CERAMIC MEMBRANE PILOT PLANT FOR DRINKING WATER TREATMENT

Emma Cross, Andreas Fischer, Louis Ortenzio (Lutra)

ABSTRACT (500 WORDS MAXIMUM)

Together with Waipā District Council, Lutra operated a 3,600 Liters per hour silicon carbide (SiC) ceramic membrane pilot plant for several months at one of their river source water treatment plants drawing from the Waikato River. The objective was to gather in-situ operational and performance data, such as sustainable flux rates (L/m^2/h) and trans-membrane pressure (TMP) development, specific fluxes (L/m^2/h/bar), water efficiency (fraction treated of total volume abstracted), cleaning chemicals consumption, as well as general operational experience.

Ceramic membranes are used for liquid/solids separation in water treatment processes. Typical ceramic membranes manufacturing materials include alumina, silica, titania, and zirconia. While some characteristics between materials differ, in general ceramic membranes offer several benefits compared to polymeric membranes. These include higher flux rates (L/m^2/h, or LMH), pH resistance, temperature resistance, chemical resistance, oil resistance, and longer service life.

The higher flux rates of ceramic membranes (L/m^2/h) result in less membrane area (m^2) required for the same flow (L/h). Where polymeric membranes may need frequent replacements of individual membrane units due to failure, ceramic membranes are much more durable. Their general resistance allows for more thorough and frequent cleaning and restoring the membranes to original performance. The principal downside is that ceramic membranes are more expensive than polymeric membranes. However, the higher flux rates and increased durability makes ceramic membranes likely an economically viable option, based on whole-of-life costs.

Ceramic membranes are used widely in industrial wastewater applications due to their resistance and durability. In drinking water treatment, their use is more prevalent in Asia (e.g., Japan, China, Singapore), but installations are increasing globally. There is widespread interest and research into drinking water applications, and manufacturing costs are decreasing.

The trial results can be summarized as below:

- The ceramic membranes were able to meet the turbidity requirements of the Drinking Water Quality Assurance Rules (DWQAR).
- The membranes proved resilient and were restored to original performance multiple times despite heavy buildup of sludge in the filtration tank.
- The sustainable flux rates during the trial were found to be 200 LMH and up to 220 LMH. Bench-scale results with actual raw water from the membrane supplier indicated even higher sustainable flux rates of 250 LMH and more.

- The trial results indicate that pre-treatment plays a significant role in achieving optimum performance, similar to polymeric membranes. The pilot plant received pre-dosed water, with reliance on in-line mixing and flocculation. We expect that with a dedicated pre-treatment infrastructure (such as a rapid mix and flocculation tank, pH and possibly ORP correction), the performance of the ceramic membrane system will increase.
- To mitigate the performance risks, the supplier of a ceramic membrane system should be responsible to ensure adequate pre-treatment to their specifications and provide performance guarantees.

In conclusion, we found that ceramic membranes are a viable alternative to polymeric membrane systems for drinking water treatment.

KEYWORDS

Ceramic membranes, drinking water treatment, wastewater treatment, innovation, pilot plant, pilot trial

PRESENTER PROFILE

Emma Cross is a process engineer at Lutra. She has 4.5 years' experience in the water and wastewater industry in Aotearoa. The longer Emma is involved in this industry, she says the more passionate she becomes.

Andreas Fischer is the Innovation Lead and a Senior Process Engineer at Lutra Ltd. Originally from Switzerland, Andreas came to New Zealand 7 years ago and has 12 years of experience in municipal drinking water and wastewater treatment. Andreas worked mainly for consultancies, and was involved in designing, project managing and commissioning of works on existing and new treatment plants. His current role involves bringing existing and new technology to the New Zealand water treatment sector. He is interested in development cooperation, and two of his career highlights involved work in Tanzania and with the Te Mato Vai project in Rarotonga.

INTRODUCTION

In late 2021, Lutra completed a review of options for upgrading Waipā District Council's 6.5 Megaliters per day (MLd) Alpha Street Water Treatment Plant (WTP) in Cambridge. One option that was not shortlisted in the options report due to insufficient information at the time was ceramic membranes. However, a review of this technology speculated that it could provide a robust, low footprint solution at a cheaper whole of life cost than the alternatives identified in the options study.

As a result, Waipā DC and Lutra employed a pilot plant at Alpha St WTP to study the capability and suitability of ceramic membranes. This paper details some findings from the trial.

The objective of this paper is to introduce ceramic membrane technology to a wider audience, and share performance data.

CERAMIC MEMBRANE TECHNOLOGY

Ceramic membranes are used for liquid/solids separation in water treatment processes. Typical ceramic membranes are manufactured from alumina, silica, titania, and zirconia. While some characteristics between materials differ, in general, all ceramic membranes offer several benefits when compared to polymeric membranes. These include higher flux rates (L/m2/h, or LMH), pH resistance, temperature resistance, chemical resistance, oil resistance, higher solids tolerance compared to polymeric membranes, higher transmembrane pressure (TMP) limits to enable quicker cleaning methods than polymeric membranes and longer service life.

The higher flux rates of ceramic membranes (L/m^2/h) result in less membrane area (m^2) required for the same treated water flow capacity (L/h). Where polymeric membranes typically require scheduled renewals/replacement, ceramic membranes are much more durable and do not require as frequent replacement if at all. Their general durability and resistance to breakdown allows for more thorough and frequent cleaning and restoring the membranes to original performance. The principal downside is that ceramic membranes are more expensive than polymeric membranes. However, the higher flux rates and increased durability makes ceramic membranes likely an economically viable option, based on whole-of-life costs.

Ceramic membranes are used widely in industrial wastewater applications due to their general durability and resistance to breakdown. In drinking water treatment, their use is more prevalent in Asia (e.g., Japan, China, Singapore), but installations are increasing globally with a new focus in the US and the UK. There is widespread interest and research into drinking water applications, and manufacturing costs are decreasing.

