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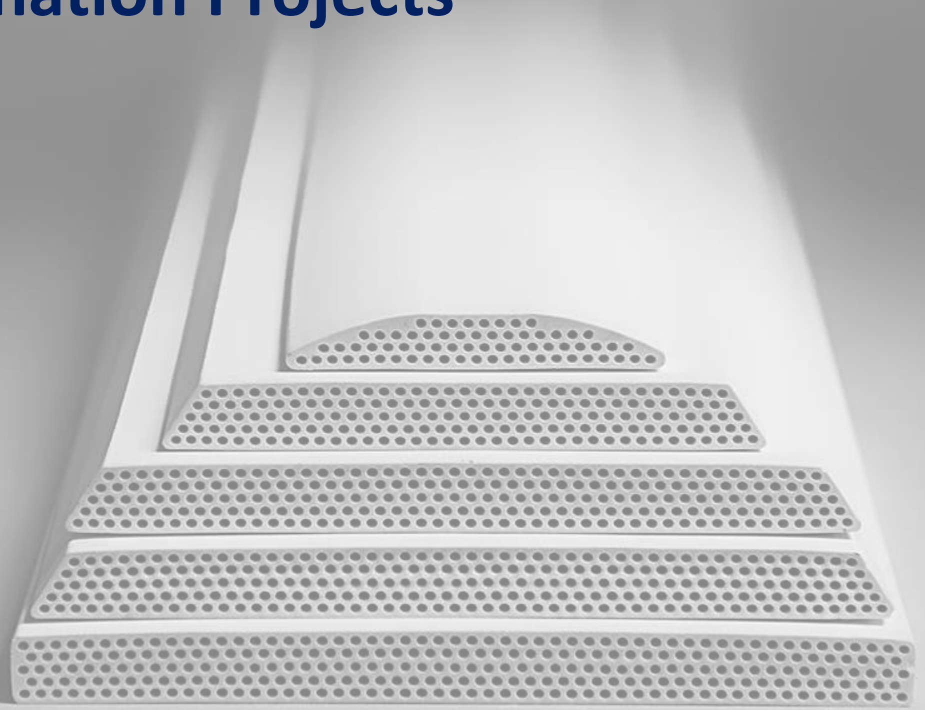
# MENA Desalination Projects

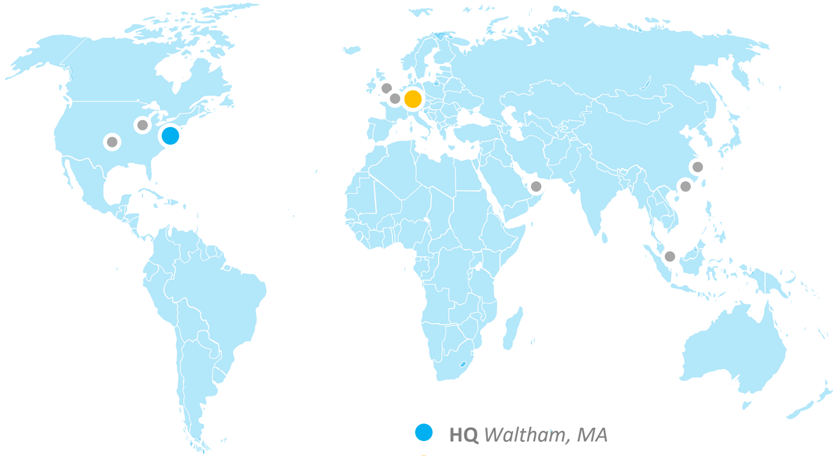
*April 2021*



# Company Background

- **2012** – True North Venture Partners acquires established innovative ceramic technology, launches **Nanostone Water**
- **2014** – R&D advances to prototype and alpha product field testing; pilot production line upgraded
- **2015** – Beta product launched and initial demonstration projects deployed
- **2016** – Commercial product development and qualification and commercial production line design and retrofit
- **2017** – First commercial installations; microelectronics, boiler feed
- **2018** – First commercial drinking water installations
- **2019** – Largest industrial and drinking water installations in operation
- **2020** – Global expansion of both business and resources
- **2021** – Expand into Desalination

2012 2013 2014 2015 2016 2017 2018 2019 2020 2021



- **HQ** *Waltham, MA*
- **Manufacturing** *Halberstadt, GER*
- **Sales & Engineering Offices**

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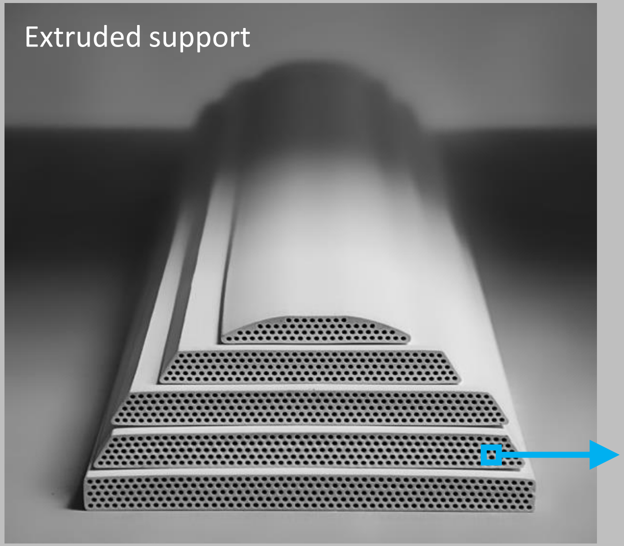
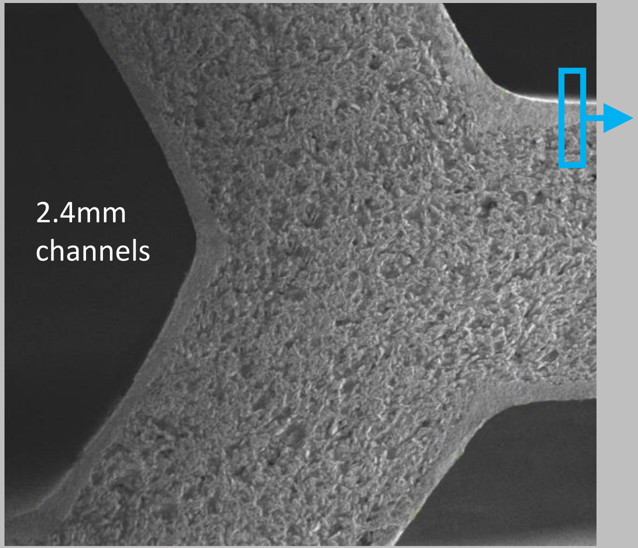
**Halberstadt, Germany:** Automated production line with largest ceramic membrane capacity in the world.

