^3 of flue gas will be generated from 1 kg of fuel oil burned with about 10% excess air.

The above estimated figures show that NO_x and PM emission concentrations will be in excess of maximum permissible limits as per PDO's specifications. As indicated earlier, there are no maximum permissible emission concentrations in Omani regulations. In the absence of detailed DG stack information or air quality data near rig sites, it is not possible to determine whether there is any non-compliance with ambient air quality standards.

4.2.3 Flare and Burn Pit Emissions

Ground flares are employed to burn the associated gas encounter during the drilling. If the quantity of the gas is not adequate to burn by itself, then it is vented to the atmosphere. The associated gas produced during the well testing is also burned in the ground flares. Open burn pits are provided at the rig site to burn the crude oil during well testing, if it is not possible to transfer the oil to a production station.

The constituents in the flare and burn pit emissions are not different from those of stacks, except for their composition. The emission factors depend on the fuel composition, system (flare / burn pit) and combustion efficiency. No specific emission control systems are provided except ensuring good combustion efficiency. 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*). In the case where the flare is unlit (cold vent), the emissions have the characteristics as the vented gas. For burn pits, there are no estimates for emissions in EP 95-0377. In their absence, it is assumed that the flare emissions factors also apply for the burn pit emissions, as shown 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

In the equations above, E is the flare efficiency (assumed to be 95% for flares and about 80% for burn pits) as percentage and S is the mass % of sulphur in the fuel.

The average emission loads from flares and burn pits are calculated based on the above emission factors. It is noted that the quantity of gas flared and oil burned will vary from site to site. Therefore, based on the annual data (for year 2002) for the well engineering asset as a whole, the average emissions for a rig site are estimated as shown below in Table 4.2.

Table 4.2: Emission Loads from Flares and Burn Pits In Rig Sites

Area	Average Fuel Combusted per Site (t)	Quantity of Emissions (t)				
		CO_2	SO_2	NO_X as NO_2	CO	HC
Flares (average)	567	14.8	0.6	0.9	4.9	0.1
Burn pits (average)	160	3.5	0.2	0.2	1.4	0.1

Note: For average day emission rates, it may be assumed that the flaring and open pit burning will take place over a single day at any site. Thus, the above values represent average daily emission loads.

4.2.4 Vent and Fugitive Emissions

The only sources for venting emissions into air are the diesel and clean crude storage tanks at the rig site. The diesel storage tanks are kept in open atmosphere exposed to hot sun. Hydrocarbon vapour escapes during the breathing of the tank due to the temperature variations. Rig sites are the only places where bulk fuel storage facilities are provided. The fugitive emissions from all sources are basically hydrocarbon vapours.

The vent and fugitive hydrocarbon vapour emissions 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 hydrocarbon emissions are methane and the remaining 85% are non-methanes. Based on the above, the vent and fugitive hydrocarbon emissions from these sources of Well Engineering asset are estimated as given in Table 4.3 below.

Table 4.3: Vent and Fugitive Emissions of Hydrocarbon Vapours from Well Engineering Asset Sources

Sources and Location	Quantity (Tonnes per Year)
Vent emissions from diesel storage tanks	Data not available
Vent emissions from clean crude storage tanks	Data not available
Fugitive emissions during drilling	Data not available
Asset total	Data not available

Note: About 85% of these hydrocarbons are assumed to be methane and the rest non-metahnes.

4.2.5 Mobile Source Emissions

Road vehicles used by the asset personnel for the transportation of equipment (including rigs), materials and personnel within their areas of operation constitute the mobile air emission sources. The types of road 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 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 simplicity, EP 95-0377 specification uses common emission factors for all categories of land transport vehicles, and common emission factors for all categories of marine vessels as shown below:

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

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 4.4 below.

Table 4.4: Air Emissions from Mobile Sources for Well Engineering Asset

Parameter	Quantity per Year (t)
Total quantity of fuel (petrol / diesel) consumed in the well engineering asset by road vehicles for transportation of equipment, material and personnel	Data not available
Total emission of CO_2	Data not available
Total emission of CO	Data not available
Total emission of NO_x	Data not available
Total emission of SO_2	Data not available
Total emission of HC	Data not available

4.3 Liquid Effluents

The liquid effluents generated from the activities performed by well engineering asset are also of short duration (typically 10 days to 4 weeks) for a given site. For a site, during the period of field activity, the liquid effluent streams may be classified as continuous, intermittent and accidental.

Sewage generated in the rig site and the rig camp is the major effluent, which is generated continuously throughout the field activity. The other effluent stream is the produced water generated from the well testing, which is intermittent in nature. The drill cutting and waste drilling fluids are semi-solid in nature and hence considered under solid wastes and addressed in the next section.

Any accidental leaks and spills of oil and chemicals are considered separately in Section 4.6, and are considered as liquid effluents.

Sewage generated in the rig sites is collected into underground septic tanks. The overflow from the septic tanks flows into soak pits. The sewage generated in the rig camps is also handled in the same manner.

No records are available with respect to the quantity of sewage generated and their characteristics. Therefore, based on domestic water consumption by the rig staff the quantity of sewage generated per rig is estimated. Based on 2002 data, the total annual domestic water consumption was 342,978 m^3 for well engineering asset. Since about 32 rigs are in operation, the average consumption per rig is estimated as 10,718 m^3/year or 29.4 m^3/d. It is assumed that rig staff are located on staff throughout the year. Assuming that the average number of staff deployed at a rig is 80, average per-capita consumption of domestic water works out as about 370 L per day per person. For sewage generation, it is assumed that 95% of domestic water consumed results as sewage. Based on this, the average sewage generation is estimated as about 28 m^3/d. Out of this, about 85% may be taken as sewage generation at rig campsite and the remaining 15% as sewage generation at rig site. The characteristics of overflow from the septic tank into the soak pits are estimated based on literature data.

Produced water is generated only during well testing. The total quantity of produced water generated during the year 2002 from well testing is about 4,000 m^3 from about 450 wells drilled. Since not all the wells drilled are well tested, the quantity of produced water generated per well testing will be about 10-15 m^3. The characteristics of produced water vary from site to site depending on the reservoir characteristics. The produced water generated from well testing is disposed into the waste pits for evaporation.

The typical characteristics of sewage and produced water generated from the well engineering asset activities are summarised in Table 4.5 below.

Table 4.5: Liquid Effluents from Rig Sites and Rig Camp Sites

Parameter	Sewage	Produced Water
Source of generation	Overflow from septic tanks located in rig sites and rig camp site	Generated from a new well under testing
Nature of generation	Continuous for the duration of rig operation at a site	Intermittent (generated at one time only at a site)
Average quantity generated per site	28 m^3/d average per rig unit (85% from rig camp site and 15% from rig site)	10-15 m^3 per well tested

Parameter	Sewage	Produced Water
Typical characteristics of raw effluent	pH: 6.5-8.5 TDS: 500-1000 mg/L TSS: 100-200 mg/L BOD: 150-200 mg/L COD: 250-400 mg/L Oil & grease: <50 mg/L	TDS: 5000 – 250,000 mg/L Oil & grease: 50-250 mg/L BOD: Negligible COD: Negligible

4.4 Solid Wastes

In PDO, the solid wastes are classified into broad categories as non-hazardous and hazardous. The sub-groups in each category are as below:

Non-hazardous wastes: domestic and office waste; water based drilling mud and cuttings; non-hazardous industrial waste.

Hazardous wastes: 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).

From the activities performed by the well Engineering asset, several types of wastes are generated. Among them, drill cuttings and waste drilling muds are unique to the well engineering asset. During the drilling process, the ddrilling mud is pumped into the borehole through the drill string and returned to the surface through the annular space between the drill string and the casing. The drilling fluid carries with it drill cuttings, silt, sand etc. to the surface. On the surface, these materials recovered from the drilling fluid cuttings, silt, sand and any gases are separated from the drilling fluid using shale shaker, desilter, desander, and sometimes centrifuge. The fluid is recirculated and the separated drill cuttings and other solids are discharged into the waste pit.