NEW ZEALAND DRINKING WATER QUALITY ASSURANCE RULES

Under the Drinking Water Quality Assurance Rules 2022 (DWQARs), most drinking water suppliers serving more than 500 people must provide a 3 to 4 log-removal protozoa barrier. Ceramic membranes can be used for T1, T2 filtration or T3 membrane filtration treatment. Under the T3 protozoa treatment, membranes provide up to 4-log removal credits.

Below are some noteworthy T3 membrane filtration rules:

- Membranes must be certified to comply with NSF/ANSI 61: Drinking Water System Components – Health Effects and NSF/ANSI 419 Public Drinking Water Equipment Performance – Filtration or equivalent.
- Daily direct integrity testing is required. It must be applied in such a manner that a 3 μm hole effects the response from the test.
- Filtrate exceeding 0.1 NTU for more than 15 minutes requires a direct integrity test, and
- Filtrate turbidity must not exceed 1 NTU at any time.

MEMBRANE PERFORMANCE PARAMETERS

Ceramic membranes share the same performance parameters as polymeric membranes. Important parameters are listed below.

Trans membrane pressure (TMP): the pressure differential between one side of the membrane and the other, measured when water passes the membrane. The higher the flux rate, the higher the required TMP to make water pass the membrane. Usually measured in bar, mbar, KPa or PSI.

Flux: The flow through a membrane per membrane area, commonly given as $L/m^2/h$ or LMH. Since temperature plays such an important role in performance, it is common to differentiate between the flux at the actual, measured temperature (J_m), and to calculate the membrane flux at a standardised 20°C (J_s). This allows to compare membrane performance between different temperatures. A common way to calculate the flux at a specific temperature is[1]:

$$J_s = J_m \times 1.03^{(T_s - T_m)} \quad (1)$$

J_s	Flux at standard temperature (typically 20°C), $L/m^2/h$
J_m	Flux at measured temperature, $L/m^2/h$
T_s	Standard temperature, °C
T_m	Measured temperature, °C

Specific flux or permeability: The specific flux calculation allows to compare membrane performance between different temperatures and different flux rates. A higher flux rate will result in a higher TMP, and a lower flux rate will result in a lower TMP. By dividing specific flux through TMP, this can be normalized for comparison.

$$J_{sp} = \frac{J_s}{TMP} \quad (2)$$

J_{sp}	Specific flux at standard temperature (typically 20°C), $L/m^2/h/bar$
TMP	Measured trans membrane pressure (bar)

In this report, we also mention the specific flux at the measured temperature ($J_{sp,T} = J_m/TMP$), which strictly speaking would not be termed "specific flux".

Plant efficiency: Ratio between volume of treated water produced (to supply) and volume of water abstracted from the environment per unit of time (e.g., day). The balance of the water is discharged to waste. In a membrane plant, the

---

[1] From MWH's Water Treatment: Principles and Design, Third Edition, 2012. When using a standard temperature of 20°C, the equation is accurate within 5 percent over a temperature range of 1 to 28°C. If outside of this range, different approximations should be used.

water efficiency is increased by recovering the process waste water, such as from backwash and drain operations[2]. In this trial we calculated the water efficiency without water recovery and with water recovery. For the water recovery, we estimated a recovery percentage of 80%. This is a conservative, low estimate.

Temperature: water temperature does not fit in with the other performance parameters, as it is an environmental condition. However, it has a significant influence on performance which is described briefly to increase understanding. It changes the viscosity of water (warmer water has a lower viscosity), and some membrane materials' inherent performance is also impacted by temperature. For the same flux, warmer water results in a smaller trans membrane pressure than colder water.

PILOT STUDY METHODOLOGY

OBJECTIVES

The pilot study was carried out together with the Waipā District Council on their Alpha Street Water Treatment Plant (WTP) in Cambridge. The pilot study was to serve as a feasibility study for the ceramic membrane technology.

The objectives of the pilot study were to evaluate:

- Sustainable flux rates, specific flux rates, and production efficiencies
- Chemical cleaning frequencies and chemical consumption.

By sustainable it is meant that the pilot plant could be operated for extended periods without requiring recovery soaks, and that any fouling can be removed by the normal chemical cleans as defined in section "Membrane Cleaning Operations". This usually means that the temperature corrected specific flux ($L/m^2/h/bar$ at a standard temperature of 20°C) can be brought back to the starting value after each chemical cleaning cycle.

If temperature and system flux rate stay the same, it means that the TMP can be brought back to the starting value after each chemical cleaning cycle.

ALPHA STREET WATER TREATMENT PLANT

The Alpha Street WTP abstracts water from the Waikato River. Figure 1 shows a plan view of the current site. Water is dosed with the coagulant poly-aluminium chloride (PACl, usually around 40 mg/L as active ingredient) and relies on in-line mixing for coagulation and flocculation. Dosed water enters two clarifiers. In the summer months, 3 mg/L of powdered activated carbon (PAC) is added to the

[2] E.g. through the use of a separation device such as a lamella clarifier, to settle solids and return the clear supernatant

inlet boxes of the two clarifiers. The clarified water enters one automatic valveless gravity filter (AVG). Filtered water is then chlorinated, enters a chlorine contact tank, undergoes UV treatment, and is pumped into the supply network.

During the trial, water was taken from two locations. At the start of the trial, water was taken from downstream of the clarifiers. Later, the pilot plant received water from upstream of the clarifiers but after the PACl had been dosed (but no PAC).

