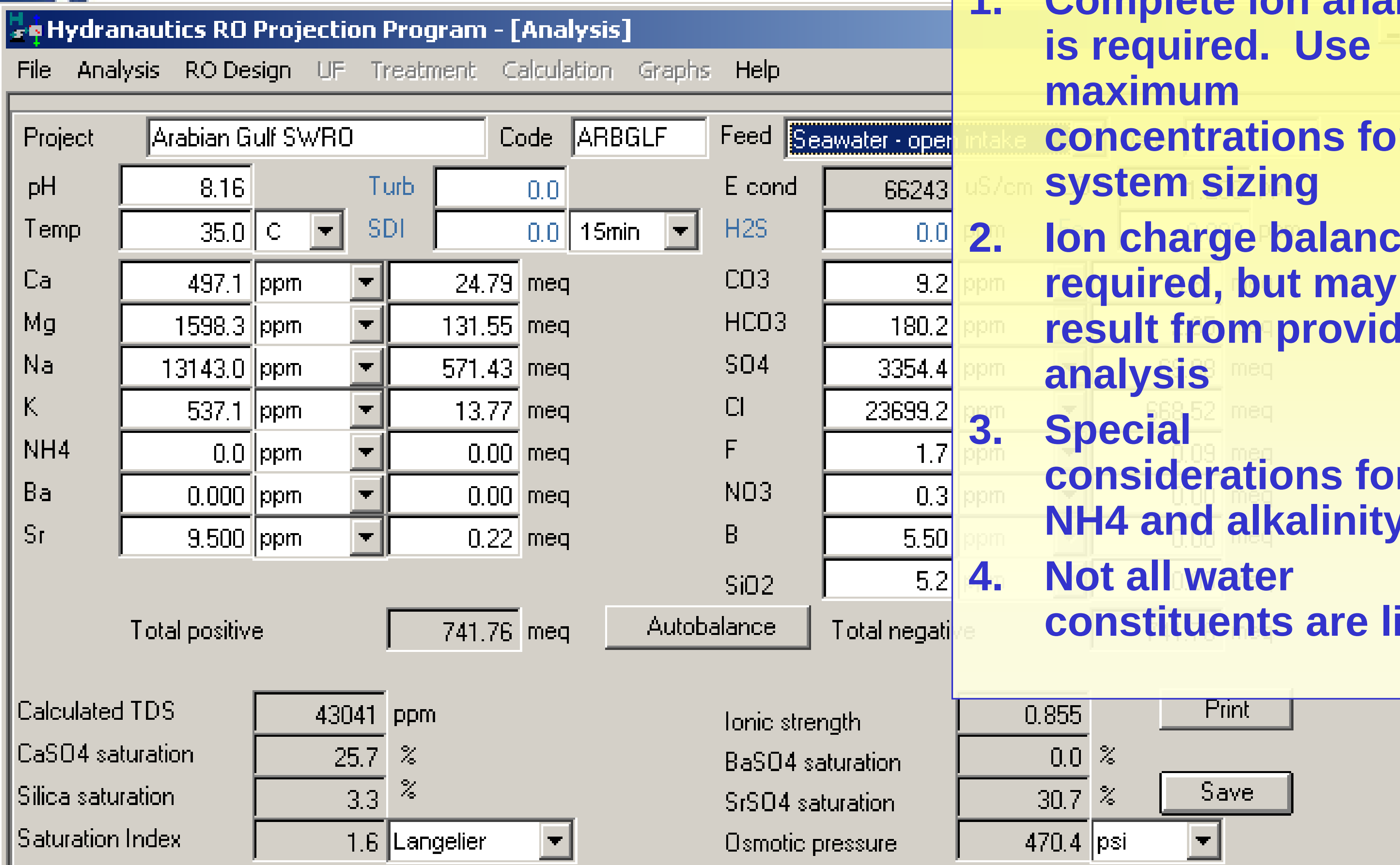
RO / NF Process Design

April 2009

SYSTEM DESIGN CONSIDERATIONS

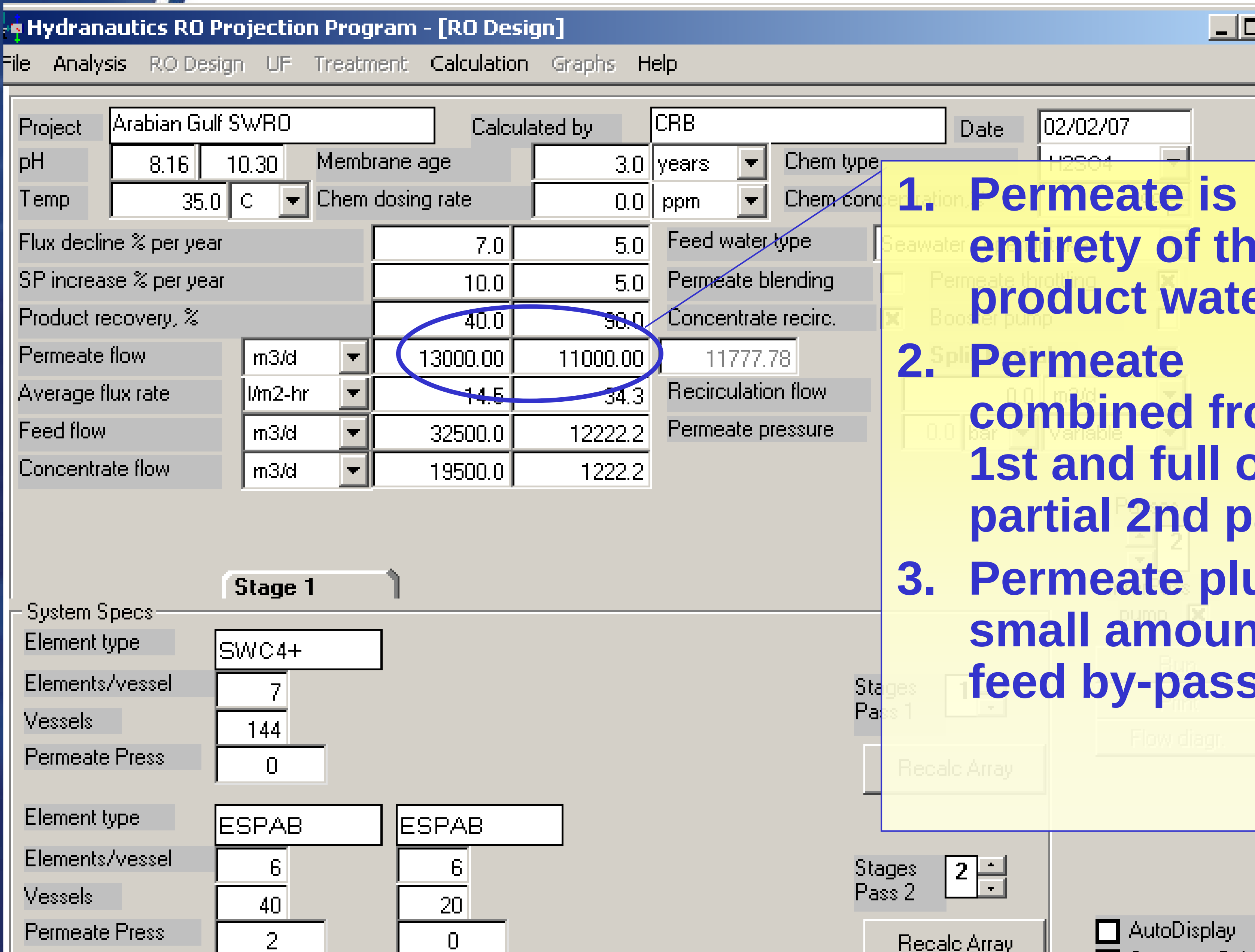
- Permeate capacity and quality
- Permeate recovery ratio
- Membrane type
- Average permeate flux rate
- Size of RO trains and array design
- pH adjustment for optimum performance
- Energy Recovery devices

Feedwater and Temperature



1. Complete ion analysis is required. Use maximum concentrations for system sizing
2. Ion charge balance is required, but may not result from provided analysis
3. Special considerations for NH4 and alkalinity
4. Not all water constituents are listed

Product Water Flow

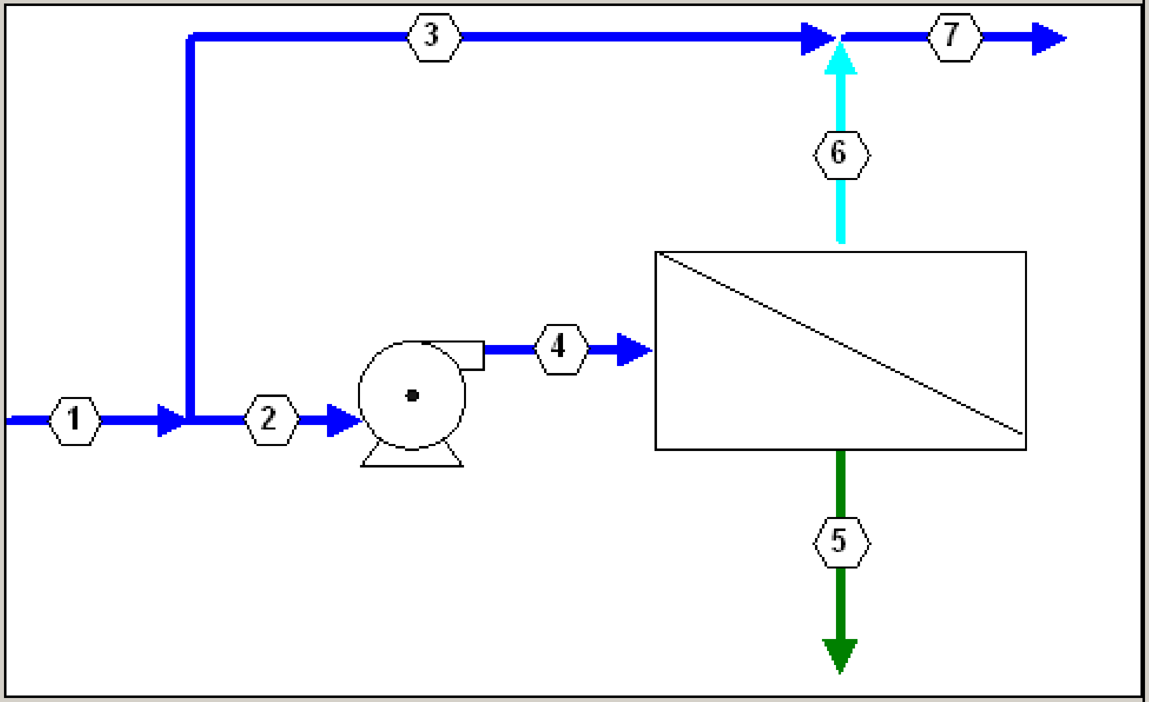


1. **Permeate is entirety of the product water**
2. **Permeate combined from 1st and full or partial 2nd pass.**
3. **Permeate plus small amount of feed by-pass**

Process Flow Diagram – Feed Bypass

Flow Diagram

Permeate BLENDING



		1	2	3	4	5	6	7
Flow	m3/hr	305.0	275.0	30.0	275.0	55.0	220.0	250.0
Pressure	bar	0.0	0.0	0.0	7.7	5.1	0.0	0.0
TDS (ppm)		830.3	830.3	830.3	830.3	4060.5	22.7	119.6

