

EVALUATING AND TESTING CERAMIC MEMBRANES TO EXPAND TREATMENT CAPACITY¹

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Introduction

The City of El Dorado, Kansas is considering expansion of their surface water treatment facility to serve their community and surrounding communities. The City's water supply is provided by an 8,000-acre reservoir, El Dorado Lake. A yield study of the lake has shown there are sufficient resources to expand the water plant from the existing 9 million gallon per day (MGD) [34 million liter per day (MLD)] by adding additional capacity of up to 30 MGD (114 MLD). The City is considering a variety of options for using these resources. As part of the planning the City has been evaluating high rate water treatment technologies, such as ceramic microfiltration or ultrafiltration (C-MF/UF) membranes. Results from a C-MF/UF membrane pilot program are presented in this paper.

Membrane filtration has the advantages of providing high-quality finished water e.g., low turbidity with high microbial log removal), fitting in a small footprint, with a high level of automation allowing remote operation, and energy efficiency by utilizing available head from El Dorado Lake to drive water through the membrane. The City has piloted polymeric MF/UF membranes and wanted to evaluate the ability of ceramic membranes to treat their water. C-MF/UF provides the same advantages as polymeric MF/UF. In addition, C-MF/UF provides additional advantages. One key advantage is that ceramics have minimal fiber break/integrity issues and have a projected membrane life of 20 years, compared to 7 to 10 years for polymeric membranes. Regarding cleaning, ceramic membranes allow use of a wider range of cleaning and pre-treatment chemicals, which in turn helps maintain permeability and plant capacity. The physical properties of ceramics also allow use of higher pressures during both filtration and backwashing cycles, which additionally helps maintain permeability and plant capacity. These features of ceramic membranes indicate that C-MF/UF addresses two primary limitations of some polymeric MF/UF installations: (1) stable maintenance of permeability, and thereby plant capacity, long term and (2) reducing on-going maintenance costs for membrane repair and replacement.

While polymeric MF/UF has been widely applied for surface water treatment, only a few large-scale, multi-mgd ceramic facilities have been built. Outside North America this is primarily the 32-MGD (120-MLD) Andijk 3 plant in the Netherlands, which has a planned commissioning date in late 2013, as well as installations in Japan. The main full-scale example in North America, a 10-MGD (38-MLD) water treatment plant in Parker, Colorado, was delayed for a few years, but is also currently under construction. Another American facility that had initially planned to use

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ceramic membranes, Emeryville, California, was first delayed and then redesigned and subsequently built with polymeric membranes.

Ceramic membrane pilot programs, such as from Singapore, Sweden, and Bakersfield, California, have shown that ceramic membranes are technically promising and viable, but the limited number of full-scale installations indicates that product developments and improvements are on-going. The El Dorado study presented here illustrates the most recent features of ceramic membrane systems to facilitate comparison to polymeric options.

Existing Facility and Water Quality

El Dorado's existing water treatment plant (WTP) and source water quality are shown in Figure 1 and Table 1, respectively. The existing WTP applies conventional surface water treatment consisting of prechlorination, addition of a coagulant, which is a blend of aluminum chlorohydrate (ACH) and a polymer, flash mix, ammonia addition, mechanical flocculation, sedimentation in rectangular basins, seasonal addition of powdered activated carbon (PAC), addition of a low dose of the coagulant blend, and granular media filtration.

Figure 1. Schematic Diagram of Existing WTP in El Dorado, KS

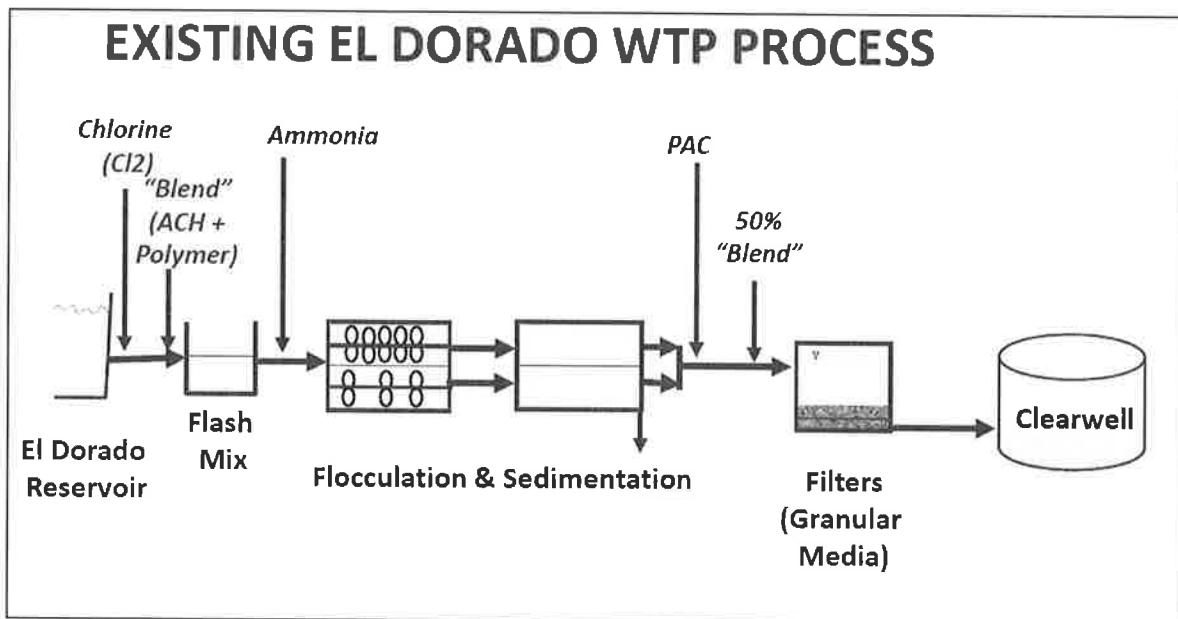


Table 1. Summary of Raw Water Quality, El Dorado Lake
(values in mg/L as such unless otherwise noted)

Parameter	Typical Value / Range
Temperature, C	2 to 28
pH, standard units	8 to 9
Turbidity, NTU	3 to 20; up to 200
Alkalinity, mg/L as CaCO ₃	100 to 120
Hardness, mg/L as CaCO ₃	100 to 130
Iron	0.5 to 1
Total Dissolved Solids (TDS)	250 to 300
Total Organic Carbon (TOC)	2.5 to 4.2
True Color, TCU	1 to 15; up to 50

Piloting

The City's ceramic membrane pilot test program included the following objectives:

- (1) Consider the application of ceramic type membrane filtration under site-specific conditions.
- (2) Gather data from the pilot program to establish design and operating parameters for implementation of a possible future full-scale membrane filtration facility, including flux, recovery, and backwash, maintenance wash (MW), clean-in-place (CIP) procedures and type of pretreatment (with or without coagulant and/or powdered activated carbon (PAC) addition).
- (3) Assist the City staff and local regulatory agency, the Kansas Department of Health and Environment (KDHE), in learning about ceramic membrane filtration.

Materials

A single module test stand was used as summarized in Table 2. Membrane materials conform to ANSI/NSF Standard 61 and chemicals used conform to ANSI/NSF Standard 60. Cycle times and conditions in the pilot unit are similar to those of a full-scale unit except for practical limitations, such as relative volumes. Generally an air-pressure-hold type of direct integrity test that met USEPA Membrane Filtration Guidance Manual requirements confirming at least 4-log removal of 3 micron particles was conducted daily. No integrity breaches were observed.

