International Water Association
World Water Congress & Exhibition
BUSAN KOREA
16-21 September 2012 BEXCO, 43 APEC-ro, Haeundae-gu, Busan
Paradise Hotel, Busan

Optimising RO and Energy Footprints in Desalination and Water Reuse

SUEZ ENVIRONNEMENT
&
Water Globe Consulting

Outline

13:00-14:00 Reverse Osmosis Fundamentals
14:00-15:00 Applying RO for Water Reuse
15:00-15:15 Coffee Break
15:15-16:00 Applying RO for Desalination

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Water Globe Consulting

13:00-14:00

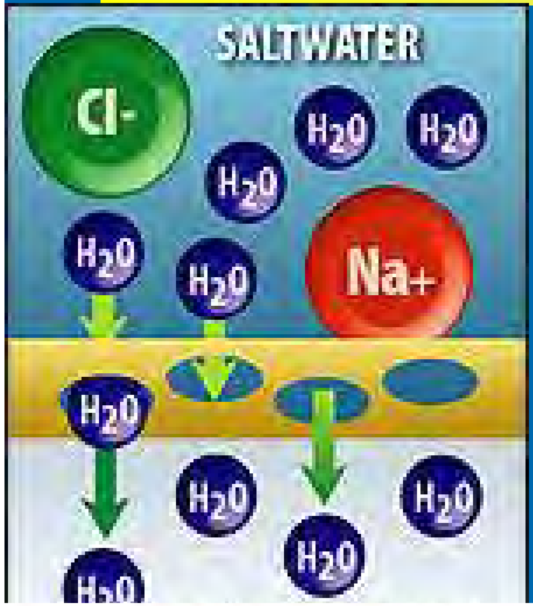
Reverse Osmosis Fundamentals

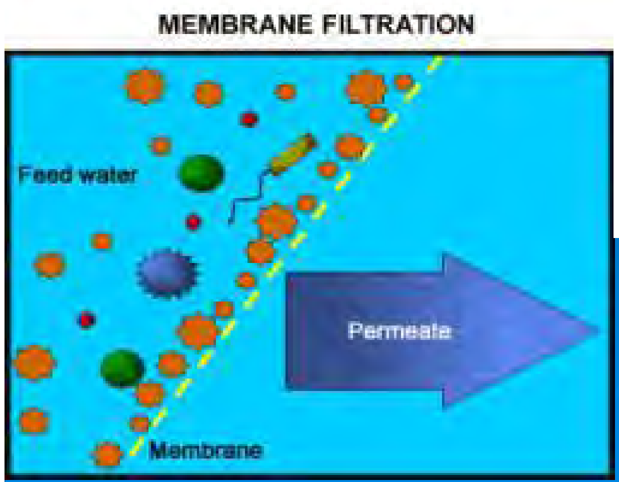
Nikolay Voutchkov, PE, BCEE

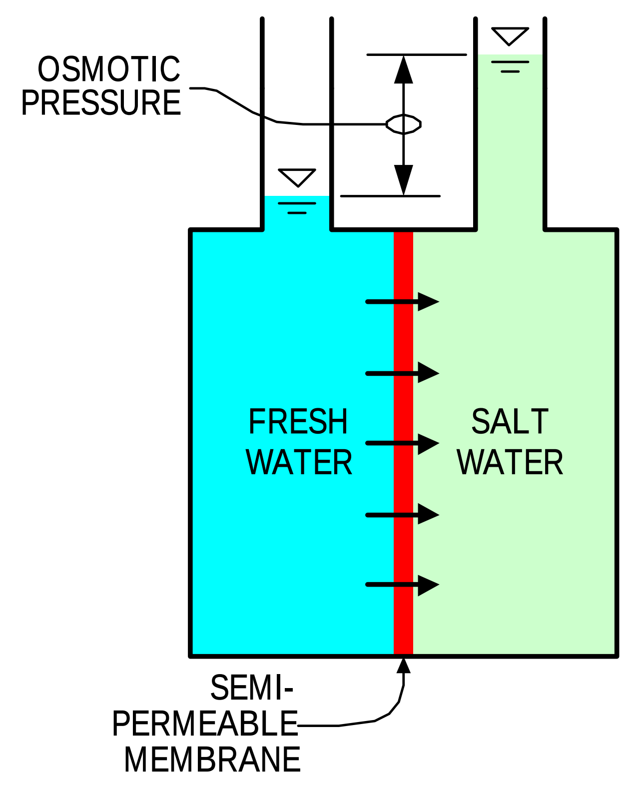
Reverse Osmosis Fundamentals - Outline

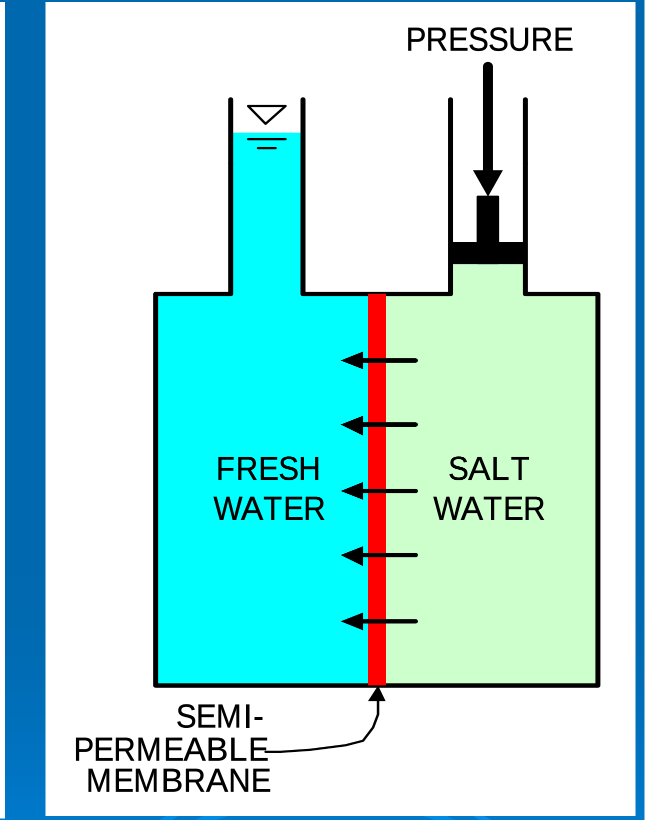
- Basic Principles
- Key Performance and Design Parameters
- RO System Components

What is Osmosis and Why It Has to be Reversed?




MEMBRANE FILTRATION





Calculating Osmotic Pressure

Approximate Estimate: Po = TDS/100 psi
= TDS/1470 Bar

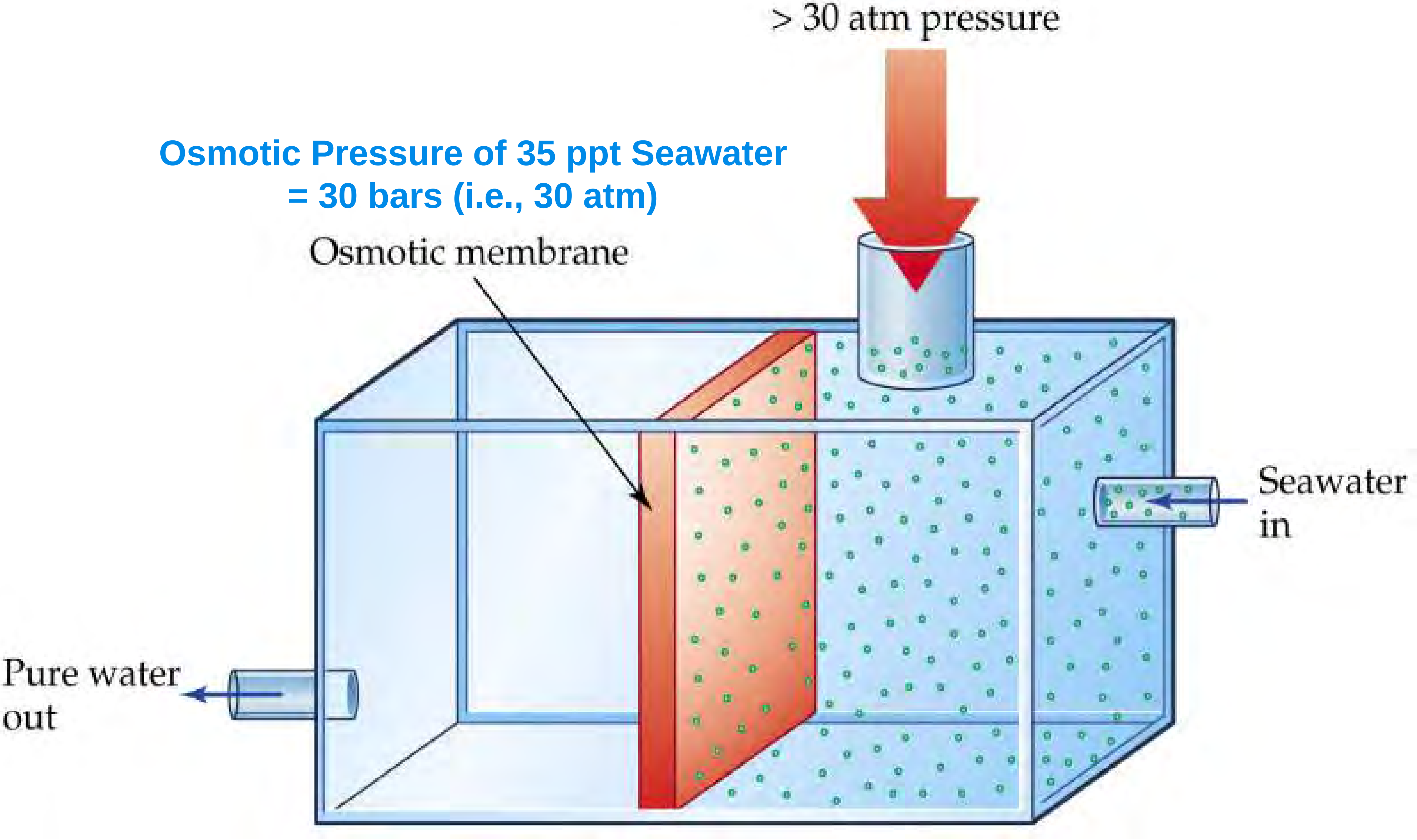
More accurate method :
Po = R T ∑ (n/v), where R = 0.083
and ∑ (n/v) = sum of ionic concentrations
T - temperature

For 1,000 mg/l NaCl solution, @ 25^{o}C
$(n/v)_{Na}$ = 0.0172
$(n/v)_{Cl}$ = 0.0172

Therefore Po = 0.083*(273+25)*(2 x 0.0344)
= 0.851 bar, 12.3 psi

For Typical Seawater @ 35,000 mg/L & 25^{o}C
(35,000 mg/L /1,000 mg/L) x 0.851 bar = 29.8 bar (430 psi)

Reverse Osmosis

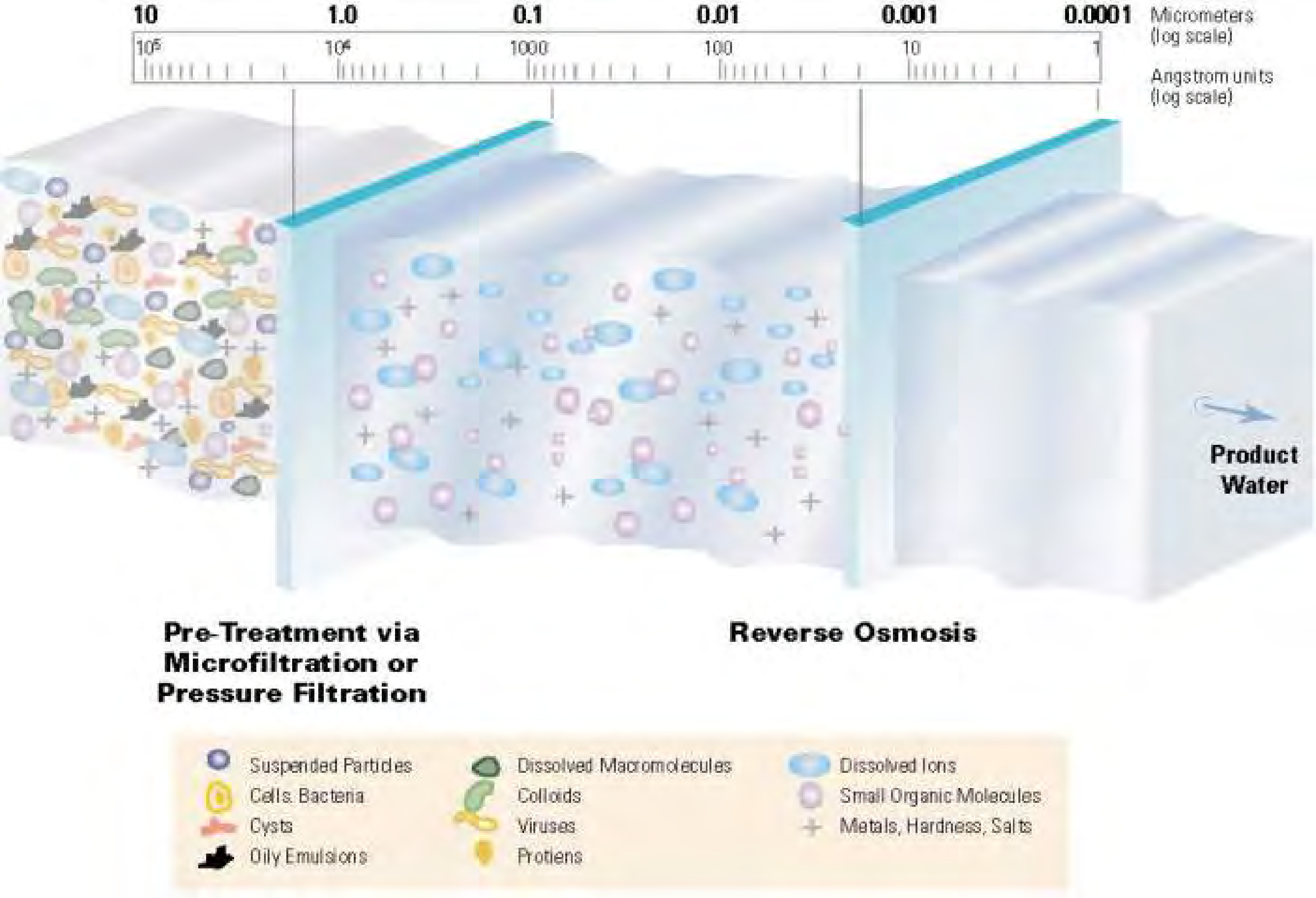


Osmotic Pressure of 35 ppt Seawater = 30 bars (i.e., 30 atm)

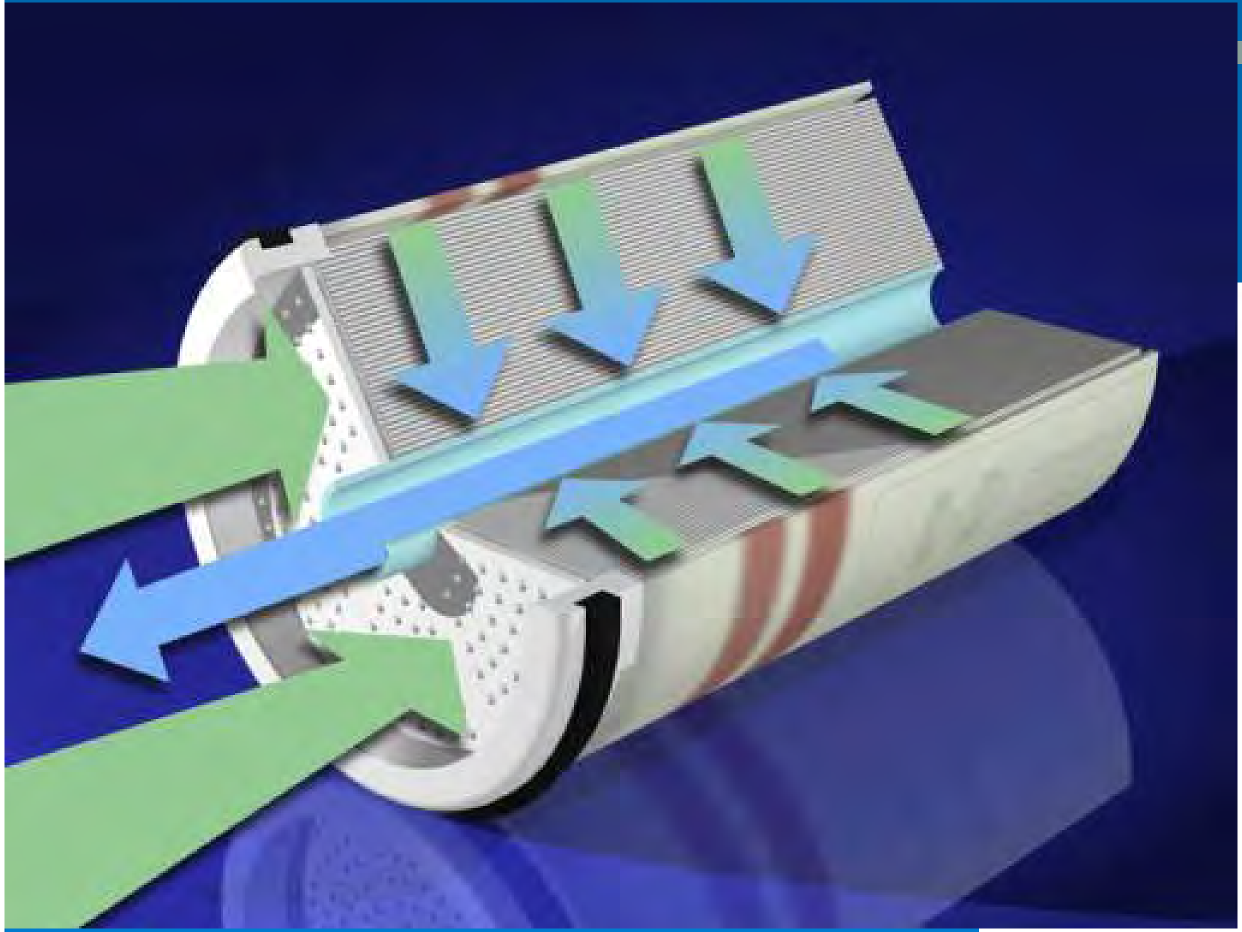
RO Membranes

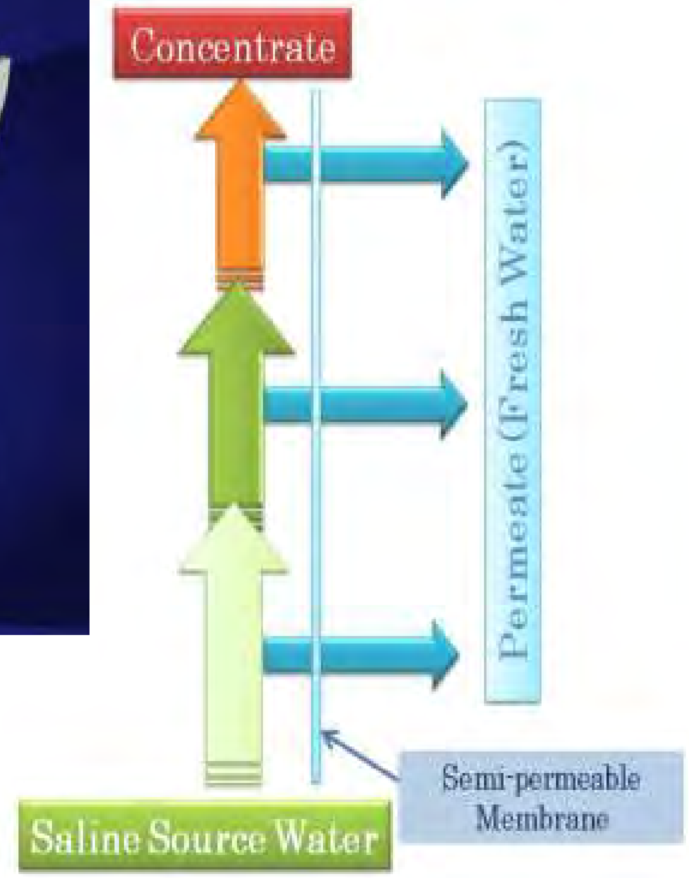
- Made of Semi-permeable Plastic Material
- Remove Dissolved Solids by Selective Rejection
- Driving Force – Pressure Applied on the Membranes
- Can Reject Molecules with Size of 180 Daltons or More:
    - Na & Cl
    - Multivalent Ions (Hardness)
    - Organics
    - Pathogens (Bacteria, Viruses, Protozoa, etc.)

How RO Compares to Other Membranes?



Cross-Flow Filtration



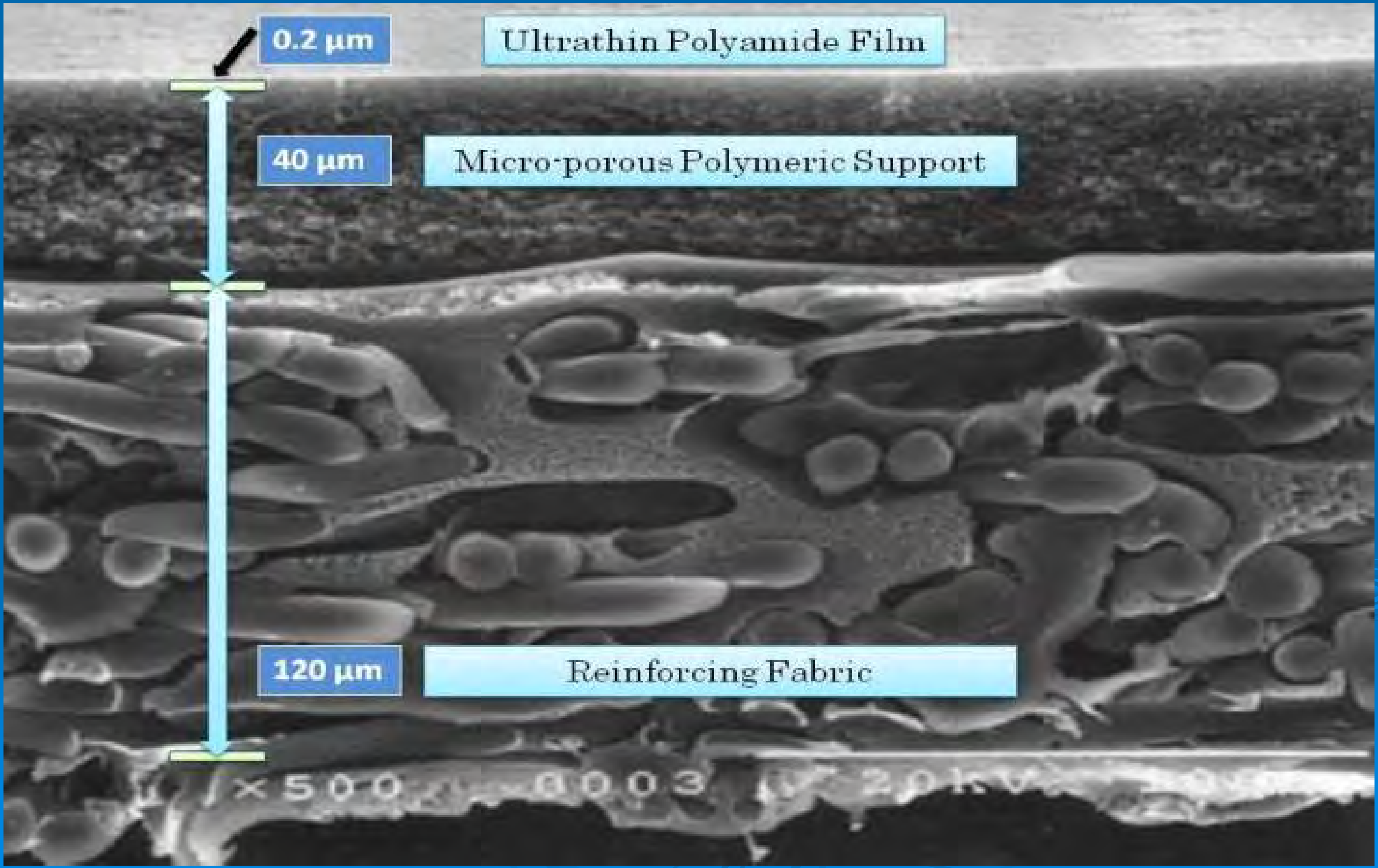


Membrane Materials

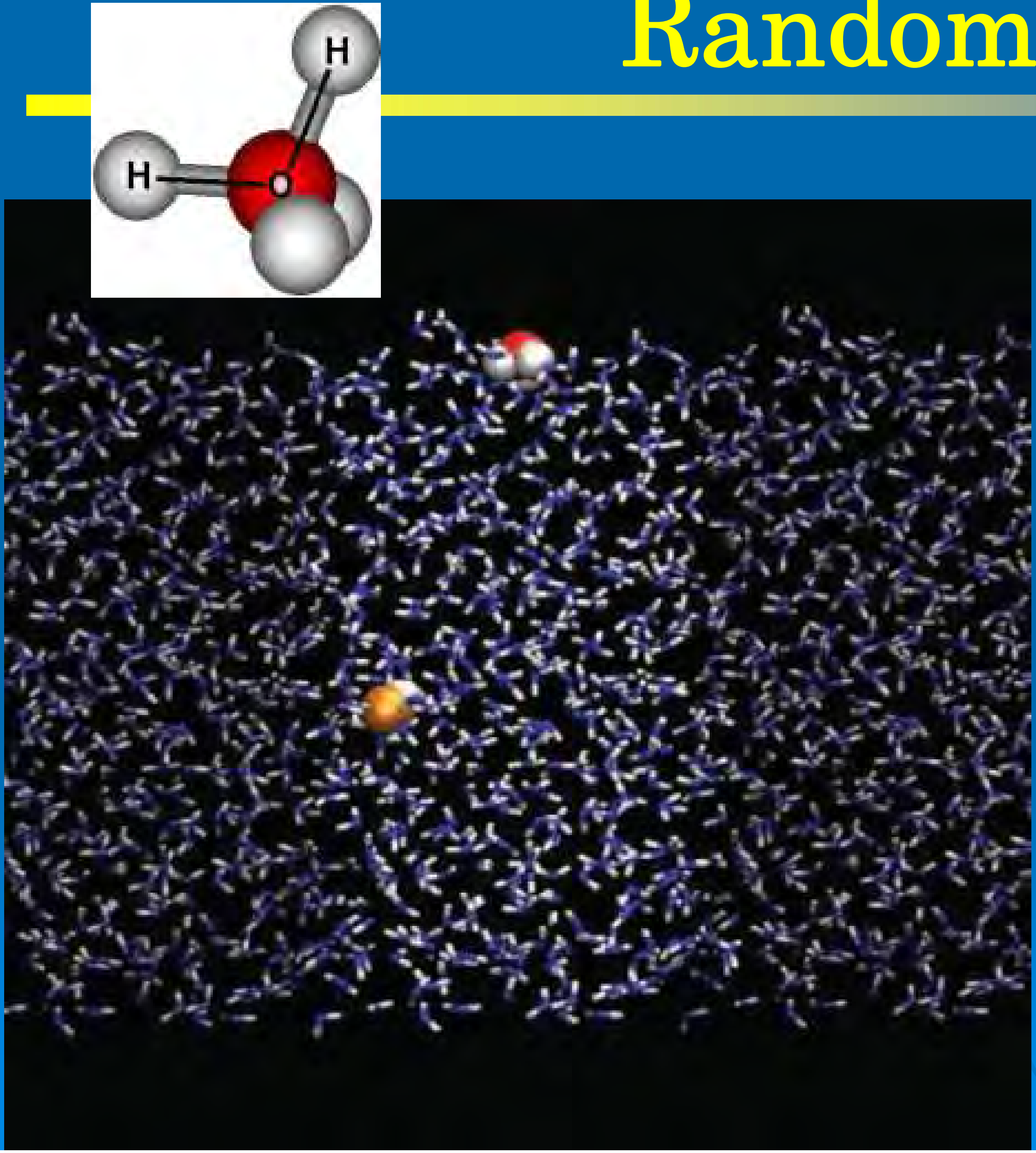
- Polyamide (Thin-Film Composites):
  - Key Advantages – Not Subject to Microbial Degradation/Have Higher Salt Rejection
  - Key Disadvantage – Sensitive to Oxidants

- Cellulose Acetate:
  - Key Advantage - Tolerant to Oxidants
  - Key Disadvantages – Biodegradable/ Optimum Performance within a Narrow pH Range (4.5 to 6.5)

Thin-Film Membrane Structure



Thin Polyamide Film Has Random Structure



Thin Film

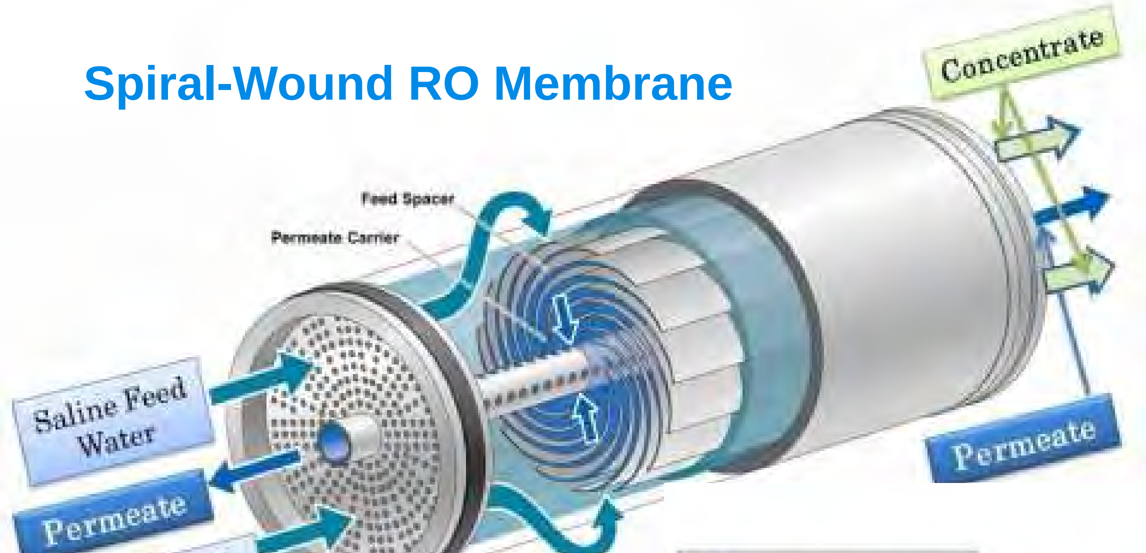
Two Key Types of RO Membrane Configurations

- Spiral-wound:
  - Membrane formed into leafs
  - Leafs glued around three sides and rolled around central tube to form membrane element

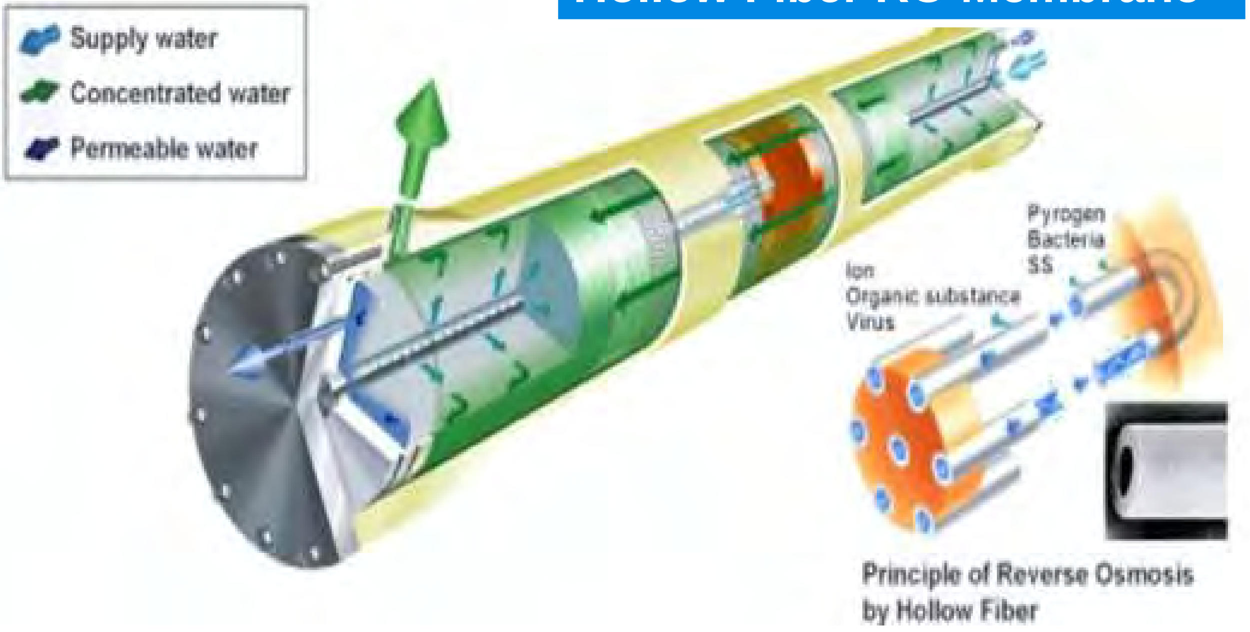
- Hollow Fiber:
  - Membrane formed into fine fibers
  - Fibers bundled together into element

Spiral-Wound vs. Hollow-Fiber Membrane

Spiral-Wound RO Membrane

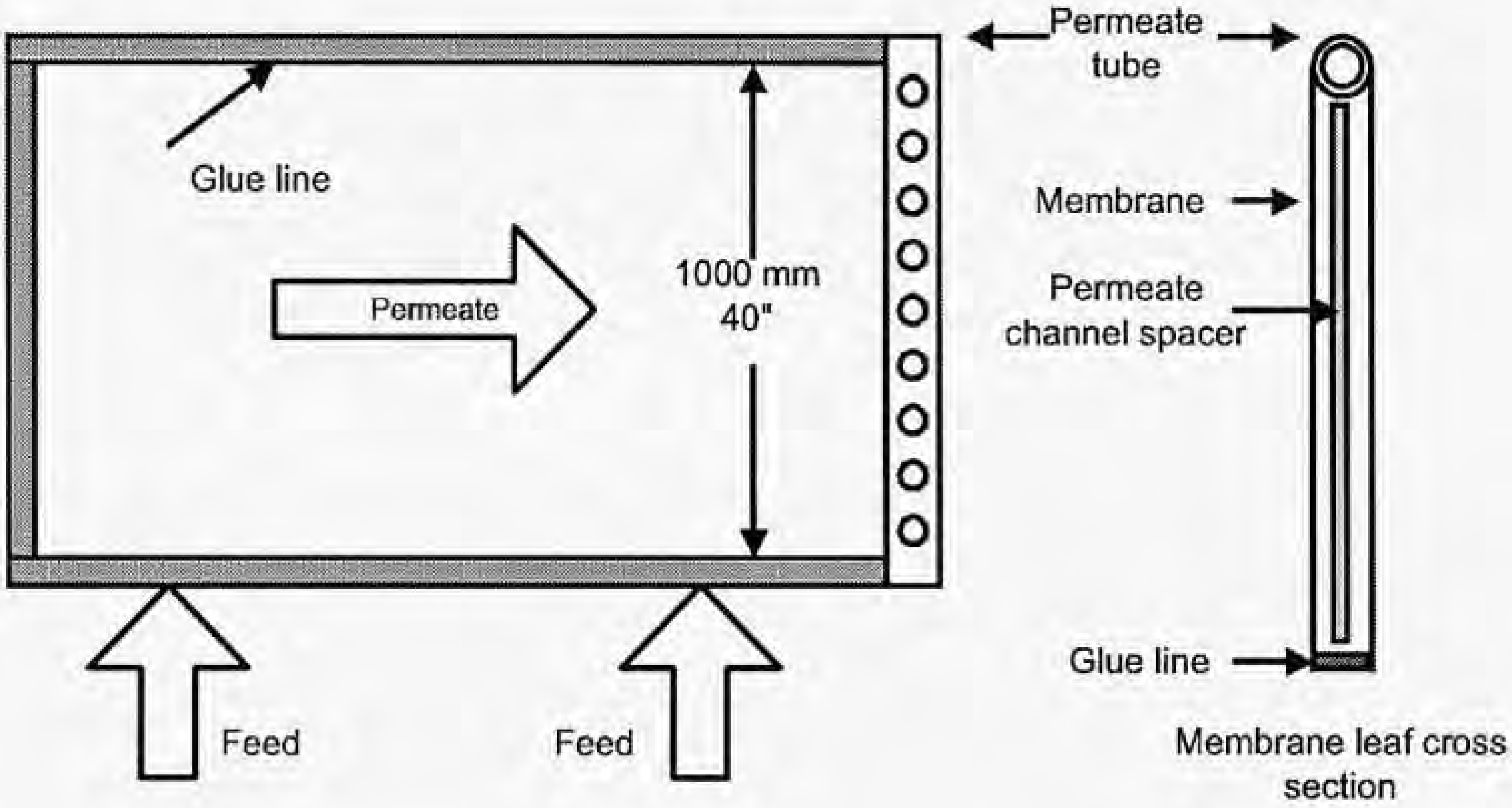


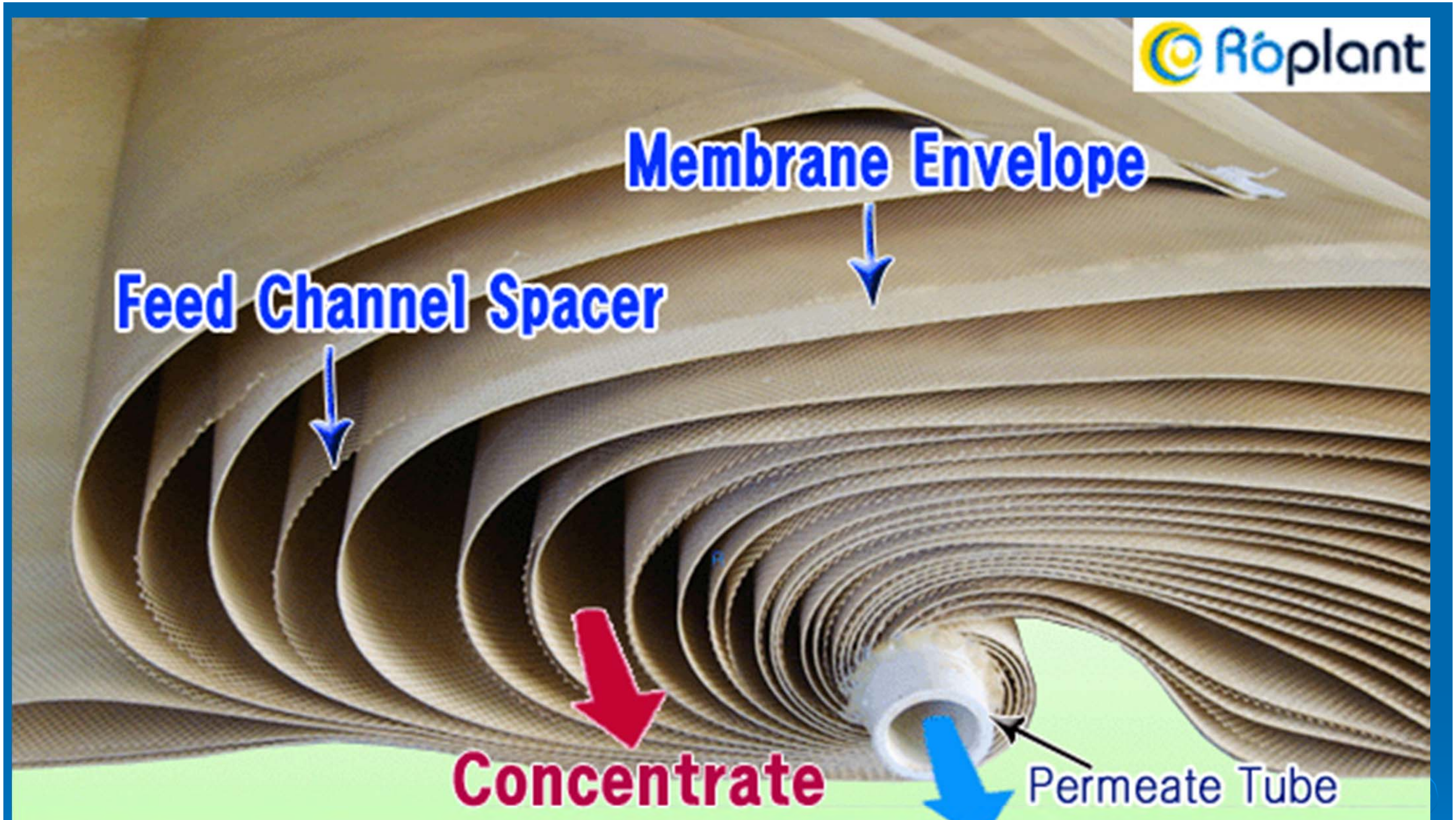
Hollow Fiber RO Membrane



Principle of Reverse Osmosis by Hollow Fiber

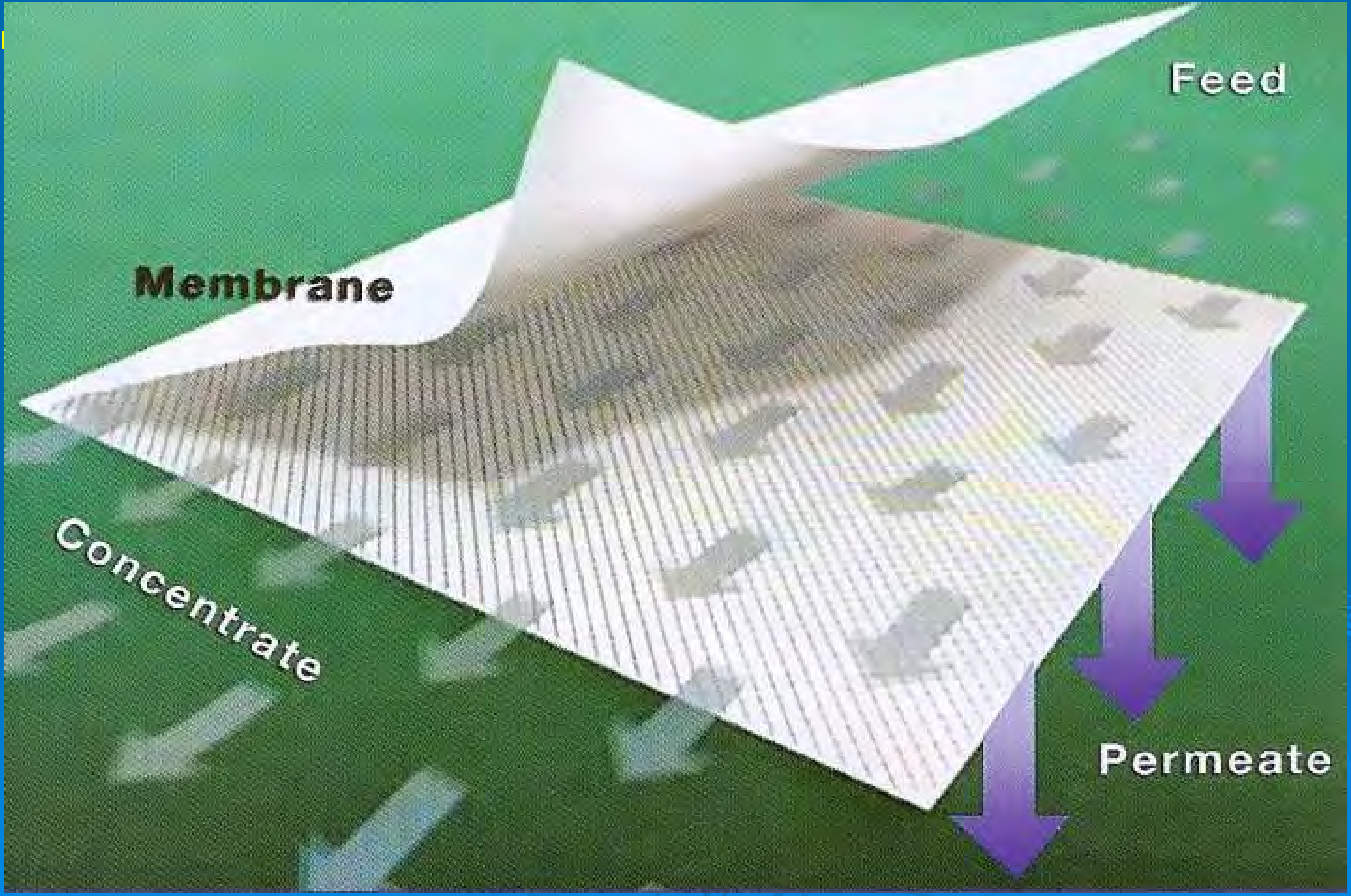
Spiral-Wound RO Membrane Leaf



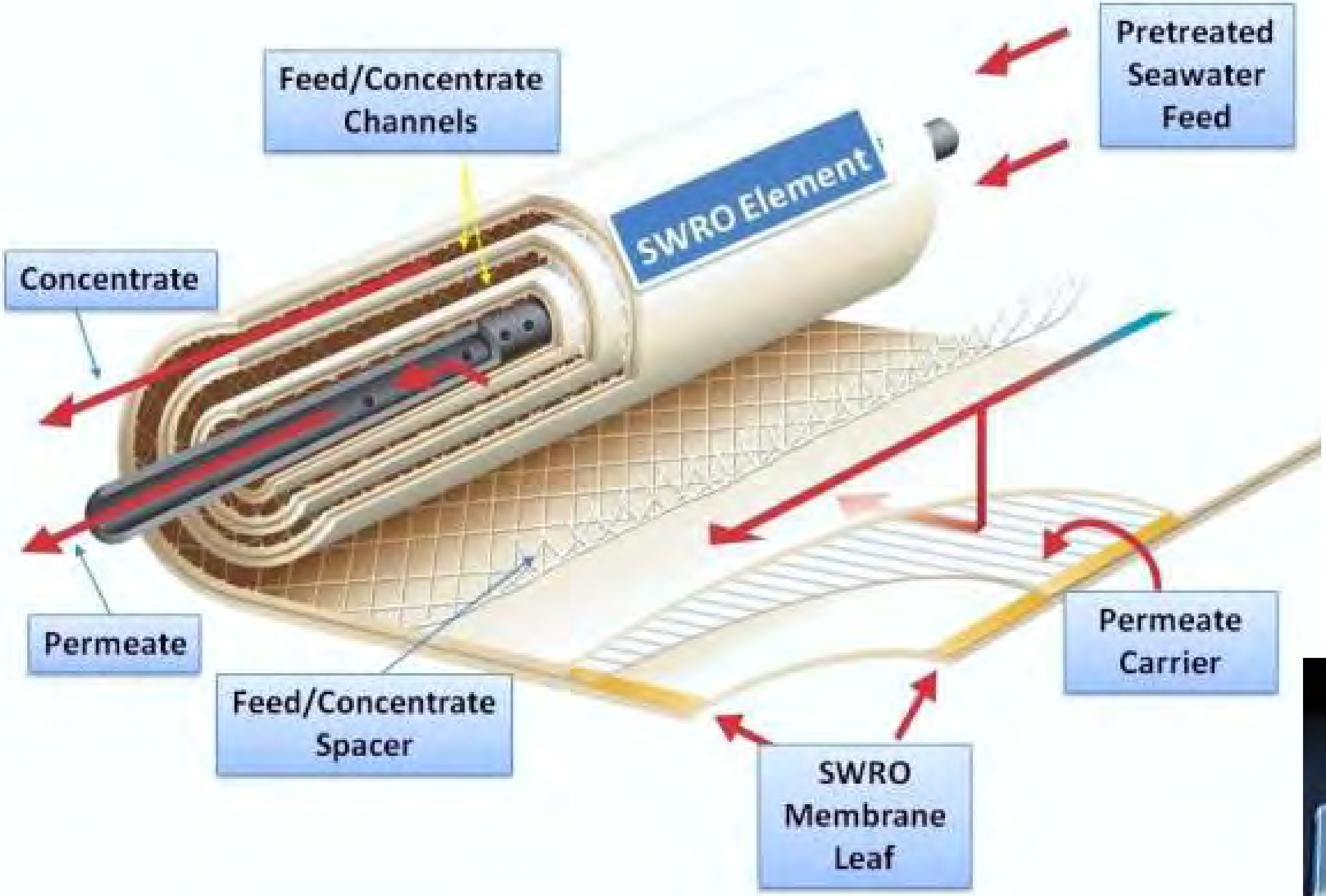

Röplant
Membrane Envelope
Feed Channel Spacer
Concentrate
Permeate Tube
Permeate

<Spiral-Wound RO Membrane(End View)>

Water Movement Between Two the Membrane Leafs



Spiral-wound Membrane Element

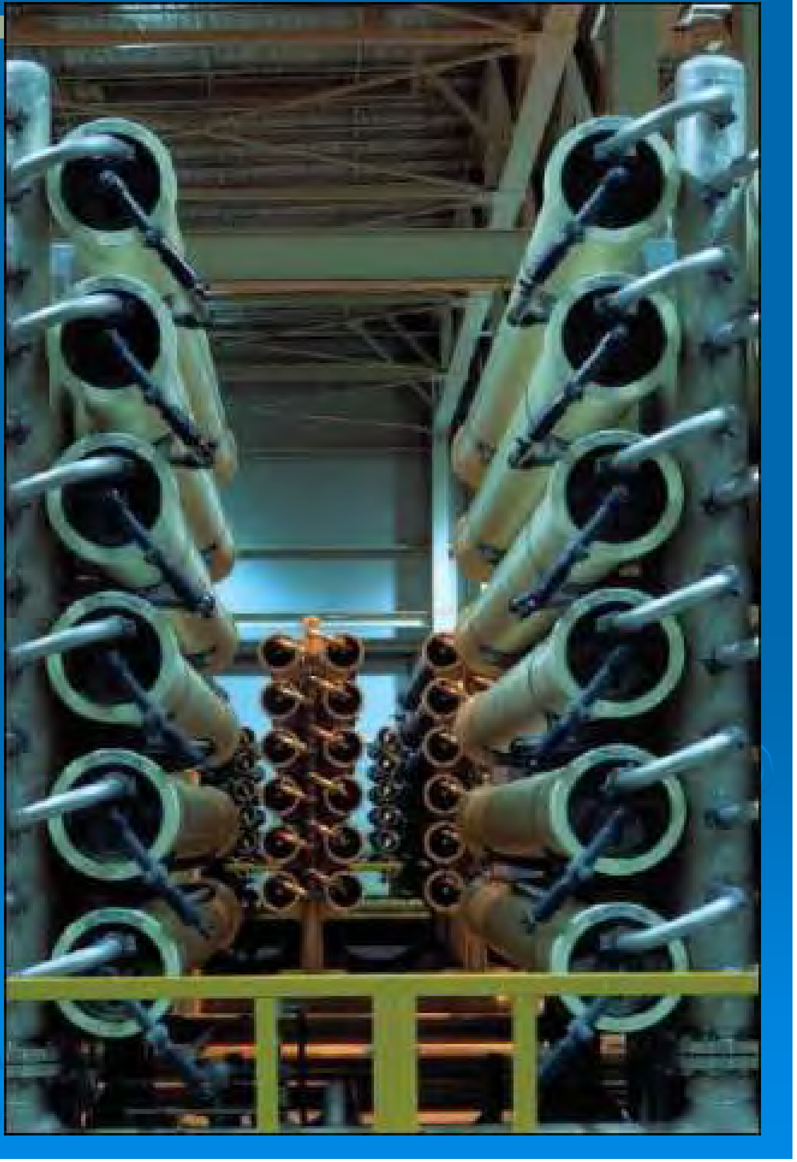


Typical SWRO Membrane Element:

