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Cost evaluation of desalination and sewage treatment based on plants operated in Oman and use of software models

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ABSTRACT

The performance of desalination and sewage treatment plants operated by contractors at sites of a large company in Oman was evaluated in relation to benchmark costs. Such benchmark costs, which are dependent on plant size and process used, were established based on estimates provided in research literature and based on site-specific estimates made using software models. Desalination economic evaluation program software was used to estimate site-specific costs of desalination and financing for environmental, affordable, and strategic investments that bring on large scale expenditure software was used to estimate site-specific costs of sewage treatment. The estimated site-specific benchmark cost of desalination was 1.20 US$/m^3. The desalination cost subject to many variables reported in the literature ranges between 0.52 and 1.30 US$/m^3. The estimated site-specific benchmark operational cost of sewage treatment up to the BOD level of 10–15 mg/L of treated water was 0.29 US$/m^3. The cost of sewage water treatment, up to the BOD level of 10–15 mg/L of treated water, averages to 0.41 US$/m^3 based on studies conducted. The evaluation of costs reveals that the cost of desalination and sewage treatment at the company sites was close to benchmark costs provided in the research literature as well as site-specific estimates made using software models.

Keywords: Cost evaluation; Desalination; Sewage treatment; Oman; DEEP; FEASIBLE

1. Introduction

Arid countries are increasingly adopting desalination and sewage treatment to enhance water supplies. The Sultanate of Oman, located in the southeast corner of the Arab Peninsula, is an arid country with a mean annual rainfall of less than 100 mm. The national annual renewable water resources have been estimated as 1,400 Mm^3 (million cubic meter). Groundwater is the country's main water resource. The annual total water extraction as estimated in year 2003 has been 1,321 Mm^3. Nearly 88.4% has been used for agricultural purposes and 10.1–1.5% for municipal and industrial purposes, respectively. Annual groundwater depletion has been estimated as 134 Mm^3. The annual water shortage has exceeded 300 Mm^3 [1].

The Omani government has adopted an intensive water augmentation/conservation program. Augmentation is sought through explorations, water harvesting by recharge dams, brackish water use in agriculture and industry, desalination, and wastewater

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reuse. Recharge dams are built across the country to intercept runoff, which would otherwise drain to the sea. In 2006, the total dam capacity was 88.4 Mm^3. The annual total production of desalinated water by 2006 has been around 109 Mm^3. In 2006, 37 Mm^3 were treated and reused mostly in landscape irrigation [1]. Conservation is sought through efficient irrigation, agronomic management of drought and salt tolerant crops and introduction of modern irrigation systems to replace traditional flood irrigation [2].

This study analyzes and evaluates the operational performance of desalination and sewage treatment plants operated by contractors on behalf of a company. The company is a major corporate entity in the sultanate of Oman in exploring and extracting petroleum resources, thus contributing significantly to gross domestic product, employment, and social welfare. The extraction sites of the company are distributed geographically widely and in the interior deserts where access to fresh water is absolutely scarce and supplies from conventional sources are extremely expensive. Hence, the company sites depend on desalination of brackish ground water for drinking and other domestic purposes and reuse of treated sewage and gray water for landscaping the camp environment. The company has been a pioneer in introducing and use of desalination and wastewater treatment in Oman. This study is a cost evaluation of the performance of desalination and sewage treatment plants adopted by the company. Performance is evaluated through a benchmark analysis of unit cost of desalination and sewage treatment at selected company sites. It is expected that the evaluation would provide guidance to consider potentials to reduce costs, through choice of technology in the long run and managing short-run operational costs. The information could also be used to guide negotiations on offering contracts to manage desalination and sewage treatment plants.

Empirical research published post year 2000 indicates that the increased demand for water, particularly in rapidly developing arid regions and the invention of improved desalination technology have led to increased adoption of desalination. Several empirical studies have been conducted: to examine the economic rationality of desalination vis-à-vis other water supply methods and to compare alternative desalination technologies. The alternatives of desalination technology can be considered in terms of the combinations of desalination process (thermal and membrane) and the power source (fossil fuel, nuclear, and renewable).