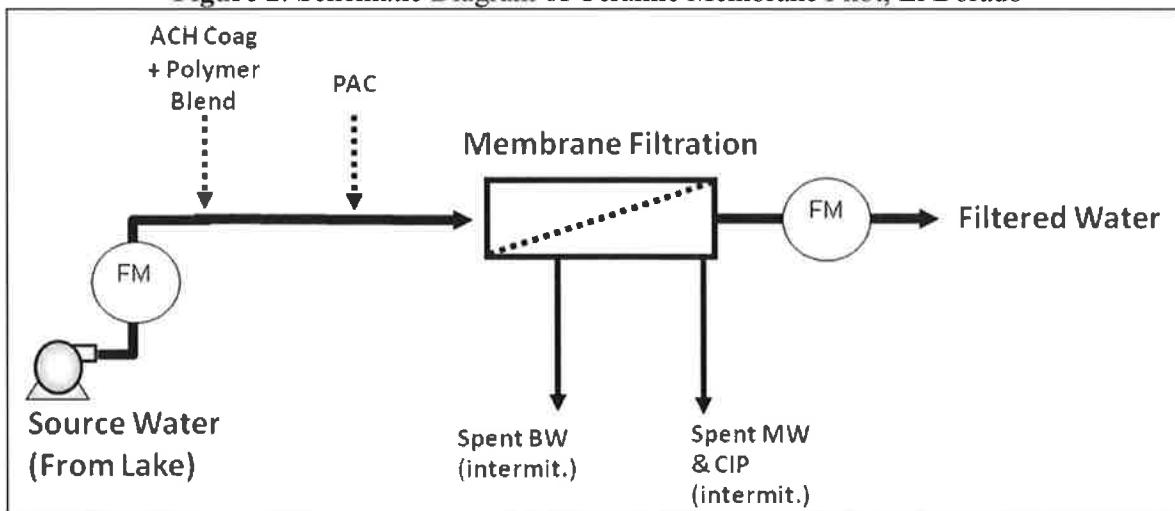
Methods

A schematic diagram of the piloted process is shown in Figure 2. The membrane filtration was operated in a direct filtration mode treating feed water containing coagulant* and/or PAC flowing directly to the membrane without sedimentation part of the time and without coagulant or PAC part of the time. During the filtration cycle the membranes were operated in a dead end mode without any recirculation.

* Advance Chemical Solutions, Tulsa, OK, 74170, Coagulant Number WT-8565.

Table 2. Ceramic Membrane Pilot Description for El Dorado, Kansas

Manufacturer	METAWATER*
Membrane Model Number	431011
Type of System	Encased (pressurized)
Membrane Material	Ceramic; Aluminum Oxide
Flow Pattern	Inside – Out
Module Dimensions, diam x L, inch (nominal)	7.1 x 59.1
Surface area on the feed water side of module, ft ²	269 ft ² (25 m ²)
Nominal pore size, micron	0.1
Modules installed	1
Prescreen rating, micron	1,000
Module Conditions From Manufacturer:	
Maximum Operating TMP, psi	55
Flow Rate Range, gpm	9 – 28
Filtration Cycle Time Between BWs, min	60 – 120
BW Cycle Duration, min	<3
BW Pressure, psi	<72

Figure 2. Schematic Diagram of Ceramic Membrane Pilot, El Dorado

The pilot program consisted of two main phases: (1) optimization and (2) fixed setpoint trials. During the optimization phase a range of operating conditions were tested to determine conditions to be evaluated during the subsequent fixed setpoint trials. During the fixed setpoint

* METAWATER USA, Inc, Rutherford, NJ 07070.

trials operating conditions were generally not revised during trials conducted for 30 to 45 day intervals between clean in place (CIP) cycles. The intention of this approach is for each setpoint trial to mimic full-scale conditions as much as practical to determine if these would provide stable and reliable performance long term. Before selecting initial fixed point conditions, an optimization trial run of at least 4 days at those or more challenging conditions (e.g., at the selected flux or greater) had to show daily transmembrane pressure (TMP) increase did not exceed 4 percent of the difference between the clean TMP and the terminal TMP. The reason for this guideline is to focus fixed setpoint trials on conditions highly likely to achieve long term stable performance.

The pilot performance criteria are summarized in Table 3. A CIP cycle was conducted after each fixed setpoint trial and the resulting permeability monitored and compared to a clean baseline value that was measured during the initial trials. A key goal of the pilot program is to determine operating conditions, including CIP conditions, that yield stable post-CIP permeability (e.g., within 85% of the baseline value). It is the authors' opinion that if the membrane cannot be cleaned to a repeatable, stable value at the piloted conditions, that there would be no strong indication that full scale performance would be reliable. Intervals of at least 30 days of run time between CIP cycles and MW not more often than 72 hours were selected to provide the operators flexibility in future full-scale plant operations. Recovery of at least 95% was established to control waste flow rate and to sufficiently utilize the raw water resource. The DIT and filtered water turbidity criteria were set to achieve desired water quality, and, it should be noted, these conditions are easy to achieve with all commercially successful membrane systems. The downtime goal for the pilot system was set at up to 3 days per trial, which is essentially 10% of a 30-day run, as a practical consideration. If a pilot program has excessive downtime it can be difficult to evaluate the results.

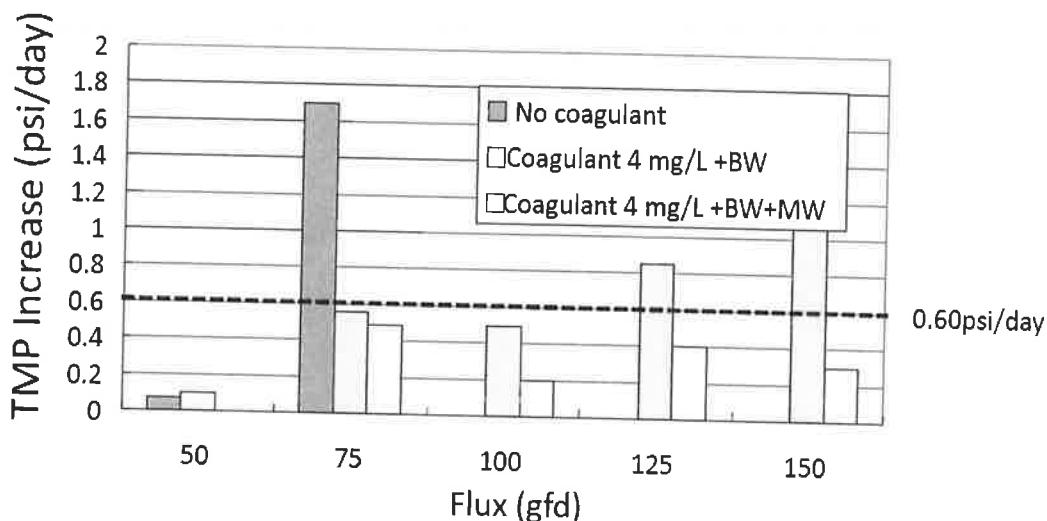
Table 3. Pilot Performance Criteria

Parameter	Criteria
Permeability goal	Post-CIP permeability within 85% of baseline
CIP Interval	Greater than/equal to 30 days
Maintenance Wash Interval	Not more often than 1 every 72 hrs
Recovery	Greater than/equal to 95% (Target > 96%)
DIT	Pass Daily DIT
Turbidity	Less than 0.1 NTU (99% of the time) Less than 0.3 NTU (100% of the time)
Downtime goal	Less than 3 working days per run

Results

The impact of flux and other variables were on the rate of TMP increase was considered during the optimization phase. Examples of this are shown on Figure 3, which demonstrates that higher flux was achievable with an acceptable rate of TMP increase when pretreatment included coagulant addition. As expected, performance improved when backwash and maintenance wash cycles were included.

