VOLUME 1

Observation and Evaluation of Pilot Testing of OVIVO RapidStorm Treatment System at King County

Volume 1: Report and Appendix A

Prepared for

King County

September 2021

Prepared by

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Parametrix
ENGINEERING . PLANNING . ENVIRONMENTAL SCIENCES

VMS
Value Management Strategies

September 2021 | 216-7922-002

CITATION

TetraTech, Parametrix, and Value Management Strategies. 2021. Observation and Evaluation of Pilot Testing of Ovivo RapidStorm Treatment System at King County. Prepared by TetraTech, Parametrix, and Value Management Strategies. September 2021.

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ACRONYMS AND ABBREVIATIONS

µg	micrograms
µS	microsiemens
ACH	aluminum chlorohydrate
BOD	biochemical oxygen demand
BOD5	5-Day Biochemical Oxygen Demand
C	Celsius
Ca	Calcium
$CaCO_3$	calcium carbonate
CIP	clean-in-place
Cl_2	Chlorine
cm	centimeter
cm^{-1}	reciprocal centimeter
COD	Chemical Oxygen Demand
County	King County
CSO	combined sewer overflow
Ecology	Washington State Department of Ecology
EFF	Pilot Effluent
FOG	fats, oils, and grease
gfd	gallons per square foot per day
gph	gallons per hour
gpm	gallons per minute
HEM	Hexane Extractable Material
HRT	Hydraulic Retention Time
INF	Pilot Influent
L	liter
Mg	Magnesium
mg	milligrams
mL	milliliter
MPN	most probable number of cells
N	Nitrogen
NaOCl	sodium hypochlorite
NaOH	sodium hydroxide

ACRONYMS AND ABBREVIATIONS (CONTINUED)

nm	nanometers
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity units
P	Phosphorus
PE	Primary Effluent
ppm	parts per million
psi	pounds per square inch
scfm	standard cubic feet/minute
sCOD	Soluble COD
SiC	silicon carbide
SS	Settleable Solids
SSOs	sanitary sewer overflows
tCOD	Total COD
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TMP	transmembrane pressure
TNK	Membrane Tank
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UV	ultraviolet
UV254	UV absorbance at 254 nanometers
UVT	UV Transmittance
VSS	Volatile Suspended Solids
West Point	West Point Treatment Plant

EXECUTIVE SUMMARY

King County is investigating combined sewer overflow (CSO) treatment options for new CSO treatment facilities and to cost-effectively improve the quality of the discharge from its existing CSO treatment facilities to meet or exceed requirements of the County's National Pollutant Discharge Elimination System (NPDES) permit (WA0029181) and the consent decree with the Washington State Department of Ecology and the U.S. Environmental Protection Agency. This report evaluates the performance of the Ovivo RapidStorm Treatment System, a new technology that uses aluminum-based coagulation and silicon carbide (SiC) membrane filtration to treat CSO prior to discharge into a receiving water.

Based on performance testing that King County and the manufacturer (Ovivo) conducted in Austin, Texas, in 2017, King County leased a 200-gallon-per-minute pilot treatment unit for long-term testing at the West Point Treatment Plant (West Point). The pilot testing used the technology to treat diluted and undiluted primary effluent from West Point, which served as a surrogate for CSO wastewater.

The Ovivo pilot was originally envisioned to be tested at the Elliott West Wet Weather Treatment Station; however, in 2019 a determination was made to locate the pilot unit at West Point. Having the pilot unit at West Point allowed for the ability to conduct testing with primary effluent on demand as opposed to opportunistic testing only during wet weather events at Elliott West.

Preliminary Tests

Bench tests and a series of preliminary test runs were conducted at West Point to establish operational criteria for detailed process and performance pilot testing of the RapidStorm system. Between July 29, 2019, and August 27, 2020, 34 preliminary test runs were completed to establish the manufacturer's operational criteria for coagulant type (chemical selection) and dosing strategy, 24-hour continuous pilot operation, multiple peak flux conditions, cleaning optimization, clean-in-place (CIP) procedures, and system testing and modification.

Process and Performance Tests

Process and performance pilot testing at West Point established a baseline of system performance and confirmed operational criteria defined by Ovivo from the preliminary testing at West Point. Eleven test runs and four supplemental test runs were completed between September 3, 2020, and November 17, 2020, to verify the following:

- Effluent water quality
- Operational criteria
- Other considerations relevant to the implementation of a full-scale system

Effluent Water Quality

The process and performance pilot testing demonstrated the performance of treatment and the ability to meet discharge permit requirements under test conditions as follows:

- Total suspended solids (TSS) removal efficiencies from all pilot test runs ranged from 88 percent to 100 percent, far better than the 50 percent removal required by the County's NPDES permit.
- Fecal coliform bacteria analyses of the effluent during pilot testing showed results consistently lower than the permit-defined maximum monthly geometric mean of 400 most probable number of cells (MPN) per 100 milliliters.
- Effluent settleable solids results were measured well below the 0.3 milliliter per liter per hour annual average permit-defined maximum for settleable solids.
- pH of the effluent measured during pilot testing decreased to lower than the permit-defined limit of 6.0 during several test runs. This indicates a need for supplemental pH adjustment in a full-scale application.
- The testing showed excellent average removal efficiencies (90 percent or higher) for copper, lead, and total phosphorus, with varying degrees of removal for other metals and organics (non-permit parameters).

Manufacturer's Operational/Design Criteria Comparison to Test Results

Table ES-1 summarizes the manufacturer's operational criteria and confirmed results from the process and performance pilot tests. Overall, the pilot testing confirmed the operational criteria developed by Ovivo. The pilot unit was able to achieve the desired instantaneous flux rates defined by Ovivo but required that the coagulant dosing be increased to 0.6 milligram (mg) of aluminum (Al) per mg of influent TSS for a 0.6 Al:TSS dose ratio.

Table ES-1. Operational/Design Criteria Confirmation

Description	Manufacturer's Criterion	Tested Results	Results Meet Criterion
Peak Day – 24 Hour Flux Rate	100 gfd[a]	24+ hours @ 0.6 Al:TSS dose ratio	✓
Peak 16 – Hour Flux Rate	125 gfd	16+ hours	✓
Peak 12 – Hour Flux Rate	150 gfd	12+ hours	✓
Peak 8 – Hour Flux Rate	175 gfd	8+ hours	✓
Peak 4 – Hour Flux Rate	200 gfd	4+ hours	✓
Peak Hour Flux Rate	225 gfd	1+ hours	✓
Coagulant Dosage with Aluminum Sulphate Expressed as Aluminum (Al)	0.4 Al/(influent) TSS dose ratio	Increased to 0.6 Al/TSS dose ratio	
Recommended Maximum Suspended Solids	6,000 mg/L[b]	Preliminary Testing at 6,000 mg/L	✓
Membrane Clean-in-Place Soak Duration	Minimum of 4 hours (Typical)	Tested at 30-minute short clean.[c]	✓

a gfd = gallons per square foot of membrane per day

b mg/L = milligram per liter

c Several 30 Minute CIP were preformed and effectiveness was based on the recovery of the membranes

Implementation of Full-Scale Facility Design

As a result of the process and performance pilot testing, data analysis, and field observations, the following lessons learned, and innovations have been identified for future consideration:

- **Air Entrainment:** Air entrainment interfered with turbidity and flow meter readings at test run startup. This can be avoided in the future by designing the permeate header to avoid entrapped air or installing a system to remove entrapped air.
- **Solids Wasting:** Design must address solids wasting in order to maintain optimum solids concentrations. Data suggests that the maximum desired solids level is somewhere between 4,000 and 6,000 mg/L TSS due to changes in flux at those higher solids levels.
- **Scum and Foam:** For a full-scale facility design, scum and foam will need to be addressed. Given access to an adequate source of permeate water, using sprays to control foam or surface scum removal (i.e., floating scum device) should be evaluated. A defoaming agent could also be evaluated.
- **Instrumentation and Controls:** TSS measurement on a full-scale facility would need to be designed to provide accurate measurements with a high correlation to lab-tested TSS. Monitoring similar to that used for the pilot testing is appropriate and may be supplemented with additional monitoring for biochemical oxygen demand, total organic carbon (TOC), alkalinity, and pH. These monitors are used at treatment plants and it would have to be determined if it is suitable for CSO applications.
- **Chemical Addition:** When a coagulant is used, there must be consideration of the impact to alkalinity to meet permit pH requirements. Final chemical selection will require consideration of application location, control, safety, handling, storage, availability, and environmental requirements.
- **Mixing:** Coagulant mixing should be included in any full-scale design. Alternatives to the in-line mixing used in the pilot testing should be evaluated.
- **Dosing Control:** TSS was used as the indicator for dosing control. More work should be done to evaluate other means of dosing control to determine the most suitable for full-scale operation of a CSO treatment plant.
- **Storage Requirements:** Storage will be required for three chemicals types: coagulant, CIP chemicals, and alkalinity adjustment. CIP chemicals are not anticipated to require significant space, but coagulant and alkalinity adjustment will require significant space.
- **Basin Cleaning:** The pilot membrane basin was equipped with a flushing device that flushed debris deposited at the bottom of the membrane tank to a drain at the end of each test run. Total basin cleaning was not specifically addressed during the pilot tests. Spray nozzles could be positioned above the membranes to wash any residuals from the surface of the membrane. Permeate could also be used in a flushing device such as a tipping bucket to flush solids from the basin floor.

- **Screening:** Materials that could block or clog the space between the membranes need to be removed upstream of the membrane tank. The spacing between the membranes in the pilot module was 6.7 mm, so a screen with 6 mm openings was used.
- **Membrane Integrity:** Before effluent bacteria testing results are available, which can take several days, turbidity is used as an initial indicator of piping and membrane integrity. It would be prudent to develop testing protocols in the event that elevated turbidity values (turbidity spikes) are encountered.

Conclusions

Pilot testing of the RapidStorm technology demonstrated its performance and areas for innovation at full scale. Further evaluation as a full-scale alternative for CSO treatment is necessary to determine whether the technology is financially viable or otherwise advantageous for a specific site. Additional system testing of this technology on actual CSO wastewater would serve to further validate the test results from West Point.

1. INTRODUCTION

1.1 Background

King County (the County) is investigating additional options for combined sewer overflow (CSO) treatment for new CSO facilities and to improve the quality of discharge from its CSO treatment facilities. The goal is to meet or exceed requirements of the Washington State Department of Ecology (Ecology), the National Pollutant Discharge Elimination System (NPDES) permit, and the County's consent decree with the U.S. Environmental Protection Agency, while saving capital costs associated with the County CSO Program.

Tetra Tech and Parametrix assisted the County in evaluating a new technology for CSO treatment that uses a physical chemical coagulation filtration process incorporating aluminum (Al) coagulation and a silicon carbide (SiC) membrane filter. The technology produces high-quality effluent and could be used to treat some or all of the flow from a CSO site prior to discharge into surface water. The equipment used for the technology has the potential to have a small footprint.

The technology is the Ovivo RapidStorm Treatment System, which is patterned after Ovivo's stormBLOX side-stream process. RapidStorm uses a SiC membrane and is designed for treatment of CSOs and sanitary sewer overflows (SSOs). Ovivo states that RapidStorm can be activated rapidly during wet weather to treat CSO and SSO flows.

King County, Tetra Tech, and Parametrix participated in Ovivo's initial performance tests conducted over 3 days in October 2017 using various test scenarios at a pilot treatment plant in Austin, Texas. The results are described in the report titled *Alternative CSO Treatment Technology; Ovivo stormBLOX Manufacturer Testing and Evaluation* (Tetra Tech and Parametrix, December 20, 2017).

Based on the positive results of the performance testing conducted in Austin, King County leased a 200-gallons per minute (gpm) pilot treatment plant (capacity at a flux of 100-gallons per square foot per day [gfd]). This pilot plant was used for long-term pilot testing of the new treatment technology at the West Point Treatment Plant (West Point). The pilot testing used the Ovivo SiC membrane technology to treat West Point primary effluent, with and without dilution, as a surrogate for CSO water with many properties similar to CSO water. The pilot testing at West Point consisted of three phases:

- **Bench-scale Tests**: In preparation for the pilot testing, King County conducted bench-scale tests at West Point using a single SiC membrane plate. The bench-scale testing investigated different coagulants, coagulant concentrations, and cleaning chemicals for the membranes. The results of this bench-scale testing informed the development of the next two phases of testing at West Point.
- **Preliminary Tests**: A series of preliminary tests was conducted by King County and Ovivo using the 200-gpm pilot treatment plant at West Point to establish key design criteria for the SiC membrane technology. The results of the preliminary tests informed the development of the last phase of testing at West Point. These results are discussed in a preliminary testing report developed by Ovivo. A summary of preliminary testing results is in Section 3.1.
- **Process and Performance Tests**: This report describes the results of the process and performance tests at West Point. The process and performance tests were conducted to confirm the key design criteria established by Ovivo and to measure other performance attributes of the technology.

1.2 Manufacturer's Performance Claims

The potential advantages of the SiC membranes compared to other CSO treatment methods include the following:

- Rapid treatment at the onset of a storm
- A physical barrier against solids and bacteria
- A compact footprint
- 24-hour continuous operation
- Consistent treatment despite variable water quality conditions and flow rates
- Resilient to some equipment failure, such as blowers
- Tanks can be emptied, and membranes left dry

With these advantages, the system has the potential to provide significant benefits in CSO treatment, especially in urban areas where space is limited for settling tanks and chlorination and dechlorination contact time, and where rapid startup is needed to treat sudden increases in flow. Additionally, resilience to equipment failure and reliability under variable conditions are important for CSO applications where operators are frequently not on-site and equipment operation is intermittent.

The manufacturer's specific design criteria related to many of the above claims are listed in Section 3.1.11.

1.3 Pilot Test System Configuration

1.3.1 Influent Water Source

Influent for the pilot test consisted of primary effluent from West Point and simulated CSOs created by diluting primary effluent with potable water. The primary parameter used to establish dilution ratios was total suspended solids (TSS), with BOD as a secondary parameter. Table 1-1 shows basic water quality information for the West Point undiluted primary effluent, diluted primary effluent, and CSO from the Elliott West CSO Treatment Plant. Note that the West Point treatment system is a combined sewer system, so water quality can vary substantially due to weather. Data for the primary effluent was observed during the test runs. Note that while the CSO water quality varies substantially, it skews towards the lower values of total suspended solids (TSS) and biochemical oxygen demand (BOD) rather than the high end.

Table 1-1. Basic Water Quality Parameters for West Point Primary Effluent and Elliott West CSO Water

	Undiluted Primary Effluent (PE)	2 Potable: 1 PE	Elliot West CSO
TSS	15-95	5-35	0-450 (median 80)
BOD	40-160	10-35	0-100
pH	6.6-7.3	7.2-7.5	4-9
Alkalinity	60-195	60-140	No Data

Note: Primary effluent and diluted primary effluent data taken during pilot testing. Elliot West CSO water quality was historical data from 2013 to 2018.

Conducting the process and performance pilot test runs at West Point provided the following benefits versus testing the pilot at a CSO treatment facility:

- A continual supply of low TSS water (primary effluent) and potable water for dilution
- Convenient access for King County engineering, operations, and laboratory staff
- Operational control to schedule and conduct tests, instead of waiting for CSO events to occur

Although there are differences in water quality between West Point primary effluent and true CSOs, the West Point test runs provided useful information to address pilot program objectives.

1.3.2 Pilot Plant Layout

The pilot plant is shown in Figure 1-1, and a basic process diagram is shown in Figure 1-2. The pilot consisted of a prefabricated unit housing the influent screen, membrane tank and membranes, permeate/backwash pumps, chemical feed pumps, permeate tank, air scour blowers, programmable logic controller (PLC), and related electrical and instrumentation/control appurtenances. Influent, effluent, and wasting piping was connected to the unit. Influent and effluent samples were taken from the influent pipe and the permeate pipe, respectively. Coagulant (and caustic soda in Test Run 1) were injected into the influent pipe.

Figure 1-1. Picture of the Pilot Unit

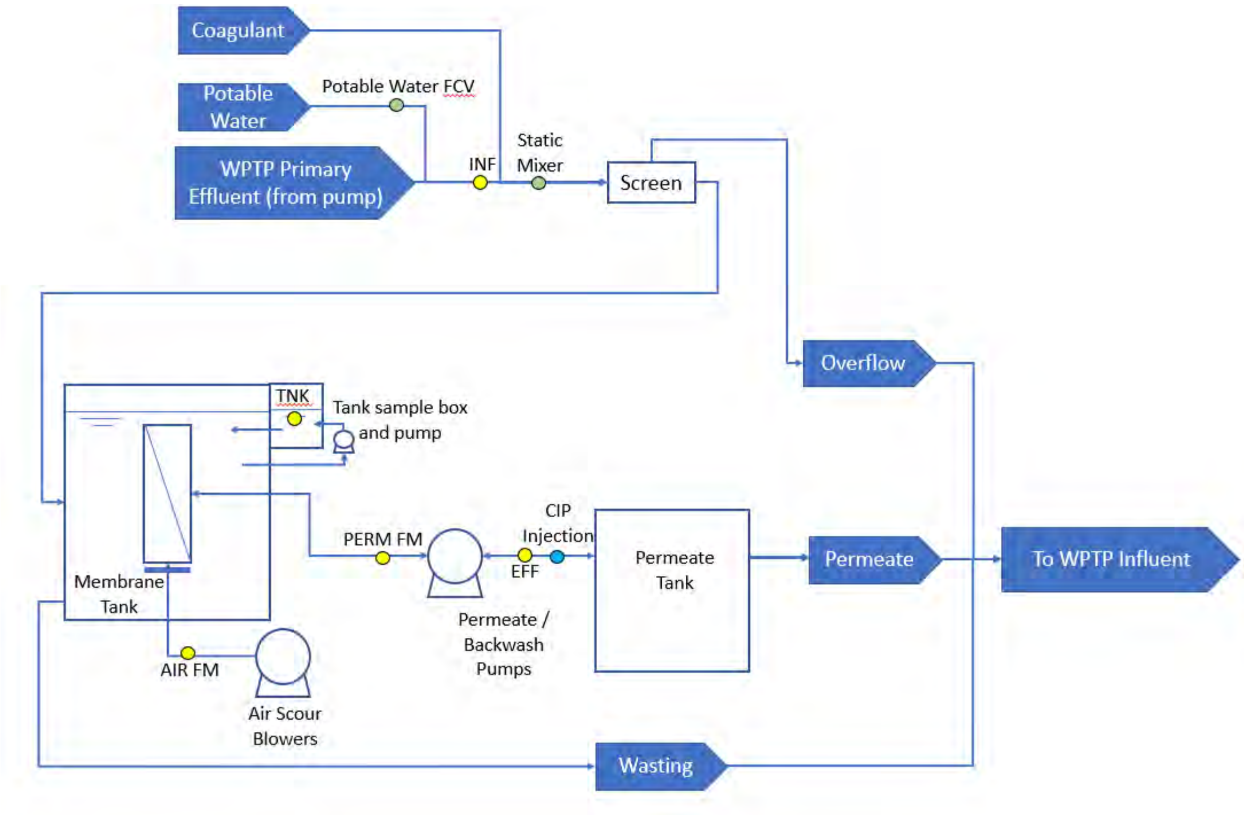


Figure 1-2. Pilot Unit Process Diagram

Notes: INF = influent TSS probe, flow meter, and sample location; TNK = tank TSS and conductivity probes; EFF = effluent pH and turbidity probes and sample location; PERM FM = permeate flow meter; AIR FM = air flow meter; FCV = flow control valve

Influent entered the influent screen at a constant rate, based on a constant-speed submersible pump delivering primary effluent to the unit and the potable water flow control valve setting. The flow control valve was set manually. Water flowed from the screen into the membrane tank based on the level in the tank and excess influent flowed to an overflow box and drainpipe back to West Point.

Water could also flow over a weir out of the membrane tank into the overflow to prevent the level in the membrane tank from getting too high. This inadvertently occurred during membrane backwashing, which led to wasting of membrane tank solids during test runs. The overflow was returned to the treatment plant (see Figure 1-3).

Figure 1-3. Permeate Tank Overflow Pipe (behind staircase) and Membrane Tank Overflow Pipe (right of staircase)

The membrane tank contained three SiC membrane stacks, each with a surface area of 975 square feet, for a total surface area of 2,925 square feet. Each membrane stack consisted of 15 modules with 40 membrane plates each (for a total of 600 plates per stack). Each stack had an air diffuser for scour air, with blowers located on the upper deck of the unit. The dimensions of the membrane tank were 3.75 feet wide and 10.75 feet long, for a surface area of 40.3 square feet. An additional 3.75-foot by 3.75-foot area (14.1 square feet) in the membrane tank was used for the automatic tank flushing system, for a total tank area of 54.4 square feet. The side-water depth is 10 feet for a tank volume of approximately 3,600 gallons. See Figure 1-4 for a rendering of the pilot unit configuration, including cutaway showing the membrane stacks.

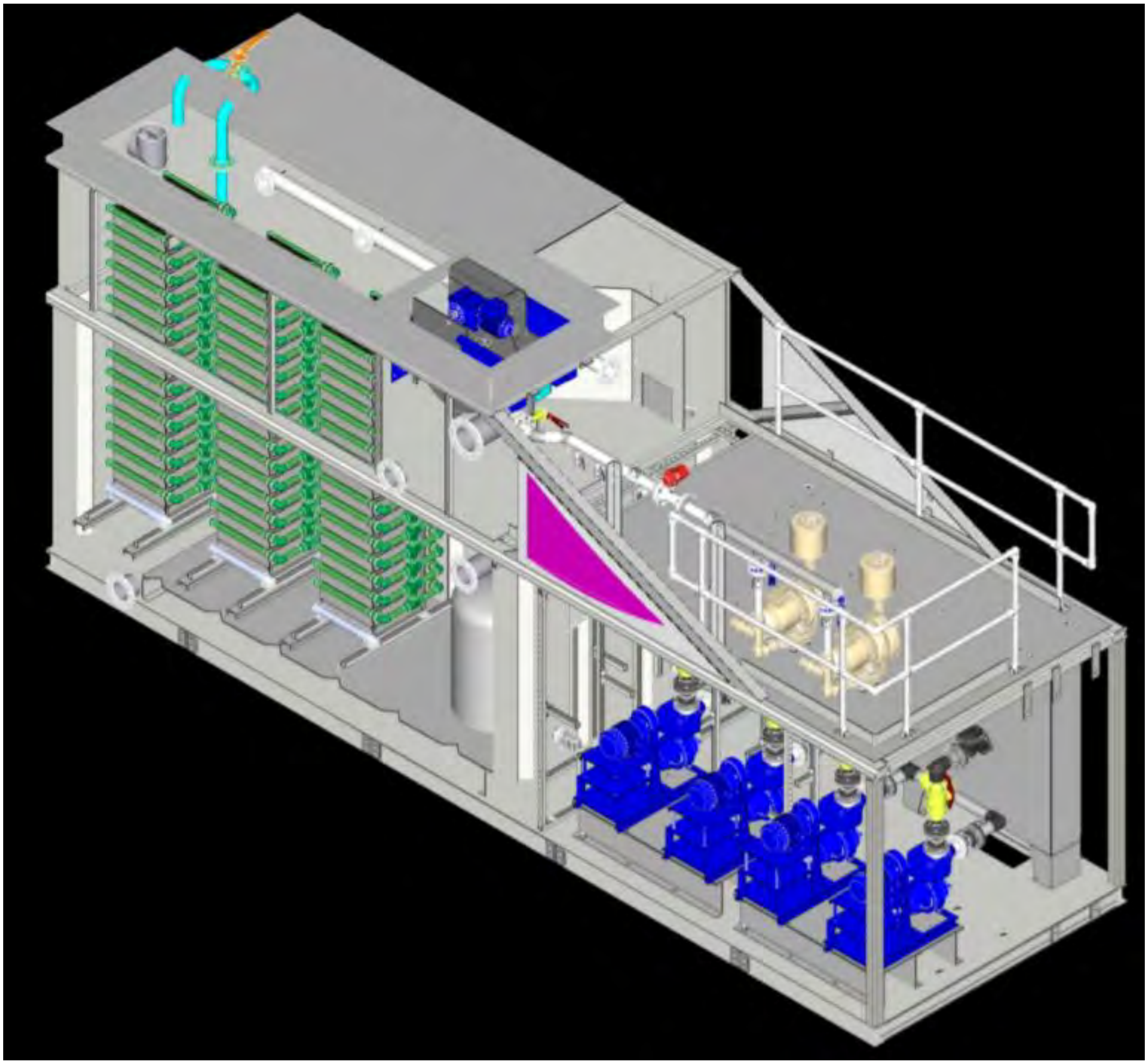


Figure 1-4. Preliminary Pilot Unit Rendering Showing the Stacks Inside the Membrane Tank
Note: The final unit only had three permeate/backwash pumps rather than four as shown

Permeate/backwash pumps (see Figure 1-5) pulled permeate through the membranes and pumped it into the permeate tank, which was adjacent to and the same size as the membrane tank. These pumps also ran in reverse to push backwash from the permeate tank through the membranes.

There were two wasting lines from the membrane tank, but they were not used during process and performance testing. The preliminary testing found that no wasting was necessary because solids wasting from the overflow during backwash cycles limited the solids accumulation, and thus concentration, in the membrane tank.

Permeate left the permeate tank via an overflow pipe (see Figure 1-3), which directed it back to the treatment plant influent.

Figure 1-5. Pilot Unit Equipment Area, with Permeate/Backwash Pumps (bottom front), Chemical Feed Pumps (back wall), PLC (cabinet behind ladder), and Blowers (upper)

Peristaltic chemical feed pumps (see Figure 1-5) were used to feed coagulant and caustic soda (Test Run 1 only) to the influent, and caustic soda, sodium hypochlorite (NaOCl), and citric acid for the clean-in-place (CIP). Coagulant was fed to the influent line just before a static mixer (Figure 1-5, lower left). Caustic soda was fed to the influent line about 10 feet downstream of the static mixer.

Influent and effluent samples were collected from saddle taps on the influent and permeate pipes. The influent and effluent samples passed through a bucket to the drain. The effluent sample bucket is shown in Figure 1-6. Grab and composite samples were collected from these buckets except for fecal coliform grab samples which were collected from a dedicated sample tap. The effluent pH probe was located in the effluent sample bucket. The influent TSS probe was located in a pipe spool on the influent pipe upstream of the chemical addition locations.

Figure 1-6. Effluent Sample Line and Sample Bucket

The following equipment was located on the pilot unit skid:

- Influent screen
- Membranes (three stacks) and membrane tank
- Permeate tank
- Permeate/backwash pumps (three)
- Chemical feed pumps (three)
- Control system

- Blowers (two) and diffusers
- Instrumentation, including effluent pH and turbidity probes, permeate flow meter, air flow meter, basin TSS and conductivity probes, level sensors, and pressure transducers.

The following equipment was not located on the pilot unit skid:

- Influent pump to provide primary effluent
- Influent, effluent, wasting, and overflow pipes
- Static mixer
- Composite samplers
- Influent TSS probe
- Chemical totes and drums

1.3.3 Controls and Data Acquisition

Control of the unit was done through the control touchscreen (PLC human machine interface [HMI]) located on the unit's electrical panel. Through this panel, operators could start and stop the pilot, initiate a CIP or end-of-event, and perform other functions. Additionally, operators could adjust the various setpoints of the pilot. Many aspects of pilot operation are available as operator setpoints, including the following:

- Filtration mode duration and backwash cycle timing, duration, and flow
- Coagulant dose or dose ratio depending on the coagulant control mode
- High transmembrane pressure (TMP) limit
- Air scour flow rate
- CIP chemical flow rates and durations

The unit's control panel also collected data from the various instrumentation and equipment and stored that in the unit, where it could be retrieved manually. Additionally, a cellular modem transmitted selected operating data via cellular signal and the internet. During the test runs, this data was stored by WaterExpert, Ovivo's web-based monitoring and data storage platform, which allowed the unit to be remotely monitored in real time. The WaterExpert website also enabled data to be downloaded in spreadsheet format for analysis.

1.3.4 Pilot Operation

For each test, the operators set the dose control strategy and influent flow rate, then the pilot unit controlled the membrane system largely automatically during the test runs. Operators monitored the pilot and intervened occasionally to adjust dosing strategy. Operators were also required to change the permeate flow rates in accordance with the test plans.

1.3.4.1 Test Run Operation Description

To start the unit, the operators activated the unit on the control screen, which caused the unit to arm and begin dosing coagulant at a set flow rate while the pilot unit filled. The operator then started the influent pump, supplying primary effluent, and adjusted the influent valves, controlling potable water flow as necessary for the test. The influent flowed through the screen and began filling up the membrane tank. After an initial period of dosing coagulant at a set flow rate, when the membrane tank filled to a set operating level, the unit changed to dosing based on the influent TSS probe and the operator setpoint aluminum-to-TSS (Al:TSS) dose ratio. When the water reached the operating level in the membrane tank, the permeate pumps started, and the unit began to operate in filtration mode.

Filtration mode consisted of 13 minutes of filtration, 30 seconds of relaxation, 60 seconds of backwash, and 30 seconds of relaxation; then another filtration cycle began. This cycle continued until the unit was stopped or high TMP was reached.

Following a run, a CIP procedure was manually initiated at the pilot unit control screen. The pilot unit automatically controls CIP chemical dose, soak time, and flushing based on the operator set chemical injection rates of sodium hypochlorite and sodium hydroxide (NaOH), injection time, and soak time. Following the CIP, the tanks were drained to prepare for further tests. Prior to the CIP, the operators stopped the influent flow pump and closed the related valves.

The pilot unit was left empty between testing runs.

1.3.4.2 Automated Control Narrative

Significant aspects of the pilot unit operation were automated, including the following:

- Permeate flow: The permeate flow, relax, and backwash cycle was controlled automatically based on operator set durations. Additionally, if the water level in the membrane tank was below the operating level, the unit would not allow the permeate pumps to start until the water level rose to the operating level. Thus, it responded automatically to lack of influent flow or resumption of influent flow, as appropriate.
- Coagulant dose: The coagulant injection could be a set flow rate, flow-based dosing, or it can be based on influent flow meter and influent TSS probe readings. In this latter mode, which was used throughout the testing, the operator set an Al:TSS ratio, and the coagulant flow rate was automatically varied based on the mass load of influent TSS to maintain the set Al:TSS ratio.
- TMP-based shutdown: The system monitored the TMP and would automatically run a backwash cycle if the TMP rose too high. If the TMP was not reduced adequately by the backwash cycle, the system automatically shut the system down to prevent excess membrane pressure.
- CIP: A CIP was initiated manually by the operators. Once initiated, however, it proceeded automatically through the chemical injection, soak, and flushing phases according to operator setpoints.

1.3.4.3 Operation and Maintenance

Operators knowledgeable about the system and its operation were required for several tasks. Tasks specific to test run operation included the following:

- Initiating influent flow to the pilot and adjusting influent flow rate and dilution ratio per the test plan
- Setting the desired coagulant dose ratio and flux setpoints and adjusting them per the test plan

- Monitoring the TMP and the TMP rise rate during operation and adjusting the coagulant dose ratio and/or influent flow appropriately
- Collecting samples for analysis and performing field measurements
- Initiating the post-event cleaning
- Noting the header pressure during a CIP and the TMP after a CIP to determine whether the CIP was effective prior to starting a subsequent test
- Securing the membrane system between runs
- Downloading data

Between runs, additional operator tasks included:

- Cleaning and calibrating the various instruments, as necessary
- Checking that equipment was operable, and maintaining it, as necessary
- Verifying sufficient chemical supply was available for the anticipated test runs

1.4 Performance Testing Objectives

The purpose of the process and performance pilot testing at West Point was to evaluate the performance of the unit for treating CSO discharges, to verify the manufacturer design criteria, and to determine effluent quality and removal efficiency of a variety of water quality constituents, including organic carbon species, nutrients, and metals in addition to the permit parameters of TSS, settleable solids, and fecal coliforms. The following specific manufacturer criteria were evaluated:

- Coagulant dose
- Peak fluxes and corresponding durations
- CIP procedures

Additionally, the system reliability was tested through simulated failure and recovery.

1.5 Innovation During Piloting

1.5.1 Pilot Physical Improvements

During the preliminary testing and process and performance testing, the following troubleshooting and improvements were made to the pilot unit to improve operation:

- **Permeate line air evacuation**: An air evacuation device (eductor) and associated compressor were added to the permeate header. It was observed that the permeate flow meter and the effluent turbidimeter would give erratic readings during pilot operation due to significant air in the permeate lines. The air evacuation device significantly improved performance.
- **Programming:** The pilot control logic was troubleshot and improved throughout the testing to better operate the pilot.
- **Tank sample box**: The membrane tank was drained between most early tests, exposing the tank conductivity and TSS probes to air, which is detrimental to their operation and calibration. A

small sample pump and sample box were added. The pump would continuously withdraw water from the tank to the sample box, where the tank probes were relocated. The sample box would overflow back into the tank, but it would not drain when the tank was drained. This allowed the probes to stay submerged.

- **Influent static mixer**: During preliminary testing, there were issues with poor coagulant performance. A rapid mixer and a static mixer were tested, and the static mixer was permanently added to the influent line after the coagulant addition point, improving mixing of the coagulant. Unfortunately, this added significant head loss to the influent line, limiting the potential influent (primary effluent) flow rate to about 200 gpm due to the total head limitations of the pump supplying primary effluent to the pilot.
- **Instrumentation:** The effluent pH probe was moved to the effluent sample flow bucket to provide a more stable reading.

1.5.2 Pilot Optimization Improvements

Preliminary testing showed that a coagulant dosing ratio of 0.4 Al:TSS was effective. However, during the early process and performance testing runs, the rate of TMP rise was greater than experienced during preliminary testing. Adjustments were made to the coagulant dosing ratio, based on the manufacturer's recommendations, before the dosing ratio was permanently changed to 0.6 Al:TSS. The TMP rise rate was used as a tool to evaluate the need to adjust the coagulant dose.

Aluminum chlorohydrate (ACH) was used as the coagulant during much of preliminary testing; however, the coagulant was changed to alum for the bulk of process and performance testing. While ACH was found to be effective, late in the preliminary testing it became clear that it has a tighter range of effective doses than alum, making effective dosing difficult when influent water quality is not consistent. Additionally, ACH requires more mixing energy and contact time than alum, and the pilot configuration may not adequately provide these conditions.

Also, different combinations of cleaning chemicals were tested. These changes are discussed further in Section 3.1.

2. PILOT TESTING AND SAMPLING PLAN

2.1 Objectives

The purpose of the process and performance pilot test runs at West Point was to build a baseline of knowledge and experience with the Ovivo RapidStorm Treatment System, observe pilot operations, and confirm key design criteria that were defined by Ovivo during preliminary testing at West Point. The process and performance pilot tests provided a basis to support full-scale project planning. The following objectives established testing critical to the potential design of a full-scale facility:

1. Evaluate alum coagulant dosing strategy to control membrane fouling rates.
2. Confirm manufacturer's criteria: design fluxes, coagulant type and dose, operating parameters, and CIP parameters (See Section 3.1.11 for more information).
3. Demonstrate the treatment performance and the ability to meet discharge permit requirements under test conditions.
4. Simulate system failure modes and their impacts on membrane fouling rates.
5. Simulate system failure modes to evaluate recovery procedures.

2.2 Formal Testing Approach

2.2.1 Process and Performance Tests

Test runs were divided into two broad categories based on the goals of the test and the subsequent type and quantity of sampling. The primary purpose of process tests was to evaluate the operation and basic performance of the pilot unit, and the process tests were the majority of test runs. Performance tests involved samples of additional constituents and were designed to give greater information about the treatment performance of the membranes and the resulting effluent quality. See Section 2.2.3 for more information on the sampling plans.

2.2.2 Test Run Summaries

The following are summaries of the process and performance tests conducted:

- **Test Run 1**: This run operated at steady-state flux (100 gfd) with undiluted primary effluent for 24 hours as a process test.
- **Test Run 2**: This run operated at steady-state flux (100 gfd) with varying blend ratios from undiluted primary effluent to dilution with three parts potable water for 12 hours as a process test.
- **Test Run 3**: This run operated at steady-state flux (100 gfd) with full-strength primary effluent for 10 hours as a performance test to evaluate and confirm treatment performance.
- **Test Run 4**: This run operated at varying flux rates (100 to 200 gfd in 25 gfd intervals up and down) with full-strength primary effluent for 10 hours as a process test to confirm peak flux.

- **Test Run 5**: This run operated at varying flux rates with a front-loaded hydrograph (200 to 50 gfd) with variable influent conditions (1:1 primary effluent/potable water from 200 to 150 gfd, then full-strength primary effluent from 100 to 50 gfd) for 24 hours as a process test.
- **Test Run 6**: This run operated at varying flux rates with a back-loaded hydrograph (50 to 200 gfd) with variable influent conditions (full-strength primary effluent from 50 to 100 gfd, then 1:1 primary effluent/potable water from 150 to 200 gfd) for 12 hours as a performance test to evaluate and confirm treatment performance.
- **Test Run 7**: This run operated at different ratios of alum coagulant to influent TSS, including no coagulant addition for 30 minutes, to test system response, impact, and recovery from equipment failure. The test ran at constant flux (100 gfd) with full-strength primary effluent for approximately 8 hours as a process test.
- **Test Run 8**: This run operated with air scour or backwashing turned off for 3 to 4 hours, with CIP in between simulated system failures, to test system response, impact, and recovery from equipment failure. The test ran at a constant flux (100 gfd) with full-strength primary effluent for approximately 7 hours as a process test.
- **Test Run 9**: This run operated at varying flux rates with a middle-loaded hydrograph (50 to 200 gfd then back down to 50 gfd) with variable influent conditions (1:1 primary effluent/potable water from 50 to 200 gfd and back down to 150 gfd, then full-strength primary effluent from 100 gfd to 50 gfd) for approximately 14 hours as a process test.
- **Test Run 10**: This run operated at varying flux rates with a variable hydrograph (from 200 to 50 gfd flux rates not in ordered increments) to simulate actual discharge from historical Elliott West CSO treatment facility with variable influent conditions (1:1 primary effluent/potable water and full-strength primary effluent) for approximately 24 hours as a performance test.
- **Test Run 11**: This run operated with on/off (start/stop) cycles to mimic back-to-back events and test the unit's resilience. Variable flux rates (50 to 200 gfd) and variable influent conditions (all primary effluent and 1:1 primary effluent/potable water) were used, and the test ran for approximately 12 hours as a process test.
- **Supplemental Test Run 1**: This run operated at steady-state flux (150 gfd) with 1:1 primary effluent and potable water for 6 hours to confirm Ovivo's peak 12-hour instantaneous design condition of 150 gfd. The TMP rise rate from this test run was used to extrapolate and confirm operating under these conditions to 12 hours.
- **Supplemental Test Run 2**: This run tested two different flux rates with 1:1 primary effluent and potable water. It first operated at 200 gfd for 4 hours to test Ovivo's peak 4-hour design condition of 200 gfd. Then, after a CIP and a brief run at 100 gfd to confirm recovery, it was run for 1 hour at 225 gfd to verify the peak hour design flux of 225 gfd.
- **Supplemental Test Run 3**: This run operated at steady-state flux (100 gfd) with full-strength primary effluent for 24 hours. The primary purpose of this test run was to compare the TMP rise rate with Test Run 1, which was also operated at 100 gfd for 24 hours but with a lower ratio of alum coagulant to TSS dosing.

- **Supplemental Test Run 4**: This run operated at steady-state flux (100 gfd) with full-strength primary effluent for approximately 6 hours. The primary purposes of this test run was to examine the effects of varying alum coagulant dosages on fouling rates and to collect data on ultraviolet absorbance at 254 nanometers (UV254) on both the influent and effluent.

Details about each process and performance pilot run are provided in Chapter 3.

2.2.3 Water Quality Sampling and Analysis Test Plans

King County staff conducted water quality sampling and analysis for process and performance test runs. The *Process Test Sampling and Analysis Plan* (see Table 2-1) represented a baseline level of sampling to be performed for each test. The *Performance Test Sampling and Analysis Plan* (see Table 2-2) represented a more intensive level of sampling designed to demonstrate the water quality performance of RapidStorm across a broad range of water quality parameters. The water quality sampling and analysis was designed to help determine whether the pilot testing met the following objectives:

- Determine if RapidStorm treatment process can meet discharge permit requirements under test conditions, especially with respect to removing TSS and coliforms under varying influent and operating conditions.
- Determine if RapidStorm treatment process can yield other secondary benefits, such as removal of other constituents such as copper.
- Evaluate the alum coagulant dosing strategy with respect to correlating influent TSS concentrations with organics loading in the influent.

Table 2-1. Process Test – Sampling and Analysis Plan

Analyte (Parameter)	Hold Time Limit	Sample Min. Volume Required (milliliter [mL])	Turn Around Time (days)	Location of Analysis	Location – Pilot Influent (INF)					Location – Pilot Effluent (EFF)					Location – Membrane Tank (TNK)				
					Sample Type		Sample Frequency		No. of samples per Test Run	Sample Type		Sample Frequency		No. of Samples per Test Run	Sample Type		Sample Frequency		No. of Samples per Test Run
					Grab	Composite	Grab	Composite		Grab	Composite	Grab	Composite		Grab	Composite	Grab	Composite	
pH	–		–	Field	X		1/run			X		1/run			X		1/run		3
Conductivity	–		–	Field	X		1/run			X		1/run			X		1/run		3
Temperature	–		–	Field	X		1/run			X		1/run			X		1/run		3
Turbidity	–		–	Field						X		1/run		1					1
Total Suspended Solids (TSS)	7 days		1	Field and West Point Lab	X	X	1/run	hourly	2		X		hourly	1	X		1/run		1
Total Volatile Suspended Solids (VSS)	7 days		1	West Point Lab	X	X	1/run	hourly	2		X		hourly	1	X		1/run		1
Chlorine Demand Test	Within 15 minutes		1	West Point Lab						X		1/run		1					
Settleable Solids (SS)	48 hours		1	West Point Lab						X		1/run		1					
Alkalinity	14 days		1	West Point Lab		X		hourly	1		X		hourly	1					
UV254; report out in transmittance	48 hours	80 mL	2	West Point Lab							X		hourly	1					
5-Day Biochemical Oxygen Demand (BOD5), total	48 hours		5	West Point Lab							X		hourly	1					
Total Organic Carbon (TOC), total	28 days	60 mL	21	King County Environmental Lab	X	X	8/run	hourly	9		X		hourly	1					
Chemical Oxygen Demand (COD), total	28 days		1	West Point Lab		X		hourly	1										
Fecal Coliform	“6+2” hours	100 mL	2	West Point Lab	X		2/run		2	X		4/run		4					

Table 2-2. Performance Test – Sampling and Analysis Plan

Analyte (Parameter)	Hold Time Limit	Sample Min. Volume Required (ml)	Turn Around Time (days)	Location of Analysis	Location – Pilot Influent (INF)					Location – Pilot Effluent (EFF)					Location – Membrane Tank (TNK)				
					Sample Type		Sample Frequency		No. of samples per Test Run	Sample Type		Sample Frequency		No. of Samples per Test Run	Sample Type		Sample Frequency		No. of Samples per Test Run
					Grab	Comp	Grab	Composite		Grab	Comp	Grab	Composite		Grab	Comp	Grab	Composite	
pH	-		-	Field	X		3/run			X		3/run			X		1/run		7
Conductivity	-		-	Field	X		3/run			X		3/run			X		1/run		7
Temperature	-		-	Field	X		3/run			X		3/run			X		1/run		7
Turbidity	-		-	Field						X		3/run		1					3
TSS	7 days	200 mL (EFF), 100 mL (INF and TNK)	1	Field and West Point Lab	X	X	1/run	hourly	2		X		hourly	1	X		1/run		1
Total VSS	7 days	200 mL (EFF), 100 mL (INF and TNK)	1	West Point Lab	X	X	1/run	hourly	2		X		hourly	1	X		1/run		1
Chlorine Demand Test	Within 15 minutes	At least 200 mL	-	West Point Lab						X		1/run		1					
SS	48 hours	At least 250 mL	1	West Point Lab						X		1/run		1					
Alkalinity	14 days	100 mL	1	West Point Lab		X		hourly	1		X		hourly	1					
UV254; report out in transmittance	48 hours	50-125 mL	1	West Point Lab							X		hourly	1					
BOD5, total	48 hours	500 mL	5	West Point Lab							X		hourly	1					
TOC, total	28 days	60 mL	21	King County Environmental Lab	X	X	3/run	hourly	4		X		hourly	1					
COD, total	28 days	100 mL	1	West Point Lab		X		hourly	1										
Fecal Coliform	"6+2" hours	100 mL	2	West Point Lab	X		2/run		2	X		4/run		4					
Total Phosphorus	28 days	100 mL	1	West Point Lab	X		3/run		3	X		3/run		3					
Total Kjeldahl Nitrogen (TKN)	28 days	500 mL	1	West Point Lab	X		3/run		3	X		3/run		3					
Ammonia - Nitrogen	28 days	200 mL	1	West Point Lab	X		3/run		3	X		3/run		3					
Fats, Oils, Grease	28 days	1,000 mL	21	King County Environmental Lab	X		3/run		3	X		3/run		3					
Metals, Total (Calcium [Ca] and Magnesium [Mg]) – One bottle for Ca/Mg, Priority Pollutant metals and Mercury	180 days	500 mL	21	King County Environmental Lab	X		3/run		3	X		3/run		3	X		3/run		3
Metals, Total (Priority Pollutant) – One bottle for Ca/Mg, Priority Pollutant metals and Mercury	180 days	500 mL	21	King County Environmental Lab	X		3/run		3	X		3/run		3	X		3/run		3
Metals, Total (Mercury) – One bottle for Ca/Mg, Priority Pollutant metals and Mercury	28 days	500 mL	21	King County Environmental Lab	X		3/run		3	X		3/run		3	X		3/run		3

3. PILOT RUNS

3.1 Observations from Preliminary Tests

Prior to the process and performance testing, 34 preliminary test runs were completed between July 29, 2019, and August 27, 2020. Details about these preliminary runs are presented in a report titled *Ovivo CSO PILOT, King County, Preliminary Test Report* (Draft, October 5, 2020). This subsection provides an overview and key observations from those preliminary runs.

The preliminary runs established or confirmed design criteria for formal testing as described in Section 3.1.11. The objective was to determine conditions for 24-hour continuous operation, peak flux rates and corresponding durations, maximum basin TSS concentration, optimal coagulant dose, type, and dosing strategy, and CIP procedures. The influent was the same as was used for the process and performance testing: primary effluent at West Point with or without additional potable water dilution to simulate CSO conditions.

3.1.1 Sustainable 24-Hour Operation

The pilot was operated for 24 continuous hours on undiluted primary effluent to verify sustainable performance at 100 gfd. Three runs (3, 8, 13) were completed to investigate the ability to meet the 24-hour performance requirement in dry and wet weather conditions. An additional 24-hour, 100-gfd run was conducted to demonstrate repeatable performance. The rate of TMP increase observed for this run was 0.17 pounds per square inch (psi)/hour. The estimated acceptable rate of TMP increase is 0.35 psi/hour at 100 gfd based on assuming a conservative starting TMP of 1.5 psi, a maximum operating TMP of 10 psi, and linear TMP increase rate.

3.1.2 Coagulant Evaluation

Ovivo traditionally uses alum for the physical chemical process. During the preliminary runs, both alum and ACH were tested. Conclusions were as follows:

- **Alum:** With the use of alum, there is significant alkalinity consumption, which negatively impacted effluent pH. As shown in several test runs, effluent pH from the pilot frequently dropped below 6.0, which would be in violation of the County's CSO discharge permits. Caustic addition for the purpose of adding alkalinity to the wastewater was not part of the preliminary test but would need to be considered in any large-scale application using alum.
- **ACH:** Ovivo had never before used ACH in this application. The preliminary runs indicated that overdosing of ACH did create rapid fouling and process shutdown based on high TMP. ACH showed good, stable performance over a wide range of Al:BOD and Al:TSS dose ratios but exhibited significant increases in fouling once the ratios exceeded certain values.

3.1.3 Mixing Energy

The preliminary runs looked at two types of in-line mixing for coagulant addition: static mixer and in-line propeller. The two runs that were completed showed that the propeller mixer provided a better, lower TMP rise rate than the static mixer, although the results with the static mixer were acceptable. With only two runs, this finding did not provide conclusive data on which method is better. The ACH chemical supplier preferred the use of the static mixer, and that was what was used for the remainder of the preliminary tests.

ACH requires more energy to mix than alum. ACH is an inorganic polymer and requires more energy to disperse. Alum easily dissociates in water and is less dependent on mixing. In addition to mixing energy, the overall time that the solution that is dosed with a coagulant can also impact the dispersion and effectiveness of the dosed coagulant for adsorbing organic foulants. Because ACH is already prehydrolyzed and polymeric, longer mixing times could also lead to better results in terms of lower TMP rise rates.

3.1.4 Dosing Strategy

TSS was used as the surrogate for dosing control because an in-line TSS probe can provide real-time influent TSS data for coagulant dose control. Ovivo felt that BOD and COD represented the best variables to control dosing because they are good indicators of the concentrations of organic compounds in wastewater that are known to foul membranes (American Water Works Association 2016; Liu et al. 2001). But accurate real-time measurements of BOD and COD in CSO applications had not yet been demonstrated. Because an Al:TSS dose ratio of 0.4 for BOD:TSS ratios up to 2.38 was developed for alum, TSS was used as a surrogate for BOD for alum coagulant dosing control.

During the preliminary runs, aggressive ACH fouling was observed during a storm event as the BOD:TSS ratio changed dramatically. This demonstrated that dosing control still needed to be refined in any future full-scale application.

Preliminary observations indicated, based on the fouling rates as a function of aluminum to BOD ratios, that a 0.4 AL:TSS dosing ratio when using alum is optimum and would provide adequate coagulant for 99 percent of influent water quality conditions at the County's Elliott West CSO Treatment Facility (based on available 'Main Solids Return Pumping' sample data since 2012). Ovivo concluded that the key for a TSS-based dosing strategy using alum was to design it based on the maximum BOD:TSS ratio to ensure that sufficient coagulant is applied to bind up organic material prior to membrane filtration.

