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COST COMPARISON IN WATER SUPPLY ALTERNATIVES IN SAUDI ARABIA

INTRODUCTION

Fresh water resources in Saudi Arabia are very limited and exhibit a potential problem for planners at the national and local levels. Most water supplies in the Kingdom come from shallow ground water aquifers that have limited areal extents and supplies. The most extensively developed aquifer systems are located in the eastern and north-eastern regions of the Kingdom where extensive sedimentary layers have been deposited along the flanks of the pre cambrian Arabian shield complex. Localized shallow alluvial aquifers predominate in the western and south-western regions where extensive wadi systems have been developed during the quaternary period.

Rainfall in the Kingdom is very sparse and whatever of it reaches the soil surface, evaporates fast and therefore little or no recharge of these aquifers takes place. The amount of available water in these aquifers is therefore limited and the water levels have been declining sharply for the past few years. More and more water is being needed to keep up with rising use in agriculture, industry and municipal supplies. The affluence from the income of oil production, thus brought with it large development schemes that need yet larger and larger quantities of water, in which case the available sources could never meet. The attention of the planners have thus shifted to alternative sources of water supplies to satisfy these future needs. One of the first alternatives that have been utilized extensively is the desalination of sea water from the Red Sea in the west and the Arabian Gulf in the east. The first major desalination plant became operational in 1970, and produced 5 mgd to augment the increasing municipal demands of the city of Jeddah. This was followed by another plant in 1974 at Al-Khobar on the Arabian Gulf, and produced 7.5 mgd to supply the population of Al-Khobar, Dammam, and Qatif. Since then more plans for major desalination projects have mushroomed and the planned daily production capabilities have exceeded thousand million gallons. A major pipeline is under construction to transport desalinated water from Jubail at the Arabian Gulf to feed the capital city of Riyadh some 460 kilometers towards the interior.

Besides desalination other conventional and unconventional sources of water supplies have been also contemplated. Amongst these, the most controversial was the transport of icebergs from Antarctica to the Red Sea coast. Research on this project is still going on by private investors who may one day see the feasibility of such projects and find it more economical to undertake. Amongst the more conventional sources of fresh water that has not been talked about much yet is the import of surface water via canals or pipes from the lower reaches of the Tigris and Uphratis rivers in Iraq. Although it may be more economically feasible to import water from such sources, yet the political atmosphere in the area is probably the most recognized stumbling block against the realization of such a project. The import of water via incoming oil tankers is yet another scheme that could be thought of and implemented if some sort of encouragement is considered. By declaring certain lucrative discounts to tanker owners who buy their oil supplies from Saudi Arabia, many shippers will begin to seriously think of such discounts especially with the current staggering rises of fuel prices and the negligible cost of renovating the tankers to accomodate for shipping fresh water.

No economic studies have so far been conducted on the cost comparison of such water supply alternatives for Saudi Arabia. Due to lack of data in importing water via tankers and canals or pipes, the present study will, therefore, be limited to desalination processes and potential use of iceberg utilisation.

The major objectives of this study are: to develop a cost model relating water cost with the system capacity and efficiency of removal of hardness and total dissolved solid (TDS); to establish cost-capacity relationships for various desalination processes; and to evaluate the use of icebergs as potential fresh water resource.

COST EVALUATION OF WATER SUPPLY SYSTEMS

Water supply system can be grouped into collection, purification and distribution subsystems. Collection subsystem is used to supply the source water in adequate quantities on intermittent or continuous basis to the purification subsystem. It is then treated to an acceptable quality and conveyed to the consumers through transmission and distribution subsystems. The cost of water thus collected, purified and supplied to the consumers depends on the capital cost of the whole system as well as the operations and the maintenance costs of the various components of the system. The cost of water supply is also related to the capacity of the system which is expressed as:

$$C = a(Q)^b \qquad (1)$$

where

C is the cost of water supply system,

a is constant which decides the cost of unit capacity,

Q is the capacity of water supply system,

and b is the economies of scale.

The constant 'b' is usually less than one. It means that the total cost increases with the capacity of the water supply system but at a decreasing rate. If variable, 'C' represents unit water cost and coefficient 'b' is negative, the cost per unit volume of water decreases with the increase in the capacity of water supply system.

