THE MIDDLE EAST DESALINATION RESEARCH CENTER

Cost Estimating of SWRO Desalination Plants

Day 1: Plant Cost Fundamentals

June 25, 2013

13:00-14:30

1.3 Construction Costs for Intakes and Pretreatment Systems

Water Globe Consulting

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Construction Costs for Intakes and Pretreatment Systems

- Plant Site-related Construction Costs
- Intake Costs
  - Costs for Subsurface Intakes
  - Costs for Open Intakes
  - Intake Piping and Pump Station Costs
  - Intake Screen Costs

- Pretreatment Facility Construction Costs
  - Chemical Conditioning Costs
  - Costs for Gravity and DAF Clarifiers
  - Costs for Granular Media Filters
  - Costs for UF and MF Membrane Pretreatment
  - Cartridge Filter Costs

Plant Site-related Construction Costs

- Include costs for:
  - Land
  - Site Preparation
  - Roads
  - Parking
- Cost Range – US\$15 – 200/m^3.day of plant production capacity
- Cost Variation Mainly Due to:
  - Differences of land prices;
  - Land Requirements.

How Much Area In Needed for the Desalination Plant Site?

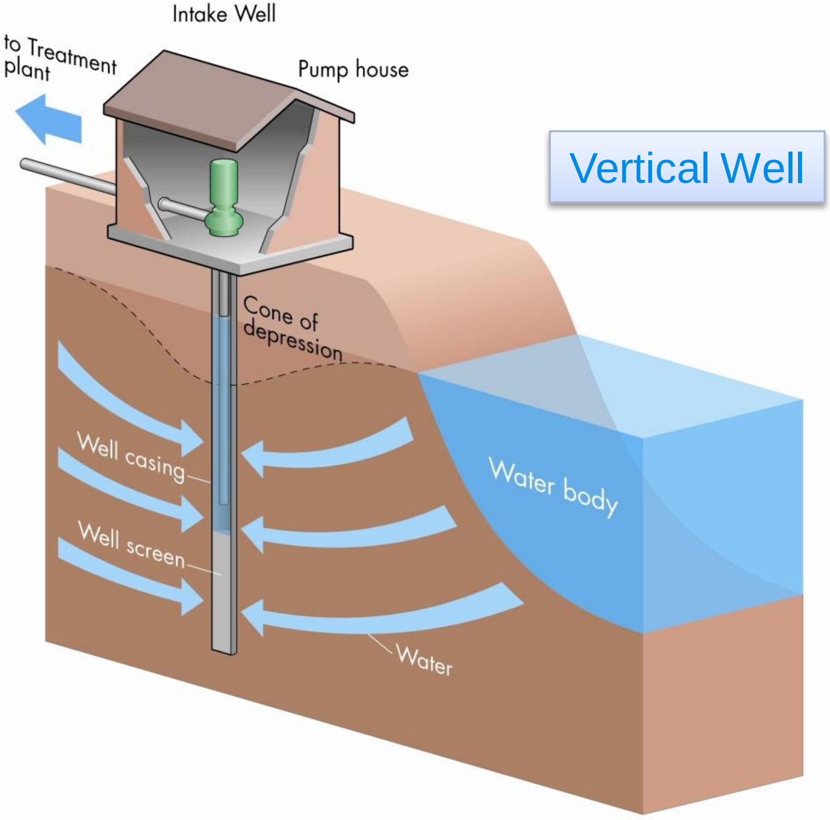
Plant Capacity m³/day	Typical Plant Site Size (m²)	Typical Plant Site Size (acres)
1,000 m3/day	800 – 1,600	0.2 – 0.4
5,000 m3/day	2,000 – 3,200	0.5 – 0.8
10,000 m3/day	6,100 – 8,100	1.5 – 2.0
20,000 m3/day	10,100 – 14,200	2.5 – 3.5
40,000 m3/day	18,200 – 24,300	4.5 – 6.0
100,000 m3/day	26,300 – 34,000	6.5 – 8.5
200,000 m3/day	36,400 – 48,600	9.0 – 12.0

Intake Facilities

- **Subsurface Intakes;**
- **Surface (Open) Intakes;**
- **Collocation: Intake Connection to Power Plant Discharge.**

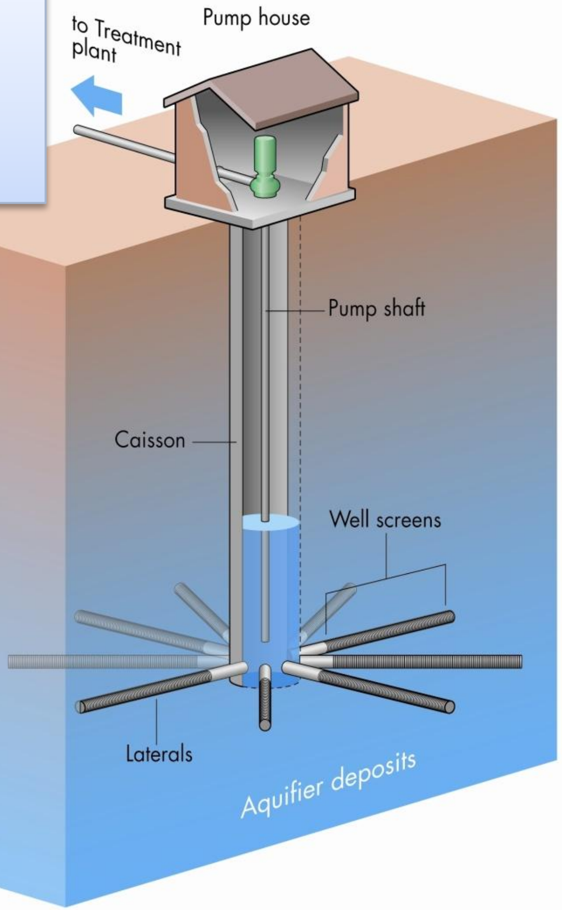
Subsurface Intake Facilities (Wells)

Vertical Well



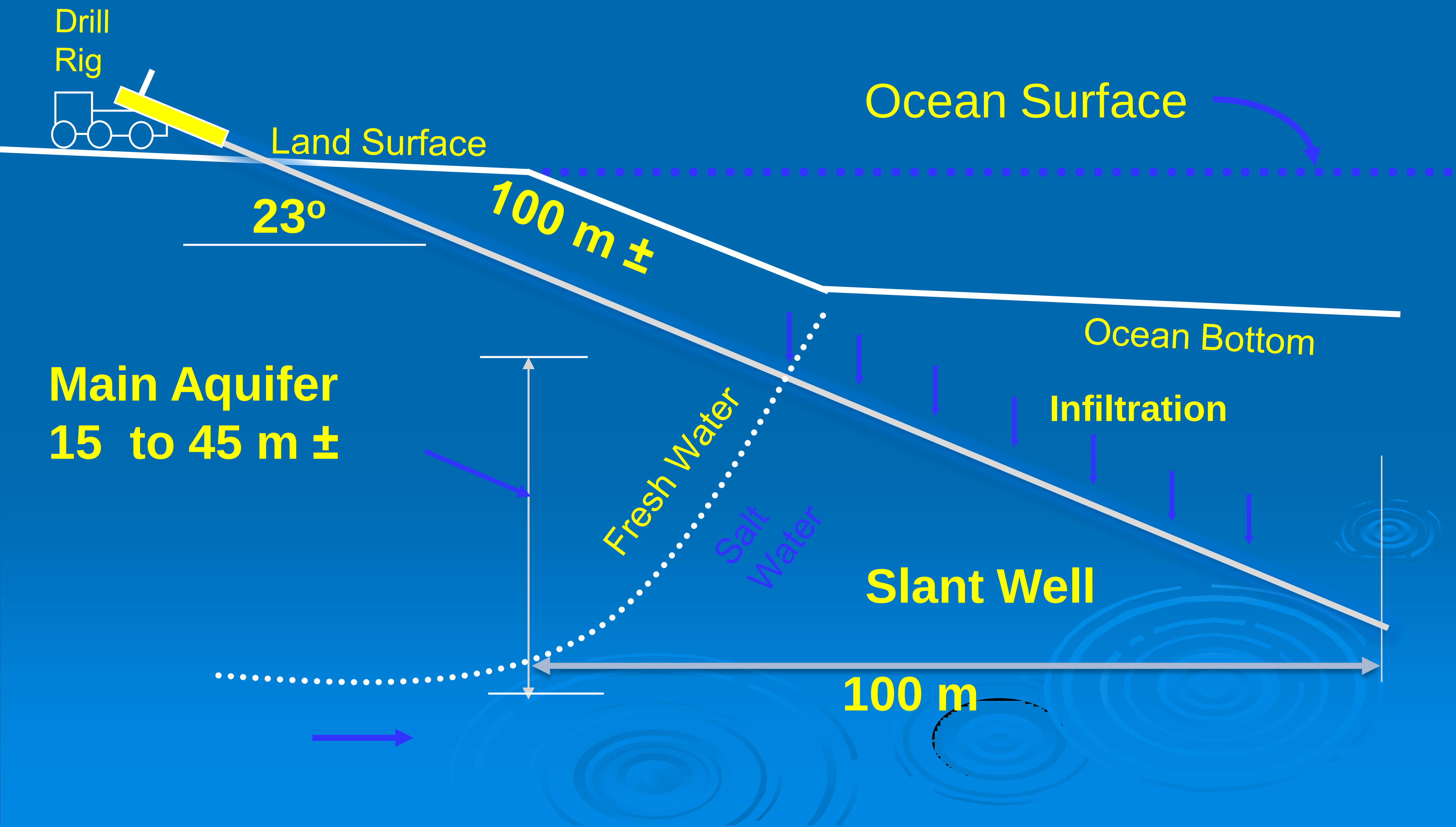
Typical Capacity: 100 to 3,000 m3/day

Horizontal Radial Collector Well

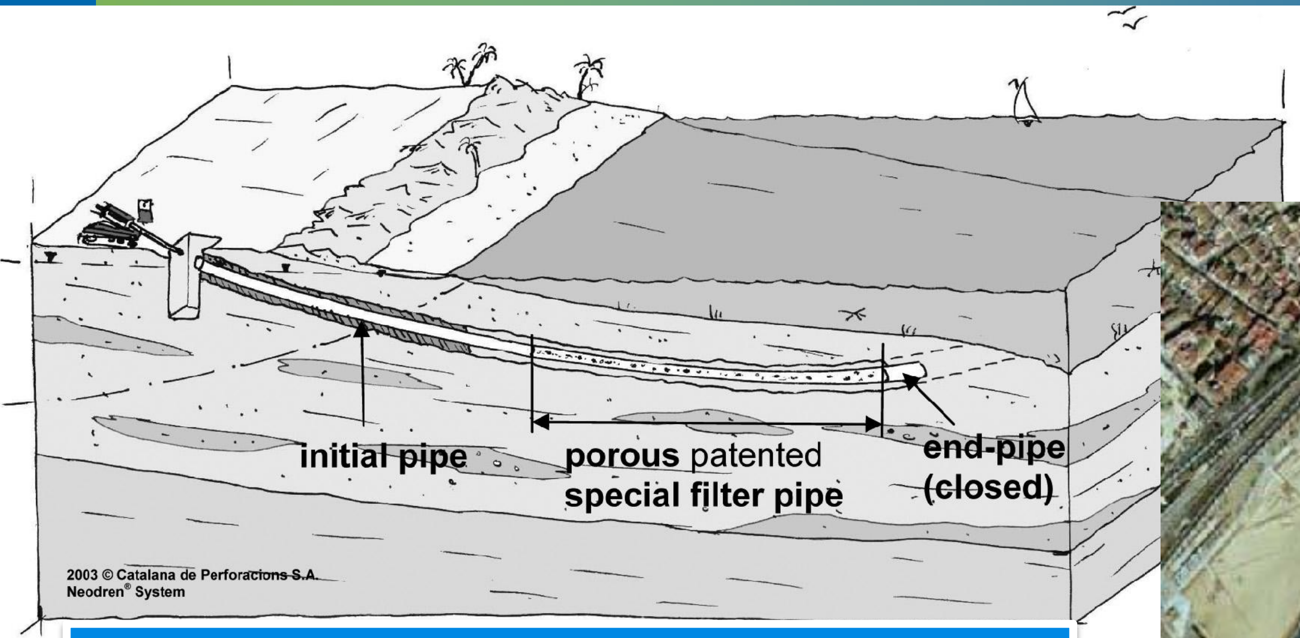


Typical Capacity: 4,000 to 20,000 m3/day

Slant Well Schematic



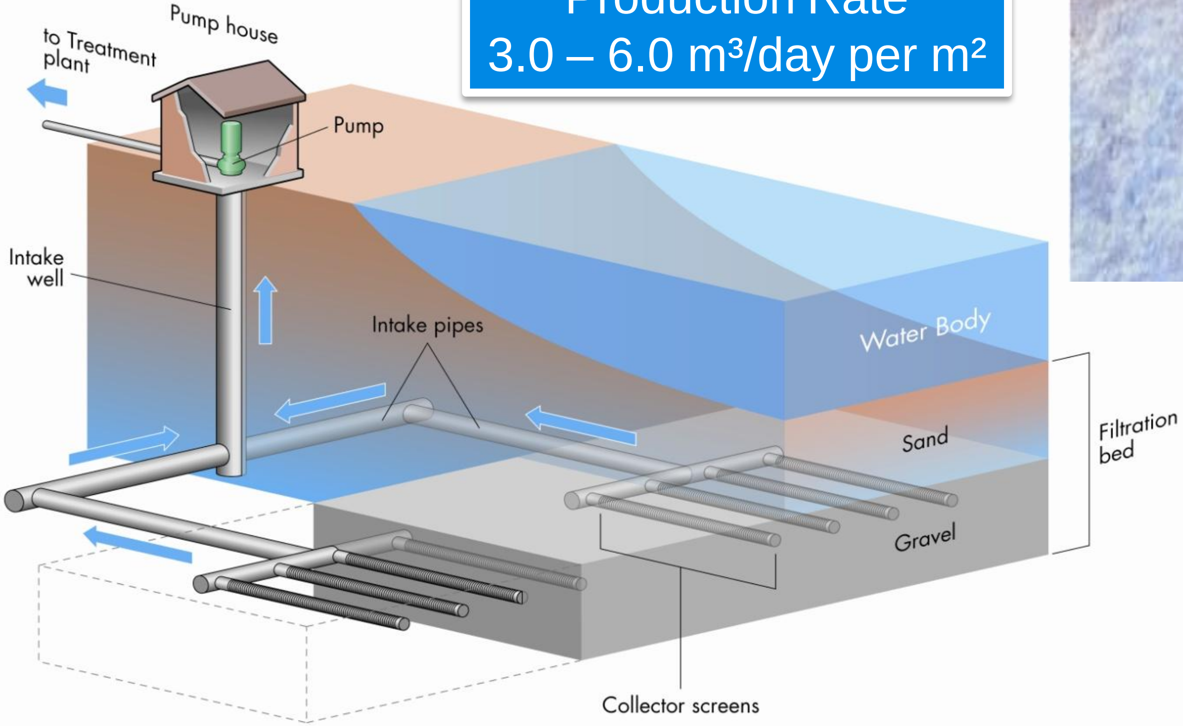
Horizontal Directionally Drilled (HDD) Wells



- NEODREN Technology
- Perforated HDPE Pipes w/ 120-µ Openings
- Typical Pipe Size – 350 mm
- Pipe Depth – 5 to 10 Below Ocean Bottom
- Pipe Length – 200 to 600 m

- 65 ML/d Cartagena I SWRO Plant, Spain
- 20 Pipes @ 350 mm - 6 ML/d per Pipe

Riverbed/Seabed Filtration System



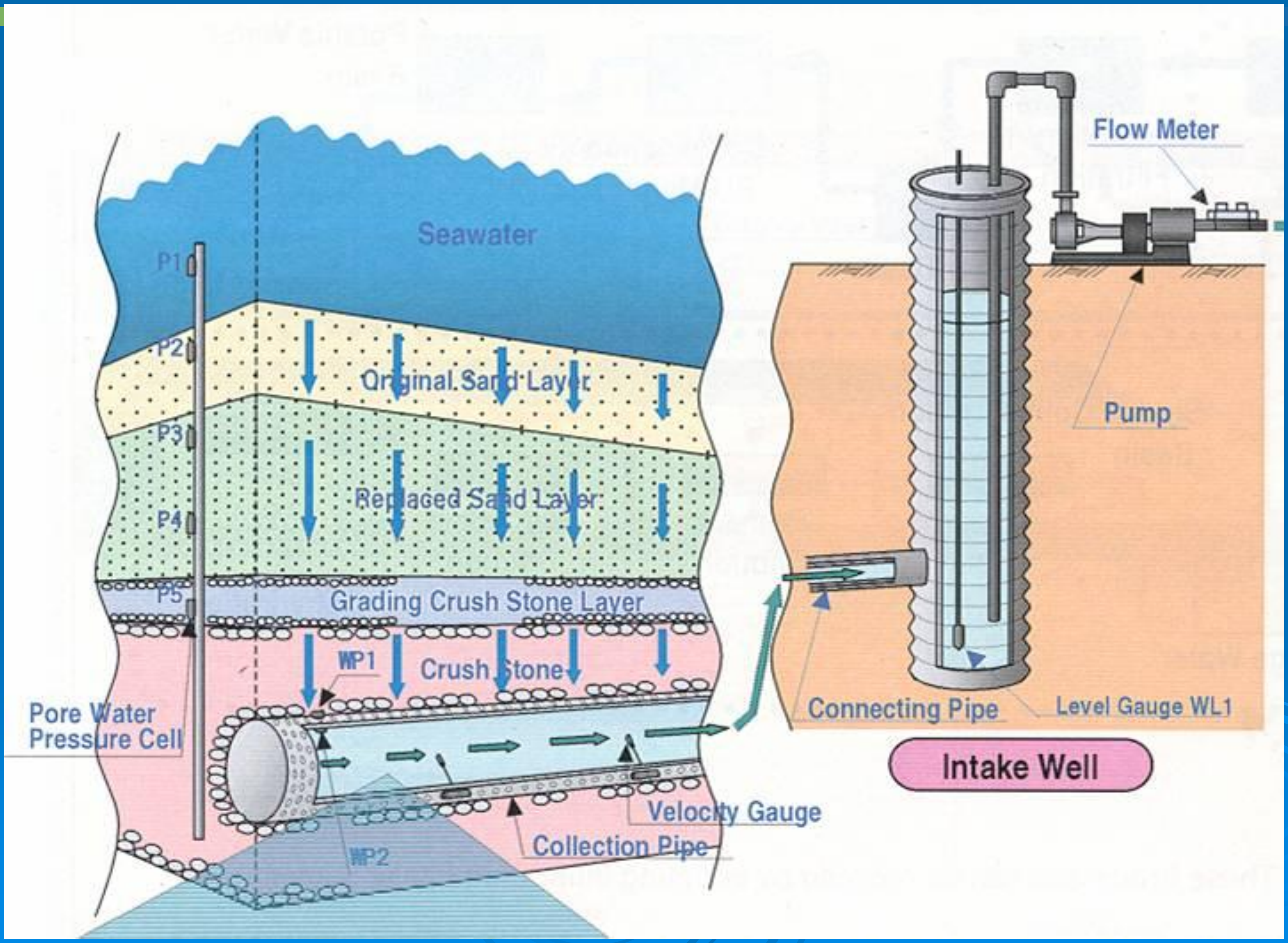
Production Rate
3.0 – 6.0 m³/day per m²

<u>Fukuoka SWRO Plant, Japan</u>

- 50 ML/d
- Intake Area – 7.2 acres

- Construction Costs – 1.2 to 2.3 times higher than vertical wells

Subsurface Beach Gallery



Well Productivity & Costs

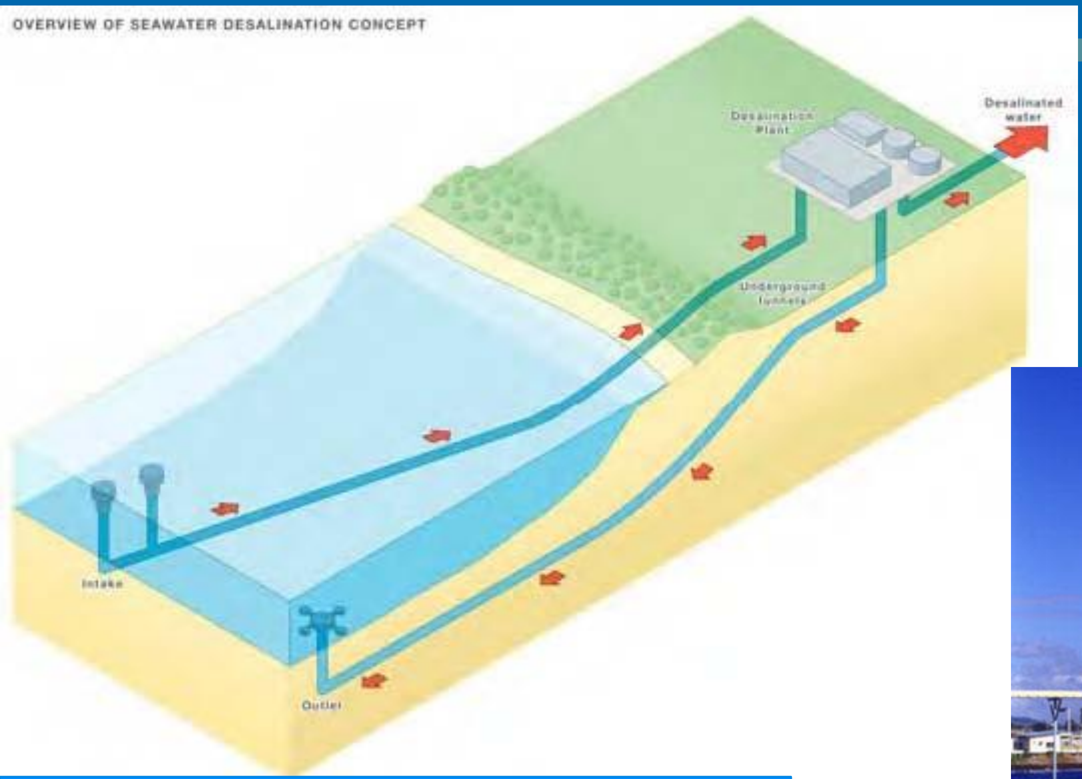
Well Type	Typical Production Capacity (Yield) of Individual Well (ML/d)	Cost of Individual Well (US$ MM)
Vertical Well	0.1 – 3.5 ML/d	$0.2 - $2.5 MM
Horizontal Radial Collector Well	0.5 – 20 ML/d	$0.7 – $5.8 MM
Slant Well	0.5 – 10 ML/d	$0.6 - $3.0 MM
HDD Well (i.e., Neodren)	0.1 – 5.0 ML/d	$0.3 - $1.3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

