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MEDRC

TOOLBOX
OF
GRAPHIC AND NUMERIC MODELS FOR ESTIMATING COSTS OF SEAWATER REVERSE OSMOSIS DESALINATION PROJECTS

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List of Acronyms

CRF	Capital Recovery Factor
DAF	Dissolved Air Flotation
H	Depth
HDD	Horizontal Directionally Drilled
HDPE	High Density Polyethylene
MENA	Middle East and North Africa
mg/L	milligrams per liter
MM	million
ML/d	Mega liters per day
O&M	Operation and Maintenance
Q	flow
RO	Reverse Osmosis
SWRO	Seawater Reverse Osmosis
TDS	Total Dissolved Solids
m^3/day	Cubic meters per day
US$	United States Dollars
Yr.	Year

1 Executive summary

1.1 Introduction

The seawater desalination project toolbox consists of a compendium of capital cost curves (graphic cost models) for all key components of desalination plants (intake, pretreatment, RO system, post treatment) which can be used to prepare cost estimates of future desalination projects. The cost curves are calibrated and validated against the actual capital expenditures for delivery of recent large seawater membrane reverse osmosis desalination projects in the Middle East and North Africa (MENA) region.

The toolbox also includes methodology for cost estimating of seawater reverse osmosis desalination plants and an example of the use of the methodology for preparation of desalination cost estimate.

1.2 Intended Users

The desalination toolbox is developed to be used by engineers, planners, decision-makers and cost estimators involved in the development and implementation of desalination projects. The content of the toolbox is catered to the needs of the MENA region.

1.3 Purpose

The purpose of this toolbox is to be used for preparation of budgetary cost estimates of seawater reverse osmosis (SWRO) desalination projects developed in the MENA region.

1.4 Applicability

The toolbox is applicable for the cost estimating of medium and large size membrane seawater reverse osmosis desalination projects of fresh water production capacity between 5,000 and 400,000 m^3/day.

1.5 Limitation of the Use of the Toolbox

The use of this toolbox is limited to seawater reverse osmosis desalination projects only. The cost models cannot be used for the calculation of the costs of thermal desalination plants or brackish water desalination plants.

The applicability of the cost estimating models and methodology is limited to projects with fresh water production capacity between 5,000 and 400,000 m^3/day. Since the cost estimating curves are derived from projects in the MENA Region, their use for projects outside of this region may not provide accurate cost projections. The accuracy range of the models and associated cost estimates is - 15 to + 30 %.

2 PROJECT COST ESTIMATING OVERVIEW

2.1 Introduction

World's oceans contain over 97.2 % of the planet's water resources. Because of the high salinity of ocean water and the significant costs associated with seawater desalination most of the global water supply has traditionally come from fresh water sources – groundwater aquifers, rivers and lakes. Changing climate patterns observed worldwide over the past decade combined with accelerating population growth pressures and limited availability of new and inexpensive fresh water supplies are shifting water industry's attention to an emerging trend – seawater desalination.

Until recently, use of seawater desalination was limited to desert-climate dominated regions. Latest technological advances and associated decrease in water production costs and energy demand have expanded its use in coastal areas traditionally supplied with fresh water resources. At present, desalination plants provide approximately 1 % of the world's drinking water supply. Fresh water production capacity from saline sources (brackish and seawater) has been increasing exponentially over the past 15 years.

In 2010, more than 15,000 desalination plants worldwide produced a total of 65.2 million cubic meters per day (m^3/day) of fresh water from seawater and brackish water (IDA, 2011). Approximately 60 % of the installed plant production capacity is attributed to reverse osmosis (RO) membrane desalination plants and 34.8 % by thermal distillation facilities.

A clear recent trend in seawater desalination is the construction of larger capacity plants, which deliver an increasingly greater portion of the fresh water supply of coastal cities around the globe. While most of the large desalination plants built between year 2000 and 2005 were typically designed to supply only 5 to 10% of the drinking water of large coastal urban centers, today most regional or national desalination project programs in countries such as Spain, Australia, Israel, Algeria and Singapore aim to secure 20 to 25 % of their long-term drinking water needs with desalinated seawater.

Currently, reverse osmosis is the most commonly used desalination technology because for most saline sources and applications, it yields fresh water at overall energy use and costs lower than these of other traditional alternative desalination technologies. Therefore this toolbox focuses on the methods and factors for determining all-inclusive costs for construction, operation and maintenance (O&M), and overall fresh water production by seawater reverse osmosis (SWRO) desalination.

2.2 Project Cost Definitions

The key economic parameters of a seawater reverse osmosis desalination project are:

- Capital costs;
- Operation and maintenance costs;
- Cost of water production.

2.3 Capital Costs

Capital costs include all expenditures associated with desalination project implementation: from the time of conceptual development, through design, permitting, financing, construction, commissioning and acceptance testing for continuous operation. Construction costs encompass all direct expenditures needed to: build plant source water intake and concentrate discharge systems and all project-related structures; procure and install all facility equipment, install and connect plan piping and service utilities; and deliver desalinated water to final user/s. Because of their direct association with the construction of physical facilities, construction costs are also referred to as “direct” or “hard” capital costs. Construction costs are typically 50 to 85 % of the total capital costs.

The remaining 15 to 50 % of capital costs are often referred to as “indirect” of “soft” costs. These costs are associated with all engineering, administrative, permitting, and funding efforts necessary to bring the project to fruition; as well as expenditures needed to secure procure contractors for design, construction and operation of the desalination project.

Total project capital costs are typically presented in monetary units (i.e., US$) and are estimated either for the year when project construction is initiated or are referenced to the middle of the construction period. Depending on the type, length and term of project funding, capital costs are often converted in monetary units per year and referred to as amortized or annualized costs (US$/yr.). In addition, both capital and construction costs are sometimes presented as expenditures per unit of desalination project fresh water production capacity (i.e., US$/m^3.day or US$/1,000 gallons).

2.4 Operation and Maintenance Costs

Operation and maintenance costs are all expenditures associated with: SWRO plant operations (power, chemicals, labor, and replacement of consumables, such as membranes and cartridge filters); with maintenance of plant equipment, buildings, grounds and utilities; and with compliance with all plant operation and environmental permits, and other pertinent regulatory requirements. The operation and maintenance costs associated with a given project are typically expressed as the all-inclusive operational expenditures for a period of one year (i.e., US$/yr.) or as operational costs for the production of unit volume of desalinated water (i.e., US$/m^3).

Operation and maintenance costs may be divided into two main categories: fixed and variable. Fixed O&M costs are annual expenditures that are not a function of the actual amount of fresh water produced by the desalination plant. Such O&M expenditures include: labor costs (staff wages and fringe benefits); costs for routine preventive equipment maintenance; environmental and performance monitoring, operational insurance; administrative costs, and other miscellaneous overhead expenses. Variable O&M costs are typically proportional to the actual volume of desalinated water produced by the SWRO plant and include expenditures for: power; chemicals; replacement of RO membranes and cartridge filters, and for waste disposal. Typically variable costs are 50 to 85 % of the total annual O&M costs, while the fixed costs are 15 to 50 % of these expenditures.

2.5 Cost of Water

Cost of water is an economic parameter that incorporates all project capital and annual O&M expenditures associated with water production, and is typically presented as monetary units per unit volume of desalinated water (i.e., US$/m³). The total cost of fresh water production (cost of water) is calculated by dividing the sum of the amortized (annualized) capital costs (i.e., US$/yr.) and the annual O&M costs (i.e., US$/yr) by the total annual desalination plant fresh water production volume (m³/yr). For a typical SWRO plant, the amortized capital costs and the O&M costs are usually in a range of 40 to 60 % of the total cost of water, each.

Although, the ratio between the key cost components varies from project to project, the "largest pieces of the cost pie" are usually the plant construction expenditures (i.e., the direct capital costs), power, and the other O&M costs (i.e., maintenance, chemicals, membranes, etc.). The indirect capital costs, which mainly include expenditures for project engineering, development and finance, are also a significant portion (typically 10 to 20 %) of the water production costs.

3 CAPITAL COSTS

Project capital costs can be divided into two broad categories: (1) construction costs (sometimes also referred to as "direct capital costs" or "hard project costs") and (2) other project related capital costs (engineering, development, financing, and contingencies), which are often referred to as "indirect capital costs" or "soft project costs". A typical breakdown of the project capital costs for low-complexity and high-complexity desalination projects is presented in Table 1.

Table 1 SWRO Project Capital Cost Breakdown

Cost Item	Percentage of Total Capital Cost (%)	
	Low-Complexity Project	**High-Complexity Project**
Direct Capital (Construction) Costs		
1. Site Preparation, Roads and Parking	1.5 – 2.0	0.5 – 1.0
2. Intake	4.5 – 6.0	3.0 – 5.0
3. Pretreatment	8.5 – 9.5	6.0 – 8.0
4. RO System Equipment	38.0 – 44.0	30.5 – 36.0
5. Post-Treatment	1.5 – 2.5	1.0 – 2.0
6. Concentrate Disposal	3.0 – 4.0	1.5 – 3.0
7. Waste and Solids Handling	2.0 – 2.5	1.0 – 1.5
8. Electrical & Instrumentation Systems	2.5 – 3.5	1.5 – 2.5
9. Auxiliary and Service Equipment and Utilities	2.5 – 3.0	1.0 – 2.0
10. Buildings	4.5 – 5.5	3.0 – 5.0
11. Start Up, Commissioning and Acceptance Testing	1.5 – 2.5	1.0 – 2.0
Subtotal Direct (Construction) Costs (% of Total Capital Costs)	**70.0 – 85.0**	**50.0 – 68.0**

Table 1 (Continued) SWRO Project Capital Cost Breakdown

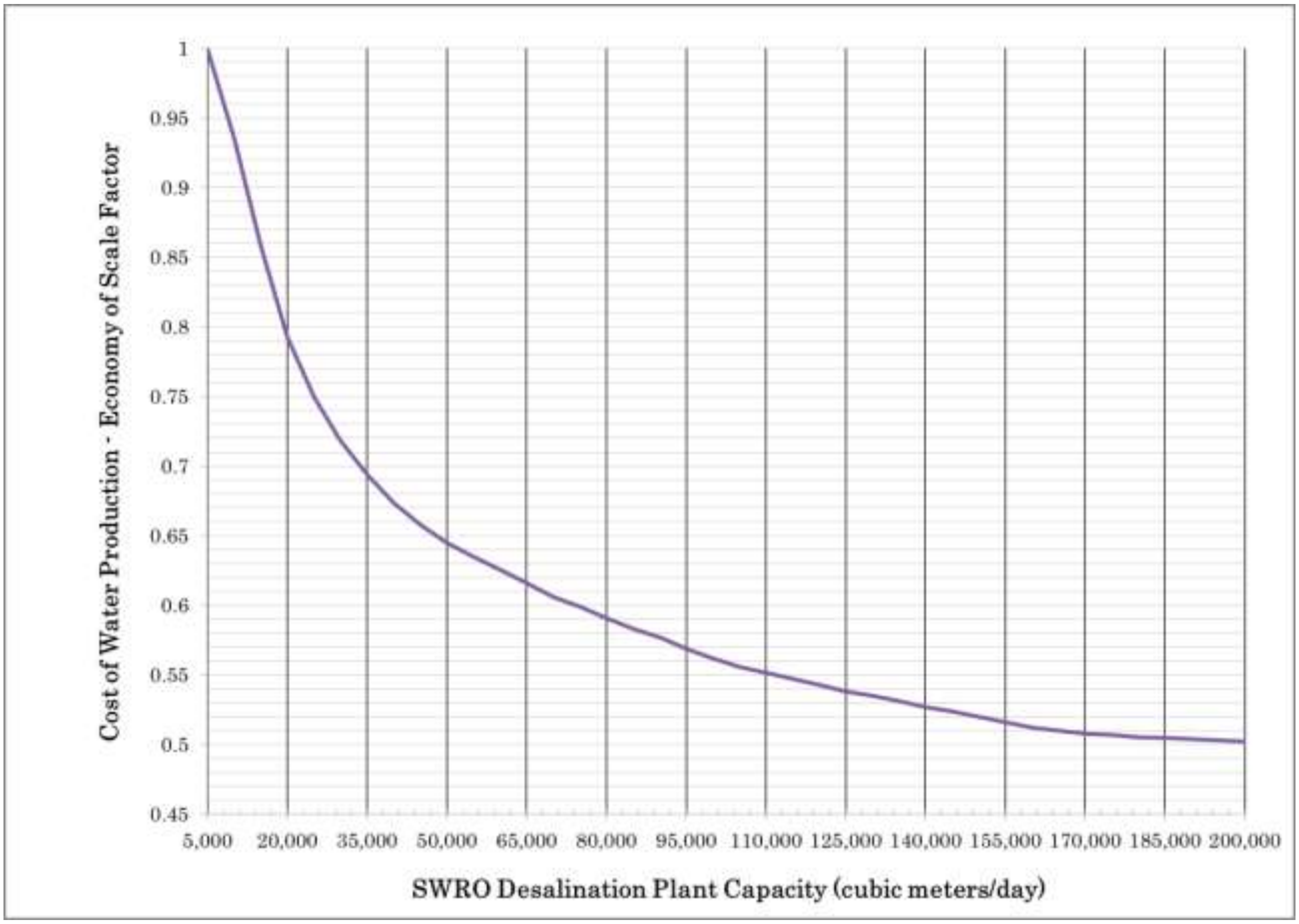
Cost Item	Percentage of Total Capital Cost (%)	
	Low-Complexity Project	**High-Complexity Project**
Project Engineering Services		
1. Preliminary Engineering	0.5 - 1.0	0.5 – 1.5
2. Pilot Testing	0.0 - 0.5	1.0 – 1.5

