OPTIMIZED CHEMICAL PRETREATMENT AND MEMBRANE ELEMENT PERFORMANCE AT A 10 MGD NANOFILTRATION PLANT

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Abstract

The City of Pompano Beach has a 50 million gallon per day (mgd) water treatment plant that includes a 10 mgd nanofiltration (NF) process. The NF process includes five 2-mgd NF units. The units are two-stage, in a 36:16 array. The NF units were previously populated with a hybrid of membrane elements that were installed in 2009. These membranes were selected to achieve the City's permeate hardness, permeate iron, and other permeate quality goals (e.g., color, TDS, organics) and utilized acid and antiscalant chemical pre-treatment to condition the feedwater.

In preparation for the 2020 NF Membrane Element Replacement, the City designed, permitted, and constructed a 2:1 array pilot test unit consisting of three full-size (8-inch diameter, 7-element) membrane pressure vessels with independent pre-treatment chemical feed systems, cartridge filters, feed pump, and instrumentation. The pilot unit was permitted to withdraw raw water from the full-scale plant feed water header and discharge concentrate and permeate to the full-scale plant concentrate and permeate headers, respectively.

The City's objective for the pilot testing program was to develop an operating protocol that allows for the complete elimination of chemical pre-treatment (no acid or antiscalant) to optimize chemical and power costs. After satisfying the pilot testing objective, the City proceeded with procurement. Membrane element replacement was completed in May 2020 and the NF Process was started up with new membrane elements and without chemical pretreatment. Since start up, it has been operating successfully without chemical pre-treatment and continues to meet specified performance and permeate quality goals.

Background

The City of Pompano Beach (City) is located in northeast Broward County, Florida and provides potable water service to a population of approximately 84,000. The City's current potable water annual average day demand (ADD) is approximately 13.6 million gallons per day (mgd), and the maximum day demand (MDD) is approximately 17.4 mgd. The City owns and operates a 50 mgd water treatment plant (WTP) that utilizes conventional lime softening (LS) and nanofiltration (NF) to treat the raw water. These processes run in parallel and are blended at approximately 40% to 50% NF:LS ratio in a blending clearwell prior to four-log virus treatment disinfection and distribution. Both process streams treat raw water from the shallow Biscayne Aquifer, which is high in dissolved organics including precursors for regulated trihalomethanes and haloacetic acids. Typical raw water quality is summarized in Table 1.

Table 1 – Typical Raw Water Quality

Constituent/Parameter	**Value**
Total Hardness	247 mg/L as $CaCO_3$
Total Dissolved Solids	495 mg/L
Color	80 Color Units
Total Organic Carbon	20 mg/L
pH	7.2
Iron	1.70 mg/L
TTHMFP	0.40 mg/L
HAA5FP	0.30 mg/L

The NF process was constructed and placed into service in 2002 and includes five 2-mgd NF units. This process was added to improve the removal of dissolved organics to maintain compliance with the Stage 2 Disinfectant/Disinfection By-Product Rule (D/DBPR) and all primary and secondary drinking water standards. Each NF unit is two-staged in a 36:16 array, and the system was designed to operate at an 85% recovery rate with an average flux of 13.7 gallons per square foot per day (gfd). Since placing the NF process into service, the City has replaced the membrane elements twice. The first membrane element replacement occurred in 2009, where the vessels were populated with a hybrid configuration of membrane elements (Hydranautics ESNA1-LF and ESNA1-LF2), and the second replacement occurred 2020, as described herein.

As presented in Table 1, the raw water is relatively high in organics and has an average iron concentration of approximately 1.7 mg/L. In order to remain in compliance with the D/DBPR and primary and secondary drinking water regulations, the City established goals for concentrations of certain constituents in the finished blended water. To achieve these goals, the City set NF permeate quality and membrane performance criteria for each the 2009 and 2020 membrane element replacement projects, as presented in Table 2.

Table 2 – Specified Permeate Quality and Membrane Performance

Constituent/Parameter	Existing Membranes (2009)	Replacement Membranes (2020)
Bicarbonate	25 to 75 mg/L	25 to 75 mg/L
Color	< 3 Color Units	< 3 Color Units
Total Dissolved Solids	< 250 mg/L	< 200 mg/L
Total Hardness	20 mg/L as $CaCO_3$	Min 25 mg/L as $CaCO_3$
Iron	0.25 mg/L	0.20 mg/L
Total Organic Carbon	< 1.0 mg/L	< 1.0 mg/L
TTHM Formation Potential	< 0.040 mg/L	< 0.040 mg/L
HAA5 Formation Potential	< 0.030 mg/L	< 0.030 mg/L
Maximum TMP	90 psi	73 psi

When the City began preparing for the 2020 membrane element replacement project, they were interested in investigating the possibility of reducing operating costs by taking advantage of advancements in membrane technology to reduce power costs and eliminate chemical pretreatment of feedwater while maintaining finished water quality. Prior to the 2020 membrane replacement, the City utilized physical and chemical pretreatment of the NF feedwater. Physical pretreatment of the NF feedwater consisted of four 5-micron cartridge filters, each rated at a 2,117 gpm capacity and chemical pretreatment entailed dosing the feedwater with acid to lower the pH to 5.8 and Nalco 1850T antiscalant at a dosage rate of 1.0 mg/L.

In 2016, when the City began planning to replace the membrane elements with their optimization goals in mind, the City requested letters of interest (LOI) from three leading nanofiltration membrane element manufactures (MEM); Hydranautics, Dow Water and Process Solutions, Inc. (Dow), and Koch Membrane Systems, Inc. The City received responses from Hydranautics and Dow.

These LOI's requested membrane selections from the MEM's, in preparation for prequalification pilot testing of the proposed membrane selections from each manufacturer. The purpose of the pilot testing was to verify that the membrane element selections met the City's specified permeate quality and membrane performance requirements, as presented in Table 2. Meeting these permeate quality and membrane performance requirements during pilot testing allowed the MEM's proposed membrane element selections to prequalify for installation in the City's full-scale NF units under the 2020 NF Membrane Element Replacement Project.

To facilitate pilot testing the City designed, permitted, and constructed a pilot unit with full-size pressure vessels (8-inch diameter, 7-element) in a 2:1 array with independent cartridge filters and pre-treatment chemical feed systems. The pilot unit was permitted to withdraw feedwater from the NF process raw water header and discharge permeate and concentrate to the plant's respective headers. Figure 1 presents a schematic of the pilot test unit.