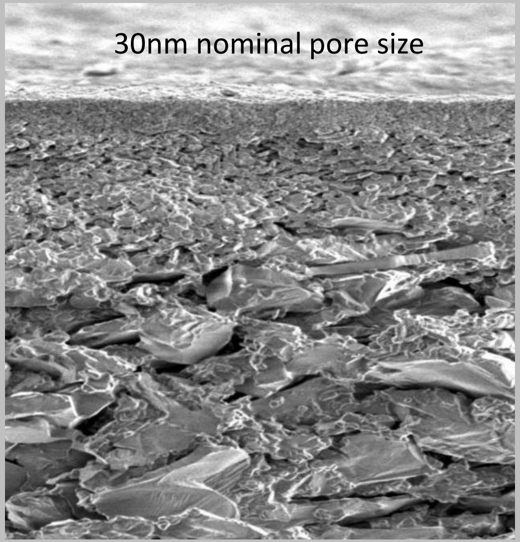
# Manufacturing and Technical Center – Halberstadt, Germany

*Nanostone's advanced manufacturing plant is home to the* ***largest ceramic membrane production capacity*** *in the world*

*Co-locating R&D, manufacturing, and administrative staff also helps drive increased* ***collaboration*** *and* ***innovation***




# Innovation in design improving performance

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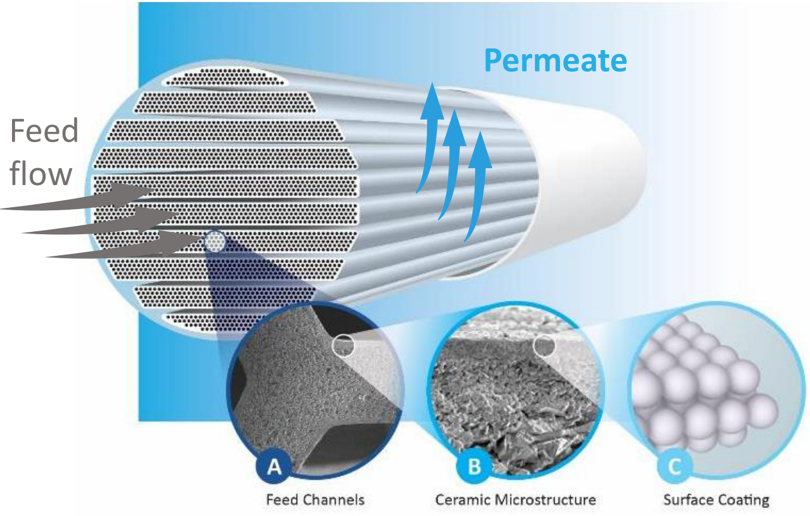
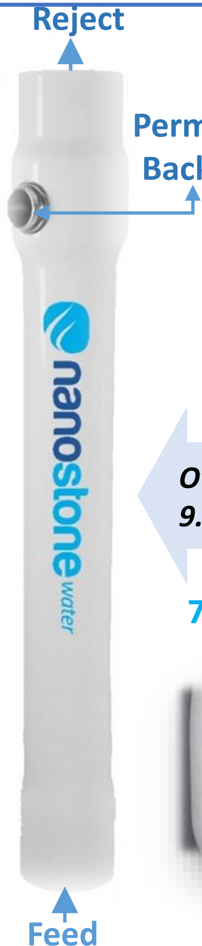
- Nanostone Water is leading the industry with our **innovative ceramic design**
- We've optimized our product and production process to **optimize yield** and **lower capital costs** and **operating costs**
- The ceramic surface coating also enables tight pore size distribution, resulting in **improved performance and reliability**

# Nanostone Module (Universal Design)





*Overall vessel height 75.5 in, Dia 9.8 in, Shipping weight 95 kg*

**262 ft$^2$/24.3 m$^2$ area**
**α- $Al_2O_3$ ceramic membrane**

**Inside-Out Filtration**
**Dead-end operation**

**7 Bar rated FRP vessel**

**Super Duplex 2507 Permeate Port**

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https://www.youtube.com/watch?v=J7ZAiiMPoaU

# Nanostone Ceramic Membranes – Key Features and Benefits


- Operates at **very high flux** (3–6 times higher than PUF)
- Higher **recovery** than polymeric MF/UF
- Runs stably at **high solids loading**, especially inorganics
- Dosing of **coagulant** is well-tolerated and even **improves performance**
- Stable operation **without pre-treatment** (ceramic UF eliminates the need for clarifiers and multi-media filters which are often used before polymeric UF)
- **CapEx-competitive** on a system-to-system basis with compact footprint
- **pH resistance** from 1–13 in cleaning, 2–12 in operation
- **Operational temperature** 33 –113 °F (0.5 –45 °C)
- Depending on application, membranes may be **guaranteed for up to 20 years**
- **Robust and reliable** (no fibers to break or repair)
- **Lower operational complexity and cost** (no air scour required, fewer chemicals and electricity when removing treatment steps, higher water recovery)

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# Nanostone Ceramic Membranes Installed Capacity 2017-2021


- Total installed capacity since 2017 is **307 MLD**
  - ✓ Municipal: **85 MLD** (all retrofits of the existing PUF membranes)
  - ✓ Industrial: **222 MLD**( majority greenfield, 30% retrofits)
- Biggest industrial plant **48 MLD** (Inner Mongolia, China), coal mining
- Biggest municipal plant **54 MLD** (Canyon Regional Water Authority, TX, US), drinking water
- Relatively rapid growth installed capacity mainly caused by:
  - ✓ Failing polymeric membrane (integrity and fouling issues)
  - ✓ Advantages of ceramic ultrafiltration membranes
  - ✓ Same “simple” or standard infrastructure makes it easy to switch to ceramic UF membrane (or back)
- This polymeric retrofit capability makes the Nanostone ceramic ultrafiltration membrane unique in the market