Figure 1: Plan view of the current Alpha Street WTP

PILOT SYSTEM ARANGEMENT

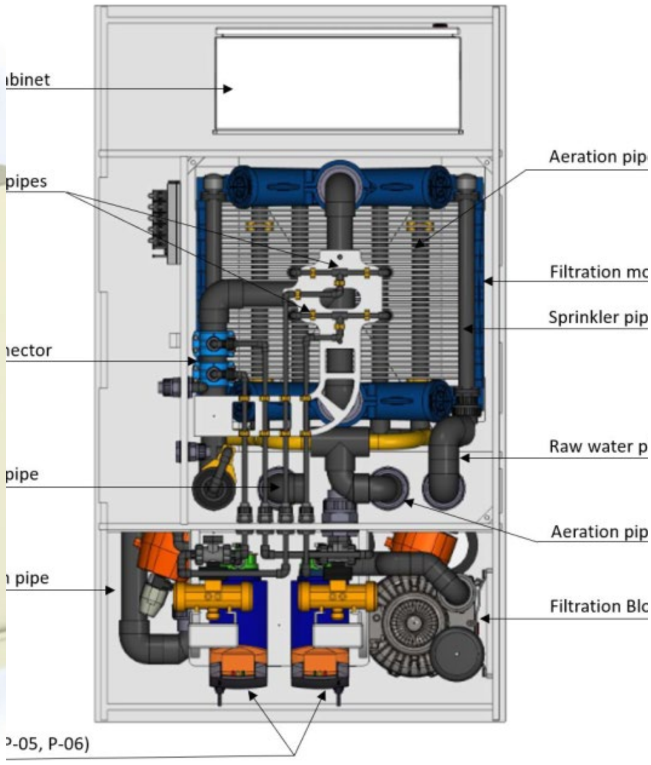
The ceramic membrane pilot plant is installed inside a 20 ft shipping container, as can be seen in Figure 2. The actual membrane skid is visible in the front. It was manufactured and supplied by Cerafiltec, a ceramic membrane solutions provider located in Germany and represented in NZ/AUS by Infinite Water. The pilot skid contains 18 m^2 of flat-sheet silicon carbide (SiC) membranes. Table 1 shows a summary of the skid specifications.

Table 1: Ceramic membrane skid data

Parameter	Unit	Value
Skid manufacturer		Cerafiltec
Membrane material		Silicon carbide (SiC)

Parameter	Unit	Value
Membrane area	m^2	18
Membrane pore size	µm	0.3 to 0.5
Configuration		Flat-sheet membranes, three modules with 6 m^2 membrane area each
Filtration flow	L/h	1,200 – 10,000

Figure 2: Top left: the pilot plant container with the Cerafiltec membrane skid visible in the front. Top right: View of the filtration tank while raw water enters. White membrane sheets visible at the bottom. The small diameter lines are used for chemical cleaning, either spraying onto the membranes (CapClean), or injecting into the filtration/backwash line (CEB). Bottom left: 3D model of skid (from Cerafiltec). Bottom right: top view of skid with labelled components (from Cerafiltec).

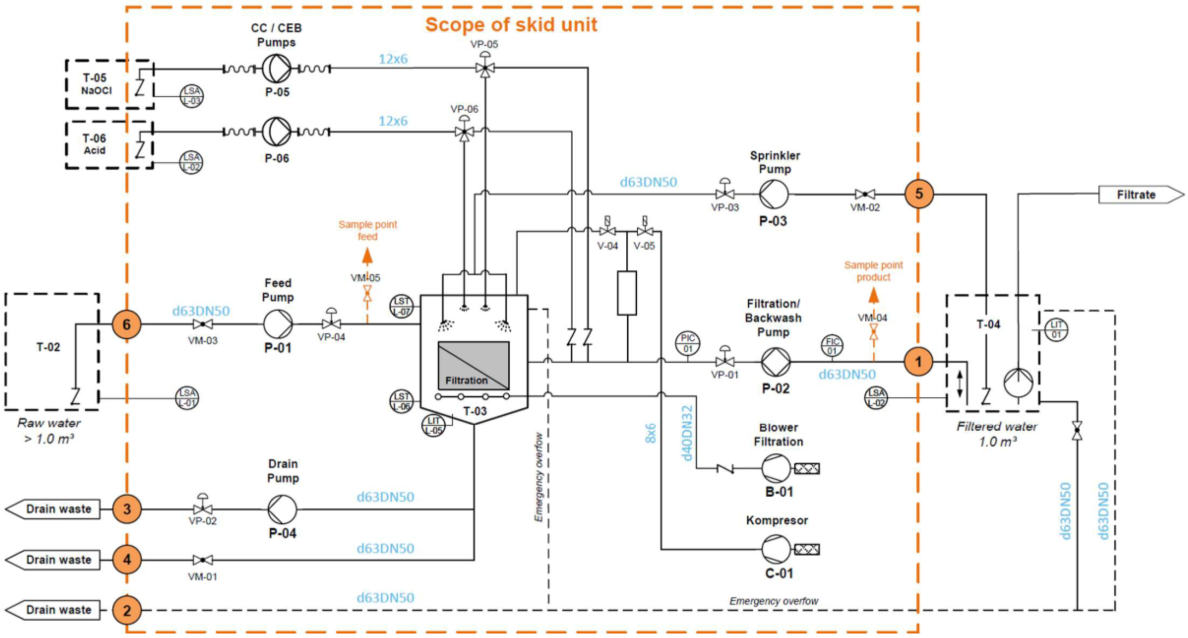


The following other equipment items were needed to operate the pilot plant.

- **Raw IBC**: enables steady flow into the filtration tank, and provides an approximate 15-minutes hydraulic residence time
- **Blower**: provides scour aeration to the system when needed. Variable control for aeration during backwash and filtration mode.
- **Feed pump**: transports water from the raw IBC into the membrane tank.
- **Permeate pump:** the permeate pump is a dual pump which pulls water through the ceramic membranes and into the permeate IBC, and reverses flow for backwash applications.
- **Permeate IBC**: holds backwash water volumes.
- **CIP chemicals**: sodium hypochlorite and citric acid were used to clean the ceramic membranes. The concentrations for each chemical were varied between 5 to 10 g as active ingredient per liter.
- **Raw and treated turbidity analysers**: Endress+Hauser Turbimax probes on a E+H head unit.

A process and instrumentation diagram (P&ID) is shown in Figure 3.

Figure 3: Process and instrumentation diagram of the ceramic membrane pilot plant (Source: Cerafiltec)



COMMON PILOT PLANT OPERATIONS

This section describes the common ceramic membrane plant operation modes that were available in the pilot skid. Figure 4 shows a graphical representation of filtration, backwash and chemical cleaning operations.

Filtration: The feed pump delivers raw water into the filtration tank, and the permeate pump pulls water through the membranes into the permeate tank, according to the permeate flow (flux) setpoint. The blower may provide scour air either in intervals, continuously, or be turned off.