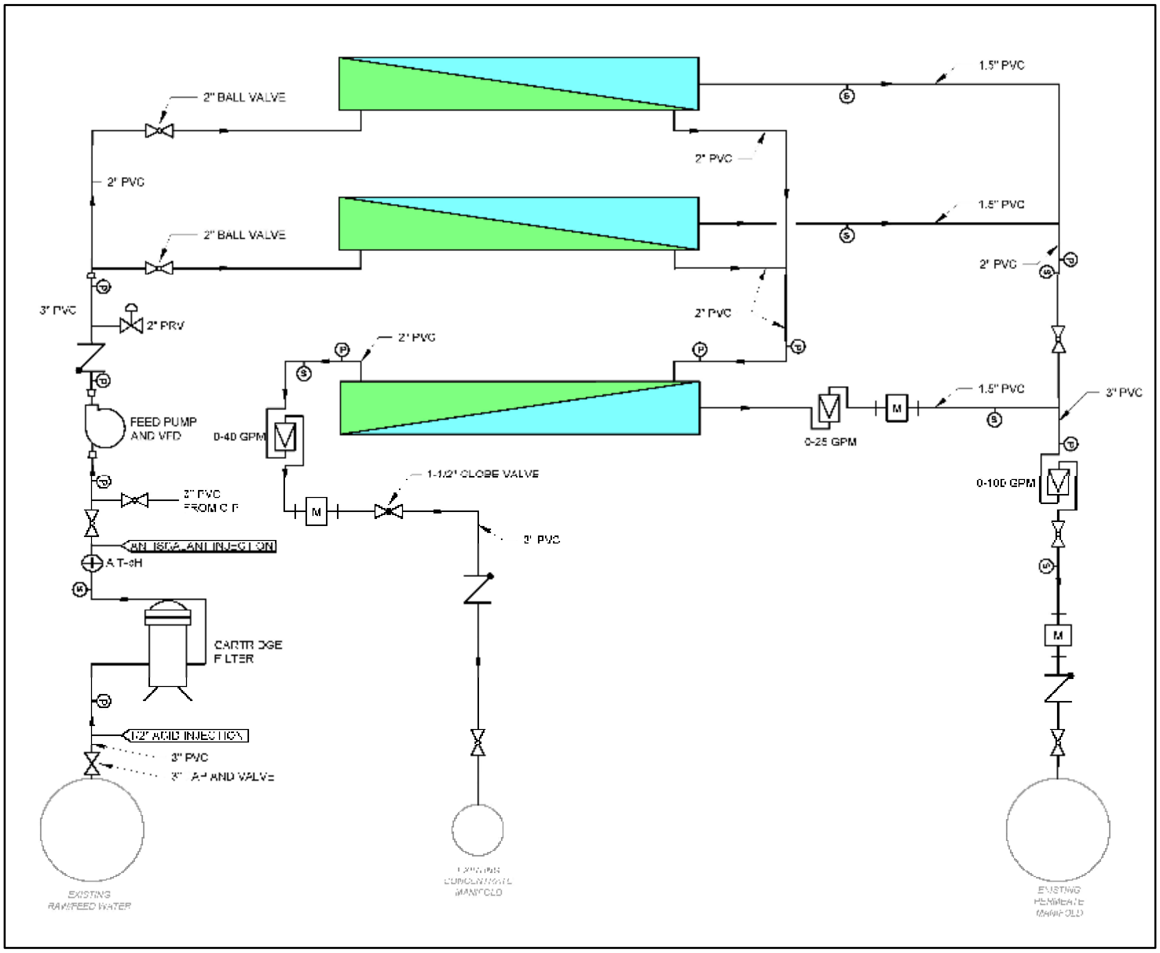

Figure 1 – Pilot Test Unit Schematic

NF Membrane Pilot Testing

Pilot testing with the pilot unit was conducted in two phases. Phase 1 was aimed at confirming that the City could meet the specified permeate quality and membrane performance requirements with the proposed replacement membrane elements under the current operating conditions of full-scale NF process (acid and antiscalant chemical pretreatment, 85% recovery rate, and 13.7 gfd average flux). The objective of Phase 2 was to evaluate the performance of the membrane selection and potential fouling tendencies under modified operating conditions (no chemical pretreatment, an 82% recovery rate, and a 12.2 gfd average flux). In general, the purpose of Phase 2 of pilot testing was to evaluate the potential for stable operation without acid or antiscalant pretreatment under the subject modified operating conditions (i.e., essentially to reproduce the operating conditions of the nearby Boca Raton NF process which has operated without acid or antiscalant pretreatment since 2005 under similar recovery rate and flux conditions).

It should be noted that ultimately, Dow and Hydranautics both successfully prequalified for installation in the City's full-scale NF units under the 2020 Nanofiltration Membrane Element Replacement Project. However, the remainder of this manuscript will focus solely on the performance of the Hydranautics membrane elements since they were identified as the lowest responsive bidder 2020 NF Membrane Element Replacement Project and their membrane elements populate the City's pilot unit to this date, which being used to attempt to further optimize the City's full-scale NF units.

Hydranautics Pilot Testing

Phase 1 prequalification pilot testing occurred from October 22, 2018 through November 27, 2018. During Phase 1 the pilot unit was populated with all model ESNA1-LF2-LD Hydranautics membrane elements in the first- and second-stage. During Phase 1 testing the feed pressure, differential pressure, and specific flux (Figures 2, 3, 4, respectively) reflected stable operation. Throughout Phase 1 of pilot testing, all water quality and performance parameters were within compliance of the specified criteria, except for a total hardness sample on October 23, 2018 (24 mg/L as $CaCO_3$) and an iron sample on November 12, 2018 (0.20 mg/L), as presented in Figures 5 and 6, respectively

Phase 2 of prequalification pilot testing began on December 5, 2018 and ended on January 26, 2019. At the start of this phase (Phase 2A) the pilot unit was populated with Hydranautics membrane elements in the following configuration: six ESPA4-LD elements and one ESNA1-LF2-LD tail element in the first-stage and all ESNA-LF2-LD elements in the second-stage. Following the initial stabilization period (December 5 through December 10), throughout Phase 2A testing, all water quality and performance parameters were within compliance with the specifications and the feed pressure, differential pressure, and specific flux (Figures 2, 3, 4, respectively) continued to reflect stable operation. This concluded Hydranautics prequalification pilot testing,

However, following Phase 2A, with direction from the City, Hydranautics was authorized to continue pilot testing in an attempt to further optimize the performance of the membrane elements. The following summarizes the subsequent phases of pilot testing that are described in greater detail herein.

- Phase 2B: Occurred January 27, 2019 through August 15, 2019 (200 days), with no changes to the pilot unit operating parameters or the membrane element loading configuration.
- Phase 2C: Occurred August 16, 2019 through September 26, 2019 (41 days), changes were made to the first-stage membrane element loading configuration.
- Phase 2D: Occurred September 27, 2019 through December 18, 2019 (82 days), the pilot unit average flux was modified from 12.2 gfd average flux to 13.0 gfd.
- Phase 2E: Currently ongoing and began December 19, 2019 (489 days and counting), the pilot unit operating parameters were further modified to an 83% recovery rate an average flux rate 13.7 gfd.