Desalination is emerging as an economically viable alternative to supply potable water. This is due to improvements in desalination technology and the use of alternative energy sources. Generally, it has been predicted that the use of nuclear energy would make desalination economically viable [3]. Further, irrespective of the energy source, the lowest cost of desalination is obtained through reverse osmosis (RO) process as compared to other desalination technologies.

As reported by Reddy [4] based on a review of international experiences, the cost of producing potable water is 0.52–0.78 US$/$m^3$ through RO and thermal technology, respectively. Further Reddy [4] has opined that viability of desalination technology is location specific. Thermal technology is preferred over RO in the Gulf region due to technical factors such as high fouling tendency of seawater and due to the preferred practice of co-generating power and water. In general, it has been identified that the cost of desalination and the choice of technology would depend on salinity and quality of water treated, plant capacity, energy cost, reliability, concentrate disposal and regulatory issues, and land cost and subsidies. Recent studies confirm above estimates and opinion of Reddy [4]. Ghaffour et al. [5] conclude that the cost of desalinated water has fallen to below 0.50 US$/$m^3$ for large-scale seawater RO at a specific location and conditions, while the cost may be more commonly up to 1.00 US$/$m^3$ when location and conditions vary.

Al-Ajmi and Abdel Rahman [6], upon analyzing water management issues in Oman, have reported that the weighted (different types of technology, plant capacity, and source water) average cost of desalination as 1.30 US$/$m^3$. RO technology is opined to have performed better than others. Quoting World Water (1997) the authors have predicted that by year 2015 desalination cost would be 0.52–0.26 US$/$m^3$ for sea and brackish water, respectively. Andrianne and Alardin [7] on comparing cost structures of thermal and membrane processes of desalination concluded choice of technology as being case/site specific. The study reports the cost of desalination of a RO plant in Ashkelon in 2001 as 0.53 US$/$m^3$. Ashour and Ghurabi [8] estimated the desalination cost based on plants operated in Libya as 0.94–1.02 and 1.25–2.81 US$/$m^3$, for thermal and membrane processes, respectively.

Blank et al. [9] doubts the validity of cost of desalination estimated (0.52 US$/$m^3$) by previous studies, as those have been based on erroneous assumptions and have particularly used unrealistically low energy prices. They have predicted that the desalination cost of thermal and membrane processes may converge and with 2006 energy costs desalination cost could be about 1.35 US$/$m^3$ if moderate research and development efforts are made to bring down costs.

The research literature post year 2000 as quoted above on cost and economics of desalination reveals the following.

(1) Desalination is becoming an economically viable water supply option, particularly in arid regions.
(2) The economic viability of desalination has improved due to technological improvements in the desalination process.
(3) The current increases in the fossil fuel costs are dampening the economic viability of desalination and alternative energy sources as nuclear energy is becoming more economically viable.
(4) Membrane processes compared to thermal processes of desalination are more economical, particularly at small scales.
(5) The economic viability and the choice of the desalination technology are site specific.
(6) The cost of desalination obtained through RO varies subject to various factors such as plant capacity, technology used and importantly input water salinity between 0.52 and 1.3 US $/m^3.

Several software have been produced to estimate desalination costs. The earliest software on the estimation of desalination has been reported in 1991 (Reddy [4]). Some of the software are proprietary and are not available in the public domain. Reddy [4] has reviewed the validity (accuracy and reliability) of publicly available software that could estimate the cost of desalination and has concluded that most software does not adequately account for location-specific conditions. Two widely quoted, publicly available software that could estimate desalination costs are: desalination economic evaluation program (DEEP) produced by international atomic energy agency and WTCost© produced by US Bureau of Reclamation.