Figure 3. TMP Increase During Optimization Trials.
TMP Increase During Optimization Trials



Fixed Setpoint runs focused on a flux of 150 gfd (255 lmh) with pretreatment including 4 mg/L of coagulant addition, as shown in Figure 4 and Table 4. Subsequent piloting, which was conducted after the publication date of this paper, also considered PAC addition as part of the pretreatment. Going from the May-June trial to the June-July trial, the interval between BW cycles was extended from 90 min to 120 min, but at the longer BW interval the TMP increased too rapidly after day 20. For the next trial, Aug-Sept, the BW interval was reset back to 90 min and a 2-step MW was implemented with a hypochlorite step (100 mg/L) conducted before the acidic (pH 2) step. Some earlier testing had indicated that the hypochlorite MW was not as beneficial as the acidic MW but subsequent observations indicated that periodic hypochlorite MW is helpful at lowering the rate of increase in TMP. It is too early to tell, but there may be a seasonal aspect to selecting optimal MW chemistry.

Figure 4. Results from Fixed Setpoint Trials.

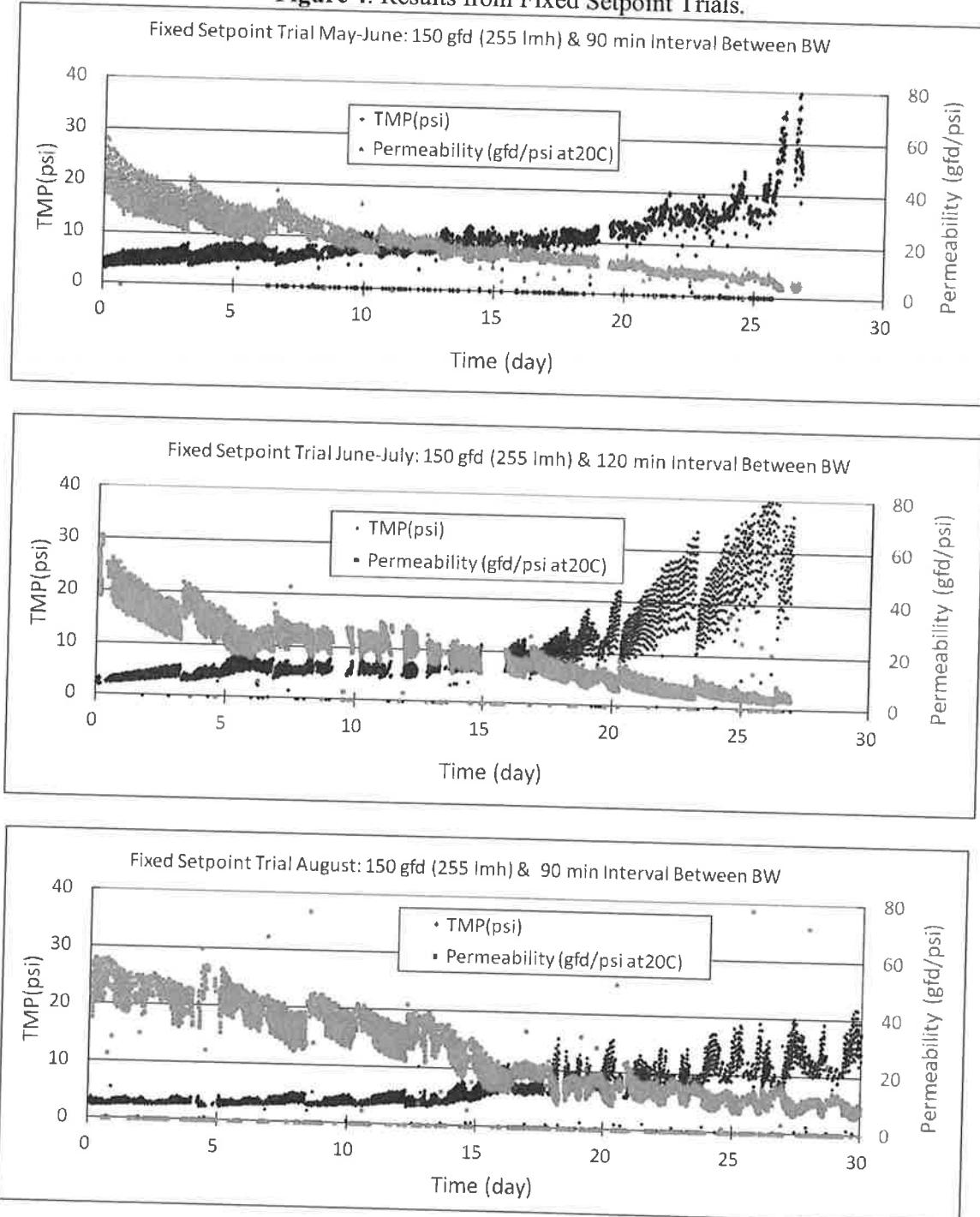


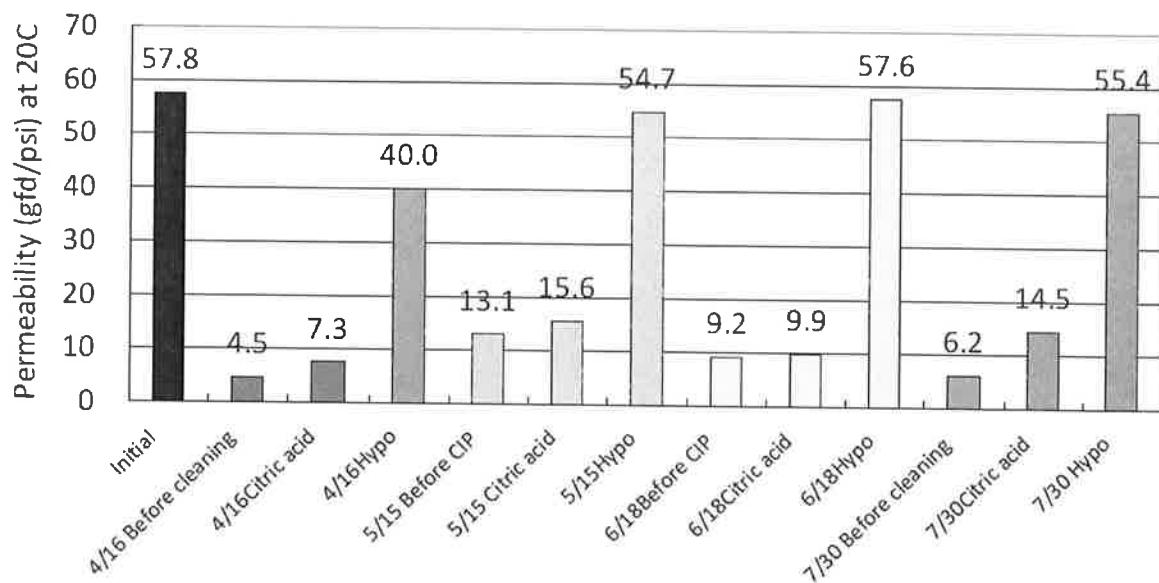
Table 4. Fixed Setpoint Trial Conditions

Parameter	May-June	June-July	August
Flux, gfd (l/mh)	150 (255)	150 (255)	150 (255)
BW Interval, min	90	120	90
MW Freq	1 every 3 days	1 every 3 days	1 every 3 days
MW Type	pH 2 sulfuric acid	pH 2 sulfuric acid	100 mg/L hypochlorite then pH 2 sulfuric acid
Pretreatment ACH Dose, mg/L	4	4	4
Water Temperature Range, C (Average)	4 – 22 (19.8)	23 – 27 (25.5)	23 – 27 (24.7)
Raw Water Turbidity Range, NTU	7 – 15	5 – 22	10 - 20

As discussed previously a major goal of the pilot program is to verify that the operating conditions result in good recovery of permeability by CIP cleaning. This recovery is shown in Figure 5.