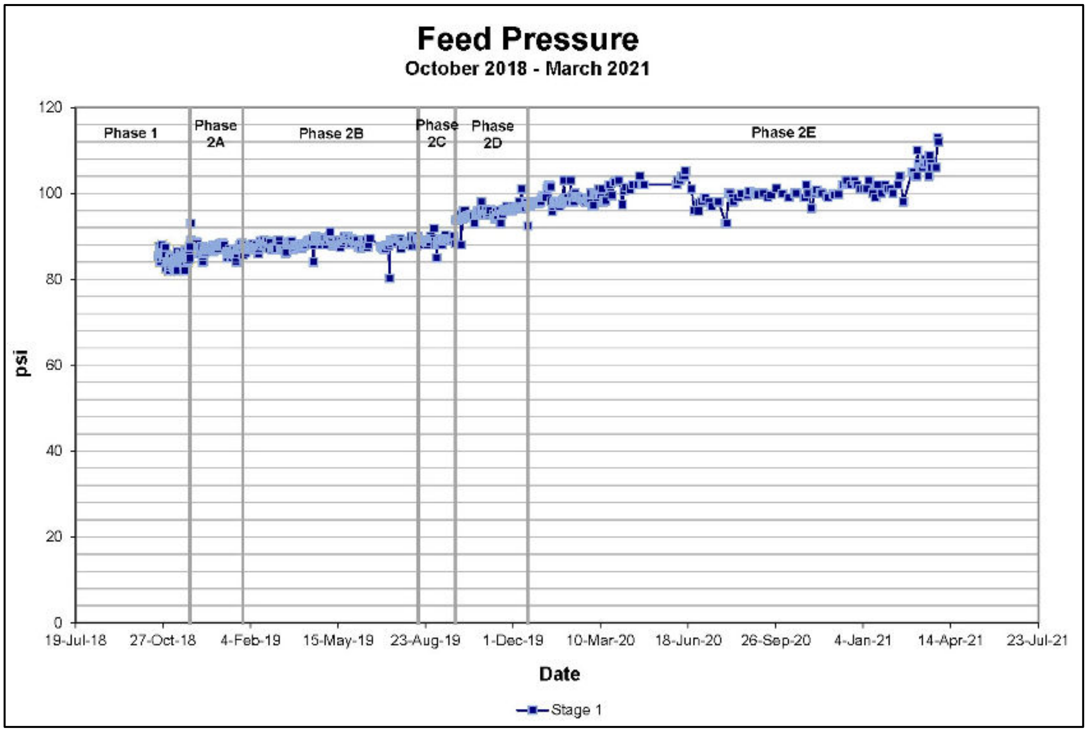

Figure 2 – Pilot Unit Feed Pressure

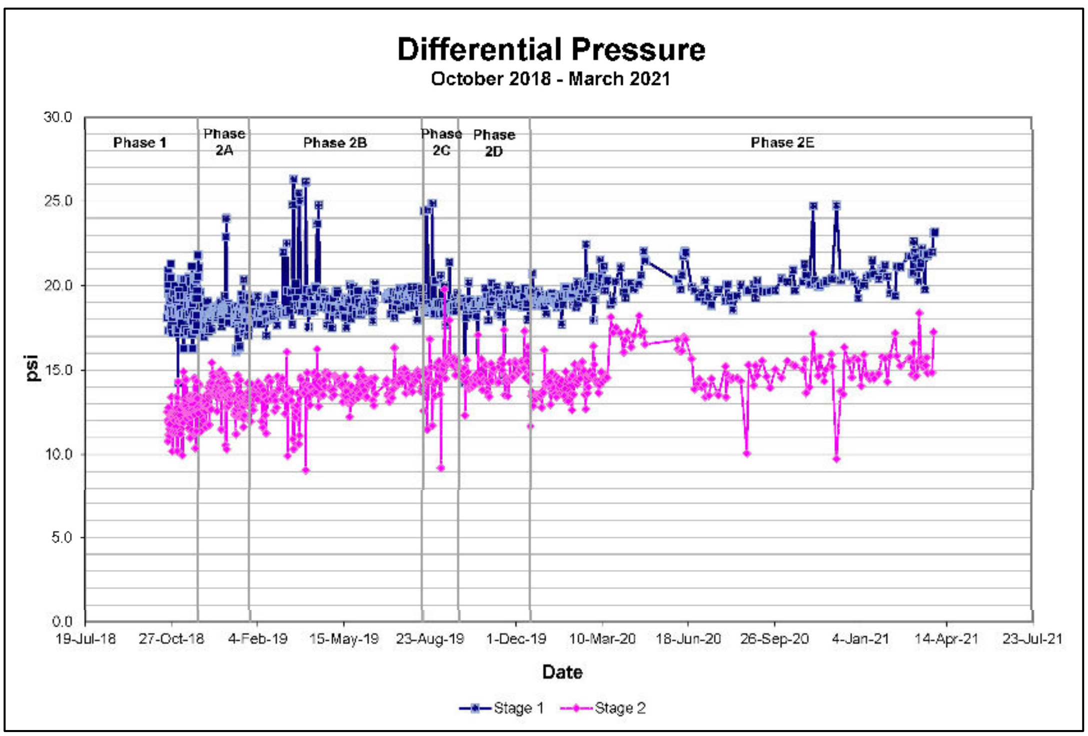

Figure 3 – Pilot Unit Differential Pressure

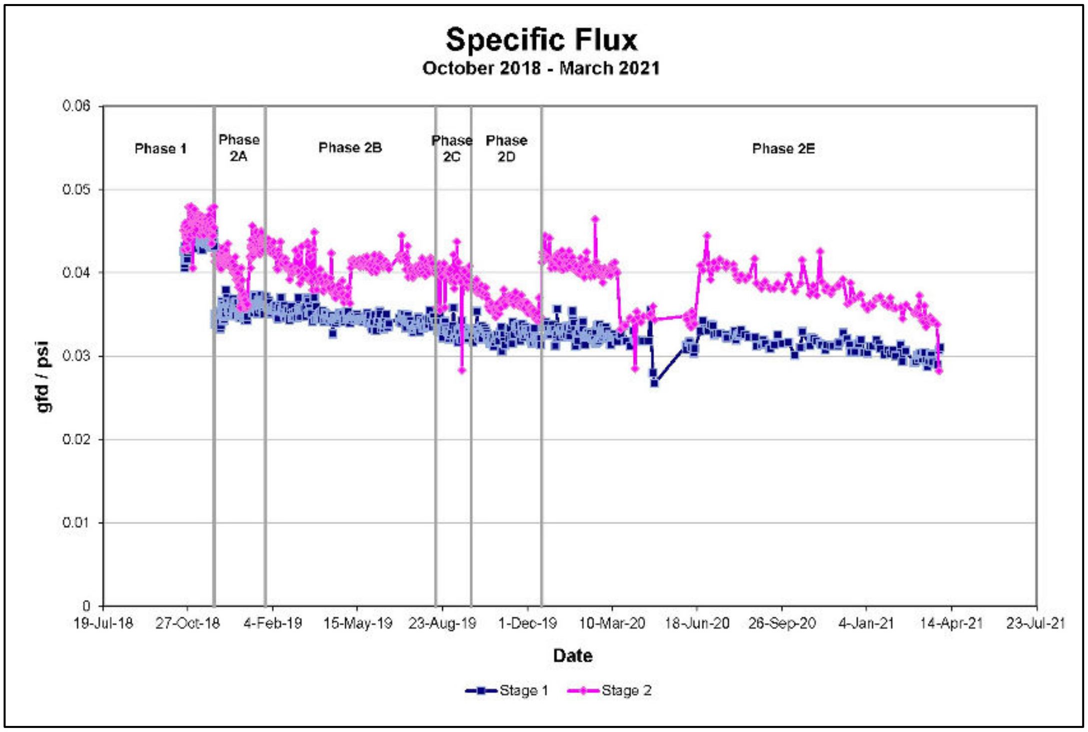

Figure 4 – Pilot Unit Specific Flux

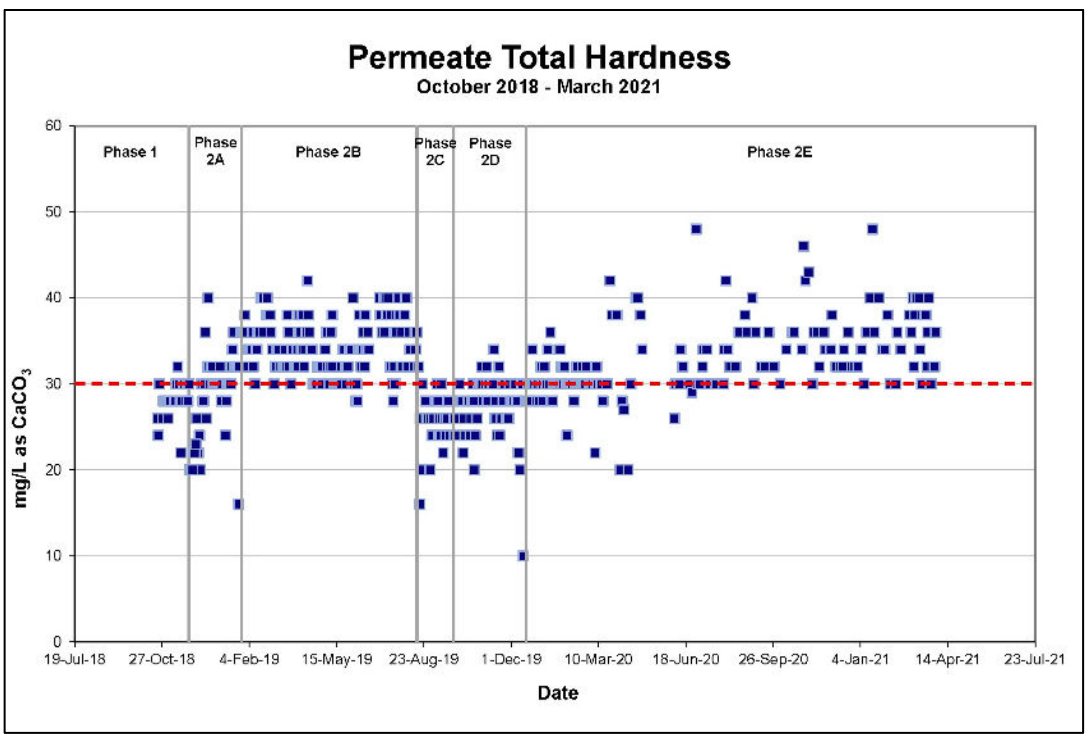

Figure 5 – Pilot Unit Permeate Total Hardness

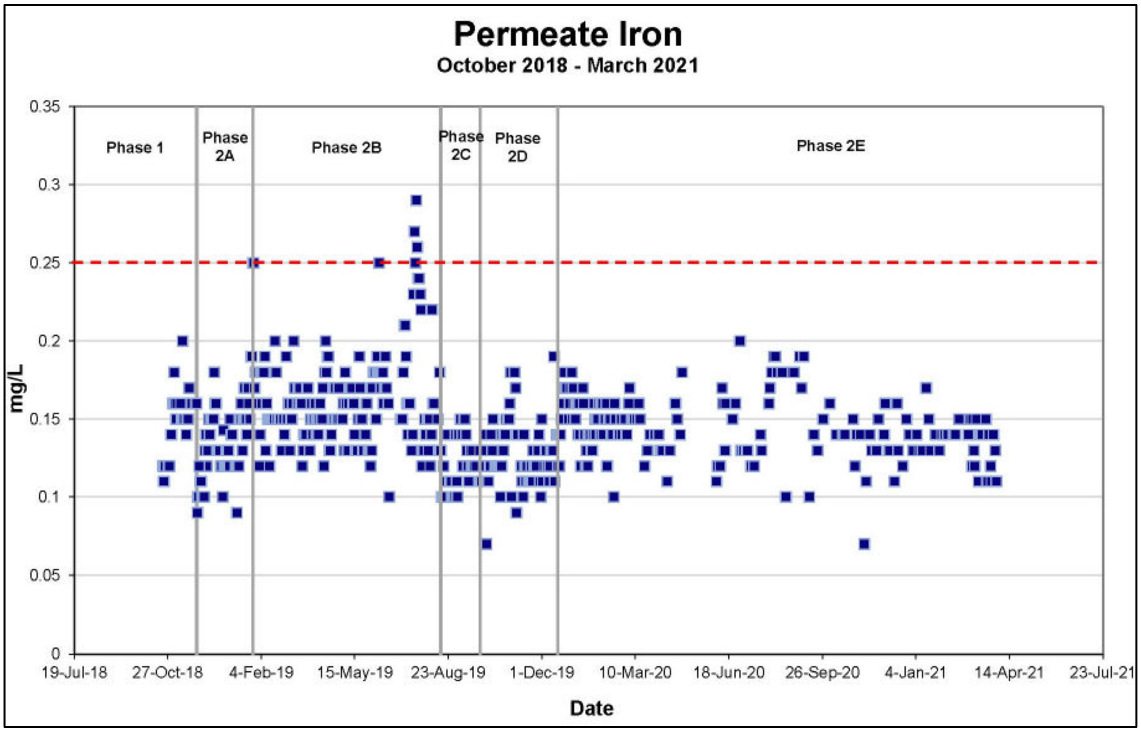

Figure 6 – Pilot Unit Permeate Iron

Phase 2B

During this phase of pilot test, the pilot unit continued to operate under Phase 2A operating conditions for an additional eight-month period. During this time, the pilot unit met all specified permeate quality and performance parameters with the exception of iron samples on three days (Figure 6). With the exception of the marginally increased permeate iron concentrations over the last few weeks of testing, the proposed Hydranautics membrane element selection met all permeate quality goals and reflected stable operation without chemical pretreatment throughout Phase 2B of pilot testing.