Waters in arid regions like Saudi Arabia are usually hard and contain high concentration of TDS. The removal of these constituents below a maximum permissible level is, therefore, a necessity. In addition to the capacity of water supply system, the unit water cost will also be affected by the extent of removal of the these constituents.

A model, determining the unit water supply cost should include hardness and TDS as additional parameters. Such an attempt is made by using multiple regression analysis and is expressed as:

$$C_u = a(Q)^b \,(HARDEFF)^c \,(TDSEFF)^d \qquad (2)$$

where

C_u is the unit water cost,

Q is the water supply capacity,

HARDEFF is the efficiency of hardness removal in percent,

TDSEFF is the efficiency of TDS removal percent.

a, b, c, and d are regression coefficients.

The regression coefficients for the reverse osmosis desalination process are estimated using the data listed by Miller (Ref. 18). This relationship is as follows:

$$C_u = 0.790(Q)^{-.073}(HARDEFF)^{-.722}(TDSEFF)^{1.944} \qquad (3)$$

The correlation coefficient for the above model was highly significant (r^2 = .969).

In Eq.(3), C_u is expressed in cents/cum and Q in 1000 cubic meter per day. HARDEFF and TDSEFF are defined in Eq.(2).

Similar relationships can be developed for other water supply systems.

COST-CAPACITY RELATIONSHIPS FOR DESALINATION PROCESSES

Commercially important desalination processes are multistage flash (MSF), reverse osmosis (RO) and electrodialysis (ED). Among these, MSF and RO are commonly used in Saudi Arabia. Multistage flash is used for treating seawater (high salinity water), whereas RO is mainly used for treating brackish water. Since RO and MSF are commonly used in the Kingdom, therefore, cost-capacity relationships of these processes will only be established.

Total cost as well as unit cost models based on 1979 United States index (Ref. 16), are developed for the above mentioned desalination processes. Total cost models are categorised into direct capital, total capital and annual operations and maintenance models.

Cost-capacity relationships (Eq. 1) for both total cost and unit cost models can be generalised as follows:

$$C = a X^b$$

The variables and coefficients in this model have earlier been defined. The cost-capacity relationships are established using the data listed by Larson and Leitner (Ref. 16).

The variable 'C' in the case of total costs is expressed in million dollars and, in the case of unit cost models, it is defined as the cost in dollars per cum. The capacity X is in thousand cubic meter (CUM) per day. The regression coefficients thus obtained are listed in Tables 1 and 2.

Table 1 Regression coefficients for cost-capacity models (MSF: Seawater)

Items	Regression Coefficients a	Regression Coefficients b	Correlation Coefficient γ^2
1. Total cost			
a) Direct Capital Cost	1.842	0.773	0.99
b) Total Capital Cost	2.934	0.792	0.99
c) Annual Cost without Energy	0.565	0.787	0.99
2. Unit Cost of Water			
a) Oil fired boiler	1.983	-0.168	0.98
b) High Sulfur coal boiler	2.015	-0.176	0.97
c) Low Sulfur coal boiler	1.964	-0.170	0.98
d) Dual purpose	1.955	-0.171	0.97

Table 2 Regression coefficients for cost-capacity models (RO Process)

Items	Regression Coeff-icients a	Regression Coeff-icients b	Correlation Coefficient γ^2
Seawater Desalting			
1. Total Cost			
a) Direct Capital	1.316	0.862	0.99
b) Total Capital	1.664	0.868	0.99
c) Total Annual	0.204	0.889	0.99
2. Unit Cost	1.546	-0.122	0.97
Brackish Water Desalting			
1. Total Cost			
a) Direct Capital	0.388	0.802	0.99
b) Total Capital	0.473	0.817	0.99
c) O&M Cost	0.248	0.634	0.89
2. Unit Cost	0.405	-0.114	0.90

EVALUATION OF UNIT WATER COST FOR SAUDI ARABIA

The following assumptions were made in analysing the unit cost of water using various desalination processes in Saudi Arabia.