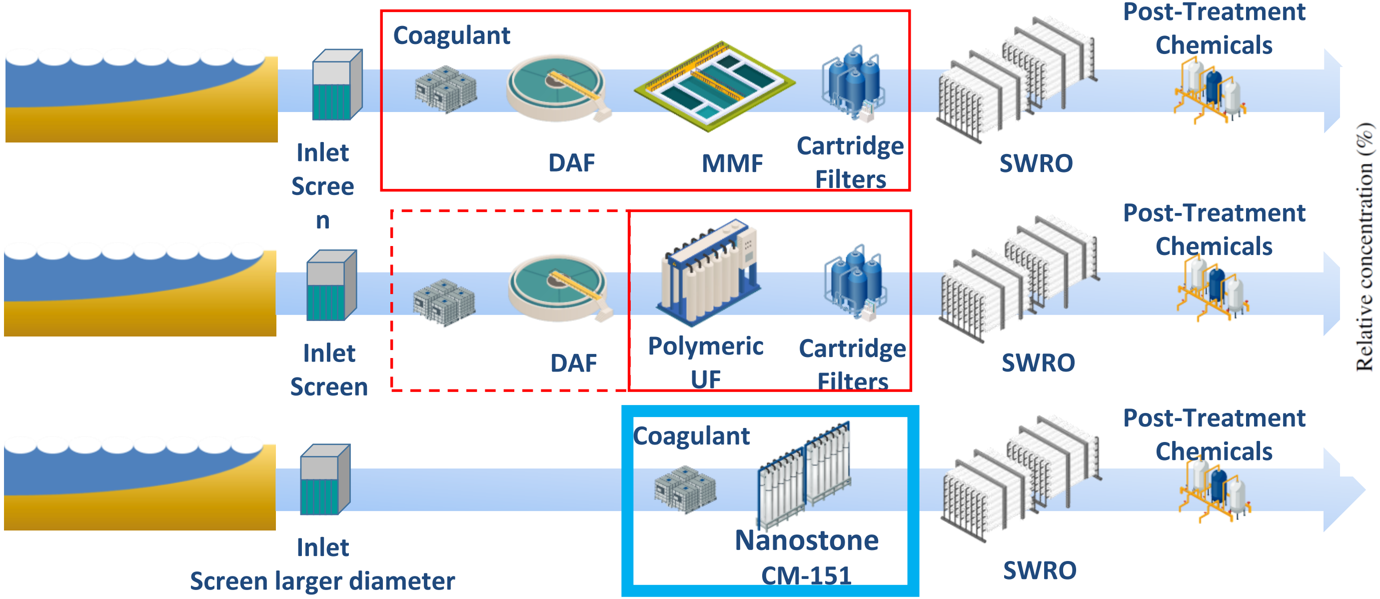
# Desalination pretreatment issues

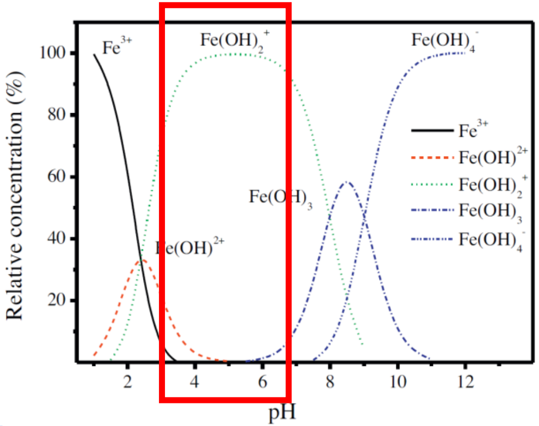
- Seawater challenges
  - Algal blooms / red tide
  - High variability – tidal effect
  - Dissolved organic content (DOC) – such as Transparent Exopolymer Particles (TEP)
- Polymeric Membranes
  - Implemented in many plants beginning ~15 years ago to address concerns with conventional treatment
  - Suitable for surface water but desalination plants have struggled
    - Permit pass-through of DOC leading to excessive fouling of RO
    - Unable to maintain capacity even at extremely low design flux
    - Susceptible to fiber breaking, therefore breakthrough

# Desalination pretreatment today

- Dissolved Air Flotation (DAF) now being added ahead of polymeric membranes
  - Adds significant capital cost
  - Requires large footprint
  - High operating cost associated with chemical dosing and sludge removal
- "State-of-the-art today is DAF and multi-media filtration"
  - Leading seawater utility manager at Global Water Summit in April 2019
  - Polymeric membranes have failed
- DAF + MMF have their own problems
  - Expensive
  - Footprint
  - Significant risk of solids carry-over

# Scheme Optimization & Lowest pretreatment Costs-Seawater Desalination




- "Enhanced" Coagulation for Algae/DOC removal
- Direct seawater filtration
- No fibers = no air blower/scouring

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# Nanostone's ceramic membrane and module ideally suited for desalination pre-treatment

- Membrane and module are sea water resistant
- Large channels (2.4 mm) can hold a large amount of solids and algae
- Minimal pre-treatment (coagulation only) is necessary to function optimally
  - no need for Dissolved Air Floatation (DAF) or other forms of clarification,
  - saving space and complexity while improving reliability
- Can operate optimally with coagulation removing organics significantly improving downstream RO operations
  - many membrane systems avoid coagulation placing burden on downstream processes
- High fluxes (> 200 lmh) can be achieved reducing foot print
  - many desalination plants are located in urban areas land is a premium
- Rigorous cleaning can be achieved with high flow backwashing and chemicals

# Overview or Pilot at Tuas (Singapore PUB)


*Tuas derives its intake 1.4 km off-shore*

| | |
|---|---|
| **Objectives** | • Stable UF-performance at economical feasible flux<br>• Highest possible NOM/DOC removal for downstream RO<br>• Absolute filtration for SS (low Turbidity, SDI) |
| **Pre-treatment** | • Continuous 5 days 2 ppm NaOCl dose, +6 ppm shock dose for 2 days (8ppm)<br>• Sieve 20 mm<br>• Rough screen 2mm (other MF/UF pilots on site have a 400µm or finer screen)<br>• In-line coagulation with $FeCl_3$, pH-control and 1-3 minute contact time |
| **Logistics** | • Trial of 6 months<br>    • 3 months optimization<br>    • 3 months longer-term monitoring |

