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## Treatment of agricultural drainage water: technological schemes and financial indicators

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### Abstract

Treatment and application of agricultural drainage water (ADW) has become mandatory to cope with the shortage of potable water. In Egypt, current water supply plans comprise increasing utilization of the ample resource of ADW. The current limitations facing wider utilization of secondary sources in general and, ADW of particular, need extensive funding requirements. Best available technologies and consequently high level of capital have been required to implement treatment works. This paper presents techno-economic aspects of treatment and reuse of polluted surface water resulting from mixing river water with ADW. Proposed technological treatment schemes are first discussed. Further, the selected integrated treatment scheme based on conventional and advanced physico-chemical techniques is elucidated. Membrane separation has been incorporated to achieve removal of residual pollutants as well as salinity reduction. Further, the paper is concluded with a techno-economic assessment of the proposed treatment train for 110,000 m<sup>3</sup>/d treatment facility. The results indicate promising features of the proposed scheme. Complementary studies are needed to assess potential environmental impacts under normal conditions.

*Keywords:* Drainage water; Treatment; Cost; Membrane

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## 1. Introduction

The utilization of agricultural drainage water (ADW) and marginal quality surface water is an emerging necessity to deal with severe water shortage in arid and semi-arid land. Upgrading of ADW may enable appropriate schemes for controlled application depending on treated ADW or via mixing with other sources of surface water.

Obviously, the issue of utilization of marginal quality water is governed by numerous considerations comprising level of treatment technology, economic limitations, applicable environmental legislations and social acceptability.

Recent technological advances enabled identification of technically feasible schemes for the treatment of marginal quality water [1–5]. Those packages rely on recent innovations in the areas of biological and physico-chemical treatment. In addition, the last two decades witnessed the development of reliable membrane separation systems enabling cost-effective processing of marginal quality water to achieve the most stringent health and environmental standards. Dual and triple membrane separation schemes such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO) and MF/NF/RO are examples of powerful integrated membrane schemes.

The optimal performance of membrane separation technology is closely related to the successful selection and operation of a pretreatment system whose selection is related to the characteristics of feed stream and the requirements of downstream membrane separation. Numerous integrated packages have been proposed for the treatment of ADW including but not limited, to the following:

- Plain sedimentation.
- Chemical precipitation and aerated lagoons.
- Activated sludge.
- Tertiary treatment comprising chemical precipitation, biofiltration and sand filtration.
- Physico-chemical treatment comprising chemical precipitation, sand filtration, activated carbon

adsorption, nanofiltration and ozonation.

- Chemical precipitation, sand filtration, chemical oxidation, activated carbon, EDR and ion exchange.

This paper addresses the techno-economic aspects of ADW treatment with identification of techno-economically feasible intervention scenarios. Moreover, the results of reassessment of polluted surface water treatment package will be discussed.

## 2. Treatment rationale

Planning of treatment interventions pertaining to ADW or mixed ADW and surface water should consider the following:

The characteristics of ADW should be monitored for sufficient length of time to quantify pollution loads and seasonal changes. In addition, hazardous contaminants level and their possible sources should be identified and eliminated. Further retrospective data should be also considered.

Consideration of TADW uses:

- Identification of potential uses of TADW and structured interview of different aspects of demand pattern.
- Careful definition of treatment objectives to meet the requirements of potential concerns.
- Exploring the reliability and economics of alternative water supplies.

Feasible technological schemes should be identified and assessed based on techno-economic, environmental and social grounds. Initial screening is based on environmental impact consideration and risk assessment. Addressing of biological treatment is needed in case of land availability due to reliability in remote arid zones. Additional advanced post treatment may be needed to remove residual hazardous components to meet target criteria of specific consumers.

Process design of the target treatment scheme should permit:

- Multiple outlets along the process line to cope

with quality needed.

- Mixing TADW with other surface water stream to cope with availability and quality considerations.

### 3. Technology modules

Numerous technologies are commercially established to enable removal of suspended solids, biological/organic and inorganic pollutants. Selection of an integrated package should consider reliability and cost effectiveness for each specific module. Performance indicators of some adopted treatment technology modules are shown in Table 1.

### 4. Proposed ADW treatment packages

Three ADW treatment packages have been proposed as shown in Figs. 1–3 [9–12]. These schemes cope with seasonal variations of ADW characteristics. The selected schemes comprise:

#### *a Integrated biological/membrane separation*

This scheme assumes availability of cheap lands for construction of aerated lagoons and polishing ponds. The biologically treated ADW will be further processed by triple filtration assembly including sand, carbon and nanofiltration. The use of RO is optional in case of high dissolved solids. This scheme enables multiple outlets specifically after sand filtration, nanofiltration and RO.

