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CONSIDER PRODUCED WATER AN ASSET NOT A WASTE

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INTRODUCTION

For many years, produced water has been considered a waste product that has to be dealt with in order to produce oil and gas. In the early years of oil production it was considered a nuisance and was disposed of in the quickest possible way in order to continue with the production of the saleable products.

Little was known or understood of the problems that were contained in the produced water and technology was not available to correct the problems. This has resulted in millions of dollars having to be spent to correct environmental and process problems in order to continue with the production of oil and gas.

In many areas produced water is still considered a waste and although there are uses for the fluid it is either disposed of in the oceans or reinjected into the formations it came from.

This paper is an update of the work that has been going forward in many areas of the world to change the mind set with respect to produced water and prove that the fluid, treated properly, can be an asset for many parts of the world where there is a shortage of water.

Consider the following:

- **The surface of the earth is covered by 70% water. About 97% is saltwater and 3% is fresh water. Less than 1% is readily available[4] (Fig. 1). Most of the freshwater is used for irrigation[5,6]**
- **The world population is 6.6 billion as of September 2007. By 2050 the number is projected to be 9 billion[7]. (Fig. 2).**
- **About 44% of world's population will live in water-stressed and water-scarce regions by 2050[8] (Fig. 3).**
- **The societal thirst for water varies greatly by country ranging from 27 to 200 L/day (7 - 53 gals/day). Engineers design water treatment systems based on 284 to 757 liters per person per day (75 to 200 gallons per person per day)[9, 1]**
- **People drink water; cook; bath; water lawns and gardens; wash vehicles; grow crops, livestock, fish and trees; and manufacture. The need for water reuse and conservation is here to stay. Water is important to sustaining both the public and private sector**

Produced water from the extraction of petroleum deposits is not considered part of the world water balance. It is found water. Although the composition of produced water can vary greatly, it can be beneficially reused. Frequently, produced water can with only minimal treatment meet irrigation water quality standards. Reuse for agriculture is one application that helps to preserve groundwater for drinking. Produced water that once was considered a useless by-product may now partially become asset.

At present, there are uses for some produced water when the total dissolved solids are low and the conditioning of the water is governed by the lack of water for drilling and production and the process of cleaning is economical. Examples are the Methane in the Midwest of the USA and the steam flooding of the formations for the recovery of heavy oil.

In most cases the water is either discharged to the ocean after treatment or reinjected back into the formation, again after treatment for waterflood or pressure maintenance of the formation. However, the bulk of the water is injected into disposal wells with little or no pretreatment. (Figs. 5, 6, 7, 8, & 9).

There are no exact figures to show how much produced water is generated each day, worldwide but it would appear that the best estimates at present give the total at about 43/45 million barrels per day. Therefore it can be seen that there is every incentive to find a solution to make all this water useful in society. It will also create work that is in addition to the oilfield employment and produce products that are useful, and productive. This, it is believed has been found in "Reed Bed Technology and the additional processes that will condition the water. It would be cleaned in stages to allow such processes as fish farming, cotton growing, fruit and nut production, salt production, irrigation, potable water and lastly where economical or needed the process of generating drinking water (Fig. 10).

REED BED TECHNOLOGY

Reed bed technology is a general term which is however not quite correct. The description of the overall process is termed "Constructed Wetlands" of which the reed bed filtration is an integral part. The technical term is "Phytoremediation"

The technology is the mainstay in the removal of dissolved hydrocarbons en route to the final conditioning of the water. It is not the intention of this paper to delve into the technical aspects and process evaluations; however the biggest impediment to the cleaning or conditioning has been the removal of the dissolved content in the water. This is now achievable with the reed beds, trees and other mechanical process and it should be realized that with the removal of hydrocarbons, there are now many uses for the fluid which can be productive such as fish farming. Tilapia is one fish that is high salt tolerant and can live in heavy brine water plus there are many others.

Water can be circulated through the fish farms and then filtered for other uses. There are various strains of cotton that can be grown with salty water but normally the salt would be removed and then used as irrigation for many varieties of produce that are needed to feed populations world wide.

Side streams can be taken off the main process for ultra filtration or reverse osmosis to produce different qualities of water and then the waste streams from these processes can be returned to the mainstream for dilution and further cleaning.

There are also further byproducts and processes in connection with the main flow of the produced water cleanup. Replacement reeds will be considerable which will call for the set up of a market garden facility to grow the new reeds. Also the waste reeds have a high calorific value and therefore can be used with the modern day hydrogen burners instead of natural gas to create steam and electricity.

