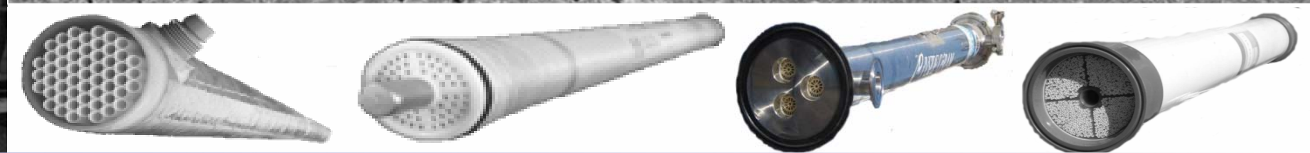
Membrane Pilot Plant Trials

Albury Desalination Project Peer Review Workshop



Future with Water

Membrane Pilot Plant Trials

Lasse Blom, Liz Taylor

Albury Desalination Project Peer Review Workshop

20th November 2008

Norske Skog

Outline

1. Pilot plant capability
   - The 3-stage membrane pilot (the hardware)
   - Simplified P&ID
   - Membrane element piloting
     - Pilot performance
     - Hydraulic loads
     - Analytical results
2. Locations trial results
   - Paper Machine
   - Recycled Fibre plant
   - Tertiary Clarifier
3. Tertiary Clarifier
   - Membrane selections
   - Membrane comparison tables
   - Chemical usage
4. Proposed membrane arrangement
   - Final Configuration
     - Pre-filtration
     - Membranes
   - Optimum operation (cleaning frequency)
   - Overall conclusions

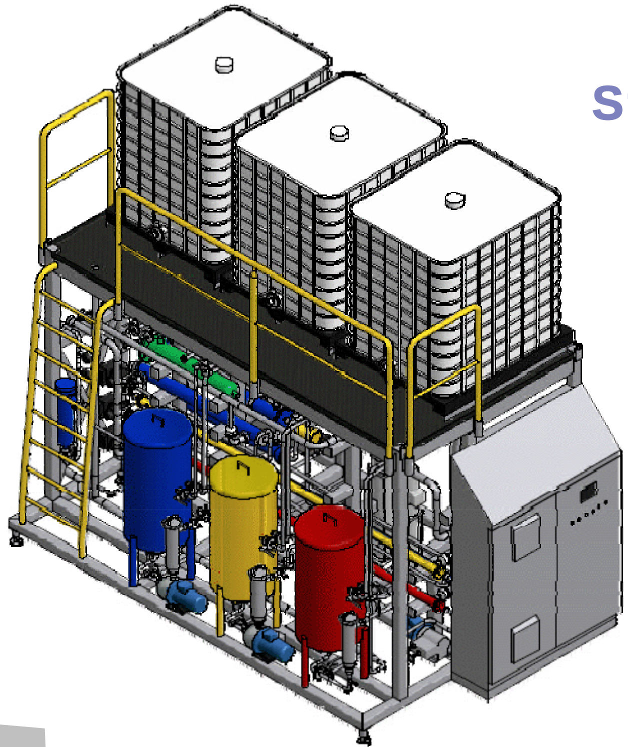
The 3-stage membrane pilot

Pilot Plant Trials

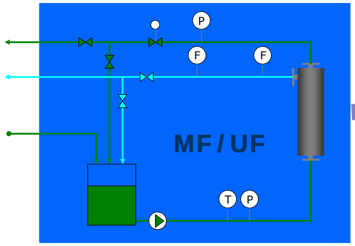
Introduction – Picture from test site

Pilot Plant Trials
The 3-stage membrane pilot

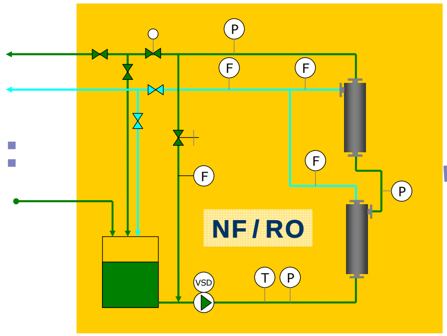
- Pilot stages



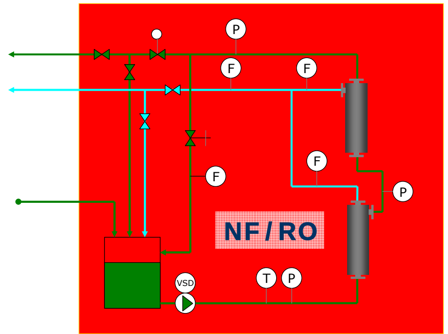
Stage 1:

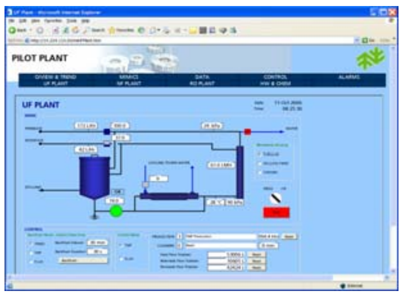


Stage 2:



Stage 3:





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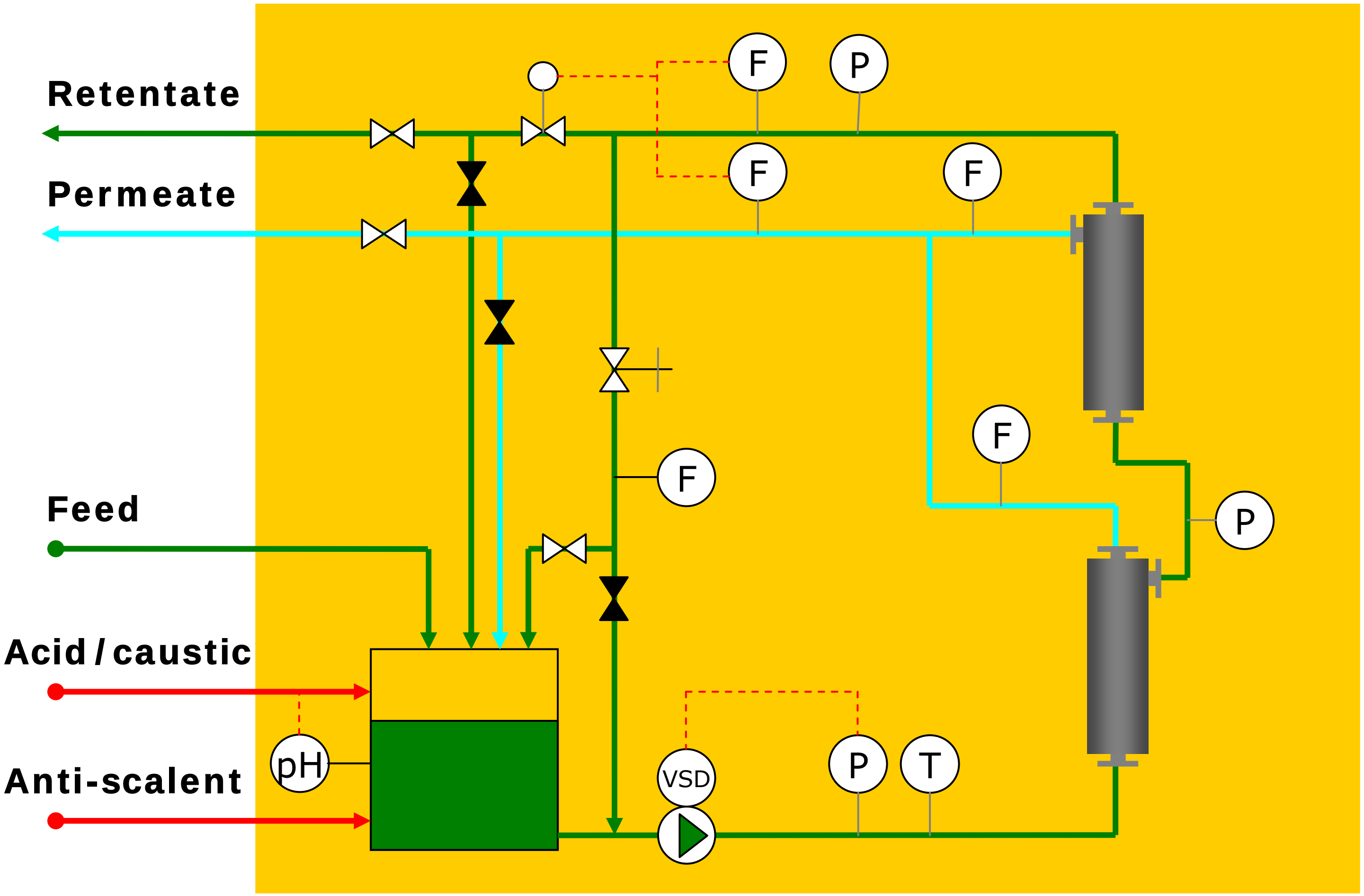
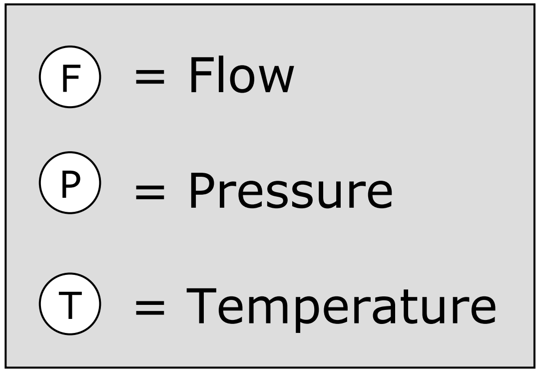
Pilot Plant Trials
The 3-stage membrane pilot

- Simplified pilot P&ID of the three stages





Data logging:
- Feed pressure
- Loop temperature
- Pump speed (VSD)
- Permeate flow
- Retentate flow
- Operating modus

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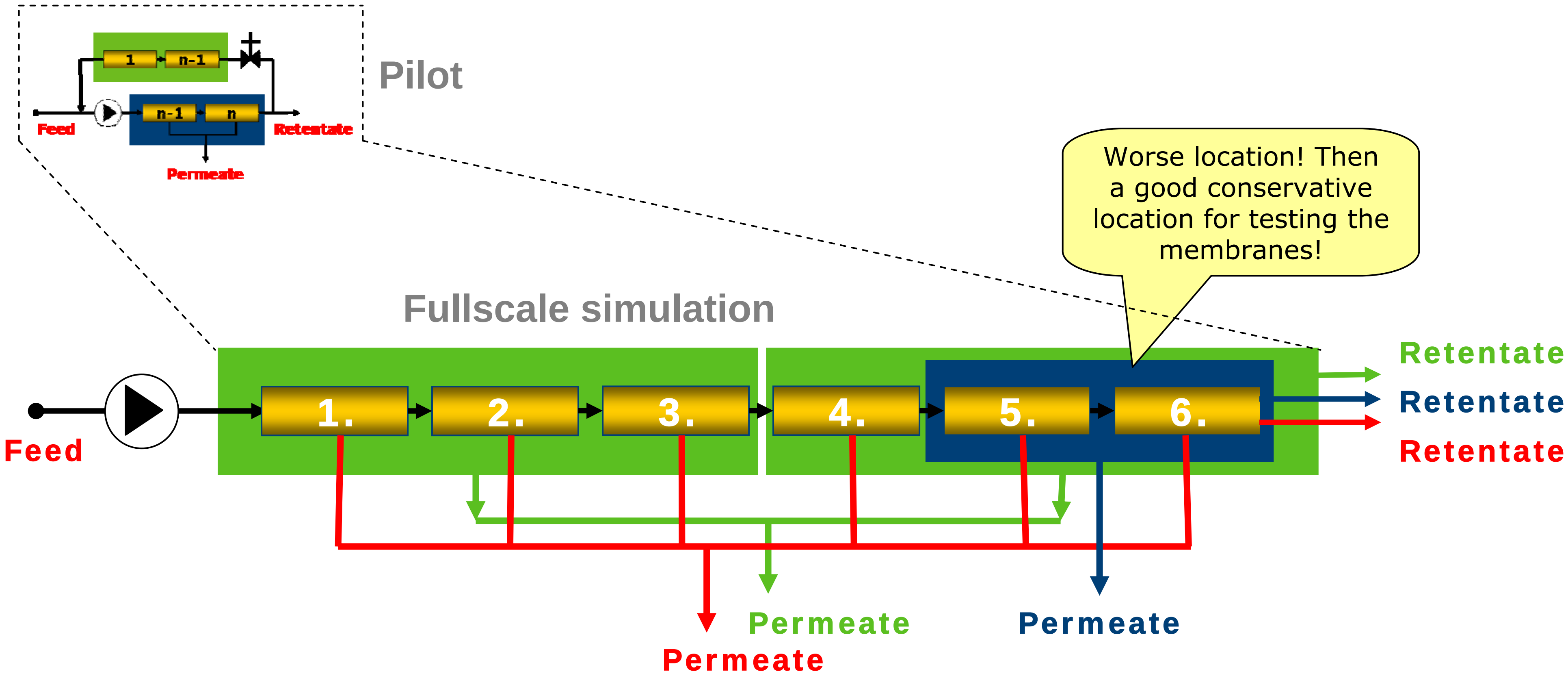
Membrane element piloting