Vertical Beach Wells - Costs

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

Open Intakes – Types



Off-shore Intake for Sydney Water Desalination Plant, Australia

Near-shore Intake – Point Lisas Desalination Plant, Trinidad

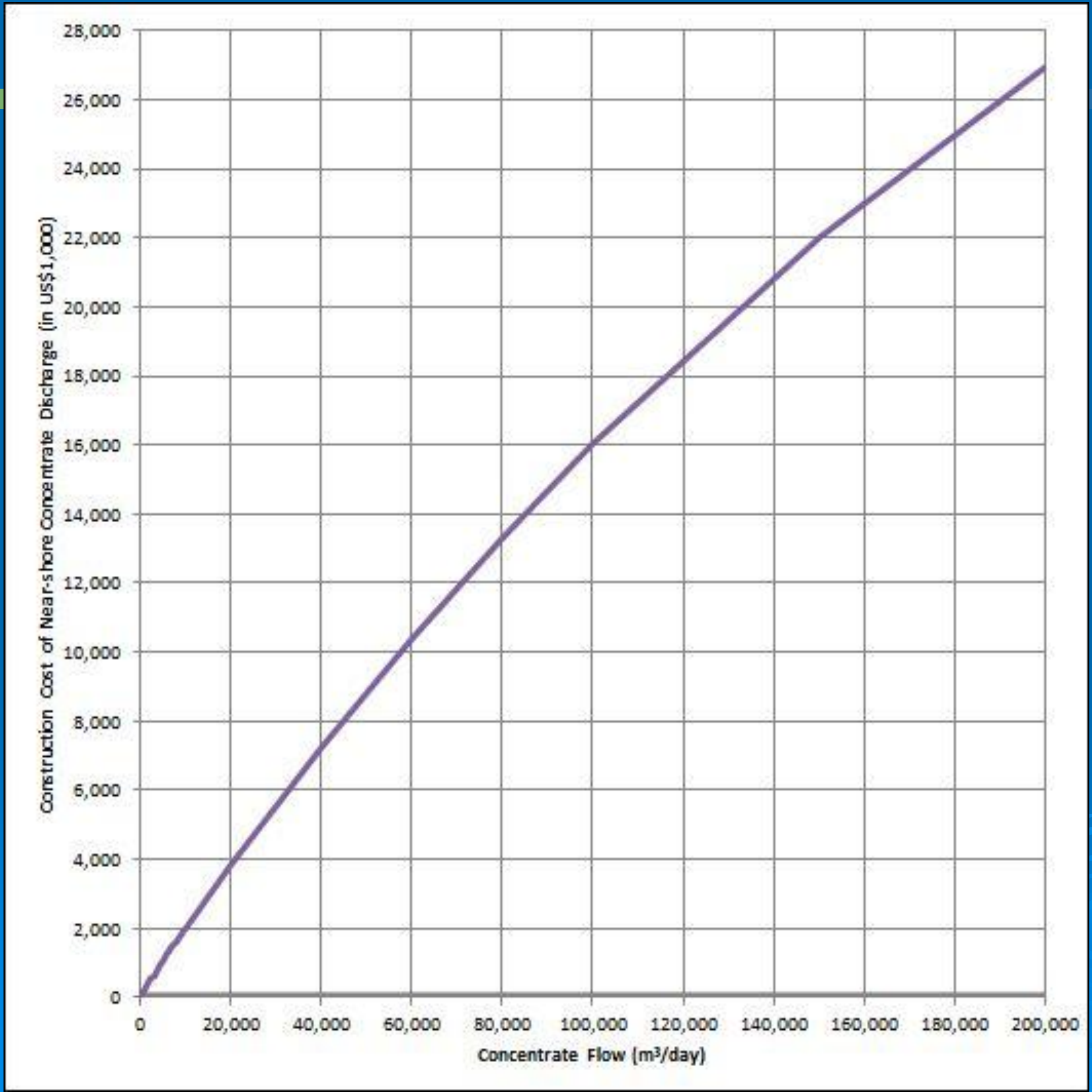
Examples of Large Open Ocean Intakes

Examples of Large Open Intakes for Seawater Desalination Plants

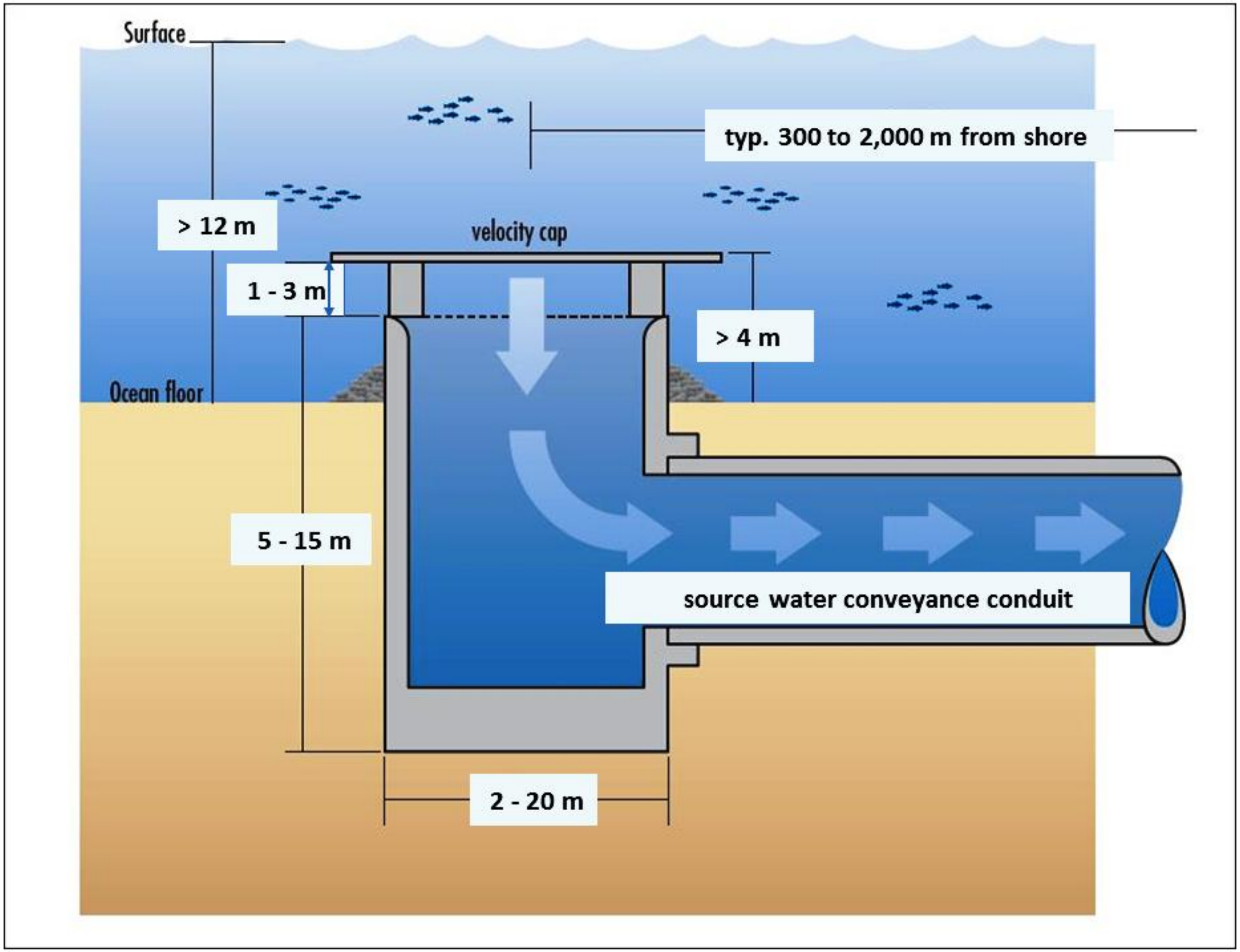
Desalination Plant/ Production Capacity	Max Entrance Velocity m/s /fps	Depth below Water Surface m/ft	Distance from the Bottom m/ft	Number of Inlet Structures & Conduits	Inlet Structure Diameter, m/ft & Screen Size mm/in	Conduit Diameter, m/ft, Material & Distance from Shore m/ft
Adelaide, Australia 300,000 m^3/day	0.15/0.50	18/59	5.0/16.4	1/1	9.5/31.2 100/4	2.8/9.2 Tunnel 1,000/3,300
Sydney, Australia 500,000 m^3/day	0.15/0.50	24/79	6.0/20.0	4 inlet structures on common tunnel	8.5/27.9 340/13	3.4/11.2 Tunnel 300/980
Gold Coast, Australia 136,000 m^3/day	0.05/0.16	22/72	4.4/14.4	1/1	5.8/19.0 140/5.5	2.8/9.2 Tunnel 1,400/4,600
Perth I, Australia 130,000 m^3/day	0.10/0.33	8/26	4.0/13.0	1/1	100/4	2.8/9.2 GRP Pipe 300/1,000
Perth II, Australia, 300,000 m^3/day	0.15/0.50	10/33	4.0/13.0	2	7.0/23 100/4	2.4/9.1 HDPE Pipes 500/2,600
Fujairah I, UAE 170,000 m^3/day	0.10/0.33	10/33	6.0/19.7	3/3	3.0/9.8 80/3	2.0/6.6 GRP Pipes 380/1,250
Al Dur, Bahrain 240,000 m^3/day	0.10/0.33	4/13	2.3/7.5	4/4	7.2/23.6	2.4/7.9 GRP Pipes 1,500/4,920