On point has to be stressed however. The system will not function efficiently without the removal of all suspended oil and solids from the produced water before it is introduced into the reed beds. Pictures #

Areas where the process is being already being piloted or used

- **USA**
- **Sudan**
- **Oman**
- **Africa**
- **Canada**
- **United Kingdom**
- **Others**

Conclusions

Water is life. The lack of available freshwater and an increasing world population will make water reuse and conservation key to the sustainability of public and private sectors. Cities must have water. So must industry and farmers.

The petroleum industry is a position to create value out of what was once considered a useless by-product. Produced water (and other water) can be beneficially reused (agriculture, aquaculture, Silviculture and wildlife habitat).

The Future

Water reuse in the future may entail:

- **Policies to promote water reuse, water conservation and sustainability,**
- **Tax incentives,**
- **Water exchange banks,**
- **Additional water reuse standards,**
- **Changes in public attitudes related to water reuse, and**
- **Links to biofuel production and carbon sequestration.**

As water becomes scarcer governments and institutions are likely to pursue policies that promote water reuse, water conservation and sustainability. We may see tax incentives. Water exchange banks may help broker deals to match those with water with those who need water. As additional water is reused, it is expected that more complete water reuse standards will develop. Produced water may also be reused to grow biofuel crops and sequester carbon.

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Figures and Tables

Distribution of earth's water[5]. Easily accessible freshwater represents less than 0.01% of the earth's water

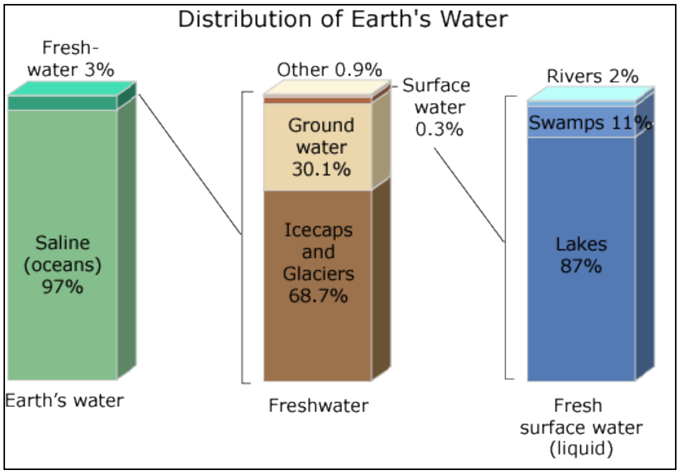


Figure (1)

The Projection of Water Availability in 2025[4].

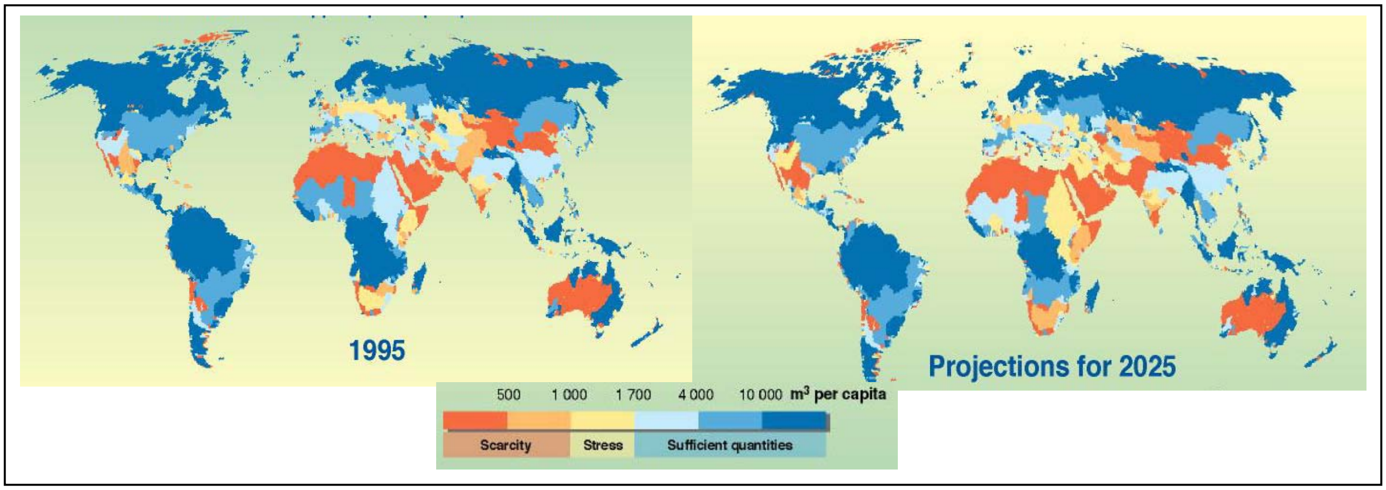


Figure (2)