#### *b Complementary treatment using membrane separation*

This scheme comprises chemical precipitation and biological filtration. Filtration will be conducted the same filtration assembly using sand/carbon/membrane filtration. EDR will be used to desalt low salinity brackish water. The generated brines will be subjected to further water extraction by RO. Obviously, this scheme is suitable in locations manifesting scarcity of land and low salinity ADW.

Table 1  
Performance indicators of selected treatment modules [6–8]

	Module	% removal			
		SS	DS	BOD	T. heavy metal
1	Screen	2			
2	Grit removal	2		3	
3	Equalization			10	
4	Chemical treatment	50–75		30–48	83–92
5	Dissolved air flotation	84		50	80
6	Sand filter	68		28	
7	Wet land	62		87	
8	Activated sludge	71		88	15
9	Trickling filter	80		85	
10	Aerated lagoons	68		80	
11	Anaerobic lagoons	60		79	
12	Activated carbon	60		63	60
13	Ultra filtration	96	90		
14	Ion exchange	97	95		80
15	Micro filtration	90			
16	Electrodialysis		95		
17	Reverse osmosis		95	10	

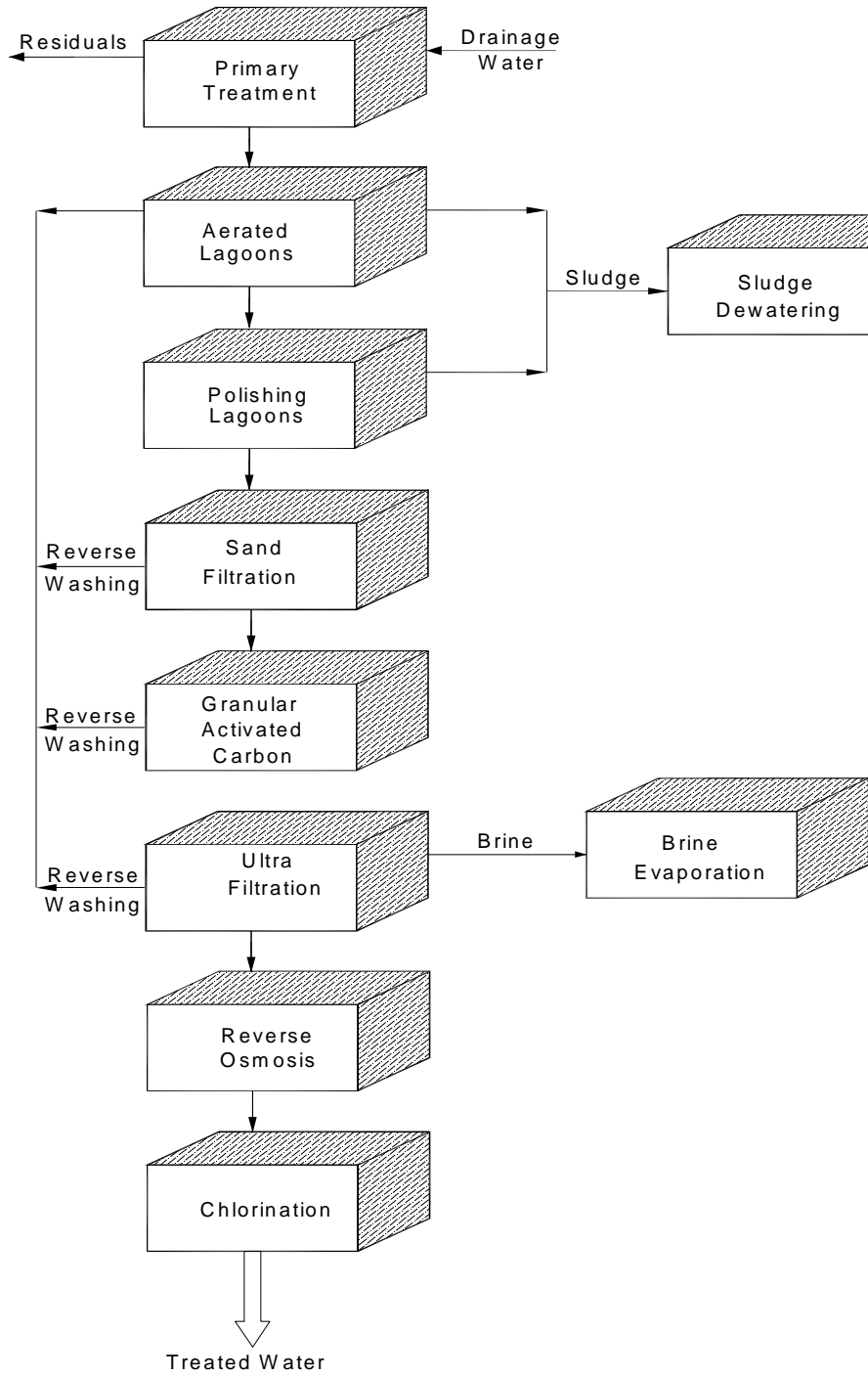


Fig. 1. Integrated biological-membrane treatment scheme (a).

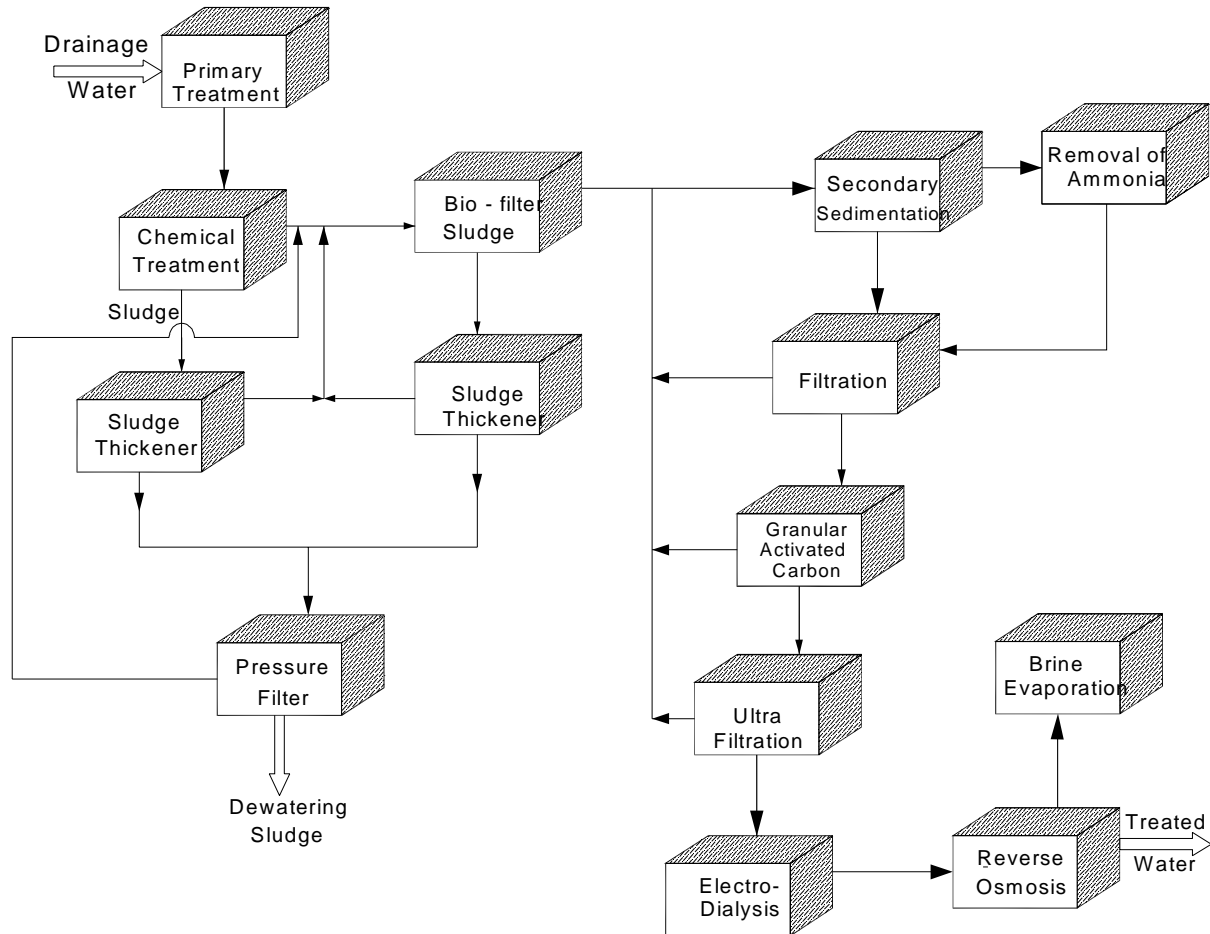


Fig. 2. Complementary treatment through membrane systems (b).

