

CPET, Continued
Professional
Education
and Training



THE MIDDLE EAST DESALINATION RESEARCH CENTER

Cost Estimating of SWRO Desalination Plants

*Day 3: Desalination Project
Costs - Trends, Examples and
Interactive Session*

June 27, 2013

10:30-12:00

**3.2 Example of SWRO
Project Cost Estimate**

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Water Globe

Example of Cost Estimate - Outline

- ▶ Project Description
- ▶ Breakdown of Project Capital Costs
- ▶ Annual O&M Costs
- ▶ Cost of Water Estimate



40 MLD SWRO Desalination Project - Mediterranean Water

- ▶ Plant Production Capacity:
 - Average Annual Production = 40 MLD
 - Minimum Production = 36 MLD
 - Maximum Production (Installed Capacity) = 44 MLD
 - Installed Capacity = 44 MLD (10 % operational margin)
- ▶ Plant Availability = 96 % (350 days per year)
- ▶ Open Offshore Intake - Depth 10 m & 500 m Length
- ▶ Discharge with Diffusers – 200 m length

Effect of Product Water Quality on 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	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	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	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	1.36 – 1.50

Source and Product Water Quality Single Pass RO System

Reverse Osmosis Permeate Water Quality Seawater Source – Mediterranean Sea

Water Quality Parameter	Mediterranean Source Seawater Quality	Permeate Water Quality	
		Single Pass SWRO System	Split Partial Two Pass RO System
Temperature, °C	16-28	17-29	18-30
pH	8.1	6.3-7.2	7.9-8.1
Ca ²⁺ , mg/L	480	1.0-2.0	0.35-0.45
Mg ²⁺ , mg/L	1,558	1.9-2.8	0.5-1.0
Na ⁺ , mg/L	12,200	98-196	15-34
K ⁺ , mg/L	480	3.0-5.5	0.8-1.8
CO ₃ ²⁻ , mg/L	5.6	0.0	0.0
HCO ₃ ⁻ , mg/L	160	1.7-2.4	0.5-0.8
SO ₄ ²⁻ , mg/L	3,190	2.9-6.3	1.4-2.95
Cl ⁻ , mg/L	22,340	169-260	25-52
F ⁻ , mg/L	1.4	0.7-1.1	0.5-0.8
NO ₃ ⁻ , mg/L	0.00	0.00	0.00
B ⁻ , mg/L	5.0	0.9-1.5	0.4-0.6
Br ⁻ , mg/L	80	0.9-1.3	0.35-0.6
TDS, mg/L	40,500	280-480	45-95

Open Offshore Intake – Key Source Water Quality Parameters Related to Pretreatment Selection

- ▶ Turbidity = 0.5 – 10 NTU (avg. = 2 NTU);
- ▶ TSS = 2 – 20 mg/L (avg. = 5 mg/L);
- ▶ SDI₅ = 8 – 16 (avg. 10)
- ▶ Algal Count = 500 – 20,000 cells/L
- ▶ TOC = 0.2 – 1.5 mg/L
- ▶ Chlorophyll a = 0.2 – 0.8 µg/L