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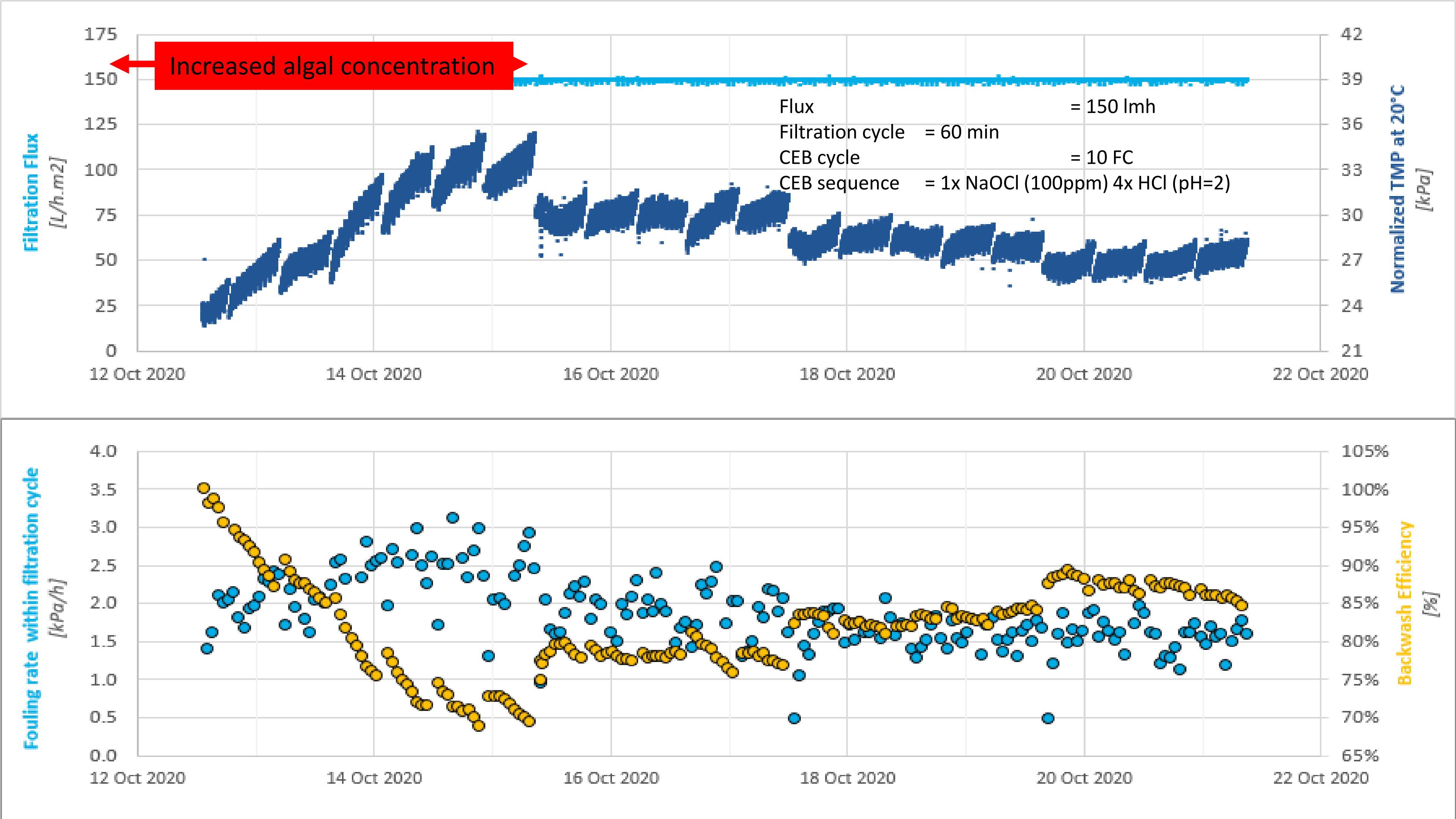
# Status of Pilot at Tuas (Singapore PUB)

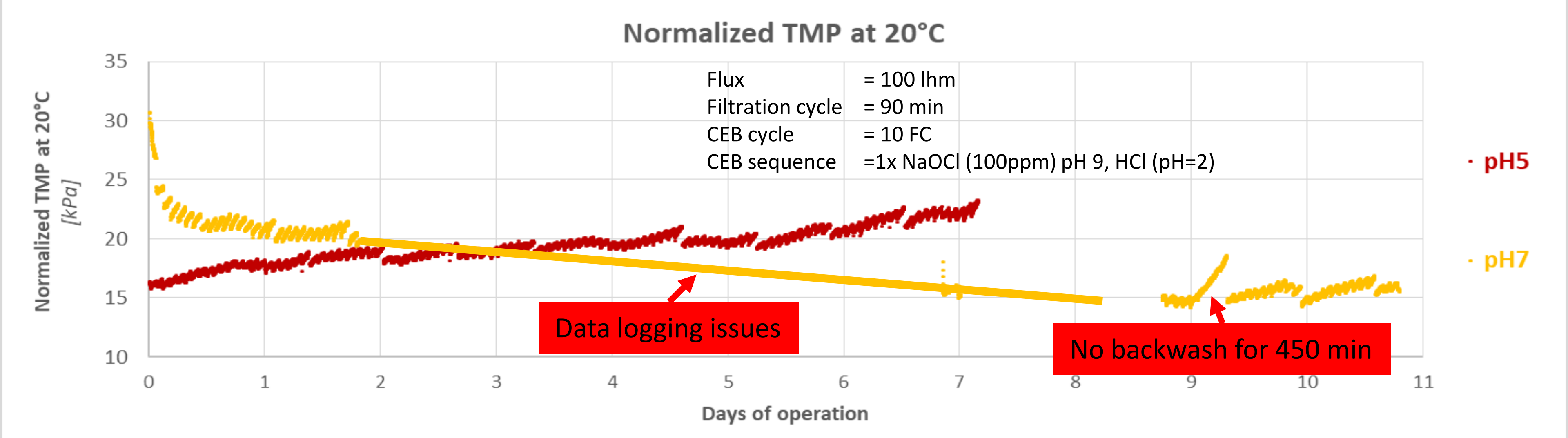
| | |
|---|---|
| **Jar Testing** | • Find initial coagulant dose and pH-range (done) |
| **Commissioning** | • Delayed by Covid-19 circuit breaker events |
| **In-line coagulation** | • Initial optimization, 4 weeks (done)<br>• Confirm jar tests in a continuous process<br>• Find optimum pH (done) |
| **Optimization** | • Establish critical flux, 4 weeks (done)<br>• Establish filtration time or optimum load L/m2, 2 weeks (done)<br>• Establish CEB frequency, 3 weeks (done) |
| **Long-Term Operation** | • Confirm/validate optimum operation, 12 weeks |