Backwash: After the filtration time has elapsed, the feed and permeate operation stops. The permeate pump reverses and pushes filtered water back through the membranes into the filtration tank. The blower provides continuous scour air to dislodge particles from the membranes. After the backwash, the membrane plant enters normal filtration again without draining the filtration tank contents. The cycling of filtration and backwash results in an accumulation of solids over time in the filtration tank.

Backwash and drain: After the set number of filtration and backwash cycles, the membranes are backwashed, and the filtration tank drained to remove accumulated solids. This water volume can go into a water recovery step (e.g. a sludge settling vessel with supernatant pumped back to the start of the plant) to increase the water efficiency of the overall plant.

Clean in place (CIP): After a set number of backwash and drain cycles, a chemical clean is initiated. Refer to the next section "Membrane Cleaning Operations" for more details.

After the chemical clean, the plant enters the filtration stage again, and the overall cycle repeats.

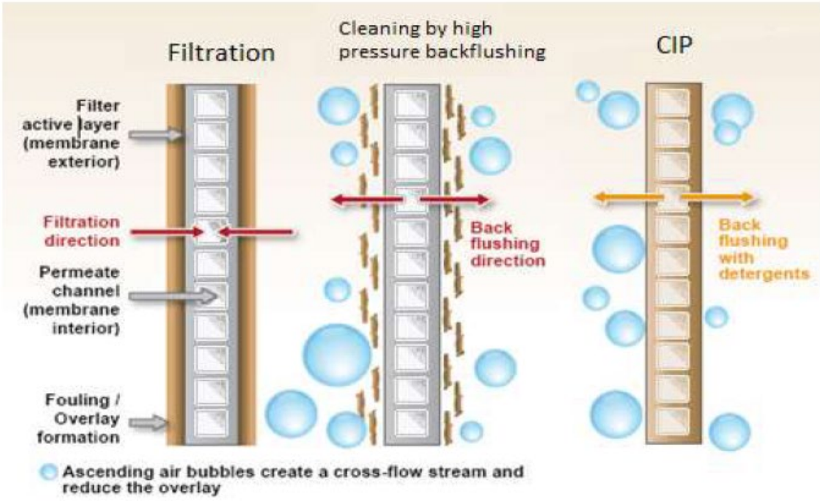


Figure 4: Common membrane filtration, backwashing and CIP operation schematic (Liqtech, 2021)

MEMBRANE CLEANING OPERATIONS

Like polymeric membranes, ceramic membranes need regular chemical cleaning to retain performance and counter the effects of fouling.

The small wastewater volume from this operation contains residual chemicals. In a full scale plant, it is usually captured separately and the water neutralised. Neutralisation often involves pH correction to neutral (to counter any effects of acids), and depletion of available chlorine.

Three chemical cleaning methods were used during the trial. These were:

- CapClean – sprays hypo and citric acid on top of the membranes, with washes in between to prevent mixing the two chemicals.
- Chemically enhanced backwash (CEB) – injects hypo or citric into the backwash line, and then transports the chemicals across the membranes.
- Recovery soaks –the membranes are soaked in the hypo solution for 12 hours and then citric for 4 hours.

CapClean and **CEB** are done multiple times per day and are part of normal operation of a ceramic membrane plant. The filtration tank is emptied and the chemical solutions are applied onto the membranes directly. For each mode, hypo is usually applied first, allowed to soak, then washed off and drained. Then citric acid is applied with the same steps. CapCleans and CEB's are usually sufficient to enable long term stable operation. Important parameters for either mode include:

- Chemical dose per area of membrane (mL chemical solution / m^2) – we experimented with settings between 10 and 46 mL/m^2.
- Soaking time, how long the chemical solution was allowed to be in contact with the membrane – we experimented with settings between 10 and 600 seconds.
- Number of chemical applications (cycles) per CapClean or CEB – usually 2 to 3 for CapCleans (e.g. hypo, hypo, citric, citric), and 1 for CEB (hypo, citric).

The made-up chemical solutions for hypo and citric had a strength of 5 to 10 g active ingredient/L.

Recovery soaks are used when the membrane performance has fallen significantly, likely due to organic and inorganic fouling, which can't be removed by CapCleans or CEB's. During the trial, we carried out 5 recovery soaks as we experimented with performance parameters (refer to section "Impact of Recovery Soaks").

The hypo soak and citric acid soak solutions had a strength of 1 and 3 g active/L, respectively.

TIMELINE

The trial timeline is presented in Table 2 below. The results section of this paper mainly focuses on the period from March 2023 onwards when the pilot operation was optimised and produced reliable data.

Table 2: Timeline of the trial

Time	Activity
November 2022	Site set-up. Changes to operating parameters had to be done on site until enabling of remote control in February 2023.
December 2022	Operation on post clarifier water, with infrequent manual chemical cleans only. Maximum flux rates for short intervals.
Jan 2023	Switched feed to pre-clarifier water that had been dosed with PACl, and used this water source for the remainder of the trial. Plant frequently shut down because of raw water flow problems. Once shut down, it required a site visit to restart the plant. This was resolved in late January.
Feb 2023	Remote control enabled
March 2023	Amended discharge piping to enable unattended chemical washes. From 23 March onwards, pilot plant operated continuously until the end of the trial.
April – June 2023	Incremental changes to optimise operational parameters including flux rates, and CIP chemical concentrations and types.

Time	Activity
June 2023	Decommissioning

RESULTS

This section describes the results obtained throughout the trial duration. The results will focus on the period between end of March and June 2023. The pilot plant received raw water that had been dosed with PACl during this time.

RAW WATER QUALITY AND ENVIRONMENTAL FACTORS

Figure 5 shows the Alpha Street WTP raw water quality – turbidity, pH, and conductivity as measured at the plant's inlet; true colour[3]; and the water temperature as measured by the ceramics pilot plant. It also shows the applied PACl dose as mg PACl as active ingredient/L. The grey shaded areas indicate when the pilot plant was treating water.