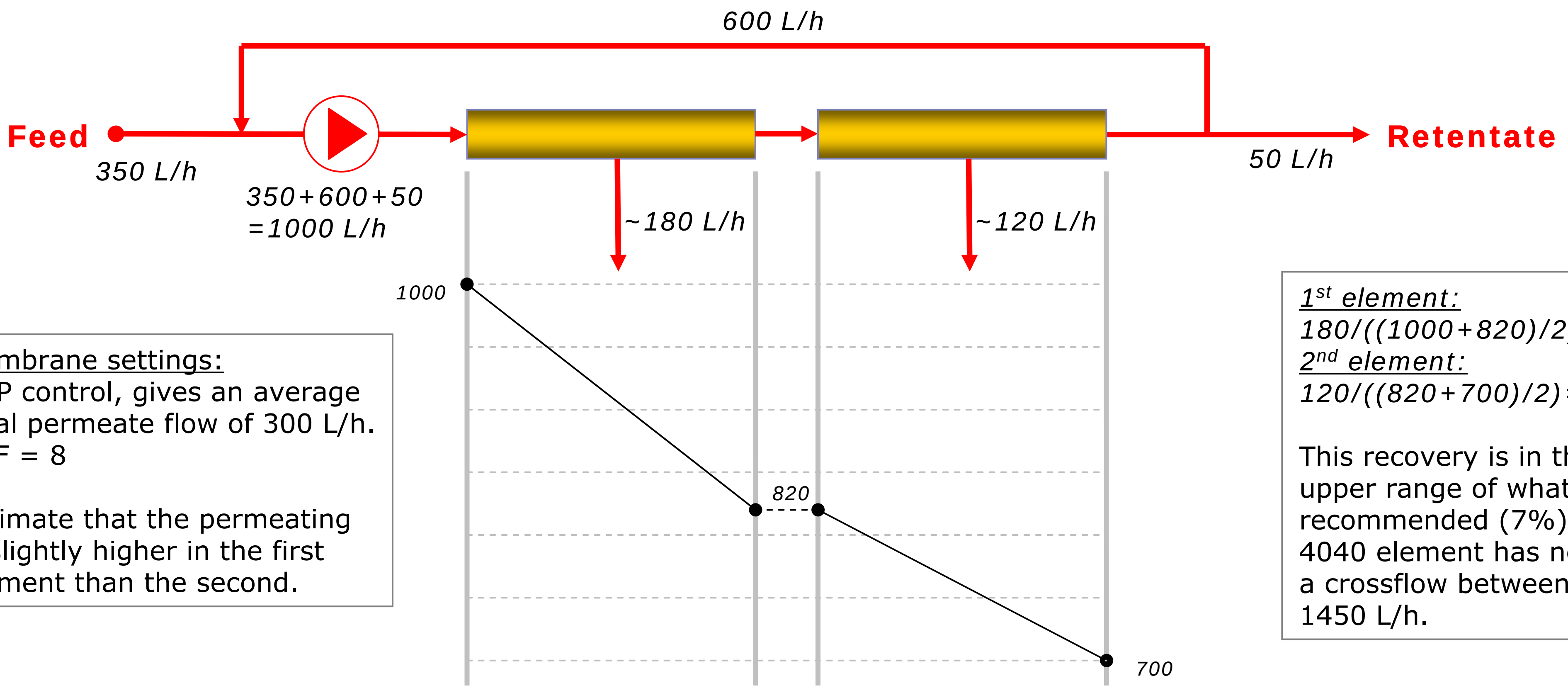
Pilot Plant Trials
Membrane element piloting

- An illustrating example of **hydrodynamic simulation** & **analysis simulation** vs a **fullscale installation**



Pilot Plant Trials
Membrane element piloting - hydrodynamic

- The pilot **crossflow profile** – Customised design



<u>Membrane settings:</u>
TMP control, gives an average total permeate flow of 300 L/h.
VCF = 8

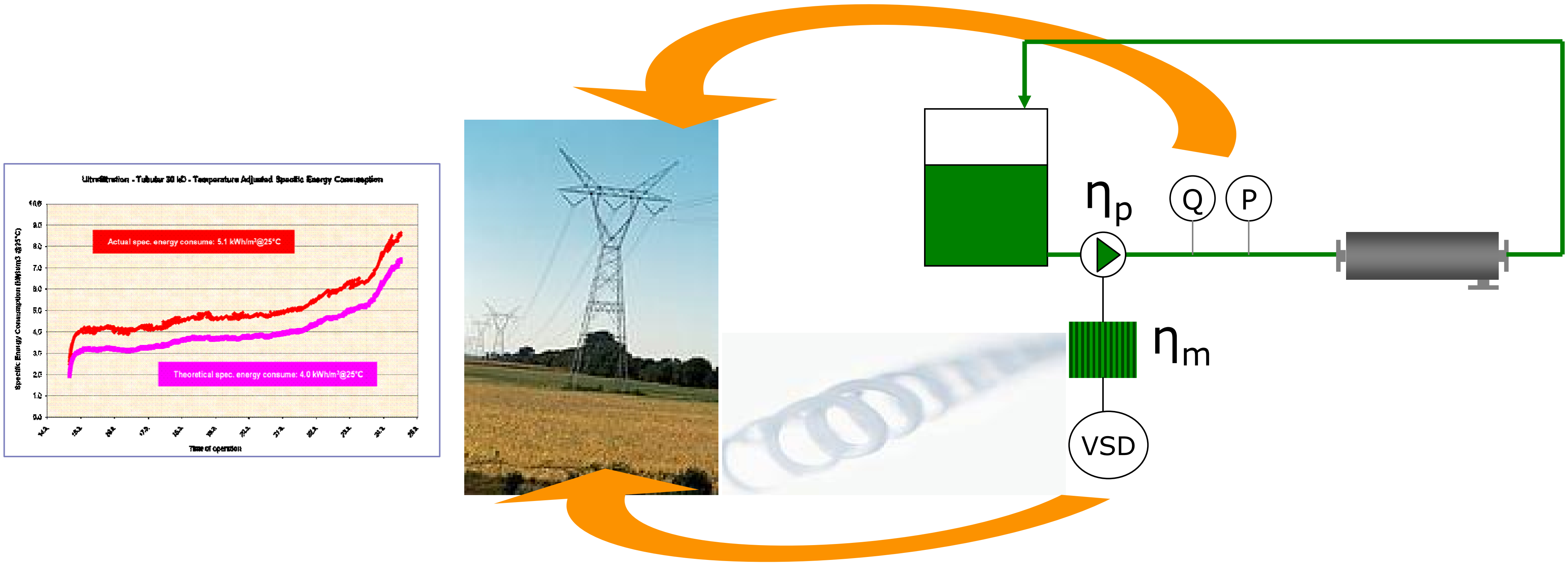
Estimate that the permeating is slightly higher in the first element than the second.

<u>1st element:</u>
180/((1000+820)/2)=10%
<u>2nd element:</u>
120/((820+700)/2)=8%

This recovery is in the upper range of what is recommended (7%).
4040 element has normally a crossflow between 450 to 1450 L/h.

Pilot Plant Trials
Membrane element piloting - Energy

- Two calculation methods for energy consumption
  - Process to power grid - **Theoretical calculations**
  - VSD to power grid - **Actual pump calculations**
- These are mainly used for troubleshooting.



Pilot Plant Trials
Membrane element piloting - Analysis

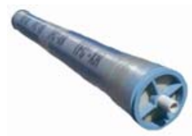
- Analysis performed at the Albury lab
  - Total suspended solids (SS onto 0.45 um paper), only feed
  - Total dissolved inorganic solids (0.45 um paper, 180°C evaporated)
  - Turbidity
  - Colour
  - UV254 (Lignin)
  - Chemical Oxygen Demand (on total)
  - Conductivity
  - pH
  - Total Alkalinity (HCO_3^-)
  - Cations: Na^+, Mg_2^+, Ca_2^+, SiO_2, Mn_3^+, Fe_3^+
  - Anions: Cl^-, SO_4^{2-}

Pilot Plant Trials
Membrane element piloting – Membranes

- Tested membranes & locations

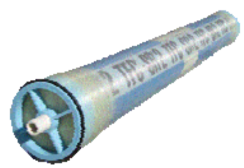


						Test locations		
Membrane type:		**Manufacturer:**	**Name:**	**MWCO:**	**Material:**	**TC**	**PM**	**RCF**
MF	Hollow Fiber	X-Flow, NORIT	Capfil - UFC M5	200 kD	PES/PVP	X	X	na
UF	Tubular polymeric	X-Flow, NORIT	Comp.-F5385 - ID 8mm	30 kD	PVDF	X	X	X
	Tubular polymeric	X-Flow, NORIT	Comp.-F5385 - ID 5mm	30 kD	PVDF	X	na	na
	Tubular ceramic	Tami Industries	InsideCeram	8 kD	TiO_2	X	na	na
NF	Spiral Wound	Filmtec	NF270-400	300 D	Polyamide	X	X	X
	Spiral Wound	Osmonics	Duracon NF4040F	150-300 D	Polyamide	X	X	X
	Spiral Wound	Hydranautics	Hydracore 50-4040	1000 D	SPS	X	na	na
	Spiral Wound	Hydranautics	ESNA1-LF/LF2	200 D	Polyamide	X	na	na
	Spiral Wound	KOCH	TFC-SR2	300-400 D	na	X	na	na
BWRO	Spiral Wound	Hydranautics	ESPA2	~30	Polyamide	X	na	na
	Spiral Wound	KOCH XR4	KOCH XR4	~30	Polyamide	X	na	na
SWRO	Spiral Wound	Hydranautics	SWC1-4040	~30	Polyamide	X	X	X







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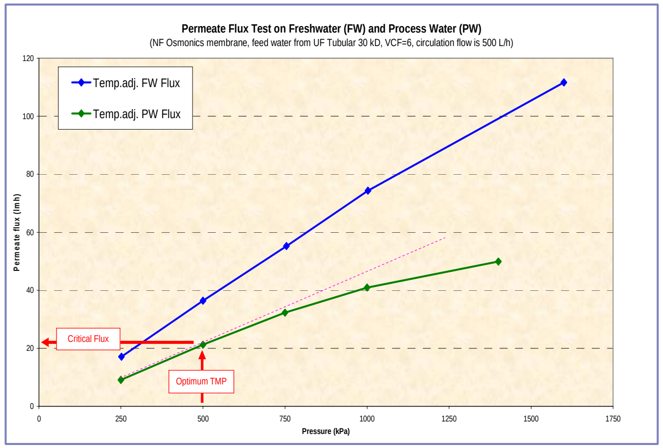
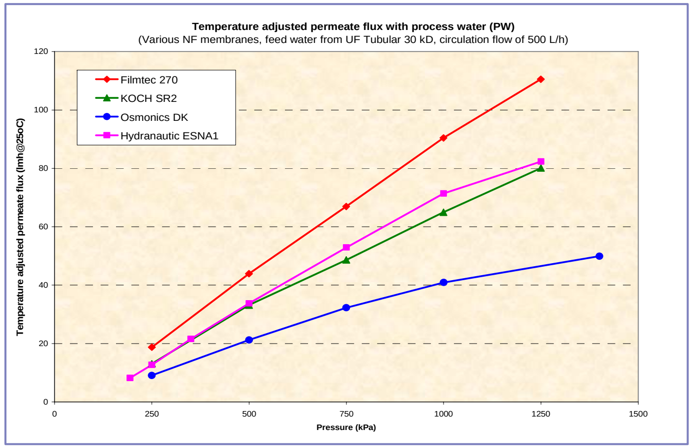
Pilot Plant Trials
Membrane element piloting

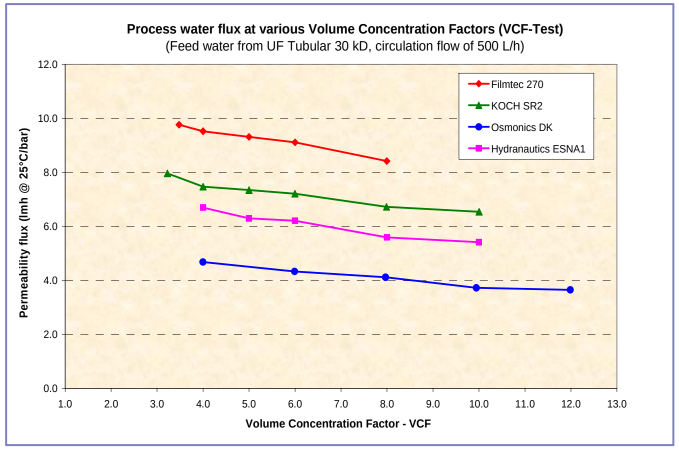
- **Initial start-up tests** to find the optimum operating parameters
  - It is only the RO that has a linear flux as the pressure increases, the other membrane vary with changing pressure and these test gives us an indication of where the operating parameters should be:



Critical flux test



Pressure test



Concentration test

Locations trial results

Pilot Plant Trials
Locations trial results

- Based on initial analysis screening of 21 locations in the mill, **three test locations** was selected for piloting

Parameters	RCF	PM	TC
Temp. (°C)	54	52	31
COD–GFC (mgO_2/L)	2192	1850	434
Turbidity (NTU)	39	29	3
Cat.dem. (meq/L)	1652	881	662
Colour (Hazen)	229	85	185
Cond. (µS/cm)	2632	2001	2133
Sodium	580	318	348
pH	7.4	6.6	7.5
Total Solids (mg/L)	3594	2956	1900
TDIS (mg/L)	2623	1860	1583
Iron (mg/L)	0.44	0.82	0.42
Manganese (mg/L)	1.0	1.6	1.0
Calcium (mg/L)	44	96	70
CaCO3 (mg/L)	427	146	554
Magnesium (mg/L)	6.8	10.1	8.7
Chloride (mg/L)	98	30	8
Silica (mg/L)	150	50	84
Sulphate (mg/L)	277	327	259

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Pilot Plant Trials

Test location 1 – Paper machine

- PM test conclusions
  - Three different white water qualities were tested
    - Rich Clear-, Clear,- and Super Clear filtrate
  - The ceramic tubular membrane plugged quickly.
  - The HF operated well, but needed very good pre-filtration.
  - All the three water qualities gave high fouling of the UF Tubular membrane but it operated the best out of all the options
    - We learned that too high circulation flow (cross flow velocity) generated too much foam in the system.
  - The VCF could at most be 4 for the NF stage.
  - Only two runs performed with the RO due to problems with the UF stage which did not operate long enough.
  - Operation summary:
    - UF Tubular (VCF=2, TMP Control) – 3 days
    - NF Osmonics (VCF=4, TMP Control) – 2 days
    - RO Hydranautics (VCF=5, TMP Control) – 2 days

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Pilot Plant Trials
Test location 1 – Paper machine

- PM test conclusions - pictures

Pilot Plant Trials
Test location 2 – Recycled Paper Furnish

- RCF test conclusions
  - Too high circulation flow generates too much foam in the system and was not sustainable for the ceramic and tubular membrane.
  - Backwashing on the UF Tubular membrane improved the operating time drastically, from only 1 day to 7 days.
  - The MF HF operated for 10-13 days, with backwashing.
  - The NF operation is around 5 days when the upstream pre-filtration is a UF. The NF was the bottle neck in this location.
  - The RO operated relatively well in this position (VCF=3).
  - Operation summary:
    - UF Tubular (VCF=5, TMP Control) – 7 days
    - NF Osmonics (VCF=4, TMP Control) – 5 days
    - RO Hydranautics (VCF=3, TMP Control) – 8 days

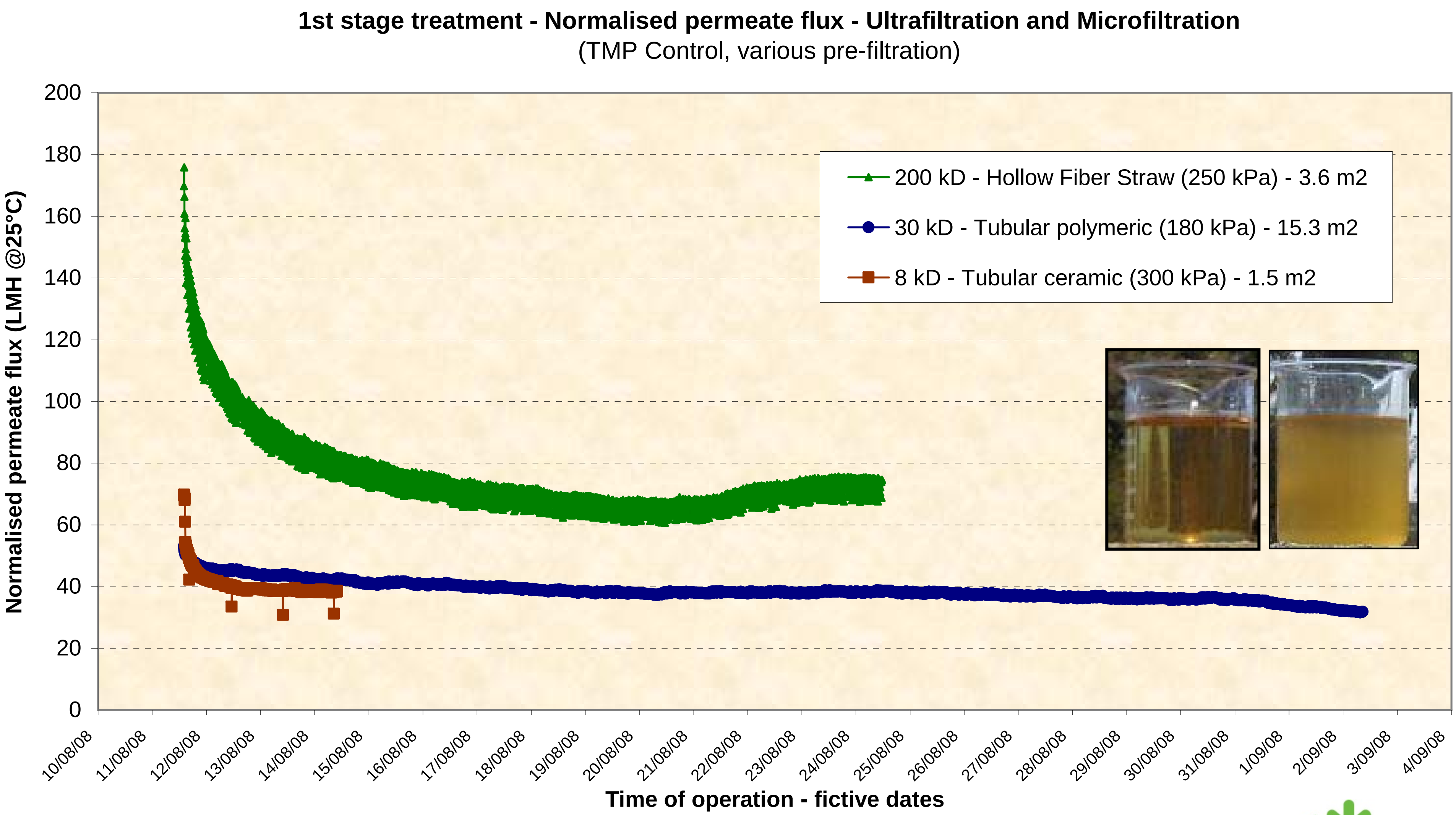
Pilot Plant Trials

Test location 2 – Recycled Paper Furnish

- RCF test conclusions - pictures

Test location 3: Tertiary Clarifier

Pilot Plant Trials
Test location 3 – MF/UF stage



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Pilot Plant Trials
Test location 3 – MF/UF stage

- Comparison of the Ultrafiltration membranes trialled

Membrane:	Permeate Produced (l/h)	Specific energy: (kWh/m^3) (1	Average flux: (lmh @25°C)	TMP: (kPa)	Specific Flux: (lmh/bar)	VCF:	Spec. invest. cost (A$/m^2)	Operating time: (days)
Tubular Ceramic (8 kD)	50	42.7	41	300	13.7	3	1123	2 (2
Hollow Fibre (200 kD)	240	9.7	77	250	30.8	5	445	13
Tubular (30 kD, 50% circ) (3	306	5.3	77	90	85	5	675	17
Tubular (30 kD, 84% circ) (4	530	3.5	38	180	21	5	675	22

1) Compare only as relative numbers, and not absolute.
2) Could be operated longer, but due to low flow had to be cancelled because of time limits.
3) One element (5.1 m^2).
4) Three elements in series (15.3 m^2).

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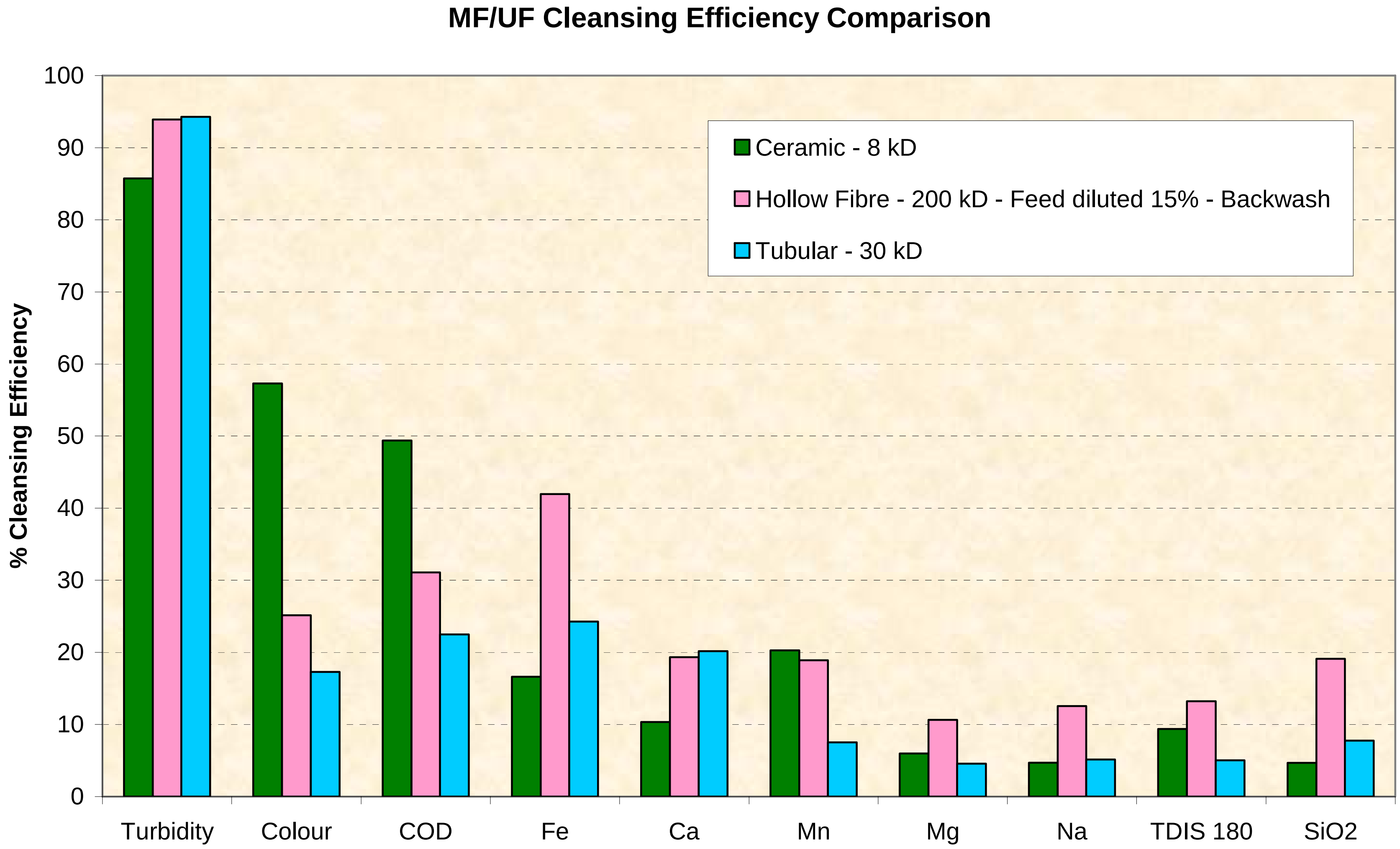
Pilot Plant Trials
Test location 3 – MF/UF stage