3. Detailed Design	3.5 - 4.5	5.0 – 6.0
4. Construction Management and Oversight	1.0 – 2.0	2.5 – 3.5
Subtotal Engineering Services	***5.0 – 8.0***	***9.0 – 12.5***
Project Development		
1. Administration, Contracting and Management	1.0 – 1.5	2.0 – 3.0
2. Environmental Permitting (Licensing)	0.5 – 3.5	4.5 – 5.0
3. Legal Services	0.5 – 1.0	1.5 – 2.0
Subtotal Project Development	***2.0 – 6.0***	***8.0 – 10.0***
Project Financing Costs		
1. Interest During Construction	0.5 - 2.5	1.0 – 4.5
2. Debt Service Reserve	2.0 – 5.5	4.5 – 8.5
3. Other Financing Costs	0.5 – 1.0	3.5 – 4.5
Subtotal Project Financing	***3.0 – 9.0***	***9.0 – 17.5***
Contingency	***5.0 – 7.0***	***6.0 – 10.0***
Subtotal Indirect Capital Costs (% of Total Capital Costs)	***15.0 – 30.0***	***32.0 – 50.0***
Total Capital Costs	**100 %**	**100 %**

3.1 Desalination Costs – Economy of Scale

The cost of water production is a function of desalination plant capacity (see Figure 1)

Figure 1 – Desalination Plant Economy of Scale



3.2 Desalination Plant Site Requirements

Desalination plant site costs are proportional to the size of the site and the unit cost of land. Table 2 provides guidance on the size of the site needed for a given desalination project as a function of its production capacity. The larger the plant site the higher the cost and land requirements.

Table 2 - Seawater Desalination Plant Land Requirements

Plant Capacity (m^3/day)	Typical Plant Site Land Requirements	
	m^2	acres
1,000	800 – 1,600	0.2 to 0.4
5,000	2,000 – 3,200	0.5 to 0.8
10,000	6,100 – 8,100	1.5 to 2.0
20,000	10,100 – 14,200	2.5 to 3.5
40,000	18,200 – 24,300	4.5 to 6.0
100,000	26,300 – 34,400	6.5 to 8.5
200,000	36,400 – 48,600	9.0 to 12.0
300,000	45,200 – 60,000	11.5 to 15.0

Note: Land Requirements Based on Conventional Plant Layout. Compact Plants May Require Less Land.

3.3 Capital Costs of Intakes

Intake costs are a function of the plant size and the type of intake. Offshore open intakes (see Figure 2) are most commonly used in medium and large desalination projects.

Figure 2 – Open Ocean Intake

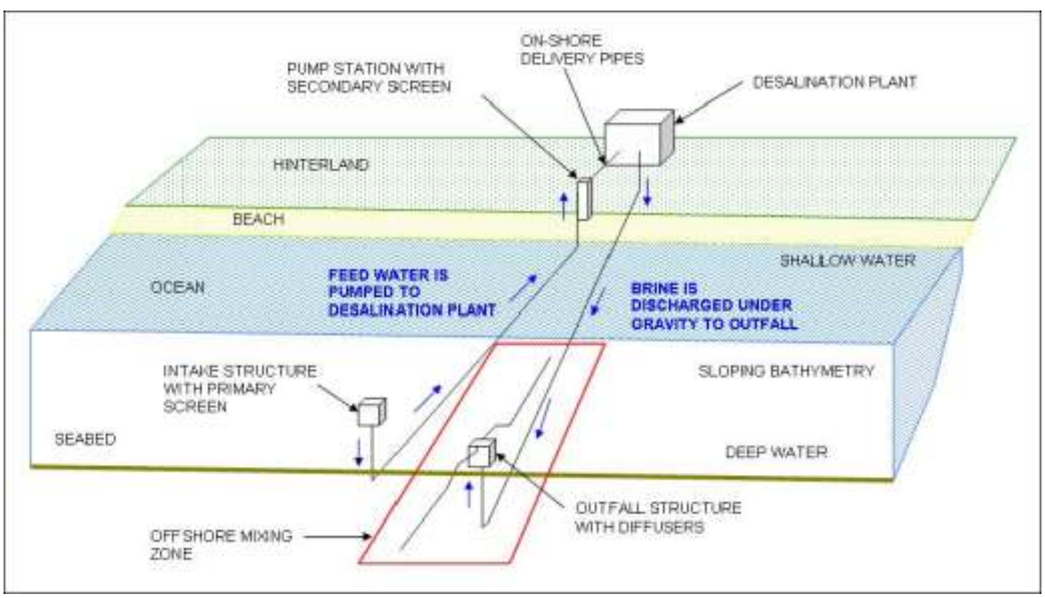


Figure 3 presents the cost curve for offshore intakes constructed as concrete tunnels and high density polyethylene (HDPE) pipe. The figure incorporates costs for the two most commonly used types of offshore intakes – concrete tunnels and HDPE pipe. For a given size of intake, the figures allow to determine the unit cost of the intake per meter of intake pipe/tunnel. The total intake cost is calculated by multiplying the unit cost of the intake and the actual length of the intake pipe/tunnel.

Figure 3 – Costs of Offshore Open Intakes

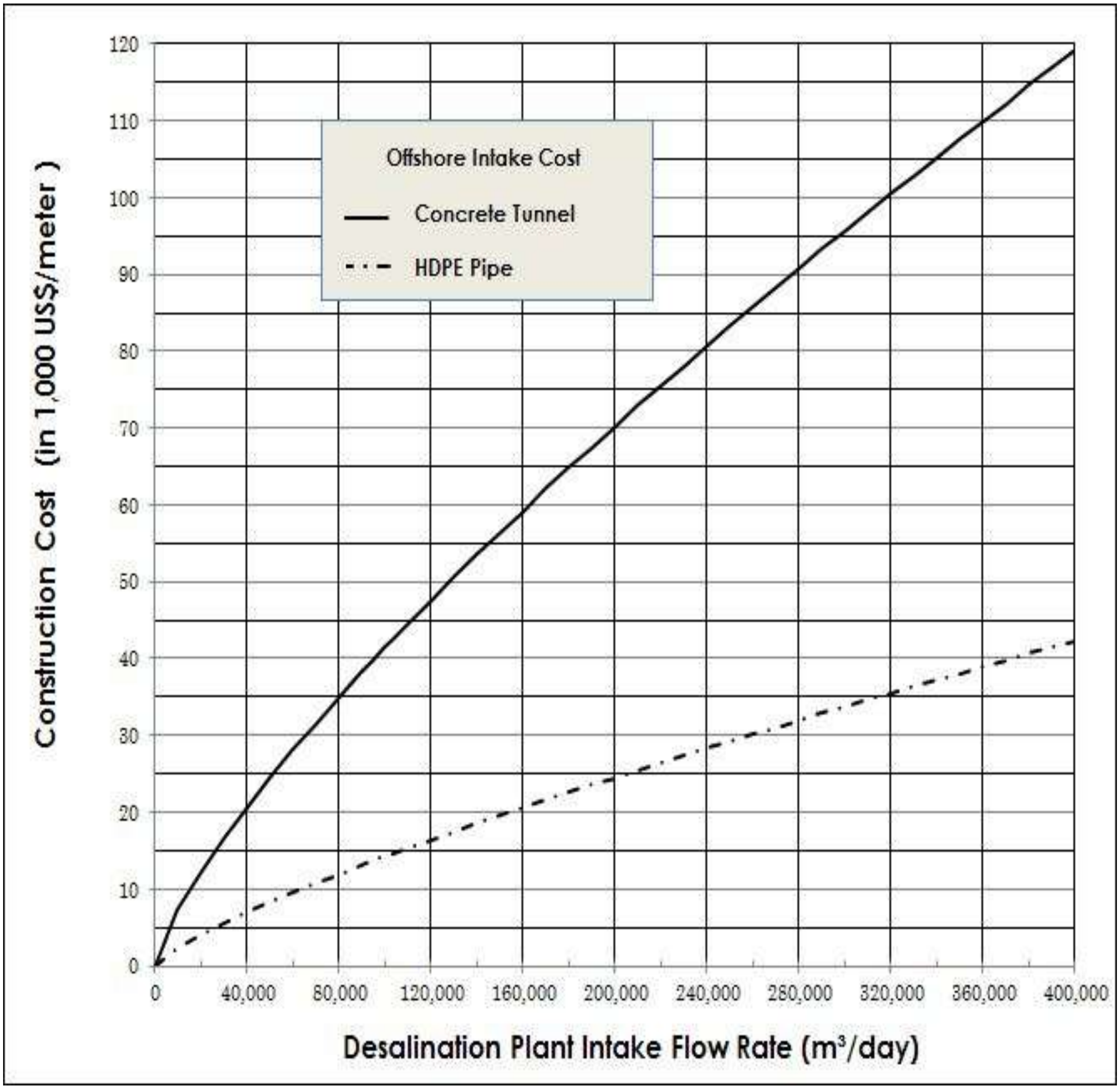


Figure 4 depicts onshore intake costs. On-shore intakes are used at a number of seawater desalination plants in the MENA region. This graph presents the construction cost of onshore intakes as a function of the intake seawater collection capacity. As described in previous sections of this toolbox, this cost graph was developed based on the cost of actual onshore intakes of desalination and power plants in the MENA region.

Figure 4 – Costs of Onshore Open Intakes

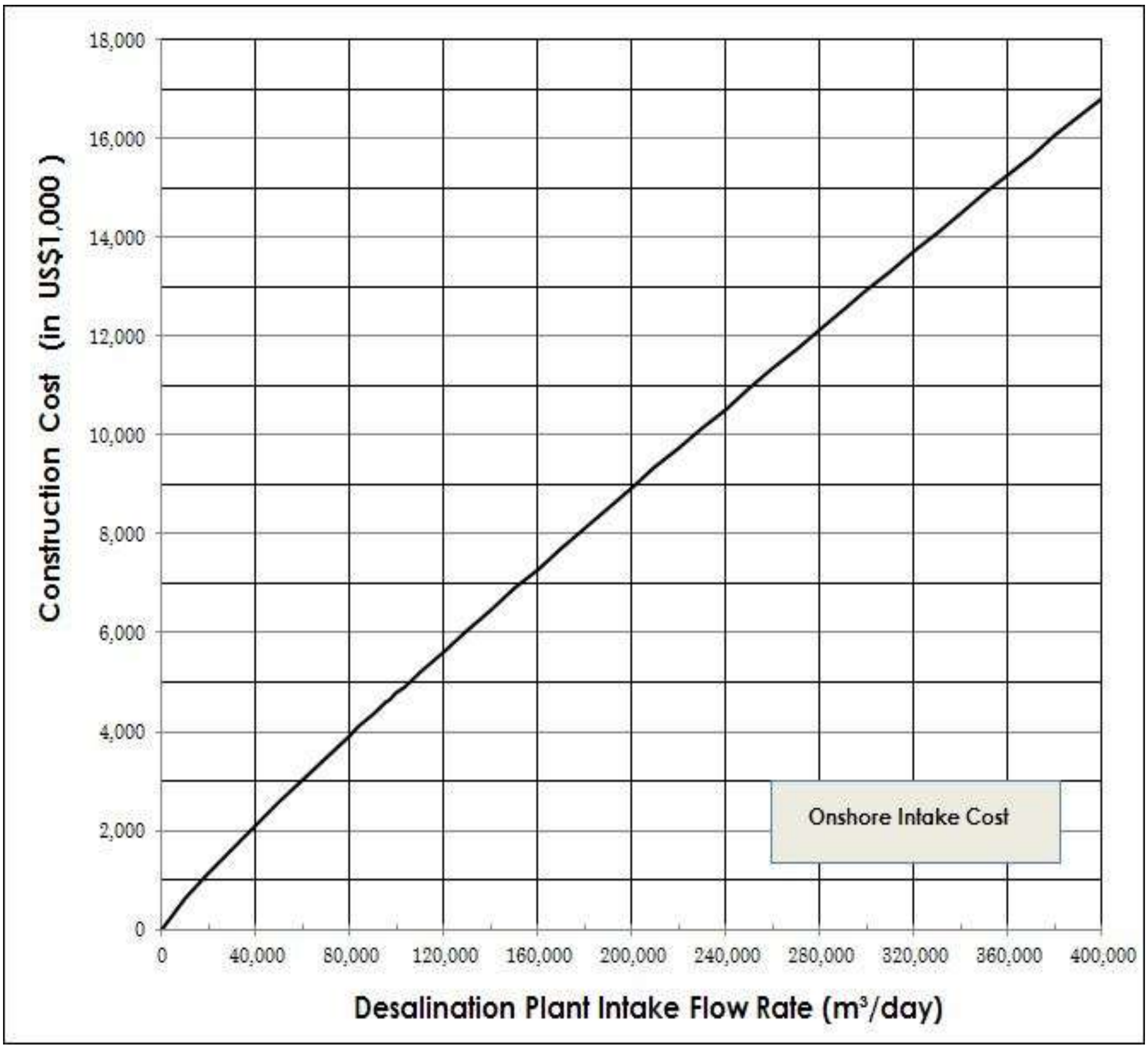


Table 3 provides cost functions that can be used for the estimating of the construction costs of vertical well intakes. Table 4 summarizes costs of various types of intakes.