- 8-inch diameter
- 40-inch (1-m) long
- Feed/Concentrate Channel – 0.7 to 0.9 mm wide
- 40 membrane leafs
- Total Membrane Area = 35 to 36.8 m²

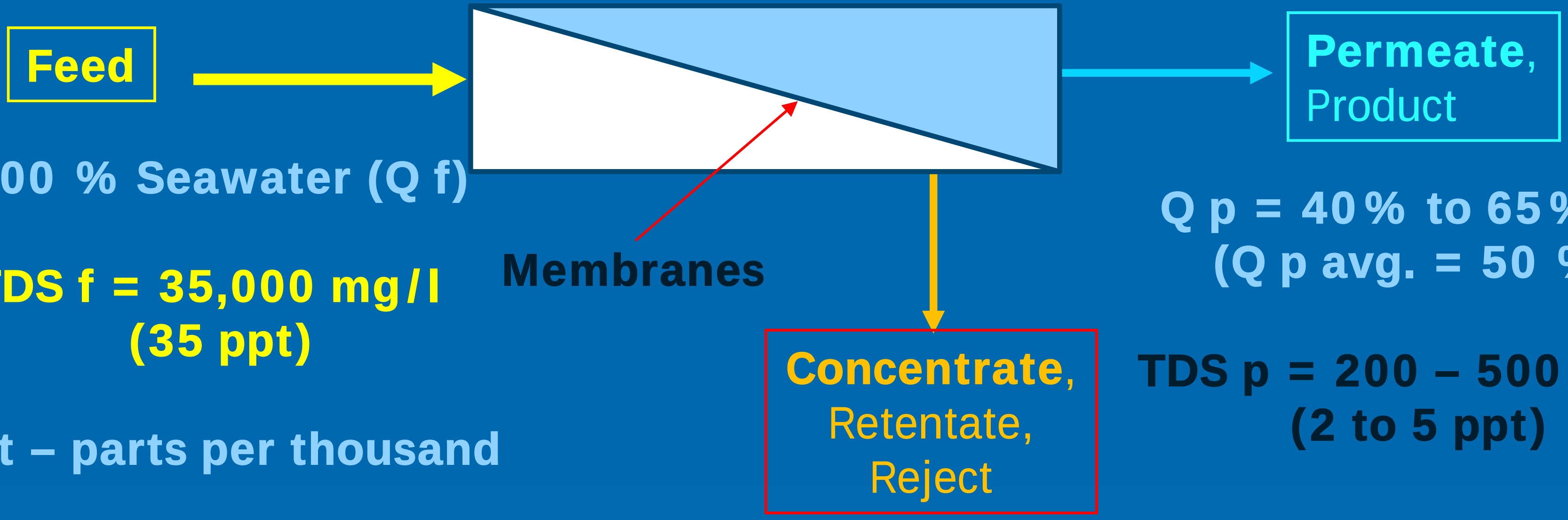
Key RO System Performance and Design Parameters

- RO System/Plant Recovery
- Membrane Rejection
- Salt Passage
- Concentrate Salinity
- Concentration Factor
- Feed Pressure
- Membrane Flux



Key Terminology

Membrane Element / Module



Feed

Permeate,
Product

Membranes

Concentrate,
Retentate,
Reject

100 % Seawater (Q f)

TDS f = 35,000 mg/l
(35 ppt)

ppt – parts per thousand

Q p = 40% to 65% Q f
(Q p avg. = 50 %)

TDS p = 200 – 500 mg/L
(2 to 5 ppt)

Q c = 35 % to 60% Q f
(Q c avg. = 50 %)

TDS c = 50 to 70 ppt

$$Pr = \text{Permeate Recovery (\%)} = \frac{\text{Permeate Flow (Q p)}}{\text{Feed Flow (Q f)}} \times 100 = \frac{50\,\%\ Qf}{Qf} = 50\,\%$$

% Salt Rejection = (1 – permeate TDS/feed TDS) =

(1 – 200 mg/l/35,000 mg/l) = 99.4 %

Salt Rejection and Passage

Salt Rejection = $(1-TDS_p/TDS_f)$ x100%

Example:

For TDSp = 0.5 ppt & TDSf = 35 ppt – Salt Rejection = 98.6 %

Salt Passage = 100 – Salt Rejection,%

Example:

For Salt Rejection = 99.4 % - Salt Passage = 100 – 99.4 = 0.6 %

Can be used for TDS and for specific ions

Concentrate Salinity

- **TDSc = [TDSf – (TDSp x Pr/100)]/(1-Pr/100)**

- For Example:
  - Source Seawater Salinity - TDSf = 35,000 mg/L
  - Permeate Recovery - Pr = 50% = 0.5
  - Permeate Salinity – TDSp = 200 mg/L

TDSc = (35,000 mg/L – 200 mg/L x50%/100)/(1- 50%/100) =
= 69,800 mg/L

Concentration Factor

$$CF = 1/(1-Y)$$

Where:

Y = Recovery as a decimal

$$CF = C_{ci}/C_{fi}$$

C_{ci} = spec. ion concentration in concentrate

C_{fi} = specific ion concentration in feed

Example:

For TDS Recovery = 50 % - CF = 1/(1-0.5) = 2

(i.e., on average the TDS conc. will increase two times)

Water Flux

Flux = permeate flow/unit membrane area/unit time

Expressed as liters/m^2/hour

(or gallons/ft^2/day)

Flux = Q_p/A

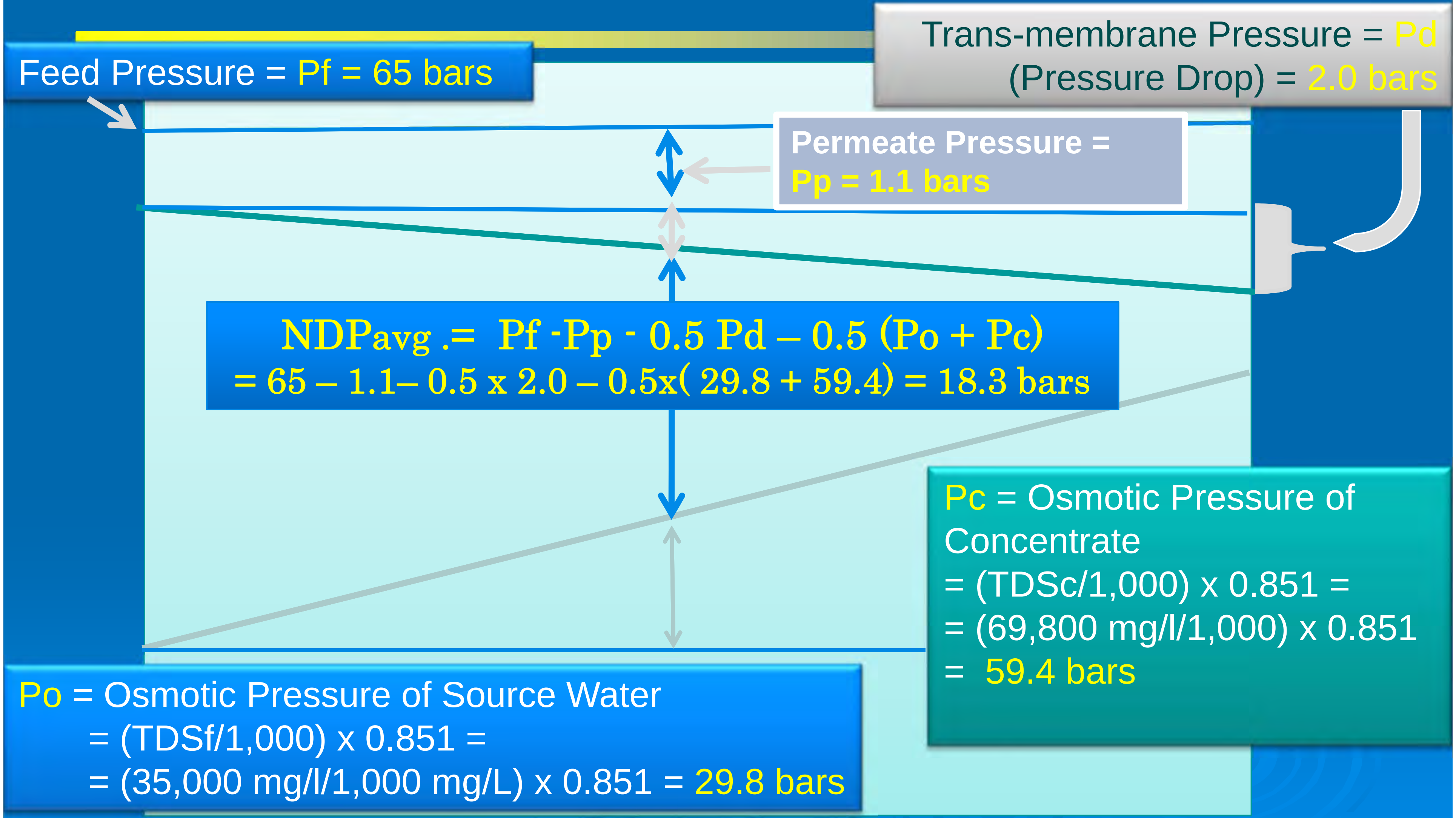
Q_p = Permeate Flow

A = No. of membranes x Membrane Area

Typical SWRO Membrane Flux –

12 to 18 liters/m^2/hour

Net Driving Pressure (NDP)



Feed Pressure = Pf = 65 bars

Trans-membrane Pressure = Pd
(Pressure Drop) = 2.0 bars

Permeate Pressure =
Pp = 1.1 bars

NDPavg .= Pf -Pp - 0.5 Pd – 0.5 (Po + Pc)
= 65 – 1.1– 0.5 x 2.0 – 0.5x(29.8 + 59.4) = 18.3 bars

Pc = Osmotic Pressure of Concentrate
= (TDSc/1,000) x 0.851 =
= (69,800 mg/l/1,000) x 0.851
= 59.4 bars

Po = Osmotic Pressure of Source Water
= (TDSf/1,000) x 0.851 =
= (35,000 mg/l/1,000 mg/L) x 0.851 = 29.8 bars

Permeability & Relative Salt Transport

- Permeability = Flux / Net Driving Pressure (l/m².hr/bar)
  Typical Range: 1 – 1.5 l/m².hr/bar

- Relative Salt Transport = Salt Passage x Flux
  Typical Range: 0.05 – 0.12

Example (SWC4+ SWRO Element):

Test Flux = 27.6 l/m².hr; Test NDP = 27.6 bars;

Salt Rejection = 99.8 % (at test conditions);

Salt Passage = 100% – 99.8% = 0.2%

Permeability = 27.6 l/m².hr / 27.6 bars = 1.0 l/m².hr/bar

Relative Salt Transport = (0.002) (27.6 bars) = 0.055

Checking the Membrane Flux of SWRO System

Example:

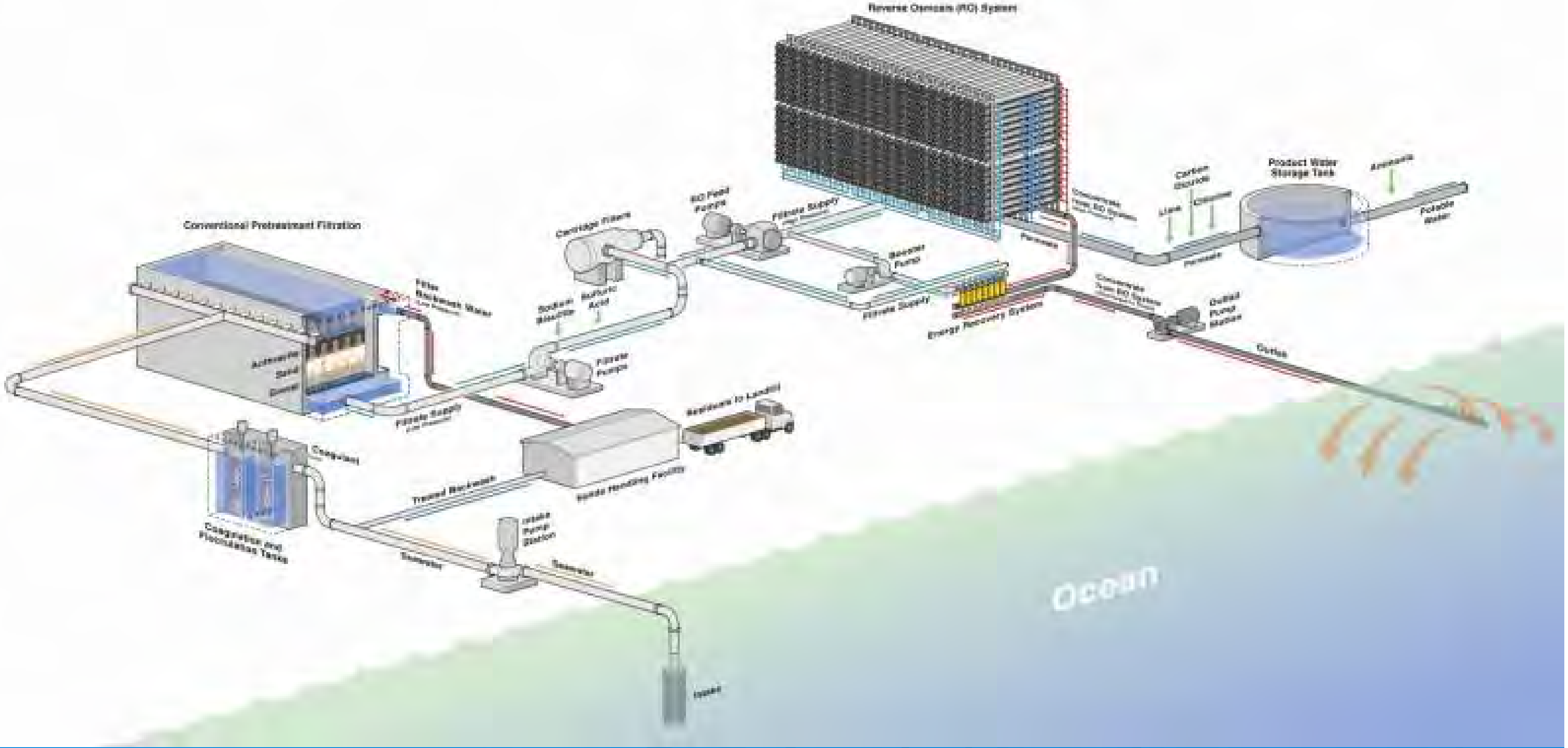
- RO train produces 100 m^3/hour
  (2.4 ML/day) of permeate
- Train has 30 vessels, 7 elements/vessel
- SWRO Membrane Area is 35 m^2

- Total membrane area (A) = 30*7*35 = 7,350 m^2

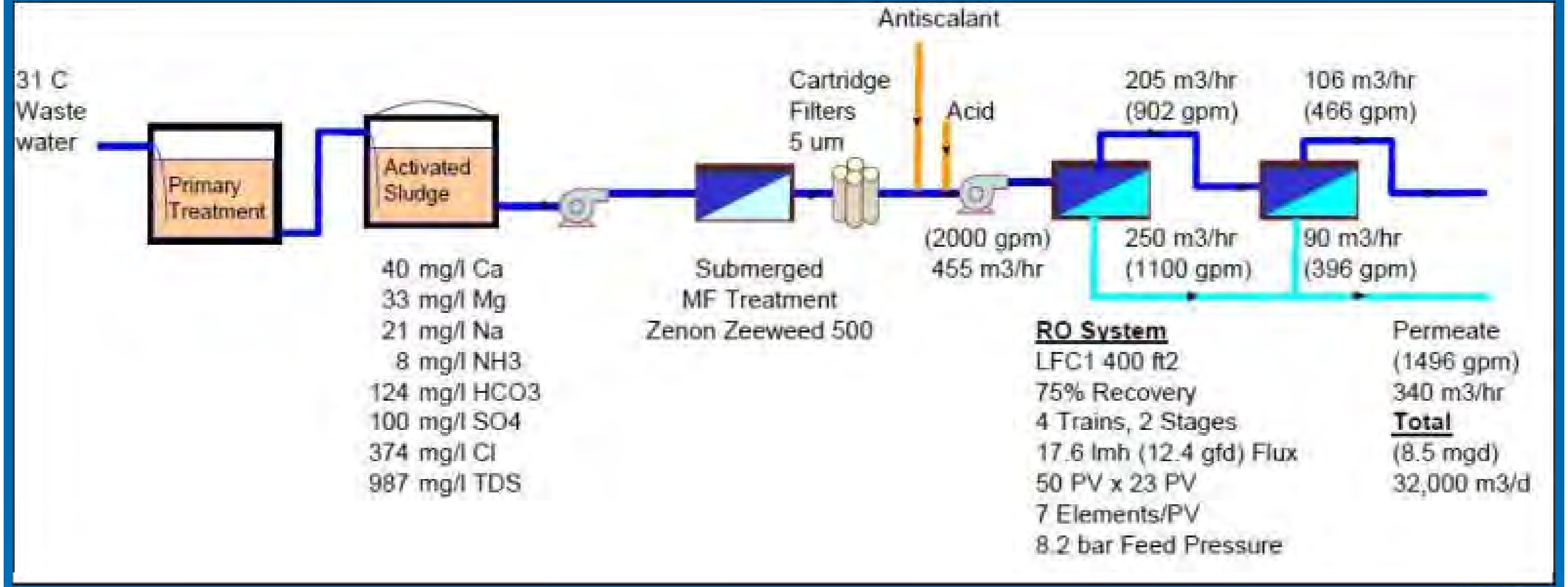
- Permeate Flow Q = 100,000 L/hour
- Flux Q/A = 100,000 L/hour / 7,350 m^2 =
  13.6 L/m^2/hour

- **Typical SWRO membrane water flux is**
  12-18 L/m^2/hour

SWRO Plant – Key Components



Membrane Water Reuse Plant – Key Components



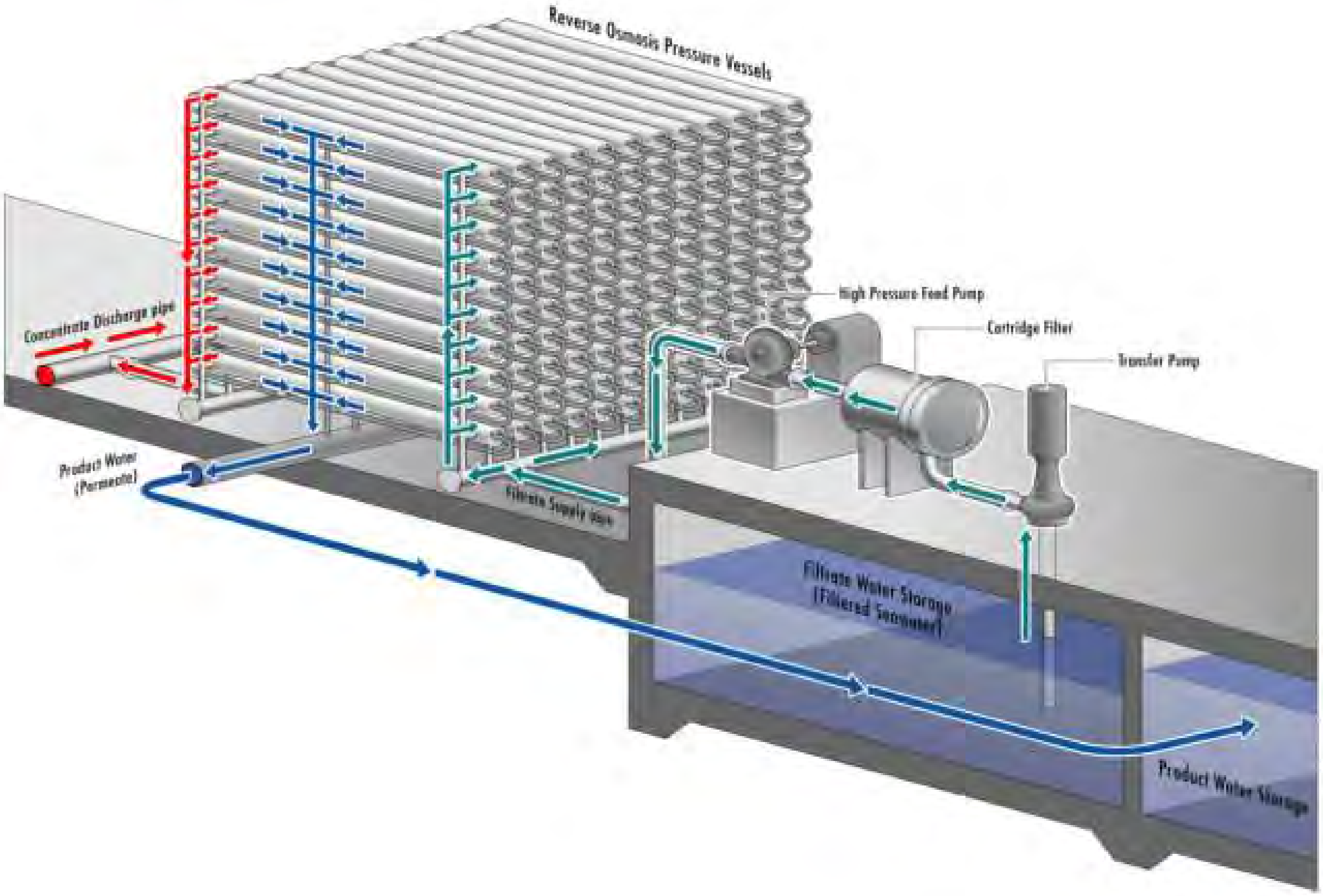
40 mg/l Ca
33 mg/l Mg
21 mg/l Na
8 mg/l NH3
124 mg/l HCO3
100 mg/l SO4
374 mg/l Cl
987 mg/l TDS

RO System
LFC1 400 ft2
75% Recovery
4 Trains, 2 Stages
17.6 lmh (12.4 gfd) Flux
50 PV x 23 PV
7 Elements/PV
8.2 bar Feed Pressure

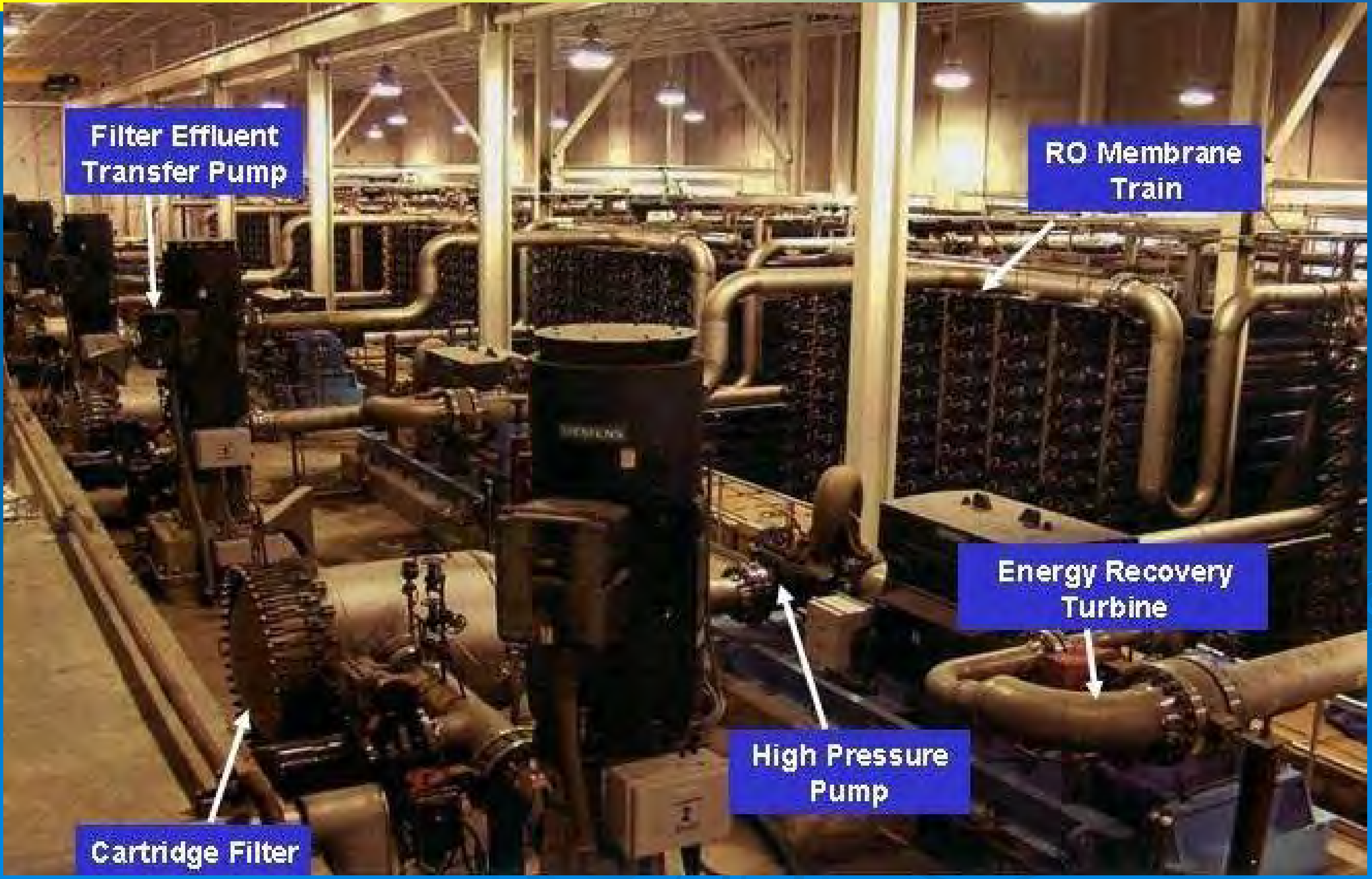
Permeate
(1496 gpm)
340 m3/hr
Total
(8.5 mgd)
32,000 m3/d

32,000 m^3/day Bedok WWTP, Singapore

RO System – Components and Configuration



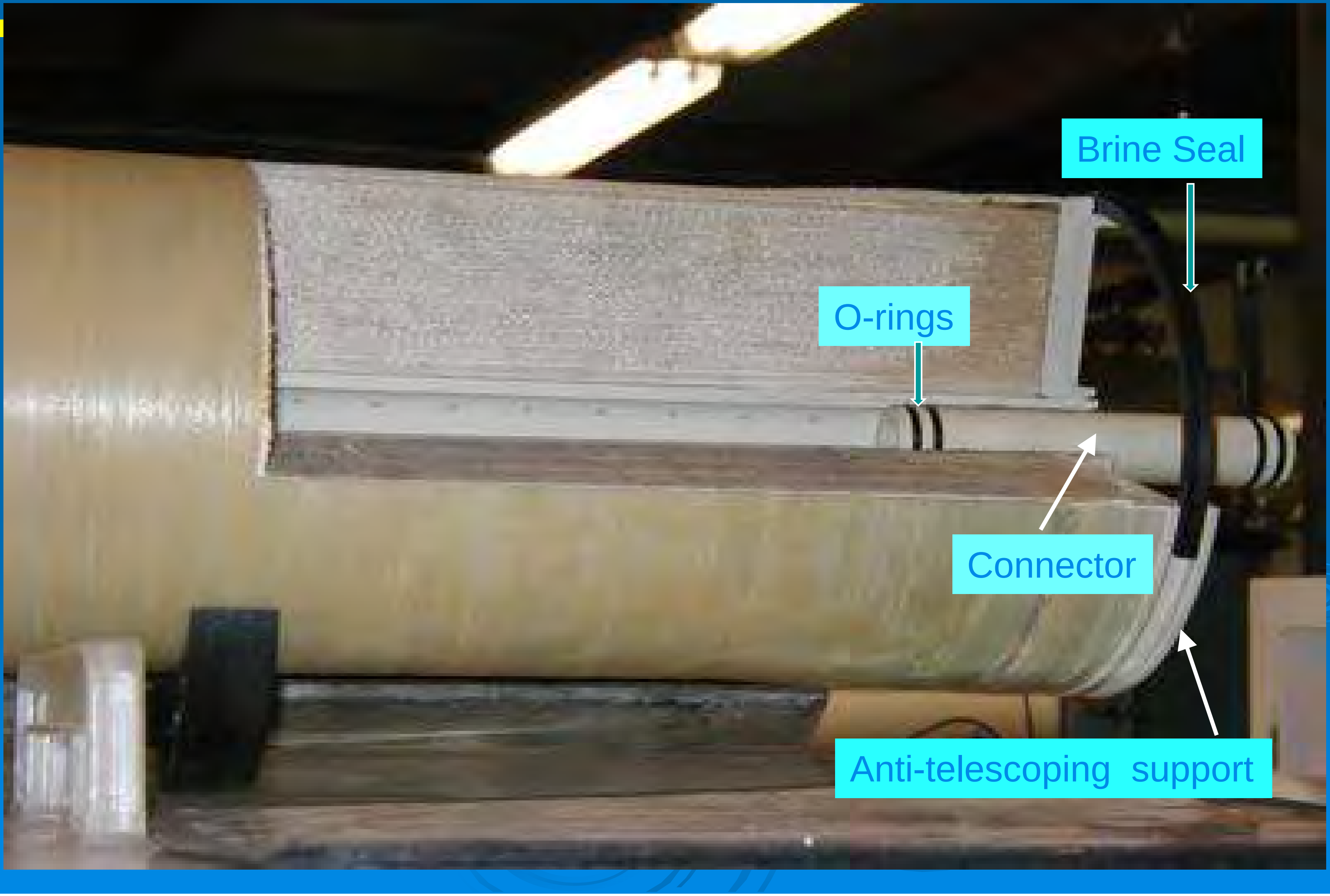
Key RO System Components – Tampa Bay SWRO Plant



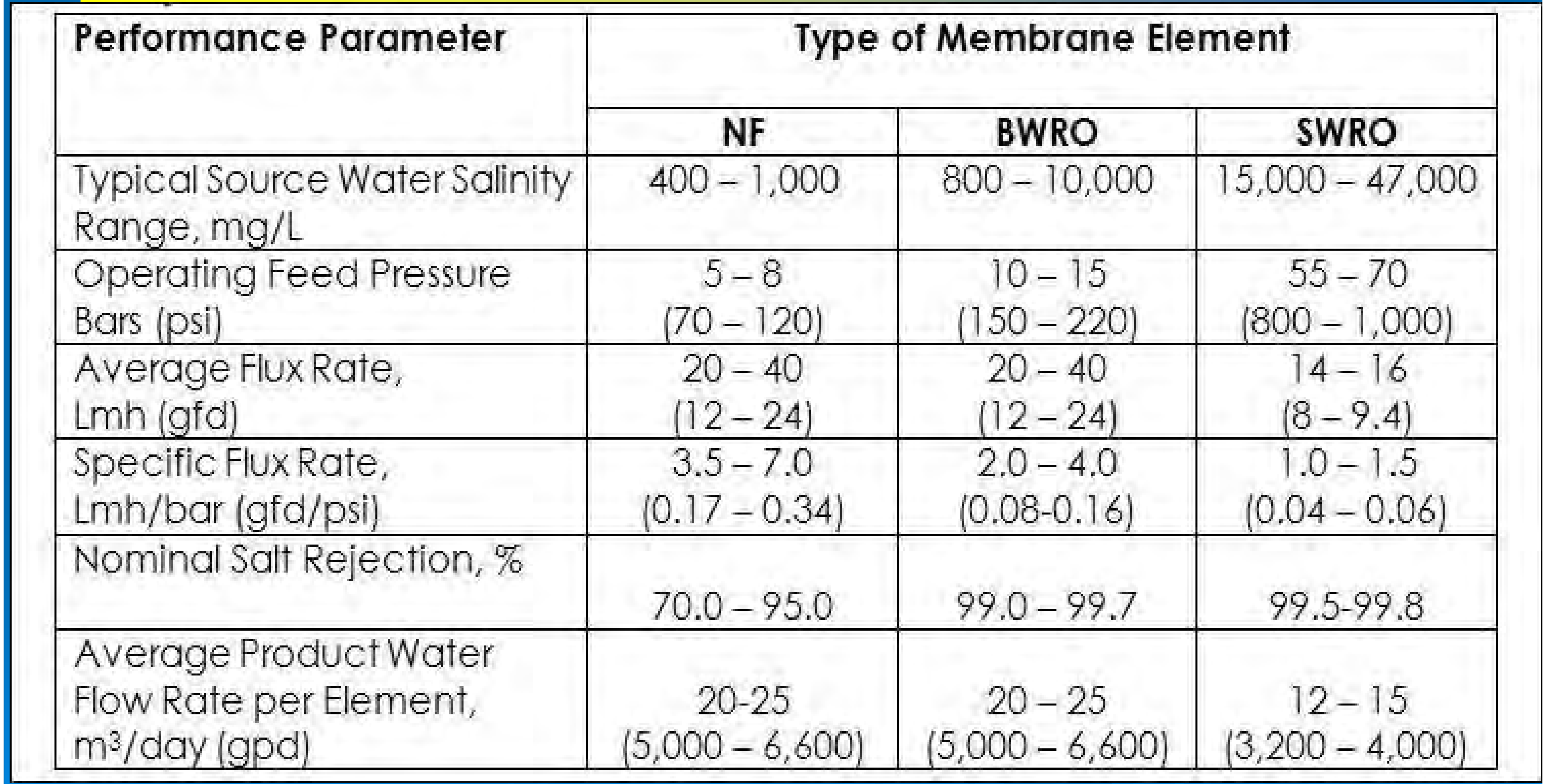
Key RO System Components

- Membrane Elements:
  - Diameter 4” to 16” (8” – most widely used);
  - Length – 40-in (60-in also available).
- Membrane Vessels:
  - Fiberglass Reinforced Plastic;
  - 6 to 8 Membranes per Vessel;
  - Installed on Welded Steel or FRP Support Racks.
- Membrane Process Trains:
  - Membrane Vessels Connected with Ports to Feed, Concentrate and Product Water Lines.

Cross-Section of Membrane Element



Performance Summary of Most Widely Used RO Elements



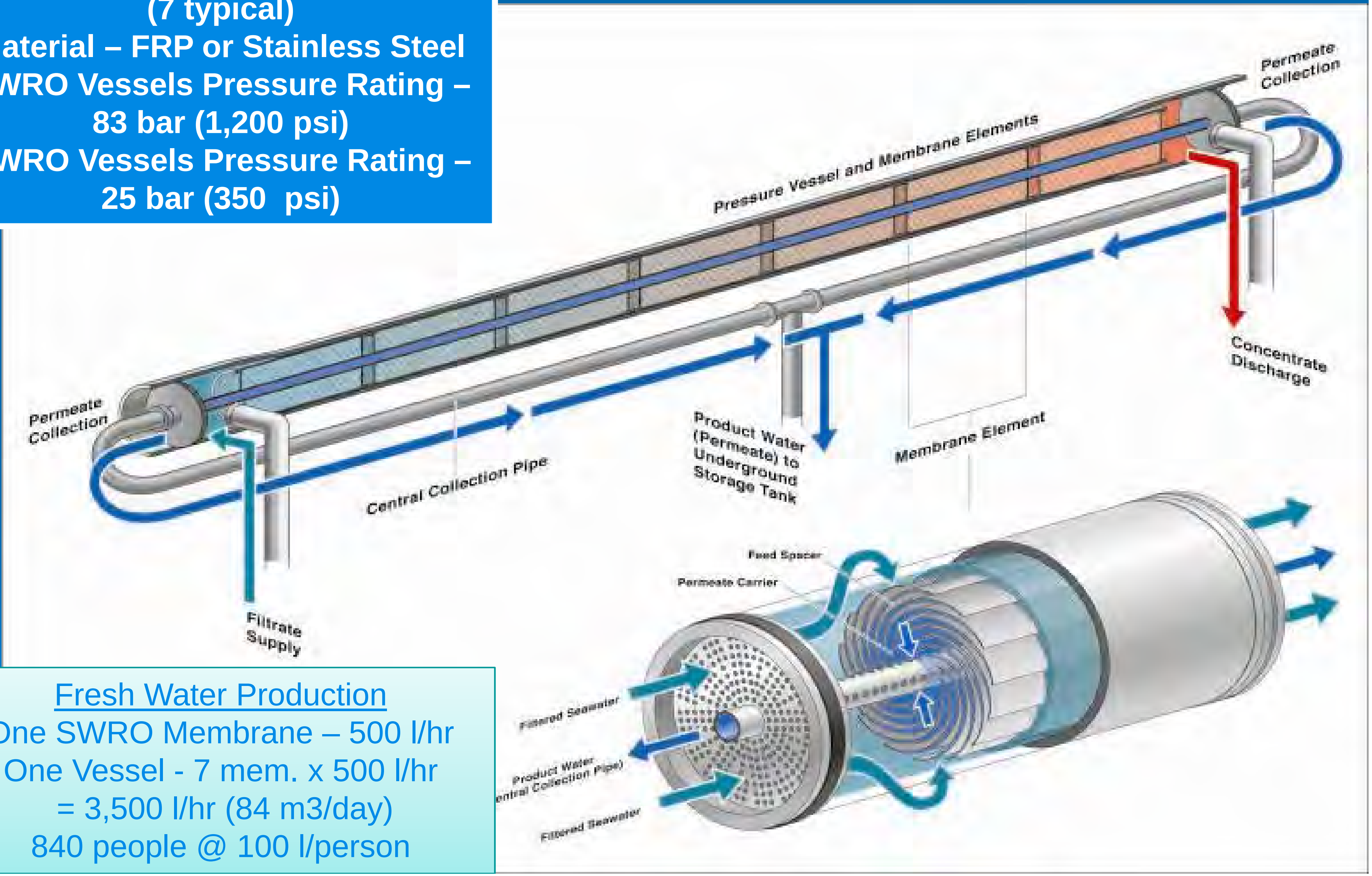
Performance Parameter	Type of Membrane Element		
	NF	BWRO	SWRO
Typical Source Water Salinity Range, mg/L	400 – 1,000	800 – 10,000	15,000 – 47,000
Operating Feed Pressure Bars (psi)	5 – 8 (70 – 120)	10 – 15 (150 – 220)	55 – 70 (800 – 1,000)
Average Flux Rate, Lmh (gfd)	20 – 40 (12 – 24)	20 – 40 (12 – 24)	14 – 16 (8 – 9.4)
Specific Flux Rate, Lmh/bar (gfd/psi)	3.5 – 7.0 (0.17 – 0.34)	2.0 – 4.0 (0.08-0.16)	1.0 – 1.5 (0.04 – 0.06)
Nominal Salt Rejection, %	70.0 – 95.0	99.0 – 99.7	99.5-99.8
Average Product Water Flow Rate per Element, m^3/day (gpd)	20-25 (5,000 – 6,600)	20 – 25 (5,000 – 6,600)	12 – 15 (3,200 – 4,000)

Membrane Element Rejection & Productivity

Courtesy Hydranautics

RO Membrane Vessel

6 to 8 Membranes per Vessel
(7 typical)
Material – FRP or Stainless Steel
SWRO Vessels Pressure Rating – 83 bar (1,200 psi)
BWRO Vessels Pressure Rating – 25 bar (350 psi)



Fresh Water Production
One SWRO Membrane – 500 l/hr
One Vessel - 7 mem. x 500 l/hr
= 3,500 l/hr (84 m3/day)
840 people @ 100 l/person

Membrane Vessels

- Key Manufacturers:
  - Pentair (Codeline) – www.codeline.com
  - BEL Composite America, Inc. – www.belvessels.com
  - Bekaert Progressive Composites, Corp. www.bekaert.com

End-port

Side-port

Membrane Vessels – Multiple Ports

Membrane Vessels – Even Flow Distribution is Critical

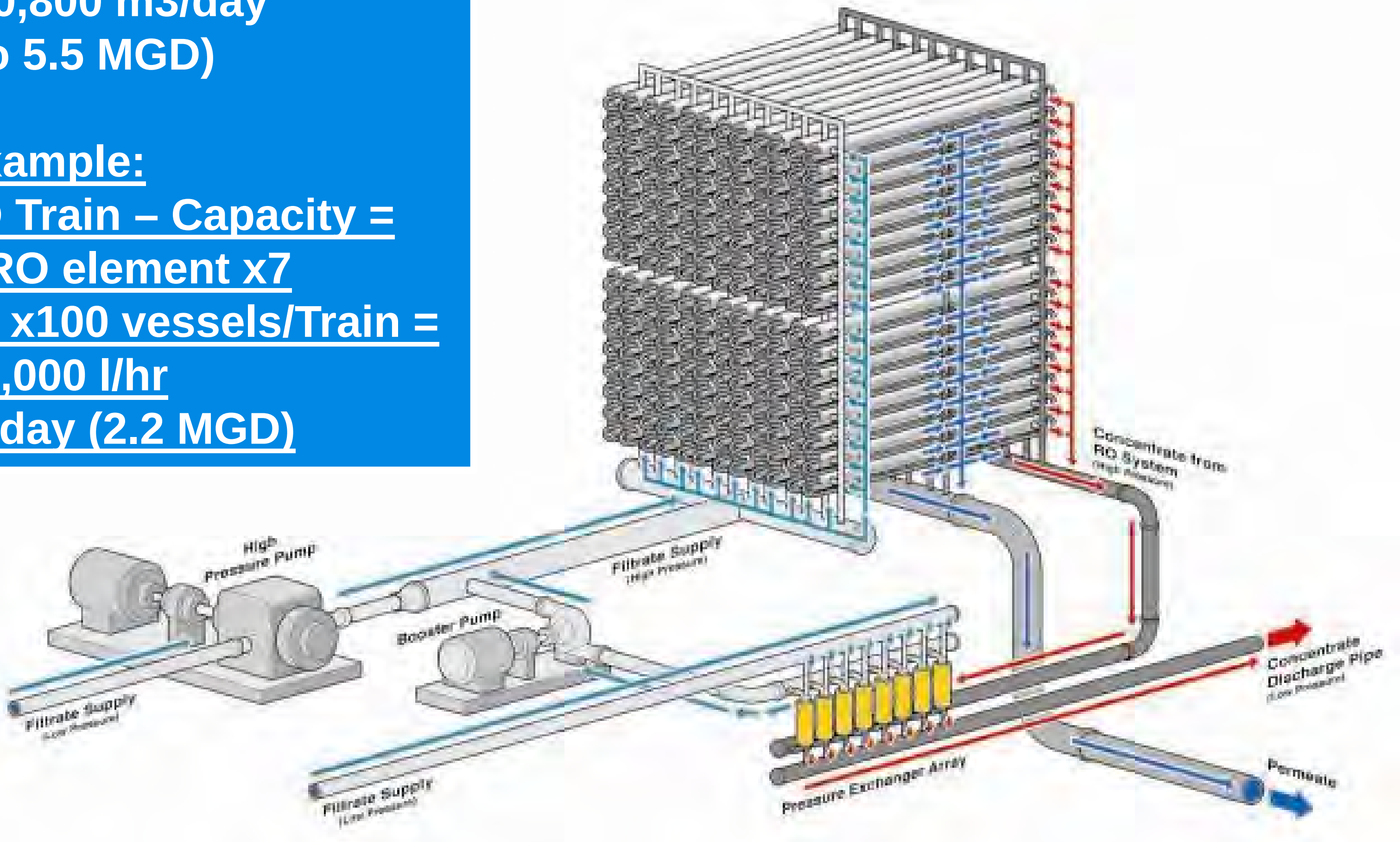
SWRO Membrane Train

Membrane Vessels Connected in Parallel

100 to 200 Vessels per RO Train

**Typical SWRO Train Capacity =
750 to 20,800 m3/day
(0.2 to 5.5 MGD)**

**Example:
100 Vessel RO Train – Capacity =
500 l/hr /RO element x7 elements/Vessel x100 vessels/Train =
350,000 l/hr
8,400 m3/day (2.2 MGD)**



