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The Economics of Desalination

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Cost is a major factor in implementing desalination technologies and usually is site specific. This chapter provides an overview of factors that determine desalination cost, typical desalination cost estimation models, various cost factors, and approximate costs based on a review of case studies and available literature.

Factors Affecting Desalination Costs

Several factors affect desalination cost. In general, cost factors associated with implementing a desalination plant are site specific and depend on several variables. Major cost variables are briefly described below. Details are provided in various documents (Cost Estimating Procedures 2003).

Quality of Feedwater. The quality of feedwater is a critical design factor. Low TDS concentration in feedwater (e.g. brackish water) requires less energy for treatment compared to high TDS feedwater (seawater). Low TDS allows for higher conversion rates and the plant can operate with less dosing of antiscalant chemicals. The pre-treatment of surface waters such as tidal waters will be more costly compared to brackish groundwater because of the potential existence of more contaminants in these waters.

Plant Capacity. Plant capacity is an important design factor. It affects the size of treatment units, pumping, water storage tank, and water distribution system. Large capacity plants require high initial capital investment compared to low capacity plants. However, due to the economy of scale, the unit production cost for large capacity plants can be lower.

Site Characteristics. Site characteristics can affect water production cost. For example, availability of land and land condition can determine cost. The proximity of plant location to water source and concentrate discharge point is another factor. Pumping cost and costs of pipe installation will be substantially reduced if the plant is located near the water source and if the plant concentrate is discharged to a nearby water body. Also, costs associated with water intake, pretreatment, and concentrate disposal can be substantially reduced if the plant is an expansion of an existing water treatment plant as compared to constructing a new plant.

Regulatory Requirements. These costs are associated with meeting local/state permits and regulatory requirements.

Desalination Implementation Costs

Desalination plant implementation costs can be categorized as construction costs (starting costs) and operation and maintenance (O & M) costs.

Construction Costs

Construction costs include direct and indirect capital costs. The indirect capital cost is usually estimated as percentages of the total direct capital cost. Indirect costs may include freight and insurance, construction overhead, owner's costs, and contingency costs. Below is a description of various direct and indirect costs associated with constructing a desalination plant.

Direct Costs.

- ***Land.*** The cost of land may vary considerably, from zero to a sum that depends on site characteristics and plant ownership (public vs. private).

- ***Production wells.*** The cost of well construction depends on plant capacity and well depth. Also, see auxiliary equipment below.

- ***Surface water intake structure.*** The cost of water intake structures depends on plant capacity and meeting environmental regulations. Also, see auxiliary equipment below.

- ***Process equipment.*** The process equipment includes water treatment units (membranes), instrumentation and controls, pre- and post-treatment units and cleaning systems. Process equipment costs depend on plant capacity and feedwater quality.

- ***Auxiliary equipment.*** Auxiliary equipment includes open water intakes, wells, storage tanks, generators, transformers, pumps, pipes, valves, electric wiring, etc.

- ***Buildings.*** Building costs include the construction of structures such as control room, laboratory, workshops, and offices. Construction cost is site-specific depending on site condition and type of building.

- ***Concentrate disposal.*** The cost of concentrate disposal system depends on the type of desalination technology, plant capacity, discharge location, and environmental regulations.

Indirect Costs.

- ***Freight and insurance.*** Freight and insurance (or premium) cost is typically estimated as 5% of total direct costs.

- ***Construction overhead.*** Construction overhead costs include labor costs, fringe benefits, field supervision, temporary facilities, construction equipment, small tools, contractor's profit and miscellaneous expenses. This cost is typically estimated as 15 percent of direct material and labor costs.

- ***Owner's cost.*** The owner's cost includes land acquisition, engineering design, contract administration, administrative expenses, commissioning and/or startup costs, and legal fees. It is estimated as approximately 10 percent of direct materials and labor costs.

- ***Contingency cost.*** This cost is included for possible additional services. It is generally estimated at 10 percent of the total direct costs.

Operating and Maintenance Costs

The operating and maintenance (O & M) costs consist of fixed costs and variable costs.