Onshore Intakes – Typically Used for Thermal Desalination Plants

Construction Costs of Near-shore Intakes

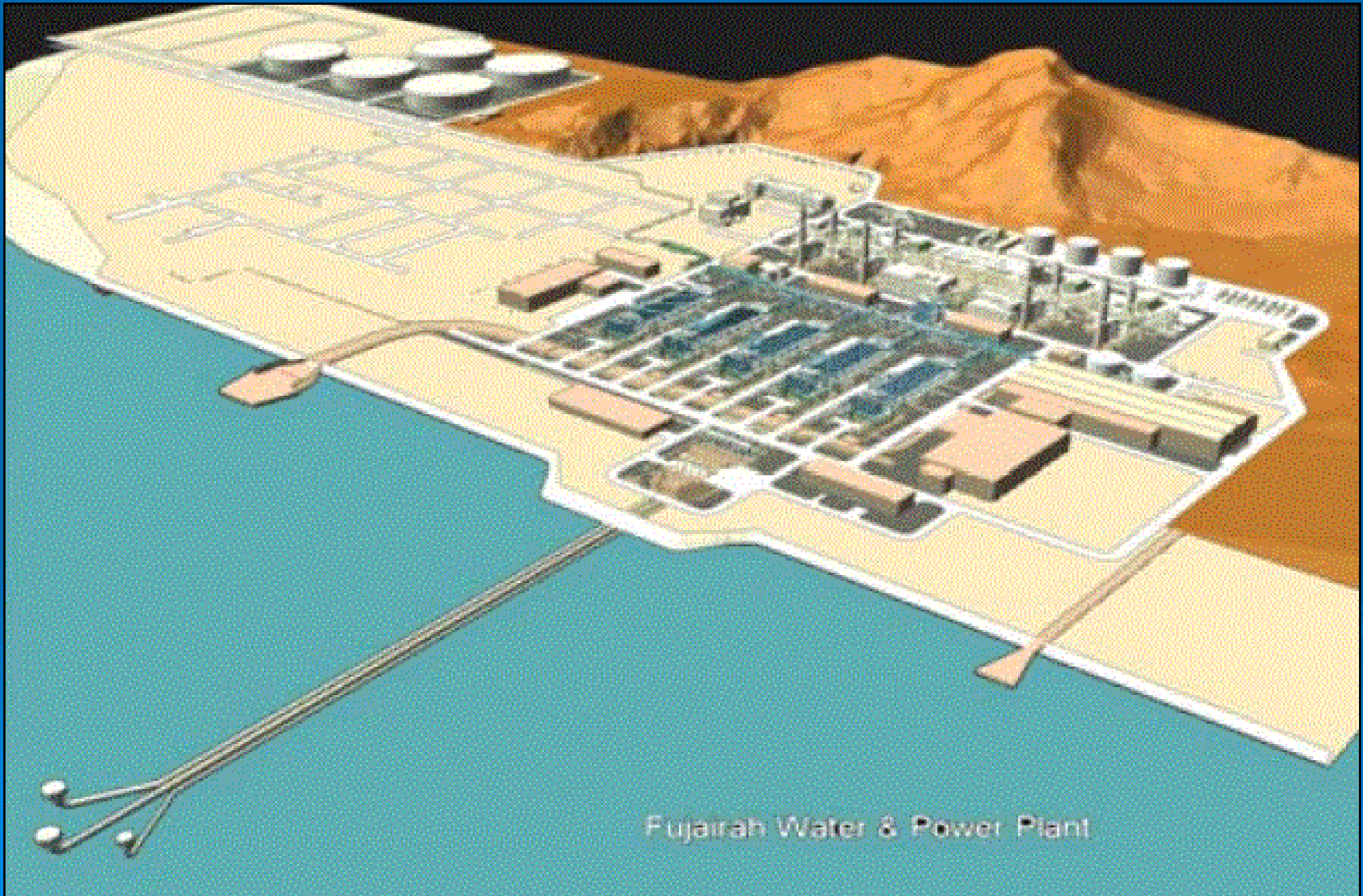


Offshore Coarse Screens – Location & Configuration



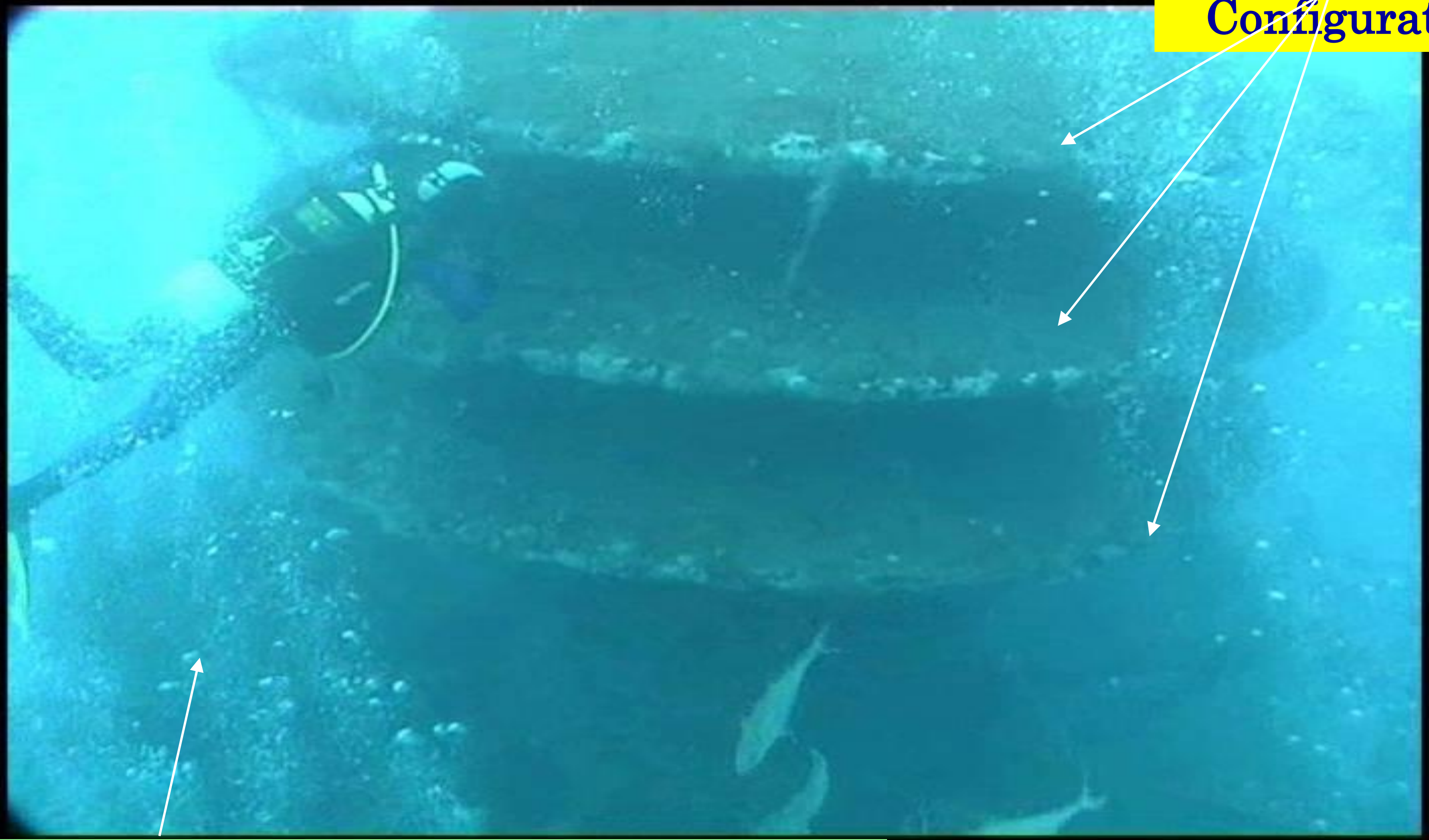
Gold Coast SWRO Plant Intake Structure

Fujairah Intake System

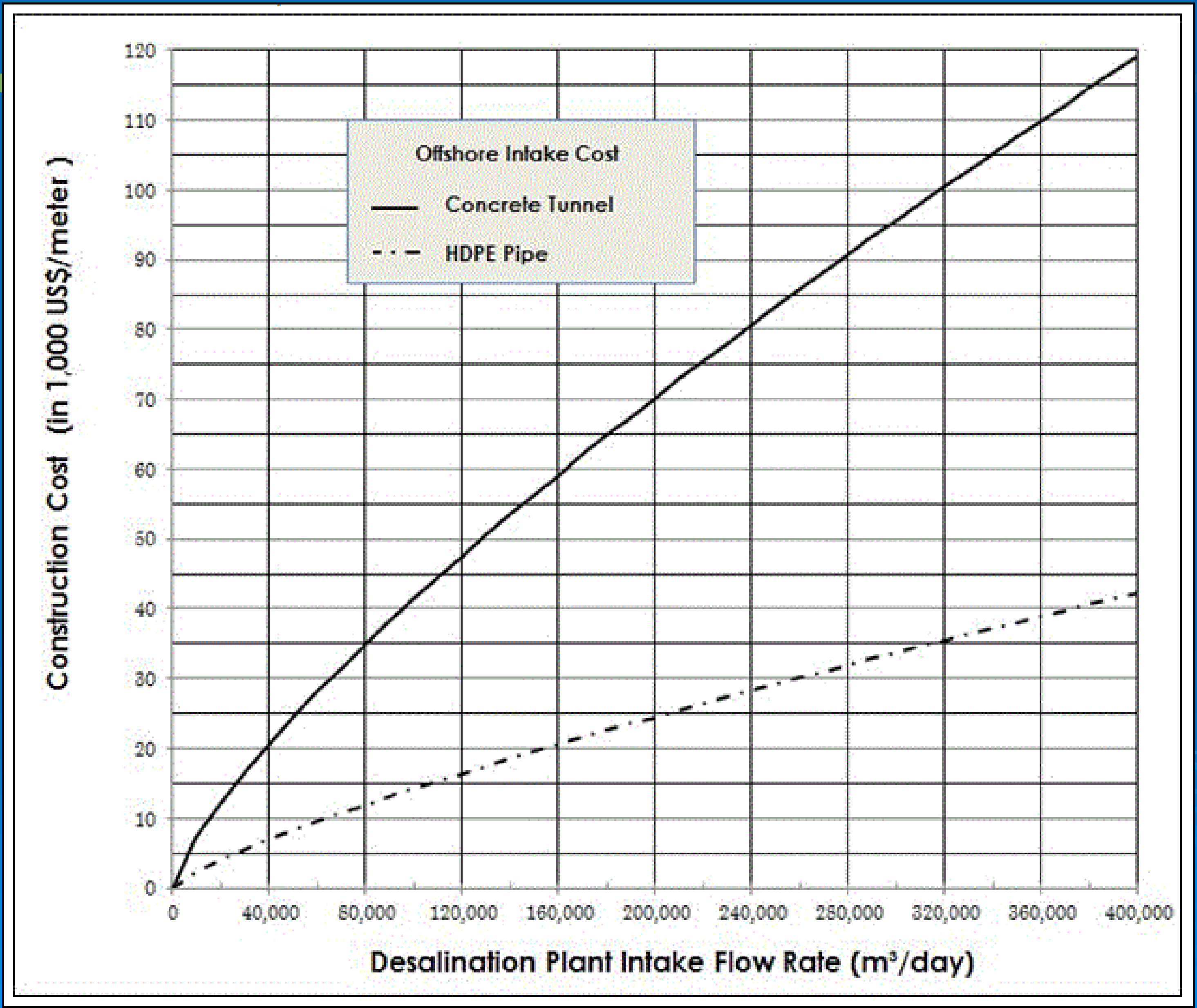


Intake of Larnaka, Cyprus SWRO Plant – 50,000 m3/day

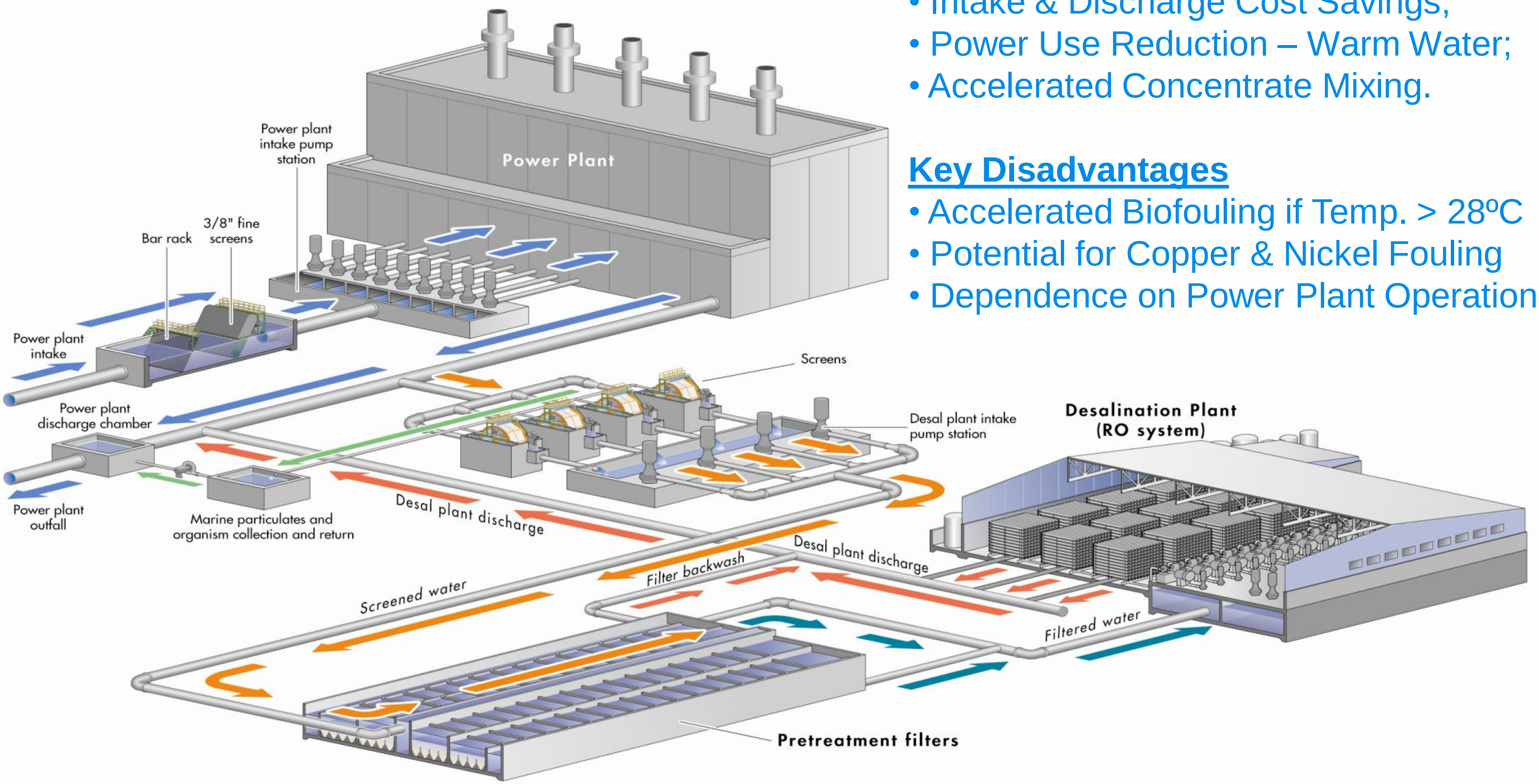
Intake of 330,000 m3/day Ashkelon Desalination Plant, Israel



Construction Costs of Off-shore Intakes



Power Plant Collocation –
Use of Existing Intake & Discharge



Key Advantages:

- Intake & Discharge Cost Savings;
- Power Use Reduction – Warm Water;
- Accelerated Concentrate Mixing.

Key Disadvantages

- Accelerated Biofouling if Temp. > 28ºC
- Potential for Copper & Nickel Fouling
- Dependence on Power Plant Operation

Collocation – Capital Cost Savings

- Avoidance of Construction of New Intake & Discharge Facilities – 10 to 30 % of Construction Costs;
- Avoidance of Construction & Operation of New Screening Facilities;
- Electrical System Cost Savings:
  - Lower or No Power Grid Use Tariff Charge;
  - Use of the “Spinning Reserve” of “Must Run” Power Plants.

Intake Screens

Classification of Screens

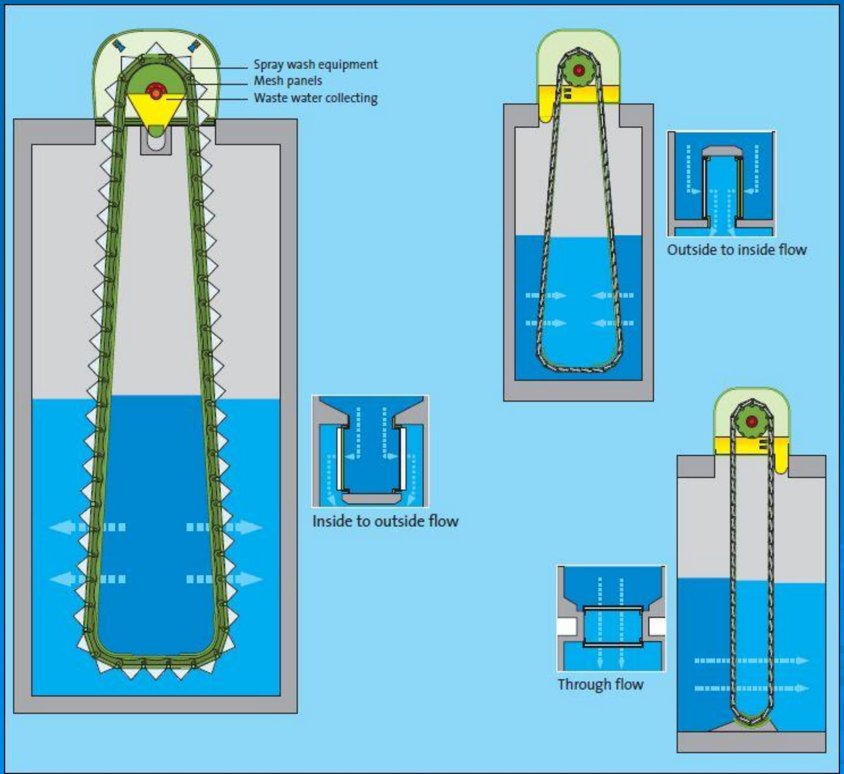
- Coarse Bar Screens (Bark Racks):
  - Offshore
  - Onshore
- Fine Screens
  - Rotating (Band and Drum Screens)
  - Wedgewire Screens
- Micro-screens
  - Band Micro-screens
  - Micro-strainers
  - Disk Filters

Coarse Bar Screens – Installed on Offshore and Onshore Intakes

- Function: Prevention of Large Debris and Aquatic Life From Entering the Plant Intake
- Flow-through Velocity – 0.10 to 0.15 m/s (to minimize I&E)
- Distance Between Bars –
  - 50-300 mm
- Screen Bars –
  - Super-duplex Stainless Steel
  - Cu-Ni Alloys

Fine Screens - Types

- Rotating Screens
  - Bar Screens
  - Band Screens
  - Drum Screens
- Stationary – Wedgewire Screens

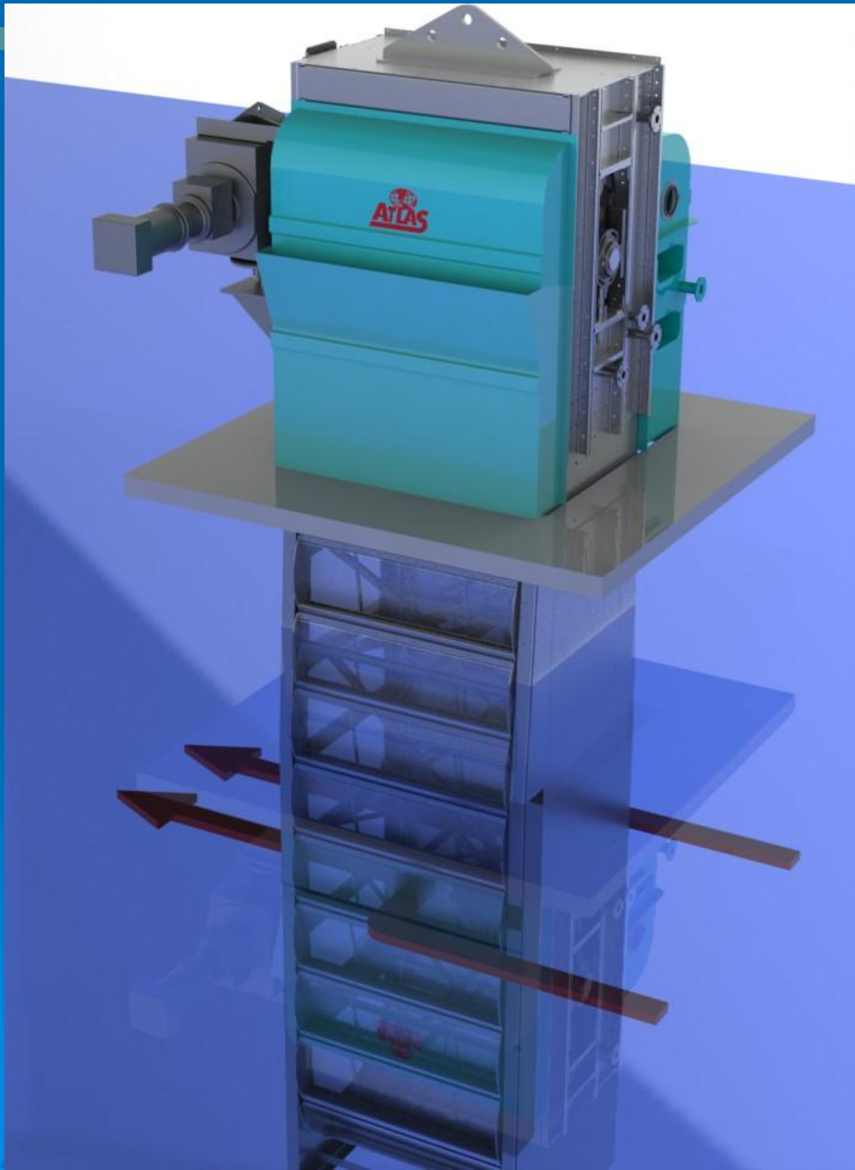


Intake Bar Screens

Mainly Used for SWRO Plants with Deep Intakes
Distance Between Bars – 3 to 10 mm

Rotating Band Screens – Most Commonly Used in SWRO Plants

- Vertical Screens Rotating at Velocity of 2 to 10 m/min
- Individual Screening Panels with Fine Mesh Openings Attached on Roller Chains
- Low-pressure Sprays Remove Debris from Screens
- Screen Panel Mesh Made of
  - Plastic
  - Duplex Stainless Steel



Perth Seawater Desalination Project
On-shore Active Screening – Band Screen

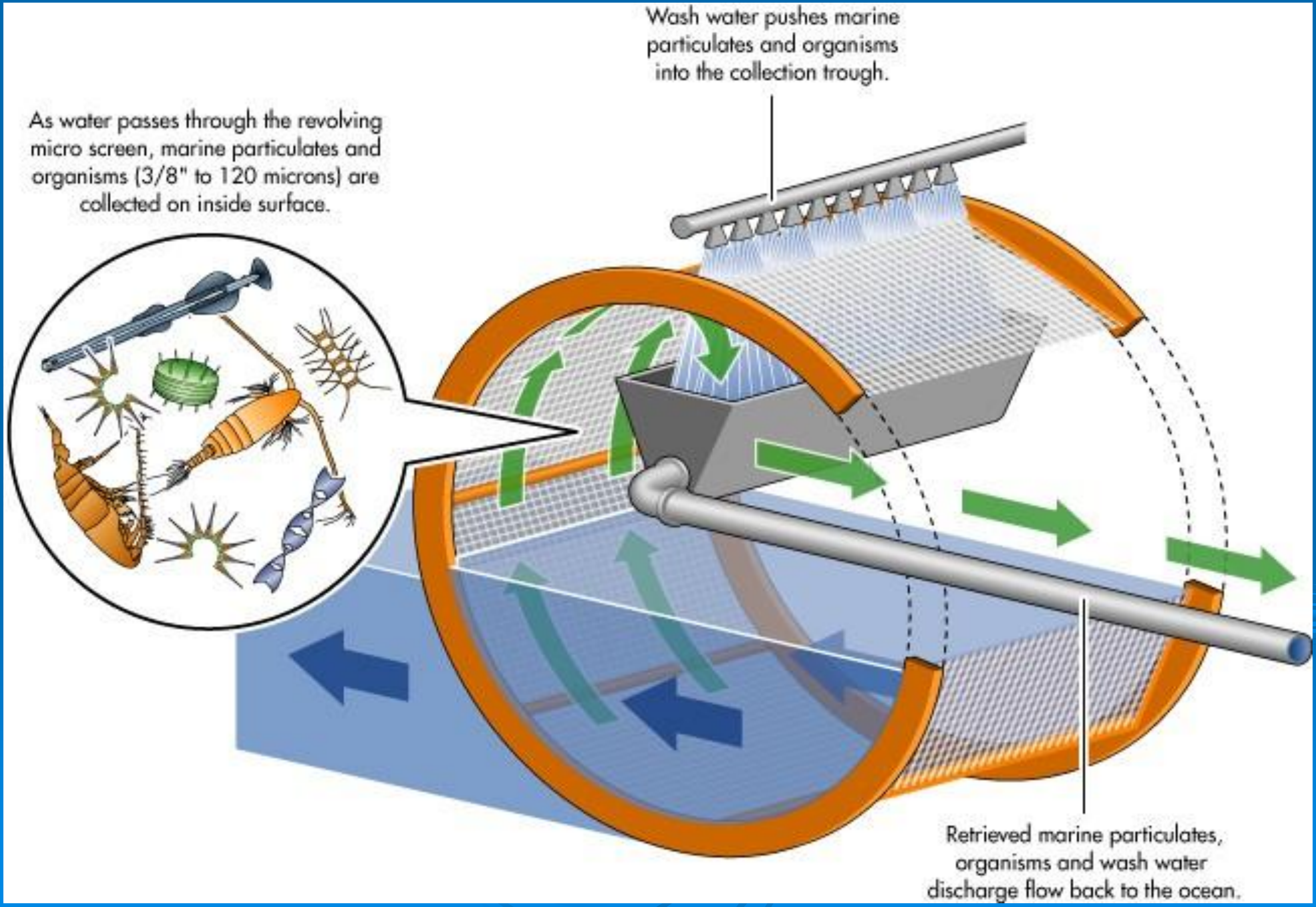
Courtesy of the Water Corporation

Drum Screens

- Rotating Cylindrical Frame Covered with Mire-mesh Fabric
- Frame Located in Screen Structure
- Screen is Supported on Central Shaft
- Most Common Configuration – Double Entry