# Technical background/research at TUAS (PUB) – Optimizing ILC

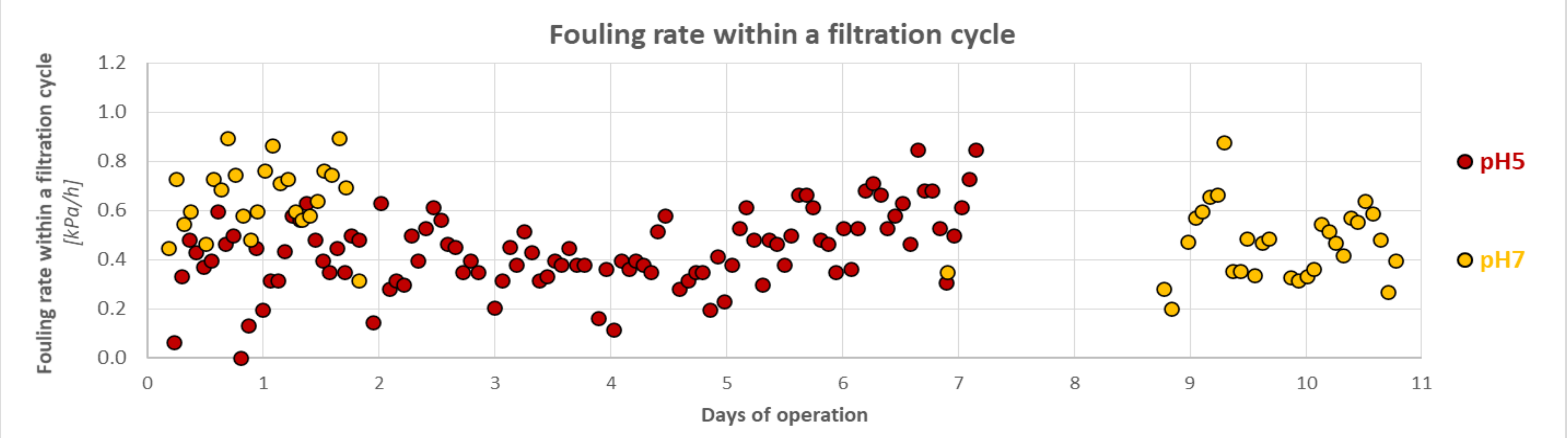
- Based on theory expectations for pH 5 are:
  - Closer to "Enhanced" coagulation
  - Higher removal percentage DOC (humic fraction)
  - Some irreversible fouling caused by charged matter
  - Charged metal organic complexes formed
- Based on theory expectations for pH 7 are:
  - Closer to "Sweep" flocculation
  - Lower removal rate DOC (mainly HMW fraction)
  - Less irreversible fouling caused by formation of uncharged $Fe(OH)_3$



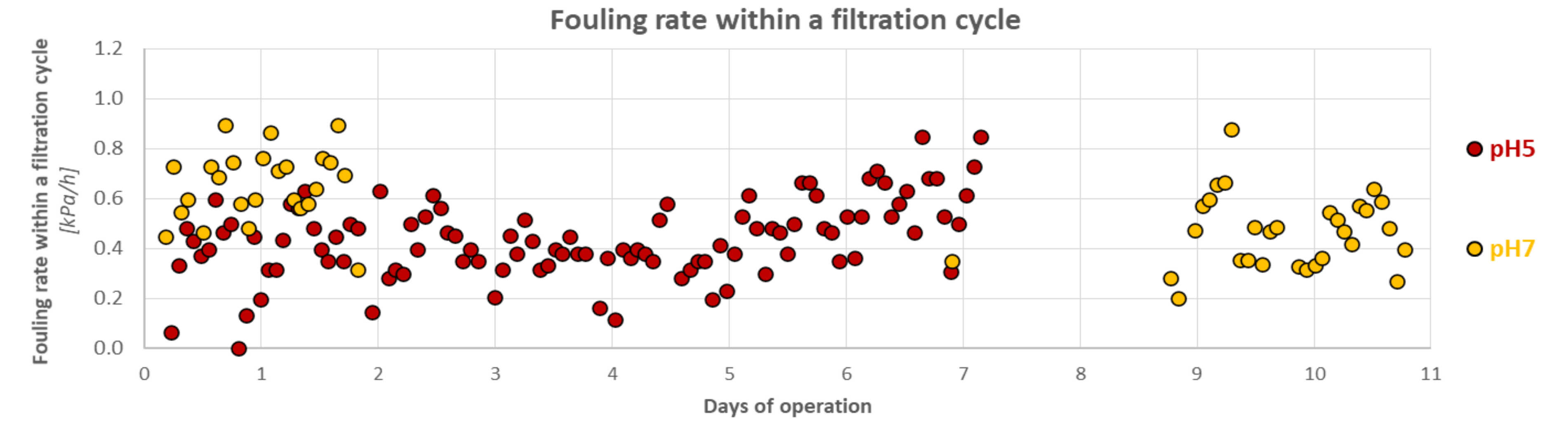
Increased algal concentration
Flux = 150 lmh
Filtration cycle = 60 min
CEB cycle = 10 FC
CEB sequence = 1x NaOCl (100ppm) 4x HCl (pH=2)
Filtration Flux [L/h.m2]
Normalized TMP at 20°C [kPa]
Fouling rate within filtration cycle [kPa/h]
Backwash Efficiency [%]
12 Oct 2020
14 Oct 2020
16 Oct 2020
18 Oct 2020
20 Oct 2020
22 Oct 2020

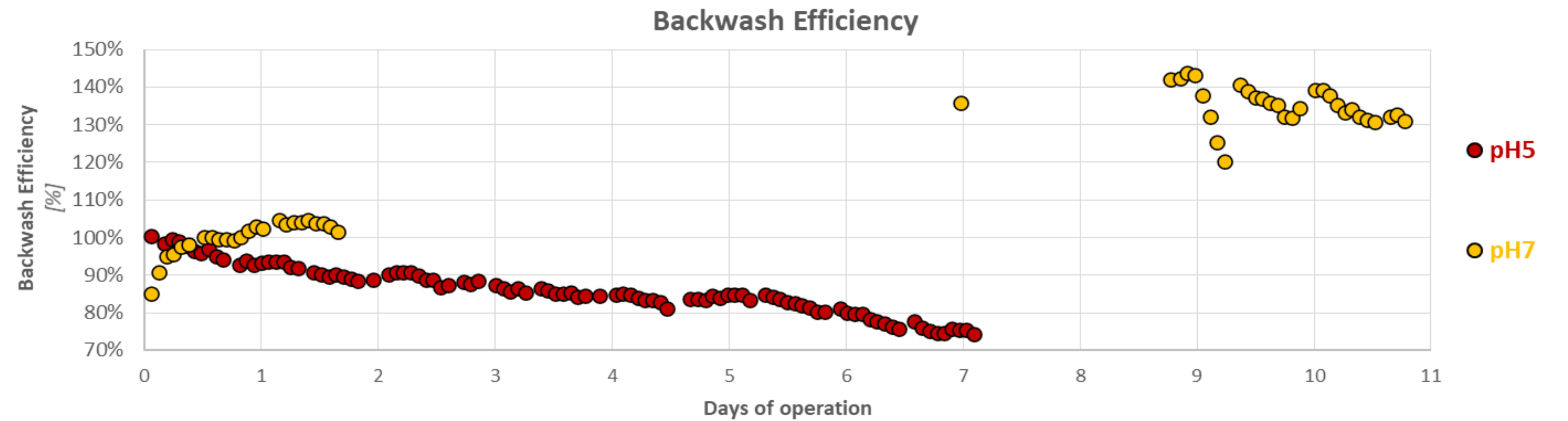


Normalized TMP at 20°C
Normalized TMP at 20°C [kPa]
35
30
25
20
15
10
0
1
2
3
4
5
6
7
8
9
10
11
Days of operation
Flux = 100 lhm
Filtration cycle = 90 min
CEB cycle = 10 FC
CEB sequence =1x NaOCl (100ppm) pH 9, HCl (pH=2)
Data logging issues
No backwash for 450 min
pH5
pH7