The waste pits are compacted earthen pit of 30 m by 40 m size with 1.2 m depth. Expect in environmentally sensitive areas (such as areas where shallow groundwater is encountered), the water and waste pits are not lined with any impermeable liners such as plastic films. In the waste pits, the water is allowed to dry due to solar evaporation and at the end of the drilling period. If the dried solids are classified as non-hazardous, they are not removed from the waste pit. Otherwise, they are transferred to the nearest PDO waste management centre for disposal. The waste pits are then backfilled.

Depending on the nature of the drilling muds used and the nature of the geology, the drill cuttings are classified as hazardous or non-hazardous. If water based drilling muds are used, the drilling cuttings and waste muds are classified as non-hazardous. If oil based muds are used, they are classified as hazardous. In addition, if any drill cuttings contain any naturally occurring radioactive materials (NORM), they are classified as NORM wastes.

The types and quantities of solid wastes generated from the activities of well engineering asset during the year 2002 are summarised in Table 4.6. The methods of disposal of the various wastes, which comply with PDO's specification on waste management (SP-1009) are also shown.

Table 4.6: Solid Wastes Generated by Well Engineering Asset Activities

Waste Type	Source of Generation	Quantity Generated (during 2002)	Method of Disposal
Non-hazardous waste			
Non-hazardous domestic waste	Camp site and rig site	17,245 t	Wastes are disposed off by burring at camp site or sent to the nearby PDO waste management centre
General industrial waste	Gloves, wooden pallets, waste paper, plastic bags of chemicals	1,354 t	Sent to the nearest PDO waste management centre
Scrap steel	Pipes, broken tools and tackles	542 t	Sent to the nearest PDO waste management centre
Wooden pallets returned for reuse	Chemical storing and transport	2,258 pieces	Returned to the concerned chemical stores
Hazardous waste			
Oil sludge	Crude centrifuge	unknown	Sent to the nearest PDO waste management centre for oil recovery
WBM muds and drill cuttings	Drilling with water based muds	182,706 m^3	Buried at site in waste pits
Oil based muds and drill cuttings	Drilling with oil based muds	2,626 m^3	Sent to the nearest PDO waste management centre for oil recovery or land farming
Lube oil/ grease	Rotating equipment	5.5 m^3	Sent to nearest PDO waste management centre for oil recovery
Oily sands	Oil spill contamination, sand removed from waste pit	Unknown	Sent to the nearest PDO land farm for bio-remediation.
Waste tyres	Vehicles	1 piece	Sent to nearest PDO waste management centre
Batteries	Vehicles, Standby power supply	0	Sent to nearest PDO waste management centre
Chemical wastes	Offspec, expired or contaminated chemicals	1,595 t	Disposed off into the waste pit or sent to chemical stores (from waste pit, sent to the nearest PDO waste management centre)

Waste Type	Source of Generation	Quantity Generated (during 2002)	Method of Disposal
Clinical waste	From the camp site clinic	107 kg	Sent to MAF waste management centre for incineration
NORM waste	NORM contaminated pipes or drill cuttings	0	Sent to the PDO's NORM storage facility in Zauliyah in Bahja

4.5 Noise

The rigs' sites are generally noisy areas. The rig unit consisting of heavy rotating equipment is a major and principal noise generating source. The diesel generators, nitrogen generator units and the various other pumps and motors on site also generate significant noise at source. These sources generate noise either continuously or intermittently. The continuous sources include drilling rig, diesel generators, rotary pumps, compressors, electrical motors, 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.

For the rig campsites, the DGs are the only major noise generation sources. The mobile sources include the road transportation vehicles such as cars, vans, buses and trucks used by the well engineering asset staff, and for the transportation of the materials and equipment.

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. Currently, no data are available on the noise levels for either point sources or area sources. Further, no data are available on workplace or ambient noise levels. 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. It is also suspected that the noise levels in the rig campsites will also be in excess of permissible ambient noise standards (refer Table 2.12 in Chapter 2) at sometimes.

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

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

Another type of accidental loss in drilling units is the loss of radioactive sources. In well logging by radioactivity, a radioactive source is pressed onto the borehole wall by a pad. If the radioactive source is accidentally lost in the borehole, then the well is abandoned and separate program is initiated to prevent further radiation outside the borehole as per PDO's specification SP-1218 (Drilling Specification – Radioactive Materials).

The radioactive sources are stored in shielded storage compartments that are fitted to wireline logging trucks. When sources are removed from the logging truck and temporarily stored on the well site, a 4m by 4 m area is cordoned off around the source and clearly visible radiation warning signs are posted.

For the current year (2002), the leaks and spills are reported by the well engineering asset are summarized in Table 4.7.

Table 4.7: Accidental Leaks and Spills Reported by Well Engineering Asset

Description	Incidents Reported in 2002			
	Oil Leaks and Spills	Chemical Leaks and Spills	Water Leaks and Spills	Accidental Loss of Radioactive Source
Total number of incidents	16	0	7	0
Number of spills into wadis	0	0	0	Not applicable
Total volume leaked / spilled (m^3)	22.2	0	20,000	Not applicable
Total land area impacted (m^2)	Not reported	0	Not reported	0
Total quantity of soil contaminated (t)	Data not available	0	Not applicable	0

Generally, it is observed throughout PDO that incident reporting is not accurate. Therefore, it is likely that the leak and spill volumes, impacted areas and contaminated soil quantities are under-reported.

5 ENVIRONMENTAL SETTING

5.1 Introduction

Well engineering asset is one of the eight technical service providers in PDO. Its areas of operation cover the entire concession area in south and central Oman. The asset is primarily responsible for the design, construction, in-well maintenance and abandonment of production and exploration wells throughout PDO's concession area. The wells include oil, gas and water wells. The other technical activities of the asset include the development and implementation of new drilling technologies and maintaining well data from drilling and pumping operations throughout the concession area.

As seen from these maps, the areas of operation of well engineering asset stretch from Marmul in south Oman to Lekhwair north Oman, covering a vast land area of 113,550 km^2. From an environmental viewpoint, the terrestrial environment is of interest in the areas of operation of well engineering asset and currently coastal environment (PDO's MAF area) is of no relevance.

The detailed description of environment throughout the PDO concession area is given in the individual environmental impacts assessment reports prepared for all the production assets (*Reference 4*). In this chapter, a brief description of the environment within the interior areas of operation of well engineering asset is presented.

5.2 Topography

The topographical features of the PDO's concession area shows two distinct zones as below:

- Desert plains with very low populations within most of the concession area
- Low to medium altitude hills over the southernmost and northernmost parts

Most of the concession area falls under central and south-central Oman and is characterised by flat gravel desert plains with occasional rocky outcrops interspersed with a few wadi channels. The altitude in the plains is mostly in the range of 100-150m above the mean sea level. The desert plains are very thinly populated.

Sand dunes occur over the western parts of central Oman forming a part of Rub Al Khali (the empty quarter). A large area constituting the southern part of Yibal asset and northwest part of Qarn Alam asset fall under Umm as Samim, the largest sabka (natural salt pan) of the Arabian Peninsula.

The natural vegetation is composed of desert plants and grasses, and is restricted to the wadi plains only. Among all the assets, Nimr and Marmul assets have relatively denser vegetation. Wadi Raunib in Rima is one of the most significant naturally vegetated areas. Rahab Farms in Marmul asset are the most significant cultivated vegetated areas within the concession area.

