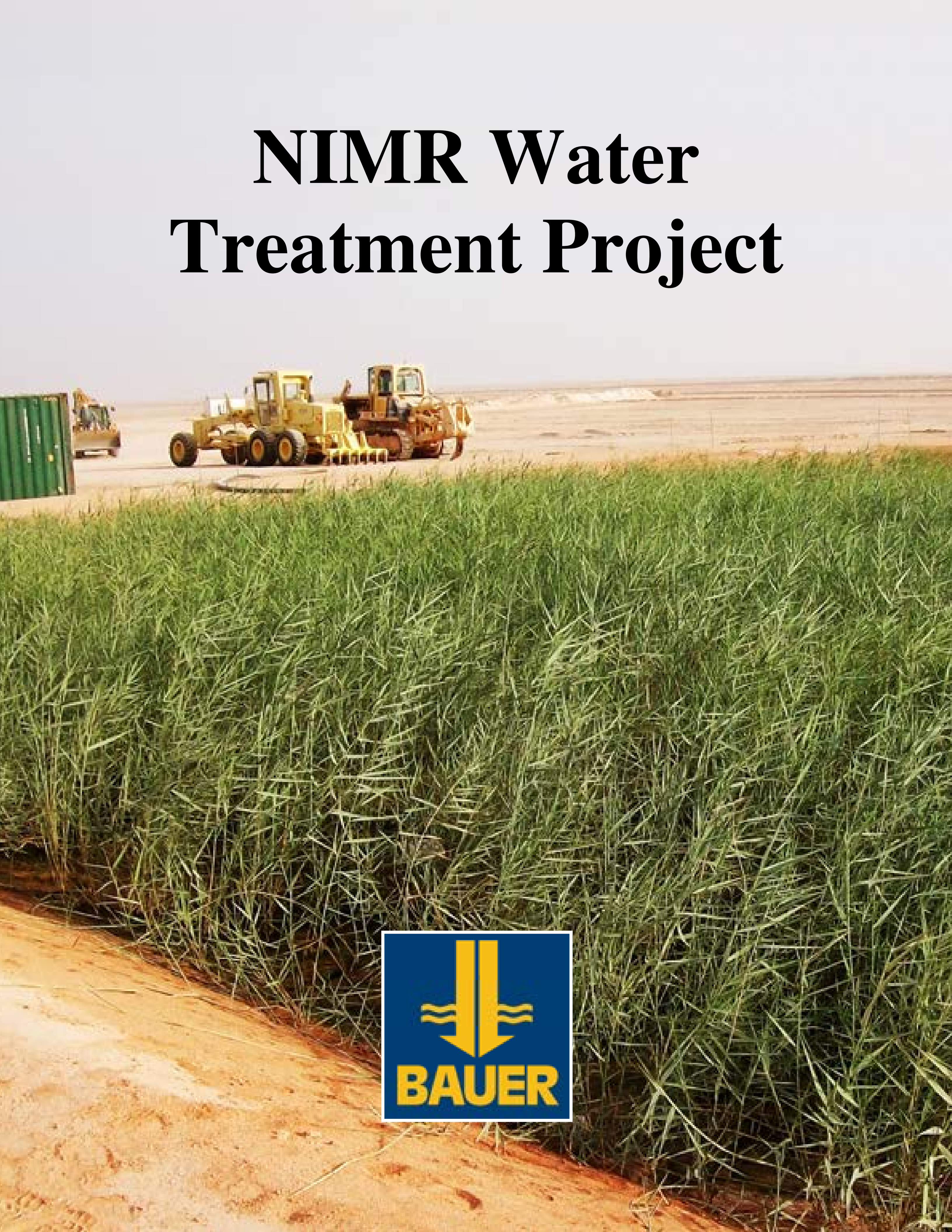
NIMR Water Treatment Project



COMMERCIAL SCALE PRODUCED WATER TREATMENT USING WETLANDS–REDUCING THE ENVIRONMENTAL IMPACT OF OILFIELD OPERATIONS

Roman Breuer, BAUER Umwelt GmbH, Edelshausen, Germany

ABSTRACT

The Nimr Water Treatment Project is being set up for the residual waters produced from the Petroleum Development Oman (PDO) oil wells in its Nimr Oil Field with a capacity to process a minimum of 45,000 m^3/day produced water. PDO initially established a pilot project 10 years ago in the Nimr Oilfield in the Sultanate of Oman and is now aiming to upscale the pilot by installing the first commercial produced water treatment plant based on wetland technology.