During the preliminary testing and process and performance tests, the coagulant dose was set at a constant rate, usually 8 gallons per hour (gph), when the membrane basin was filling. After the membrane basin was filled, the coagulant dosing switched to using an operator-set Al:TSS dose ratio of aluminum to influent TSS based on readings from an influent TSS probe. When the pilot unit operated on a set Al:TSS dose ratio, the coagulant dosing pump rate was controlled by calculating the required coagulant dosage in milligrams (mg)/liter (L) as Al and based on the set Al:TSS ratio and calculating the required pumping rate of the coagulant based on influent flow rate and the aluminum-based coagulant's specific gravity and concentration by weight.

3.1.5 Maximum Basin TSS

TSS concentration in the membrane basin has an impact on system performance, so understanding the maximum concentration is essential in any design of a full-scale facility. The maximum TSS concentration was determined by increasing basin TSS until TMP increased at a rapid rate.

Based on the limited data collected during the preliminary runs, the maximum achievable basin TSS concentration during the test was 6,000 mg/L. At that concentration, the fouling rate increased. Up until 6,000 mg/L basin TSS concentration, the rate of TMP increase was linear at 0.13 psi/hour. After the basin TSS concentration reached 6,000 mg/L, the rate of TMP increased to 0.25 psi/hour.

The concentration of 6,000 mg/L is slightly higher than the level determined during the pilot testing at Austin, Texas. During that testing, it appeared that the change occurred around 4,000 mg/L of basin TSS.

3.1.6 Peak Flux Testing

During the preliminary runs, flux rates greater than the 100 gfd baseline value were evaluated. Testing was performed by increasing the membrane flux from 50 to 200 gfd in increments of 50 gfd. As expected, there was a strong correlation between flux and rate of TMP increase, as shown in Table 3-1. As flux was reduced from the peak of 200 gfd, there was significant reduction in the fouling rates, suggesting that some of the fouling was reversible.

Table 3-1. Instantaneous Flux and TMP Increase Rate

Flux (gfd)	Rate of TMP Increase (psi/hour)
50	0.01
100	0.16
150	0.47
200	2.07

3.1.7 Hydrograph Simulation

A run was completed to simulate a storm event hydrograph. The system was able to acceptably perform over a 24-hour period at varying flux rates and influent TSS load. A key result was the ability of the membranes to maintain over 200 gfd for a 2-hour period. Being able to use the membranes for short-term peaks is critical for minimizing the number of membranes needed for a full-scale system.

3.1.8 Cleaning Optimization

The preliminary observations indicated that for alum, a single clean using a combination of sodium hypochlorite (“hypo”) and sodium hydroxide (“caustic”) reliably recovered the membranes. The cleaning protocol is summarized in Table 3-2.

Table 3-2. Alum Single Clean Protocol from Preliminary Testing

12.5% by weight NaOCl (gph)	25.0% by weight NaOH (gph)	Target NaOCl Concentration (% by weight)	Target NaOH Concentration (% by weight)	Fill Rate (gpm)	Fill Duration (minutes)	Minimum Soak Time (hours)
100	50	0.25	0.25	100	10	4.0

A single-step hypo-plus-caustic CIP also proved effective for recovery from over-dosing of ACH in the absence of residual aluminum species in the membrane pores. In the event of an ACH over-dose, a sequence of high pH, then low pH, then high pH was found to be the most effective at breaking down the mixture of organic and inorganic material plugging the membrane pores.

Ovivo noted that for a full-scale design, the permeability observed during the chemical fill sequence and a post-CIP backwash can be used to determine whether the CIP recovered the membranes. The Ovivo CSO Pilot King County Preliminary Test Report (Ovivo 2020) discussed using the header pressure during the chemical fill step during a CIP as an indicator for successful chemical clean. It was postulated that a drop in header pressure to less than 2.1 psi at the end of a chemical fill step indicated membrane recovery. Data for the chemical fill step during the CIPs are provided under the membrane recovery subsections for each test run.

When inorganic fouling was suspected, citric acid was used to clean the membranes. During preliminary testing, ACH was deliberately overdosed until a noticeable increase in TMP was observed. Citric acid was then added to a standard backwash and showed a reduced TMP from 2.58 to 1.72 psi.

3.1.9 Turbidity

For all runs performed, there was elevated effluent turbidity at startup. Ovivo indicated that this was due to residual air in the system. Because the pilot plant was designed with a portion of the permeate pipe above the level of water in the membrane, a negative pressure zone was created in the pipe. This may have resulted in pulling gas out of the permeate, or it may have just made it very easy for air to become trapped, even with the addition of an air evacuation system. Once the air was removed, the effluent turbidity was consistently below 0.1 nephelometric turbidity units (NTU).

3.1.10 Key Findings

The following are key findings from the preliminary test runs:

- The system demonstrated sustainable performance for periods greater than 24 hours at 100 gfd in dry and wet weather conditions.
- Both alum and ACH were effective at providing stable membrane performance under a variety of conditions. Both coagulants demonstrated sustainable membrane performance at 100 gfd for 24 hours.
- Optimum alum dosage ratio was identified as 0.4 Al:TSS. Optimum ACH dosage ratio was identified as 0.2 Al:TSS.
- Alum provided a wider window of operation as excess coagulant did not appear to adversely impact the membranes and accelerate fouling. However, the use of alum would most likely require alkalinity addition to ensure pH levels do not drop below 6.0.
- A dosing ratio of 0.4 Al:TSS was developed for BOD:TSS ratios up to 2.38.
- While ACH demonstrated lower dosage rates while maintaining effluent pH levels greater than 7.2, it presented significant challenges in terms of membrane performance and recovery. Excess ACH can rapidly foul the membranes, requiring more extensive cleaning.
- In order to effectively use ACH without negatively impacting membrane performance, more extensive instrumentation is needed to ensure the ratio of aluminum to organics (i.e., BOD, COD) remains within an acceptable range. Better mixing of the ACH coagulant in terms of higher mixing energy and longer mixing time may also make use of ACH more effective.
- Optimization of alum dosage is also critical for maintaining good membrane performance if alum is used as the coagulant. And because alum consumes more alkalinity than ACH and depresses the pH more, using alum would require an additional pH adjustment system, which would increase the system footprint.
- The system reliably performed during a simulated hydrograph test over the flux range of 50 to 200 gfd for 24 hours.

- The system showed peak flux capabilities as high as 200 gfd for durations greater than 1.0 hour on simulated CSO water (primary effluent diluted with potable water).
- The system reliably showed effluent turbidity of less than 0.1 NTU.
- Mixing energy proved critical for ACH. Alum was less dependent on high mixing energy. An in-line static mixer was determined to provide sufficient mixing for the pilot application for alum.
- Chlorine combined with caustic proved an effective and reliable cleaning solution when using alum. The same cleaning protocol was not always reliable if ACH overdoses fouled the membranes.
- Membrane performance is stable at 100 gfd at basin TSS concentrations up to 6,000 mg/L.
- Diluted primary effluent with potable water proved to be a reliable method for simulating CSO water in terms of BOD loading. Fouling rates with diluted primary effluent were consistent with those observed when operating with primary effluent during storm events at West Point.

3.1.11 Manufacturer's Design Criteria

Based on the data and results of preliminary tests, Ovivo developed the design criteria shown in Table 3-3 through Table 3-7 for formal testing.

Table 3-3. Manufacturer-Specified Peak Flux and Duration Limits

Flux Condition	Design Flux (gfd)
Peak Day	100
Peak 16-hour	125
Peak 12-hour	150
Peak 8-hour	175
Peak 4-hour	200
Peak Hour	225

Table 3-4. Inlet Screening Specifications

Type	Wedge-Wire-Type Screen with Mechanical Brushes on Inlet and Outlet Sides of Screen
Size (spacing)	6 x 6 mm openings
Minimum Screening Retention Value	34%

Table 3-5. Coagulant Dosing Parameters

Coagulant Type	Aluminum sulfate (alum) supplied in concentration approximately equivalent to 8% Al_2O_3
Dosing Strategy	Mass ratio of aluminum to total suspended solids
Coagulant Dosage	0.4 Al:TSS dose ratio (for BOD:TSS ratios up to 2.38; above that, adjust dosage so that Al:BOD is greater than 0.17)
Mixing Requirements	In-line static mixer
Residence Time from Injection Point to Membrane Basin	≥ 2.0 minutes

Table 3-6. Operating Parameters

Maximum TMP (psi)	10.0
Backwash Cycle Length (minutes)	15
Backwash Duration (seconds)	60
Backwash Pre- and Post-Relaxation Durations (seconds)	30 each
Backwash Flow (gpm)	2X permeate flux
Air scour rate (standard cubic feet/minute [scfm])	35 per stack
Maximum Stack Height	15 feet
Operating Temperature (minimum)	10 degrees Celsius (C)
Maximum Suspended Solids in Basin Before Discharge (mg/L)	6,000
Basin Hydraulic Retention Time (HRT)	20 minutes
Membrane Packing Density (square feet of membrane/gallon basin volume)	0.731

Table 3-7. Cleaning Specifications

Stock Chemicals	12.5% NaOCl 25.0% by weight NaOH
Cleaning Solutions	0.25% by weight NaOCl; 0.25% by weight NaOH
Cleaning Protocol	1. Chemical fill (backwash plus chemical injection) 2. Static soak 3. Backwash flush 4. Relaxation
Dosage Rates (Pilot)	100 gph NaOCl 50 gph NaOH
Fill Rate	50 gfd of permeate (100 gpm on pilot)
Fill Duration	10 minutes
Soak Duration	4 hours (minimum soak time for post-run cleaning); 30 minutes soak time for mid-run CIP
Post CIP Soak Backwash	100 gfd for 3 minutes
Post CIP Relaxation	35 scfm/stack airflow for 60 seconds
Post CIP Basin Drain	Basin is completely drained, followed by an additional backwash at 200 gfd for 60 seconds

3.2 Test Run 1

This process run, performed on September 3, 2020, and September 4, 2020, was designed as a basic run with a constant flux of 100 gfd using full-strength primary effluent with a coagulant dose ratio of 0.4 Al:TSS. The purpose of the run was to verify the basic operational characteristics of the unit for a 24-hour continuous run.

Alum and then caustic soda (to balance the pH) were added to the influent upstream of the membrane tank. The initial caustic soda dose was estimated based on stoichiometry with alum. At the start of the run, the TMP rise rate was higher than expected, therefore, the coagulant dose was doubled to 0.8 Al:TSS. The alum dosing increase caused the pH to drop so the caustic feed rate was manually adjusted as needed to maintain the effluent pH above 6.0. However, the pH dropped below 6 during the night when no operators were on-site to continue adjusting the coagulant dose.

3.2.1 Observations

Notable observations/events during this test run were as follows:

- Significant light, white, fluffy foam was observed in the membrane tank (see Figure 3-1).
- Initial TMP rise rate was higher than expected, so coagulant dose was increased. Consequently caustic dose initially had to be increased due to low pH from the elevated coagulant dose, then later decreased after the effluent pH rose above 7. The TMP rise rate reduced about 15 minutes after the first caustic dose reduction, as discussed in further detail in Section 3.2.4.2.
- Coagulant and caustic doses were adjusted as follows:
  - At 10:08 (time)—Increased Al:TSS dose ratio from 0.4 to 0.8.
  - At 10:28—Increased caustic dose from 1.9 gallons per hour (gph) to 3.9 gph due to low pH.
  - At 10:33—Increased caustic dose from 3.9 gph to 5 gph due to low pH.
  - At 13:01—Reduced caustic dose from 5 gph to 1.9 gph due to high pH.
  - At 13:47—Reduced caustic dose from 1.9 gph to 1.0 gph due to high pH.
- Ovivo determined that coagulant dose was incorrectly recorded in the PLC, so that data is not available for this test run. The PLC data tag was corrected after this run.
- The effluent composite sampler failed, so only a small sample was collected, limiting the tests that could be run. The sampler was replaced after this run.
- Data collection ended after 23 hours, but the pilot was left running. After a further 2 hours, the unit shut down due to high TMP. That was 1 hour longer than the planned run duration.

Figure 3-1. Foam Observed at Pilot

This was a successful run in terms of the primary purposes of operating the pilot for 24 hours and trialing the operating and sampling procedures. However, the TMP rise rate was higher than expected based on preliminary testing, and effectively controlling the effluent pH with influent caustic soda was difficult. As a result, additional preliminary tests were conducted following this run (not reported in this document) to determine if caustic soda addition was feasible. It was determined that for the purposes of further pilot testing, caustic soda addition would be discontinued because pH control was difficult and caustic addition appeared to increase the fouling rate. The mechanism by which caustic affected the fouling rate is unknown, but it may be due to insufficient mixing prior to the membrane tank.

3.2.2 Operational Data

Key operational data collected during this run are presented in Figure 3-2 through Figure 3-5.

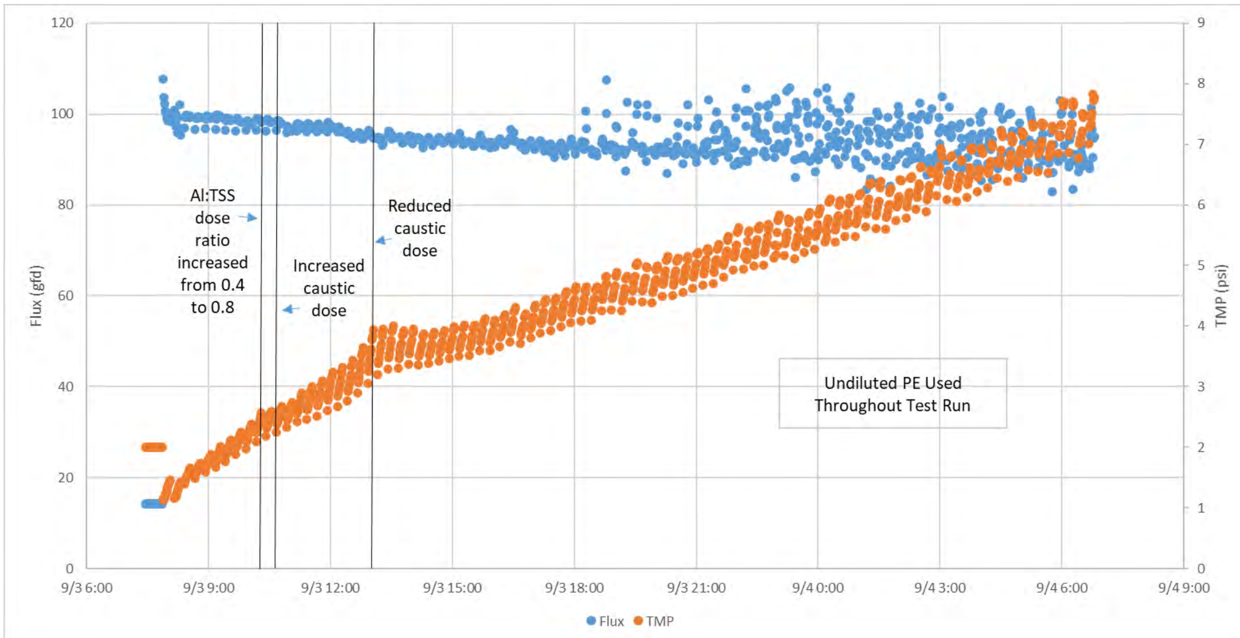


Figure 3-2. Flux and TMP, Run 1

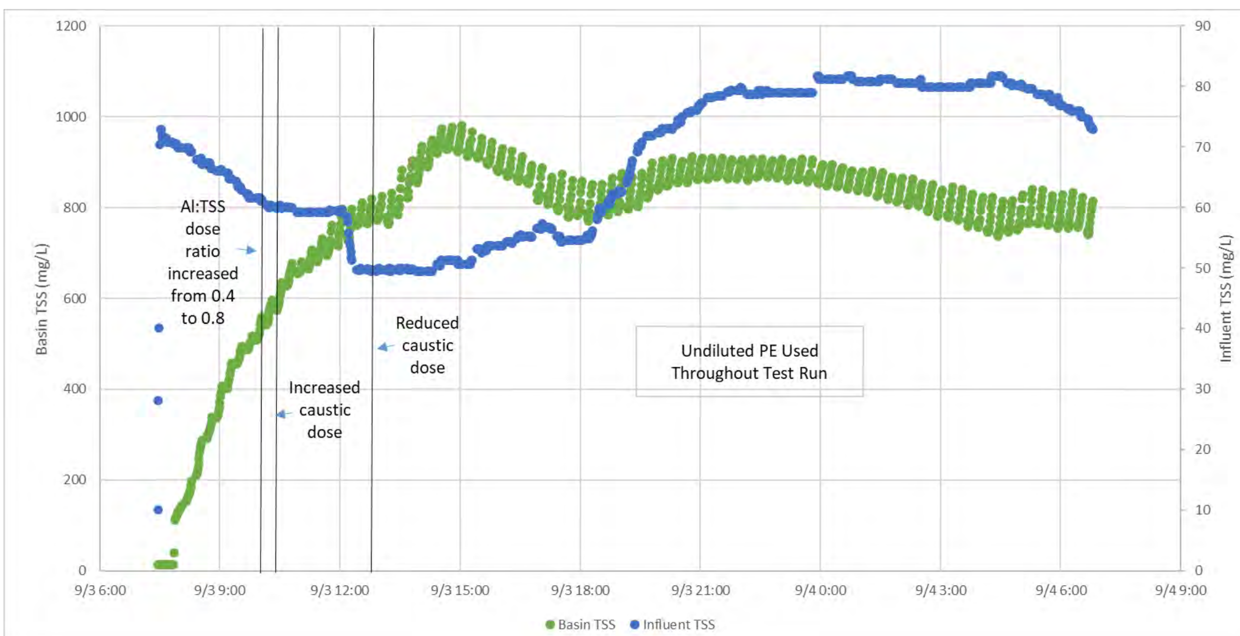


Figure 3-3. TSS, Run 1

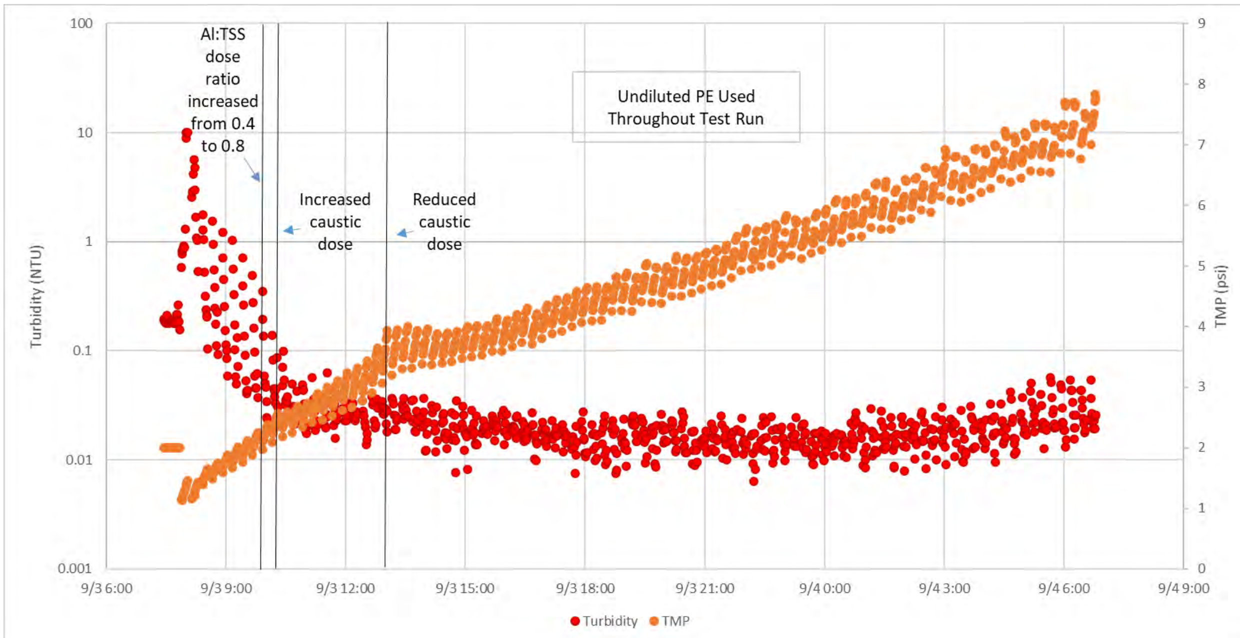


Figure 3-4. Effluent Turbidity and TMP, Run 1

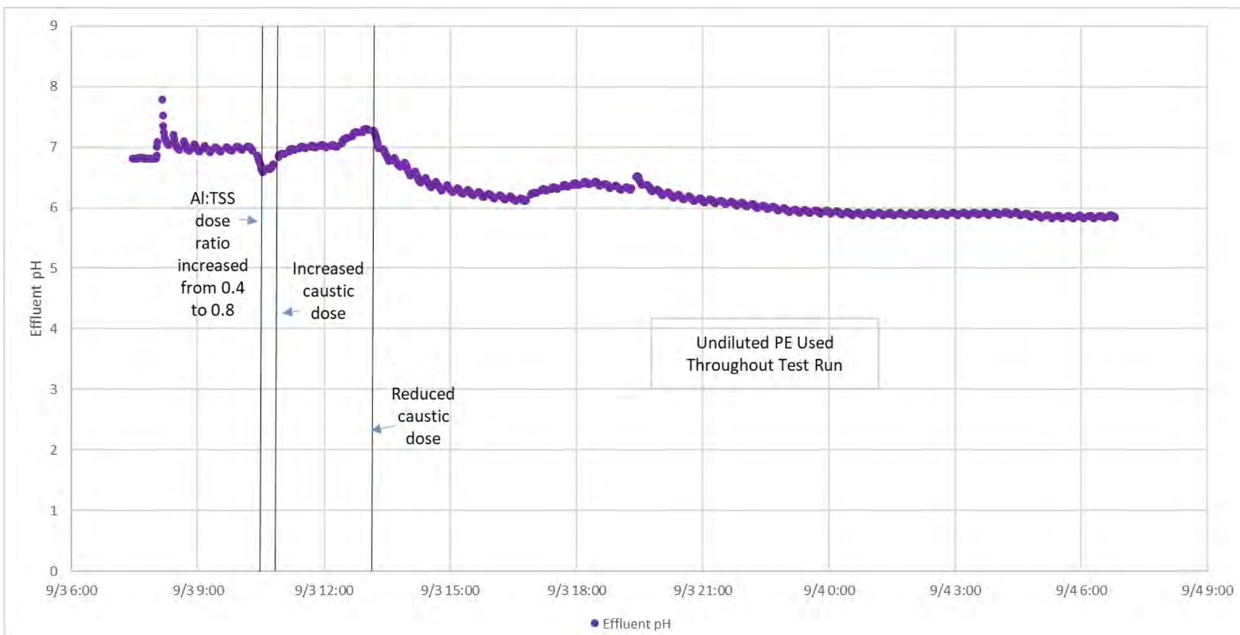


Figure 3-5. Effluent pH, Run 1

Note: Coagulant dose not shown because of inaccurate data for this test run.

3.2.3 Sampling Results

Key sampling results collected during this run are presented in Table 3-8 and Table 3-9.

Table 3-8. Water Quality Data, Run 1

		9/3/2020 (Time Stamps Below)											9/4/2020 (Time Stamps Below)				
		730	900	1105	1130	1300	1330	1500	1730	1900	2230	2300	300	430	710		
Parameter	**Location**	**Undiluted PE**											**Undiluted PE**			**Grab. Average**	**Composite[a]**
TSS (mg/L)	INF			23												23	30
	EFF																0
	TNK			1,560												1,560	
VSS (mg/L)	INF			19												19	27
	EFF																<1
	TNK			825												825	
SS (mL/L/hour)	EFF			0												0	
Total COD (tCOD) (mg/L)	INF	311		333	238		244		372		379			373		321	321
	EFF			141												141	
	TNK			1,735												1,735	
Soluble COD (sCOD) (mg/L)	INF			143												143	
	EFF			137												137	
	TNK			154												154	
TOC (mg/L)	INF		46.3	63.4		56.1		51.7		63.2		86.3	89.8		81.8	67.3	
	EFF			37.3												37.3	
BOD (mg/L)	INF			156												156	156
Alkalinity (mg/L)	INF			193												193	198
	EFF			131												131	50
	TNK			225												225	
Fecal Coliform (most probable number of cells [MPN]/100 mL)	INF			9,200,000												9,200,000	
	EFF		24,000,000	0		0									0	70 (geomean)	
Chlorine (Cl_2) Demand (mg/L)	EFF			2.83												2.83	
UV254 (reciprocal centimeter [cm^{-1}])	EFF																0.248

a The effluent composite sampler failed part way through the test, so effluent composite samples are only representative of the first few hours.

Table 3-9. Field Sampling, Run 1

Parameter (units)	Location	9/3/2020 1100
pH	INF	6.83
	TNK	6.9
Temperature (degrees C)	INF	22.0
	TNK	21.6

3.2.4 Data Analysis

3.2.4.1 Coagulant Dose Ratio

The ratio of coagulant to organic compounds was evaluated because organic compounds are likely the primary fouling agents of the membranes in the primary effluent used in the pilot testing. This is consistent with caustic soda and sodium hypochlorite CIPs being the most effective cleaning regimen for restoring membrane capacity after fouling during the pilot testing. Table 3-10 shows the ratios for this run. Ratios are calculated at 11:05, when the majority of sampling was done and the TMP rise rate was high, and at two later data points after the coagulant dose was adjusted and the TMP rise rate decreased. Data based on the composite sample compared to a flow weighted average of aluminum dose is also included.

Table 3-10. Ratio of Coagulant to Organic Compounds, Run 1

Ratio	Time Stamps			Composite
	1105	1300	1330	
Al:tCOD	0.07		0.16	0.09
Al:sCOD	0.16			
Al:TOC	0.37	0.71		
Al:BOD	0.15			0.19
Al:TSS	0.8	0.8	0.8	NA

3.2.4.2 TMP Rise Rate

In this run, the TMP rise rate started high at 0.44 psi/hour compared to 0.16 psi/hour at 100 gfd during preliminary testing. About 1.5 hours after the coagulant dose was increased and 15 minutes after caustic dose was reduced at approximately 1315, the TMP rise rate decreased to 0.21 psi/hour and stayed roughly steady for the rest of the run. Table 3-11 summarizes these results.

Table 3-11. TMP Rise Rate, Run 1

	Time	Instantaneous Flux Setpoint (gfd)	Average TMP Rise (psi/hour)
Initial Period	0800 – 1315	100	0.44
Final Period	1315 – 0645 (next day)	100	0.21
Overall	0800 – 0645 (next day)	100	0.26

Further preliminary testing following this run confirmed that the caustic addition led to a higher rate of TMP increase under equivalent conditions compared to operating without the addition of caustic. The influent BOD and COD concentrations were significantly higher than previously observed in preliminary testing, but TSS was comparable to previous tests. It is likely that the initial high fouling rate was caused by the high organic levels in the influent with insufficient coagulant. The high caustic dose likely exacerbated this condition because the fouling rate did not decrease until the coagulant was increased and caustic was reduced.

3.2.4.3 Turbidity

As shown in Figure 3-4, turbidity was over 1 NTU at the start of the test. The turbidity gradually declined, and after about 2.5 hours was consistently below 0.1 NTU. It remained low for the duration of the test. Ovivo determined in its preliminary testing report that high initial values are caused by air in the permeate line.

3.2.4.4 pH

At the start of the test, the effluent pH was around 7. It was initially controlled by adjustments to the caustic dose; however, after the caustic dose was reduced at 13:01, the pH gradually decreased, eventually ending the test at around 5.8.

3.2.4.5 Net Permeate and Flux

In membrane treatment design, net flux is an important parameter that uses the average flow rate and accounts for the backwashing and relaxation phases of membrane treatment. Net flux, and not instantaneous flux, determines the treatment capacity of a facility. Because of this, net permeate and net flux have been estimated for most of the test runs.

The following were the key results for net permeate and flux for Test Run 1:

- Total operating time: 1,380 minutes
- Approximate net permeate produced (permeate minus backwash): 185,600 gallons
- Net flux accounting for backwash: 66.2 gfd

3.2.4.6 Other

The first effluent fecal coliform sample result was 24 million MPN per 100 mL, which is higher than the measured influent value. All three other effluent fecal coliform samples measured 0, so the first sample was significantly different from other measured values. It may be the result of contamination of the dedicated effluent sampling tap, which is consistent with the fact that the effluent turbidity was approximately 0.1 NTU at the time that this first effluent fecal coliform sample was collected.

3.2.5 Membrane Recovery

The Ovivo CSO Pilot King County Preliminary Test Report (Ovivo 2020) discussed using the header pressure during the chemical fill step of a CIP as an indicator for successful chemical clean. It was postulated that a drop in header pressure to less than 2.1 psi at the end of a chemical fill step indicates membrane recovery. Table 3-12 shows the TMP at the end of Test Run 1 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill and at the end of the CIP chemical fills. Data were consistent with membrane recovery after the CIP.

Table 3-12. Run 1 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi
7.8 (100)	0.9 (100)	2.6	1.8

3.3 Test Run 2

This run, performed on September 22, 2020, was designed as a 12-hour run with a constant flux of 100 gfd using variable influent water quality. The test began with undiluted primary effluent. After 2.5 hours it was diluted approximately 1 to 1 with potable water. The dilution was increased to 2 to 1 after a further 3 hours and to 3 to 1 after another 3 hours. The coagulant dose ratio was 0.4 Al:TSS throughout.

The purpose of the run was to verify the operational performance of the unit with variable influent water quality, and in particular to see how it responds as dilution increases, as may be experienced in a storm event. No caustic soda was added for pH control in this run or any future tests.

3.3.1 Observations

A notable observation during this test run was as follows:

- Significant light, white, fluffy foam was observed in the membrane tank, as with the previous test.

This run demonstrated significantly lower TMP rise rates with a lower influent strength. It also showed the pilot was able to handle changes in influent strength automatically.

3.3.2 Operational Data

Key operational data collected during this run are presented in Figure 3-6 through Figure 3-9. There was no direct wasting of solids from the membrane basin. However, whenever a backwash occurred it pushed water over the level-regulating weir in the influent box, which results in wasting of solids. As a result, the basin TSS concentration decreases once dilution of the influent starts.

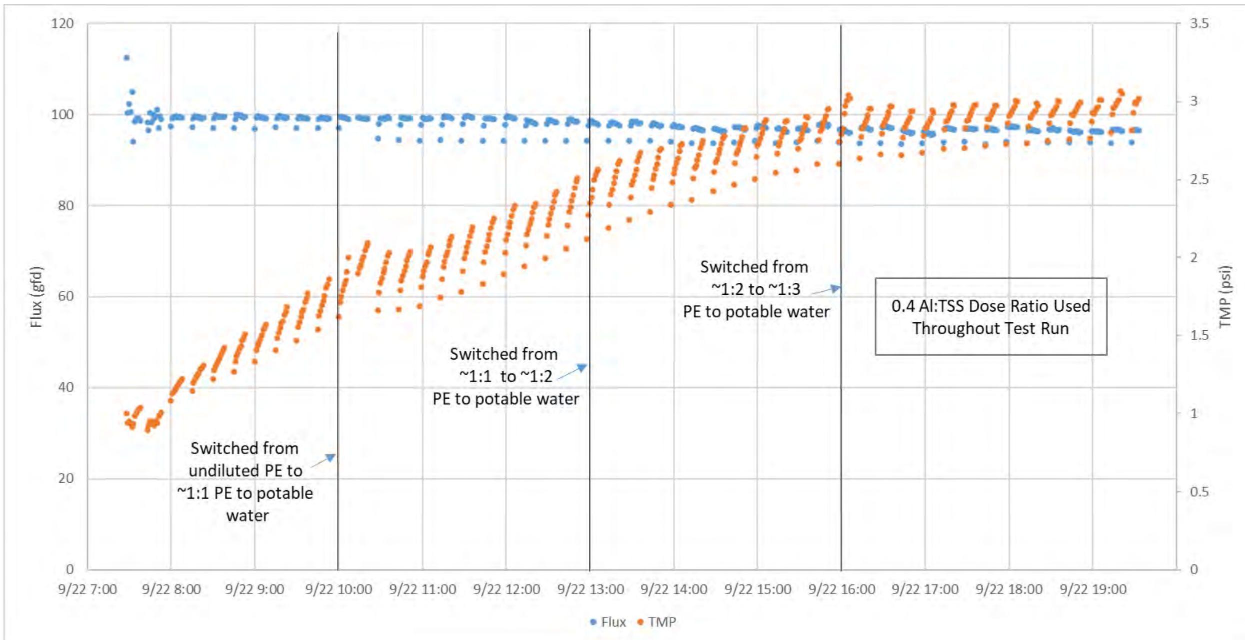


Figure 3-6. Flux and TMP, Run 2

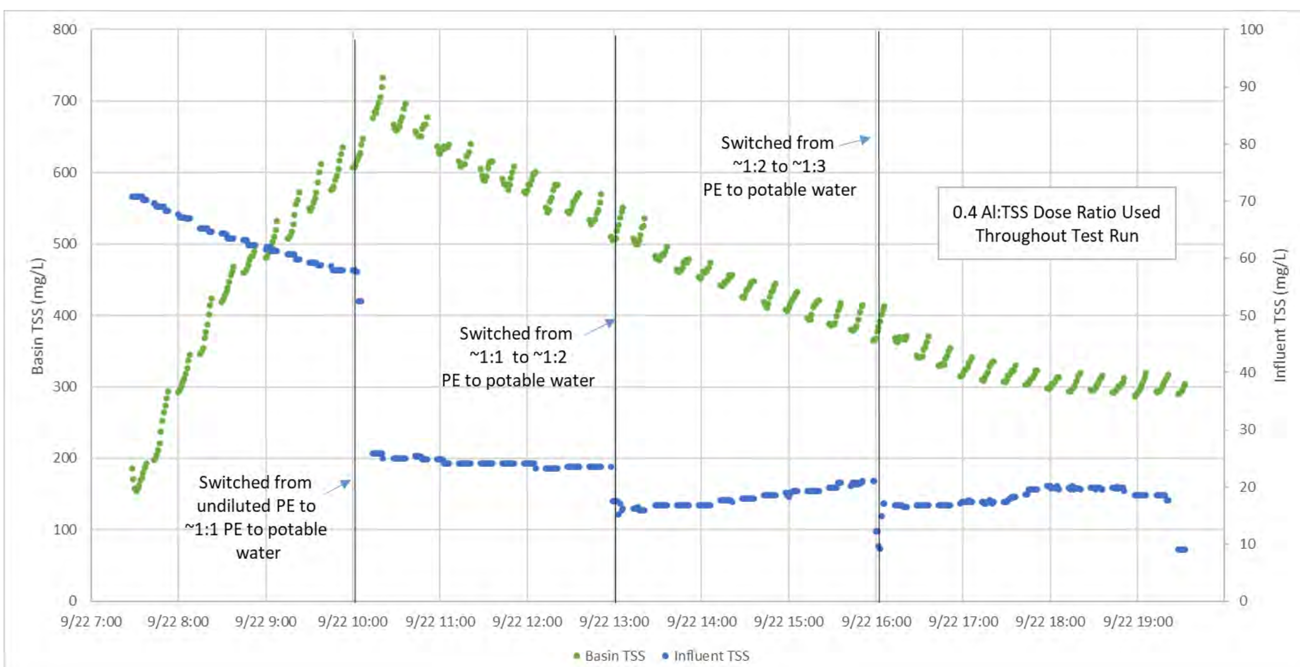


Figure 3-7. TSS, Run 2

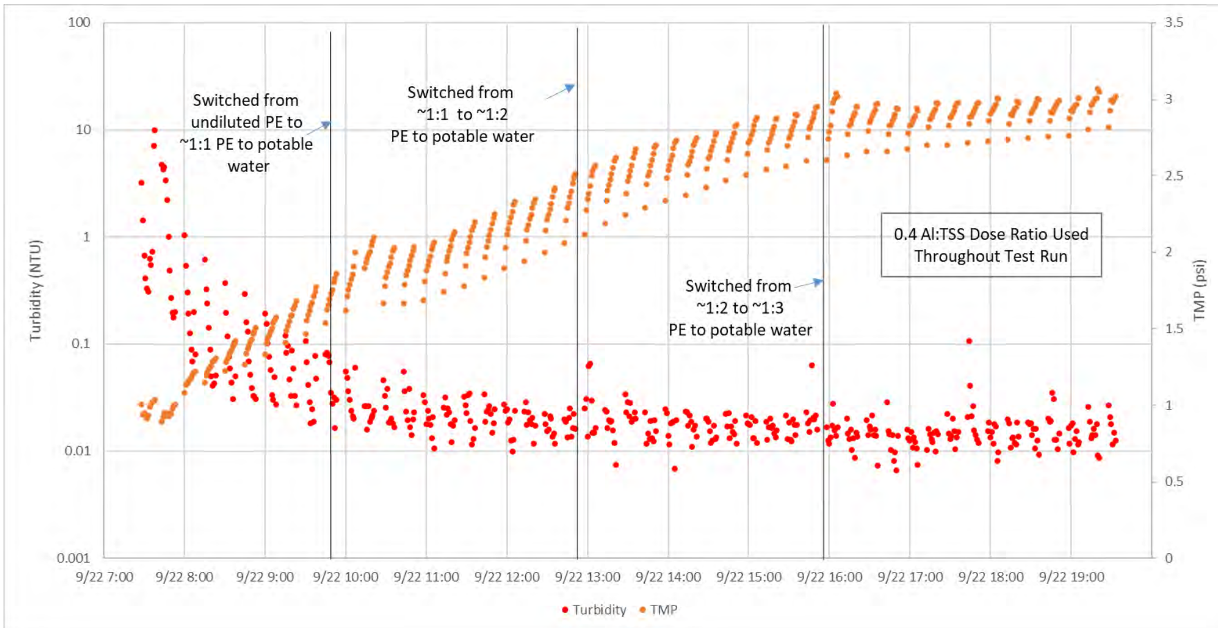


Figure 3-8. Effluent Turbidity and TMP, Run 2

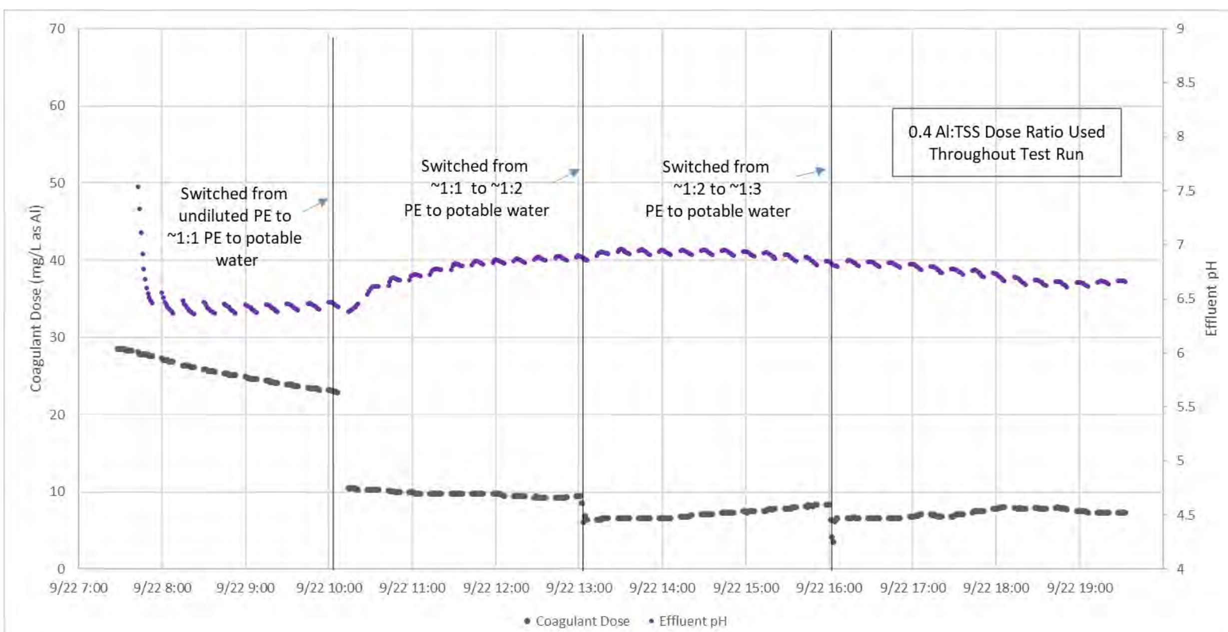


Figure 3-9. Coagulant Dose and Effluent pH, Run 2

3.3.3 Sampling Results

Key sampling results collected during this run are presented in Table 3-13 and Table 3-14.

Table 3-13. Water Quality Data, Run 2

Parameter	Location	9/22/2020 (Time Stamps Below)									Grab Average	Composite
		835	1030	1130	1230	1330	1430	1630	1730	1830		
		Undiluted PE	1:1 PE to Potable Water			1:2 PE to Potable Water		1:3 PE to Potable Water				
TSS (mg/L)	INF	44	33	17			20		8		24	21
	EFF											1
	TNK		1,430									
VSS (mg/L)	INF		23									18
	EFF											1
	TNK		750									
SS (mL/L/hour)	EFF		0									
tCOD (mg/L)	INF		104								104	106
	EFF		113									
	TNK		1,358									
sCOD (mg/L)	INF		58									
	EFF		60									
	TNK		70									
TOC (mg/L)	INF	52.1	20.7		21.5	15		15.4		18	23.8	
	EFF		14.9									
BOD (mg/L)	INF		56									45
	EFF											24
Alkalinity (mg/L)	INF		105									107
	EFF		63									58
	TNK		142									
Fecal Coliform (MPN/100 mL)	INF		2,300,000			2,300,000					2,300,000	
	EFF	0	0		0	0					1 (geomean)	
Cl_2 Demand (mg/L)	EFF		1.34									
UV254 (cm^{-1})	EFF											0.111

Table 3-14. Field Sampling, Run 2

Parameter	Location	9/22/2020 1030
pH	INF	7.4
	EFF	7.02
	TNK	6.99
Temperature (degrees C)	INF	20.0
	EFF	20.8
	TNK	21
Conductivity (microsiemens [µS])	INF	937
	EFF	1174
	TNK	1120

3.3.4 Data Analysis

3.3.4.1 Coagulant Dose Ratio

The aluminum to organic compound ratios were slightly higher in this run than in the initial period of the first run. Table 3-15 summarizes the ratios for this run.

Table 3-15. Ratio of Coagulant to Organic Compounds, Run 2

Ratio	Time Stamps		Composite
	1030	1630	
Al:tCOD	0.10		0.11
Al:sCOD	0.18		
Al:TOC	0.50	0.43	
Al:BOD	0.18		0.26
Al:TSS	0.4	0.4	0.4
TMP Rise Rate (psi/hr)	0.20	0.14	NA

3.3.4.2 TMP Rise Rate

As the dilution increased, and thus the concentration of potential fouling constituents (organics) in the influent decreased, the TMP rise rate decreased as shown in Table 3-16 even though the coagulant dose was reduced proportionally to the influent TSS. This is expected.

Table 3-16. TMP Rise Rate, Run 2

Dilution	Time	Flux (gfd)	TMP Rise Rate (psi/hour)
No dilution	730-1000	100	0.32
1:1	1000-1300	100	0.20
2:1	1300-1600	100	0.14
3:1	1600-1930	100	0.04
Overall	730-1930	100	0.15

3.3.4.3 Turbidity

Similar to the first run, turbidity (see Figure 3-8) was over 1 NTU at the start of the test and after about 2.5 hours decreased to and remained below 0.1 NTU. Ovivo stated in the preliminary testing report that high initial values are caused by air in the permeate line.

3.3.4.4 pH

The starting pH was above 7 due to residual caustic left in the permeate tank from the previous test CIP procedure. It quickly dropped to 6.4 once the pilot started permeating. The pH remained between 6.4 and 7.0 during this test run. It was lowest when the influent TSS concentration, and thus the coagulant dose, was highest.

3.3.4.5 Net Permeate and Flux

The following were the key results for net permeate and flux:

- Total operating time: 726 minutes
- Approximate net permeate produced (permeate minus backwash): 100,700 gallons
- Net flux accounting for backwash: 68.3 gfd

3.3.5 Membrane Recovery

Table 3-17 shows the TMP at the end of Test Run 2 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill and at the end of the CIP chemical fills. Data are consistent with membrane recovery after the CIP.

Table 3-17. Run 2 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi[a]
3.0 (100)	0.8 (100)	2.7	1.9

a A header pressure of less than 2.1 psi at the end of a chemical fill step is understood to indicate membrane recovery.

3.4 Test Run 3

This run, performed on October 1, 2020, ran for 10 hours and was designed as a performance test to examine steady-state flux operation using undiluted primary effluent as the influent with a constant flux of 100 gfd. The alum coagulant dose ratio was set to 0.4 Al:TSS. This was a performance test, so more sampling and data were obtained than for process tests, in order to evaluate water quality performance of the Ovivo RapidStorm Treatment System.

3.4.1 Observations

A notable observation during this test run was as follows:

- As with many other test runs; white, fluffy foam in the membrane tank was observed.

This first performance test was successful in terms of obtaining useful data. However, the TMP rise rate was higher than expected, based on preliminary testing. The higher TMP rise rate may have been due to insufficient coagulant dosing to mitigate the influent organics loading. TOC concentrations in the influent were higher than in other runs (see Section 3.4.3.)

3.4.2 Operational Data

The test run operated from 06:23 to 16:33. Figure 3-10 shows the flux and TMP during the run; the flux was maintained near the target 100 gfd throughout the run, while the TMP steadily increased over the more than 10 hours of the test run.

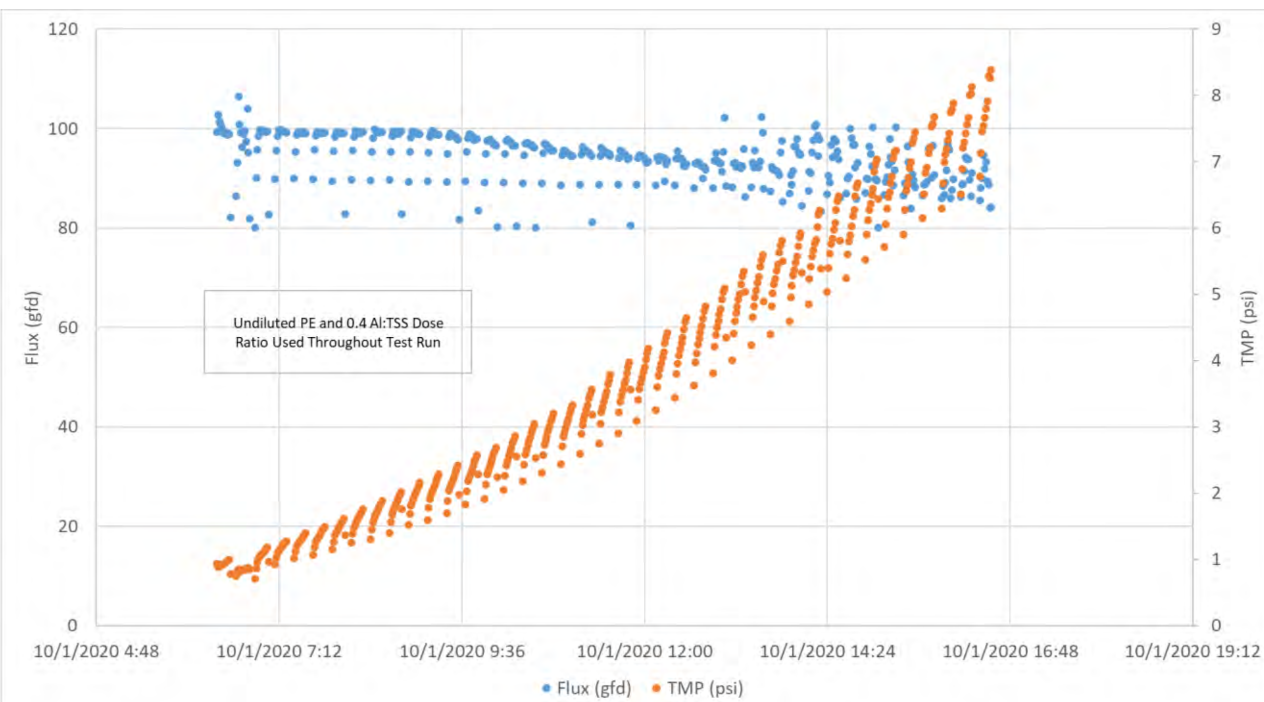


Figure 3-10. Flux and TMP, Run 3

Figure 3-11 shows the basin TSS and influent TSS through the test run. The basin TSS tapers off at approximately 900 mg/L, which is thought to be due to losses of TSS during backwashes.

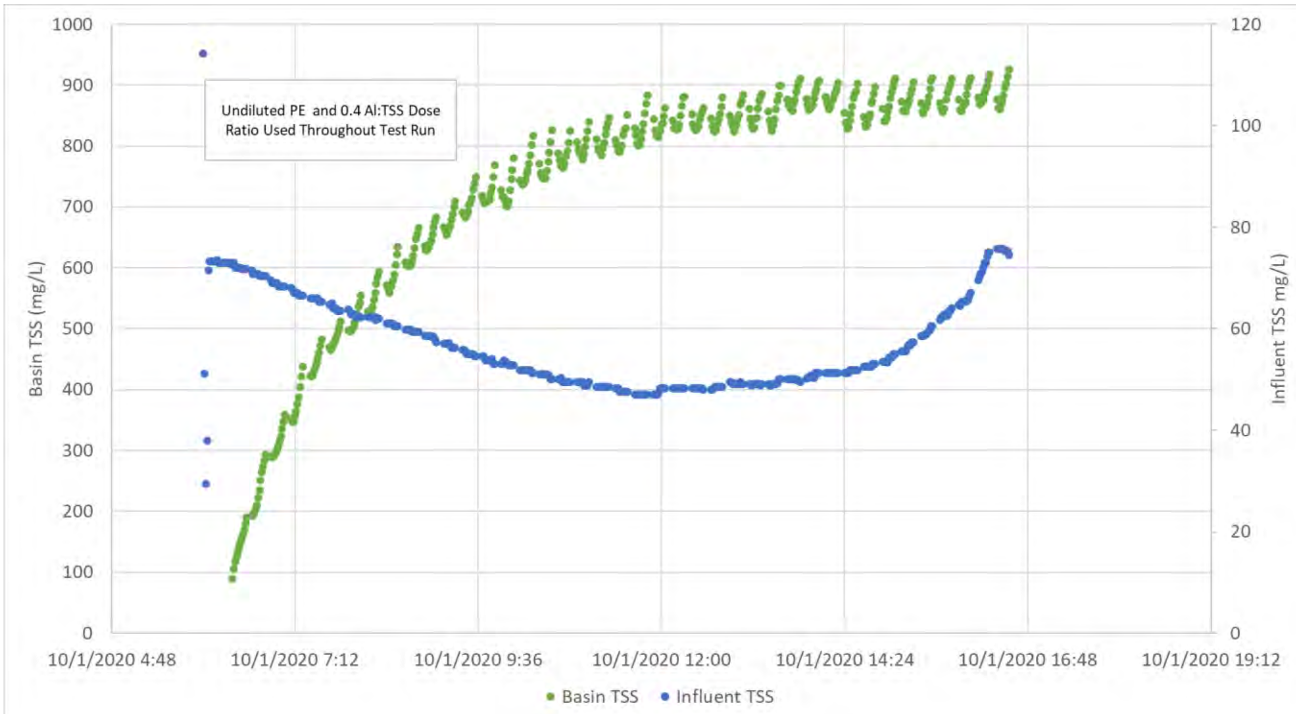


Figure 3-11. TSS, Run 3

Figure 3-12 shows the permeate turbidity and TMP through the test run.