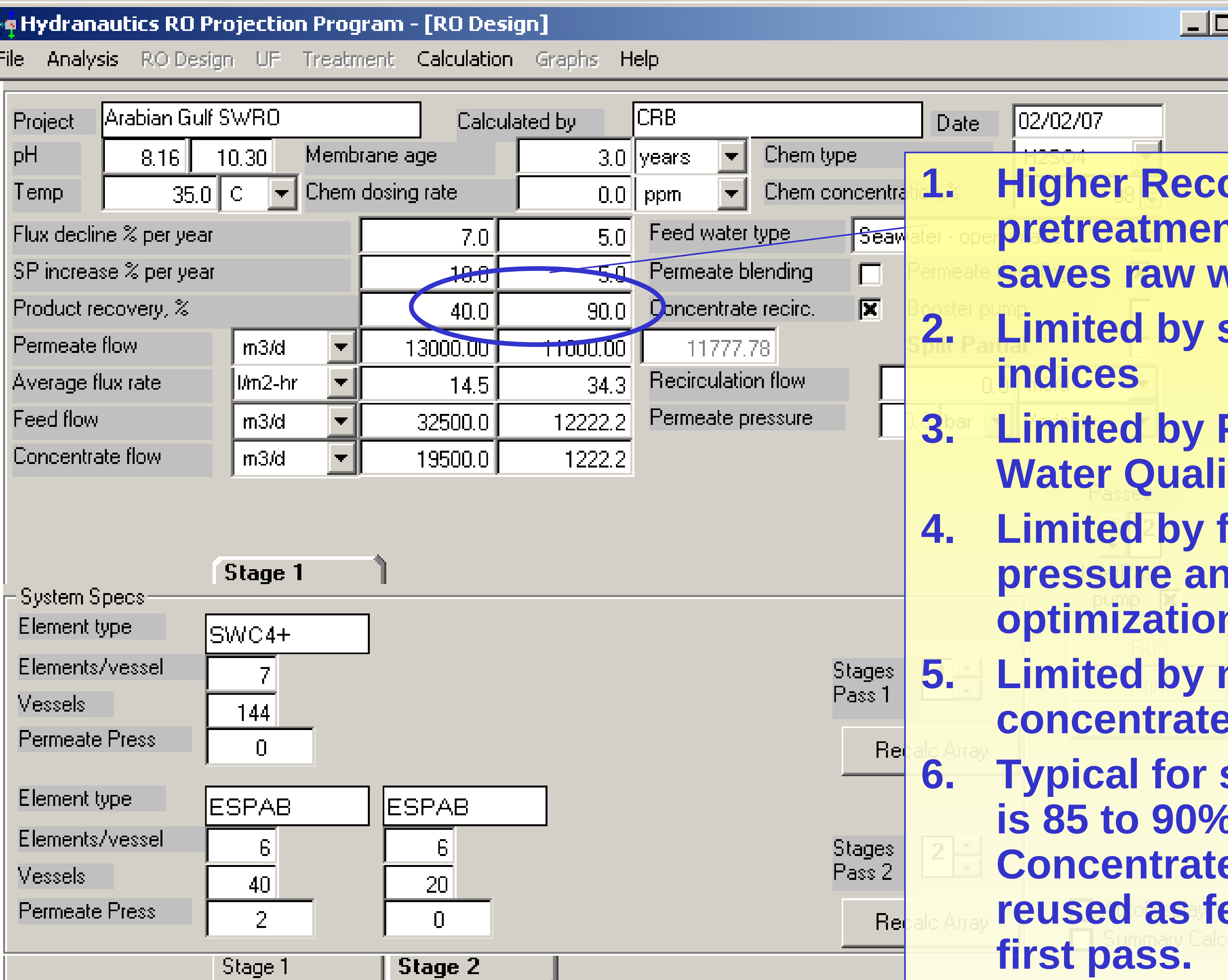
Variable Permeate Back Pressure is applicable - check printout

Close

Clipboard

Print

Selecting Your Recovery



1. Higher Recovery lowers pretreatment costs and saves raw water
2. Limited by scaling indices
3. Limited by Permeate Water Quality
4. Limited by feed pressure and energy optimization
5. Limited by minimum concentrate flow
6. Typical for second pass is 85 to 90%. Concentrate from 2nd reused as feed to the first pass.

Recovery Limitations: Scaling

Hydranautics (warnings in program)

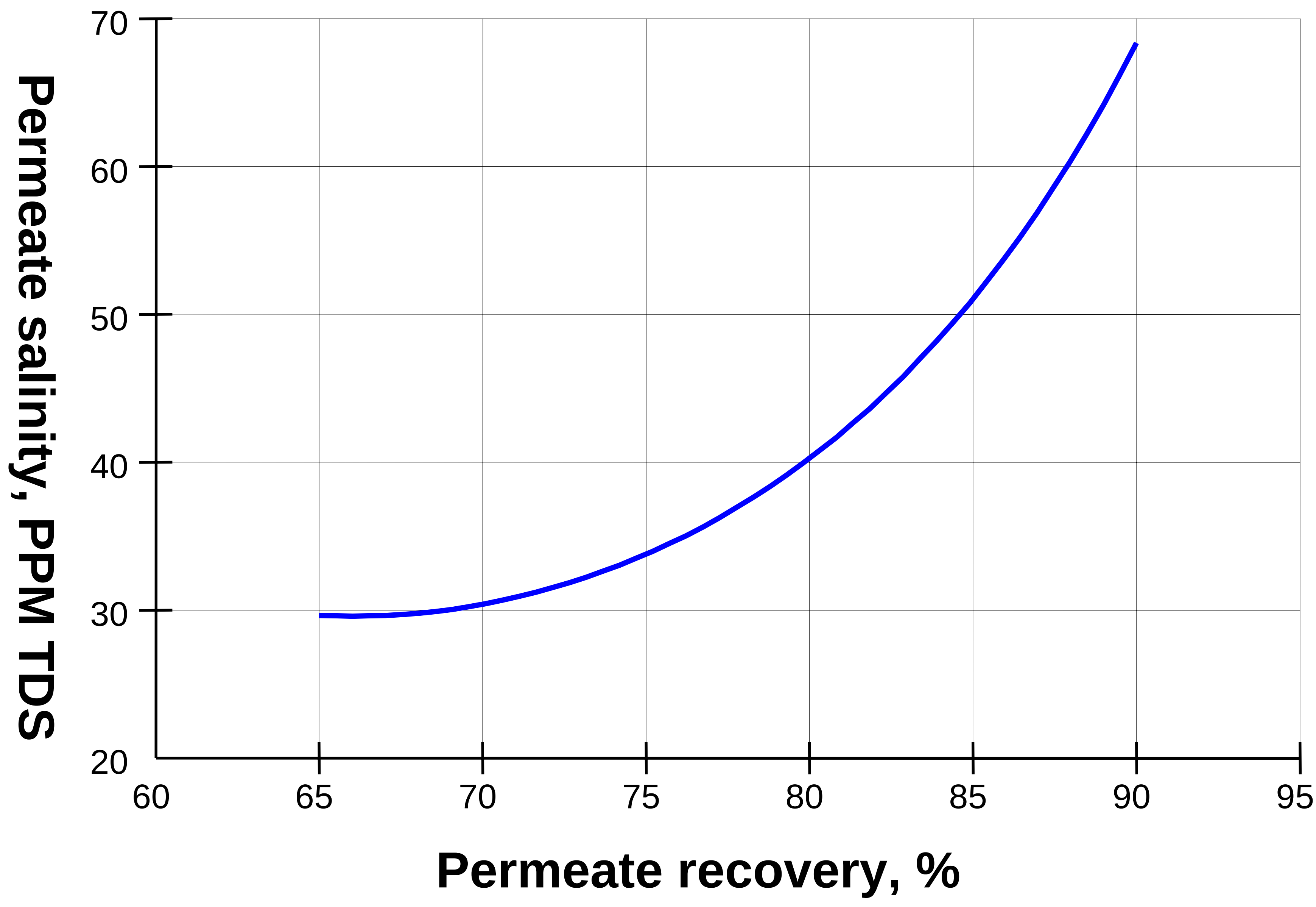
Saturation Limits:

CaSo4	230 %
SrSO4	800 %
BaSO4	6000 %
SiO2	100 %
LSI	<1.8 (Brackish Feed w. Scale Inhibitor)

Proprietary Chemicals (software provided by vendors)

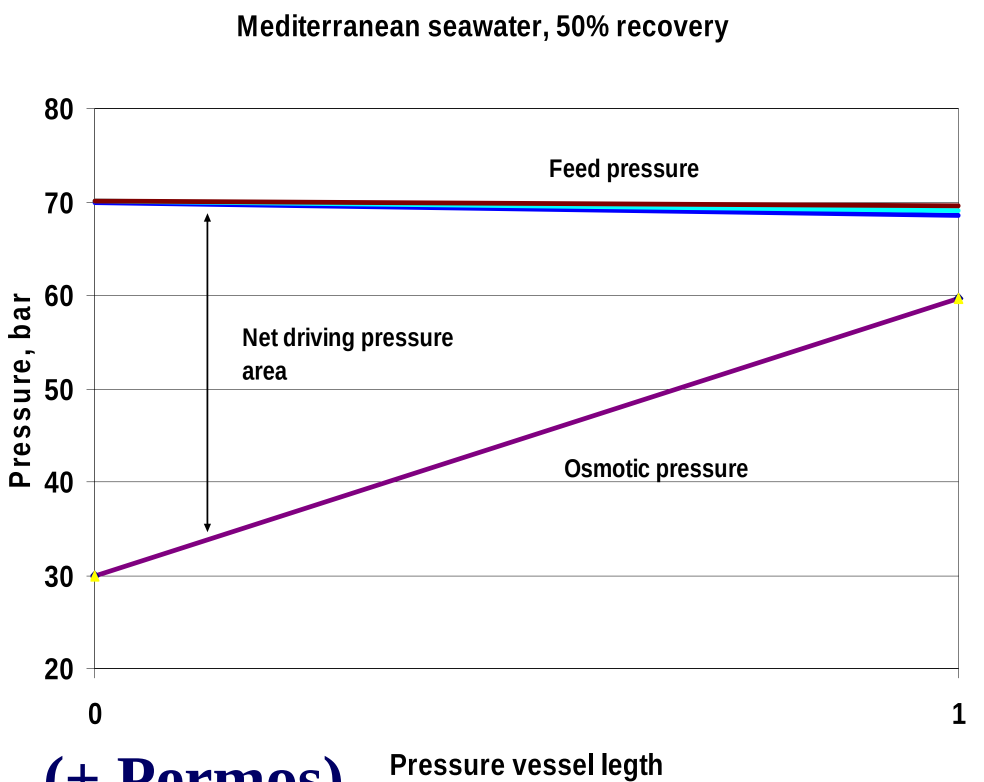
	Product A	Product B
$CaSO_4$	350%	250%
Sr_2SO_4	3500%	3000%
Ba_2SO_4	10500%	6500%
SiO_2		240 mg/L
$CaCO_3$	L.S.I. 3.0	L.S.I. 2.5
CaF_2	1300000%	10000%

Brackish Water Salinity vs recovery



Net Driving Pressure (NDP)