The technology used for the pilot plant was adapted and changes were made based on pilot test results, an extended study of the water characteristics and climate data. The result is the construction of an approximately 600 ha large facility comprising of an Oil/Water Separator to recover remaining crude oil, a Surface Flow Constructed Wetland to degrade dissolved hydrocarbons and in a second project phase an engineered salt works facility shall be installed to include the option for salt recovery from the saline discharge water.

The project was designed as a Build-Own-Operate contract with a design and construction phase of two years and an operational phase of 20 years.

In a third project phase potential benefits of biomass utilisation and carbon credit shall be investigated to be potentially included into the project after commissioning.

Nimr Oilfield landscape in the Sultanate of Oman

INTRODUCTION

In Oman about 800,000 m^3/d produced water are generated in the oilfields all over the country. The Nimr oilfield itself has a daily water output of more than 240,000 m^3, which was likely to increase to more than 270,000 m^3 by the end of 2009 (PDO 2007) (1). In the USA Texas only is producing 3.2 Mio m^3 of produced water a day along with its oil and gas production (Veil 2010) (2), while the USA produces 8.8 Mio m^3/d.

The project is bound to set up a facility with a capacity of 45,000 m^3/day produced water by means of Oil/Water Separation, a Constructed Wetland and finally Evaporation Ponds to initially treat 1/5 of the daily water output. Furthermore provisions have been made to increase the facility to a capacity of 90,000 m^3/d.

The Nimr oilfield itself is located in the Southern part of Oman about 700 km away from its capital Muscat. Infrastructure in this area is very limited and only existent to cater for the oilfield facilities.

Deep wells have been used in the Nimr Oilfield where the water is disposed by booster pumps into aquifers. Disposal into shallow aquifers was phased out in 2005 due to environmental issues (Al-Masfry et al.) (3) leaving PDO with a deep water disposal option only. This activity is causing high energy consumption in an environment with limited power supply.

On average, per barrel oil produced in the world about nine barrels produced water will be pumped to the surface. This water has to be handled, treated and disposed off. Worldwide a daily crude oil production of 87 Million barrels per day was recorded (in 2005 (Khatib et al. 2003)) (4). The Nimr oilfield produces between 120,000 to 140,000 barrels of oil per day which translates to an oil water ratio of 1/10.

Start of the levelling works on site

Installation of a HDPE liner in the buffer pond area

SCOPE AND TECHNICAL BACKGROUND

From the client side a 32 km² plot was made available for the purpose of setting up the facilities as well as a pipeline to connect the oil production facilities with the water treatment plant. BAUER as the contractor is responsible for treating and reuse of the treated water for a period of 20 years.

The produced water characteristics typically show high dissolved solid content as well as high Sodium and Chloride concentrations and some very specific elements like Boron and Strontium, see Table 1.

Table 1: Produced Water Data, Nimr Oilfield

Parameter		**Concentration**	
Conductivity @ 21 °C		11.18	ms/cm
pH @ 20 °C		7.9	
Aluminium	Al	2.2	mg/L
Boron	B	4.1	mg/L
Calcium	Ca	86	mg/L
Magnesium	Mg	31	mg/L
Manganese	Mn	0.19	mg/L
Potassium	K	29	mg/L
Silicon	Si	10	mg/L
Sodium	Na	2450	mg/L
Strontium	Sr	4.3	mg/L
Sulphur	S	99	mg/L
Chloride	Cl^-	3058	mg/L
Sulphate	SO_4^{2-}	260	mg/L
Bicarbonate	HCO_3^-	488	mg/L
Total Dissolved Solids(TDS)		6980	mg/L
Total Suspended Solids(TSS)		20	mg/L
Oil in Water		150	ppm

On average, the remaining oil concentration is at 150 ppm but can be as high as 1,000 ppm at peak times. The proposed technical solutions had to cope with all these circumstances and provide a comprehensive solution.

The core of the system is an advanced and innovative, technically upgraded Reed Bed treatment system (Constructed Wetland) based on the experience of an existing pilot plant at Nimr and experience from wetland systems designed and build by BAUER in Germany, Europe and the Middle East (Breuer 2010) (5), see Figure 1 Nimr Water Treatment Plant – Design Overview.