Sydney Water SWRO Plant Intake Drum Screens

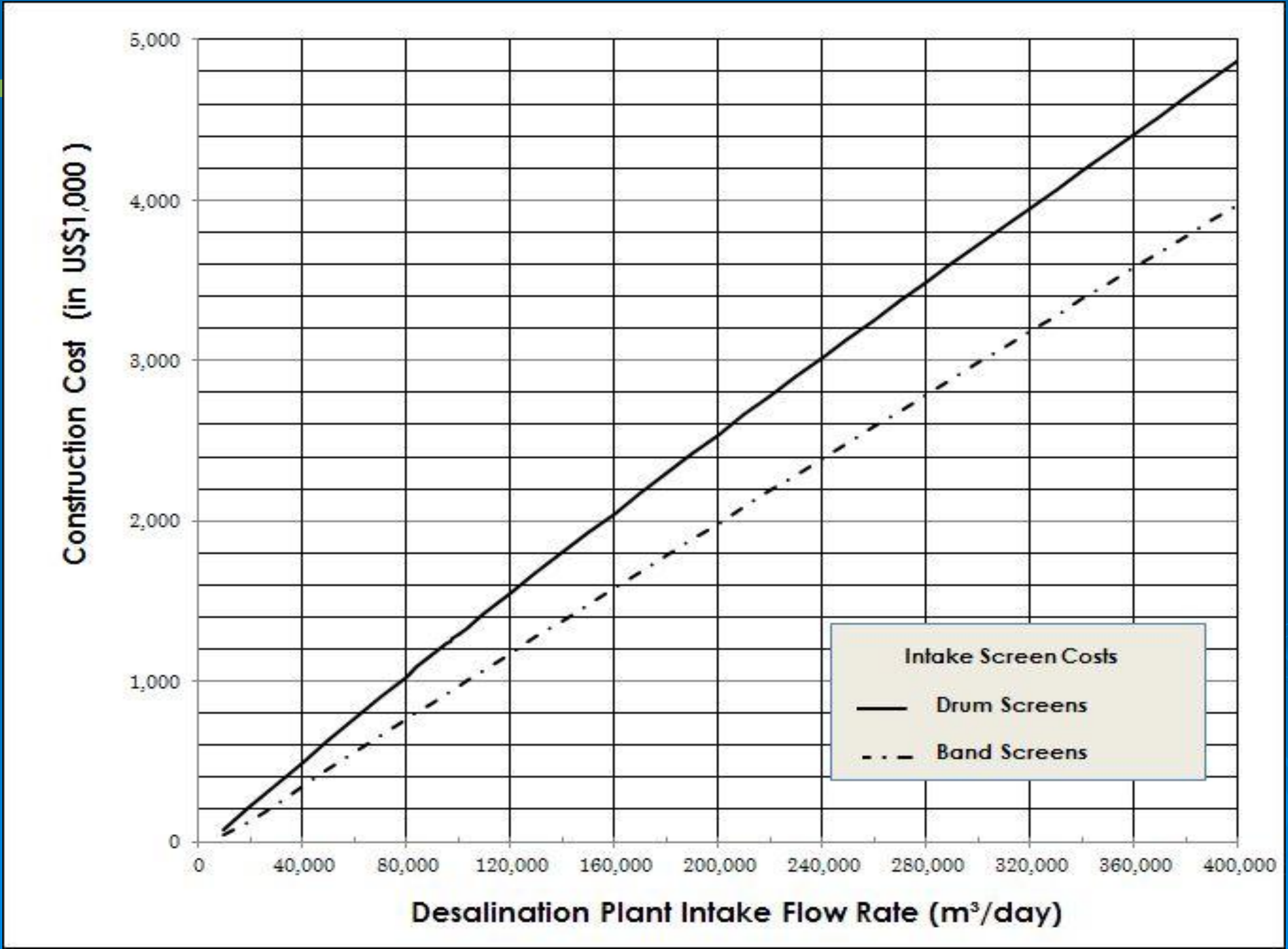
Drum Screens - Configuration



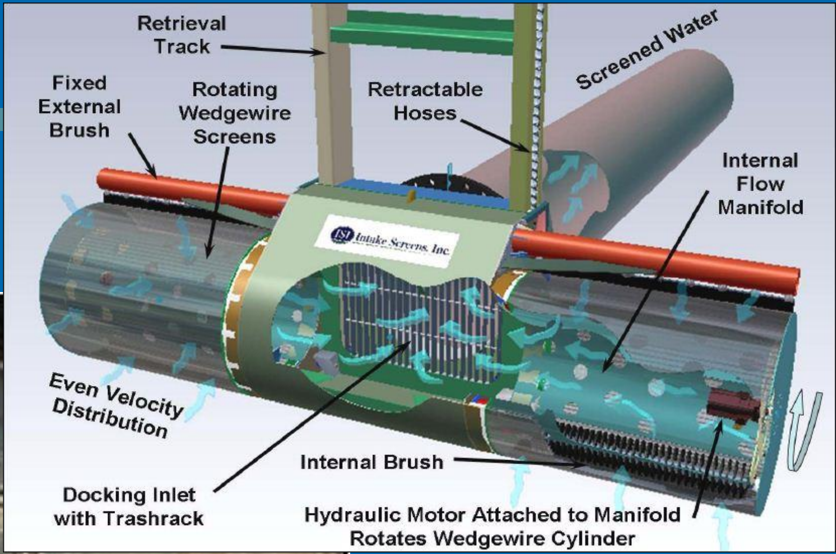
Comparison of Drum and Band Screens

- Band Screens:
  - Have 30 to 50 % Smaller Footprint
  - Are 30 to 40 % Less Costly
- Drum Screens:
  - Have Lower Maintenance Costs
  - Handle Varying Flows and Solid Loads Better
  - Create Lower Flow-thorough Headloses

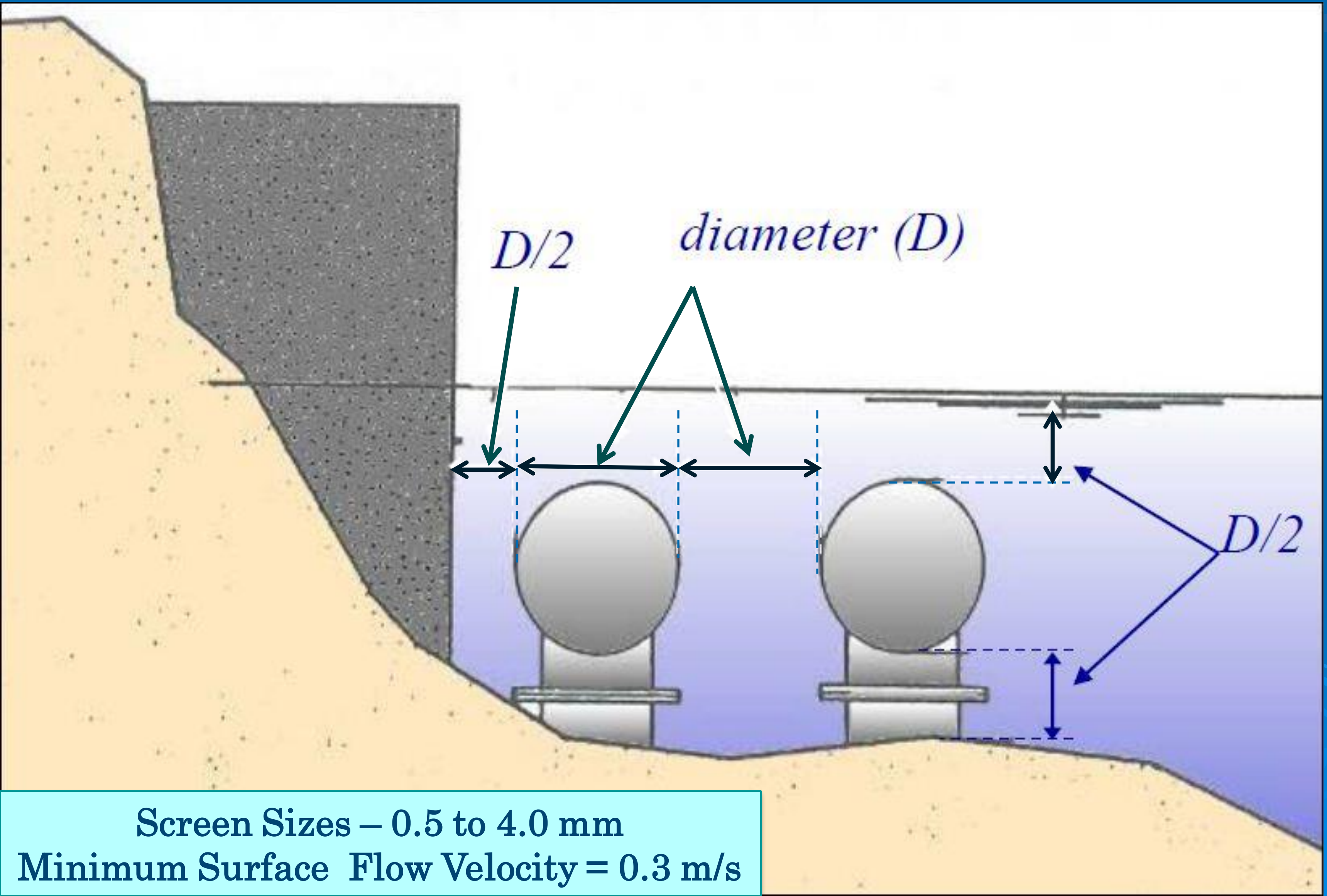
Cost Comparison of Drum and Band Screens



Wedgewire Screens



Wedgewire Screens – Preferred for Shallow Intakes



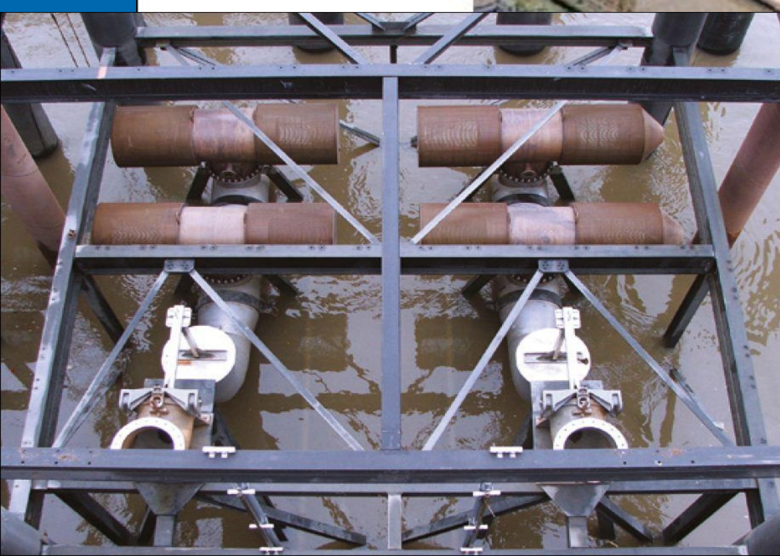
Screen Sizes – 0.5 to 4.0 mm
Minimum Surface Flow Velocity = 0.3 m/s

Comparison of Rotating and Wedgewire Screens

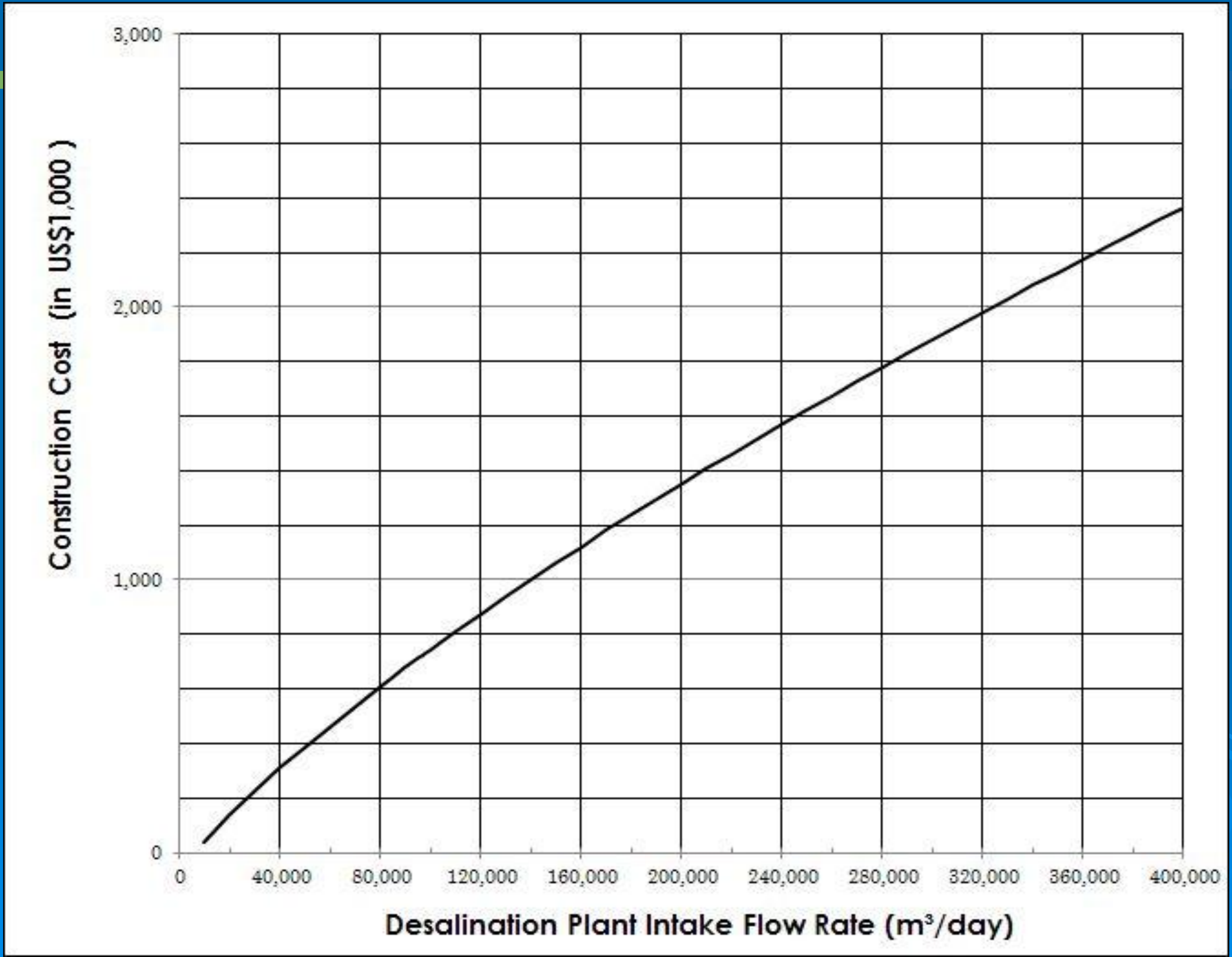
- **Rotating Screens**
  - Suitable for Intake Locations of At Least 5 m Depth
  - More Universal in Terms of Location
  - Preferable to Be Installed Away from Underwater Currents
  - Used in All Large SWRO Plants in Australia, the Mediterranean and Spain

- **Wedgewire Screen Intake**
  - Can be Installed at Shallow Locations (Depth of 5 m or less)
  - Requires Minimum Underwater Current Velocity of 0.3 m/s to Prevent Clogging
  - Most Existing Full-scale Applications are for Small Plants
  - Successfully Used for the 150 MLD Plant in Beckton, London (UK)

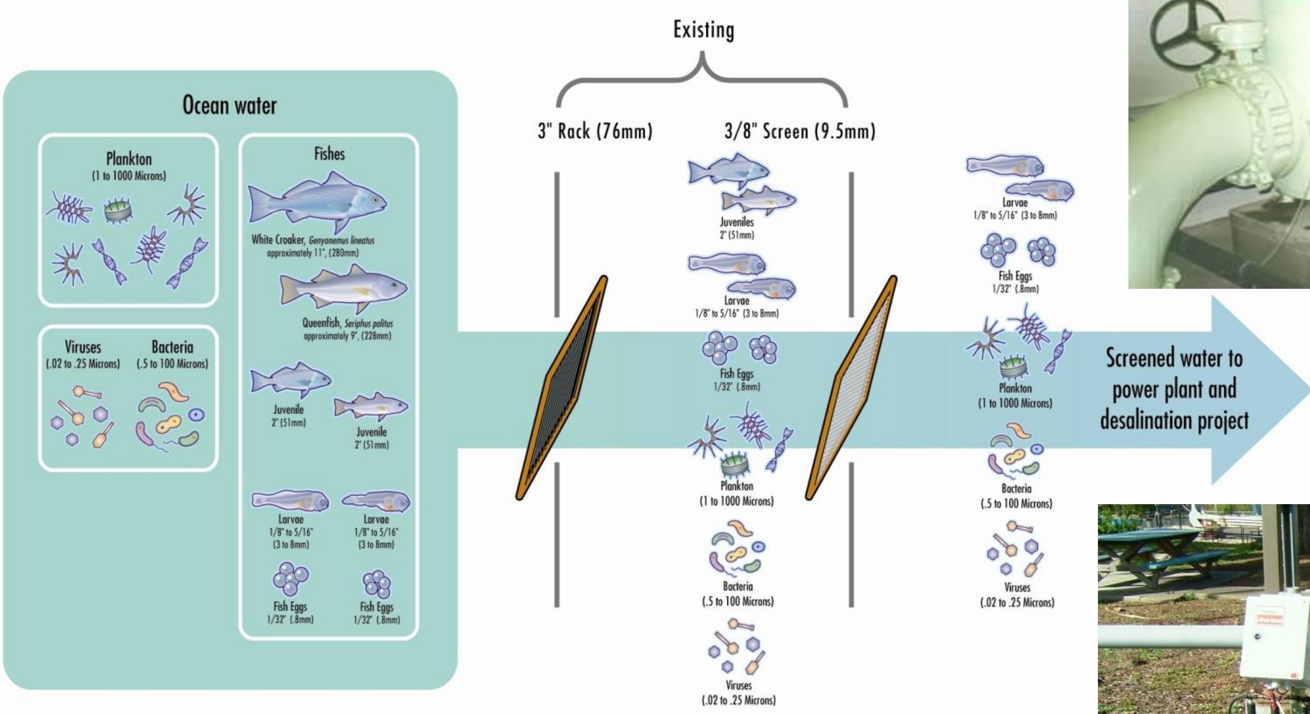
150,000 m³/day Beckton Plant, London Wedgewire Screen Intake



Wedgewire Screen Construction Costs



Open Intakes – Micro-screens



Open Intakes – Mechanical Screens

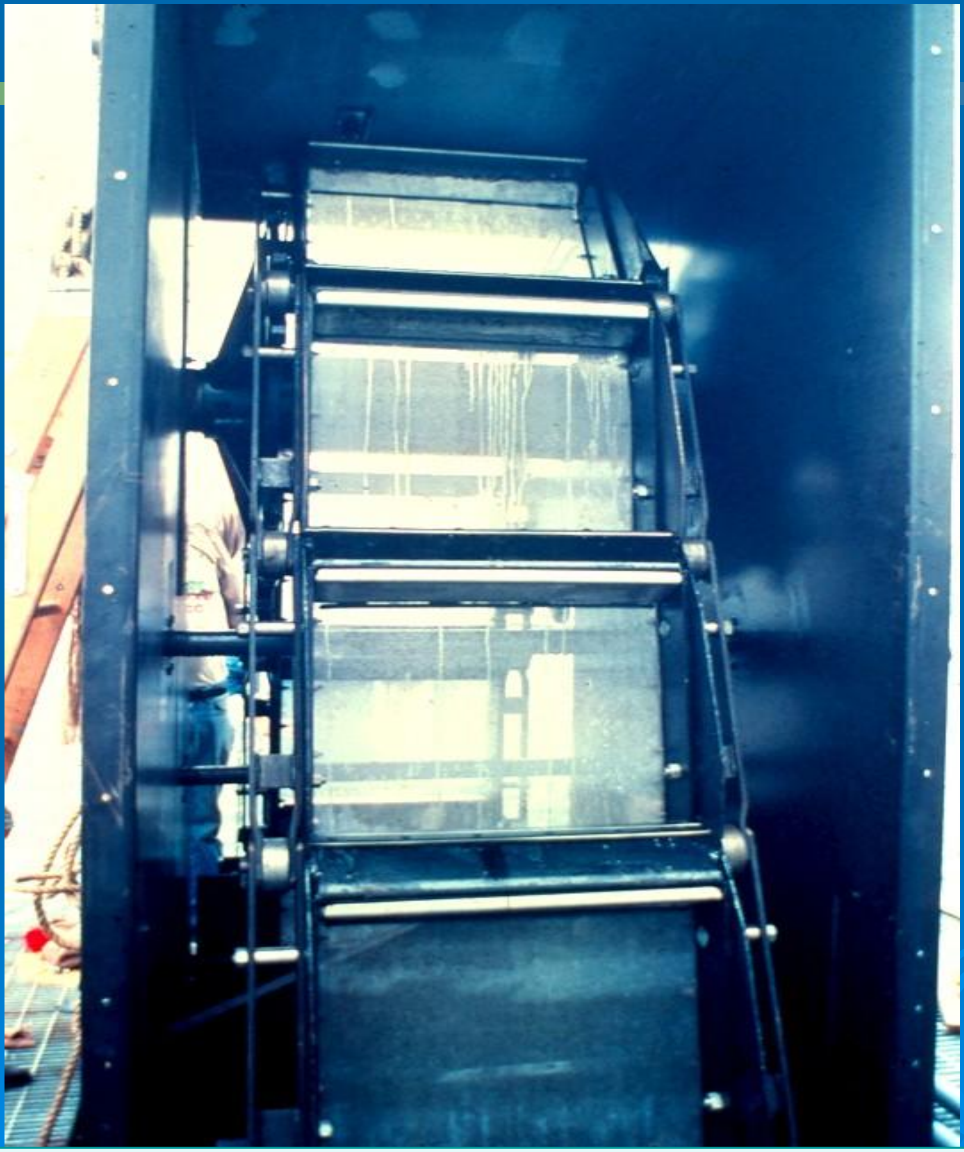
500-µ Strainers

120-µ Disk Filters

Why Micro-screens Are Needed?
Membrane Damage

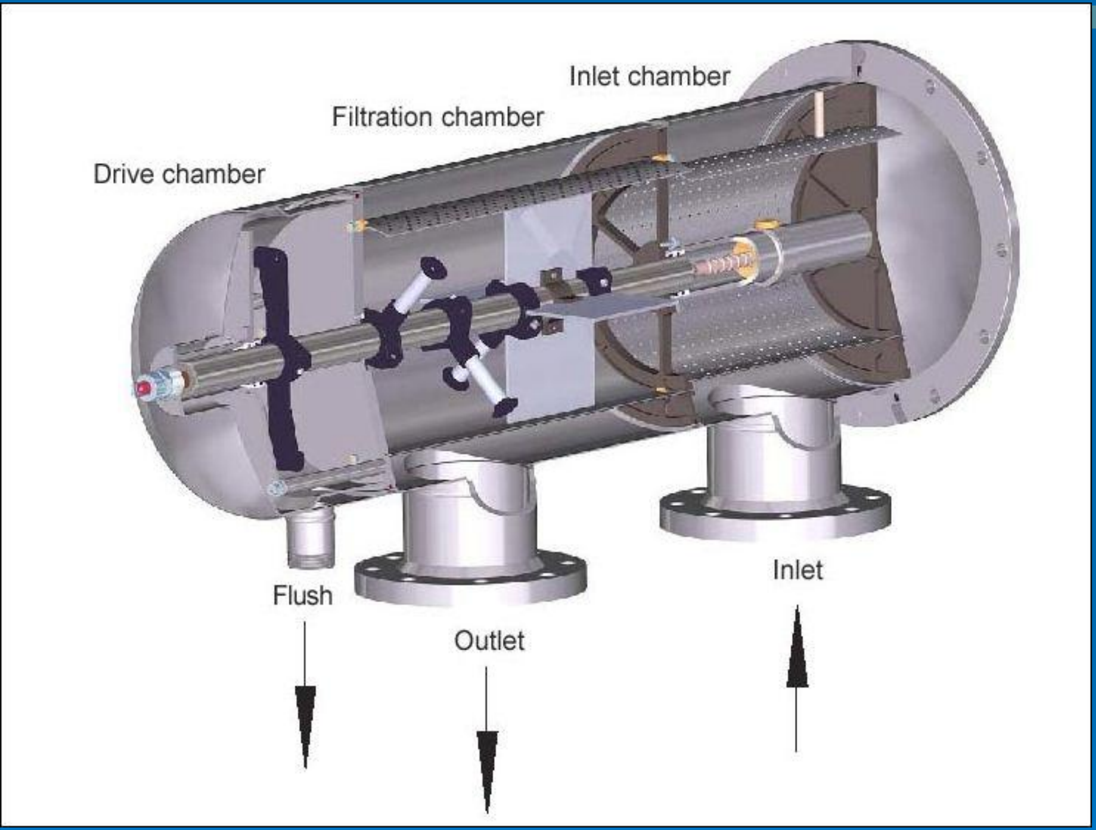
- Sand: **50 - 250 µ**
- Seaweed, Macro-Algae, Fibers: **100 - 500 µ**
- Zooplankton - Rotifera, Crustaceans, etc: 80 – **100 µ**
- Shell debris: **50 - 500 µ**
- Mineralized Colonies of Sponges and Other Marine Organisms: **>100 µ**
- Microbiological Bio-fouling & Tank Wall Crustations