Table 3 Construction Costs of Vertical Intake Wells

Intake Well Production Capacity (m^3/day)	Construction Costs in 2012 US$ as a Function of Well Intake Flow, Q (m^3/day) and Well Depth, H (m)
1,000 - 2,000	40 Q + 700 H + 25,000
2,000 - 4,500	50 Q + 850 H + 50,000
4,500 – 6,500	65 Q + 1,100 H + 80,000
6,500 – 10,000	76 Q + 2,000 H + 150,000
10,000 – 15,000	85 Q + 2,100 H + 190,000
15,000 – 30,000	90 Q + 3,300 H + 260,000

Table 4 Comparison of Production and Costs of Various Types of Wells

Well Type	Typical Production Capacity (Yield) of Individual Well (ML/d)	Cost of Individual Well (US$ MM)
Vertical Well	0.1 – 3.5 ML/d	$0.2 - $2.5 MM
Horizontal Radial Collector Well	0.5 – 20 ML/d	$0.7 – $5.8 MM
Slant Well	0.5 – 10 ML/d	$0.6 - $3.0 MM
HDD Well (i.e., Neodren)	0.1 – 5.0 ML/d	$0.3 - $1.3 MM
Infiltration Gallery	0.1 - 50 ML/d	$0.5 - $27.0 MM

3.4 Intake Screen Costs

Figures 5, 6 and 7 provide estimates of drum screens and band screens which at present are most commonly used in desalination plants in the MENA region. As seen from the graph, drum screens are more costly than band screens. However, drum screens generate less headlosses and usually easier to maintain. Figures 6 and 7 provide an estimate of the construction costs of the screens as a function of plant intake capacity.