Water Scarcity & Stress[6]

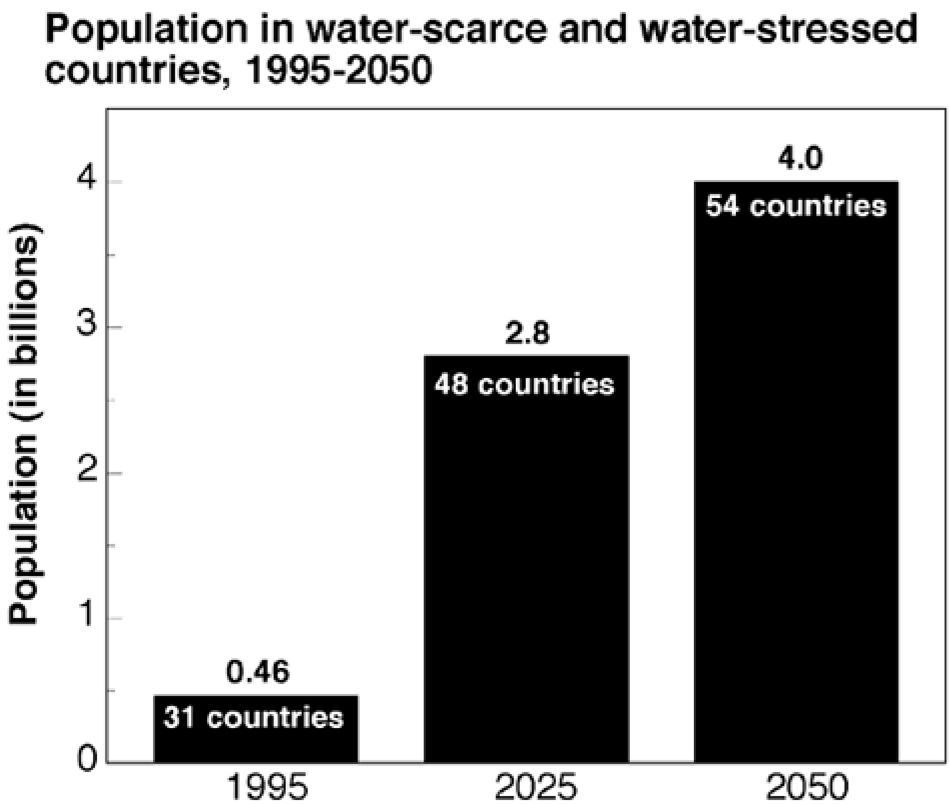


Figure (3)

Convergence of Petroleum Industry, Water Shortage and Human Population

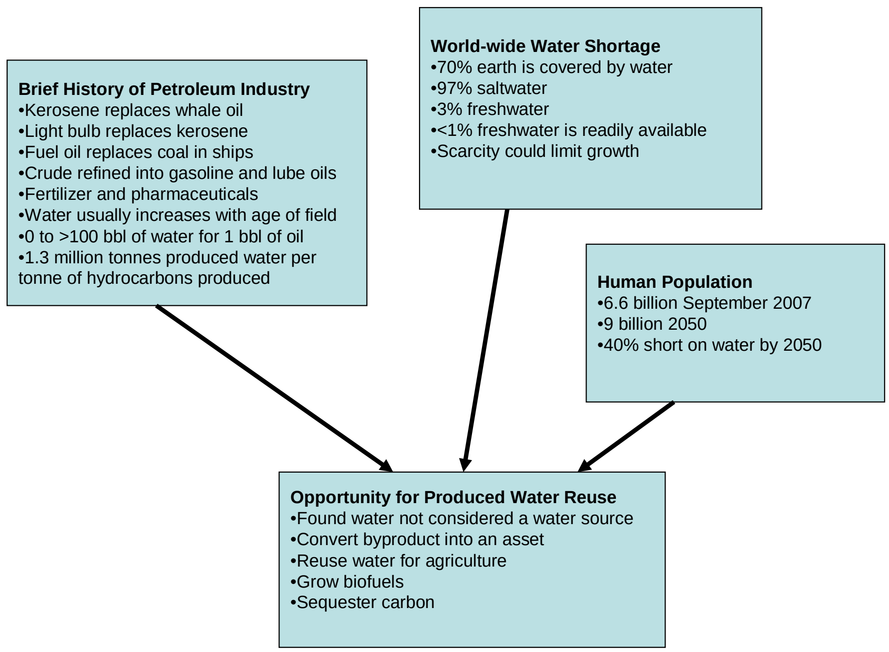


Figure (4)