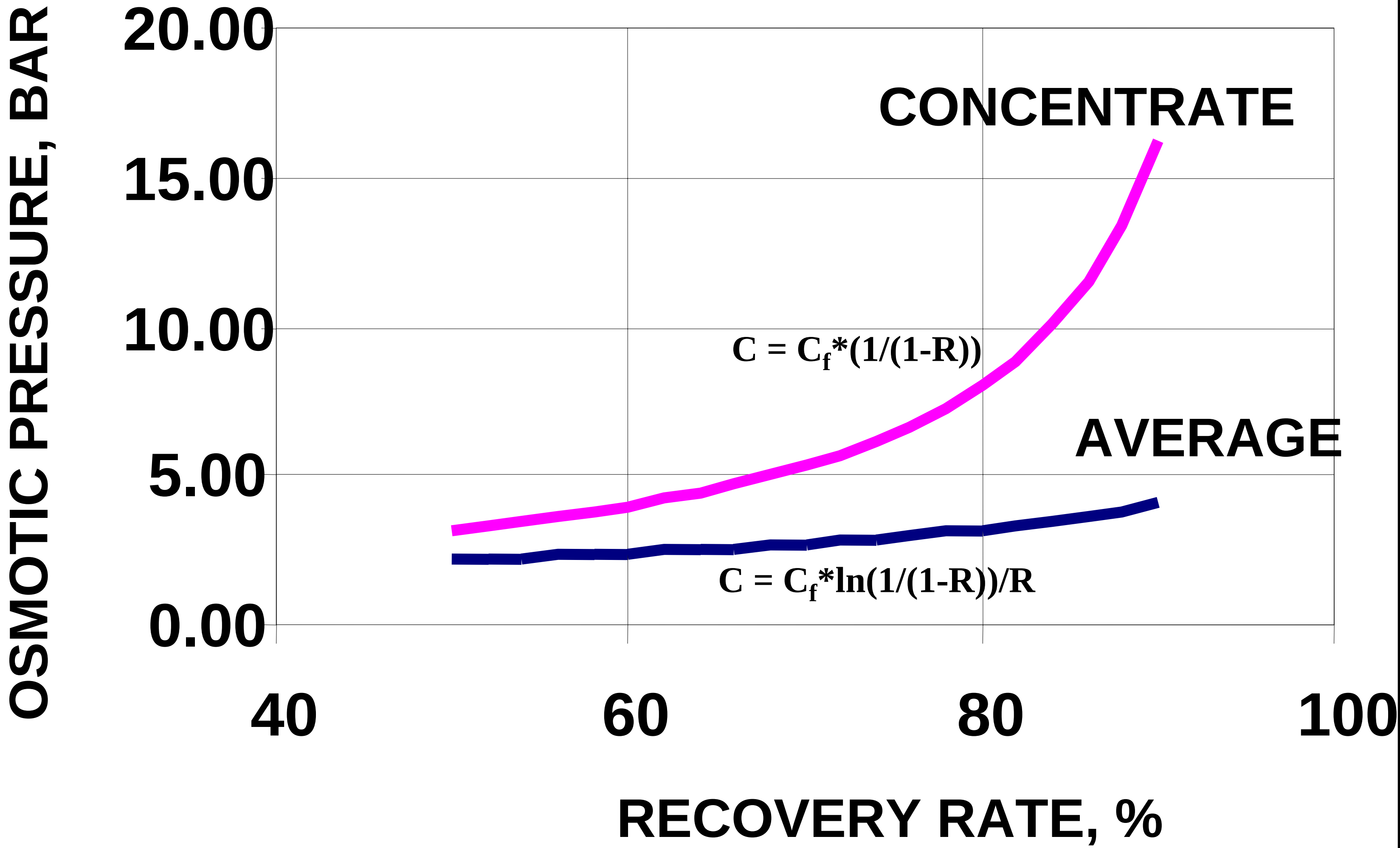
NDP - net driving pressure
Driving force of the water transport (flux) through the membrane.



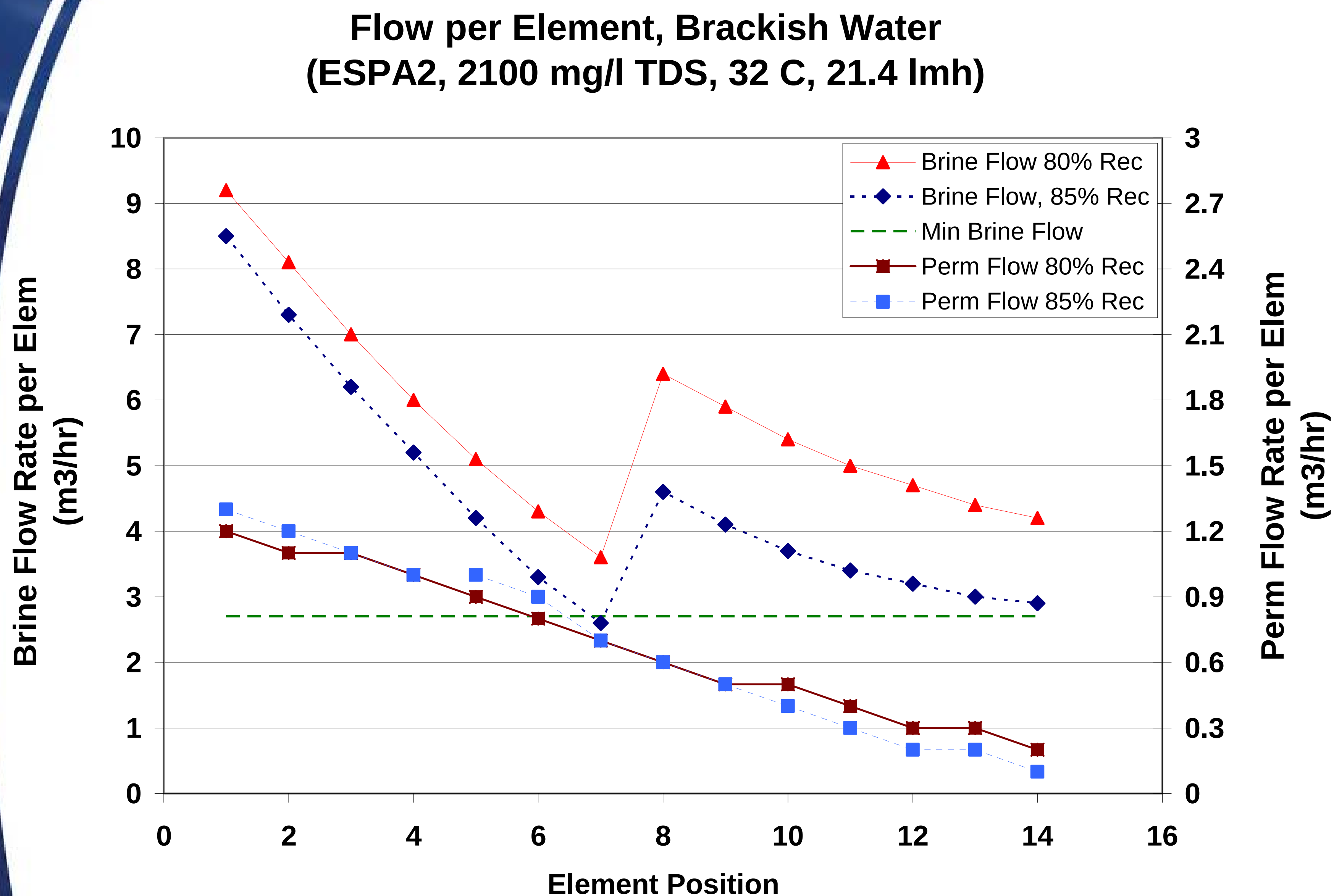
$NDP = P_f - \overline{P}_{os} - P_p - 0.5 * P_h$ (+ Permos)

- P_f - applied feed pressure
- $\overline{P}_{os}$ – osmotic pressure (Avg Fd P_{os} – Perm P_{os})
- P_p - permeate pressure
- P_h - hydraulic pressure drop across RO element