Figure 5 – Drum and Band Screen Costs

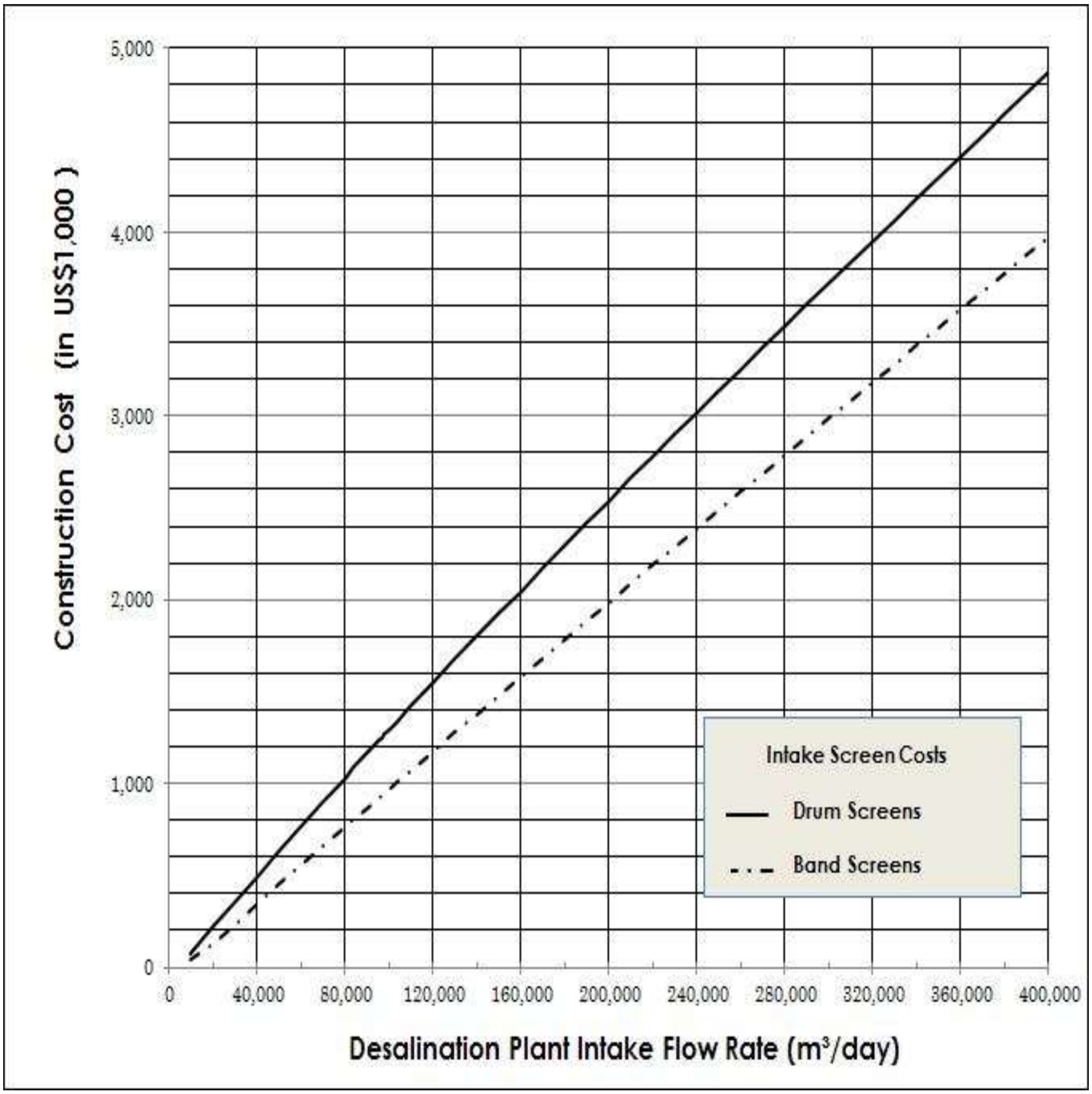


Figure 6 – Wedgewire Screen Costs

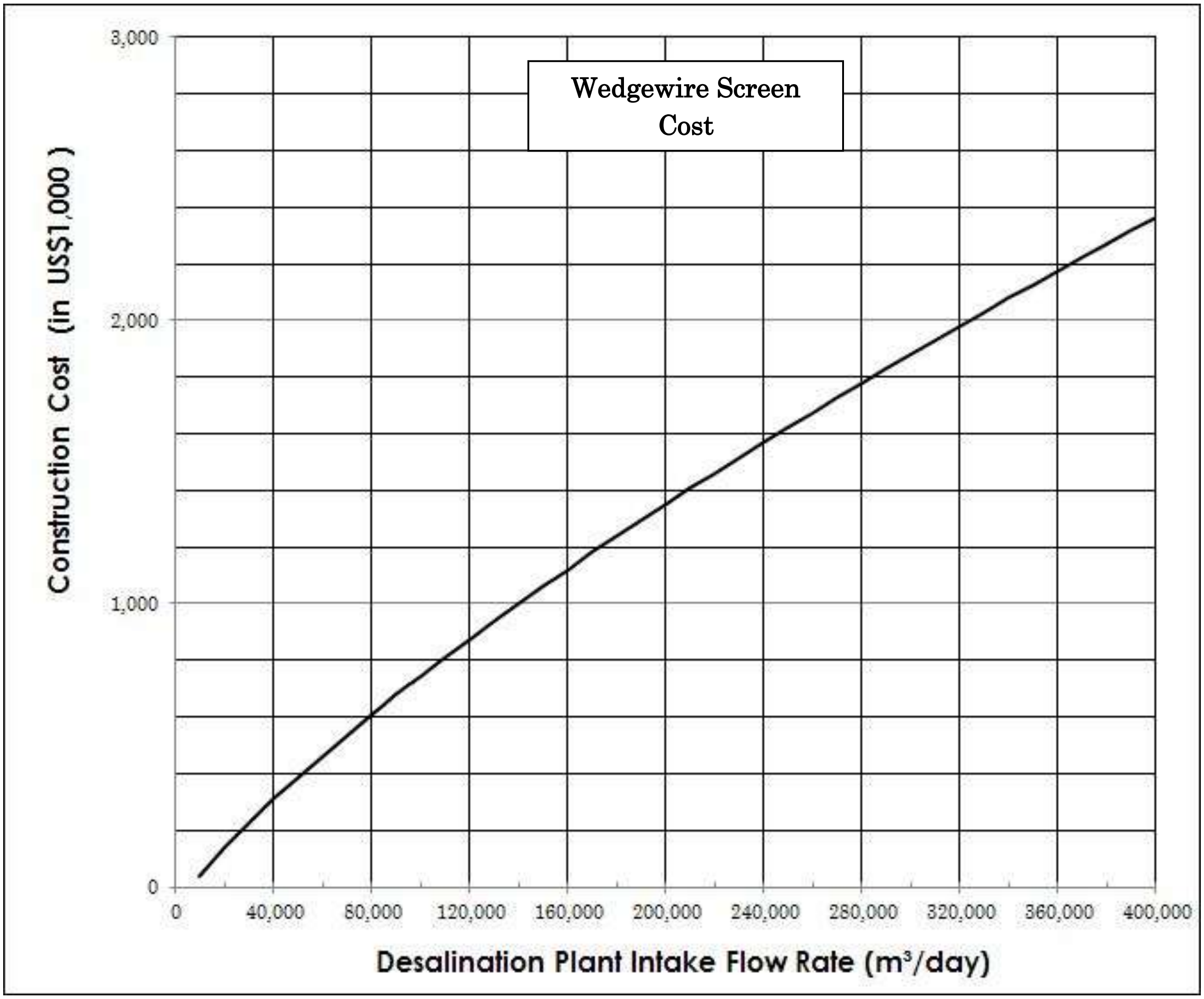


Figure 7 – Cartridge Filter Costs

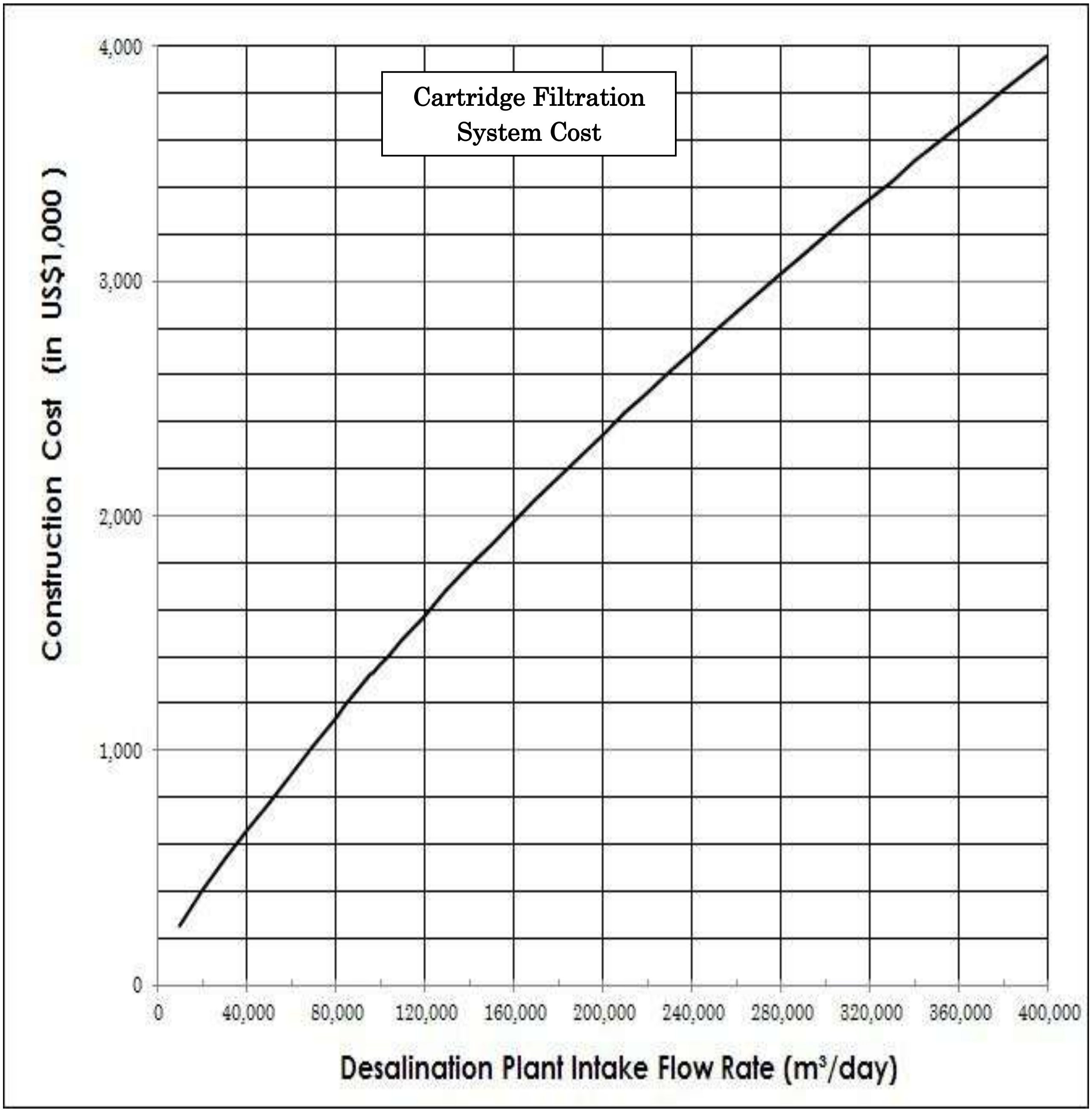
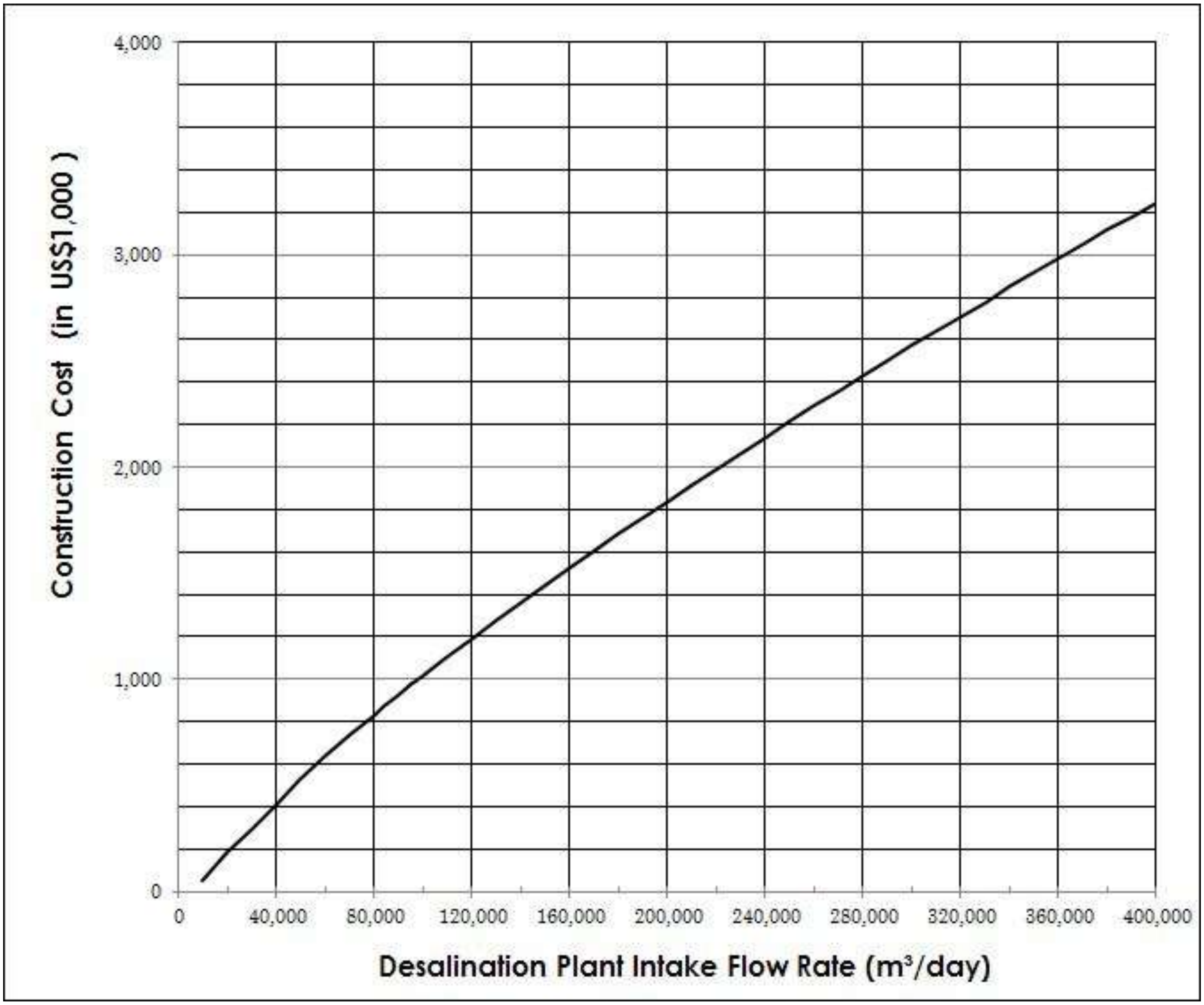


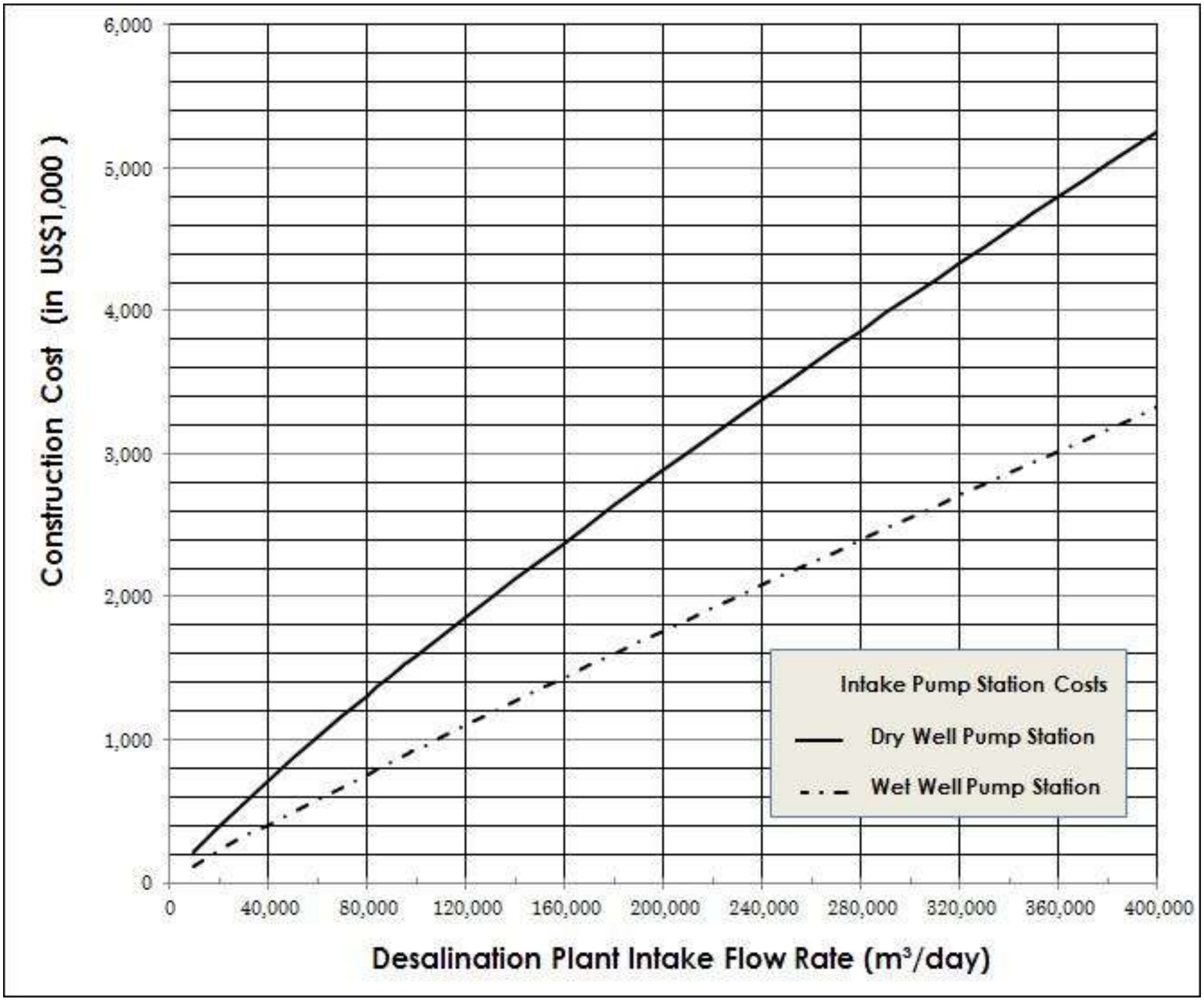
Figure 8 - Microscreens



3.5 Intake Pump Station Costs

Figure 8 depicts intake pump station costs. These costs are presented for both dry and wet well configurations.

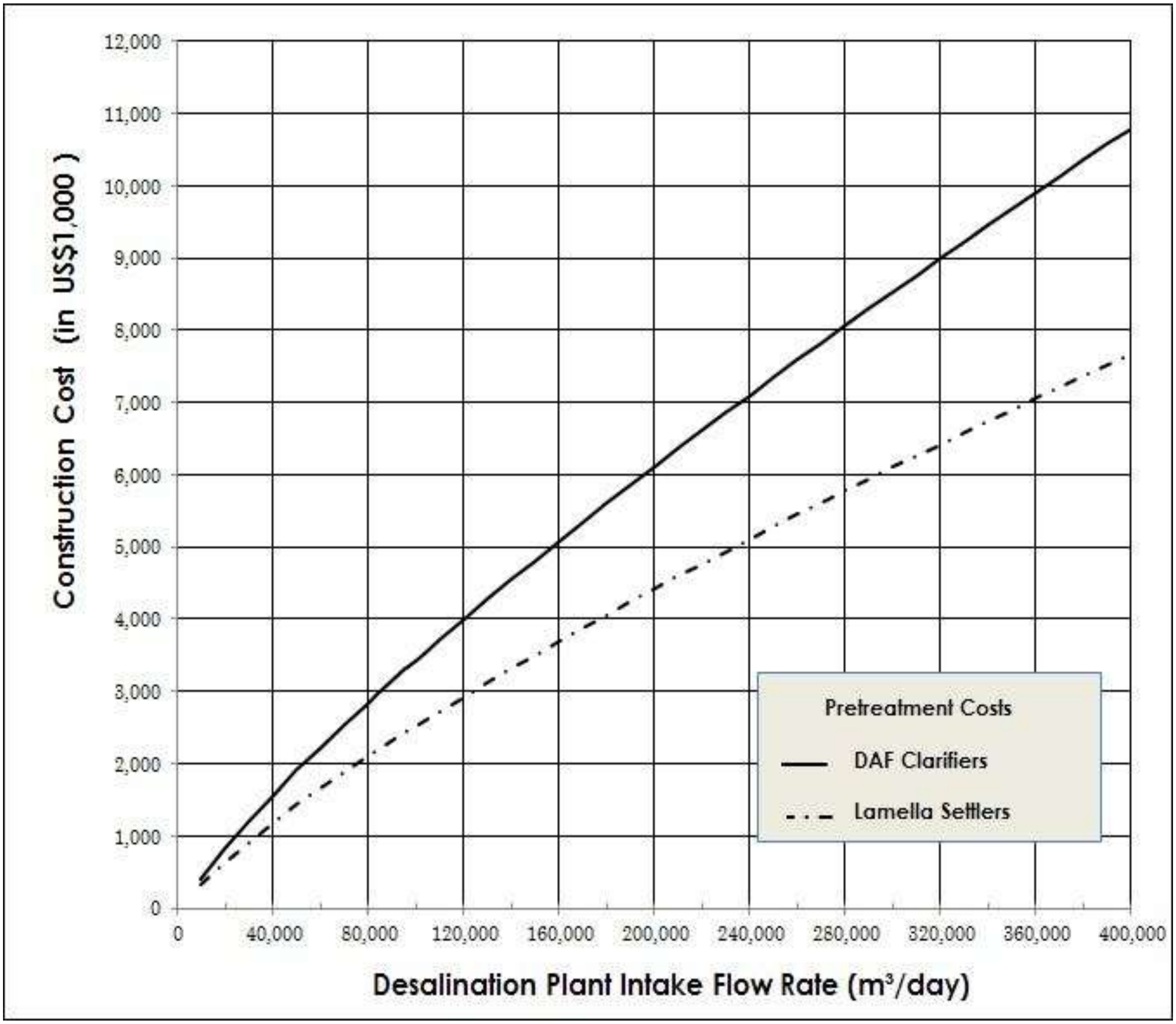
Figure 9 – Intake Pump Station Costs



3.7 Lamella and DAF Costs

Costs for lamella settlers and dissolved air flotation clarifiers are presented on Figure 10.

