oceans EWS
Engineered Wetland Solutions

Former company name at time of presentation, now
Wetland Treatment Solutions - WTS

ETAP SUBMISSION UNDER REVIEW

Wetland Bioremediation of Produced Water Derived Naphthenic Acid, PAH & BTEX

An MSR Technology™ Wetland Case Study

MSR Technology™

The technology of designing bespoke wastewater treatment systems, by balancing the scientific selection of soils and reeds, to promote the optimal environment for microbiological processing to achieve the desired level of treatment and reduce sludge accumulation. The correct design of the specialized matrix is necessary to maintain the intricate interactions between bacteria, yeasts, cyanobacteria, algae, protists, rotifers, actinobacteria, fungi and other microbes necessary for degradation of complex organic compounds, that are not provided within traditional wetland water and gravel media.

Project Overview

In 2003 Greater Nile Petroleum Operating Company commissioned Oceans-ESU (partner of Oceans-EWS) to develop a pilot project within the Heglig Oilfield to investigate the large scale treatment of produced water using MSR Technology™.

The main contaminants of the produced water in Heglig and the wider Muglad Basin are Naphthenic Acids, Polyaromatic Hydrocarbons (PAHs) and the BTEX suite.

Whilst it was a pilot project, the system itself was capable of treating 30,000m^3/day of produced water, as such the pilot aspect of the project was only as development of a treatment model throughout the wider oilfield.

In addition to being a pilot for the remediation of produced water it contained areas for fishery and forestry as part of a whole catchment approach. The whole area had to be integrated into the catchment in order that any forestry or agriculture could have access to rainfall management to maintain these areas beyond the life of the oilfield. As a result not only was the produced water treated beyond all international standards, the area within which it was embedded began to function as a brand new ecosystem in what had been a very arid and denuded part of Sudan.

Together with the benefits to whole area in terms of a major increase in biodiversity of flora and fauna persuaded GNPOC to roll out a programme throughout all of the oilfields.

In 2005, after 18 month of continuous operation and monitoring, the pilot system was declared a success and was already handling double its design capacity As such the government office for Oil Exploration and Production Administration (OEPA) advised that the same system of treatment should be used as the standard method of treatment for oilfield produced waters throughout the Sudanese oil industry.

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Pilot System Control Model

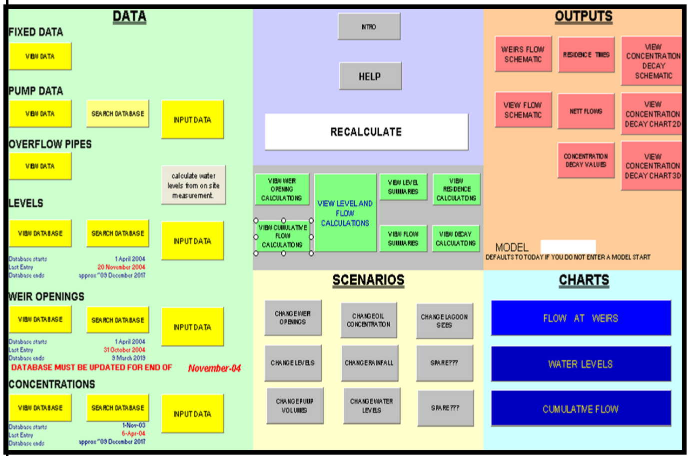

Figure 1 - Input Parameter Control Sheet

Hydraulic and chemical modelling allowed for predictive management of potential excursions and provided the user with the hydraulic system configuration required to continue meeting the produced water discharge standards.