### c Heavy metals containing effluents treatment

This scheme comprises slow sand filtration, activated carbon adsorption and ion exchange separator. This scheme is suitable ADW with low BOD and significant concentrations of heavy metals. Effluents produced through bed regeneration or carbon backwash are considered hazardous and should be treated by specially designed evaporation lagoon and subsequent disposal onto secure land fill.

The quality of TADW matches the anticipated specifications of numerous commercial and in-

dustrial uses. Financial indicators of the adopted ADW treatment schemes are summarized in Tables 2 and 3 [13–20].

### 5. Treatment of mixed ADW and surface water stream

An earlier study provided a detailed technical package for the treatment of mixed ADW and surface water [6]. The elements of technical package are shown in Fig. 4. Reassessment of the proposed package indicates the following:

- Excessive consumption of chemicals would

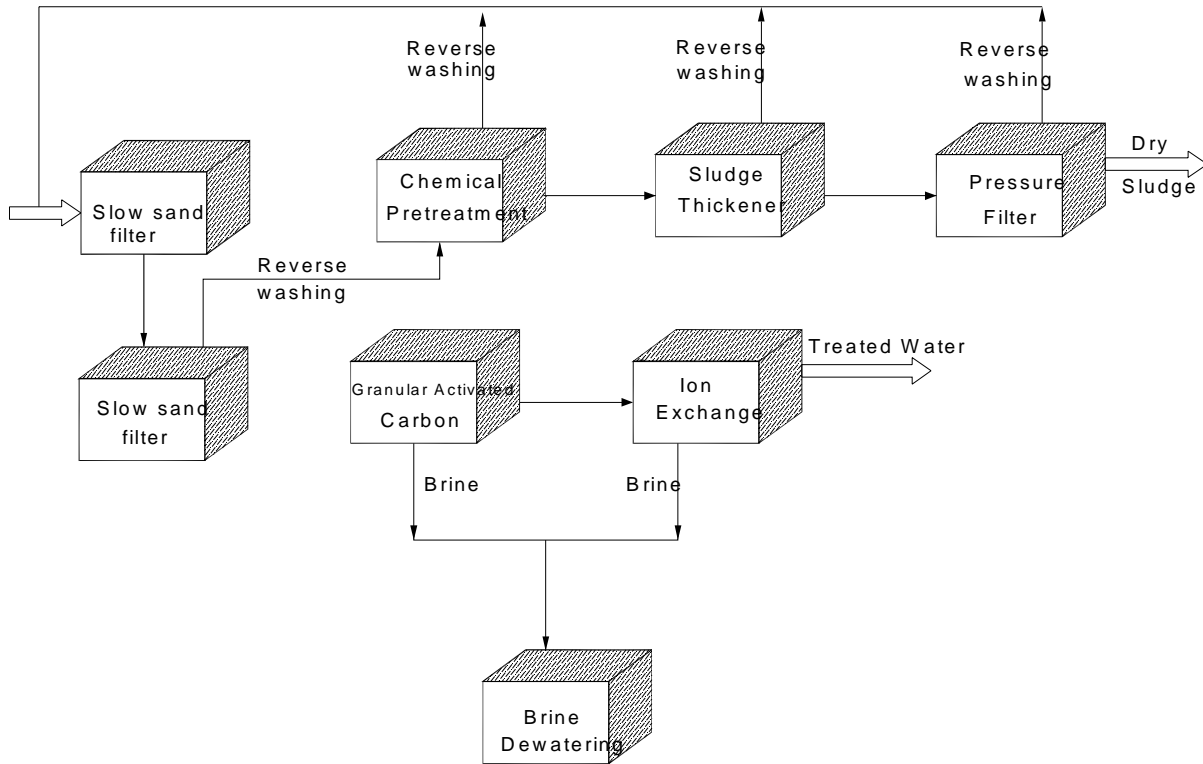


Fig. 3. Process flow diagram for T. heavy metals containing effluents treatment (c).