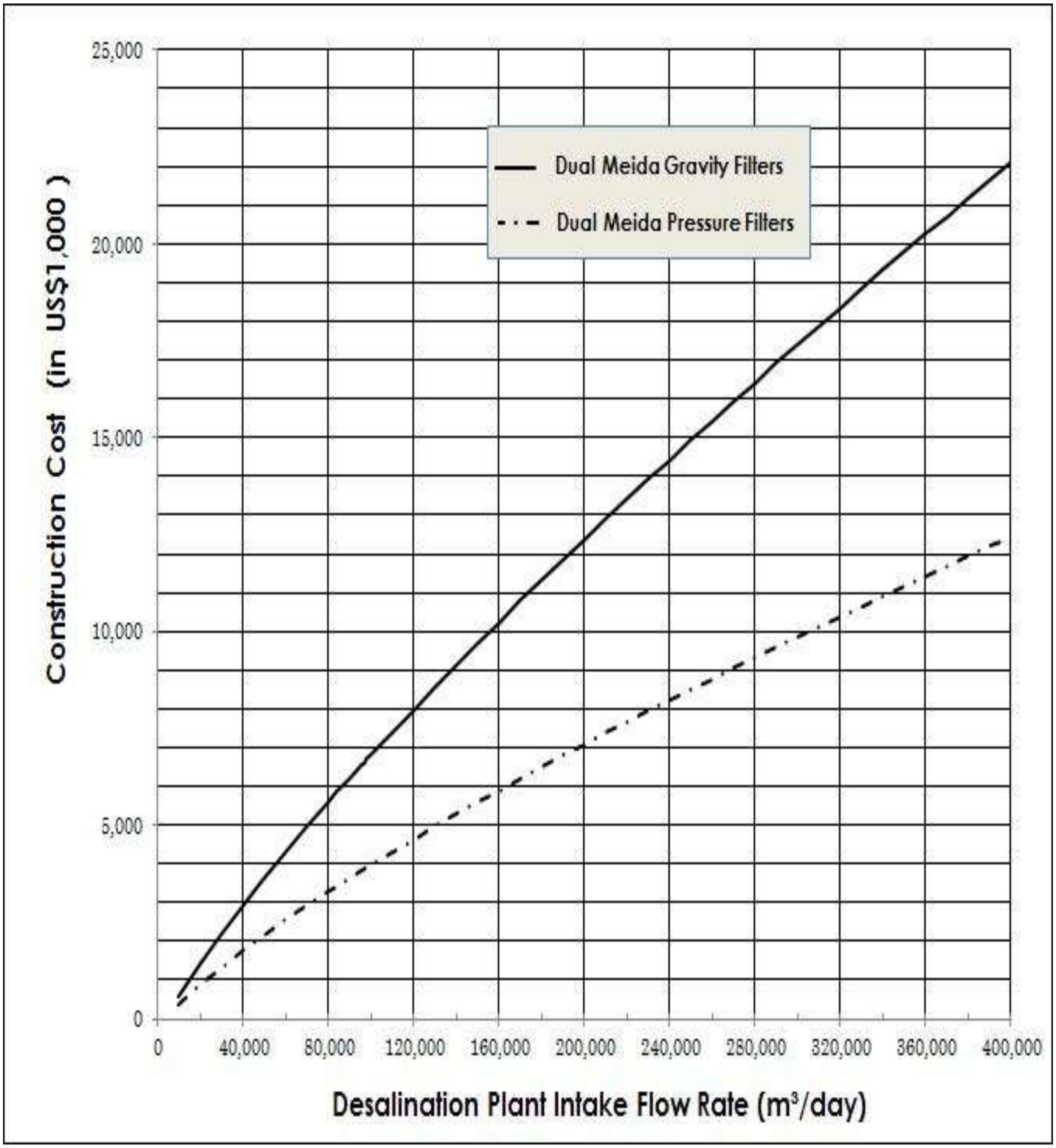
Figure 10 – Costs of Lamella and DAF Clarifiers



3.8 Granular Media Filters (Anthracite & Sand)

Figure 11 depicts the costs of dual media filters (sand and anthracite). The figure contains the costs of both gravity and pressure filters.

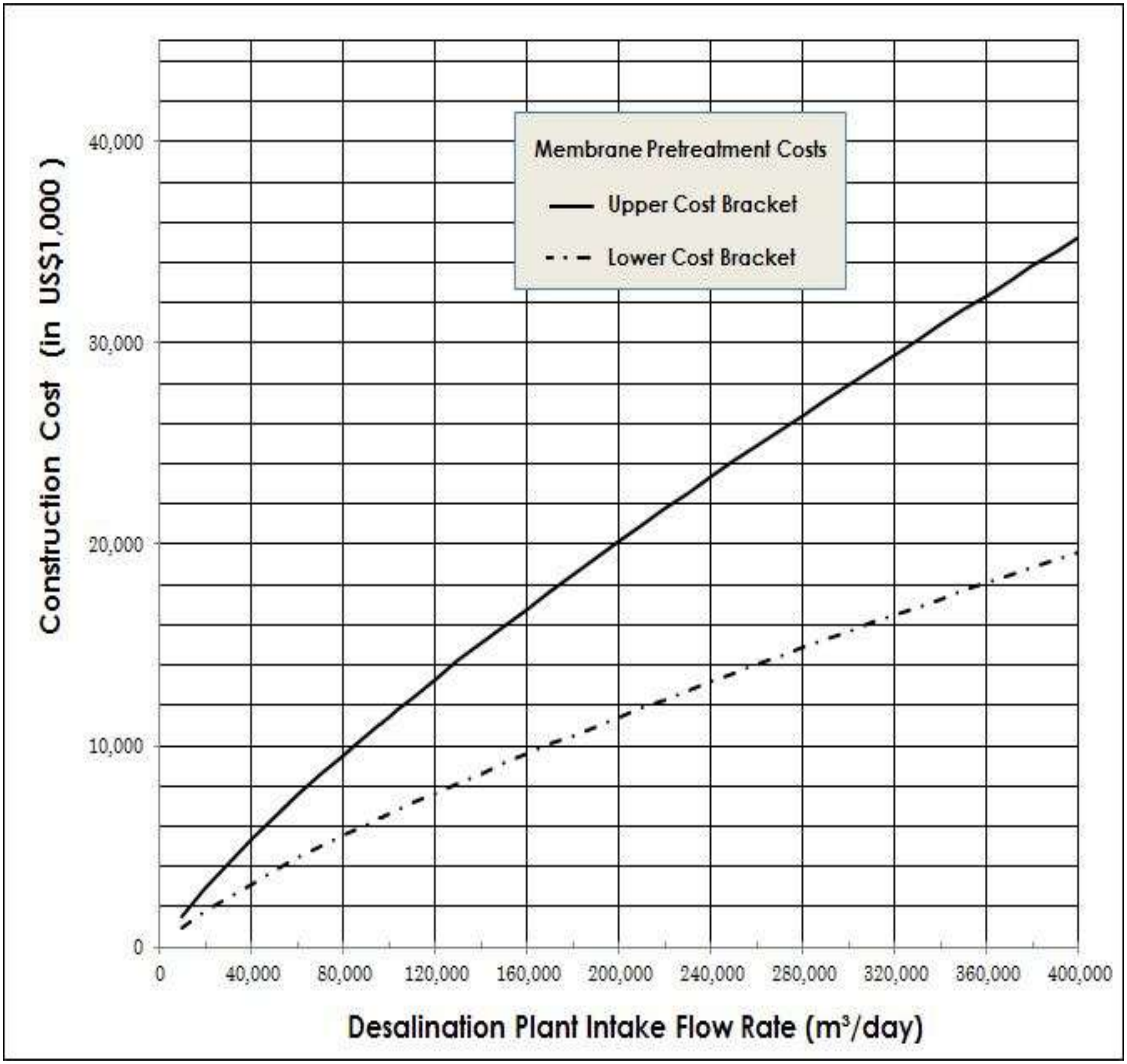
Figure 11 – Costs of Dual Media Filters



3.9 Membrane Pretreatment Filters

Figure 12 shows the costs of membrane pretreatment filters.

Figure 12 – Membrane Pretreatment Filters



3.10 Reverse Osmosis System

Table 5 summarizes the costs of key components of the reverse osmosis systems of seawater desalination plants.

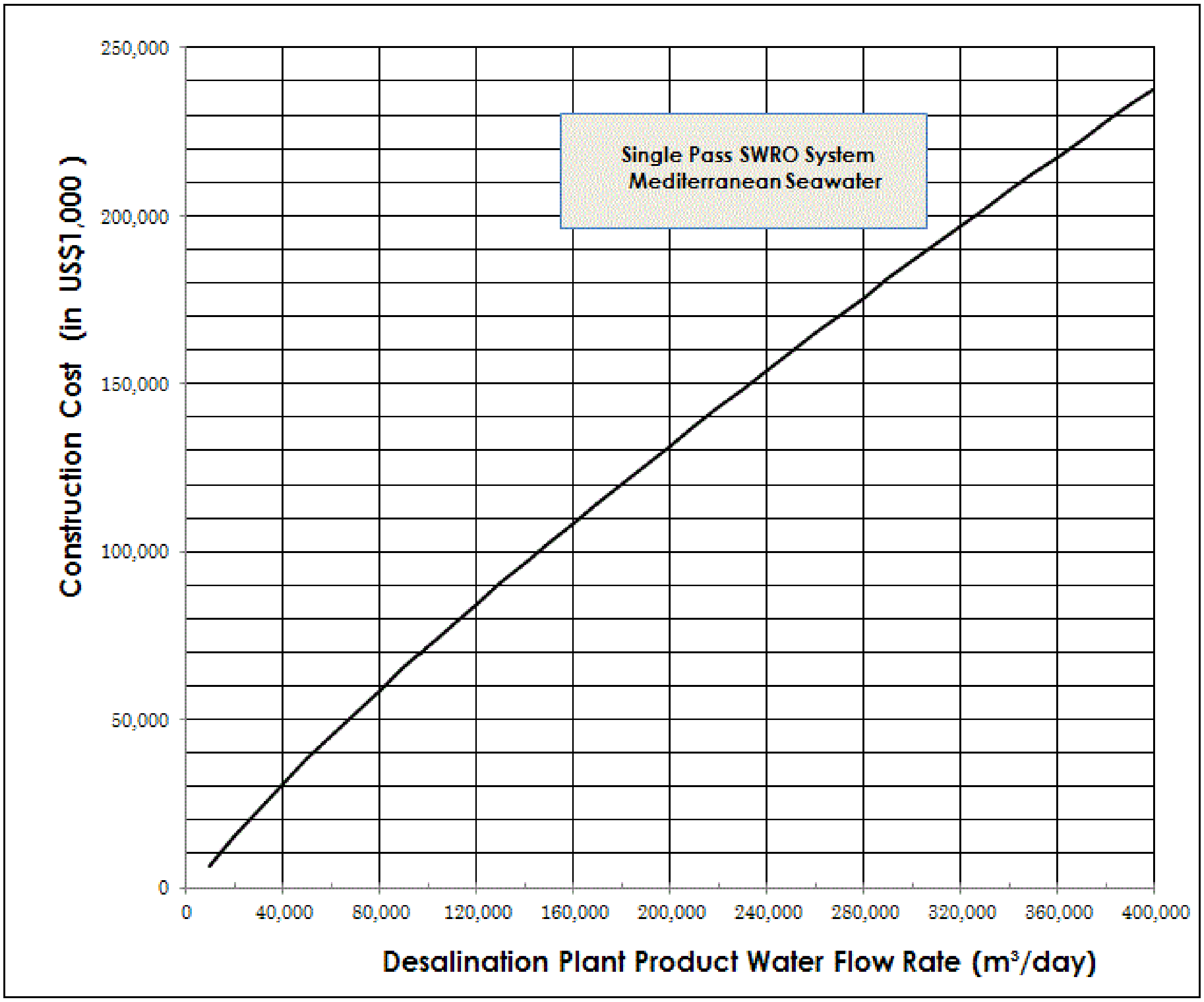
Table 5 Construction Costs of Key Membrane RO System Components

Item	Construction Cost (US$/item or as indicated)
8-inch Brackish RO Membrane Elements	US$250 – US$350/element
8-inch SWRO Membrane Elements	US$400 – US$600/element
16-inch SWRO Membrane Elements	US$2,800 – US$3,300/element
Brackish RO Pressure Vessels for 8-inch Elements	US$1,000 – US$1,300/vessel
SWRO Pressure Vessels for 8-inch Elements	US$1,300 – US$1,800/vessel
SWRO Pressure Vessels for 16-inch Elements	US$3,600 – US$5,000/vessel
RO Train Piping	US$250,000 – US$750,000/RO Train
RO Train Support Frame	US$150,000 – US$550,000/RO Train
RO Train Instrumentation and Controls	US$30,000 – US$150,000/RO Train
High Pressure Pumps	US$150,000 – US$2,400,000/RO Train

3.11 RO System Costs for Single Pass SWRO System for Mediterranean Water

The graph shown below (Figure 13) is used as a baseline graph for all cost estiates. The costs of SWRO systems which treat different water are adjusted upwards with the coefficents shown in Table 6. In table 6, SWRO systems treating Mediterranean water are considered to have a unit cost of 1.