Fixed Costs. Fixed costs include insurance and amortization costs. Usually, insurance cost is estimated as 0.5 percent of the total capital cost. Amortization compensates for the annual interest payments for direct and indirect costs and depends on the interest rate and the life-time of the plant. Typically, an amortization rate in the range of 5-10 percent is used.

Variable Costs. Major variable costs include the cost of labor, energy, chemicals, and maintenance. Labor costs can be site-specific and also depend on plant ownership (public or private) or special arrangements such as outsourcing of plant operation. Energy cost depends on availability of inexpensive electricity (or other power source). For example, energy cost can be reduced if the desalination plant is co-located with a power generation plant. Chemical use depends mainly on feedwater quality and degree of pre-/post-treatment and cleaning process. The cost of chemicals is affected by type and quantity of such chemicals as well as global market prices and special arrangements with vendors.

The major maintenance cost pertains to the frequency of membrane replacement, which is affected by the feedwater quality. For low TDS brackish water, the replacement rate is about 5% per year. For high TDS seawater, the replacement could be as high as 20%. The cost for maintenance and spare parts is typically less than 2% of the total capital cost on an annual basis.

Cost Estimation Models

Several models are available for estimating desalination costs. Model applications are mostly limited to site specific conditions and give approximate estimates. Nevertheless, cost models can be used as an indicator of potential costs for planning a desalination facility. Three typical cost models are described below.

WTCost© Model

The Bureau of Reclamation, with the assistance of I. Moch & Associates and Boulder Research Enterprises has developed WTCost©, a computer program that estimates the capital and operation & maintenance costs (Cost Estimating Procedures 2003). The model provides estimates for the following desalination technologies: Brackish water reverse osmosis (BWRO), seawater reverse osmosis (SWRO), mechanical vapor compression (MVC), multiple effect distillation (MED), multi-stage distillation (MSF), nanofiltration (NF), and electrodialysis reversal (EDR). The model provides a set of default values for all input parameters, but default parameters can be overridden when more accurate information becomes available.

WTCost© model provides estimates of capital costs and indirect costs described above. Capital costs include start-up costs for desalination technologies, various pretreatment and post-treatment options, and concentrate disposal options (surface water discharge, disposal to sewer system, land application, evaporation ponds, deep well injection, and zero discharge (using concentrators). Other capital costs include feedwater intake infrastructure (seawater and brackish surface water, seawater and brackish well water), feedwater pipeline, general site development, auxiliary equipment, and buildings. The model gives estimates of indirect depreciating and non-depreciating capital costs. Depreciating costs include freight and insurance, interest during construction, construction overhead, owner's expenses, and contingency. Non-depreciating costs (costs that do not lose value or expense) include land and working capital costs (ready cash on hand to cover the day-to-day expense of operating the facilities).

WTCost© estimates annual costs. Annual costs vary directly with the quantity of water produced and are indexed to the price levels at the date of estimate. Annual cost estimations are provided for labor (for staff requirements and plant size), chemical costs (for type of desalination technology), energy (cost of electricity in $/kWh), type of desalination technology including plants co-located with power plants, replacement parts and maintenance materials, membrane replacement cost, insurance (assuming 5% of total capital costs), annual cost of capital, and plant factor (the percent of time the units will operate during the year at the percent design capacity.

Desalination Economic Evaluation Program (DEEP)

The International Atomic Energy Agency (IAEA) has developed the Desalination Economic Evaluation Program (DEEP) to perform economic analysis of desalination using nuclear energy versus alternative sources of energy (International Atomic Energy Agency 2004). The model is applicable to large-scale (>25 MGD capacity) desalination plants and is designed for research purposes, not industrial cost analysis. Information about DEEP is available on the IAEA Nuclear Desalination Unit's website at www.iaea.org. Currently, DEEP version 2.1 is available on CD-ROM at no charge from the IAEA, but license agreement and use permission is required. A brief description of DEEP follows.