The cost of sewage treatment depends on the technological aspects as well as the environmental standards to which water is treated. As Fine et al. [10] reports: "Two general approaches to effluent sanitation are currently followed: one is a 'zero-risk' approach that adopts the 'best available technology'; the other is 'calculated-risk' approach that is based on existing epidemiological evidence and considers irrigation as an additional treatment stage".

The FAO guideline has recommended (quoted by [10]) not more than 1,000 fecal coliforms per 100 mL for unrestricted irrigation of all crops. Mara has argued (quoted by [10]) that effluent reuse is often over-regulated with respect to public health parameters, thus entailing higher costs on treatment. Fine et al. [10] has analyzed the cost of upgrading wastewater treatment in Israel to meet higher sanitation levels, such as from using treated water for irrigating non-edible crops (such as in landscapes) to levels mandated to unrestricted irrigation (<10 fecal coli/100 mL). They have estimated that such upgrading would cost $69 million, given that current effluent reuse in Israel is 350 Mm^3/y, and concluded this as rather wasteful. Fine et al. [10] has provided the following estimates of sewage treatment at the city level in Israel.

(1) 0.12 US$/m^3 for ponding in a reservoir or of treatment in an oxidation pond, including reservoir construction and maintenance and water pumping.
(2) 0.21 US$/m^3 to treat sewage to standards of BOD and TSP of 20–30 mg/L through mechanical biological treatment plant (MBTP).
(3) 0.29 US$/m^3 for soil-aquifer treatment or equivalent sand filtration and chlorination.
(4) 0.41 US$/m^3 to treat sewage water to be discharged to rivers or the sea (BOD, N-NH_4, total N, residual chlorine (all mg/L), and fecal coliforms not exceeding 10,10,1.5, 10, 1, and 200, respectively).
(5) 0.76 US$/m^3 for desalination of sewage water.

Table 1 provides the cost of wastewater treatment for incremental quality [10]. The same data are presented in Fig. 1. It is evident that treatment costs increase exponentially with improved quality of treated water.

Alhumoud et al. [11] has estimated the following costs on wastewater treatment and desalination in Kuwait:

(1) Secondary treated effluent (1,000 fecal coliform/100 mL): 0.39 US$/m^3.
(2) Tertiary treated effluent (0 fecal coliform/ 100 mL): 0.47 US$/m^3.
(3) Desalinated water: 2.21 US$/m^3.

Based on the above review, it could be concluded that the cost of sewage treatment increases with higher quality of treated water and the operational cost of sewage water treatment to treated water quality of about 10–15 mg/L BOD is about 0.40 US$/m^3.

Several software to estimate cost of sewage water treatment have been developed to evaluate environmental conservation and development investments. These software are based on meta-cost functions, developed based on past investments and operation of sewage water treatment, vendor data, and empirical studies. Following is a list of such software.

Table 1
Cost of sewage treatment to achieve different levels of water quality

Treatment level	Cost US $/m^3$
Low: BOD > 60 mg/L: e.g. Through oxidation pond effluent with detention time ≤10 d	0.12
Medium: BOD 20–60 mg/L, TSS 30–90 mg/L, or oxidation ponds effluent with detention time >10 d	0.13
High: MBTP, BOD, and TSS levels of 20 and 30 mg/L, respectively	0.21
Very high suitable for unrestricted irrigation: Removal of pathogens through deep sand filtration, prolonged ponding >60 d or dilution in reservoir to <10% of water. Fecal coliforms ≤ 10/100 mL and turbidity ≤ 5 NTU (or TSS ≤ 10 mg/L) and 1 mg/L residual chlorine	0.36

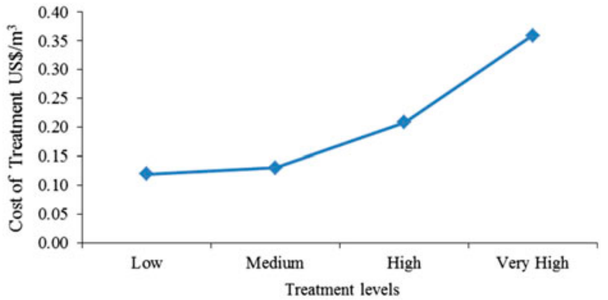

Fig. 1. Cost of sewage treatment for increased output water quality.