Band Micro-screens



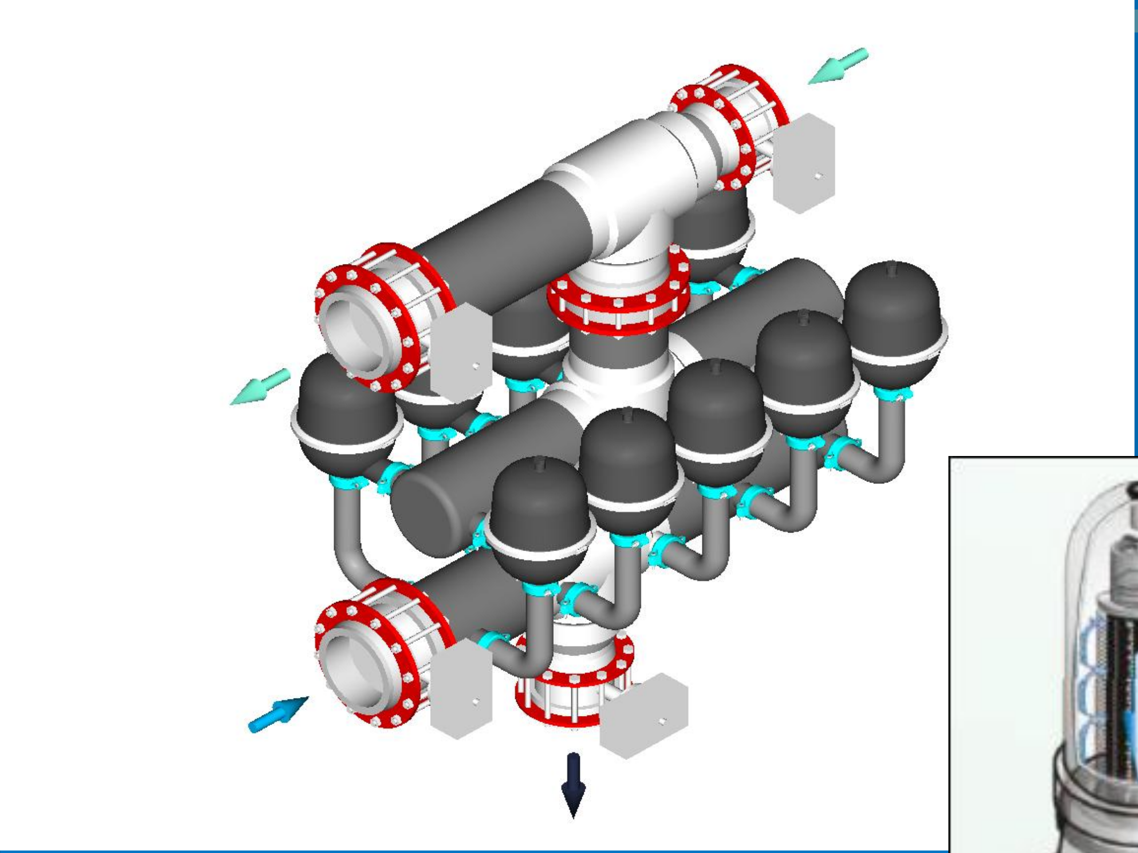
500 µTravelling Band Micro-screens – Tampa Bay Water SWRPO Plant Intake

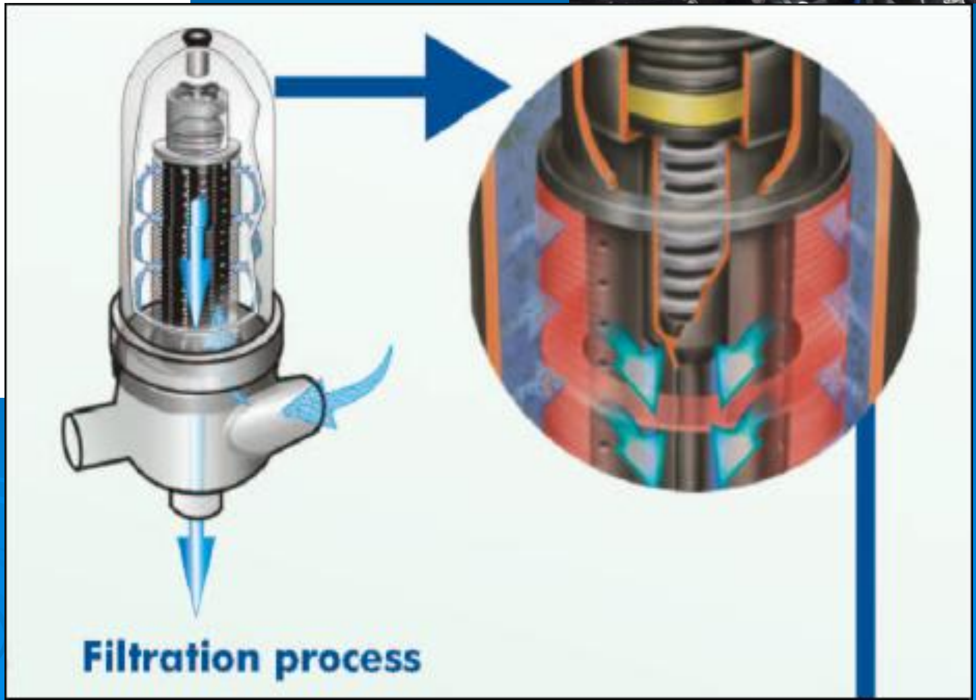
Micro-strainers



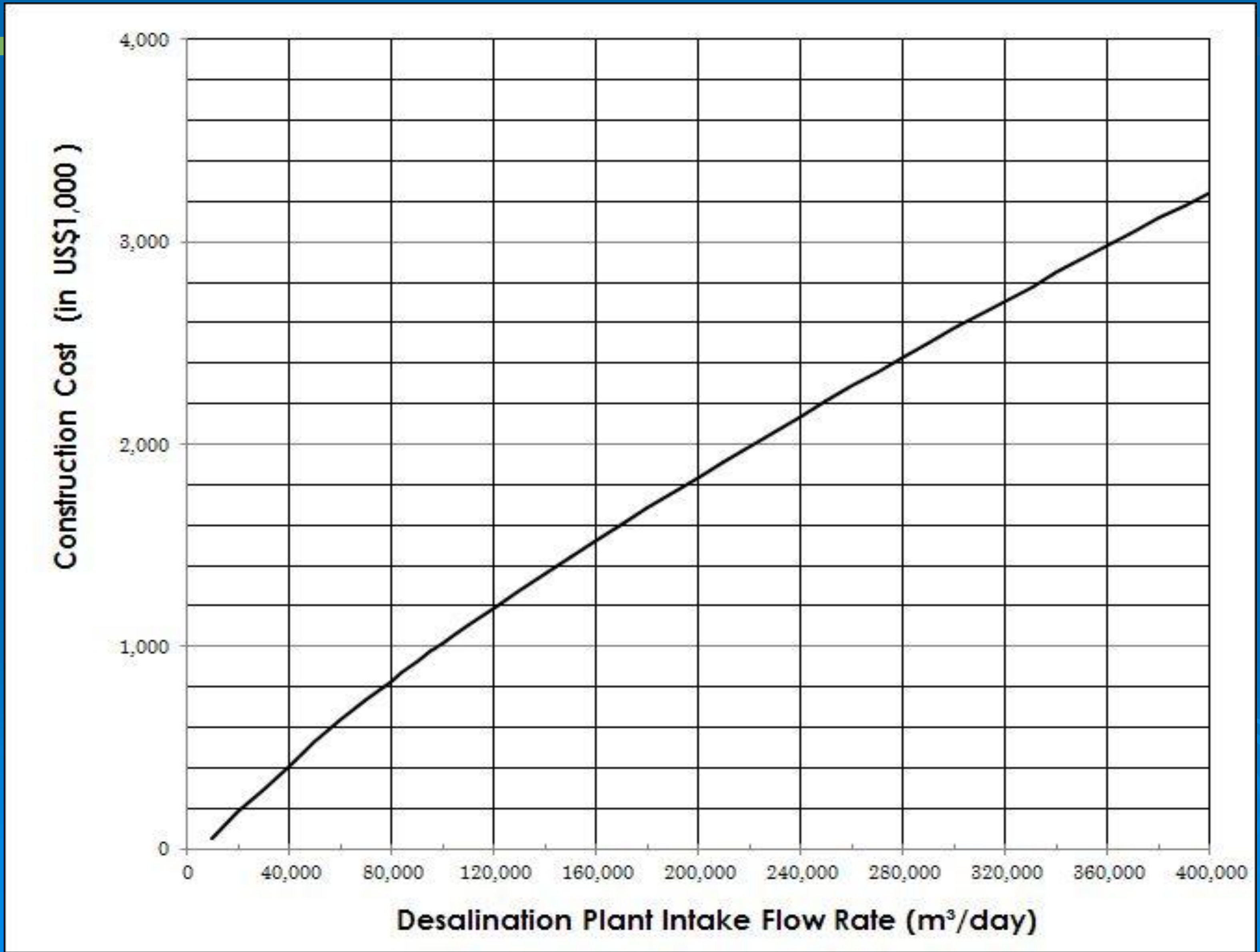
- Source Water Enters Inner Side and Moves Radially Through the Screen
- Gradual Buildup on the Inner Walls Creates Cake from Source Water Residuals
- Preset Headloss Triggers Self-Cleaning

Disk Filters (80 to 120 μ)





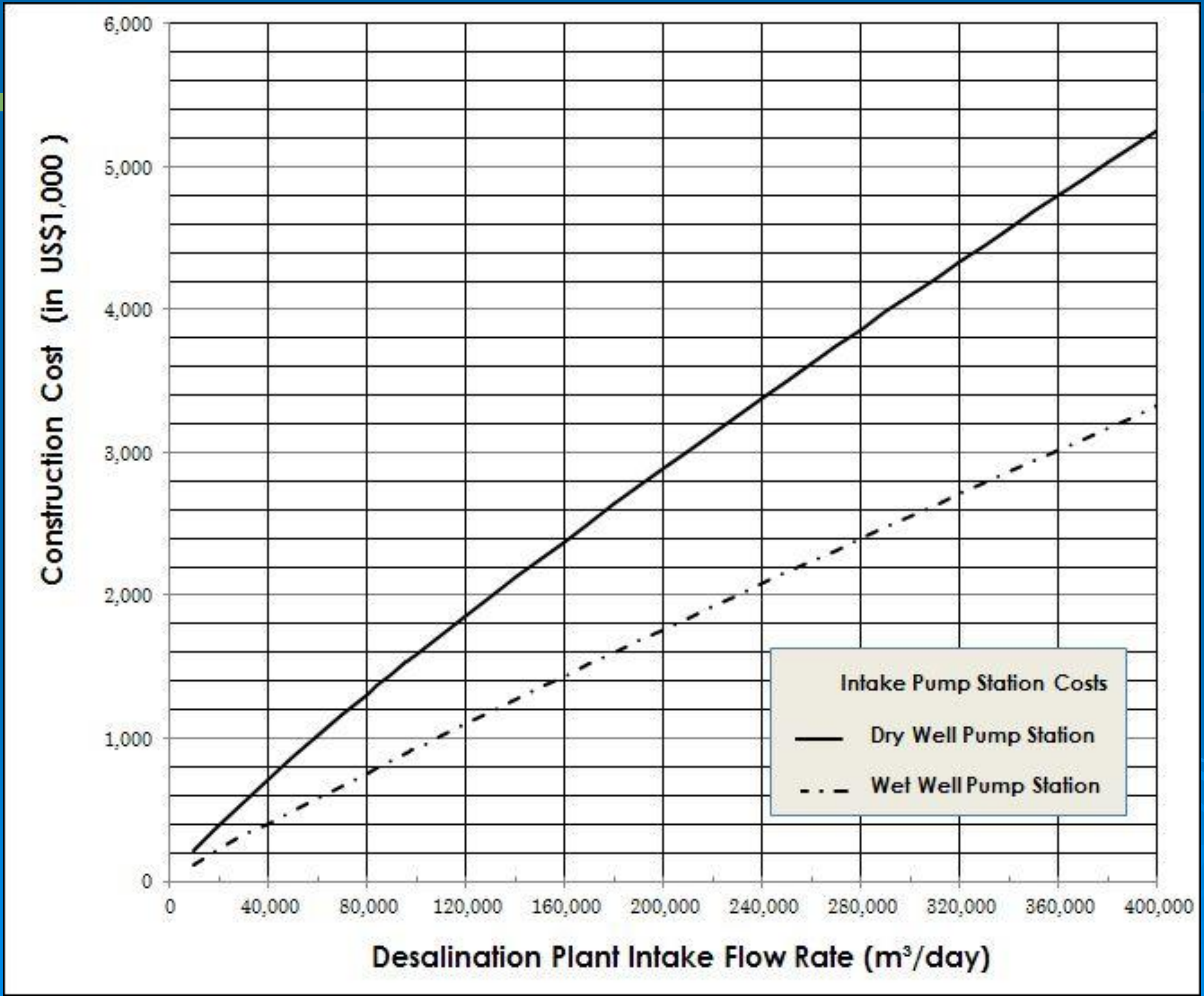
Micro-screens – Construction Costs



Summary of Intake Construction Costs

- Very Dependent on Source Water Quality
- Usually Between US$50 and 100/$m^3$/day
- Beach Well Intakes Usually Less Costly
- Horizontal and Slant Wells Comparable to Open Intakes
- Infiltration Galleries Often are More Expensive than Open Intakes

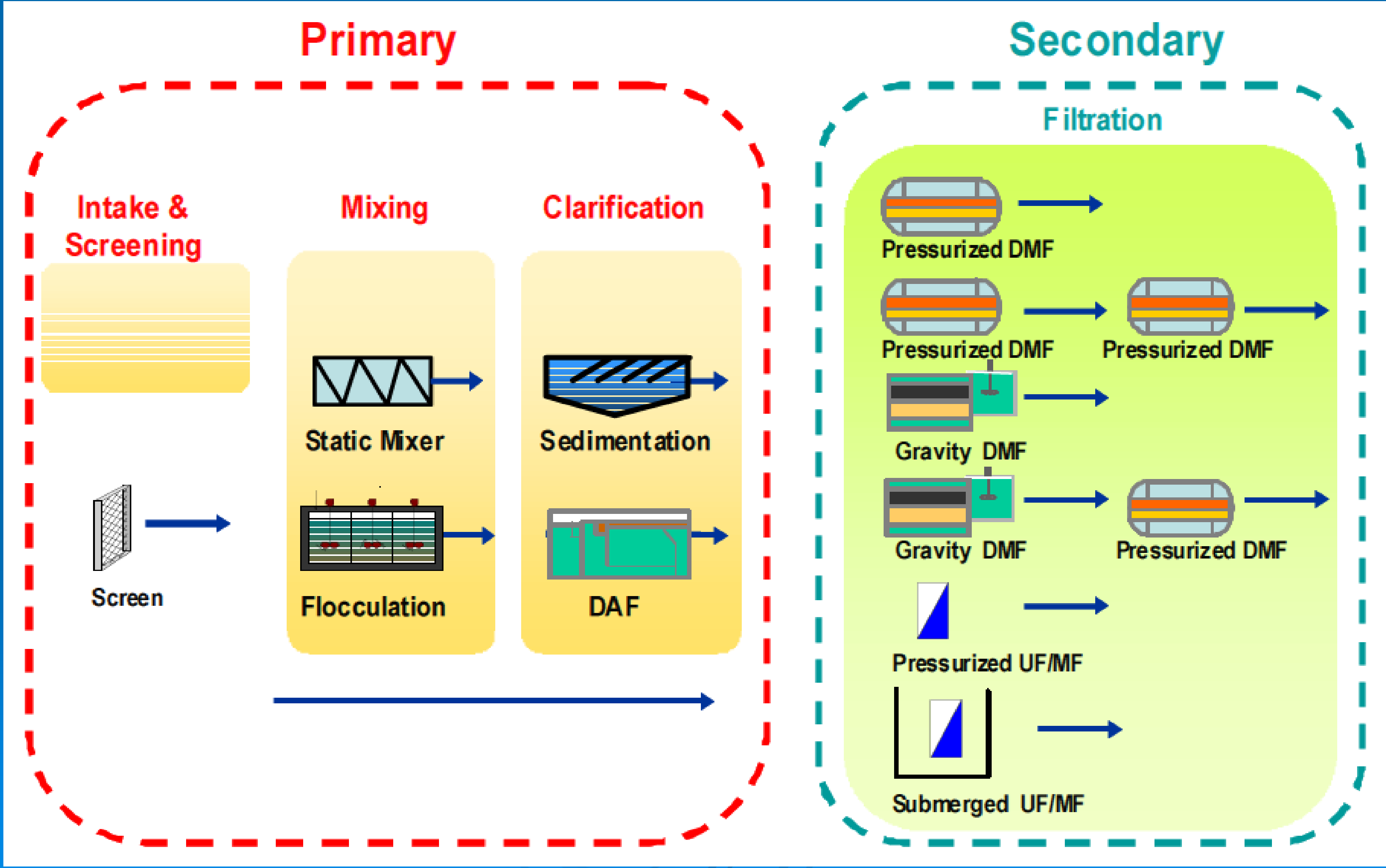
Intake Pump Station Costs



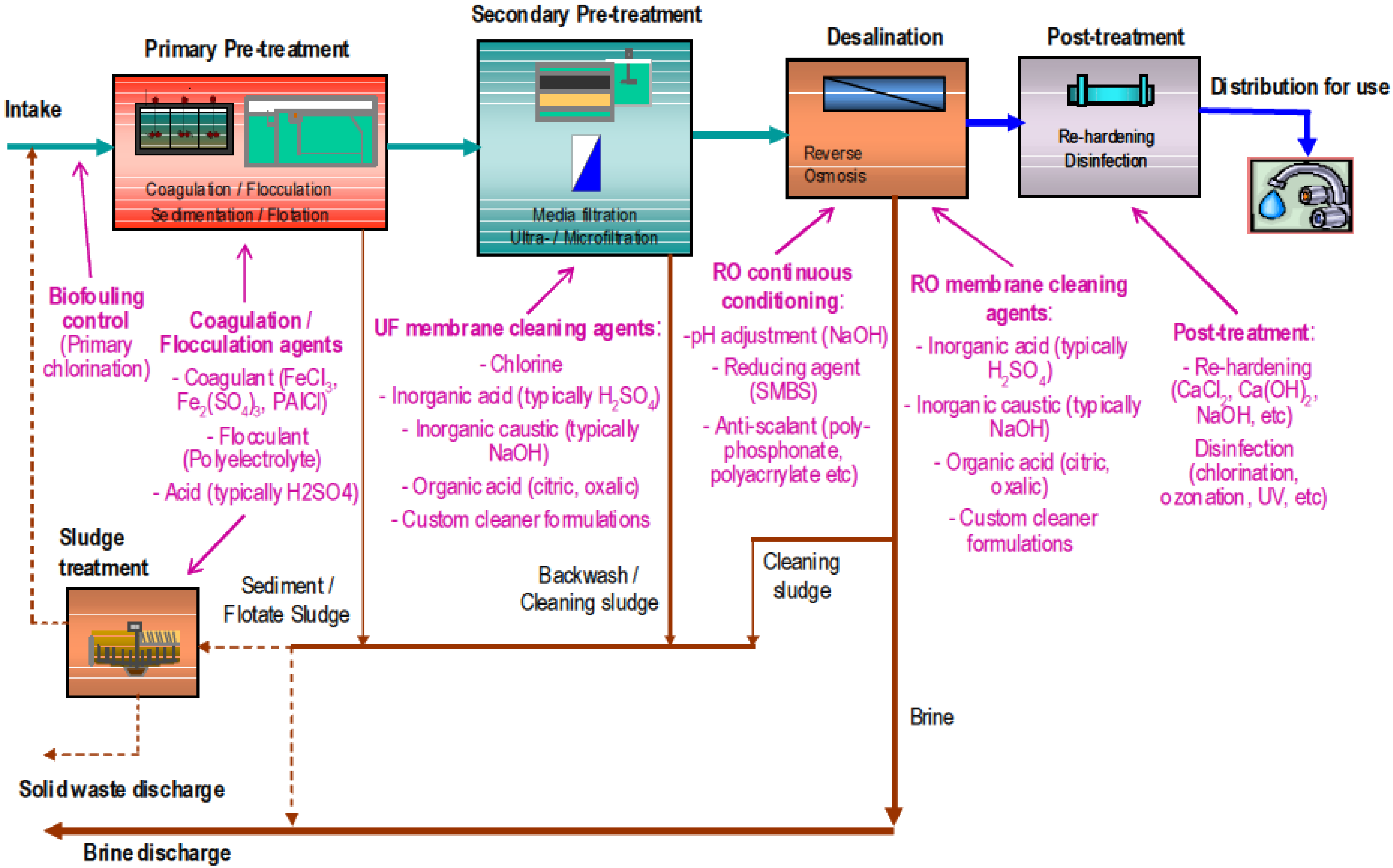
Source Water Pretreatment

- Coagulation & Flocculation;
- Conventional and Enhanced Sedimentation;
- Granular Media Filtration;
- UF and MF Filtration;
- Suppression of Scale Formation on the Membranes;
- Oxidant Removal.