Wastewater Treatment Classification

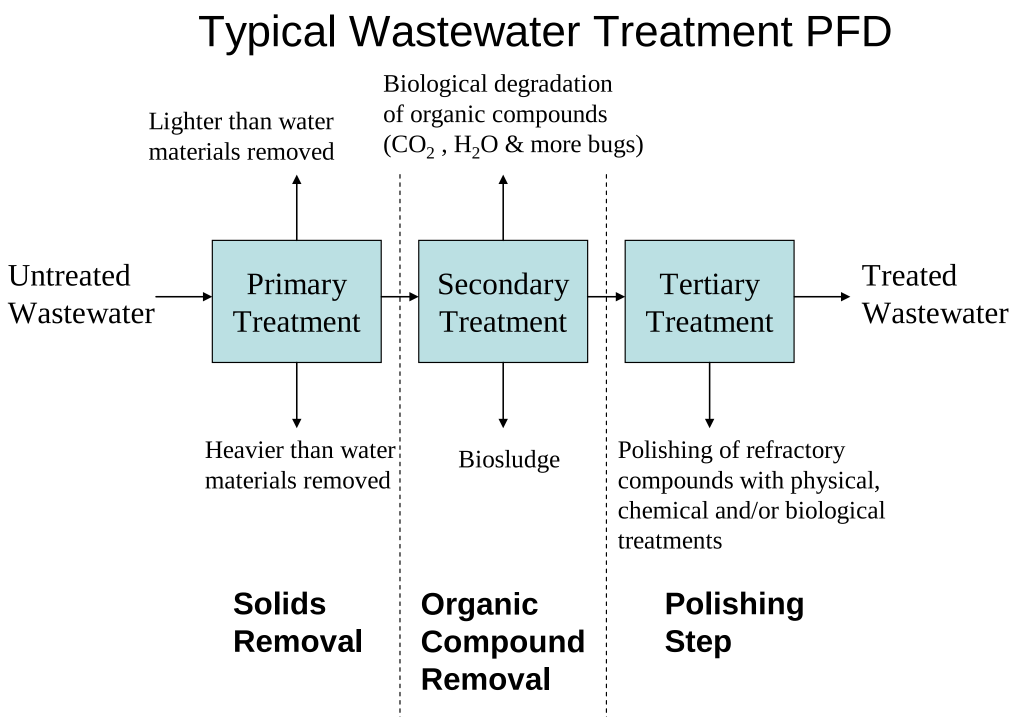


Figure (5)

Refinery Wastewater Treatment Example PFD

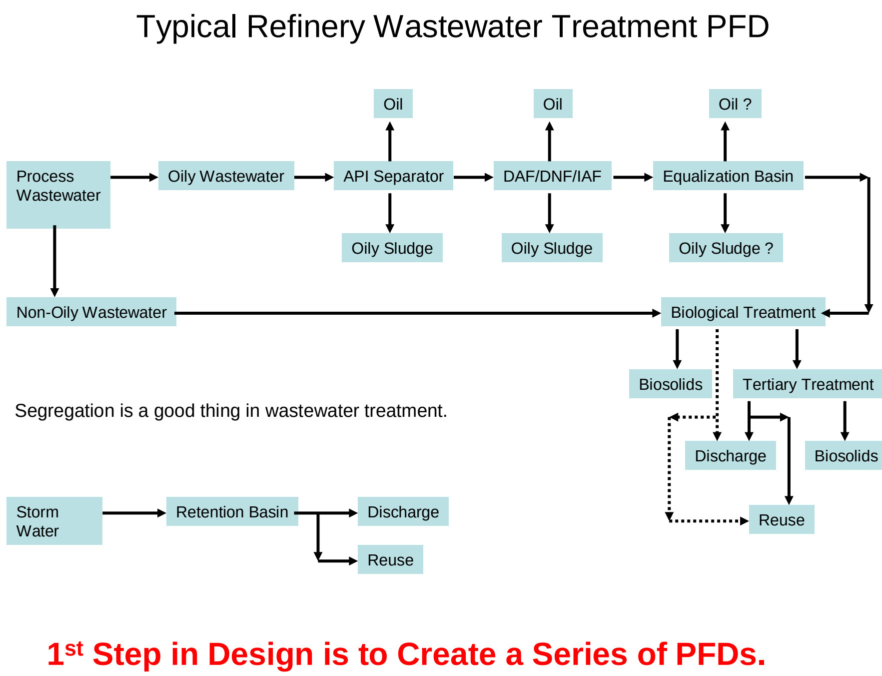


Figure (6)