Hills of low to medium altitude are encountered over the southernmost and northernmost parts of the concession area. In the south, from Thuleilat (Marmul asset) onward, the altitude rises steeply up to 600m above the men sea level into Dhofar mountains. Similarly, in the north from Fahud onward, several hills up from 300-600m altitude are encountered. At the high point of MOL near Izki, the altitude is about 670 m above the mean sea level.

5.3 Geology and Soil

The geology of most of the PDO's concession area comprises of mainly limestone with shale, dolomite and sandstone. The central plains mostly consist of flat limestones of oligocene and miocene ages to mid-tertiary. The limestone plains are covered sparsely with alluvial gravel or aeolian sand. Toward the north, the low hills are comprised of tertiary sedimentary sandstones, limestones and conglomerates overlying igneous and metamorphic rocks formed under ocean sediments in the Mezozoic period. The rock types include gabbros, Hartsburgites, basalts and locally pillow larva.

The simplified stratigraphy map of Oman is shown in Figure 5.1.

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 general soil map of Oman is shown in Figure 5.2.

5.4 Hydrogeology and Groundwater Quality

The tertiary aquifers are the potentially exploitable groundwater resources in PDO's concession area. Tertiary aquifer systems in Oman are recharged from the flow from the Oman mountains to the north and Dhofar mountains to the south. Surface hydrology in this area is of no significance due to very scanty rainfall.

The shallow aquifer systems consists of the Fars formations (0-150 m depth), Dammam formations (150-200 m depth), Rus formations (200-300 m depth) and Um er Raduma (UeR) formations (300-600 m depth).

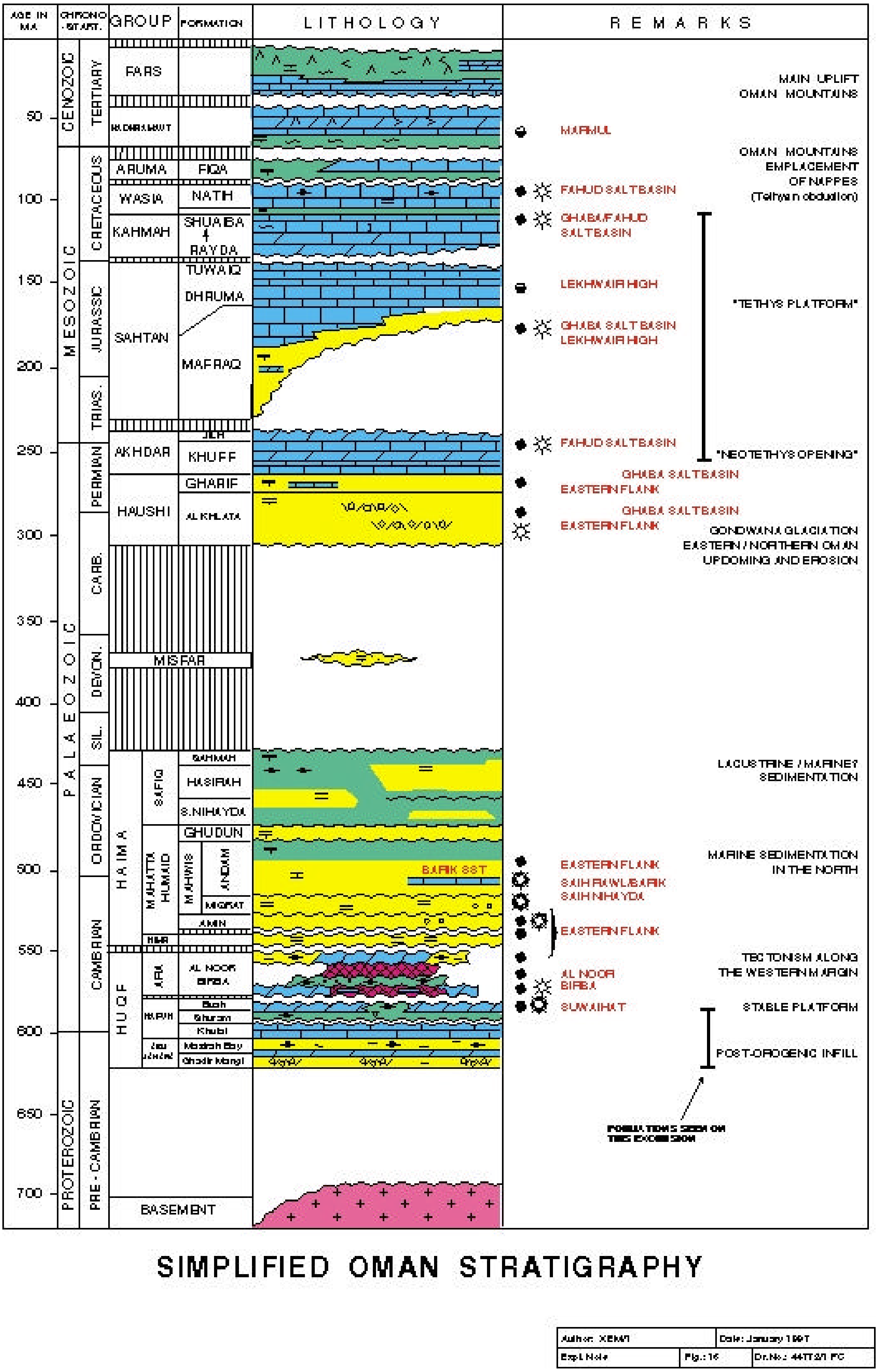


Figure 5.1: Simplified Stratiography Map of Oman

Fars formations are basically formed by sedimentary carbonates. Groundwater water availability in these formations is not significant in most of the assets. Dammam formations are primarily limestone beds and have very limited groundwater potential due to their reduced thickness. Rus formations are formed by and gypsum anhydrite beds. They have significant groundwater potential in some assets. This aquifer appears to be confined at some places and connected with the UeR aquifer at other places.

UeR aquifer is the main prolific aquifer in the area. UeR formations are sub-divided into lower, middle and upper layers. The upper and middle layers are composed of limestone and dolomite, while the lower layers are composed of thin impermeable shale and marl. UeR aquifer is recharged in Dhofar mountains in south during monsoon from July to September. The groundwater is estimated to travel at a velocity of 10 m per year.

The mineral content in UeR water increases as it travels from south to north. Within the entire PDO concession area, only Marmul asset has groundwater that is potable without any pre-treatment. In all other assets the UeR water is very saline. The total dissolved solids content ranges from 1000 mg/L to 150,000 mg/L. The groundwater salinity map of the region is shown in Figure 5.3.

The historical well yield and water quality data collected from various water supply wells in the concession area have not shown any significant change over most parts of the concession area.

5.5 Climate

PDO's concession area as whole has an arid climate, with very low rainfall. The climate is typically hot with significant fluctuations between maximum and minimum temperatures. The hottest temperatures occur throughout summer months (May – August) and cooler temperatures occur during the winter months (November-February). The mean monthly temperatures range from around 20^{o}C in December/ January (with mean minimum of about 12^{o}C and mean maximum of about 28^{o}C) to about 35^{o}C in July (with mean minimum of about 24^{o}C and mean maximum of about 45^{o}C). The maximum absolute temperature will be as high as 50^{o}C and the minimum absolute temperature will be as low as 5^{o}C.