- Comparison of the MF/UF membranes trialled



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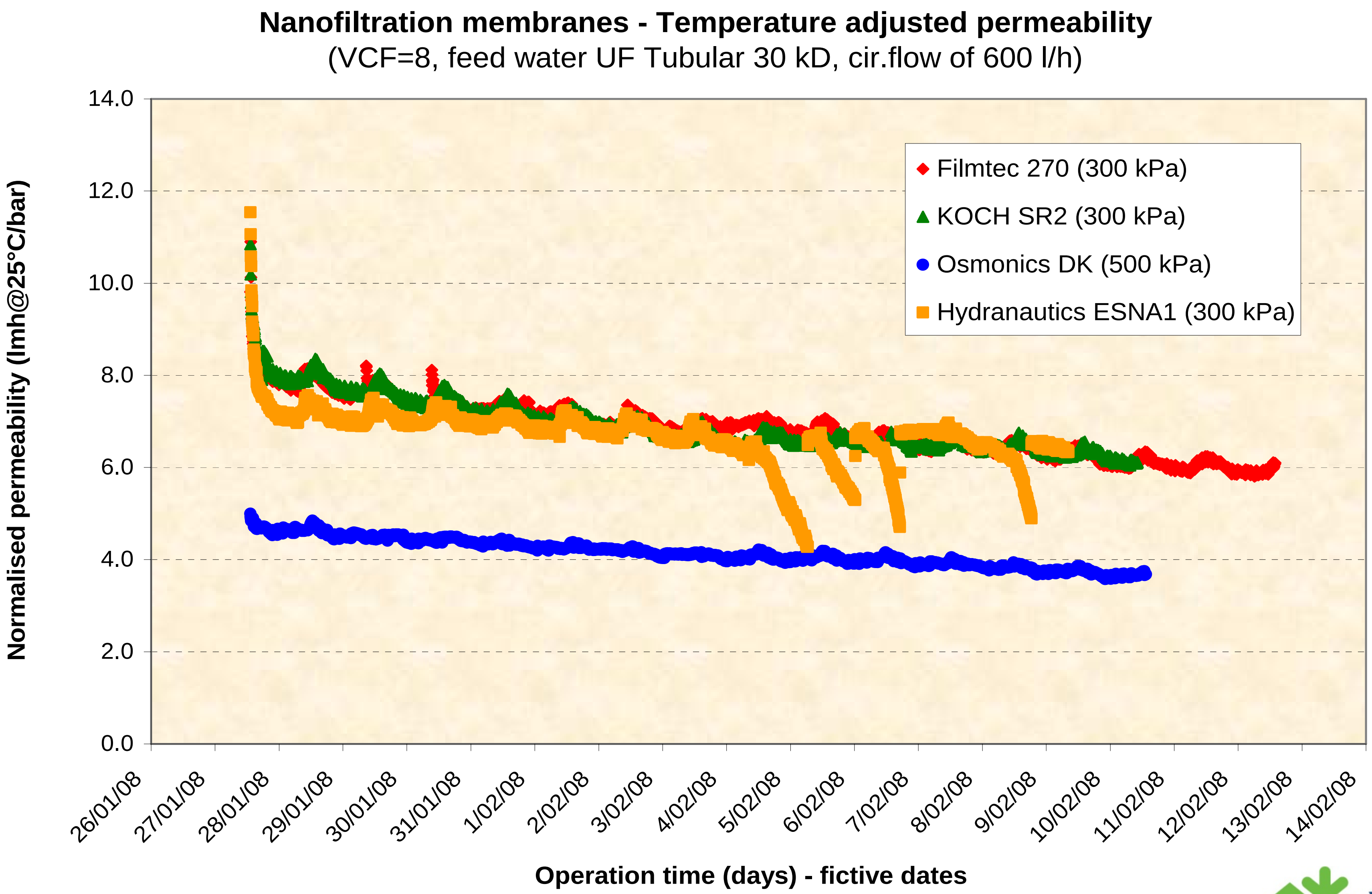
Pilot Plant Trials
Test location 3 – MF/UF conclusions

- The Tubular membrane was selected due to its operation duration of up to 14 days and the need for less pre-filtration
- The Hollow Fibre (Tube) operated for a similar time to the Tubular polymeric membrane, but it needs better pre-filtration and backwashing water and makes the arrangement more complex.
- The specific energy consumption is quite different. The Tubular membrane uses half of the energy used for the Hollow Fibre. The main difference is that the HF uses the energy for pressure.
- It should be noted that the Tubular membrane has a lower cut-off (30 kD) which is much denser than the Hollow Fibre membrane of 200 kD
- One negative issue with the Tubular membrane installation compared to the Hollow Fibre, is that it uses more space, but this will not be an issue for Albury.

Pilot Plant Trials
Test location 3 – Nanofiltration



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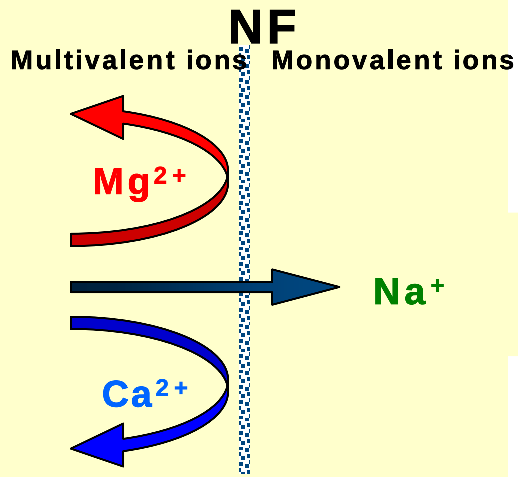
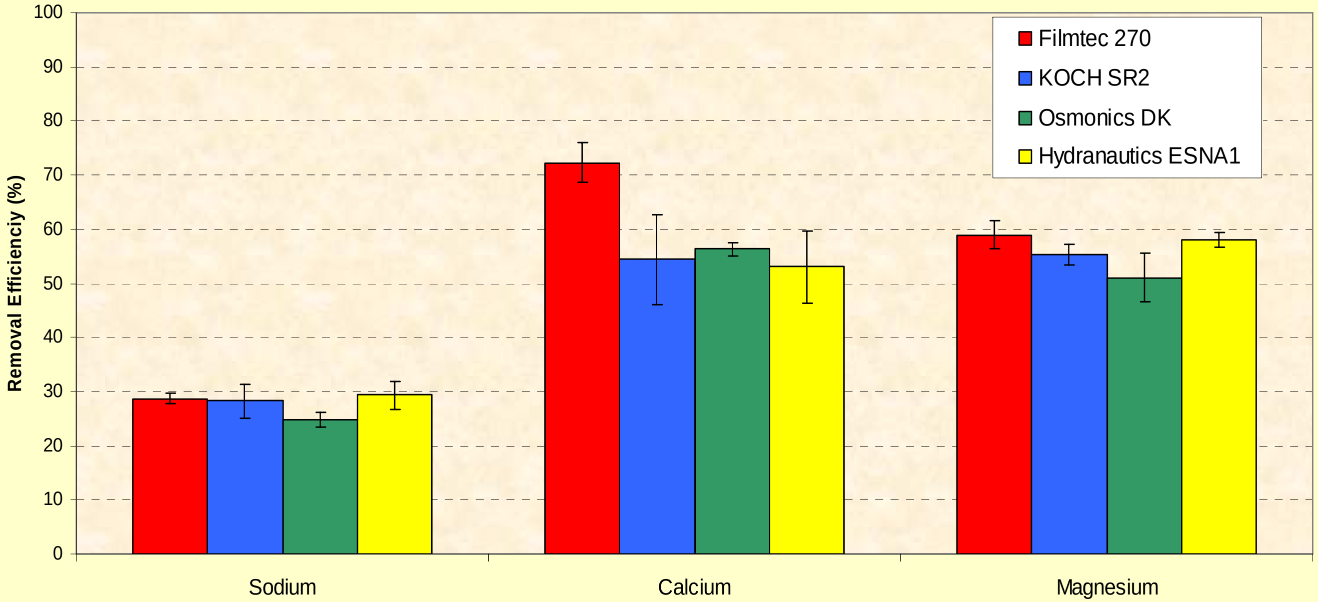
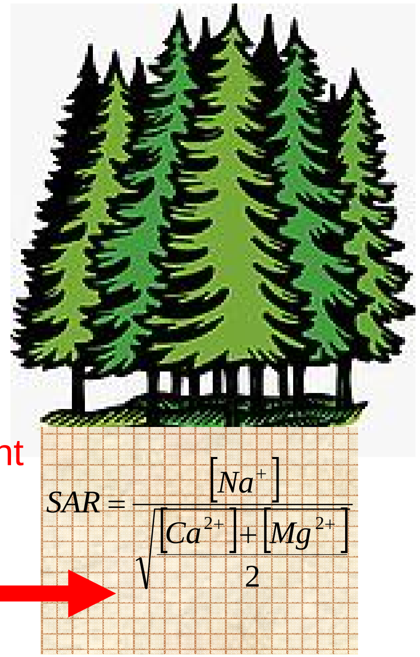
Pilot Plant Trials
Test location 3 – SAR optimisation



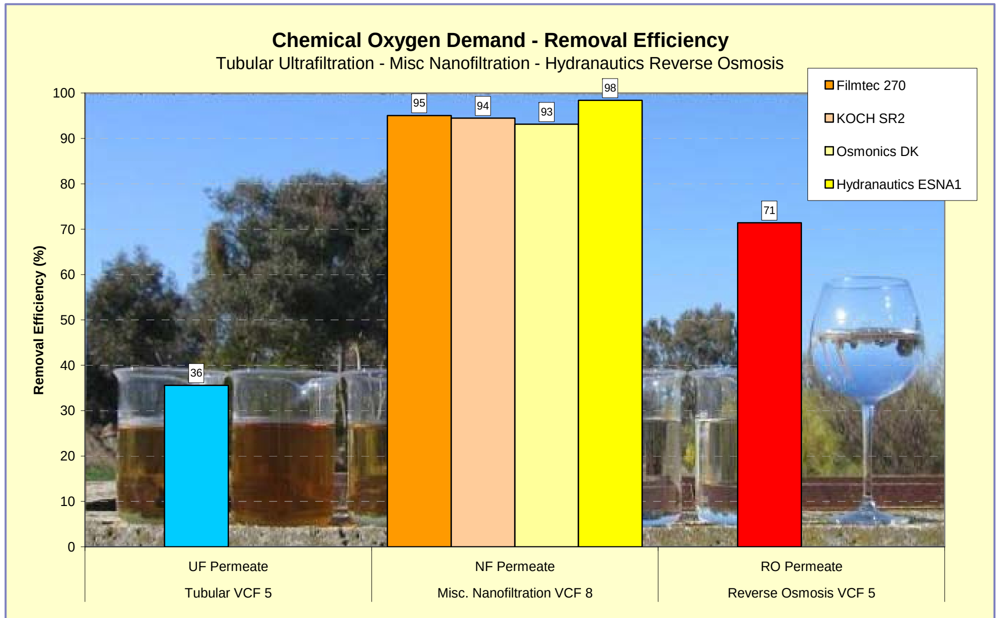
"Tailor-made-water"

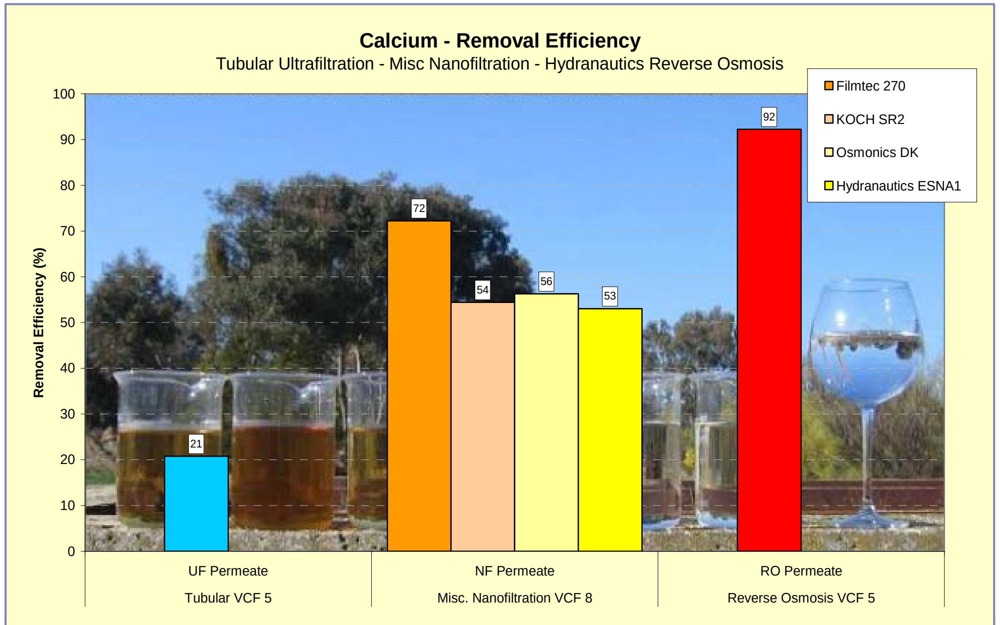


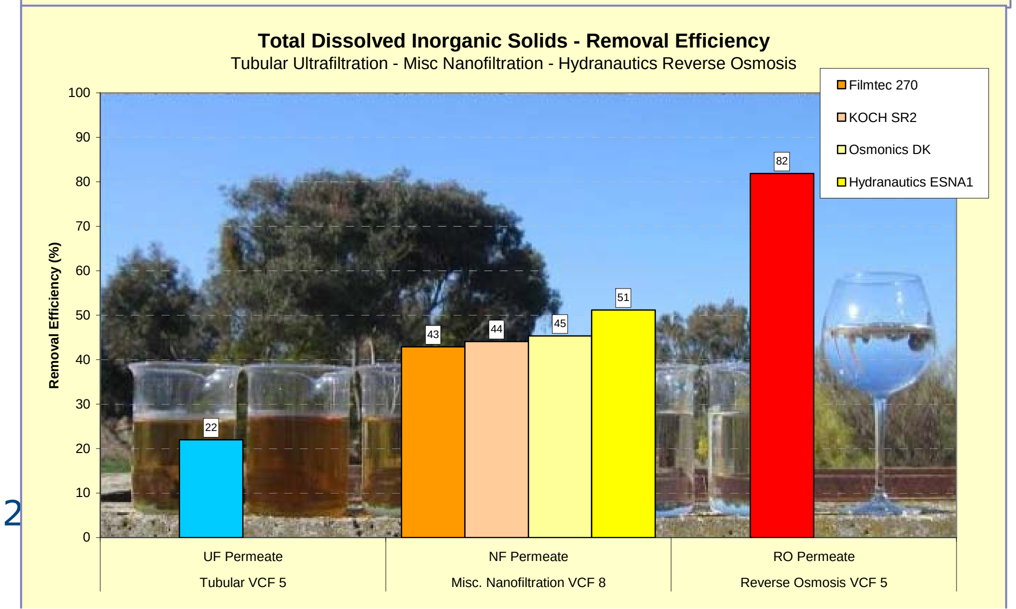
Minor improvement of the soil structure!