Produced Water Reuse Alternatives PFD

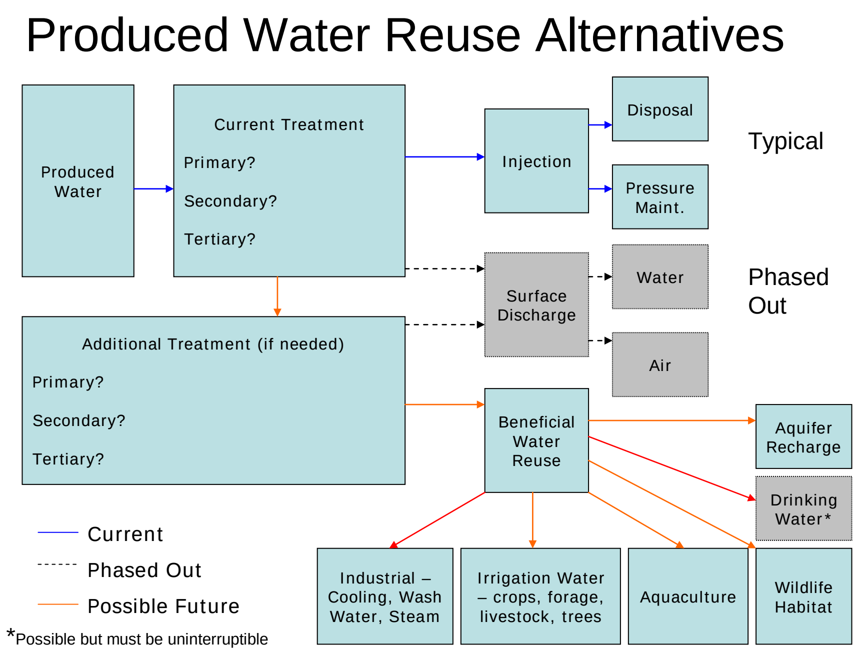
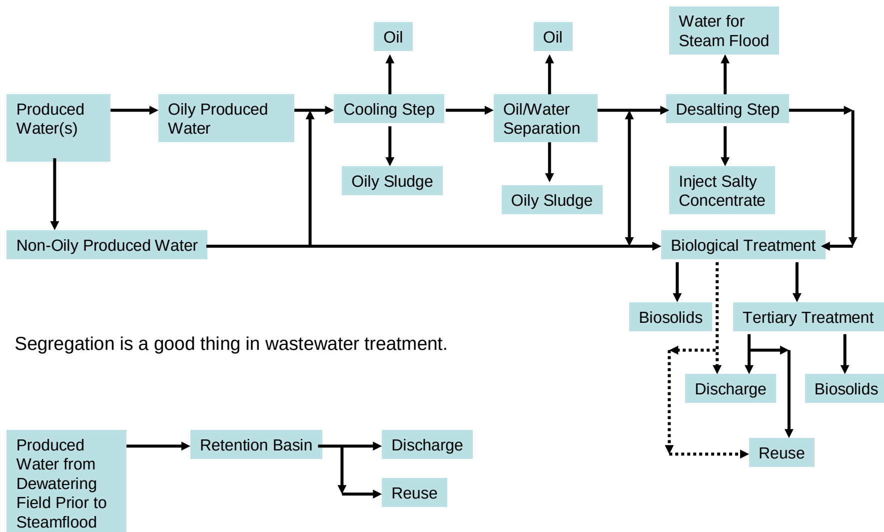


Figure (7)

Produced Water Treatment Example PFD

Typical Produced Water Treatment PFD



1st Step in Design is to Create a Series of PFDs.