Figure 5. Permeability Recovery by CIP from Fixed Setpoint Trials.

Post-CIP Permeability Recovery



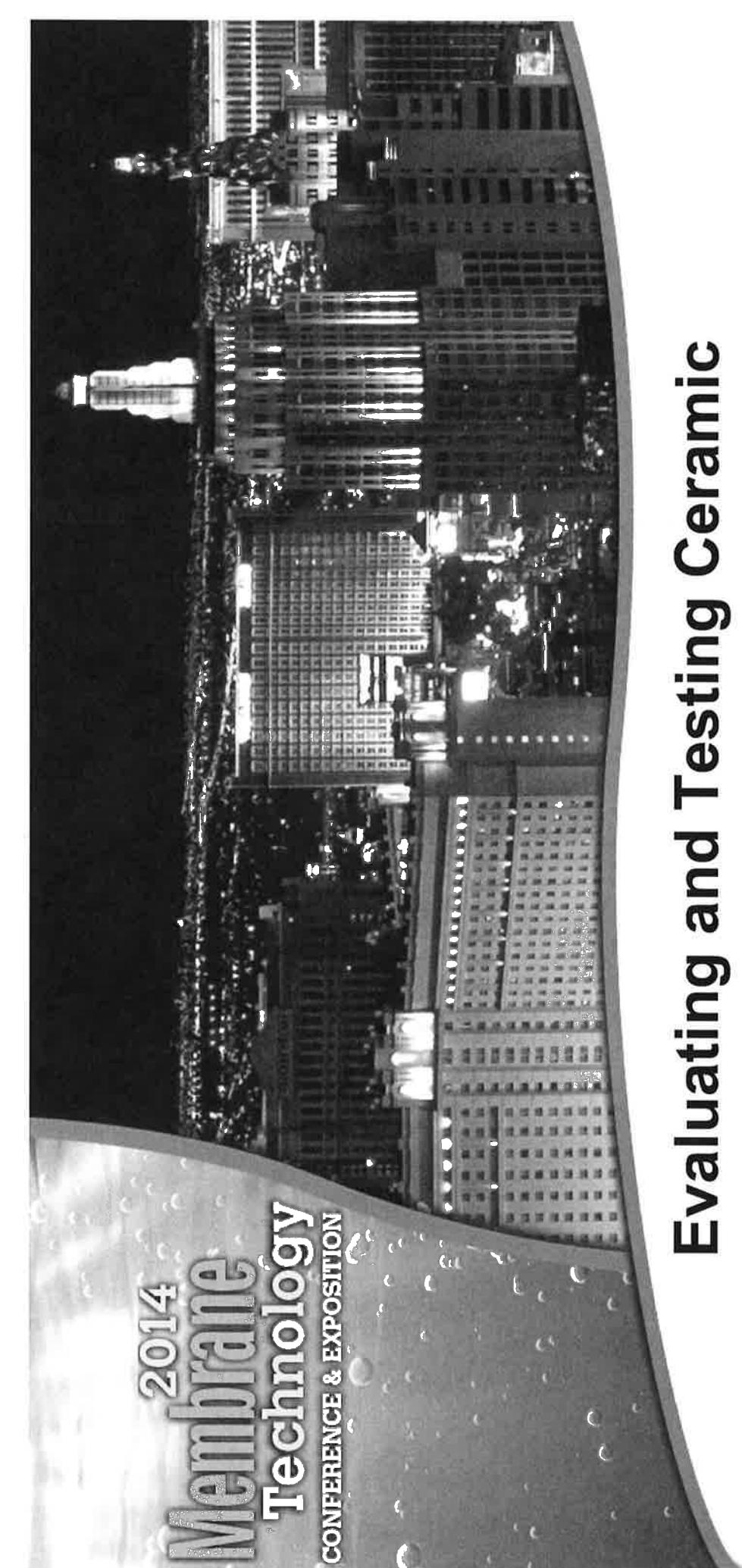
Summary

The pilot results indicate successful and stable performance with the METAWATER model 431011 - 269 ft² (25 m²) ceramic membrane module when operated on El Dorado lake feed water at the following conditions:

- Pretreatment with addition of 4 mg/L of ACH coagulant.
- Flux during filtration cycle of 150 gfd (255 lmh).
- BW after 90 minutes of filtration.
- MW every 3 days (2-step process with 100 mg/l hypochlorite MW followed by a pH 2 – sulfuric acid MW).

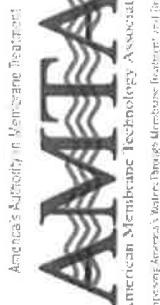
Acknowledgements

The authors would like to acknowledge the METAWATER staff, including Shinjiro Kanaya, Marino Woo, and Joseph Campanaro, as well as their local representative Dan Batliner (Ray Lindsey Co, Belton, MO), for the use of the pilot equipment and their hard work. This program would not have been possible without them.



Evaluating and Testing Ceramic Membranes to Expand Treatment Capacity

Kurt Bookout
City of El Dorado, Kansas



Overview

- Existing WTP 9 MGD
- El Dorado Lake Additional Water Available
 - May Add Up To 30 MGD
 - To Service Growing El Dorado and Neighboring Communities
- Options Include Ceramic Membranes
- Piloting Ceramic Membranes



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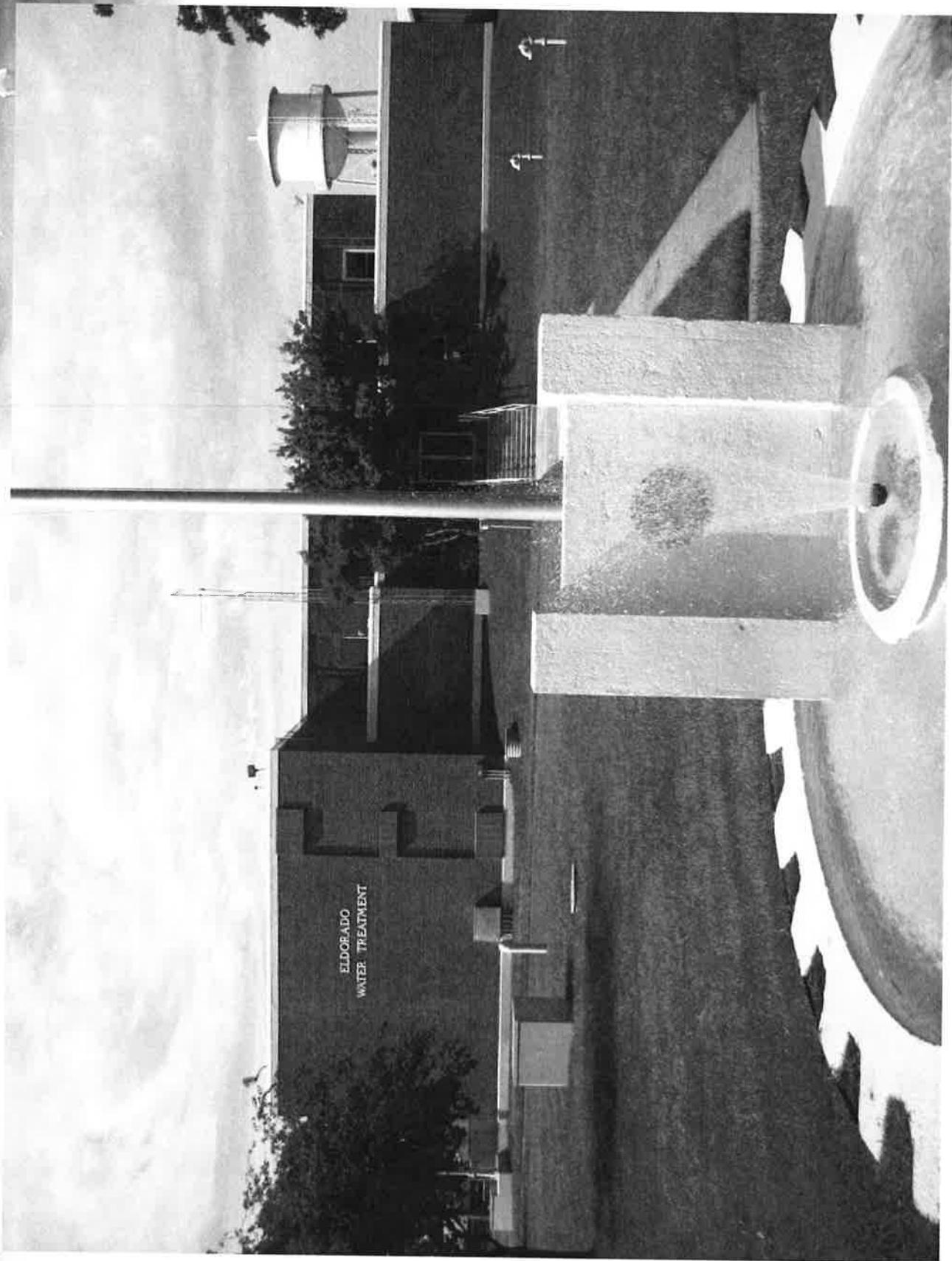