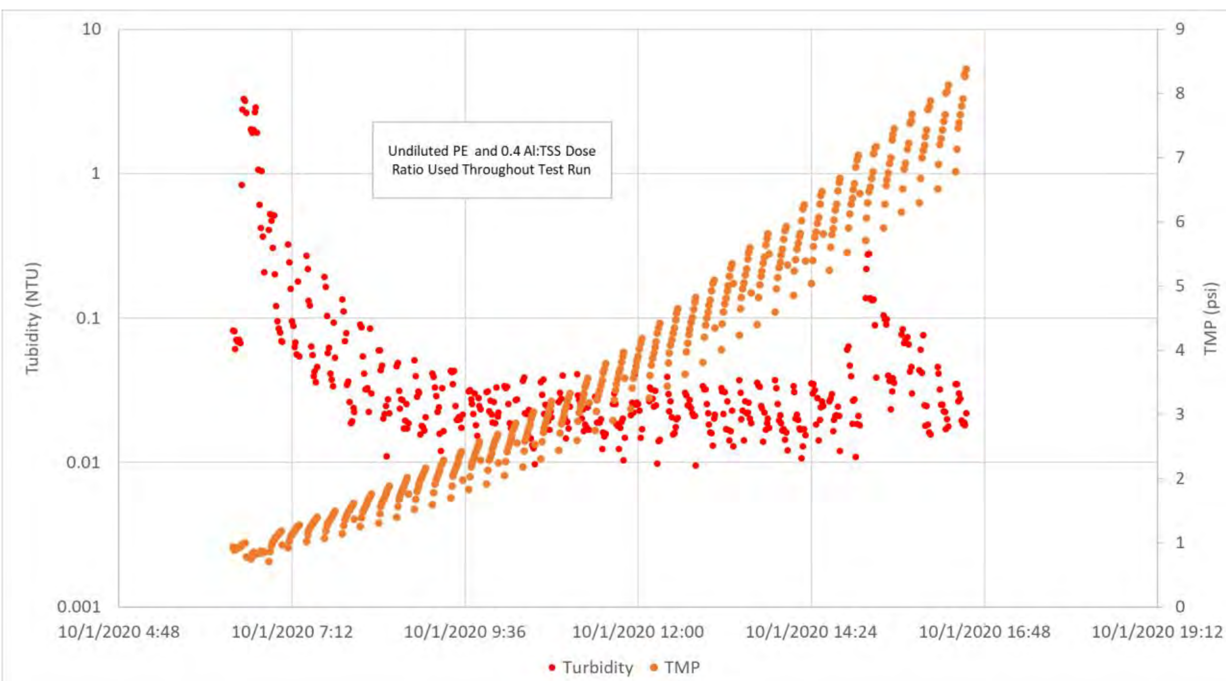


Figure 3-12. Effluent Turbidity and TMP, Run 3

Figure 3-13 shows the relationship between the coagulant dose and effluent pH.

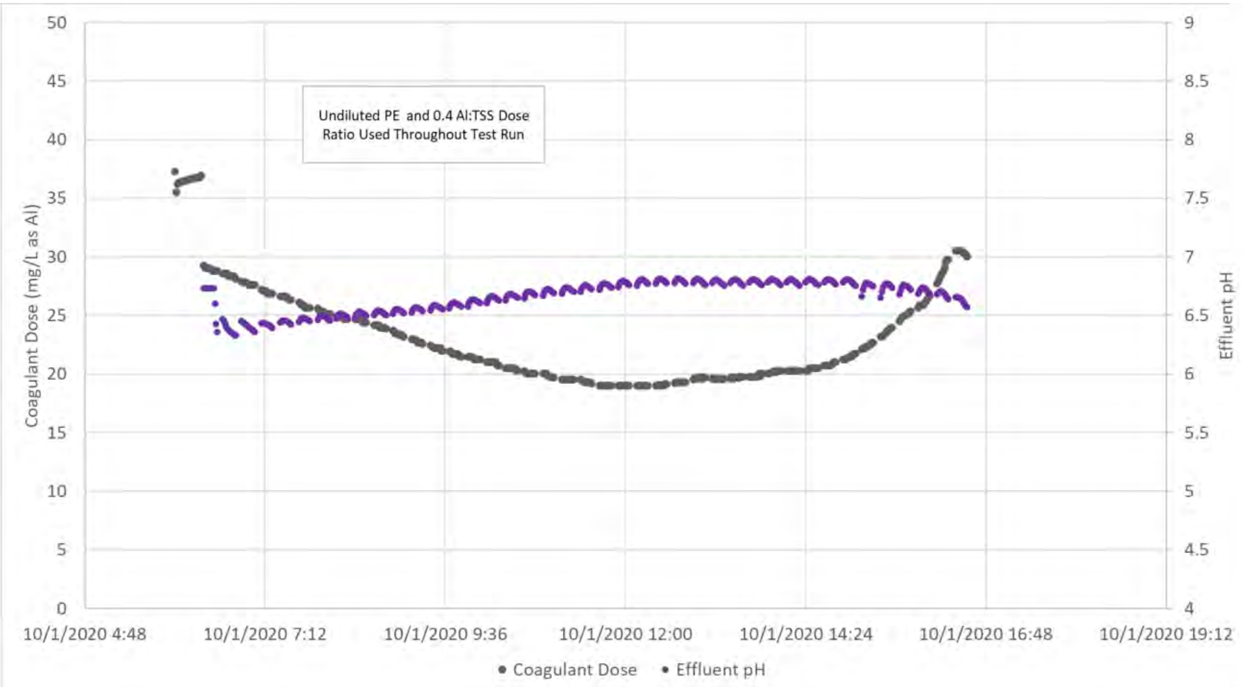


Figure 3-13. Coagulant Dose and Effluent pH, Run 3

3.4.3 Sampling Results

Key sampling results collected during this run are presented in Table 3-18 through Table 3-21. This was the first of the three Performance Tests during pilot testing (the other Performance Tests being Test Runs 6 and 10. The more intense sampling compared to Process Tests yielded more insights about the capability of the pilot unit for removing nutrients and metals. These results are discussed in greater detail in Section 4.1.4.

Table 3-18. Water Quality Data, Run 3

Parameter	Location	10/1/2020 (Time Stamps Below) 730	740	1000	1010	1200	1210	Grab Average	Composite
		Undiluted PE							
TSS (mg/L)	INF			38				38	43
	EFF								2
	TNK			1,550				1,550	
VSS (mg/L)	INF			32				32	36
	EFF								1
	TNK			870				870	
SS (mL/L/hour)	EFF	0						0	
tCOD (mg/L)	INF								196
TOC (mg/L)	INF	61.3				45.3		53.3	42
	EFF								25.8
BOD (mg/L)	EFF								42
Hexane Extractable Material (HEM) (mg/L)	INF	23.9		17.1		16.4		19.1	
	EFF		1.6		1.4		1.6	1.5	
Alkalinity (mg/L as calcium carbonate [$CaCO_3$])	INF								193
	EFF								98
Fecal Coliform (MPN/100 mL)	INF			22,000,000		13,000,000		17,000,000	
	EFF		0	20	20		0	4 (geomean)	
Cl_2 Demand (mg/L)	EFF	1.04						1.04	
UV254 (cm^{-1})	EFF								0.199

Table 3-19. Nutrients Data, Run 3

Parameter	Location	10/1/2020 (Time Stamps Below) 730	740	1000	1010	1200	1210	Grab Average
		Undiluted PE						
Total Phosphorus (P) (mg/L)	INF	4.17		3.76		3.99		3.97
	EFF		0.20		0.10		0.14	0.15
Orthophosphate-P (mg/L)	INF	2.74		2.50		2.77		2.67
	EFF		0.01		0.01		0.02	0.01
TKN (mg/L)	INF	37.61		35.63		38.40		37.21
	EFF		31.64		30.92		31.64	31.40
Ammonia-Nitrogen (N) (mg/L)	INF	25.32		25.78		28.34		26.48
	EFF		26.52		26.26		27.99	26.92
Nitrate-N (mg/L)	INF	0		0		0		0
	EFF		0		0		0	0
Nitrite-N (mg/L)	INF	0		0		0		0
	EFF		0		0.017		0	0.006

Table 3-20. Metals Data, Run 3

Parameter	Location	730	735	740	1005	1010	1200	1205	1210	Unknown Time	Grab Average
		10/1/2020 (Time Stamps Below)									
		Undiluted PE									
Arsenic (micrograms [µg]/L)	INF	1.78					1.90			1.83	1.84
	EFF			0.83		0.85			0.913		0.86
	TNK		5.79		9.18			12.5			9.16
Cadmium (µg/L)	INF	0.12					0.095			0.086	0.10
	TNK		0.586		0.828			1.06			0.82
Copper (µg/L)	INF	25.6					23.5			24.9	24.7
	EFF			2.14		1.9			2.17		2.07
	TNK		119		202			268			196
Lead (µg/L)	INF	1.56					1.77			1.76	1.70
	EFF			0.16		0.13			0.13		0.14
	TNK		7.79		11.9			15.7			11.80
Nickel (µg/L)	INF	3.37					2.94			3.31	3.21
	EFF			2.94		2.65			2.49		2.69
	TNK		6.84		9.05			10.6			8.83
Zinc (µg/L)	INF	59.3					50.3			48.3	52.6
	EFF			22.3		15.9			14.6		17.6
	TNK		237		375			493			368

Table 3-21. Field Water Quality Data, Run 3

Time	Location	pH	Temperature (degrees C)	Total Dissolved Solids (TDS) (parts per million [ppm])	Conductivity (µS/centimeter [cm])
7:30	INF	7.12	18.4	855	1209
7:35	TNK	6.72	18.1	906	1275
10:00	INF	7.16	18.2	731	1011
10:05	TNK	7.00	18.4	785	1090
10:10	EFF	6.86	18.6	745	1049
12:00	INF	7.11	19.5	616	871
12:10	EFF	7.08	19.4	648	913

3.4.4 Data Analysis

3.4.4.1 Coagulant Dose Ratio

The ratio of coagulant to organic compounds was evaluated because organic compounds are likely the primary fouling agents of the membranes in the primary effluent used in the pilot testing. The ratios of coagulant to organic compound from Test Run 3 are shown in Table 3-22. As discussed in the subsequent section on TMP rise rate, the coagulant dose ratio used in Test Run 3 was observed to be insufficient to mitigate membrane fouling.

Table 3-22. Ratio of Coagulant to Organic Compounds, Run 3

Ratio	Time Stamps			Composite
	730	1000	1200	
Al:tCOD				0.12
Al:TOC	0.43		0.42	0.56
Al:TSS	0.4	0.4	0.4	0.4

3.4.4.2 TMP Rise Rate

The TMP rise rate was high in this run, with an average increase of 0.70 psi/hour over the 10-hour run. TMP exceeded the high alarm setpoint of 8 psi near the end of the run, reaching 8.4 psi (Figure 3-10). There was a distinct change in TMP rise rate beginning at 11:33, 5 hours and 10 minutes after the beginning of the run. The TMP rise rate was 0.49 psi/hour over the first 5 hours and 0.89 psi/hour over the second 5 hours (Table 3-23).

Table 3-23. TMP Rise Rate, Run 3

	Time	Instantaneous Flux Setpoint (gfd)	Average TMP Rise Rate (psi/hour)
First Period	0623-1133	100	0.49
Second Period	1133-1633	100	0.89
Overall	0623-1633	100	0.70

The overall TMP rise rate in this run was likely caused by insufficient coagulant to remove sufficient organic compounds to mitigate fouling. This is consistent with the fact that later test runs that used a higher Al:TSS ratio of 0.6 recorded lower TMP rise rates at 100 gfd than Test Run 3.

At approximately the same time as the observed rise in TMP rise rate, the influent TSS concentration also increased from approximately 45 mg/L to above 70 mg/L (Figure 3-11). The ratios of coagulant to organic compounds (Table 3-22) were not lower during the second half of the test run. However, assuming that the removal efficiencies for organic foulants are comparable at the same coagulant:TSS ratio of 0.4 or comparable coagulant:organics ratio, higher influent TSS and organic compounds would result in higher organics concentrations remaining in the wastewater that can foul the membranes. Higher residual organic concentrations despite higher coagulant dosing could explain the higher TMP rise rate in the latter portion of the run, regardless of the fact that the coagulant dosing correlated with influent TSS concentrations.

3.4.4.3 Turbidity

As shown in Figure 3-12, the turbidity in the permeate was over 1 NTU at the start of the test due to residual air in the system. The permeate turbidity gradually declined, and after approximately 1.5 hours was consistently below 0.1 NTU. It remained below 0.1 NTU for most of the remainder of the test except between 15:09 and 15:16, when it was between 0.13 and 0.28.

3.4.4.4 pH

The effluent pH decreased because the applied alum consumed alkalinity in the influent primary effluent; caustic soda was not used to control the pH. The pH stayed above 6 for the duration of the test. It went up when the alum dose was lowered in response to lower influent TSS and down when the alum dose was raised in response to higher TSS (Figure 3-11 and Figure 3-12). The average coagulant dose for the test run was 23.3 mg/L Al, which would theoretically consume 129 mg/L of alkalinity. The composite alkalinity data (Table 3-18) shows that an average of 95 mg/L of alkalinity as $CaCO_3$ was consumed in the test run.

The discrepancy between the theoretical and actual observed alkalinity consumption is likely attributable mostly to the samples being composite rather than grab samples. The key thing to note about pH and alkalinity is that the full-strength primary effluent used in this test run had a composite total alkalinity of 193 mg/L, which was sufficient to buffer and keep the pH above 6 throughout the test run, which had coagulant dosages at higher than 30 mg/L at times.

3.4.4.5 Nutrient Removal

The performance tests, including Test Run 3, sampled and analyzed for the following nutrients: total phosphorus, orthophosphate, TKN, ammonia, nitrate, and nitrite (Table 3-19). Table 3-24 lists the removal percentages for nutrients during the test run. Total phosphorus and orthophosphate both showed high removal percentages, while some TKN was also removed. There was no ammonia removal. No nitrate or nitrite was present in the influent, so their removal efficiencies are not shown. The nutrient removal results are expected. Ammonia is highly soluble, and the treatment process should not remove ammonia. Total phosphorus and orthophosphate are expected to adsorb to aluminum hydroxide from the alum coagulant and be removed. The observed TKN removal is likely due to fractions of reduced nitrogen organic compounds, such as proteins, peptides, or amino acids, being removed by the treatment process.

Table 3-24. Nutrients Removal Efficiency, Run 3

Parameter	Location	Grab Average	Removal Percentage
Total P (mg/L)	INF	3.97	96.3%
	EFF	0.15	
Orthophosphate-P (mg/L)	INF	2.67	99.5%
	EFF	0.01	
TKN (mg/L)	INF	37.21	15.6%
	EFF	31.40	

3.4.4.6 Metals Removal

Priority pollutant metals were sampled and analyzed in Test Run 3 as part of the performance sampling and analysis. Table 3-25 shows the removal percentages. In addition to the removal percentages, it should also be noted that the concentrations of the metals in the membrane tank steadily increased throughout the test run (Table 3-20). This is consistent with metals being retained by the treatment process. No attempt was made to perform mass balance calculations on the metals based on volumes of wastewater treated and influent, effluent, and membrane tank metals concentrations because a fraction of the solids in the membrane tank were lost from backwashing.

Table 3-25. Metals Removal Efficiency, Run 3

Parameter	Location	Grab Average (µg/L)	Removal Percentage
Arsenic	INF	1.8	53%
	EFF	0.86	
Copper	INF	24.7	92%
	EFF	2.1	
Lead	INF	1.7	92%
	EFF	0.14	
Nickel	INF	3.2	16%
	EFF	2.7	
Zinc	INF	52.6	66.6%
	EFF	17.6	

3.4.4.7 Net Permeate and Flux

The following were the key results for net permeate and flux:

- Total operating time: 610 minutes
- Approximate net permeate produced (permeate – backwash): 81,900 gallons
- Approximate net flux accounting for backwash: 66.1 gfd

3.4.5 Membrane Recovery

Table 3-26 shows the TMP at the end of Test Run 3 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill and at the end of the CIP chemical fills. Data are consistent with membrane recovery after the CIP.

Table 3-26. Run 3 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi[a]
8.4 (100)	1.0 (100)	2.5	2.1

a A header pressure of less than 2.1 psi at the end of a chemical fill step is understood to indicate membrane recovery.

3.5 Test Run 4

This test run was performed on September 29, 2020, and ran for 10 hours. It was designed as a process test to confirm a peak flux operating range from 100 to 200 gfd. The alum coagulant dose ratio was set to 0.4 Al:TSS.

Starting at a flux rate of 100 gfd, the pilot was operated for 1 hour with undiluted primary effluent. The flux rate was then set to 125 gfd and operated for another hour, when the influent dilution ratio was changed to approximately 1:1 primary effluent and potable water. This increase in flux setup by 25 gfd for 1-hour intervals continued up to a peak flux rate of 200 gfd, which was operated for 2 hours. After operating at the 200 gfd setpoint, the flux was decreased by 25 gfd intervals, operating at 1 hour each until reaching the 100 gfd setpoint again. By this method, each flux rate was tested for a total of 2 hours. This test was designed to observe the impact of both increasing and decreasing the flux rates on the TMP, along with comparing impacts to the TMP at the same flux rates while the flux rates were stepped up versus when they were stepped down.

The range of flux values tested was achieved through a combination of changing the permeate flow setpoint and taking membrane stacks out of service when necessary, as shown in Table 3-27. Adjusting the permeate flow setpoint required going from 100 percent primary effluent at 100 gfd to adjusting flows of primary effluent and potable water to achieve approximately 1:1 primary effluent and potable water. The number of membrane stacks in service was reduced by one for the flux setpoint of 150 gfd, going to only one stack in service at the 200-gfd flux setpoint.

Table 3-27. Operational Setpoints for Test Run 4

Influent Dilution	Permeate Flow Setpoint (gpm)	Number of Membrane Stacks in Service (#)	Membrane Surface Area in Service (sq. ft.)	Instantaneous Flux (gfd)	Test Plan Flux Goal (gfd)	Run Time (hours)
Undiluted PE	204	3	2,925	100	100	1
~1:1 PE to Potable Water	240	3	2,925	118	125	1
	203	2	1,950	150	150	1
	237	2	1,950	175	175	1
	136	1	975	201	200	2
	237	2	1,950	175	175	1
	203	2	1,950	150	150	1
	240	3	2,925	118	125	1
	204	3	2,925	100	100	1

3.5.1 Observations

A notable observation during this test run was as follows:

- Significant light, white, fluffy foam was observed in the membrane tank.
- The TMP rise rates decreased after flux rates were decreased.

This was a successful run in terms of demonstrating the ability to operate from 100 to 200 gfd and operating at 200 gfd setpoint for 2 hours continuously without excessive fouling of the membrane, even at the relatively low coagulant dose ratio of 0.4 Al:TSS.

3.5.2 Operational Data

Figure 3-14 shows the flux rates and TMPs during the 10-hour run. Figure 3-15 shows the basin TSS and influent TSS through the test run. Figure 3-16 shows the permeate turbidity and TMP through the test run and Figure 3-17 shows the coagulant dose and permeate pH.

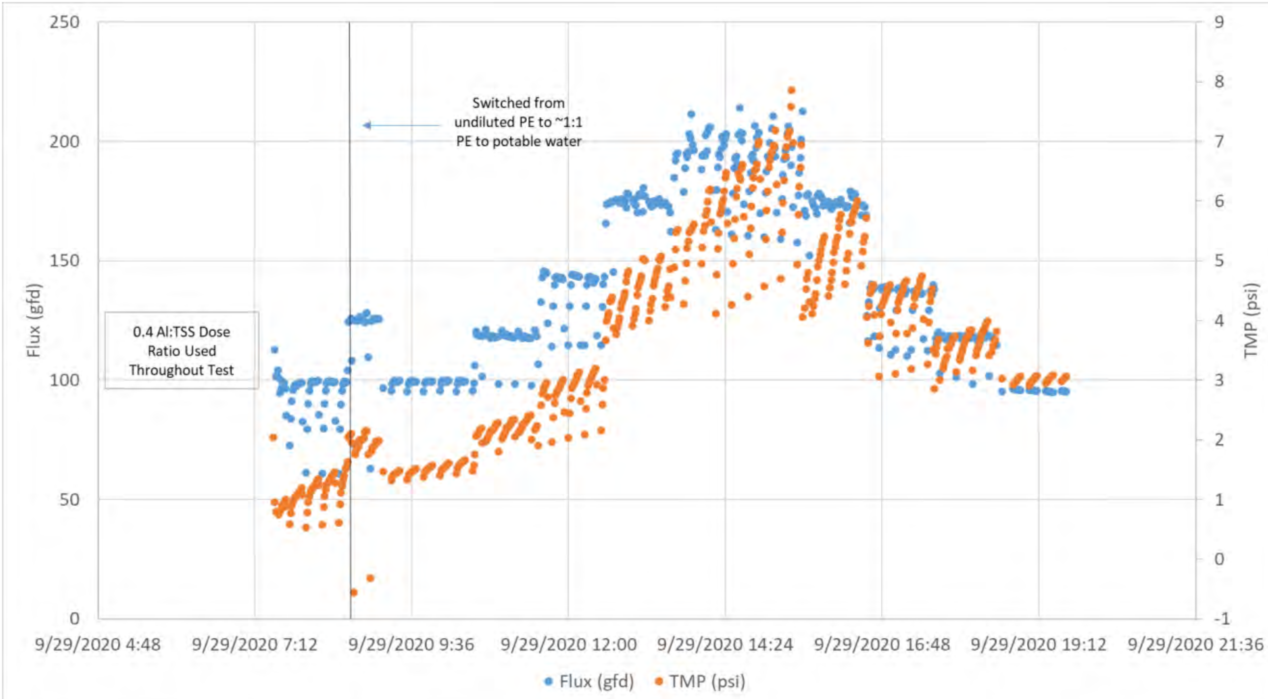


Figure 3-14. Flux and TMP, Run 4

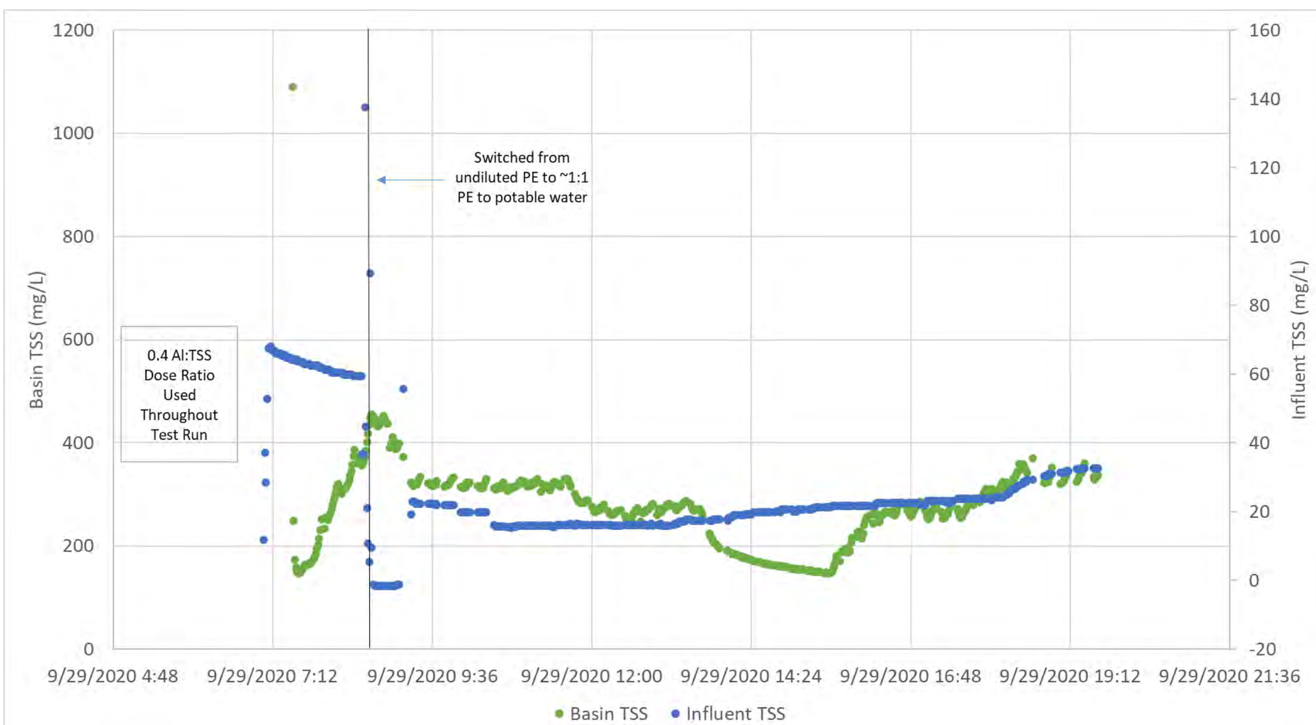


Figure 3-15. TSS, Run 4

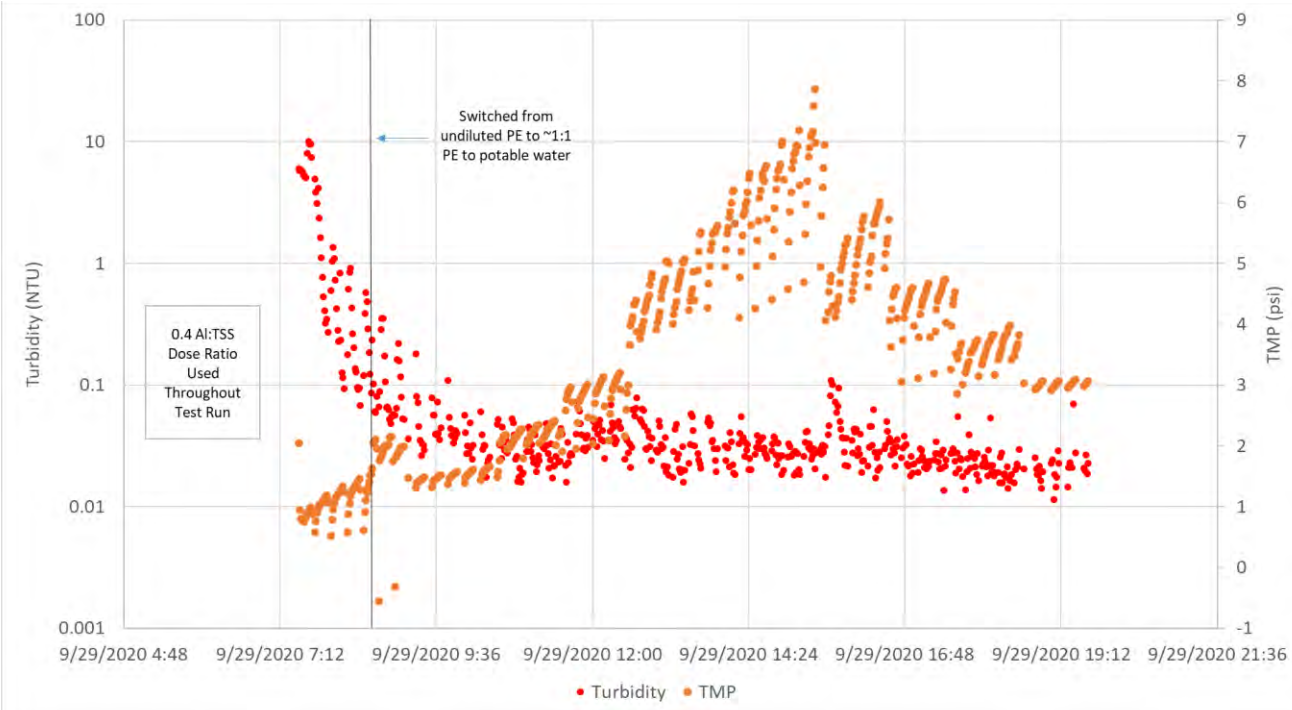


Figure 3-16. Turbidity and TMP, Run 4

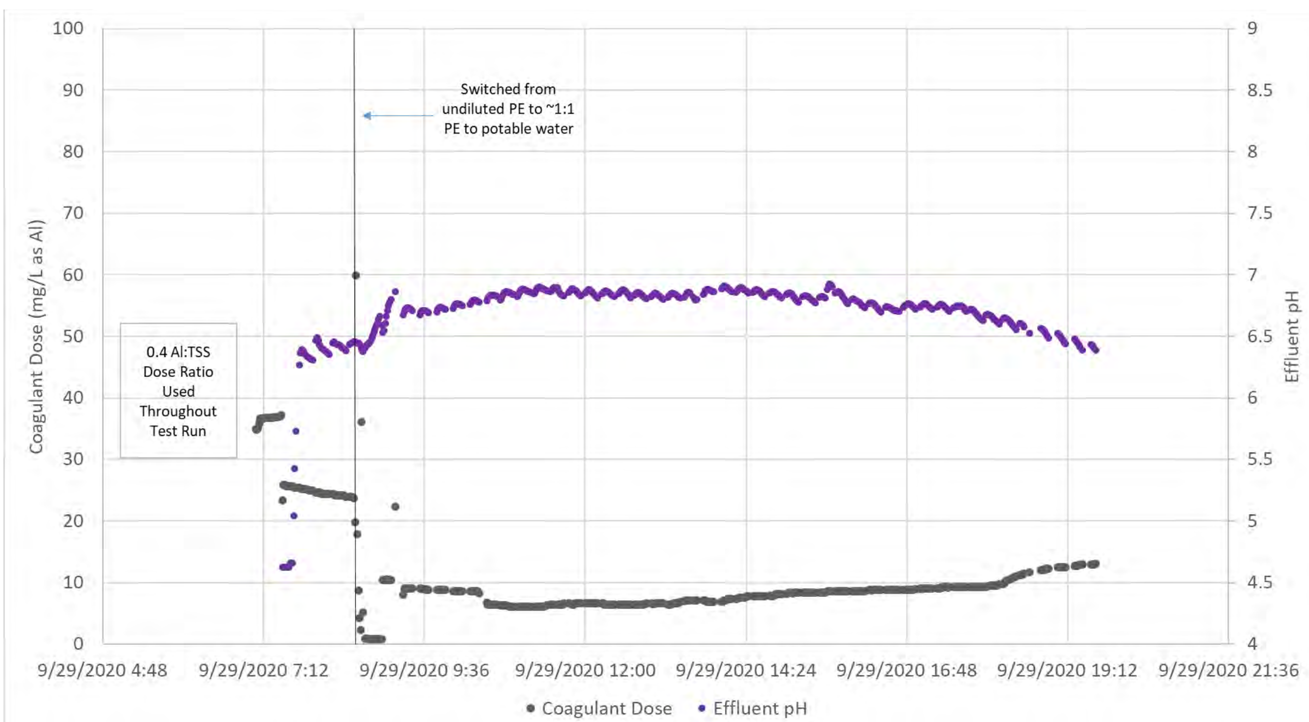


Figure 3-17. Coagulant Dose and Effluent pH, Run 4

3.5.3 Sampling Results

Key sampling results collected during this run are presented in Table 3-28 and Table 3-29.

Table 3-28. Water Quality Data, Run 4

Parameter	Location	9/29/2020 (Time Stamps Below) 810	900	1100	1210	1400-1417	1600	1800	1905	Grab Average	Composite
		Undiluted PE	1:1 PE to Potable Water								
TSS (mg/L)	INF					24				24	
	EFF										1
	TNK					490				490	
VSS (mg/L)	INF					21				21	
	EFF										<1
	TNK					290				290	
SS, (mL/L/hour)	EFF					0.1				0	
tCOD (mg/L)	INF					79				79	
	EFF					27				27	
	TNK					463				463	
sCOD (mg/L)	INF					30				30	
	EFF					27				27	
	TNK					22				22	
TOC (mg/L)	INF	58	1.04	14	13	15	19	19	26	21	
	EFF										12.3
BOD (mg/L)	INF					38				38	20
Alkalinity (mg/L as CaCO3)	INF					83				83	
	EFF					54				54	50
	TNK					80				80	
Fecal Coliform (MPN/100 mL)	INF					1,300,000				1,300,000	
	EFF	0			45	0				3.6 (geomean)	
Cl_2 Demand (mg/L)	EFF					0.7255				0.7255	
UV254 (cm^{-1})	EFF										0.0865

Table 3-29. Field Water Quality Data, Run 4

Time	Location	pH	Temperature (degrees C)	TDS (ppm)	Conductivity (µS/cm)
14:00	INF	7.26	21.0	296	407
14:05	TNK	7.28	19.9	268	378
14:10	EFF	7.04	19.6	269	389

3.5.4 Data Analysis

3.5.4.1 Coagulant Dose Ratio

The ratio of coagulant to organic compounds was evaluated because organic compounds are likely the primary fouling agents of the membranes in the primary effluent used in the pilot testing. The ratios of coagulant to organic compound from Test Run 4 are shown in Table 3-30. A low influent TOC data point at 09:00 (Table 3-28) skews the Al:TOC ratio at that time; the other data points show a consistent Al:TOC ratio based on dosing alum coagulant at a 0.4 Al:TSS ratio.

Table 3-30. Ratio of Coagulant to Organic Compounds, Run 4

Ratio	Time Stamps								Composite
	810	900	1100	1210	1400-1417	1600	1800	1905	
Al:tCOD					0.09				
Al:sCOD					0.24				
Al:TOC	0.42	10.00	0.44	0.51	0.48	0.45	0.49	0.48	
Al:BOD					0.19				0.57
Al:TSS	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

3.5.4.2 TMP Rise Rate

The TMP rise rate increased as the target instantaneous flux increased (Table 3-31). The highest TMP rise rates occurred at 175 and 200 gfd setpoints. After operating at 200 gfd for 2 hours, the TMP and TMP rise rate decreased as the flux was decreased back down in 25 gfd intervals.

Table 3-31. TMP Rise Rate, Run 4

Time	Instantaneous Flux Setpoint (gfd)	Average TMP Rise Rate (psi/hour)
0930-1030	100	0.16
1030-1130	125	0.25
1130-1230	150	0.62
1230-1330	175	0.98
1330-1530	200	0.97
1530-1630	175	1.25
1630-1730	150	0.36
1730-1830	125	0.60
1830-1937	100	0.05

3.5.4.3 Turbidity

The turbidity in the permeate was over 1 NTU at the start of the test run and gradually declined to consistently below 0.1 NTU, including during the peak flux of 200 gfd (Figure). Two data points were slightly above 0.1 NTU: 0.11 and 0.10 NTU at 15:40 and 15:41, respectively.

3.5.4.4 pH

The permeate pH stayed above 6 throughout Test Run 4. The pH was slightly lower during the lower flux rates with higher proportions of primary effluent. This may be due to the higher applied alum dosages when higher proportions of primary effluent were used in the influent.

3.5.4.5 Net Permeate and Flux

Because Test Run 4 focused on fouling rates at various flux rates, the net permeate and net flux are not reported for this test run.

3.5.5 Membrane Recovery

Table 3-32 shows the TMP at the end of Test Run 4 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill and at the end of the CIP chemical fills. Although the header pressure at the end of the CIP chemical fill was slightly higher than the approximately 2.1 psi indicator for membrane recovery discussed in the Ovivo CSO Pilot King County Preliminary Test Report (Ovivo 2020), the TMP data after the CIP is consistent with membrane recovery from the CIP.

Table 3-32. Run 4 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi[a]
3.1 (100)	0.9 (100)	2.6	2.2

a A header pressure of less than 2.1 psi at the end of a chemical fill step is understood to indicate membrane recovery.

3.6 Test Run 5

This run, performed on October 6, 2020, and October 7, 2020, was a 24-hour run with a high initial flux followed by decreasing fluxes, roughly representing a storm with high initial rainfall that then tails off. The test run was designed to simulate a front-loaded hydrograph (Figure 3-18) that was modeled after one of the storm patterns seen in the area.

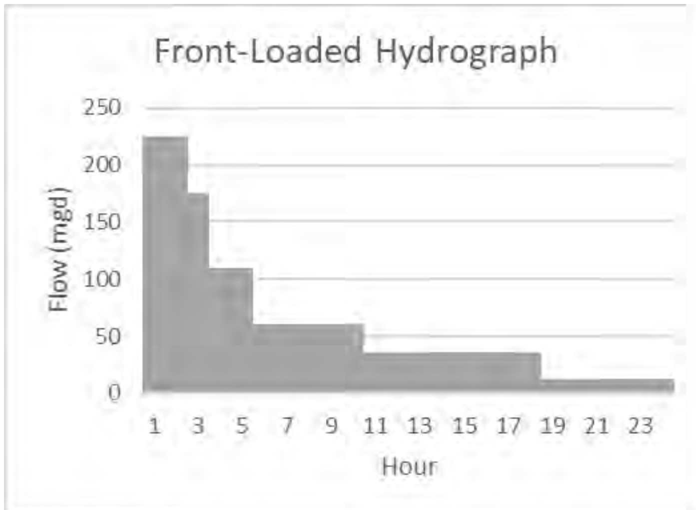


Figure 3-18. Front-Loaded Hydrograph

At fluxes above 100 gfd, the influent was diluted 1:1 with potable water. At 100 gfd or lower, the influent was undiluted primary effluent. The coagulant dose ratio was 0.4 Al:TSS to start, and it was increased to 0.5 at 11:40 based on observed TMP rise rate at the time, which increased as the influent switched from dilution with potable water to undiluted primary effluent at 10:50 when the target flux rate switched from 150 to 100 gfd.

The purpose of the run was to verify the operational characteristics of the unit with variable flux and influent water quality.

3.6.1 Observations

Notable observations/events during this test run were as follows:

- Air was seen in the tubing leading to the turbidimeter at 08:00 on October 6, 2020.
- This run showed that TMP and TMP rise rate are affected by flux. At low fluxes, the unit can run for a long time with minimal TMP increase. At fluxes above 100 gfd, the TMP rises rapidly, even with low influent strength.
- TMP rise rate is also affected by the influent strength, with higher TMP rise rates at higher influent strength as seen when the influent switched from dilution with potable water to undiluted primary effluent at 10:50 when the target flux rate switched from 150 to 100 gfd.
- This run demonstrated the ability of the membrane to handle a brief period of high flux without negatively impacting subsequent treatment ability based on TMP rise rates decreasing to acceptable levels at lower flux rates after brief periods running at high flux rates.

3.6.2 Operational Data

Key operational data collected during this run are presented in Figure 3-19 through Figure 3-22.

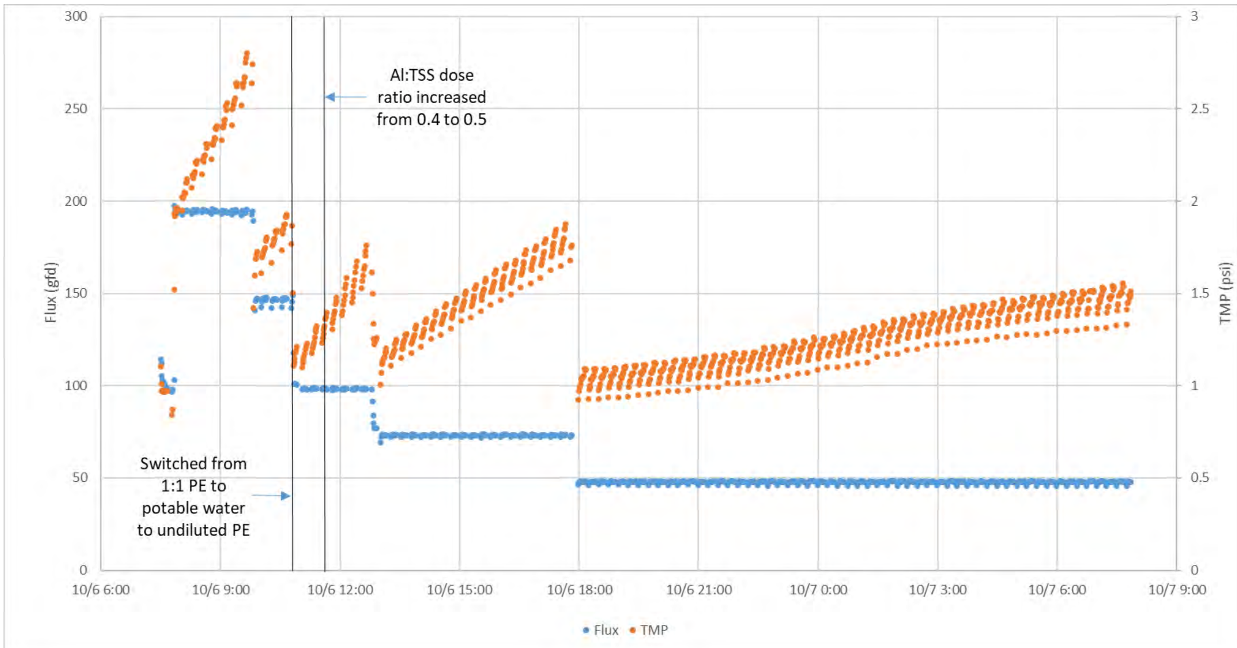


Figure 3-19. Flux and TMP, Run 5

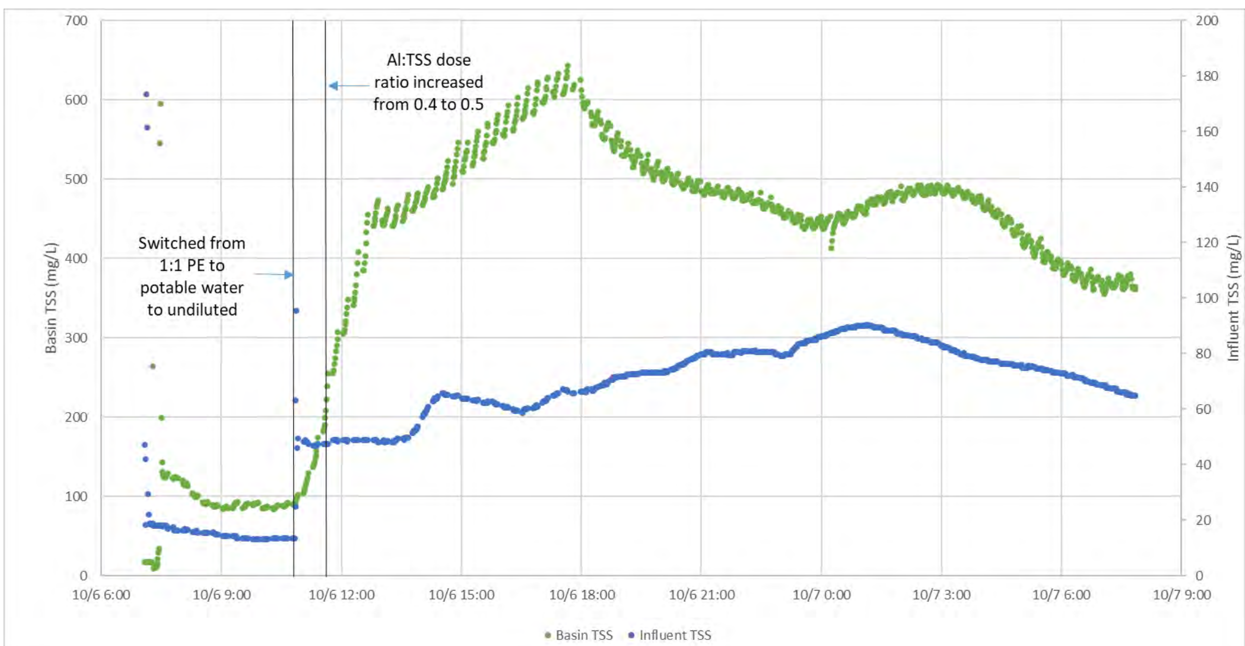


Figure 3-20. TSS, Run 5

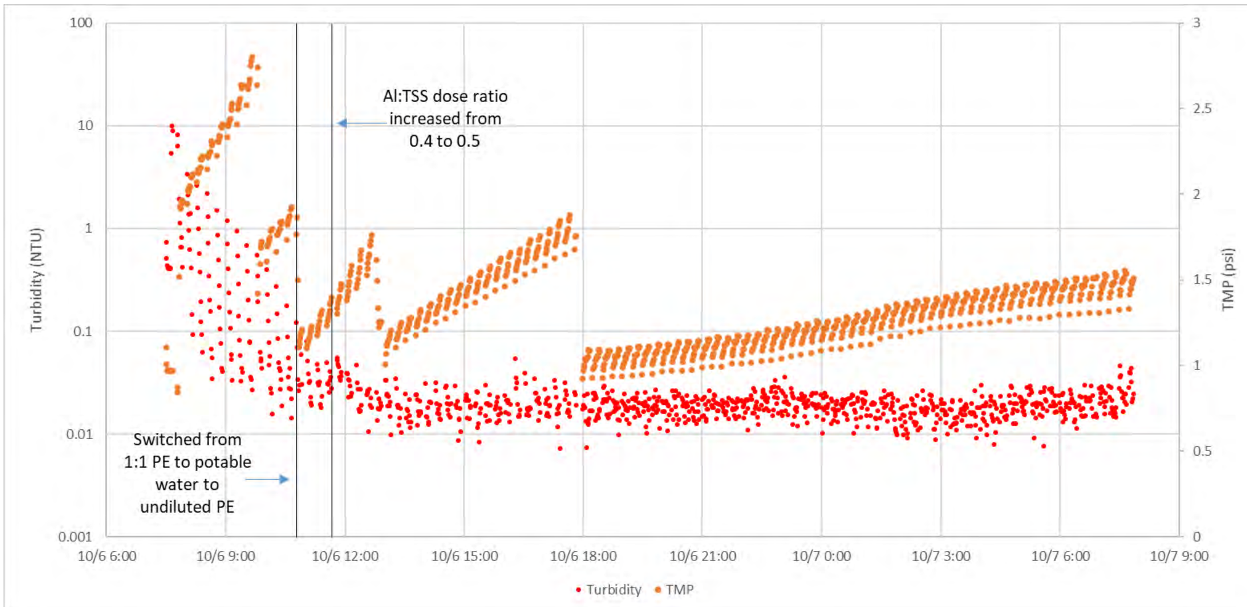


Figure 3-21. Effluent Turbidity and TMP, Run 5

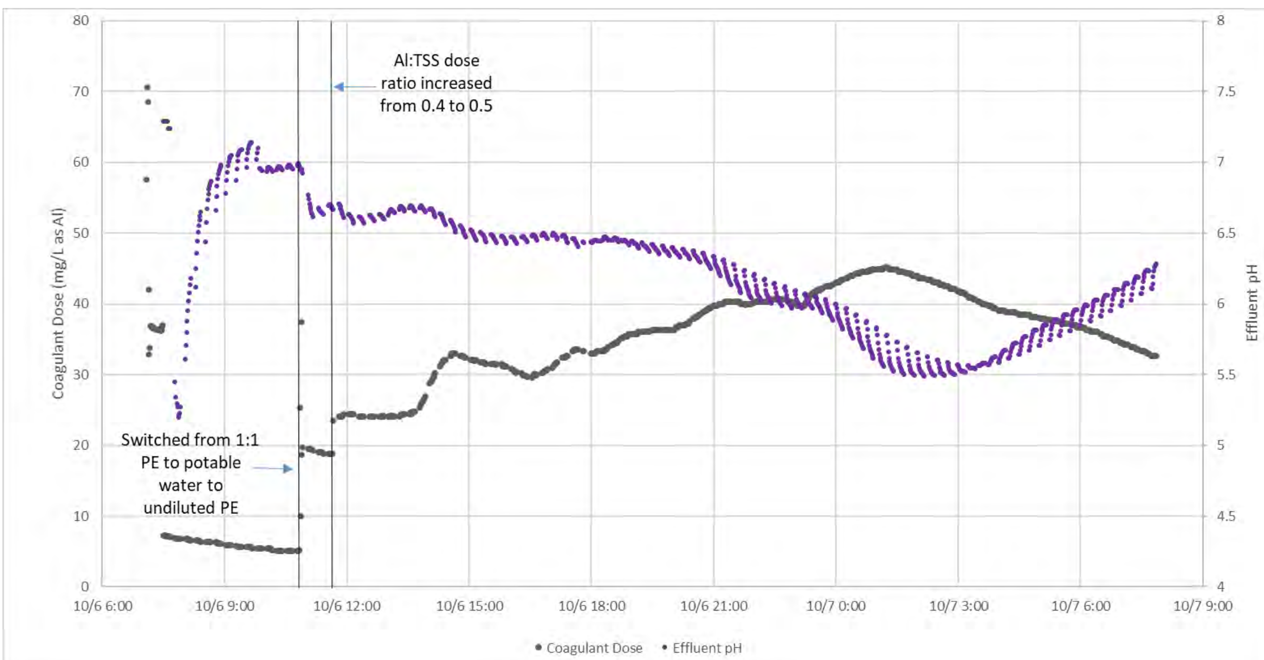


Figure 3-22. Coagulant Dose and Effluent pH, Run 5

3.6.3 Sampling Results

Key sampling results collected during this run are presented in Table 3-33 and Table 3-34.