DEEP is based on hybrid Microsoft Excel spreadsheet and Visual Basic methodology. There are three categories of input requirements: Model Data, User Input Data, and Default Data. Model Data refers to certain specified technical parameters that are built within the model and cannot be changed by the user. User Input Data are parameters that should be input by the model user. User Input Data are mostly site specific and include information such as plant location, type of technology, plant capacity, and feedwater salinity. Default Data are parameters that characterize plant performance (e.g. energy recovery efficiency) and economic parameters (e.g. interest rate). Default Data are specified by DEEP, but can be changed by the user as more accurate information becomes available. DEEP Output includes plant performance indicators such as recovery ratio, energy consumption, daily and annual water production, product water TDS, various cost factors that include levelized cost of water and power ($/m^3 or $/kWh), and breakdown of cost components for various scenarios.

WRA RO Desalination Cost Planning Model

Water Resources Associates (WRA) has developed the Reverse Osmosis Desalination Cost Planning Model (Water Resource Associates, Inc. 2005). The WRA model facilitates the cost analysis of a range of desalination project implementation options based on capital, O & M, and life cycle costs. The Version 2.0 model is Windows-based with user-friendly features. Major components of the model include: Master Data Input Form (for a user less knowledgeable about desalination process or its economic components), Advanced Input Form (which allows the user to customize the model by inputting 38 different default settings and make appropriate assumptions), Capital Cost Output, and O & M Cost Outputs. The model input requirements include 33 parameters or default values. The O & M cost output displays the annual O & M costs based on input or default values and a total annualized O & M cost based on the interest rate, inflation rate and life cycle period.

Desalination Approximate Cost Estimates

Desalination cost is affected by several factors such as type of technology, energy availability, geographic location, plant capacity, and feedwater quality. Other important factors include costs associated with transporting water from source to desalination plant, distribution of treated water, and concentrate disposal. Factors such as financing options and subsidies also affect the product water cost.

A 2003 Sandia National Laboratories Report provides a comprehensive review of literature and information on desalination costs (Table 1). It should be noted that because costs documented in various reports are not calculated in a consistent fashion and therefore they are approximate at best and do not represent a conclusive picture.

Table 2 shows the percent cost of various factors for desalination of brackish water and seawater in RO plants. These data are reported in the Sandia National Laboratories report compiling data from other sources (Miller 2003).

Table 1. Desalination Costs for Various Desalination Technologies ($\$/m^3$ freshwater – multiply by 3.8 for $/1000gal)

Reference Sources	MSF (Seawater)	MEE (Seawater)	TVC (Seawater)	RO (Seawater)	RO (Brackish water)	ED ED(Brackish water)
A	1.10-1.50	0.46-85	0.87-0.92	0.45-0.92	0.20-0.35	-
B	0.80	0.45	-	0.72-0.93	-	-
C	0.89	0.27-0.56	-	0.68	-	-
D	0.70-0.75	-	-	0.45-0.85	0.25-0.60	-
E	-	-	-	1.54	0.35	-
F	-	-	-	1.50	0.37-0.70	0.58
G	1.31-5.36	-	-	1.54-6.56	-	-
H	1.86	1.49	-	-	-	-
I	-	1.35	-	1.06	-	-
J	-	-	-	1.25	-	-
K	1.22	-	-	-	-	-
L	-	-	-	-	0.18-0.56	-
M	-	-	0.46	-	-	-
N	-	-	-	1.18	-	-
O	-	1.17	-	-	-	-
P	-	-	0.99-1.21	-	-	-
Q	-	-	-	0.55-0.80	0.25-0.28	-
R	-	-	-	0.59-1.62	-	-
S	-	-	-	1.38-1.51	-	-
T	-	-	-	0.55-0.63	-	-
U	-	-	-	0.70-0.80	-	-
V	-	-	-	-	0.27	-
W	-	-	-	0.52	-	-

Source: (Miller 2003). Other sources for cost estimates are documented in Appendix 1.

Table 2. Percent Distribution of Cost Factors

	Brackish water(%)	Seawater(%)
Fixed costs	54	37
Electric power	11	44
Labor	9	4
Membrane-replacement	7	5
Maintenance and parts	9	7
Consumables (chemicals)	10	3

Source: Miller 2003

Several observations can be made from these data.