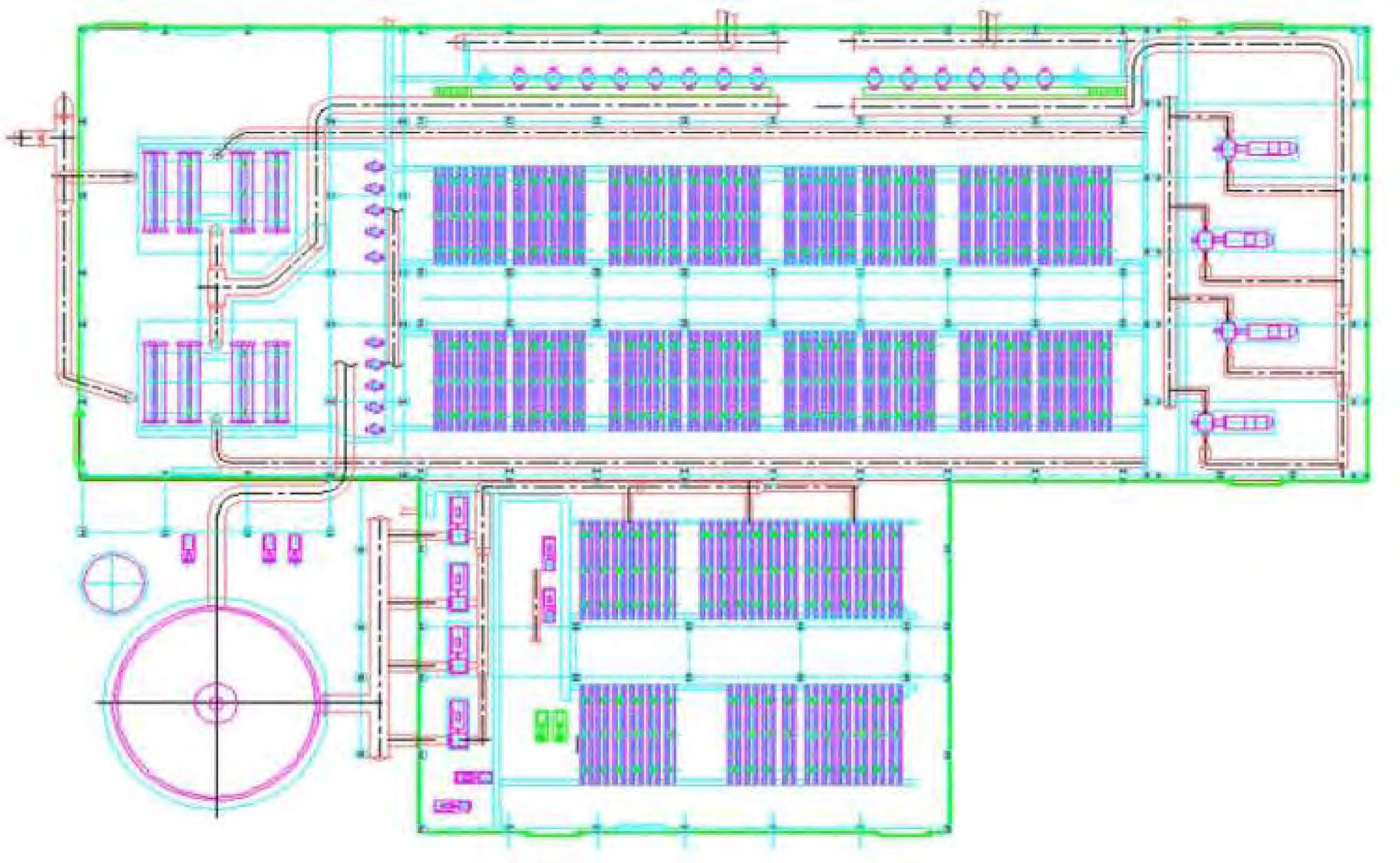
RO Membrane Trains – Alternatives

- One High Pressure Pump Per One RO Train
- One High Pressure Pump per Two RO Trains
- One High Pressure Pump Serving 50 % of the Trains

One HP Pump – One RO Train

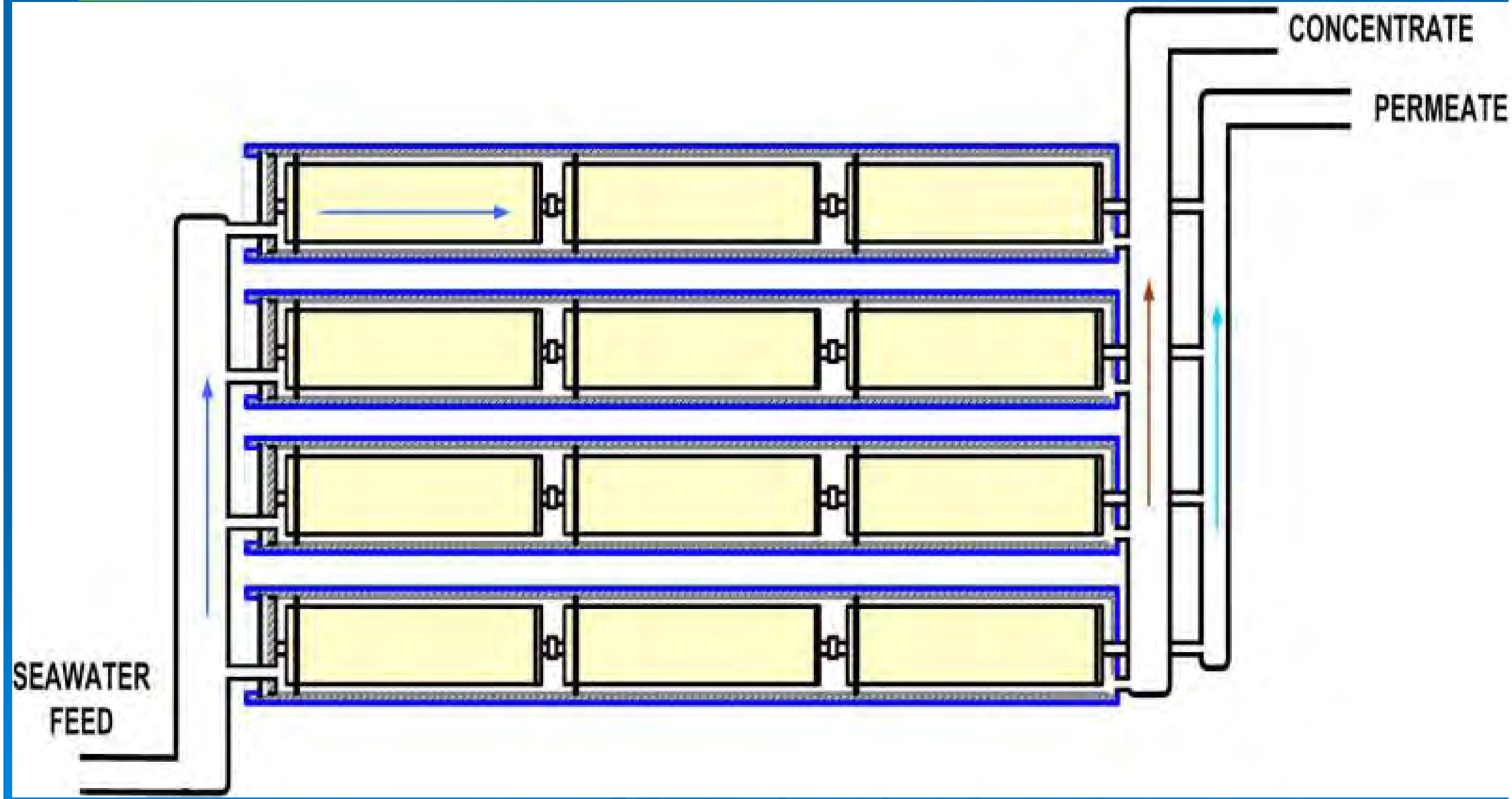
One HP Pump – Two RO Trains

Three Duty HP Pumps – All SWRO Trains

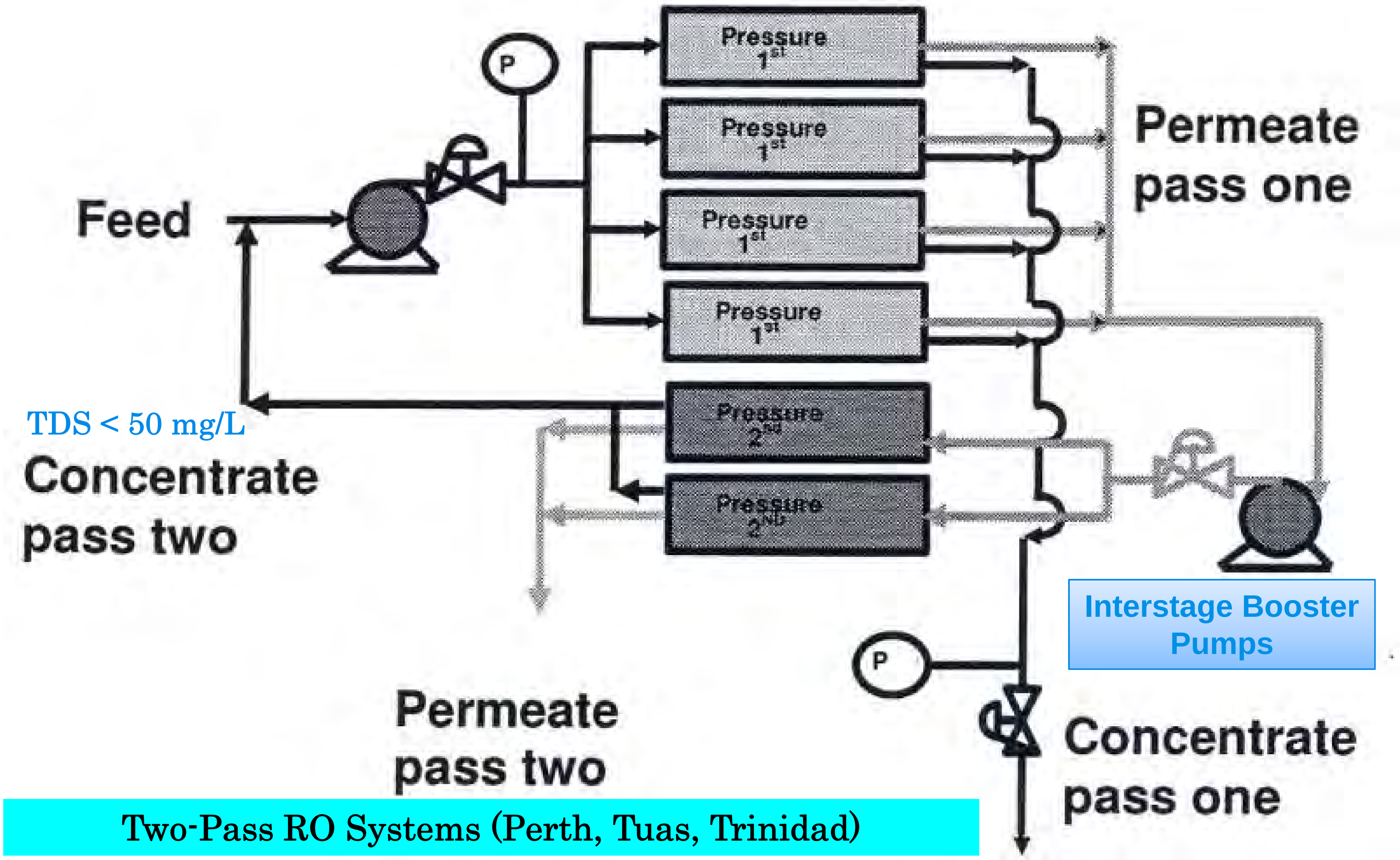


Alternative RO System Configurations

Single-Pass SWRO System



Two-Pass RO Systems

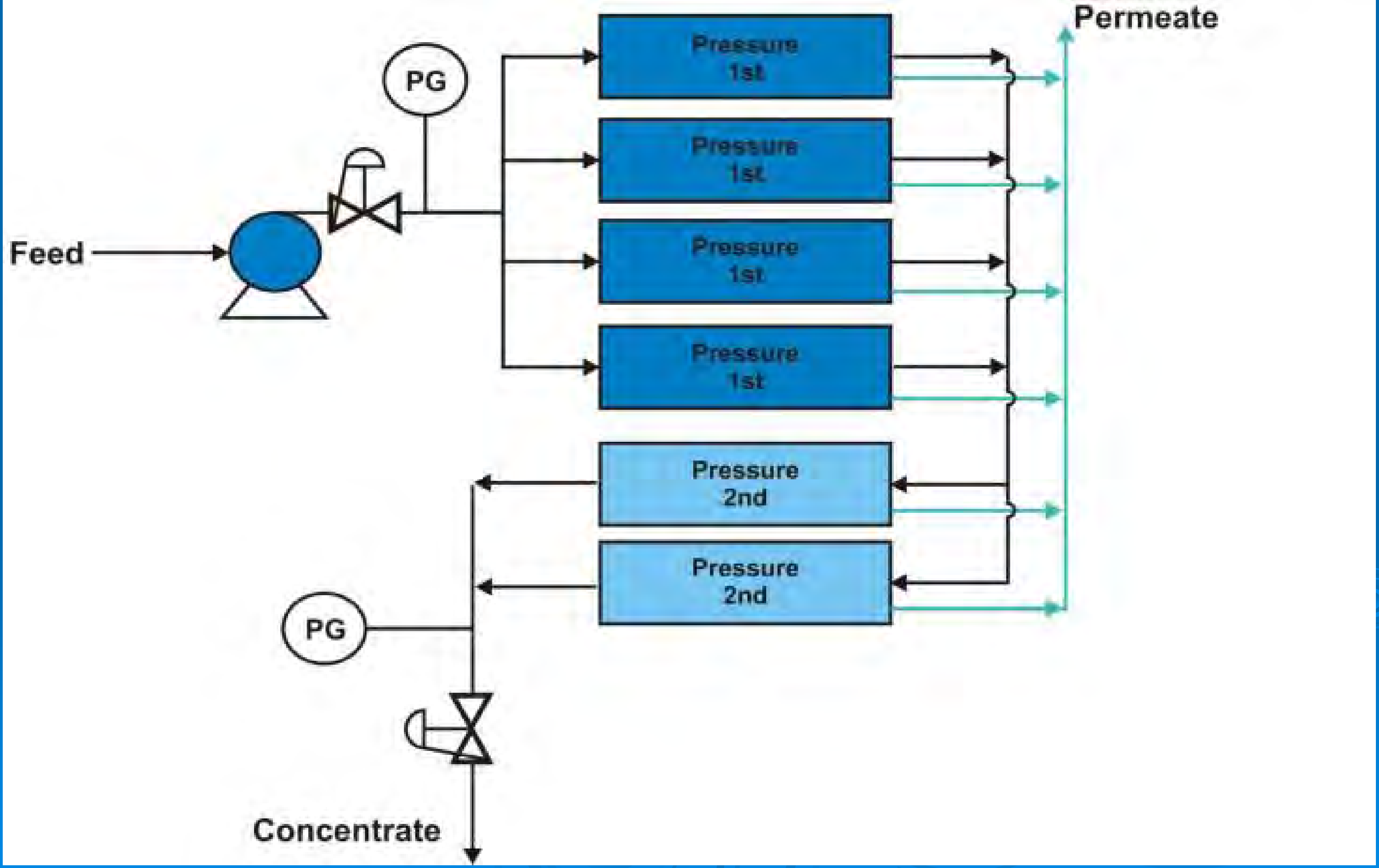


TDS < 50 mg/L

Interstage Booster Pumps

Two-Pass RO Systems (Perth, Tuas, Trinidad)

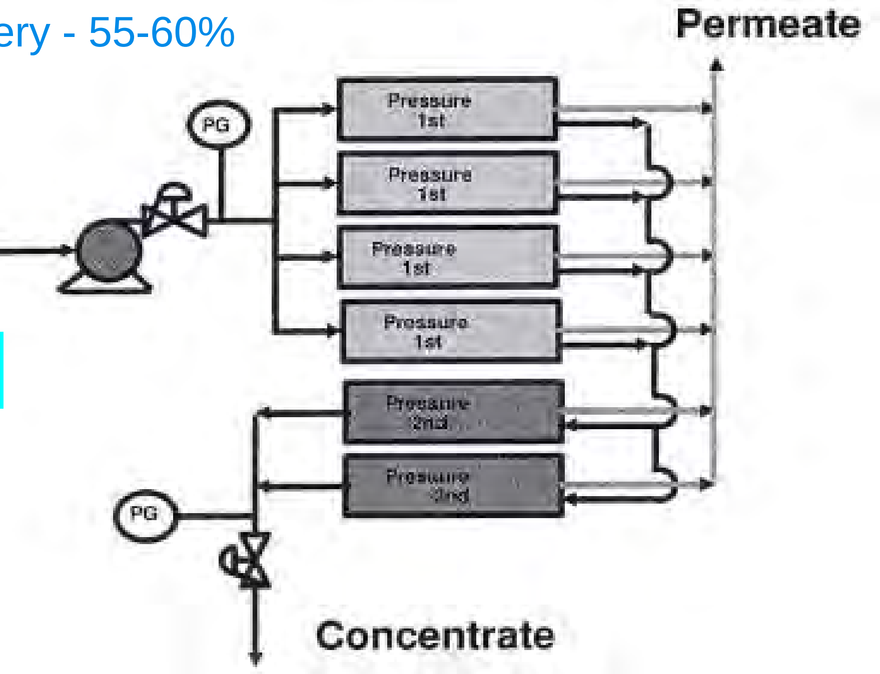
Two-Stage RO Systems



Two-Pass vs. Two-Stage RO Systems

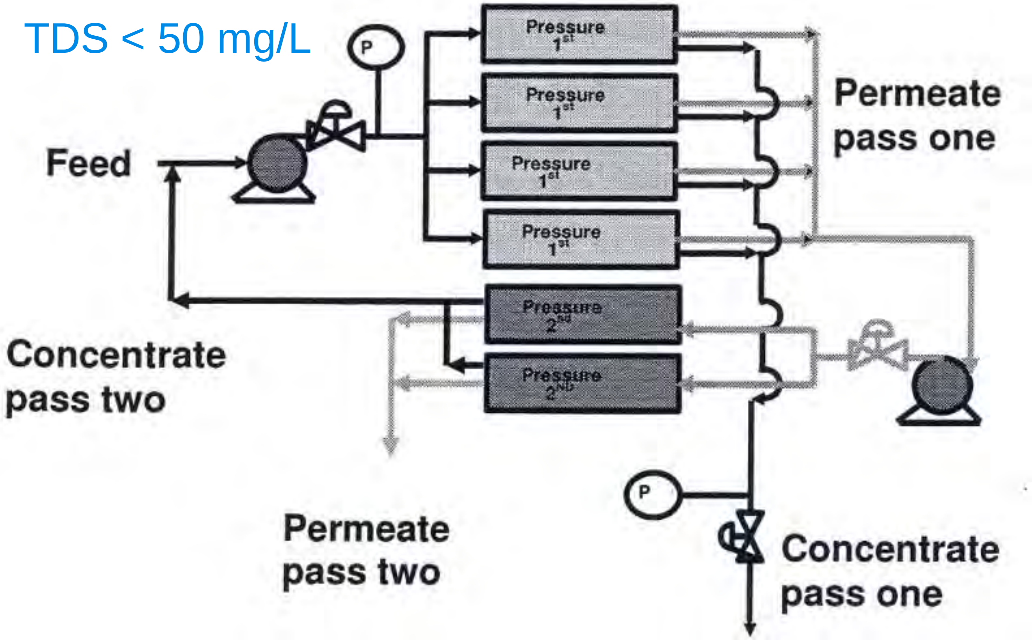
Two-Stage RO System (Mas Palomas)

Recovery - 55-60%



Two-Pass RO System (Trinidad)

TDS < 50 mg/L



**Adding Extra Pass –
to Improve Water Quality**

**Adding Extra Stage –
To Produce More Water**

Sizing of Key Components of SWRO System

- RO System Configuration
- Number of Membranes
- Number of Trains

Key Design Steps

- Determine Source Water Quality
- Establish Product Water Quantity and Quality
- Complete Initial (Desktop) Design
- Computer RO Software Design

Design Water Quality Parameters (After Pretreatment)

Dissolved Minerals	Foulants (Particulate & Organic)	Foulants (Colloidal & Mineral)	Other Parameters
TDS = 35 ppt	Turbidity = 0.06 NTU	Fe = 0.05 mg/L	Temp = 23–32ºC (25ºC avg.)
Boron = 5 mg/L	TSS (mg/) < 1	Mn = 0.02 mg/L	pH = 7.8 – 8.3
Br = 75 mg/L	SDI (units) = 3	Cu = 0.03 mg/L	Chlorine <0.01 mg/L
Silica = 4 mg/L	TOC = 0.5 mg/L	CO3 = 30 mg/L	ORP < 200 mV
Cl = 19 ppt	Oil & Gr. = 0.01 mg/L	Sulfate = 2,900 mg/L	DO = 6 to 8 mg/L
Na = 10 ppt		HCO3 = 119 mg/L	
Ca = 1.100 mg/L		Fluoride = 1.5 mg/L	
Mg= 1,500 mg/L		Nitrate = 0.1 mg/L	

Example:

Plant Production Capacity = 10,000 m3/day (417 m3/hr)

Product Water Quality

- TDS
- Conductivity
- Boron
- Chloride

- Temperature
- DO
- pH
- Alkalinity
- Hardness
- Disinfection Type
- Turbidity

Example:

TDSp = 500 mg/L [Removal Needed: (35,000 – 500)/35,000 = 85.7 %]

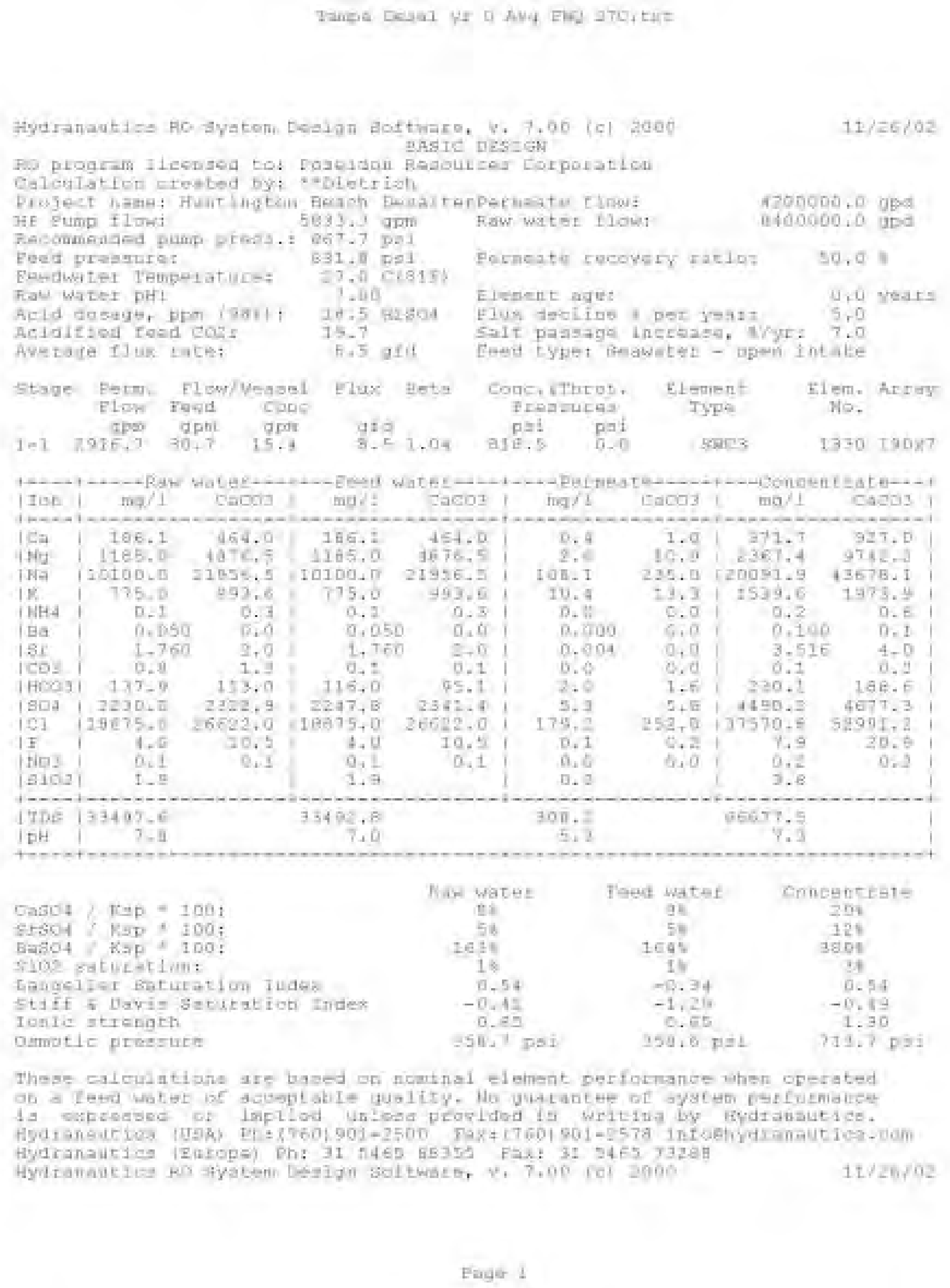
Boron = 1 mg/L [Removal Needed: (5-1)/5 = 80 %]

Chloride = 250 mg/L [Removal Needed: (19,000-250)/75 = 98.7 %]

Membrane Projection Software

Free Design Software

- ➢Hydranautics – IMSDesign
- ➢ Filmtec – ROSA
- ➢Toray – TORAYDS
- ➢Koch – KMS ROPRO



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                    Tampa Desal yr 0 Avg FWQ 270.txt

Hydranautics RO System Design Software, v. 7.00 (c) 2000              11/26/02
                              BASIC DESIGN
RO program licensed to: Poseidon Resources Corporation
Calculation created by: **Dietrich
Project name: Huntington Beach DesalterPermeate flow:          #200000.0 gpd
HP Pump flow:              5833.3 gpm     Raw water flow:        8400000.0 gpd
Recommended pump press.:  867.7 psi
Feed pressure:            831.8 psi     Permeate recovery ratio:     50.0 %
Feedwater Temperature:     27.0 C(81F)
Raw water pH:               7.80        Element age:                  0.0 years
Acid dosage, ppm (98%):   18.5 H2SO4    Flux decline % per year:      5.0
Acidified feed CO2:        15.7         Salt passage increase, %/yr:  7.0
Average flux rate:          8.5 gfd     Feed type: Seawater - open intake

Stage  Perm.   Flow/Vessel   Flux  Beta   Conc.&Throt.    Element     Elem. Array
       Flow   Feed    Conc                 Pressures       Type        No.
        gpm    gpm     gpm     gfd           psi     psi
1-1  2916.7  30.7   15.4      8.5 1.04   818.5    0.0       SWC3       1330 190x7

+----+------Raw water--------Feed water-----+----Permeate------+---Concentrate---+
|Ion |   mg/l     CaCO3 |   mg/l      CaCO3 |   mg/l     CaCO3 |   mg/l    CaCO3 |
+----+------------------+-------------------+------------------+-----------------+
|Ca  |   186.1    464.0 |   186.1     464.0 |    0.4       1.0 |  371.7    927.0 |
|Mg  |  1185.0   4876.5 |  1185.0    4876.5 |    2.6      10.8 | 2367.4   9742.3 |
|Na  | 10100.0  21956.5 | 10100.0   21956.5 |  108.1     235.0 |20091.9  43678.1 |
|K   |   775.0    993.6 |   775.0     993.6 |   10.4      13.3 | 1539.6   1973.9 |
|NH4 |     0.1      0.3 |     0.1       0.3 |    0.0       0.0 |    0.2      0.6 |
|Ba  |    0.050     0.0 |     0.050     0.0 |    0.000     0.0 |    0.100    0.1 |
|Sr  |    1.760     2.0 |     1.760     2.0 |    0.004     0.0 |    3.516    4.0 |
|CO3 |     0.8      1.3 |     0.1       0.1 |    0.0       0.0 |    0.1      0.2 |
|HCO3|   137.9    113.0 |   116.0      95.1 |    2.0       1.6 |  230.1    188.6 |
|SO4 |  2230.0   2322.9 |  2247.8    2341.4 |    5.3       5.6 | 4490.3   4677.3 |
|Cl  | 18875.0  26622.0 | 18875.0   26622.0 |  179.2     252.0 |37570.6  52991.2 |
|F   |     4.0     10.5 |     4.0      10.5 |    0.1       0.2 |    7.9     20.8 |
|NO3 |     0.1      0.1 |     0.1       0.1 |    0.0       0.0 |    0.2      0.2 |
|SiO2|     1.9          |     1.9           |    0.0           |    3.8          |
+----+------------------+-------------------+------------------+-----------------+
|TDS | 33407.6          | 33492.8           |  308.2           | 66677.5         |
|pH  |     7.8          |     7.0           |    5.3           |    7.3          |
+----+------------------+-------------------+------------------+-----------------+

                                        Raw water      Feed water     Concentrate
CaSO4 / Ksp * 100:                          8%             9%            20%
SrSO4 / Ksp * 100:                          5%             5%            12%
BaSO4 / Ksp * 100:                        163%           164%           380%
SiO2 saturation:                            1%             1%             3%
Langelier Saturation Index                 0.54          -0.34           0.54
Stiff & Davis Saturation Index            -0.41          -1.29          -0.49
Ionic strength                             0.65           0.65           1.30
Osmotic pressure                         358.7 psi      358.6 psi      713.7 psi

These calculations are based on nominal element performance when operated
on a feed water of acceptable quality. No guarantee of system performance
is  expressed  or  implied  unless provided in  writing by  Hydranautics.
Hydranautics (USA) Ph:(760)901-2500  Fax:(760)901-2578 info@hydranautics.com
Hydranautics (Europe) Ph: 31 5465 88355  Fax: 31 5465 73288
Hydranautics RO System Design Software, v. 7.00 (c) 2000              11/26/02


                                 Page 1
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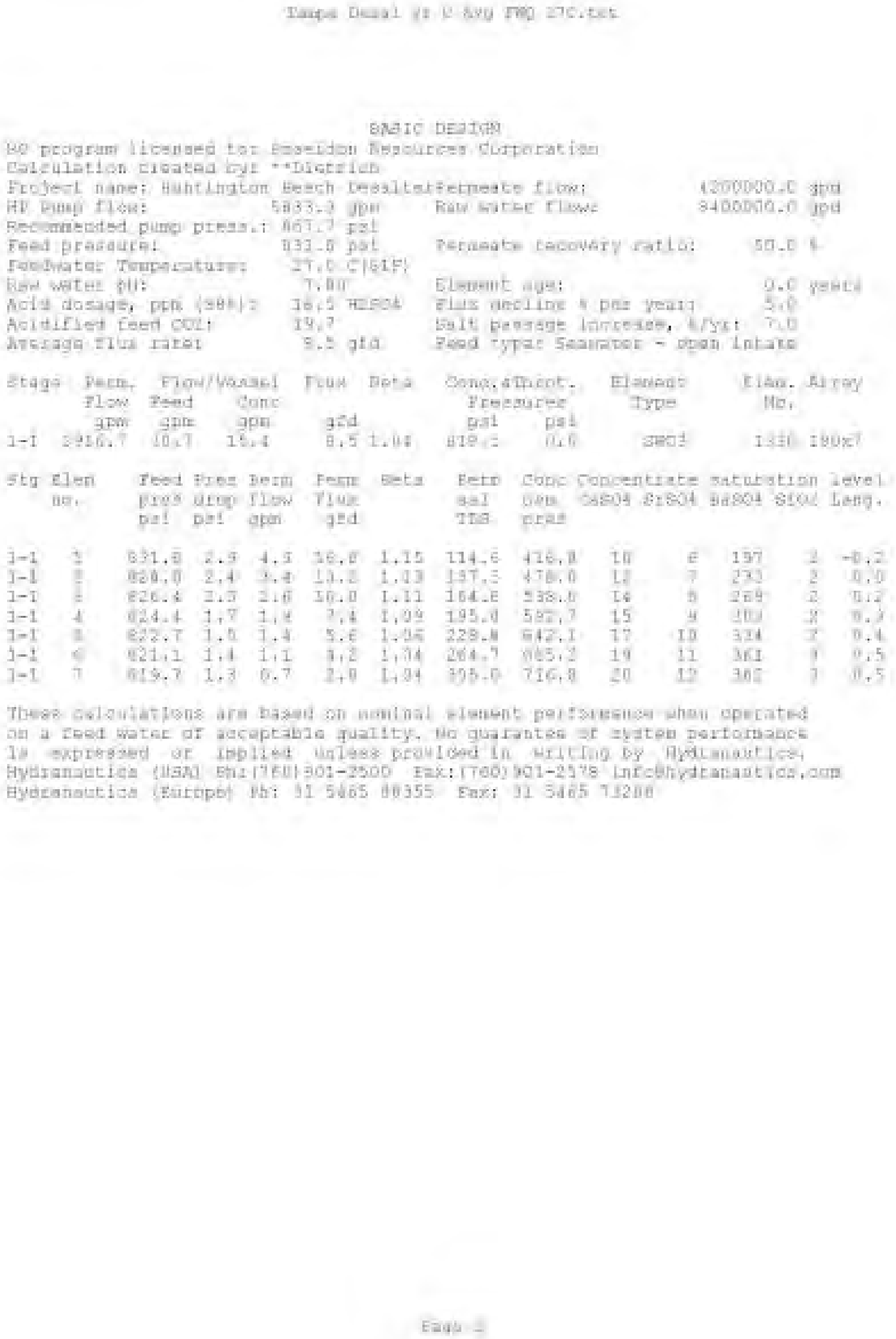
Membrane Software - 2