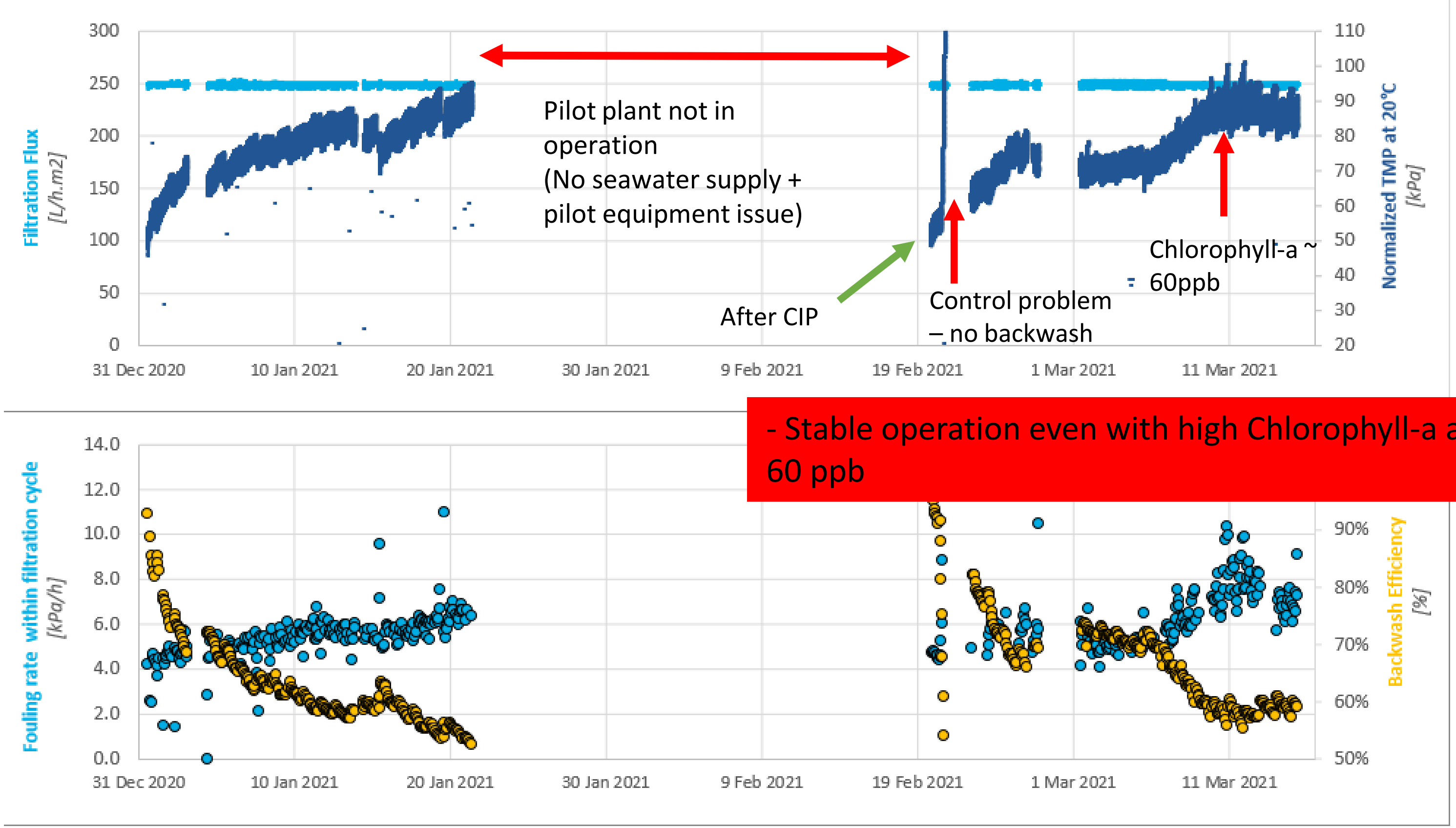



Fouling rate within a filtration cycle
Fouling rate within a filtration cycle [kPa/h]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
Days of operation
pH5
pH7


Fouling rate within a filtration cycle
Fouling rate within a filtration cycle
[kPa/h]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
Days of operation
pH5
pH7


Backwash Efficiency
Backwash Efficiency
[%]
150%
140%
130%
120%
110%
100%
90%
80%
70%
0
1
2
3
4
5
6
7
8
9
10
11
Days of operation
pH5
pH7

# Long Term Operation




- Stable operation even with high Chlorophyll-a at around 60 ppb

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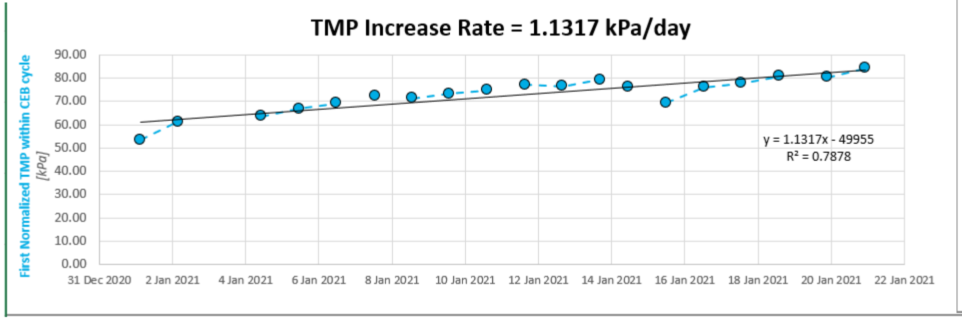
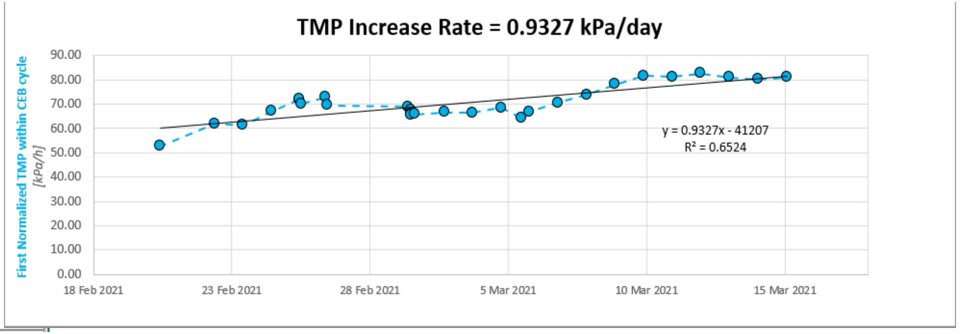
# Estimated CIP Frequency