(1) Computer assisted procedure for the design and evaluation of wastewater treatment systems (CAPDET), developed by U.S. army corps engineers.
(2) W/W Cost program (WWC) developed by CWC engineering software.
(3) Sewage Treatment Optimization Model (STOM) [12].
(4) Financing for Environmental, Affordable, and Strategic Investments that bring on Large scale expenditure (FEASIBLE) developed by COWI consultants for organization de cooperation et de development economiques (OCDE).

Among the above-mentioned software FEASIBLE developed by COWI consultants is the most recent and it is also available in the public domain (www.cowi.com) for public use.

2. Methodology

Benchmark analysis is a management tool, through which organizations evaluate performance of its activities by comparing with best practices, i.e. benchmarks. This analysis establishes benchmarks on unit cost of desalination and sewage treatment based on estimates provided in published research literature and estimates made using publicly available software.

The DEEP software (for the desalination plant) is used in this study mainly due to its technical appropriateness for the study and due to widely reported applications. The software is accessible through the web. The version 3.1 that is used in this study has been released in 2006. DEEP is an Excel spreadsheet-based model. This software enables the estimation of cost and technical performance indicators for combinations of desalination technologies and power options. Thus, it enables the comparison of different combinations of technology, power alternatives of producing water through desalination. Features that have been added recently are the option of including cost of water supply through water transport and cost of carbon taxing for fossil fuel use. The DEEP model contains standard technical parameters that are built into the model (that could be changed if required) as well as site-specific parameters that the users could define. Some of the user definable parameters are process of desalination and power options, plant capacity, feed water salinity, and financial parameters as the capital cost, operational, management cost, etc.

The FEASIBLE software (for sewage treatment plant) is used in this analysis to estimate the benchmark cost of sewage water treatment. The FEASIBLE software enables the estimation of standardized cost of water supply, sewage treatment, and solid waste management technologies, in a regional or national scale. It also enables the estimation of required finance and examines alternative means of generating finance for water supply, sewage treatment, and solid waste management. The cost is estimated based on generic cost functions that have been derived based on international data. Cost functions are derived for collection, transport, pumping, and treatment of sewage as capital and operational costs. Detailed description on the method of estimation and the numerical functions of these generic cost functions are provided in the FEASIBLE user manual. The software allows the user to change some of the technical and cost parameters to match with specific situations. This analysis uses only part of the capability of FEASIBLE software *viz*. estimate the cost of sewage treatment by investing in new treatment plants with the currently adopted technology. FEASIBLE provides the possibility to estimate sewage treatment cost, based on alternative wastewater treatment technologies, such as septic tanks, reed bed, biological sand filters, stabilization ponds, and advanced mechanical, chemical, and biological methods.

3. Results and discussions

3.1. Benchmark cost of desalination

Data on the desalination plant at Site 1 were collected by visiting the site and interviewing the technical officer in charge of the plant and reviewing records maintained at the site office. The actual operational cost of desalination could not be objectively estimated due to unavailability of data. Data on operational costs are maintained by contractors who change periodically. This process is ongoing hence data are incomplete to objectively estimate the costs. Given the lack of objective data on site-specific operational costs of desalination, the operational cost subjectively revealed by the technicians was considered. It was revealed that the cost of producing a m^3 of desalinated water through the RO plant using brackish groundwater at Site 1 was 3.90 **US$**. The cost of production of water in Site 1 is high, one reason identified being the need for pretreatment due to the prevalence of H_2S in the feed water. The prevalence of H_2S is site specific. The cost of pretreatment on H_2S could not be factored out due to lack of data. It was revealed that earlier the company had paid to contractors, 2.21 **US$**/$m^3$ and now pays 1.02 **US$**/$m^3$ for desalinated product water.