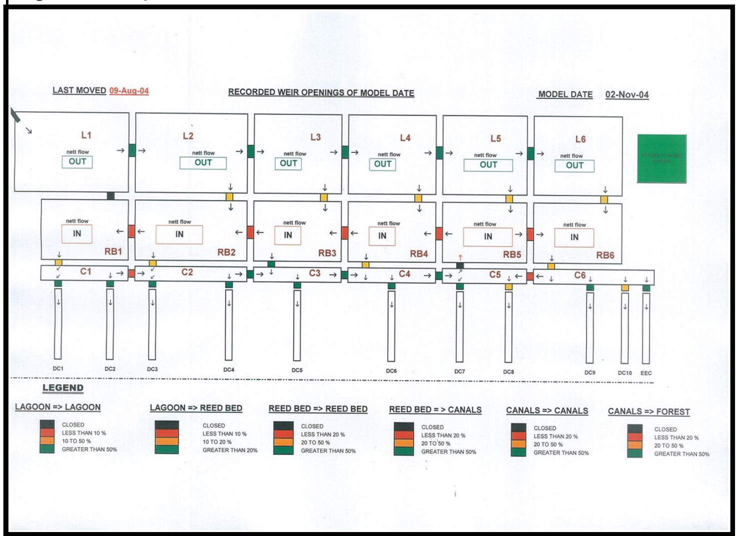

Figure 2 - Hydraulic Control Sheet

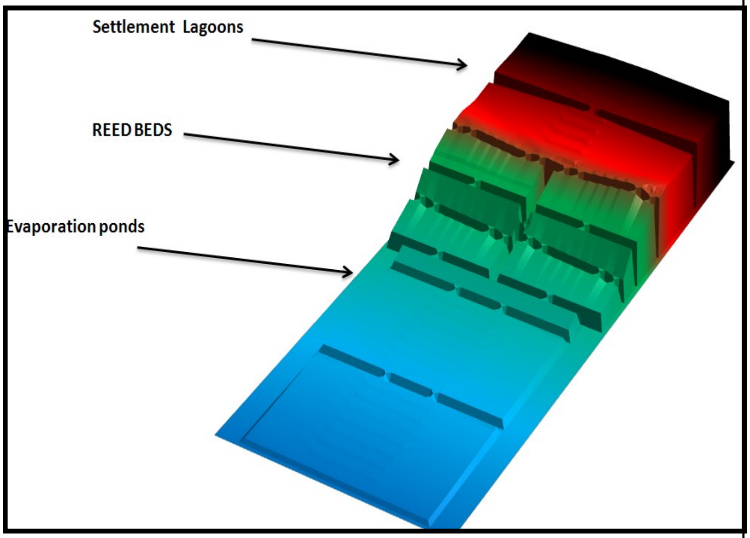

Figure 3 - Chemical Degradation Model

Contaminants &Monitoring

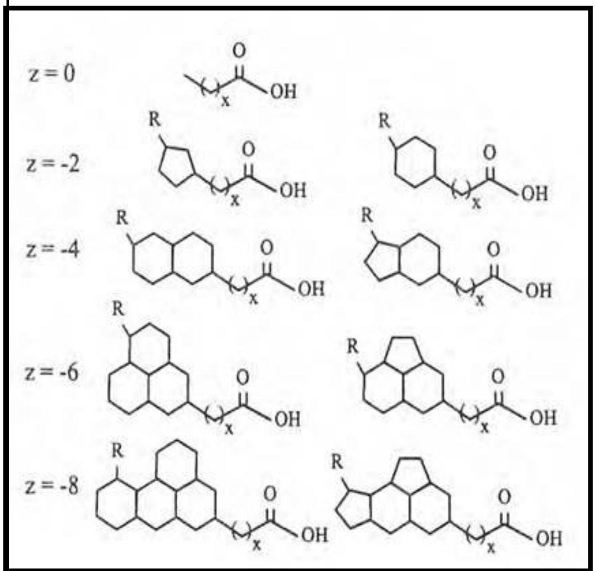

Fig.4 - Naphthenic Acid Structures

Water Soluble Faction (Naphthenic Acid, PAH & BTEX)

Following recovery of all insoluble hydrocarbon as Total Petroleum Hydrocarbons, the Produced Water at Heglig CPF is sent to the Bioremediation System for treatment of all dissolved phase contaminants. Dissolved phase hydrocarbons, known as the Water Soluble Faction, requiring treatment are comprised of the soluble compounds of hydrocarbon based origin including Polyaromatic Hydrocarbons (PAHs), **Naphthenic Acids** and BTEX.