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Raw Water El Dorado Lake

Table 1. Summary of Raw Water Quality, El Dorado Lake
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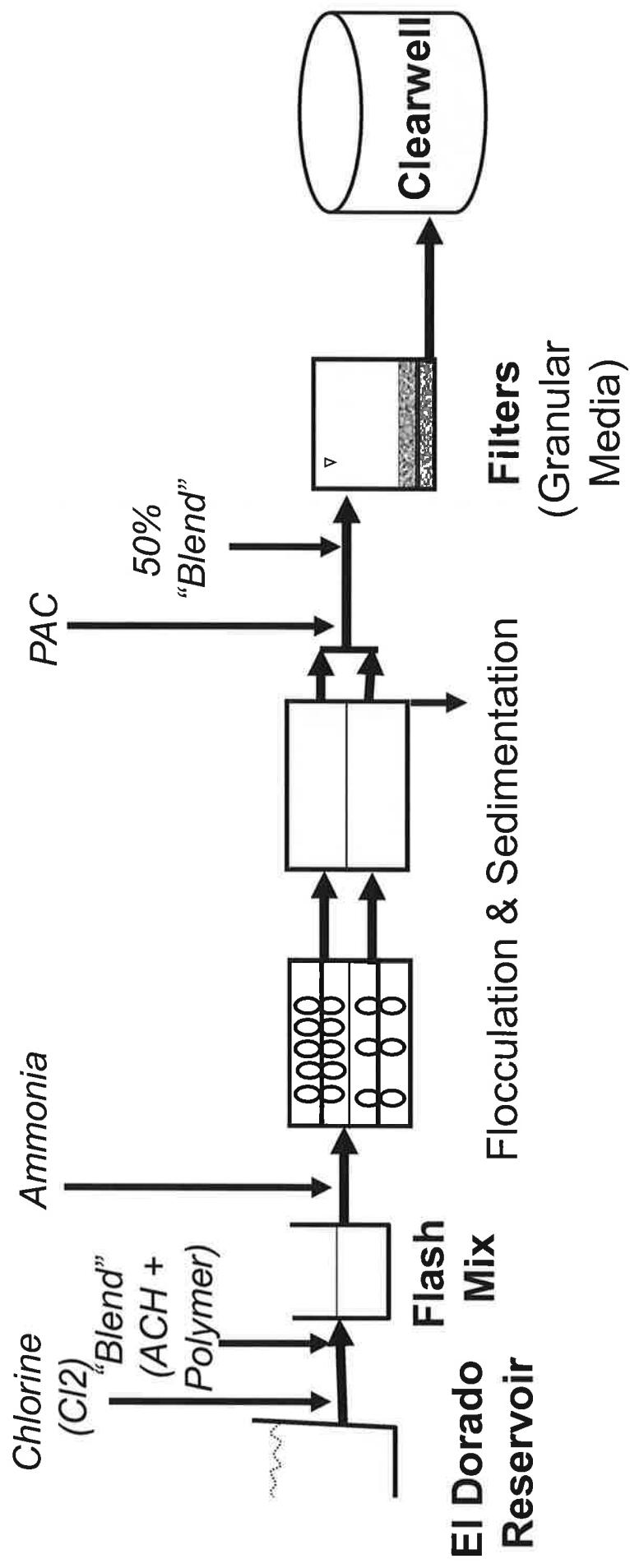
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EXISTING EL DORADO WTP PROCESS

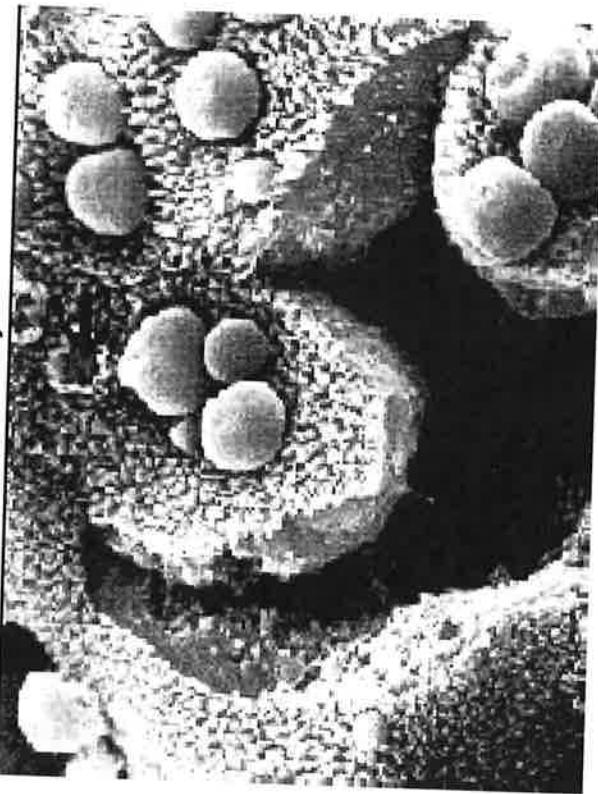


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Why Consider MF/UF?

- Many Reasons, including Cyst & Turbidity Control
- High Log Removal Giardia & Crypto
- Low Turbidity (<0.1 NTU All the Time)
- Also:
 - Compact
 - Automated

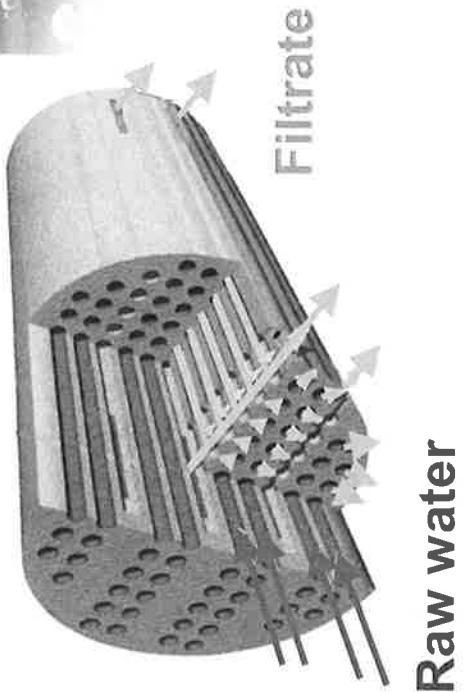


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Why Consider Ceramic?