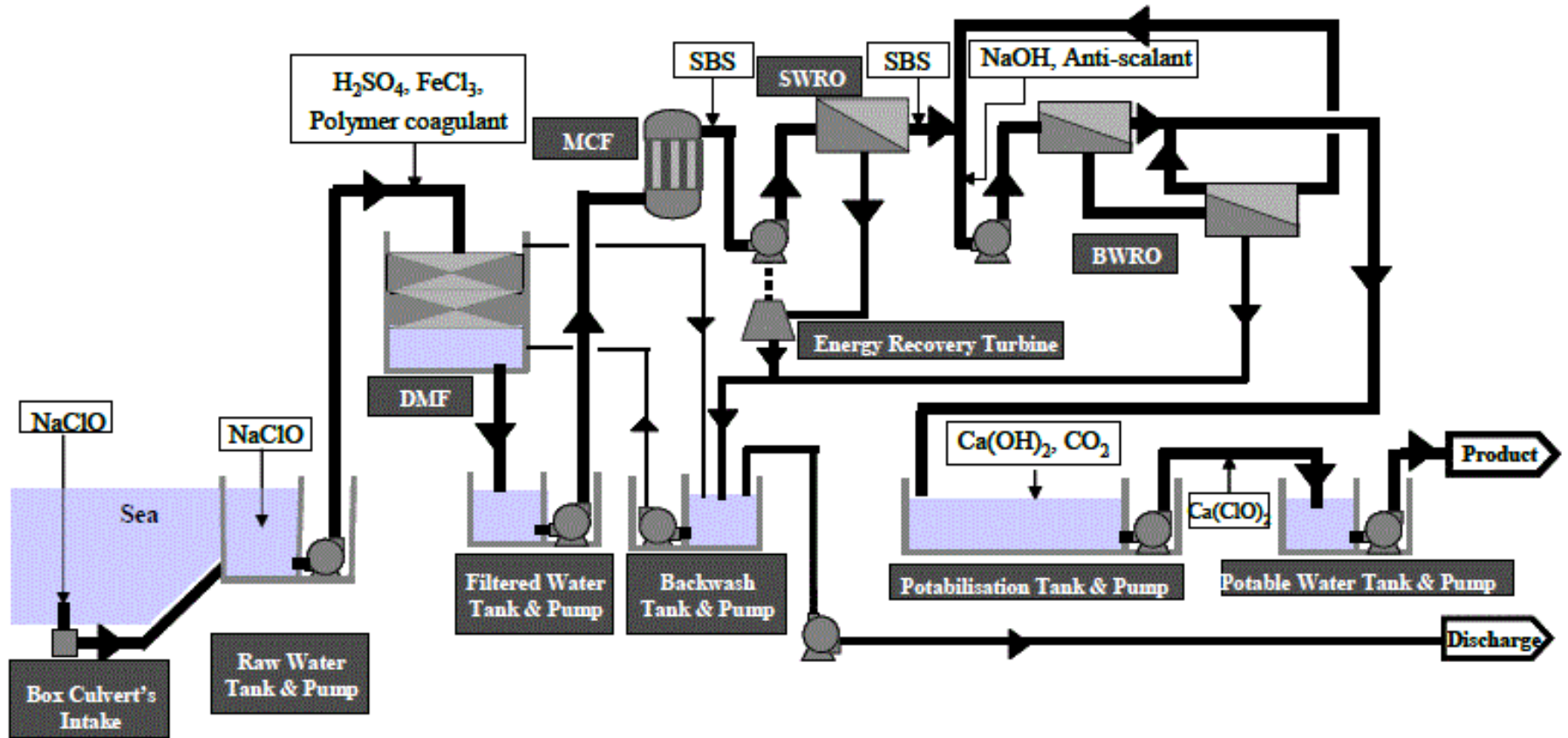
Selection of Pretreatment System

Source Water Quality	Recommended Configuration	Notes
Turbidity < 0.1 NTU SDI < 2/TOC < 1	Cartridge Filters or Bag Filters Only	Grit Removal May be Needed
Turbidity > 0.1 NTU < 5 NTU SDI < 5/ TOC < 1	Single Stage Dual Media Filters + Cartridge Filters Or MF/UF	Coagulant Addition Usually Not Needed if UF Used
Turbidity > 5 NTU < 30 NTU SDI > 5/ TOC < 4	Single Stage Dual Media Filters + Cartridge Filters Or MF/UF	Coagulant Addition Usually Needed
Turbidity > 30 NTU < 50 NTU SDI > 5/ TOC > 4 and/or Oil Spill Potential	Sedimentation/DAF + Single Stage Dual Media Filters + Cartridge Filters Or Sedimentation/DAF + MF/UF	Coagulant Addition Needed
Turbidity > 30 NTU < 50 NTU SDI > 5/ TOC > 4 and High Oil Spill Potential	High-rate Sedimentation/DAF + Two Stage Dual Media Filters + Cartridge Filters Or High-rate Sedimentation/DAF + MF/UF	Coagulant Addition Needed

Key Observations for Selecting Plant Configuration

- ▶ Intake Depth > 8 meters means low fouling source water
- ▶ Selected:
 - Single Stage Gravity Granular Media Filtration Pretreatment
 - High Plant Recovery – 45 %
- ▶ If Water Was Highly Fouling Water – two stage filtration and lower recovery (38 to 40 %) needed

40 MLD SWRO Plant Schematic



Capital Costs



Site Preparation Costs

- ▶ **Site Preparation Costs @ US\$15-200/m³.day =**
US\$15/m³.day x 40,000 m³.day = **US\$0.6 MM**
- ▶ **Low End of the Cost Bracket Selected – Site is Not Contaminated and is Free from Structures and Other Infrastructure.**

Determination of Intake Design Flow

▶ Intake Design Flow = $\frac{\text{Product Water Flow} \times 1.1}{\text{Recovery (\%)}}$

Intake Flow for the 40 MLD Plant:

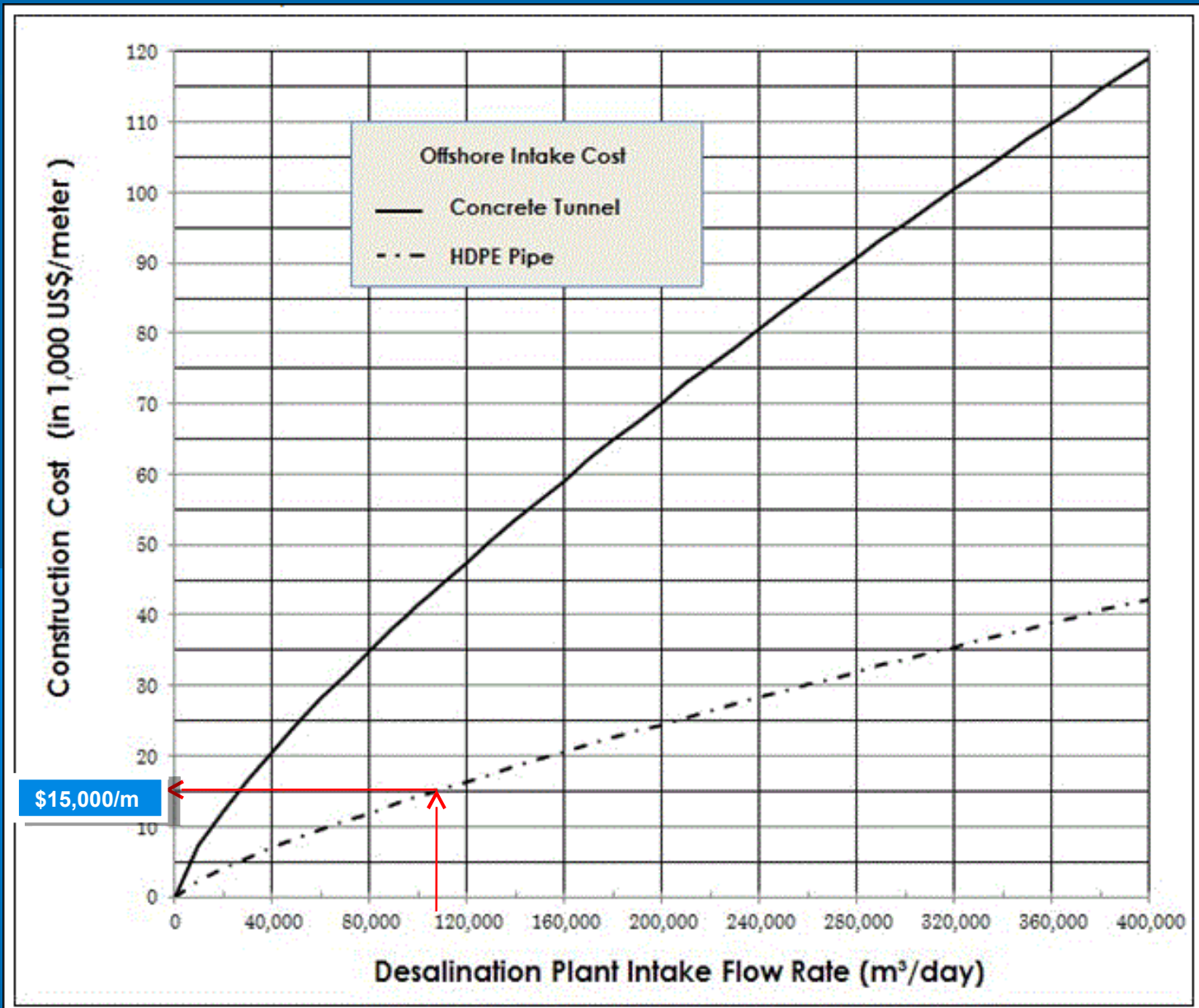
- ▶ Average = $40 \text{ MLD} \times 1.1 / (0.45) = 98 \text{ MLD}$
- ▶ Minimum Flow = $36 \text{ MLD} \times 1.1 / (0.45) = 88 \text{ MLD}$
- ▶ Max Flow = $44 \text{ MLD} \times 1.1 / (0.45) = 108 \text{ MLD}$