Table 3-33. Water Quality Data, Run 5

		10/6/2020 (Time Stamps Below)					10/7/2020 (Time Stamps Below)				
		830	**1100**	**1400**	**1630**	**2200**	**000**	**400**	**700**		
Parameter	**Location**	**1:1 PE to Potable Water**	**Undiluted PE**				**Undiluted PE**			**Grab Average**	**Composite**
TSS (mg/L)	INF		42							42	40
	EFF										3
	TNK		354							354	
VSS (mg/L)	INF		35							35	32
	EFF										1
	TNK		202							202	
SS (mg/L)	EFF		0							0	
tCOD (mg/L)	INF		257							257	242
	EFF		54							54	
	TNK		420							420	
sCOD (mg/L)	INF		117							117	
	EFF		53							53	
	TNK		45							45	
TOC (mg/L)	INF	11	46.3	49.4	57.1	73.7	91.6	84.8	70.4	60.5	
	EFF										31.5
BOD (mg/L)	INF		110							110	106
	EFF										53
Alkalinity (mg/L)	INF		187							187	178
	EFF		71							71	52
	TNK		81							81	
Fecal Coliform (MPN/100 mL)	INF		11,000,000						4,900,000	7,300,000	
	EFF	0	230	0					0	4 (geomean)	
Cl_2 Demand (mg/L)	EFF		0.865							0.865	
UV254 (cm^{-1})	EFF										0.189

Table 3-34. Field Sampling, Run 5

Parameter (units)	Location	10/6/2020 1100
pH	INF	7.1
	EFF	6.88
	TNK	7.25
Temperature (degrees C)	INF	20.1
	EFF	19.3
	TNK	19.3
Conductivity (µS)	INF	988
	TNK	497
TDS (ppm)	INF	729
	EFF	503
	TNK	406

3.6.4 Data Analysis

3.6.4.1 Coagulant Dose Ratio

Table 3-35 summarizes the coagulant dose ratios for this run.

Table 3-35. Ratio of Coagulant to Organic Compounds, Run 5

Ratio	Time Stamps		Composite
	1100	1630	
Al:tCOD	0.08		0.13
Al:sCOD	0.17		
Al:TOC	0.42	0.52	
Al:BOD	0.18		0.30
Al:TSS	0.5	0.5	NA

3.6.4.2 TMP Rise Rate

This run indicates that TMP rise rate is related to influent strength and flux. Table 3-36 summarizes TMP rise rates varying with flux. While there are not enough data points for a strong correlation, the TMP rise rate appears roughly proportional to flux to the power of 2 or higher (at the same influent strength). The TMP rise rate at 100 gfd was about 10 times that at 50 gfd. Results from Test Run 5 also show that while the TMP rise rate is higher at higher flux rates, there is also recovery (i.e., lower TMP increase) at lower flux rates after the previous high flux rates.

Table 3-36. TMP Rise Rate, Run 5

Dilution	Time	Flux (gfd)	TMP Rise Rate (psi/hour)
1:1	0800-0950	200	0.43
1:1	0950-1050	150	0.18
None	1050-1300	100	0.33
None	1300-1800	75	0.13
None	1800-0800 (next day)	50	0.03

TMP rise rate was also related to influent strength. At a flux of 100 gfd with full-strength influent, the TMP rise rate was about double that at a flux of 150 gfd with diluted influent.

3.6.4.3 Turbidity

Similar to the previous test runs, this run saw turbidity (see Figure 3-21) over 1 NTU at the start of the run, decreasing to 0.1 NTU after about 2.5 hours and remaining below that level thereafter. The high initial readings are likely associated with air seen in the sample line early in the test.

3.6.4.4 pH

Similar to previous test runs, pH was between 5.5 and 7 for this run. Also similar to other test runs, the pH was lowest in the middle of the night when TSS, and thus coagulant dose, was highest. The pH was also low at the beginning of the test run, which was likely due to the higher coagulant dose when the pilot unit was started at the beginning of the test run, when the coagulant was fed at a steady dose for approximately 20 minutes instead of at the set coagulant:TSS dose ratio.

3.6.4.5 Net Permeate and Flux

The following were the key results for net permeate and flux:

- Total operating time: 1,085 minutes
- Approximate net permeate produced (permeate – backwash): 131,300 gallons
- Net flux accounting for backwash: 59.6 gfd

3.6.5 Membrane Recovery

Table 3-37 shows the TMP at the end of Test Run 5 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill and at the end of the CIP chemical fills. Although the header pressure at the end of the CIP chemical fill was slightly higher than the approximately 2.1 psi indicator for membrane recovery discussed in the Ovivo CSO Pilot King County Preliminary Test Report (Ovivo 2020), the TMP data after the CIP is consistent with membrane recovery from the CIP.

Table 3-37. Run 5 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi
1.6 (50)	1.0 (100)	2.8	2.2

3.7 Test Run 6

This run, performed on October 8, 2020, was designed as a back-loaded scenario, in which the lengths of time to run at each flux were proportional to CSO hydrographs experienced at the Elliott West CSO Treatment Facility during storms. The test ran nearly 12 hours, with fluxes beginning at 50 gfd and increasing to 200 gfd. While running at 200 gfd, the pilot unit shut down due to high TMP.

The test run was designed to simulate a back-loaded hydrograph as shown in Figure 3-23.

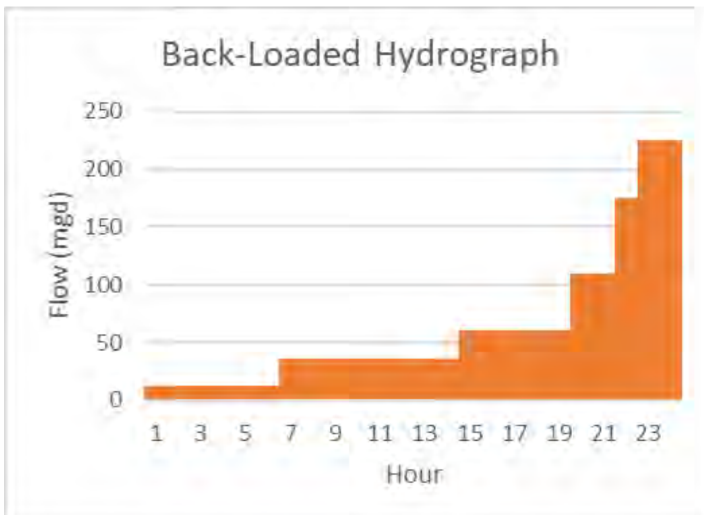


Figure 3-23. Back-Loaded Hydrograph

For this test run, all three membrane stacks were operated for flux rates of 100 gfd and less; due to influent flow limitations, only two stacks were used at 150 gfd, and only one stack was used at 200 gfd.

This run began with a coagulant dose ratio of 0.4 Al:TSS, but it was increased to 0.5 Al:TSS partway through the test when the flux rate was increased from 50 to 75 gfd.

3.7.1 Observations

This run demonstrated that high flux rates are prohibitive after significant run time. Once fouling has had a chance to build up, it may not be possible to increase the flux to levels that were successful at the beginning of test runs. This may also be due to underdosing coagulant, especially at high flux rates, which would allow fouling to build up more quickly compared to similarly underdosing coagulant at lower flux rates.

This run also showed significant removal of phosphorus and several metals and metalloids, as well as compounds that absorb ultraviolet (UV).

3.7.2 Operational Data

Figure 3-24 shows the flux and TMP during the run. The flux setpoint started at 50 gfd and was increased incrementally to 200 gfd. The time at each flow rate was based on flow hydrographs during storm events at the Elliott West CSO facility.

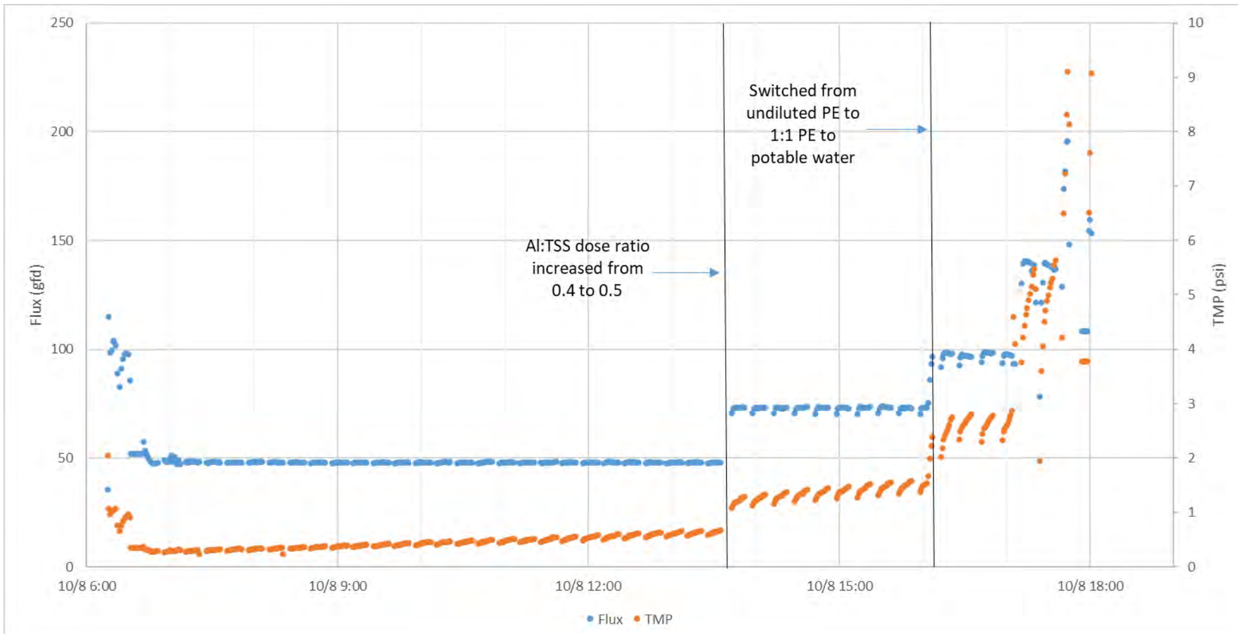


Figure 3-24. Flux and TMP, Run 6

Figure 3-25 shows the basin TSS and influent TSS through the test run. The coagulant dosing was initially set to 0.4 Al:TSS ratio and was increased to 0.5 at 13:43 when the flux setpoint was set to 75 gfd to slow down membrane fouling as the flux was set to be increased in the back-loaded hydrograph simulation test run.

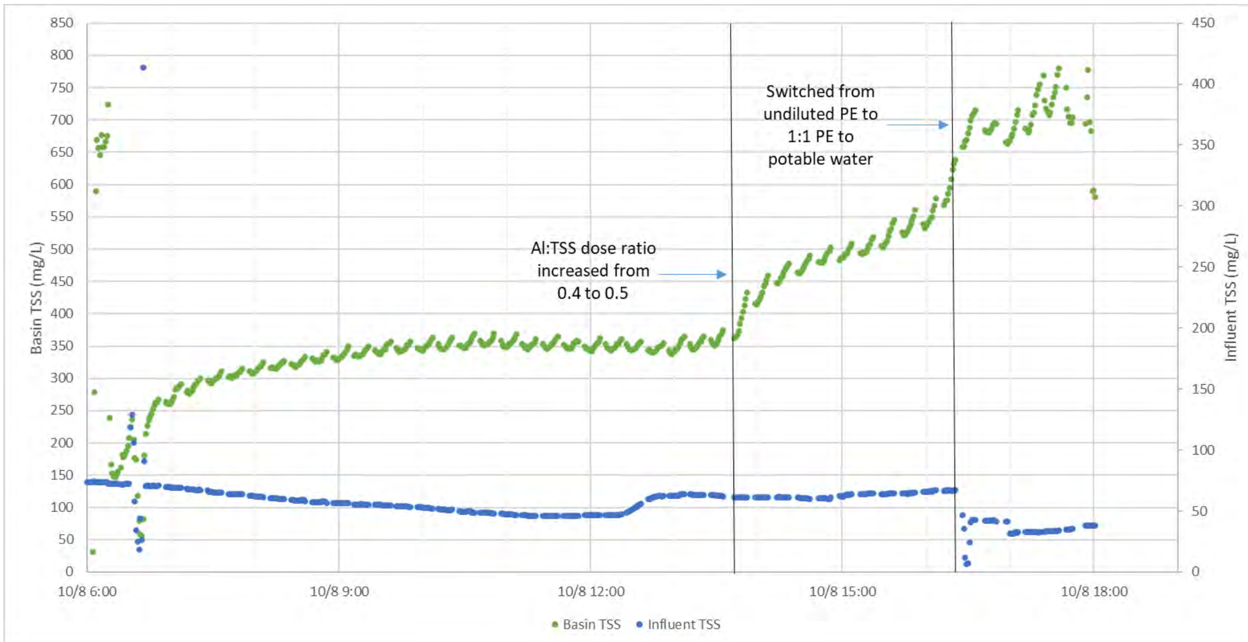


Figure 3-25. TSS, Run 6

Figure 3-26 shows the permeate turbidity and TMP through the test run, and Figure 3-27 shows coagulant dose and effluent pH of the same run.

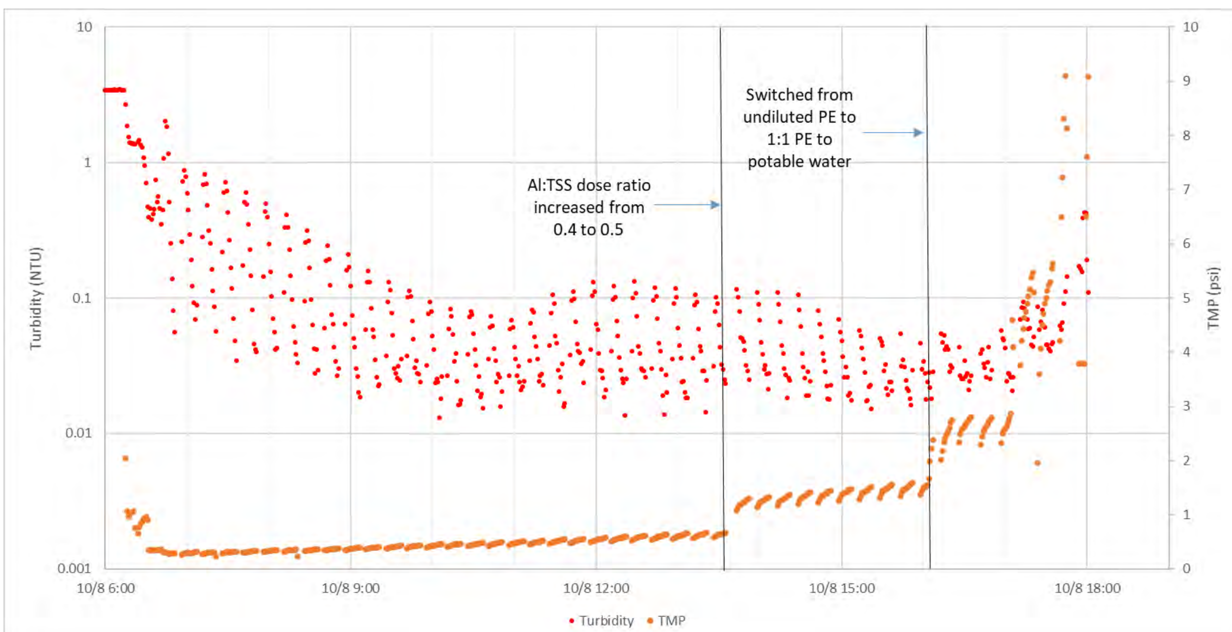


Figure 3-26. Effluent Turbidity and TMP, Run 6

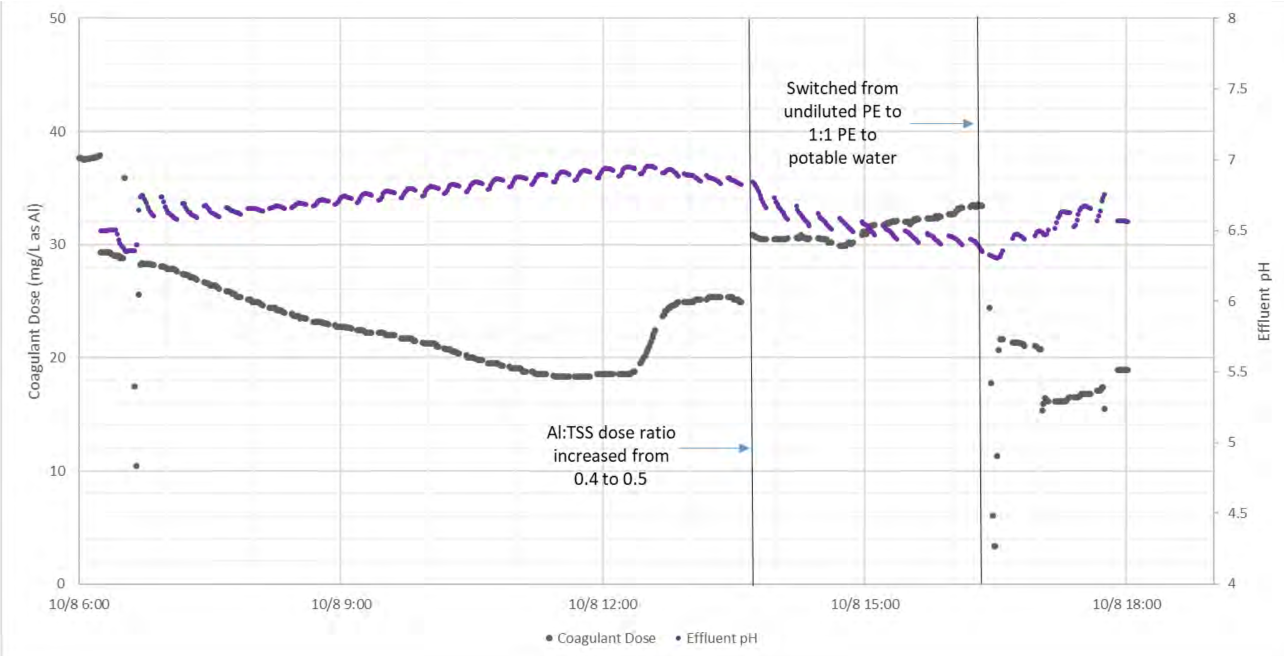


Figure 3-27. Coagulant Dose and Effluent pH, Run 6

3.7.3 Sampling Results

Key sampling results collected during this run are presented in Table 3-38 through Table 3-40.

Table 3-38. Water Quality Data, Run 6

		10/8/2020 (Time Stamps Below)							
		700	730	930	1130	1310	1710		
Parameter	Location	Undiluted PE					1:1 PE to Potable Water	Grab Average	Composite
TSS (mg/L)	INF					53		53	36
	EFF								1
	TNK					780		780	
VSS (mg/L)	INF					46		46	30
	EFF								<1
	TNK					455		455	
SS (mL/L/hour)	EFF					0		0	
tCOD (mg/L)	INF								236
TOC (mg/L)	INF	47.6	65.7			55.2	32.8	50.3	
	EFF	31						31.0	
BOD (mg/L)	EFF								54
HEM (mg/L)	INF		23.1			18.7	10.2	17.3	
	EFF		1.4			1.5	1.4	1.4	
Alkalinity (mg/L)	INF								186
	EFF								85
Fecal Coliform (MPN/100 mL)	INF		13,000,000			3,300,000		6,500,000	
	EFF		0	0	18	110		6.7 (Geomean)	
Cl_2 Demand (mg/L)	EFF					1.61		1.61	
UV254 (cm^{-1})	EFF								0.1965

Table 3-39. Nutrients Data, Run 6

		10/8/2020 (Time Stamps Below)			
		730	1310	1705	
Parameter	Location	Undiluted PE		1:1 PE to Potable Water	Grab Average
Total P (mg/L)	INF	4.19	4.56	2.79	3.85
	EFF	0	0	0	0
Orthophosphate-P (mg/L)	INF	2.94	3.45	1.77	2.72
	EFF	0.05	0.06	0.02	0.04
TKN (mg/L)	INF	37.81	40.75	23.28	33.95
	EFF	31.93	30.5	23.91	28.78
Ammonia-N (mg/L)	INF	27.84	31.83	18.2	25.96
	EFF	29.65	27.5	22.05	26.40
Nitrate-N (mg/L)	INF	0	0	0	0
	EFF	0	0	0	0
Nitrite-N (mg/L)	INF	0	0	0	0
	EFF	0	0	0	0

Table 3-40. Metals Data, Run 6

		10/8/2020 (Time Stamps Below)			
		730	1310	1705	
Parameter	Location	Undiluted PE		1:1 PE to Potable Water	Grab Average
Arsenic (µg/L)	INF	1.68	2.38	1.43	1.83
	EFF	0.8	0.961	0.826	0.86
	TNK	2.91	5.57	10.6	6.36
Cadmium (µg/L)	INF	0.12	0.08	0.05	0.08
	TNK	0.23	0.357	0.705	0.43
Copper (µg/L)	INF	30.3	26.6	16	24.3
	EFF	2.04	2.31	1.5	1.95
	TNK	71.6	108	233	138
Lead (µg/L)	INF	1.58	2.07	1.16	1.60
	EFF	0.14	0.11	0.1	0.13
	TNK	3.88	6.94	17.9	9.57
Nickel (µg/L)	INF	2.94	3.02	1.7	2.55
	EFF	2.96	2.43	1.78	2.39
	TNK	4.78	5.42	9.75	6.65
Zinc (µg/L)	INF	53.5	63.1	36.7	51.1
	EFF	13.7	13.3	10.6	12.5
	TNK	135	221	516	291

3.7.4 Data Analysis

3.7.4.1 Coagulant Dose Ratio

The ratios of coagulant to organic compounds from Test Run 6 are shown in Table 3-41.

Table 3-41. Ratio of Coagulant to Organic Compounds, Run 6

Ratio	Time Stamps			Composite
	730	1310	1710	
Al:tCOD				0.10
Al:TOC	0.40		0.49	
Al:TSS	0.4	0.4	0.5	NA

3.7.4.2 TMP Rise Rate

The TMP rise rate began very low, as expected with a low flux. As the flux increased, the TMP rise rate also increased (see Table 3-42). A TMP rise rate could not be estimated for the last two phases at 150 and 200 gfd because those phases were too short to observe a trend.

Table 3-42. TMP Rise Rate, Run 6

Time	Instantaneous Flux Setpoint (gfd)	Average TMP Rise (psi/hour)
0650-1335	50	0.06
1335-1600	75	0.13
1600-1700	100	0.29
1700-1735	150	Unknown
1735-1800	200	Unknown

3.7.4.3 Turbidity

As shown in Figure 3-26, the turbidity in the permeate was over 1 NTU at the start of the test, then decreased to below 0.1 NTU. Ovivo determined in its preliminary testing report that high initial values are caused by air in the permeate line.

However, unlike many other tests, the turbidity did not stay below 0.1 NTU while running at 50 gfd, despite no changes to the process. The turbidity fluctuated before dropping below 0.1 NTU again. Finally, the turbidity spiked again up to 0.43 NTU during the last 15 minutes of the test while running at 200 gfd with very high TMP.

The turbidity fluctuations are likely due to air in the permeate rather than being caused by breeches in the integrity of the membranes. This is consistent with low effluent fecal coliform results at times when the effluent turbidity was high. For example, at approximately 07:30 during the test, when the effluent turbidity fluctuated between <0.1 and 0.7 NTU for approximately 10 minutes, the effluent fecal coliform sample collected during that time was 0 MPN/100 mL (Table 3-38).

3.7.4.4 pH

The effluent pH remained fairly steady between 6 and 7 during this run. During the first part of the test, the pH slowly increased as the influent TSS concentration decreased, and thus, the coagulant dose decreased. Then the pH decreased after influent TSS concentrations increased and the coagulant dose ratio was increased. Finally, it dropped again after dilution of the influent began for the high-flux portions of the run.

3.7.4.5 Nutrient Removal

Nutrient concentrations are shown in Table 3-39. Table 3-43 lists nutrient removal percentages. Total phosphorus and orthophosphate both showed high removal percentages, while some TKN was also removed. There was no ammonia removal and no nitrate or nitrite in the influent, so their removal efficiencies are not shown.

Table 3-43. Nutrients Removal Efficiency, Run 6

Parameter	Location	Grab Average	Removal Percentage
Total P (mg/L)	INF	3.85	100.0%
	EFF	0.00	
Orthophosphate-P (mg/L)	INF	2.72	98.4%
	EFF	0.04	
TKN (mg/L)	INF	33.95	15.2%
	EFF	28.78	

3.7.4.6 Metals Removal

Priority pollutant metals were sampled and analyzed in Test Run 6 as part of the performance testing sampling and analysis plan. Table 3-44 shows the removal percentages of select metals or metalloids.

The concentrations of the metals in the membrane tank steadily increased throughout the test run (Table 3-40). This is consistent with metals being retained by the treatment process.

Table 3-44. Metals Removal Efficiency, Run 6

Parameter	Location	Grab Average (µg/L)	Removal Percentage
Arsenic	INF	1.8	53%
	EFF	0.86	
Copper	INF	24.3	92%
	EFF	2.0	
Lead	INF	1.6	93%
	EFF	0.12	
Nickel	INF	2.6	6%
	EFF	2.4	
Zinc	INF	51.1	75.5%
	EFF	12.5	

3.7.4.7 Net Permeate and Flux

The following were the key results for net permeate and flux:

- Total operating time: 706 minutes
- Approximate net permeate produced (permeate minus backwash): 71,100 gallons
- Net flux accounting for backwash: 54.4 gfd

3.7.5 Membrane Recovery

Table 3-45 shows the TMP at the end of Test Run 6 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill. There was no data for the header pressure at the end of the CIP chemical fill due to a connection error. The TMP after CIP data is consistent with membrane recovery after the CIP.

Table 3-45. Run 6 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi[a]
9.1 (200)	0.9 (100)	2.5	No data due to connection error

a A header pressure of less than 2.1 psi at the end of a chemical fill step is understood to indicate membrane recovery.

3.8 Test Run 7

This run was performed on September 24, 2020, prior to Test Runs 3 through 6 due to scheduling constraints. The purpose of this run was to verify the resilience of the membranes to loss of coagulant. After running normally for an hour, the coagulant pump was turned off for 30 minutes. Then it was turned back on, and the dose set at double the normal dose. Following that, a CIP was performed, and the unit was run normally for 3 hours to verify recovery.

There was a significant storm the day before and during this test run. Thus, the influent strength at the beginning of the test was significantly lower than in previous tests. Based on TSS measurements, it was about half the strength of dry-weather primary effluent. In the later part of the test, the influent TSS was more typical of previously observed dry weather primary effluent.

3.8.1 Observations

Notable observations/events during this test run were as follows:

- The TMP rose rapidly 20 minutes after coagulant was stopped.
- About 20 minutes after coagulant was restarted, the TMP rise rate decreased to double the normal levels.
- A short, 30-minute soak CIP almost fully restored the membrane and it operated normally afterwards.

This run shows that while coagulant loss leads to rapid shutdown, the system can be restored to normal operation by restoring coagulant and performing a short, 30-minute soak CIP procedure.

3.8.2 Operational Data

Key operational data collected during this run are presented in Figure 3-28 through Figure 3-31.

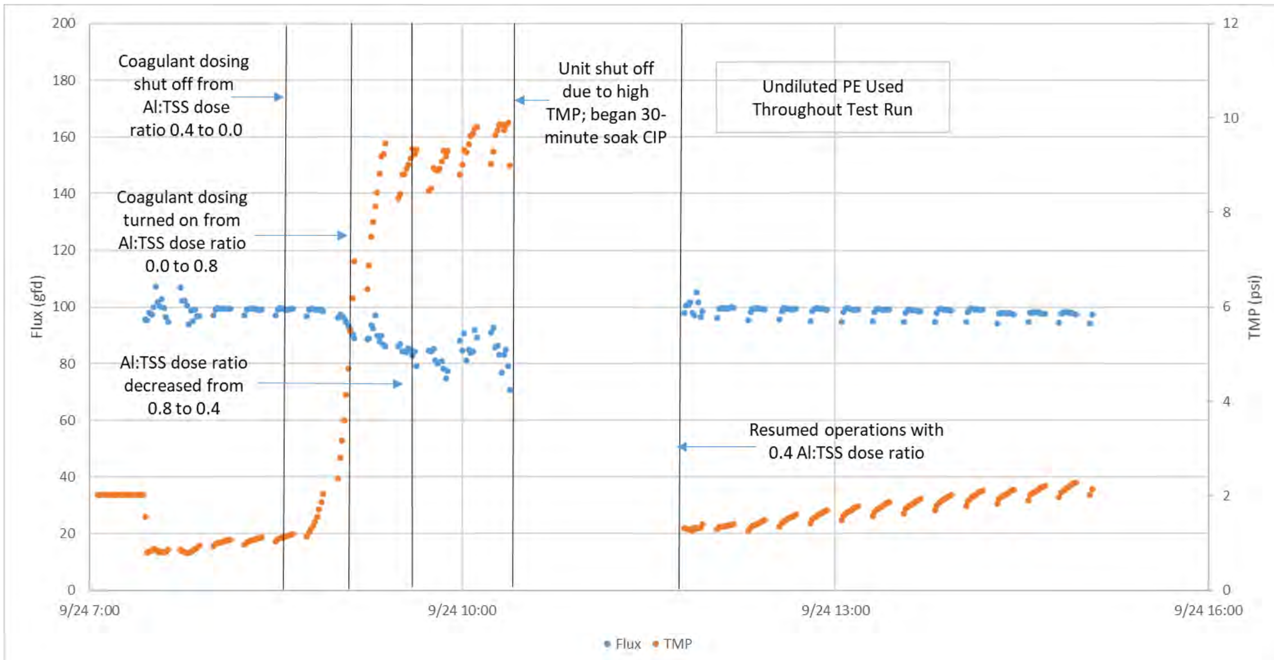


Figure 3-28. Flux and TMP, Run 7

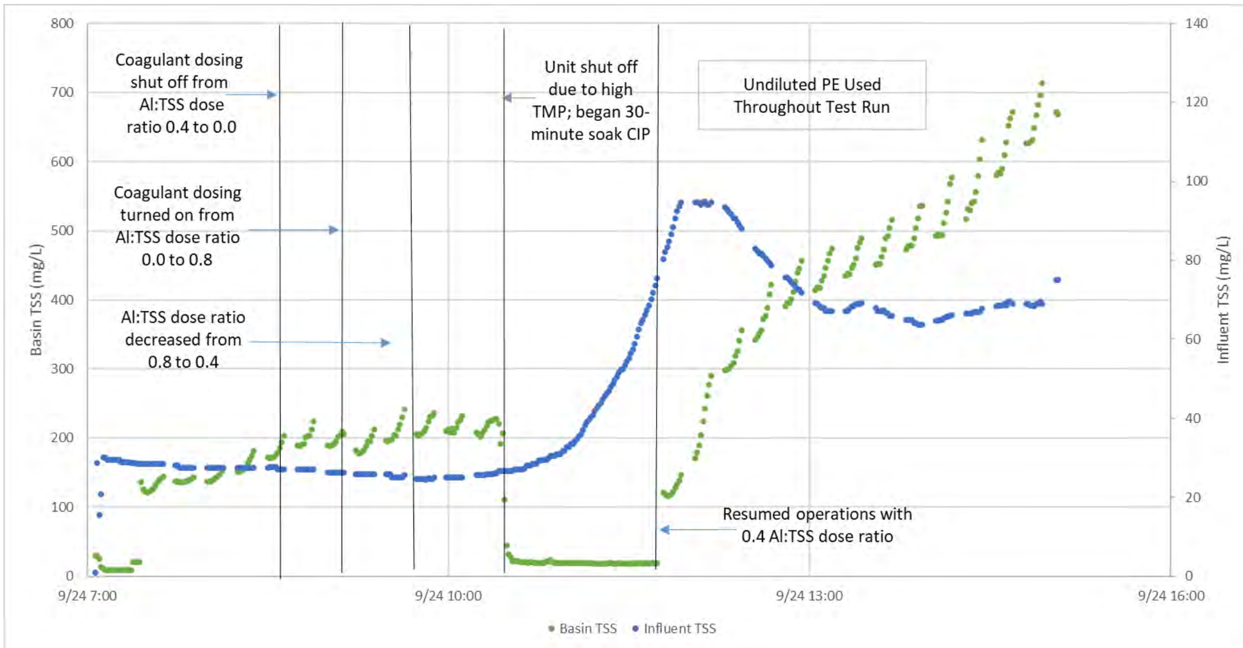


Figure 3-29. TSS, Run 7

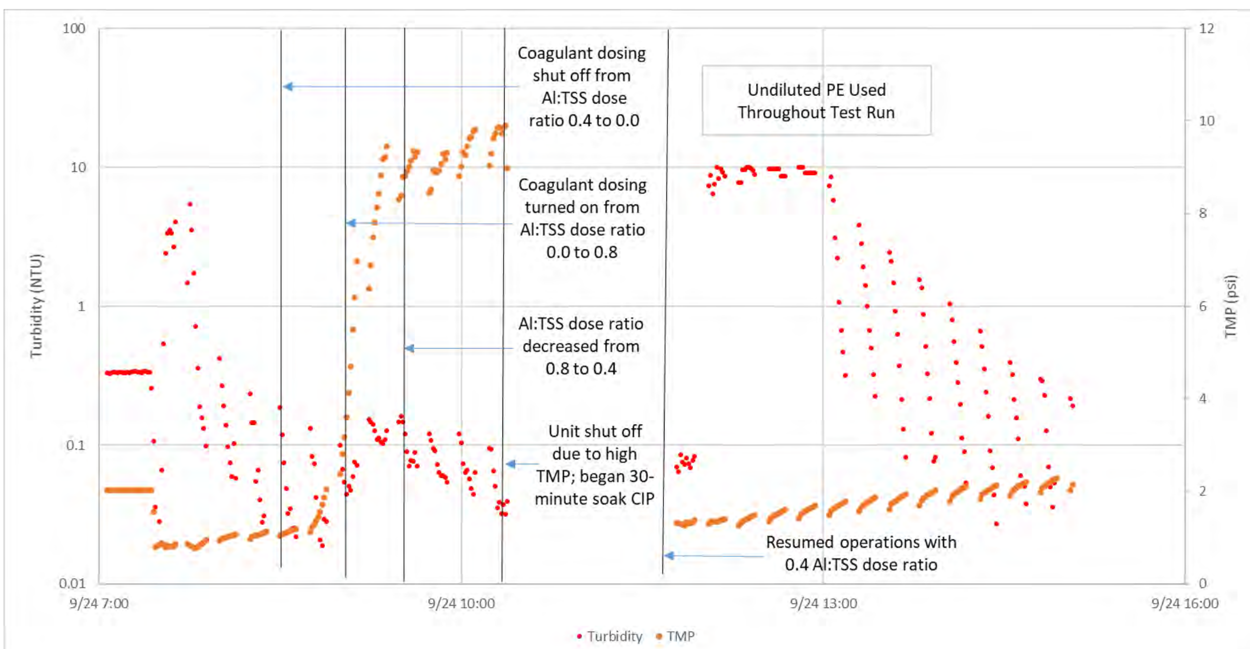


Figure 3-30. Effluent Turbidity and TMP, Run 7

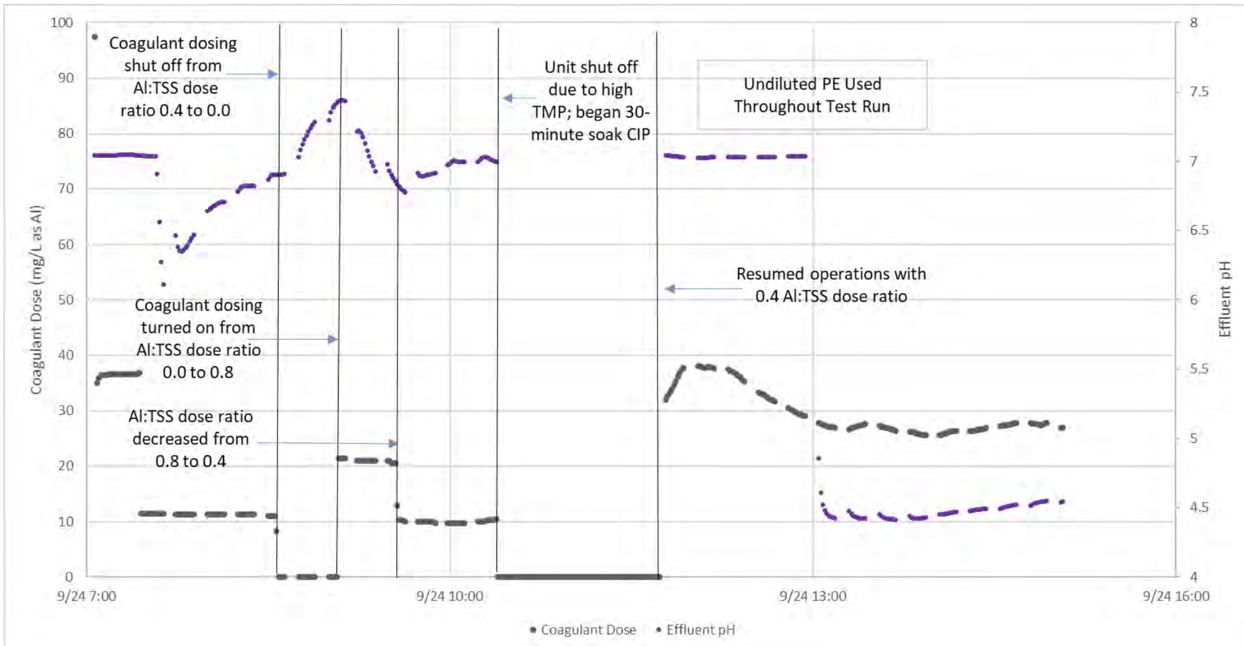


Figure 3-31. Coagulant Dose and Effluent pH, Run 7

3.8.3 Sampling Results

Key sampling results collected during this run are presented in Table 3-46 and Table 3-47. Due to the start and stop nature of this run, the composite samples were composite of two grab samples, one taken before the shutdown and one after the shutdown. As a result, it may not reflect the full variability observed by the online probe compared to composite samples taken from other test runs.

Table 3-46. Water Quality Data, Run 7

Parameter	Location	9/24/2020 815	9/24/2020 925	9/24/2020 1020	Grab Average	Composite
		Undiluted PE	Undiluted PE	Undiluted PE		
TSS (mg/L)	INF		27		27	33
	EFF					2
	TNK		570		570	
VSS (mg/L)	INF		21		21	25
	EFF					2
	TNK		310		310	
SS (mL/L/hour)	EFF		0		0	
tCOD (mg/L)	INF		110		110	122
	EFF		28		28	
	TNK		516		516	
sCOD (mg/L)	INF		41		41	
	EFF		32		32	
	TNK		45		45	
TOC (mg/L)	INF	26.4	24.7	21.7	24.3	
BOD (mg/L)	INF		42		42	41
	EFF					8
Alkalinity (mg/L)	INF		137		137	128
	EFF		93		93	75
	TNK		122		122	
Fecal Coliform (MPN/100 mL)	INF		1,400,000	4,900,000	2,700,000	
	EFF	0	20	130	14	
Cl_2 Demand (mg/L)	EFF		0.1877		0.1877	
UV254 (cm^{-1})	EFF					0.1215

Table 3-47. Field Sampling, Run 7

Parameter (units)	Location	9/24/2020 925
pH	INF	7.3
	EFF	7.3
Temperature (degrees C)	INF	18
	EFF	17.3
Conductivity (µS)	INF	681
	EFF	627

3.8.4 Data Analysis

3.8.4.1 Coagulant Dose Ratio

Table 3-48 summarizes the coagulant dose ratios for this run. The samples were taken while the coagulant dose was doubled to 0.8 Al:TSS. As a result, the ratios of coagulant to organic compounds were all higher than previous tests.

Table 3-48. Ratio of Coagulant to Organic Compounds, Run 7

Ratio	Time Stamp 925	Composite
Al:tCOD	0.19	0.15
Al:sCOD	0.51	
Al:TOC	0.85	
Al:BOD	0.50	0.44
Al:TSS	0.8	NA

3.8.4.2 TMP Rise Rate

The TMP rise rate began at a typical rate compared to previous tests and remained that way for about 20 minutes after the coagulant dosing pump was shut off. This is likely due to residual coagulant in the membrane tank. About 20 minutes after coagulant dosing was stopped, the TMP rapidly shot up, rising 7 psi in 30 minutes. About 10 minutes after the TMP rise started, the coagulant pump was restarted at double the normal dose; 20 minutes after that the TMP leveled off again, though it continued rising at about double the normal rate. Finally, after a brief CIP was performed, the TMP was reduced back to normal starting levels, and the TMP rise rate was also typical. Table 3-49 summarizes the TMP rise rates over the course of the run.

While loss of coagulant clearly results in rapid fouling, restoration of coagulant stops that rise. Also, the TMP recovery during the short CIP shows that the rapid fouling is reversible.

Table 3-49. TMP Rise Rate, Run 7

Description	Time	Flux (gfd)	TMP Rise Rate (psi/hour)
Beginning	0730-0830	100	0.33
Rapid Rise (no coagulant)	0850-0920	100	14.9
Coagulant Restored	920-1020	100	0.85
After CIP	1150-1500	100	0.30

3.8.4.3 Turbidity

As is typical, the turbidity started high and decreased over time. Following the CIP in the middle of the run, the turbidity was once again high before decreasing. Ovivo determined in its preliminary testing report that high initial values are caused by air in the permeate line.

3.8.4.4 pH

The pH varied roughly inversely with coagulant dose, except following restart after the CIP, when higher initial coagulant dosing did not lead to lower pH.

3.8.4.5 Net Permeate and Flux

The following were the key results for net permeate and flux:

- Total operating time: 377 minutes
- Approximate net permeate produced (permeate – backwash): 52,100 gallons
- Net flux accounting for backwash: 68.0 gfd

3.8.5 Membrane Recovery

Table 3-50 shows membrane recovery data from Test Run 7. In the test run, a short, 30-minute soak CIP was performed when the unit was shut off due to high TMP. Additionally, a regular CIP was performed at the end of the run. Although the header pressures at the end of the CIP chemical fill for both CIPs were slightly higher than the approximately 2.1 psi indicator for membrane recovery discussed in the Ovivo CSO Pilot King County Preliminary Test Report (Ovivo 2020), the TMP data after the CIPs are consistent with membrane recovery from the CIPs. These results suggest that 30-minute soak CIPs are as efficient as the standard minimum 4-hour soak CIPs.

Table 3-50. Run 7 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi
10.0 (100)[a]	1.3 (100)[a]	2.8[a]	2.3[a]
2.0 (100)	0.8 (100)	3.1	2.2

a Short, 30-minute soak CIP

3.9 Test Run 8

This test run was a process test designed to test failure and system recovery from two types of failure: loss of air scour and loss of backwash. It was performed on October 13, 2020, and ran for approximately 7 hours, not counting CIPs. The sequence was as follows:

- Scenario 1—The system operated at a 100 gfd setpoint for 1 hour with normal operations, followed by 2 hours without air scour. A 30-minute CIP was performed after the first 3 hours.
- Scenario 2—The system operated at 100 gfd setpoint with air scour but without backwashes for another 3 hours. Afterwards, another CIP of approximately 30 minutes was performed.
- Scenario 3—The system operated at the 100 gfd setpoint with both air scour and backwashes.

Intervals of about 1 hour and 45 minutes each occurred between Scenarios 1 and 2 and between Scenarios 2 and 3 to accommodate the CIP procedure and draining the membrane and permeate tanks prior to restarting operations.

All of Test Run 8 used undiluted primary effluent, and the alum coagulant dose ratio was set to 0.6 Al:TSS.

3.9.1 Observations

Notable observations/events during this test run were as follows:

- There was heavy rainfall during this test period; West Point's secondary effluent flow rate was greater than 250 million gallons per day during Test Run 8.
- The heavy rainfall resulted in lower alkalinity in the primary effluent than in other test runs.
- Less foam was observed on the membrane tank surface than in other test runs.
- Yellow or light brown colored sludge was observed in the membrane tank.

This was a successful run in terms of demonstrating the ability to use CIPs to recover from fouling due to loss of air scour or backwash while operating at 100 gfd using full-strength primary effluent. It also demonstrated that, at the test conditions using an alum coagulant to TSS ratio of 0.6 Al:TSS, backwashing is more important than air scouring for mitigating membrane fouling.

3.9.2 Operational Data

Figure 3-32 shows the flux rates and TMP during the three run scenarios (no air scouring, no backwashes, and normal operations).

Figure 3-33 shows the basin TSS and influent TSS through the test run. Backwashing was not conducted during the middle portion of the run, and the membrane basin TSS concentration continued to increase during this time. This is consistent with the observation that backwashing leads to loss of membrane basin TSS in the pilot unit and with backwashing being the reason that the membrane basin TSS concentration does not consistently increase during most pilot runs.

Figure 3-34 shows the permeate turbidity and TMP through the test run. Figure 3-35 shows the coagulant dose and effluent pH.

There was rain before and during Test Run 8. Figure 3-36 shows the West Point secondary effluent flow rate during Test Run 8.