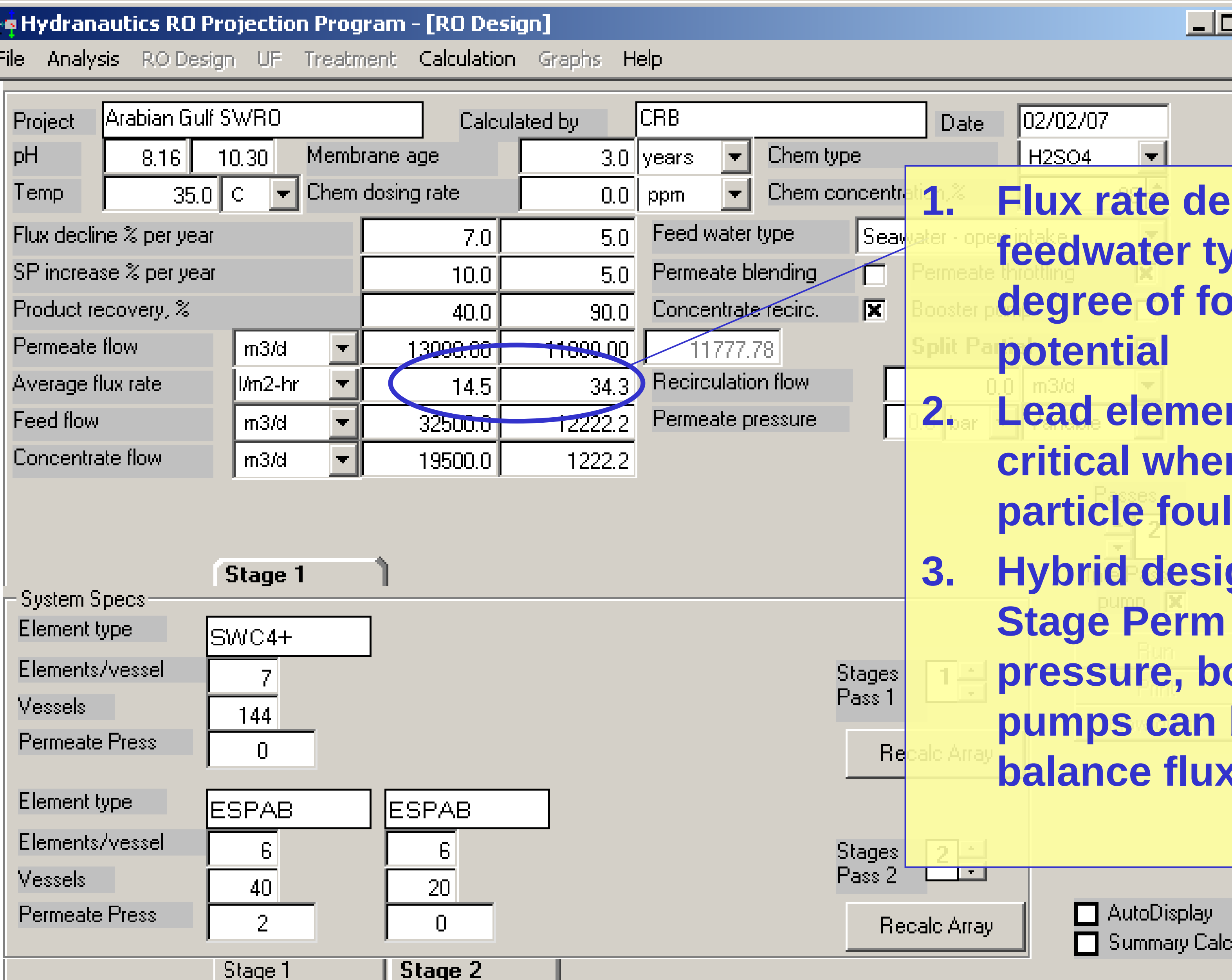
EFFECT OF RECOVERY RATE



Effect of Recovery on Brine Flow

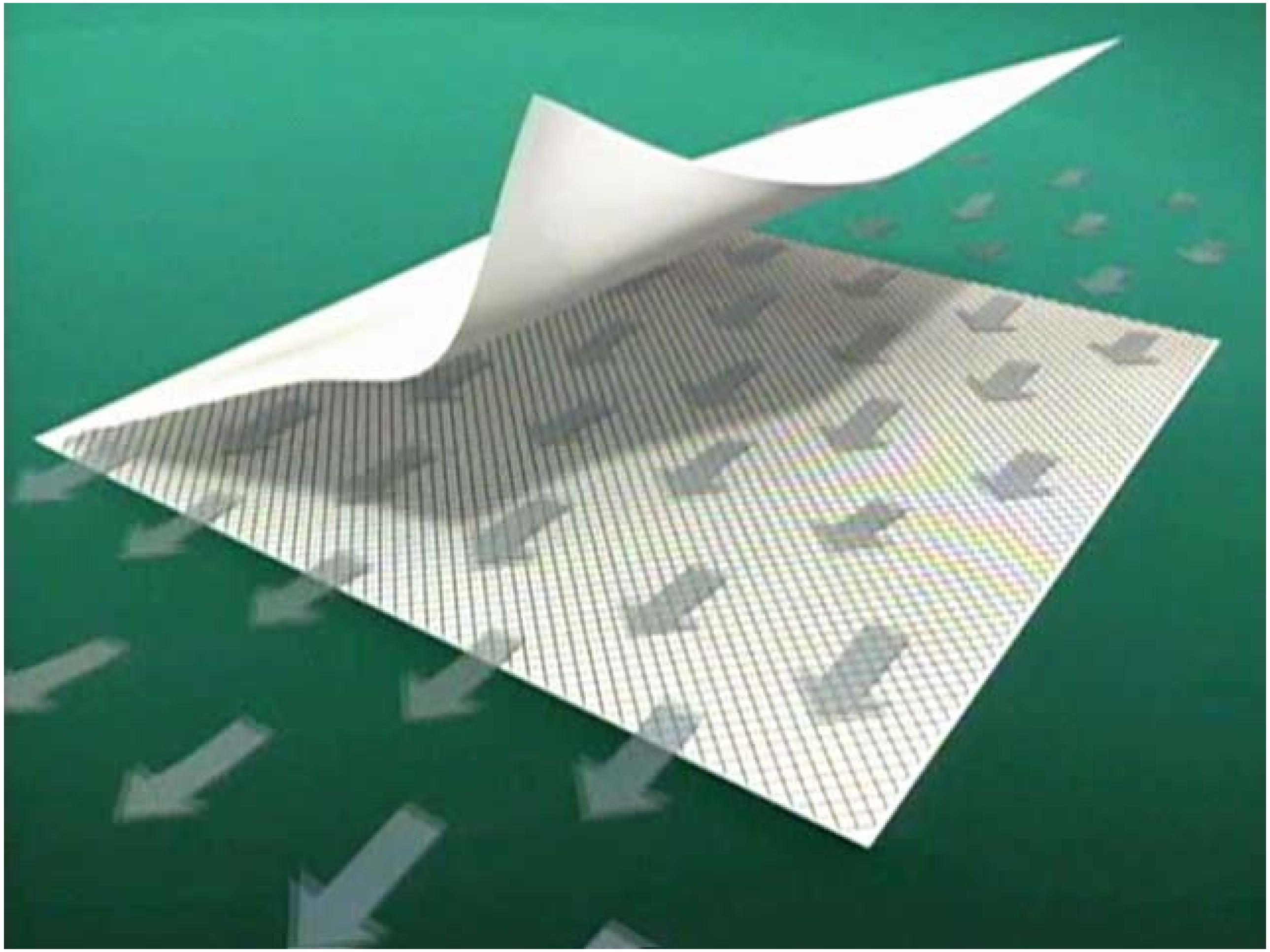


Selecting Your Flux Rate

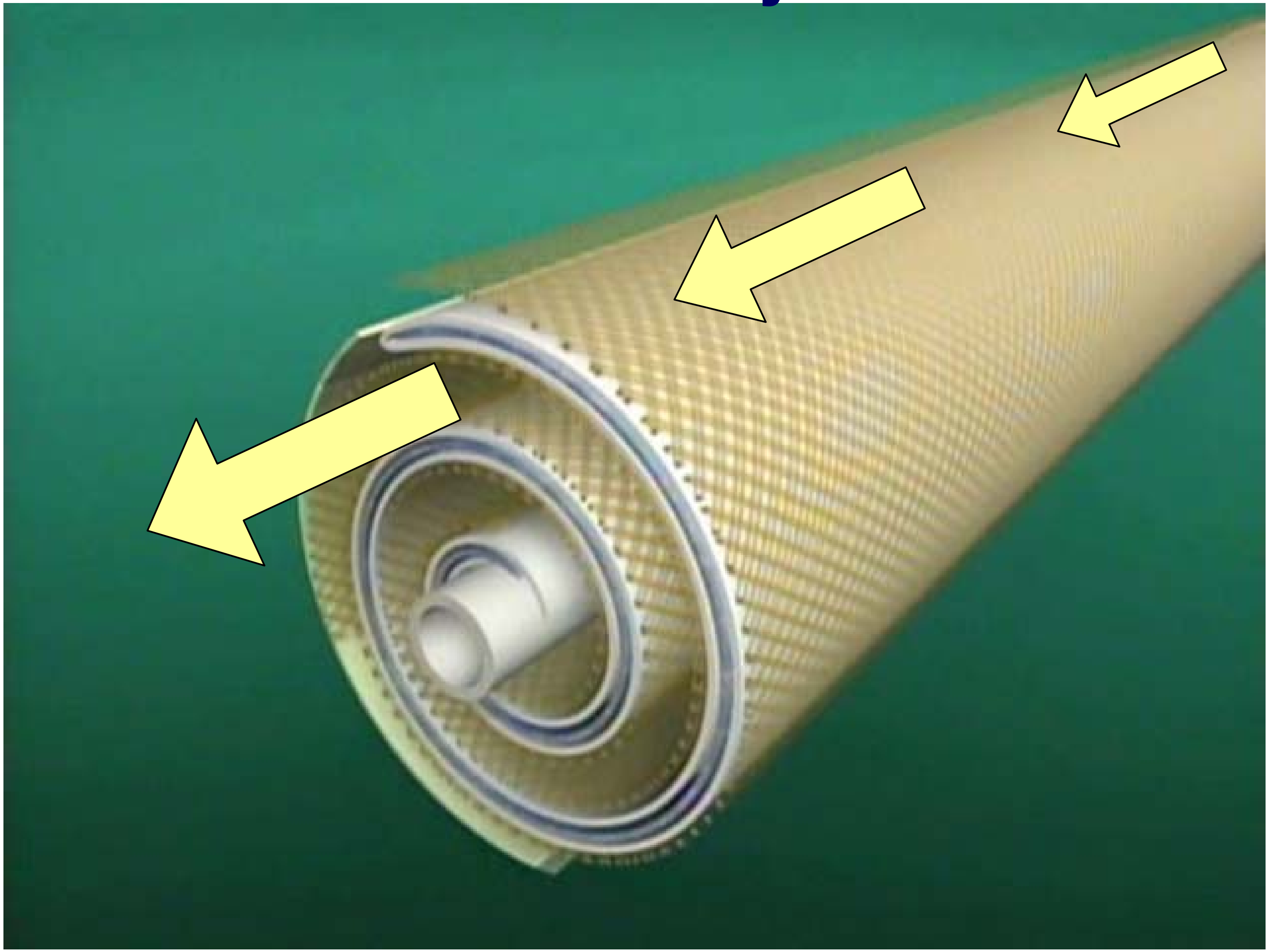


1. **Flux rate depends on feedwater type and degree of fouling potential**
2. **Lead element flux is critical when TOC or particle fouling is likely**
3. **Hybrid designs, 1st Stage Perm Back pressure, booster pumps can be used to balance flux**

Cross Flow in a Spiral Element Sheet



Cross Flow in A Spiral Wound Element Removes Rejected Material



Expected average raw water quality from well, surface intake and secondary effluent

Quality parameter	Well water	Surface water (seawater)	Secondary effluent
Turbidity, NTU	<0.1	<2	<2
SDI	<2	6-12	6-12
Suspended solids, parts per ml	< 1	< 5	< 20
TOC, ppm	< 3	< 5	< 20
Scaling potential	Low to high	Low	Low (except in presence of high concentration of phosphate)

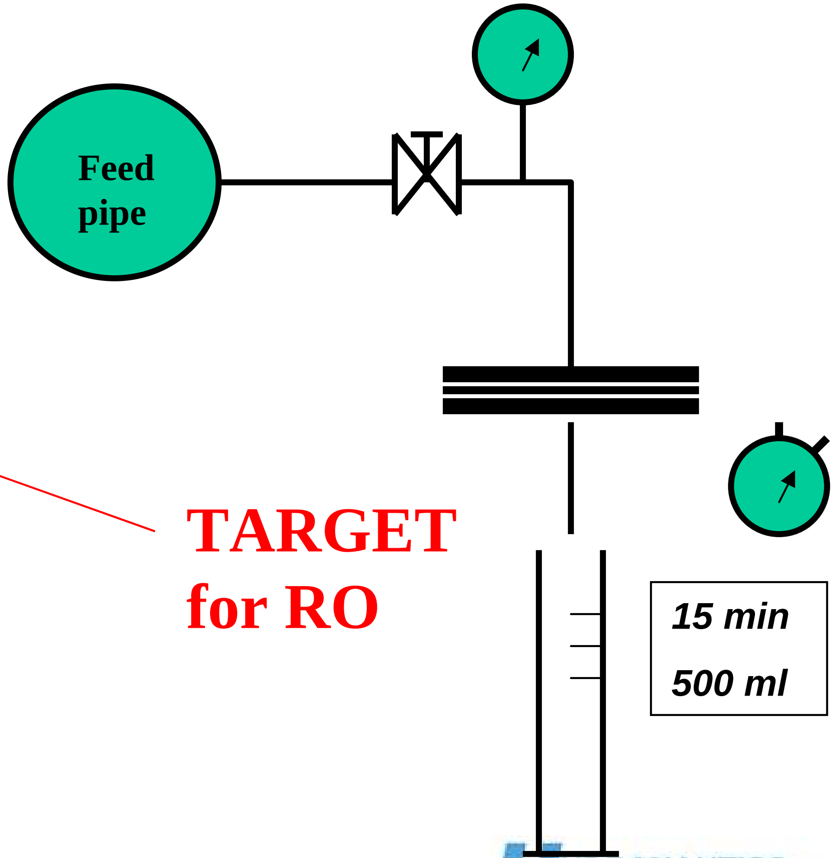
Particles and bacteria cause rapid fouling of RO membranes

Measurement of Feedwater Quality for SWRO Plants: SDI

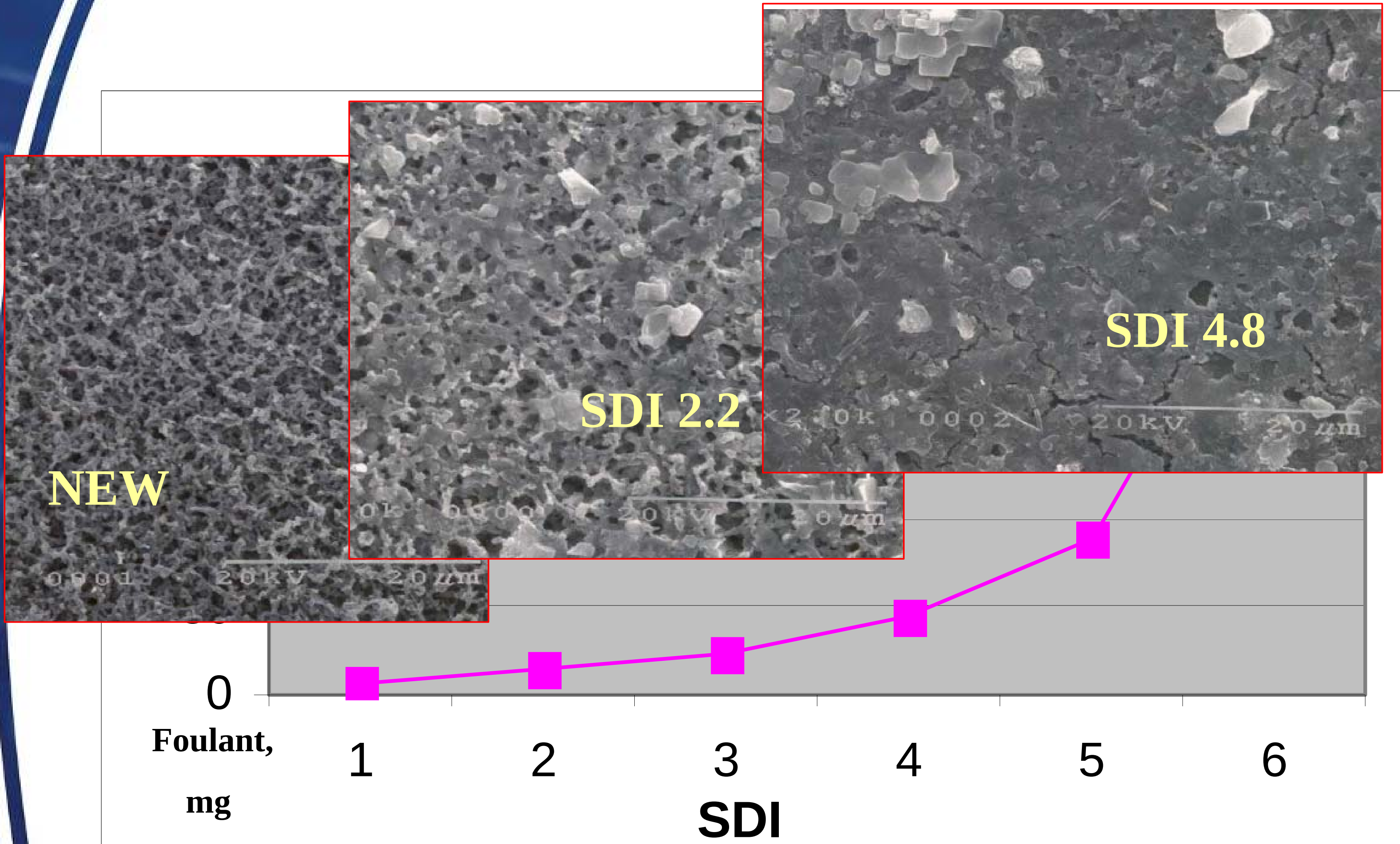
Silt Density index : $SDI = 100*(1 - t_0/t_{15})/15$

t_0	t_{15}	SDI (15 min)
18	22	1.2
20	33	2.6
26	73	4.3
46	50	0.5 (?)