Pretreatment Alternatives



Source Water Chemical Conditioning

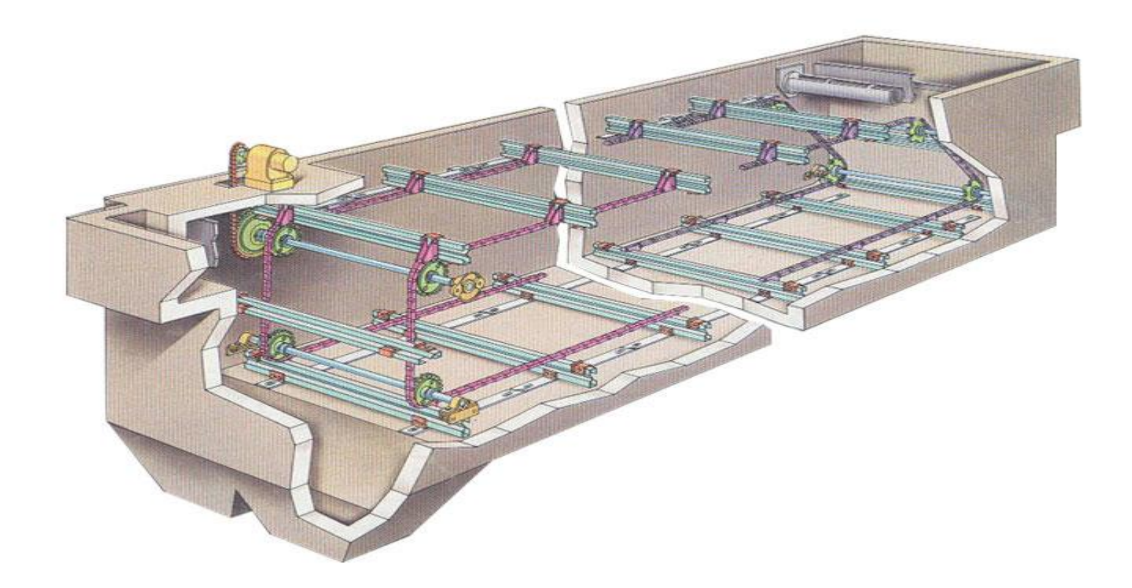


Coagulation and Flocculation

- Purpose – Enlargement of the Size of Colloidal & Particulate Foulants to Enhance their Removal
- Coagulants - Iron Salts – neutralize negative charges of particles in the source seawater to facilitate sedimentation and filtration
- Flocculants – Polymers – increase the size of the coagulated particles for easier filtration
- Acids – add positive charge to the coagulant and thereby enhance its ability to attract particles

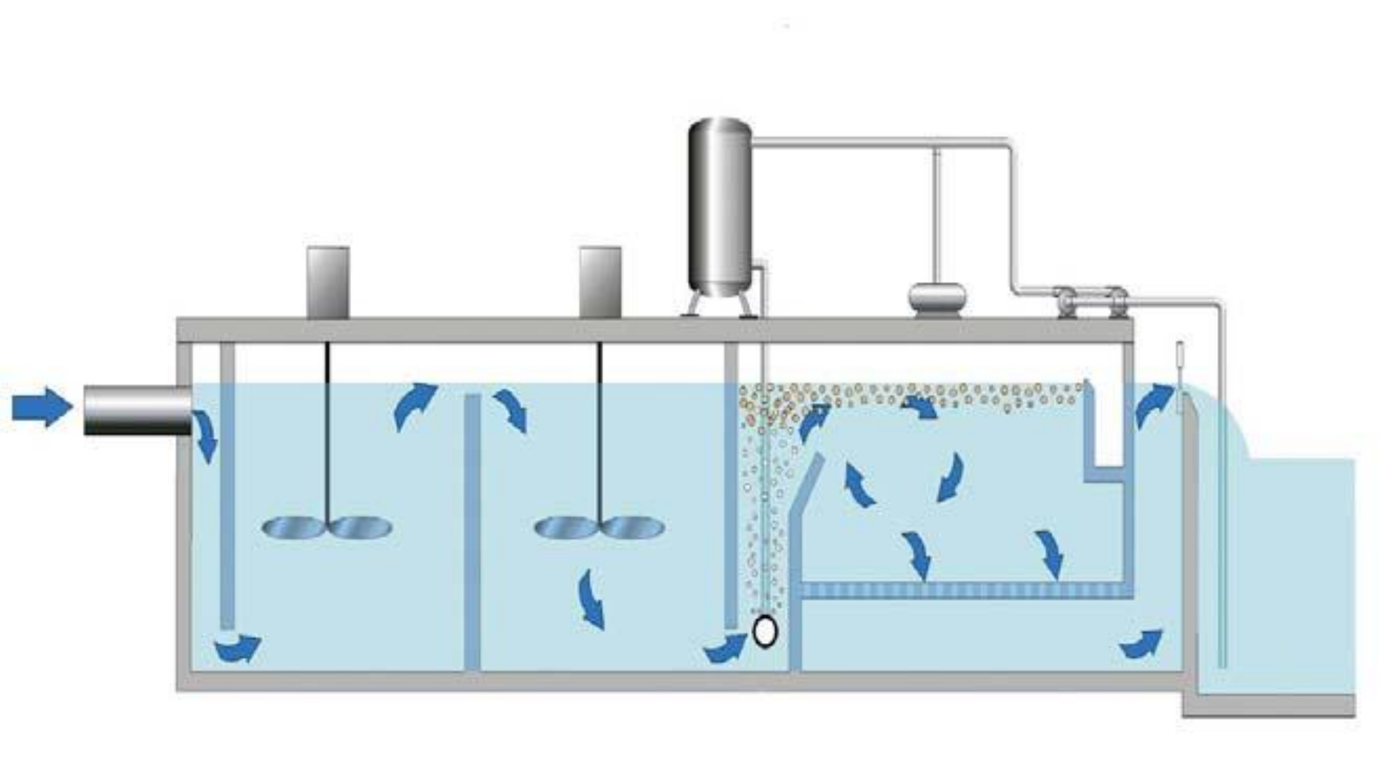
Conventional & Enhanced Sedimentation

- Conventional Sedimentation – to remove coagulated particles by settling in clarifiers
- Enhanced Sedimentation (Lamella Settlers) – to process seawater of high solids content

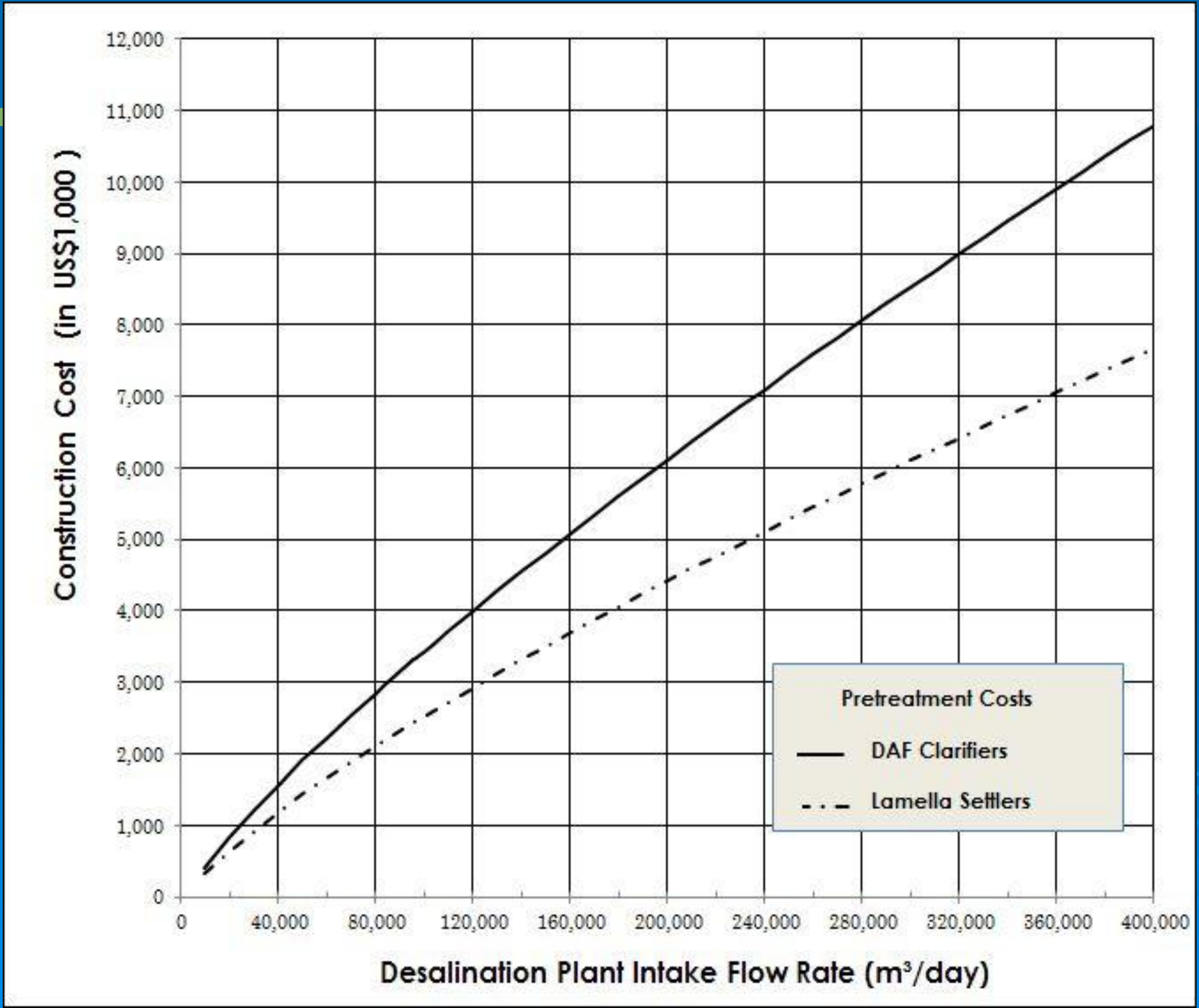


Dissolved Air Flotation (DAF)

- Purpose:
  - Removal of Algae and other floatable particles;
  - Removal of Oil & grease;



Construction Costs of Gravity and DAF Clarifiers



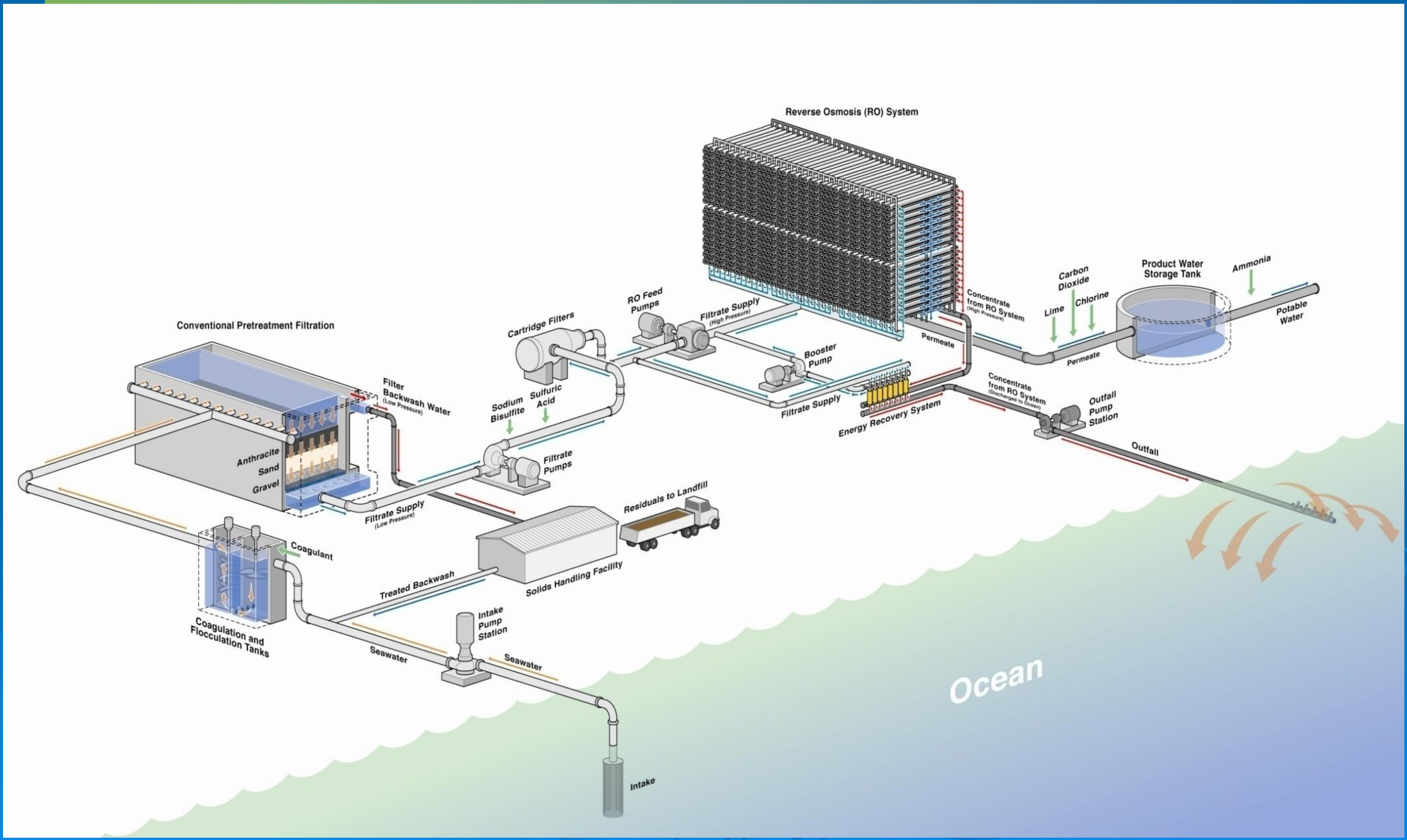
Pretreatment Filtration Alternatives

- Purpose: Removal of Solid Particles from the Source Seawater prior to SWRO Separation

- Granular Media Filters – filtration through granular media (anthracite or pumice and sand)
  - Gravity or Pressure-Driven;
  - Single & Two-Stage.

- Membrane Filters – filtration through porous plastic or ceramic membranes
  - UF & MF;
  - Vacuum & Pressure-Driven.