Intake Configuration

- ▶ Offshore Intake
- ▶ Onshore Screens
- ▶ Onshore Pump Station



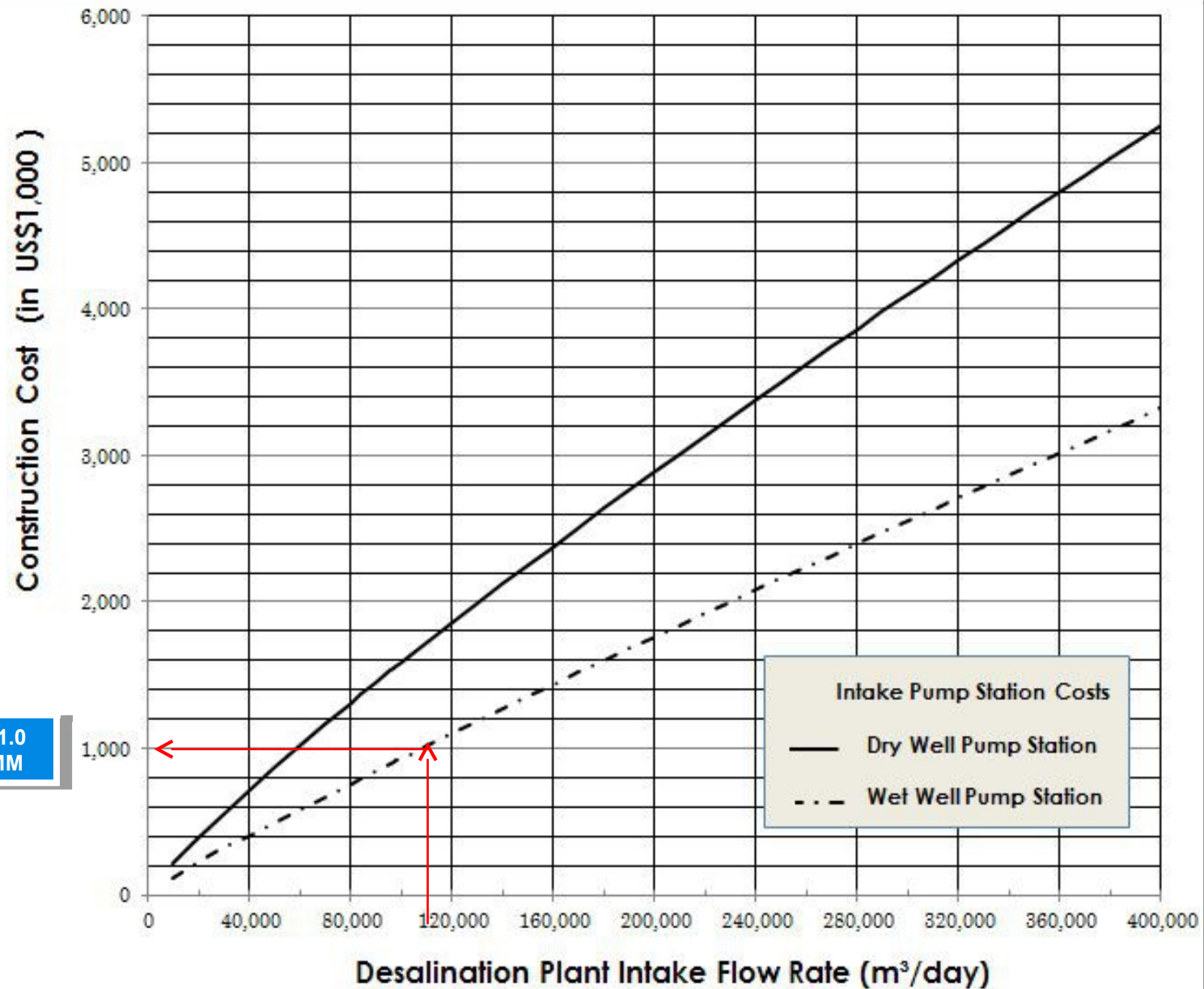
Construction Costs of Off-shore Intakes



Offshore Intake Cost

- ▶ Open Intake Cost = Unit Intake Cost x Length of Intake Pipe
- ▶ Open Intake Cost = US\$15,000/m x 500 m = US\$7.5 million