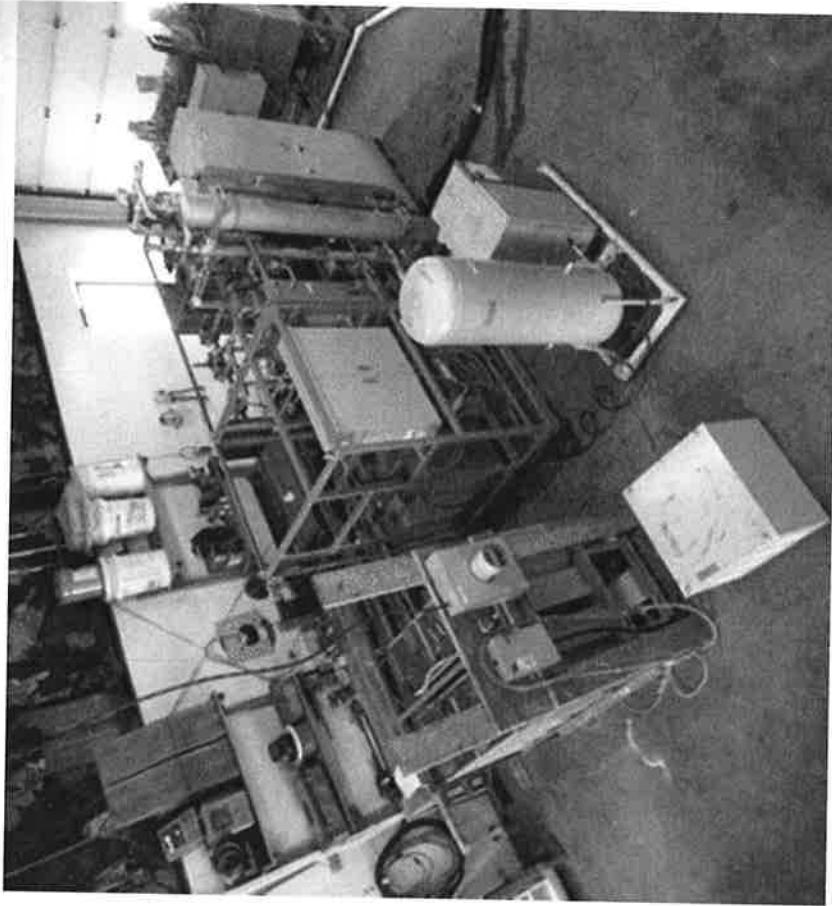
- No Broken Fibers
 - Reduced Repair Costs
- Long Service Life
 - Reduced Replacement Frequency
- Tolerates High Pressure Backwash and Wide Range of CIP Chemicals
 - Easier to Keep Clean



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Ceramic Pilot Objectives



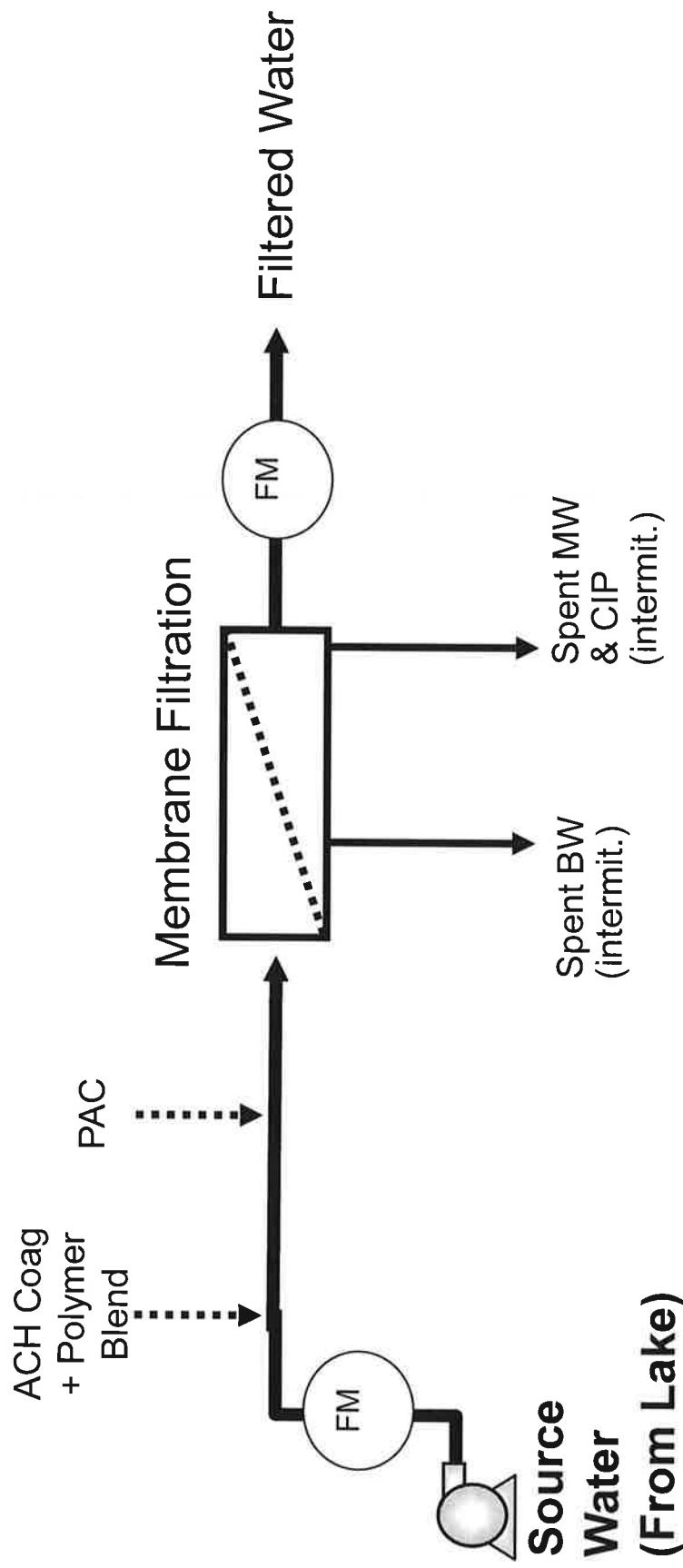
- Site-Specific Performance
- Determine Parameters
 - E.g., Flux, Backwash (BW) Frequency, etc
- Staff & Regulator
 - Learn About Ceramic Membrane Operations