1. Plant life = 30 years
2. Amortization factor = \$0.0641/year based on 30 years plant life and interest rate 4.875% (Ref. 1)
3. Plant capacity factor = 66%
4. Plant availability factor = 92%
5. Load factor = 90%
6. In case of MSF desalination system, a credit of \$500 per KWH of electrical capacity is assumed in the analysis.
7. In cases, where data on O&M are not given, the annual operation and maintenance cost is computed as a percentage of known capital cost data (Ref.16). These values are as follows.

   MSF seawater desalting = 24.23%
   RO seawater desalting = 9.81%
   RO brackish water desalting = 20.32%

Based on the above assumptions, the unit water cost for desalination processes were computed. The result of these computations are listed in Table 3.

Table 3 Cost evaluation of desalination process operating/proposed in Jeddah.

Location	Approx. operating yr.	No. of units	Power (MW)	Water (mgd)	Process	Contract (10^6\$)	Cost (\$/1000 gal.)	Cost (\$/m^3)
Jeddah I	1970	2	--	5	MSF	19	5.84	1.54
Jeddah II*	1977	4	80	10	MSF	182	14.69	3.88
Jeddah Seawater	1978	9	--	3.2	RO	30	7.36	1.94
Jeddah III*	1980	4	200	20	MSF	428	16.97	4.48
Jeddah IV*	1983	10	500	50	MSF	718	9.68	2.56

* In Jeddah II, III and IV desalination plants the contract value included the capital costs as well as operations and maintenance costs for a period of two years.

ICEBERGS

The utilisation of icebergs, as freshwater supply alternative for Saudi Arabia, is very attractive. It is believed that the transport of icebergs is economically and technically feasible and will not pose a potential hazard to marine environment (Ref. 17 and 20). The Kingdom of Saudi Arabia has seriously considered the implications of the icebergs on terrestrial environment (Ref. 6).

The major factors, in transporting an iceberg, are ocean currents, towing technology, and shape, hardness and size of the iceberg. It is suggested that transporting icebergs from the South Pole is relatively economical and feasible because of the favourable ocean currents in towing Antarctic icebergs. Moreover, Antarctic icebergs are more regular in shapes (Ref. 18). During transport, the icebergs can be wrapped into insulating material, like polyurethene to minimize evaporation and melting losses (Ref. 15).

The shallowness of the Arabian Gulf will restrict the use of icebergs only to the Western Coast of Saudi Arabia. The Red Sea near Jeddah is also shallow and icebergs must be sliced, probably near Aden, prior to towing to Jeddah or other coastal cities of Saudi Arabia.

The energy required to move the icebergs, the velocity at which it will travel, the density and shape of icebergs are deciding factors in determining the cost of water obtainable from them. The cost of iceberg utilisation, computed by various theorists, is listed in Table 4.

Table 4 The cost of iceberg utilization as water supply alternative

Iceberg Theorists	Ice Moved tons/Newton	Velocity (m/s)	Yield (km^3)	Cost in (¢/cum)
ISAACS	640	0.5	1.1	3.3
Weeks-Campbell	425	0.5	10.3	4.7
Halt Ostrander	144	0.5	10.3	24.0
CICERO	14	0.8	1.9	202.0

It may be noted in Table 4 that assumptions, like energy requirements and water yield, made by different theorists vary significantly and reflect on the necessity of further research in the area. The cost of icebergs utilization in Saudi Arabia is compared with other sources of freshwater in Table 5.

Table 5 The cost of freshwater obtained from different sources in Saudi Arabia

Sources	Cost (U.S.\$/m^3)
Reverse Osmosis	1.94
MSF Desalination	1.54 - 4.5
Icebergs	0.03 - 2.02

DISCUSSIONS AND CONCLUSIONS

Any definite conclusion on cost-capacity relationships can not be drawn for Saudi Arabia unless sufficient cost data are obtained and analysed. The reulsts listed in Tables 1 and 2 can be modified to establish cost-capacity models for Saudi Arabian desalination process provided a reliable statistical mean value of the unit water cost for RO and MSF is evaluated.

By comparing unit water cost models for seawater reverse osmosis and MSF process (Tables 1 and 2), it is concluded that for relatively small capacity RO is more economical than MSF.

As shown in Table 5, the most economical alternative is the iceberg utilisation. Further research and analysis are needed. It is also evidenced from Table 5 that the unit water cost to treat seawater in Jeddah using RO is usually lower than MSF alternative.

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