Free Design Software

- Hydranautics – IMSDesign
- Filmtec – ROSA
- Toray – TORAYDS
- Koch – KMS ROPRO



```
                 Tampa Desal yr 0 Avg FWQ 27C.txt

                           BASIC DESIGN
RO program licensed for: Poseidon Resources Corporation
Calculation created by: **Dietrich
Project name: Huntington Beach DesaltinPermeate flow:         4200000.0 gpd
HP Pump flow:             5833.3 gpm     Raw water flow:      8400000.0 gpd
Recommended pump press.:  867.7 psi
Feed pressure:             831.8 psi     Permeate recovery ratio:    50.0 %
Feedwater Temperature:     27.0 C(81F)
Raw water pH:               7.80         Element age:                 0.0 years
Acid dosage, ppm (98%):    16.5 H2SO4    Flux decline % per year:     5.0
Acidified feed CO2:        19.7          Salt passage increase, %/yr: 7.0
Average flux rate:          8.5 gfd      Feed type: Seawater - open intake

Stage  Perm.  Flow/Vessel  Flux  Beta   Conc.&Throt.  Element     Elem. Array
       Flow   Feed   Conc                Pressures     Type        No.
        gpm    gpm    gpm    gfd         psi    psi
1-1   2916.7  30.7   15.4    8.5 1.04   819.2    0.0     SWC3       1330 190x7

Stg Elem    Feed Pres Perm  Perm  Beta   Perm  Conc Concentrate saturation level
    no.     pres drop flow  Flux         sal   osm  CaSO4 SrSO4 BaSO4 SiO2 Lang.
            psi  psi  gpm   gfd          TDS   pres

1-1  1     831.8  2.5  4.5  16.6  1.15  114.6  416.8   10     6   157    2  -0.2
1-1  2     829.0  2.4  3.4  12.5  1.13  137.3  478.0   12     7   232    2   0.0
1-1  3     826.6  2.2  2.6  10.0  1.11  164.8  538.8   14     8   269    2   0.2
1-1  4     824.4  1.7  1.9   7.4  1.09  195.0  587.7   15     9   303    2   0.3
1-1  5     822.7  1.5  1.4   5.6  1.06  228.8  642.1   17    10   334    2   0.4
1-1  6     821.1  1.4  1.1   4.2  1.04  264.7  685.2   19    11   361    2   0.5
1-1  7     819.7  1.3  0.7   2.9  1.04  305.0  716.8   20    12   382    2   0.5

These calculations are based on nominal element performance when operated
on a feed water of acceptable quality. No guarantee of system performance
is  expressed  or  implied  unless provided in  writing by  Hydranautics.
Hydranautics (USA) Ph:(760)901-2500  Fax:(760)901-2578 info@hydranautics.com
Hydranautics (Europe) Ph: 31 5465 88355  Fax: 31 5465 73288

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Concluding Remarks

- Reverse Osmosis is a Process Where Water is Moved From the High-salinity to Low-salinity Side of the Membrane by Pressurization
- Osmotic Pressure is a Function of Salinity & Temperature (0.85 bars/1,000 mg/L)
- Spiral-Wound, Thin-Film Composite Polyamide SWRO Membranes Are Most Widely Used Today
- Membranes Have Standard Size –

  8-inch x 40-inch Elements Most Common

Questions?

International Water Association
World Water Congress & Exhibition
BUSAN KOREA

Applying Reverse Osmosis for Water Reuse

14:00-15:00

Valentina Lazarova

SUEZ ENVIRONNEMENT

Chair of the IWA Specialist Group on Water Reuse

Member of the International Water Academy

Application of Reverse Osmosis in Water Reuse

- RO Systems for Water Reuse
  - ❒ Overview of Water Reuse Status and Trends
  - ❒ Typical Configurations and Role of Membranes in Water Reuse
  - ❒ Energy Footprint of Water Reuse Systems
  - ❒ Economics of Water Reuse Systems

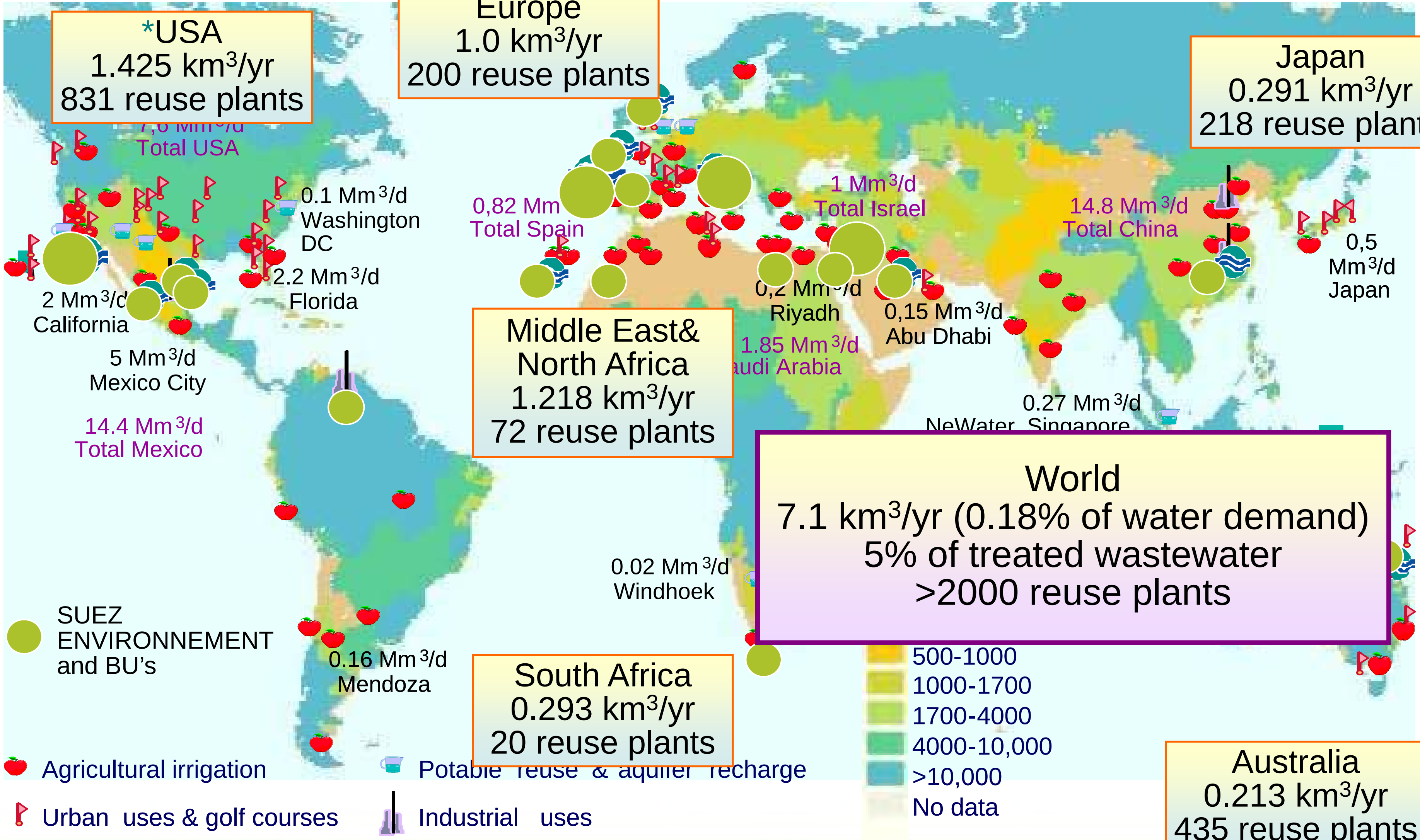
- Key Challenges and Solutions
  - ❒ Control of RO Membrane Fouling
  - ❒ Product Water Quality
  - ❒ Energy Use

Water Reuse Status and Trends

Water Reuse: a Global Trend towards Sustained Growth in All Continents

- **Recycled water** is becoming to be recognized as a **beneficial resource** and not a waste lost in the ocean
  - Policy targets for 20 to 100% recycling ratio of treated wastewater (Australia, California, Cyprus, Florida, Israel, Spain, Singapore)

Water Reuse: a Global Trend of Sustained Growth in All Continents



*USA
1.425 km³/yr
831 reuse plants

Europe
1.0 km³/yr
200 reuse plants

Japan
0.291 km³/yr
218 reuse plants

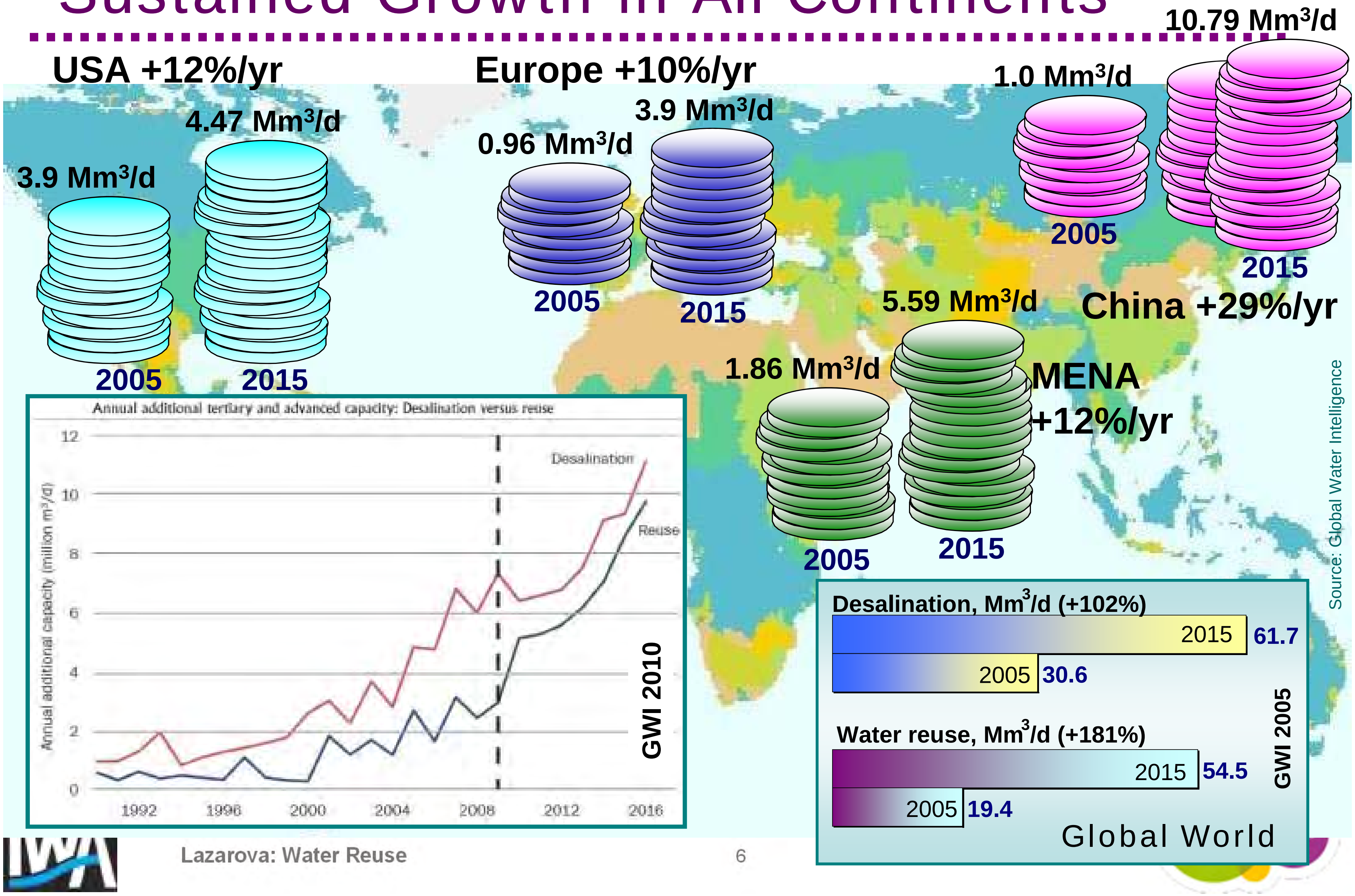
Middle East&
North Africa
1.218 km³/yr
72 reuse plants

World
7.1 km³/yr (0.18% of water demand)
5% of treated wastewater
>2000 reuse plants

South Africa
0.293 km³/yr
20 reuse plants

Australia
0.213 km³/yr
435 reuse plants

Water Reuse: a Global Trend towards Sustained Growth in All Continents



Source: Global Water Intelligence

Water Reuse: a Global Trend of Diversification of Water Reuse

Sustainable Water Cycles
Role and Benefits of Water Reuse

- **Economic value** of water is becoming an issue
- **Environmental value** of water is the channel to public education
- Trend towards one quality of water for one usage, **fit to use**
- Expensive **desalinated water** will have **to be used as many times as possible** through water reuse
- Recycled water becomes to be **recognized as a beneficial resource** and not a waste lost in the ocean
  - ❒ Targets for 20 to 100% recycling ratio of treated wastewater (Australia, California, Cyprus, Florida, Israel, Spain, etc.)

How to Manage Risks in Water Reuse Operation? = Hihg Water Quality + RELIABILITY

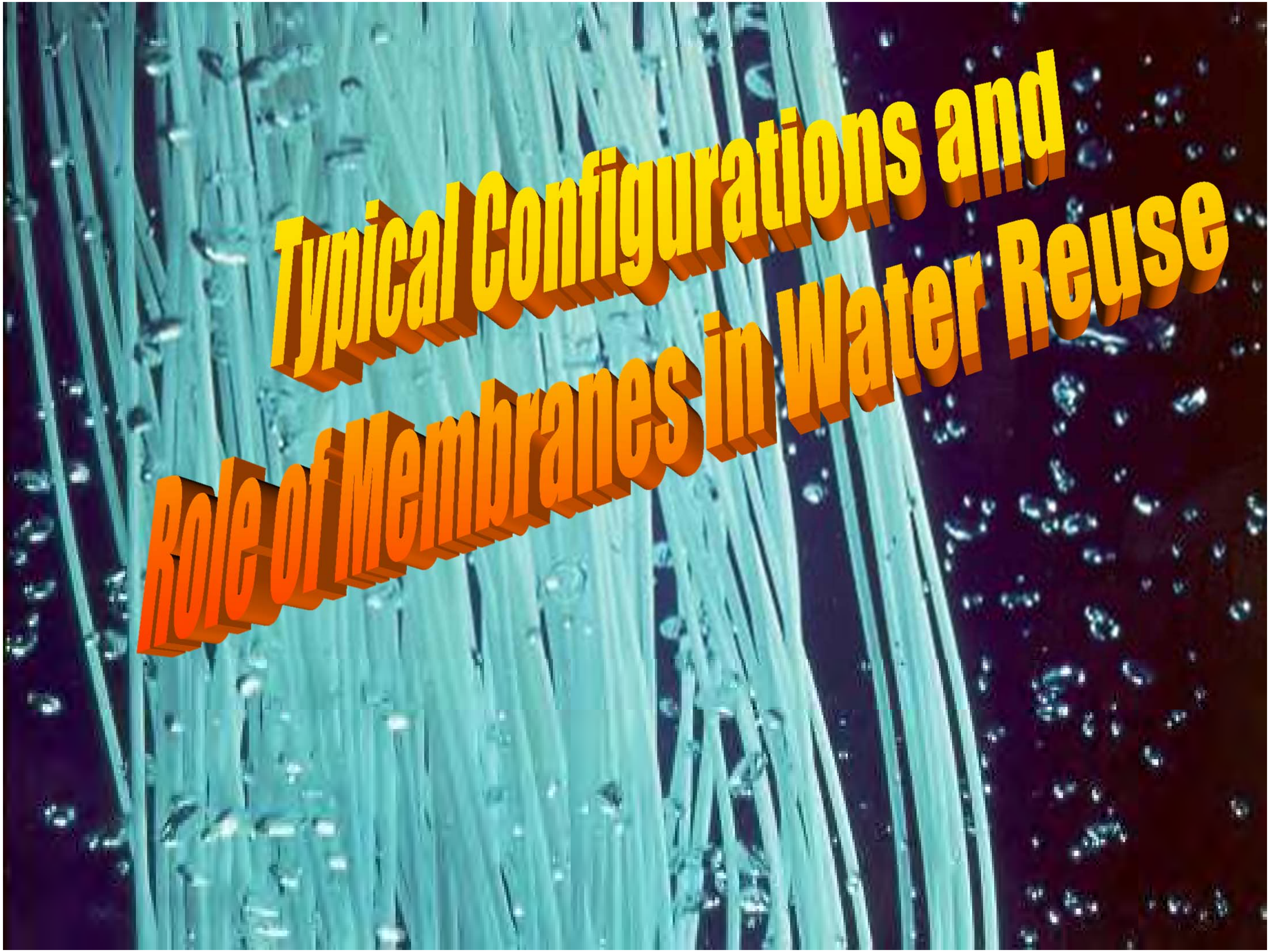
Adequate choice of treatment

\+

Good design

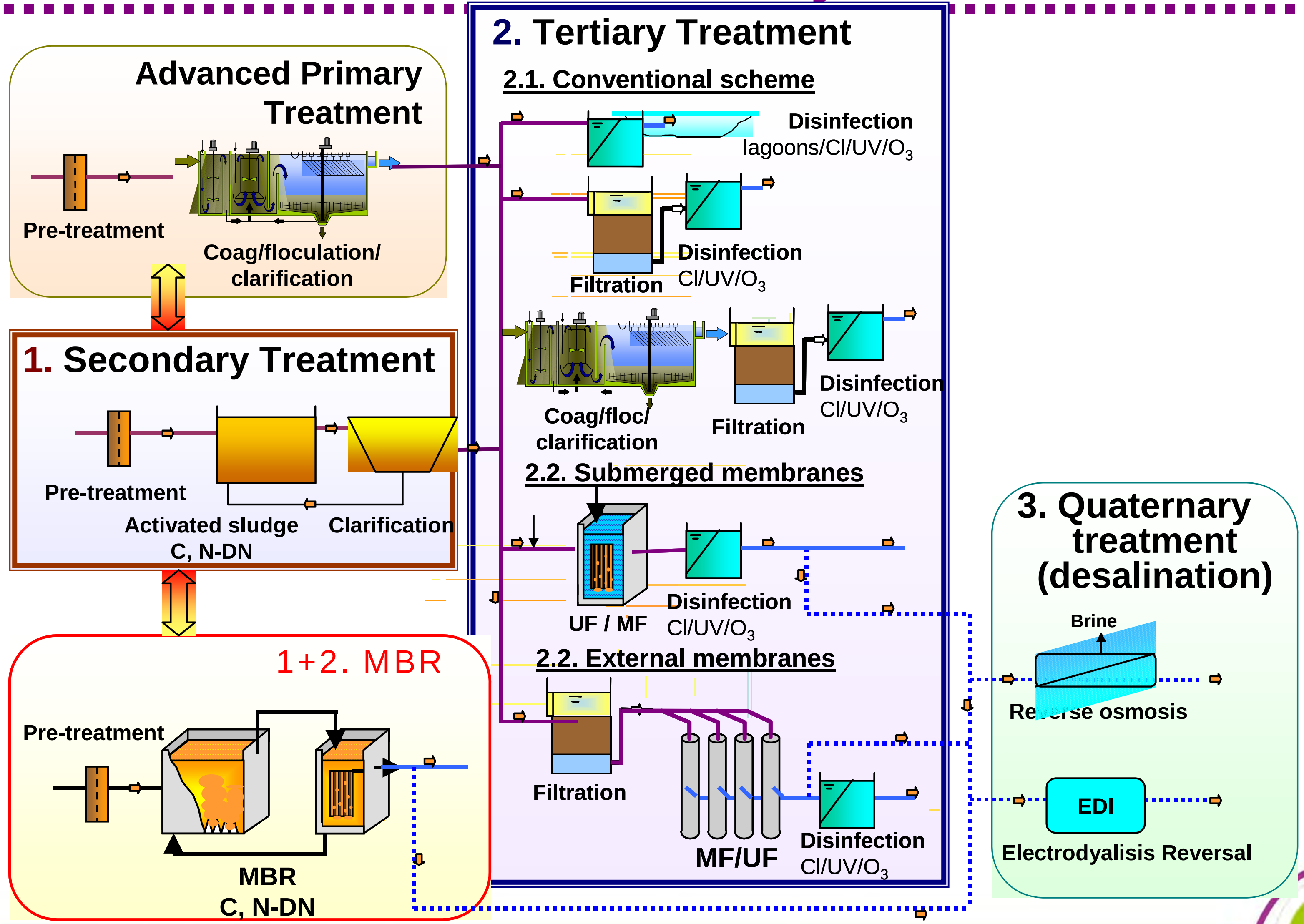
\+

Good operation



Typical Configurations and Role of Membranes in Water Reuse

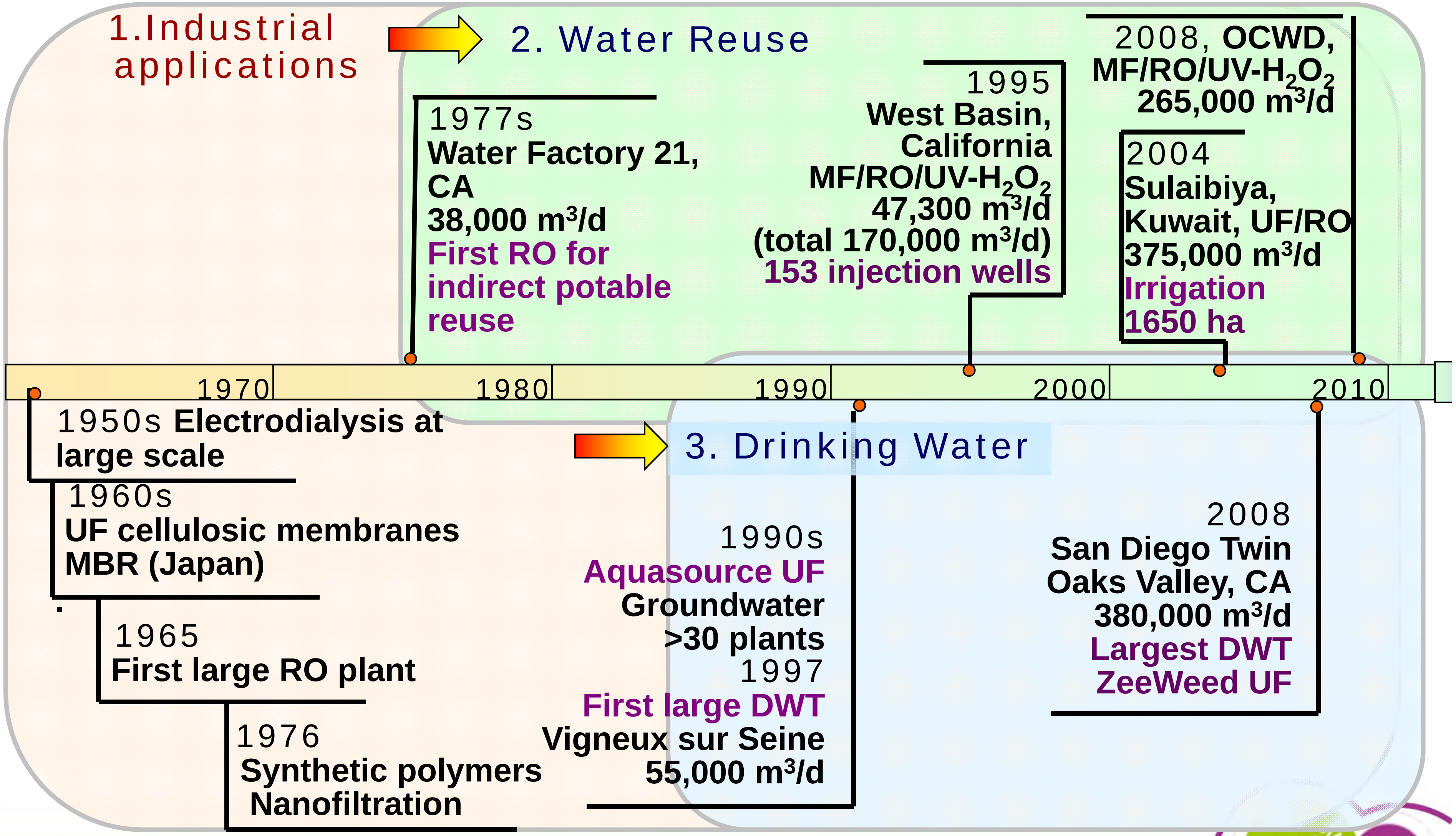
Integration of Membranes in Wastewater Treatment and Reuse Systems



Source: Lazarova et al. 2011

Implementation of Membrane Technologies

Milestones



1.Industrial applications

2. Water Reuse

1977s
Water Factory 21, CA
38,000 m³/d
First RO for indirect potable reuse

1995
West Basin, California
MF/RO/UV-H_2O_2
47,300 m³/d
(total 170,000 m³/d)
153 injection wells

2008, **OCWD,**
MF/RO/UV-H_2O_2
265,000 m³/d

2004
Sulaibiya, Kuwait, UF/RO
375,000 m³/d
Irrigation 1650 ha

1950s **Electrodialysis at large scale**

1960s
UF cellulosic membranes
MBR (Japan)

1965
First large RO plant

1976
Synthetic polymers
Nanofiltration

3. Drinking Water

1990s
Aquasource UF
Groundwater
>30 plants
1997
First large DWT
Vigneux sur Seine
55,000 m³/d

2008
San Diego Twin Oaks Valley, CA
380,000 m³/d
Largest DWT
ZeeWeed UF

Lessons Learned

Aquifer recharge, Orange County, California

Highlights

- **1976:** Water Factory 21 for seawater barrier (1976-2004), 57,000 m^3/d, 23 injection wells, **first RO in 1977**, 67% recycled water
- 2004-2008 Interim Water Factory MF/RO/UV (19,000 m^3/d)
- **2008**: Groundwater replenishment system, 265,000 m^3/d
  - Advanced Water Purification: MF / 3 stage TFC RO / UV+H_2O_2 / on-line monitoring
  - Extension of the seawater barrier with 100% recycled water and replenishment of existing spreading basins

Lessons Learned

Aquifer recharge, Orange County, California

Highlights

- **1976:** Water Factory 21 for seawater barrier (1976-2004), 57,000 m³/d, 23 injection wells, **first RO in 1977**, 67% recycled water