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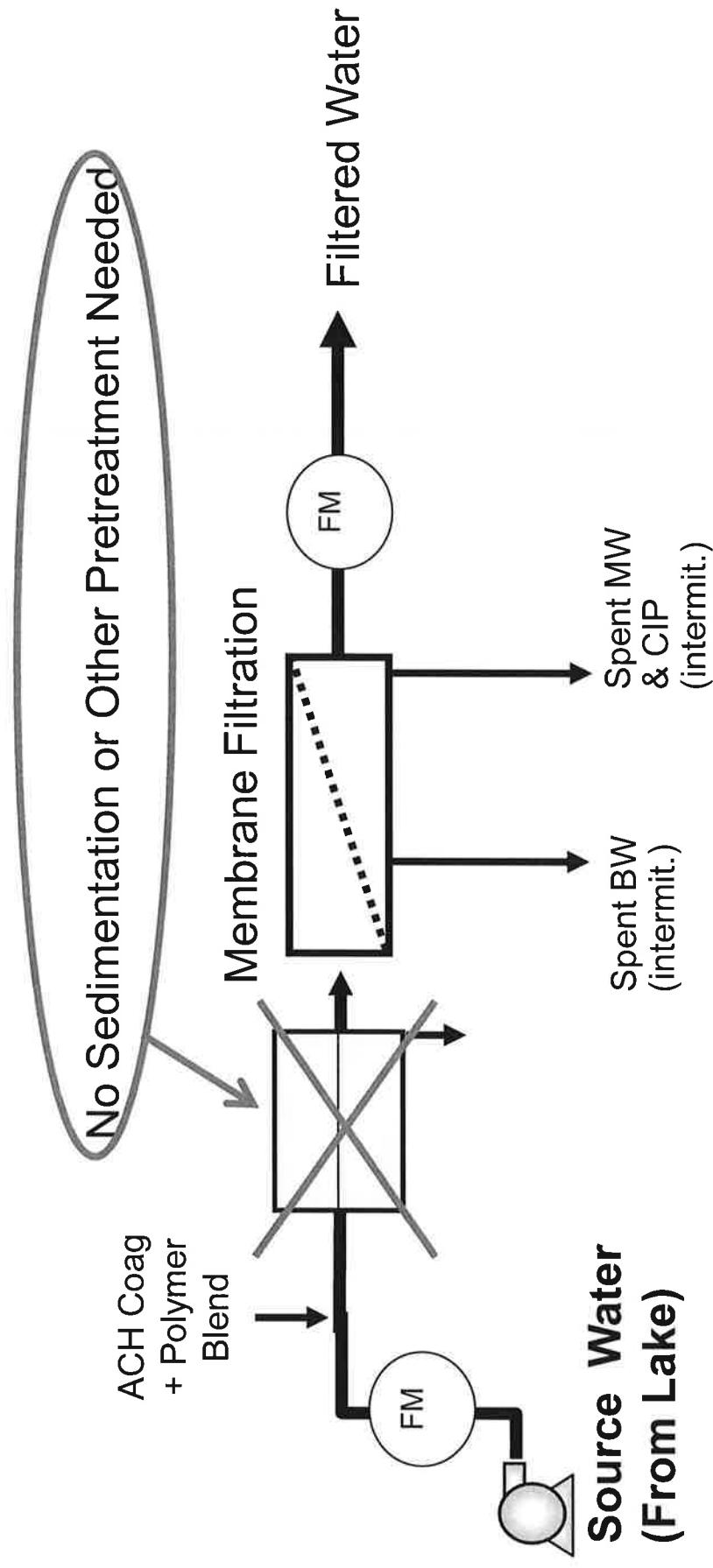
Ceramic Pilot Schematic



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Ceramic Pilot El Dorado



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Pilot Equipment Details

Table 2. Ceramic Membrane Pilot Description for El Dorado, Kansas

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Membrane Model Number	431011
Type of System	Encased (pressurized)
Membrane Material	Ceramic; Aluminum Oxide
Flow Pattern	Inside – Out
Module Dimensions, diam x L, inch (nominal)	7.1 x 59.1
Surface area on the feed water side of module, ft ²	269 ft ² (25 m ²)
Nominal pore size, micron	0.1
Modules installed	1
Prescreen rating, micron	1,000
Module Conditions From Manufacturer:	
Maximum Operating TMP, psi	55
Flow Rate Range, gpm	9 – 28
Filtration Cycle Time Between BWs, min	60 – 120
BW Cycle Duration, min	<3
BW Pressure, psi	<72

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Pilot Performance Criteria

Table 3. Pilot Performance Criteria

Parameter	Criteria
Permeability goal	Post-CIP permeability within 85% of baseline
CIP Interval	Greater than/equal to 30 days
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Downtime goal	Less than 3 working days per run

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Piloting Main Phases

(1) Optimization

- Vary Range of Operating Conditions

(2) Fixed Setpoint Trials

- Fixed for 30 to 45 Days Between CIPs
- Mimic Full-Scale Conditions

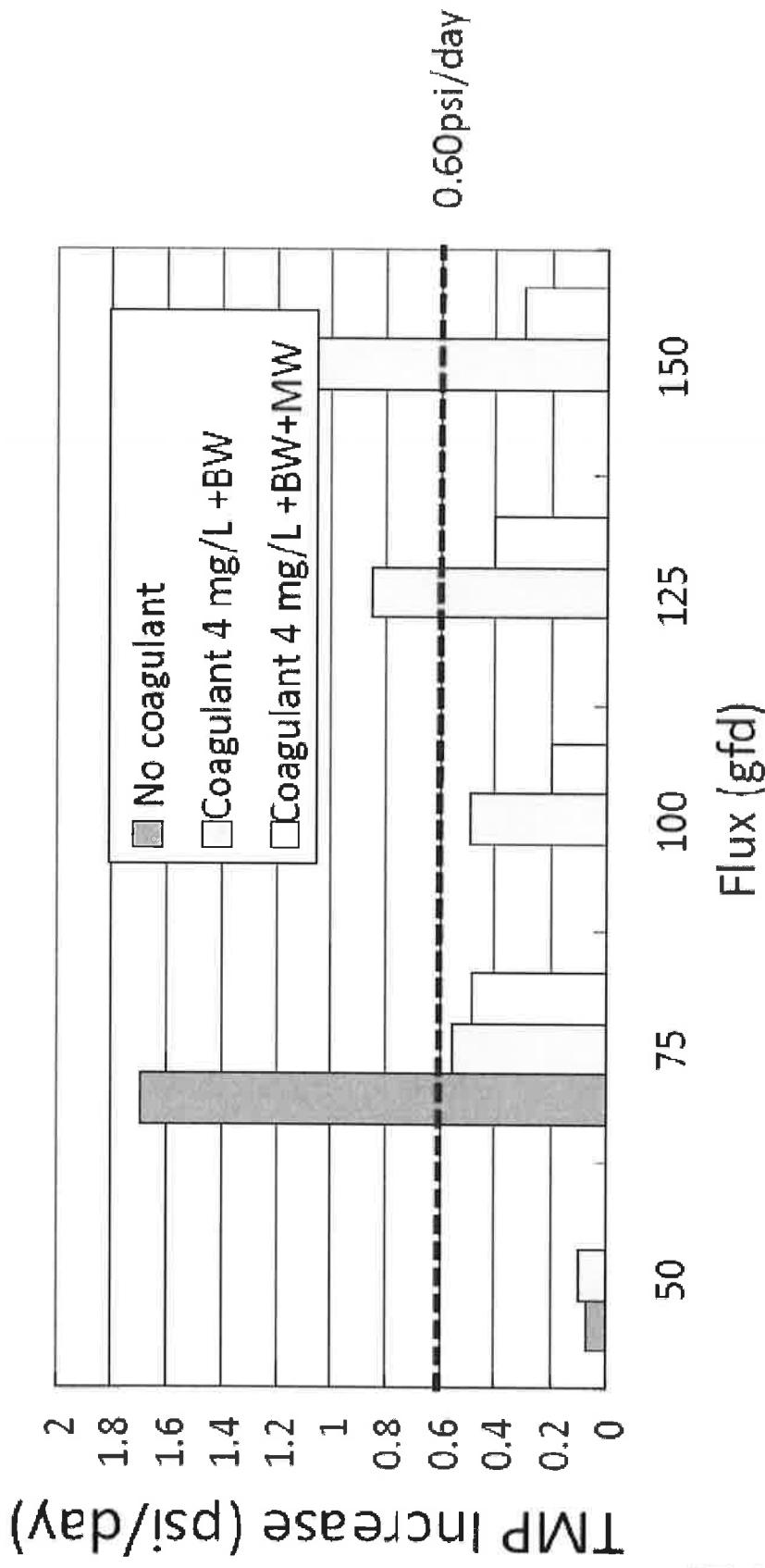


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TMP Increase During Optimization