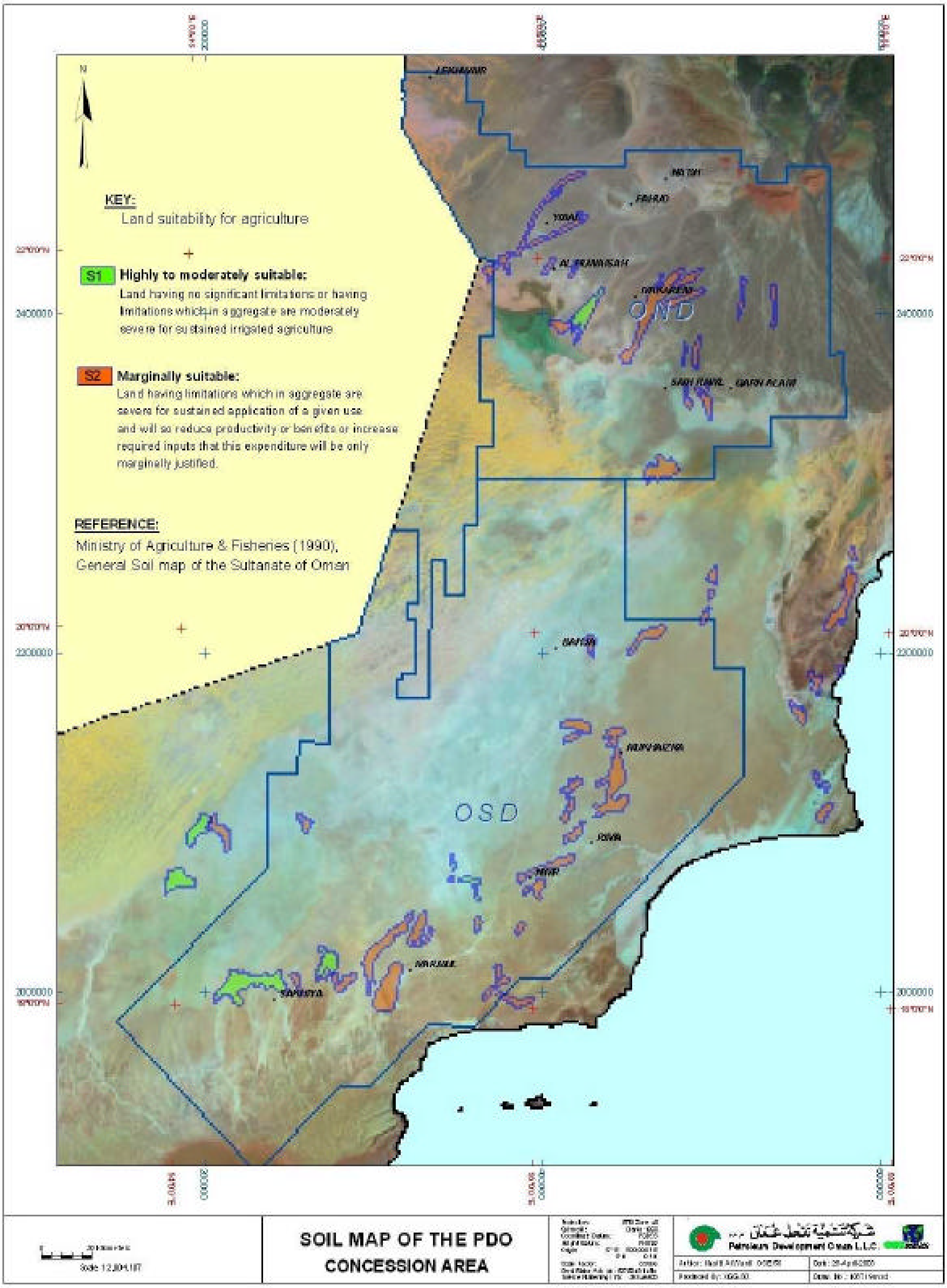


Figure 5.2: Soil Map of PDO's Concession Area

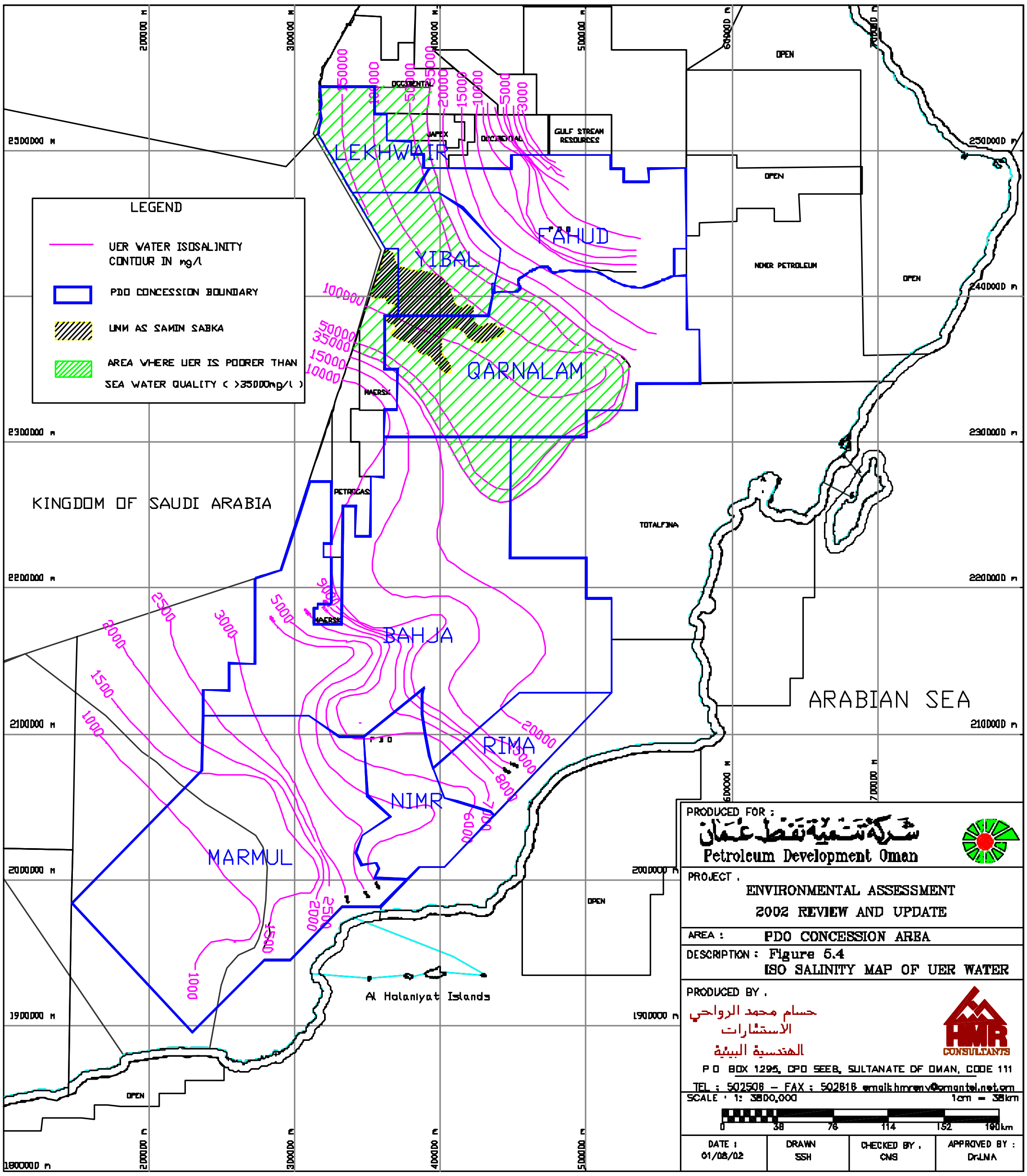


Figure 5.3: Iso-salinity Map of UeR Aquifer in Oman

Rainfall in this region is scanty and is highly variable in time and space. Historical data give an average of 36 mm per annum. Although the annual average rainfall is very low, flash floods are known to have occurred in the area. Most of the rainfall occurs during the winter season (December - February) with secondary peaks expected in late summer. Little rainfall is expected throughout the rest of the year.

Wind speeds vary considerably from calm to strong gusts. The dominant wind direction is from the south with an average wind speed of 8 knots.