Comparing the Phase 2A start-up conditions to the averages over the last week of Phase 2B operation, the first-stage feed pressure increased by 1%, the first- and second-stage differential pressure increased by 7% and 10% respectively, second-stage specific flux decreased by 2%, and there was no change observed in the first-stage specific flux. However, one performance parameter that was a cause for concern was the first-stage permeate conductivity, which experienced an increase of 61% at the conclusion of Phase 2B, as evidenced by Figure 7. It should be noted that during this eight-month period of runtime, no cleanings were performed on the elements populating the pilot unit, exceeding the City's existing membrane elements with respect to runtime between cleanings (seven months).

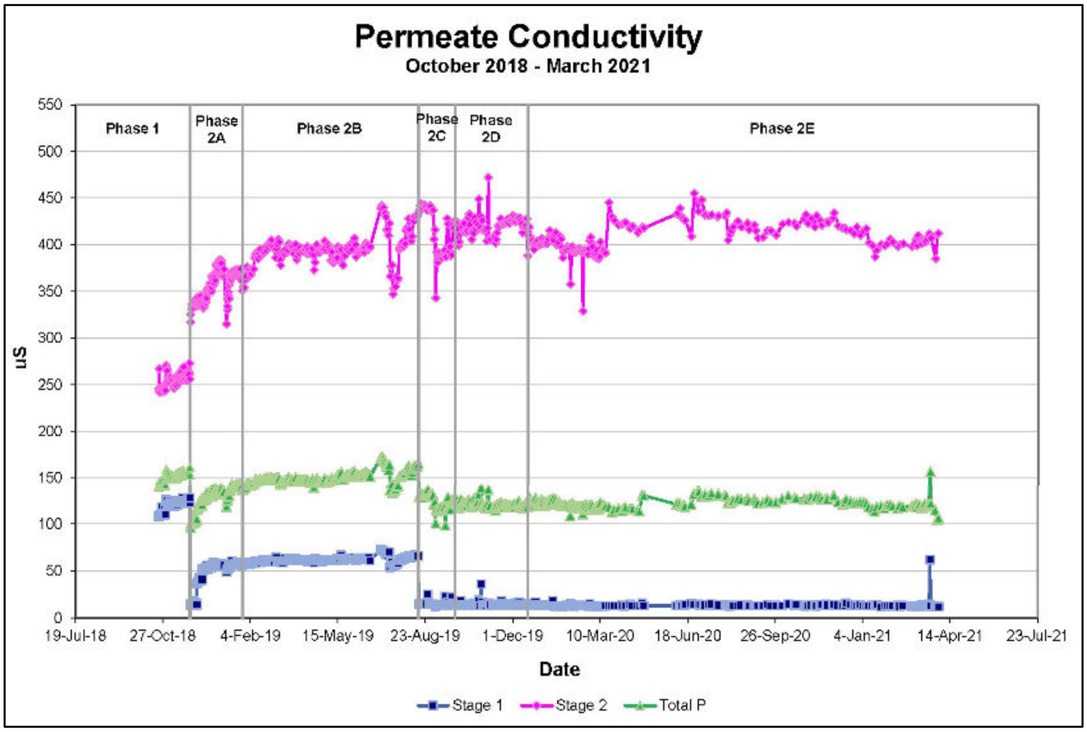

Figure 7 – Pilot Unit Permeate Conductivity

Phase 2C

At the start of Phase 2C, with assistance from Hydranautics, the configuration of the pilot unit's first-stage was modified (Phase 2C) to be all ESPA4-LD membrane elements (in-lieu of six ESPA4-LD followed by one ESNA1-LF2-LD tail element), the membrane element configuration in the second-stage remained the same (all ESNA-LF2-LD elements). This change was made to specifically address the increased first-stage permeate conductivity observed at the end of Phase 2B.