Figure 3. TMP Increase During Optimization Trials.
TMP Increase During Optimization Trials

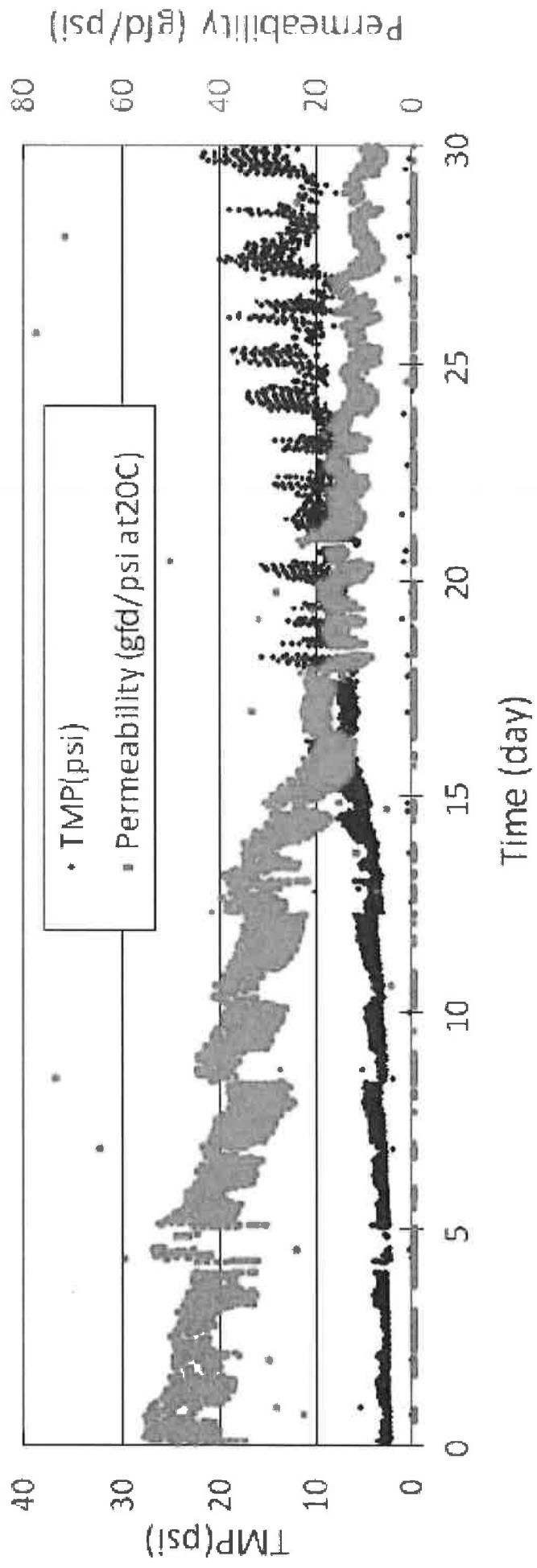


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Fixed Setpoint Example

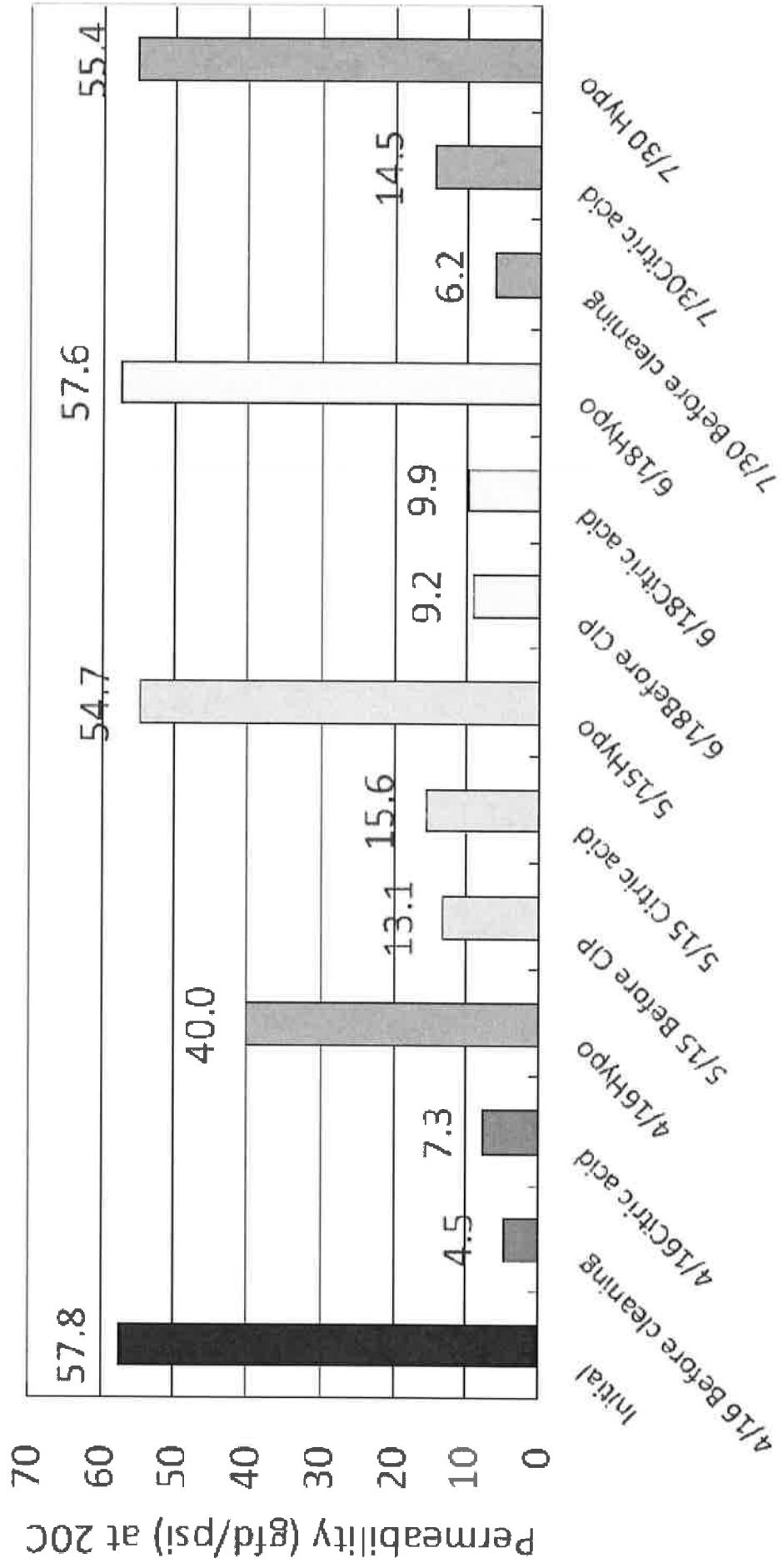
Fixed Setpoint Trial August: 150 gfd (255 l/mh) & 90 min Interval Between BW



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Post-CIP Permeability



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Summary

- CIP Recovers Permeability
- At Piloted Conditions:
 - Pretreatment 4 mg/L of ACH Coagulant
 - Flux of 150 gfd
 - During Filtration, i.e., Instantaneous Flux
 - BW After 90 min of Filtration
 - Maint. Wash every 3 days
 - (2-step 100 mg/L hypochlorite MW followed by pH 2 with sulfuric acid MW)



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