TARGET for RO



Amount of Foulant vs SDI



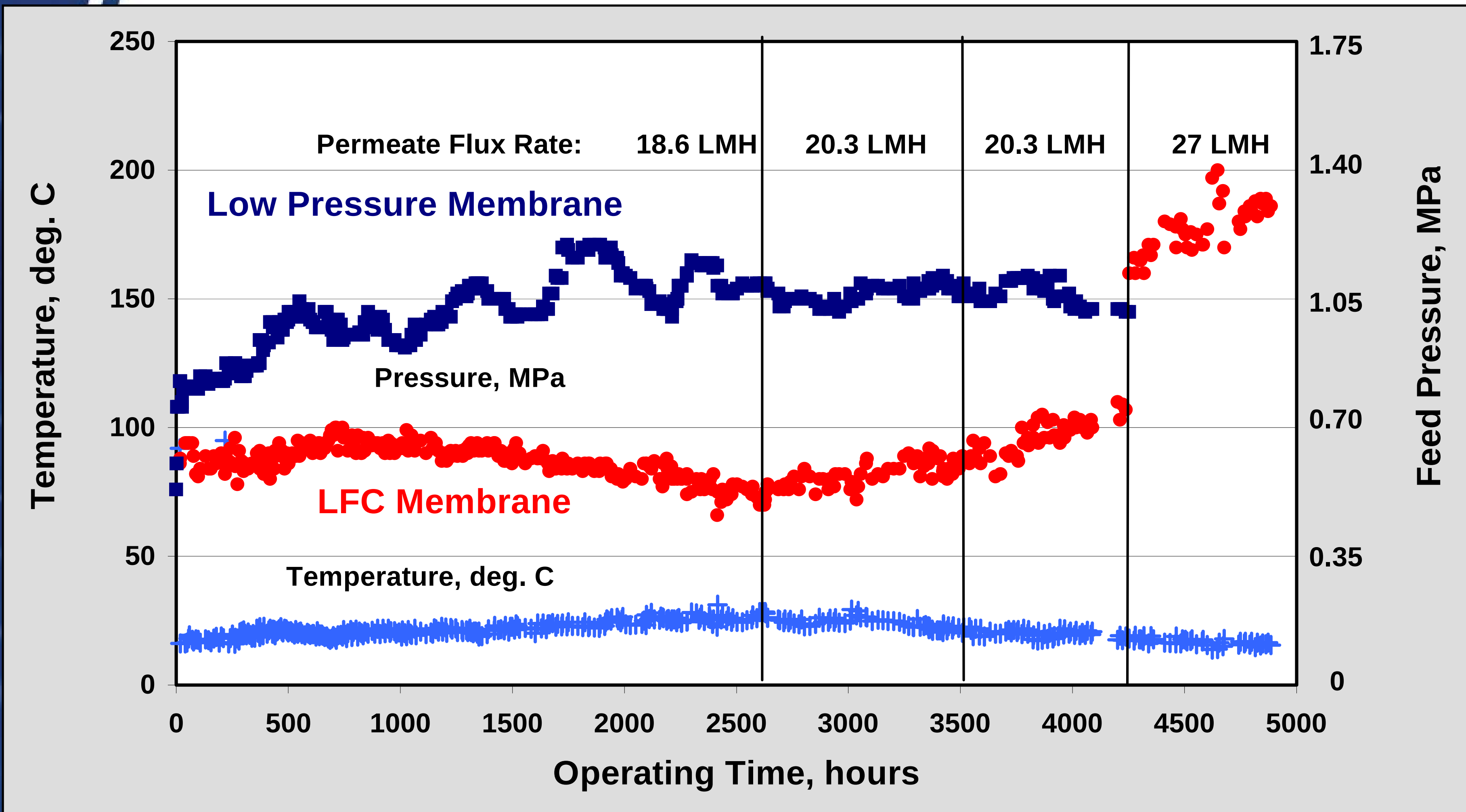
Flux Selection- Brackish, Good Quality

Raw Water source		RO Perm	Brackish Well	Brackish Surface	Brackish Surface
Pretreatment type		RO	Not Soft	Conv.	MF/UF
TOC content		Low	Low	Low	Low
Feedwater Parameters					
Recommended Maximum:					
SDI @ 15 minutes	Maximum	1	3	4	2
Turbidity as NTU	Typical	0.1	0.1	0.1	0.1
TOC ppm as C	Typical	2	2	2	2
BOD ppm as O2 (est. as TOC x 2.0)	Maximum	4	4	4	4
COD ppm as O2 (est. as TOC x 3.0)	Maximum	6	6	6	6
Particle Count (2um particles / ml)	Typical	100	100	100	100
System Average Flux (in LMH)	Conservative	30.6	23.8	17	23.8
	Typical	35.7	27.2	20.4	27.2
	Aggressive	40.8	30.6	23.8	30.6
Lead Element Flux (in LMH)	Conservative	49.3	35.7	25.5	30.6
	Typical	51	40.8	30.6	35.7
	Aggressive	59.5	45.9	35.7	40.8

Flux Selection- Brackish, Poor Quality

Raw Water source			Brackish Surface	Brackish Surface	Waste Tertiary	Waste Tertiary
Pretreatment type			Conv.	MF/UF	Conv.	MF/UF
TOC content			High	High	High	High
Feedwater Parameters						
Recommended Maximum:						
SDI @ 15 minutes	Maximum		4	2	4	2
Turbidity as NTU	Typical	0	0.1	0.1	0.1	0.1
TOC ppm as C	Typical		5	5	5	5
BOD ppm as O2 (est. as TOC x 2.0)	Maximum	0	10	10	10	10
COD ppm as O2 (est. as TOC x 3.0)	Maximum	0	15	15	15	15
Particle Count (2um particles / ml)	Typical	#	100	100	100	100
System Average Flux (in LMH)	Conservative		17	18.7	11.9	13.6
	Typical		18.7	23.8	17	18.7
	Aggressive		23.8	28.9	20.4	22.1
Lead Element Flux (in LMH)	Conservative		25.5	27.2	18.7	20.4
	Typical		30.6	32.3	25.5	27.2
	Aggressive		35.7	37.4	30.6	32.3

Increased Fouling Rate When Design Flux Rates are Exceeded



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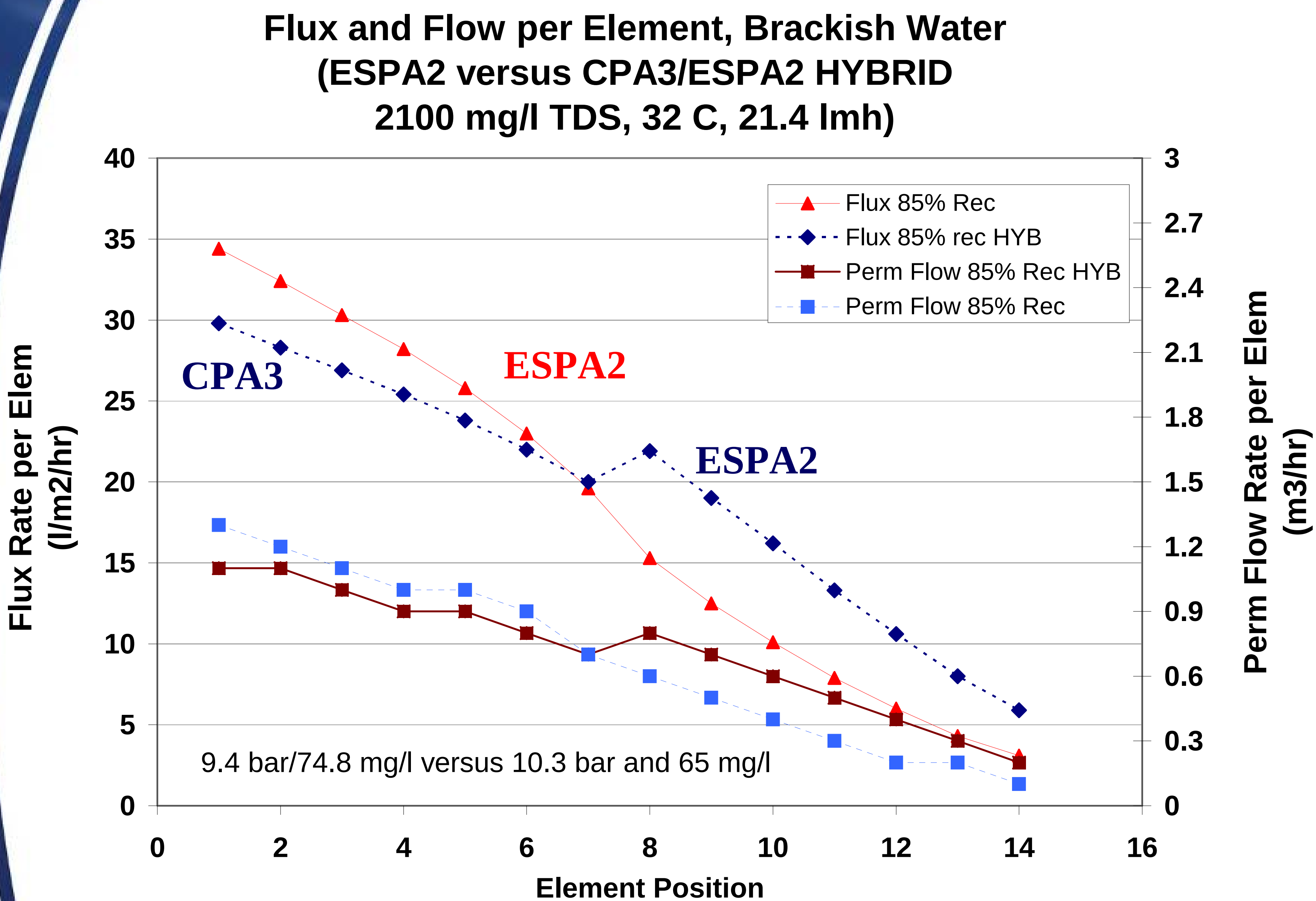
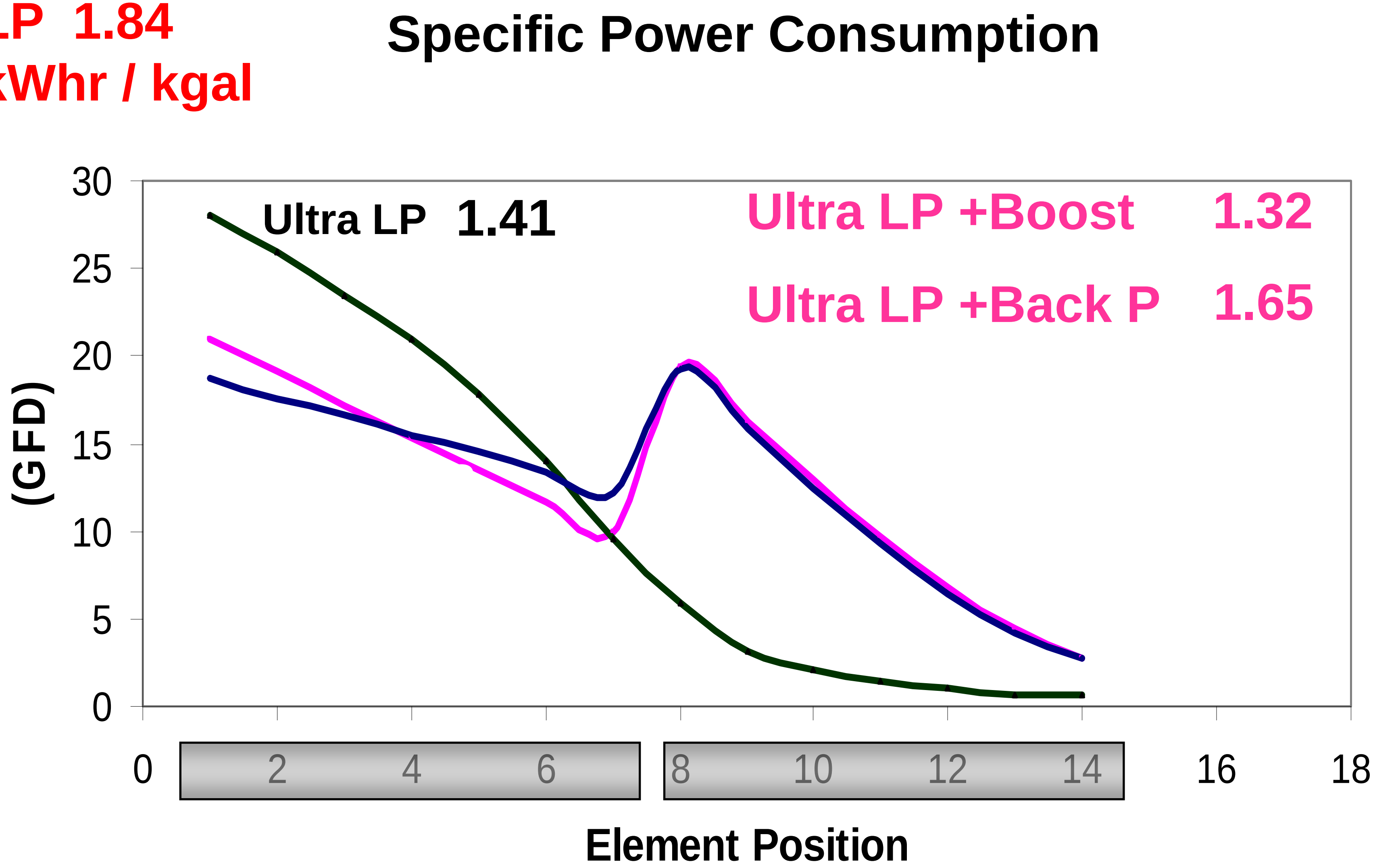
Hybrid Designs Balance Flux