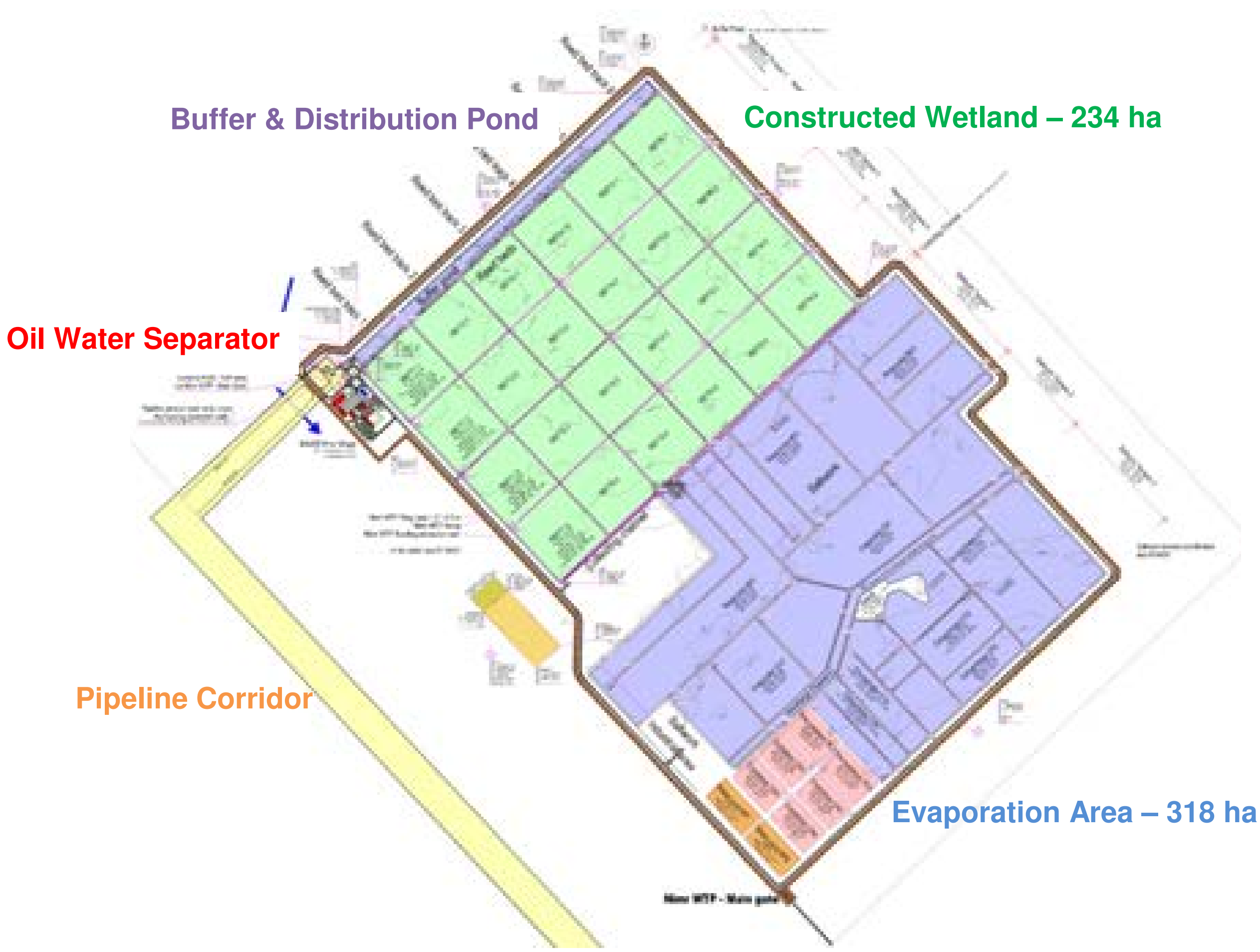


Figure 1: Nimr Water Treatment Plant Design

To improve the treatment process BAUER has thoroughly evaluated the disadvantages of the existing pilot system. The major deficiencies have been eliminated and the system has been designed with focus on minimising operational costs (Breuer 2010) (5).