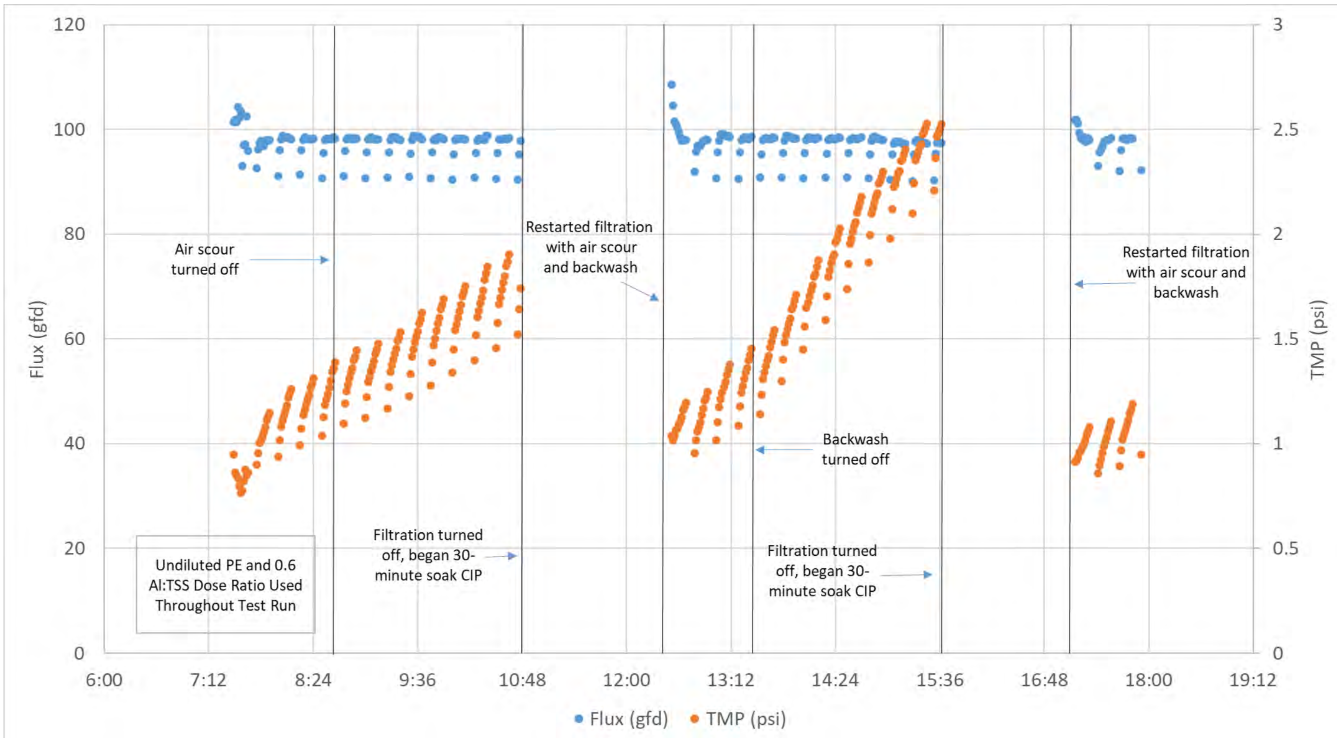


Figure 3-32. Flux and TMP, Run 8

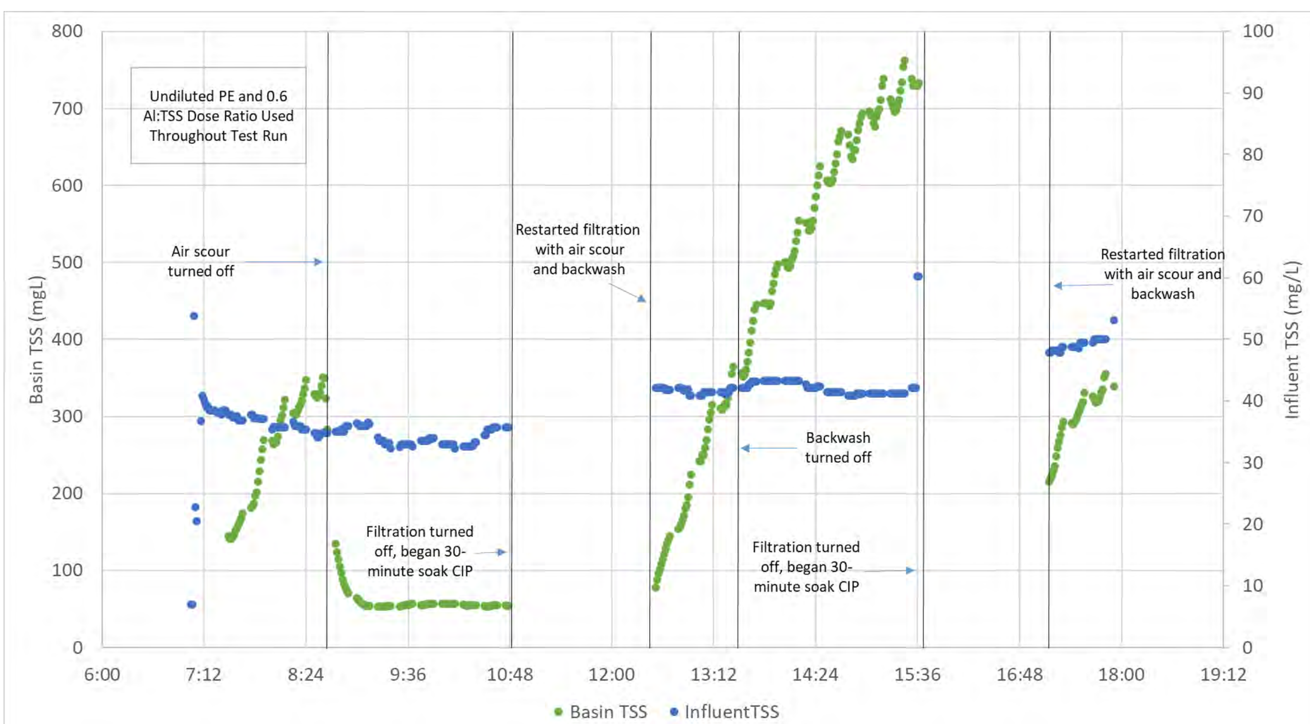


Figure 3-33. TSS, Run 8

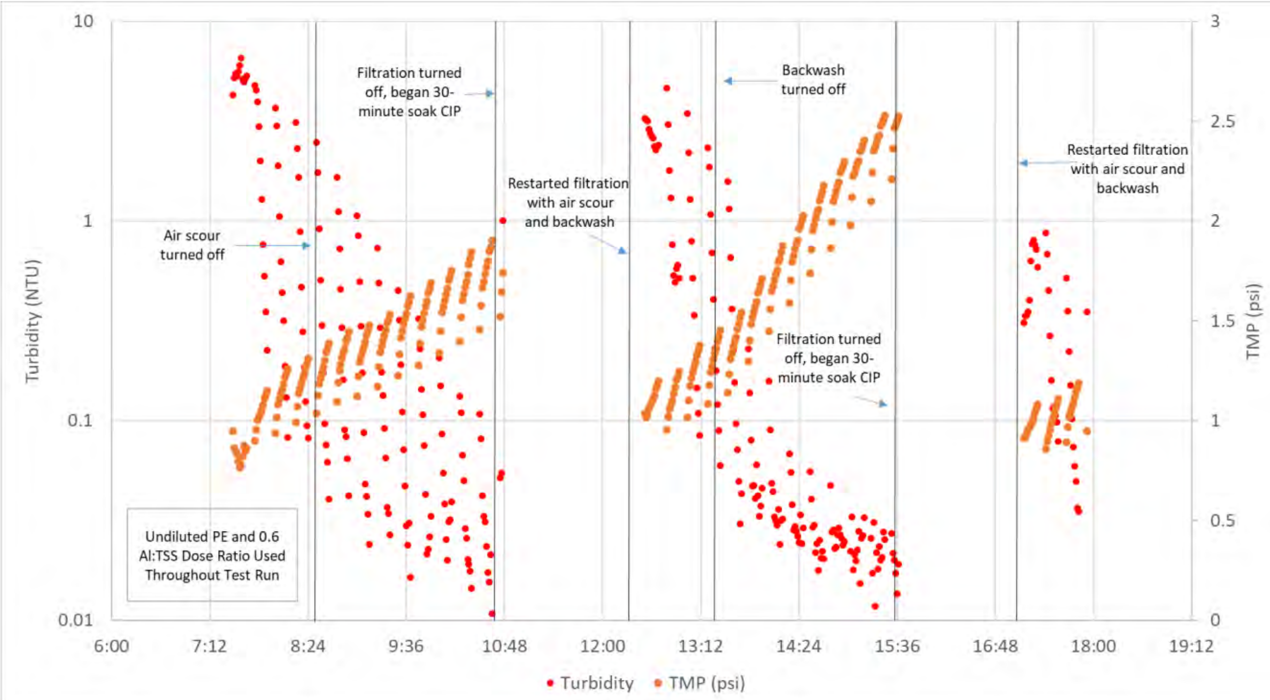


Figure 3-34. Effluent Turbidity and TMP, Run 8

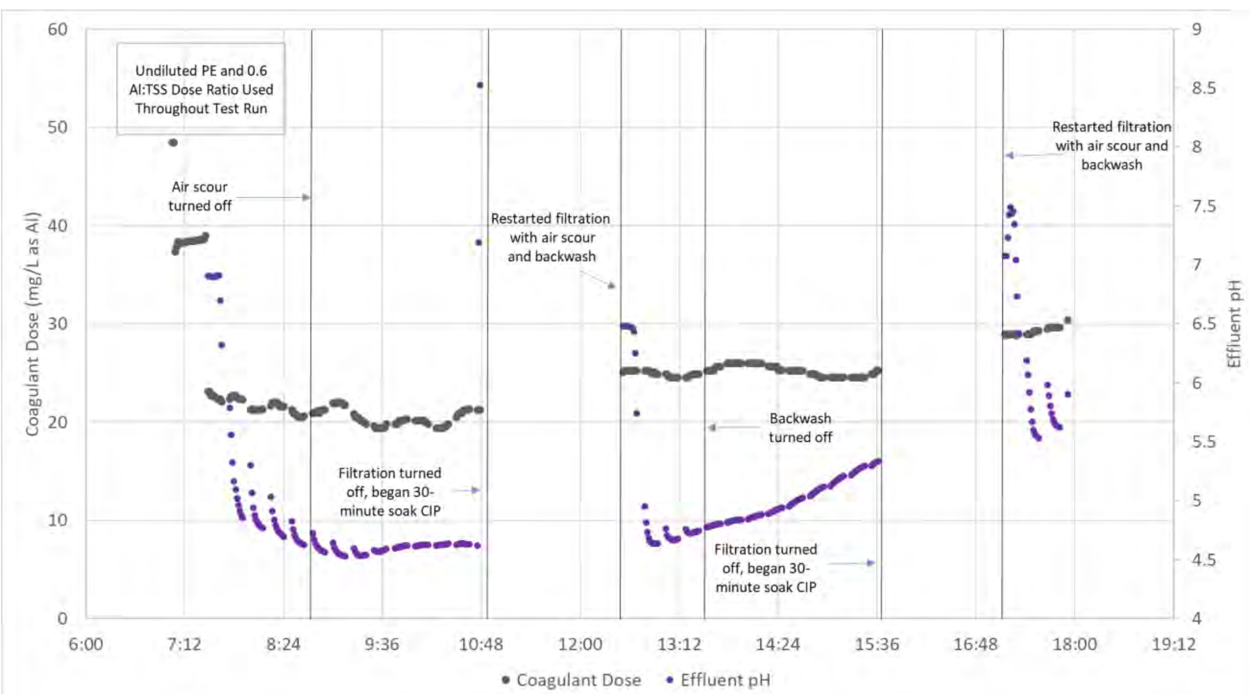


Figure 3-35. Coagulant Dose and Effluent pH, Run 8

Figure 3-36. West Point Secondary Effluent Flow Rate, Run 8

3.9.3 Sampling Results

Key sample analytical results collected during this run are presented in Table 3-51 and Table 3-52.

Table 3-51. Water Quality Data, Run 8

Parameter	Location	10/13/2020 (Time Stamps Below)						Grab Average	Composite
		0815-0820	1035-1045	1301-1315	1355-1400	1458	1705		
		Undiluted PE							
TSS (mg/L)	INF		63					63	69
	EFF								1
	TNK		84					84	
VSS (mg/L)	INF		41					41	48
	EFF								1
	TNK		40					40	
SS (mL/L/hour)	EFF		0					0	
tCOD (mg/L)	INF		106.5					107	136
	EFF		16					16	
	TNK		66.5					67	
sCOD (mg/L)	INF		32					32	
	EFF		18					18	
	TNK		22					22	
TOC (mg/L)	INF	14	22	30	33		45	29	
	EFF								21.2
BOD (mg/L)	INF								50.0
	EFF		38					38	13
Alkalinity (mg/L)	INF		60					60	82
	EFF		3					3	3
	TNK		4					4	
Fecal Coliform (MPN/100 mL)	INF		460,000			3,300,000		1,200,000	
	EFF	0	0	0	0			1 (geomean)	
Cl_2 Demand (mg/L)	EFF		0.789					0.7890	
UV254 (cm^{-1})	EFF								0.089

Table 3-52. Field Water Quality Data, Run 8

Time	Location	pH	Temperature (degrees C)	TDS (ppm)	Conductivity (µS/cm)
10:35	INF	6.62	15.4	161	202
10:40	TNK	4.43	14.9	188	263
10:45	EFF	4.47	14.9	199	281

3.9.4 Data Analysis

3.9.4.1 Coagulant Dose Ratio

The ratios of coagulant to organic compound from Test Run 8 are shown in Table 3-53. The Al:TOC ratio decreased throughout Test Run 8 with the alum coagulant dose set at a 0.6 Al:TSS ratio. This was likely due to decreasing rainwater dilution such that the TOC concentration went up faster than the TSS concentration throughout the test run. This means that the TSS:TOC ratio decreased over the course of the run. The higher coagulant:TOC ratios during the earlier portions of the test run may also have masked the effect of loss of air scour on the TMP rise rate, as discussed in the following subsection.

Table 3-53. Ratio of Coagulant to Organic Compounds, Run 8

Ratio	Time Stamps					Composite
	0815-0820	1035-1045	1301-1315	1355-1400	1705	
Al:tCOD		0.20				0.18
Al:sCOD		0.66				
Al:TOC	1.51	0.98	0.84	0.78	0.64	
Al:BOD						0.50
Al:TSS	0.6	0.6	0.6	0.6	0.6	0.6

3.9.4.2 TMP Rise Rate

For Test Run 8, the TMP rise rate was highest when no backwashing was performed, with an average TMP rise rate of 0.50 psi/hour. The TMP rise rate was lowest at 0.18 psi/hour when both air scouring and backwashing were employed under normal operations. The no-air-scouring test showed an intermediate TMP rise rate of 0.26 psi/hour (Table 3-54).

Table 3-54. TMP Rise Rate, Run 8

	Time	Instantaneous Flux Setpoint (gfd)	Average TMP Rise Rate (psi/hour)
Normal	0730-0830	100	0.26
No Air Scour	0830-1047	100	0.23
No Backwash	1232-1537	100	0.50
Normal, both Air Scour and Backwash	1709-1755	100	0.18

The finding that the no-air-scouring scenario saw a higher TMP rise rate than with both air scour and backwash does not necessarily indicate that air scour is the reason for the slightly lower membrane fouling rate in the latter scenario. The air scour was on between 07:35 and 08:35 for the test run, and the TMP rise rate did not increase after the air scour was turned off between 08:35 and 10:47 (Figure 3-35). It is possible that the higher Al:TOC ratio (Table 3-53) during the no-air-scouring scenario testing masked the potentially detrimental effect of losing air scour.

3.9.4.3 Turbidity

The turbidity was high in the effluent and did not consistently decrease to below 0.1 NTU during Test Run 8 (Figure 3-34).

3.9.4.4 pH

The permeate pH dropped to below 6 for most of the test. This is consistent with the relatively low alkalinity in the pilot influent and was likely the result of rainwater dilution.

3.9.4.5 Net Permeate and Flux

The following were the key results for net permeate and flux:

- Total operating time: 430 minutes
- Approximate net permeate produced (permeate minus backwash): 59,600 gallons
- Approximate net flux accounting for backwash: 68.2

3.9.5 Membrane Recovery

Table 3-55 shows membrane recovery data from Test Run 8. In the test run, a short, 30-minute soak CIP was performed after the test run segment with the air scouring turned off. And another short, 30-minute soak CIP was performed after the test run segment with backwashing turned off. A regular CIP was then performed at the end of the run. Although the header pressures at the end of the CIP chemical fill for both short, 30-minute soak CIPs were slightly higher than the approximately 2.1 psi indicator for membrane recovery discussed in the Ovivo CSO Pilot King County Preliminary Test Report (Ovivo 2020), the TMP data after the three CIPs are consistent with membrane recovery from the CIPs. These results suggest that 30-minute soak CIPs are as efficient as the standard minimum 4-hour soak CIPs.

Table 3-55. Run 8 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi
1.9 (100)[a]	1.0(100)[a]	2.5[a]	2.2[a]
2.5(100)[b]	0.9 (100)[b]	2.6[b]	2.2[b]
1.2 (100)	0.2 (50)	2.3	2.1

a First short, 30-minute soak CIP

b Second short, 30-minute soak CIP

3.10 Test Run 9

This test run was a process test to evaluate different flux rates combined with two different water qualities. It was performed from October 15 to October 16, 2020, and ran for approximately 24 hours. The test run was designed to simulate a middle-loaded hydrograph, as shown in Figure 3-37, with a peak flux of 200 gfd in the middle. The alum coagulant dose ratio was set to 0.6 Al:TSS for the test run.

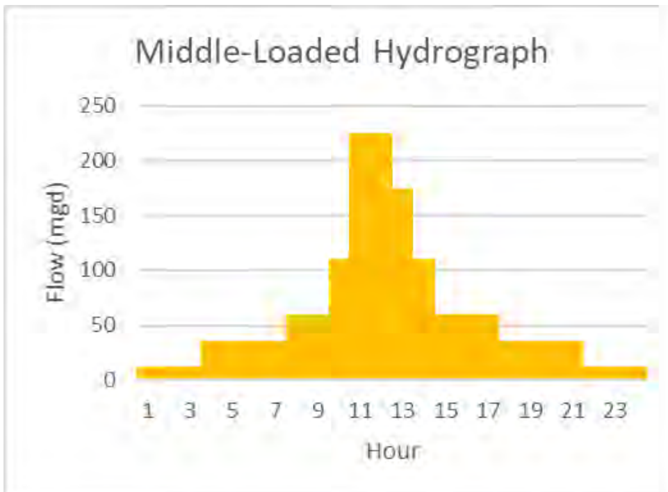


Figure 3-37. Middle-Loaded Hydrograph

The run sequence was as follows:

- 1:1 primary effluent/potable water for 13.5 hours in the following sequence:
  - 50 gfd setpoint for 7 hours
  - 75 gfd setpoint for 2.5 hours
  - 100 gfd setpoint for 1 hour
  - 150 gfd for 0.5 hours
  - 200 gfd for 2 hours
  - 150 gfd for 0.5 hours
- Undiluted primary effluent for 10.5 hours in the following sequence:
  - 100 gfd for 1 hour
  - 75 gfd for 2.5 hours
  - 50 gfd for 7 hours

Table 3-56 summarizes the permeate flow setpoints, number of membrane stacks in service, and other relevant information.

Table 3-56. Operational Setpoints for Test Run 9

Influent Dilution	Permeate Flow Setpoint (gpm)	Number of Membrane Stacks in Service	Membrane Surface Area in Service (square feet)	Instantaneous Flux (gfd)	Test Plan Flux Goal (gfd)	Run Time (hours)
~1:1 PE to Potable Water	102	3	2,925	50	50	7
	153	3	2,925	75	75	2.5
	204	3	2,925	100	100	1
	203	2	1,950	150	150	0.5
	136	1	975	201	200	2
	203	2	1,950	150	150	0.5
Undiluted PE	204	3	2,925	100	100	1
	153	3	2,925	75	75	2.5
	102	3	2,925	50	50	7

3.10.1 Observations

A notable observation during this test run was as follows:

- Less foam in the membrane tank was observed when the test run was treating 1:1 primary effluent/potable water than when it treated full-strength primary effluent.

This was a successful run in terms of demonstrating the ability to operate at different flux rates and with different water quality conditions. Data was also obtained to evaluate TMP rise rates at different flux rates and for the same flux rates with different influent water quality.

3.10.2 Operational Data

Figure 3-38 shows the flux rates and TMP during the test run. Figure 3-39 shows the basin TSS and influent TSS. Figure 3-40 shows the permeate turbidity and TMP. And Figure 3-41 shows the coagulant dose and permeate pH.

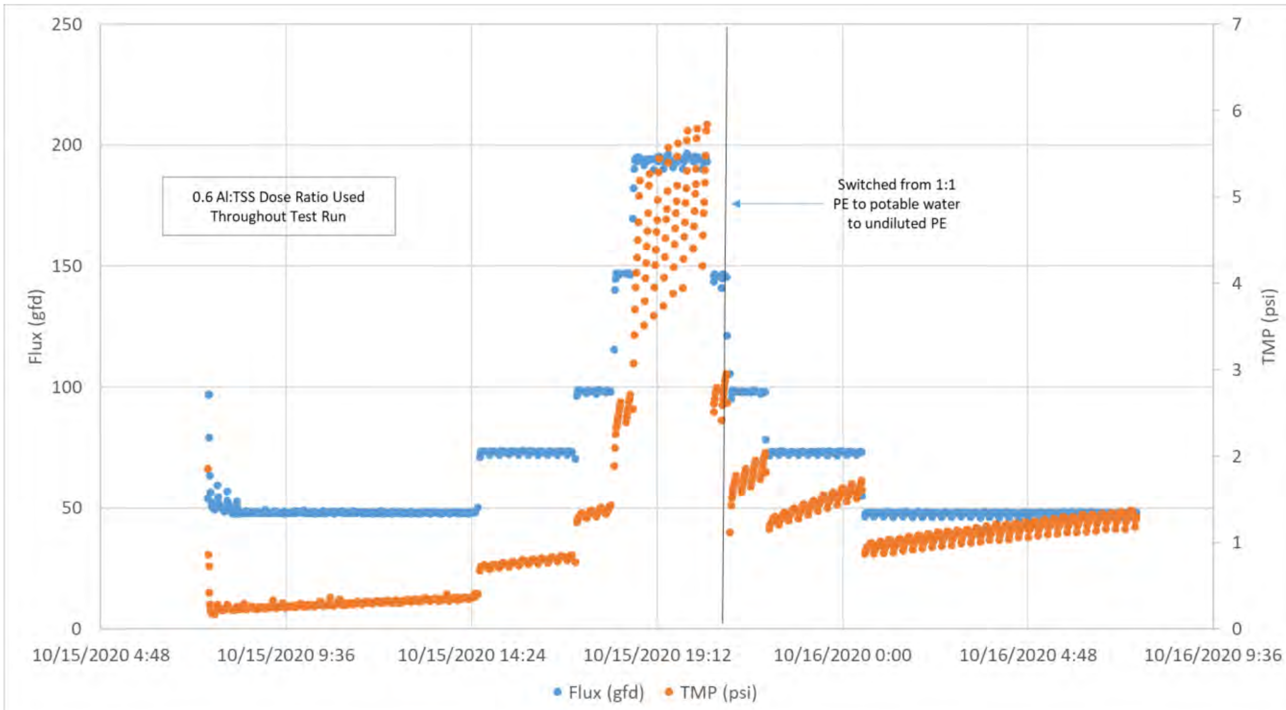


Figure 3-38. Flux and TMP, Run 9

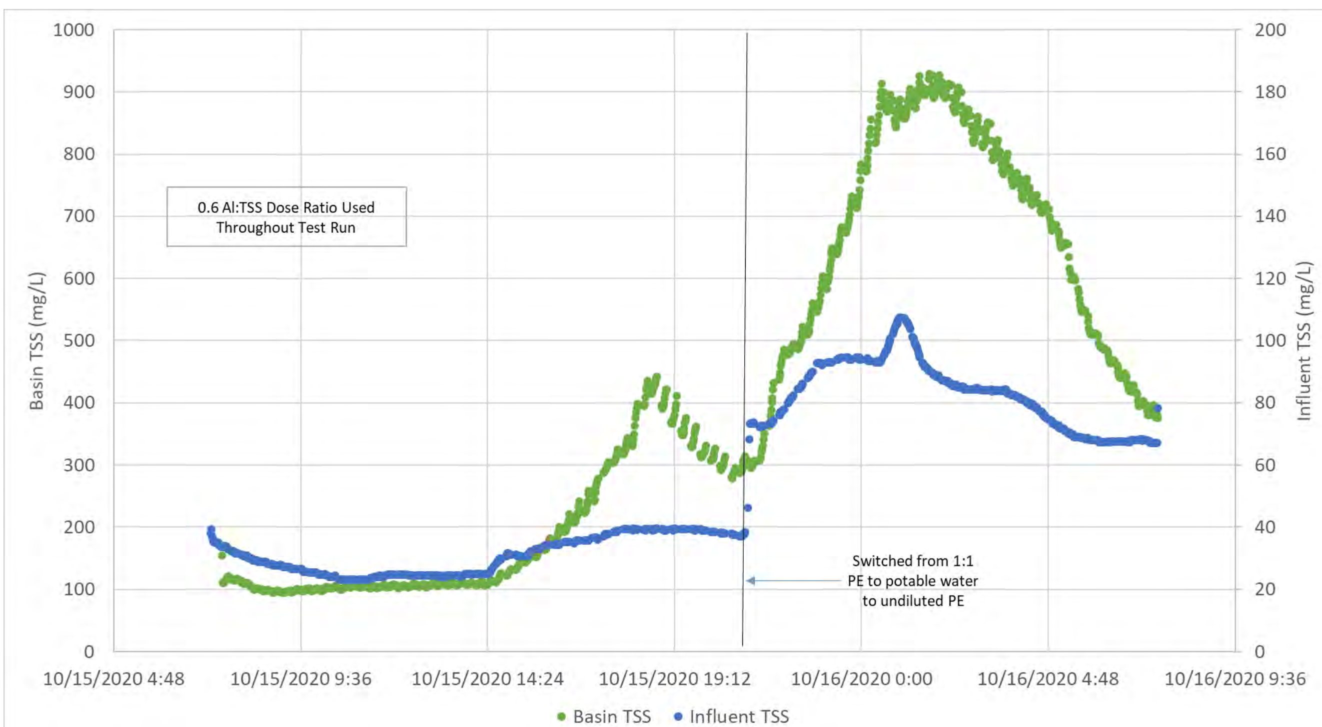


Figure 3-39. TSS, Run 9

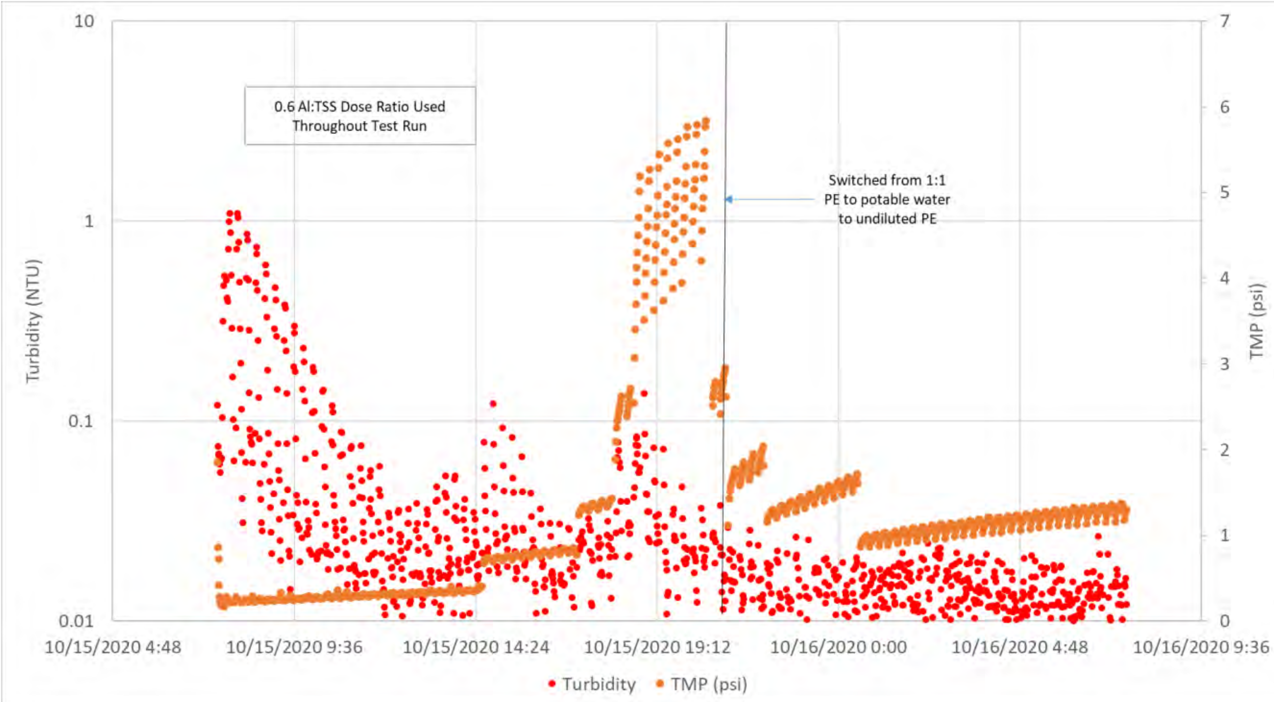


Figure 3-40. Effluent Turbidity and TMP, Run 9

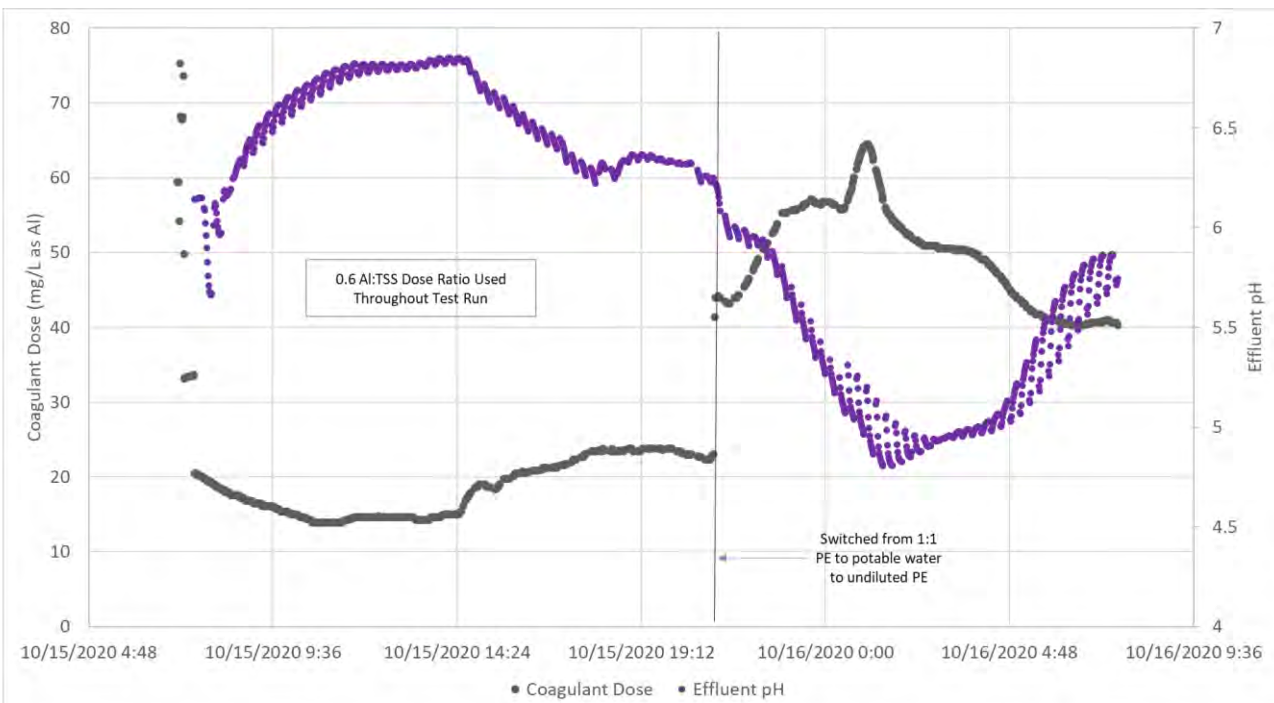


Figure 3-41. Coagulant Dose and Effluent pH, Run 9

3.10.3 Sampling Results

Key sampling results collected during this run are presented in Table 3-57 and Table 3-58.

Table 3-57. Water Quality Data, Run 9

		10/15/2020 (Time Stamps Below)					10/16/2020 (Time Stamps Below)				
		830	1130-1140	1400-1405	1630	2000	0030	0400	0700-0705		
Parameter	**Location**	**1:1 PE to Potable Water**					**Undiluted PE**			**Grab Average**	**Composite**
TSS (mg/L)	INF		21							21	36
	EFF										3
	TNK		261							261	
VSS (mg/L)	INF		19							19	28
	EFF										1
	TNK		138							138	
SS (mL/L/hour)	EFF		0							0	
tCOD (mg/L)	INF		105							105	202
	EFF		32							32	
	TNK		258							258	
sCOD (mg/L)	INF		44							44	
	EFF		30							30	
	TNK		27							27	
TOC (mg/L)	INF	31.2	26.3	25.9	37.5	47.0	95.4	84.5	67	52	
	EFF										30.5
BOD (mg/L)	INF		15							15	92.0
	EFF										58
Alkalinity (mg/L)	INF		117							117	155
	EFF		53							53	33
	TNK		73							73	
Fecal Coliform (MPN/100 mL)	INF		2,200,000						4,900,000	3,300,000	
	EFF	0	0	0					0	1 (geomean)	
Cl_2 Demand (mg/L)	EFF		0.622							1	
UV254 (cm^{-1})	EFF										0.15

Table 3-58. Field Water Quality Data, Run 9

Time	Location	pH	Temperature (degrees C)	TDS (ppm)	Conductivity (µS/cm)	UV Transmittance (UVT) (%)	UV254 (cm^{-1})
11:30	INF	7.3	19.8	497	702		
11:35	TNK	7.1	20.6	382	538		
11:40	EFF	7.0	18.3	385	543		
11:55	EFF					82.1	0.085
14:00	INF					47.6	0.321
14:15	EFF					81	0.091

3.10.4 Data Analysis

3.10.4.1 Coagulant Dose Ratio

The ratios of coagulant to organic compounds from Test Run 9 are shown in Table 3-59. The Al:TOC ratio held relatively steady throughout the run with the alum coagulant dose set at a 0.6 Al:TSS ratio. This is consistent with the TSS:TOC ratio in the primary effluent not varying significantly over the course of the 24-hour test run. Because there should be minimal TSS or TOC in the potable water used for the 1:1 dilution, the TSS:TOC or Al:TOC ratios should not have changed much between the periods with 1:1 primary effluent/potable water and full-strength primary effluent if the TSS:TOC ratio remained steady in the primary effluent. The results presented in Table 3-59 are consistent with the TSS:TOC ratio not changing much during the run.

Table 3-59. Ratio of Coagulant to Organic Compounds, Run 9

Ratio	10/15/2020 (Time Stamps Below)					10/16/2020 (Time Stamps Below)			Composite
	830	1130-1140	1400-1405	1630	2000	0030	0400	0700-0705	
Al:tCOD		0.14							0.16
Al:sCOD		0.33							
Al:TOC	0.56	0.54	0.58	0.56	0.51	0.53	0.58	0.61	
Al:BOD		0.95							0.35
Al:TSS	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

3.10.4.2 TMP Rise Rate

TMP rise rates for Test Run 9 are shown in Table 3-60. The TMP rise rates increased as the instantaneous flux rates increased. The TMP rise rates were higher when treating full-strength primary effluent than when treating 1:1 primary effluent/potable water at the same flux rates.

Table 3-60. TMP Rise Rate, Run 9

Influent Flow Ratio	Time	Instantaneous Flux Setpoint (gfd)	Average TMP Rise Rate (psi/hour)
1:1 PE to Potable Water	0734-1434	50	0.021
	1437-1659	75	0.052
	1708-1753	100	0.13
	1811-1840	150	0.49
	1841-2028	200	0.55
	2041-2100	150	0.64
Undiluted PE	2107-2200	100	0.39
	2207-0030	75	0.18
	0031-0737	50	0.053

3.10.4.3 Turbidity

The turbidity in the permeate stayed consistently below 0.1 NTU after running for approximately 3 hours (Figure 3-40).

3.10.4.4 pH

The permeate remained above pH 6 while the pilot run treated 1:1 primary effluent/potable water and dropped to below pH 6 after it switched to treating full-strength primary effluent (Figure 3-40). This can be explained by the higher alum coagulant dosage needed to maintain the 0.6 Al:TSS ratio with higher TSS concentrations in the full-strength primary effluent (Figure 3-39).

Although potable water contains almost no TSS or TOC, so that 1:1 primary effluent/potable water contains approximately half the concentration of TSS and TOC as undiluted primary effluent, it does have some alkalinity. This is why treating 1:1 primary effluent/potable water using the 0.6 Al:TSS ratio results in a higher treated water pH than treating full-strength primary effluent. The 1:1 primary effluent/potable water blend has a higher ratio of alkalinity to TSS or TOC than full-strength primary effluent has.

3.10.4.5 Net Permeate and Flux

The following were the key results for net permeate and flux:

- Total operating time: 1,440 minutes
- Approximate net permeate produced (permeate minus backwash): 122,500 gallons
- Approximate net flux accounting for backwash: 45.0 gfd

3.10.5 Membrane Recovery

Table 3-61 shows the TMP at the end of Test Run 9 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill and at the end of the CIP chemical fills. Data are consistent with membrane recovery after the CIP.

Table 3-61. Run 9 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi[a]
1.4 (50)	1.4 (50)	2.8	2.0

a A header pressure of less than 2.1 psi at the end of a chemical fill step is understood to indicate membrane recovery.

3.11 Test Run 10

This run, performed from 07:41 on October 22, 2020, to 10:54 on October 23, 2020, evaluated a variable flux scenario. The run durations for each flux were proportional to CSO hydrographs experienced at the Elliott West CSO Treatment Facility during storms. The test run was designed to simulate a variable-loaded hydrograph as shown in Figure 3-42. The test ran with fluxes varying between 50 gfd and 200 gfd.

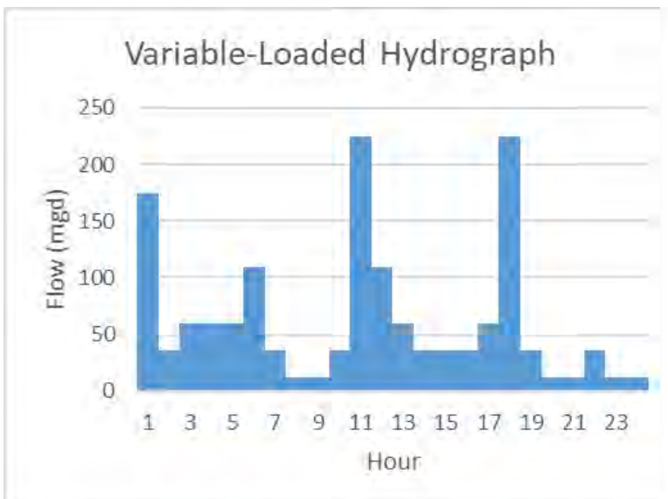


Figure 3-42. Variable-Loaded Hydrograph

The influent wastewater was diluted 1:1 for approximately the first 11 hours, then it was set to undiluted primary effluent. It was briefly diluted again the next morning while running at 200 gfd.

During this test run, the facility experienced loss of influent as a result of maintenance activities at West Point unrelated to the pilot. This loss shut the pilot down for 2 hours in the middle of the night. When primary effluent was again available, the pilot unit resumed operation without intervention from an operator. As a result of the delay, the treatment run was extended in the morning to achieve 24 hours of run time.

During this test run, all three membrane stacks were operated for flux of 100 gfd and less. Due to influent flow limitations, only two stacks were used for a flux of 150 gfd, and only one stack was used for a flux of 200 gfd. This run had a constant coagulant dose ratio of 0.6 Al:TSS.

3.11.1 Observations

This run demonstrated the ability of the membranes to handle significant flow variability without detrimental effects on treatment. It also showed the system's ability to automatically stop and start based on influent availability. Results showed significant removal of phosphorus and several metals and metalloids, as well as compounds that absorb UV.

3.11.2 Operational Data

Figure 3-43 shows the flux rates and TMP during the test run. Figure 3-44 shows the basin TSS and influent TSS. Figure 3-45 shows the permeate turbidity and TMP. And Figure 3-46 shows the coagulant dose and permeate pH.

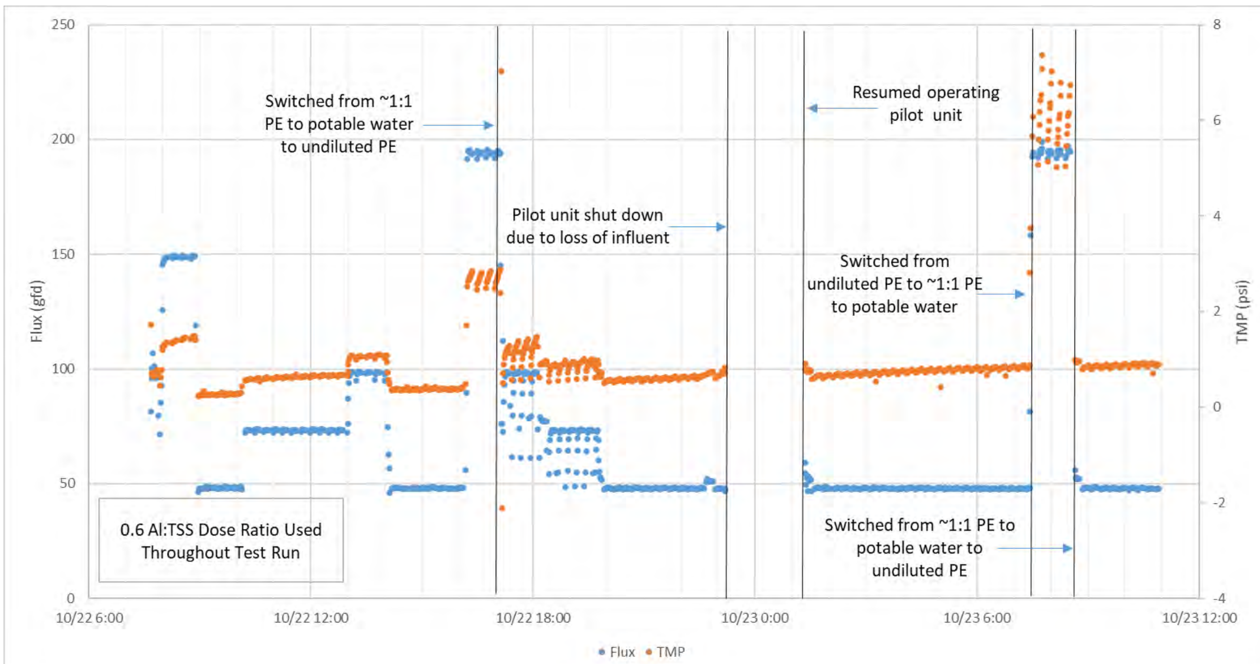


Figure 3-43. Flux and TMP, Run 10

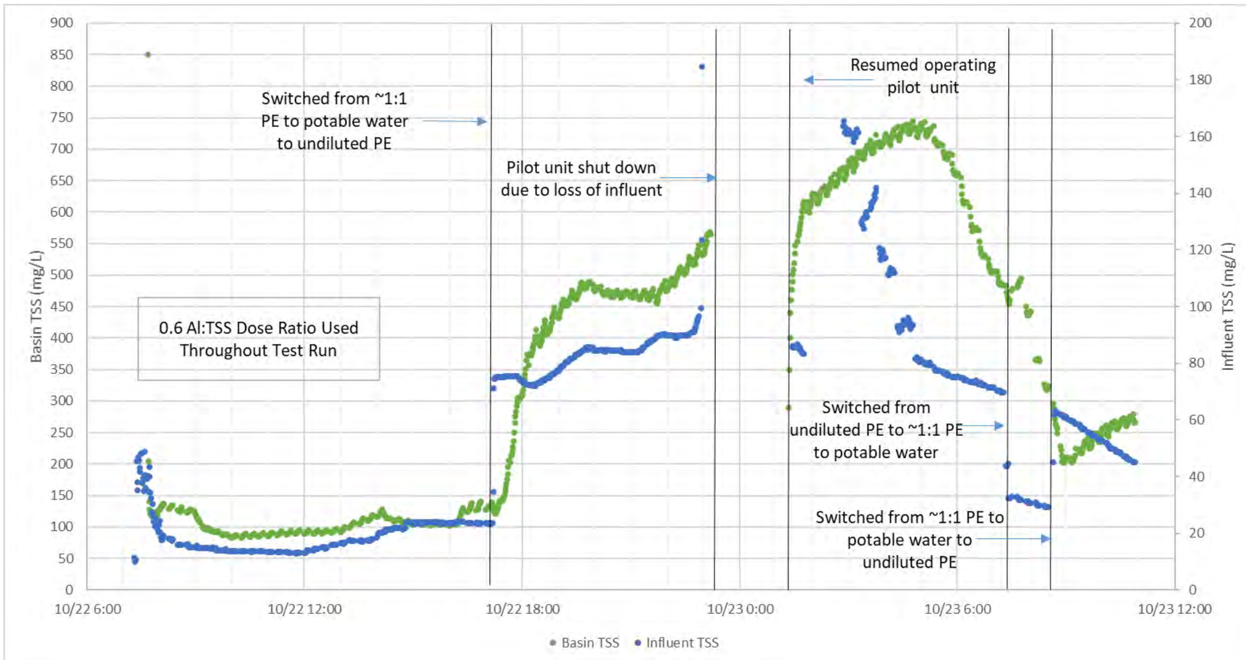


Figure 3-44. TSS, Run 10

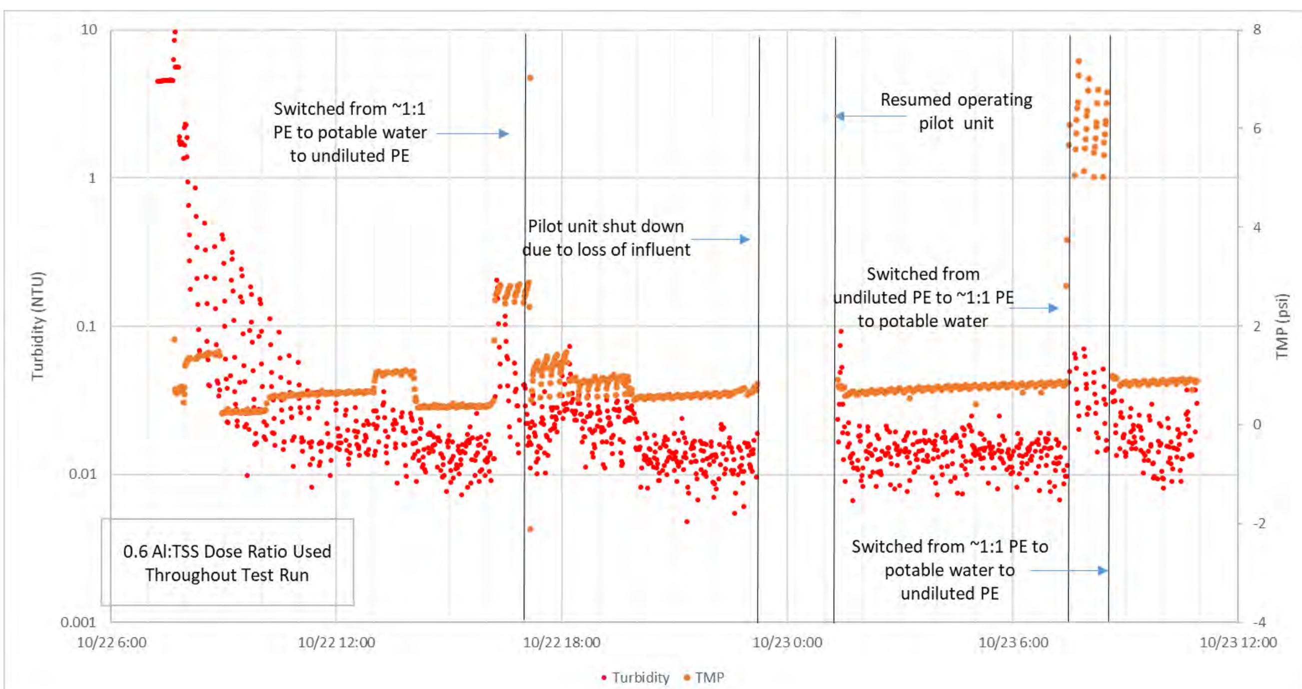


Figure 3-45. Effluent Turbidity and TMP, Run 10

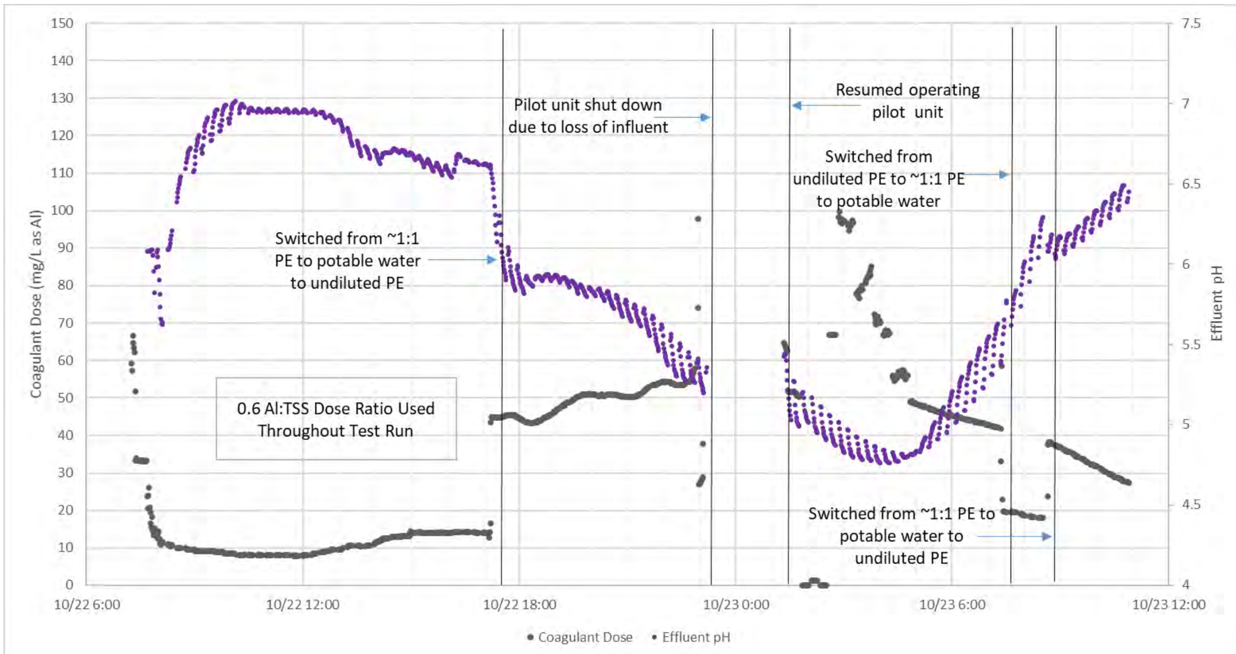


Figure 3-46. Coagulant Dose and Effluent pH, Run 10

3.11.3 Sampling Results

Key sampling results collected during this run are presented in Table 3-62 through Table 3-64.

Table 3-62. Water Quality Data, Run 10

Parameter	Location	10/22/2020 (Time Stamps Below)				10/23/2020 (Time Stamps Below)		
		900	930	1100	1330	900		
		1:1 PE to Potable Water				Undiluted PE	Grab Average	Composite
TSS (mg/L)	INF				12		12	53
	EFF							0
	TNK				382		382	
VSS (mg/L)	INF				14		14	46
	EFF							0
	TNK				200		200	
SS (mL/L/hour)	EFF				0		0	
tCOD (mg/L)	INF							224
TOC (mg/L)	INF	54.7	15.4		16.3	70.8	39.3	
	EFF		25.4				25.4	
BOD (mg/L)	INF							90
	EFF				30			43
HEM (mg/L)	INF		5		5	20.1	10.0	
	EFF		0		0	0	0.0	
Alkalinity (mg/L)	INF							140
	EFF							26
Fecal Coliform (MPN/100 mL)	INF				350,000	11,000,000	2,000,000	
	EFF	20	20	0	0	0	3 (geomean)	
Cl_2 Demand (mg/L)	EFF				0.7892		0.79	
UV254 (cm^{-1})	EFF							0.158

Table 3-63. Nutrients Data, Run 10

Parameter	Location	10/22/2020 930 1:1 PE to Potable Water	10/22/2020 1330 1:1 PE to Potable Water	10/23/2020 900 Undiluted PE	Grab Average
Total P (mg/L)	INF	1.51	1.36	4.02	2.30
	EFF	0.04	0.02	0.04	0.03
Orthophosphate-P (mg/L)	INF	1.16	1.00	2.50	1.55
	EFF	0.03	0.01	0.02	0.02
TKN (mg/L)	INF	11.75	10.53	32.99	18.42
	EFF	10.68	9.15	23.19	14.34
Ammonia-N (mg/L)	INF	10.09	8.35	23.68	14.04
	EFF	10.02	8.55	21.02	13.20
Nitrate-N (mg/L)	INF	0.130	0.152	0.221	0.168
	EFF	0.104	0.143	0.102	0.116
Nitrite-N (mg/L)	INF	0.009	0.102	0.011	0.041
	EFF	0.010	0.122	0.008	0.047

Table 3-64. Metals Data, Run 10

Parameter	Location	10/22/2020 930 1:1 PE to Potable Water	10/22/2020 1330 1:1 PE to Potable Water	10/23/2020 900 Undiluted PE	Grab Average
Arsenic (µg/L)	INF	1.1	1.12	1.63	1.28
	EFF	0.438	0.439	0.644	0.51
	TNK	2.76	5.08	2.86	3.57
Cadmium (µg/L)	INF	0	0	0.075	0.03
	TNK	0.082	0.16	0.17	0.14
Copper (µg/L)	INF	10.5	8.09	20.5	13.0
	EFF	1.4	0.91	1.7	1.34
	TNK	26.6	44.5	44	38
Lead (µg/L)	INF	0.651	0.695	1.12	0.82
	EFF	0	0	0.13	0.04
	TNK	2.03	3.66	2.93	2.87
Nickel (µg/L)	INF	0.935	0.968	2.91	1.60
	EFF	0.855	0.846	2.35	1.35
	TNK	1.64	2.21	3.49	2.45
Zinc (µg/L)	INF	19.5	20	45.6	28.4
	EFF	5.37	6.47	16.2	9.3
	TNK	51.4	81.8	85	73

3.11.4 Data Analysis

3.11.4.1 Coagulant Dose Ratio

The ratios of coagulant to organic compounds from Test Run 10 are shown in Table 3-65.