Table 2  
Cost indicators of the selected ADW treatment schemes

Treatment scheme	Capital cost (M US\$)	Operating cost (M US\$)		Total annual (M US\$)	Cost/m <sup>3</sup> (\$/m <sup>3</sup> )
		O&M	Depreciation		
a Based on 25 Mm <sup>3</sup> /y treated water	33,960	4	1.85	6.67	0.27
b Based on 28 Mm <sup>3</sup> /y treated water	78,632	4.97	2.07	7.04	0.26
c Based on 33 Mm <sup>3</sup> /y treated water	16,351	10.43	1.91	12.34	0.37

\* Updated to the price of the 2nd quarter of 2005 using M&S cost index.

- increase unit water treatment cost and generate excessive amount of sludge.
- The selection of biological treatment is not appropriate for remote desert communities where abundant land is available at almost negligible cost.
- Selection of two types of desalting technologies (EDR & RO) would consulate operational and maintenance difficulties. Thus, the new proposed technological package

Table 3  
Basis for maintenance and operating cost estimated of the selected treatment schemes

Item	Treatment scheme		
	a (M US\$)	b (M US\$)	c (M US\$)
1 Electricity	0.94	0.86	0.66
2 Chemical and other materials	1.2	1.1	7.4
3 Membrane replacement	0.87	1.07	—
4 Labour	0.47	0.5	0.43
5 Maintenance	0.83	0.93	0.85
6 Others	0.48	0.5	1.04
Total	4.8	4.97	10.43

manifests reliance on land treatment (aerated lagoon), elimination of pretreatment chemicals and adoption of two stage reverse osmosis. The modified technological package is shown in Fig. 5. The treatment train comprises two main parts. The first part with a capacity of 110,000 m<sup>3</sup>/d producing treated water for industrial purpose. The second part producing high quality water at a rate of 46 m<sup>3</sup>/d. The main treatment modules for the two main phases are conducted in Table 4 that comprises the capital, operating and unit cost estimates of the proposed treatment scheme. The basis of design, cost analysis and adopted cost functions are illustrated in the Appendix.