This configuration performed at the Phase 2 operating conditions (no chemical pretreatment, 82% recovery rate, and 12.2 gfd average flux) until September 26, 2019 and typically met the permeate quality and membrane performance criteria; except for permeate total hardness, which failed to exceed the minimum specified concentration on ten of the forty-two days of testing, or 24% of the test period. This indicates that the new ESPA4-LD first-stage tail element increased hardness rejection from the first-stage of the pilot unit, as evidenced by the sharp decrease in first-stage permeate conductivity and salt passage (Figures 7 and 8, respectively) that occurred immediately after the new membrane element was installed. It was expected that over time the membrane performance will continue to stabilize and the permeate conductivity, hardness, and iron concentration will consistently meet the specified requirements.

Comparing the Phase 2A start-up conditions to the averages over the final week of Phase 2C operation, the feed pressure increased by 1%, the first- and second-stage differential pressure increased by 6% and 16% respectively, and the first- and second-stage specific flux decreased by 6% and 5% respectively.

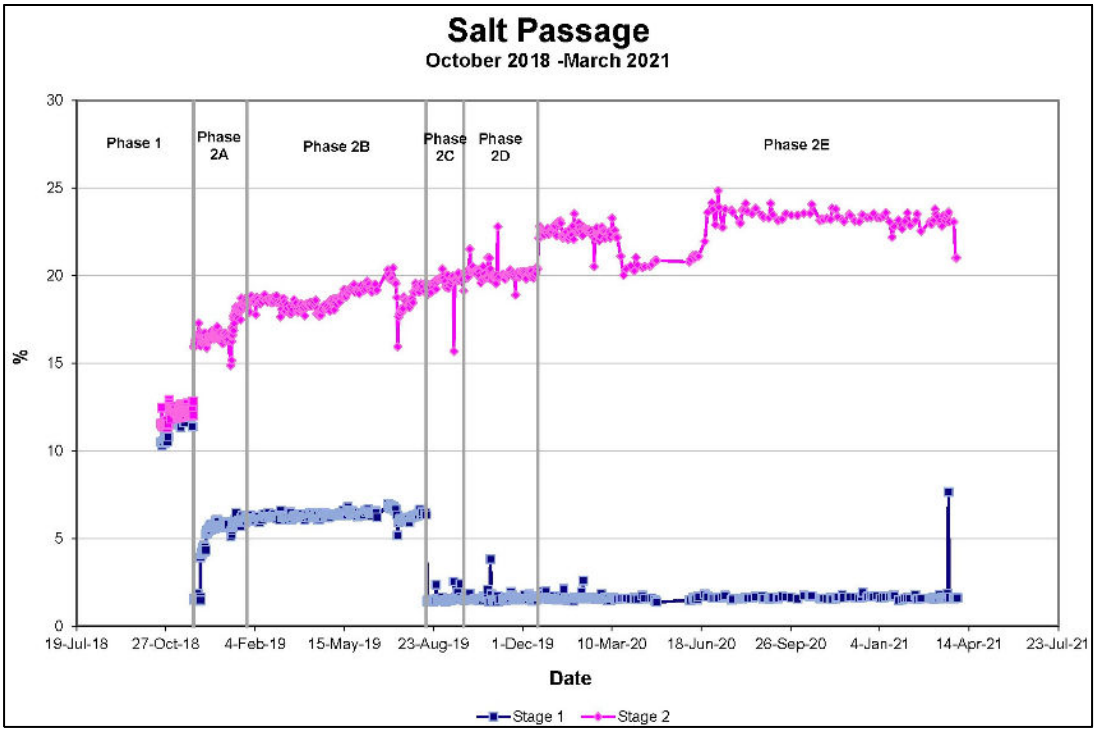

Figure 8 – Pilot Unit Salt Passage

Phase 2D

The City, satisfied with the pilot unit's performance and improved permeate quality (decreased permeate hardness) produced under the continued Phase 2 pilot testing, authorized Hydranautics to continue pilot testing without chemical pretreatment while incrementally increasing average flux and recovery rates. The City's objective of this continued pilot testing was to further optimize the pilot unit's operating parameters to maximize permeate production while maintaining specified permeate quality without chemical pretreatment with a long-term goal of producing permeate from the full-scale NF units at their original design flow rate.

At the start of Phase 2D, the pilot unit was operated at an 82% recovery rate with an average flux of 13.0 gfd, instead of an 82% recovery rate and a 12.2 gfd average flux as in the previous stages of Phase 2 pilot testing. It should be noted that during this time no cleanings had occurred and that the membrane element configuration in the pilot unit had remained unchanged since Phase 2C.

As evidenced in Figures 5 and 6, during this phase the pilot unit produced permeate similar in quality to the Phase 2C of testing. The permeate total hardness did not exceed the minimum specified concentration on thirteen of the eighty-two days of testing, or 16% of the test period. Comparing the Phase 2A start-up conditions to the averages over the last week of Phase 2D operation, the feed pressure increased by 11%, the first- and second-stage differential pressure increased by 9% and 16% respectively, and the first- and second-stage specific flux decreased by 7% and 9% respectively. The data indicated the membrane elements will continue to meet the specified permeate quality and membrane performance requirements as fouling occurs.

Based on the performance parameters of the pilot unit at the end of Phase 2D the City, with assistance from Hydranautics, elected to perform a membrane element cleaning on pilot unit. On December 17, 2019 the pilot unit was cleaned with a sodium chloride, sodium hydroxide, and detergent solution at a pH of 11.0, flushed with permeate, and then filled with permeate and left to soak overnight. The next day it was cleaned with hydrochloric acid, flushed with permeate, and then placed back into service under Phase 2D operating conditions for less than one day, until the start of Phase 2E pilot testing.

Phase 2E

Phase 2E of pilot testing formally began on December 19, 2019 and is currently in progress, making it the longest phase of pilot testing (418 days). As previously indicated, this phase entailed modifying the pilot unit's recovery rate to 83% with an average flux rate 13.7 gfd. During this time, the pilot unit's operation and permeate quality has been stable with the exception of the impacts of typical membrane fouling, as evidenced in Figures 2 through 8.

Part way through this phase of pilot testing, Hydranautics and City staff performed a cleaning of the membrane pilot unit to address the impacts of membrane fouling. This cleaning occurred on June 24, 2020 and consisted of a high-pH cleaning with Caustic and EDTA, a low-pH cleaning with citric acid, and an overnight soak in permeate before being placed back into service. In comparing performance data in the weeks before and after the cleaning, it can be determined that the cleaning resulted in a decrease in feed pressure of 6%, a decrease in first- and second-stage differential pressure of 7% and 17%, respectively, and a 6% and 17% increase in first- and second-stage specific flux, respectively. The cleaning also resulted in a 11% increase in second-stage permeate conductivity and salt passage, as indicated in Figures 7 and 8. This suggests that the cleaning protocol utilized was effective at restoring the pilot unit's membrane element performance.

When comparing the Phase 2A start-up conditions to the averages over the most recent week of Phase 2E operation the feed pressure has increased by 18%, the first- and second-stage differential pressure increased by 19% and 16% respectively, the first-stage specific flux decreased by 15%, and the second-stage specific flux decreased by 23%. Additionally, first-stage permeate conductivity decreased by 18%, while second-stage permeate conductivity increased by 16%, respectively. This data suggests that the City's pilot unit is currently due for a cleaning. The next cleaning is scheduled to occur in May 2021, with assistance from Hydranautics, and will generally include a high-pH (Caustic and EDTA) cleaning followed by a low-pH (Citric Acid) cleaning, similar to the cleaning that occurred in June 2020.