1) For both, brackish water and seawater, fixed costs are a major factor;
2) The major difference in cost between desalination of brackish water and seawater is energy consumption, while the remaining factors are decreased proportionally, but remain about the same; and
3) Costs associated with membrane replacement, maintenance & parts and consumables are relatively small. These costs depend on the status of technology and may be further reduced as technology evolves, but will not have significant impact on the overall cost of desalination.

Treatment costs are affected by salinity and overall water quality. High salinity water (e.g. seawater) consumes more energy and is therefore more costly to desalinate. It can be noted that cost efficiency of seawater desalination is a critical parameter in order to make it economically viable. From a water source perspective, desalination of brackish groundwater is the least costly. Surface waters (e.g. tidal waters) contain higher salinity and other impurities. Treatment of high salinity water will require more pre-treatment and perhaps a combination of various technologies, therefore making it more costly.

Desalination plant capacity is a major cost factor. Literature shows that in general, large capacity plants require a high initial capital investment compared to low capacity plants. Also, the increase in cost of product water (per 1000 gallons) is proportional to energy cost (per KwHour). However, due to the economies of scale, operation and management costs, the unit production costs for large capacity plants can be lower (LBG-Guyton Associates 2003, Younos 2004).

Concentrate disposal is a major economic factor and is affected by several factors that include site characteristics (geologic features, soil conditions, proximity to potential disposal site), regulatory requirements, public approval, and the type of concentrate disposal method. Based on those limitations, concentrate disposal cost can range from 5 to 33 percent of the produced water cost (Tsiourtis 2001).

In general, surface water disposal is the most common and affordable option when costs associated with concentrate transport, post-treatment, and outfall structures are considered. However, disposal costs for inland desalination plants are generally higher than those for coastal plants because inland plants cannot dispose to surface waters unless the concentrate can be treated to an acceptable quality. The second common and economic concentrate disposal method is combining the concentrate with effluent from wastewater treatment plants. Costs associated with land application techniques (evaporation ponds, spray irrigation, and percolation) depend on the site characteristics. The cost of deep well injection depends on the volume of the concentrate to be disposed of and is considered most expensive at very small volumes. The Zero liquid discharge (ZLD) method is the most expensive option due to the high energy requirement, whereas with other techniques the energy associated cost is insignificant (Mickley 2001).

Table 3 shows design parameters and capital cost factors for various concentrate disposal options. This table can be used to compare available options and to determine the most appropriate method of disposal for a selected desalination plant (Mahi 2001).

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Table 3 Design Variables and Capital Cost Items for Different Methods of Disposal

	Methods of Disposal						
	Surface Water Disposal	Sewage Treatment Plant	Deep Well Injection	Percolation	Spray Irrigation	Evaporation Pond	Zero Discharge
Design Variable							
Distance	Y	Y	Y	Y	Y	Y	Y
Volume	Y	Y	Y	Y	Y	Y	Y
Depth	—	—	Y	—	—	—	—
Number of tubing transitions	—	—	Y	—	—	—	—
Evaporation rate/ hydraulic loading	—	—	—	Y	Y	Y	—
Land availability, type, cost	—	—	—	Y	Y	Y	—
Storage time	—	—	—	Y	Y	—	—
Sprinkling spacing	—	—	—	—	Y	—	—
Reject flow	—	—	—	—	—	—	Y
Energy cost	—	—	—	—	—	—	Y
Capital Cost Item							
Transport system (pipe, pump)	Y	Y	Y	Y	Y	Y	Y
Treatment system (includes blending)	Y	Y	—	Y	Y	—	—
Outfall structure	Y	—	—	—	—	—	—
Injection well (depth, pump, materials)	—	—	Y	—	—	—	—
Monitoring wells	—	—	Y	Y	Y	Y	—
Land, land preparation	—	—	—	Y	Y	Y	—
Distribution system (pipe, pump)	—	—	—	Y	Y	—	—
Wet weather storage	—	—	—	Y	Y	—	—
Alternate disposal system	—	—	Y	—	—	—	—
Subsurface drainage system	—	—	—	(Y)	Y	—	—
Disposal fee	—	Y	—	—	—	—	—
Skid mounted system	—	—	—	—	—	—	Y

Methods with 'Y' must consider the design variable or cost item when used for concentrate disposal.

Source: Mahi 2001

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