Onshore Intake Pump Station Costs

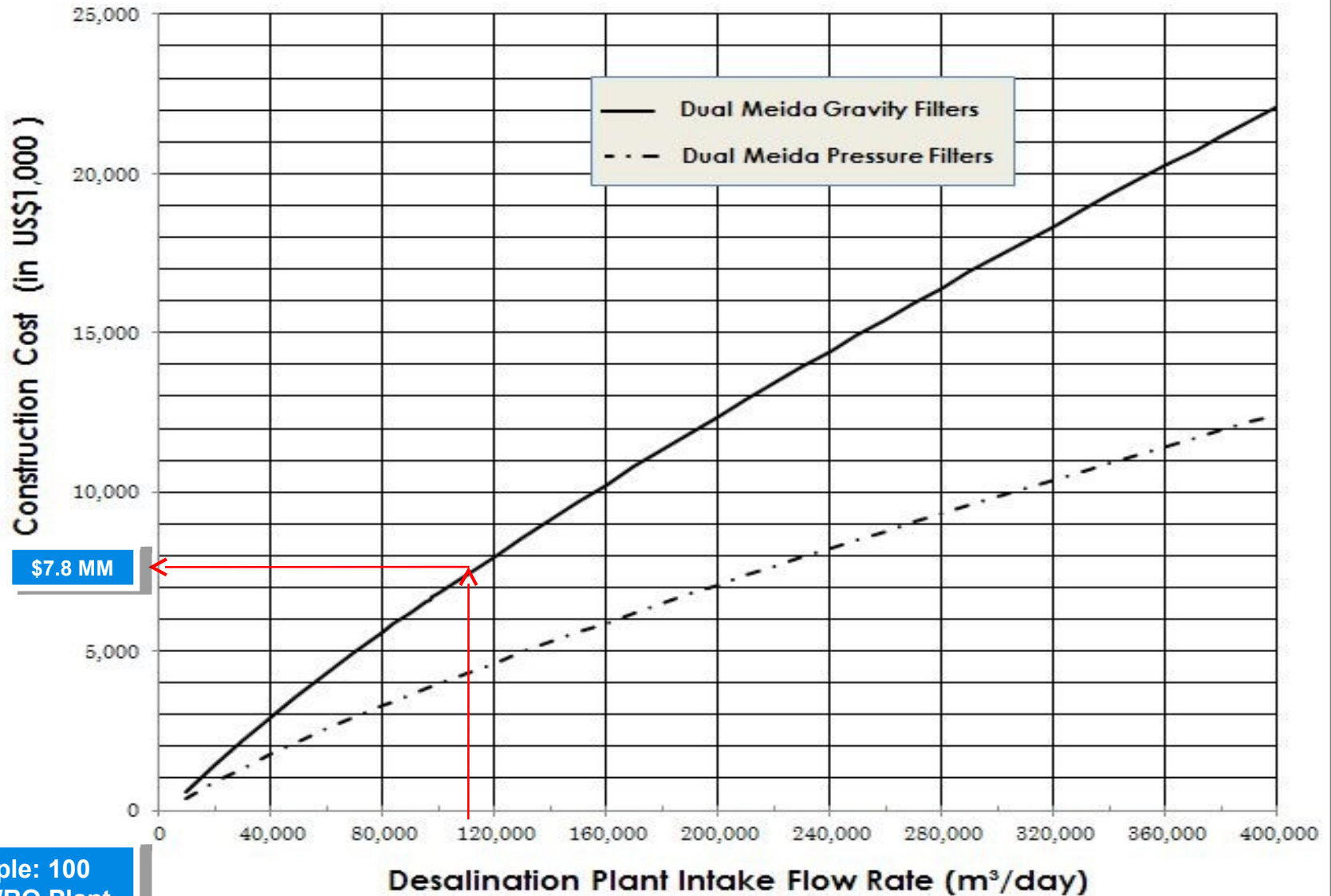


\$1.0
MM

Total Intake Construction Cost

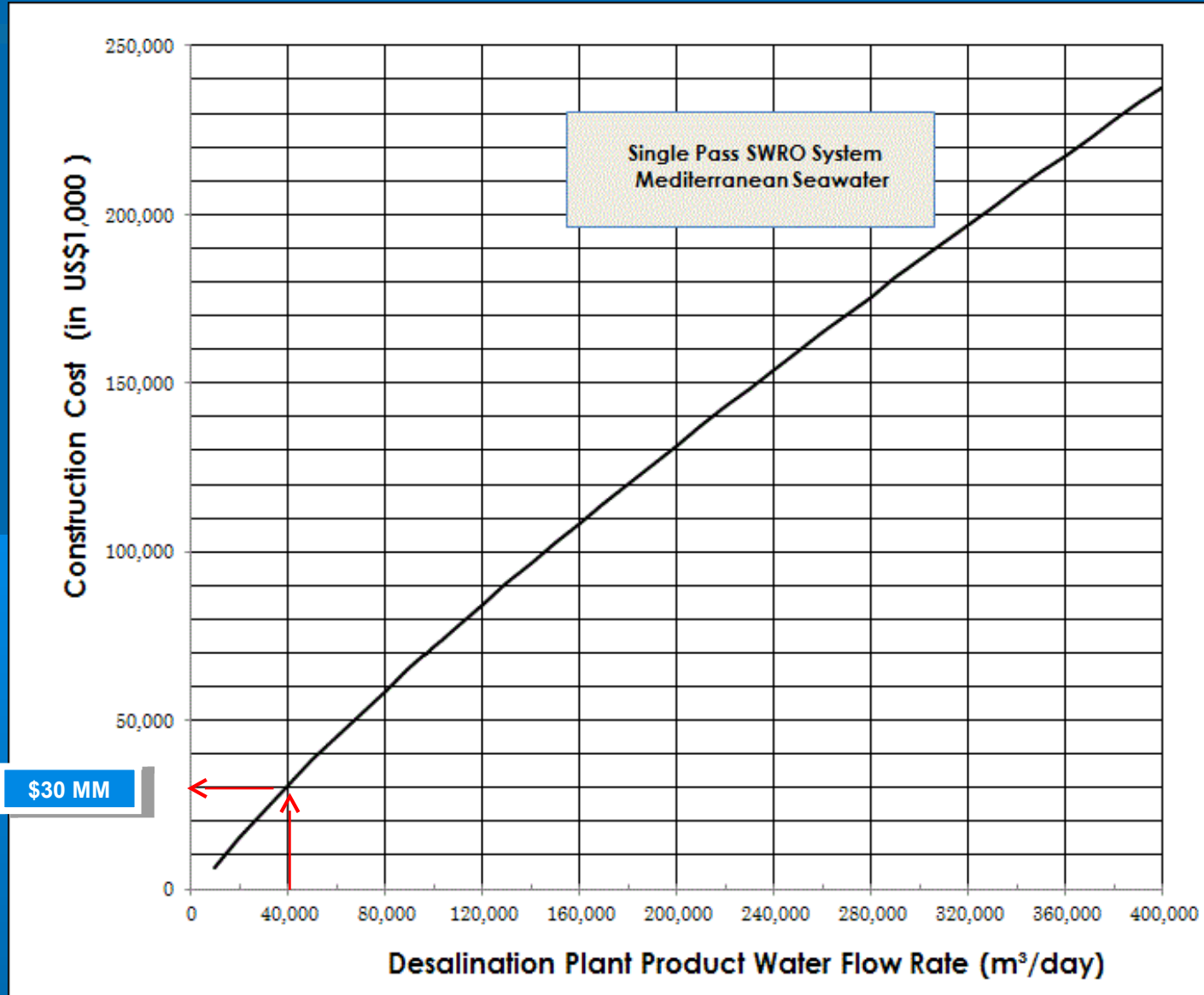
- ▶ Offshore Intake = US\$7.5 MM
 - ▶ Onshore Screens = US\$1.0 MM
 - ▶ Onshore Intake Pump Station = US\$1.0 MM
- Total = US\$9.5 MM**