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The origin of PAH is natural within the oil reservoir and therefore is carried as a solute within the Produced Water. The presence of Naphthenic Acids in Produced Water is due to reservoir biodegradation, either natural or due to the anthropogenic introduction of microbial bacteria during drilling and extraction. The biodegradation and resultant oxidation of aromatic rings within PAHs produces a blend of cyclohexyl and cyclopentyl carboxylic acids that are collectively known as Naphthenic Acids.

Naphthenic Acids are known to occur naturally within the crude oil reservoirs of the Muglad Basin in Sudan, giving the crude oil a high Total Acid Number.

As such, the hydrocarbon based produced water contaminants requiring treatment within Heglig Bioremediation System are comprised of the Water Soluble Faction, primarily the following groups;

- Polyaromatic Hydrocarbons (PAH)
- Naphthenic Acids (NAs)
- BTEX (Benzenes, Toulene, Ethyl Benzenes and Xylenes)

Chemical Water Quality Monitoring

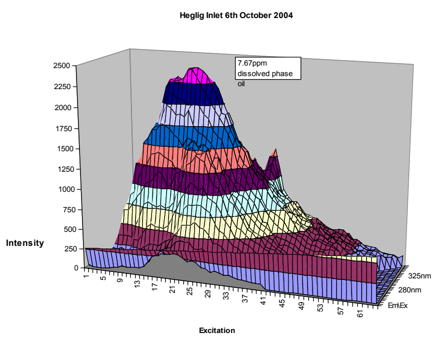


Fig.5—Fluospectrometry Scan at inlet

Chemical monitoring over 40 sample points throughout the system for PAHs, NAs and BTEX using fluospectometry techniques, as well as standard water quality parameters (pH, TDS, etc) was undertaken on a daily basis.
Continual analysis has showed a sustained quality of processed water over many years, consistently achieving <0.1ppm of free phase and dissolved phase oilfield chemicals. Performance was maintained, even for periods when excursions of free and dissolved hydrocarbons occurred at the inlet to the system.

Owing to the source, the metal content of the produced water at Heglig is relatively high. The reed bed system provides a mechanism for adsorption and accumulation, thereby facilitating removal of metals from the produced water to below FAO water standards