The analysis on estimating the benchmark cost is based on the assumptions of opportunity cost of land as zero, not including the operational cost of brine disposal of the desalination process and environmental costs of desalination (such as burning fossil fuel and disposal of brine). The site-specific technical and cost data that were used are given in Tables 2 and 3, respectively. Other standard technical parameters as provided in DEEP software are given in Table 4. The estimated benchmark cost of desalinated water production at Site 1 is 1.60 US$/$m^3$ including fixed cost and the operational cost (excluding the fixed cost) is 1.20 US$/$m^3$. Thus, the company is benefitted by paying price less than the actual cost in this specific site. However, the contractors undertake business operations in several sites, which would provide overall profits.

Table 2
Technical data: Site 1 RO desalination plant

Data	Unit	Measure
Required water plant capacity at site	m^3/d	600
Feed water salinity	ppm	9,200
Feed water temperature at water intake	℃	36
Booster pump head	bar	2.13
Recovery ratio		0.65
Feed pump head	bar	2.1
High head pump pressure rise	bar	30.1

3.2. Performance evaluation of desalination

The international, national, and benchmark estimates derived through use of software on the cost of desalination at Site 1 are compared with the actual price paid for produced water by the company to contractors, and costs revealed by the technician of producing desalinated water at Site 1 are as in Fig. 2. It is evident that the cost of production of water as revealed by the technician at Site 1 (3.9 US$/$m^3$) is about 3 times of the estimated benchmark cost (1.20 US$/$m^3$). The cost revealed by the technician at Site 1 is influenced by the unique need to treat for H_2S of inlet water in a remote location, hence is not representative of the general cost. The present payment by the company (1.02 US$/$m^3$) to contractors for desalinated water can be considered as a better representative estimate of the cost of desalination at the company sites. It is observed this estimate of brackish water desalination is lower than the estimated benchmark cost and is also between the minimum (0.20 US$/$m^3$) and maximum (1.30 US$/m^3) costs reported in the literature for seawater desalination.

3.3. Benchmark cost of sewage treatment

The sewage treatment cost for Site 2 was estimated using FEASIBLE considering a new investment, beginning in year 2008 and a viable life period of 20 years. The following information was gathered through site visits and based on interviews with technicians operating the sewage treatment plants (Table 5).

Although the Site 2 camp site has a capacity to house about 850 persons, it has been housing between 600 and 650 persons. A recent project to improve

Table 3
Cost data: Site 1 RO desalination plant

Data	Unit	Measure
Lifetime of water plant	a	20
Reference unit size for cost	m^3/d	600
Base unit cost	US$/ ($m^3/d$)	1,300
Number of management personnel		2
Number of labor personnel		5
Average management salary	US$/month	2,080
Average labor salary	US$/month	520
Purchased electricity cost	US$/kWh	0.47

residential facilities at Site 2 has projected the population at 1,000 residents. However, for this analysis, the base population at Site 2 was considered as 600 persons. The per capita wastewater generation was estimated to be approximately 60 m^3/year/person. This is below the default value considered in the software which is 72 m^3/year/person. The BOD level of sewage water was considered as 500 mg/L.

The treatment plant was close to the camp site. The default data of the software were used as input data. Site 2 had 2 pumps, of which one was operational. The installed capacity of a pump is 200 W and electricity consumption was estimated through the default values of the software as 15,000 kWh. The electricity consumption of the sewage treatment plant is not measured separately.

Mechanical–chemical–biological technology of treatment, that enables to treat sewage to output water with 15 mg/L of BOD, was considered. The sludge is dried and disposed.