Comparison of financial indicators of the pre-

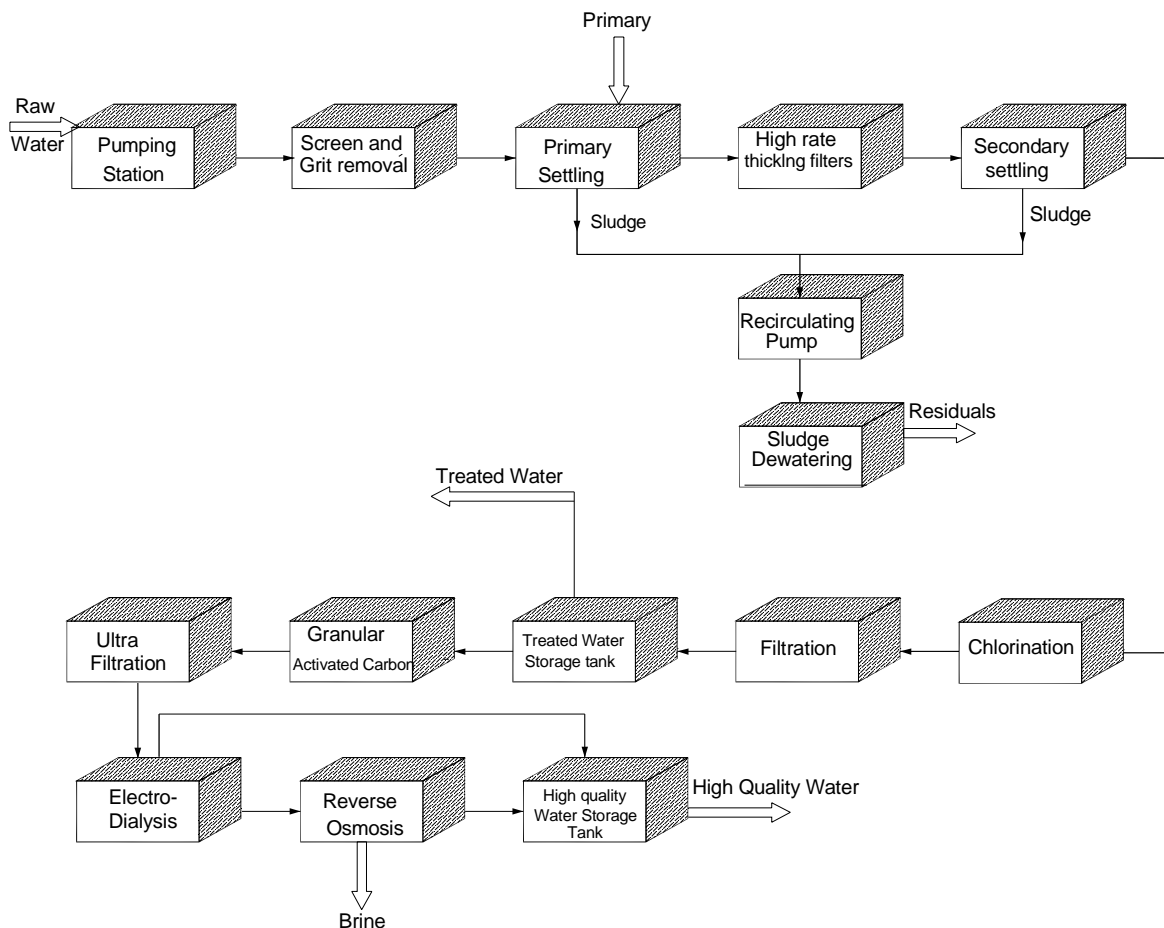


Fig. 4. Process flow diagram for mixed water treatment system (previous scheme).

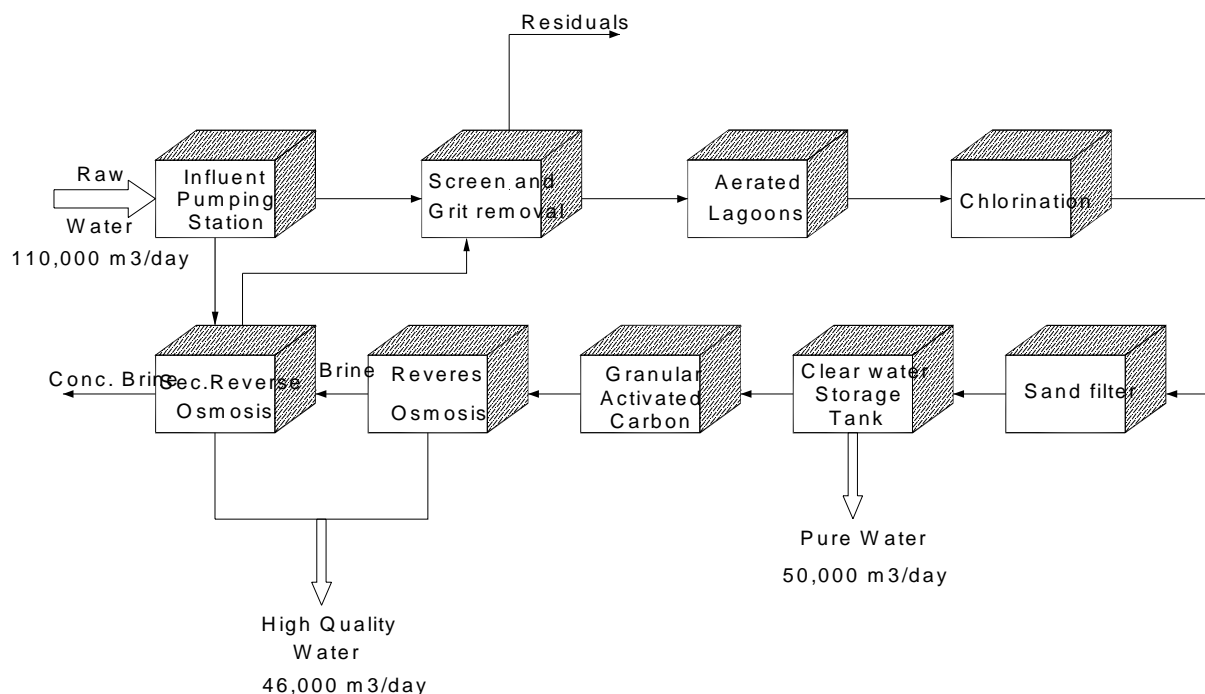


Fig. 5. Block flow diagram of the proposed treatment train.