The pilot plant was not exposed to powdered activated carbon (PAC) which is dosed into the clarifier inlet at Alpha St WTP.

FILTERED TURBIDITY PERFORMANCE

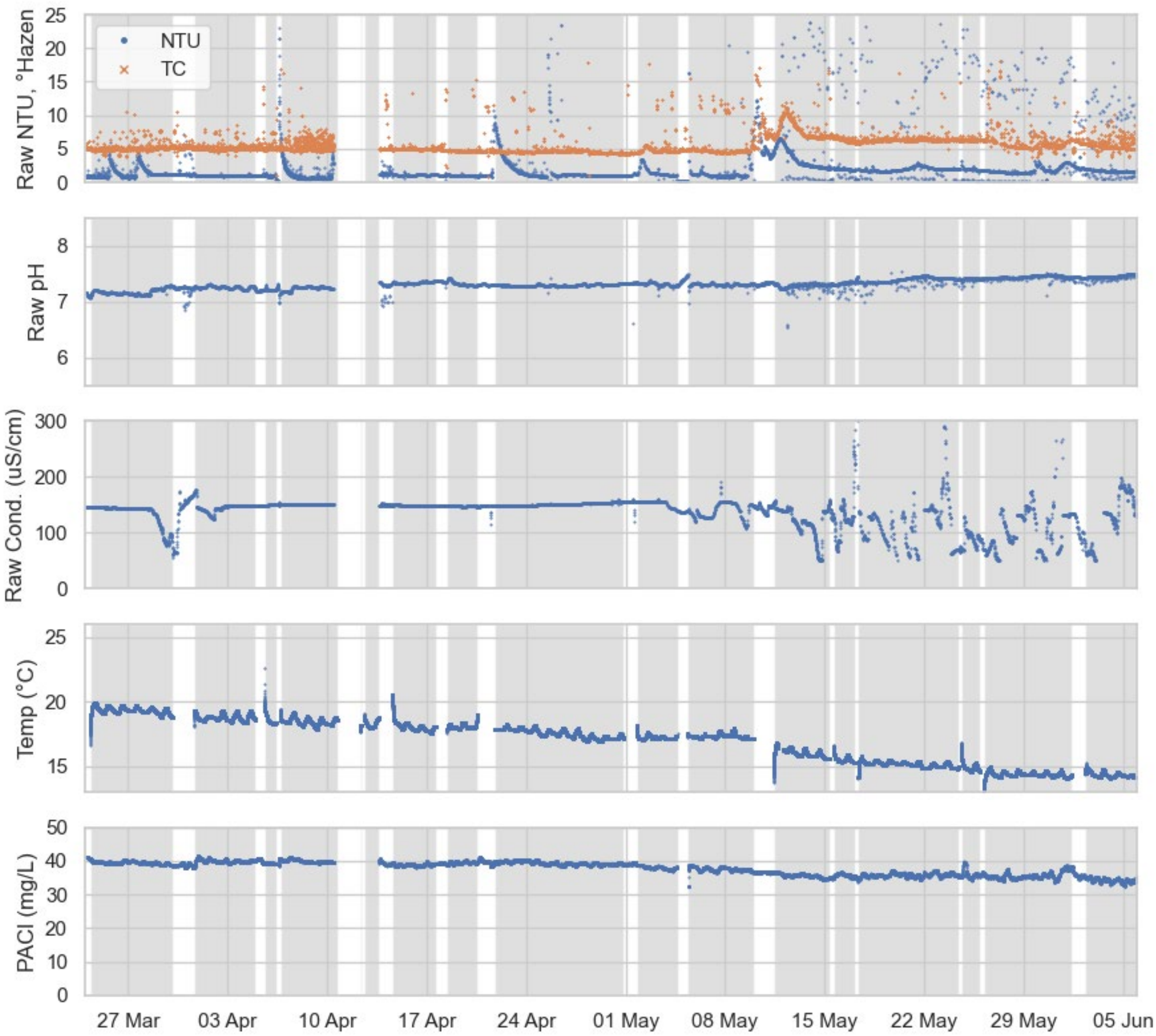
The filtered water turbidity was consistently measured as less than 0.04 NTU, and thus compliant with the DWQAR. The treated turbidity data is not shown in the following results sections.

TRIAL OVERVIEW

Figure 6 below provides an overview of important parameters between March and June 2023. The report will reference back to this figure multiple times as it summarises key findings from the trial. The figure contains a lot of information which the following paragraphs aim to summarise.

[3] True Colour was taken from a S::CAN spectrophotometer surrogate measurement from the nearby Parallel Road WTP which draws from the same source.