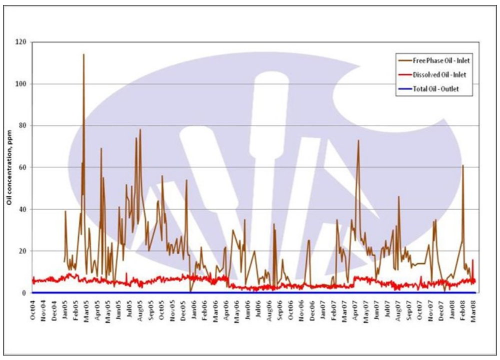


Fig.7—Water Soluble Faction Content

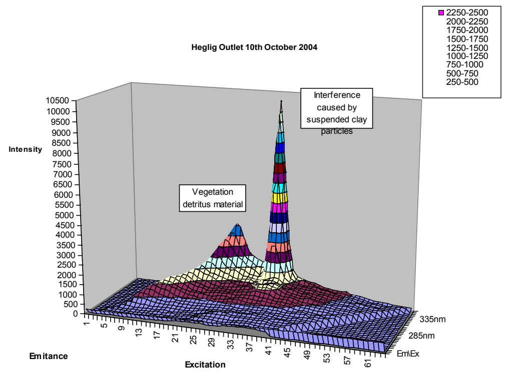
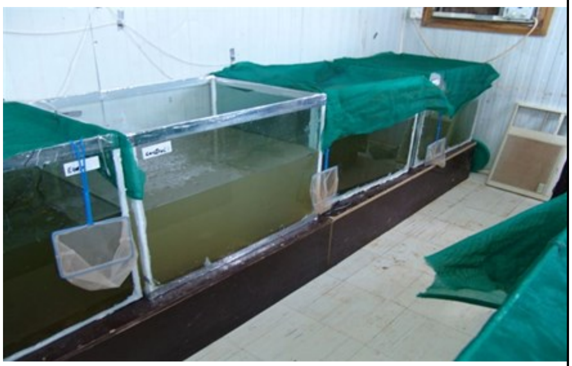


Fig.6—Fluospectrometry Scan at outlet

Toxicological Monitoring

Toxicological studies for bioaccumulation of Water Soluble Faction concentrations below the limits of detection was carried out by maintaining aquaria of fish species at various points throughout the system. The fish grown in aquaria at the inlet to the system showed reduction in body mass and length and their internal organs showed damage attributable to hydrocarbon oilfield chemicals. At points beyond the reed bed treatment no such effects were observed.