Figure 13 – Cost of Single pass SWRO System for Mediteranean Water



Because of their higher salinity, SWRO systems processing water other than Mediterranean will be higher and are derived from the RO system cost of the Mediterranean water for a give project muptilied with the factor in Table 6.

Table 7 can be used to adjuist costs of the RO systems which have more than one pass and are designed to produce water quality better than drinking water.

Table 6 – Adjustment Coefficients for Conversion of Cost of Water for Mediterranean Project to Other Locations

Seawater Source	Unit Construction Costs	Unit O&M Costs	Unit Water Costs
Mediterranean	1.0	1.0	1.0
Gulf of Oman	1.09	1.07	1.08
Red Sea	1.12	1.10	1.11
Arabian Gulf	1.16	1.14	1.15

Table 7 – Adjustment Coefficients for Conversion of Cost of Water for Mediterranean Project with Single Pass RO to RO Systems

Effect of Target Product Water Quality on Water Costs			
Target Product Water Quality	Construction Costs	O&M Costs	Cost of Water
TDS = 500 mg/L Chloride = 250 mg/L Boron = 1 mg/L Bromide = 0.8 mg/L	1.00	1.00 Single Pass RO System	1.00
TDS = 250 mg/L Chloride = 100 mg/L Boron = 0.75 mg/L Bromide = 0.5 mg/L	1.15 – 1.25	1.05 – 1.10 Partial Second Pass RO System	1.10 – 1.18
TDS = 100 mg/L Chloride = 50 mg/L Boron = 0.5 mg/L Bromide = 0.2 mg/L	1.27 – 1.38	1.18 – 1.25 Full Two-Pass RO System	1.23 – 1.32
TDS = 30 mg/L Chloride = 10 mg/L Boron = 0.3 mg/L Bromide = 0.1 mg/L	1.40 – 1.55	1.32 – 1.45 Full Two-Pass RO System + IX	1.36 – 1.50

Figure 14 provides example of the calculation of the SWRO system costs for water qualities other than Mediterranean water.

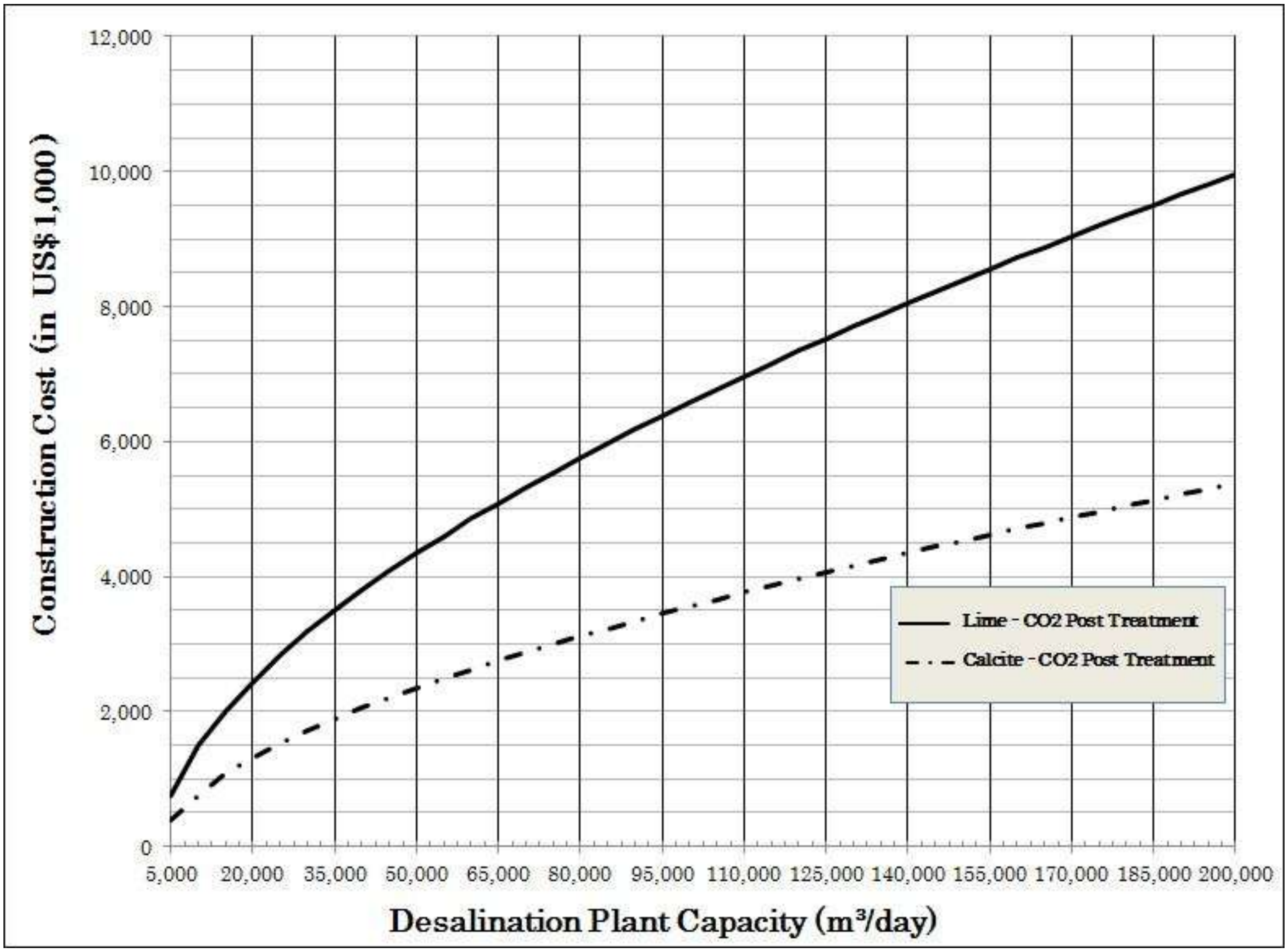
Figure 14 – Example of RO System Costs

3.12 Post-treatment Construction Costs

Lime and Calcite Systems

Figure 15 depicts the construction costs for lime and calcite post-treatment systems.

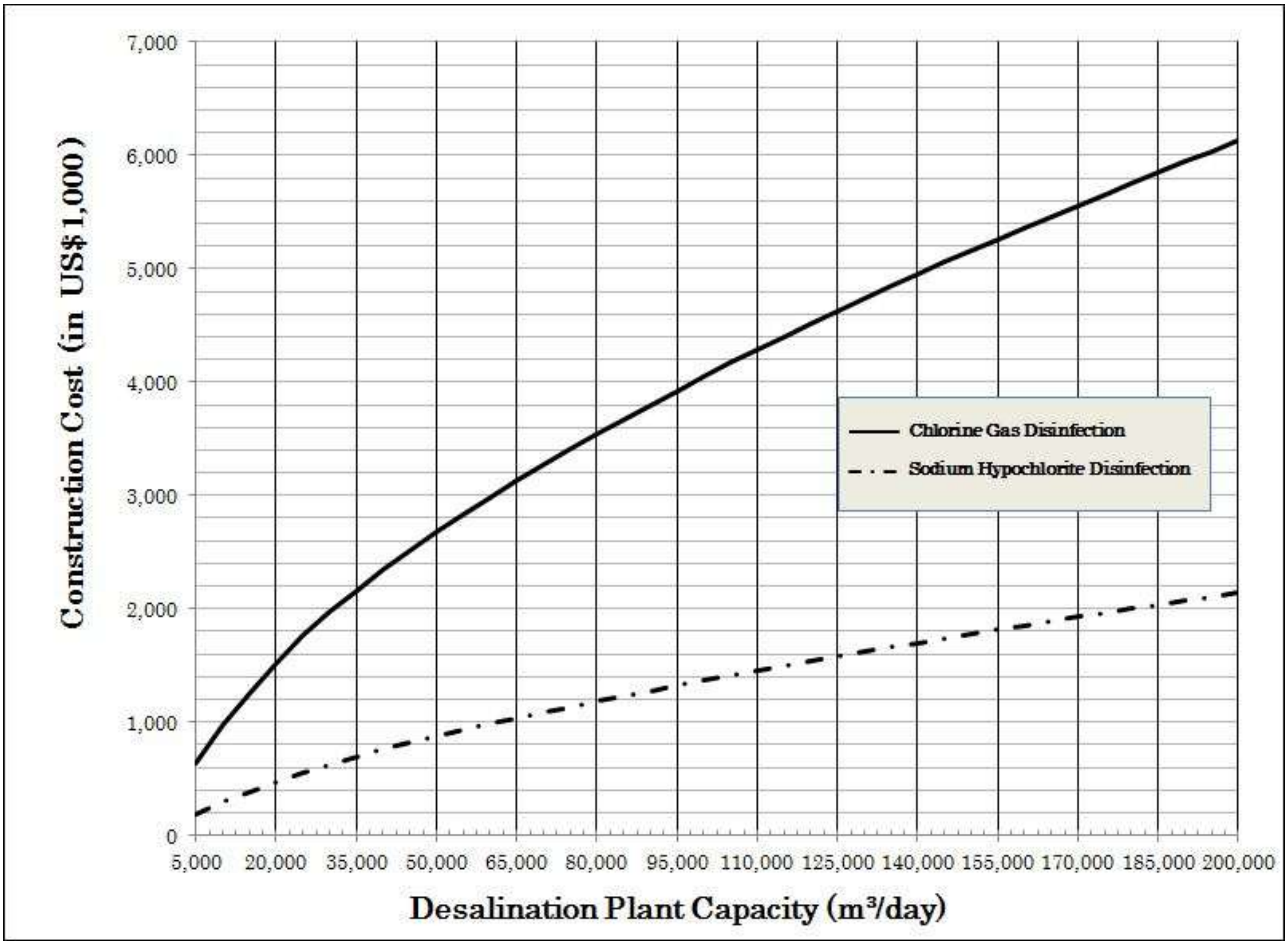
Figure 15 – Lime and Calcite System Costs



Disinfection System

Figure 16 illustrates cost of water disinfection as a function of plant capacity.