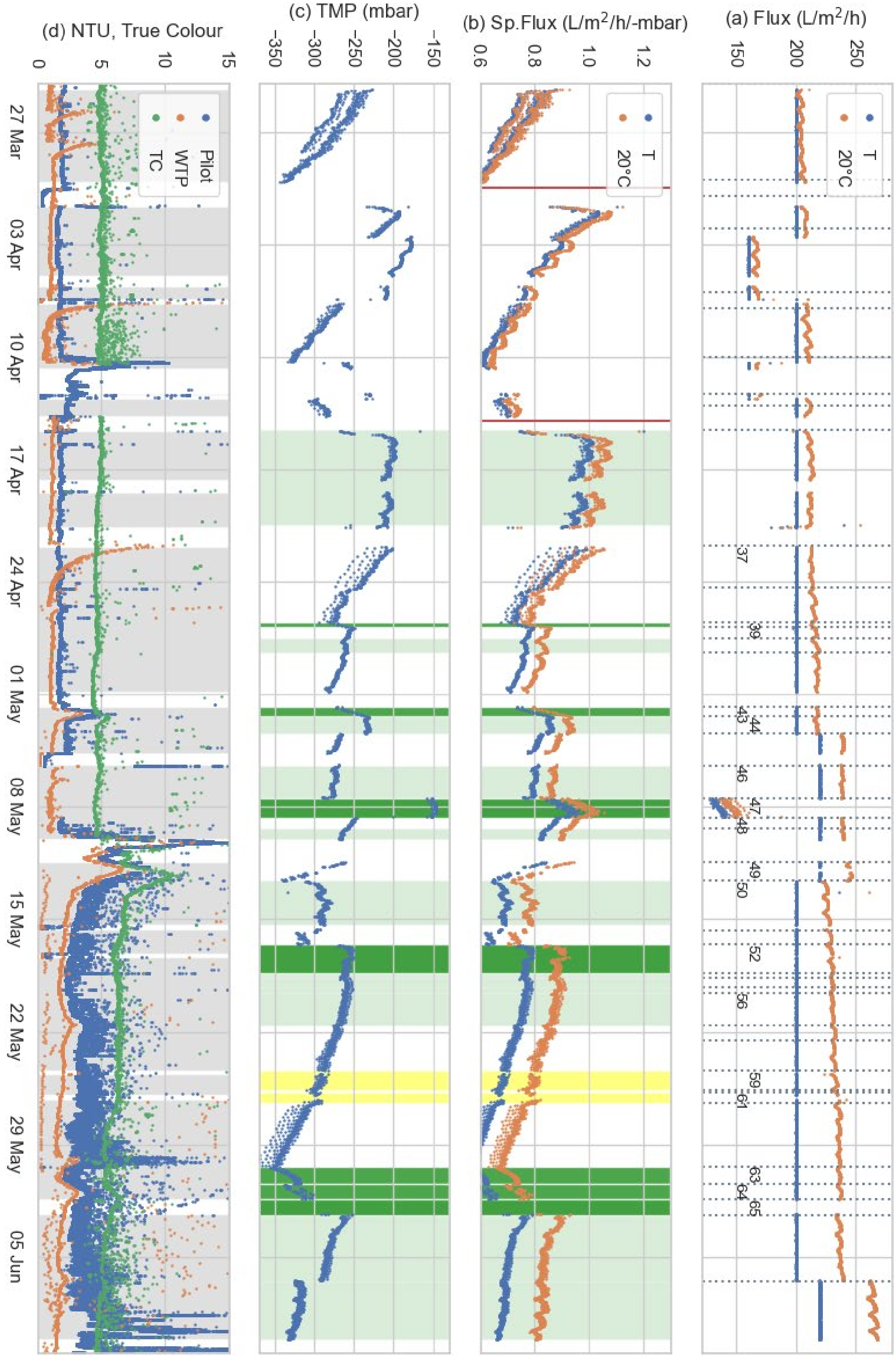
Figure 5: Raw water quality of the Alpha Street WTP (except true colour which is from Parallel Rd WTP raw water), and the applied PACl dose (mg/L as active). The gray shaded areas indicate when the pilot plant was operational.



Graph (a) shows the flux in L/m^2/h (or LMH), at the measured temperature ("T"), and also standardized to 20°C, using equation (1). In the beginning of the trial, we experimented with higher flux rates of up to 400 LMH. During the period shown here, we focused on lower flux rates of around 200 LMH. As the raw water got colder, the difference between actual and standardized flux rates increased significantly. For example, while the pumps drew 200 LMH through the membranes in cold temperatures, at 20°C the same TMP would have yielded 240 LMH.

The grey bars in graph (a) indicate when an operating parameter was changed, such as filtration length, backwash settings, or chemical clean settings. The numbers next to the grey bars identify the run numbers that are mentioned in this paper.

Figure 6: Overview of the trial, showing flux, specific flux, TMP and raw water quality.



Graph (b) shows the specific flux (refer to equation 2), again at the measured temperature ("T"), and calculated with the standardized flux ("20°C"). A higher specific flux value is better.

The two red bars show when we did recovery soaks (refer to section "Membrane Cleaning Operations"). The efficiency of recovery soaks can be judged by the specific flux before and after the soak. The goal is to get the specific flux back to the original values. The section "Impact of Recovery Soaks" further down will provide more detailed results about recovery soaks. After the last soak, our goal was to operate the plant without any further soaks, as these are usually done only infrequently (approximately every 6 months). We tested a few operations to increase the specific flux, such as intensive chemical cleaning cycles (CapCleans and CEBs), and the effect of relaxations (refer to section "Recovery of Specific Flux without Recovery Soaks").

The green shaded areas indicate when we judged the operation to be reasonably sustainable, meaning the specific flux was stable. These periods and parameters are described in more detail in the next section "Sustainable Operating Settings and Performance".

The dark green and yellow shaded areas in graph (b) and (c) are related to operational settings that were able to recover specific flux. These are described in more detail in section "Recovery of Specific Flux without Recovery Soaks".

Graph (c) shows the measured trans-membrane pressure (TMP) in millibar. Higher values (less negative) are better than lower values (more negative). The green shaded areas are as described in graph (b). If the temperature stays the same, a sustainable operation means the TMP should remain stable. As the temperature drops, the TMP for the same flux can reduce, however the specific flux (graph (b), orange dots "20°C") can remain stable. This is visible in the last green block at the beginning of June.

Graph (d) shows the raw water quality that was sent to the pilot plant, similar to Figure 5 (a) but it includes the pilot plant mounted raw water turbidimeter ("Pilot"). The difference between the plant raw water turbidimeter ("WTP") and pilot plant raw turbidimeter is that coagulant has been dosed between the two sample points, and some coagulation and flocculation has occurred. The raw water true colour surrogate measurements ("TC") are from the s::can device (UV/vis photo spectrometer) from the nearby Parallel Road WTP. The grey shaded areas indicate when the pilot plant was operating.

SUSTAINABLE OPERATING SETTINGS AND PERFORMANCE

The pilot plant was able to be operated in a sustainable manner during the trial. These periods are highlighted in green in Figure 6. An overview of operating parameter combinations during these periods is shown in Table 3. The table contains four performance metrics, namely production efficiency with and without recovery, and chemical usage. The chemical usage is proportional to the membrane area. There were a few other combinations, but these three ones were the most frequent.