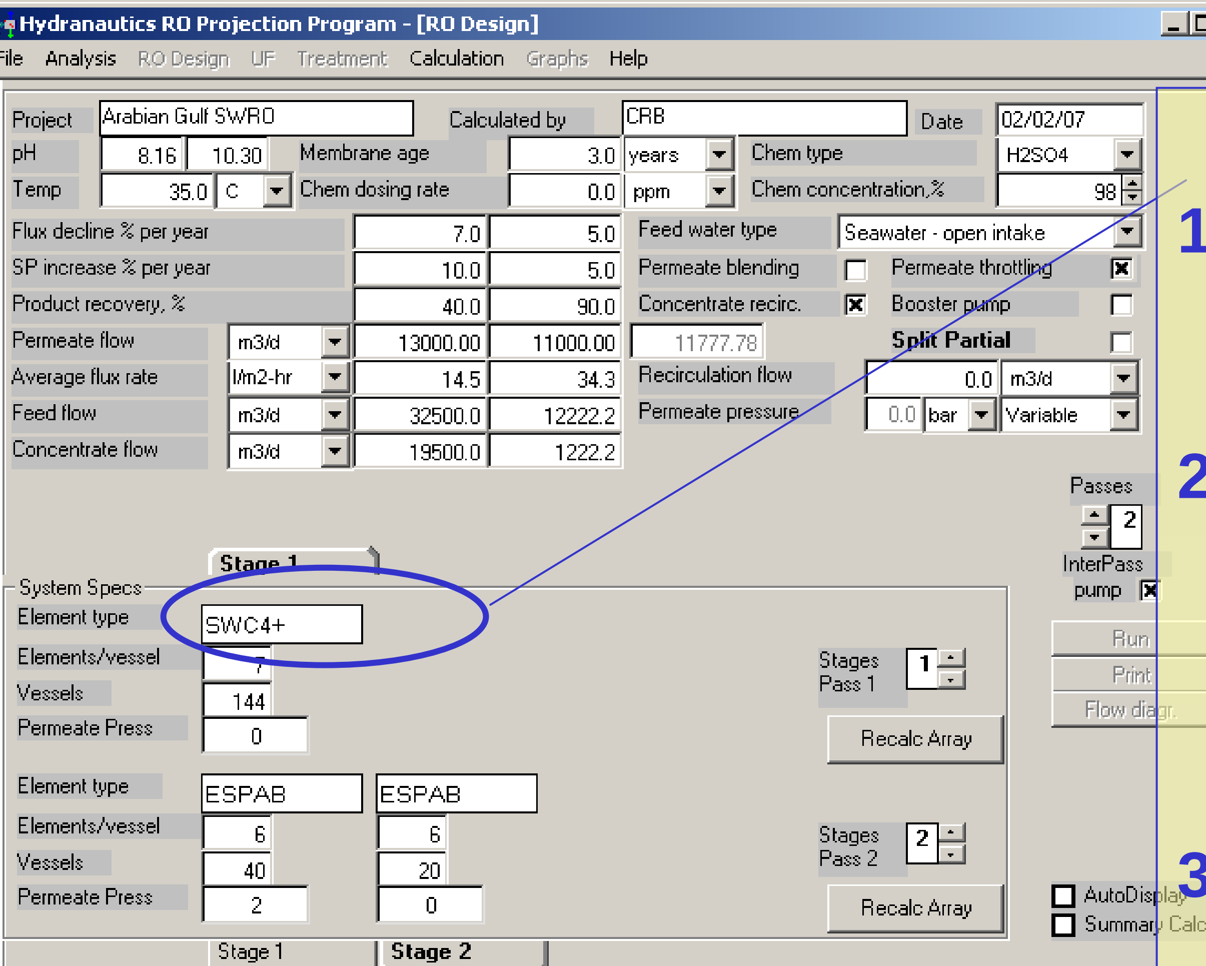


Options to Control Lead Elem Flux

LP 1.84 kWhr / kgal



Selecting Your Membrane



1. Low pressure versus low permeate TDS
2. Select Elements that meet permeate quality, then optimize for pressure
3. NF Membranes

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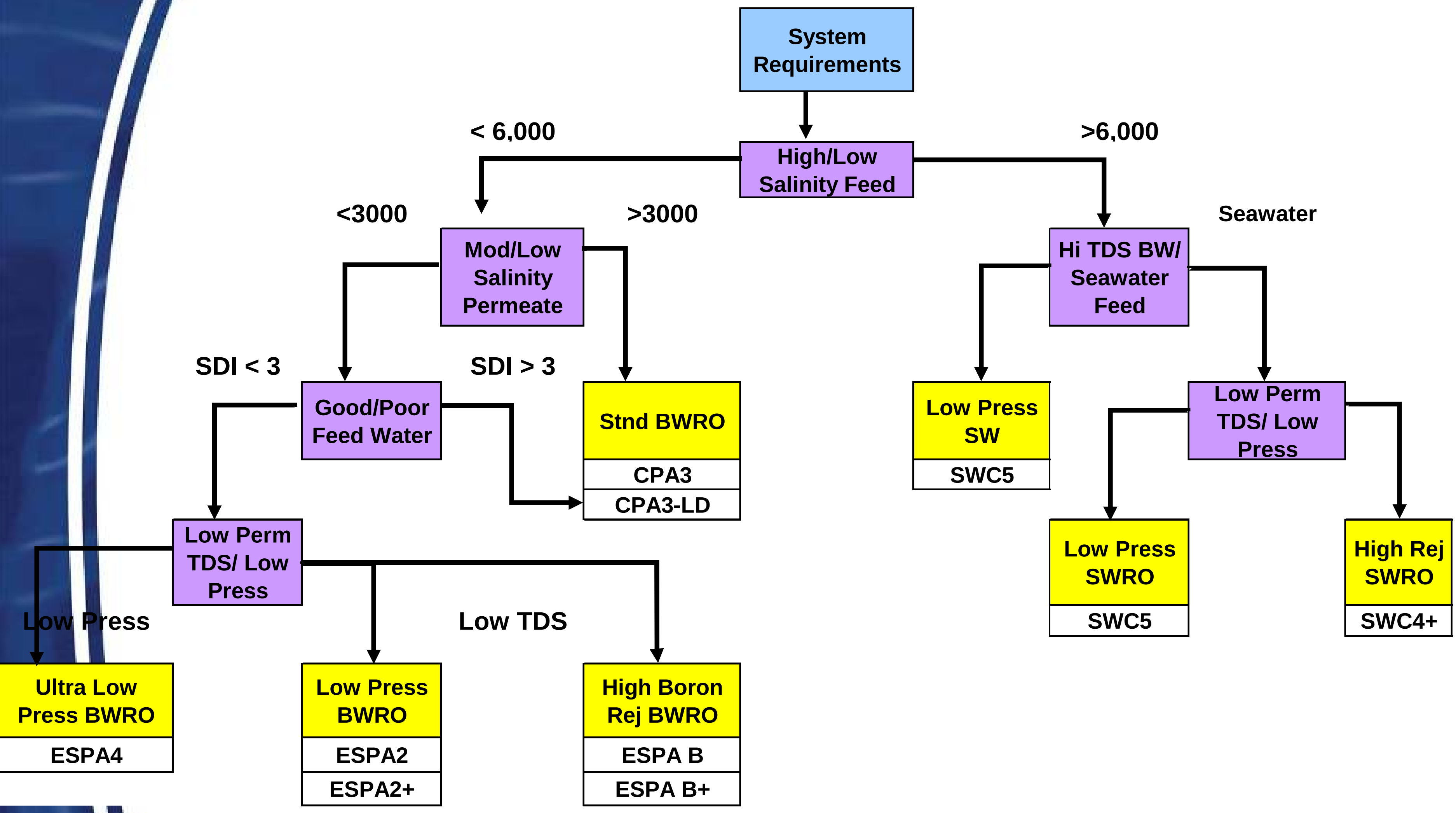
Membrane Selection Logic