In general, throughout pilot testing the pilot unit has had relatively stable performance and permeate quality, and continues this trend with the current membrane element loading configuration, at current operating conditions, and both the permeate iron and total hardness concentration have typically conformed to the specified permeate quality requirements. The City will continue to monitor the pilot unit's performance and modify its operating conditions to further optimize the performance of the membrane elements in the full-scale NF process stream without the use of chemical treatment.

NF Membrane Element Replacement Project and Performance

Project Background
In May 2019, the City advertised bid documents for this project and following evaluation of bid packages, Hydranautics was identified as the low bidder. The City issued the Notice to Proceed to Hydranautics in December 2019 to commence work on the Nanofiltration Membrane Element Replacement Project. Under this project Hydranautics furnished and installed 1,827 membrane elements, with the objective of operating the City's full-scale NF process under conditions similar to Phase 2 of pilot testing (average flux of 12.2 gpd, a recovery rate of 82%, and without acid and antiscalant chemical pretreatment pretreatment).

As previously indicated, the membrane elements that previously populated the City's full-scale NF units were ESNA1-LF & ESNA1-LF2 membranes that were loaded and started up in March to July 2009, therefore most of them were a few months shy of being 11 years old when changed out in January to March 2020. The existing elements exceeded the expected 7-year service life expectancy, and the observed flux decline, higher feed and differential pressures, increased salt passage were all due to aging and increased resistance built up inside these elements. All of these factors contributed to why the membrane elements required replacement in 2020.

Membrane Replacement
Membrane element replacement began in January 2020. The initial loading configuration was a hybrid design of low pressure reverse osmosis (RO) membrane elements and NF membrane elements, consistent with the configuration of the pilot unit during Phases 2C through 2E of pilot testing (seven ESPA4-LD membrane elements in the first-stage and seven ESNA1-LF2-LD membrane elements in the second-stage). When the first NF unit (NF-3) was loaded and started-up, it was discovered that the membrane element loading configuration not meeting the specified permeate quality goals, as presented in Table 2. Specifically, it was found that NF-3 was rejecting too much hardness and producing a permeate with a total hardness of 17 mg/L as $CaCO_3$, instead of the specified great than 25 mg/L as $CaCO_3$.

To address this, Hydranautics made the decision to use a first-stage vessel and a second-stage vessel in NF-3 to test modified membrane element loading configurations that would achieve a hardness passage to meet specified permeate quality goals. In order to increase salt passage less RO membrane elements and more NF membrane elements were required. However, salt passage had to be limited to an extent to achieve a specified permeate iron concentration less than 0.20 mg/L. Meaning that the first-stage required less ESPA4-LD and more ESNA1-LF2-LD membrane elements, instead of seven ESPA4-LD membrane elements.

Hydranautics tested various ESPA4-LD to ESNA1-LF2-LD ratios in NF-3's first-stage test vessels (e.g., 6:1, 5:2, 4:3, and 3:4). Each time the unit was restarted, it was given time to stabilize before reading for conductivity and sampling for first-stage, second-stage, and total permeate total hardness and iron. After testing, it was determined the most favorable results came from the 3:4 split of ESPA4-LD and ESNA1-LF2-LD membrane elements in the first-stage, while maintaining seven lower rejecting ESNA1-LF2-LD membrane elements in the second-stage. To achieve this configuration on NF-3, Hydranautics moved the first four higher rejecting ESNA1-LF2-LD elements out of the second-stage, placed them into the four positions of the first-stage, and then loaded four lower hardness rejecting ESNA1-LF2-LD elements into the second-stage. Figure 9 presents the original (Hybrid 1) and modified (Hybrid 2) membrane element loading configurations. The Hybrid 2 membrane element loading configuration was ultimately utilized on the City's five full-scale NF units.

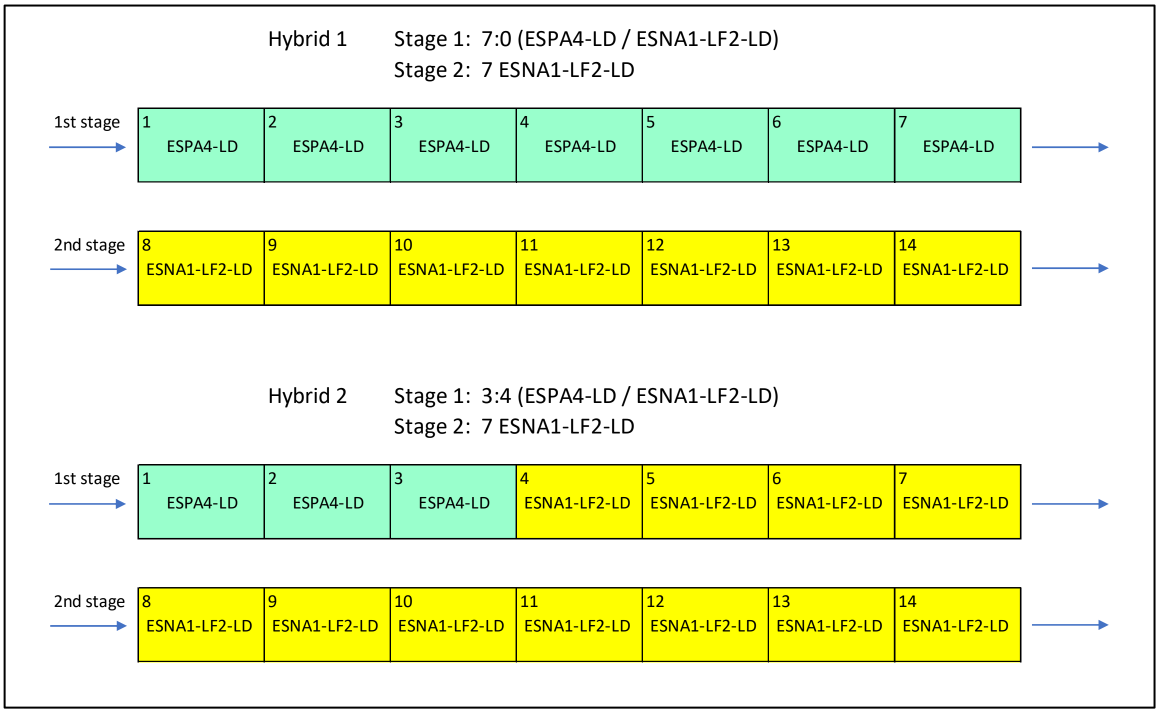

Figure 9 – Membrane Element Loading Configurations

Performance Acceptance Testing

Once satisfied with the new membrane element loading configuration in NF-3, Hydranautics was required to complete performance acceptance testing of the unit before proceeding with membrane element replacement the next NF unit. Performance acceptance testing (PAT) consisted of a seven-day test where the NF unit's performance was monitored and recorded on an hourly basis for review and acceptance by McCafferty Brinson Consulting, LLC (MBC) and the City with respect to the specified permeate quality and membrane performance parameters. The results of the PAT for each NF unit are presented in Table 3.

It should be noted that, NF-3 netted a 22.3 total hardness during PAT. This was acceptable to MBC, the City, and Hydranautics based on observations made during the pilot testing that indicated that the membrane element would pass more total hardness and alkalinity over time while continuing to reject iron and produce water with low TTHM and HAA5 formation potential.