The cost of land was ignored as the opportunity cost of land at the camp site was considered low. Inflation was ignored. The wages of skilled and unskilled labor was considered as 2,080 and 520 US

Table 4
Standard technical parameters as provided in DEEP software

RO plant technical data	Unit	Measure
RO feedwater inlet temperature (if 0, default of 30 is used)	℃	36.00
RO plant modular unit size	m^3/d	0.00
Seawater pump head	bar	2.10
Seawater pump efficiency		0.85
Feed salinity	ppm	9,200
Recovery ratio		0.65
Design flux	$l/(m^2\ h)$	13.60
Energy recovery fraction		0.95
Booster pump efficiency		0.85
High head pump pressure rise	bar	25.09
High head pump efficiency		0.85
Hydraulic pump coupling efficiency		0.97
Other specific power use	$kW(e)\ h/m^3$	0.40
Planned outage rate		0.03
Unplanned outage rate		0.06
Plant availability (if 0, value is calculated)		0.90
RO plant cost data	Unit	Measure
RO plant base unit cost	$\$/(m^3/d)$	1,300.00
Infall/outfall cost (% of construction cost)	%	7.00
Plant cost contingency factor		0.10
Plant owners cost factor		0.05
Plant availability (if 0, value is calculated)		0.00
Average management salary	$/a	20,280.00
Average labor salary	$/a	6,240.00
O&M membrane replacement cost	$\$/m^3$	0.07
O&M spare parts cost	$\$/m^3$	0.04
Specific chemicals cost for pre-treatment	$\$/m^3$	0.03
Specific chemicals cost for post-treatment	$\$/m^3$	0.01
Plant O&M insurance cost	%	0.50
Num. of management personnel (if 0, value is calculated)		2.00
Number of labor personnel		5.00

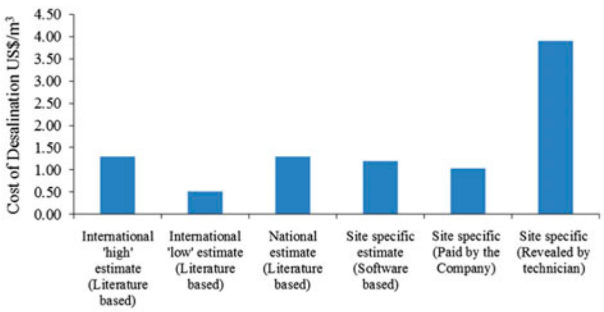

Fig. 2. Cost of desalination at Site 1 and other such costs.

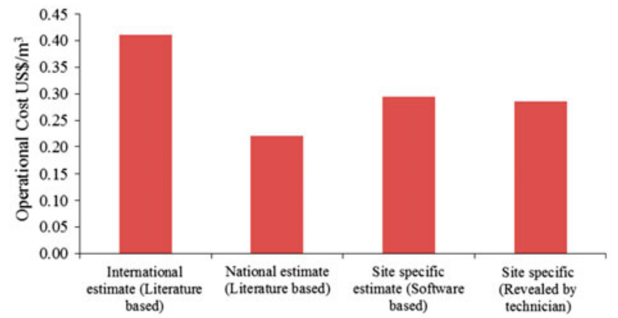

Fig. 3. Comparison of operational cost of sewage water treatment between 10 and 15 mg/L BOD.

Table 5
Base data of Site 2 used to estimate benchmark cost of sewage treatment

Item	Unit	Measure
Base year		2008
Viable period	Years	20
Population	Persons	600
Per-capita wastewater	m^3/year/person	60
BOD of sewage water	mg/L	500
BOD of treated water	mg/L	15
Pumps	Number	1
Installed capacity of pump	W	200
Wage of skilled labor	US$/year/person	2,080
Wage of unskilled labor	US$/year/person	520
Price of electricity	US$/kWh	0.03
Price of fuel	US$/liter	0.31

$/year/person, respectively. The electricity price and fuel price were considered as 0.03 US$/kWh and 0.31 US$/liter, respectively.

With input of above data for Site 2 the following benchmark cost of sewage treatment was estimated.