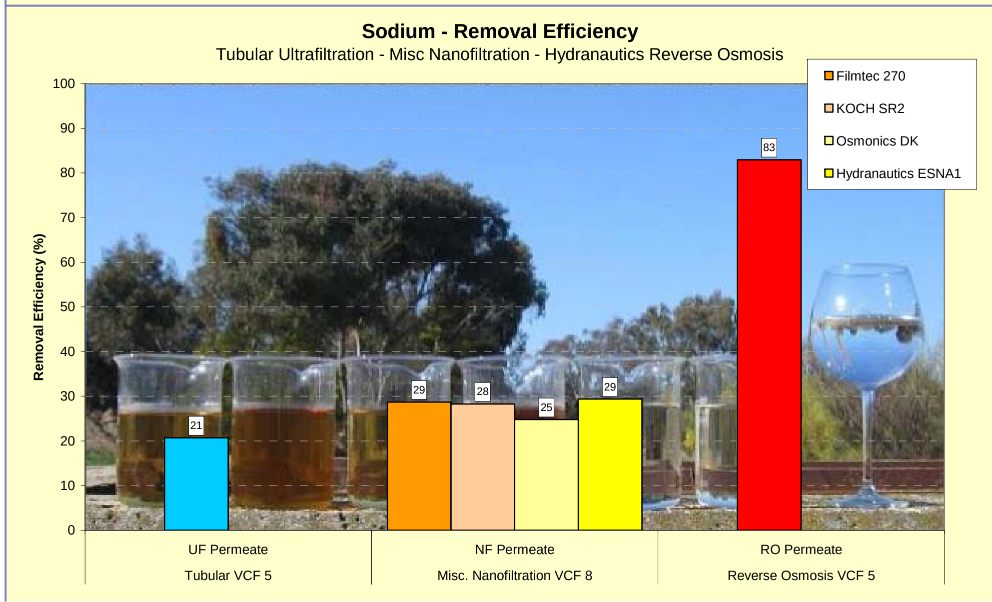


Pilot Plant Trials
Test location 3 – Nanofiltration

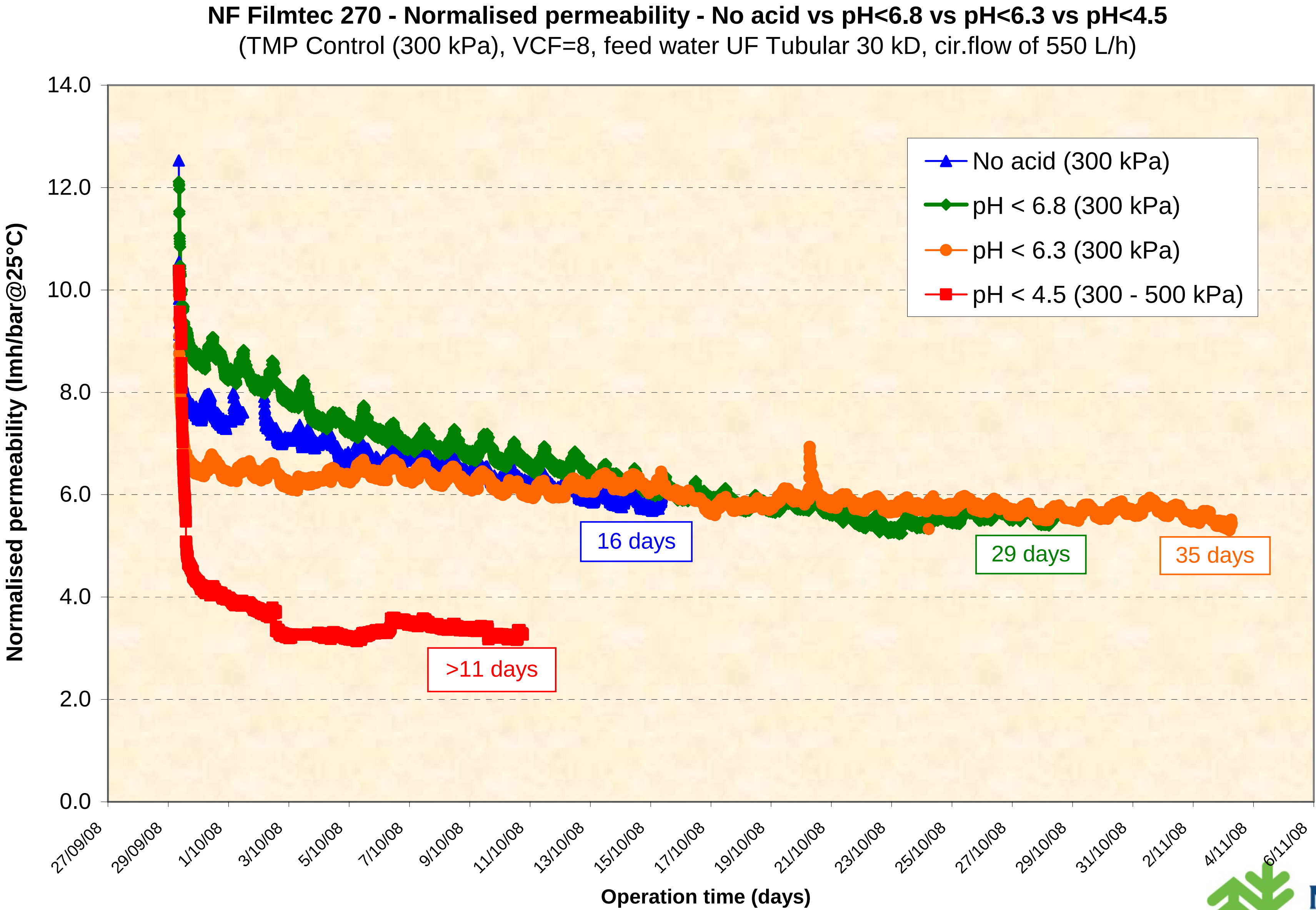








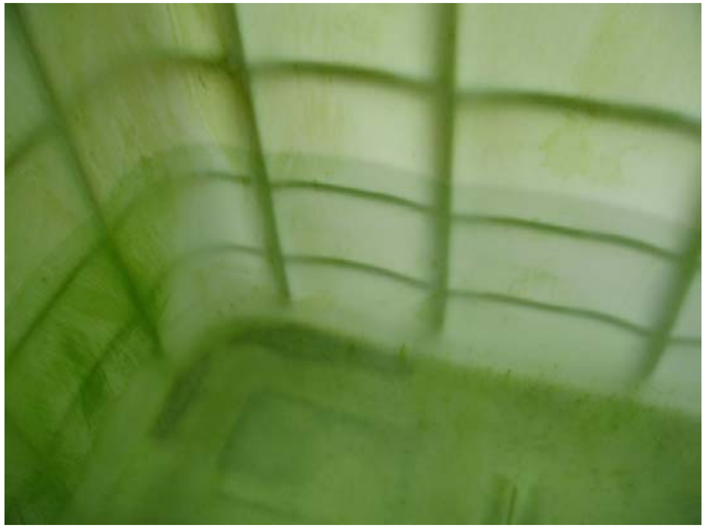
Pilot Plant Trials
Test location 3 – Nanofiltration



Pilot Plant Trials
Test location 3 – Nanofiltration

- Comparison of the Filmtec 270 permeate tank with different pH dosing levels

pH = ~8.0
– Two week of operation



pH < 6.8
- Four weeks of operation
- Similar to the Osmonics without any chemical dosing

pH < 4.5
- At least 11 days

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Pilot Plant Trials
Test location 3 – Nanofiltration

- Summary of the NF membranes tested (average of 10 first days of operation)

Membrane:	Permeate Produced (l/h)	Specific energy: (kWh/m^3)	Average flux: (lmh@25°C)	TMP: (kPa)	Specific Flux: (lmh@25°C/ bar)	VCF:	Spec. invest. cost: (A$/m^2)	Operating time: (days)
KOCH SR2 300-400 D	235	1.6	21.0	300	7.0	8	55	14
Osmonics DK 150-300 D	185	2.0	21.0	500	4.2	8	125	14
Hydra. ESNSA1 LF/LF2 200 D	152	1.5	20.0	300	6.7	8	45	13
Filmtec 270 300 D	250	1.6	20.8	300	7.0	8	145	16
Filmtec 270 300 D, pH<6.8	220	1.4	22.7	300	7.6	8	145	29
Filmtec 270 300 D, pH<6.3	190	1.6	19.1	300	6.4	8	145	35
Filmtec 270 300 D, pH<4.5	185	2.5	16.3	450	3.6	8	145	>11

Pilot Plant Trials

Test location 3 – Nanofiltration conclusions

- In general, most of the NF membranes trialled are quite similar in respect to concentration levels, while the flow differs
- When selecting membranes based on best permeate quality, the Osmonics DK membrane performed the best
- When selecting based on best permeate flux performance, the Filmtec 270 membranes performed best
- The ESNA1 had a relative high flux and a good removal efficiency, so it is placed between the Osmonics DK and Filmtec 270
- The KOCH SR2 membrane looked promising, but it looks as if the performance deteriorated during the trials due to membrane degradation
- We selected the Filmtec 270 for pre-filtration before the RO stage during our longevity tests.