Table 3: Operating parameter combinations that resulted in sustainable operation

Setting	Combination 1	Combination 2	Combination 3
Flux rate (LMH)	200	220	220
Filtration (F) length (minutes)	30	30	15
Aeration during filtration	intermittent – 20 sec off/on	intermittent – 20 sec off/on	intermittent – 20 sec off/on
Backwash (BW) settings	30 seconds, at double the flux rate	30 seconds, at double the flux rate	30 seconds, at double the flux rate
F+BW cycles to CIP	4 to 5, a CIP within every 2.5- to 3-hour period	5, a CIP within every 3-hour period	9, a CIP within every 2.75-hour period
CIP method	both CapClean and CEB were used [4]	CapClean only in this period	CEB only in this period
CapClean settings	Hypo: 3 x 5 min soaks at 10 to 12 mL/m^2, then Citric: 3 x 5 min soaks at 10 to 12 mL/m^2	Hypo: 3 x 5 min soaks at 12 mL/m^2, then Citric: 3 x 5 min soaks at 12 mL/m^2	n/a
CEB settings	Hypo: 1 x 10 min soak at 24 mL/m^2, then Citric: 1 x 10 min soak at 24 mL/m^2	n/a	Hypo: 1 x 10 min soak at 24 mL/m^2, then Citric: 1 x 10 min soak at 24 mL/m^2
Performance outcomes			
Production efficiency without water recovery	88.6 to 91%	92.7%	90.4%
Production efficiency with water recovery[5]	95 to 96%	97.1%	96%
Hypochlorite base product usage (13% w/w) (mL/d)	140 to 200	200	145
Citric acid (100%) powder usage (g/d)	34 to 56	50	36

[4] Not together – some runs were done with CapCleans, and other runs were done with CEB

[5] The calculation is done with a conservative, low recovery fraction of 80%. 90% and more are common in full scale plants.

PERFORMANCE IN DIRTY WATER EVENTS

The sustainable operation periods include a few dirty water events, such as shown in Figure 6, run numbers 44, 48, 50.

A full-scale membrane plant would adjust the operating parameters based on the raw water quality or based on TMP development. For example, if the raw water contains more turbidity, they will accumulate faster in the filtration tank, and thus backwash and drains should occur more frequently.

However, at times we wanted to observe how a raw water event would influence the membrane performance with the current parameters, without adjusting them. This often resulted in performance reduction (Figure 6, run numbers 37, 48, 49, 56).

SECONDARY OBSERVATIONS

IMPACT OF RECOVERY SOAKS

During the trial, five recovery soaks were carried out, as described in section "Membrane Cleaning Operations". The ideal outcome was that the specific flux or permeability could be restored to initial values. The specific flux before and after recovery soaks are shown graphically in Figure 7, with the green bars indicating the recovery soak. The last two soaks are also visible in the trial overview Figure 6.

In general, recovery soaks were found to be effective to recover specific flux.

This is despite of the membranes being subjected to heavy sludging during the trial, as shown in Figure 8 (the corresponding recovery soak occurred on 28 Feb).

Figure 7: Impact of the five recovery soaks on the specific flux during the pilot trial. The red bar shows the recovery soak, with performance before and after.

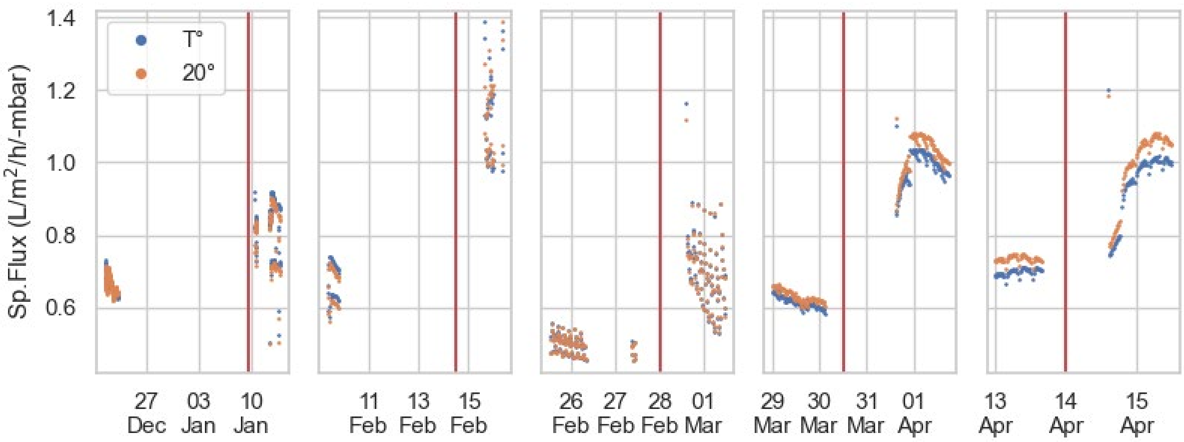
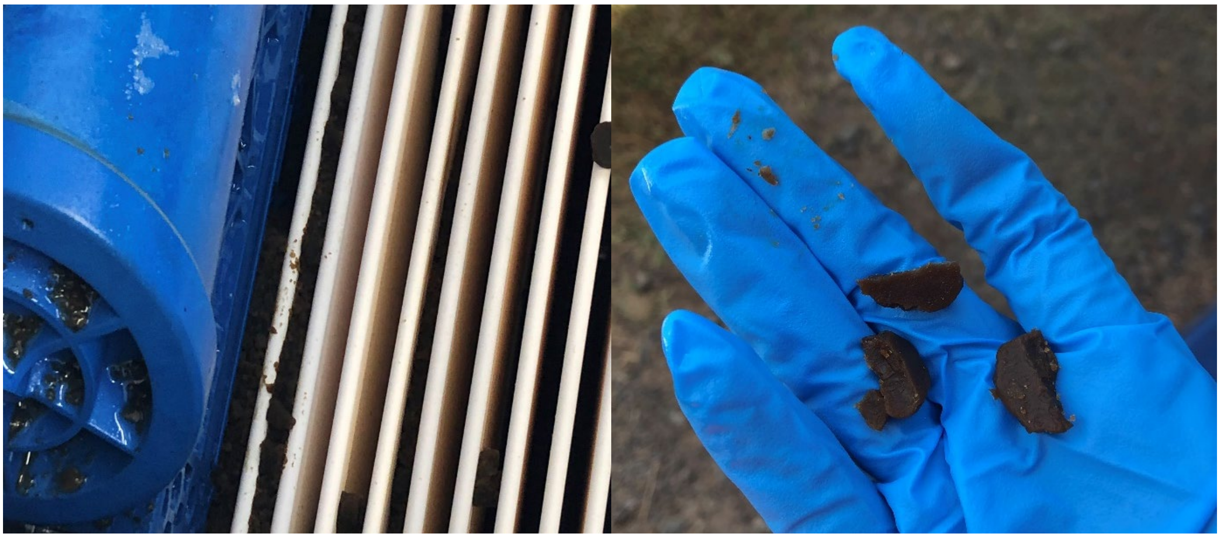