SWRO Plant with Conventional Pretreatment

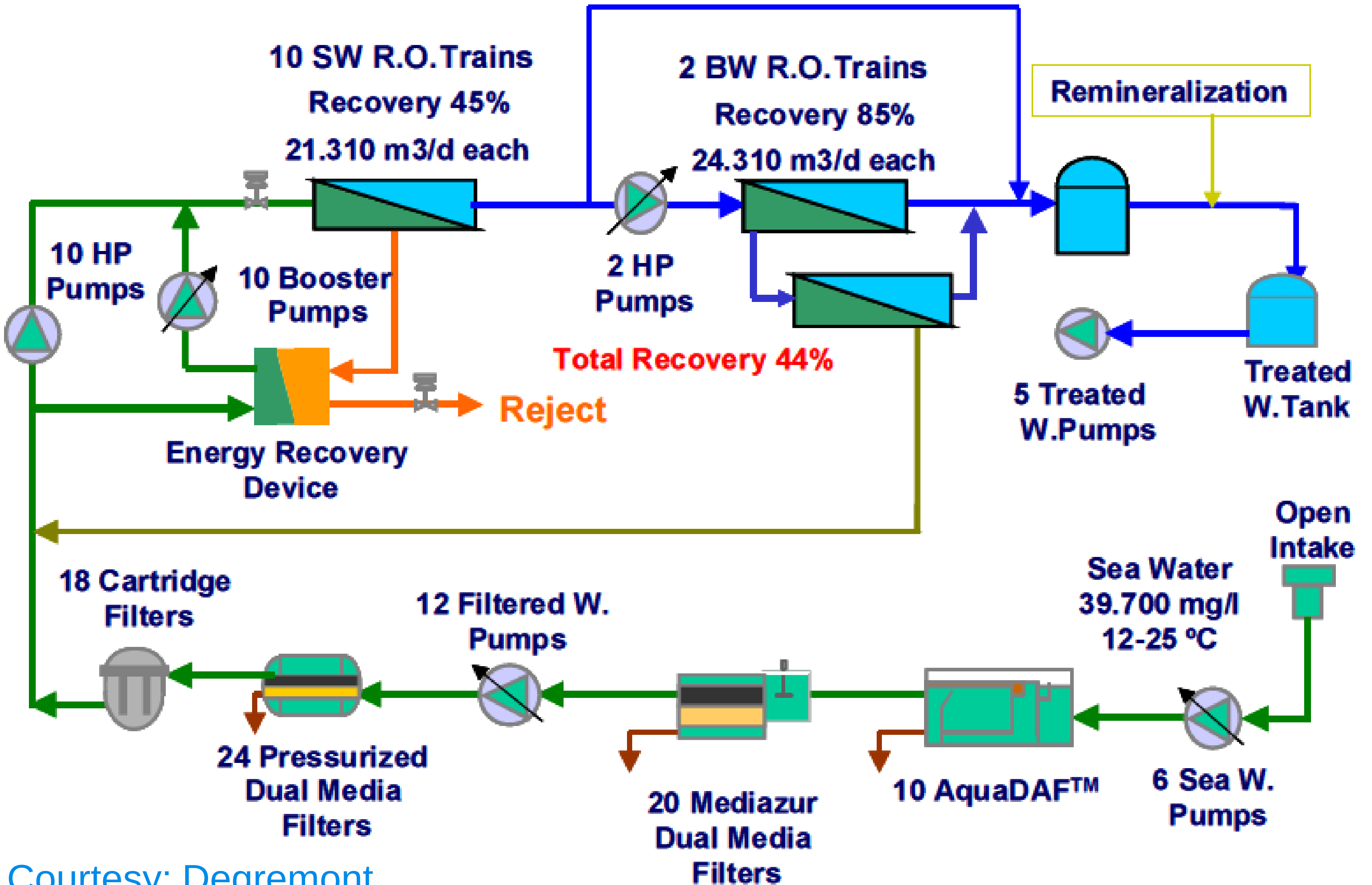


Gravity and Pressure Filtration

Carboneras, Spain
Pressure Filtration

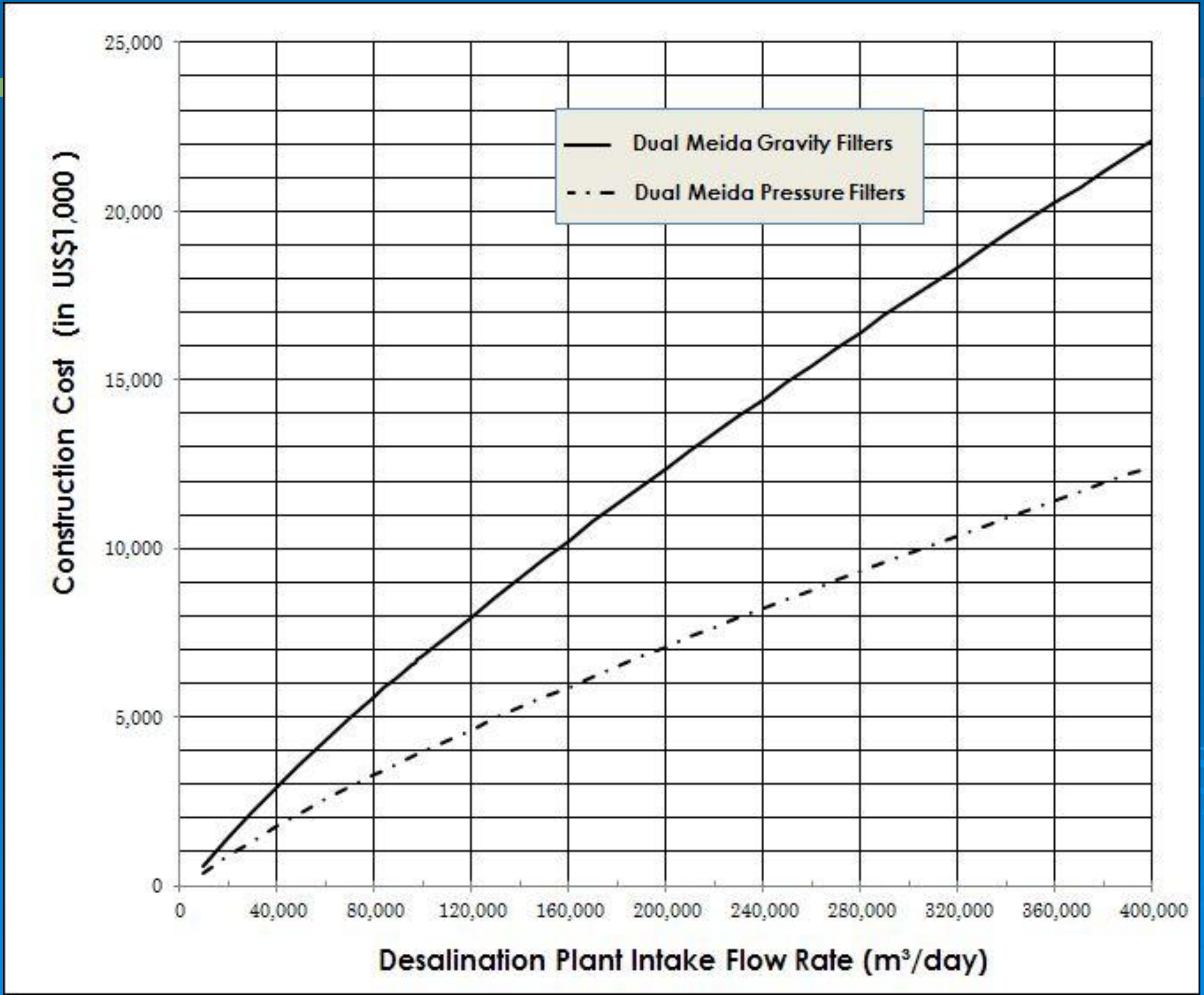
Ashkelon, Israel
Gravity Filtration

200 ML/d Barcelona Plant – DAF + Gravity Filters + Pressure Filters

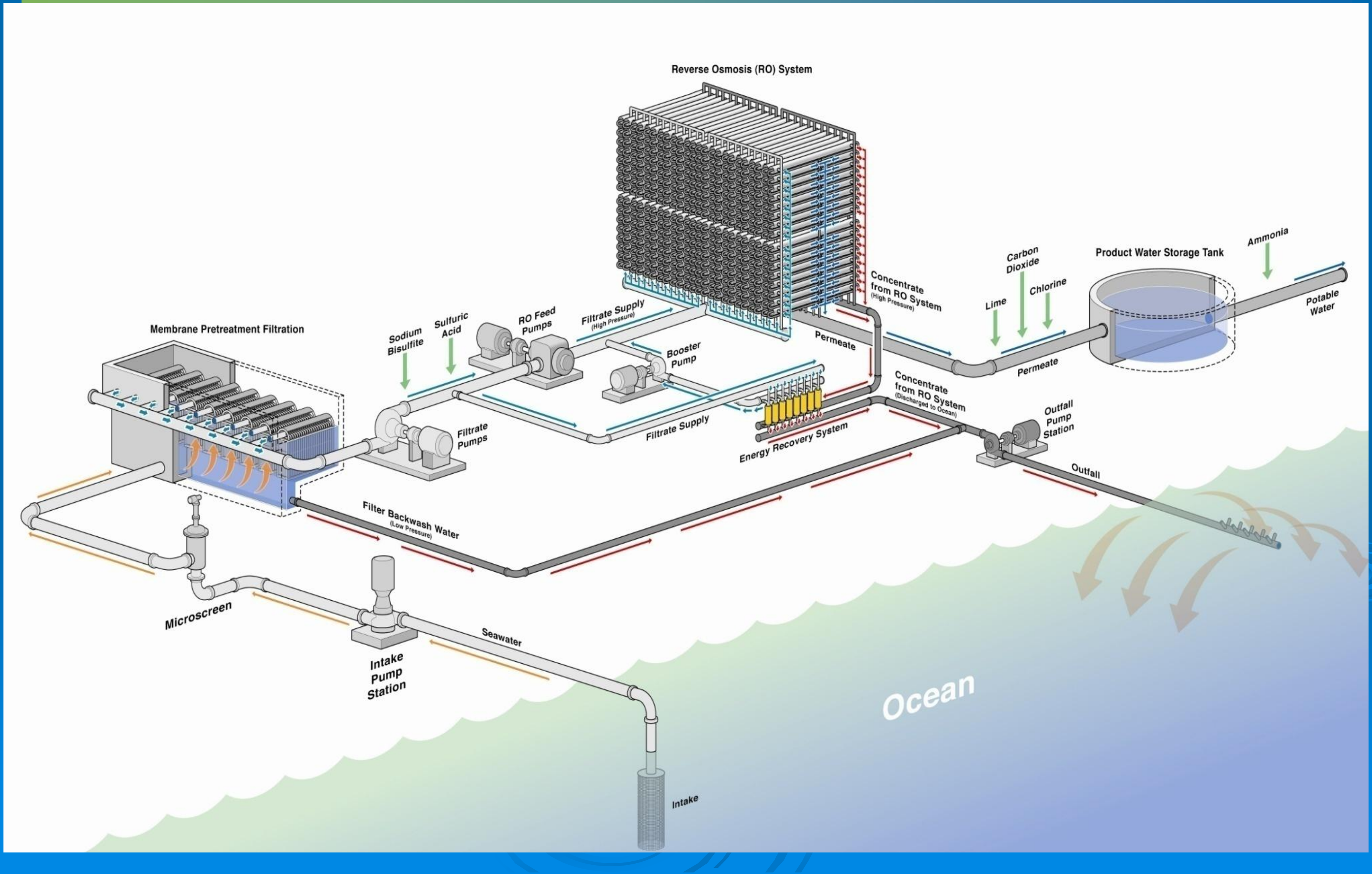


Courtesy: Degremont

Construction Costs of Granular Media Filters



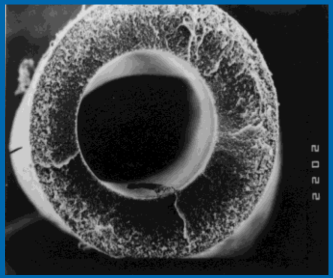
Seawater Plant with Membrane Pretreatment

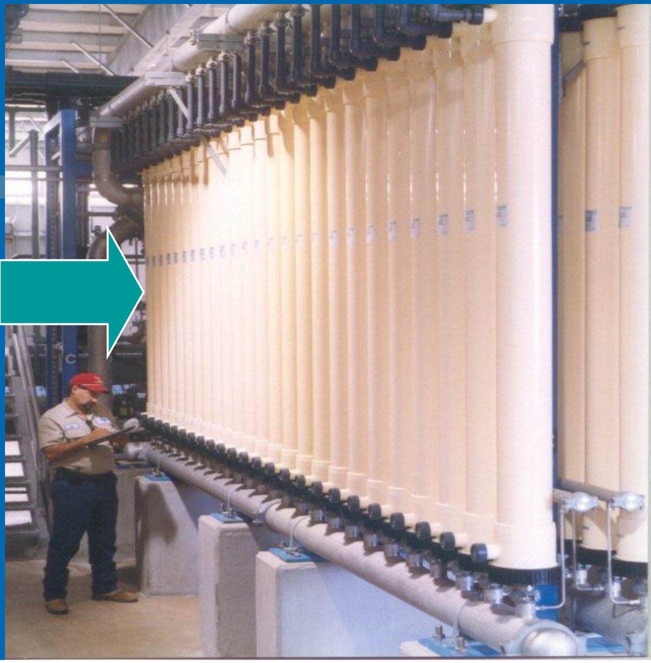


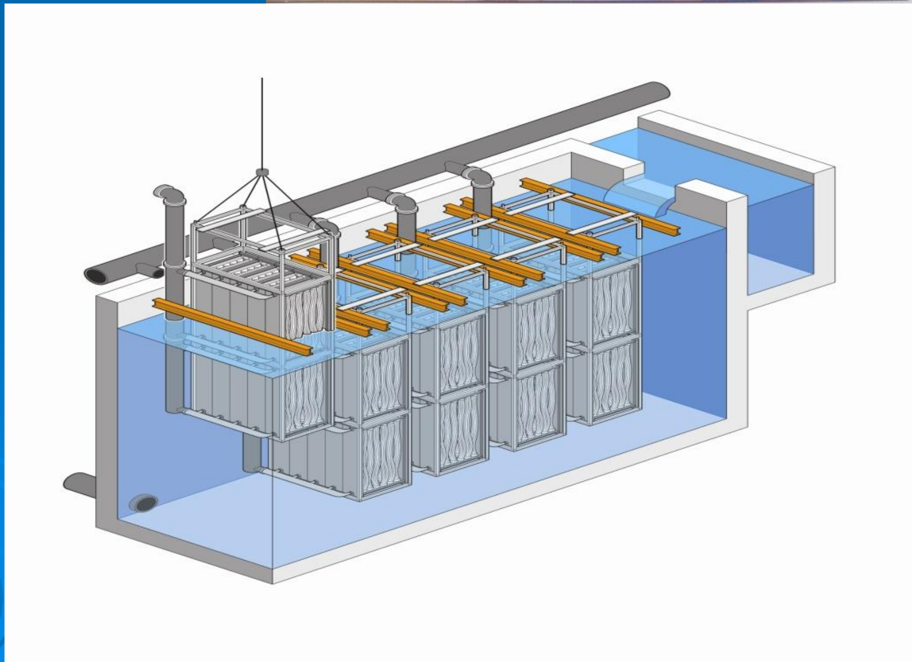
Membrane Pretreatment – Potential Benefits

- **For Pretreatment System:**
- Superior Microbial Removal;
- Smaller Footprint;
- No Source Water Chemical Conditioning Required;
- Less Residuals to Handle;
- Easier to Operate.

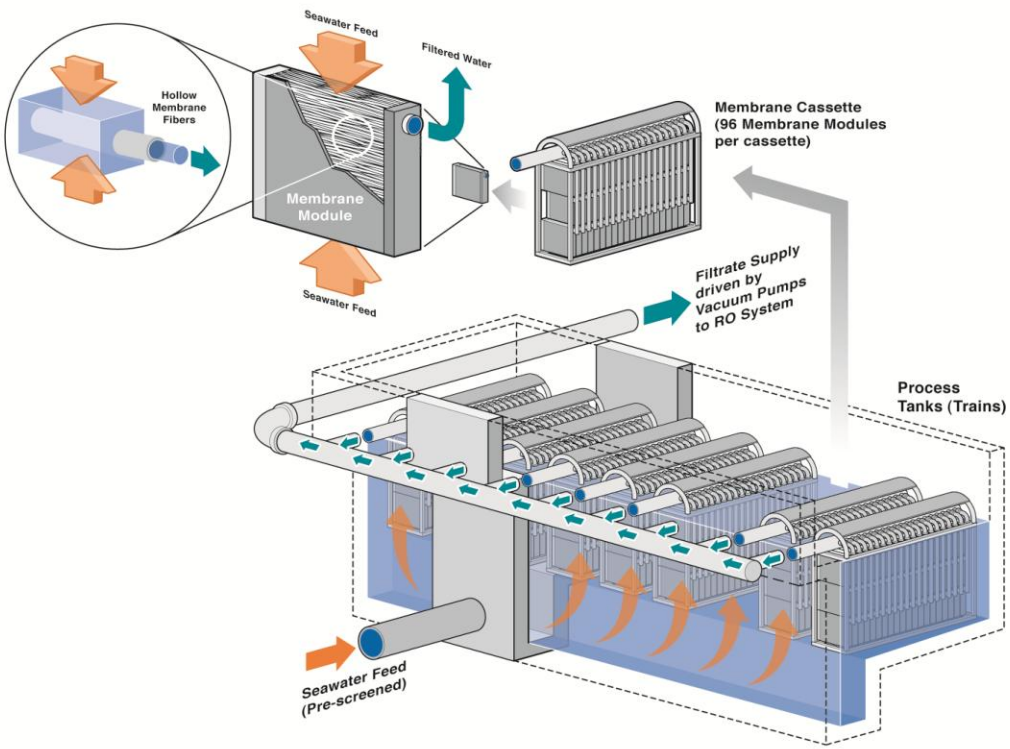
- **For RO System:**
- Longer Membrane Life;
- Potential Operation at Higher Flux (less membranes needed);
- Reduced Membrane Replacement and Cleaning Costs.