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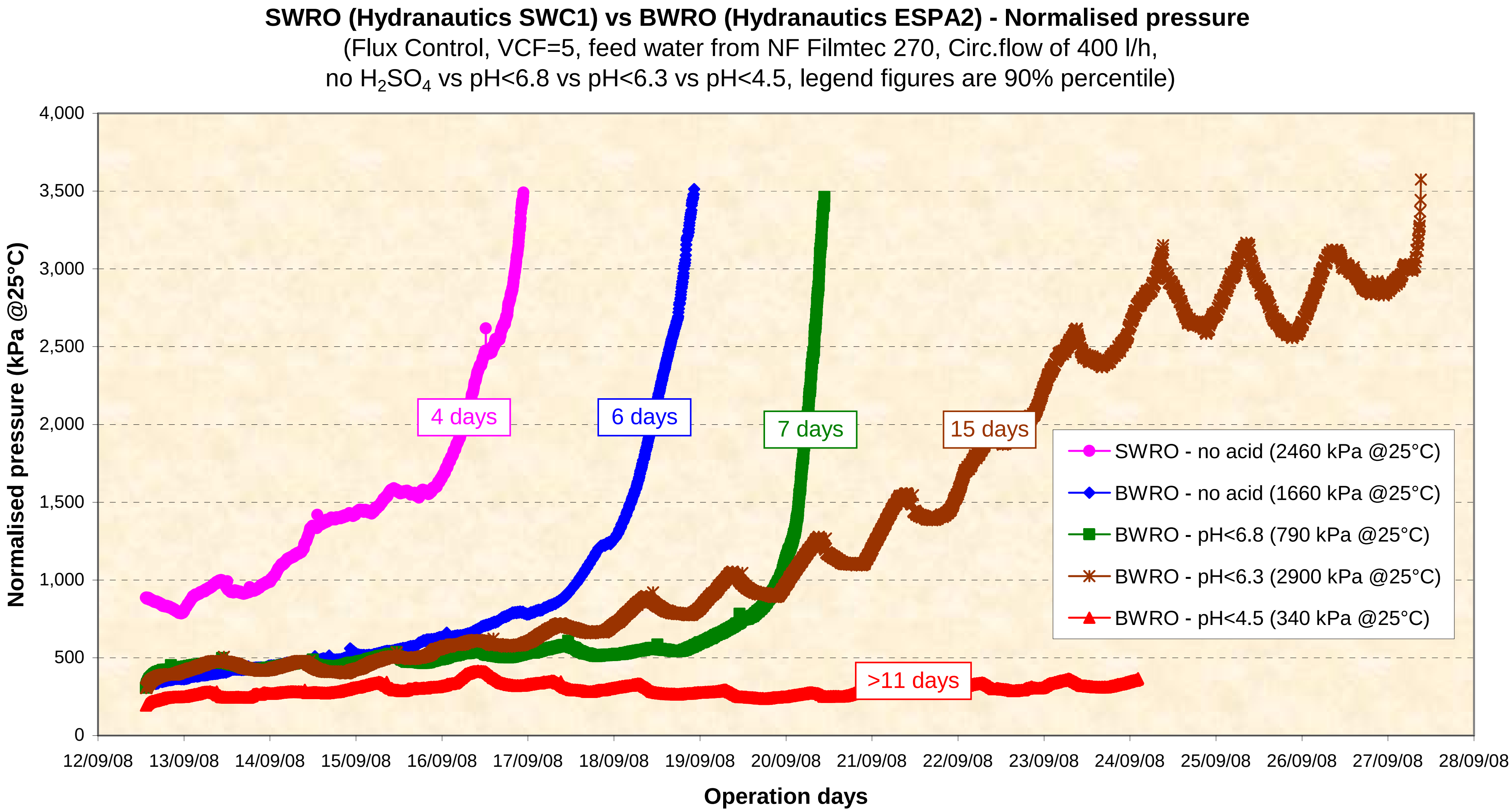
Pilot Plant Trials
Test location 3 – Reverse Osmosis - Flux



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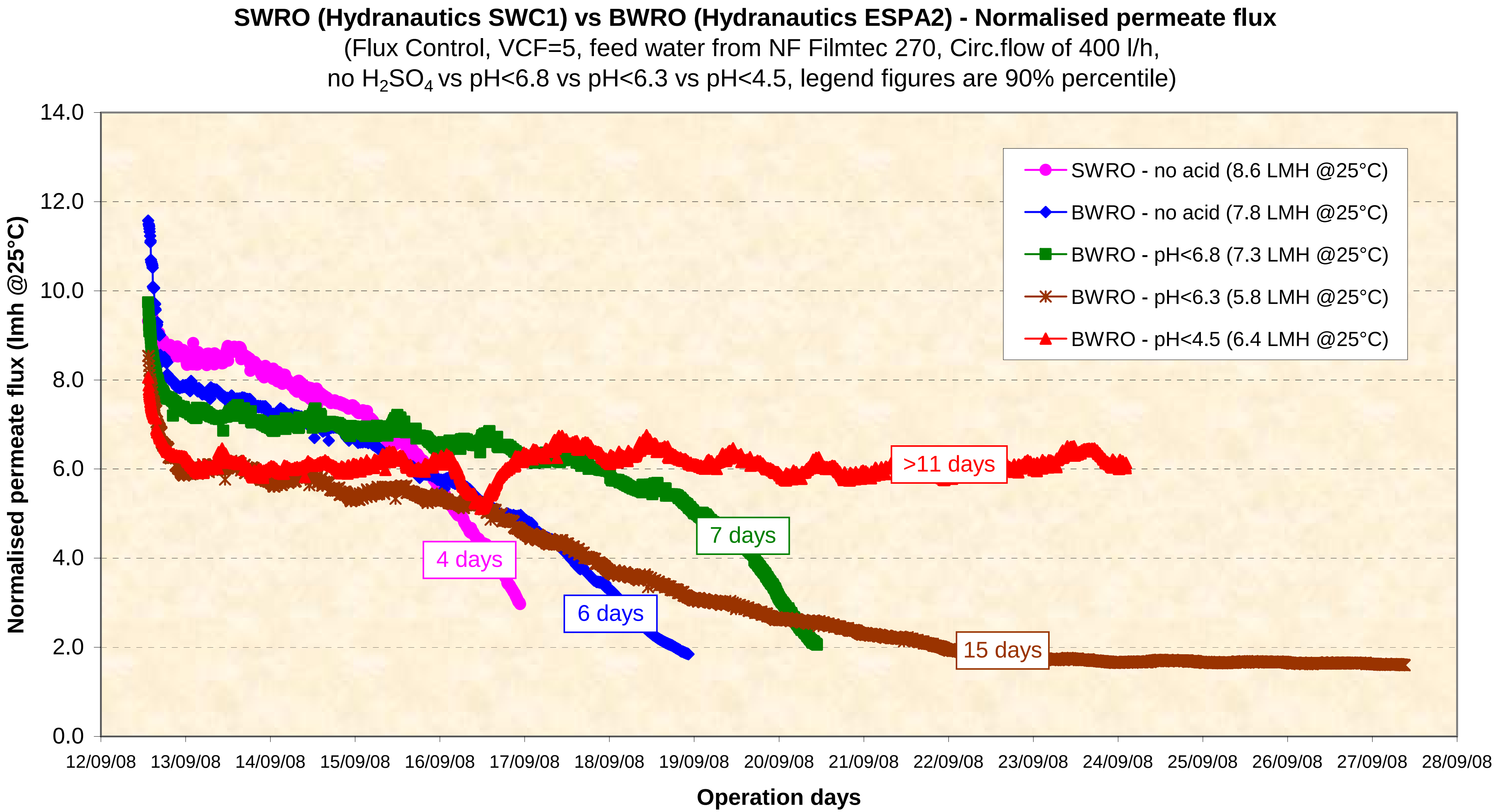
Pilot Plant Trials
Test location 3 – Reverse Osmosis - Flux



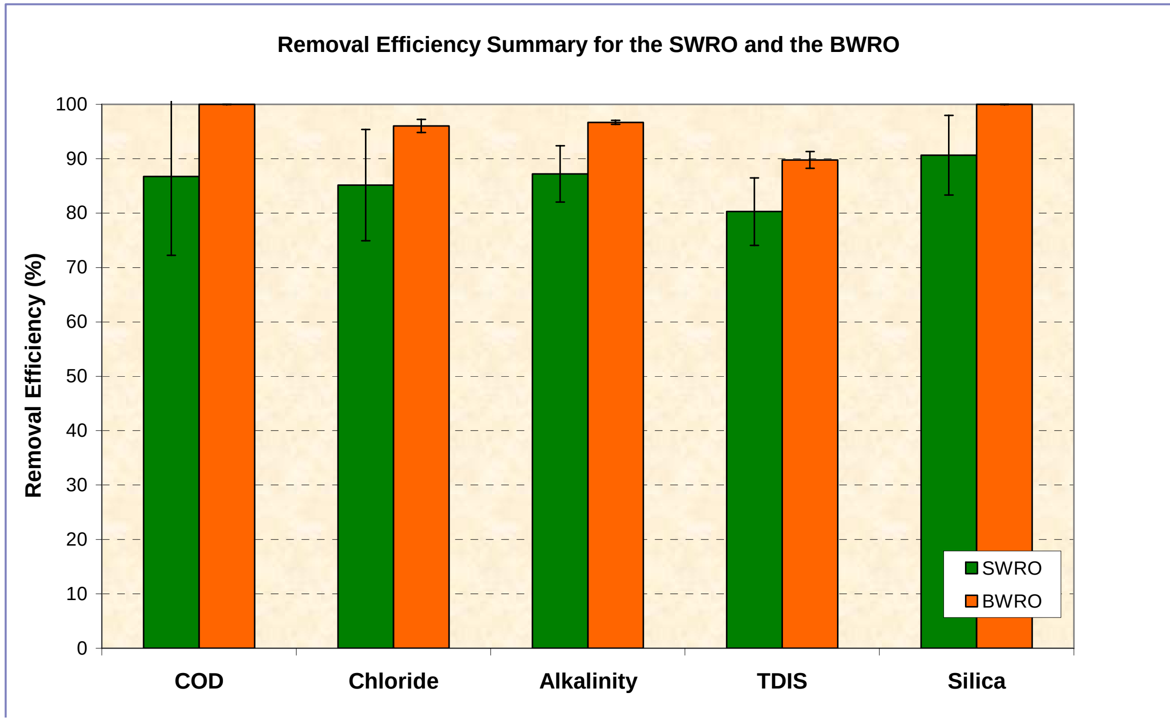
Pilot Plant Trials
Test location 3 – Reverse Osmosis

- Comparison of the Reverse Osmosis membranes trialled

Membrane:	Permeate Produced (l/h)	Specific energy: (kWh/m^3)	Average flux: (lmh@25°C)	TMP: (kPa)	Permeability: (lmh/bar @25°C)	VCF:	Spec. invest. cost: (A$/m^2)	Operating time: (days)
SWRO Hydranautics SWC1	120	6.6	6.9	1460	0.5	5	78	4.0
BWRO KOCH XR4	120	5.2	5.3	620	0.9	5	42	5.0
BWRO Hydranatics ESPA2	100	3.7	6.6	535	0.9	5	27	6.0
BWRO Hydranatics ESPA2, pH<6.8	100	3.7	6.8	500	1.4	5	27	7.0
BWRO Hydranatics ESPA2, pH<6.3	100	7.4	5.6	485	1.2	5	27	15
BWRO Hydranatics ESPA2, pH<4.5	100	6.8	6.0	310	2.0	5	27	>11

Pilot Plant Trials
Test location 3 – Reverse Osmosis conclusions

- Using BWRO versus SWRO reduced the energy consumption by 25% at the same flux.
- The BWRO removal efficiency was slightly better than the SWRO.
- The KOCH XR4 membrane degraded during our tests.
- There does not seem to be much variation between the RO membranes as between the NF and UF membranes. We selected the Hydranautics ESPA2 membrane for our longevity test.



Pilot Plant Trials
Test location 3 – Chemical usage

- Cleaning of membranes
  - Ultrasil 110 (Caustic)
  - Ultrasil 75 (Acid)
  - Hypochlorite
  - Ultrasil 02 (Surfactant)
- Anti-scaling
  - CleanTreat 4500 (Ecolab)
  - Hypersperse (GE Betz)
  - Flocon (GE Betz)
- pH scale control
  - Acid (Citric, acetic, hydrochloric, sulphuric)
  - Caustic (NaOH)
- Preservation
  - Ultrasil 73 (Ecolab)
- Sanitiser
  - Oxysan – H2O2 based (Ecolab)