Figure 16 – Disinfection System Costs

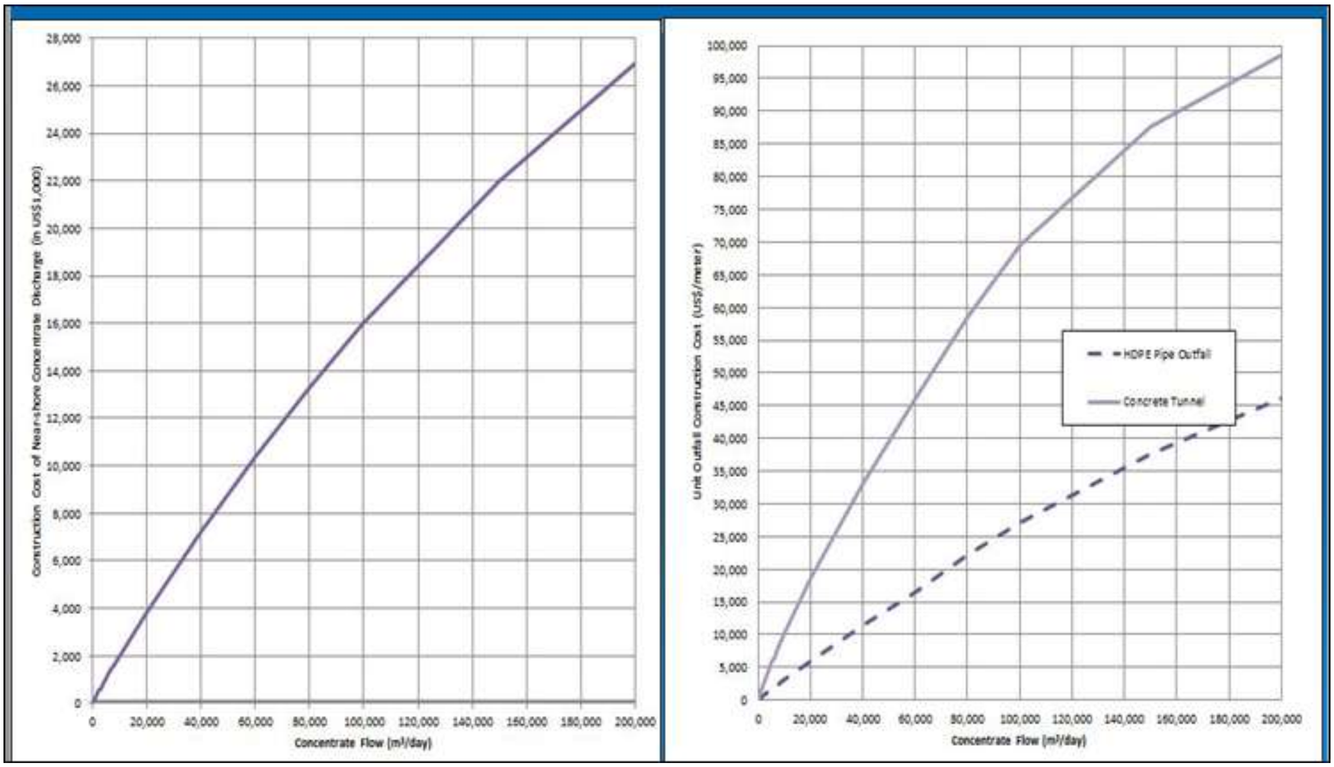


3.13 Concentrate Disposal Costs

Figure 17 depicts construction costs for near and offshore concentrate disposal.

Near vs. Offshore Discharge

Figure 17 – Near and Offshore Concentrate Disposal Costs



3.14 Other Construction Costs

Other construction costs are summarized on Figure 18. This figure illustrates the calculation of such costs for a 40,000 m³/day plant. Table 9 illustrates direct capital costs for 40,000 m³/day project. Table 10 provides recommended cost ranges for indirect construction costs. This table also contains example of such costs for 40,000 m³/day plant.

Figure 18 – Other Construction Costs

Table 9 – Direct Cost Summary of 40 MLD SWRO Project Treating Mediterranean Water with Single Pass RO System

Cost Item	Cost (US$)
Site Preparation, Roads and Parking	0.6 MM
Intake	9.5 MM
Pretreatment	7.8 MM
RO System Equipment	30.00 MM
Post Treatment	2.1 MM
Concentrate Disposal	3.0 MM
Waste and Solids Handling	1.8 MM
Electrical & Instrumentation	8.0 MM
Auxiliary and Service Facilities	3.2 MM
Buildings	2.4 MM
Startup, Commissioning and Acceptance Testing	2.0 MM
Direct Capital (Construction) Costs	*US$70.4MM*

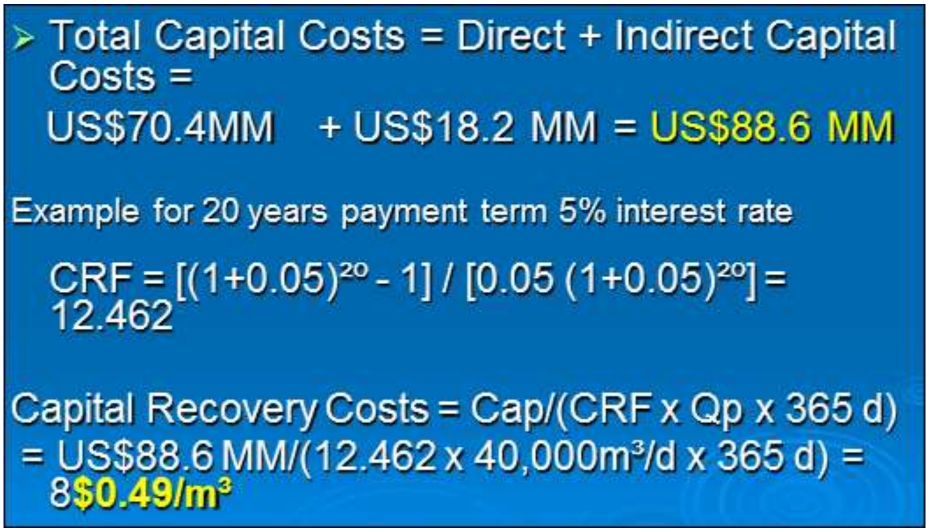
Table 10 – Indirect Cost Summary of 40 MLD SWRO Project Treating Mediterranean Water with Single Pass RO System

Cost Item	Unit Cost (US$/m³.day)	Cost (US$)
Preliminary Engineering	30-100	1.2 MM
Pilot Testing	10-50	0.4 MM
Detailed Design	75-175	3.0 MM
Construction Management and Oversight	40-80	1.6 MM
Administration, Contracting and Management	25-50	1.0 MM
Environmental Permitting and Public Outreach	20-200	0.8 MM
Legal Services	20-150	0.8 MM
Interest During Construction	20-180	0.8 MM
Debt Service Reserve Fund	80-340	3.2 MM
Other Financing Costs	20-80	0.8 MM
Contingency	5-10 % of Total	4.6 MM
Indirect Capital Costs		*$18.2MM*

3.15 Total Capital Costs

Total capital costs are estimated as a sum of direct and indirect capital costs. In order to determine the annualized total capital costs these costs are divided by a capital recovery factor (CRF) as illustrated on Figure 19.

Figure 19 – Total Capital Costs



4 ANNUAL O&M COSTS

Breakdown of annual O&M costs is shown on Table 11.

Table 11 - Annual O&M Cost Breakdown

Annual O&M Cost Breakdown		
Cost Item	**Percentage of Total O&M Cost (%)**	
	Low-Complexity Project	**High-Complexity Project**
Variable O&M Costs		
5. Power	45.0 – 61.0	35.0 – 58.0
6. Chemicals	3.0 – 6.5	5.5 – 9.0
7. Replacement of Membranes and Cartridge Filters	5.0 – 9.0	6.5 – 11.0
8. Waste Stream Disposal	2.5 – 5.5	3.5 – 7.0
Subtotal - Variable O&M Costs	***55.5 – 82.0***	***50.5 – 85.0***
Fixed O&M Costs		
5. Labor	5.0 – 9.5	4.0 – 11.0
6. Maintenance	6.5 – 12.5	3.0 – 13.0
7. Environmental and Performance Monitoring	0.5 – 4.0	1.0 – 5.0
8. Indirect O&M Costs	7.5 – 18.5	7.0 – 20.5
Subtotal - Fixed O&M Costs	***19.5 – 44.5***	***15.0 – 49.5***
Total O&M Costs	**100 %**	**100 %**

Table 12 indicates energy use for desalination plants of difference seawater source.

Table 12 – Energy Use as a Function of the Source of Seawater

Seawater Source	SWRO System Energy Use (kWh/m³)
Mediterranean	3.6 – 4.0
Gulf of Oman	3.9 – 4.2
Red Sea	4.0 – 4.3
Arabian Gulf	4.2 - 4.5

Direct and indirect O&M cost components are defined in Table 13. This table shows typical range for each cost component estimated as a function of the plant size.

Table 13 – Unit O&M Costs and Example of Cost Estimate for 40 MLD Plant

Cost Item	Unit Cost (US$/m³)	Cost (Million US$/year)
Variable O&M Costs		
Power @ 4.0 kWh/m³ @ US$0.06/kWh	Function of Water Source and Tariff	3.504
Chemicals	0.025-0.075	0.365
Replacement of Membranes and Cartridges	0.020-0.070	0.292
Waste Stream Disposal	0.015-0.035	0.219
Total Variable O&M Costs		*4.380 MM*
Fixed O&M Costs		
Labor	0.015-0.040	0.219
Maintenance – 2 to 4 % of Direct Capital Costs	0.035-0.075	0.511
Environmental and Performance Monitoring	0.005-0.015	0.073
Indirect O&M Costs	0.025-0.075	0.365
Total Fixed O&M Costs		*1.168 MM*
Total O&M Costs		*$5.548/year*

5 COST OF WATER PRODUCTION

As illustrated on Table 14, the total cost of water production consists of variable and fixed water production costs. This table shows the size of the individual cost components for an example of 40,000 m^3/day plant.

Table 14 – Cost of Water Breakdown

Cost of Water – Variable and Fixed Components		
Cost of Water Item	Costs, (US$/m³)	Costs, (% of Total)
Variable Cost of Water Components		
Power	0.240	27.6%
Chemicals	0.025	2.9%
Replacement of RO Membranes & Cartridge Filters	0.020	2.3%
Waste Stream Disposal	0.015	1.7%
Total Variable Costs	***0.30***	***34.5%***
Fixed Cost of Water Components		
Capital Recovery Costs	0.490	56.3%
Labor	0.015	1.7%
Maintenance	0.035	4.0%
Environmental & Performance Monitoring	0.005	0.6%
Other O&M Costs	0.025	2.9%
Total Fixed Costs	***0.57***	***65.5%***
Total Water Production Costs	*0.87*	*100 %*

Variable components in this table are the same as the variable components of the O&M costs. The fixed components of the cost of water are the sum of the fixed O&M costs and the capital recovery costs.

Tables 15 and 16 provide costs of recent desalination projects in the MENA region.

Table 15 – Cost of Water – Recent Projects In North Africa & the Mediterranean

Plant	Size (MLD)	Year of Cost Bid	Cost of Water (US$/m³) For Year of Cost Bid & in (2013$)
Dhekelia, Cyprus	50	1997/2007	1.19/0.88 (1.18)
Larnaka, Cyprus	54	1999/2009	0.76/1.0 (1.22)
Arzew, Algeria	86	2005	0.90 (1.33)
Beni Saf, Algeria	150	2008	0.70 (0.89)
Cap Dijnet, Algeria	100	2005	0.73 (1.09)
Douaouda, Algeria	120	2005	0.75 (1.11)
Hamma, Algeria	200	2008	0.82 (1.05)
Skikida, Algeria	100	2008	0.74 (1.13)
El Tarf, Algeria	50	2008	0.89 (1.14)
Magtaa, Algeria	500	2008	0.56 (0.72)
Tenes, Algeria	200	2008	0.59 (0.75)
Palmahim, Israel (NanoH2O)	82/123	2005/2013	0.78 (0.78)
Hadera, Israel	368/456	2008	0.60 (0.77)
Ashkelon, Israel	326	2008	0.53/(0.78)
Sorek, Israel	410	2013	0.59

Table 16 – Cost of Water – Recent Projects Red Sea and Arabian Gulf

Plant	Size (MLD)	Year of Cost Bid	Cost of Water (US$/m³)
Al Taweelah C, UAE	325	2000	0.72 (1.12)
Shuaqaiq, Saudi Arabia	214	2006	1.03 (1.45)
Jeddah – Barge, S. Arabia	52	2008	2.27 (2.88)
Jeddah – Land, S. Arabia	240	2009	1.15 (1.40)
Ras Azzur, Saudi Arabia	300	2010	1.09 (1.26)
Fujairah, UAE	140	2004	0.86 (1.10)
Fujairah II, UAE		2008	0.81 (1.03)
Sur, Oman	80	2010	0.98 (1.13)
Al Dur, Bahrain	218	2012	0.95 (1.00)
Shuwaikh, Kuwait	136	2012	1.10 (1.16)
Shuaibah, Saudi Arabia	150	2011	0.94 (1.04)

6 COST-ESTIMATING METHODOLOGY

Cost estimating curves presented in sections 3, 4 and 5 of this document are used for the development of the desalination costs of a given project. Cost estimating for a given project is typically completed following the sequence below:

1. Determine project production capacity, source water quality and product water quality
2. Determine plant recovery and intake capacity
3. Establish the type of intake and outfall – for the selected intake and outfall type determine the costs of the intake using Figures 3 and 4 or Tables 3 or 4 for open ocean intakes or well intakes respectively.
4. Determine the type of source water screening facility and using Figures 5, 6 or 8 determine the screening system costs depending on the type of screen.
5. Determine the cost of the plant intake pump station using Figure 9.
6. Determine the type of pretreatment needed based on the source water quality and use Figures 7, 8, 10, 11 and 12 to estimate construction costs for the pretreatment systems.
7. Define the type of RO system – single pass, partial two pass or full two pass RO system.
8. Using Figure 13 determine the construction cost of single pass SWRO system treating Mediterranean water;
9. If the source water is not Mediterranean, than use Table 6 to adjust the costs determined from Figure 13.
10. If the system is not a single pass RO system, than use Table 7 to adjust the costs estimated from Figure 13.
11. Determine post-treatment costs using Figures 15 and 16.
12. Use Figure 17 to determine the cost of the desalination plant discharge.
13. Calculate other construction costs using the unit costs indicated on Figure 18.
14. Calculate the total direct capital (construction) cost as a sum of all costs listed above.
15. Calculate project indirect capital costs using Table 10.
16. Calculate total capital costs as a sum of the direct and indirect capital costs.
17. Determine annual O&M costs based on the unit cost ranges recommended in Table 13. Cost of power is determined based on the estimated plant power use and the unit cost of water.
18. Determine cost of water production as a sum of the O&M costs and the capital recovery cost. As shown on Figure 19, the capital recovery cost is calculated based on the payment term for the loan for the project and the interest rate of the loan.