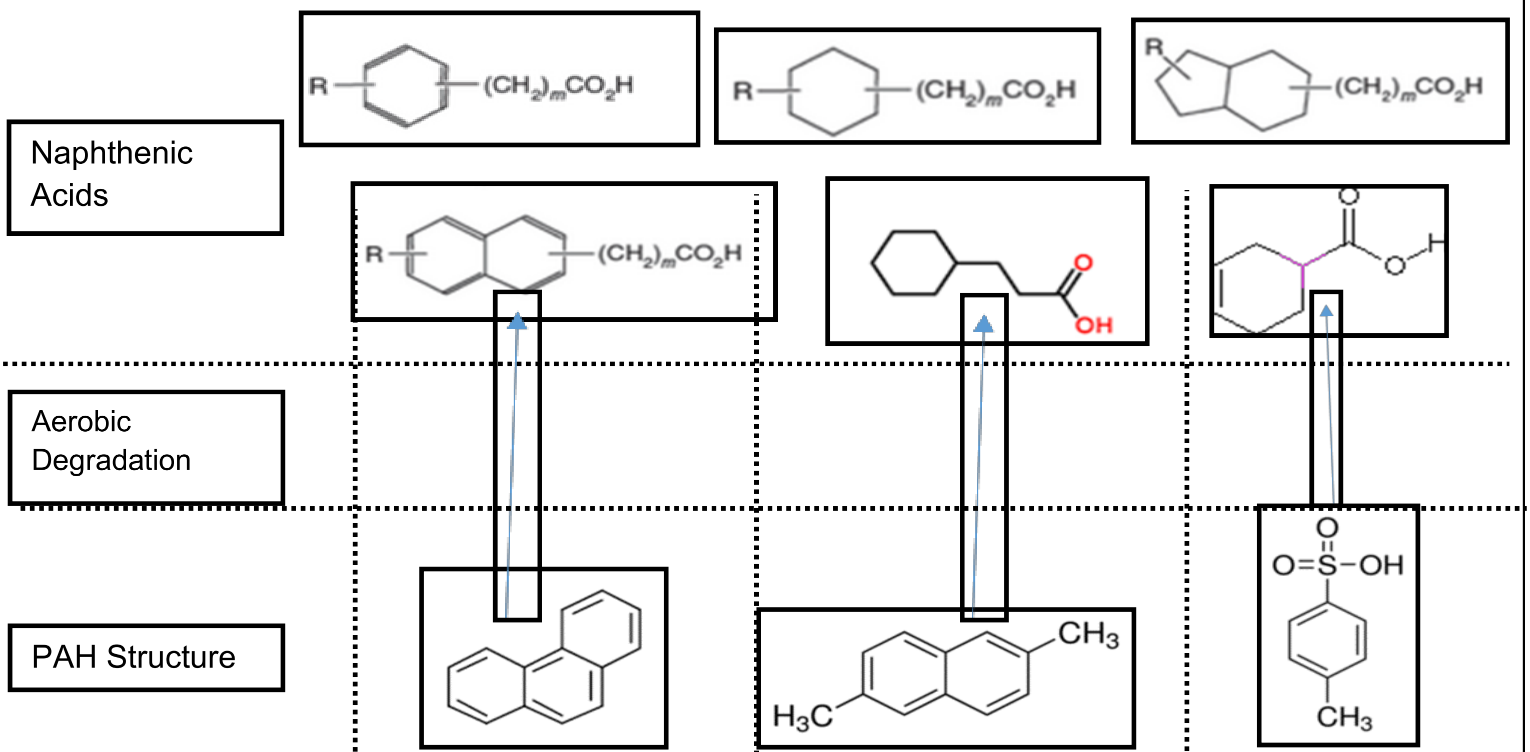


All other parameters indicated that the remediated water would pass on all international standards of anions and cations for beneficial reuse in the fields of horticulture, agriculture and forestry. With analytical equipment registering below the limits of detection at 1mg/l and with no significant defects to fish stock beyond the reed bed treatment area, water treated by the system was authorised for “beneficial reuse”.

The water was also passed as being suitable for use for cattle, however until a longer continuous period of monitoring had been sustained there as to be no use for drinking water for the local population without further treatment.

Degradation & Treatment

Monitoring of the degradation of PAH within the MSR Technology™ systems has identified a number of autochthonic and zymogenic reaction pathways. The systems have been studied to identify the microbial degradation pathways. A number of these pathways have been studied in order to characterise the reaction coefficients, enabling more accurate treatment system design.



Identified PAH	Phenanthrene Sulphonic	2,6-Dimethylnapthalene	Toluene
Degradation Pathway	Single Stage Degradation	Cometabolic Degradation	Cometabolic Degradation
Degradation Coefficient	Kv = 0.014	Kv = 0.012	Kv = 0.019

Cost Analysis

The overall CAPEX cost of the pilot project at Heglig was $8.4million. Based on the expected 25 year life of the project this represents a produced water treatment cost of $0.01 for every barrel of produced water. The gravity feed based system requires no energy, therefore the nominal OPEX costs are derived only from the limited maintenance required.

Even during the currently depressed oil market ($35/barrel of oil) treatment of produced water at Heglig (90% water : 10% oil) only equates to approximately 0.04% of the oil revenue.

Across the wider GNPOC oilfield concession, the total CAPEX cost for treatment of all oilfield produced water (>1.1million bbls/day) was $93.6million, including all lagoons, reed beds canals and forestry areas. This is equivalent to an average treatment cost across the concession of $0.01/bbl and a CAPEX construction cost of $100/bbl/day.

Disposal options	Cost per barrel ($)	Social Wellbeing	Environmental Benefits
MSR Technology™	0.01	Forestry, local employment, food & fuel	Habitat creation
Other technologies	0.15 - 2.50	No interaction	None

National & International Recognition

National Recognition

Following the successful implementation and operation of the Heglig Pilot Treatment System over the course of 18 months, the government office of the OEPA issued a statement permitting MSR Technology™ as the preferred option for the treatment of all oilfield produced waters throughout Sudan.

International Recognition

In 2009 Heglig Bioremediation System was visited by Sir. Mark Moody-Stuart (formally Chairman of Royal Dutch Shell) as his capacity as chairman of the United Nations Global Compact to report on the adoption of sustainable and socially responsible practices being implemented in Sudan.