Table 3-65. Ratios of Coagulants to Organic Compounds, Run 10

Time	930	1330	900	Composite
Al:tCOD				0.15
Al:TOC	0.59	0.65	0.52	
Al:TSS	0.6	0.6	0.6	0.6

3.11.4.2 TMP Rise Rate

As with other tests, the TMP rise rate varied with flux and influent concentration. During the initial period with dilution, the influent solids were exceptionally low (less than 25 mg/L) and the TMP rise rate was very slow, even at 200 gfd. Once dilution stopped (influent TSS greater than 70 mg/L), the TMP rise rate rose by a factor of almost 10, to be in the same range as previously observed. During the second run period at 200 gfd, the TMP was so variable (likely due to how close to the limit it was) that a TMP rise rate could not be estimated. Table 3-66 summarizes TMP rise rate over the course of the run.

Table 3-66. TMP Rise Rate, Run 10

Time	Instantaneous Flux Setpoint (gfd)	Dilution	Average TMP Rise (psi/hour)
10/22 0800-0900	150	1:1	0.14
0900-1010	50	1:1	0.047
1010-1300	75	1:1	0.023
1300-1400	100	1:1	0.039
1400-1600	50	1:1	0.021
1600-1700	200	1:1	0.014
1700-1810	100	None	0.27
1810-1940	75	None	0.13
1940- (10/23) 0730	50	None	0.025
0730-0830	200	1:1	Unknown
0830-1045	50	None	0.029

3.11.4.3 Turbidity

As shown in Figure 3-45, the turbidity in the permeate was over 1 NTU at the start of the test then decreased to below 0.1. Ovivo determined in its preliminary testing report that high initial values were caused by air in the permeate line. There were small spikes to just over 0.1 NTU each time the flow rate was increased to 200 gfd, but the turbidity quickly lowered again while that flow rate was maintained.

3.11.4.4 pH

The pH remained steady around 7 while the influent was diluted. It dropped sharply when influent dilution stopped, and the coagulant dose increased to compensate. It continued to decrease as the unit ran through the night. The pH reached a minimum of 4.75 at about 04:00 in the morning, before rising again, eventually reaching 6.5 at the end of the test.

3.11.4.5 Nutrient Removal

Nutrient concentrations are shown in Table 3-63. Table 3-67 lists nutrient removal percentages. As with other test runs, total phosphorus and orthophosphate both showed high removal percentages. Some TKN was also removed. There was no ammonia removal and no nitrate or nitrite in the influent, so their removal efficiencies are not shown.

Table 3-67. Nutrients Removal Efficiency, Run 10

Parameter	Location	Grab Average	Removal Percentage
Total P (mg/L)	INF	2.30	98.5%
	EFF	0.03	
Orthophosphate-P (mg/L)	INF	1.55	98.7%
	EFF	0.02	
TKN (mg/L)	INF	18.42	22.2%
	EFF	14.34	

3.11.4.6 Metals Removal

Priority pollutant metals were sampled and analyzed in Test Run 10 as part of the performance testing sampling and analysis plan. Table 3-68 shows the removal percentages of select metals or metalloids.

The concentrations of the metals in the membrane tank increased from 09:30 to 13:30 during the test run on 10/22/2020 (Table 3-64). This is consistent with metals being retained by the treatment process.

Table 3-68. Metals Removal Efficiency, Run 10

Parameter	Location	Grab Average (µg/L)	Removal Percentage
Arsenic	INF	1.3	60%
	EFF	0.51	
Copper	INF	13.0	90%
	EFF	1.3	
Lead	INF	0.8	95%
	EFF	0.04	
Nickel	INF	1.6	16%
	EFF	1.4	
Zinc	INF	28.4	67.1%
	EFF	9.3	

3.11.4.7 Net Permeate and Flux

The following were the key results for net permeate and flux:

- Total operating time: 1,504 minutes
- Approximate net permeate produced (permeate minus backwash): 150,500 gallons
- Net flux accounting for backwash: 58.2 gfd

3.11.5 Membrane Recovery

Table 3-69 shows the TMP at the end of Test Run 10 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill and at the end of the CIP chemical fills. Although the header pressure at the end of the CIP chemical fill was slightly higher than the approximately 2.1 psi indicator for membrane recovery discussed in the Ovivo CSO Pilot King County Preliminary Test Report (Ovivo 2020), the TMP data after the CIP is consistent with membrane recovery from the CIP.

Table 3-69. Run 10 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi
0.9 (50)	2.0 (200)	2.5	2.2

3.12 Test Run 11

The purpose of this run, performed on October 20, 2020, was to demonstrate the unit's resilience to rapidly changing conditions, including high flux rates and stop/start operation. The pilot was operated at flux rates from 50 to 200 gfd and back to 50. It was stopped for nearly an hour without a CIP or draining the tank, and then run at varying flow rates again.

At 200 gfd, the influent pipes and pumps were limited by head loss and were not capable of delivering the required flow to run all three membrane stacks. To maintain the flux rate of 200 gfd, two of the three stacks were valved out of service. They were valved in when flux rates lowered.

3.12.1 Observations

Notable observations/events during this test run were as follows:

- Like other tests, significant foam was observed in the membrane tank.
- TMP rise rates after the peak flux periods were somewhat higher than before that period.

This run shows that the system can handle rapidly changing flux rates with and continue functioning well, though periods of peak flux may lead to higher fouling rates later in a run. Also, shutting down the pilot for up to an hour without a draining or cleaning the membranes does not appear to negatively impact functioning.

3.12.2 Operational Data

Key operational data collected during this run are presented in Figure 3-47 through Figure 3-50.

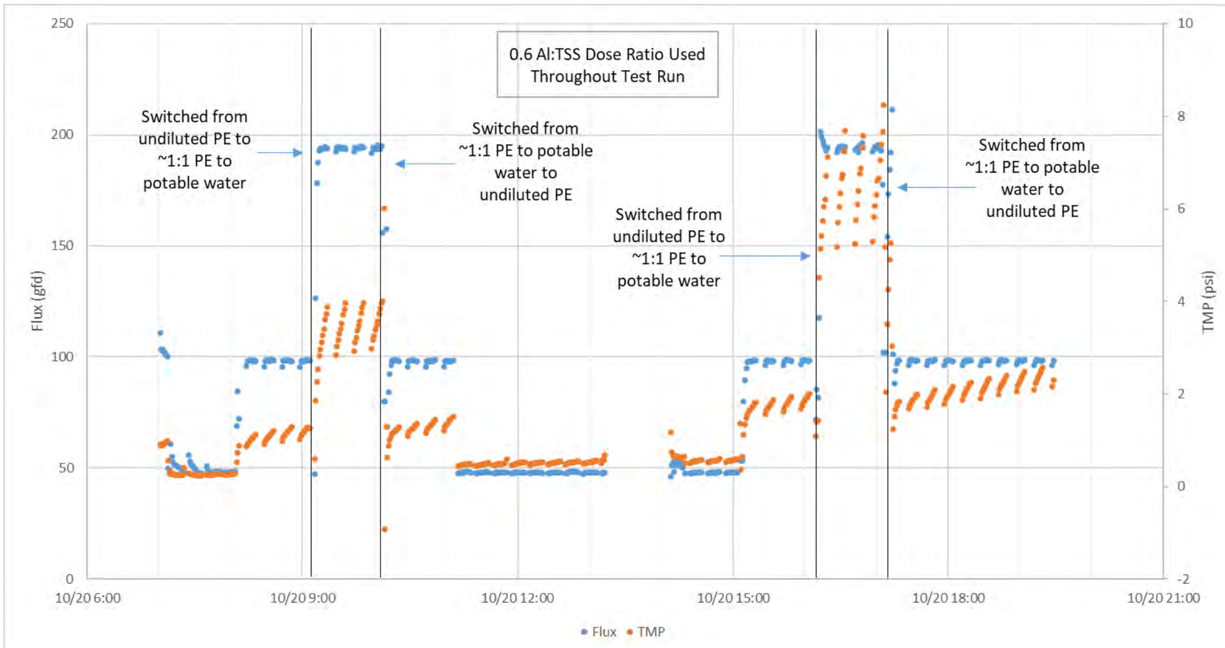


Figure 3-47. Flux and TMP, Run 11

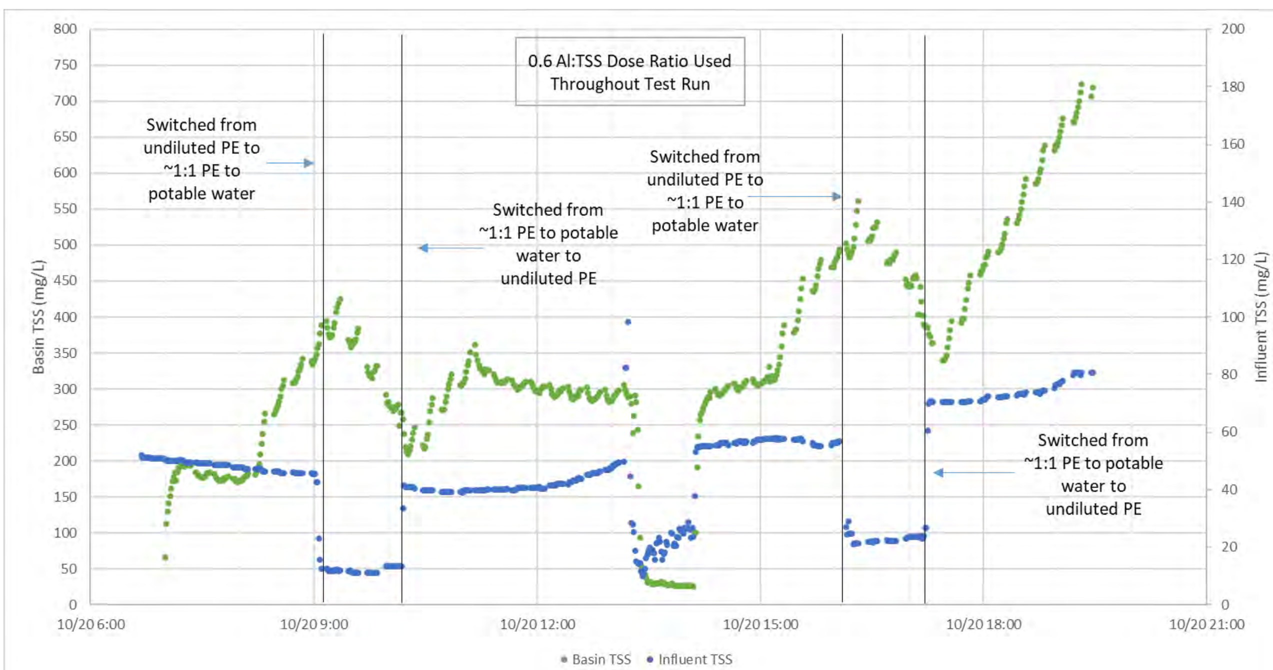


Figure 3-48. TSS, Run 11

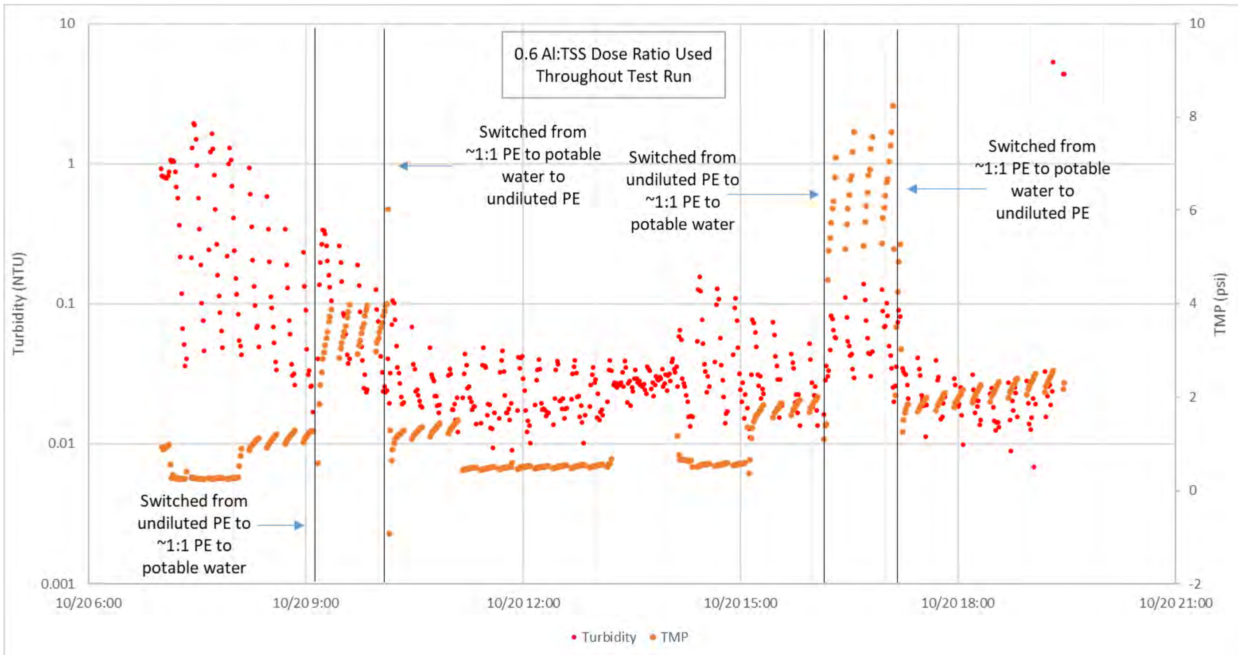


Figure 3-49. Effluent Turbidity and TMP, Run 11

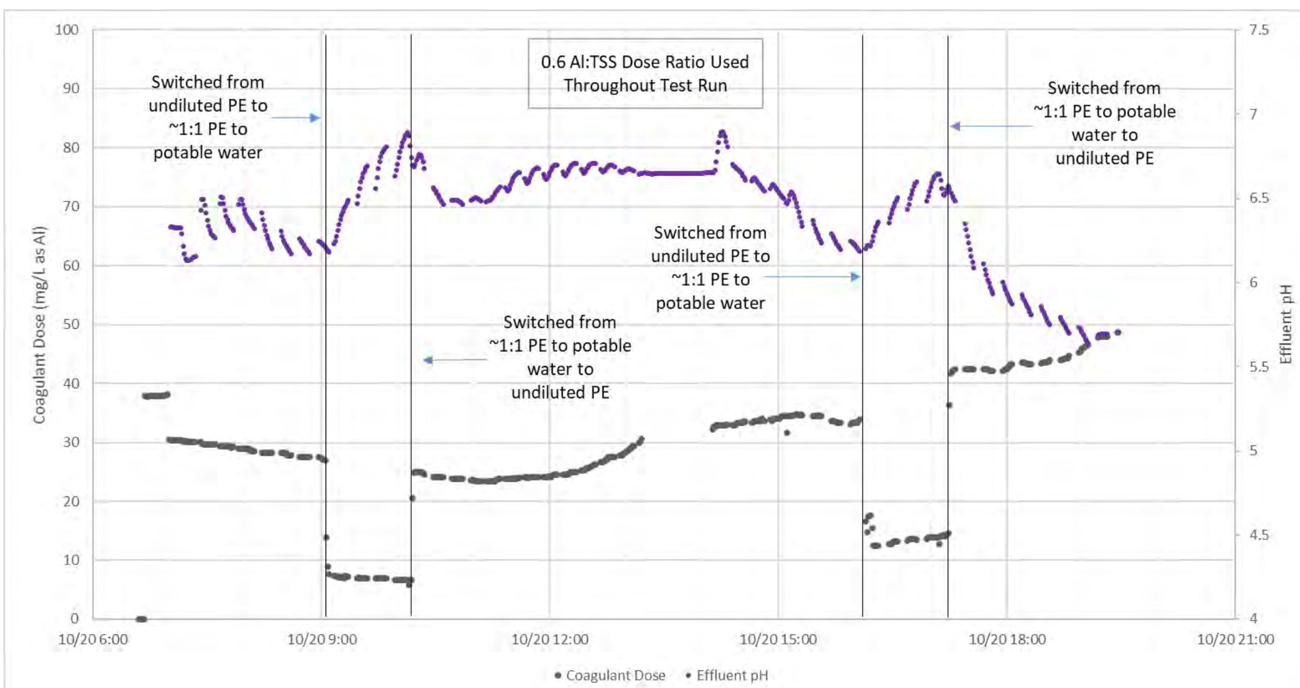


Figure 3-50. Coagulant Dose and Effluent pH, Run 11

3.12.3 Sampling Results

Key sampling results collected during this run are presented in Table 3-70 and Table 3-71.

Table 3-70. Water Quality Data, Run 11

		10/20/2020 (Time Stamps Below)								
		740	**930**	**1030**	**1230**	**1430**	**1630**	**1800**		
Parameter	**Location**	**Undiluted PE**	**1:1 PE to Potable Water**	**Undiluted PE**			**1:1 PE to Potable Water**	**Undiluted PE**	**Grab Average**	**Composite**
TSS (mg/L)	INF		15						15	19
	EFF									0
	TNK		738						738	
VSS (mg/L)	INF		11						11	17
	EFF									1
	TNK		408						408	
SS (mL/L/hour)	EFF		0						0	
tCOD (mg/L)	INF		48						48	140
	EFF		28						28	
	TNK		652						652	
sCOD (mg/L)	INF		23						23	
	EFF		30						30	
	TNK		34						34	
TOC (mg/L)	INF	43.7	11.2		44	62.3	23.2	70.3	42.5	
	EFF									19.1
BOD (mg/L)	INF		22						22	69
	EFF									29
Alkalinity (mg/L)	INF		64						64	150
	EFF		33						33	44
	TNK		87						87	
Fecal Coliform (MPN/100 mL)	INF		1,600,000						1,600,000	
	EFF	0	0	0	490				5 (geomean)	
Cl_2 Demand (mg/L)	EFF		1.608						1.608	
UV254 (cm^{-1})	EFF									0.17

Table 3-71. Field Sampling, Run 11

Parameter (units)	Location	10/20/2020 930
pH	INF	7.5
	EFF	7
	TNK	7.2
Temperature (degrees C)	INF	17.4
	EFF	17.4
	TNK	17.1
Conductivity (µS)	INF	1126
	EFF	511
	TNK	530
TDS (ppm)	INF	795
	EFF	360
	TNK	375
UVT (%)	INF	72.5
	EFF	86.7
UV254 (cm^{-1})	INF	0.139
	EFF	0.061

3.12.4 Data Analysis

3.12.4.1 Coagulant Dose Ratio

The ratios of coagulant to organic compounds from Test Run 11 are shown in Table 3-72.

Table 3-72. Ratio of Coagulant to Organic Compounds, Run 11

Ratio	Time Stamps		Composite
	930	1430	
Al:tCOD	0.15		0.20
Al:sCOD	0.30		
Al:TOC	0.62	0.53	
Al:BOD	0.32		0.40
Al:TSS	0.6	0.6	0.6

3.12.4.2 TMP Rise Rate

As with previous test runs, the TMP rise rate in this run was dependent on the flux rate. One exception was the period at 200 gfd between 09:10 and 10:10, when the TMP rise rate was low. The TMP during this portion of the run was quite high, and under these conditions the permeate pumps take longer to settle into a constant flow rate. As a result, the instantaneous flux and TMP vary considerably. As a result, the TMP data is scattered in this portion of the run, so the calculated TMP rise rate is likely not representative of actual conditions.

During the second portion of the test, the TMP and TMP rise rates were much the same as the first, showing that performance was largely unaffected by stopping and starting the system. Table 3-73 summarizes TMP rise rate over the course of the run.

Table 3-73. TMP Rise Rate, Run 11

Time	Flux (gfd)	TMP Rise Rate (psi/hour)
0710-0810	50	0.02
0810-0910	100	0.21
0910-1010	200	0.11
1010-1110	100	0.30
1110-1310	50	0.04
1410-1510	50	0.09
1510-1610	100	0.26
1610-1710	200	0.81
1710-1930	100	0.37

3.12.4.3 Turbidity

As is typical, the turbidity started high and decreased over time. Ovivo determined in its preliminary testing report that high initial values are caused by air in the permeate line. There was a small turbidity spike following the period when the pilot was off, and another when the flux was increased to 200 gfd the second time.

3.12.4.4 pH

The pH varied roughly inversely with coagulant dose. It was highest during the periods with dilution and lowest at the end of the test after an extended run time without dilution.

3.12.4.5 Net Permeate and Flux

The following were the key results for net permeate and flux:

- Total operating time: 475 minutes
- Approximate net permeate produced (permeate minus backwash): 66,900 gallons
- Net flux accounting for backwash: 69.3 gfd

3.12.5 Membrane Recovery

Table 3-74 shows the TMP at the end of Test Run 11 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill and at the end of the CIP chemical fills. Although the header pressure at the end of the CIP chemical fill was higher than the approximately 2.1 psi indicator for membrane recovery discussed in the Ovivo CSO Pilot King County Preliminary Test Report (Ovivo 2020), the TMP data after the CIP is consistent with membrane recovery from the CIP.

Table 3-74. Run 11 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi
2.6 (100)	1.3 (150)	2.8	2.5

3.13 Supplemental Test Run 1

This supplemental test run was performed on November 10, 2020, and ran for approximately 6 hours. The primary goal was to verify Ovivo's peak 12-hour instantaneous flux design condition of 150 gfd (Ovivo 2020). The TMP rise rate from the 6-hour run would be extrapolated to evaluate the efficacy for running at the peak 150 gfd for 12 hours. The test run treated 1:1 primary effluent/potable water at 150 gfd for 6 hours, followed by approximately 15 minutes at 100 gfd. The alum coagulant dose ratio was set to 0.6 Al:TSS.

3.13.1 Observations

New filter elements in blowers were installed prior to the run. Blower 1 output was low (approximately 25 scfm) and had to be switched to manual to achieve approximately 100 scfm. Blower 2 failed. However, air scouring at approximately 100 scfm was maintained throughout the test run. The target air scouring rate is approximately 35 scfm per membrane stack in operation, and two stacks were operating for the target 150 gfd flux rate for approximately 50 scfm per stack.

This was a successful run in terms of demonstrating the ability to treat 1:1 effluent/potable water for 12 hours (extrapolated) at 150 gfd without requiring a CIP.

3.13.2 Operational Data

Figure 3-51 shows the flux rates and TMP during the two run scenarios (running at 150 gfd for 6 hours and then at 100 gfd for approximately 15 minutes). Figure 3-52 shows the basin TSS and influent TSS throughout the test run. Figure 3-53 shows the permeate turbidity and TMP. And Figure 3-54 shows the coagulant dose and permeate pH.

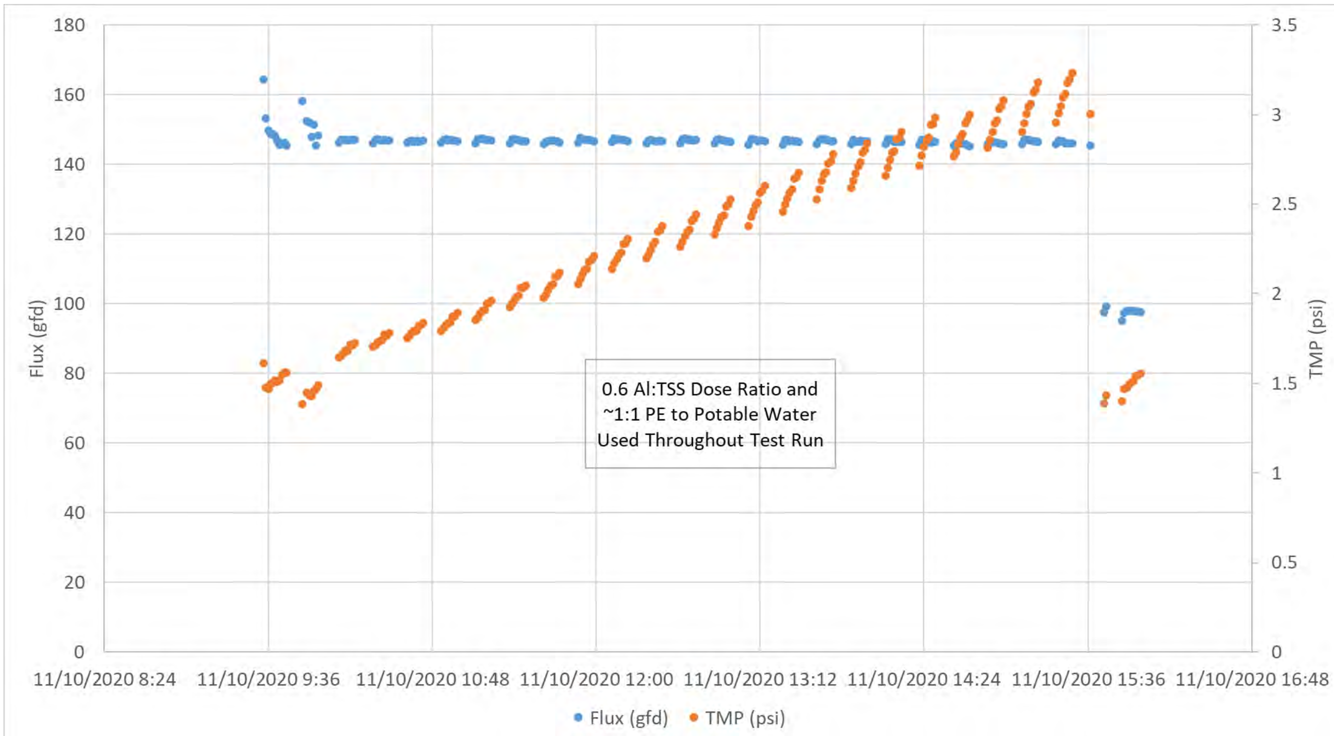


Figure 3-51. Flux and TMP, Supplemental Run 1

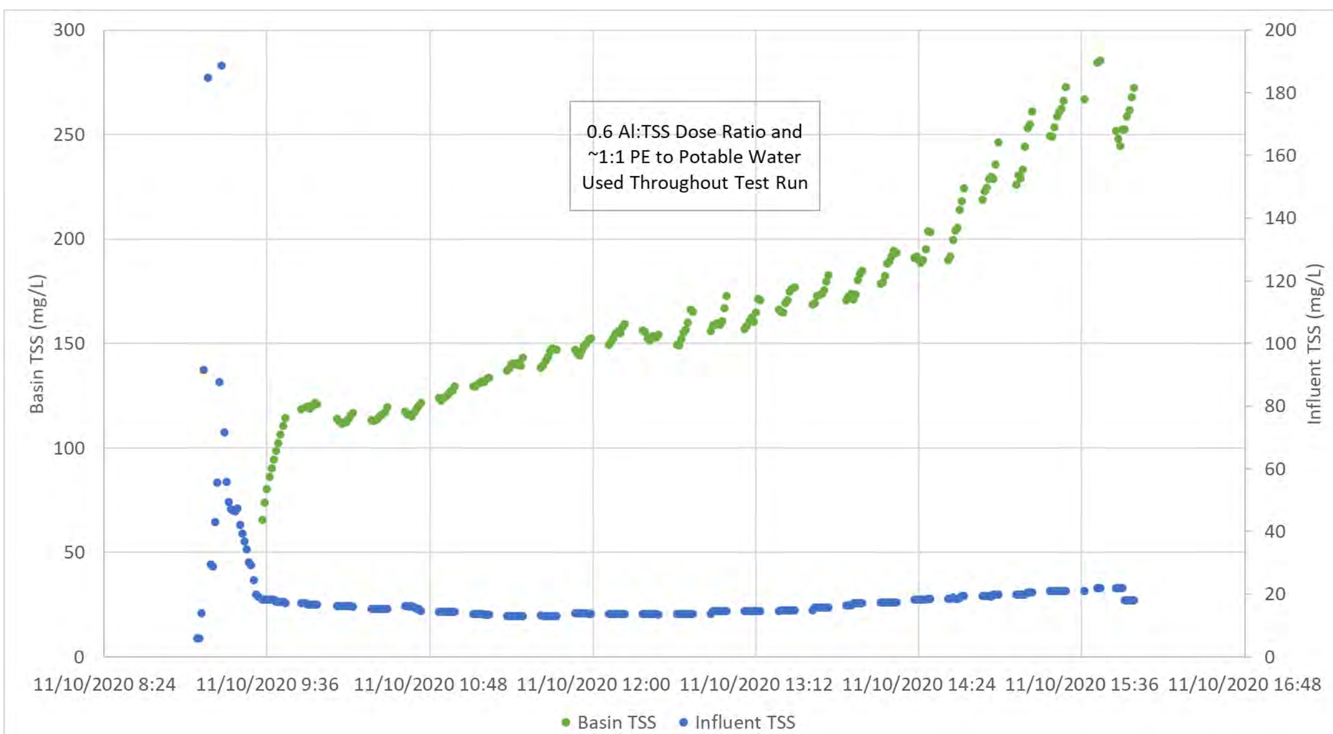


Figure 3-52. TSS, Supplemental Run 1

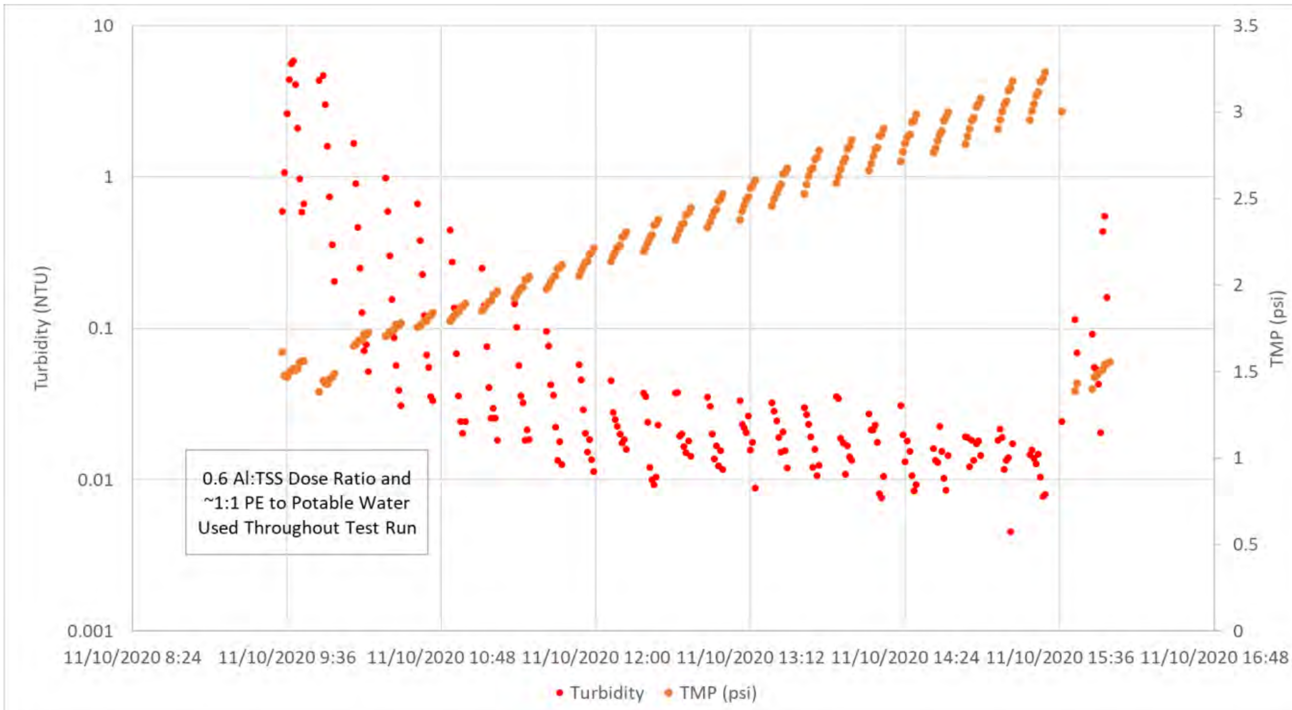


Figure 3-53. Effluent Turbidity and TMP, Supplemental Run 1

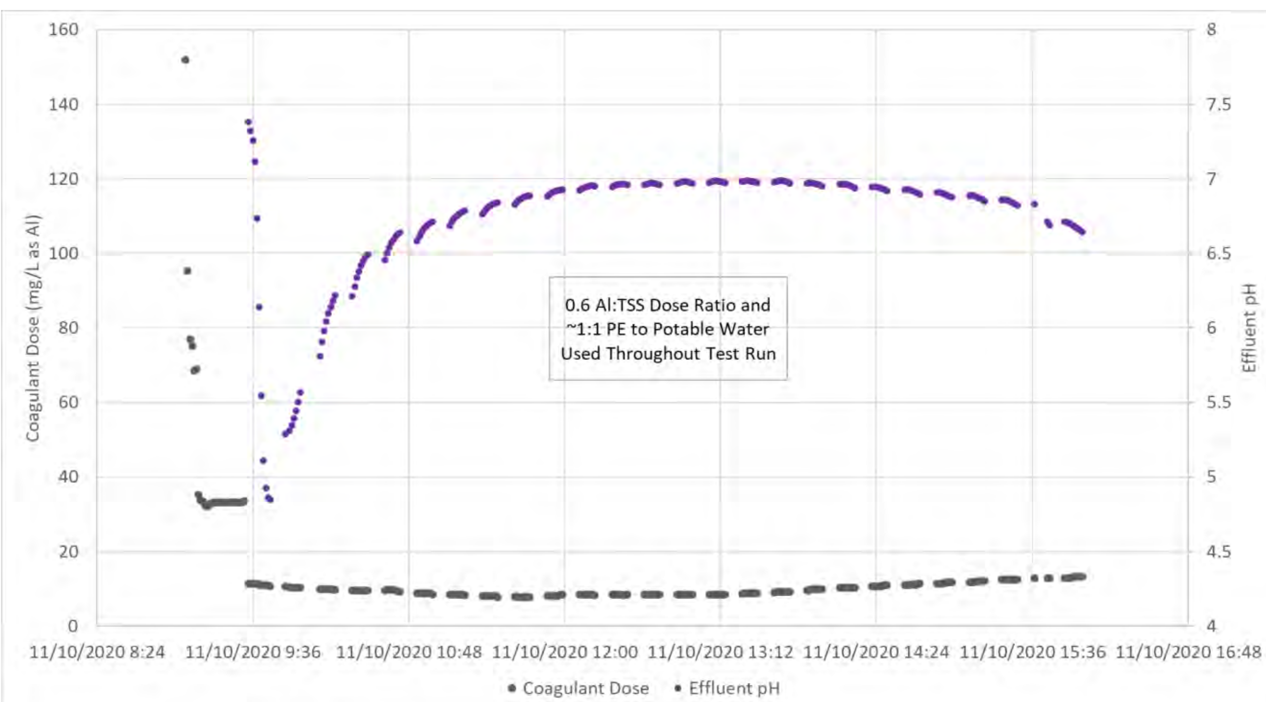


Figure 3-54. Coagulant Dose and Effluent pH, Supplemental Run 1

3.13.3 Sampling Results

Table 3-75 shows results for TSS, VSS, and tCOD analyses of grab and composite samples obtained during this test run. Table 3-76 shows field data.

Table 3-75. Water Quality Data, Supplemental Run 1

Parameter	Location	11/10/2020 (Time Stamps Below)	
		1200-1205	Composite
TSS (mg/L)	INF	16	23
	EFF	1	1
VSS (mg/L)	INF	14	17
	EFF	1	1
tCOD (mg/L)	INF	78	83
	EFF	20	32

Table 3-76. Field Water Quality Data, Supplemental Run 1

Time	Location	pH	Temperature (degrees C)	TDS (ppm)	Conductivity (µS/cm)
12:00	INF	7.5	14.0	292	411
12:05	EFF	7.3	14.3	258	363

3.13.4 Data Analysis

3.13.4.1 TMP Rise Rate

The TMP rise rate was steady through the 6-hour 150 gfd run (Figure 3-51), and the average TMP rise rate was estimated to be 0.28 psi/hour (Table 3-77). Assuming that the TMP rise rate would continue to rise at approximately the same rate, a 12-hour run is estimated to have an increasing TMP of 3.4 psi, which is an acceptable fouling rate. The TMP rise rate of 0.94 psi/hour at 100 gfd flux rate at the end of the test run was based on data from only one filtration cycle (15 minutes) and is not a reliable estimate because of the short duration.

Table 3-77. TMP Rise Rate, Supplemental Run 1

Time	Instantaneous Flux Setpoint (gfd)	Average TMP Rise Rate (psi/hour)
0930-1530	150	0.28
1535-1550	100	0.94 (unreliable due to short duration at flux rate)

3.13.4.2 Turbidity

Turbidity in the permeate declined to less than 0.1 NTU after running for approximately 2 hours and stayed below 0.1 NTU for the remainder of the run at 150 gfd (Figure 3-53).

3.13.4.3 pH

After the first half hour of operation, the permeate stayed above pH 6 for the remainder of the test run. The relatively low TSS:alkalinity ratio in the 1:1 primary effluent/potable water blend is likely a major factor for the pH remaining above 6.

3.13.4.4 Net Permeate and Flux

The following were the key results for net permeate and flux:

- Total operating time: 360 minutes (for the 150 gfd portion and not counting 100 gfd portion at the end of the test run)
- Approximate net permeate produced (permeate minus backwash): 41,000 gallons
- Approximate net flux accounting for backwash: 84.1 gfd

3.13.5 Membrane Recovery

Table 3-78 shows the TMP at the end of Supplemental Test 1 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill and at the end of the CIP chemical fills. Data are consistent with membrane recovery after the CIP.

Table 3-78. Supplemental Test 1 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi[a]
1.6 (100)	0.9 (100)	2.6	2.0

a A header pressure of less than 2.1 psi at the end of a chemical fill step is understood to indicate membrane recovery.

3.14 Supplemental Test Run 2

This supplemental test run was originally planned to take place on 1 day, but after the first portion of the run the air scour blowers failed. The second portion of the run was conducted 2 days later when the blowers were fixed and working again.

The purpose of this run, performed on November 3 and November 5, 2020, was to further test peak flux performance, with a 4-hour run at 200 gfd and a 1-hour run at 225 gfd. A short CIP was performed after the first portion of the test, as planned, followed by a brief run at 100 gfd to verify recovery. A full-length CIP was not performed until after the second portion of the test.

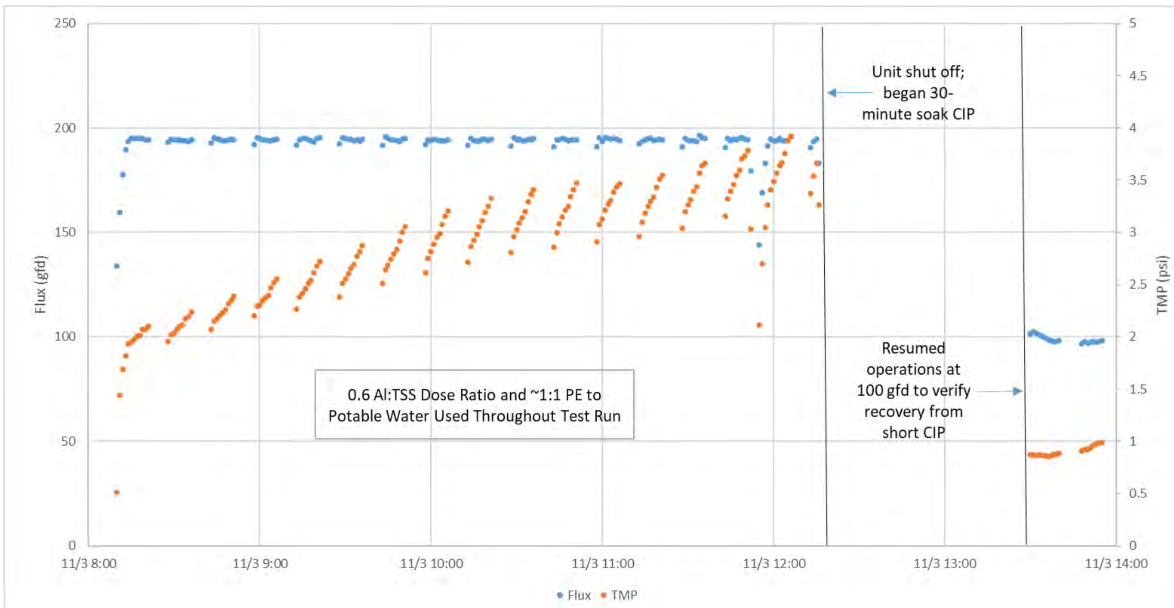
As with previous tests at high flux, the influent pipes and pumps were limited by head loss and were not capable of delivering the required flow to run all three membrane stacks. To maintain that flux rate, two of the three stacks were valved out to run at 200 gfd and 225 gfd.

3.14.1 Observations

This run successfully demonstrated the ability of the pilot unit to handle high flux rates for extended periods, and flux rates as high as 225 gfd. This confirms the manufacturer's peak flux design constraints.

3.14.2 Operational Data

Key operational data collected during this run are presented in Figure 3-55 through Figure 3-58. As a result of the delay following blower failure, the graphs are separated into two for the different portions of the test.



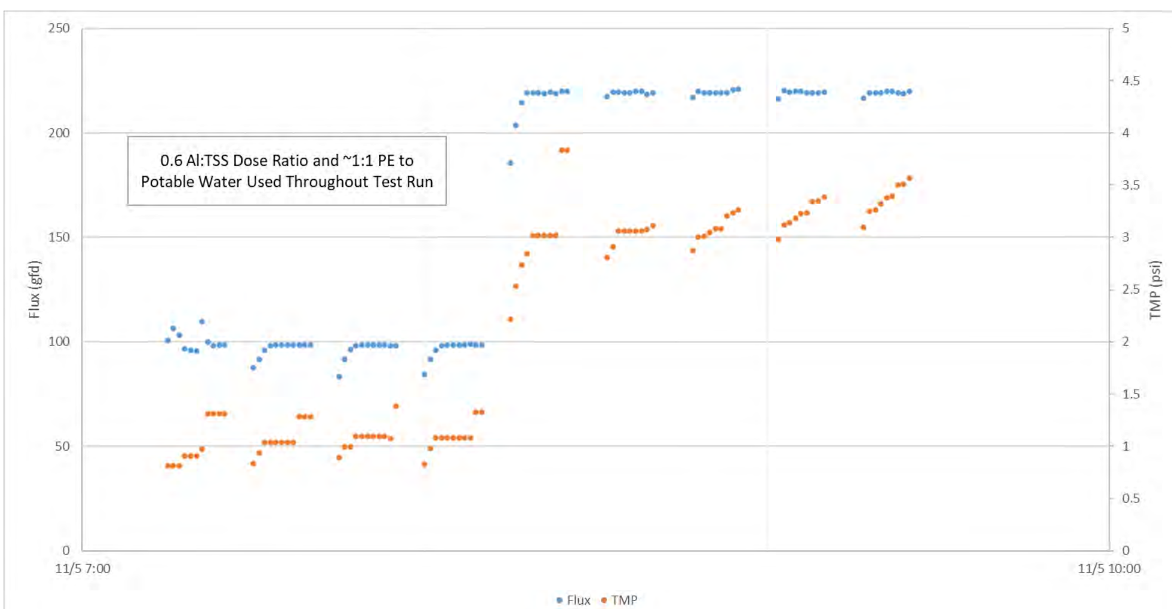
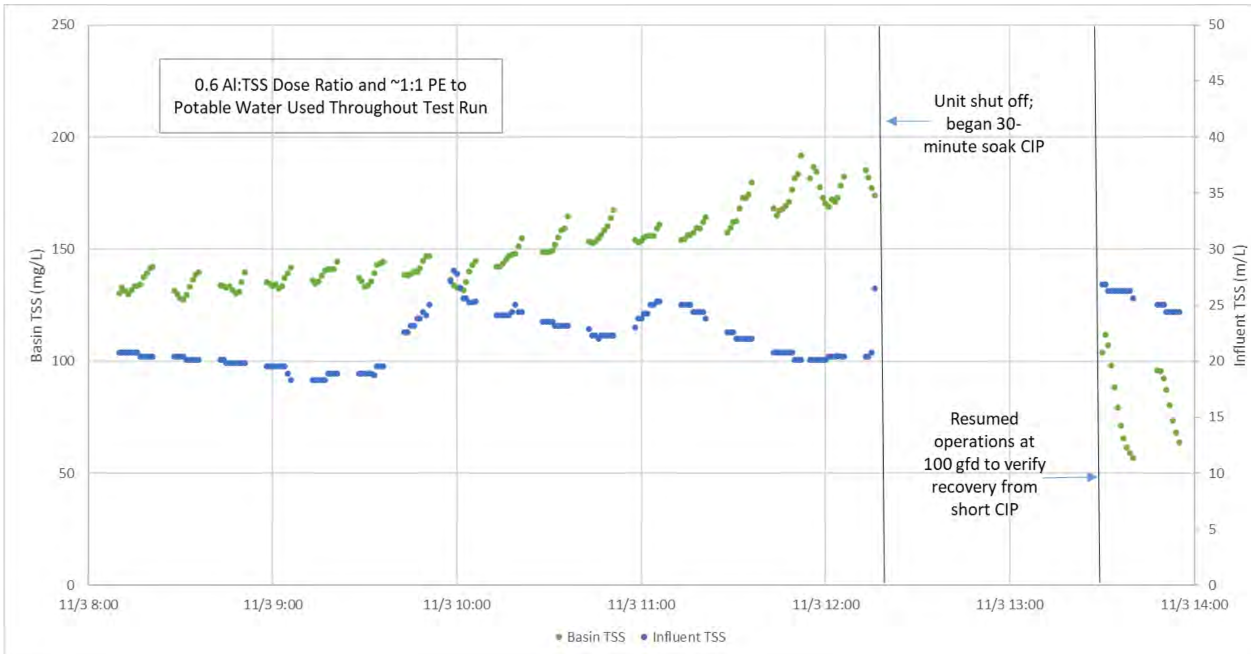