The result is the construction of an approximately 600 ha large facility comprising of an Oil/Water Separator to recover remaining crude oil from the produced water, a Surface Flow Constructed Wetland to degrade dissolved hydrocarbons as well as an evaporation area to reduce the water quantities and concentrate the effluent to provide a source for salt production.

In a second project phase an engineered salt works facility shall be installed to include the option for salt recovery from the saline discharge water.

One of the key design parameters was to ensure gravity flow of the water allowing the system to operate with a minimum external power requirement using the local topography, see Figure 2 - Nimr Water Treatment Plant – Wetland Cross Section.

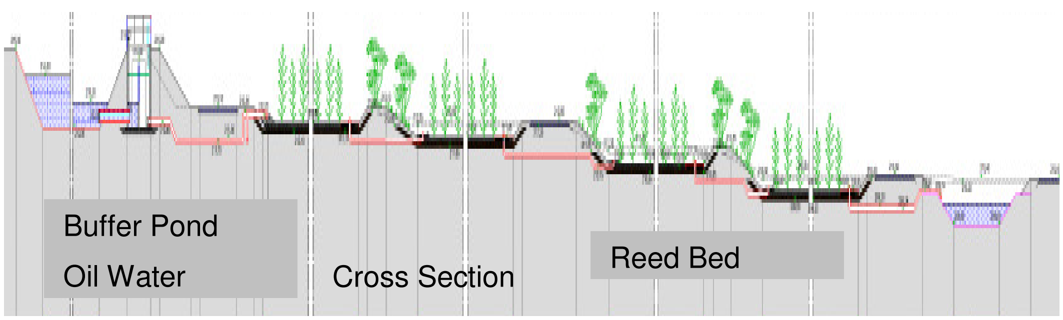


Figure 2: Nimr Water Treatment Plant – Wetland Cross Section, gravity flow operation

Therefore a suitable location nearby the oil production facilities was chosen with a favourable topography. Compared to the deep disposal wells the Wetland plant uses only 1/50 of the energy consumed including all infrastructure facilities around translating directly to reduction of Carbon Emissions.

Special mineral sealing layers have been developed using locally available soil material to reduce the environmental and cost impact by HDPE liner. HDPE liner is only used in the initial buffer and distribution area where no degradation of the hydrocarbons has taken place by the wetland system. The following picture shows the installation of the sealing layer in the buffer and distribution pond and the installation of the mineral sealing layer within the wetland area.

Installation of a mineral sealing layer

As the location is about 700 km away from the Sultanate of Oman's capital Muscat immense logistic measures would have been required to install an artificial underground sealing. Furthermore the production of HDPE materials requires high input of resources. Finally the installation of a mineral sealing layer considering the total chain of from production of material, transport up to installation is not only by more than 50 % less energy consuming but also a commercially more economic solution. Constantly performed permeability tests have proven that the previously predicted sealing permeability with a $k_f = 1*10^{-7}$m/s (resulting form laboratory tests) can almost be achieved when implemented on site with an average $k_f = 1.34* 10^{-7}$m/s.

The Reed Nursery, producing more than 1,200,000 phragmites australis

Project Implementation

The facility implementation covering 600 ha is on schedule to be commissioned in January 2011. A Wetland area of 234 ha has been completed and the plantation of 1,200,000 locally produced Phragmites australis plants will start in September 2010 to establish a mature biological system before the final commissioning. Works on a 4,000 m^3 capacity Oil/Water Separator and a 192,000 m^3 Buffer Pond are about to be completed. 42 km earth dams, 12 km roads and 800,000 m^3 sealing and substrate layer will be implemented until commissioning.

Environmental Footprint and Carbon Emission

- Oil Recovery

Potentially an average of about 40 barrels of oil can be recovered in the oil water separator per day. This translates to more than 14,600 barrels per year worth 1 Mio US $ at a price of 70 $ per barrel. All recovered crude oil will be returned at a specified quality to the client PDO allowing the oil producer to recover approximately 0.04 US $ per m^3 produced water delivered to the treatment facility.

- Biomass Production

The Wetland as a biological system fixes carbon in the plant structures through photosynthesis. Currently the common Reed, Phragmites australis is used, but other potential biomass producers shall be evaluated in the future. The later aim of the project is to utilise of the biomass.