United Nations Global Compact

Two United Nations Plaza, DC2-612, 44th Street, New York, NY 10017 <www.ungloabalcompact.org>

Mr. Ibrahmim Yusuf Gamil,
Field base Manager,
Heglig Field,
Greater Nile Petroleum Operating Co. Ltd
Sudan

7th March, 2010

Dear Ibrahim,

My colleagues in the UN Global Compact as well as the investors representing signatories to the Principles for Responsible Investment are extremely grateful for the hospitality you showed us during the out visit to the Heglig Field operations, as well as for the open and frank way in which both you and Mohamed Kamal, the Head of HSE, addressed our many questions. Please pass my thanks onto him also.

Both I and the investors representatives were very impressed by the water treatment process, I have often heard allegations about the quality of discharged oilfield water in Sudan but as someone who has spent a lifetime in the hydrocarbon industry I can say that the quality of discharged water in the GNPOC operations is extremely high and indeed sets world class standards. In this way, far from causing a problem, it is providing a benefit to forestry and wildlife. As experience develops, I am sure that ways will be devised to ensure that the benefits from the supply of water are maximized and are channelled in directions which will be sustainable after the life of the oilfield. The work done by GNPOC and Oceans-ESU, the supplier of the technology, is very thorough and clearly includes thorough tests for any potentially damaging residues from the water.

In our discussions you made very plain the approach which the company takes to security and relations with communities. Your company security personnel are unarmed and the operation clearly depends on the good will of the people. Your approach to facilitating the resolution of disputes within and between communities appears very commendable to me, although we did not have the opportunity to visit a community or to see examples of the many schools and medical facilities which you have delivered in the area. These are clearly a great contribution to the local community and economy. The approach to training members of the local communities so that they may be employed on a temporary basis by subcontractors to GNPOC is an ingenious and effective approach to a community where many of the people are nomadic. The economic effect of this approach is probably to spread the benefits more widely than would be the case through a small number of permanent jobs.

We did have the opportunity to visit Heglig hospital and we were all extremely impressed by the enthusiasm of the four Sudanese doctors who have served for many years in the area.

United Nations Global Compact

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The hospital clearly provides a high quality free service to people from a very wide area, not just the neighbouring communities. The statistics on births, maternal health and the number of operations carried out in the last five years were very impressive.

The one suggestion I made to the members of the consortium as well as to the government is to commission a study by study say development experts from the universities of Khartoum and Juba on the developmental impact of your activities. The economic and educational impact must be considerable and it would be useful to have independent corroboration of it. Such a study might also show up ways in which the impact of the excellent work being carried out could be further enhanced.

An important part of our visit was the presence of investors representing signatories to the Principles of Responsible Investment. Funds managed by the signatories of the PRI amount to some US Dollars 18 trillion. It is clearly very important to the future of Sudan that some of the country's needs can be met by foreign investment, and not just in the oil industry but in other areas such as agriculture.

Lastly, I wish you every success in your plans to address the current relatively low oil recovery factor in the operations. It should be possible to shut off some of the zones or wells producing large amounts of produced water within the oil – any increase in the recovery factor will be of immediate benefit, allowing the facilities to be used for longer. The economic effects of even modest success in this areas would be very large so it is well worth pursuing the goal with energy.

Thank you once again for a most interesting and informative visit.

Sincerely

Mark Moody-Stuart

Sir Mark Moody-Stuart
Chairman

Foundation for the Global Compact

"Both I and the investors were very impressed by the water treatment process"

"As somebody who has spent a lifetime in the hydrocarbon industry I can say that the quality of discharge water in the GNPOC operations is extremely high and indeed sets world class standards"