Figure 3-55. Flux and TMP, Supplemental Run 2



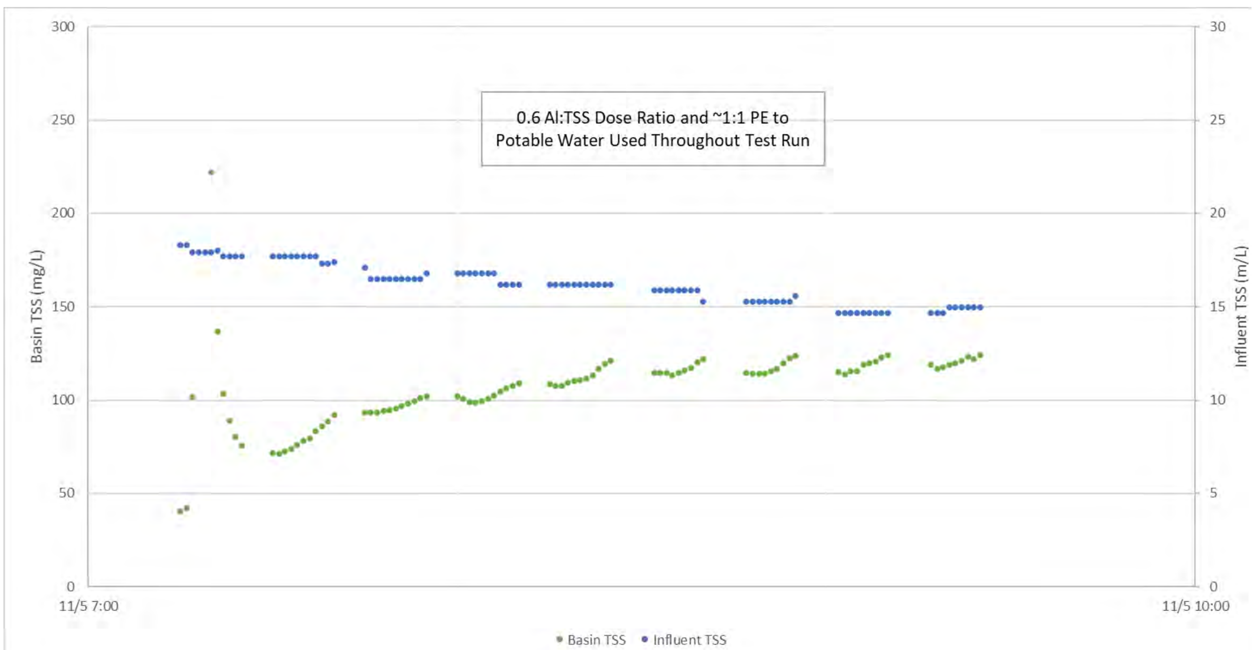


Figure 3-56. TSS, Supplemental Run 2

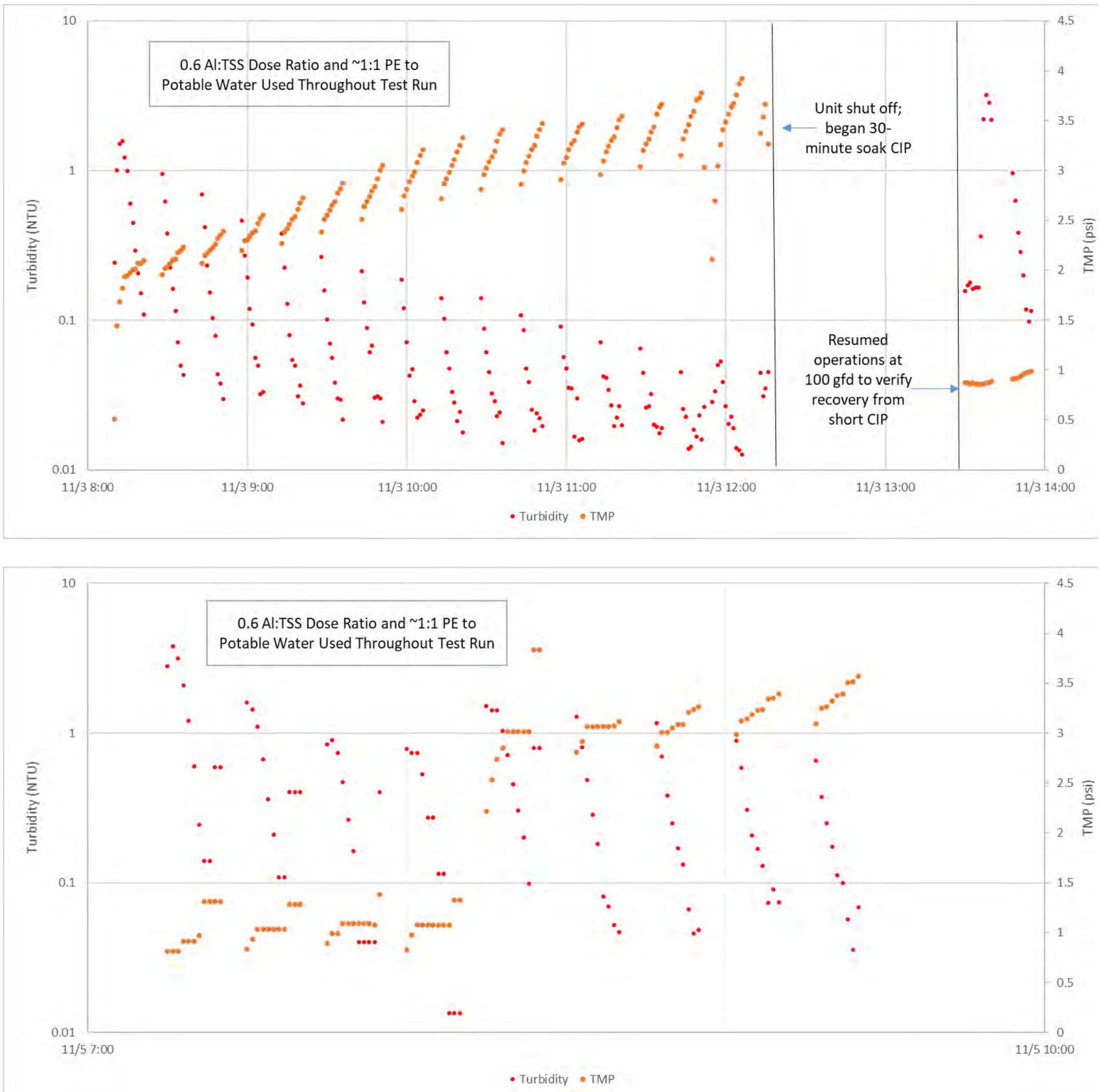
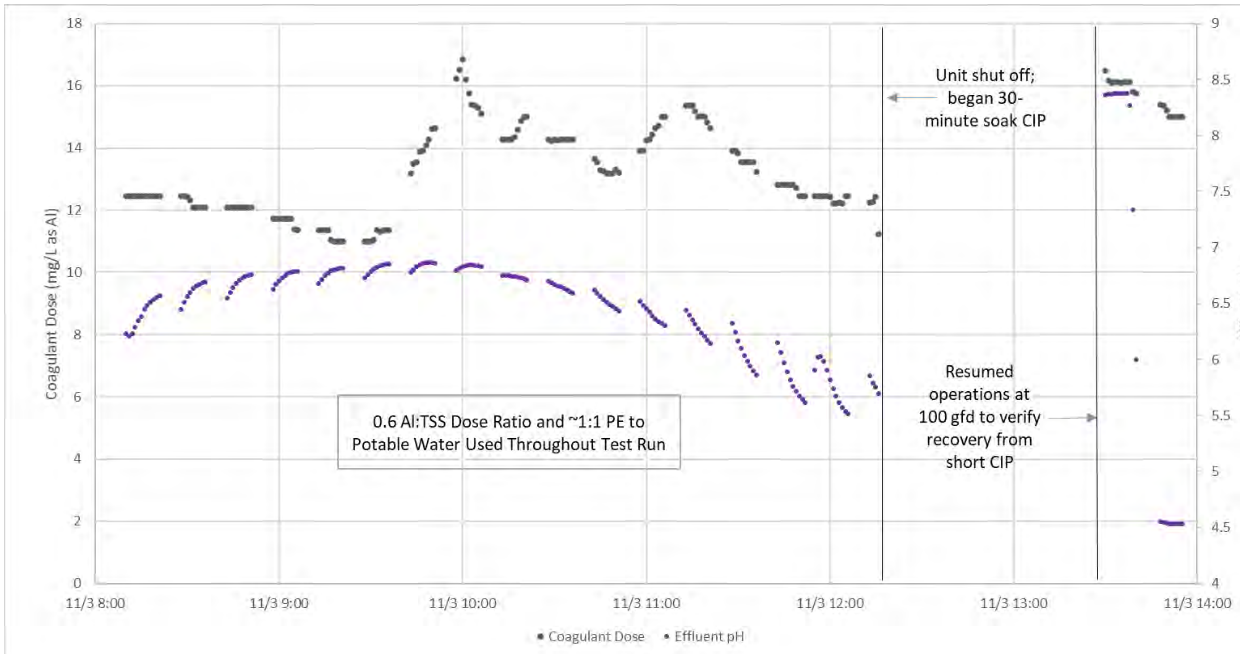


Figure 3-57. Effluent Turbidity and TMP, Supplemental Run 2



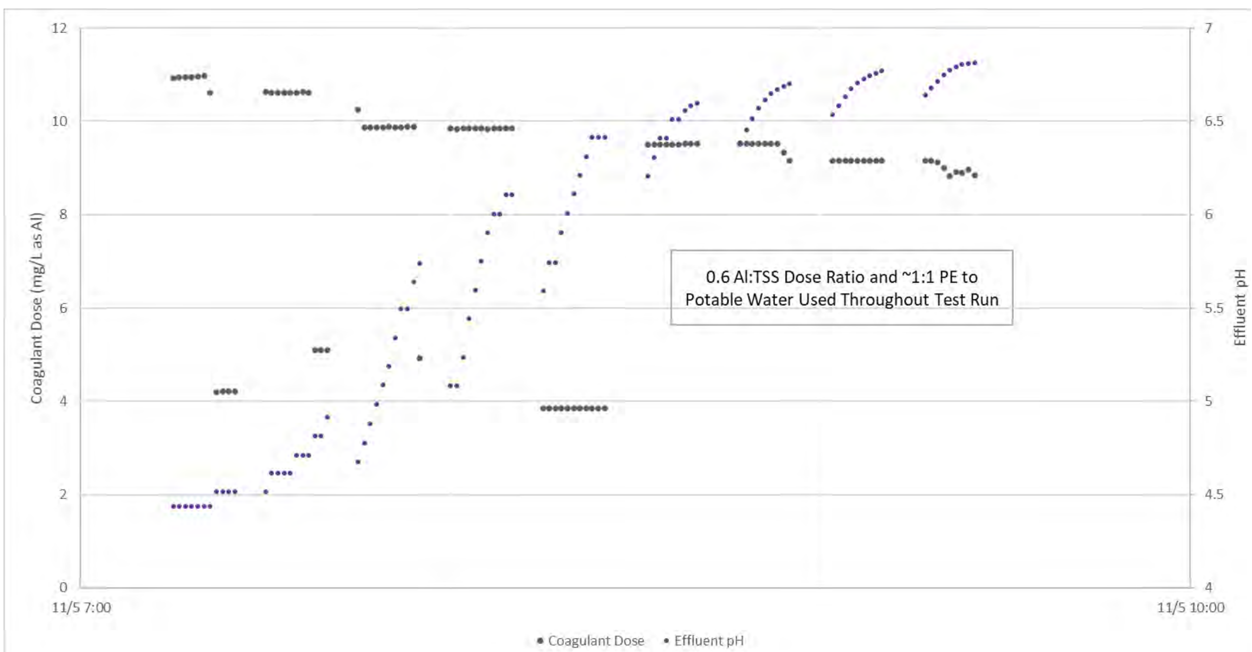


Figure 3-58. Coagulant Dose and Effluent pH, Supplemental Run 2

3.14.3 Sampling Results

Key sampling results collected during this run are presented in Table 3-79 and Table 3-80.

Table 3-79. Water Quality Data, Supplemental Run 2

Parameter	Location	11/3/2020 (Time Stamps Below) 830	1000	1145	1350	Grab Average	11/3/2020 Composite	11/5/2020 Composite[a]
		1:1 PE to Potable Water						
TSS (mg/L)	INF		34			34	26	
	EFF						3	
	TNK		492			492		
VSS (mg/L)	INF		23			23	24	
	EFF						1	
	TNK		278			278		
SS mL/L/hour)	EFF		0			0		
tCOD (mg/L)	INF		102			102	91	
	EFF		36			36		
	TNK		522.5			522.5		
sCOD (mg/L)	INF		32			32		
	EFF		35			35		
	TNK		36			36		
TOC (mg/L)	INF	33.9	22.4	16.6	18	22.7		
	EFF						9.18	
BOD (mg/L)	INF		40			40	36	
	EFF						9	
Alkalinity (mg/L)	INF		76			76	74	
	EFF		36			36	2	
	TNK		68			68		
Fecal Coliform (MPN/100 mL)	INF		3,500,000			3,500,000		
	EFF	0	0	0	0	1(geomean)		
Cl_2 Demand (mg/L)	EFF		0.84			0.84		
UV254 (cm^{-1})	EFF						0.0655	0.106

a The only data available for the 11/5/2020 composite sample was the UV254

Table 3-80. Field Sampling, Supplemental Run 2

Parameter	Location	11/3/2020		
		830	1000	1145
pH	INF		7.27	
	EFF		7	
	TNK		7.39	
Temperature (degrees C)	INF		14.5	
	EFF		14.6	
	TNK		14.4	
Conductivity (µS)	INF		1009	
	EFF		377	
	TNK		389	
TDS (ppm)	INF		737	
	EFF		266	
	TNK		276	
UVT (%)	INF	50.8		58.3
	EFF		86.7	
UV254 (cm^{-1})	INF	0.293		0.234
	EFF		0.061	

3.14.4 Data Analysis

3.14.4.1 Coagulant Dose Ratio

The ratios of coagulant to organic compounds from Supplemental Test Run 2 are shown in Table 3-81.

Table 3-81. Ratio of Coagulant to Organic Compounds, Supplemental Run 2

Ratio	Time Stamps		Composite
	1000	1350	
Al:tCOD	0.17		0.15
Al:sCOD	0.53		
Al:TOC	0.75	0.85	
Al:BOD	0.42		0.37
Al:TSS	0.6	0.6	0.6

3.14.4.2 TMP Rise Rate

This test run provided the longest period of operation at a flux of 200 gfd, giving a better estimate of the TMP rise rate at that flux level. In contrast with earlier short runs at that flux, the demonstrated TMP rise rate was lower, and much closer to the TMP rise rate at 100 gfd. This is despite the fact that the influent TSS strength was similar to past tests with 1:1 dilution. However, the concentrations of influent organic carbon indicators (tCOD, TOC, etc.) were lower than in many of the other test runs. Therefore, the ratio of coagulant to organic carbon was higher, which may explain the lower fouling rate. Table 3-82 summarizes TMP rise rate over the course of the test run. The run at 225 gfd was only an hour, so there is significant uncertainty in the estimated rise rate. Surprisingly, it was lower than at 200 gfd.

Table 3-82. TMP Rise Rate, Supplemental Run 2

Time	Flux (gfd)	TMP Rise Rate (psi/hour)
11/3: 0815-1215	200	0.42
11/5: 0815-0925	225	0.37

3.14.4.3 Turbidity

As is typical, the turbidity started high and decreased over time. The second run was not long enough for the turbidity to drop below 0.1 NTU consistently. Ovivo determined in its preliminary testing report that high initial values are caused by air in the permeate line.

3.14.4.4 pH

In the first test, the pH varied from 5.5 to 7, as was common throughout the testing. In the second test, the pH started at about 4.5, significantly lower than in previous tests.

3.14.4.5 Net Permeate and Flux

Table 3-83 summarizes key results for net permeate and flux.

Table 3-83. Net Permeate and Flux, Supplemental Run 2

	First Test	Second Test[a]
Total operating time (minutes)	246	70
Approximate net permeate produced (gallons)	26,400	8,000
Net flux accounting for backwash (gfd)	158.3	168.4

a This does not count the initial portion of the run at 100 gfd

3.14.5 Membrane Recovery

Table 3-84 shows the TMP at the end of Supplemental Test 2 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill and at the end of the CIP chemical fills. Although the header pressures at the end of the CIP chemical fill were higher than the approximately 2.1 psi indicator for membrane recovery discussed in the Ovivo CSO Pilot King County Preliminary Test Report (Ovivo 2020) for both CIPs, the TMP data after the CIPs are consistent with membrane recovery from the CIPs.

Table 3-84. Supplemental Test 2 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi
1.0 (200)	0.8 (100)	3.4	2.6
3.6 (225)	1.5 (150)	3.8	2.2

3.15 Supplemental Test Run 3

This test run was renamed from Test Run 12 to Supplemental Test Run 3 to avoid confusion with the Test Run 12 that was proposed in the *Process and Performance Test Plan*.

Supplemental Test Run 3 ran from 11:30 on November 12, 2020, to 11:30 on November 13, 2020. It treated full-strength primary effluent at 100 gfd at an alum coagulant dose ratio of 0.6 Al:TSS. The main purpose of the test was to compare the TMP rise rate with Test Run 1, which was also a 24-hour test but used a 0.4 Al:TSS dose ratio.

3.15.1 Observations

There was heavy rainfall during this test period; West Point's secondary effluent flow during the test run exceeded 250 million gallons per day.

This was a successful run in terms of demonstrating the ability to treat full-strength primary effluent at 100 gfd for 24 hours. However, the test run did not show that increasing the Al:TSS ratio to 0.6, compared to 0.4 in Test Run 1, decreased the TMP rise rate. The TMP rise rate was slightly higher in Supplemental Test Run 3 than in Test Run 1.

3.15.2 Operational Data

Figure 3-59 shows the flux rate and TMP during the run. Figure 3-60 shows the basin TSS, influent TSS, and coagulant dose (mg/L as Al).Figure 3-61 shows the permeate turbidity and pH. Figure 3-62 shows the coagulant dose and effluent pH. There was rain during Supplemental Test Run 3. Figure 3-63 shows the West Point secondary effluent flow rate during the test run.

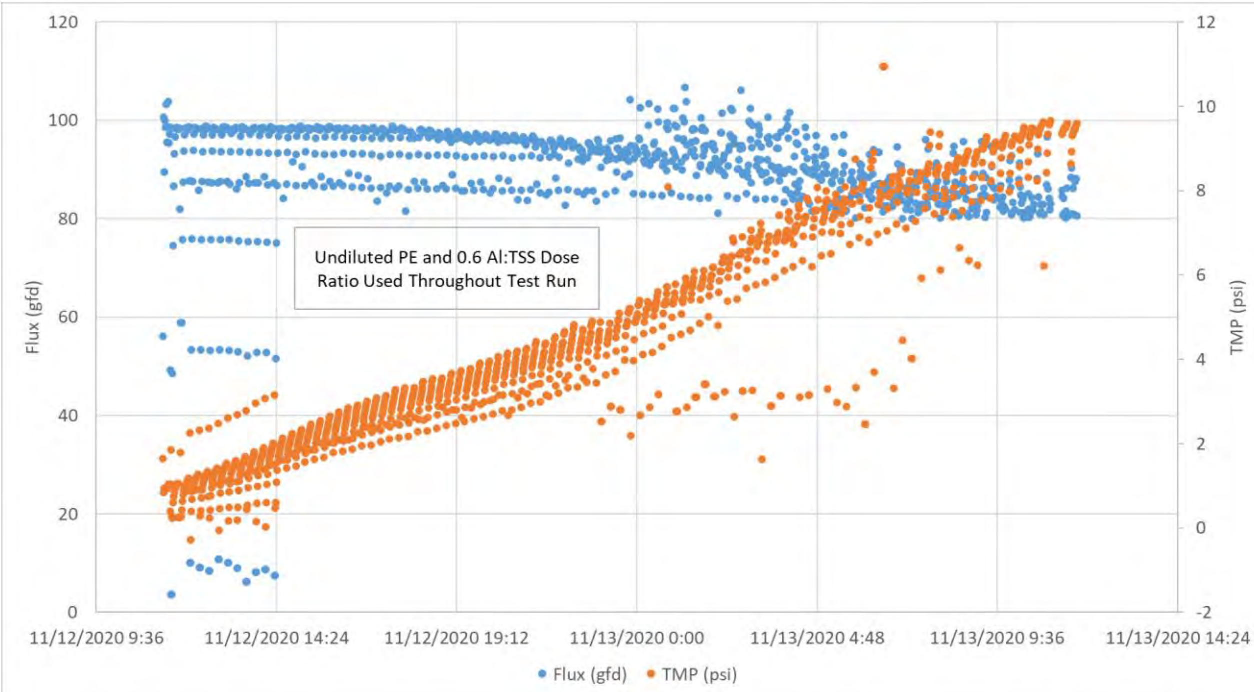


Figure 3-59. Flux and TMP, Supplemental Run 3

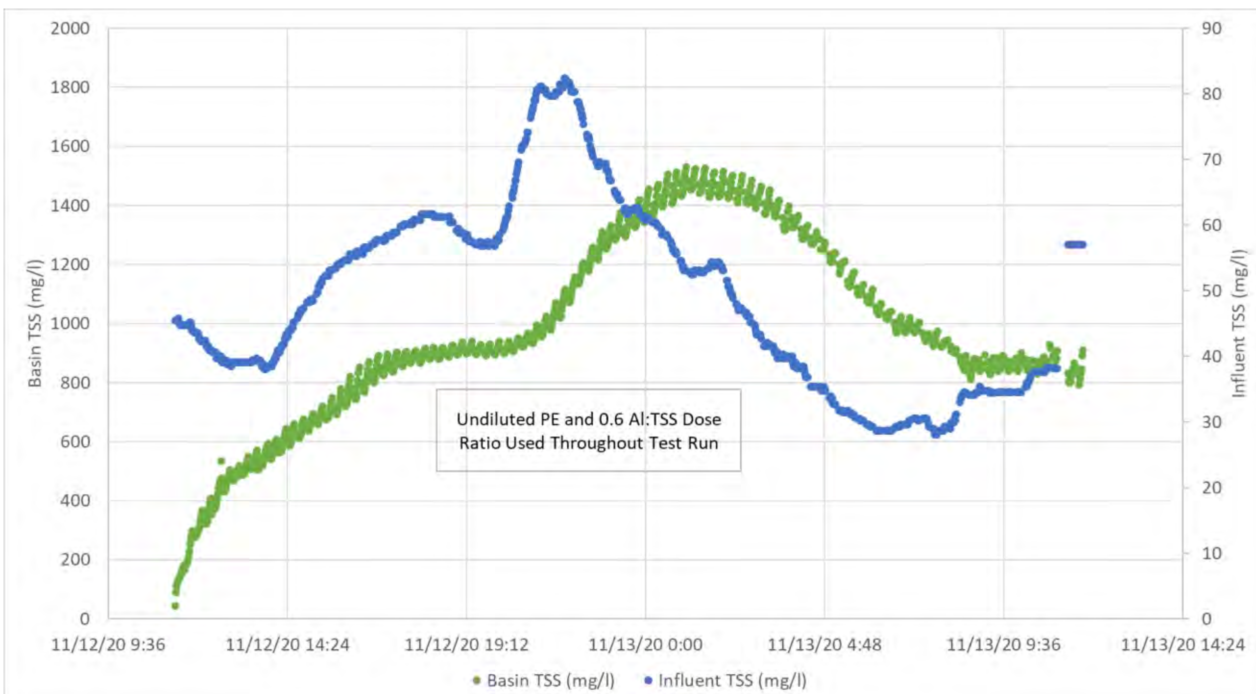


Figure 3-60. TSS, Supplemental Run 3

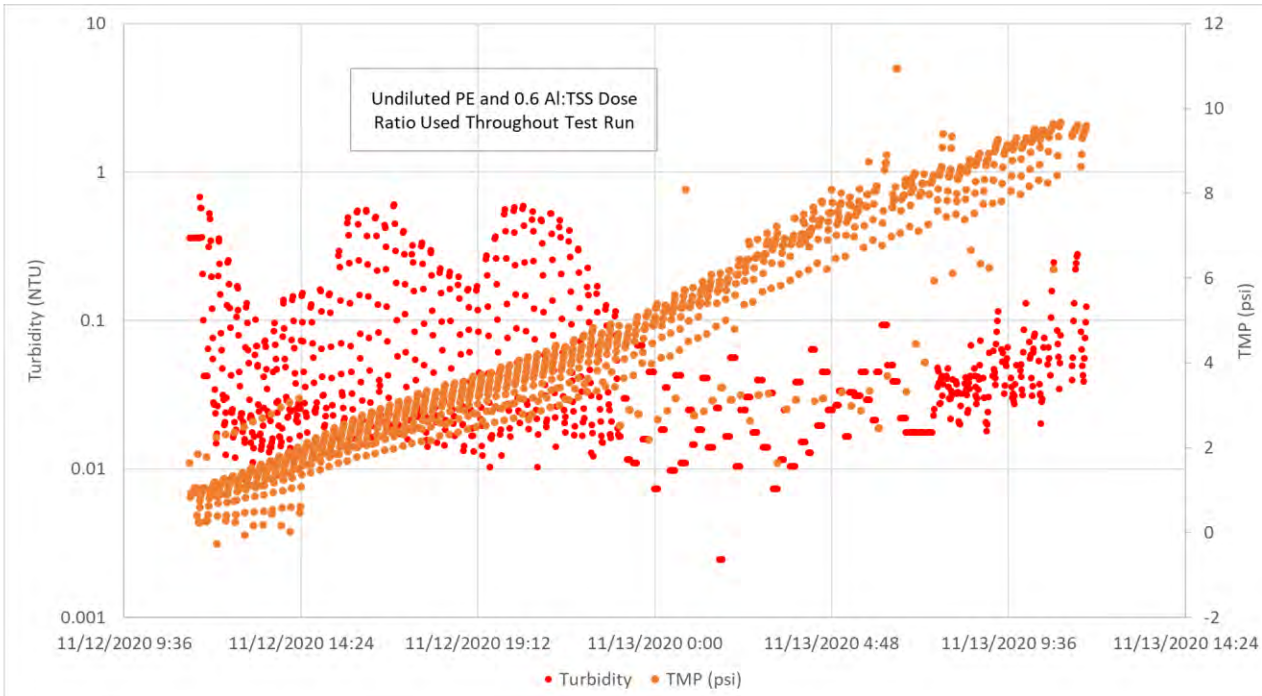


Figure 3-61. Effluent Turbidity and TMP, Supplemental Run 3

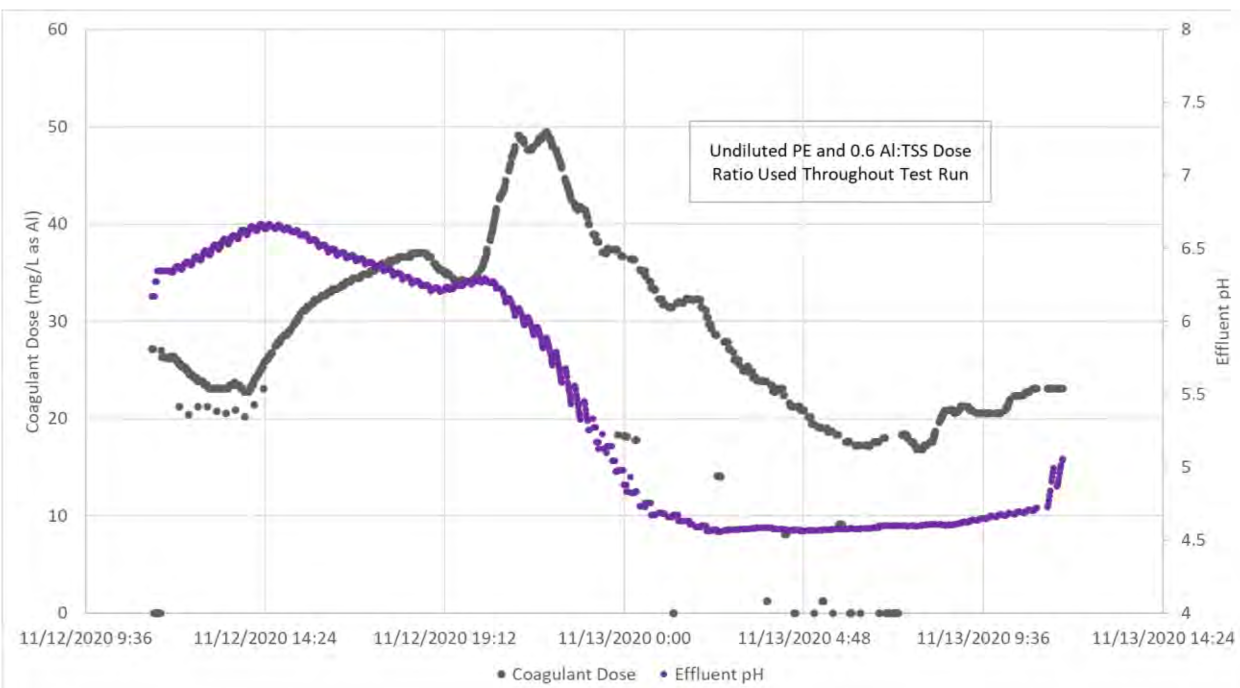


Figure 3-62. Coagulant Dose and Effluent pH, Supplemental Run 3

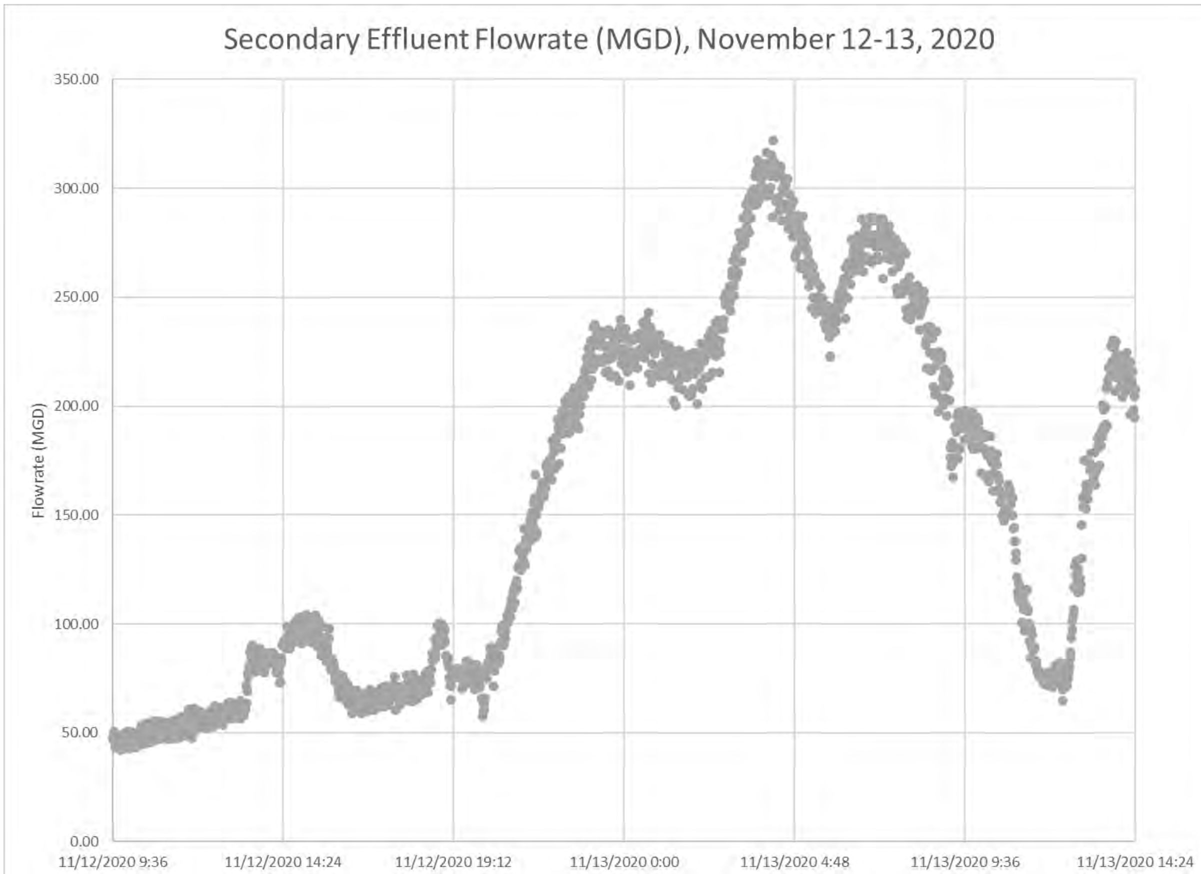


Figure 3-63. West Point Secondary Effluent Flow Rate, Supplemental Run 3

3.15.3 Sampling Results

The main goal of Supplemental Test Run 3 was examine the effects on the TMP rise rate of using a higher aluminum to influent TSS ratio than was used for Test Run 1, while treating full-strength primary effluent at 100 gfd for 24 hours. Therefore, only TSS, VSS, and tCOD sampling and laboratory analyses were obtained for this test run. The results are shown in Table 3-85. No composite sample data are available for these analytes because the sequential sampler failed during this test run.

Table 3-85. Water Quality Data, Supplemental Run 3

		11/12/2020 (Time Stamp Below)
Parameter	**Location**	**1100-1105**
TSS (mg/L)	INF	34
	EFF	1
VSS (mg/L)	INF	29
	EFF	0
tCOD (mg/L)	INF	258
	EFF	99

3.15.4 Data Analysis

3.15.4.1 TMP Rise Rate

The TMP rise rate did not change much over the course of Supplemental Test Run 3 (Table 3-86). There was a slight increase starting at 23:30 on November 13, 2020, so average TMP rise rates were calculated for three timeframes, as shown in Table 3-86. The TMP rise rate in this run was similar to the TMP rise rate in Test Run 1.

Table 3-86. TMP Rise Rate, Supplemental Run 3

Time	Instantaneous Flux Setpoint (gfd)	Average TMP Rise Rate (psi/hour)
1130-2330, 11/13/2020	100	0.31
2330 (11/13/2020) to 1130 (11/14/2020)	100	0.43
Overall	100	0.36

3.15.4.2 Turbidity

The permeate turbidity was over 1 NTU at the start of the test and gradually declined to below 0.1 NTU (Figure 3-61).

3.15.4.3 pH

The permeate dropped to below pH 6 for most of the test and was below pH 5 for the latter half of the test. This is consistent with the likelihood that as the pilot influent was diluted with rainwater, both the pH and alkalinity of the influent decreased compared to the beginning of the test run.

3.15.4.4 Net Permeate and Flux

The following were the key results for net permeate and flux:

- Total operating time: 1,440 minutes
- Approximate net permeate produced (permeate minus backwash): 190,700 gallons
- Approximate new flux accounting for backwash: 65.2 gfd

3.15.5 Membrane Recovery

Table 3-87 shows the TMP at the end of Supplemental Test 3 (TMP before CIP), TMP after CIP (TMP at the beginning of the next test run), and the highest header pressure during CIP chemical fill and at the end of the CIP chemical fills. Data are consistent with membrane recovery after the CIP.

Table 3-87. Supplemental Test 3 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi[a]
9.6 (100)	1.0 (100)	3.1	2.0

a A header pressure of less than 2.1 psi at the end of a chemical fill step is understood to indicate membrane recovery.

3.16 Supplemental Test Run 4

The purpose of this supplemental test, performed on November 17, 2020, was to demonstrate the effect of coagulant dose on fouling rates, and to collect more UV transmittance/absorbance data. The unit was started with a low coagulant dose, and the dose was gradually increased while observing the TMP rise rate.

3.16.1 Observations

Notable observations/events during this test run were as follows:

- The blowers repeatedly faulted and had to be restarted during this test run. They were running at a lower airflow than previous tests because they kept faulting out.
- Coagulant dose ratios below 0.6 Al:TSS resulted in excessive TMP rise rates. From ratios of 0.6 to 1.0, higher coagulant doses resulted in slower fouling, but performance was good at all doses. At 1.2 Al:TSS, the fouling rate was still good, though higher than at 1.0, indicating that this dose is inefficient from the perspective of chemical use.
- This run showed significant correlation between influent TSS and influent UV properties as discussed further in Section 4.2.1.4, probably because the influent water quality was fairly consistent over the duration of the test.

3.16.2 Operational Data

Key operational data collected during this run are presented in Figure 3-64 through Figure 3-67.

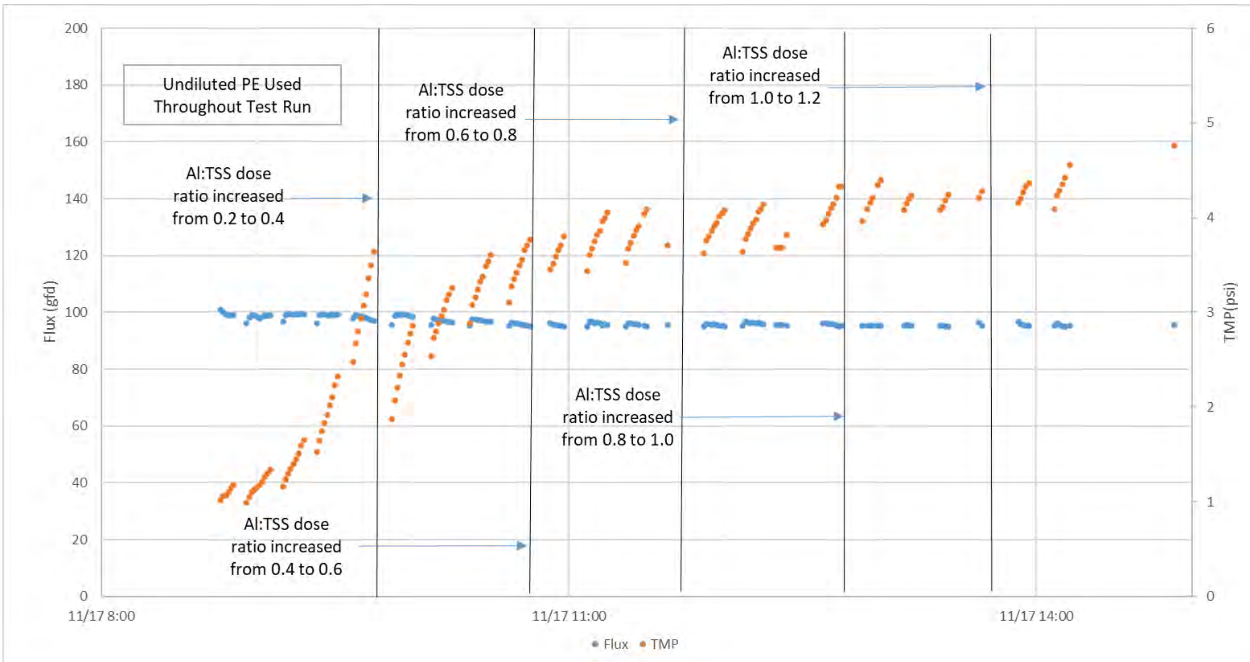


Figure 3-64. Flux and TMP, Supplemental Run 4

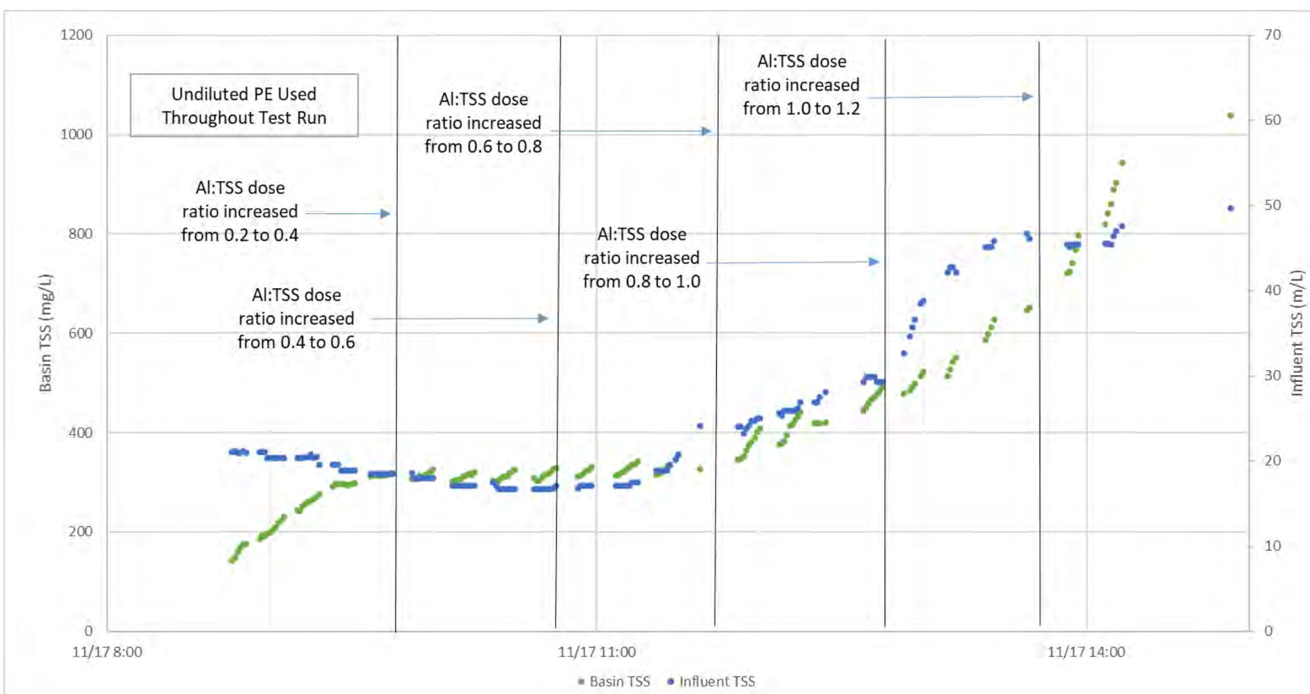


Figure 3-65. TSS, Supplemental Run 4

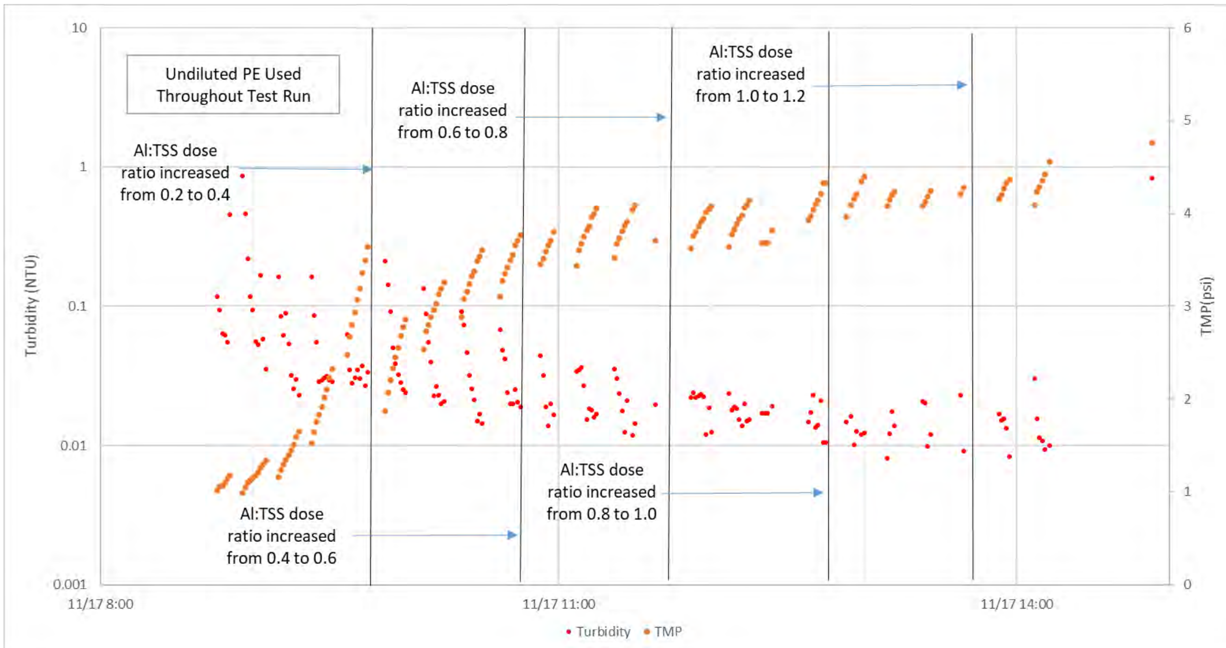


Figure 3-66. Turbidity and TMP, Supplemental Run 4

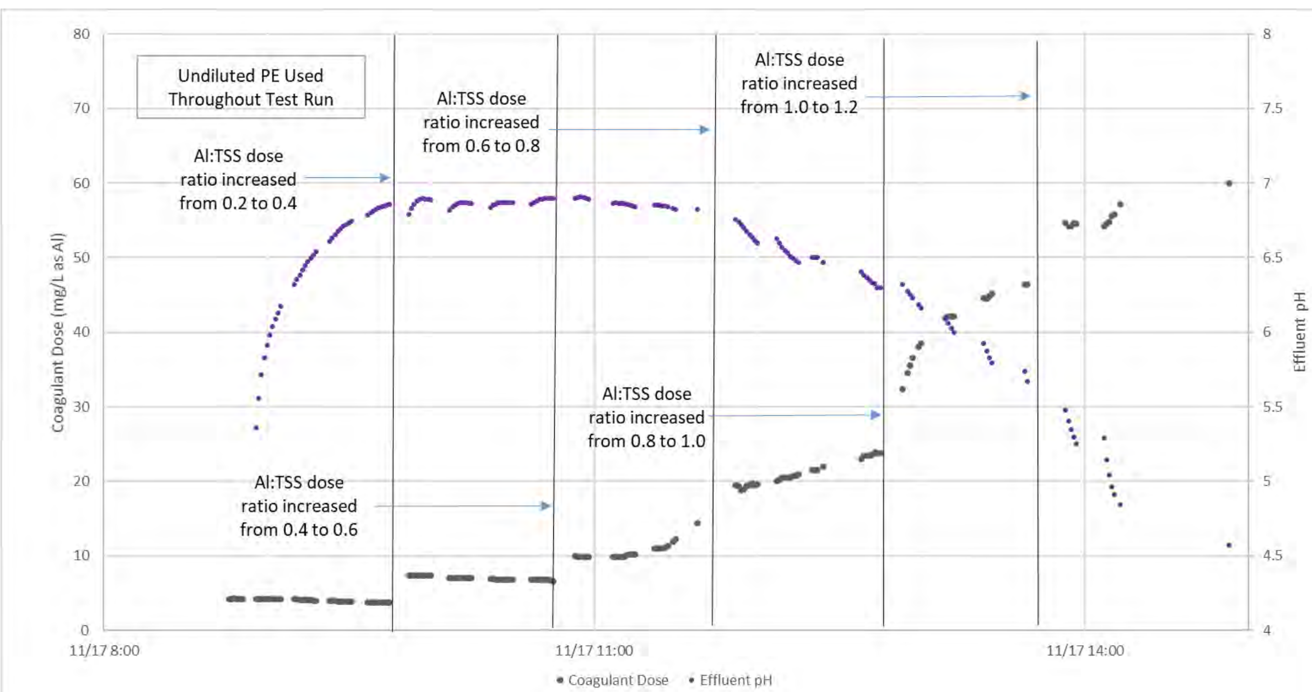


Figure 3-67. Coagulant Dose and Effluent pH, Supplemental Run 4

3.16.3 Sampling Results

No water quality samples were taken during this run. Field measurements of UV transmittance/absorbance were recorded, as shown in Table 3-88.

Table 3-88. Field Sampling, Supplemental Run 4

Parameter	Location	11/17/2020 (Time Stamps Below)					
		930	**1010**	**1130**	**1230**	**1330**	**1430**
UVT (%)	INF	43.0	43.6	40.4	35.4	25.6	28.2
	EFF	76.2	74.8	72.0	73.7	69.7	71.7
UV254 (cm^{-1})	INF	0.366	0.37	0.392	0.45	0.591	0.55
	EFF	0.117	0.125	0.142	0.13	0.156	0.14

3.16.4 Data Analysis

3.16.4.1 TMP Rise Rate

At the low starting coagulant dose, the TMP rise rate was about 10 times higher than typically seen in test runs. As the coagulant dose increased, the TMP rise rate decreased until the dose was increased to 1.2 Al:TSS. At that point, the TMP rise rate was higher than the previous step. Table 3-89 summarizes TMP rise rates over the course of the run. In past tests, especially test run 7, it took about 30 minutes for the system to respond to a change in coagulant dose. This test was run with only an hour between coagulant dose changes, so the numbers may not fully represent the effect of a coagulant dose.

Table 3-89. TMP Rise Rate, Supplemental Run 4

Al:TSS	Time	Flux (gfd)	TMP Rise Rate (psi/hour)
0.2	0840-0940	100	2.27
0.4	0940-1040	100	1.40
0.6	1040-1140	100	0.33
0.8	1140-1240	100	0.25
1.0	1240-1340	100	0.13
1.2	1340-1440	100	0.22

3.16.4.2 Turbidity

As is typical, the turbidity started high and decreased over time due to the presence of air in the permeate line, as determined by Ovivo in its preliminary testing report.

3.16.4.3 pH

The pH started very low. It rose to about 7 before declining once again when the coagulant dose reached 0.8 Al:TSS.

3.16.4.4 Net Permeate and Flux

Insufficient data was available to accurately estimate the total permeate or net flux during the run.

3.16.4.5 Other

There was good correlation between the measured influent TSS and the UVT/UV254 field test results as discussed further in Section 4.2.1.4. Over the short duration of the test, the influent water quality was likely fairly stable, meaning the concentration of organic species affecting the UV readings and the influent TSS were probably proportional to each other. This may not be the case during actual storm events.

3.16.5 Membrane Recovery

Table 3-90 shows the TMP at the end of Supplemental Test 4 (TMP before CIP). But because this was the last test run from the process and performance pilot testing, there is no TMP data at the beginning of the next test run to include. The header pressure at the end of the CIP chemical fill was slightly higher than the header pressure drop to less than 2.1 psi that was discussed in the Ovivo CSO Pilot King County Preliminary Test Report (Ovivo 2020).

Table 3-90. Supplemental Test 4 Membrane Recovery Data

TMP Before CIP, psi (Instantaneous Flux, gfd)	TMP After CIP, psi (Instantaneous Flux, gfd)	Highest Header Pressure During CIP Chemical Fill, psi	Header Pressure at End of CIP Chemical Fill, psi
4.6 (100)	No data	2.6	2.2

4. REVIEW OF TESTING RESULTS

4.1 Summary and Discussion of Results

4.1.1 Peak Design Flux

One goal of the pilot testing was to confirm Ovivo's design flux rates for the RapidStorm system, as shown in Table 4-1. Results presented in the following subsections confirm that, with proper coagulant dosing and starting with relatively clean membranes with an initial TMP of ≤1.5 psi, the peak design flux rates were achieved, based on actual run times or extrapolated from pilot data. These results are based on testing primary effluent with or without dilution, not CSO wastewater.

Table 4-1. Flux Specifications – Maximum Allowable

Flux Condition	Design Flux (gfd)
Peak day	100
Peak 16-hour	125
Peak 12-hour	150
Peak 8-hour	175
Peak 4-hour	200
Peak hour	225

4.1.1.1 100-gfd Peak-Day Flux Rate

Table 4-2 shows results from test runs where 100-gfd portions of the tests generated data on TMP rise rates: Runs 1 through 9 and Supplemental Runs 3 and 4. The following data are included in Table 4-2:

- TSS and the dose ratio of aluminum to influent TSS (Al:TSS), because the alum coagulant dosing strategy was based on this ratio for most of the test runs.
- The TSS data presented are based on average influent TSS probe readings from the duration where the test run operated at 100 gfd.
- The duration for which the pilot unit ran at 100 gfd.
- Effluent pH range.
- Influent water source.
- TMP rise rate – Observed TMP rise rates that are extrapolated to exceed a terminal TMP of 10 psi in under the design maximum duration of 24 hours are flagged in red text. These estimates assume a conservative starting TMP of 1.5 psi (starting TMP during pilot testing was generally 1 psi or lower) and a linear fouling rate. The acceptable TMP rise rate using these assumptions is 0.35 psi/hour.

Table 4-2. Summary of Results and Key Parameters at 100 gfd, Runs 1 Through 9 and Supplemental Run 3 and 4

Test Run Number	Influent TSS (mg/L, probe)	Al:TSS Dose Ratio	Duration at Flux Rate (hours)	Effluent pH	Influent Water Source	TMP Rise Rate (psi/hour)[a]
1	60	0.4	5	6.6-7.3	PE	0.44
	70	Variable, up to 0.8	18	5.8-7.1	PE	0.21
2	63	0.4	2.5	6.3-6.5	PE	0.32
	28	0.4	3	6.5-6.9	~1:1 PE to potable water	0.20
	18	0.4	3	6.8-6.9	~1:2 PE to potable water	0.14
	18	0.4	3.5	6.7-6.8	~1:3 PE to potable water	0.04
3	59	0.4	5	6.3-6.7	PE	0.49
	54	0.4	5	6.8	PE	0.89
4	21	0.4	1	6.7-6.8	PE	0.16
	31	0.4	1	6.4-6.5	PE	0.05
5	48	0.4-0.5	2	6.6-6.7	PE	0.33
6	50	0.5	1	6.3-6.5	PE	0.29
7	28	0.4	1	6.3-6.8 for period when coagulant was added	PE	0.31
	27	0	0.5	6.8-7.4 after coagulant dosing stopped	PE	14
8	36	0.6	1	4.7-6.9	PE	0.26
	35	0.6	3	4.5-4.7 for period with no air scour	PE	0.23
	42	0.6	3	4.6-6.5 for period with no backwash	PE	0.50
	49	0.6	0.75	5.5-7.5 for period with normal operations	PE	0.18
9	38	0.6	0.75	6.2-6.3	~1:1 PE to potable water	0.13
	74	0.6	0.75	5.9-6.2	PE	0.39
Suppl. 3	55	0.6	12	5.1-6.3	PE	0.36
	42	0.6	12	4.6-5.1	PE	0.43
Suppl. 4	20	0.2	1	5.4-6.8	PE	2.27
	17	0.4	1	6.8-6.9	PE	1.4
	18	0.6	1	6.8-6.9	PE	0.33
	26	0.8	1	6.4-6.8	PE	0.25
	38	1.0	1	5.7-6.4	PE	0.13
	46	1.2	1	5.0-5.7	PE	0.22

a Acceptable TMP rise rate is 0.35 psi/hour at 100 gfd for 24 hours, which assumes starting at 1.5 psi and linear fouling rate

These results confirm that sufficient coagulant dosing, represented by the Al:TSS dose ratio, is important for mitigating membrane fouling from organic compounds based on review of the TMP rise rates. The Al:TSS ratios shown are based on the alum coagulant dosing during the test runs that were set based on influent TSS probe readings. For the cases indicated in red in the table, when the TMP rise rates were higher than the target 0.35 psi/hour, the following explanations have been developed:

- Six out of 10 events occurred when the Al:TSS dose ratio was less than 0.6, suggesting that the Al:TSS dose ratio should be 0.6 rather than 0.4.
- The high fouling rate for the second row of Test Run 7 was due to stopping alum coagulant dosing to test the effects of loss of coagulant.
- The high fouling rate during Test Run 8 with a 0.6 Al:TSS dose ratio can be explained by the lack of backwashing during that period to test backwashing failure mode.
- Two reasons explain the high fouling rate at 100 gfd when using a coagulant dosing ratio of 0.6 Al:TSS in the second-row data for Test Run 9:
    - This was a middle-loaded hydrograph test run, and the second 100 gfd stretch followed by runs at 200 gfd and 150 gfd for approximately 2.5 hours.
- In Supplemental Test 4, the TMP rise rate decreased steadily as the Al:TSS dose ratio went up from 0.2 to 1.0 but then increased again when the Al:TSS dose ratio went to 1.2. This suggests the potential for adverse impacts from alum overdosing.