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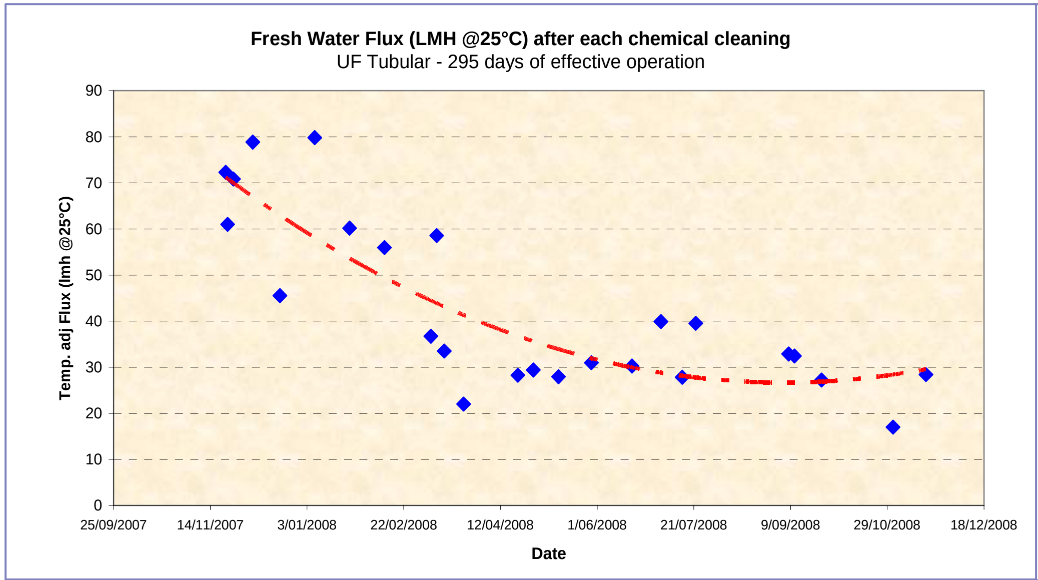
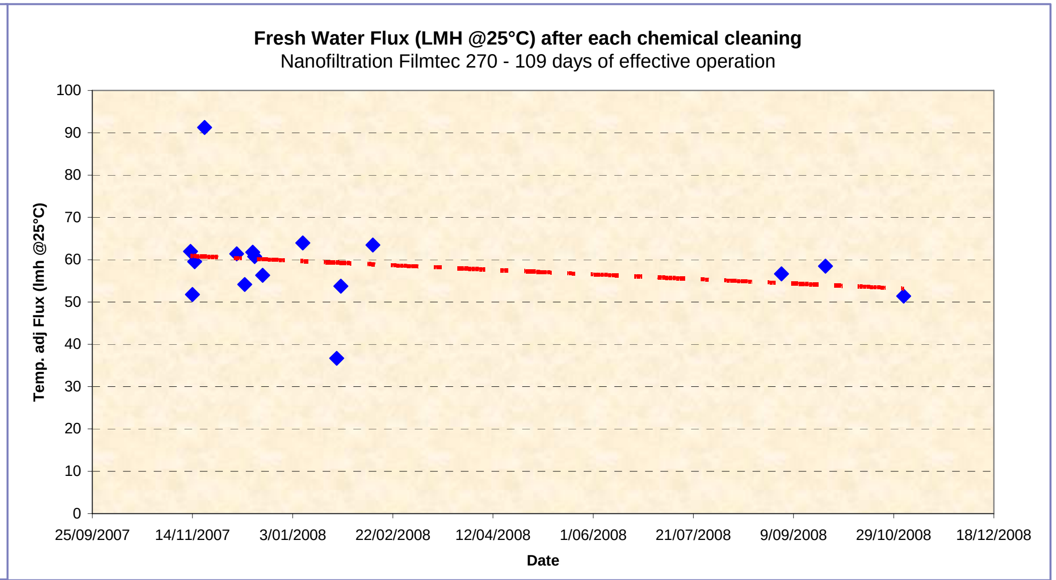
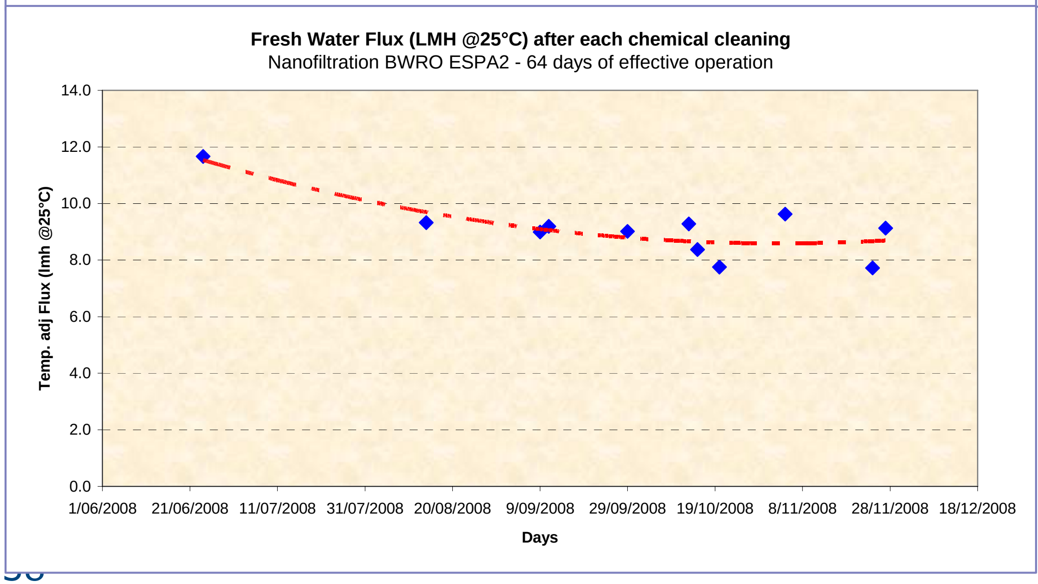
Pilot Plant Trials
Test location 3 – CIP





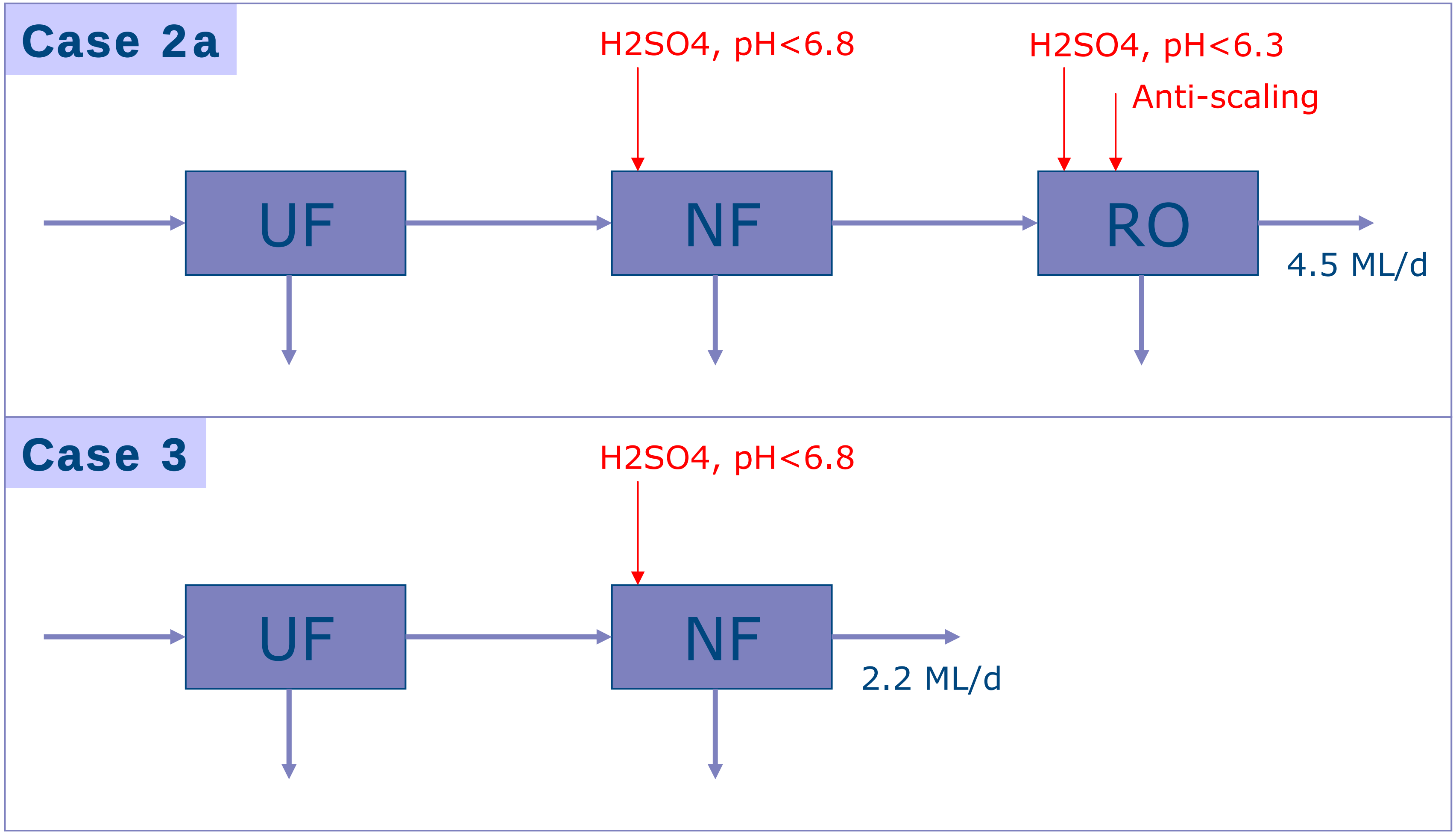


- The **UF Tubular**, 295 operating days, it is dropping the most in the beginning, but flattens as the CIP procedure is improved by soaking time and acid clean also during the maintenance CIP's.
- The **Filmtec 270**, 109 operating days, stable.
- The **Hydranautics ESPA2**, 64 operating days. relatively stable.

Proposed membrane arrangement

Pilot Plant Trials
Proposed membrane arrangement

- Overall process layout



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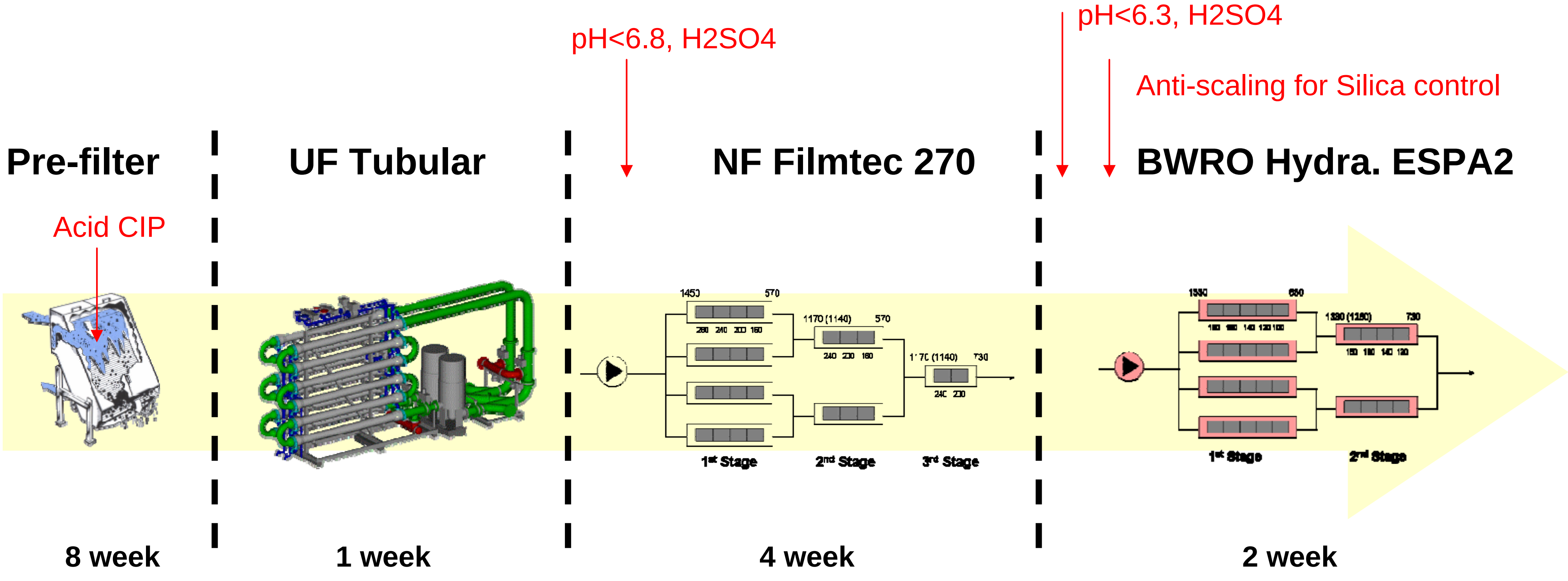
Pilot Plant Trials
Proposed membrane arrangement

- Summary of permeate fluxes

Membrane:	Permeate Produced (l/h)	Specific energy: (kWh/m^3)	Average flux: (lmh@25°C)	TMP: (kPa)	Permeability: (lmh/bar @25°C)	VCF:	Spec. invest. cost: (A$/m^2)	Operating time: (days)
UF Tubular (30 kD, 84% circ)	530	3.5	38	180	21	5	675	22
NF Filmtec 270 300 D, pH<6.8	220	1.4	22.7	300	7.6	8	145	29
BWRO Hydranautics ESPA2, pH<6.3	100	7.4	5.6	485	1.2	5	27	15