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. These 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. Particularly, due to the use of diesel oil or centrifuged crude oil fired DGs for power generation in the rig sites and rig camp sites, it is likely that the concentrations of some pollutants such as NO_x, CO and particulates are significantly high compared to the baseline concentrations. 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, Drilling units 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.

With specific reference to rig sites and rig campsites, there are several high noise generating sources concentrated at a point. The rig unit, the DGs, compressors and other rotary equipment generate high level noise. It is likely the noise levels in the rig sites, possibly in rig campsites too, are significantly higher than the baseline values. Therefore, it is necessary that noise surveys be undertaken at periodic intervals at selected locations to determine whether the noise levels in the rig sites and rig campsites are within the permissible limits.

5.8 Terrestrial Ecology

5.8.1 Flora

The natural flora in most of the concession area 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. With rainfall being very scanty and erratic, the fog moisture largely influences the vegetation in this region. The species diversity and density somewhat improves in the highlands in the southern and northern parts of the concession area.

The flora found in the central and southern plains in the concession area are typical to central Oman. Larger species such as *Prosopis cineraria* are present in low-lying sumps with deeper sand and *Acacia ehrenbergiana* is abundant. This region supports no trees or bushes, but characteristic forbs such as *Fagonia ovalifolia*, and species of *Cornulacea* and *Salsola* cover very large areas. The vegetation cover is relatively denser in the wadis with frequent grass tussocks of *Stipagrostic* sp., *Cymbogon schoenathus* and *Panicum turgidum* and includes scattered *Acacia ehrenbergiana* bushes. The wadis provide more forage for both wild and domesticated grazing animals due to plant height and coverage and the presence of grasses. Low-lying perennial shrubs cover the undeveloped areas within the concession area and serve as pastor grounds for local livestock, mostly camels and goats.

In the highlands, halophytes such as *Zygophyllum* decrease in abundance and the shrub communities become more diverse with additional species such as *Zyziphus spina-christi*, *Euphorbia larica, Fagonia sp., Dyerophytum indicum, Peroploca aphylla, Calotropis procera, Tephrosia* sp. and *Solanum*. Grass species increase in cover. With high spate flows, there is often little vegetation in the main wadi channels.

5.8.2 Fauna

Due to the sparse vegetal cover, fauna are not very abundant and diverse in this region. However several fauna groups including mammals, birds and reptiles are seen. Large mammalian species known to inhabit the area include the Arabian Gazelle (*Gazelle gazelle*), the Rhim Gazelle (*Gazella subgutturosa marica*), the Nubian Ibex (*Capra nubiana*). These animals are currently listed on the IUCN World Red List and the Regional Red List threat categories. The Arabian Oryx is seen in Mukhaizna field in Bahja asset. Mukhaizna field is located just outside the buffer zone of the Arabian Oryx Nature Reserve. Ruepell's Sand Fox and the Cape Hare are also thought to inhabit the some areas and burrow in earthen mounds associated with well development activities. A few smaller mammals, mostly gerbils, jirds and jerboas are also known be present in the vegetated areas.

Bird surveys revealed about 40 different species with a half of them breeding in this region. There are no regional Red Data Lists for birds and their threatened status in Oman is yet to be established. Distribution records for reptiles in the area indicate that 30 species inhabit the area. Both the monitor lizard (*Varanus griseus*) and the spiny tailed lizard (*Uromastyx thomasi*) are common throughout the region. All of the animal species recorded in the concession area are typical of the central plains.

5.8.3 Wildlife Sanctuaries

Two of the important wildlife sanctuaries in Oman namely the Arabian Oryx Nature Reserve and the Jebel Samhan Nature Reserve are in the proximity of in PDO concession areas. A small portion of the buffer zone of the Arabian Oryx Nature Reserve falls under into Bahja and Nimr assets. The Jebel Samhan Nature Reserve in the Dhofar governorate is to the south of Marmul asset.

- **Arabian Oryx Nature Reserve**

An area of 24785.4 km^2 in Al Wusta Region was proclaimed in 1994 as the Arabian Oryx Nature Reserve and subsequently declared a World Heritage Site by the United Nations Scientific and Cultural Organisation. At the heart of the Reserve is the Jiddah (central plateau), a foggy desert supporting diverse plant and animal communities. The Reserve is sanctuary for many wildlife species including the Arabian Oryx, which was reintroduced to the wild in 1982. The other mammals seen in the Reserve include Arabian Gazelle (*Gazelle gazelle*), Rhim Gazelle (*Gazella Subgutturosa marica*), Nubian Ibex (*Capra nubiana*), Arabian Wolf (*Canis lupus arabica*), Caracal (*Caracal caracal schmitzi*), Honey Badger (*Mellivora capensis*), Red Fox (*Vulpes*

vulpes arabica), Ruepell's Sand Fox (*Vulpes ruepelli*), Cape Hare (*Lepus capensis*) and Ethiopian Hedgehog (*Parachimus aetheopica*).

Among birds, 180 species have been recorded in the Reserve, with majority being migratory and only 26 breeding resident species. The resident species include Golden Eagle (*Aquila chrysaetos*) and Houbara Bustard (*Chlamoyodotis undulata*). Among reptiles, 24 species have been recorded including Monitor Lizard, *Malpolon moilensis*, *Cerastes cerastes* and *Uromastyx thomasi*. Over 140 species of plants have been recorded in the Reserve, with 12 endemic species. While some are short-living (rain supported), others are long-living (fog supported). Simr (*Acacia tortilis*) is scattered all over the Reserve, while Ghaf (*Prosopis cineraria*) and Salem (*Acacia ehrenbergiana*) grow mostly in shallow sand depressions called haylat.

The Reserve is presently divided into five administrative zones to facilitate management. The special protection zone is the core zone of the reserve that provides a safe haven for the Arabian Oryx and thus ensures their longterm survival in the wild of Oman. The objective is to manage this zone to keep human disturbance and competition from domestic stock to a minimum. The controlled use zone includes areas regularly used by the Oryx and tracts of land containing other important biological resources, wilderness, scenery of exceptional beauty and sites of archaeological interest. The management objective is to allow controlled access but keep development to a minimum. The buffer zone encompasses further sites of interest, but with control of activities in order to help protect the inner zones. The utility zone is demarcated for locating the essential Well Engineering facilities of the reserve. The special use zone constitutes the areas of land where a land use agreement has been reached with the government (military authorities) and private parties.

- **Jebel Samhan Nature Reserve**

The Jebel Samhan reserve covering an area of 4500 km^2 contains a wilderness of limestone highlands rising steeply from coastal plain and sloping gently toward north. The deep cayopns with water pools and many plant species provide an ideal habitat for Arabian Leopard, Nubian Ibex, Arabian Gazelle, Striped Hyaenas, Wild Cats, Foxes and Wolves. The reserve has typical monsoon vegetation and is the only Arabian location of African tree Papea capensis. The reserve has a protected core zone where minimal human activity is permitted, surrounded by multiple use zone. PDO currently does not operate in any part of the reserve.

5.9 Human Settlements

The human population density within PDO's concession area (interior areas) is extremely low and is to the order of 26 persons per 100 km^2. Within the total concession area of 114,000 km^2, the total current population is of the order of 30,000. The majority are the PDO and contractor staff living in the various accommodation camps located in the assets, and they number about 20,000 currently.

As for the civilian populations, the main populated areas are in the Wilayats of Haima (in Bahja asset) and Adam (in Fahud asset). Wilayat of Haima is in the Jiddat Al Harasiis plateau and has an estimated total civilian population of about 2500 persons. Wilayat of Adam has a total population of 8350 persons. In addition to the above, relatively small settlements can be found near to major wadis. These settlements are receiving various benefits from the PDO including water and power.