7 COST ESTIMATING EXAMPLE

The use of the cost estimating methodology described above is illustrated for the cost analysis of the 64,000 m^3/day Palm Jumeirah SWRO project in Dubai, United Arab Emirates. Schematic of the plant is shown on Figure 19.

Figure 20 – Palm Jumeirah SWRO Plant Schematic

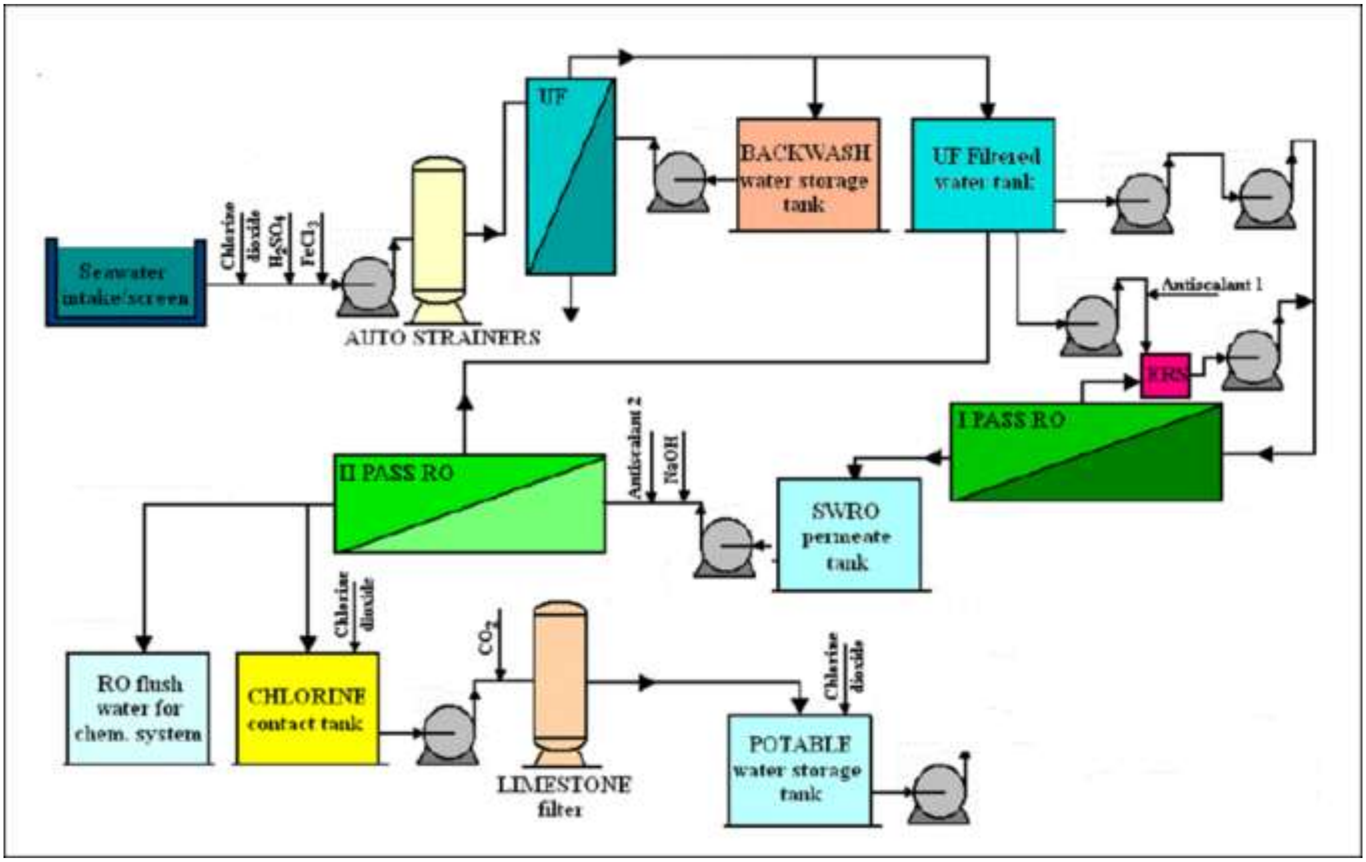


Table 17 shows plant key statistics.

Table 17 – Project Data

Parameter	Value	Parameter	Value
Capacity – MLD	64	Intake – 176 MLD Discharge – 112 MLD Intake Band Screens	Intake – Onshore Intake/Onshore Discharge Dry Well Intake PS
Date Commissioned	2008	Pretreatment System	Micro screens & UF Pressure Filters
Recovery	40 %	RO System (Hydranautics Membranes)	Conventional RO Design 2 passes/2 stages
Feed TDS, ppt	40 - 44 (42 avg.)	Energy Recovery System	DWEER Pressure Exchangers
Feed Temperature	22 to 36 °C (28 °C avg.)	Energy Use	4.1 kWh/m³
Unit Cost of Power	US$0.03/kWh	Post-treatment	Calcite Filters & CO2

The plant cost estimate is determined using the steps described in the previous section:

1. Determine project production capacity, source water quality and product water quality – production capacity is 64,000 m³/day and source water quality is determined based on the plant's shallow open intake.
2. Determine plant recovery and intake capacity – based on data from the plant design plant recovery is 40 % and the intake size is 176,000 m³/day.
3. Establish the type of intake and outfall – for the selected intake and outfall type determine the costs of the intake using Figures 3 and 4 or Tables 3 or 4 for open ocean intakes or well intakes respectively. The plant has onshore open intake as per Table 17 – using Figure 4, the cost of this intake is US$8 million.
4. Determine the type of source water screening facility and using Figures 5 or 6 determine the screening system costs depending on the type of screen. The plant has band screen – from Figure 5 the cost of the band screen is: US$1.7 million.
5. Determine the cost of the plant intake pump station using Figure 9. From Figure 9 the cost of the intake pump station is US$2.4 million. The total intake construction cost is US$8 million + US$1.7 million + US$2.4 million = US$12.1 million.
6. Determine the type of pretreatment needed based on the source water quality and use Figures 7, 8, 10, 11 and 12 to estimate construction costs for the pretreatment systems. Based on the project description the pretreatment includes microscreens and membrane pretreatment. From Figure 8, Microscreen cost is estimated at US$1.63 million. From Figure 12, the cost of the

membrane pretreatment system is estimated at US$18 million. The total cost of pretreatment is US$1.63 + US$18 million = US$19.63 million.

7. Define the type of RO system – single pass, partial two pass or full two pass RO system. From project key statistics (Table 17) the RO system is two pass RO system.
8. Using Figure 13 determine the construction cost of single pass SWRO system treating Mediterranean water; Based on this figure the baseline cost is US$49.00 million.
9. If the source water is not Mediterranean, than use Table 6 to adjust the costs determined from Figure 13. Since the source water is Arabian Gulf water, the cost above has to be adjusted using Table 6 – the cost of water penalty is 16 %.
10. If the system is not a single pass RO system, than use Table 7 to adjust the costs estimated from Figure 13. Using Table 7, the cost has to be increased with 1.33 – i.e., the total cost of water will be: 49 million x 1.16 x 1.33 = US$75.6 million.
11. Determine post-treatment costs using Figures 15 and 16. Calcite contactor cost is US$2.6 million (Figure 15). The hypochlorite disinfection system is US$1.0 million.
12. Use Figure 17 to determine the cost of the desalination plant discharge. Based on the type and discharge volume shown in Table 17, the discharge cost is estimated at US$17.1 million.
13. Calculate other construction costs using the unit costs indicated on Figure 18. Such cost estimate is shown on Figure 21 below.

Figure 21 – Other Construction Costs

1. Calculate the total direct capital (construction) cost as a sum of all costs listed above. Such costs are presented in Table 18.

Table 18 – Summary of Direct Capital Costs

Cost Item	Cost (US$)
Site Preparation, Roads and Parking	0.96 MM
Intake	12.10 MM
Pretreatment	19.63 MM
RO System Equipment	75.6 MM
Post Treatment (Calcite Filters + Disinfection System)	3.67 MM
Concentrate Disposal	17.10 MM
Waste and Solids Handling	2.88 MM
Electrical & Instrumentation	12.80 MM
Auxiliary and Service Facilities	4.88 MM
Buildings	3.84 MM
Startup, Commissioning and Acceptance Testing	3.20 MM
Direct Capital (Construction) Costs	US$156.66 MM

2. Calculate project indirect capital costs using Table 10. Table 19 shows indirect costs.

Table 19 – Indirect Capital Costs

Cost Item	Unit Cost (US$/m³.day)	Cost (US$)
Preliminary Engineering	30-100	3.20 MM
Pilot Testing	10-50	0.64 MM
Detailed Design	75-175	8.00 MM
Construction Management and Oversight	40-80	3.84 MM
Administration, Contracting and Management	25-50	2.24 MM
Environmental Permitting and Public Outreach	20-200	3.20 MM
Legal Services	20-150	1.28 MM
Interest During Construction	20-180	2.50 MM
Debt Service Reserve Fund	80-340	5.12 MM
Other Financing Costs	20-80	3.20 MM
Contingency	5-10 % of Total	10.0 MM
Indirect Capital Costs		$43.22 MM

3. Calculate total capital costs as a sum of the direct and indirect capital costs. Such costs are as shown on Figure 22 below.

Figure 22 – Total Capital Costs

- Total Capital Costs = Direct + Indirect Capital Costs =

  US$156.66 MM + US$43.22 MM = **US$199.88 MM** (say US$200 MM)

Example for 20 years payment term 5% interest rate

$$CRF = [(1+0.05)^{20} - 1] / [0.05\,(1+0.05)^{20}] = 12.462$$

Capital Recovery Costs = Cap/(CRF x Qp x 365 d)

= US$ 200 MM/(12.462 x 64,000m³/d x 365 d) = **US$0.69/m³**

4. Determine annual O&M costs based on the unit cost ranges recommended in Table 13. Cost of power is determined based on the estimated plant power use and the unit cost of water. Table 20 shows plant O&M cost estimate.

Table 20 – O&M Costs

Cost Item	Unit Cost (US$/m³)	Cost (US$/year)
Variable O&M Costs		
Power @ 4.1 kWh/m³ @ US$0.03/kWh	Function of Water Source and Tariff	2,873,280
Chemicals	0.025-0.075	584,000
Replacement of Membranes and Cartridges	0.020-0.070	934,400
Waste Stream Disposal	0.015-0.035	350,000
Total Variable O&M Costs		*4.74 MM*
Fixed O&M Costs		
Labor	0.015-0.040	467,000
Maintenance – 2 to 4 % of Direct Capital Costs	0.035-0.075	1,285,000
Environmental and Performance Monitoring	0.005-0.015	120,000
Indirect O&M Costs	0.025-0.075	585,000
Total Fixed O&M Costs		*2.46 MM*
Total O&M Costs		*$7.20 MM/year*

5. Determine cost of water production as a sum of the O&M costs and the capital recovery cost. As shown on Figure 19, the capital recovery cost is calculated based on the payment term for the loan for the project and the interest rate of the loan. Table 21 presents the plant cost of water.

Table 21 – Cost of Water Estimate

Cost of Water Item	Costs, (US$/m³)
Variable Cost of Water Components	
Power	0.123
Chemicals	0.025
Replacement of RO Membranes & Cartridge Filters	0.040
Waste Stream Disposal	0.015
Total Variable Costs	***0.203***
Fixed Cost of Water Components	
Capital Recovery Costs	0.690
Labor	0.020
Maintenance	0.055
Environmental & Performance Monitoring	0.005
Other O&M Costs	0.025
Total Fixed Costs	***0.795***
Total Water Production Costs	*US$0.998/m³*