Table 3 – Performance Acceptance Testing Results

Constituent/Parameter	Units	Avg Feed	Specified Limits	**NF-3** Permeate	**NF-1** Permeate	**NF-5** Permeate	**NF-4** Permeate	**NF-2** Permeate
Bicarbonate ion	mg/L as $CaCO_3$	213.2	25-75	30.9	37.2	34.8	33.7	33.6
Color	CU	68	< 3.0	5.0 *	5.0 *	5.0 *	5.0 *	5.0 *
Total Dissolved Solid	mg/L	306.8	< 200	56	56	61	69	78
Total Hardness	mg/L as $CaCO_3$	225.8	> 25.0	22.3	25.4	24.4	30.0	30.6
Iron	mg/L	1.252	< 0.20	0.113	0.117	0.116	0.162	0.171
Total Organic Carbon	mg/L as C	13.12	< 1.0	0.50 **	0.50 **	0.50 **	0.50 **	0.50 **
TTHM Formation Potential	mg/L	1.084	< 0.040	0.0074	0.0087	0.0095	0.0119	0.0118
HAA5 Formation Potential	mg/L	1.588	< 0.030	0.0071	0.0071	0.0087	0.0135	0.0131

* Pace Labs adjusted method detection limit for this test is 5.0 CU's
** Pace Labs adjusted method detection limit for this test is 0.50 mg/L

Membrane Performance
The City's 2020 NF Membrane Element Replacement Project reached final completion in May 2020. Since this time, the City's five NF units have been in-service with no chemical pretreatment for 14 to 15 months and no membrane element cleanings.

Since start-up, the NF unit feed pressure has increased 6-10%, with a 10-14% decrease in normalized permeate flow, and due to the organics present in NF process raw water there has been a decrease in salt passage (which has affected total hardness passage) and in permeate iron. This trend is a phenomenon that we have seen in other membrane plants in the area (e.g. the City of Boca Raton's NF process), a need to clean to get the organic layer off the membrane flat sheet. This will decrease the feed pressure, increase normalized permeate flow, and most importantly increase permeate hardness. It should be noted that generally there has not been a drastic increase in normalized differential pressures (6-10%), with the exception of NF-5. This NF unit's performance is indicating that it may be fouling at a higher rate than the City's other NF units. In an attempt to address the declined performance, the City intends to perform extended duration permeate flushes in preparation for upcoming mild membrane element cleanings, as recommended by Hydranautics.

To better understand the performance improvements associated with the 2020 membrane element replacement compared to 2009 membrane elements over comparable runtime (331 days); Figures 10 through 13 present NF unit 3's feed pressure, differential pressure, specific flux, and permeate conductivity, respectively.