The Bedouin settlements are found to be mostly in the central and western parts of the PDO's concession area mostly around wadis. Particularly, Fahud, Nimr and Bahja assets are known to have more of Bedouin populations. The central plateau region, known as Jiddat al-Harassis is historically characterised by migratory populations due to the harsh climate and lack of freshwater sources. The principal inhabitants in Jiddat al-Harassis are the Harsoosis tribe. Historically, Harsoosis sustained on migratory pastoralism and adopted a nomadic lifestyle to cope with the harsh water-starved and desolate environmental conditions. Presently however, with year-round water supply provided by PDO and the government, Harsoosis have taken up permanent settlement and are no longer nomadic. A recent socio-economic survey indicates that there are an estimated 3,000 to 3,500 members of the Harsoosis residing within the central plateau.

5.10 Archeological, Cultural and Recreation Resources

There are no forts, ruins or other archeological declared sites in PDO concession area. However, abundant marine fossils are present in Jabal Fahud and Natih areas (Fahud asset).

The significant cultural site within PDO's concession area include the old city of Adam in the Wilayat of Adam (Fahud asset), which dates back to pre-Islamic times. Adam is also the birthplace of Imam Ahmad bin Said, the founder of the Al Busaid dynasty. Within the Bahja asset, there are several traditional weavers. There is an ancient cemetery within the Nimr asset on the southeastern end of the Prosopis woodland in Wadi Ghubbarah.

Sand dunes in the western and northern part of the Lekhwair asset qualify as areas of exceptional natural beauty. The landscape is peaceful and this area is used as recreational area during the winter months. Umm as Samim, the largest sabkha of the Arabian Peninsula, and one of the largest in the world is also an area of visual interest in Qarn Alam asset. The Prosopis woodland in Al Ghubbarah and the eroded limestone hills with small caves and rock overhangs in Wadi Rawnab in the Nimr asset are also considered areas of visual interest. The dramatically sculptured shapes of the limestone hills south of Shalim in the Marmul asset are also considered as a major visual amenity.

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 2.

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 3*. 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 socio-economic and socio-cultural impacts accrue from PDO's production activities. Well engineering asset, as a key service provider to the production assets shall be credited with a proportional share of these beneficial impacts. These beneficial impacts outweigh the adverse impacts, which are discussed in the subsequent sections. The major 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. PDO accounts for over 90% of the total crude oil produced in Oman. Thus the economic benefits from PDO activities are quite significant.

- Employment

PDO currently employs over 4000 permanent staff and 16000 contractor staff. In addition, a large number of persons, including local populations in the interiors are also provided indirect employment to provide a number of supporting services. In the interior areas, providing service to PDO is the only alternative employment for the local communities, whose main occupation is farming and animal husbandry. Therefore, the beneficial impact on employment is also significant.

- Amenities

PDO provides and shares several amenities developed by PDO all over its concession area with the local populations. They include the access roads, power supply, potable water supply, clinical facilities and telecommunication facilities. In addition, the assets provide financial and other material assistance to local schools, local bodies and cultural events.

- 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 camps and the contractor camps is significantly vegetated with trees, shrubs and lawns. In addition, PDO has developed a large farm in Rahab under "Desert Agriculture Project" over an area of over 100 ha. 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 (petroleum oils)
- Consumption of construction materials
- Consumption of groundwater
- Land take

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

- **Depletion of Mineral Resources**

Large quantities petroleum oils are consumed to support the drilling activities. Most of it is used for power generation using DGs and some to prepare oil based drilling muds. Currently (2002), well engineering asset consumes annually about 53,670m^3 of crude oil and 10,425 m^3 of diesel oil throughout the concession area. While these quantities are large, they are not so significant to directly contribute to the depletion of petroleum reserves.

The major construction activity of the well engineering asset is the well pad construction. The natural construction materials used in well pad construction are soil and stone aggregates. Soil is sourced locally from borrow pits and stone aggregates from local wadi plains or stone crushers. The quantities are not significant, and their consumption is of very short duration at a given site.

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)	Short 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

 # The duration of impact at a given drilling site is of short-term

- **Depletion of Groundwater Resources**

A large quantity of the groundwater is consumed in the well engineering asset to support the drilling activities. Currently (2002), well engineering asset consumes annually 342,978m^3 of untreated groundwater and 102,289 m^3 of treated groundwater throughout the concession area. The untreated groundwater is abstracted from shallow aquifers for the preparation of drilling fluids. The average raw groundwater consumption per a well drilled is in the order of 10,000 m^3. The treated groundwater is used for domestic use in the rig sites and rig camp sites, and supplied by the production assets from their RO plants. The average treated groundwater consumption per a well drilled is about 1300 m^3.

It may be noted that the water well used for groundwater abstraction changes from site to site, depending on where a new oil well is drilled. Therefore, any potential impact from groundwater abstraction to support the drilling activities on groundwater depletion depends on local (regional) 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, considering that large quantities of groundwater are abstracted by other competing users (principally the product assets to support their production and related activities), the likelihood of adverse impact on groundwater shall be considered as medium. The quantity of groundwater consumed in drilling is about 20% of the total water consumption in all assets of PDO.

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)	Medium
Significance of impact (slight / minor / localized / major / massive)	Localised@
Potential risk level (low, medium, high and extreme)	High

 # Even though groundwater abstraction for a given drilling site is of short duration, considering that the same aquifer feeds to large number of water wells in a region, the duration of impact is taken as of long term.
@ The direct contribution from drilling activities is about 20% the cumulative impact of all PDO assets.

- **Claim on Local Assets**

The local populations within the asset are very few and their demands or claim on local assets is low. Land may be considered to have competing users. However, the entire area of land on which PDO operates has no alternate use, due to the poor soil quality, lack significant vegetation and harsh environmental conditions. The land take for well pad construction and rig camp location is not significant (less than 1 ha per rig site or rig camp site). Further, once the drilling activity is completed the land (except for the well head site) will be restored nearly to its natural state. Based on the above discussion, the overall impact on claim on local assets is rated as below:

Impact Rating	Claim on Local Assets
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)	Minor
Potential risk level (low, medium, high and extreme)	Low

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 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 contribute to global warming. For well engineering asset, the CO_2 emissions result from the consumption of fuel oils in the DGs, rig engines and road vehicles. The total CO_2 emissions from these sources are of the order of 500 tpd for the entire concession area. Methane emissions are insignificant, since they result only from any venting of the associated gas released during drilling or well testing. The total quantity of global warming gases released into the atmosphere as a result of the asset activities is not significant and the area covered by the asset is quite large. 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)	Long 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

*Even though CO_2 emissions are of short duration for a given drilling site, considering that drilling activities taken place throughout the year in PDO's concession area, the duration of impact is taken as of long term.*

- **Air Pollution**

DGs used for power generation in the rig sites and camp sites are the major sources of release of air pollutants into the atmosphere. Other sources include engines attached to the drilling units, vehicles, diesel storage tanks, ground flares and open burn pits in the rig sites. The emissions contain pollutants such as NO_x, CO, PM including unburnt HC and SO_2. For DGs, the emission concentrations of NO_x, CO and PM are quite significant. It is estimated, in the absence of measured data, that the NO_x concentration will be in the order of 5000 mg/Nm^3 (compared to the maximum permissible limit of 200 mg/Nm^3 for stationary combustion sources) and the PM concentrations in the order of 1575 mg/Nm^3 (compared to the maximum permissible limit of 100 mg/Nm^3 for stationary combustion sources). The estimated CO and SO_2 concentrations are in the order of 1360 mg/Nm^3 and 715 mg/Nm^3 (max) respectively from DG stacks.