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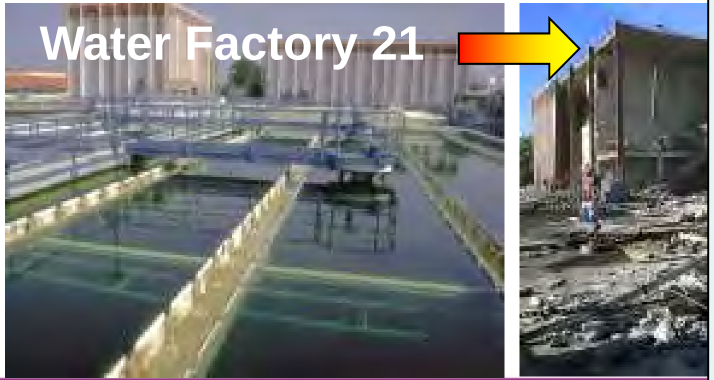
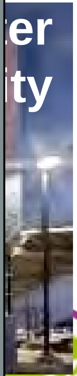
  - ❒ Advanced Water Purification: MF / 3 stage TFC RO / UV+H_2O_2 / on-line monitoring
  - ❒ Extension of the seaw water and replenishment of



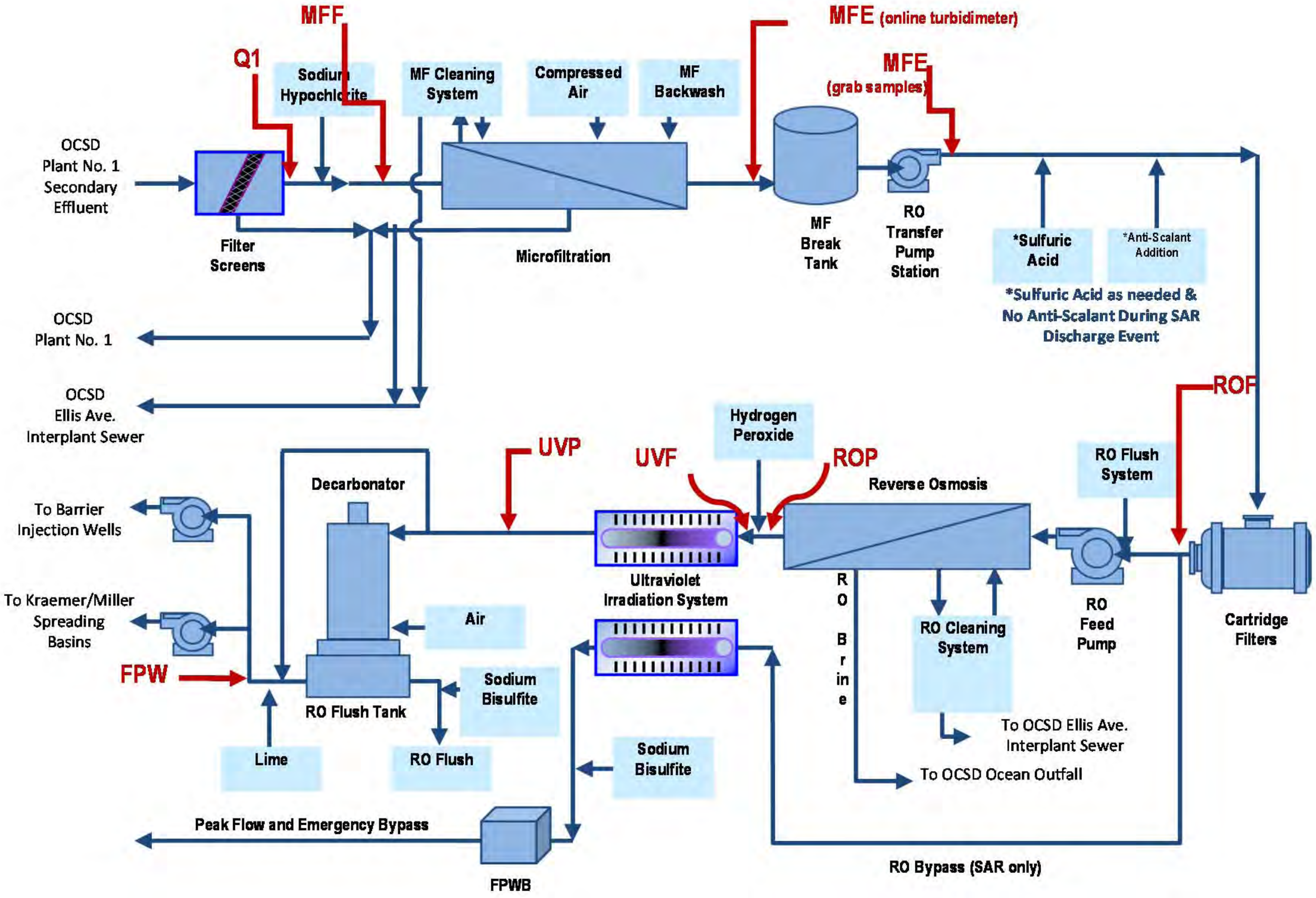
Key factors to success:

- Previous experience,
- Innovation and leading edge technology
- Stakeholder collaboration



Advanced Water Purification Facility Groundwater Replenishment System (CA)

Advanced Water Purification Facility (GWRS) Process Flow Diagram



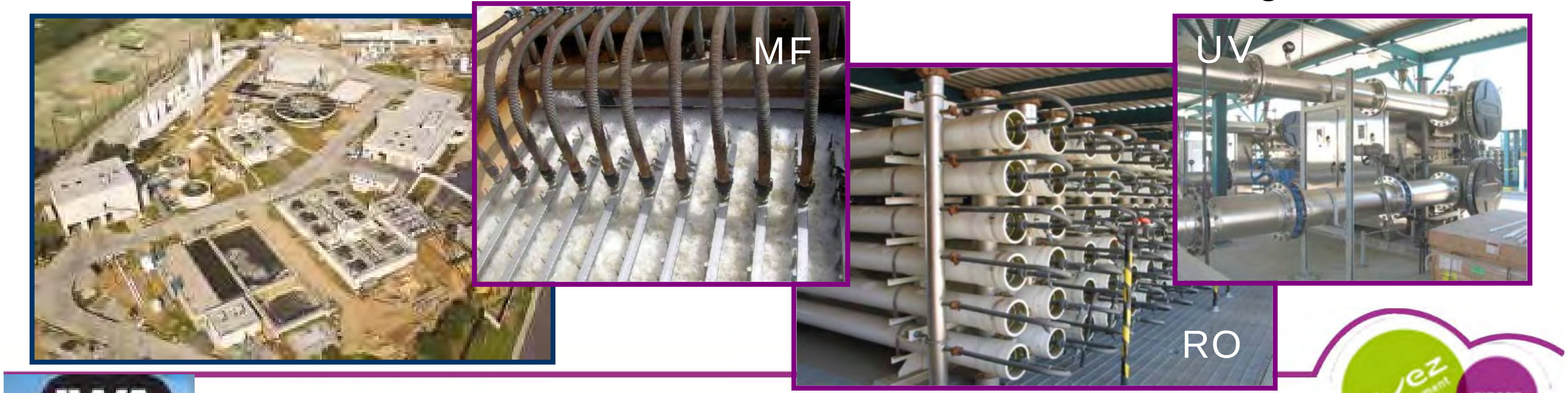
Source: Lazarova et al. 2012

Lessons Learned

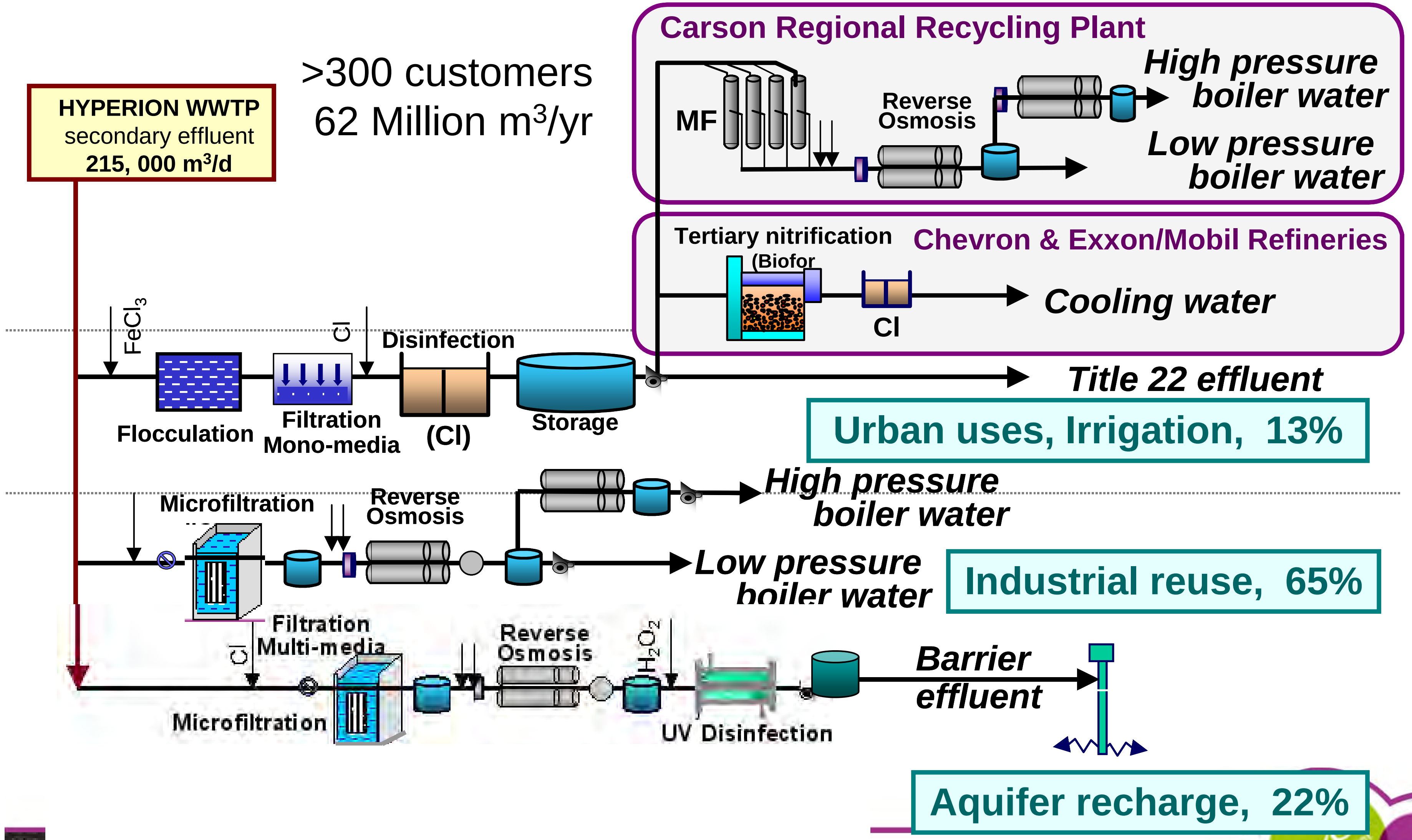
“Designer water”, West Basin, California (USA)

Highlights

- **1995:** West Basin WRP (The Edward C. Little WRP), ~**First MF/RO**, 47,300 m^3/d (five types of “designer” water, total 170,000 m^3/d) 153 injection wells
- **Step by step implementation** with permits for injection of 35% initially to currently 75% of recycled water
  - Advanced Water Treatment MF/RO/UV+H_2O_2/ on-line monitoring
  - Pilot studies and evolution of membrane technologies



Edward C. Little Water Recycling Facilities (CA) Treatment Trains and Satellite Plants



HYPERION WWTP
secondary effluent
215, 000 m^3/d

>300 customers
62 Million m^3/yr

Carson Regional Recycling Plant

Chevron & Exxon/Mobil Refineries

Urban uses, Irrigation, 13%

Industrial reuse, 65%

Aquifer recharge, 22%

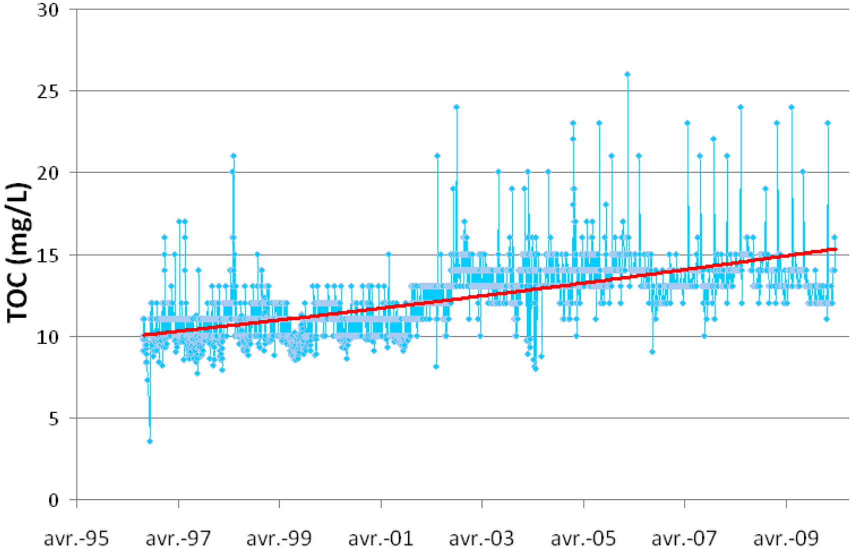
Lessons Learned

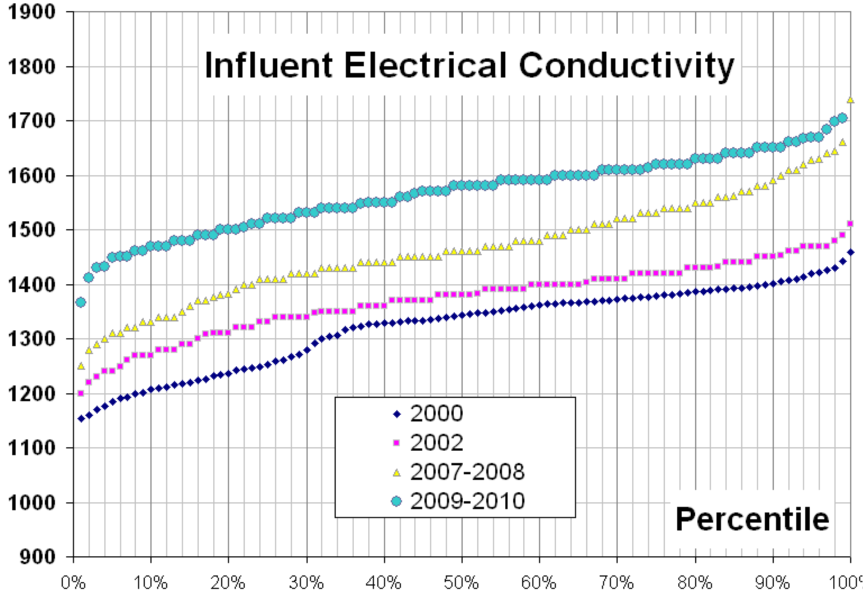
West Basin, California (USA)

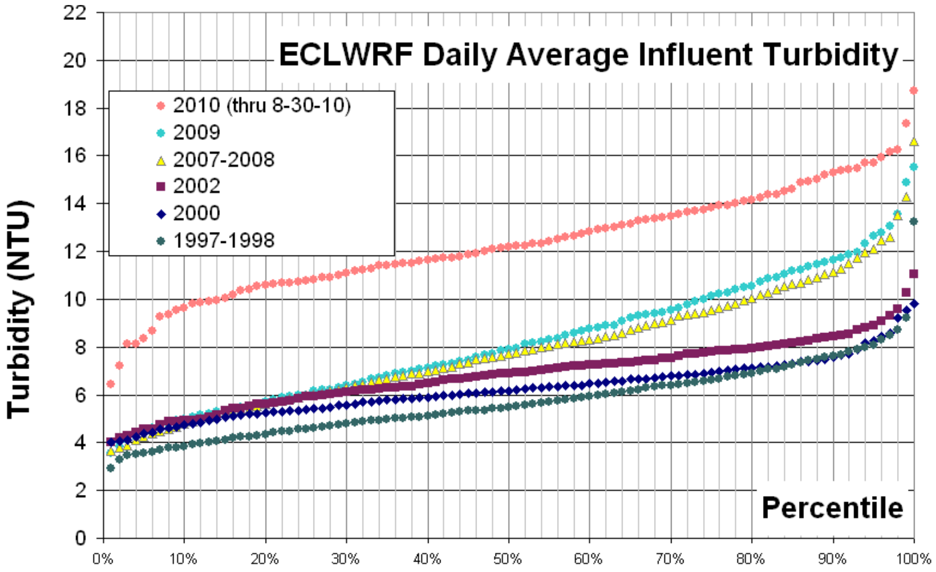
- Chevron El Segundo Refinery: Largest Single User of Reclaimed Water in California
  - ❒ 19,000 m^3/d of recycled water (**MF/RO** and **MF/RO/RO**)
  - ❒ 80% of the water supply
  - ❒ Applications: cooling towers, landscape irrigation and dust control
  - ❒ In 2010: on-site advanced RWTP, x2 reclaimed water uses

Major Technical Challenges
Maintain High Recycled Water Quality

- Deterioration of influent quality (secondary effluent)
  - +50% increase in TOC
  - +30% increase of conductivity
  - +100% increase of turbidity (impact on membrane fouling)
  - High variations

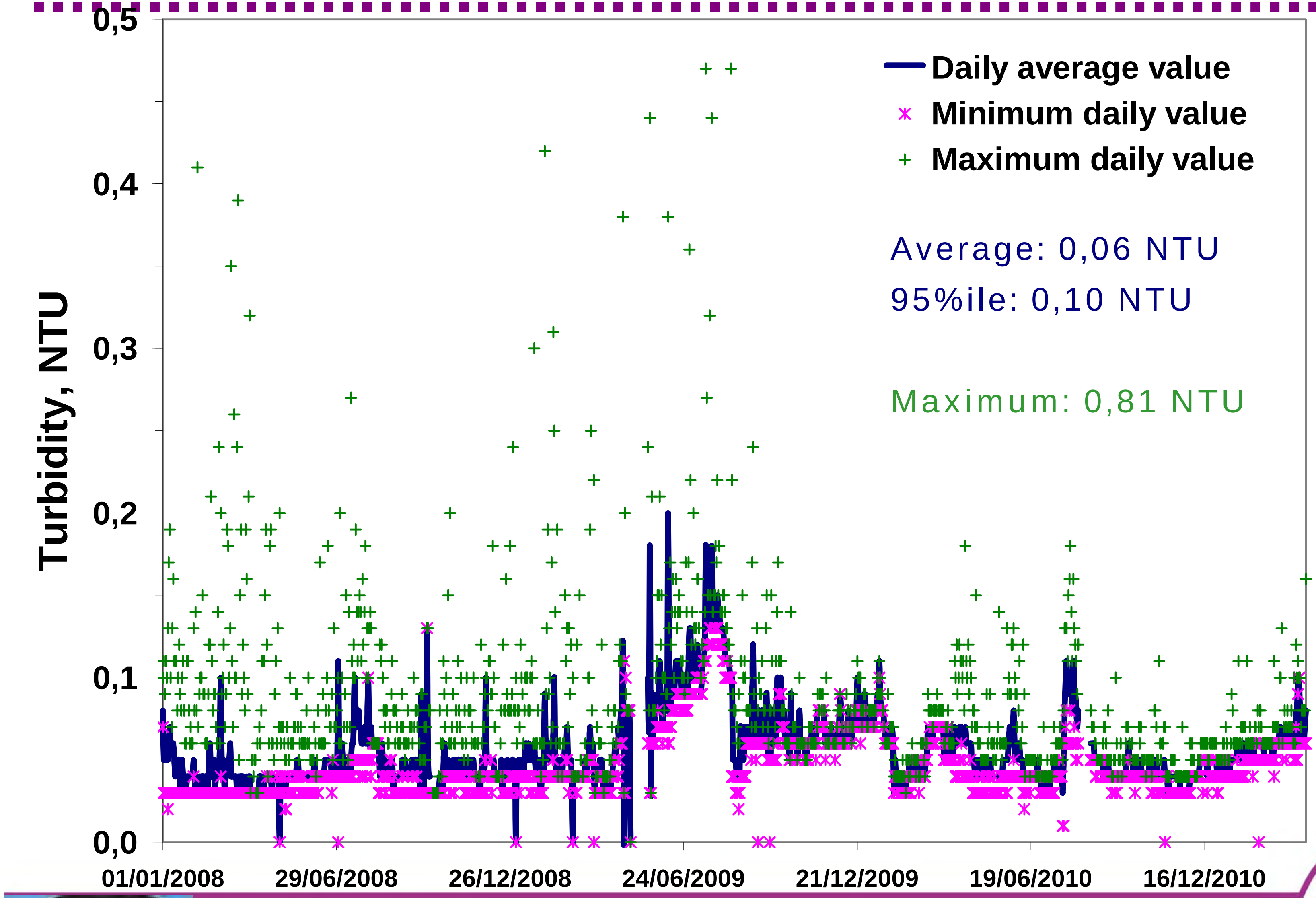






Source: Lazarova et al. 2011

Barrier Product Water: Turbidity



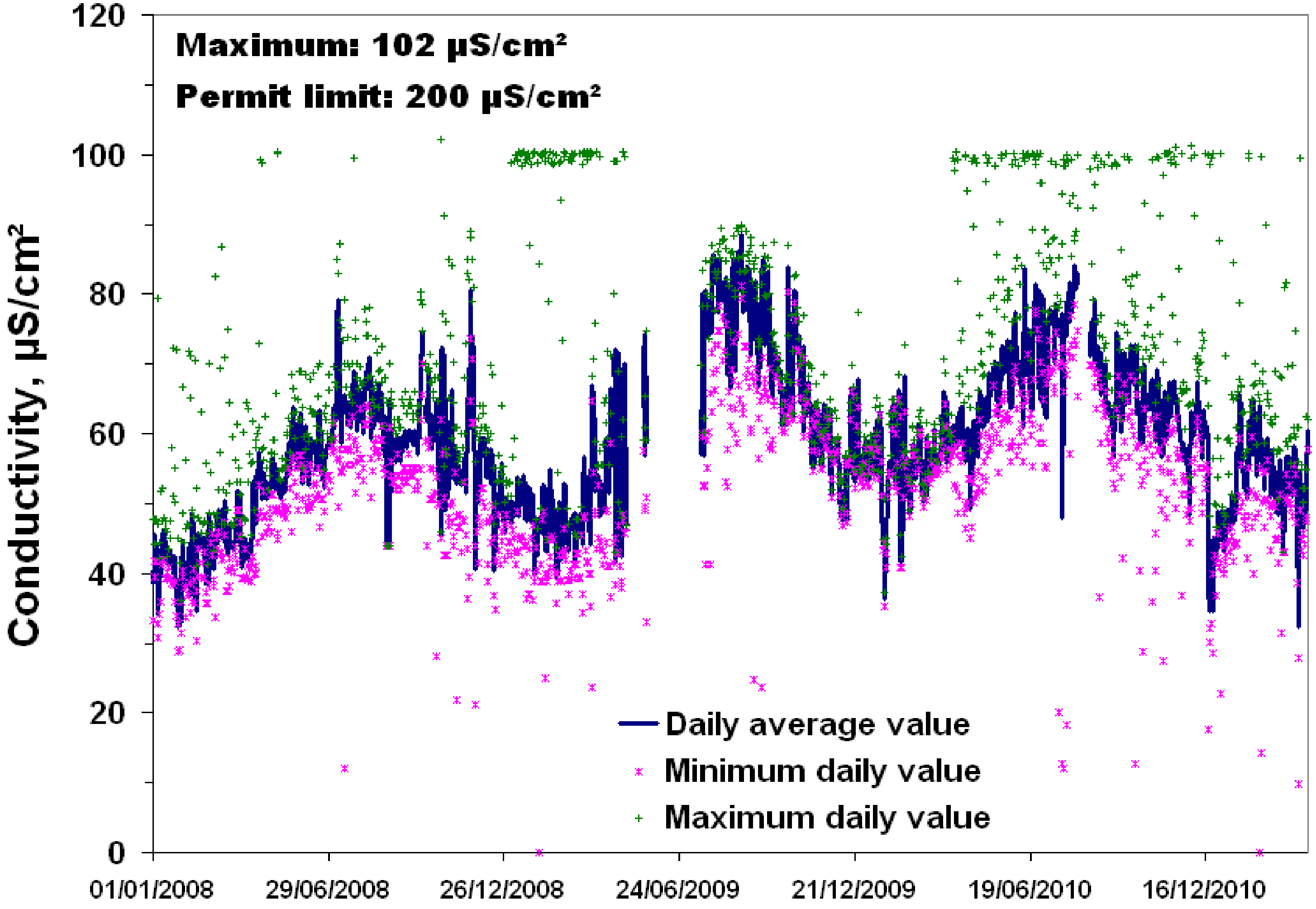
Average: 0,06 NTU

95%ile: 0,10 NTU

Maximum: 0,81 NTU

Source: Lazarova et al. 2011

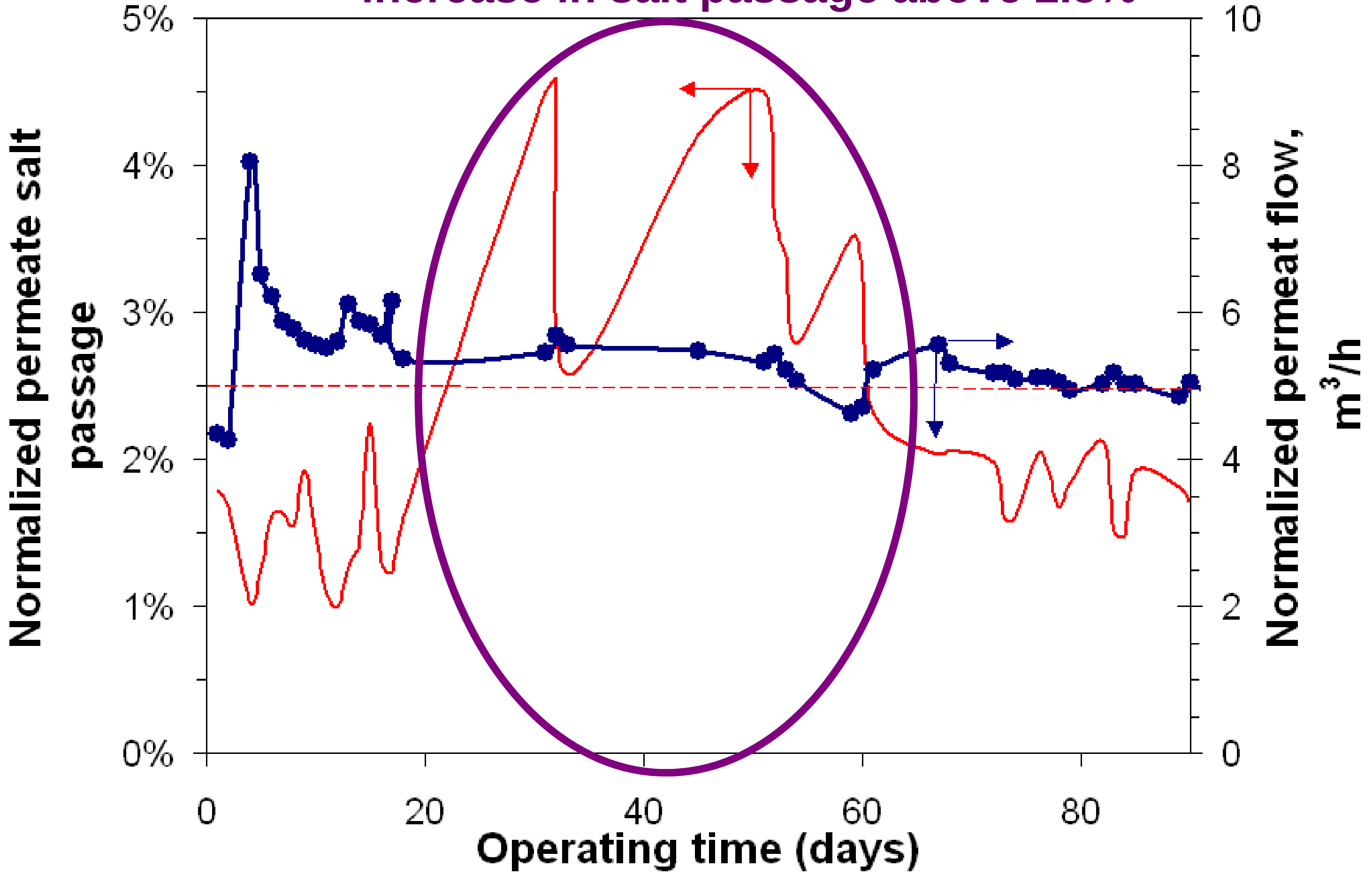
Barrier Product Water: Conductivity



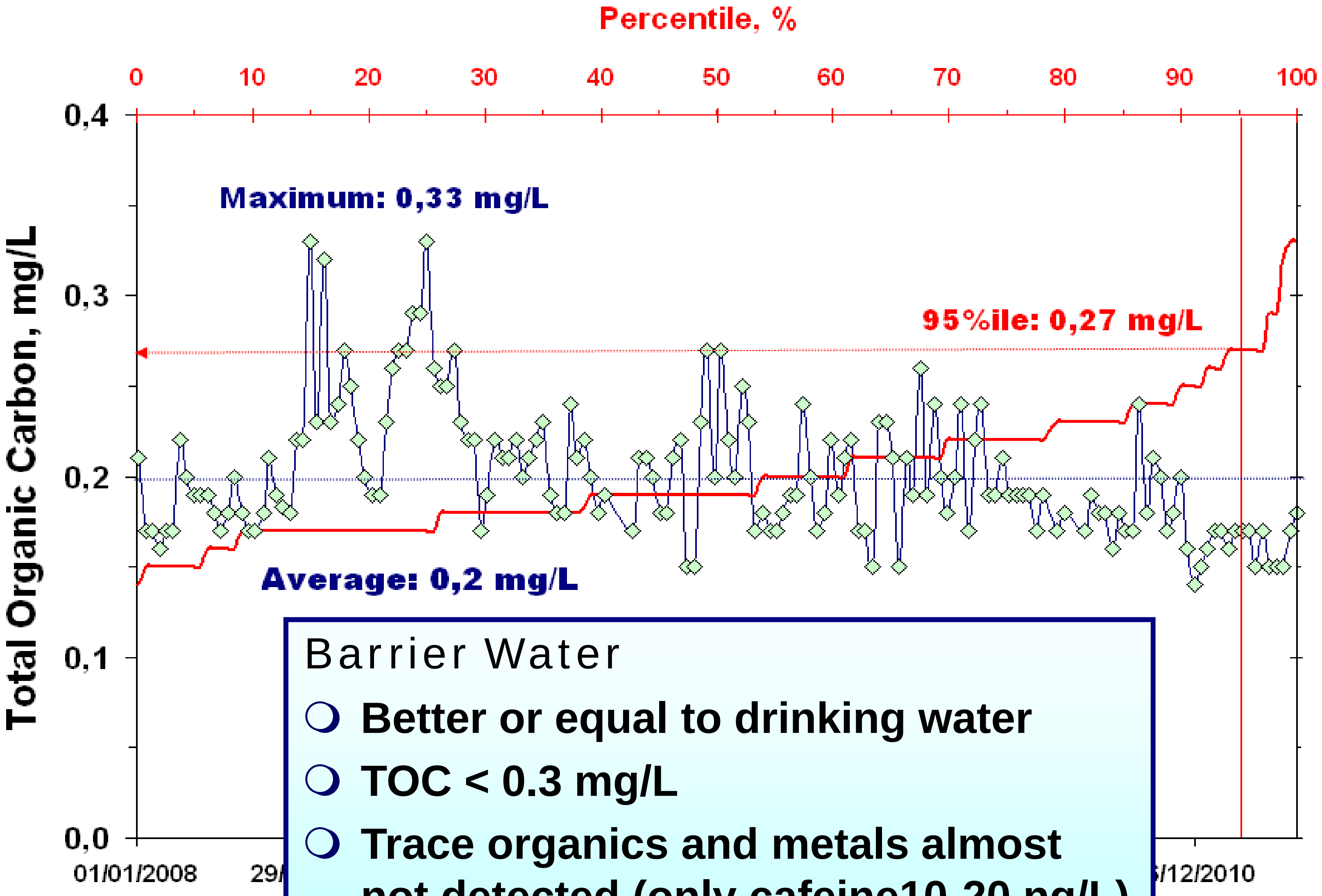
Source: Lazarova et al. 2011

Influence of salinity on membrane performance

High salinity leads to significant decrease in membrane flux combined to increase in salt passage above 2.5%



Barrier Product Water: TOC



Barrier Water

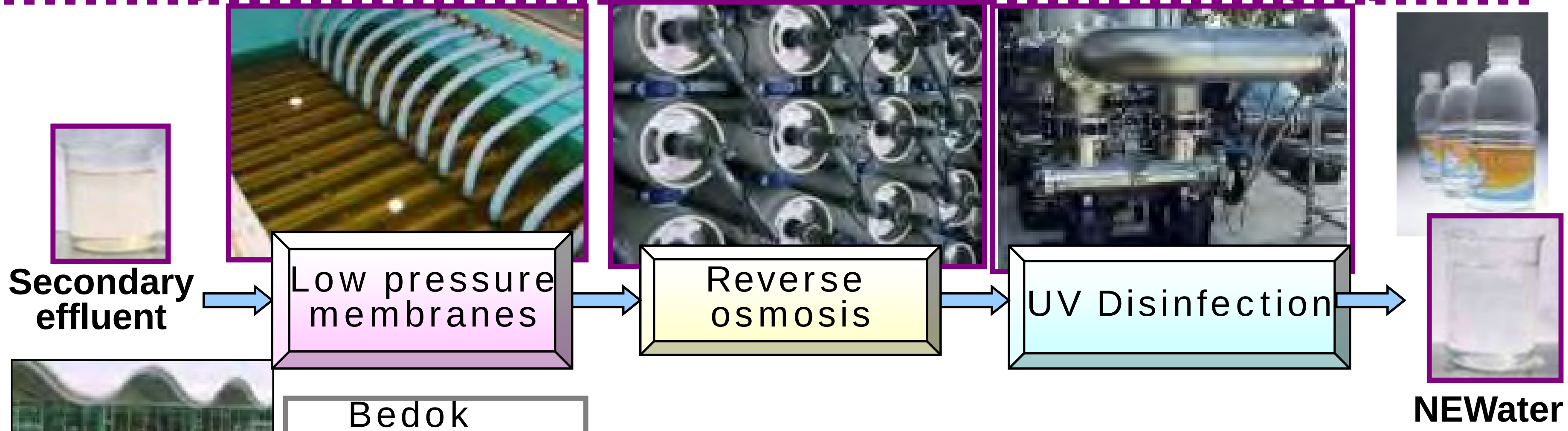
- Better or equal to drinking water
- TOC < 0.3 mg/L
- Trace organics and metals almost not detected (only cafeine10-20 ng/L)

Source: Lazarova et al. 2011

Edward C. Little Water Recycling Facility

Lessons Learned

Integrated solutions, NEWater Singapore



Secondary effluent → Low pressure membranes → Reverse osmosis → UV Disinfection → NEWater

Bedok	42,500 m³/d	max 117,000 m³/d	Jan 2003
Kranji	53,000 m³/d	max 72,000 m³/d	Jan 2003
Seletar	24,000 m³/d	max 40,000 m³/d	2004
Ulu Pandan	116,000 m³/d	max 140,000 m³/d	DBOO Dec 2006
Changi	69,000 m³/d	max 800,000 m³/d	2009

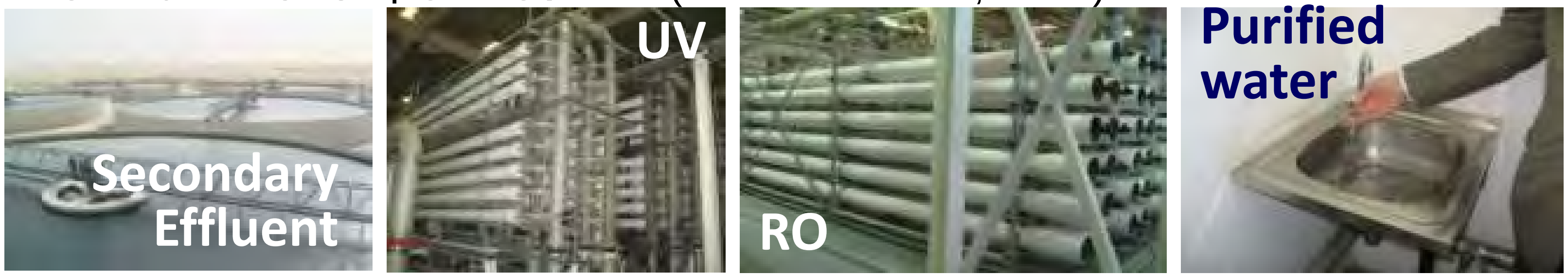
Industrial +
Indirect Potable Reuse

↳ **30% of the Singapore's water supply by 2015**

Lessons Learned

Agricultural irrigation, Sulaibiya WWTP (Kuwait)

- Key figures: start-up in 2004, 375,000 m^3/d, **UF/RO** (<2.2TC/100 mL), irrigation of 1,680 ha, 2 reservoirs of 170,000 m^3, Capex US$ 442 million or $0.78/$m^3$, charge for farmers $0.15/$m^3$ (Alhumoud et al., 2010)



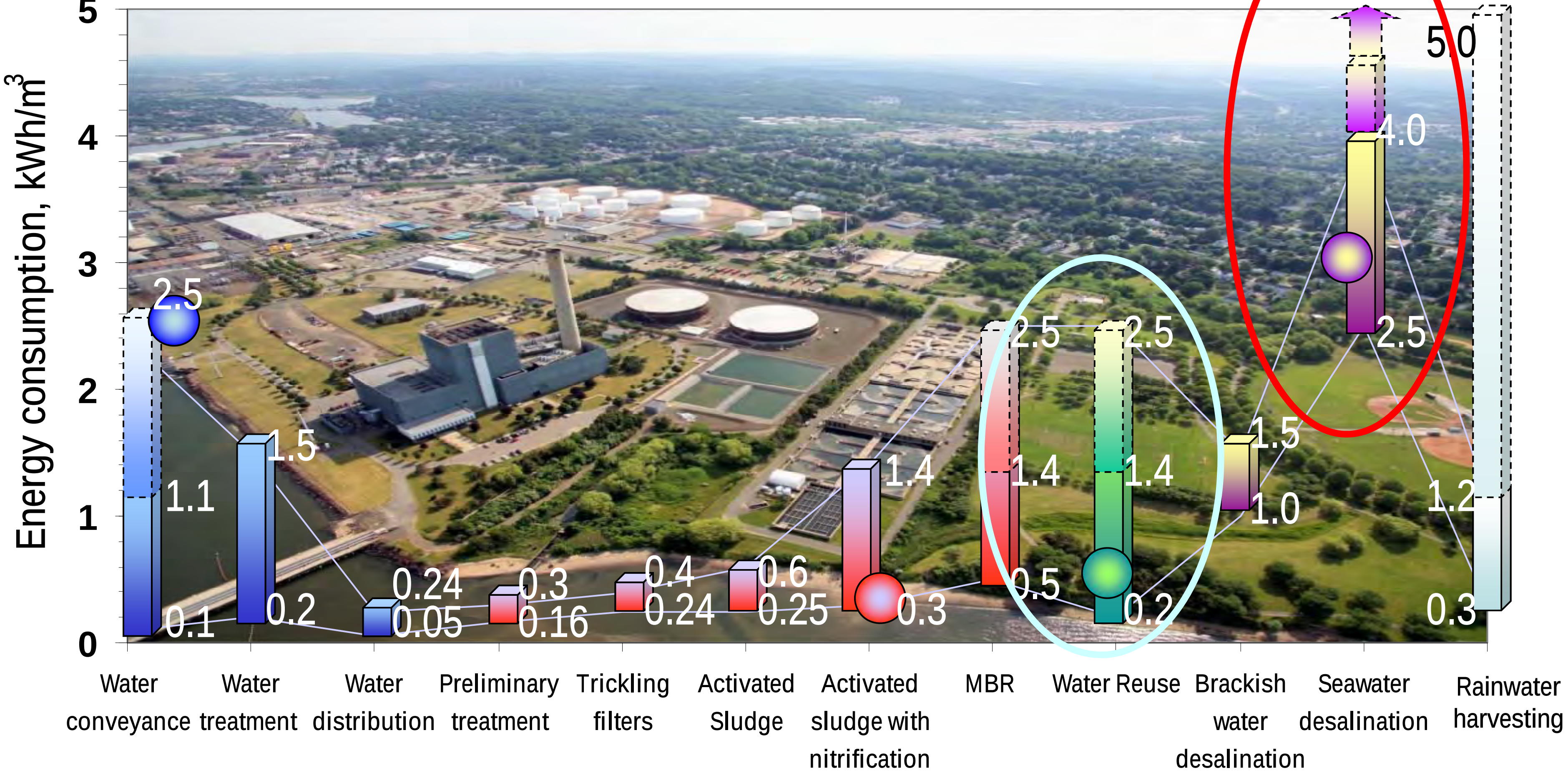
Membranes in Water Reuse
Lessons Learned

- **Keys to success**: ability to produce high-quality recycled water and improve public acceptance
  - Compliance with stringent water reuse regulations (disinfection)
  - Removal of trace organics (indirect potable reuse) and salts & inorganic micropollutants (industrial reuse)
- **Major challenges**
  - **Reliability of operation:** failure modes are not well documented, pre-treatment was underestimated
  - **Fouling control:** the first generation of MF and RO were not well adapted to wastewater quality
  - **Energy consumption:** need to be reduced
- **Innovation**: new membranes, better process control

Energy Footprint of Water Reuse

Water Reuse versus Desalination

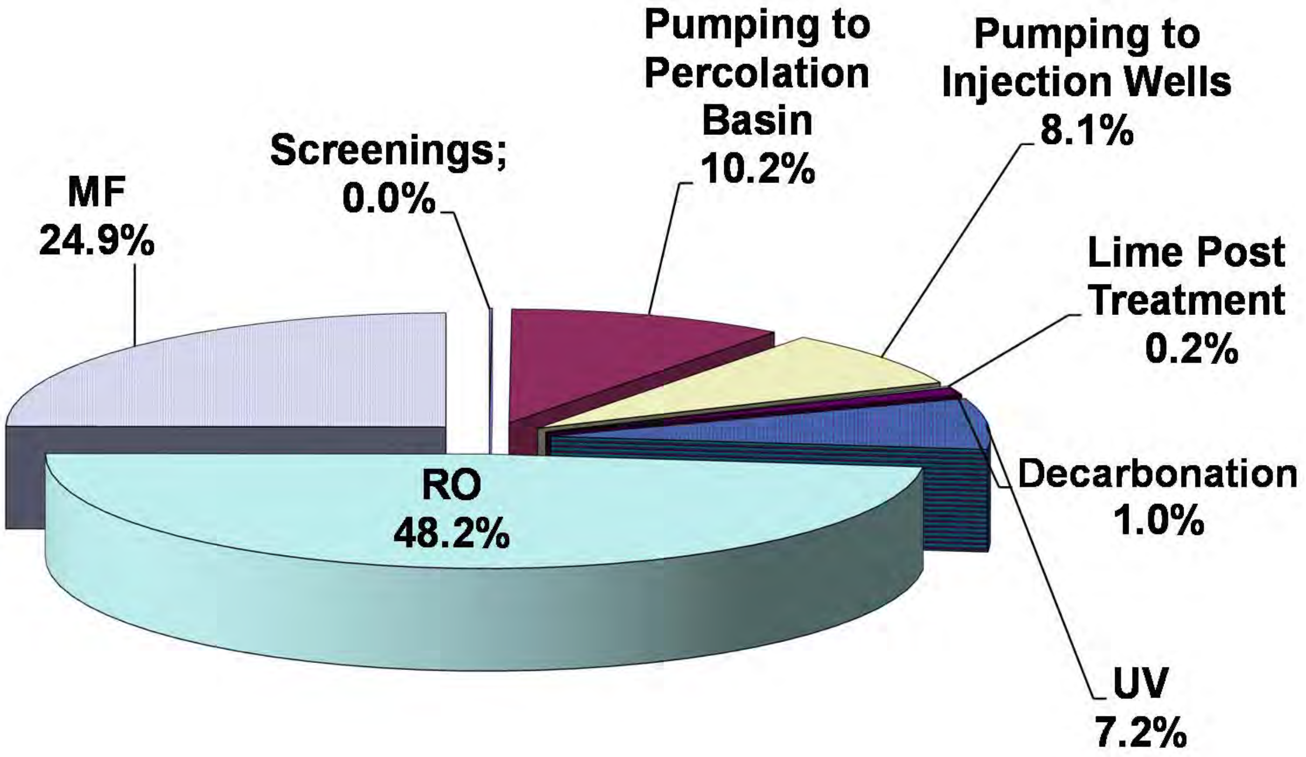
Energy Footprint of Water Resources



Source: Lazarova et al. 2012

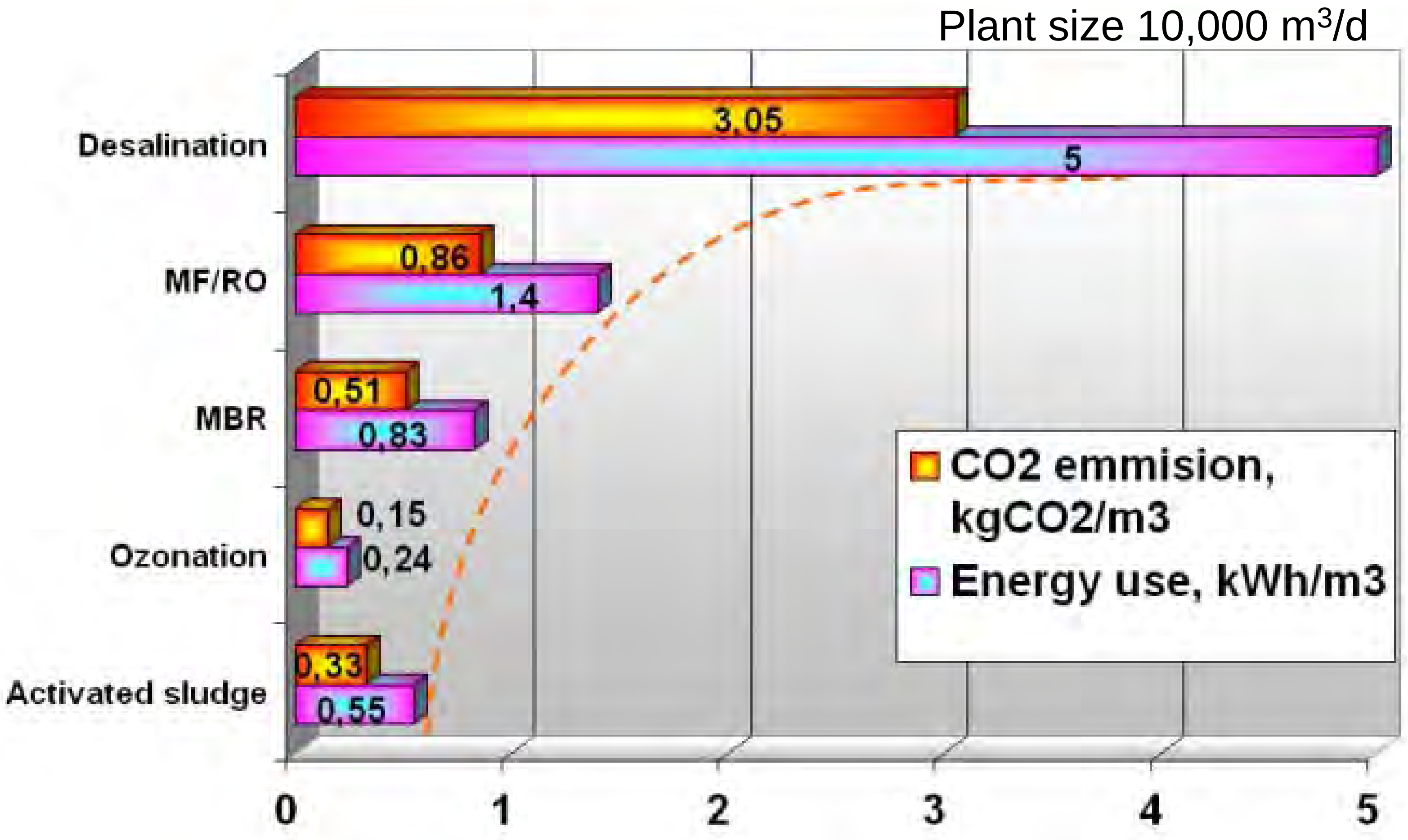
Energy Footprint
Typical Breakdown in MF/RO systems

- Advanced Purification facility in Orange County (CA): RO process is the main source of power consumption: 48.2% or 0.53 kWh/m^3



Source: Lazarova et al. 2012

Energy Footprint
Influence of the Treatment Process

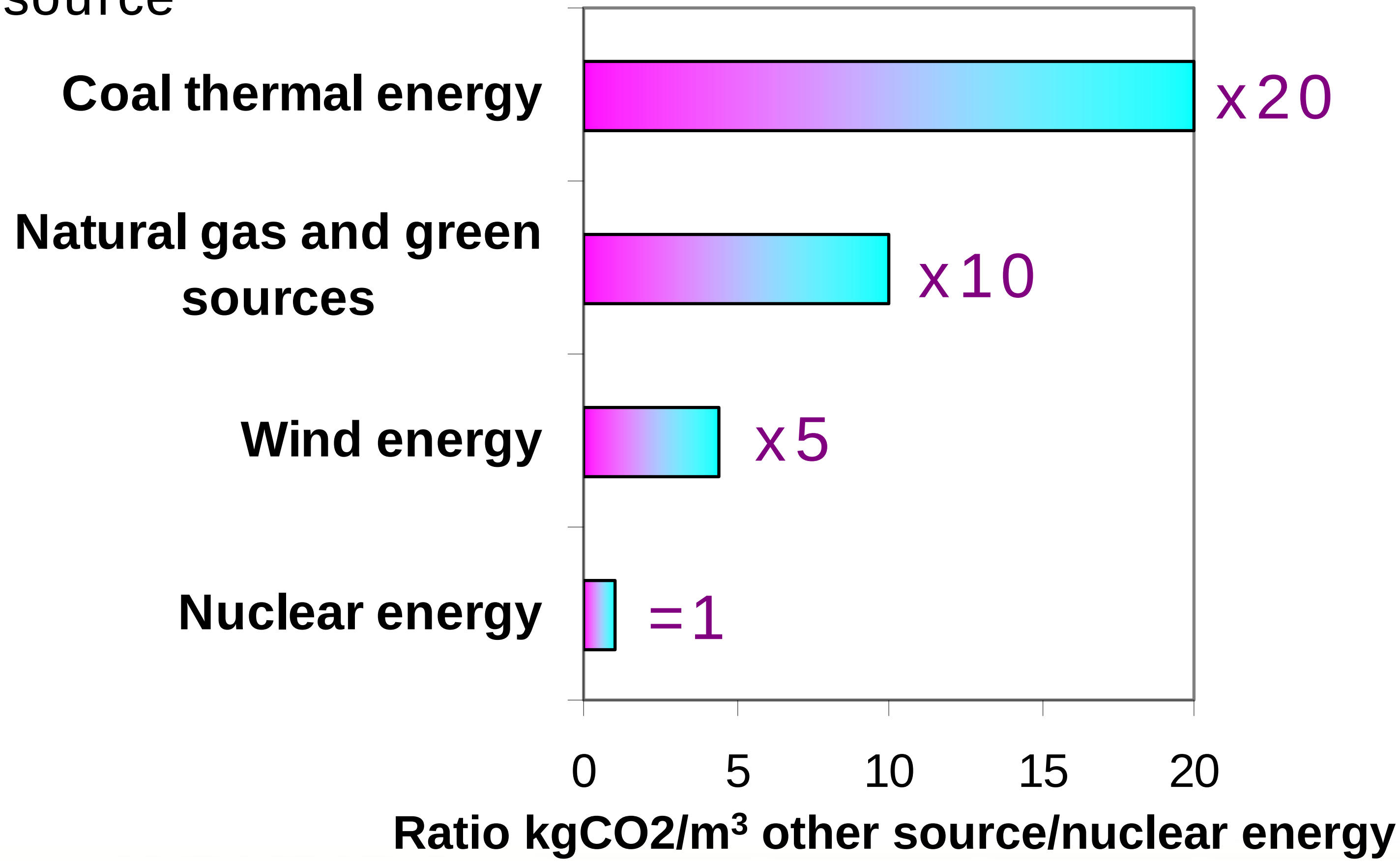


Source: Adapted from Novotny, 2010

LCA Analysis and Environmental Footprint

Influence of the Energy Sources

- Ratio between GHG emissions of a medium size **advanced recycling plant** (MF/RO/UV+H_20_2) as a function of the energy source

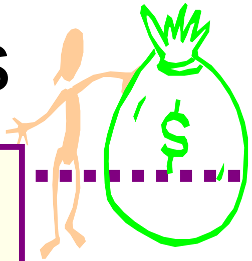


Economics of Water Reuse Systems

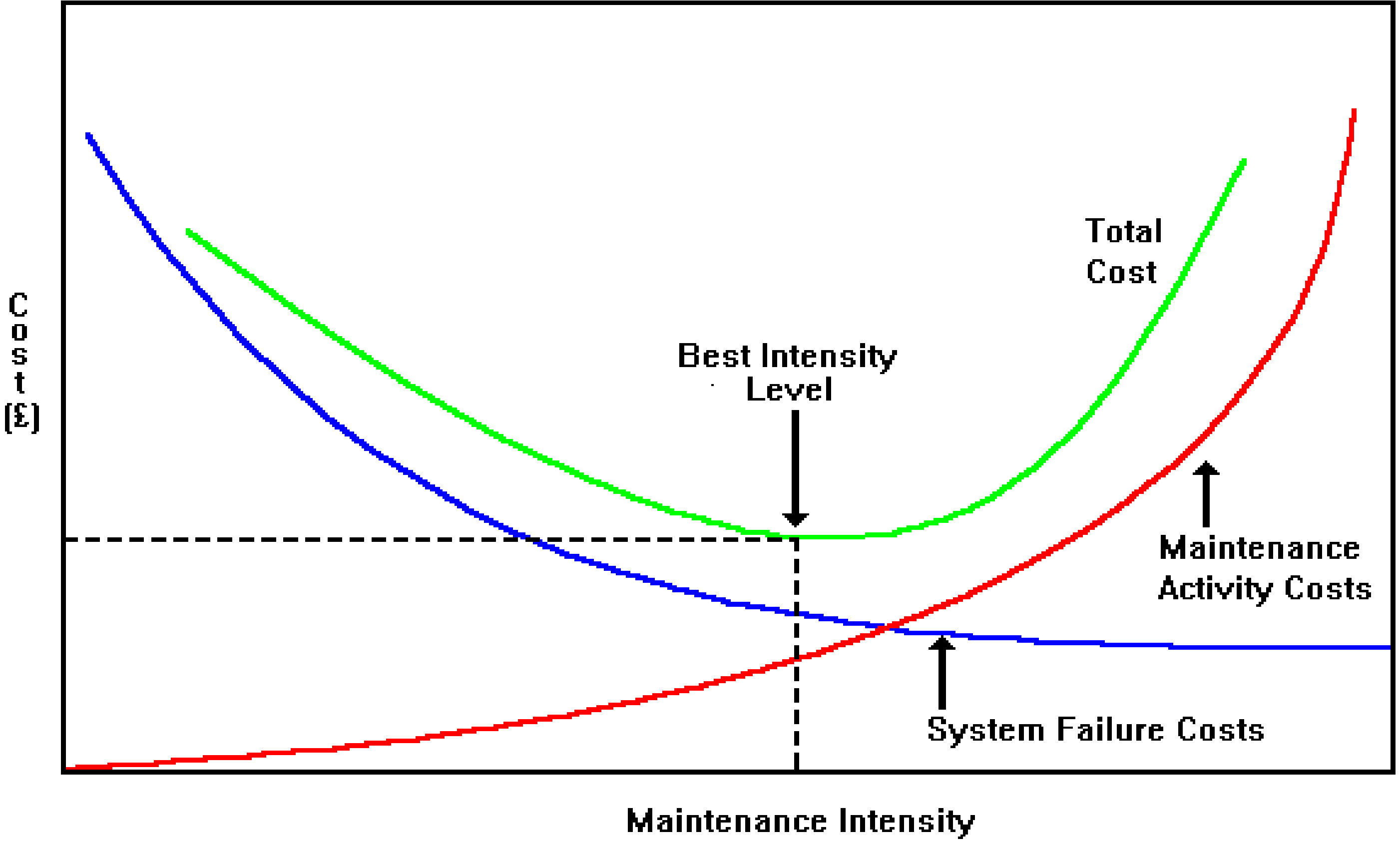
Economic Concerns of Water Reuse

- **Cost of recycled water** infrastructure:
  - ❐ additional treatment, distribution and
  - ❐ O&M costs
- Inadequate water pricing: subsidised water price and/or low price of water for farmers, for example
- **Difficult revenue and cost-recovery**: uncertain water reuse patterns
- **Seasonal variations** in demand and need for large storage capacity for the majority of irrigation projects
- Change in the market (agriculture, industry) can affect water reuse programs

Risks of Failure versus O&M Costs

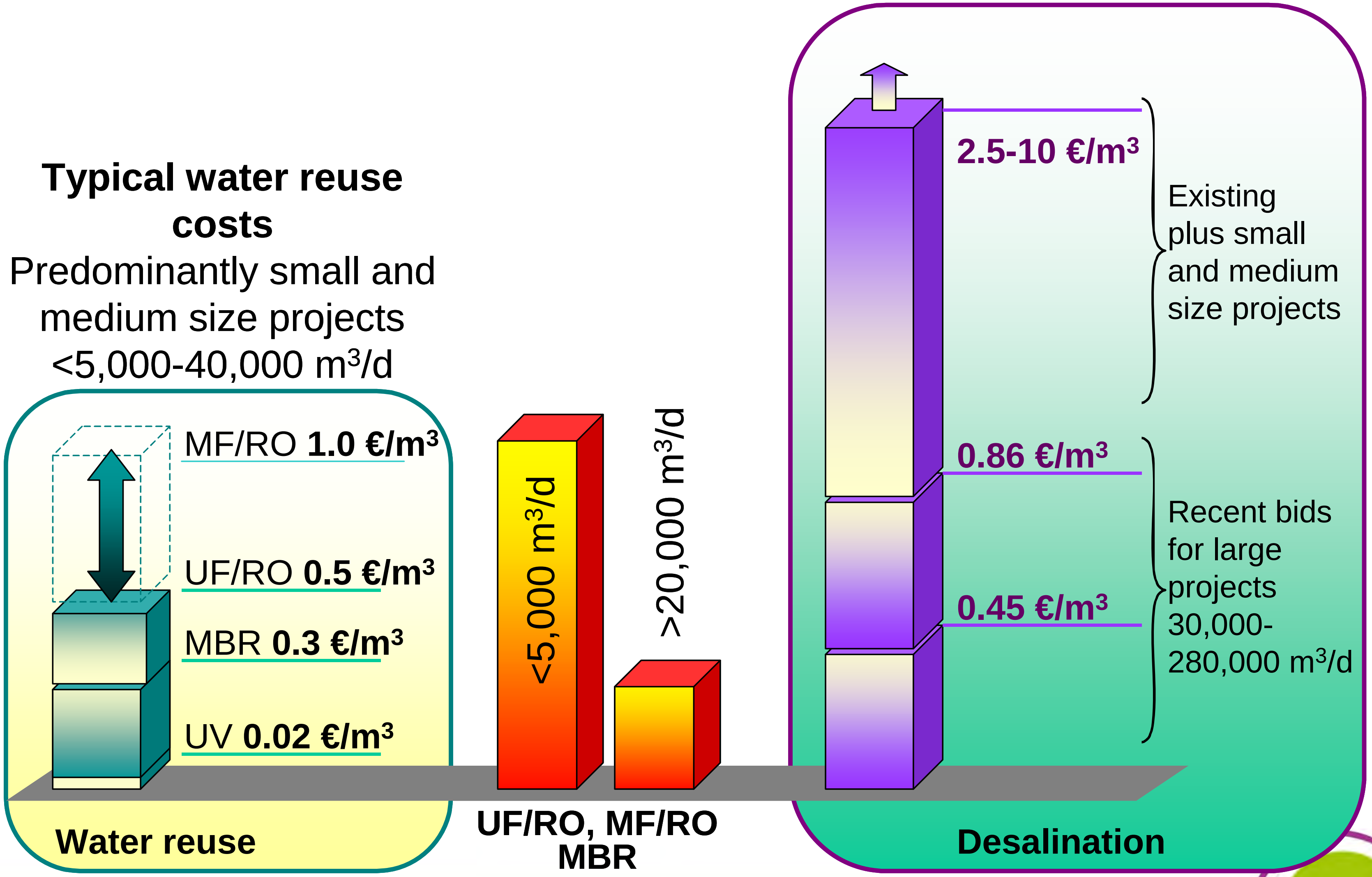


- Risks of failures should be minimised with reasonable O&M costs



Water Reuse versus Desalination
Comparison of Life Costs

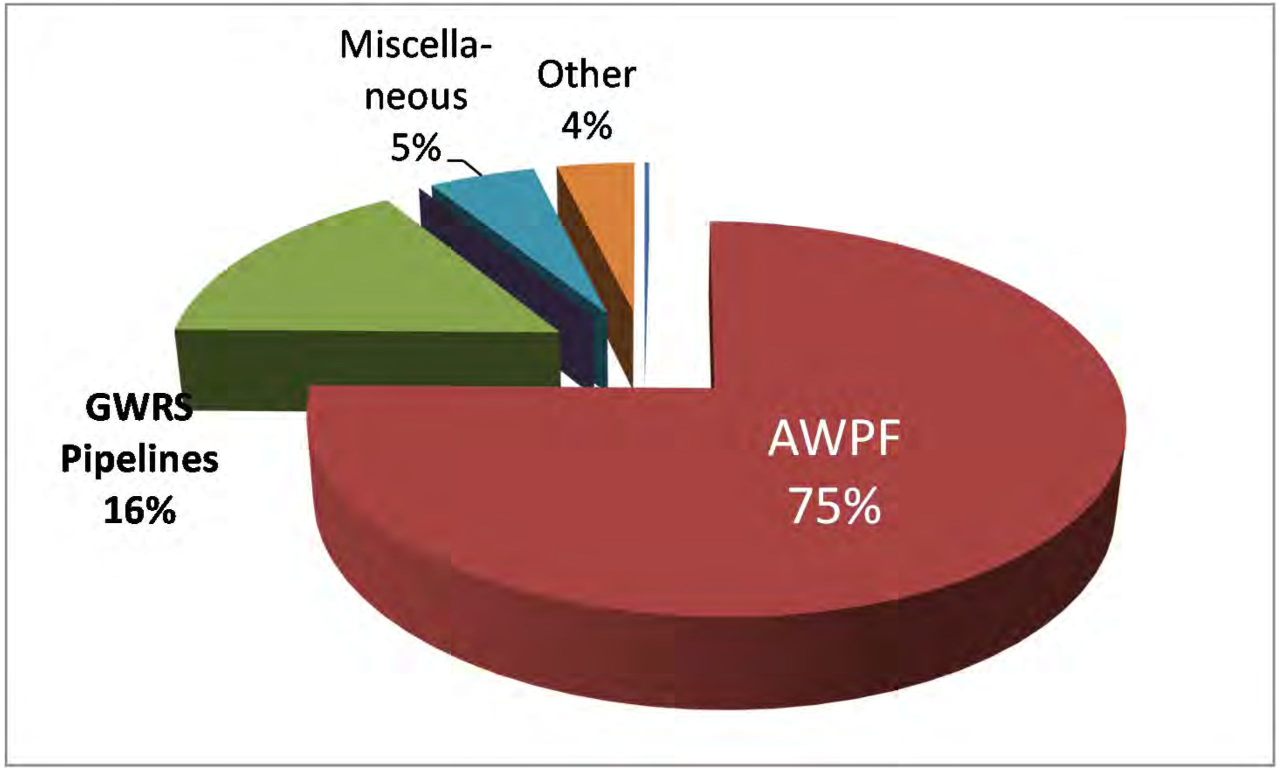
Typical water reuse costs
Predominantly small and medium size projects
<5,000-40,000 m³/d



Water Reuse Costs

Typical Breakdown of Capex of MF/RO

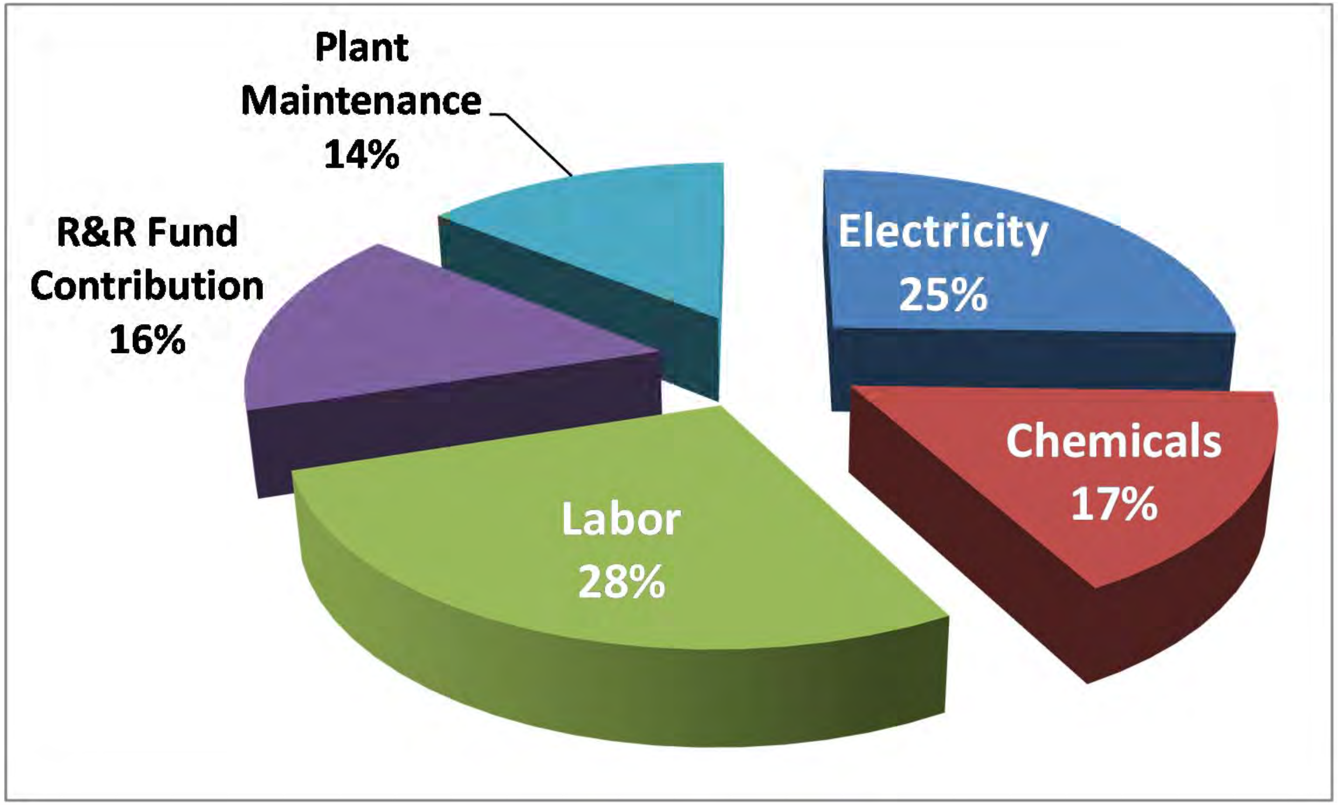
- Advanced Purification facility in Orange County (CA): Advanced Purification Facility is the main component 75%, followed by distribution networks, 16%



Source: Lazarova et al. 2012

Water Reuse Costs
Typical Breakdown of Opex of MF/RO

- Advanced Purification facility in Orange County (CA): Labor and electricity are the main components, e.g. 28 and 25%, followed by chemicals 17% and maintenance 14%



Source: Lazarova et al. 2012

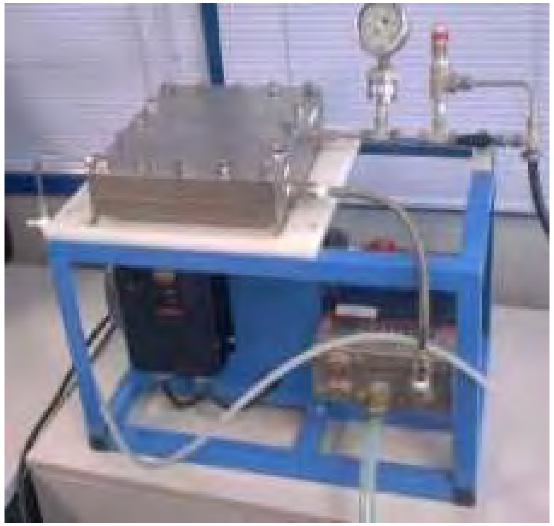
Key Challenges and Solutions

Membrane Fouling
Tools for Investigation: Membrane autopsy