Current estimates show that a yield of 4 to 44 t/ha of dry biomass per year (Timmermann et al 2003) (6), can be achieved offering a potential for producing a sustainable source for bio fuel. An average production of more than 9,600 t dry biomass per year for the Wetland area of 234 ha is expected and with the possibility to upscale the plant capacities further sources might become available.

- Carbon Credits – Energy Balance

With the Sultanate of Oman as a signatory of the Kyoto Protocol, the proposed treatment system would qualify under the Clean Development Mechanism (CDM) program of the United Nations to generate saleable CER’s (Certified Emission Reductions), commonly known as Carbon Credits. However, this process will be proposed in the future once the plant is in operation.

The current interest is focused on cost and power reductions. Calculations of PDO concerning the power consumption and cost impact of their current operations (DWD) would have resulted in the construction of two 3 to 5 MW sub-power stations if the wetland system was not implemented.

Table 2 compares the power requirements per m^3 produced water to be disposed off for deep water disposal wells currently used by PDO, as an example a common waste water treatment plant based on state of the art technology, and the chosen wetland option.

Table 2: Compared Power Consumption for Disposal Options based on 20 years operation

Disposal Options	Power	Total Power Used	CO_2 Emissions
	kWh/m^3	MWh	Tons
Deep Well Disposal	3.6 - 5.5	1,180,000 - 1,800,000	972,000 t CO_2 *)
Waste Water Treatment Plant	0.8	~ 255,000	137,700 t CO_2 *)
Wetland	0.1	~ 32,850	17,700 t CO_2 *)

*) 0.54 kg CO_2/kWh

The figures clearly show that the wetland has an overall advantage considering the power consumption and with a calculated use of 0.1 kWh/m^3 (Breuer 2010) (5). Overall, the project will reduce power consumption and the potential carbon emissions for produced water disposal in the Nimr oilfield within the next 20 years by more than 1.8 Mio MWh or 970,000 t CO_2 respectively. This figure becomes even more important if one determines the potential in the Nimr oilfield with more than 240,000 m^3/d water.

- Salt Production

An engineered salt evaporation area to reduce outflow water volumes to zero, to minimise waste disposal and to be able to set up salt crystallisers to produce technical grade Sodium Chloride finishes the technical status to the facility at the current development stage.

An available quantity of approximately 60,000 tons per year was calculated for a proposed salt production facility. So far the feasibility study for salt production is ongoing.

CONCLUSIONS AND FORECAST

The project approach by PDO has shown on a commercial basis that the Constructed Wetland technology is a highly competitive solution when it comes to disposal of produced water under desert climate conditions.

Oil recovery from the produced water, which may add up to a value of 1 Mio US $/year is equal to an active payback for the oil producer once the plant is in operation and reduces environmental pollution caused to the aquifers.

Energy savings by using a gravity flow system of up to 1,800,000 MWh during the whole project period compared to the current disposal mechanisms and additionally the reduction of CO_2 emission of more than 970,000 t add to the ecological balance of the oilfield operations and reduce the pressure of increasing power supply facilities.

Further options to add value have been already proposed and are under evaluation. Salt production retained from the elevated salt content of the produced water has a potential of generating up to 60,000 t/a Sodium Chloride. Biomass produced by the Reed plants is another future beneficial option to be looked at.

LITERATURE

1. PDO, Description of “Nimr Reed Bed Project”
2. Veil, John A., Clark C. E. (2010): SPE 12599 Produced Water Volumes Estimates and Management Practises, SPE HSE Conference Proceedings, Rio de Janeiro
3. Al-Masfry, R., van den Hoek, P., Verbeek, P., Schaapveld, M., Baaljens, T., van Eijden, J., Al-Lamki, M., Biezen, E.: Technology reaches water disposal, Water Management
4. Khatib, Z., and P. Verbeek, (2003), “Water to Value – Produced Water Management for Sustainable Field Development of Mature and Green Fields,” Journal of PetroleumTechnology, Jan., pp. 26-28
5. Breuer, Roman, Al Asmi, Said (2010): SPE 126265 Nimr Water Treatment Project – Up Scaling A Reed Bed Trail To Industrial Scale Produced Water Treatment, SPE HSE Conference Proceedings, Rio de Janeiro
6. Timmermann, T. (2003): Nutzungsmöglichkeiten der Röhrichte und Riede nährstoffreicher Moore