Figure (8)

Produced Water Evaluation PFD

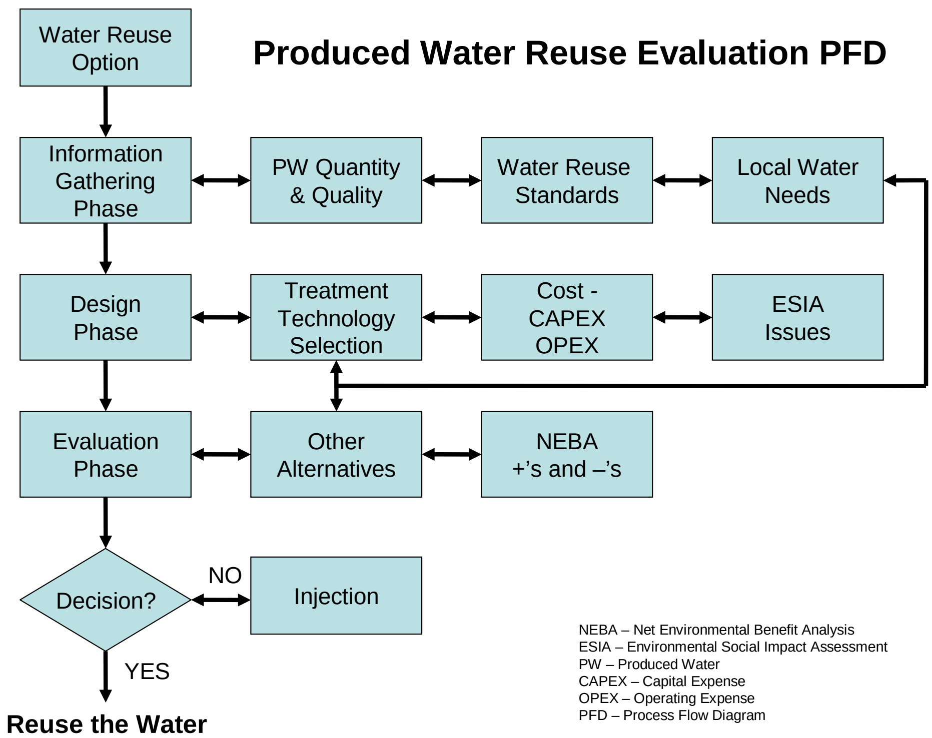


Figure (9)