- The most common way to understand the causes of the loss of membrane permeability and flux
- To allow evaluating both membrane polymer condition and foulant nature

Membrane Fouling
Methodology of Investigation

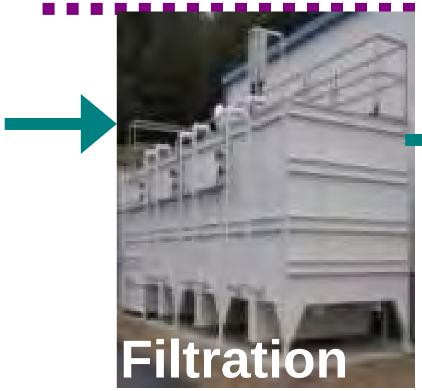
- Visual inspection and test of membrane integrity
- Estimate membrane permeability and rejection properties using a testing unit or a flat sheet test rig
- Observations by electronic microscopy of the state of the polymer and deposits
- Characterization of deposits
  - Fourier Transmission by Infrared (FTIR)
  - X-ray Photoelectron Spectroscopy (XPS)
  - scanning electron microscope (SEM) connected to energy dispersive X-ray analysis (EDAX)
  - Magnetic Nuclear Resonance
  - X-Ray Diffraction

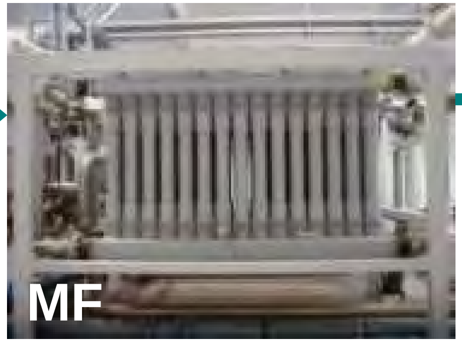


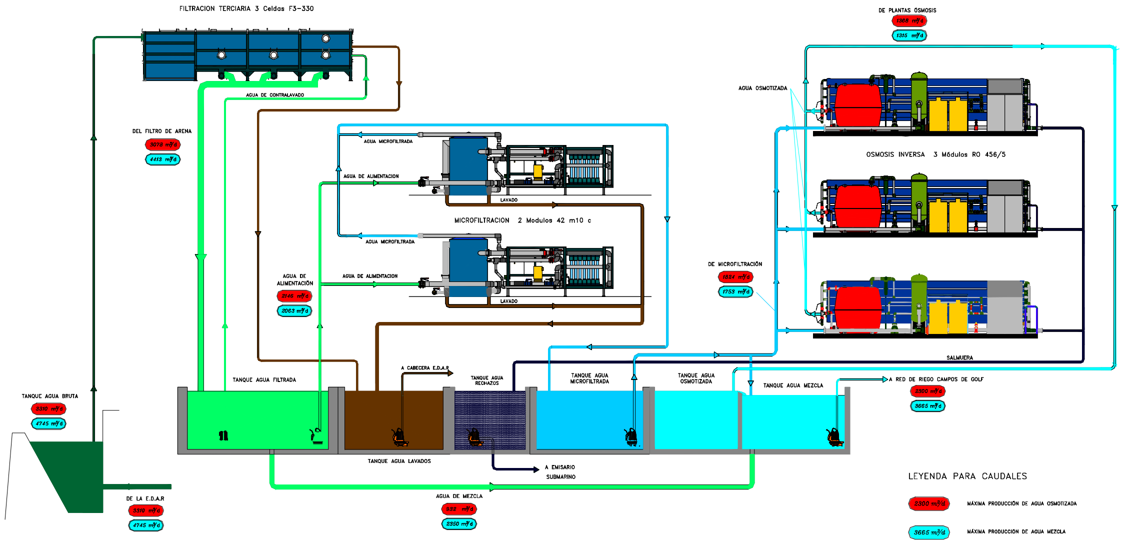
Flat sheet test rig

Lessons Learned

8 Full scale MF/RO treatment plants in Spain



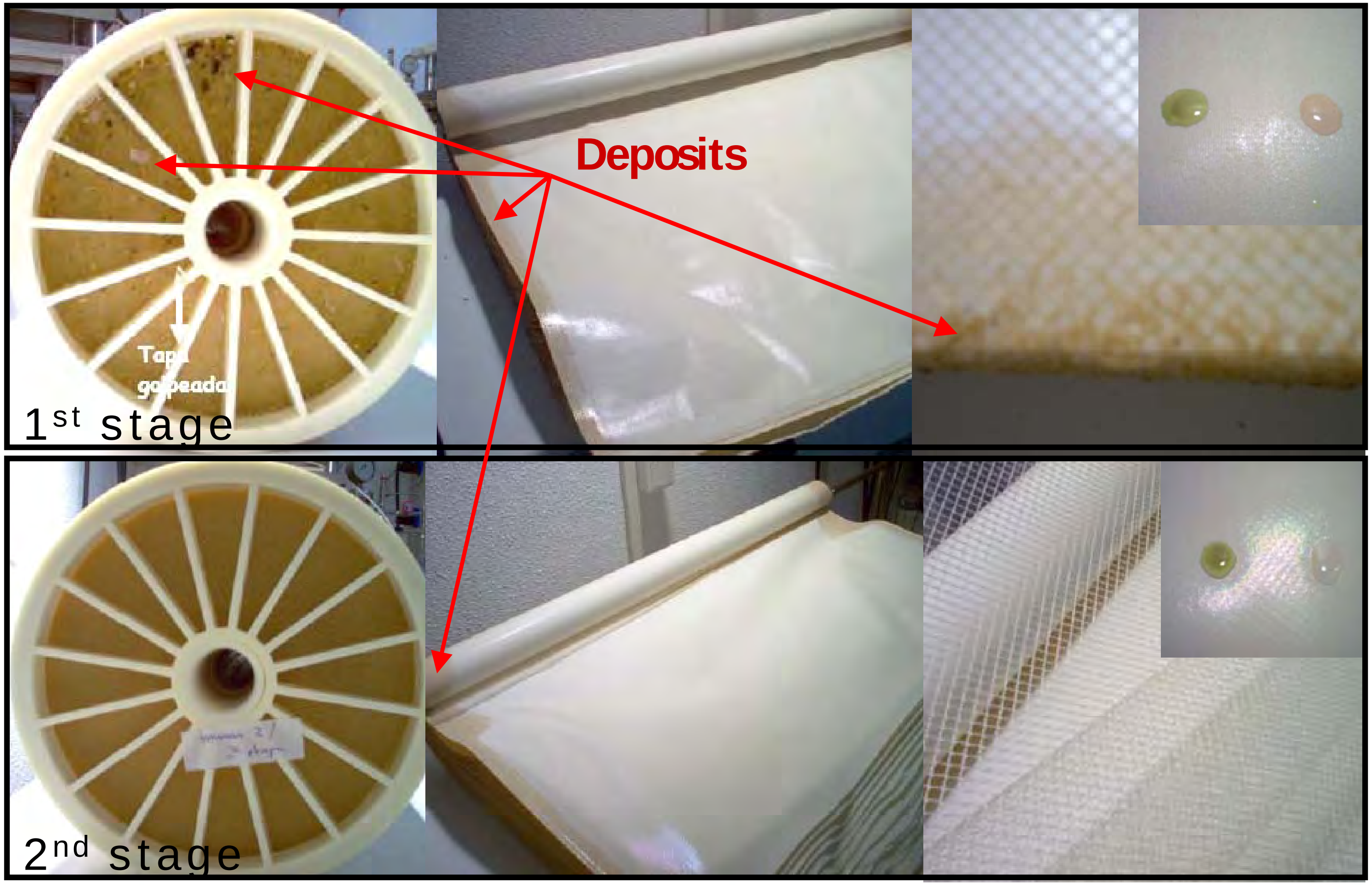




- Start-up 2001 to 2004
- 4800 to 12,000 m^3/d
- External MF, Memcor M10C, (0.2 µm, 1.5 bar)
- RO 2 and 3 steps with Dow Filmtec BW 365FR, 12 bars

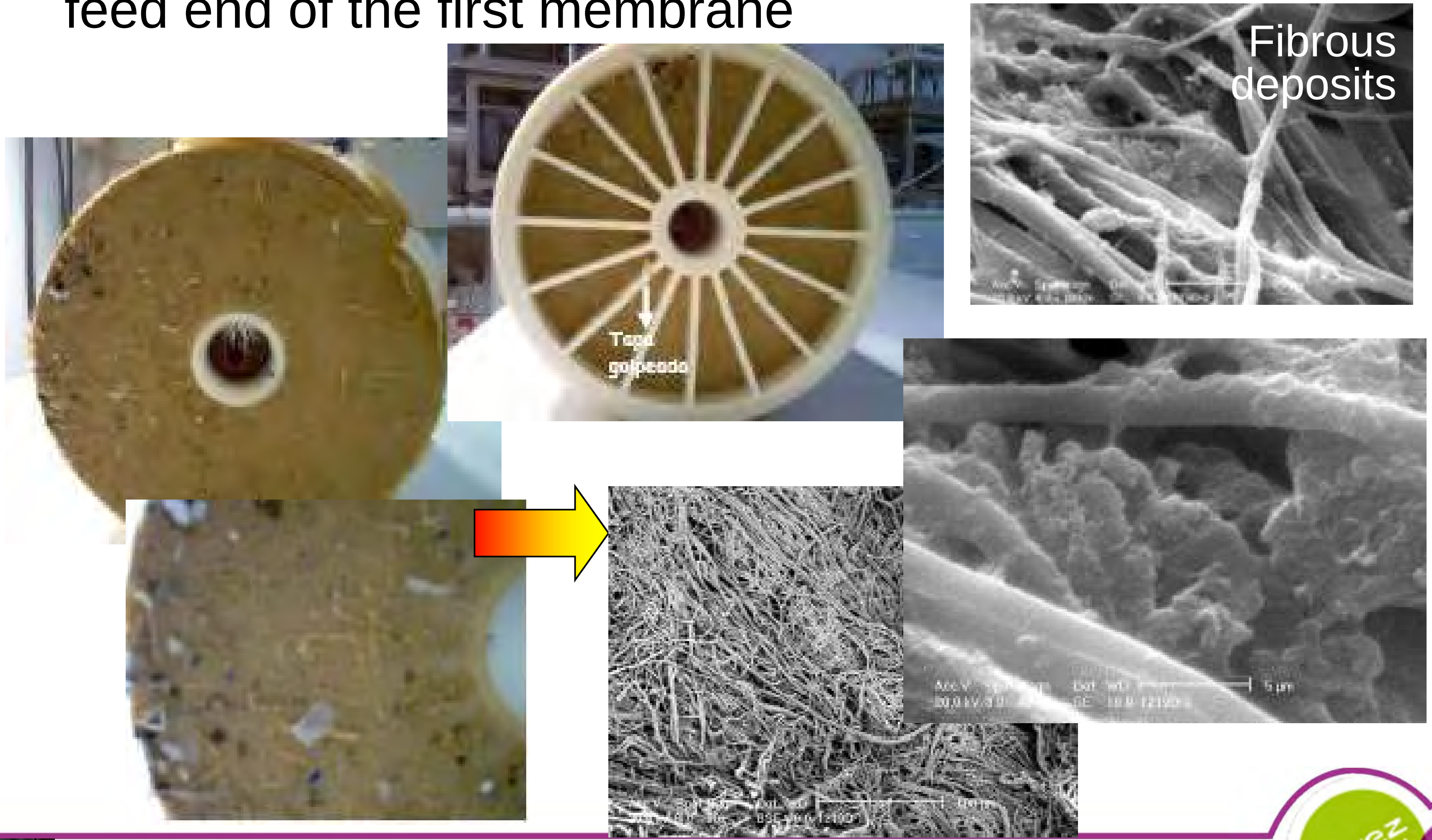
Characterisation of membrane fouling

Influence of membrane position on fouling



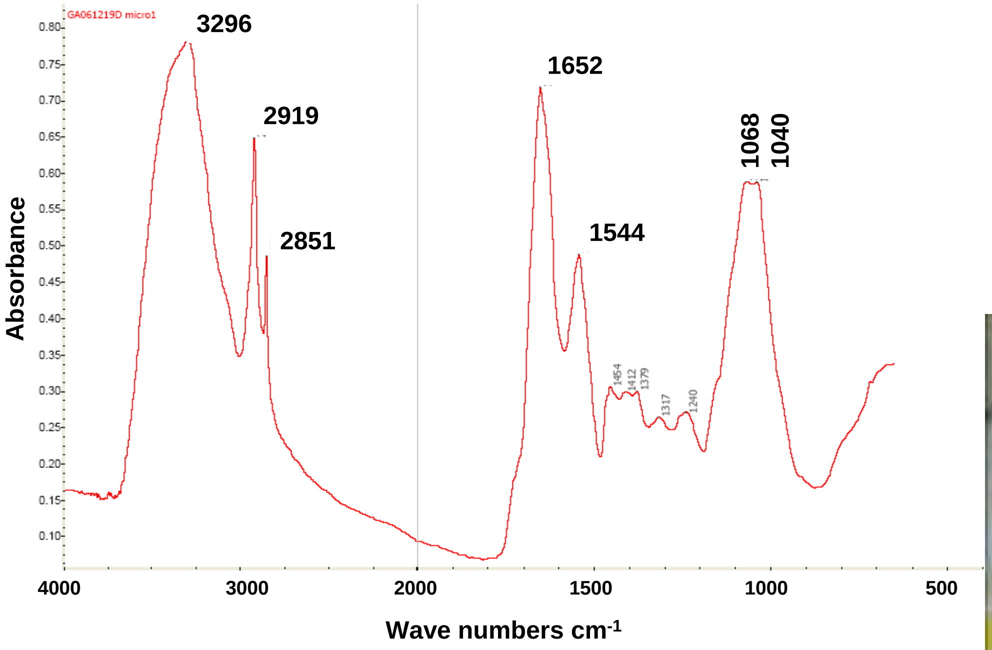
Biofouling is the predominant pathology

- Highest amount of organic deposits was observed on the feed end of the first membrane

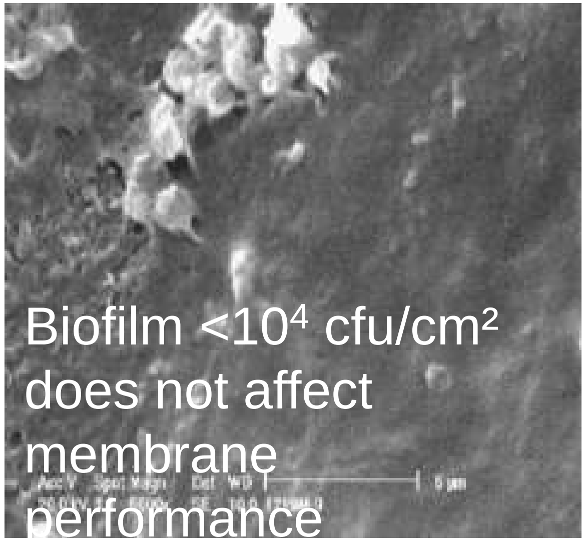


Biofouling is the predominant pathology

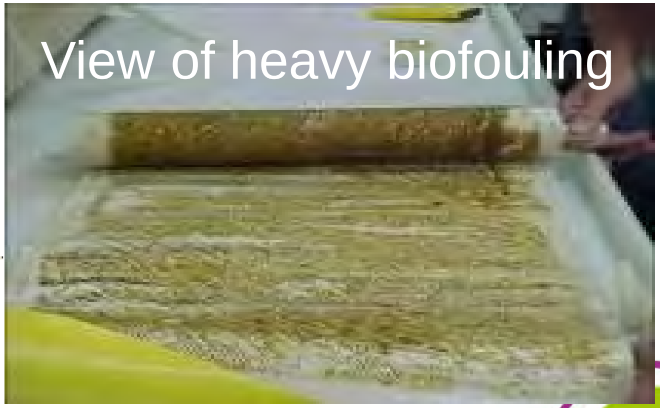
- Biofilm development is often observed despite MF pre-treatment and biocide addition
  - Major cause: improper pre-treatment and/or operation (chemical dosing)



Infrared spectrum of the fine layer showing the predominance of proteins



Biofilm <10^4 cfu/cm² does not affect membrane performance



View of heavy biofouling

Specific WW pathology: Calcium Phosphate

- Calcium phosphate fouling
  - Unusual foulant until recently, characteristic of wastewater membrane (last stage of RO membranes)
  - Major cause: high phosphate concentration in wastewater
  - Thin deposit layer that dramatically affect membrane permeability (-50% at 6 hours)

50-200 µm amorphous non crystalline mat

SEM-EDAX micrograph of calcium phosphate deposit

Other foulants that can adversely affect membrane performance

- Colloidal matter that can be difficult to remove from feed water
- Coagulants and flocculants, mostly overdosed in previous stages of wastewater treatment
  - ✓ Aluminium-based coagulants and organic polymeric flocculants are molecules with high affinity to charged membrane surface that can dramatically affect its permeability,
- Oils and fats

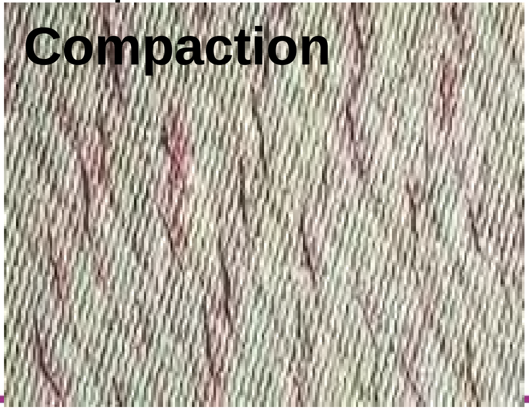
Optimisation of membrane cleaning

How to clean

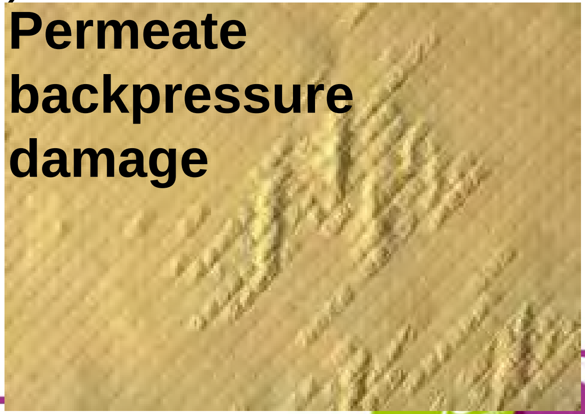
⇨ A wrong choice can aggravate scaling and fouling problems

- Acids for scaling
  - ✓ Hycrochloric acid, citric acid, phosphoric or sulfamic acid
- Alkaline for biological fouling (0.5-1% Na-EDTA + 0.1% NaOH)
- Alkaline with detergent for organic fouling (0.1% NaOH + 0.025% Na-DSS, sodium salt of dodecylsufate)
- Frequently both alkaline and acid cleanings are required (always high pH first, low pH as a second step)

Scaling



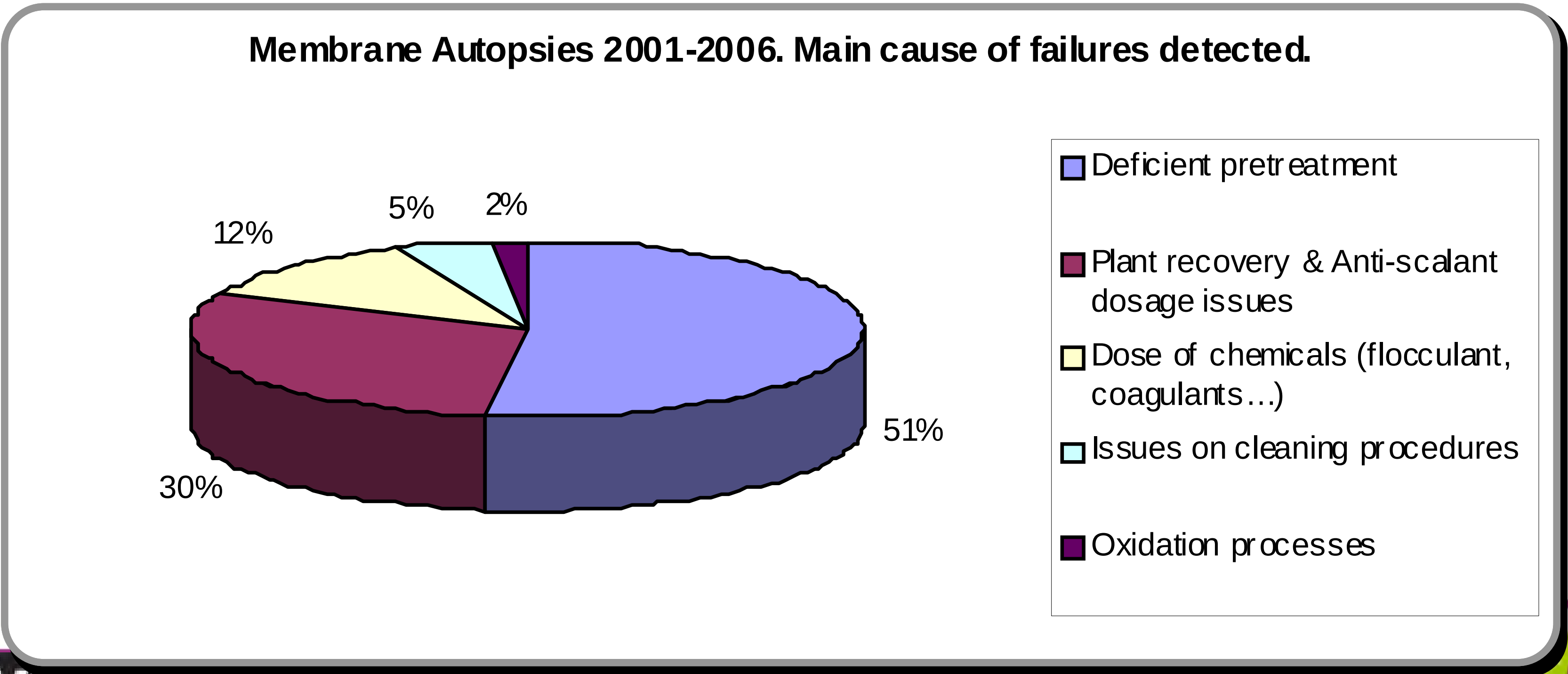
Compaction



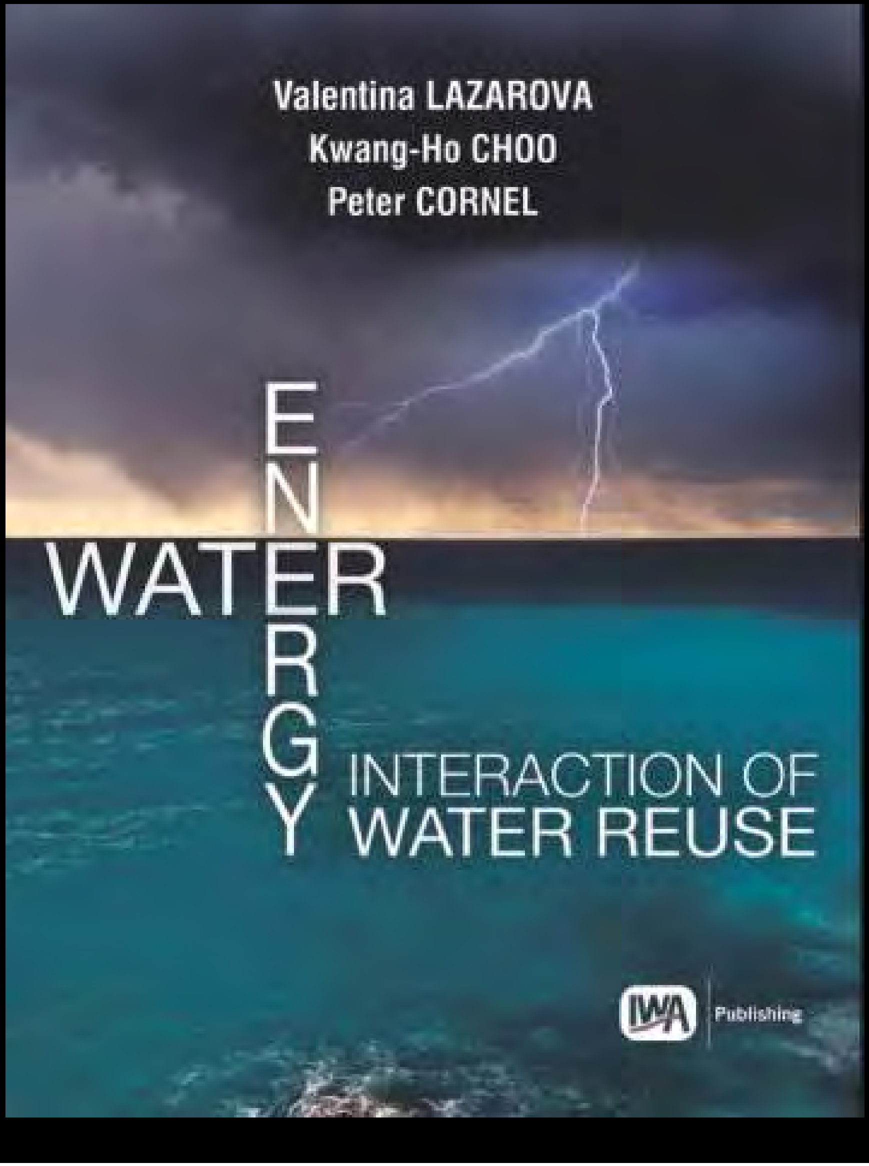
Permeate backpressure damage

Main causes of membrane fouling

- Main causes of membrane fouling are:
  - Investigated MF/RO trains: pre-treatment failure and chemical dosage
  - Statistical data for 5-year period: 50% of failure events and fouling resulted from deficient pre-treatment



Membranes and Water Reuse
Further Reading



Valentina LAZAROVA
Kwang-Ho CHOO
Peter CORNEL

WATER ENERGY INTERACTION OF WATER REUSE

IWA Publishing

COFFEE
BREAK

Optimising RO and Energy Footprints in Desalination and Water Reuse

Paradise Hotel, Busan

IWA International Water Association

World Water Congress & Exhibition

BUSAN KOREA

16–21 September 2012 BEXCO, 43 APEC-ro, Haeundae-gu, Busan

15:15-16:00

Applying RO for Desalination

Nikolay Voutchkov, PE, BCEE

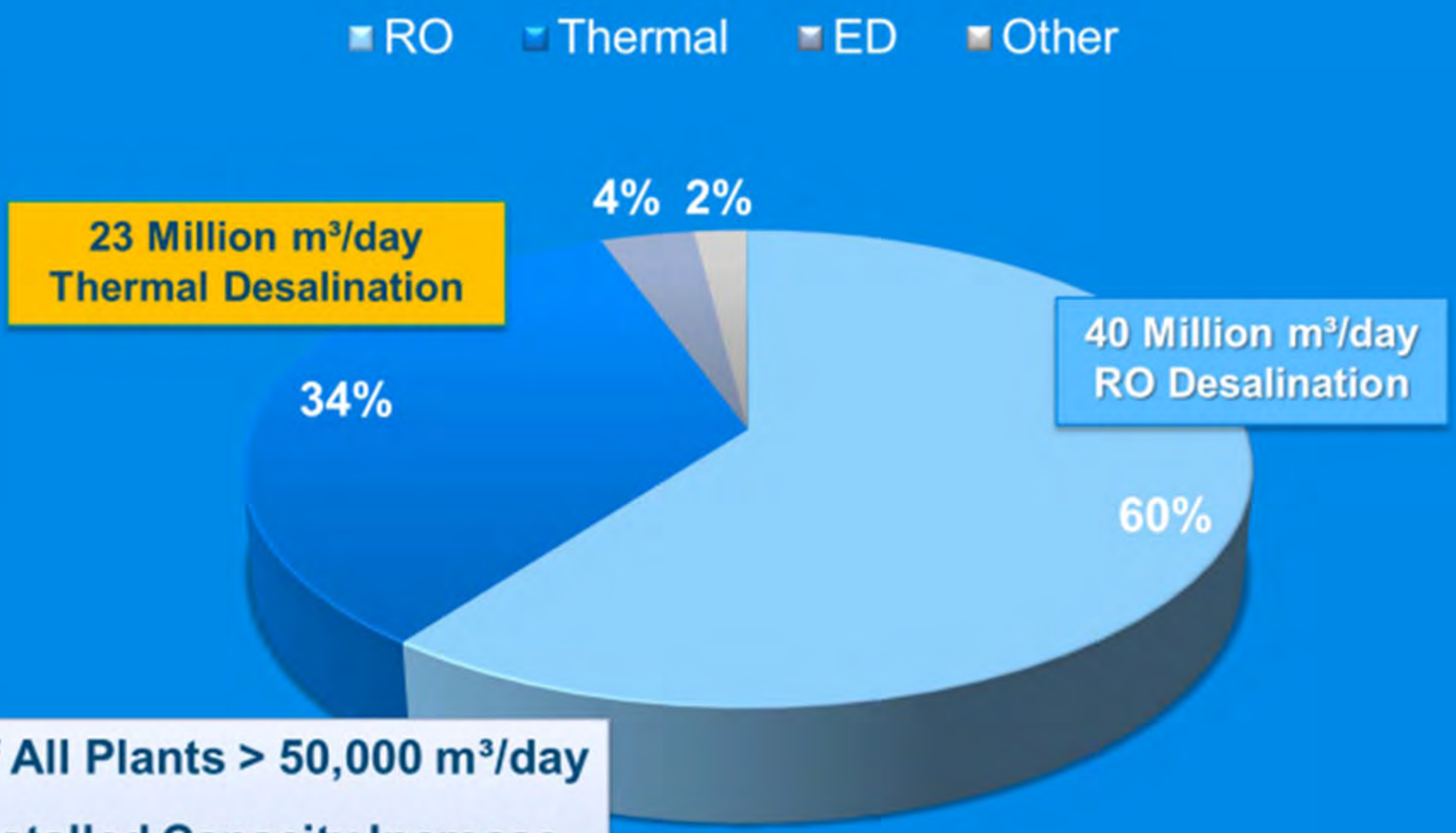
Water Globe Consulting

RO Desalination Systems Design & Costs - Outline

- Overview of Desalination Plant Design Trends;
- Novel RO Membrane Configurations.

Desalination – Where Are We Today?

16,000 Desalination Plants Worldwide – 66.4 Million m³/day



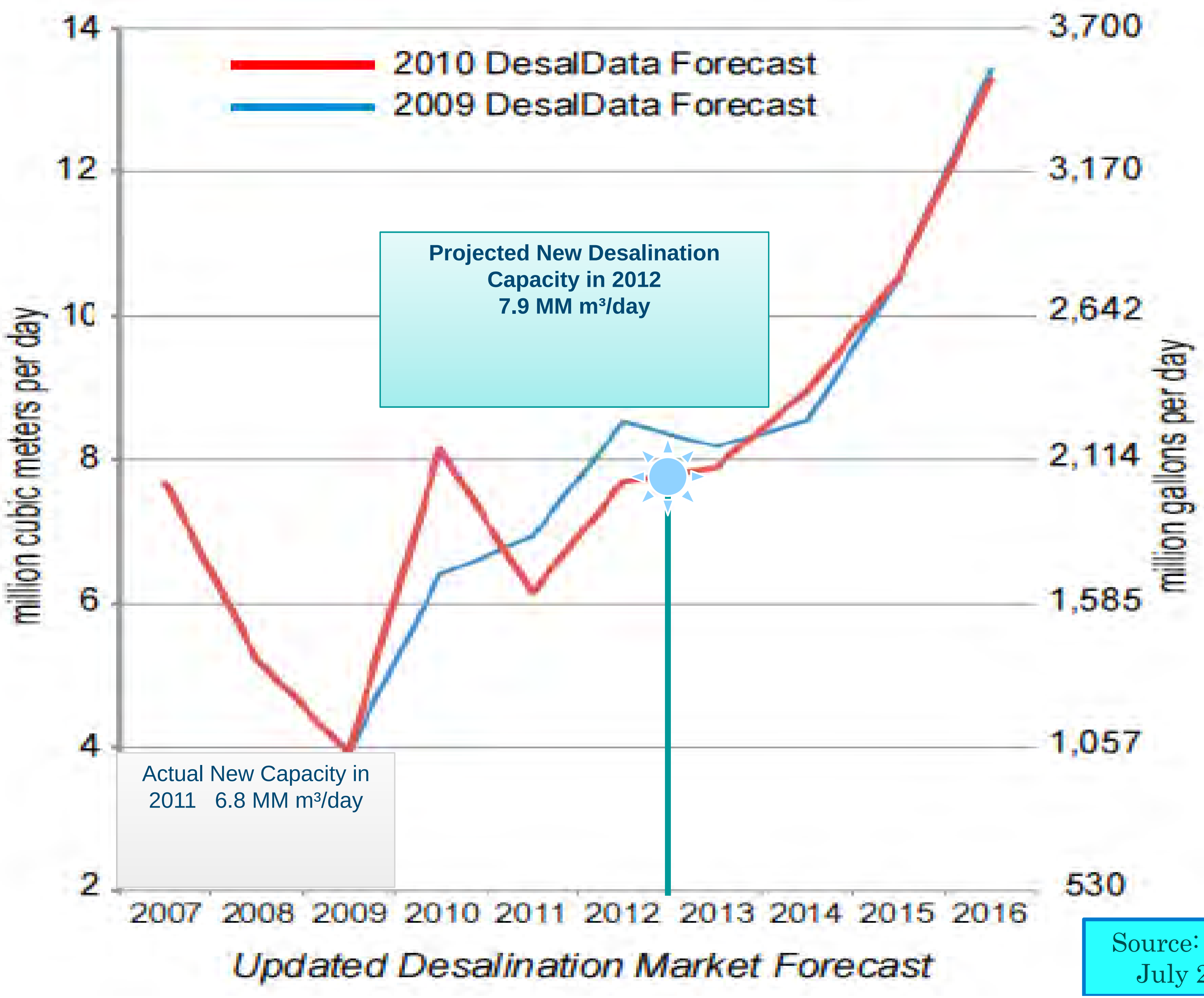
23 Million m³/day Thermal Desalination

40 Million m³/day RO Desalination

40 % of All Plants > 50,000 m³/day

65 % Installed Capacity Increase Expected by 2015

Source: IDA Desalination Yearbook 2011-2012



Projected New Desalination Capacity in 2012 7.9 MM m³/day

Actual New Capacity in 2011 6.8 MM m³/day

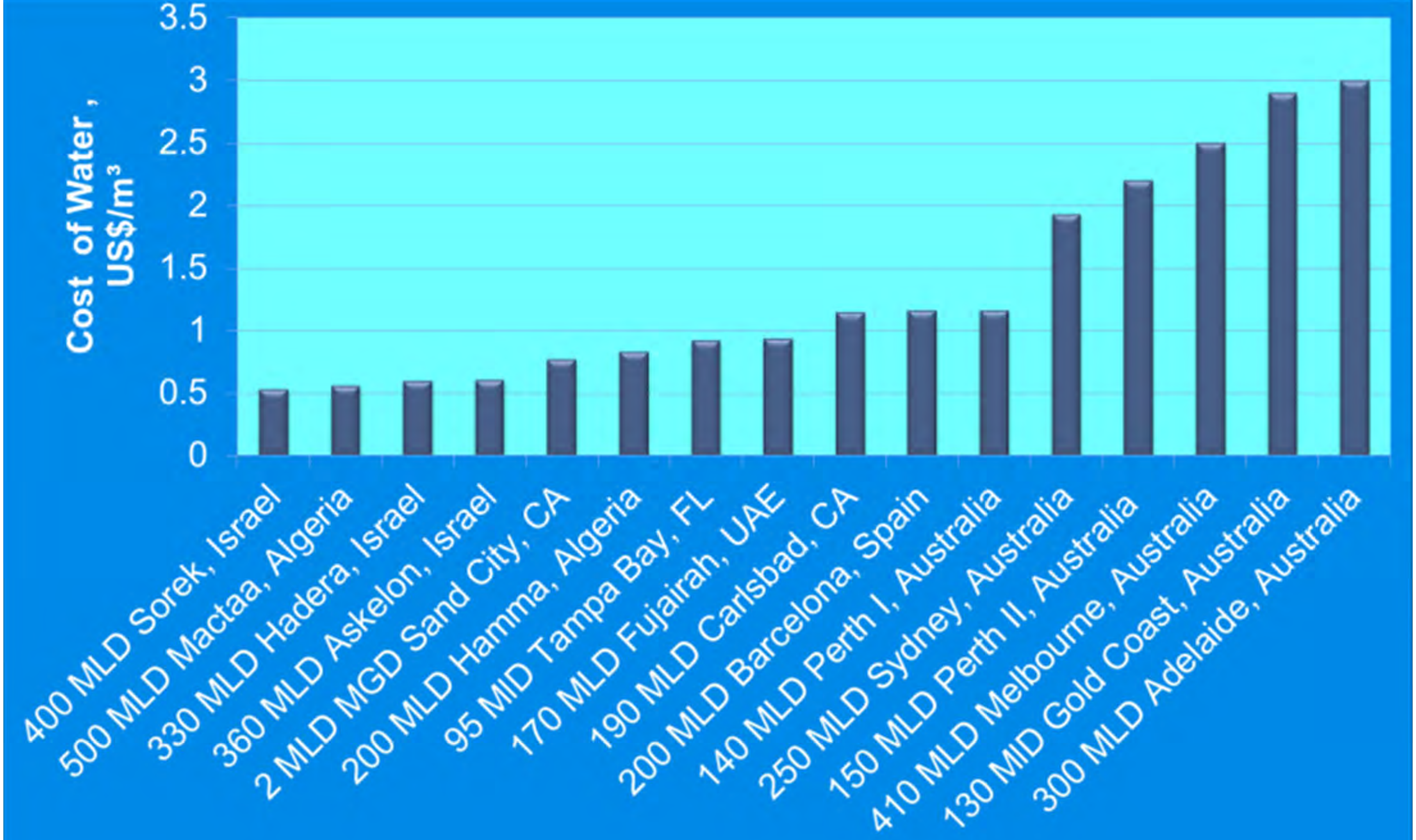
Updated Desalination Market Forecast

Source: WDR, July 2010

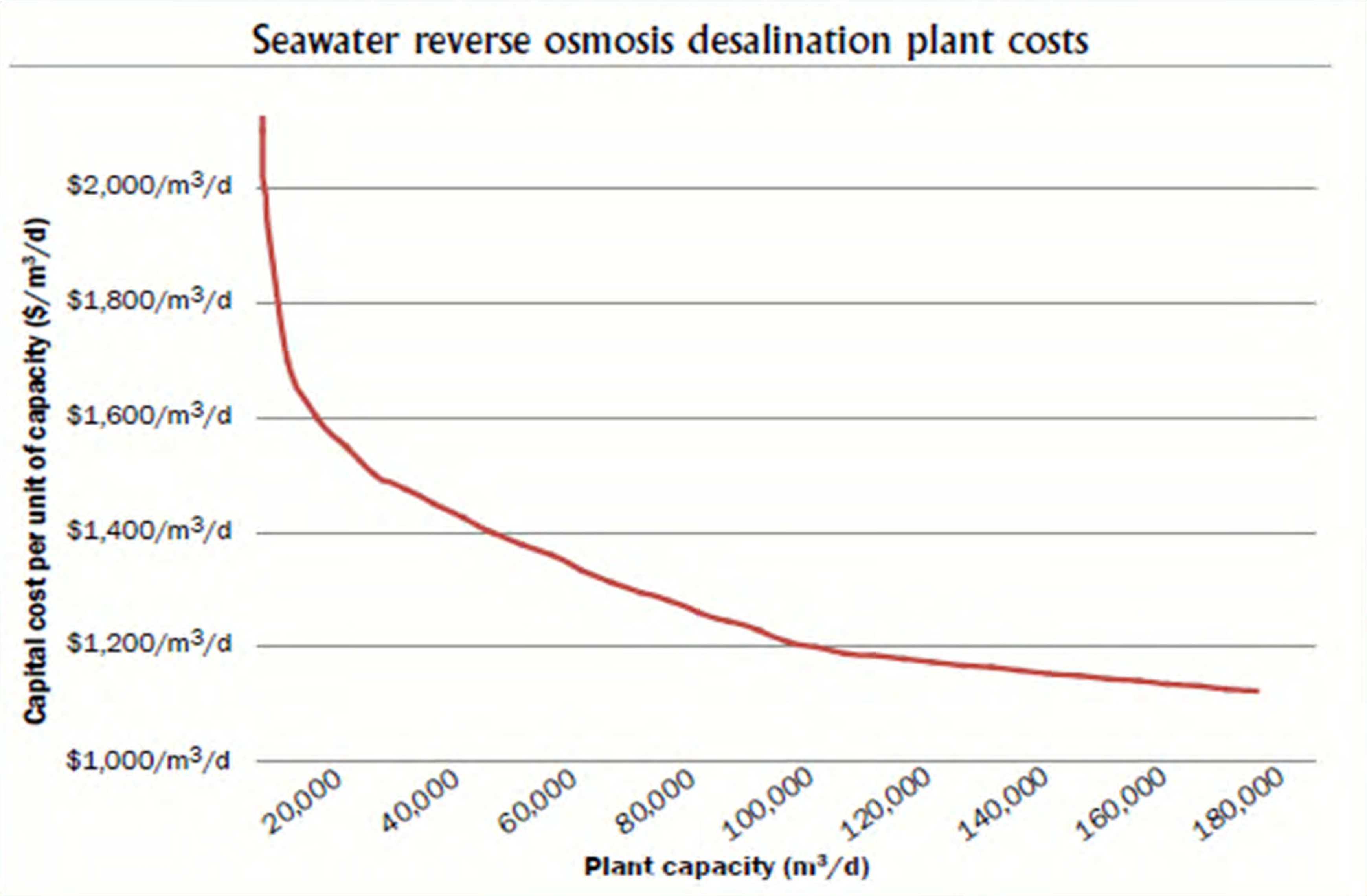
Membrane Desalination – Key Trends

- SWRO Desalination Technologies Dominate;
- Large - (over 50,000 m³/day) and Mega - (over 200,000 m³/day) Desalination Plants Are the Wave of the Future;
- Most Large Urban Coastal Centers Worldwide Have Established a Target to Produce 25 % of their Drinking Water from Desalination;
- Research &Development Activities are in 10-Year High – Likely to Yield Breakthroughs in Membrane and Desalination Technologies by 2015;
- Large SWRO Projects Are Aiming at Sustainability – Green is In!

Water Production Costs of Recent SWRO Desalination Projects



Plant Size and Construction Costs



Water Quality Targets vs. Costs

Target WQ	Constr. Costs	O&M Costs	Cost of Water
TDS/Cl = 500/250 mg/L; Boron = 1 mg/L.	**1.0**	**1.0**	**1.0**
TDS/Cl = 250/100 mg/L; Boron = 0.75 mg/L.	**1.15-1.25**	**1.05-1.10**	**1.10-1.18**
TDS/Cl = 100/50 mg/L; Boron = 0.5 mg/L.	**1.27-1.38**	**1.18-1.25**	**1.23-1.32**
TDS/Cl = 30/10 mg/L; Boron = 0.3 mg/L.	**1.40-1.55**	**1.32-1.45**	**1.36-1.50**

Typical Cost and Energy Ranges

(Medium & Large SWRO Plants)

Classification	Cost of Water Production (US\$/m³)	SWRO System Energy Use (kWh/m³)
Low-End Bracket	0.5 – 0.8	2.5 – 2.8
Medium Range	1.0- 1.5	3.0 – 3.5
High-End Bracket	2.0 – 4.0	4.0 – 4.5
Average	1.0	3.0

Plant Size and Energy Use

Plant Size	SWRO System Energy Use kWh/m³
1,000 m³/day	4.5-6.0
40,000 m³/day	3.0-4.0
200,000 m³/day	2.5-3.0

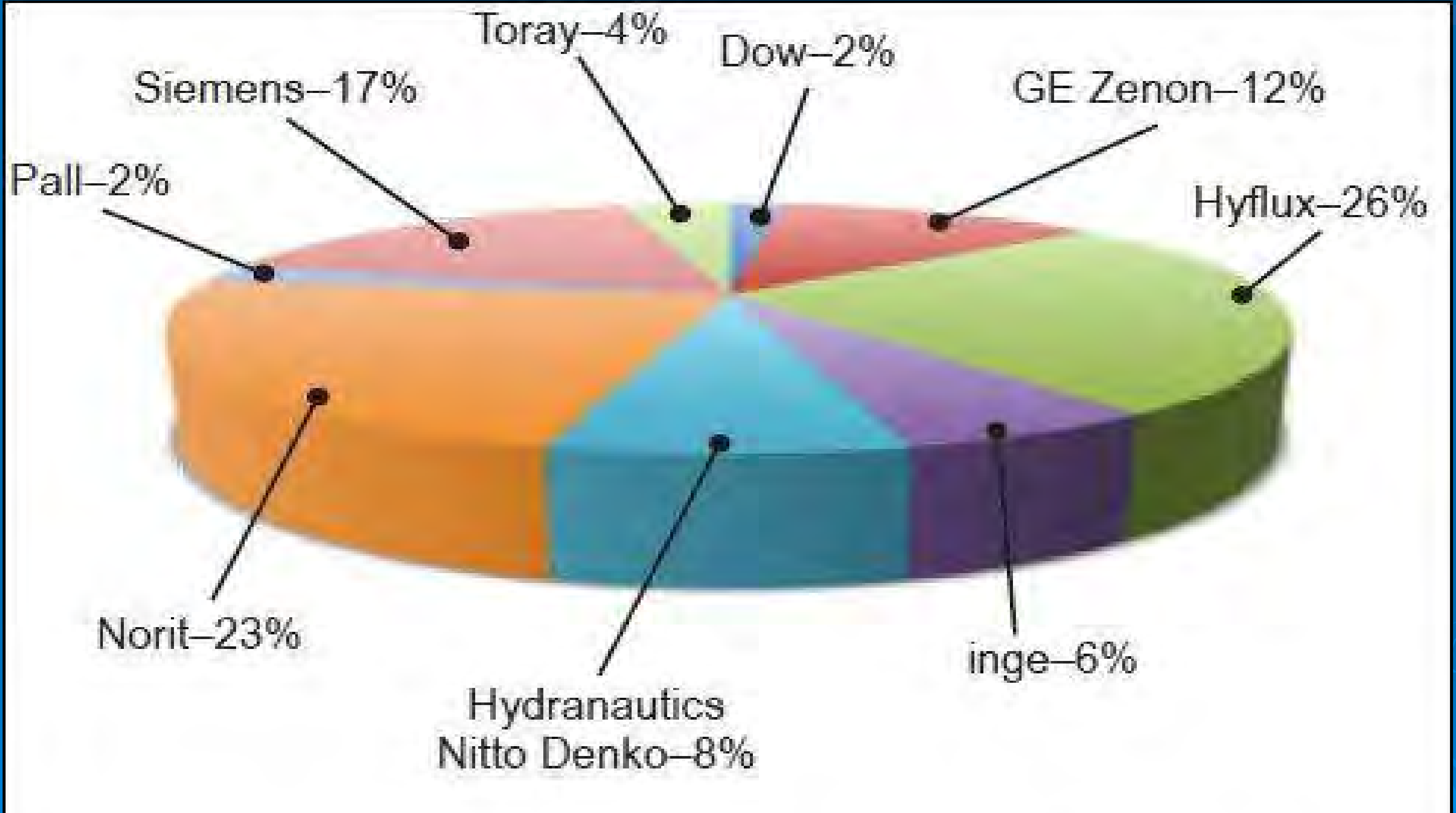
Membrane Pretreatment is Becoming More Popular for Large Plants!

- 300,000 m^3/day Adelaide SWRO Plant, Australia :
  – Disk Filters + Submersible UF;
  – Largest SWRO Facility with Membrane Pretreatment.

- **Where Membrane Pretreatment Has Worked Well?** – for Source Waters of Low Bio-fouling Potential:
  - Subsurface or Deep Open Ocean Intakes;
  - Plants w/ DAF or Other Pretreatment Ahead of UF/MF Membranes.

- **Where Membrane Pretreatment Has Faced Challenges?**
  - Shallow Open Intakes Exposed to Heavy Algal Blooms;
  - Systems Designed for Overly High Flux Rates Based on Short-term Piloting.