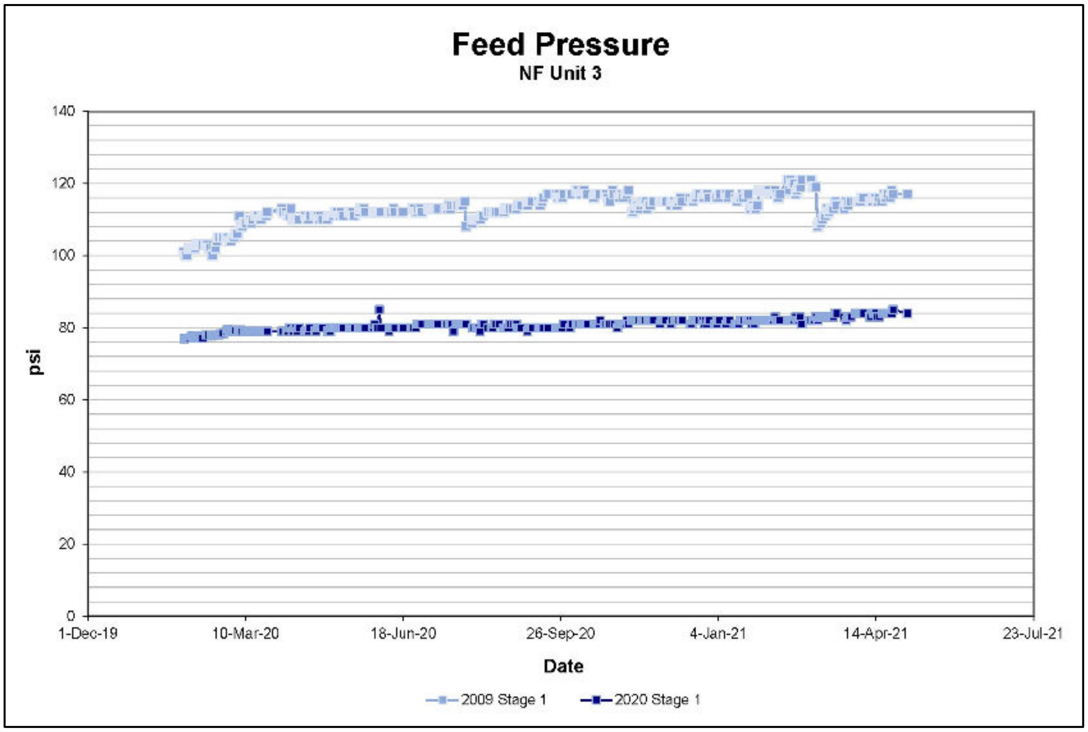

Figure 10 – 2009 and 2020 NF Unit 3 Feed Pressure

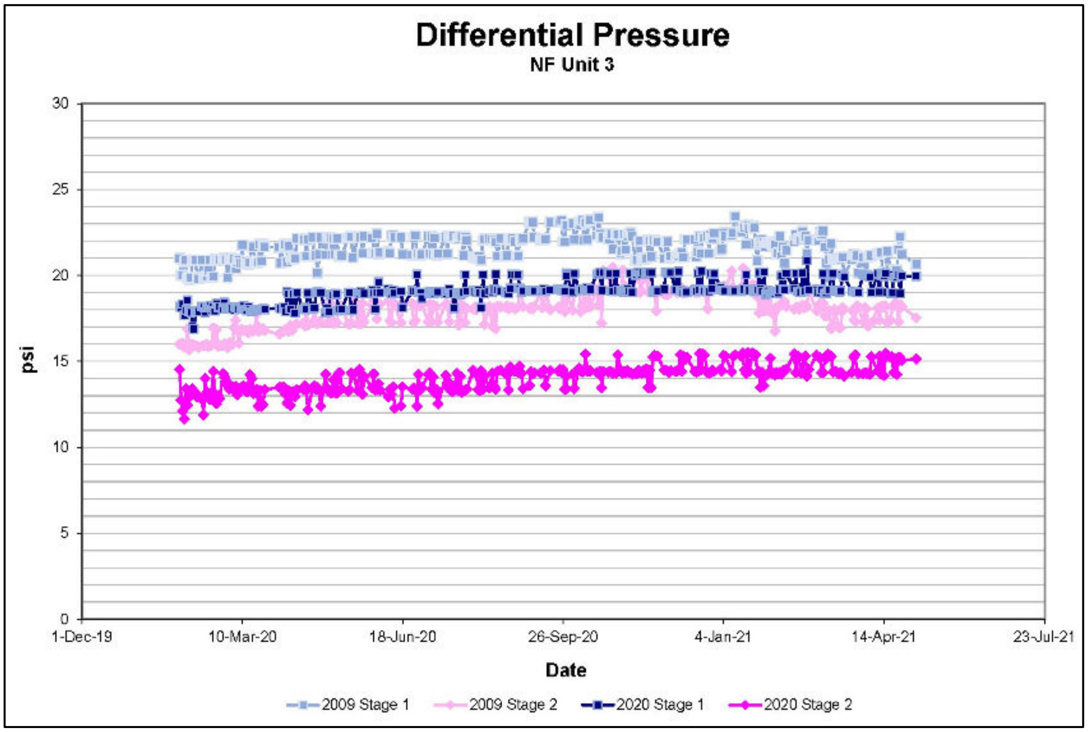

Figure 11 – 2009 and 2020 NF Unit 3 Differential Pressure

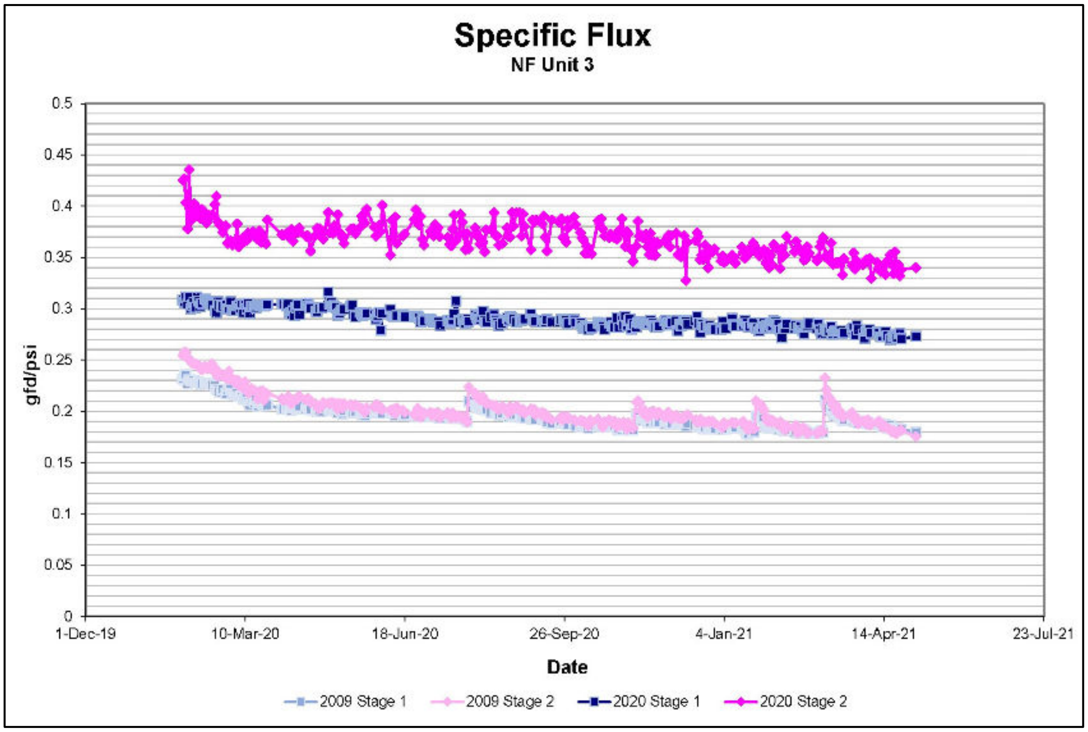

Figure 12 – 2009 and 2020 NF Unit 3 Specific Flux

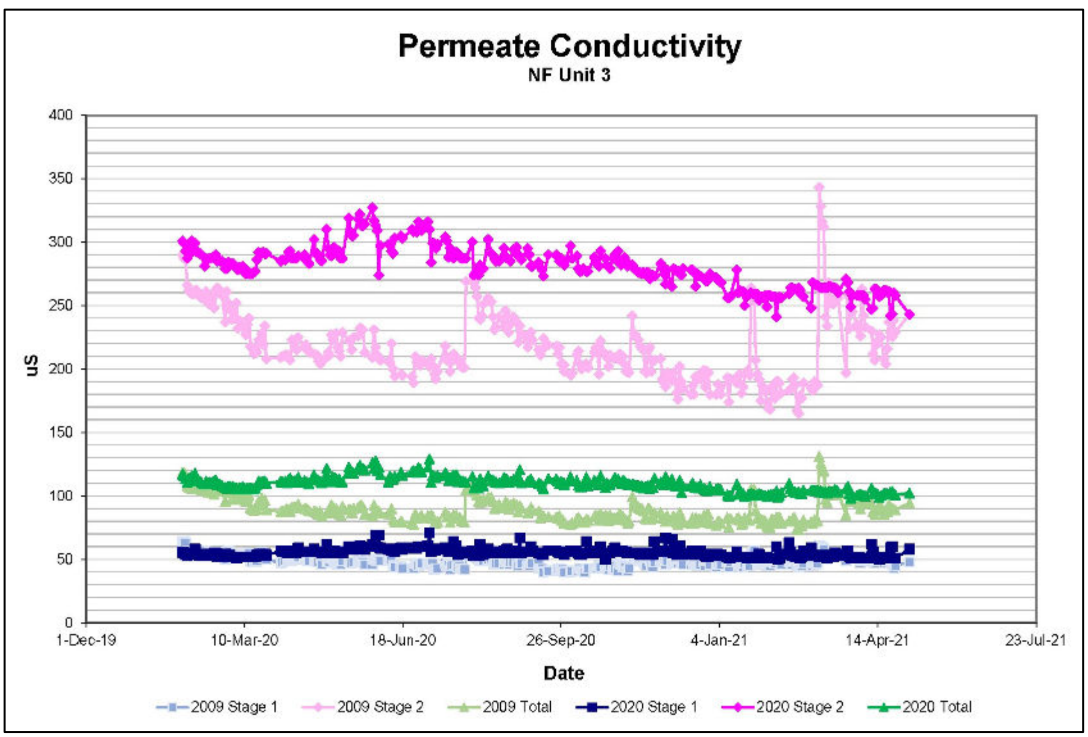

Figure 13 – 2009 and 2020 NF Unit 3 Permeate Conductivity

Notable improvements to NF Unit 3's performance parameters associated with the 2020 membrane elements, compared to the 2009 membrane elements, include the following:

Feed Pressure: At start-up, the 2020 membrane elements operated at a feed pressure of 77 psi, a 22% decrease compared to the 2009 membrane elements at start-up (99 psi). Over the first 331 days of runtime, the new membranes experienced a feed pressure increase of 9%, while the 2009 membrane elements experienced an increase of 17% over the same time period.

Differential Pressure: After 331 days of runtime the 2020 and 2009 membrane elements first- and second-stage differential pressure each increased by 2 psi and 3 psi, respectively. While that is not a big difference in pressure drop across both stages, Hydranautics has observed that the larger 34 mil feed channel spacer in the 2020 membrane elements allows for better restoration after cleanings, especially where the 2009 membrane elements 28 mil spacer had a faster, higher climb over time.

Specific Flux: After 331 days of runtime the first- and second-stage 2009 membrane elements experienced a 21% and 28% decrease in specific flux, respectively. After a comparable runtime, the first- and second-stage 2020 membrane elements experienced a 11% and 15% decrease in specific flux, respectively. A more gradual decrease compared to the 2009 membrane elements indicate that the 2020 membrane elements provide higher permeability, even with the low-pressure RO membrane elements in the front of the first-stage.

Permeate Conductivity: While both the 2009 and 2020 membrane elements appear to be quite similar, the total permeate conductivity for the 2009 membrane elements was between 80 and 90 µS/cm, and in permeate conductivity from the 2020 membrane elements is between 100 and 105 µS/cm, which corresponds to a permeate total hardness greater than 25 mg/L as $CaCO_3$ and a permeate iron less than 0.20 mg/L.

Since start-up, the membrane elements installed under 2020 NF Membrane Replacement Project have met the specified permeate quality and membrane performance requirements and have resulted in energy and chemical cost savings. Since membrane replacement the City has experienced an annual power cost savings of approximately $65,000 due to the decreased feed pressure of the NF Units and an saved an estimated $287,000 in annual pretreatment chemical costs. While the City is satisfied with the performance of the new membrane elements, and the associated cost savings, they are striving to further optimize their NF treatment process.

Continued Optimization

Because permeate from the pilot unit is recovered in the full-scale permeate stream, and concentrate is disposed of in the main concentrate header, the City is able to operate the pilot unit indefinitely, in parallel with the full-scale plant, without wasting permeate. This allows the unit to act as a true pilot-scale representation of the condition the full-scale plant. The City is currently planning to initiate the first cleaning of the full-scale NF unit membranes. In planning for the first cleaning, the pilot unit will be used to develop the optimum cleaning formula for the full-scale plant.