In terms of emission loads for a well site, the average emission loads (for an average consumption of 120 t of fuel per a new well drilling site) are estimated to be in the order of 8.5 t, 2.3 t and 2.6 t respectively for NO_x, CO and PM. For a given site, these emissions are of short duration and the emission loads are not very large.

However, as far as the drilling staff are concerned, their exposure to these pollutants is continuous since they move from one site to another along with the rigs. Therefore, while the impact on air quality at a given site may not be of much significance (short term effect) for any local populations, it is of great significance for the drilling personnel. It is noted that the emission concentrations of some pollutants from DGs are in excess of PDO's permissible limits (refer SP-1005). Further, the heights of the stacks through which DG emissions are released into the atmosphere are short; generally 6-9 m from ground level. This might adversely affect the dispersion of the DG emissions in the environment leading to elevated concentrations of pollutants in the ambient air. In the absence of any air quality data near the rig sites or the rig camp site, the compliance with ambient air quality cannot be assumed.

Based on the above discussion, the overall impact on ambient air quality 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)	Localised@
Potential risk level (low, medium, high and extreme)	High

 # Even though air emissions are of short duration for a given drilling site, the drilling personnel are continuously exposed to them and therefore the duration of impact is taken as of long term.
@ In the absence of measured data, estimate are used to characterise the emissions concentrations, which indicate repeated exceedance of standards.

- **Noise Pollution**

The rigs sites are generally noisy areas. The continuous noise generating sources include the drilling rig, diesel generators, rotary pumps, compressors, electrical motors, flares and other rotating equipment. For the rig camp sites, the DGs are the major noise generation sources. Currently, no data are available on the noise levels at source points or on workplace and ambient noise levels. 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. It is also suspected that the noise levels in the rig camp sites will also be in excess of permissible ambient noise standards at sometimes.

It is reasonable to expect that the impact of noise generation will be highly localized and unlikely to adversely affect any human populations other than the rig personnel. Even though, the drilling activities at a given site is of short duration, the drilling personnel will be exposed to the noise generated from these sources continuously.

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

Impact Rating	Increase in Ambient Noise Levels
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

 # Even though noise is generated for a short duration at a given drilling site, the drilling personnel are continuously exposed to noise and therefore the duration of impact is taken as of long term.

6.6 Impacts on Water Environment

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

<u>Environmental Hazards</u>
- Loss of drilling fluids into subsurface during drilling
- Seepage of drilling fluids into subsurface from the waste pit
- Land discharge of sewage effluents
- Accidental spills and leaks of hazardous liquids (chemicals and oils)

Potential Environmental Effects

- Groundwater pollution

During the drilling of a new well, drilling fluids containing drilling muds and chemicals are pumped at very high pressure into the borehole. Some of the fluids may be lost into the subsurface due to seepage through the pores and fissures. In fact it is known that some loss of drilling fluids occurs in any drilling operation. Further, structural deficiencies in the well casing can also leads to the loss of drilling fluids. Since the boreholes are drilled to a depth of 1100 m or more, some of the drilling muds and chemicals are likely to find their way into the aquifer and contaminate the ground water contamination. However, it may be noted that at a given site, the drilling activities lasts for only a short duration (weeks) and the area of any impact will be small.

The sewage effluents generated in the rig sites or rig camp sites are not treated in STPs. Instead, the overflows from the septic tanks are wasted into soak pits. This sewage can pollute the groundwater if it permeates into the aquifer. Similarly, the liquid content in the unlined waste pits, which contains several chemical substances can also pollute the groundwater if the liquid permeates into the aquifer. However considering that the rigs are operated for a short duration at site and the groundwater table is at least 150 m below the surface level, the probability for groundwater contamination due to surface discharge of sewage or seepage of liquids from waste pits is considered negligible.

With respect to accidental spillages hazardous liquids like chemicals and oils, it is unlikely that they permeate into the aquifer unless the quantities are very large. Based on the above discussion, the impact on the groundwater quality is assessed as below:

Impact Rating	Groundwater Pollution
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)	Medium
Significance of impact (slight / minor / localized / major / massive)	Minor
Potential risk level (low, medium, high and extreme)	Medium

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
- Well abandonment and site restoration
- Land discharge of sewage effluents
- Seepage of drilling fluids into surrounding soils
- Accidental leakage of hazardous liquids

- Accidental loss of radioactive sources

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

- **Alteration of Land Use**

The land take for well pad construction and rig camp location is not significant. The land take is typically less than 1 ha per rig site or rig camp site. Once the drilling activity is completed, the land taken for drilling except for the well head site is required to be restored nearly to its natural state. Further at the end of the life cycle of the well, the well head site is also required to be restored with complete removal of overground and underground structures. Any contaminated soil must be removed and transported to the nearest PDO waste management centre for treatment and disposal.

It is observed that site restoration in some places is not complete. Several non-performing wells are not properly closed out and contaminated sites are still to be remediated. The sites are also not restored to the fullest possible natural state. However, considering that the potential for any alternate use is low at present, the significance of any adverse impact is considered low. 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)	Long term#
Likelihood of occurrence (very low / low / medium / high / very high)	High
Significance of impact (slight / minor / localized / major / massive)	Minor
Potential risk level (low, medium, high and extreme)	High

 # Even though the duration of the activity is of short term, the impact shall be considered to be of long term.

- **Loss of Vegetation**

Loss of vegetation is directly related to land take and the density of vegetation on the land taken. Location of a well on the wadis plains may require removal of vegetation. If the area is considered ecologically sensitive, the well pad preparation and drilling activities may result in damage to important flora. Further, the mobilisation and demobilisation of rig may also leads to loss of vegetation if access roads pass through areas of high vegetation. The site selection criteria require that ecologically sensitive areas shall be avoided when selecting a drilling site or the site for locating a rig camp site.

Most of the concession area has low vegetal cover and does not include any ecologically sensitive areas. Further, after the completion of drilling activity, any removed vegetation is allowed to grow back. Based on the above, the impact on loss of 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
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

- **Land Contamination**

The land discharge of sewage effluents (overflow of septic tanks into soak pits), seepage of drilling fluids from the waste pits into the surrounding soils, accidental leakage and spillage of oil and chemicals, and accidental loss of radioactive sources may lead to land contamination. The overflows from septic tanks contain high concentration of organic matter and may carry some pathogenic organisms. However at a given site, the sewage discharge is of short duration and the organic matter is highly biodegradable. The land on which sewage effluent is discharged is usually of no alternate use. Therefore, any adverse effects will be transient and reversible.

Certain land contamination from waste pits and accidental leaks and spills shall be expected. While no chemicals are reported, sixteen oil spills resulting in the spillage of 22.2 m^3 of oil are reported by the asset throughout the concession are. The total quantity of contaminated soil generated from waste pits and accidental spills is not known. It is expected to be quite significant considering that about 350 new wells are drilled per year. As observed earlier, in several places, the contaminated sites are not completely remediated.

The use of radioactive sources in well logging operations may sometimes result in the loss of the source in the borehole. PDO's specification SP-1218 (Drilling Specification – Radioactive Materials) requires that if the radioactive source is accidentally lost in the borehole, then the well is to be abandoned and separate program is initiated to prevent further radiation outside the borehole. No such incidents were reported during 2002.

Based on the above discussion, the impact on soil quality 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)	Medium
Significance of impact (slight / minor / localized / major / massive)	Minor
Potential risk level (low, medium, high and extreme)	High

 # Due to the incomplete site restoration, the duration of impact is considered as long term

6.8 Impact on Terrestrial Ecology and Wildlife

The rig or rig camp sites are not located in or near areas considered to be ecologically significant. Similarly access roads and water pipelines do not pass through any ecologically sensitive areas. Therefore, the impact on terrestrial ecology and wildlife 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.

PDO's concession area is very thinly populated and there are no human settlements 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 populations across the asset.