Construction Cost of Granular Media Pretreatment



Example: 100
MLD SWRO Plant

RO System Construction Cost - Single Pass Mediterranean Water



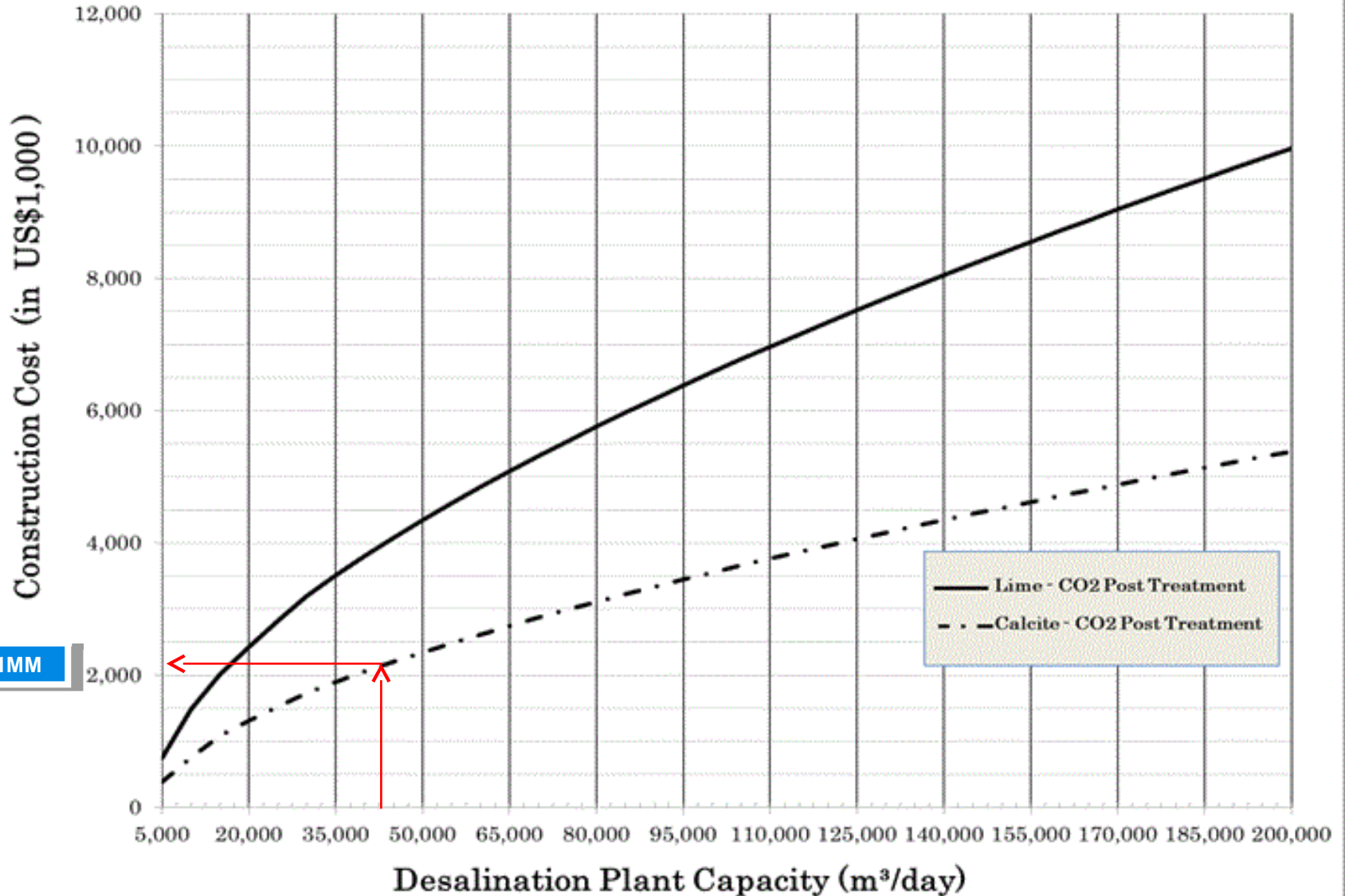
Source Water Quality - Cost Impacts

Seawater Source	Unit Construction Costs	Unit O&M Costs	Unit Capital 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

Effect of Product Water Quality on RO System Costs

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	1.00
Single Pass RO System			
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	1.10 – 1.18
Partial Second Pass RO System			
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	1.23 – 1.32
Full Two-Pass RO System			
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	1.36 – 1.50
Full Two-Pass RO System + IX			