- Flux – 250 lmh with 90 mins filtration cycle
- CEB frequency – every 24 hours
- Operation period – 31st Dec 20 – 21st Jan 21 (22 days)
- Fouling rate – 1.1317 kPa/day
- CIP Frequency – 89 days




- Flux – 250 lmh with 90 mins filtration cycle
- CEB frequency – every 24 hours
- Operation period – 19th Feb 20 – 15th Mar 21 (26 days)
- Fouling rate – 0.9327 kPa/day
- CIP Frequency – 107 days




- CIP frequency is calculated based on initial TMP = 50 kPa and TMP before CIP = 150 kPa

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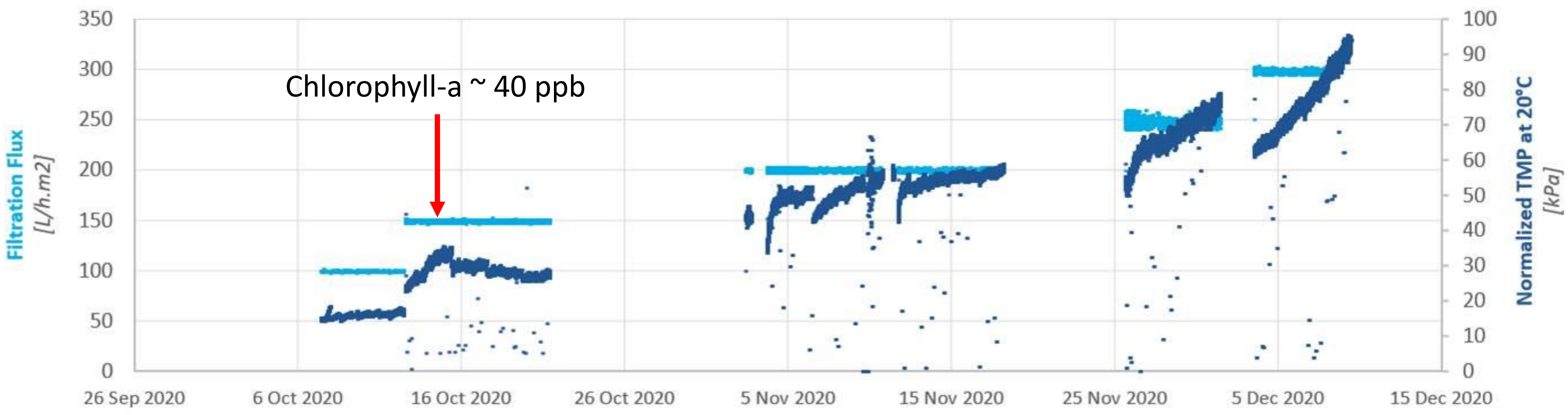
# Critical Flux Determination




- CIP Frequency:
- Fouling rate for 100 lmh run = 0.2761 kPa/day (~360 days CIP frequency)
- Fouling rate for 150 lmh run = 0.2951 kPa/day (~340 days CIP frequency)
- Fouling rate for 200 lmh run = 2.4313 kPa/day (~45 days CIP frequency)
- Fouling rate for 250 lmh run = 3.2266 kPa/day (~31 days CIP frequency)
- Fouling rate for 300 lmh run = 4.6611 kPa/day (~22 days CIP frequency)

Fouling at higher flux mainly caused by BW efficiency loss
300lmh approached hydraulic limitation of system
250 lmh chosen to further optimize (stabilization)

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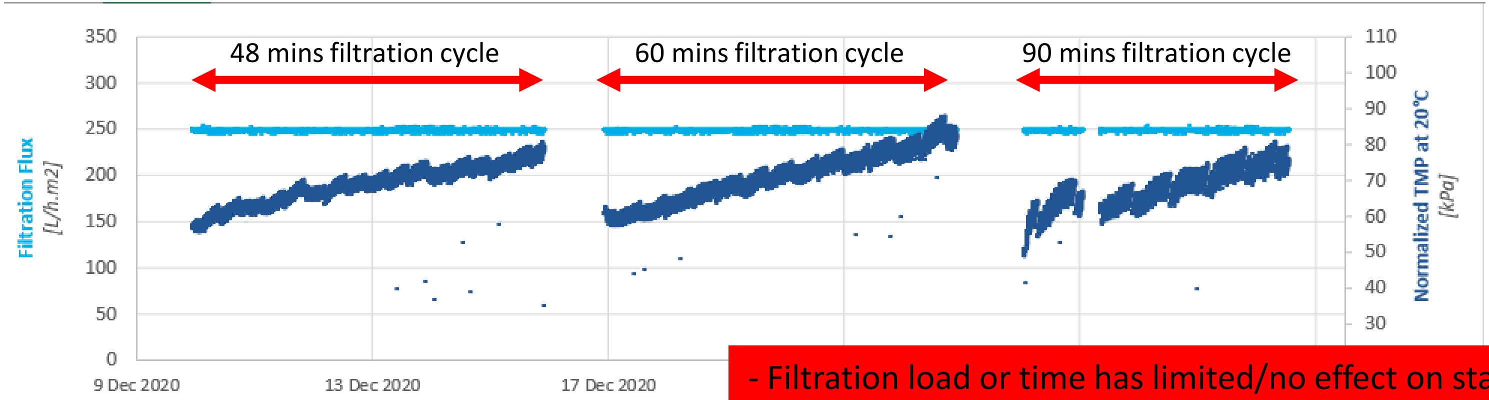
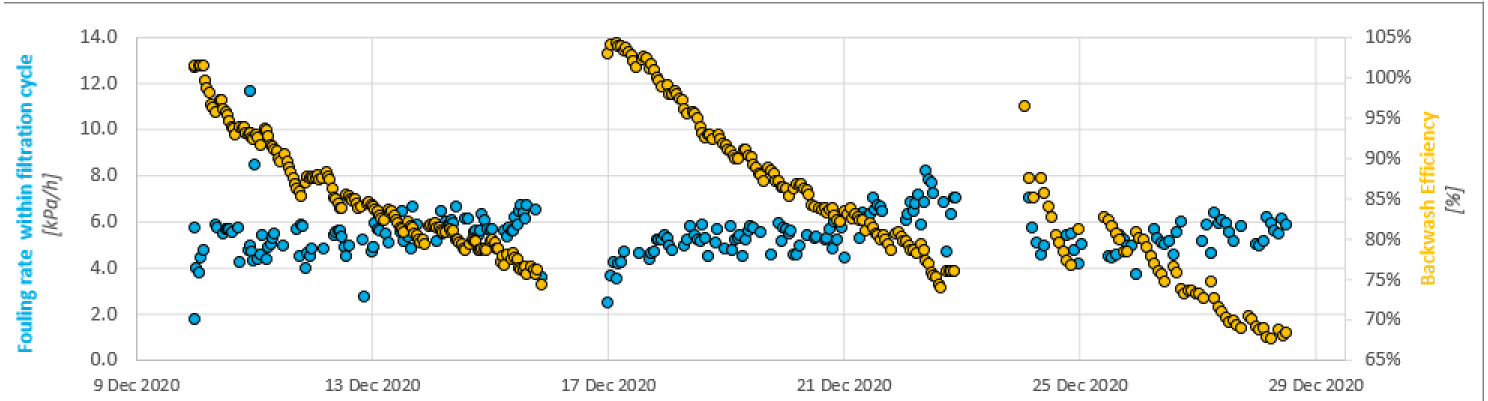
Note: based on initial TMP = 50 kPa and TMP before CIP = 150 kPa