Pilot Plant Trials
Proposed membrane arrangement

- Overall layout



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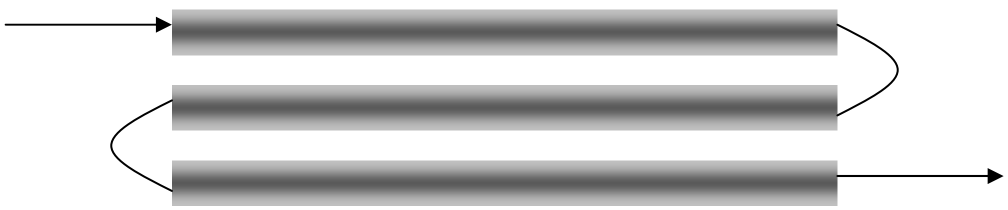
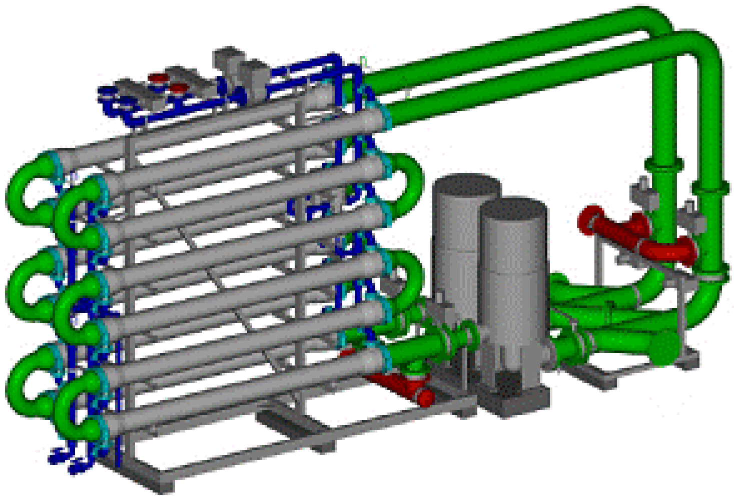
Pilot Plant Trials
Proposed membrane arrangement

- Ultrafiltration Tubular membrane

The pilot used 3 m long elements



A full scale plant should use 1.5 m long elements



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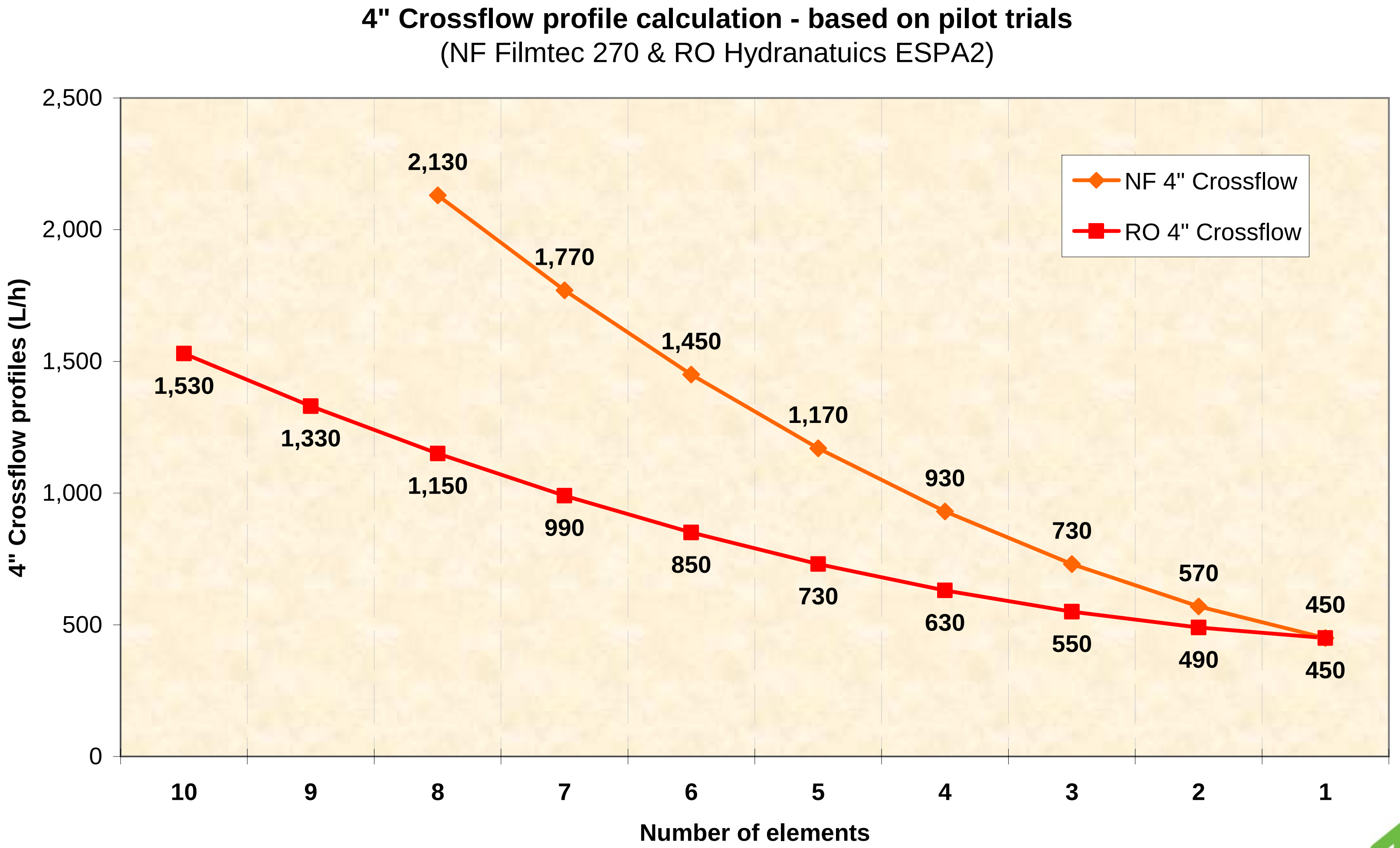
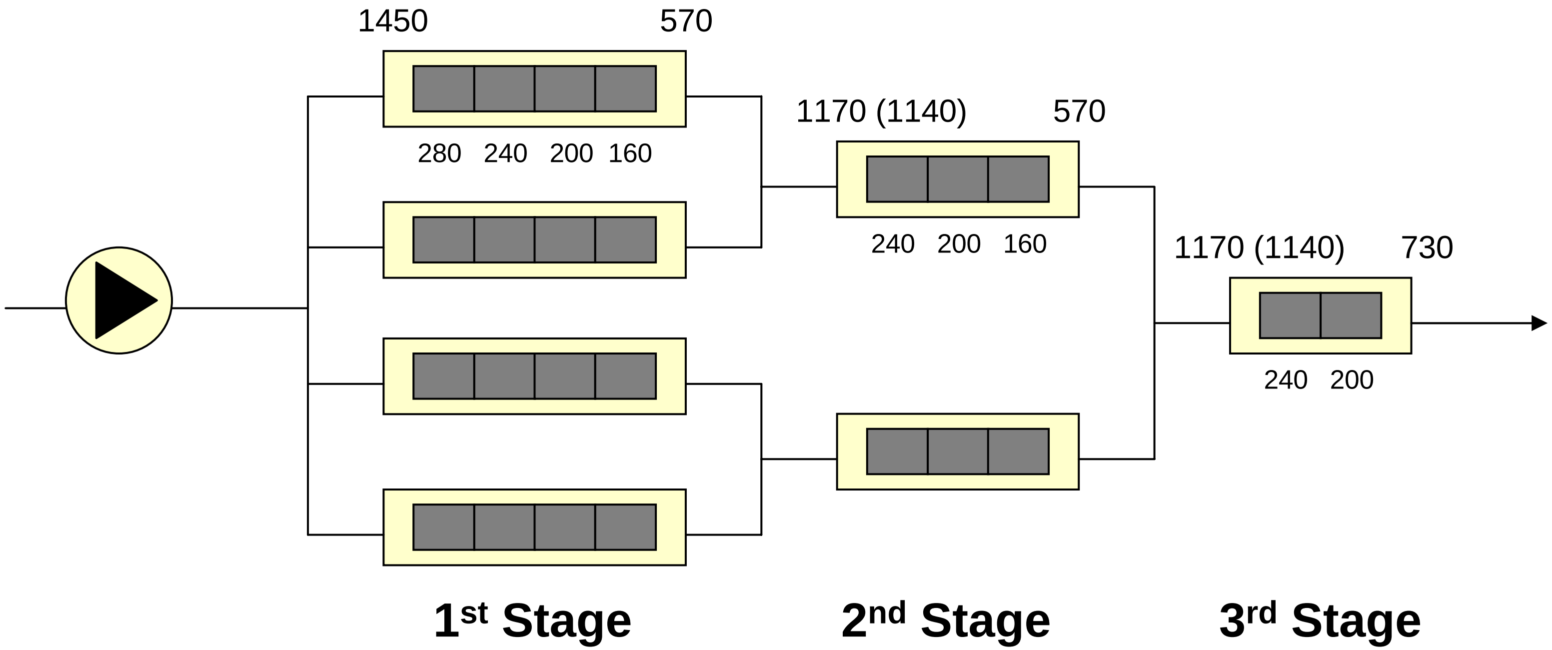
Pilot Plant Trials
Proposed membrane arrangement

- The NF & RO **crossflow profile** based on the pilot trials



Pilot Plant Trials
Proposed membrane arrangement

- A proposed NF configuration
  - Conservative and flexible

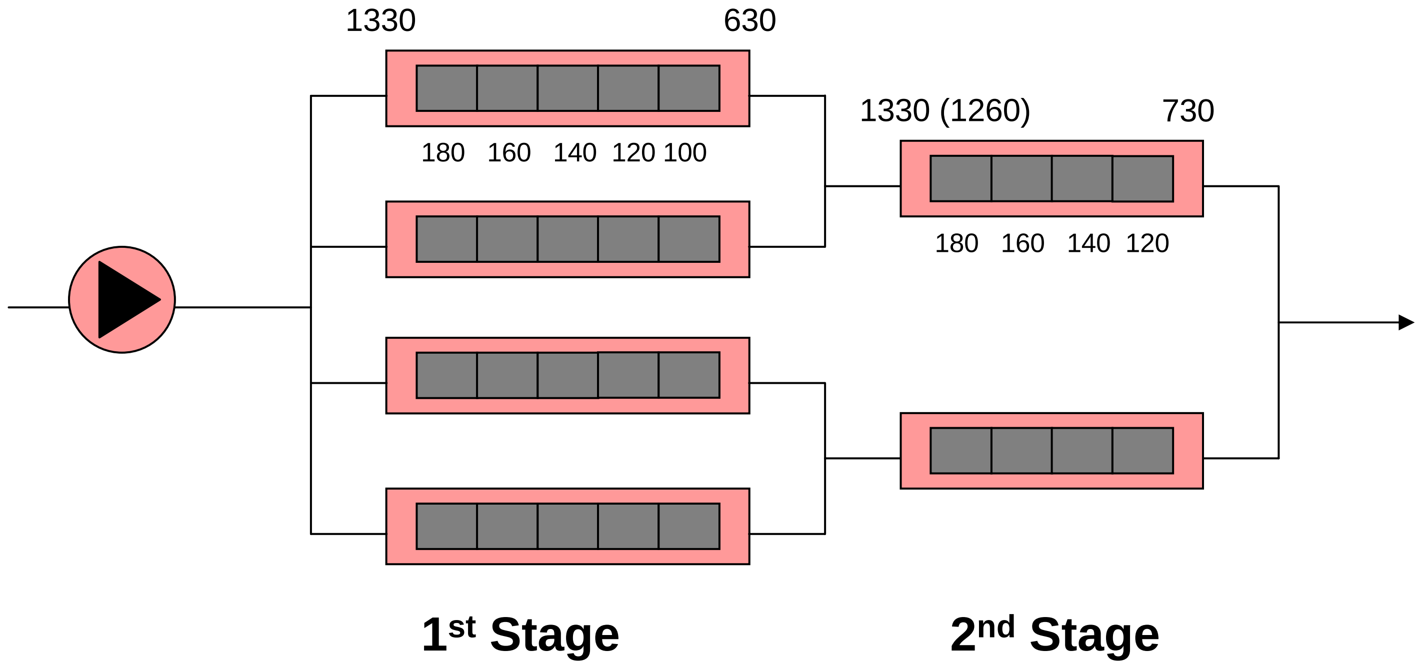


Recovery% = 87.4% (VCF=8)
Configuration: 3 stages in a 4:3:2 array
8” Qp = 15,000 L/h
8” Qf = 17,162 L/h
8” Qr = 2,162 L/h

Future Case 2a: will need 12 trains
Future Case 3: will need 6 trains

Pilot Plant Trials
Proposed membrane arrangement

- A proposed RO configuration
  - Conservative and flexible



Recovery% = 72.5% (VCF=5)
Configuration: 2 stages in a 5:4 array
8" Qp = 7,250 L/h
8" Qf = 10,000 L/h
8" Qr = 2,750 L/h

Future Case 2a: 25 trains of this

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Pilot Plant Trials
Overall operating conclusions

- Operating the pilot plant ourselves has given us the information we find relevant for this study
- UF Tubular membrane was chosen because of its robustness
- For our chosen Tubular polymeric membrane, a simple pre-filtration technique such as sand filters or a bow-screen will be good enough
- We need to operate in TMP control on the UF and NF, but Flux control was best on the RO.
- We need to adjust the pH for both the NF and RO to control the scaling issues
- SAR could not be improved much by using NF membranes

Thank you for your time!

Questions?

For more details, please contact: **lasse.blom@yahoo.com**

- The End -