Lime & Calcite/CO2 System Construction Costs

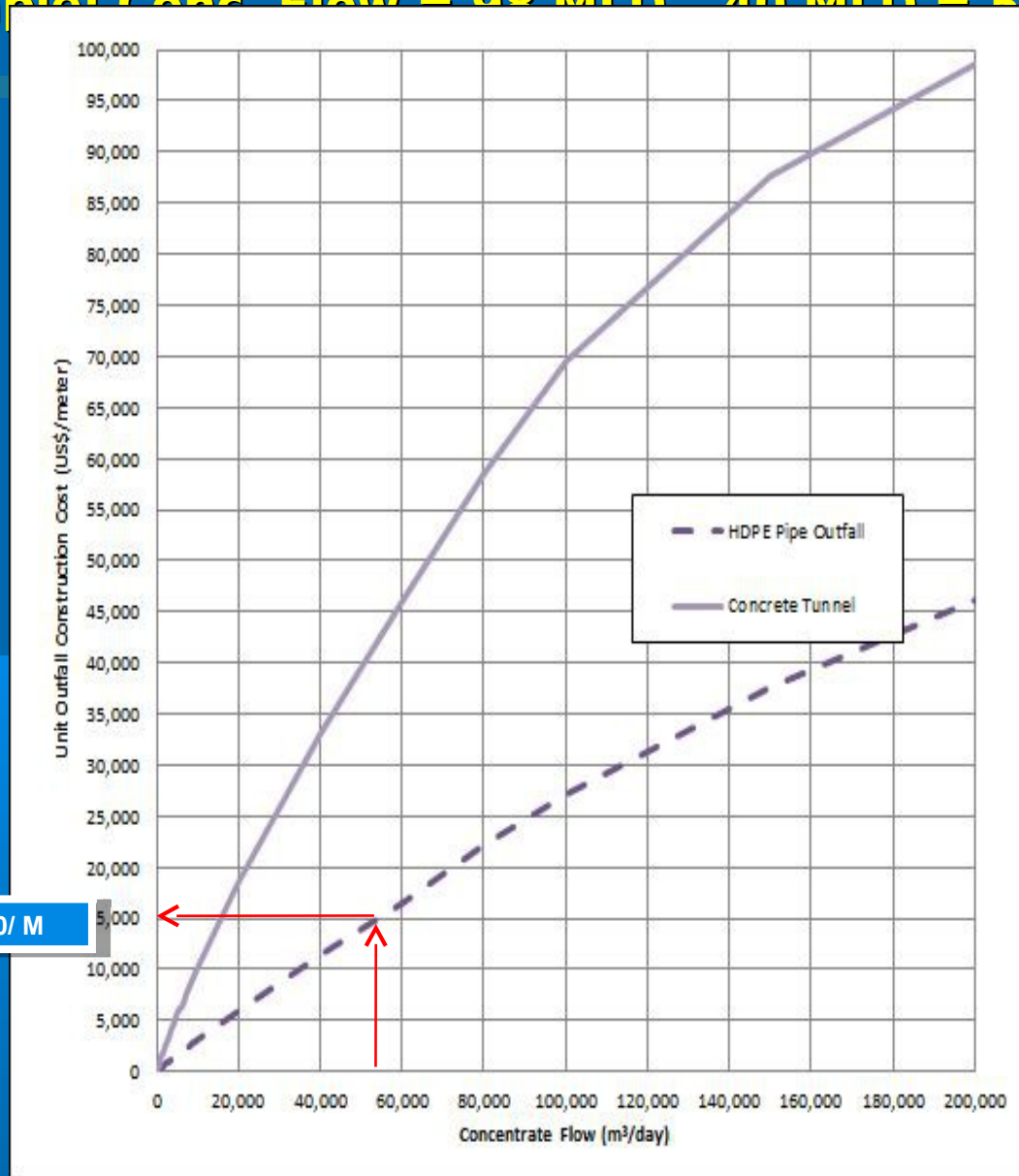


\$2.1MM

Near-shore Discharge - Costs

Conc. Flow = Intake Flow - Product Water Flow

In Example: Conc. Flow = 98 MLD - 40 MLD = 58 MLD



\$15,000/ M

Offshore Discharge Cost

- ▶ Diffuser Outfall Cost = Unit Outfall Cost x Length of Discharge Pipe
- ▶ Diffuser Outfall Cost = US\$15,000/m x 200 m
= US\$3.0 million

Other Construction Costs

Example for 40 MLD Plant

- ▶ **Waste and Solids Handling @ US\$15-75/m³.day**
(Retention Pond) = US\$45/m³.day x 40,000 m³.day = **US\$1.8 MM**
- ▶ **Electrical and Instrumentation @ US\$100-250/m³.day =**
US\$200/m³.day x 40,000 m³.day = **US\$8.0 MM**
- ▶ **Auxiliary & Service Facilities @ US\$30-150/m³.day =**
US\$80/m³.day x 40,000 m³.day = **US\$3.2 MM**
- ▶ **Buildings @ US\$50-100/m³.day = US\$60/m³.day x 40,000**
m³.day = **US\$2.4 MM**
- ▶ **Startup, Commissioning and Acceptance Test @ US\$40-**
80/m³.day = US\$50/m³.day x 40,000 m³.day = **US\$2.0 MM**

Direct Capital Costs - Example - 40,000 m³/day Plant

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\$70.4 MM

Indirect Capital Costs - 40,000 m³/day Plant

Cost Item	Unit Cost (US\$/m ³ .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		\$18.2 MM

Total Capital Costs

- ▶ Total Capital Costs = Direct + Indirect Capital Costs =
US\$70.4MM + US\$18.2 MM = **US\$88.6 MM**

Example for 20 years payment term 5% interest rate

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

$$\begin{aligned} \text{Capital Recovery Costs} &= \text{Cap}/(\text{CRF} \times \text{Qp} \times 365 \text{ d}) \\ &= \text{US\$88.6 MM}/(12.462 \times 40,000\text{m}^3/\text{d} \times 365 \text{ d}) = \\ &= \mathbf{8\$0.49/\text{m}^3} \end{aligned}$$

Operation and Maintenance Costs



Total 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 %

Energy Use and Function of Water Source

(Medium & Large SWRO Plants)

Seawater Source	SWRO System Energy Use (kWh/m ³)
Mediterranean	3.6 – 4.0
Gulf of Oman	3.9 – 4.2
Red Sea	4.0 – 4.3
Arabian Gulf	4.2 - 4.5

O&M Costs - 40,000 m³/day Plant

Cost Item	Unit Cost (US\$/m ³)	Cost (Million US\$/year)
Variable O&M Costs		
Power @ 4.0 kWh/m ³ @ 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

Cost of Water – Variable and Fixed Components

Cost of Water Item	Costs, (US\$/m ³)	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 %



Questions?



Lunch Break - 12:00 to