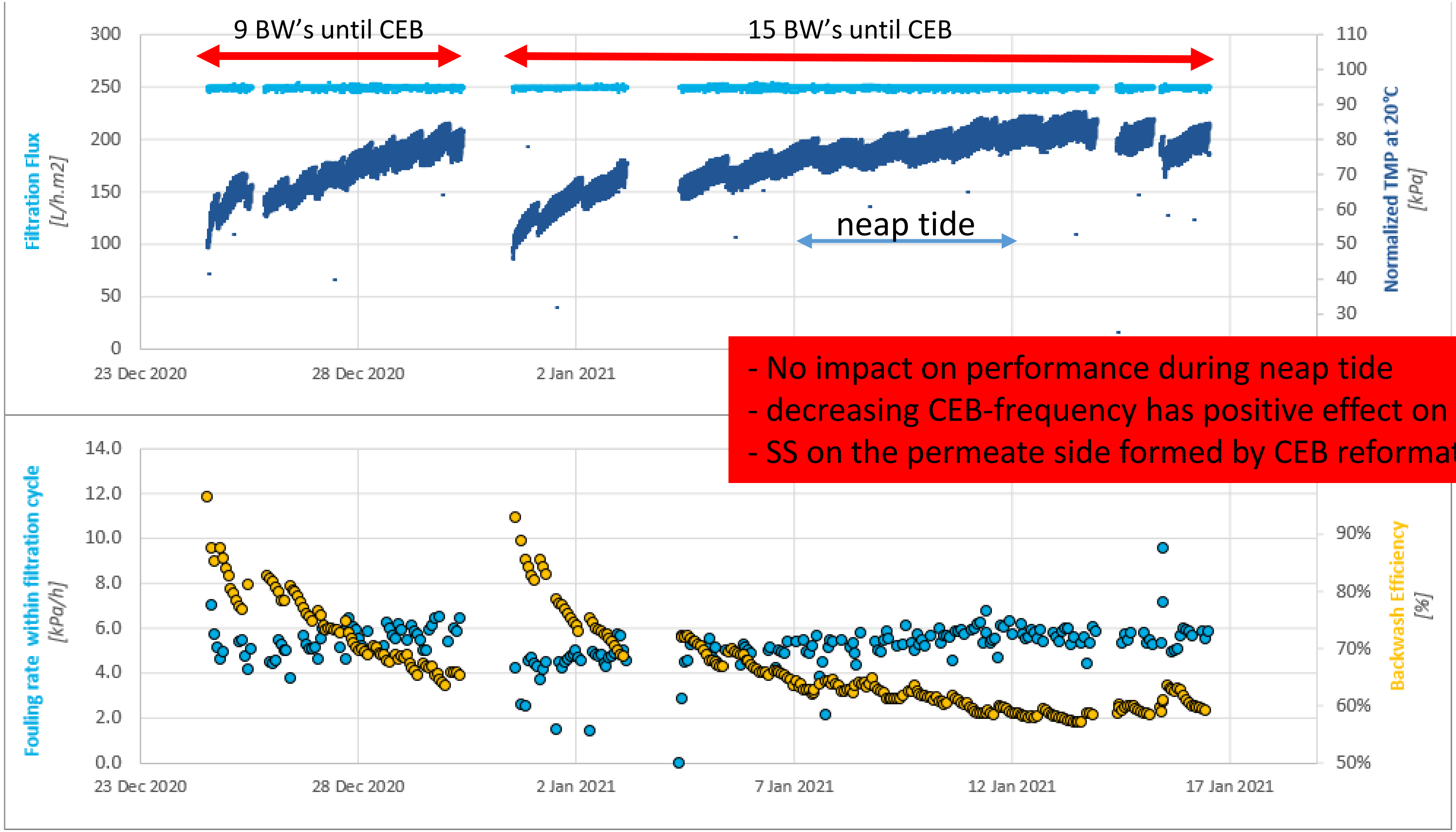
# Backwash Frequency Optimization




- Filtration load or time has limited/no effect on stability



# CEB Frequency Optimization




- No impact on performance during neap tide
- decreasing CEB-frequency has positive effect on stability!
- SS on the permeate side formed by CEB reformation

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# Water Quality permeate

- Turbidity
  - Raw water turbidity is in the range of 2-14 NTU and filtrate turbidity is below 0.05 NTU most of the time (spiked after CEB or BW only).
- TOC, DOC and UVT
  - Raw water TOC and DOC are typically in the range of 1-3 mg/l
  - The TOC and DOC removal after filtration are around 30% at typical feed quality ranges and 50-70% at higher feed water concentrations.
  - The filtrate UVT is in average around 98%.
  - LC-OCD only feasible at raw water and coagulated water, permeate gave signals that were too low to interpreted on the LC-OCD
- $SDI_{15}$
  - Filtrate $SDI_{15}$ are in average around 2. The $SDI_{15}$ was higher during the high algae concentration season (Chlorophyll-a ~ 40 ppb).
- Iron
  - The filtrate total iron and dissolved iron are less than 0.0045 mg/l

# Summary of Testing and Conclusions

- Membrane operation is stable during algae blooms and tide events with *negligible impact on performance*
- Established operating parameters demonstrate economically attractive set points
  - Flux 250 lhm at 90 min filtration cycles
  - CEB after 15 FC cycles (approx. 1/day)
- Demonstrated, sustainable and stable flux means:
  - Reduced footprint
  - Reduced CAPEX
- Demonstrated operational set points mean:
  - Increased water production efficiency
  - Increased up time and lower OPEX
- A robust, reliable and cost effective solution for desalination pre-treatment

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# Canyon Regional Water Authority – Lake Dunlap

| | |
|---|---|
| Capacity | 55 MLD |
| Source | Surface Water |
| Pre-treatment | Coagulated and Settled |
| Flux | 365 LMH |
| Filtration. cycle | 120 min |


Canyon Regional Water Authority
Retrofit of Koch PUF

# THANK YOU

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www.nanostonewater.com