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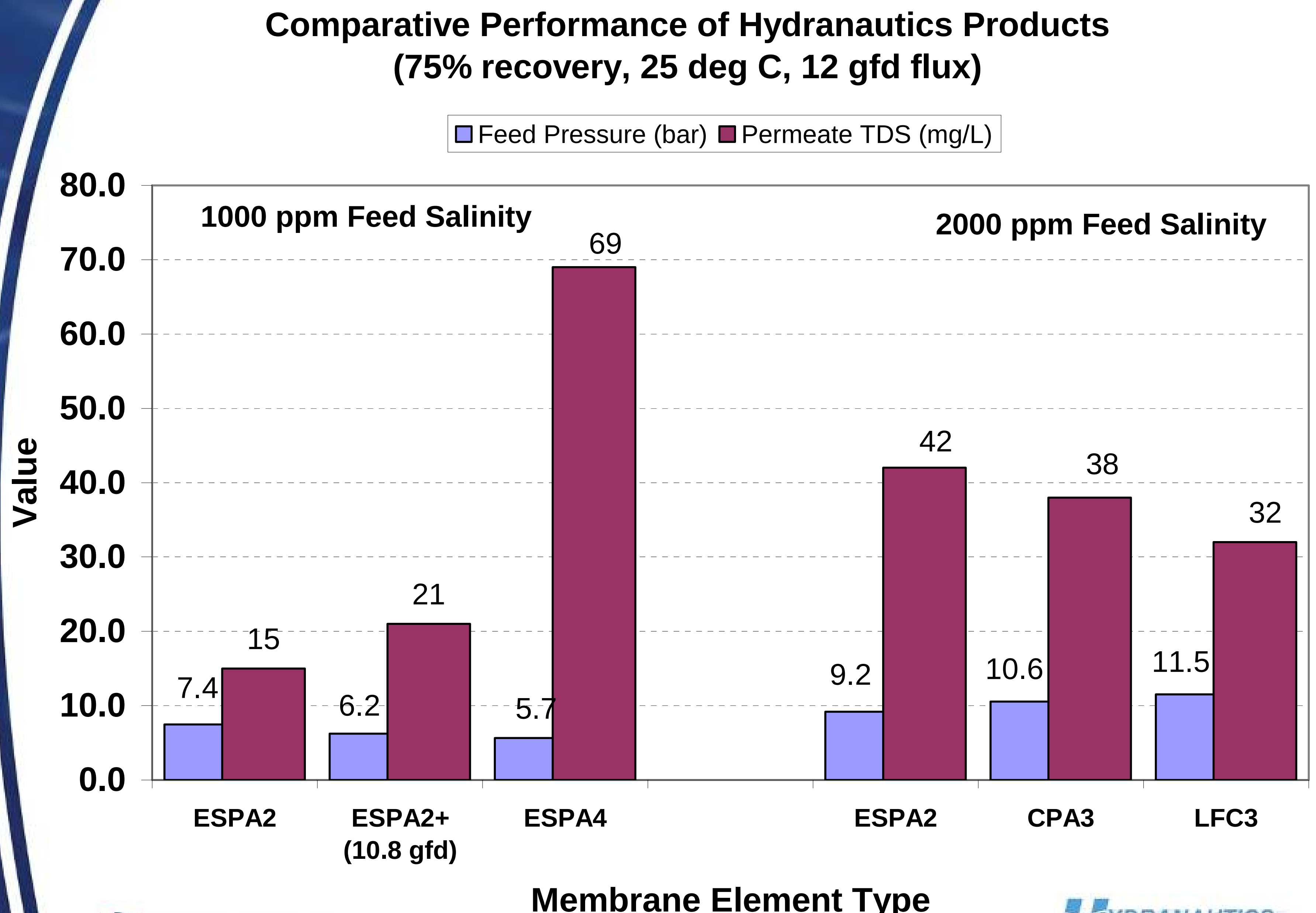
Selection of Brackish Water Membranes



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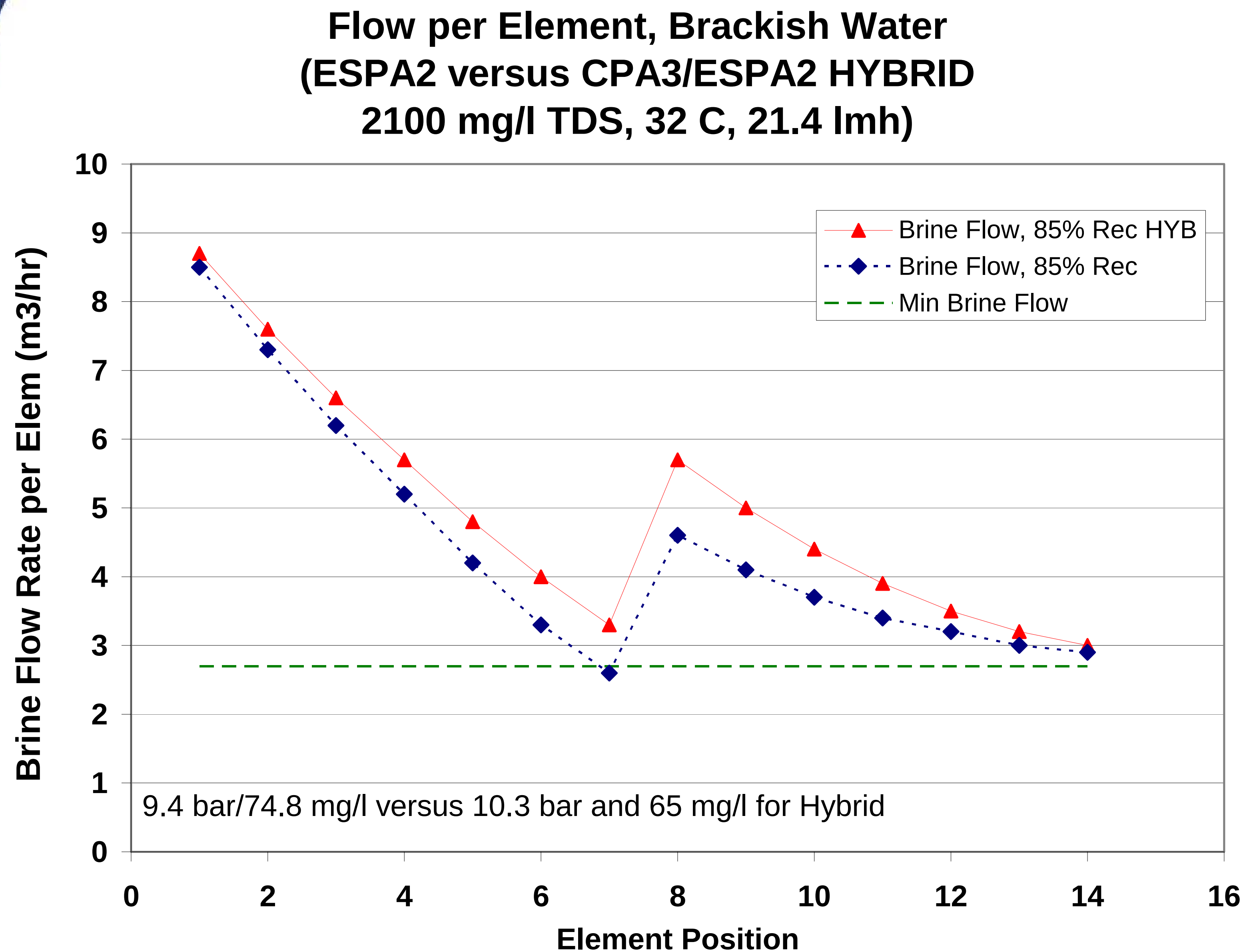
Hybrid Element Designs



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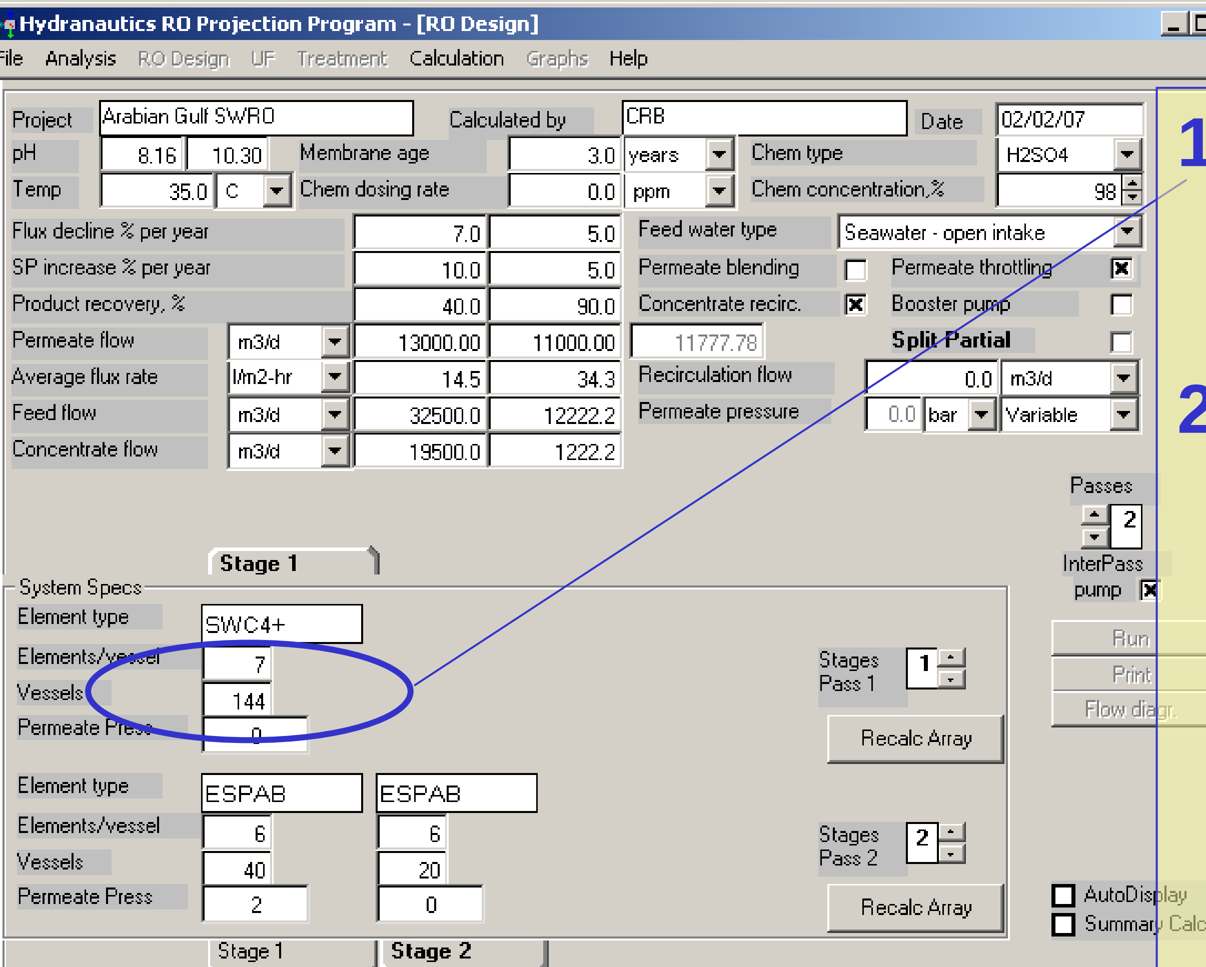
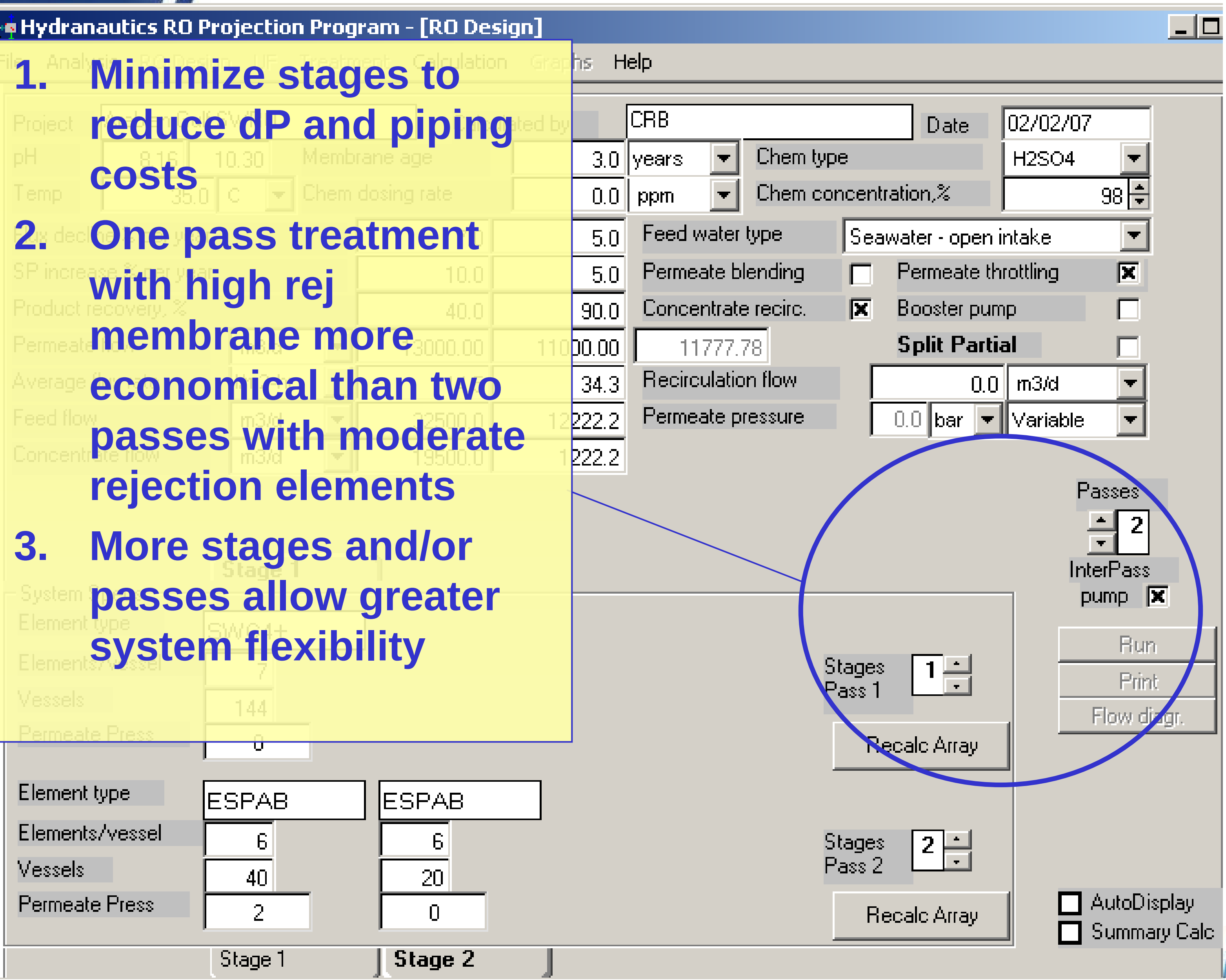
Selecting Number of Vessels and Vessel Size