Membrane Pretreatment Key Technology Providers

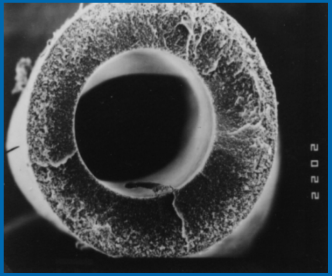


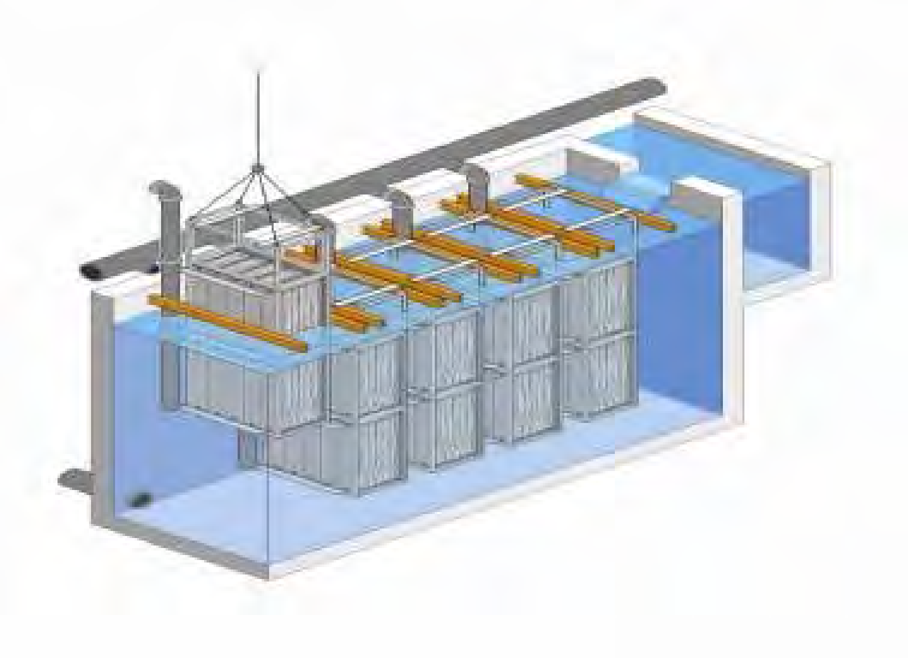
MF/UF Membrane Suppliers for SWRO Pretreatment
% of Installed/contracted Capacity

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.





40 ML/d Fukuoka SWRO Plant – One of the Largest Facilities with Membrane Pretreatment

Norit & Siemens Pressure-Driven Membrane Pretreatment

Norit – X Flow
SeaGuard
Chennai SWRO - 100 MLd
Flux - 75 Lmh
Inside-out

Perth II - Siemens
Memcor CP
Flux - 65 Lmh
Outside-in

Perth II - Memcor Pressurized Pretreatment

Pressurized LMP Memcor CP 960 System
Outside - In
2 Trains x 4 + 1 Units – 912 Units/Unit
Nominal Pore Size – 0.04 μ
Flux (Avg/Peak) = 52/65 Lmh
No Chemical Addition

Courtesy: Siemens

300 ML/d Adelaide, Australia the Largest SWRO Plant w/ Vacuum-Driven Pretreatment UF Filtration

Submerged LMP Memcor CS System
2 x 14 cells x 900 units/cell
Nominal Pore Size – 0.04 μ
Flux (avg/Max)= 52/65 Lmh
No Chemical Addition

Membrane Pretreatment – What Makes it Different for Seawater?

- Barnacles & Sharp Objects/Shells – Micro-Screens of 120 µ vs. 500 µ Needed! (More Energy & More Expensive Micro-screens);
- Red Tides – Watch Out for Elevated Organics;
- Silt (Especially if Intake is Close to Ship Channels with Heavy Traffic or is Exposed to Dredging);
- Chlorine Release After Chemically Enhanced Backwash – Effect on SWRO Membranes;
- Lower Recovery & Higher Energy Use.

Novel RO Membrane Configurations

Split Partial Second Pass Alternatives

Large RO Membrane Elements

Alternative RO Train Configurations

Evolving SWRO Membrane Performance

- Larger Membrane Element Area:
  41 m² vs. 37 m²;

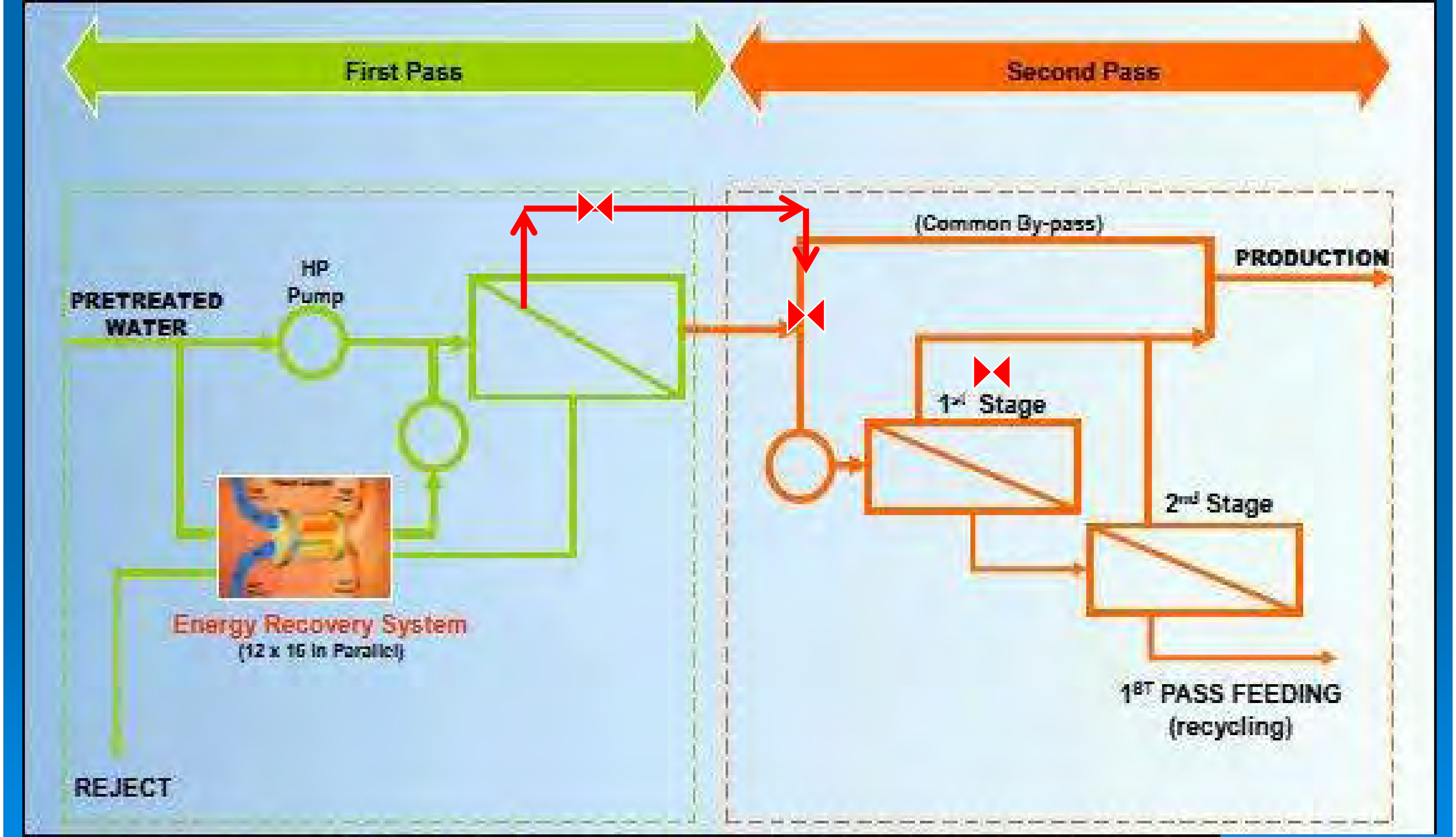
- Larger RO Element Productivity:
  28 to 47 m³/day;

- Improved Salt Rejection: 99.7 to 99.8 %;

- Increased Boron Rejection: 90 to 93 %;

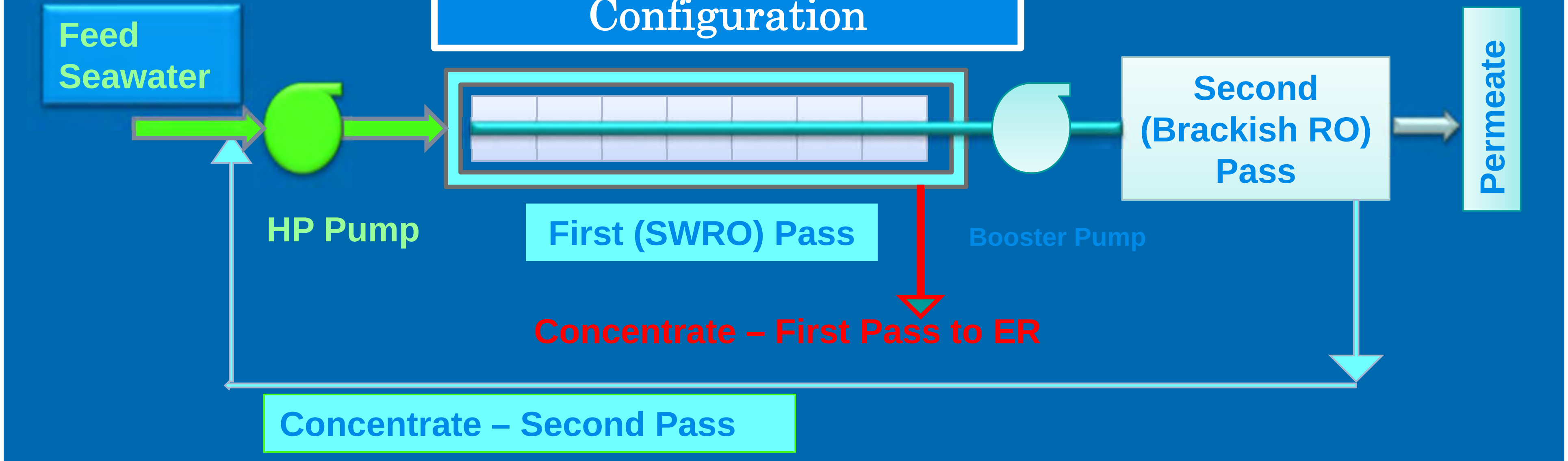
- Wider Membrane Spacers: 28 mil vs. 34 mil.

Split Partial Second Pass Configurations



Courtesy: GHD

Conventional RO System Configuration



Feed Seawater

HP Pump

First (SWRO) Pass

Booster Pump

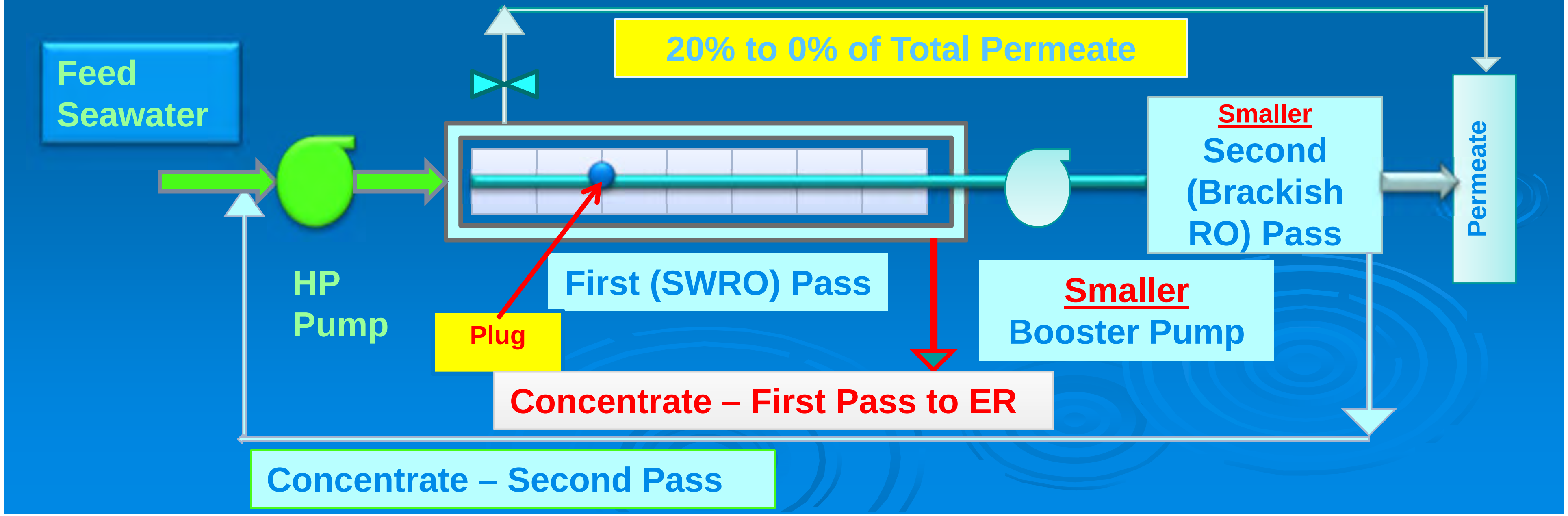
Second (Brackish RO) Pass

Permeate

Concentrate – First Pass to ER

Concentrate – Second Pass

Split "Regulated" First Pass RO System Configuration



20% to 0% of Total Permeate

Feed Seawater

HP Pump

Plug

First (SWRO) Pass

Smaller Second (Brackish RO) Pass

Smaller Booster Pump

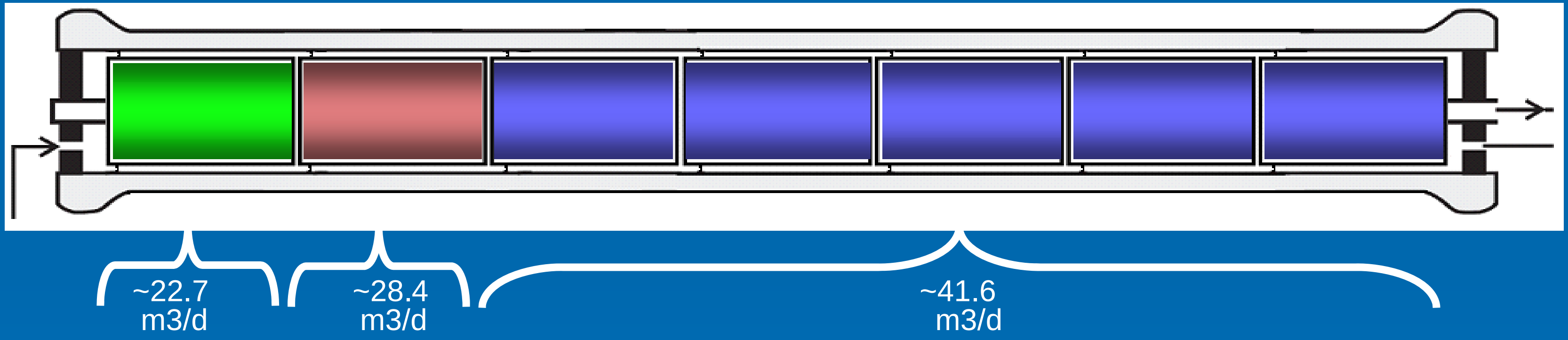
Permeate

Concentrate – First Pass to ER

Concentrate – Second Pass

Internally Staged Design (1-1-5)

Element Flow at Standard Test Conditions

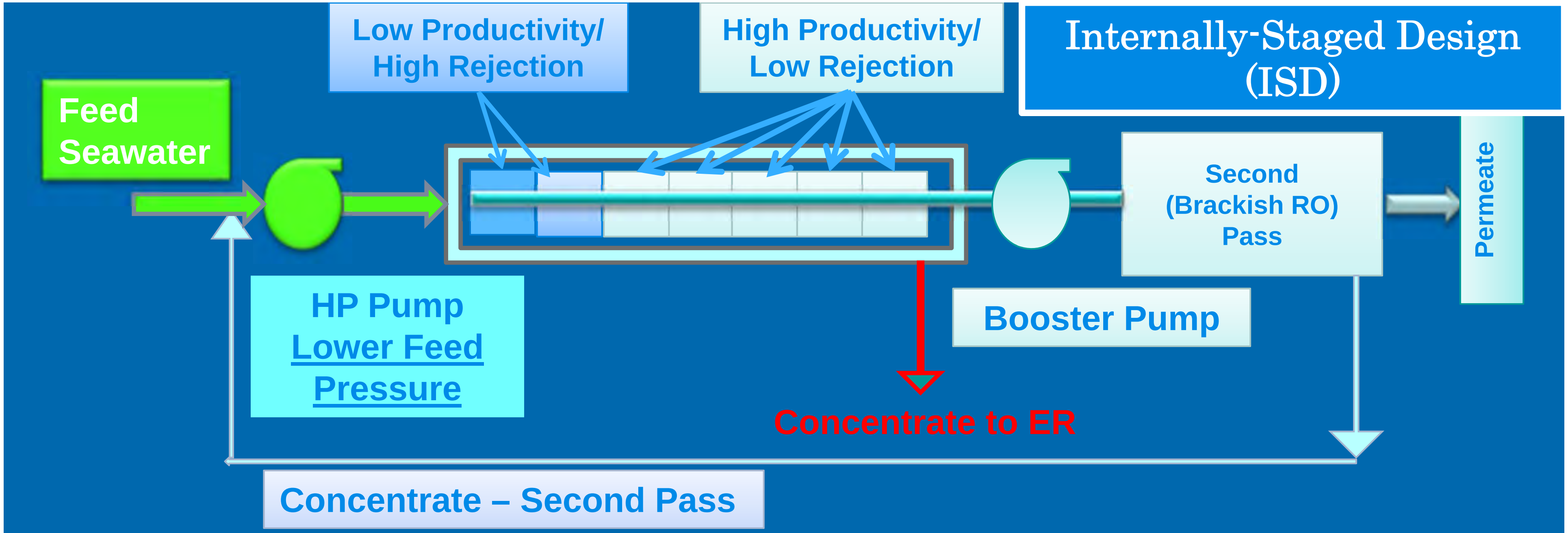


Compared to standard SWRO design, ISD SWRO offers:

- **Higher average permeate flux with same lead element flux;**
- **Good permeate quality;**
- **Energy Savings - 5% - 10%;**

Courtesy: Dow Chemical

Internally-Staged Design (ISD)



Low Productivity/ High Rejection

High Productivity/ Low Rejection

Feed Seawater

HP Pump **Lower Feed Pressure**

Second (Brackish RO) Pass

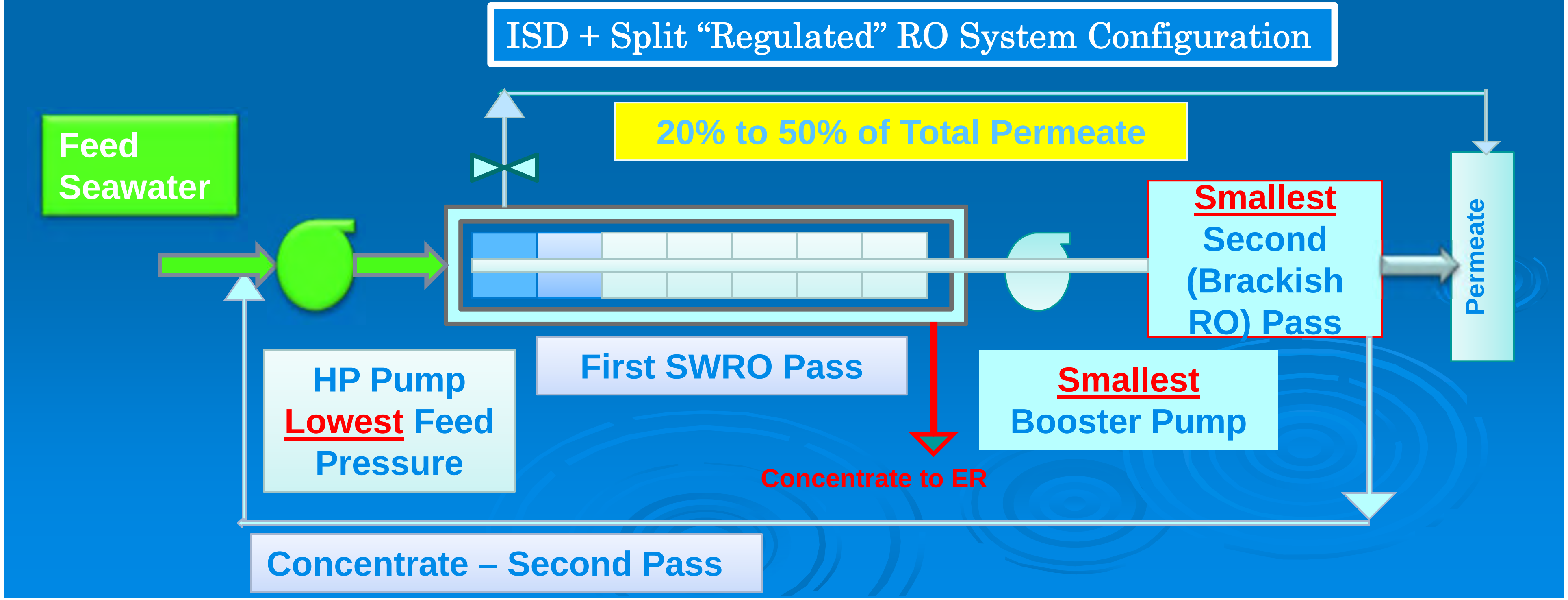
Permeate

Booster Pump

Concentrate to ER

Concentrate – Second Pass

ISD + Split "Regulated" RO System Configuration



20% to 50% of Total Permeate

Feed Seawater

Smallest Second (Brackish RO) Pass

Permeate

HP Pump **Lowest** Feed Pressure

First SWRO Pass

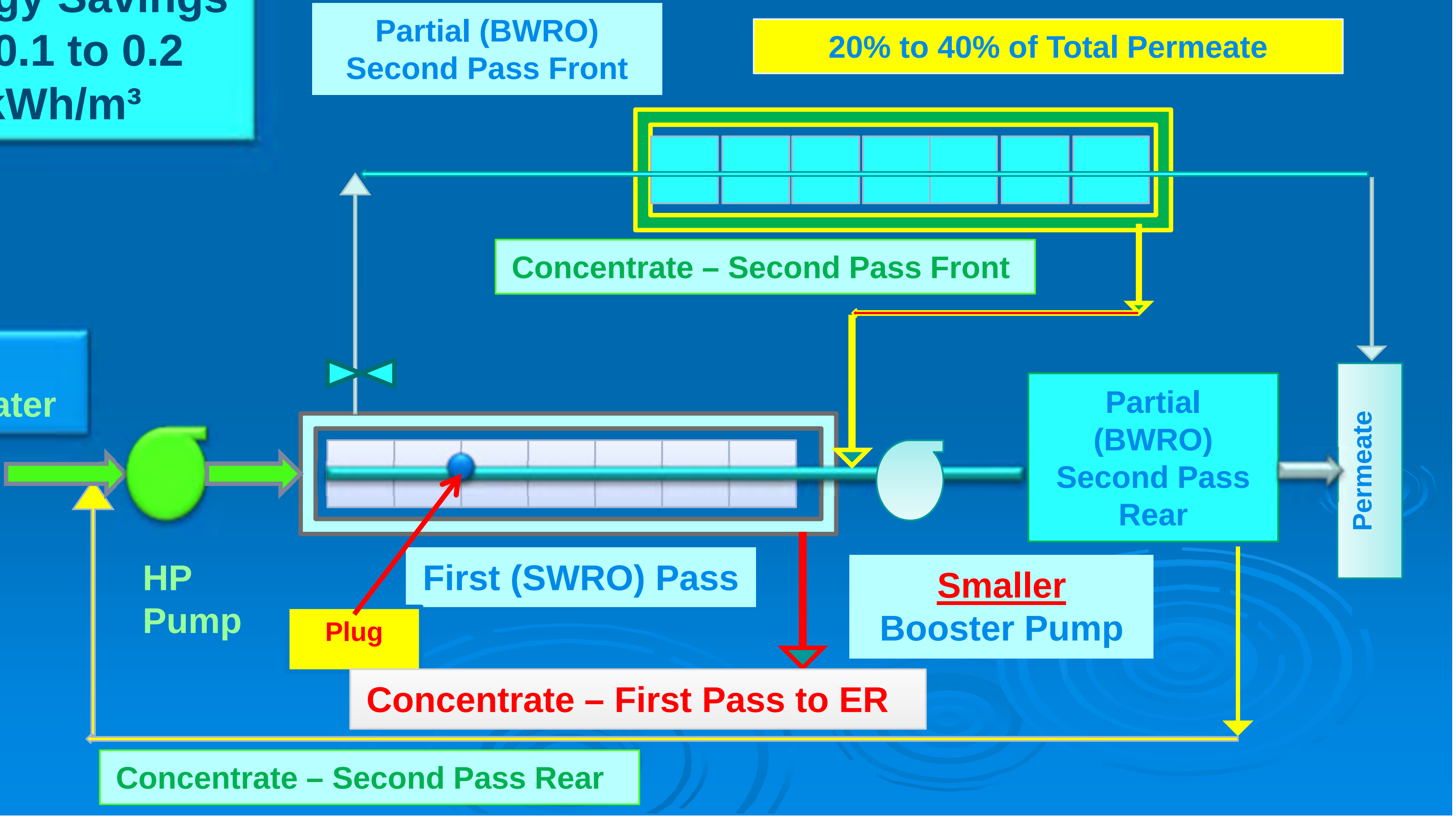
Smallest Booster Pump

Concentrate to ER

Concentrate – Second Pass

Split Partial Second Pass with Additional First Pass Treatment Maximizes Energy Use

Additional Energy Savings of 0.1 to 0.2 kWh/m³



Partial (BWRO) Second Pass Front

20% to 40% of Total Permeate

Concentrate – Second Pass Front

Feed Seawater

HP Pump

Plug

First (SWRO) Pass

Concentrate – First Pass to ER

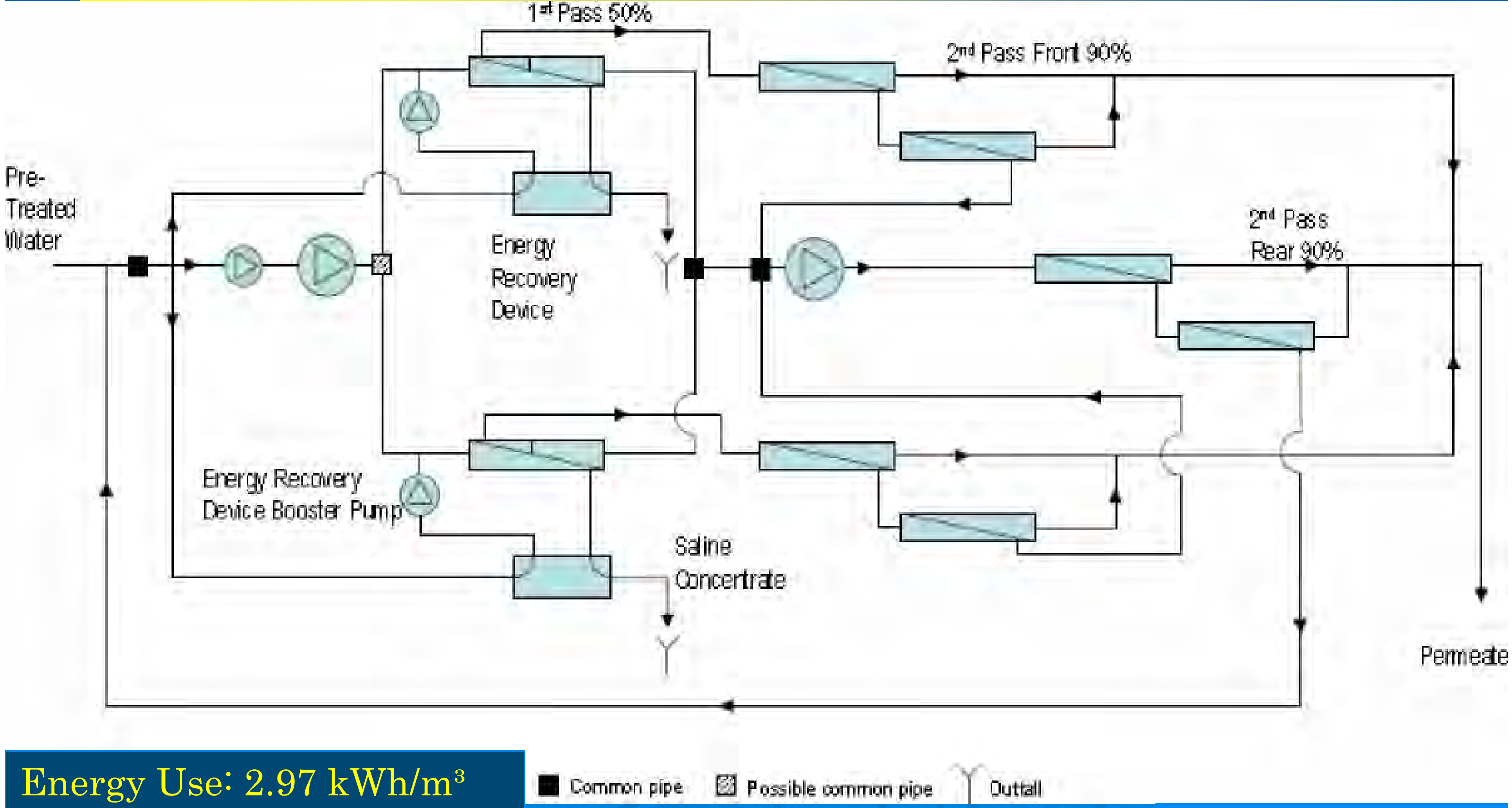
Partial (BWRO) Second Pass Rear

Smaller Booster Pump

Permeate

Concentrate – Second Pass Rear

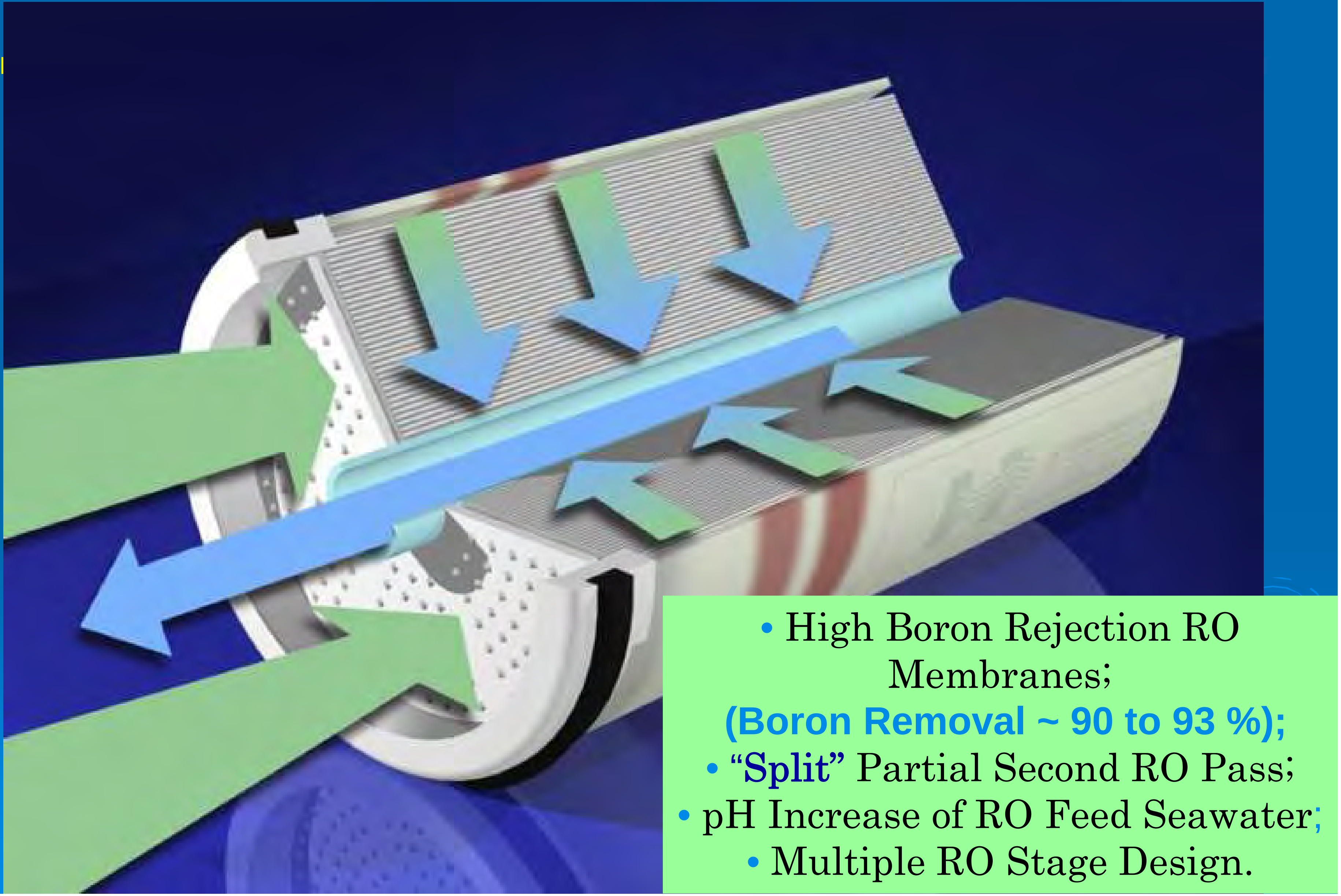
Split Partial Second Pass System (Front & Rear) with One High Pressure Pump Serving Two RO Trains – 300 MLD Adelaide Plant



Energy Use: 2.97 kWh/m^3 @ 36 ppt & Temp = 16 °C & 48 % Recovery

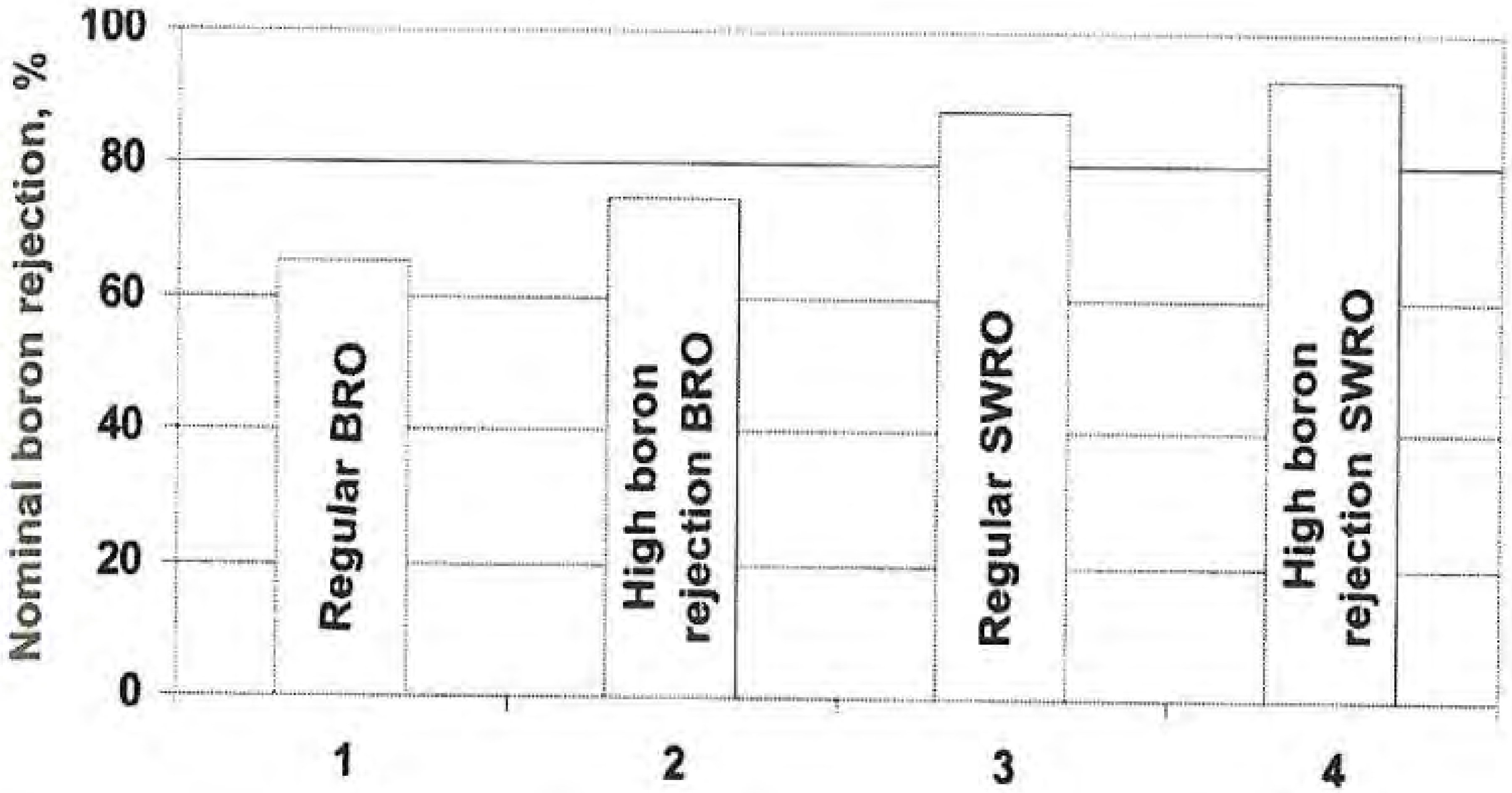
Courtesy: Acciona Agua

Optimizing Boron Removal

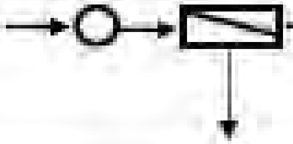
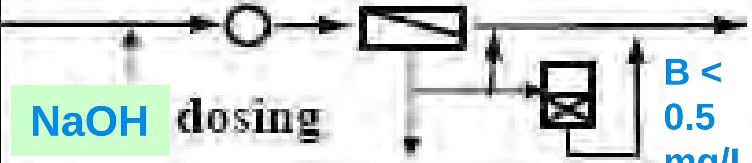
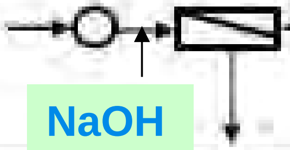
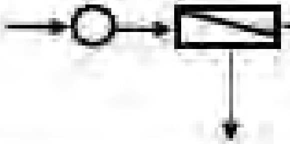
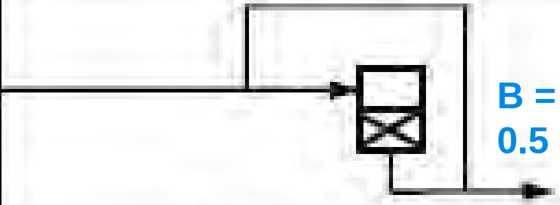
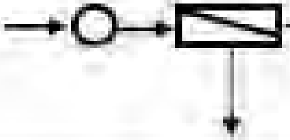
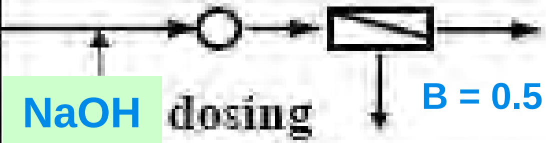
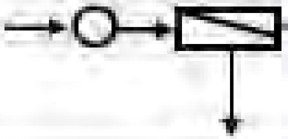
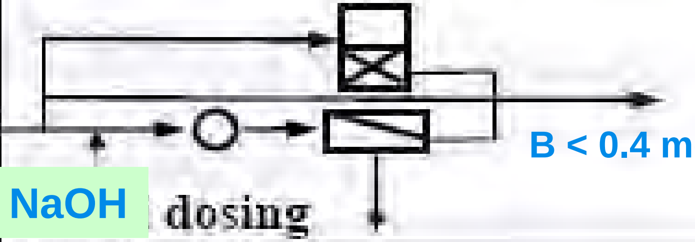


- High Boron Rejection RO Membranes;
(Boron Removal ~ 90 to 93 %);
- “Split” Partial Second RO Pass;
- pH Increase of RO Feed Seawater;
- Multiple RO Stage Design.

Boron Rejection of RO Membranes

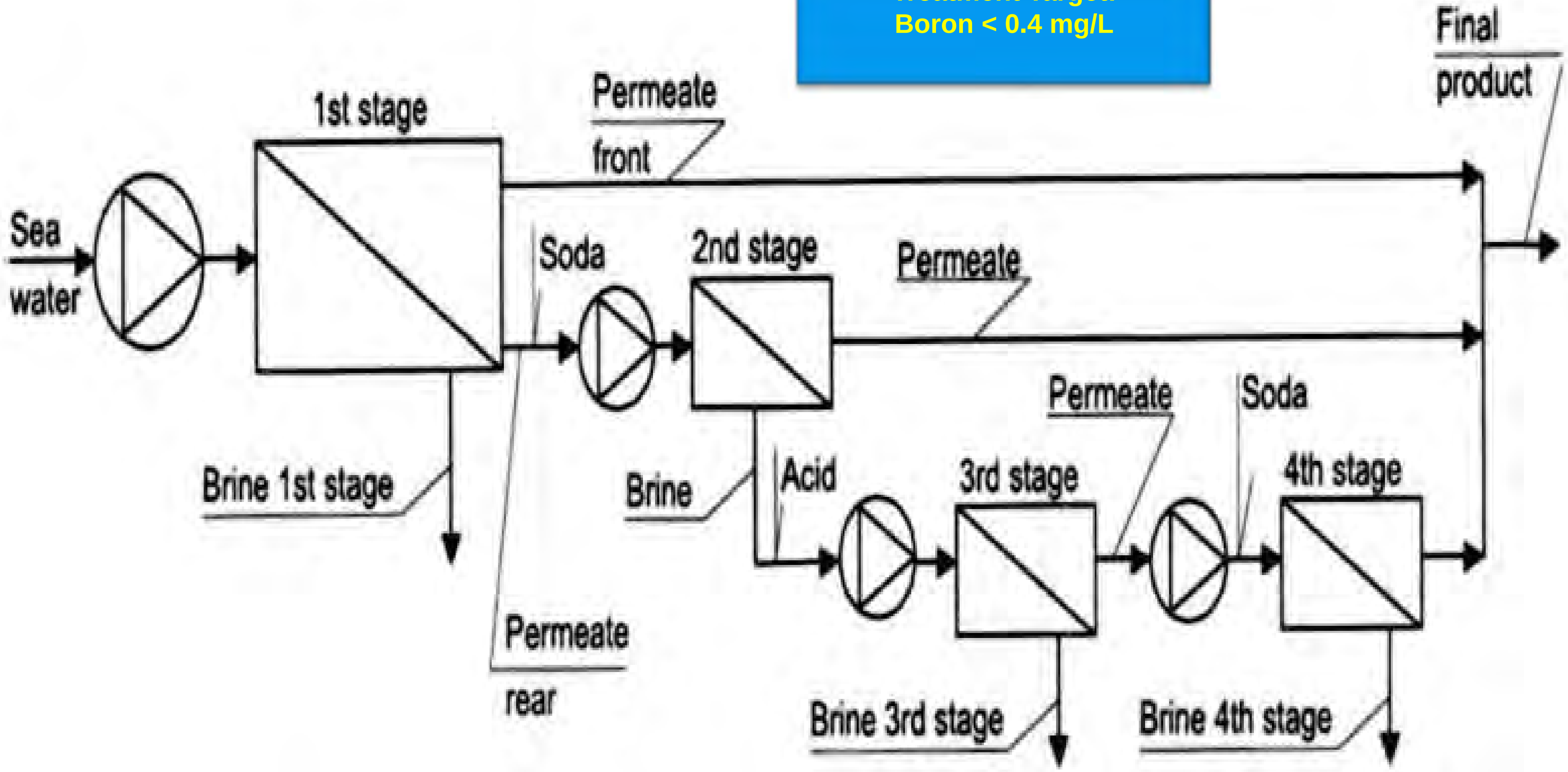


RO System Configurations for Enhanced Boron Removal

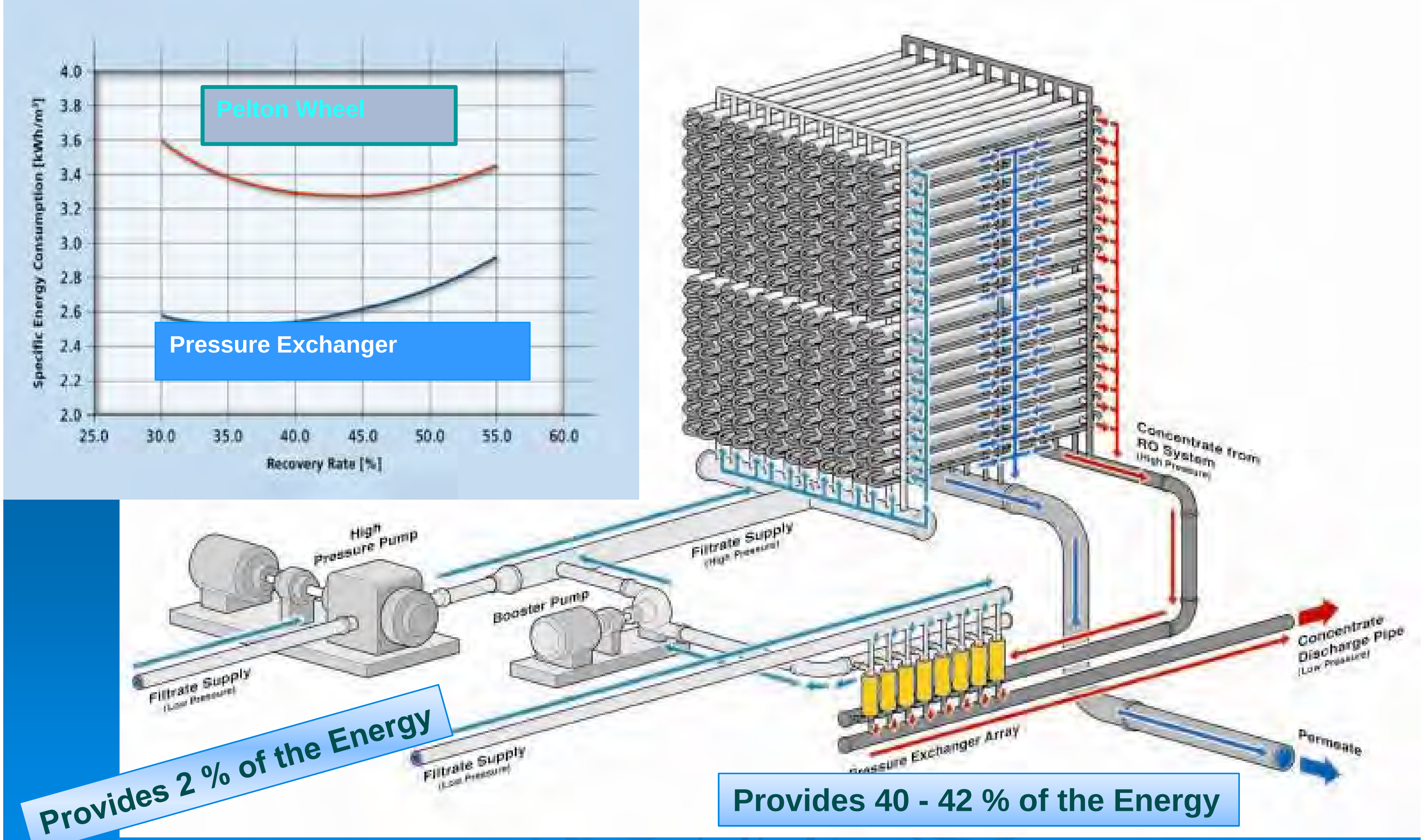
		Desalination Process	Boron Removal Process
(1)	SWRO + alkali-BWRO + conc-Adsorbent		 NaOH dosing B < 0.5 mg/L
(2)	SWRO + NaOH	 NaOH	 B = 0.8 – 1.0 mg/L
(3)	SWRO + perm-Adsorbent		 B = 0.5 – 1.0 mg/L
(4)	SWRO + alkali-BWRO		 NaOH dosing B = 0.5 – 0.75 mg/L
(5)	SWRO + perm Adsorbent / alkali-BWRO		 NaOH dosing B < 0.4 mg/L

Ashkelon, Israel – A Four-Stage RO System

Treatment Target:
Boron < 0.4 mg/L



Use of Larger Pumps/RO Trains



Pelton Wheel

Pressure Exchanger

Provides 2 % of the Energy

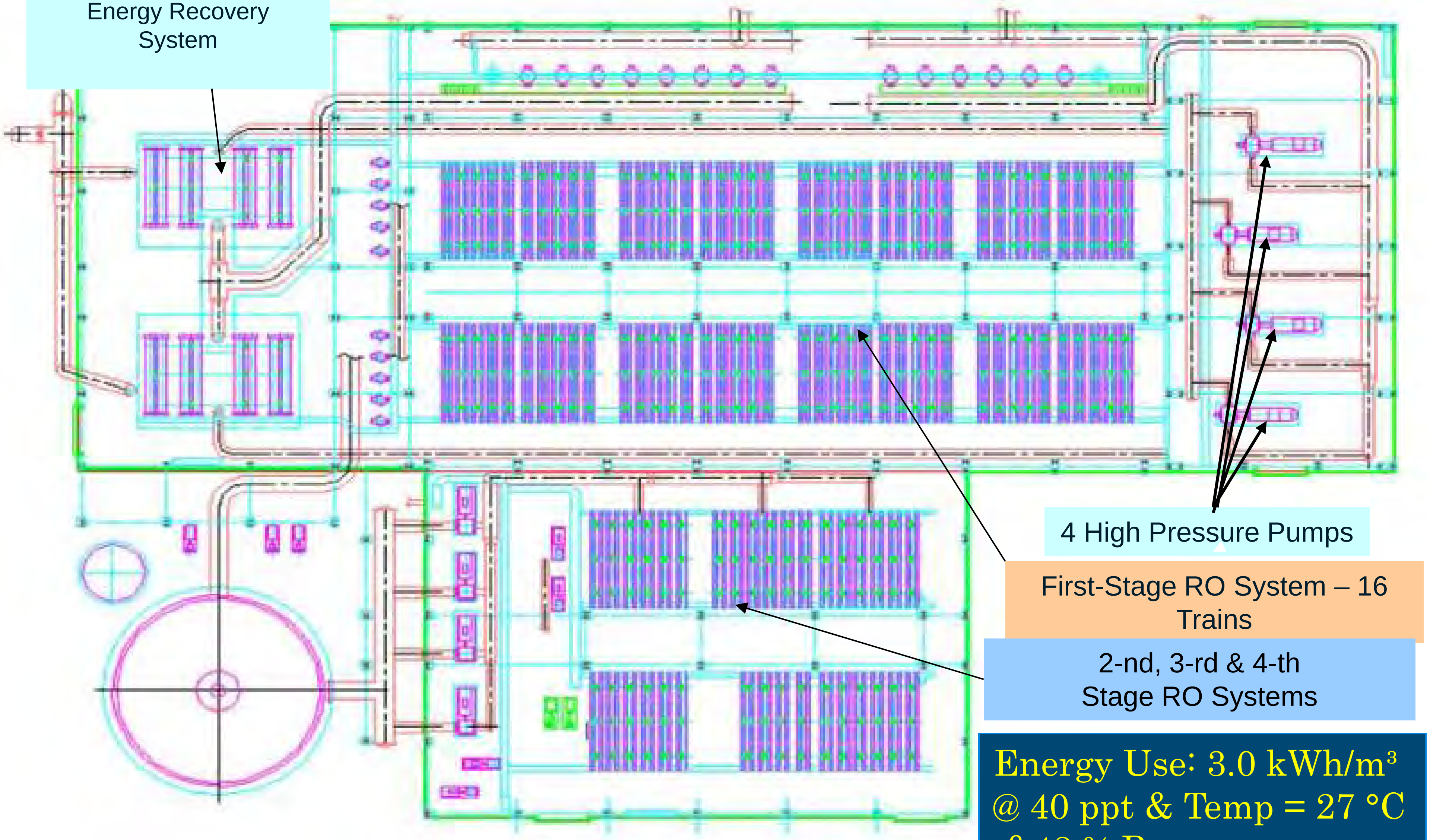
Provides 40 - 42 % of the Energy

Why Use Larger RO Trains?

Economies of Scale

- Reduced High Quality Stainless Steel Costs for Piping and Valves;
- Faster Installation;
- Expedited Commissioning;
- Limited Benefits if Plant Has to Be Designed for Large Turn-down of Production.

Three-Center RO System Configuration – 330 MLD Ashkelon SWRO Plant



Energy Recovery System

4 High Pressure Pumps

First-Stage RO System – 16 Trains

2-nd, 3-rd & 4-th Stage RO Systems

Energy Use: 3.0 kWh/m³ @ 40 ppt & Temp = 27 °C &48 % Recovery.

Courtesy: IDE

Large SWRO Membrane Elements

16” RO Membrane Element

Large Size RO Membranes – Advantages

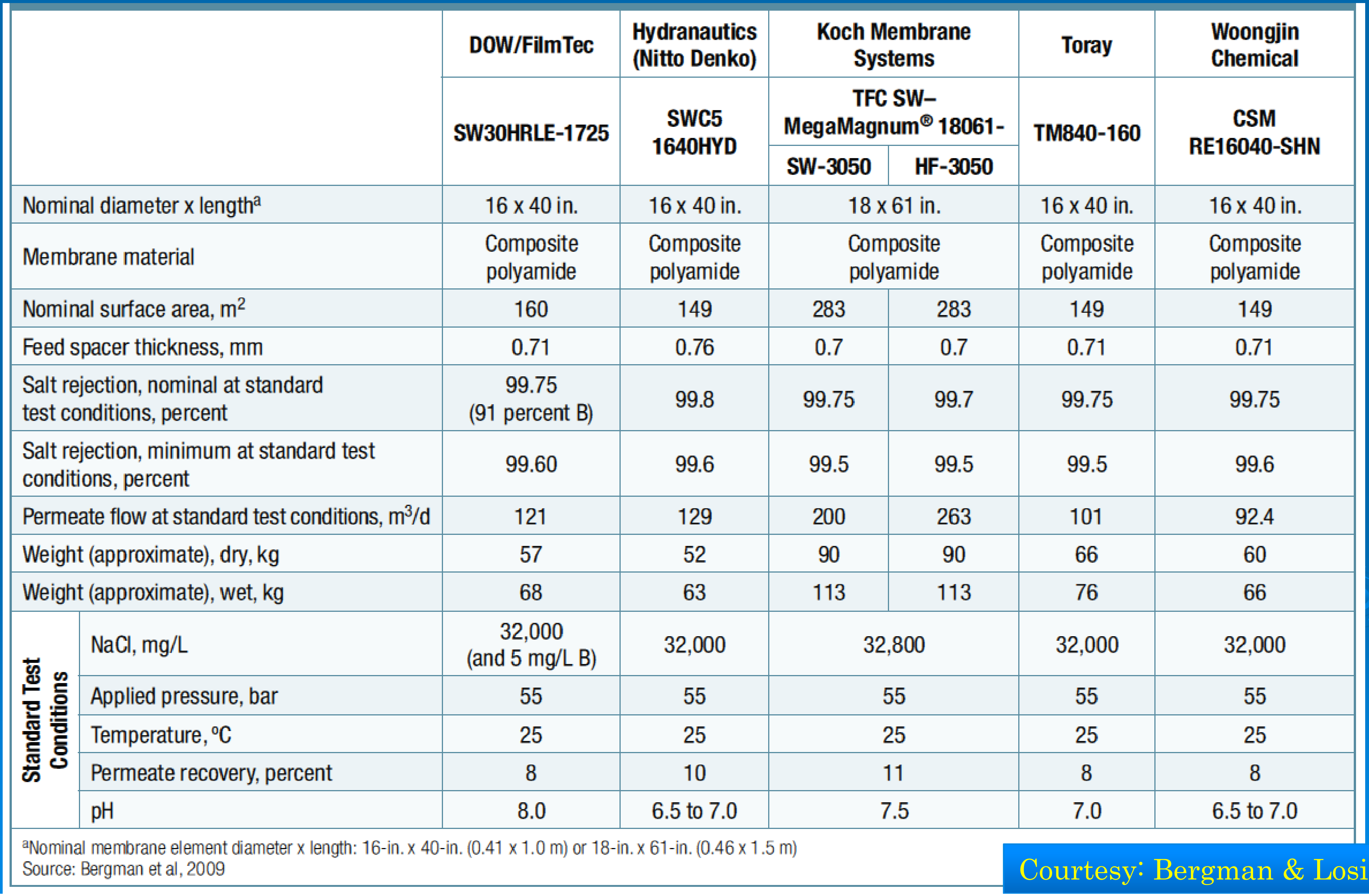
- Potential Space Savings – 10 to 15 %.
- Capital Cost Savings – 5 to 10 %.
- Total Cost of Water Savings – 4 to 6 %

Potential Disadvantages

- Loading Requires Special Equipment and Extra Space;
- Special Costlier Vessels & End Caps Needed;
- More Costly Foundations and Structure May Be Needed
- Membranes Costlier to Manufacture.

Standard 8” RO Membrane Element

16-inch Elements – Key Manufacturers & Models



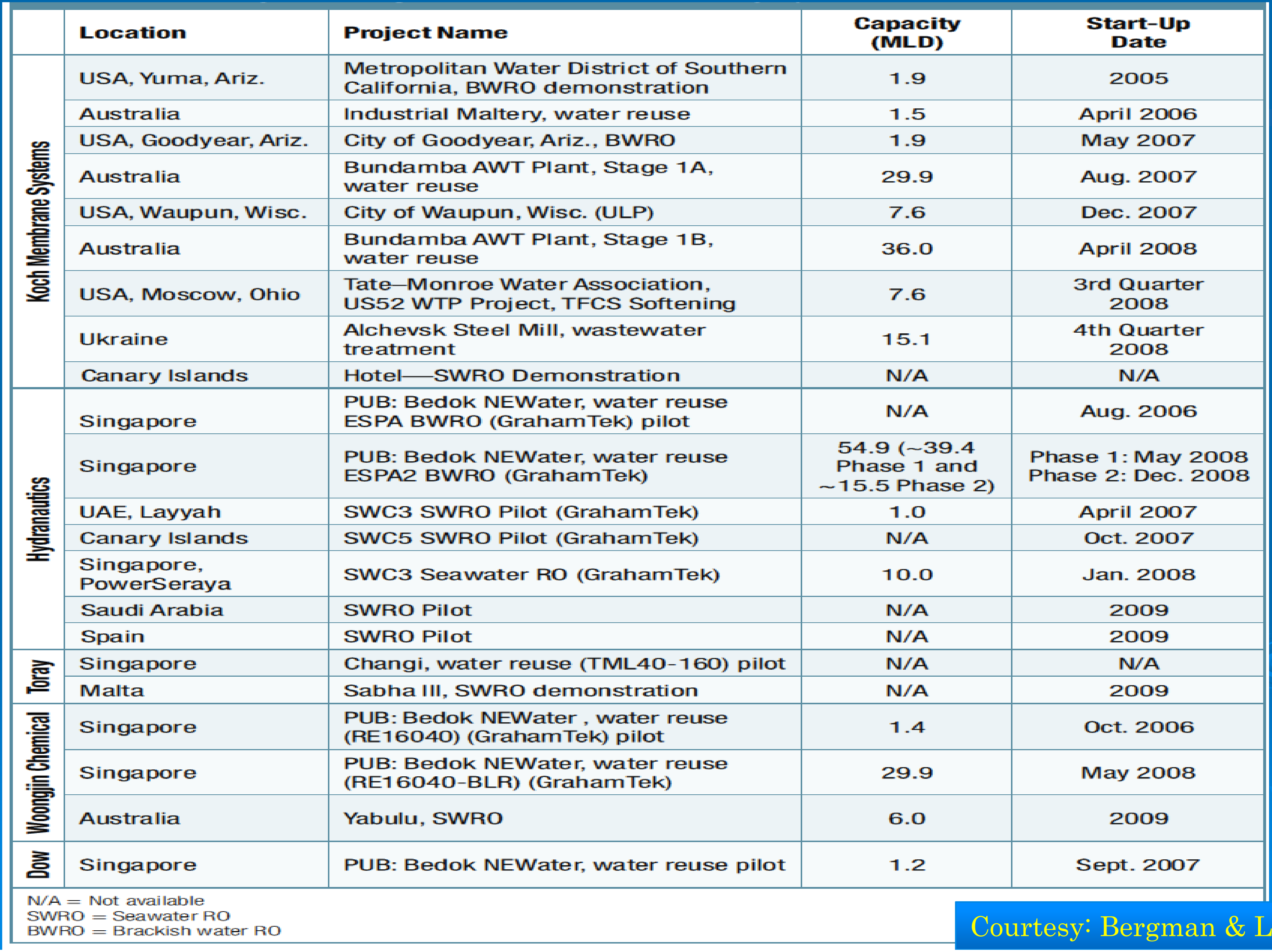
		DOW/FilmTec	Hydranautics (Nitto Denko)	Koch Membrane Systems		Toray	Woongjin Chemical
		SW30HRLE-1725	SWC5 1640HYD	TFC SW–MegaMagnum® 18061-		TM840-160	CSM RE16040-SHN
				SW-3050	HF-3050		
Nominal diameter x length[a]		16 x 40 in.	16 x 40 in.	18 x 61 in.		16 x 40 in.	16 x 40 in.
Membrane material		Composite polyamide	Composite polyamide	Composite polyamide		Composite polyamide	Composite polyamide