Typical Wetlands Process flow Diagram

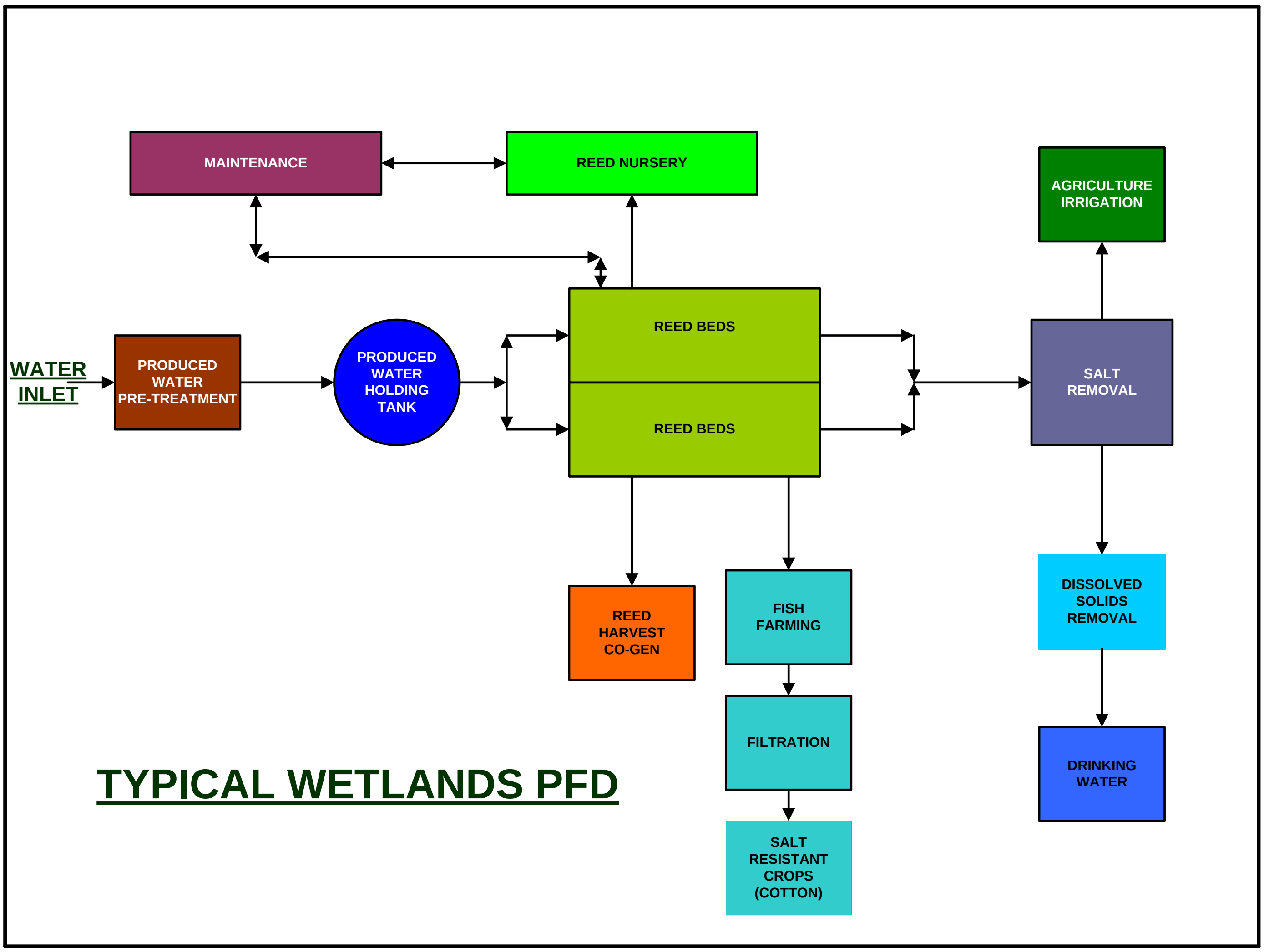


Figure (10)

Typical Wetlands adapting to Process conditions

Contaminated rainwater run-off from the Forties Pipeline pumping station at Cruden Bay has been successfully treated using reed raft technology.

The system required only minor modification to the site, was cheap to install and there have been no further breaches of the discharge consent.

Such systems could be used at any operational site where small amounts of oil, detergents and other organics enter the rainwater drainage, a problem that is

Table 1: Water Treatment Technologies

Water Treatment Grouped by Function	Comment
Primary Treatment - Oil/Water Separator/Tanks - API - CPI/Flotation/Enhanced Flotation - DAF- IAF- Clarifier - Hydrocyclone/Media Filters/Cartridge Micro/Nano Filtration - Treatment Wetland	Gravity settling of solids heavy than water. Float oils lighter than water. Entrain oil with air/gas bubbles. Use density differences to remove solids and oils. Mechanical means of fine removal Fine Particle removal Suspended and dissolved removal
Secondary Treatment - ASTU - SBR - Facultative Lagoon - RBC - Aerated Lagoon - Anaerobic Filter - Treatment Wetland - MBR - Trickling Filter - GAC	Biological treatment uses micro-organisms to consume organic compounds in an ambient temperature combustion reaction. Some of the treatments are energy intensive with small physical footprints. Others are not energy intensive but have large physical footprints.
Tertiary Treatment - Activated Carbon - Filtration - Chlorination - UV - Chemicals (FeCl, O3, H2O2)	Polishing treatments remove the refractory compounds by physical, chemical and biological means.
Salts (desalting) - RO - FO	Salt removal is typically to meet irrigation water standards (EC/TDS/salinity). Some of the membrane technologies require pre-

Water Treatment Grouped by Function		Comment
- ED - Freezing	- NF - UF	treatment (solids removal) to avoid membrane fouling.

Table 2: Potential Water Reuse[12]

Category	Typical Application
Agriculture	Crop irrigation Commercial nurseries
Livestock	Cattle Sheep Pigs Chickens Waterfowl
Aquaculture	Fish Shrimp Frogs Bait
Silviculture	Tree farming
Landscape Irrigation	Residences Golf courses Parks Cemeteries Freeway medians Greenbelts School yards
Industrial Recycling and Reuse	Boiler feed water Fire protection Cooling tower Process water Manufacturing Vehicle washing

	Dust control
Groundwater Recharge	Groundwater replenishment (water banking) Salt water intrusion control Subsidence control
Recreation	Lakes, streams and ponds Snow making
Wildlife Habitat	Marsh Restoration Habitat Enhancement Fisheries
Non Potable Urban Use	Fire protection Air conditioning Toilet flushing
Potable Use	Blending in water supply reservoirs Blending in groundwater Direct pipe to pipe water supply