1. **6-8 Elements per vessel is common**
2. **Array is chosen to meet operation flexibility and practical size limits. 10-15 MLD current largest train size**

Stages and Passes

1. Minimize stages to reduce dP and piping costs
2. One pass treatment with high rej membrane more economical than two passes with moderate rejection elements
3. More stages and/or passes allow greater system flexibility



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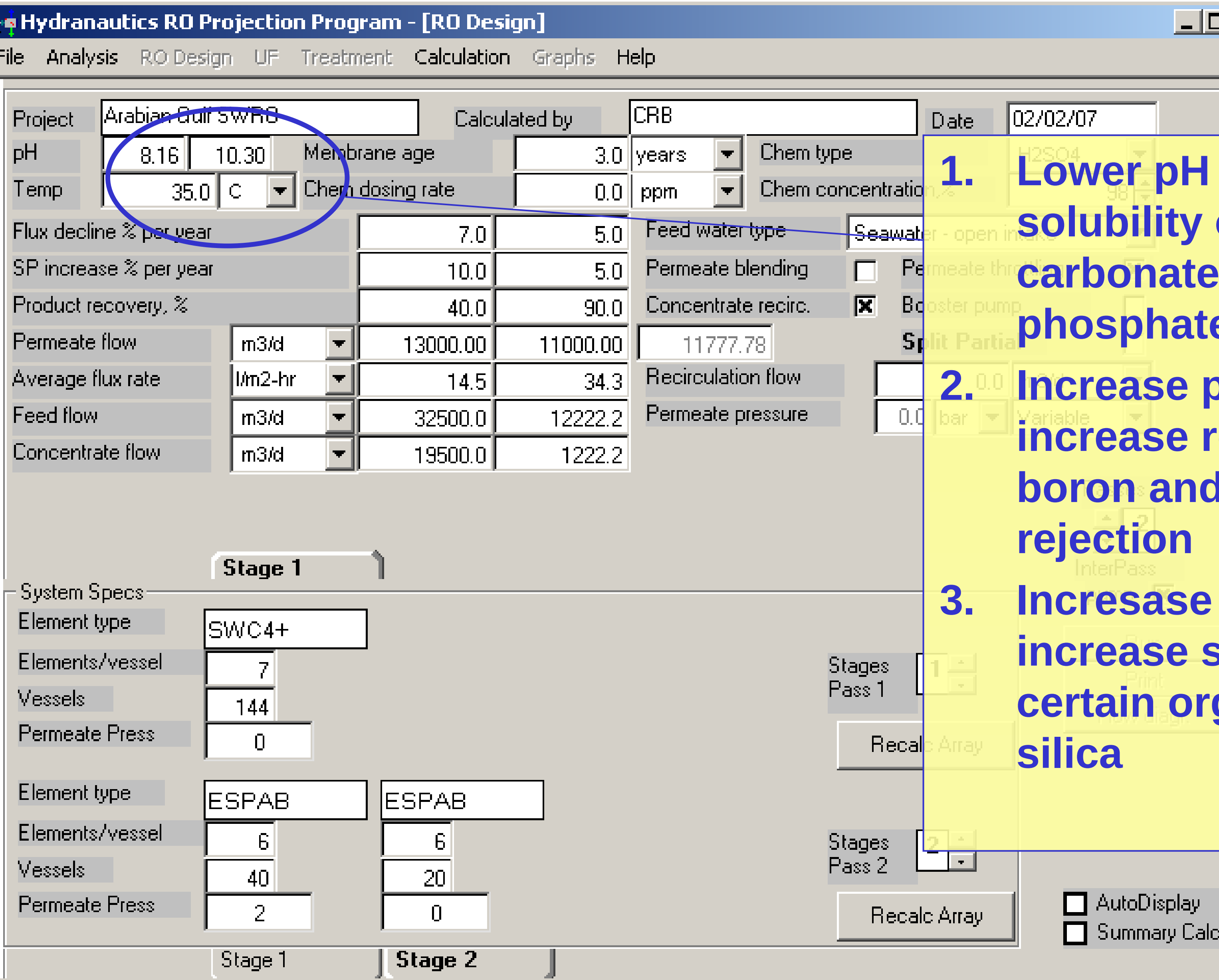
Comparison of 1 Pass and 2 Pass Approaches to Same Design

Array, first pass	4:2(7M)	6(7M)
Element type, first pass	ESPA2	SWC3+
Array, second pass	1:1 (5M)	
Element type, second pass	ESPA2	
Feed pressure, first pass, psi	573	776
Interstage booster, first pass, psi	200	
Feed pressure, second pass, psi	214	
Combined recovery rate, %	47.9	47.9
Permeate flow, m3/hr	19.2	19.2
Power consumption, 1st pass, kWhr	41.4	42.9
Power consumption, 2nd pass, kWhr	7.9	
Total power consumption, kWhr	49.3	42.9
Power consumption, kWhr/m3	2.57	2.24

pH Adjustment



1. **Lower pH to increase solubility of calcium carbonate or calcium phosphate**
2. **Increase pH to increase rejection of boron and silica rejection**
3. **Incresase pH to increase solubility of certain organics and silica**

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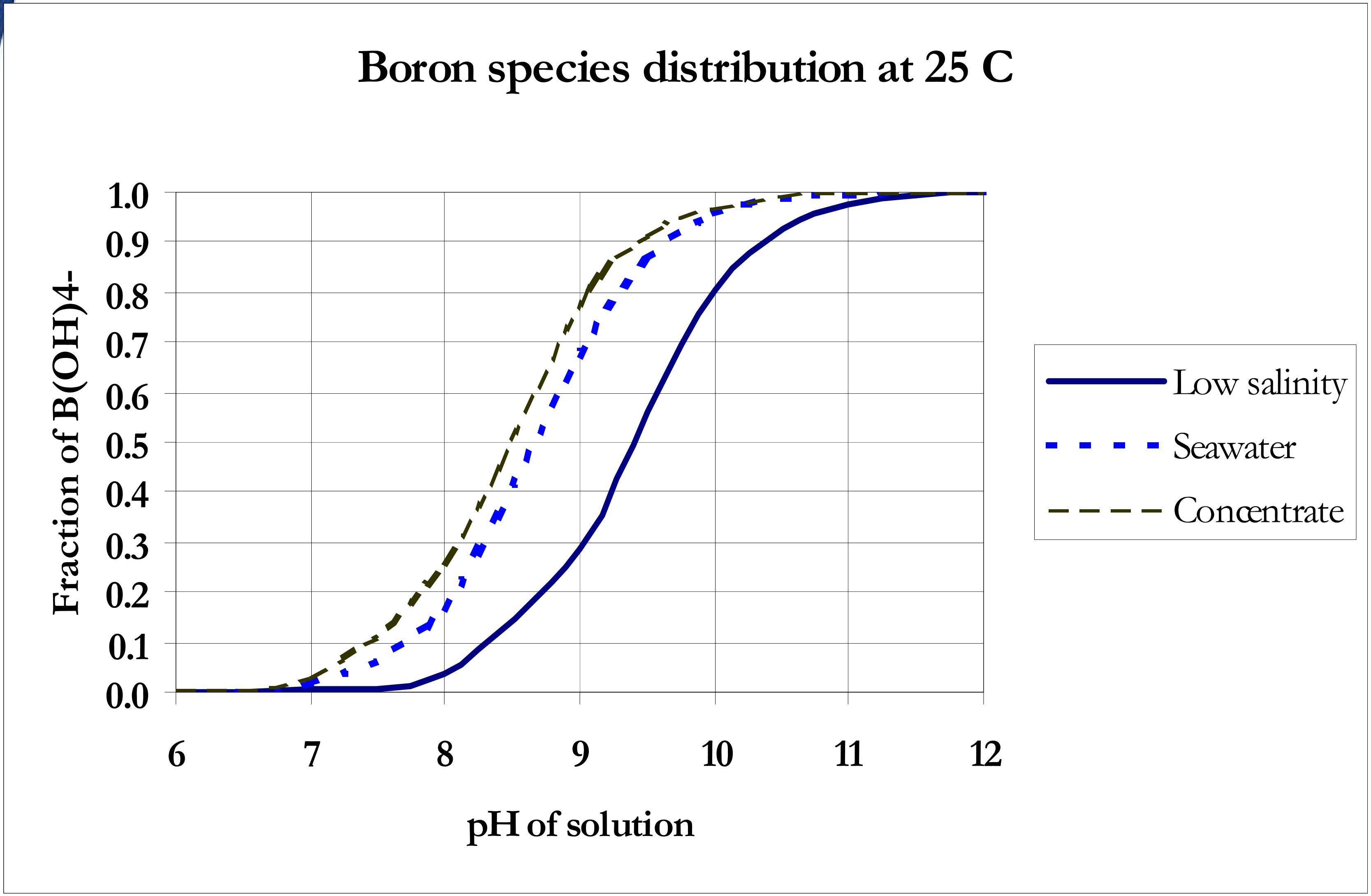
Effect of Feed pH on Boric Acid Dissociation



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Conclusions

- **Long term experience with RO systems has resulted in optimized performance**
- **Detailed consideration of all design parameters is necessary to optimize the system performance**
- **Advances in membrane technology and process design have led to a steady decline in energy consumption and system cost**
- **Sound operation of RO process should result in 5-8 years of membrane life**


THANK YOU