Nominal surface area, m^2		160	149	283	283	149	149
Feed spacer thickness, mm		0.71	0.76	0.7	0.7	0.71	0.71
Salt rejection, nominal at standard test conditions, percent		99.75 (91 percent B)	99.8	99.75	99.7	99.75	99.75
Salt rejection, minimum at standard test conditions, percent		99.60	99.6	99.5	99.5	99.5	99.6
Permeate flow at standard test conditions, m^3/d		121	129	200	263	101	92.4
Weight (approximate), dry, kg		57	52	90	90	66	60
Weight (approximate), wet, kg		68	63	113	113	76	66
Standard Test Conditions	NaCl, mg/L	32,000 (and 5 mg/L B)	32,000	32,800		32,000	32,000
	Applied pressure, bar	55	55	55		55	55
	Temperature, ºC	25	25	25		25	25
	Permeate recovery, percent	8	10	11		8	8
	pH	8.0	6.5 to 7.0	7.5		7.0	6.5 to 7.0

[a] Nominal membrane element diameter x length: 16-in. x 40-in. (0.41 x 1.0 m) or 18-in. x 61-in. (0.46 x 1.5 m)

Source: Bergman et al, 2009

Courtesy: Bergman & Losier

Projects with Large RO Elements



	Location	Project Name	Capacity (MLD)	Start-Up Date
Koch Membrane Systems	USA, Yuma, Ariz.	Metropolitan Water District of Southern California, BWRO demonstration	1.9	2005
	Australia	Industrial Maltery, water reuse	1.5	April 2006
	USA, Goodyear, Ariz.	City of Goodyear, Ariz., BWRO	1.9	May 2007
	Australia	Bundamba AWT Plant, Stage 1A, water reuse	29.9	Aug. 2007
	USA, Waupun, Wisc.	City of Waupun, Wisc. (ULP)	7.6	Dec. 2007
	Australia	Bundamba AWT Plant, Stage 1B, water reuse	36.0	April 2008
	USA, Moscow, Ohio	Tate–Monroe Water Association, US52 WTP Project, TFCS Softening	7.6	3rd Quarter 2008
	Ukraine	Alchevsk Steel Mill, wastewater treatment	15.1	4th Quarter 2008
	Canary Islands	Hotel—SWRO Demonstration	N/A	N/A
Hydranautics	Singapore	PUB: Bedok NEWater, water reuse ESPA BWRO (GrahamTek) pilot	N/A	Aug. 2006
	Singapore	PUB: Bedok NEWater, water reuse ESPA2 BWRO (GrahamTek)	54.9 (~39.4 Phase 1 and ~15.5 Phase 2)	Phase 1: May 2008 Phase 2: Dec. 2008
	UAE, Layyah	SWC3 SWRO Pilot (GrahamTek)	1.0	April 2007
	Canary Islands	SWC5 SWRO Pilot (GrahamTek)	N/A	Oct. 2007
	Singapore, PowerSeraya	SWC3 Seawater RO (GrahamTek)	10.0	Jan. 2008
	Saudi Arabia	SWRO Pilot	N/A	2009
	Spain	SWRO Pilot	N/A	2009
Toray	Singapore	Changi, water reuse (TML40-160) pilot	N/A	N/A
	Malta	Sabha III, SWRO demonstration	N/A	2009
Woongjin Chemical	Singapore	PUB: Bedok NEWater , water reuse (RE16040) (GrahamTek) pilot	1.4	Oct. 2006
	Singapore	PUB: Bedok NEWater, water reuse (RE16040-BLR) (GrahamTek)	29.9	May 2008
	Australia	Yabulu, SWRO	6.0	2009
Dow	Singapore	PUB: Bedok NEWater, water reuse pilot	1.2	Sept. 2007

N/A = Not available
SWRO = Seawater RO
BWRO = Brackish water RO

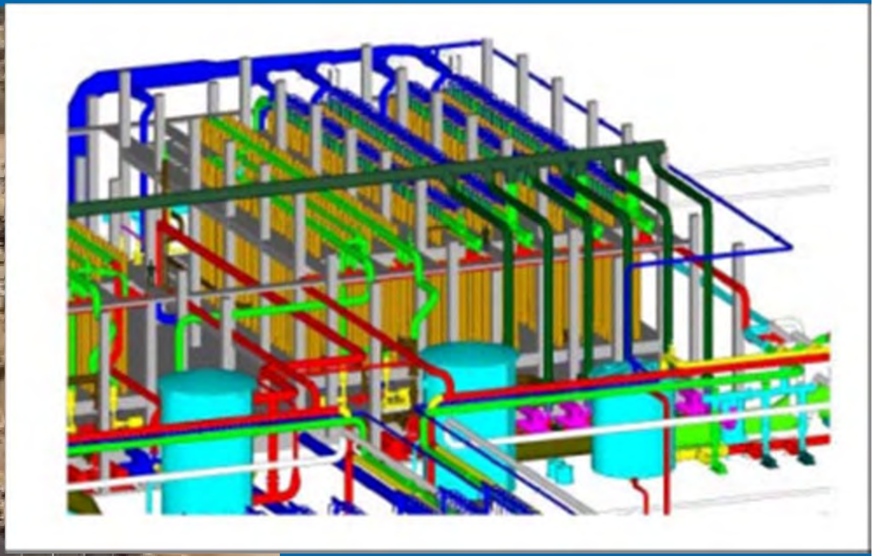
Courtesy: Bergman & Losier

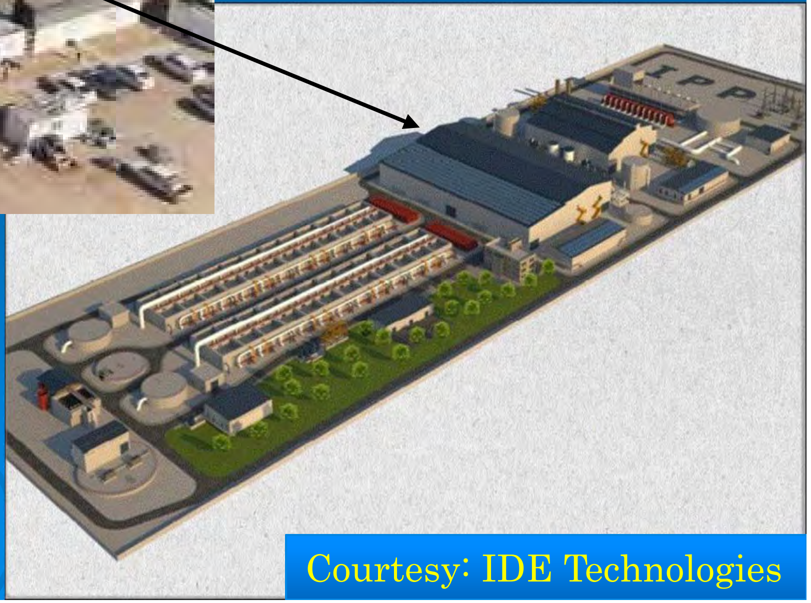
Horizontal vs. Vertical Pressure Vessel Configuration

- Horizontal Pressure Vessels Dominate SWRO Plant Configurations with 8-inch Elements:
  - Easier Manual Handling;
  - 1.5 Times Lower Height Buildings;
  - Lower Cost Foundations.
- Vertical Pressure Vessel Configuration – Found More Attractive for 16-inch Elements Where Manual Membrane Handling is Not Possible.
  - 1.5 Times Smaller Footprint;
  - 1.2 Times Less Super Duplex Piping & Fittings;
  - 15 % Lower Plant Construction Costs.

BEL's 16-inch diameter, 8-element Pressure Vessel

410,000 m³/day Sorek SWRO Plant, Israel





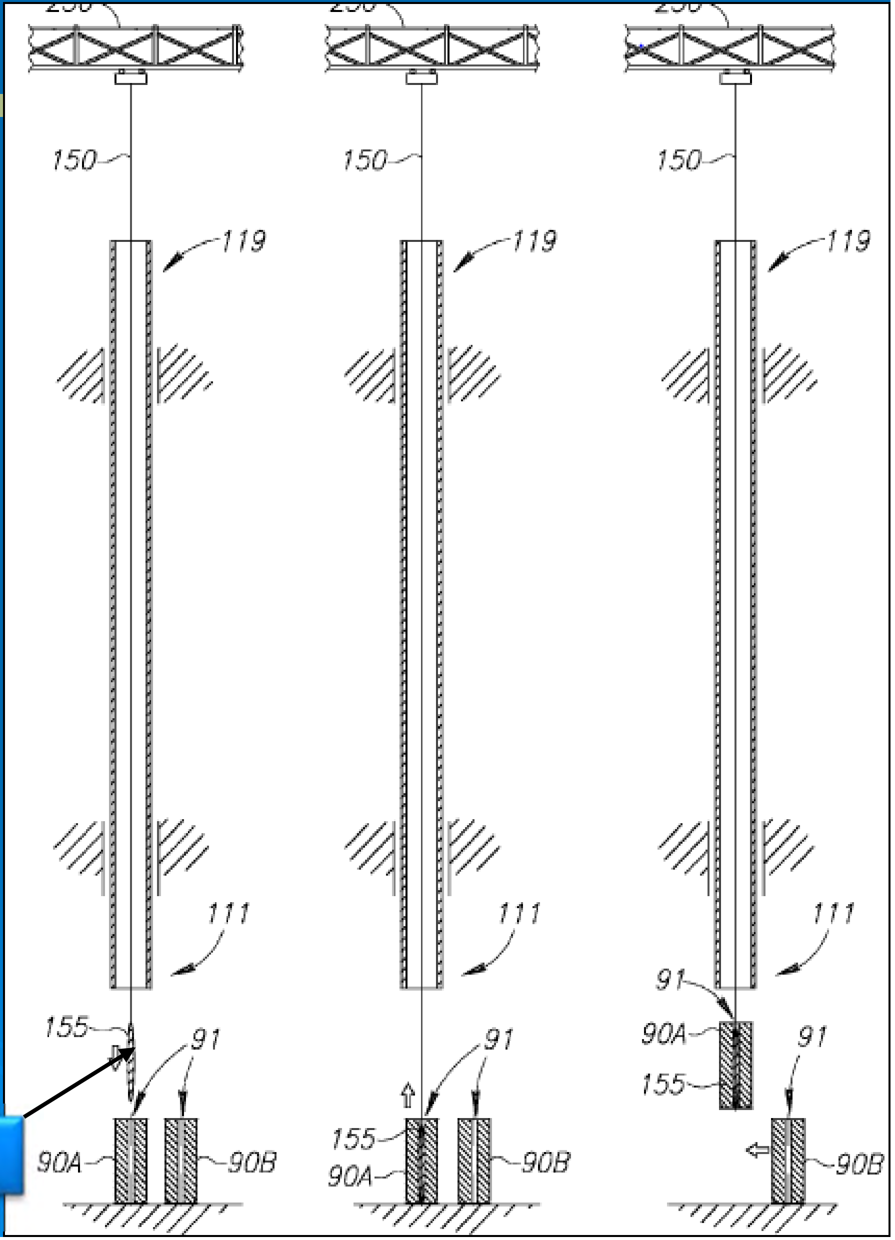
- Vertical 16-inch Vessels;
- 4.3 Times Larger Flow Rate than 8-inch Membranes;
- Scheduled for Operation in 2013;
- Record Low Water Price (US¢ 58.5/m³ - in $2009)

Courtesy: IDE Technologies

Sorek 16-inch SWRO Element System – Bottom View

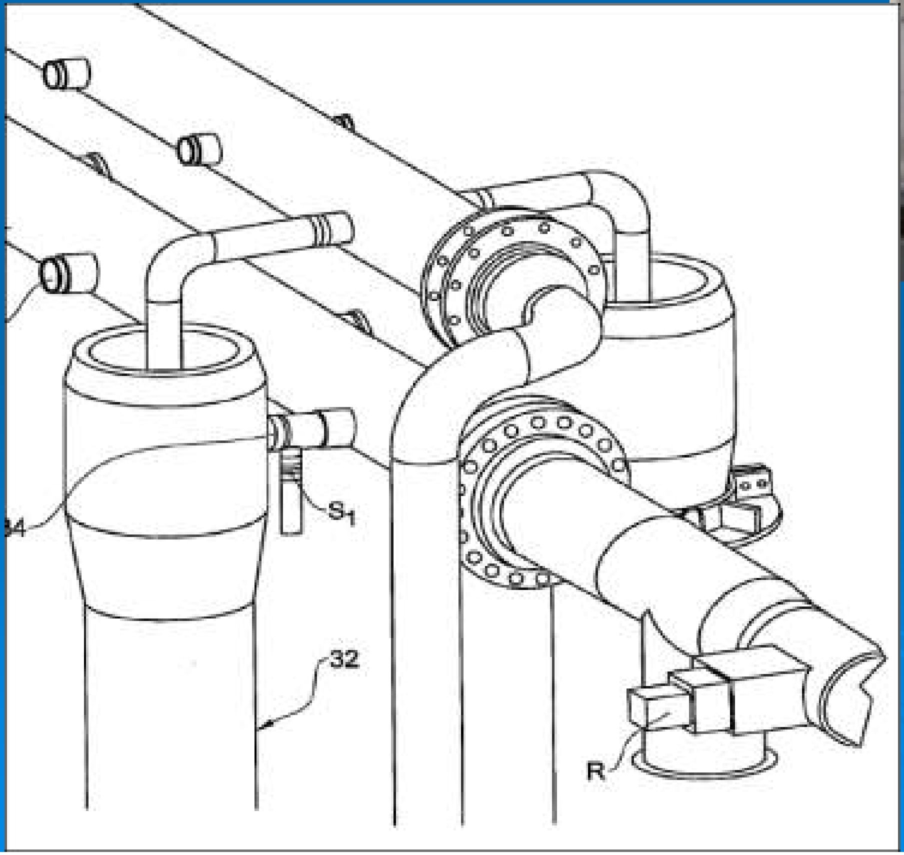
- Seawater Fed & Front Permeate Collected at the Bottom of the Vessel.
- Membranes Can Be Installed from the Top or the Bottom.

Inflatable Fastener



Sorek 16-inch SWRO Element System – Top View

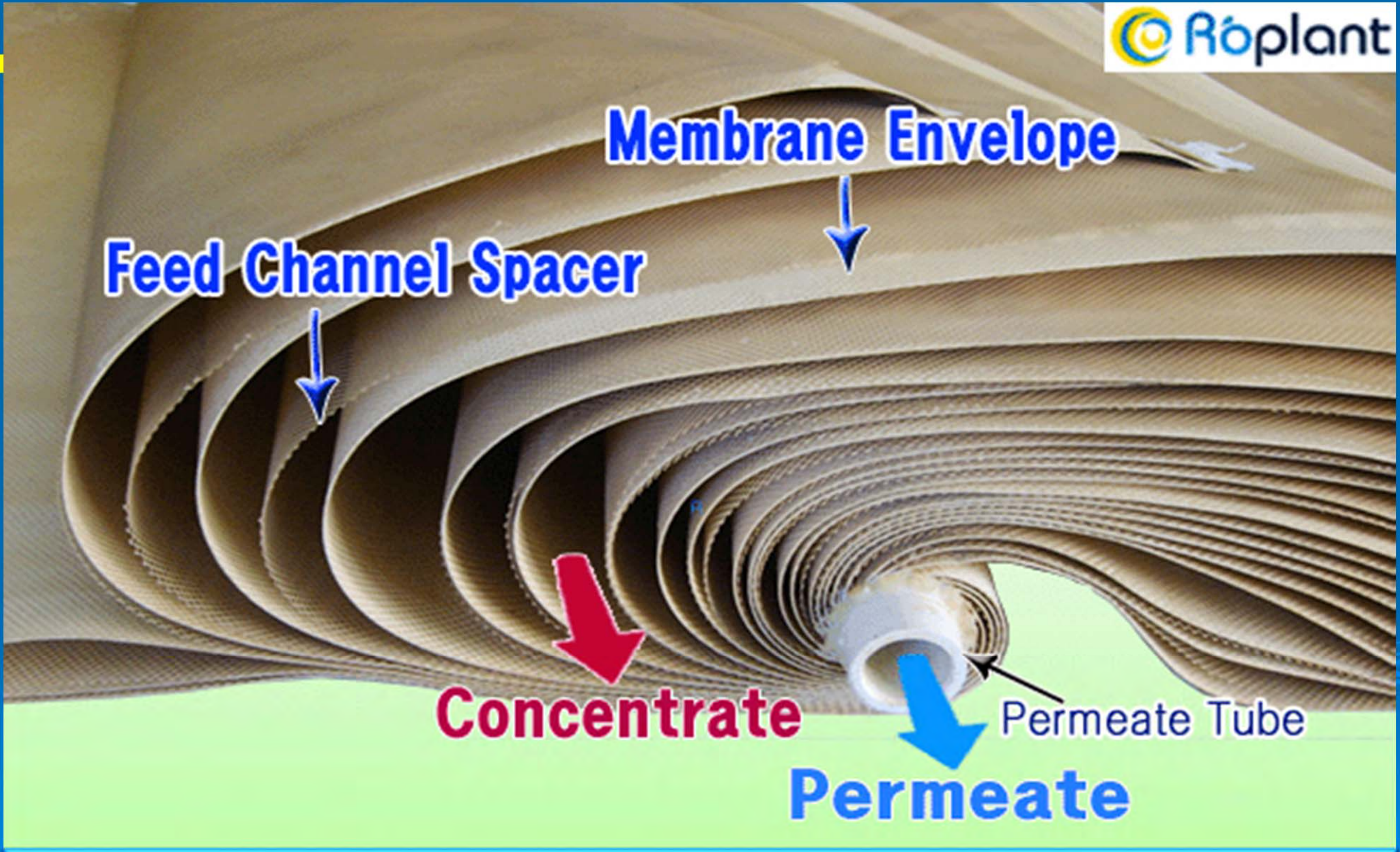
- Concentrate & Rear Permeate Collected from the Top of the Vessel.



Other Benefits and Challenges of Vertical Pressure Vessel Configuration

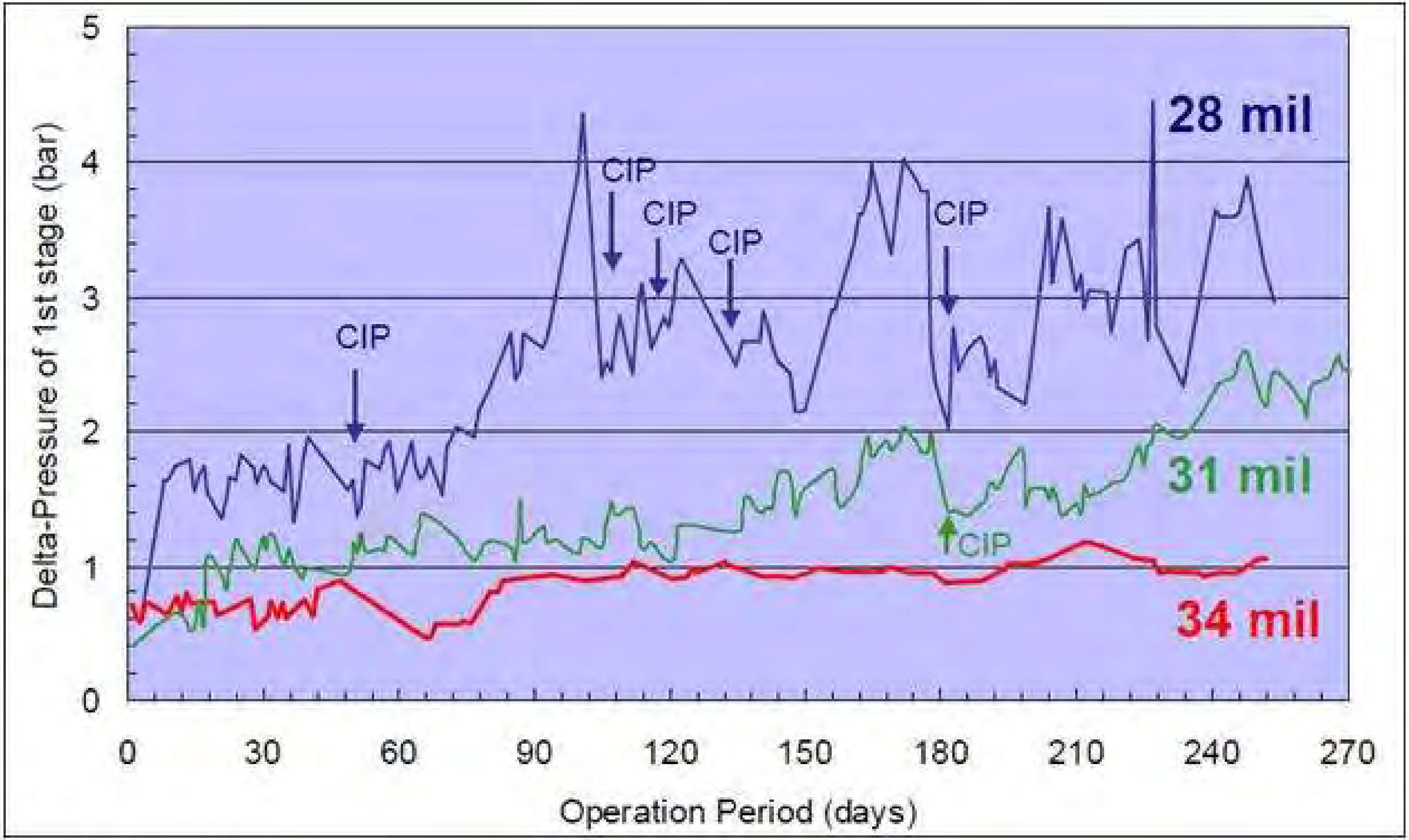
- Benefits:
  - Membrane Weight Minimizes Displacement During Startup and Shutdown;
  - Membrane Weight Eliminates the Need for Shimming Assembly Which Typically is Used to Prevent Displacement;
- Challenges:
  - Structural Complexity in Earthquake Zones;
  - More Complex Bottom End Cap to Hold Weight of All Elements;
  - Very Tall Building and Thick Foundations.

Low-Fouling Elements with Wider Spacers

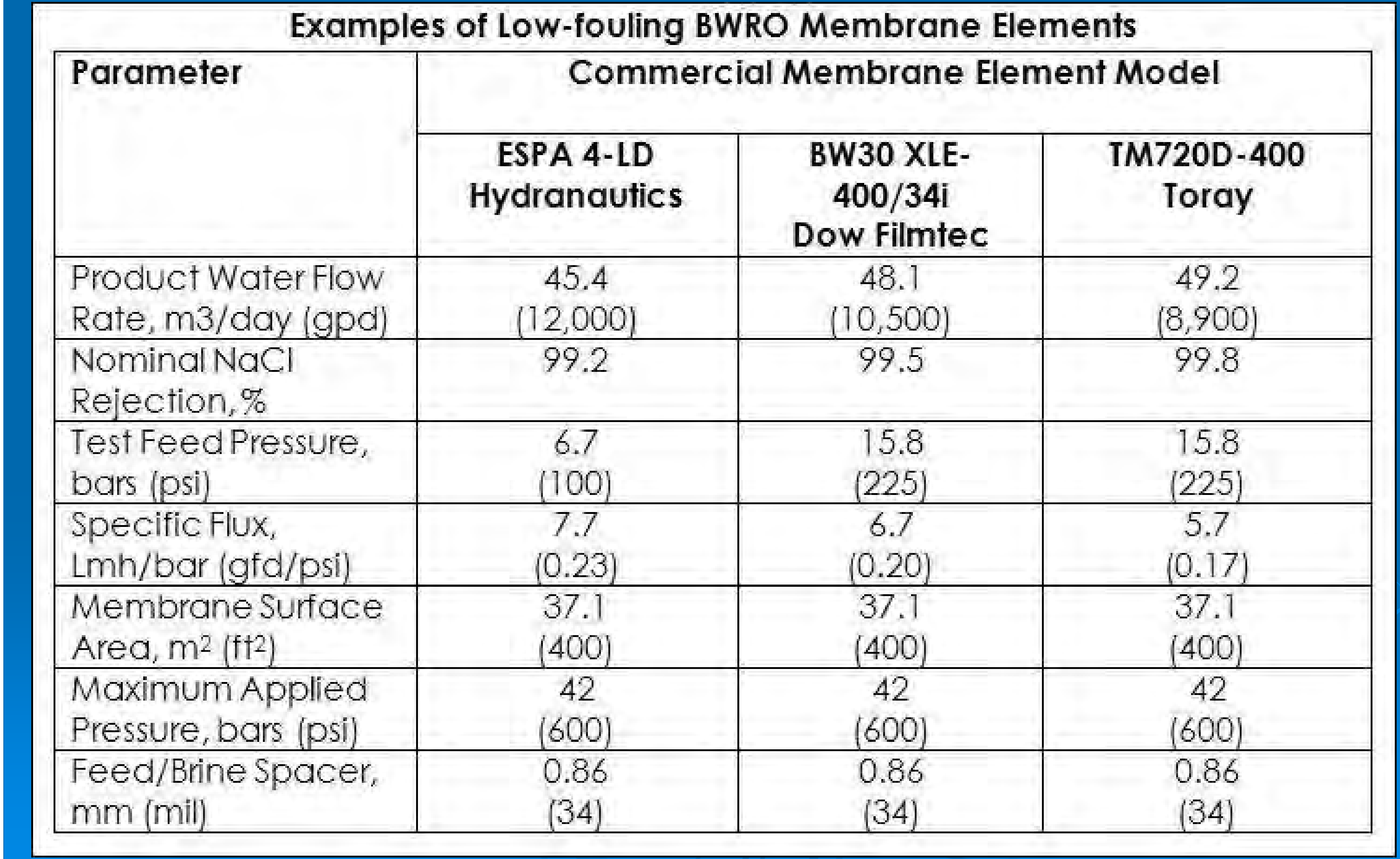


Standard (28 mil) vs. Wide (34 mil) Spacers

Use of Low-Fouling RO Elements



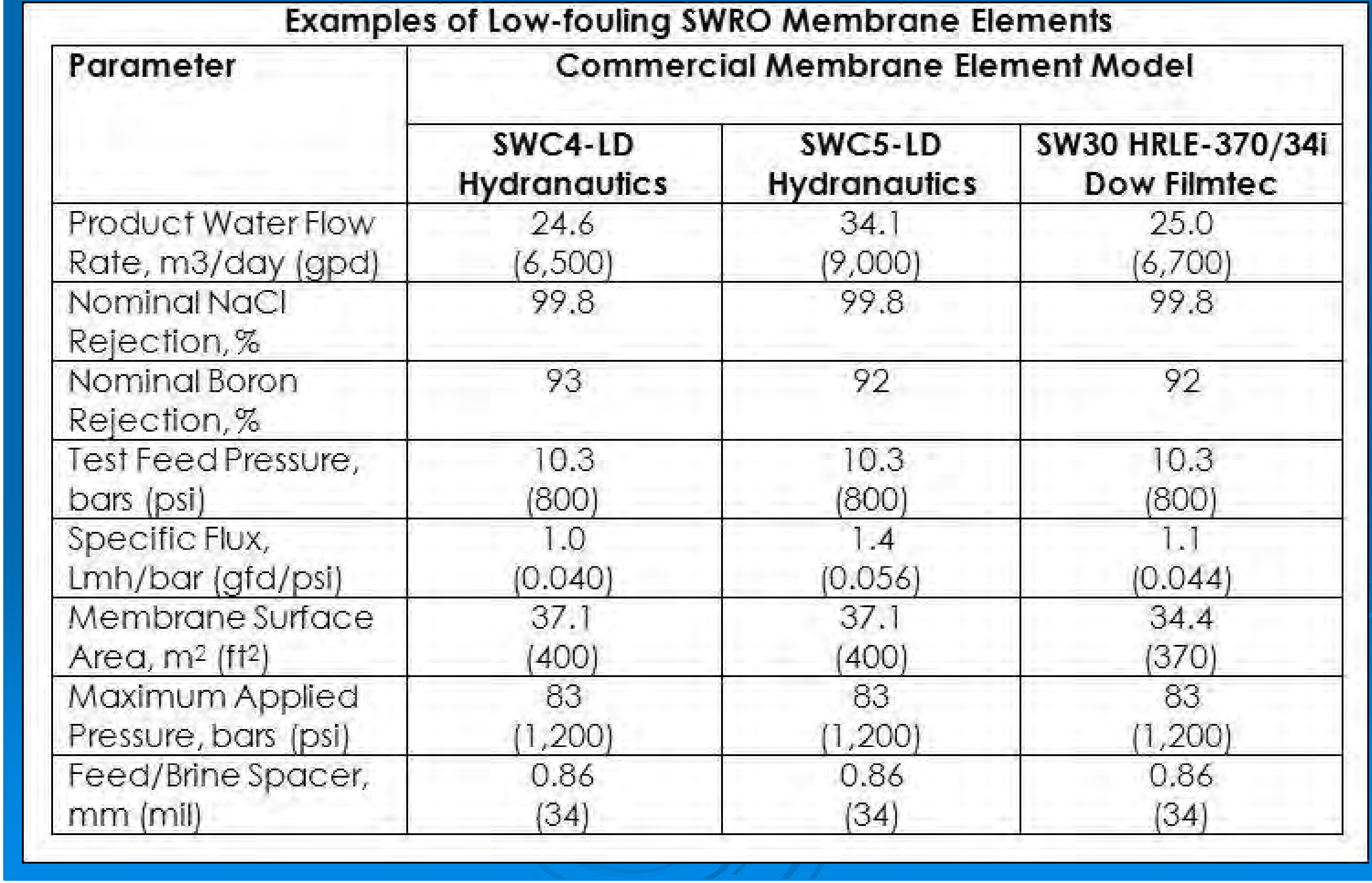
Low Fouling BWRO Elements



Examples of Low-fouling BWRO Membrane Elements

Parameter	**Commercial Membrane Element Model**		
	ESPA 4-LD Hydranautics	**BW30 XLE-400/34i Dow Filmtec**	**TM720D-400 Toray**
Product Water Flow Rate, m3/day (gpd)	45.4 (12,000)	48.1 (10,500)	49.2 (8,900)
Nominal NaCl Rejection, %	99.2	99.5	99.8
Test Feed Pressure, bars (psi)	6.7 (100)	15.8 (225)	15.8 (225)
Specific Flux, Lmh/bar (gfd/psi)	7.7 (0.23)	6.7 (0.20)	5.7 (0.17)
Membrane Surface Area, m^2 (ft^2)	37.1 (400)	37.1 (400)	37.1 (400)
Maximum Applied Pressure, bars (psi)	42 (600)	42 (600)	42 (600)
Feed/Brine Spacer, mm (mil)	0.86 (34)	0.86 (34)	0.86 (34)

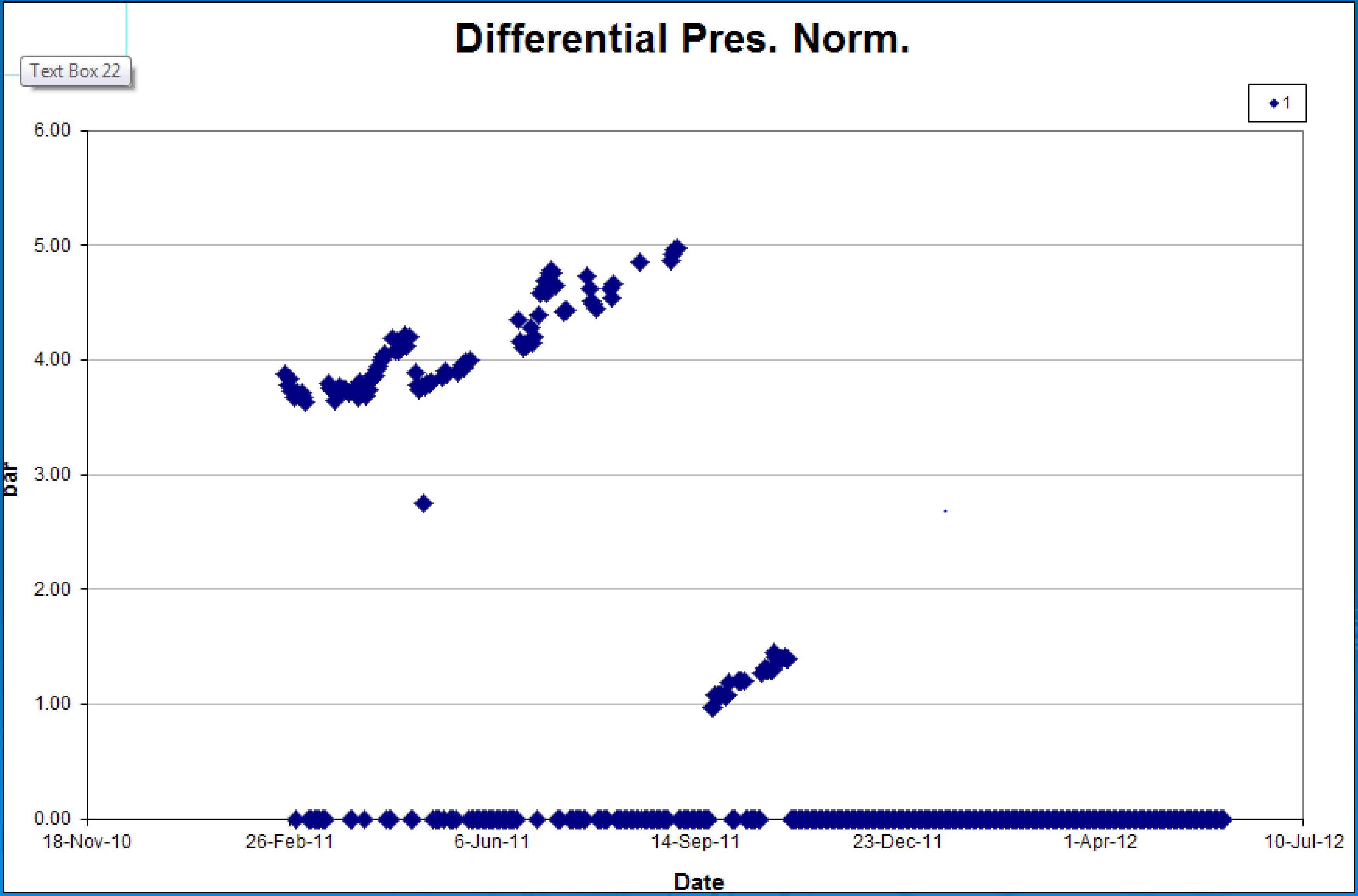
Low Fouling SWRO Elements



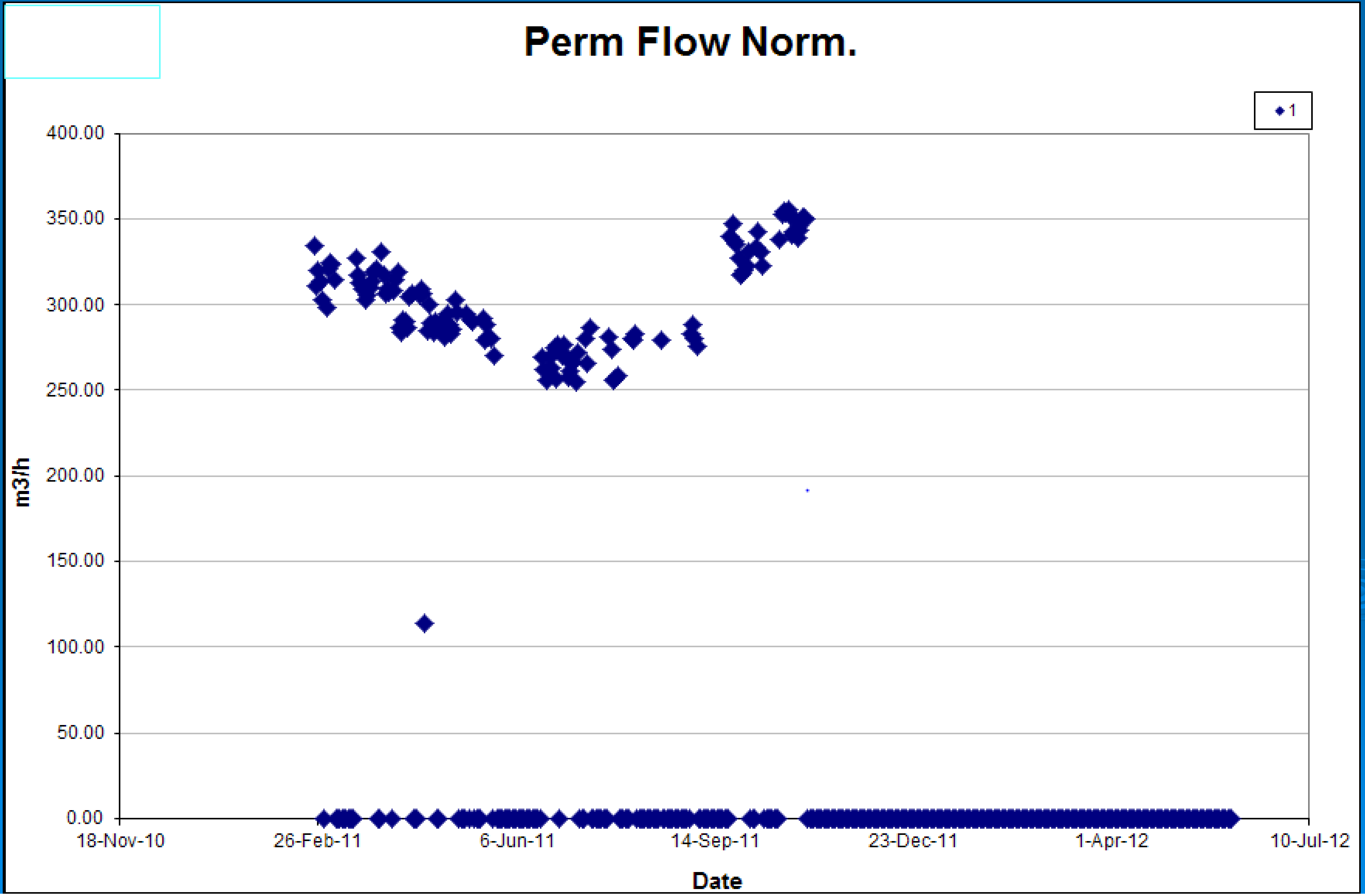
Examples of Low-fouling SWRO Membrane Elements

Parameter	Commercial Membrane Element Model		
	SWC4-LD Hydranautics	SWC5-LD Hydranautics	SW30 HRLE-370/34i Dow Filmtec
Product Water Flow Rate, m3/day (gpd)	24.6 (6,500)	34.1 (9,000)	25.0 (6,700)
Nominal NaCl Rejection, %	99.8	99.8	99.8
Nominal Boron Rejection, %	93	92	92
Test Feed Pressure, bars (psi)	10.3 (800)	10.3 (800)	10.3 (800)
Specific Flux, Lmh/bar (gfd/psi)	1.0 (0.040)	1.4 (0.056)	1.1 (0.044)
Membrane Surface Area, m^2 (ft^2)	37.1 (400)	37.1 (400)	34.4 (370)
Maximum Applied Pressure, bars (psi)	83 (1,200)	83 (1,200)	83 (1,200)
Feed/Brine Spacer, mm (mil)	0.86 (34)	0.86 (34)	0.86 (34)

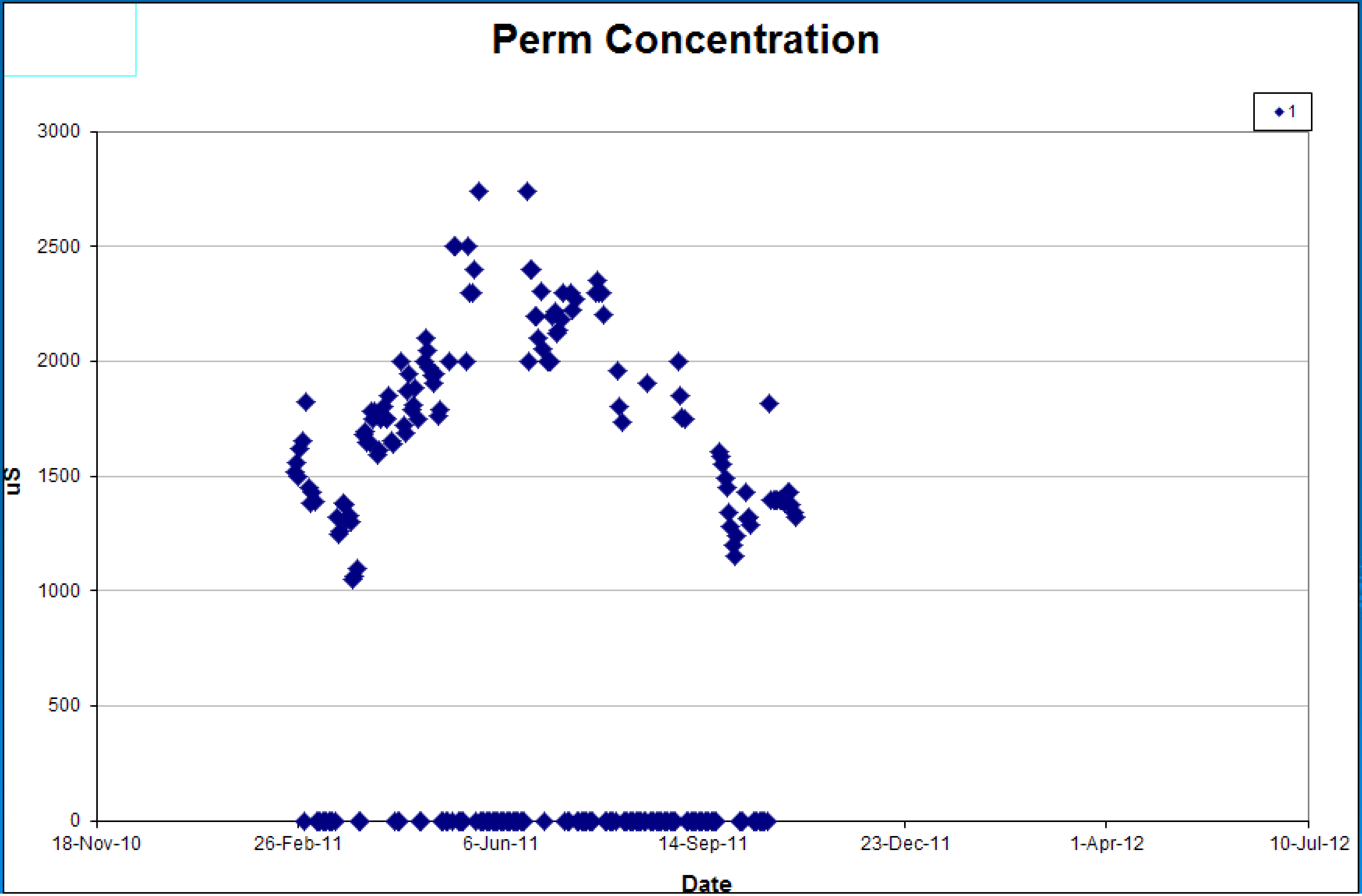
Fujairah - Effect of Replacing the First Two Elements w/ SWC4LD Membranes



Fujairah – LD Elements Effect on Permeate Production



Fujairah – LD Membrane Impact on Permeate Quality



Main Areas Expected to Yield Cost Savings in the Next 5 Years (20 % Cost & Power Reduction)

- **Improvements in Membrane Element Productivity**:
  - **Polymetric Membranes** (Incorporation of Nano-particles Into Membrane Polymer Matrix);
  - **Bio-membranes** & Enzymatic Transport of Water;
  - **Carbon Nanotube Membranes.**
- **Increased Membrane Useful Life and Reduced Fouling:**
  - Smoother Membrane Surface;
  - Use of Systems for Continuous RO Membrane Cleaning;
  - UF/MF Membrane Pretreatment.
- **Commercial Forward Osmosis Systems;**
- **Replacement of Stainless Steel w/ Plastic Pipe Materials;**
- **Larger RO Elements, Trains and Equipment.**

Questions ?