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

Environmental Hazards

- Transportation of hazardous liquids and chemicals by road
- Ground flaring and open pit burning
- Storage of fuel oils on site
- Storage of the radioactive sources on site

Potential Environmental Effects

- Public safety and health

Transportation of large quantity of fuel oils and liquid chemicals has the potential to cause damage to public health and safety in the event of an accident. The fuels are transported to rig sites by road in standard tankers. Most of the chemicals are in solid form, except for a few such as acids. Further, most chemicals posses no fire hazard or acute toxicity. Ground flaring and open pit burning during well testing do not pose any public risk since these areas are not accessible to general populations. The storage of fuel oils on site also do not pose any public risk since the rig sites are not located close to human settlements. The radioactive sources are sealed and stored always under lock and key. The storage areas are accessible to only authorised staff. Further, all the radioactive sources are accountable and spent sources are returned to the supplier.

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
Groundwater Depletion	• Adverse • Long term • Medium occurrence • Localized significance	• High risk	• The total quantity of groundwater consumed in drilling constitutes about 20% of total groundwater abstraction in PDO. • In the absence of data on aquifer recharge and groundwater balance, potential risk on groundwater depletion shall be considered high.
Air pollution	• Adverse • Long term • Medium occurrence • Localised significance	• High risk	• The air emissions from DGs used for power generation in rig sites and rig camp sites are estimated to exceed the permissible concentration limits prescribed in SP-1005 for stationary combustion sources. • The DG stack emissions may not disperse well in the atmospheric due to short stack heights. • Even though the emissions in a given site are of short duration, the drilling staff will be continuously exposed to these emissions. • No monitoring data are available demonstrating compliance with either emission standards or air quality standards in rig sites or rig camp sites.
Alteration to land use	• Adverse • Long term • High occurrence • Minor significance	• High risk	• Well abandonment and site restoration is not completed as required in SP-1012 in several places. • Contaminated soils are not remediated in several drilling sites.

Environmental Effect	Impact Rating	Potential Risk Level	Comments
Land contamination	• Adverse • Long term • Medium occurrence • Minor significance	• Medium risk	• The overflow from septic tanks into soak pit contains high concentration of organic matter and may carry pathogenic organism. • Soil contamination with oils and chemicals occurs from unlined waste pits. • Loss of radioactive source in the borehole may result in contamination of soil with radioactive materials.
Ground water pollution	• Adverse • Short term • Medium occurrence • Minor significance	• Medium risk	• Loss of drilling fluid (containing chemicals) into the borehole during drilling occurs. • Since boreholes are drilled to a depth of 1100 m or more, and therefore drilling fluids can enter the aquifer.
Noise pollution	• Adverse • Long term • Medium occurrence • Minor significance	• Medium risk	• Rig units and DGs used for power generation generate high level noise. • Even though the noise generation in a given site is of short duration, the drilling staff will be continuously exposed. • No monitoring data are available demonstrating compliance with work place or air noise standards in rig sites or rig camp sites.

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 and SP-1170.

Specification	Areas of Non-compliance or Concern	Recommended Additional Mitigation Measures
SP-1005: Specification for Emissions to Atmosphere	• The air emissions from DGs are estimated to exceed the permissible concentration limits prescribed in SP-1005 for stationary combustion sources. • The drilling staff will be continuously exposed to DG emissions. • The DG stack emissions may not disperse well in the atmospheric due to short stack heights. • No monitoring data are available demonstrating compliance with either emission standards or air quality standards in rig sites or rig camp sites.	• SP-1005 may require an amendment since standard designs of DGs are unlikely to meet these emissions standards. • Ambient air quality shall be monitored in rig camps and rig sites to check for compliance. • If ambient air standards are not met, stack heights may need to be raised, DGs shall be retrofitted with air pollution control devices, or better fuels shall be used.

Specification	Areas of Non-compliance or Concern	Recommended Additional Mitigation Measures
SP-1006: Specification for Aqueous Effluents	• The overflow from septic tanks into soak pit contains high concentration of organic matter and may carry pathogenic organism.	• Soak pits shall be avoided to the extent possible. • Soak pits shall be placed far away from public places.
SP-1007: Specification for Accidental Releases to Land and Water	• Loss of drilling fluid (containing chemicals) into the borehole during drilling occurs. • Soil contamination with oils and chemicals occurs from unlined waste pits.	• Loss of drilling fluids shall be minimised during drilling. • Waste pits shall be lined with impervious synthetic liner wherever needed.
SP-1008: Specification for Use of Energy, Materials and Resources	• Efficient use of water is not demonstrated. The total quantity of groundwater consumed in drilling quite significant and is about 20% of total groundwater abstraction in PDO. • Efficient use of fuel for the diesel generators is not demonstrated	• Flow meter for all water supply wells to be provided and abstraction of water to be reported. • Opportunities for water and fuel conservation shall be explored.
SP-1009: Specification for Waste Management	• Not all contaminated soils are removed from the waste pits.	• Waste pit soils shall always be analysed for contamination before backfilling.
SP-1010: Specification for Environmental Noise and Vibration	• Rig units and DGs used for power generation generate high level noise. • Even though the noise generation in a given site is of short duration, the drilling staff will be continuously exposed. • No monitoring data are available demonstrating compliance with work place or air noise standards in rig sites or rig camp sites.	• Work place and ambient noise levels shall be monitored to check for compliance with the standards. • If warranted, noise attenuation measures shall be taken.
SP-1011: Specification for Flora and Fauna	• None	• None
SP-1012: Specification for Land Management	• Well abandonment and site restoration is not completed as required in SP-1012 in several places. • Contaminated soils are not remediated in several drilling sites.	• SP-1012 shall be implemented at all drilling sites.
SP-1170: Specification for Management of Naturally Occurring Radioactive	• None	• None

8 REFERENCES

1. WS/Atkins, *Well Engineering asset area Environmental Assessment Report*, PDO, September 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, *EIA of PDO Production Assets - 2002 Update and Review*, 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 of infrastructure asset 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.

Name of Reviewer	Position in PDO	Role in Project Development
Dr. Muralee R. Thumarukudy	CSM/22	Senior Corporate Environmental Advisor
Ahmed Al Sabahi	CSM/25	Environmental Advisor
Andrew Young	TWM1	Sr. HSE Advisor - Well Engg
Suresh Paranjpe	TWM11	HSE Advisor - Well Engineering

APPENDIX 2: 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 exceedance 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 exceedance 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 exceedance 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 exceedance of statutory or prescribed limits				**EXTREME RISK**	

APPENDIX 3: ENVIRONMENTAL HAZARDS AND EFFECTS IDENTIFICATION MATRIX: WELL ENGINEERING 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 Drilling site preparation										**X**	**X**										
For construction of accommodation facilities										**X**	**X**										
For laying water pipelines			**X**							**X**	**X**		**X**	**X**	**X**						
For laying access roads			**X**							**X**	**X**		**X**	**X**	**X**						
For storage of materials										**X**	**X**		**X**	**X**	**X**						
Utilization of Mineral Resources																					
For construction materials	**X**																				
For road building materials	**X**		**X**																		
Utilization of Groundwater Resources																					
For drilling		**X**						**X**													
For construction water		**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 Human Resources																					
Employment of migrant construction workers																				**X**	
Employment of permanent workers																					
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**	**X**															**X**	
Release of Energy into Atmosphere																					
Hot gases from flares and stacks																					
High level noise from stationary sources						**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
High level noise from mobile sources						X															
Discharges of Liquid Effluents																					
Discharge of sewage effluent								X				X									
Accidental spillage of hazardous liquids								X				X									
Disposal of Solid Wastes																					
Handling and transport of hazardous wastes																					
Functional Activities																					
Road transport of hazardous substances														X						X	
Bulk storage of hazardous substances																				X	
Road travel														X							

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