Table 4  
Cost indicators for the proposed treatment scheme

Item	Capital cost (US\$ 4000*)	Operating cost (US\$ 1000*)		Total annual operating cost (US\$ 1000*)	Unit cost (\$/m <sup>3</sup> )
		O&M	Depreciation		
<b>A) Mixed water treatment unit (110,000 m<sup>3</sup>/d)</b>					
Construction cost					
Pumping station	2,344	197	156	353	0.009
Screen and grit removal	660	88	44	132	0.003
Aerated lagoon	2,569	310	64	374	0.0093
Chlorination unit	660	603	44	647	0.016
Filtration unit	4,063	267	203	470	0.012
Others	3,883	26		26	0.0006
<b>Total (A)</b>	<b>14,179</b>	<b>1,490</b>	<b>512</b>	<b>2,001</b>	<b>0.05</b>
<b>B) High quality water unit</b>					
Granular activated carbon (50,000 m <sup>3</sup> /d)	602	673	30	703	0.04
Reverse osmosis (40,000 m <sup>3</sup> /d)	19,365	1,953	968	2,926	0.179
Sec. reverse osmosis (brine 6,000 m <sup>3</sup> /d)	2,897	404	145	549	0.03
<b>Total (B)</b>	<b>22,865</b>	<b>3,036</b>	<b>1,143</b>	<b>4,179</b>	<b>0.246</b>
<b>Grand total</b>	<b>37,043</b>	<b>4,525</b>	<b>1,655</b>	<b>6,180</b>	<b>0.3</b>

\*According to piping, electricity, control, site preparation and others.

Table 5  
Comparison of cost indicators

Type of comparison	Proposed treatment scheme	Previous treatment scheme*
Capital cost (US\$ 1000)*		
1st part**	14,000	30,600
2nd part***	22,800	27,500
Total annual operating cost (US\$ 1000)*		
1st part	2,001	2,288
2nd part	4,179	4,131
Unit cost (\$/m <sup>3</sup> ) *		
1st part	0.05	0.06
2nd part	0.24	0.25
Grand total	0.29	0.32

\* Updated for 2005

\*\* 1st part for production of treated water (110,000 m<sup>3</sup>/d)

\*\*\* 2nd part for production of high quality water (46,000 m<sup>3</sup>/d)

vious and proposed scheme is shown in Table 5.

It is concluded that the capital cost has been decreased by 54 and 16% for the 1st and 2nd parts respectively. Also, the total annual operating cost has been decreased by 12.5% for the 1st part while it is almost the same for the 2nd part.

Further, the unit cost has been decreased by about 17% and 9% for the 1st part and 2nd part overall the system respectively.

Treatment and utilization of ADW is mandatory for development needs in arid and semi-arid zones. Planning for treatment should adopt approved rationale to come-up with optimal, reliable and socially accepted technological interventions. Three proposed technology packages have to be developed to cope with varying ADW characteristics and prevailing limitation. Reassessment of the proposed package for mixed ADW and surface water tends to confirm the improvement of the economics of the revised scheme by significant reduction in capital, operating and unit treatment cost.

Comparison of the financial indicators of the original and the revised scheme indicates about 17 and 9% reduction as far as unit treatment cost for the 1st phase and overall the system respectively, while it is almost the same for the 2nd treatment phase.

## References

- [1] Novel Technologies for Drainage Water Treatment Final Report, National Research Centre, Cairo, Egypt, 2001.
- [2] F. Huibers, Efficient use of wastewater in agriculture: potentials and limitations, International Symposium on Low-Cost Wastewater Treatment and Reuse, February 2001.
- [3] O. Sohnel and J. Garside, Precipitation Basic Principles and Industrial Applications. Butterworth – Heinemann Ltd., 1992.
- [4] Degremont, Water Treatment Handbook, 1979.
- [5] A.S.Vernick and Walker, Handbook of Wastewater Treatment Process, Marcel Dekker, Inc., 1981.
- [6] S.A. Ahmed, S.R. Tewfik and H.A. Talaat, Development and verification of a decision support system for the selection of optimum water reuse schemes, *Desalination*, 152 (2002) 339–352.
- [7] A.P. Jaclcman and R.L. Powell, Hazardous Waste Treatment Technologies, Noyes Data Corporation, Park Ridge, NJ, 1991.
- [8] D.J. De Renzo, Pollution Control Technology for Industrial Wastewater, Noyes Data Corporation, 1981.
- [9] Novel Technologies for Drainage Water Treatment. Academy of Scientific Research and Technology, National Research Centre (NRC), Third Progress Report, February 2000.
- [10] Novel Technologies for Drainage Water Treatment. Academy of Scientific Research and Technology, National Research Centre (NRC), Second Progress Report, October 1999.
- [11] Novel Technologies for Drainage Water Treatment. Academy of Scientific Research and Technology, National Research Centre (NRC), First Progress Report, July 1998 [in Arabic].
- [12] Data submitted from Drainage Research Institute, National Water Research Centre, Ministry of Water Resources and Irrigation (1998–2001).
- [13] The World Bank, Middle East and North Africa Environment Strategy, February 15–17, 1995.