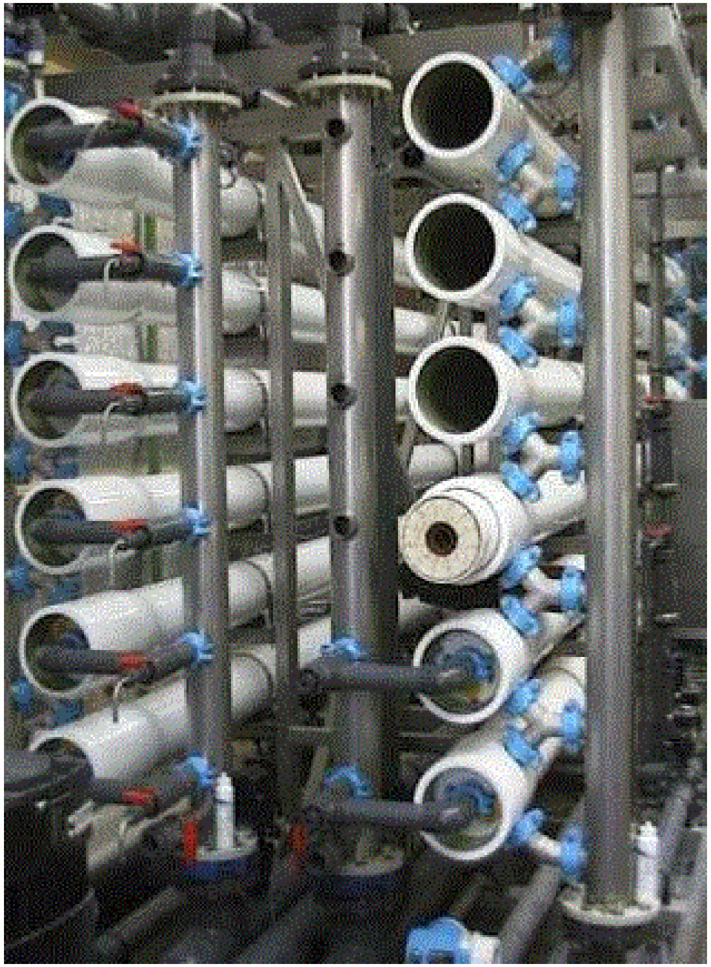




Vacuum and Pressure-Driven UF and MF Filters

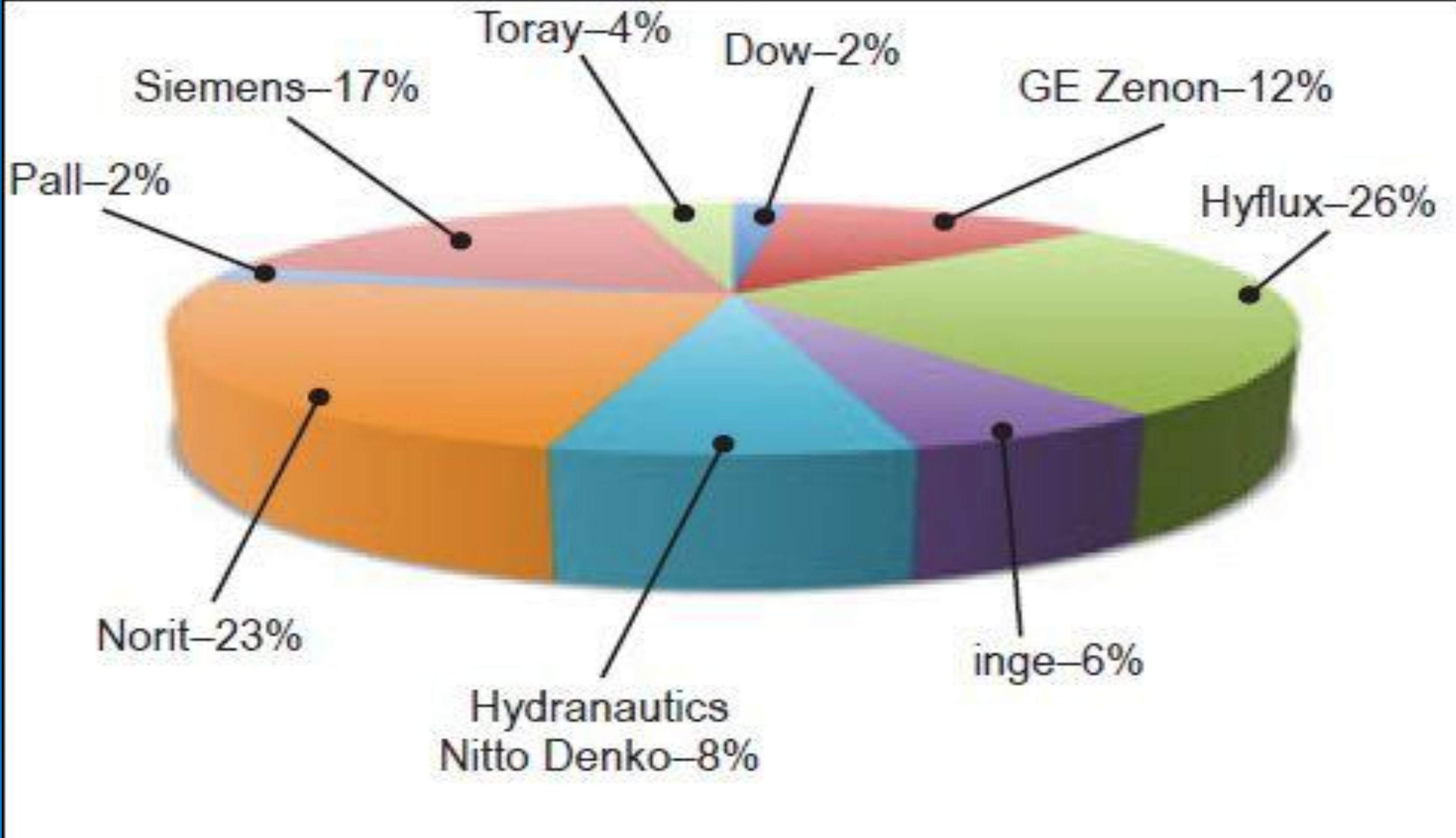


Vacuum—Driven Filters
Example - Zenon



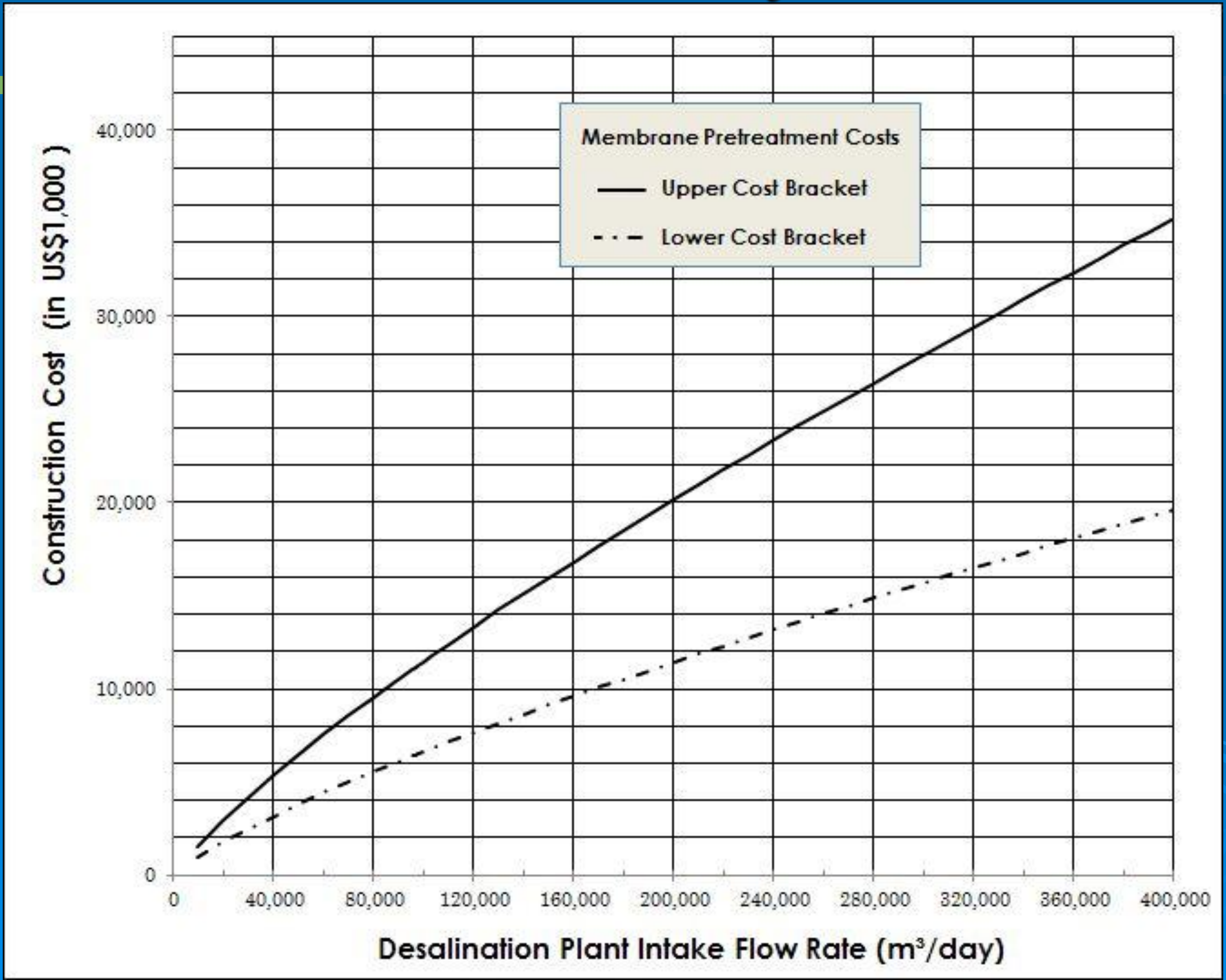
Pressure—Driven Filters
Example - Norit- Palm Jumeirah

Membrane Pretreatment Key Technology Providers



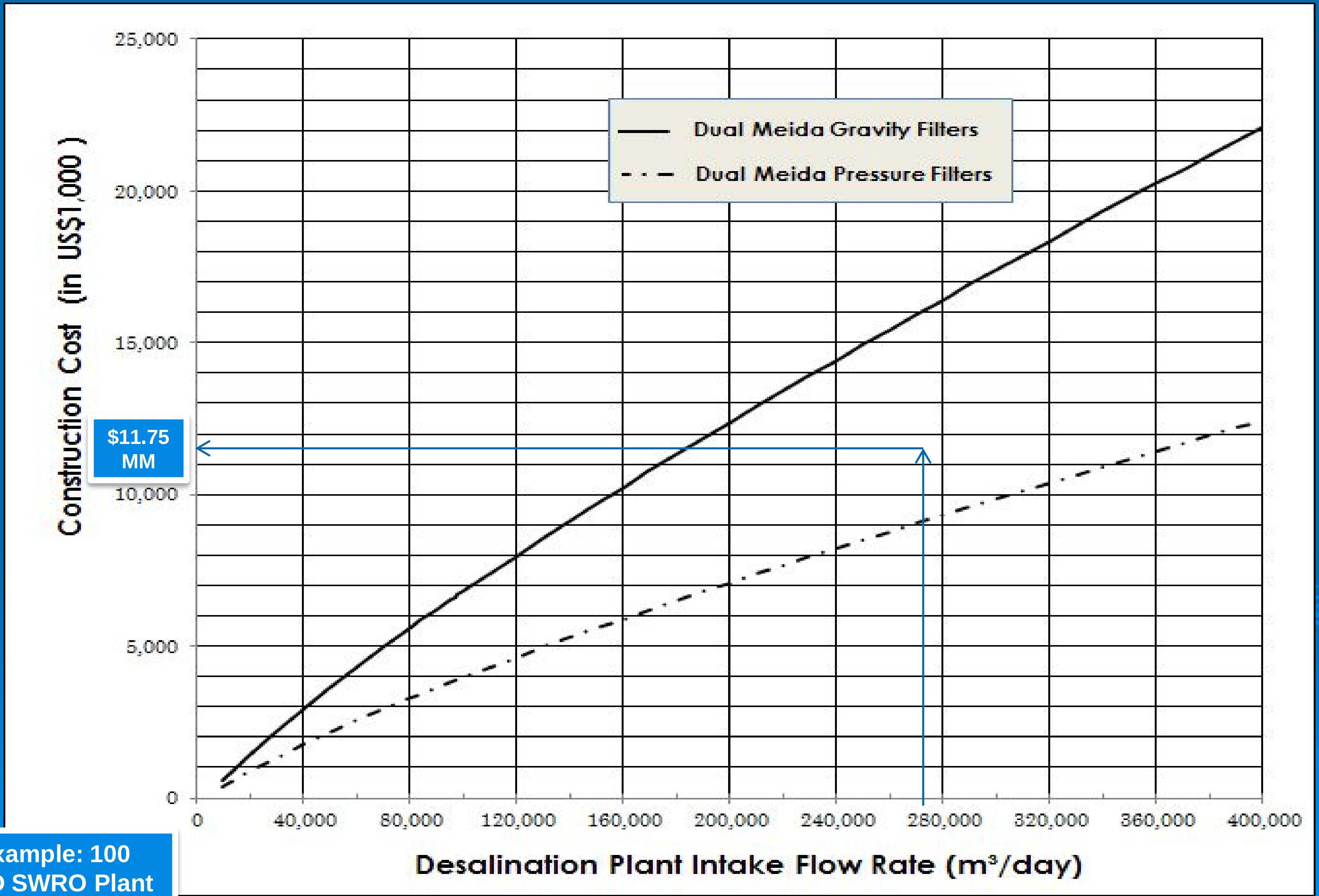
MF/UF Membrane Suppliers for SWRO Pretreatment
% of Installed/contracted Capacity

Construction Costs of Membrane Pretreatment Systems



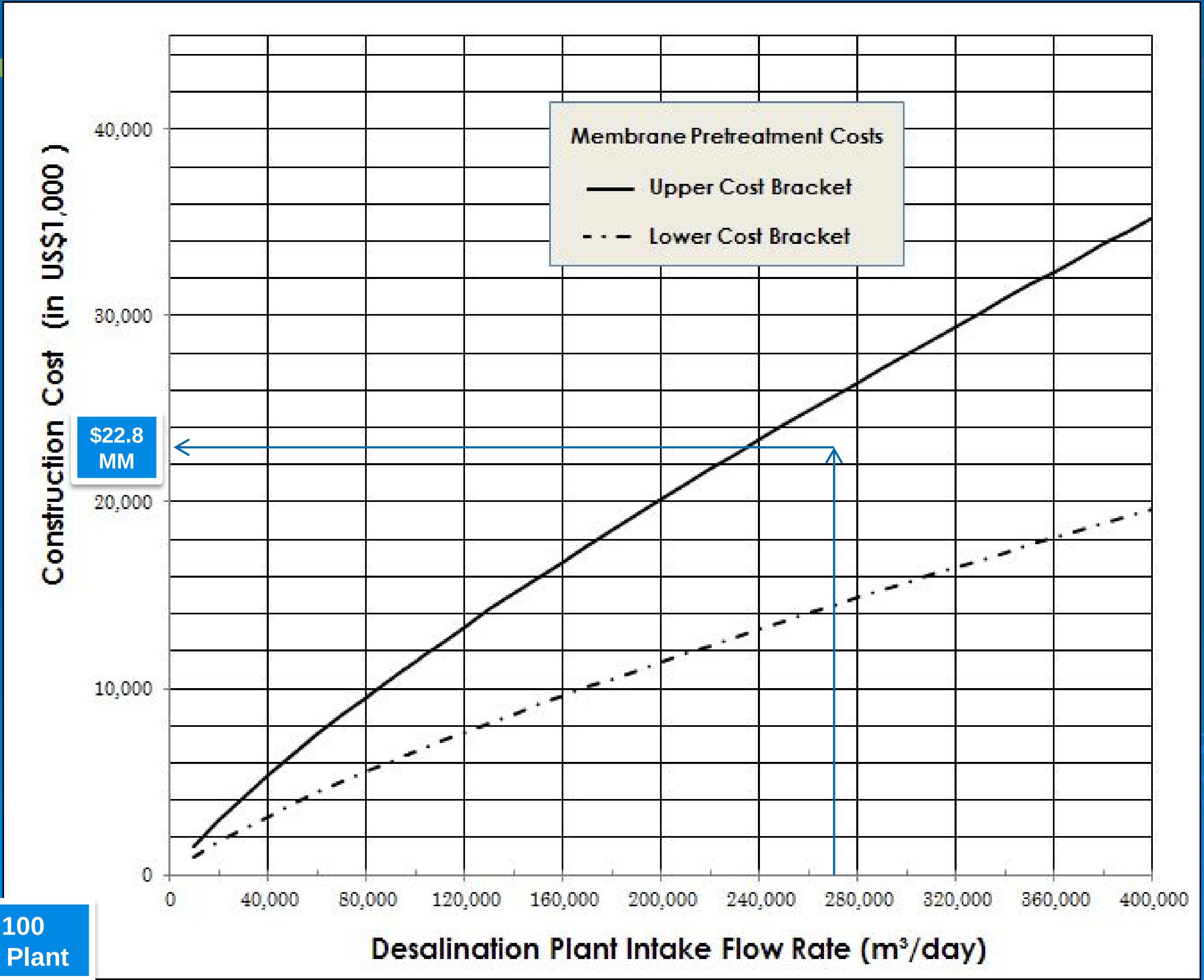
Comparison of Conventional and Membrane Pretreatment for 100 MLD Plant

Construction Cost of Conventional Pretreatment



Example: 100 MLD SWRO Plant

Construction Cost of Membrane Pretreatment



Example: 100 MLD SWRO Plant

Cost Comparison of 100 MLd SWRO Plant with Conventional and Membrane Pretreatment

	Granular Media Pretreatment		Membrane Pretreatment	
	US$ (in 1000)	€ (in 1000)	US$ (in 1000)	€ (in 1000)
Capital Costs				
Open Ocean Intake	70000	*41300*	76000	*44840*
Intake Pump Station	6500	*3835*	7000	*4130*
Coarse and Fine Screens	2100	*1239*	2500	*1475*
Microscreens	0	*0*	3200	*1888*
Coagulation/Flocculation System	3200	*1888*	0	*0*
Cartridge Filters	4100	*2419*	0	*0*
Source Seawater Chlorination System	450	*265.5*	450	*265.5*
Pretreatment Membrane Cleaning System	0	*0*	1800	*1062*
Filter Tanks (excluding Media/Membranes)	9800	*5782*	7000	*4130*
Filtration Media (Sand/Anthracite or UF Membranes)	1000	*59[illegible]*	7800	*4602*
Membrane Pretreatment System - Service Equipment	0	*0*	4600	*2714*
Filter Backwash System	950	*560.5*	1600	*944*
Dechlorination System	200	*118*	350	*206.5*
Land Costs	2500	*1475*	1800	*1062*
Seawater Reverse Osmosis System	64000	*37760*	56000	*33040*
Post-Treatment System	5100	*3009*	5100	*3009*
Solids Handling Facilities	1800	*1062*	100	*59*
Discharge Outfall	45000	*26550*	48000	*28320*
Other Facilities and Systems	4000	*2360*	4000	*2360*
Engineering and Construction Management	17000	*10030*	20000	*11800*
Start Up and Commissioning	3000	*1770*	3600	*2124*
Other Costs	9000	*5310*	9000	*5310*
Total Capital Costs	**US$249700**	*€147323*	**US$259900**	*€153341*
Amortized Capital Costs (Monetary Units/m3)	*US$0.549*	*€0.324*	*US$0.571*	*€0.337*

$11.75 MM

$22.80 MM

Comparison of O&M costs and Costs of Water Production – 100 ML/d SWRO Plant

	Conventional Pretreatment		Membrane Pretreatment	
	US$/yr (in 1000)	€/yr (in 1000)	US$/yr (in 1000)	€/yr (in 1000)
Labor	1500	885	1800	1062
Chemicals for Coagulation/Flocculation	700	413	0	0
Chemicals for Pretreatment Membrane Cleaning	0	0	280	165
Chemicals for CEB of Pretreatment Membranes	0	0	350	207
Chemicals for SWRO Membrane Cleaning	350	207	250	148
Other Chemicals	1800	1062	2000	1180
Microscreen Maintenance and Spare Parts	0	0	60	35
Cartridge Filter Replacement	150	89	0	0
Pretreatment Membrane Replacement	0	0	550	325
SWRO Membrane Replacement	850	502	600	354
Granular Media Addition	30	18	0	0
Other Maintenance & Spare Part Costs	750	443	900	531
Solids Handling & Sludge Disposal	110	65	0	0
Disposal of Spent Membrane Cleaning Solution to Sewer	80	47	210	124
Power Use for Seawater Pretreatment	146	86	913	538
Power Use by SWRO and Other Systems	10585	6245	10585	6245
Other O&M Costs	800	472	800	472
Total Annual O&M Costs	**US$17851**	**€10532**	**US$19298**	**€11386**
Annual O&M Costs (Monetary Units/m3)	*US$0.489*	*€0.289*	*US$0.529*	*€0.312*
Cost of Water Production (Monetary Units/m3)	**US$1.038**	**€0.612**	**US$1.100**	**€0.649**

$2.85 MM

$2.88 MM

Granular Media vs. Membrane Pretreatment – Issues Frequently Omitted in Life-Cycle Cost Comparisons

- Cost of Membrane Micro-screening;
- Cost of Chemically Enhanced Backwash Chemicals;
- Costs and Downtime of Membrane Cleaning;
- Cost of Membrane Backwash Treatment;
- Loss in Membrane Integrity Over Time;
- Risks/Financial Penalties Associated With:
  - Lack of Standardization & Inter-changeability of Membrane Elements Produced by Different Manufacturers;
  - Time Needed to Produce a New Set of Membranes for Your Plant if The Existing Set Experiences Complete Failure;
  - Limited Track Record for Seawater Applications.

Pretreatment Construction Costs - Summary

- Very Dependent on Source Water Quality & Type of Treatment Technologies
- Usually Between US$100 and 300/$m^3$/day
- High Quality Well Water Sources Require Only Cartridge Filtration (Low Cost Pretreatment)
- Single-stage Granular Media Filtration Usually is Less Costly than Membrane Pretreatment

Cartridge Filtration

Fujairah - Cartridge Filters

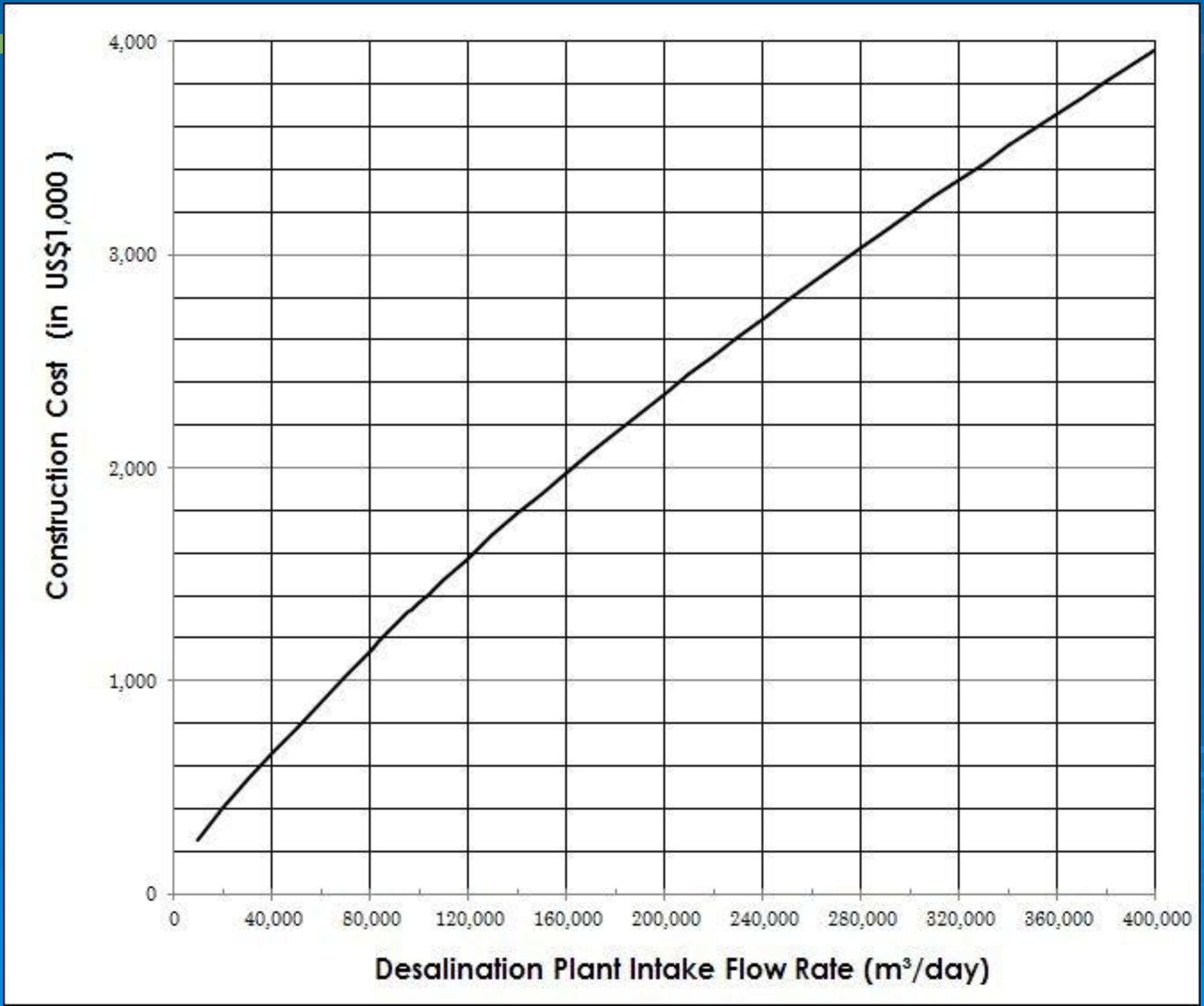
Two Lines of 9
5-μ Cartridge
Filter Vessels

360 Cartridges per CF Vessel

Functions of Cartridge Filters (CFs)

- Protection of SWRO Membranes from Algae, Bacteria and Particulates
- Well Designed CF Systems Have:
  - Differential Pressure Measurement Provisions for Each CF Vessel
  - Sampling Ports Upstream and Downstream Each CF
- If the Pretreatment System is Working Well:
  - SDI Reduction Through CFs is Less than 0.5 Units
  - CFs are Not Discolored
  - SDI Pads Before and After CFs Look the Same

Construction Costs of Cartridge Filtration Systems



Questions?

Coffee Break