Figure 8: A misconfiguration resulted in sludging of the ceramic membranes around the 20th February 2023.



RECOVERY OF SPECIFIC FLUX WITHOUT RECOVERY SOAKS

We investigated methods to recover specific flux and TMP without performing a recovery soak. The description of the performed actions and their results are summarized in Table 4. The data trends for these actions is shown in the above Figure 6, with the dark green shaded areas showing a positive impact, and yellow shaded areas showing no impact.

Table 4: Efforts to recover specific flux without recovery soaks – summary of actions and results.

Run #	Description	Result
39, 43	High frequency CapCleans 39: once within every 75 mins, for total of 7 hours 43: once within every 60 mins, for total of 15 hours (a small dirty water event took place during 43, with max raw water turbidity of 5 NTU)	Effective with clear recovery of specific flux (~0.1 L/m^2/h/-mbar for 39, ~0.15 L/m^2/h/-mbar for 43). This operation mode would likely be unusual. The WTP still produces some water, compared to a recovery soak.
47	Operate at lower flux for 28 hours (130 LMH from previously 220 LMH)	Overall a recovery of specific flux is visible, despite a downward trend at the end of the run (~0.15 L/m^2/h/-mbar). In the subsequent run 48 with 220 LMH again, the specific flux decreases initially and then stabilises (light green shaded area) on a higher level than at the end of run 46.
52	After operating the plant with CapCleans for 36 days, switch to CEB for next 14 days.	There is a significant gain in specific flux visible after the first three CEB cleans (~0.2 L/m^2/h/-mbar). Afterwards, the specific flux remains stable.

Run #	Description	Result
		This could indicate that the CEB method was able to remove fouling that CapClean was not able to remove.
59, 61	Stop permeating for 4 hours (59) and 8 hours (61), respectively (relaxation). During this time, the membranes were left sitting in raw water. During routine operation of the plant, it stopped at times, and was left sitting with raw water in the tank for extended periods (more than 24 hours, e.g. between runs 33 and 34, 36 and 37)	No visible effect on specific flux was observed for run 59 or 61. However, when the plant stopped for more than 24 hours at other times, a positive effect on specific flux was observed. The recovery effect in the two unplanned relaxations was less than half that of the one observed in 65.
63, 64	After operating plant normally with CEB for 14 days, perform CEB once within every 90 minutes for 1 day, then followed by CapClean once within every 90 minutes for 1 day.	Effective with recovery of specific flux (~0.1 L/m^2/h/-mbar). See text for run 39 and 43 above.
65	Stop permeating for 22 hours (relaxation). The membranes were left sitting in permeate (as opposed to raw water in runs 59 and 61).	Effective with recovery of specific flux (~0.18 L/m^2/h/-mbar). Most of this recovery happened during the first CEB after the relaxation (~0.13 L/m^2/h/-mbar). When compared to the results from 59 and 61, this could indicate that the water quality in the filtration tank is important for recovery performance.

DISCUSSION AND CONCLUSIONS

The trial showed that the ceramic membranes were able to meet the turbidity requirements of the DWQAR. The silicon carbide membranes that were used do not currently have the DWQAR-required NSF certification. There are alumina membranes available in the same flat-sheet configuration that have this certification.

The trial confirmed that ceramic membranes are resilient and can be restored to original performance even after intense fouling, such as the sludge buildup that they experienced during our trial. This seems to be consistent with industry experience that ceramic membranes require fewer if any replacements compared to polymeric membranes, thus reducing operational resources and replacement costs. However, we don’t have first-hand long-term experience from a full-scale installation to confirm this.

The established sustainable flux rates of 200 LMH are also higher than flux rates of comparable polymeric membranes. This results in a reduced footprint of the membrane filtration stage.

The sustainable operating parameters found in our trial require a higher chemical cleaning frequency compared to the experience of the membrane supplier. In our trial, a CIP was required every 2.5 to 3 hours, compared to up to 12 hours. The most likely cause of that discrepancy is the quality of the pre-treatment. The pre-treatment at Alpha Street WTP relies on in-line mixing and does not provide a rapid mix or flocculation tank. A full-scale ceramic plant will need to include those stages, as well as pH and potentially ORP correction. A bench-scale test performed by the membrane supplier with raw water from Alpha Street WTP supported this finding. The bench-scale test also indicated that sustainable flux rates could be 250 LMH or higher.

While the increased CIP frequency during the trial compared to supplier experience is not ideal, its implications are not significant. For a plant the size of Alpha Street, the required membrane area would increase by approximately 18% due to downtime. The increased chemical consumption costs are not significant when compared to the typical annual operating costs of membrane filtration plants.

In conclusion, we found that ceramic membranes are a viable alternative to polymeric membrane systems. As with any membrane filtration system, the overall treatment train must be designed to meet the membrane filtration requirements. To mitigate any performance risks, the supplier of a ceramic membrane system should be responsible to ensure adequate pre-treatment to the required specifications, and provide performance guarantees.

ACKNOWLEDGEMENTS

We would like to thank Waipā District Council’s Martin Mould, David Kennington and David Luke for their time and support. This trial would not have been possible without them.

We would also like to thank Infinite Water, a specialist water and wastewater treatment process engineering company. They provided invaluable expertise in operating the ceramic membrane plant.