(1) Cost of sewage treatment including capital/fixed and operational cost = 1.24 US$/$m^3$.
(2) Cost of sewage treatment considering only operational cost = 0.29 US$/$m^3$.
(3) The estimated operational cost of sewage treatment through FEASIBLE at Site 2 is on par with estimates done earlier on the cost of sewage treatment in Oman *viz*, 0.22 US$/$m^3$ [6] and also estimates provided by international studies (quoted above).

3.4. Performance evaluation of sewage treatment

An objective estimate of operational costs of sewage treatment at Site 2 could not be made due to lack of data. Such data are not maintained at the site. The operational costs in particular are maintained by contractors, who change periodically. Further at Site 2 sewage is treated to drinking water quality through RO on an experimental basis of testing a new process. Hence, the cost of treatment could be expected to be higher than otherwise. The operational cost estimates on sewage treatment quoted by the technician at another company site was 0.26 US$/$m^3$. The cost of sewage water treatment up to about a BOD level of 10–15 mg/L of treated water as provided in the literature (international and national), as estimated through software for Site 2 and the cost revealed by the technician at the site are provided in Fig. 3. The cost revealed by the technician (0.26 US$/$m^3$) is below the international estimate (0.41 US$/$m^3$), between the national estimate (0.22 US$/$m^3$) and the site-specific benchmark cost (0.29 US$/$m^3$) estimated by the software.

4. Conclusion

As found through this study the desalination and sewage treatment processes at the plants investigated are within or close to international costs and site-specific benchmark costs estimated by use of software. This study is limited by not having site-specific actual recorded cost estimates of desalination and sewage treatment at sites. Such data are not maintained at sites. Some of the operational costs are maintained by contractors and at the head office of the company, which were not available during the study period. It is recommended that cost data segregated to extent practically possible be formally maintained at site. Such data would enable identification of possibilities for cost management and for contract negotiation between companies and contractors in outsourcing management of desalination plants.

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References

[1] FAO, Aquastat Database, 2008. Available from: <http://www.fao.org/nr/water/aquastat/countries_regions/oman/index.stm>.

[2] MAF & ICBA, Oman Salinity Strategy, Ministry of Agriculture and Fisheries (MAF), Sultanate of Oman International, Center For Biosaline Agriculture (ICBA), Dubai, UAE, 2008.

[3] S. Nisan, S. Dardour, Economic evaluation of nuclear desalination systems, Desalination 205 (2007) 231–242.

[4] K.V. Reddy, Review and evaluation of desalination cost and costing methodologies, Int. J. Nucl. Desalin. 3 (2008) 79–94.

[5] N. Ghaffour, T.M. Missimer, G.L. Amy, Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability, Desalination 309 (2013) 197–207.

[6] H.A. Al-Ajmi, H.A. Abdel Rahman, Water mangement intricacies in the Sultanate of Oman: The augmenation-conservation conundrum, Water Int. 26 (2001) 68–79.

[7] J. Andrianne, F. Alardin, Thermal and membrane processe economics: Optimized selection for seawater desalination, Desalination 153 (2003) 305–311.

[8] M.M. Ashour, S.M. Ghurabi, Economics of desalination in libya, Desalination 165 (2004) 215–218.

[9] J. Blank, G. Tusel, S. Nisanc, The real cost of desalted water and how to reduce it further, Desalination 205 (2007) 298–311.

[10] P. Fine, R. Halperin, E. Hadas, Economic considerations for wastewater upgrading alternatives: An Israeli test case, J. Environ. Manage. 78 (2006) 163–169.

[11] J.M. Alhumoud, H.S. Behbehani, T.H. Abdullah, Wastewater reuse practices in Kuwait, Environmentalist 23 (2003) 117–126.

[12] B. Spearing, Sewage treatment optimization model - STOM - the sewage works in a personal computer, Proc. Instn. Civ. Engrs, Part 1, 82 (1987) 1145–1164.