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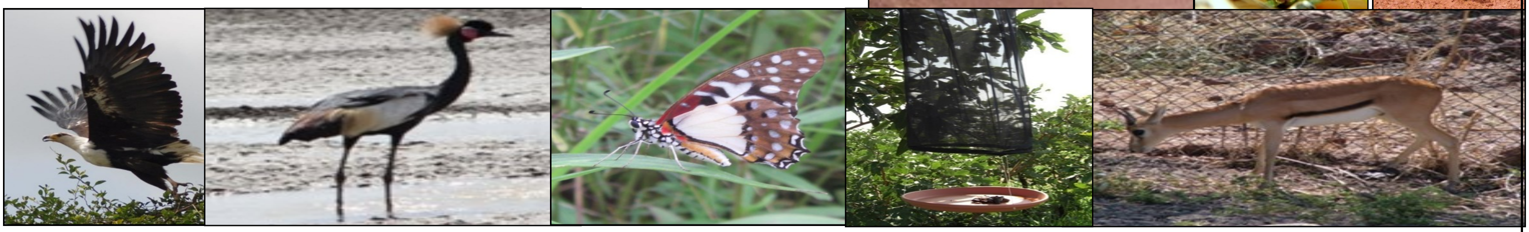
Beneficial Reuse & Ecology

The treated produced water at Heglig has allowed for the establishment of 1,122 Hectares of forestry at Heglig. In a semi-arid region, the forestry area is highly valued and regarded by the local community as a sustainable resource.

The huge scale and niche availability of improved conditions within the semi arid surrounding has allowed a flourishing ecosystem to evolve. To date 109 avian species have been identified, including 5 endangered red list species.

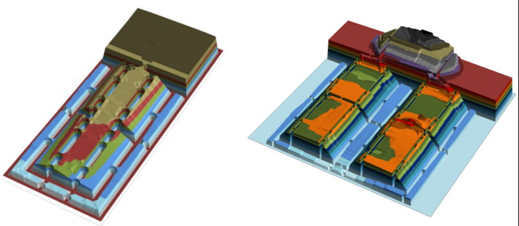


Full Scale Rollout

Following the success of the pilot treatment system at Heglig and its national and international recognition, in 2005 GNPOC took the decision to begin the process of implementing MSR Technology™ throughout all of its oilfields.

Extension of Heglig Pilot System

A second treatment system was installed at Heglig, thereby increasing the treatment potential within the Heglig oilfield to 300,000 bbls/day. An additional 45.6 hectares of lagoons were installed so as to allow for the settlement of any residual free phase hydrocarbons and recovery via skimming methods along with 738 hectares of forest



Implementation Throughout GNPOC Oilfields

In 2006 a further seven produced water bioremediation systems were designed and built using MSR Technology™. Following construction the systems provided GNPOC with a total produced water treatment capacity of 175,000m^3/day.

MSR Technology™ in the Petrochemical Industry

1998 - **BP, Pumpherston, UK**

Treatment system for polluted groundwater from former oil refinery. Project named as winner of the British Petroleum Chairman's award for environment

1998 - **PDO (Shell/Total), Oman**

Installation of world's first dedicated application of reed beds to produced water. Development of concept of produced water beneficial use for forestry

2003 - **GNPOC (CNPC/Petronas/ONGC Videsh/Sudapet), Sudan**

Installation of pilot treatment system for treatment of 25,000 m^3/day of produced water

2003 - **GNPOC (CNPC/Petronas/ONGC Videsh/Sudapet), Sudan**

Extension of Heglig treatment system to increase treatment to 50,000 m^3/day

2006 - **WNPOC (Petronas/ONGC Videsh/Sudapet), Sudan**

Design and installation of 20,000m3/day produced water treatment system

2006 - **GNPOC (CNPC/Petronas/ONGC Videsh/Sudapet), Sudan**

Design and installation of 7 additional produced water treatment systems. MSR Technology™ now providing 175,000 m^3/day treatment capacity for GNPOC

2007 - **PDOC (CNPC/Petronas/Sudapet/SINOPEC/Tri-Ocean), Sudan**

Design and installation of 3 produced water treatment systems (74,000m^3/day)

2009 **- ADNOC, Abu Dhabi**

Pilot treatment system for downstream fertiliser production

2013 **- PCFK (Petronas), Malaysia**

Pilot treatment system for downstream fertiliser production