Table 3: Brief Overview of Water Reuse Standards

Reference	Category/Comment
Health Guidelines for Use of Wastewater for Agriculture and Aquaculture by WHO (1989)	Focus on helminth removal
Guidelines for Water Reuse by USEPA (1992)	Focus on municipal water
Water Reuse[13] (2007)	Compilation of municipal and agricultural standards
Water Encyclopedia[14] (2007)	Compilation of water standards
USA State Regulations on Water Reuse	Most have USEPA like standards
Forestry Standards (several sources & university papers)	Trees tend to tolerate lower quality water than other plants
Fishery Standards (several sources & university papers)	Focus is the taste of fish in commercial fish farming operations
AB Canada	Comprehensive lists including treatment technologies

Table 4: Water Reuse Analytical Testing Parameters for Irrigation[12]

		Degree of Restriction on Use		
Irrigation parameter	units	None	Slight to Moderate	Severe
		Salinity		
EC	dS/m	<0.7	0.7-3.0	>3.0
TDS	mg/L	<450	450-2000	>2000
Sodicity				
SAR, 0-3		and EC ≥0.7	0.7-0.2	<0.2
3-6		≥1.2	1.2-0.3	<0.3
6-12		≥1.9	1.9-0.5	<0.5
12-20		≥2.9	2.9-1.3	<1.3
20-40		≥5.0	5.0-2.9	<2.9
Specific Ion Toxicity				
Sodium (Na)				
Surface irrigation	SAR	<3	3-9	>9
Sprinkler irrigation	mg/L	<70	>70	
Chloride (Cl)				
Surface irrigation	mg/L	<140	140-350	>350
Sprinkler irrigation	mg/L	<100	>100	
Boron (B)	mg/L	<0.7	0.7-3.0	>3.0
Miscellaneous effects				
Nitrogen (total N)	mg/L	<5	5-30	>30
Bicarbonate (HCO_3)	mg/L	<90	90-600	>500
(overhead sprinkling only)				

pH	s.u.		Normal range 6.5-8.4	
Residual chlorine (overhead sprinkling only)	mg/L	<1.0	1.0-5.0	>5.0

Table 5: Typical Irrigation Water Test Parameters

Constituent
Alkalinity (as $CaCO_3$ to pH 4.5)
Ammonium
Barium
Bicarbonate
Boron
Calcium
Carbonate
Chloride
Conductivity, Electrical
Free Carbon Dioxide
Hydroxide
Iron
Magnesium
Nitrate
Potassium
Residue, Filterable
Silicon
Sodium
Specific Gravity
Strontium
Sulfate
Temperature
pH

Table 6: Water Reuse Examples

Case	Setup	Reuse	Comment
California Produced Water[3]	Oil/Water Separation, Walnut Shell Filter, Cooling Pond	Agriculture	Chemical and mechanical treatment. Small footprint. Reused water grows >40 crops.
California Produced Water	Oil/Water Separation, Cooling, RO, CTW	Agriculture	RO for salt removal to meet irrigation water standards. Reused water recharges irrigation aquifer.
California Produced Water Demonstration Wetland	Oil/Water Separation, Walnut Shell Filter, Cooling Pond, Treatment Wetlands	Agriculture	Test program capturing data from multiple cells, plant species, planting densities and construction Costs.
Ohio Closed Refinery Storm & Ground Water	Oil/Water Separation, GAC, Pond, CTW	Wildlife	Wetland is winning wildlife awards (pollinator and waterfowl). WHC certified wildlife management plan.
Mid-west Refinery Wastewater	Oil/Water Separation, ASTU, Facultative Lagoon, CTW	Wildlife	Gravity fed CTW. Pump once. Let gravity do the rest. Large wetland is attracting wildlife use. IOGCC award. WHC certified.
Wyoming DOE CRADAs Pilot Studies	Oil/Water Separation, Cooling, Facultative Lagoon, CTW	Wildlife Agriculture Aquaculture	Series of pilot CTW studies. Reused water irrigates a normally dry stream creating grazing habitat for mule deer and elk.
Far East Produced Water Feasibility Study	Oil/Water Separation, Cooling Pond, CTW	Agriculture Aquaculture Silviculture	Several applications possible. Lack of infrastructure makes water hand-off challenging.

Africa Produced Water Feasibility and Pilot Studies	Oil/water Separation, Cooling Pond, CTW	Agriculture Livestock	Several applications possible. Lack of infrastructure makes water hand-off challenging.