- [14] Assessment of Egyptian Market Needs of Water Treatment Desalination Membranes, National Research Centre, Technical, Technology Studies and Consultation Fund, National Organization for Military Production (Abo-Zaabal Company for Special Chemicals), September 1997.
- [15] K. Glucina, A. Alvarez and J.M. Laíné, Assessment of an integrated membrane system for surface water treatment, *Desalination*, 132 (2000) 37–82.
- [16] M.H. Sorour, A.G. Abulnour and H.A. Talaat, Desalination of agricultural drainage water, *Desalination*, 86 (1992) 63–70.
- [17] M. Busch and B. Mickols, Desalination — reducing cost by lowery energy use, *Water Wastewater Int.*, 19(4) (2004) 18–20.
- [18] H.M. Eltouney, Evaluating of economics of desalination, *Chem. Eng. Prog.*, 98 (2002) 32–39.
- [19] Y.T. Zhou and S.J. Richard, Evaluation of the costs of desalination and WATER tRANSPORT, Working Paper, FNU-41, 2005.
- [20] M.H. Sorour, N.M. El Defrawy and H.F. Shaalan, Treatment of agricultural drainage water via lagoon/ reverse osmosis system, *Desalination*, 152 (2002) 359–366.

## Appendix

### Design and cost basis for the proposed treatment scheme

#### A. Design basis

- Plant capacity 110,000 m<sup>3</sup>/d
- Water characteristics
  - pH 7.6– 8
  - TDS 1200–1500 ppm
  - SS 350 ppm
  - BOD 120 ppm
  - COD 180 ppm
- Loading factor 90%
- Aerated lagoon
  - Average water temperature along the year 20°C
  - Surface loading 330 kg BOD/ha.d
  - Depth 4 m
  - Horsepower 8 HP/1000 m<sup>3</sup>
  - Retention time 6 d
- RO unit 1st stage
  - Unit recovery 80%
  - Salt rejection 90%
- RO unit 2nd stage
  - Brine recovery 60%
  - Salt rejection 90%
- Product water capacity
  - 1st part 110,000 m<sup>3</sup>/d

- 2nd part 46,000 m<sup>3</sup>/d
- Granular activated carbon
  - Filtration rate 10 m<sup>3</sup>/m<sup>2</sup>/d

#### B Capital cost estimates basis

- Construction cost
 

Based on process unit functions and updated published data using the relevant cost index (M&S) for the 2nd quarter of 2005, US\$ exchange rate of Egyptian pound (LE) (US = LE 5.7) (2005).
- Aerated lagoons (US \$)
 
$$\{(2E - 0.5Q + 0.4412) \cdot 1.5 + 2.8Q + 0.617\} \cdot 0.56$$
- Activated carbon ( US \$)
 
$$(0.0047Q^{0.648} \cdot 1.19)$$
- Reverse osmosis (US \$)
 
$$477 Q^{1.0014}$$

where  $Q$  in the water flow rate in m<sup>3</sup>/d.
- Piping, electricity, control, preparation of site and others that account for 10, 8, 5, 5, 10% of construction cost.

*C Operating cost estimates basis*

- Electricity consumption for pumping station, screen and grit removal, aerated lagoons, chlorination unit, filtration unit, activated carbon, 1st reverse osmosis, 2nd reverse osmosis are \$0.09, 0.05, 0.17, 0.005, produced water respectively at \$0.03 kWh.
- Membrane replacement cost for RO1, RO2 is 4 and 6% of the total plant capital cost/y.
- Chemical and materials for chlorination granular activated carbon, 1st reverse osmosis, 2nd reverse osmosis are \$0.017, 0.03, 0.02, 0.03/m<sup>3</sup>, produced water respectively.  
\**Q* water flow rate in m<sup>3</sup>/d.
- Maintenance cost 3% of the capital cost
- Labor cost \$ 0.05 /m<sup>3</sup> of produced water
- Other operation cost 10% of total operating cost
- Depreciation  
Based on 15, 40, 20 for electromechanical modules, biological module and other respectively.