The pilot testing results show that at a coagulant dosing rate between 0.6 and 1.2 Al:TSS dose ratio, the Ovivo pilot unit can operate at the peak day design flux fate of 100 gfd when treating undiluted primary effluent from West Point.

4.1.1.2 125-gfd Peak 16-Hour Flux Rate

The only test run with a flux rate of 125 gfd was Test Run 4, where the pilot unit was run with flux rates ranging from 100 to 200 gfd, in increments of 25 gfd. Table 4-3 shows results from that run during the two 125-gfd portions of the test, where an observed TMP rise rate that is extrapolated to exceed a terminal TMP of 10 psi in under the design maximum duration of 16 hours is flagged in red text. These estimates assume a conservative starting TMP of 1.5 psi (starting TMP during pilot testing was generally 1 psi or lower) and a linear fouling rate. The acceptable TMP rise rate using these assumptions is 0.53 psi/hour. The influent data presented are based on average influent TSS probe data from the duration when the unit operated at 125 gfd.

Table 4-3. Summary of Results and Key Parameters at 125 gfd

Test Run Number	Influent TSS (mg/L, probe)	Al:TSS Dose Ratio	Duration at Flux Rate (hours)	Effluent pH	Influent Water Source	TMP Rise Rate (psi/hour)[a]
4	16	0.4	1	6.8-6.9	~1:1 PE to potable water	0.25
4	25	0.4	1	6.6-6.7	~1:1 PE to potable water	0.60

a Acceptable TMP rise rate is 0.53 psi/hour at 125 gfd for 16 hours, which assumes starting at 1.5 psi and linear fouling rate

The second period of running at 125 gfd had a higher TMP rise rate compared to the first period. One possible reason is that the average influent TSS as measured by the probe was higher (25 mg/L TSS) during the second 1-hour 125 gfd period compared to the first 1-hour 125 gfd period (16 mg/L). Another possible reason for the higher TMP rise rate during the second 125 gfd period is that it occurred after the unit had operated for 10 hours total and at flux rates up to 200 gfd. The higher TMP rise rate compared to the first 125 gfd period may be explained by fouling that accumulated preceding this period. As more wastewater is treated by the membranes, suspended or colloidal matter accumulate within membrane pores or on the membrane surface. And accumulated fouling can lead to higher TMP rise rates as more wastewater has been treated by the system. Possible remedies for mitigating the effects of accumulated fouling during prolonged operation include increasing backwashing frequency or conducting short, 30-minute soak CIPs, as discussed in Section 4.1.3.1.

4.1.1.3 150-gfd Peak 12-Hour Flux Rate

Table 4-4 shows TMP rise rates from 150-gfd portions of the test runs. None of the test runs showed estimated exceedances of the terminal TMP of 10 psi within the design maximum duration of 12 hours for 150 gfd. Even at the Al:TSS dose ratio of 0.4 for Test Runs 4 and 5, the TMP rise rates were low enough to meet the design flux specification. These results are based on testing 1:1 primary effluent to potable water. The influent data presented are based on average influent TSS probe data from the duration when the unit operated at 150 gfd.

Table 4-4. Summary of Results and Key Parameters at 150 gfd

Test Run Number	Influent TSS (mg/L, probe)	Al:TSS Dose Ratio	Duration at Flux Rate (hours)	Effluent pH	Influent Water Source	TMP Rise Rate (psi/hour)[a]
4	16	0.4	1	6.8	~1:1 PE to potable water	0.62
	23	0.4	1	6.4-6.6	~1:1 PE to potable water	0.36
5	13	0.4	1	6.9-7.0	~1:1 PE to potable water	0.18
9	39	0.6	0.5	6.3	~1:1 PE to potable water	0.49
	38	0.6	0.5	6.3	~1:1 PE to potable water	0.20
10	24	0.6	1	5.6-6.6	~1:1 PE to potable water	0.14
Suppl. 1	16	0.6	6	6.0-7.0	~1:1 PE to potable water	0.28

a Acceptable TMP rise rate is 0.71 psi/hour at 150 gfd for 12 hours, which assumes starting at 1.5 psi and linear fouling rate

4.1.1.4 175-gfd Peak 8-Hour Flux Rate

The only test run with a flux rate of 175 gfd was Test Run 4, where the pilot unit was run with flux rates ranging from 100 to 200 gfd, in increments of 25 gfd. Table 4-5 shows results from that run during the two 175-gfd portions of the test, where an observed TMP rise rate that is extrapolated to exceed a terminal TMP of 10 psi in under the design maximum duration of 8 hours is flagged in red text. These estimates assume a conservative starting TMP of 1.5 psi (starting TMP during pilot testing was generally 1 psi or lower) and a linear fouling rate. The acceptable TMP rise rate using these assumptions is 1.06 psi/hour. The influent data presented are based on average influent TSS probe data from the duration when the unit operated at 175 gfd.

Table 4-5. Summary of Results and Key Parameters at 175 gfd

Test Run Number	Influent TSS (mg/L, probe)	Al:TSS Dose Ratio	Duration at Flux Rate (hours)	Effluent pH	Influent Water Source	TMP Rise Rate (psi/hour)[a]
4	16	0.4	1	6.8-6.9	~1:1 PE to potable water	0.98
4	22	0.4	1	6.7-6.8	~1:1 PE to potable water	1.25

a Acceptable TMP rise rate is 1.06 psi/hour at 175 gfd for 8 hours, which assumes starting at 1.5 psi and linear fouling rate

The Al:TSS ratio was 0.4 and the influent water source was approximately 1:1 primary effluent to potable water. The higher TMP rise rate in the second of the two periods can be explained by the fouling that accumulated and occurred at the preceding higher flux rate stages of the test run.

4.1.1.5 200-gfd Peak 4-Hour Flux Rate

Table 4-6 shows TMP rise rates from 200 gfd portions of the test runs. None of the test runs showed that the terminal TMP of 10 psi would be exceeded within the design maximum duration of 4 hours for 200 gfd when treating 1:1 primary effluent to potable water, even at the Al:TSS ratio of 0.4 for Test Runs 4 and 5. The influent data presented are based on average influent TSS probe data from the duration when the unit operated at 200 gfd.

Table 4-6. Summary of Results and Key Parameters at 200 gfd

Test Run Number	Influent TSS (mg/L, probe)	Al:TSS Dose Ratio	Duration at Flux Rate (hours)	Effluent pH	Influent Water Source	TMP Rise Rate (psi/hour)[a]
4	20	0.4	2	6.8-6.9	~1:1 PE to potable water	0.97
5	15	0.4	2	5.6-7.1	~1:1 PE to potable water	0.43
9	39	0.6	2	6.2-6.3	~1:1 PE to potable water	0.55
10	31	0.6	1	6.5-6.6	~1:1 PE to potable water	0.014
11	12	0.6	1	6.2-6.8	~1:1 PE to potable water	0.11
	23	0.6	1	6.2-6.6	~1:1 PE to potable water	0.81
Suppl. 2	22	0.6	4	5.5-6.9	~1:1 PE to potable water	0.42

a Assumes starting at 1.5 psi and linear fouling rate

4.1.1.6 225-gfd Peak-Hour Flux Rate

Table 4-7 shows results from Supplemental Test Run 2, where the pilot unit was run at 225 gfd for 1 hour. Results show that at a coagulant dosing rate of 0.6 Al:TSS, the unit can treat 1:1 primary effluent to potable water at 225 gfd without excessive fouling. The estimated run time to the terminal TMP of 10 psi from the test run is 23 hours, which far exceeds the design maximum duration of 1 hour at 225 gfd. The influent data presented are based on average influent TSS probe data from the duration when the unit operated at 225 gfd.

Table 4-7. Summary of Results and Key Parameters at 225 gfd

Test Run Number	Influent TSS (mg/L, probe)	Al:TSS Dose Ratio	Duration at Flux Rate (hours)	Effluent pH	Influent Water Source	TMP Rise Rate (psi/hour)[a]
Suppl. 2	15	0.6	1	4.4-6.8	~1:1 PE to potable water	0.37

a Acceptable TMP rise rate is 8.5 psi/hour at 225 gfd for 1 hour, which assumes starting at 1.5 psi and linear fouling rate

4.1.2 Hydrograph Testing Results

Four tests were conducted to examine the response of the pilot unit to different hydrographs that were modeled after historical storm events. Test Run 5, which used a front-loaded hydrograph, showed that TMP and TMP rise rate are both affected by the flux rate (see Table 4-8). At lower flux rates, the RapidStorm unit can run for longer with lower TMP rise rates. At 200 gfd, the TMP rose rapidly even though it was treating diluted 1:1 primary effluent to potable water. The test also demonstrated that the membrane unit can handle a brief 2-hour period of high flux rate at the beginning of a treatment period without adversely impacting the unit's ability to treat wastewater at lower flux rates later in the test run.

Table 4-8. Data from Front-Loaded Hydrograph Testing (Test Run 5)

Test Run Number	Influent TSS (mg/L, probe)	Flux Rate (gfd)	Al:TSS Dose Ratio	Approximate Duration at Flux Rate (hours)	Influent Water Source	TMP Rise Rate (psi/hour)	TMP Range (psi)
5	15	200	0.4	2	~1:1 PE and potable water	0.43	1.9-2.7
5	13	150	0.4	1	~1:1 PE and potable water	0.18	1.6-1.9
5	48	100	0.4-0.5	2	PE	0.33	1.1-1.7
5	60	75	0.5	5	PE	0.13	1.1-1.9
5	78	50	0.5	14	PE	0.03	0.9-1.5

Test Run 6, which used a back-loaded hydrograph, showed higher TMP rise rates and higher TMPs as the flux rates increased (see Table 4-9). The TMP data were too scattered in the short durations at 150 gfd and 200 gfd to determine the TMP rise rates at these flux rates.

Table 4-9. Data from Back-Loaded Hydrograph Testing (Test Run 6)

Test Run Number	Influent TSS (mg/L, probe)	Flux Rate (gfd)	Al:TSS Dose Ratio	Approximate Duration at Flux Rate (hours)	Influent Water Source	TMP Rise Rate (psi/hour)	TMP Range (psi)
6	57	50	0.4	6.5	PE	0.06	0.4-0.7
6	63	75	0.5	2.5	PE	0.13	1.1-1.7
6	50	100	0.5	1	PE	0.29	2.0-2.9
6	33	150	0.5	0.5	~1:1 PE and potable water	Undetermined	3.8-5.5
6	35	200	0.5	0.5	~1:1 PE and potable water	Undetermined	6.5-9.1

Similar to Test Runs 5 and 6, Test Run 9 showed that TMP and TMP rise rate are affected by the flux rate and that they both increase faster at higher flux rates (see Table 4-10). Test Run 9 also demonstrated that the membrane unit can handle a 2-hour period of 200 gfd in the middle of a treatment period after 11 hours of running at lower flux rates without exceeding the terminal TMP of 10 psi. This run also showed that the unit can treat wastewater at lower flux rates after ramping up from 50 to 200 gfd and then back down.

Table 4-10. Data from Middle-Loaded Hydrograph Testing (Test Run 9)

Test Run Number	Influent TSS (mg/L, probe)	Flux Rate (gfd)	Al:TSS Dose Ratio	Approximate Duration at Flux Rate (hours)	Influent Water Source	TMP Rise Rate (psi/hour)	TMP Range (psi)
9	26	50	0.6	7	~1:1 PE and potable water	0.021	0.2-0.4
9	33	75	0.6	2.5	~1:1 PE and potable water	0.052	0.7-0.8
9	38	100	0.6	1	~1:1 PE and potable water	0.13	1.2-1.4
9	39	150	0.6	0.5	~1:1 PE and potable water	0.49	1.9-2.7
9	39	200	0.6	2	~1:1 PE and potable water	0.55	3.4-5.8
9	38	150	0.6	0.5	~1:1 PE and potable water	0.64	2.4-3.0
9	74	100	0.6	1	PE	0.39	1.4-2.0
9	91	75	0.6	2.5	PE	0.18	1.2-1.7
9	80	50	0.6	7	PE	0.053	0.9-1.3

Test Run 10 was a variable-loaded hydrograph test that was experienced at the Elliott West CSO Treatment Facility during storms. This run demonstrated the ability of the unit to handle variable flow rates without adversely impacting the treatment process (see Table 4-11). It also demonstrated the unit's ability to ramp up and down rapidly based on treatment needs.

Table 4-11. Data from Variable-Loaded Hydrograph Testing (Test Run 10)

Test Run Number	Influent TSS (mg/L, probe)	Flux Rate (gfd)	Al:TSS Dose Ratio	Approximate Duration at Flux Rate (hours)	Influent Water Source	TMP Rise Rate (psi/hour)	TMP Range (psi)
10	24	150	0.6	1	~1:1 PE and potable water	0.14	0.5-1.7
10	14	50	0.6	1	~1:1 PE and potable water	0.047	0.3-0.3
10	14	75	0.6	3	~1:1 PE and potable water	0.023	0.6-0.7
10	18	100	0.6	1	~1:1 PE and potable water	0.039	1.0-1.0
10	23	50	0.6	2	~1:1 PE and potable water	0.021	0.4-0.4
10	31	200	0.6	1	~1:1 PE and potable water	0.014	2.5-2.9
10	75	100	0.6	1	PE	0.27	0.5-1.4
10	79	75	0.6	1.5	PE	0.13	0.5-1.0
10	117	50	0.6	12	PE	0.025	0.5-0.8
10	31	200	0.6	1	~1:1 PE and potable water	Undetermined	5.1-7.4
10	54	50	0.6	2	PE	0.029	0.8-1.0

4.1.3 Equipment and System Failure and Response Testing Results

One goal of the process and performance pilot testing was to conduct equipment and system failure testing and document both the system's response to and recovery from that failure. Failures tested included loss of coagulant, loss of air scour, and loss of backwashing. Observations and results from these tests are summarized below.

4.1.3.1 Loss of Coagulant

Test Run 7 was conducted at 100-gfd flux rate to test membrane response to and recovery from loss of coagulant. After running with a coagulant dosing rate of 0.4 Al:TSS dose ratio for an hour, the coagulant pump was turned off for 30 minutes. When the coagulant pump was turned back on, the coagulant was dosed at 0.8 Al:TSS dose ratio for 30 minutes and then set back to 0.4 Al:TSS dose ratio for 50 minutes. Following that, a short CIP with a 30-minute soak time was performed and the unit was operated normally for 3 hours to verify recovery. This sequence was performed both to test membrane response to loss of coagulant as well as to test an effectiveness of a short CIP for recovering the membrane (Table 3-7). Figure 4-1 through Figure 4-4, following, show TMP data from different portions of Test Run 7.

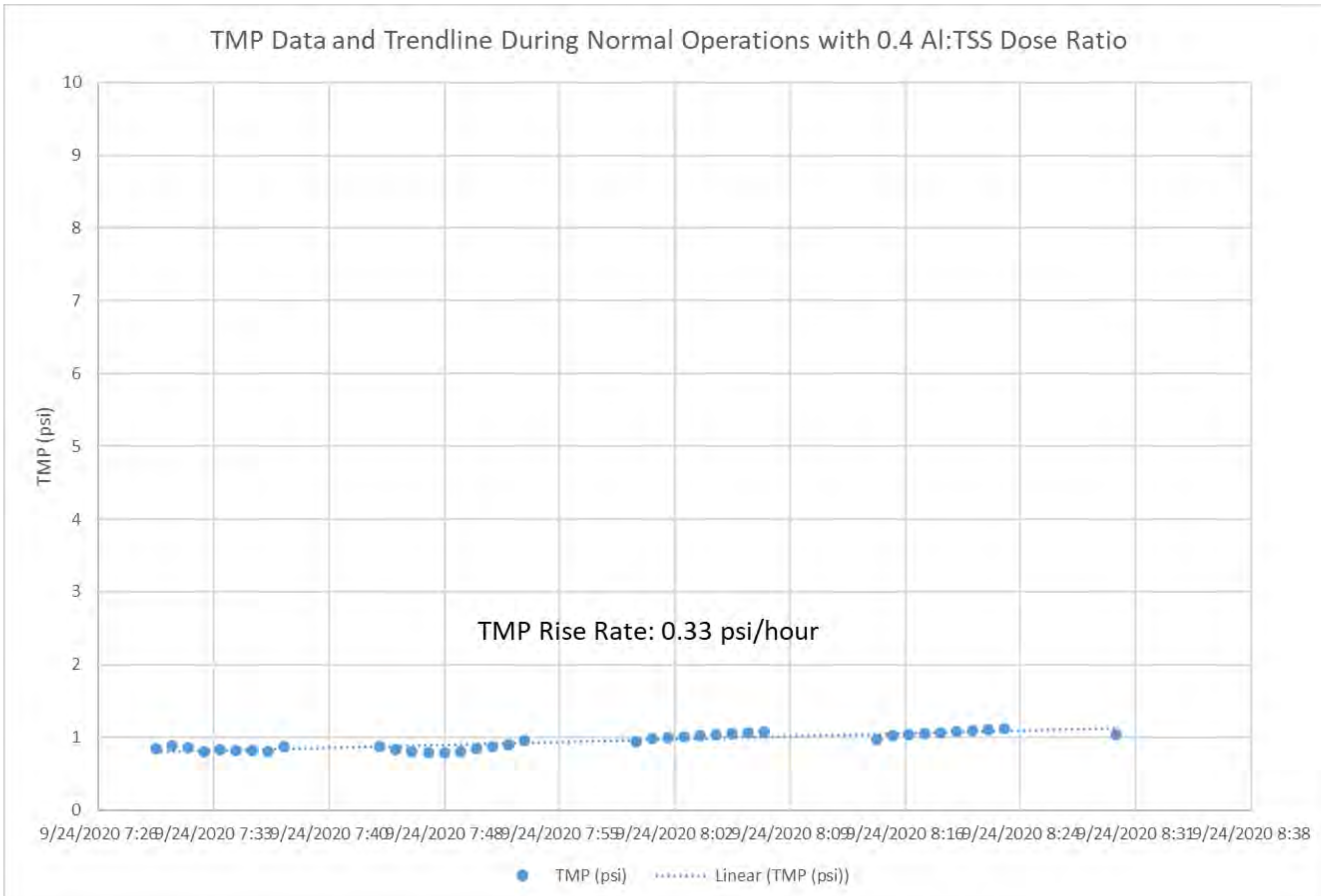


Figure 4-1. TMP Data and Rise Rate During Normal Operations

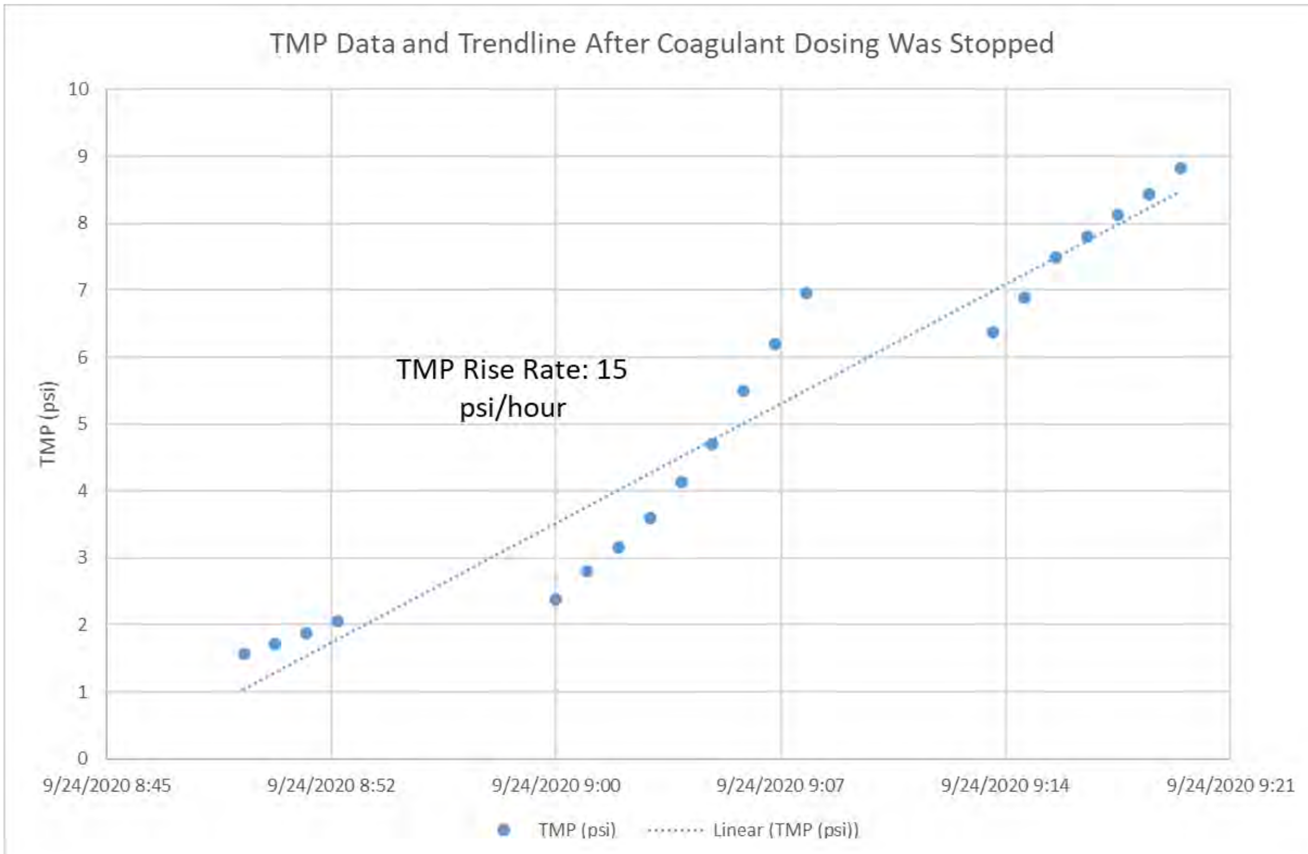


Figure 4-2. TMP Data and Rise Rate After Loss of Coagulant

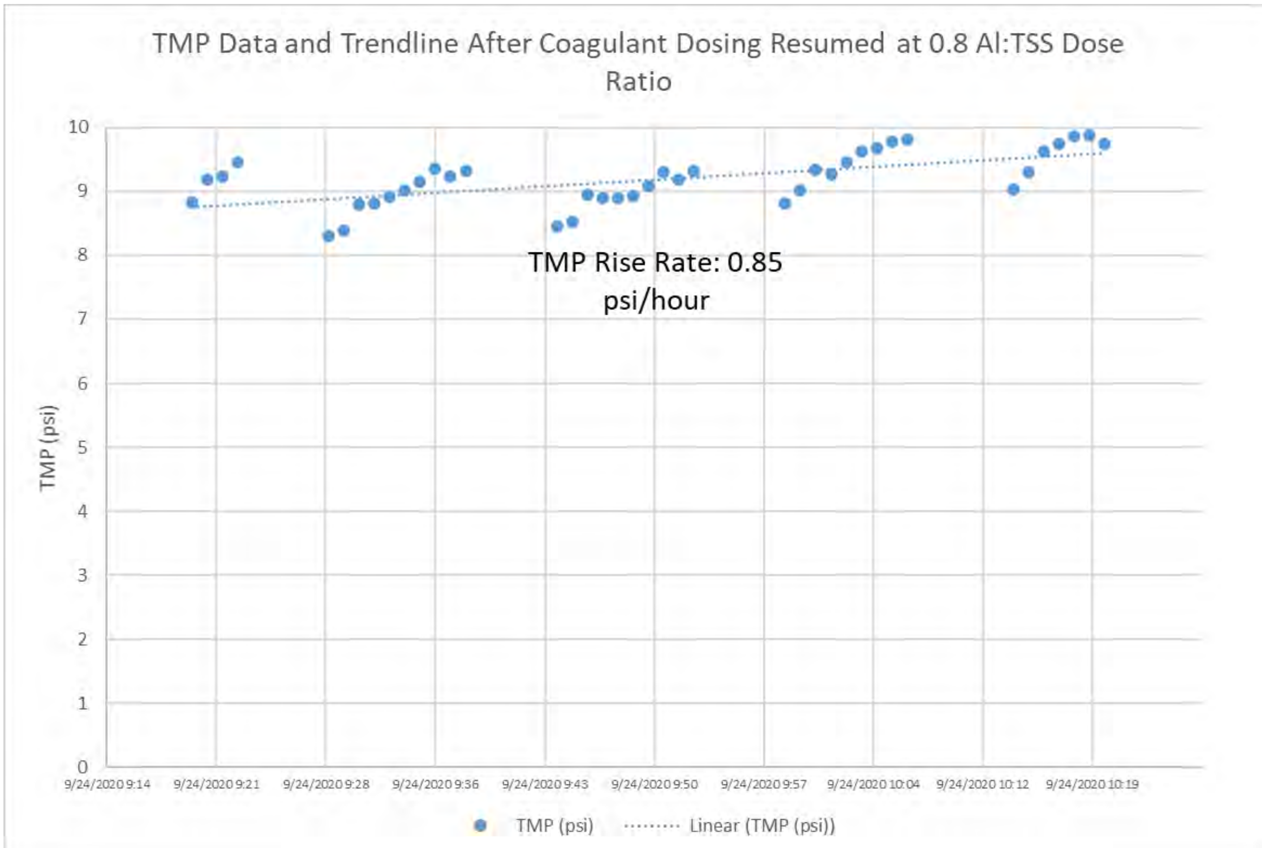


Figure 4-3. TMP Data and Rise Rate After Resumption of Coagulant Dosage

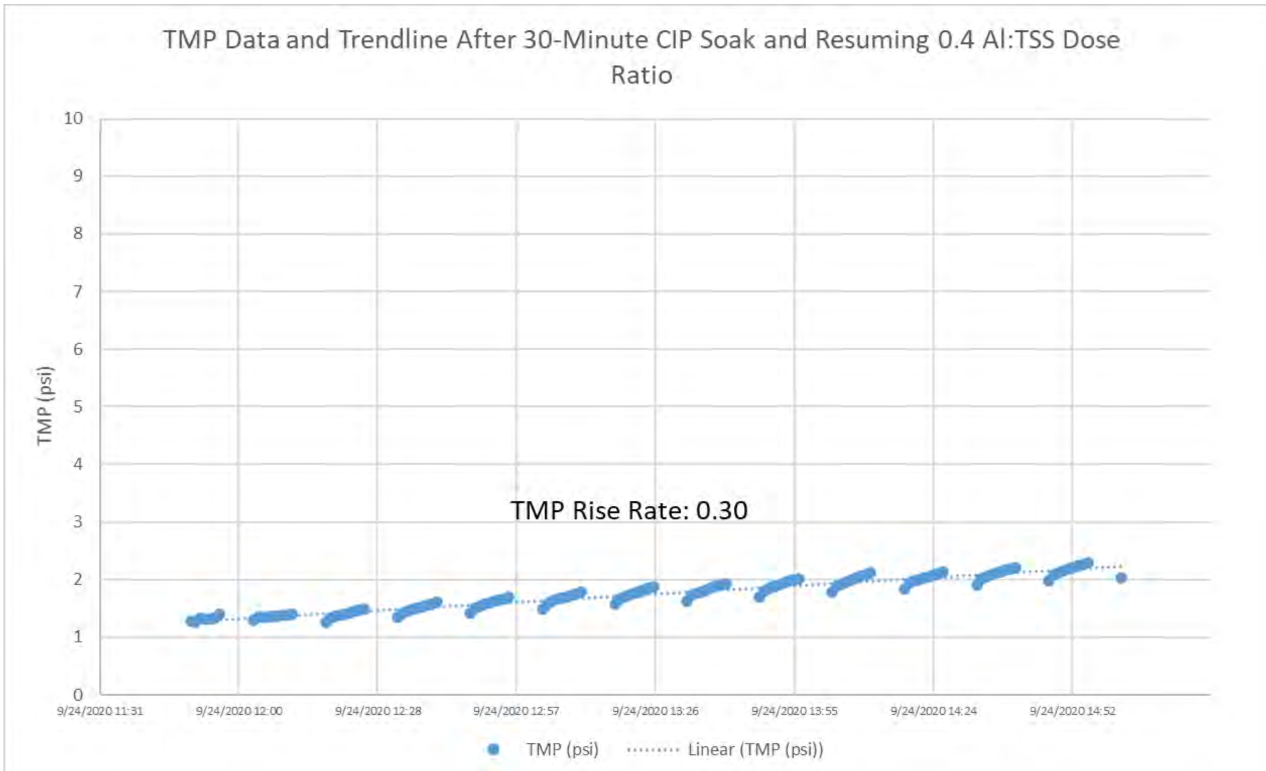


Figure 4-4. TMP Data and Rise Rate After 30-Minute CIP Soak

Summary:

- TMP rise rate was 0.33 psi/hour at the beginning of the test run under normal (0.4 Al:TSS ratio) coagulant dosage operations.
- TMP rise rate increased rapidly to 15 psi/hour beginning 20 minutes after coagulant dosing was stopped. This 20-minute delay in the response may be due to the HRT in the membrane basin. Another possibility is that residual coagulant in the membrane tank could have mitigated fouling for that timeframe after coagulant dosing was stopped.
- Approximately 20 minutes after coagulant dosing resumed at twice the starting dosage (0.8 Al:TSS dose ratio), the TMP rise rate dropped to 0.85 psi/hour. The TMP reached 9.9 psi at 10:22 a.m., and the unit was shut down at 10:23 a.m. due to the high TMP.
- After the 30-minute CIP, the TMP rise rate was 0.30 psi/hour using 0.4 Al:TSS dose ratio.

Notes:

- Test Run 7 confirmed that the membranes can recover, at least partially, in the short-term from loss of coagulant by restoring coagulant pumping at a higher dosing rate.
- This run showed nearly full membrane recovery after a 30-minute CIP.
- The treatment plant was experiencing high influent flow due to wet weather before and during Test Run 7, and the influent TSS and TOC concentrations were relatively low for full-strength primary effluent, with a composite influent TSS concentration of 33 mg/L and an average of 24 mg/L TOC in the influent. For comparison, full-strength primary effluent during Test Run 3

had a composite influent TSS concentration of 43 mg/L and an average of 42 mg/L TOC. The lower influent TSS and TOC concentrations during Test Run 7 likely resulted in a lower TMP rise rate after coagulant dosing was stopped compared to the TMP rise rate that would have resulted at higher influent TSS and TOC concentrations. However, it likely would not have affected the results from membrane recovery after the 30-minute soak CIP, since the unit would have been shut down after the TMP reached approximately 10 psi in either scenario.

4.1.3.2 Loss of Air Scour or Loss of Backwash

Test Run 8 was conducted at 100-gfd flux rate and with a 0.6 Al:TSS dose ratio to test membrane response to and recovery from loss of air scour or loss of backwash. The test run began and operated for 1 hour under normal operations, followed by two hours without air scour. After a CIP of approximately 30 minutes soaking, the second scenario in the test run operated with air scour but without backwashing for three hours. This was followed by another CIP of approximately 30 minutes of soaking. The last portion of the test run operated with both air scour and backwashing for 45 minutes. Figure 4-5 through Figure 4-8, below, show TMP data from different portions of Test Run 8.

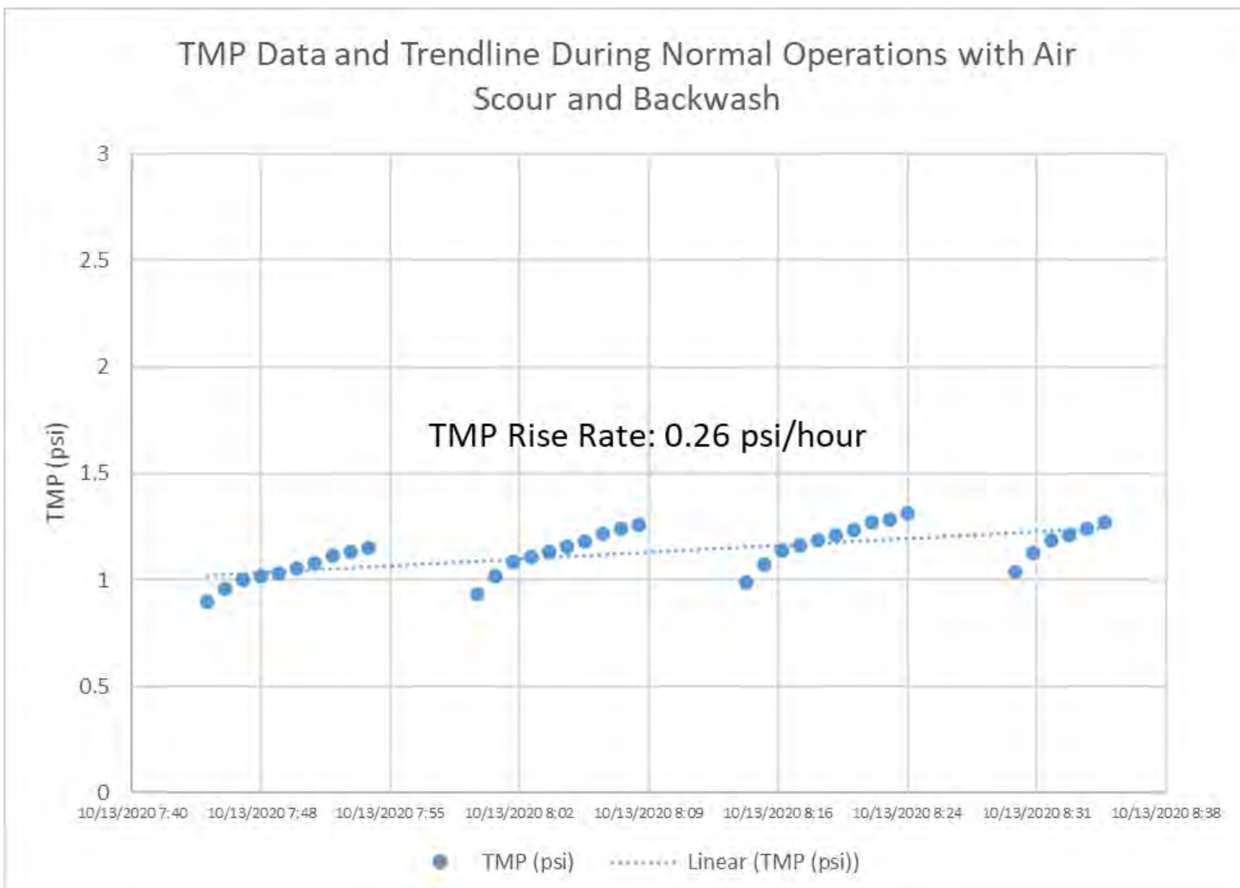


Figure 4-5 TMP Data and Rise Rate During Normal Operations

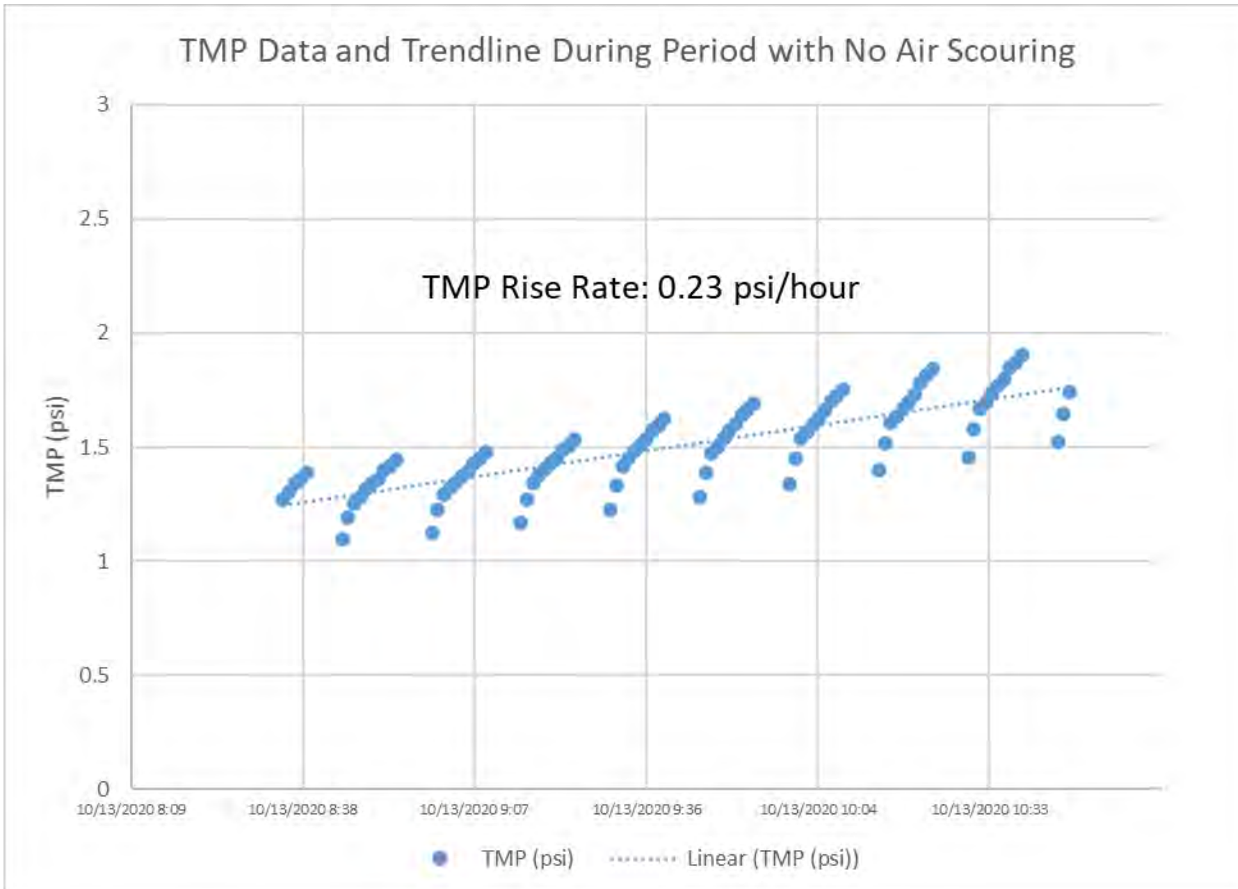


Figure 4-6. TMP Data and Rise Rate During Period with No Air Scouring

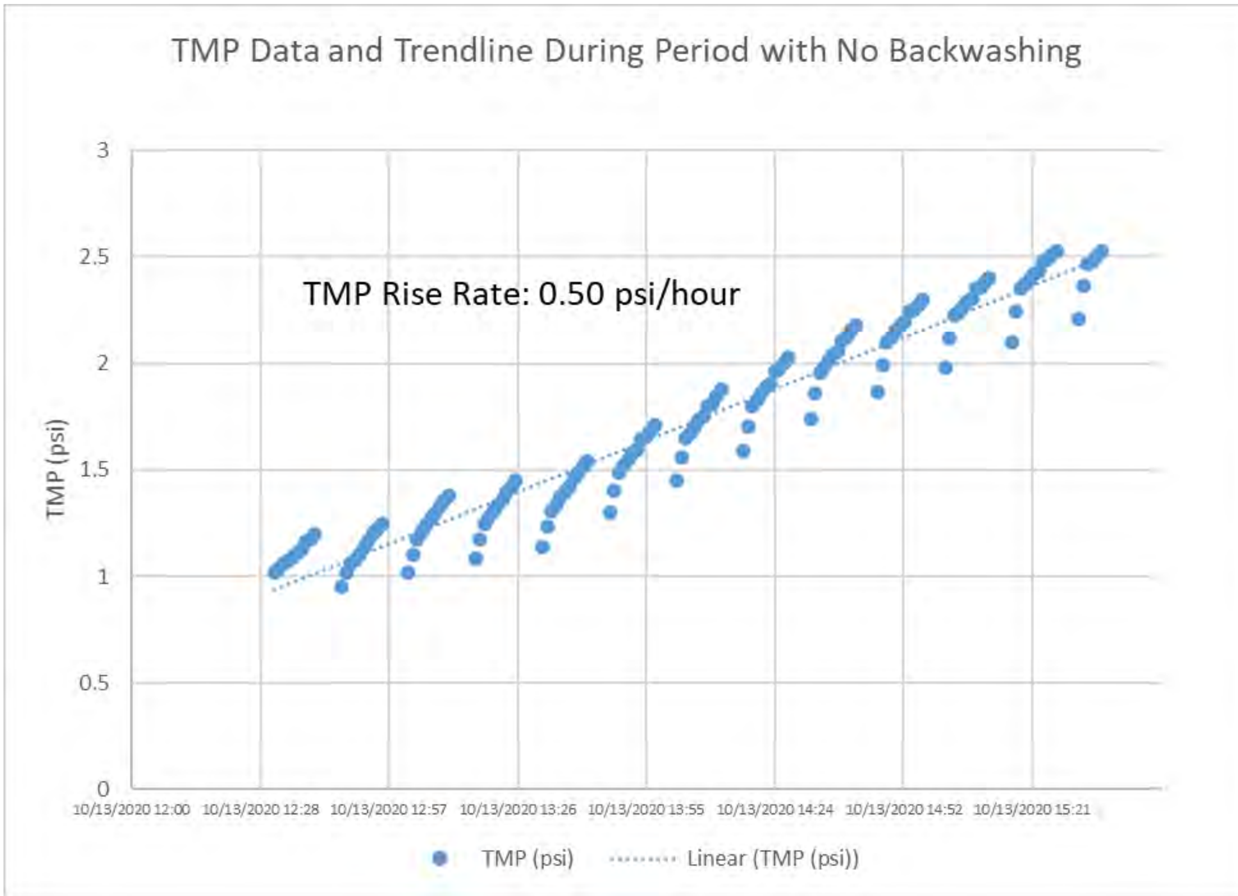


Figure 4-7. TMP Data and Rise Rate During Period with No Backwashing

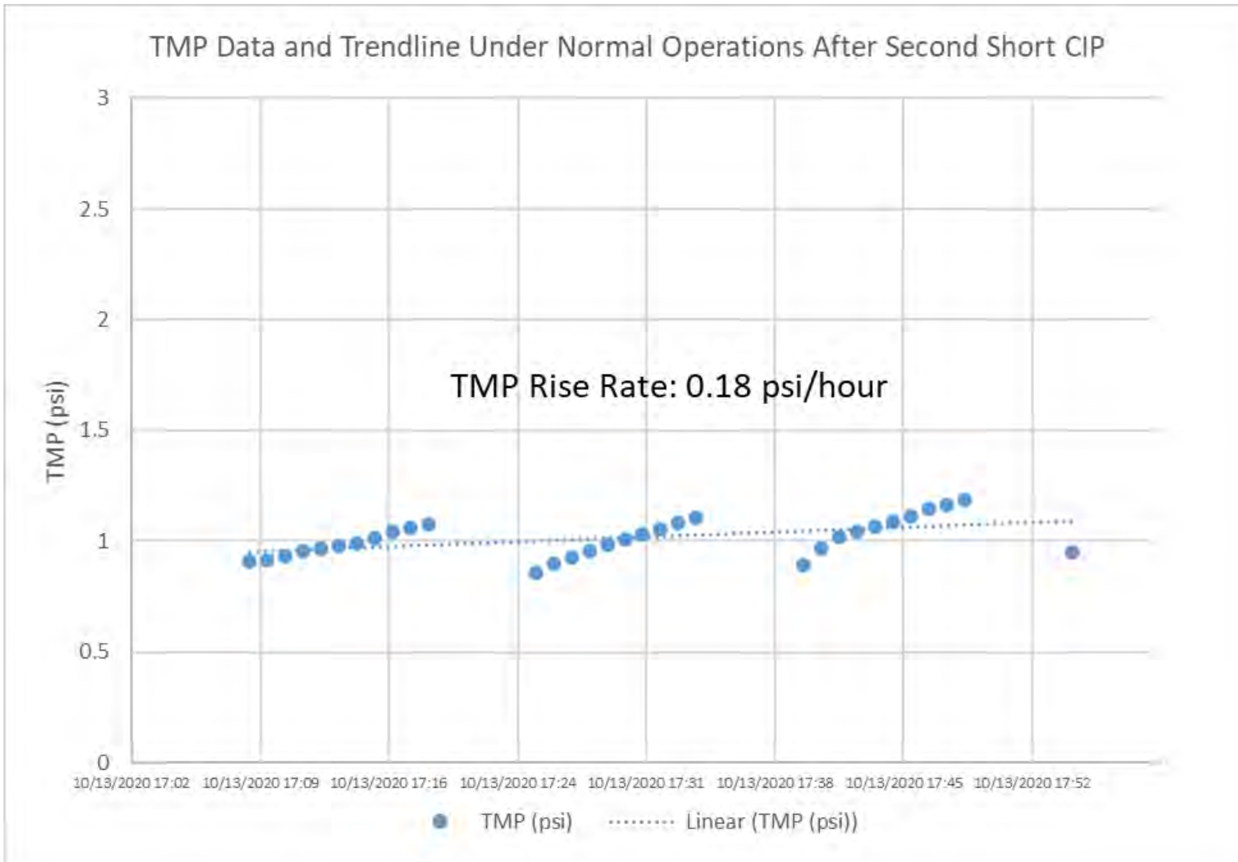


Figure 4-8. TMP Data and Rise Rate After Second Short CIP Under Normal Operations

Summary:

- TMP rise rate was 0.26 psi/hour during the initial 1-hour period with normal operations.
- TMP rise rate was 0.23 psi/hour during 2-hour period without air scour, with the TMP increasing to 1.9 psi.
- The 30-minute CIP soak performed after running with no air scour restored the TMP to approximately 1 psi.
- TMP rise rate was 0.50 psi/hour for the 3-hour period with no backwashing, ending at 2.5 psi TMP.
- The 30-minute CIP soak after running with no backwashing restored the TMP to 0.9 psi.
- TMP rise rate was 0.18 psi/hour when running with both air scour and backwash after the second CIP.

Notes:

- Test Run 8 showed that the membranes can recover from loss of backwashing.
- This run showed no effect of short-term loss of air scour under test conditions.
- This run showed nearly full membrane recovery after 30-minute CIPs.
- The treatment plant was experiencing high influent flow due to wet weather before and during Test Run 8, and the influent TSS and TOC concentrations were relatively low for full-strength primary effluent, with an average influent TSS probe reading of 34 mg/L and influent TOC of 18 mg/L when the air scouring was turned off. As a comparison, full-strength primary effluent during Test Run 1 had an average influent TSS probe reading of 68 mg/L and influent TOC of 67 mg/L, and full-strength primary effluent during Test Run 3 had an average influent TSS probe reading of 55 mg/L and influent TOC of 42 mg/L. The low TOC concentration during this portion of the test run may explain why the TMP rise rate did not increase after air scouring was turned off, in addition to the fact that air scouring itself may not be critical for mitigating fouling.

4.1.4 Effluent Quality Results

4.1.4.1 Regulatory Requirements

One goal for the process and performance pilot testing was to demonstrate treatment performance and the ability to meet discharge permit requirements under various test conditions. The following are relevant parameters for assessing the success of the pilot testing based on a typical CSO permit in the State of Washington:

- TSS removal: Annual average greater than or equal to 50 percent removal of influent TSS.
- Fecal coliform bacteria: Monthly geometric mean less than 400/100 mL.
- Settleable solids: Annual average less than 0.3 mL/L/hour.
- Instantaneous pH: 6.0 to 9.0.

TSS, fecal coliform, settleable solids, and pH results from the pilot testing are summarized in Table 4-12. The following subsections discuss relevant findings from these results.

Table 4-12. Summary of TSS, Fecal Coliform, Settleable Solids, and pH in Pilot Testing Effluent

Test Run	Flux Rate (gfd)	Influent TSS, Composite (mg/L)	Effluent TSS, Composite (mg/L)	Effluent Turbidity (NTU)	TSS Removal Percentage	Effluent Fecal Coliform Geometric Mean Per Test Run (MPN/100 mL)	Effluent Settleable Solids (mL/L/hour)	Effluent pH Range
1	100	30	< 1	< 0.1	> 97%	0	0	5.8-8.1
2	100	21	1	< 0.1	95%	0	0	6.4-7.5
3	100	43	2	< 0.1	95%	4.5	0	6.3-6.8
4	100-200-100	24	1	< 0.1	96%	3.5	0.1	6.3-6.9
5	200-50	40	3	< 0.1	93%	3.9	0	5.2-7.1
6	50-200	36	1	< 0.1	97%	6.7	0	6.3-7.0
7	100	33	2	< 0.1	94%	13	0	6.1-7.4
8	100	69	1	< 0.1	99%	0	0	4.5-8.5
9	50-200-50	36	3	< 0.1	92%	0	0	4.8-6.8
10	Variable	53	< 1	< 0.1	> 98%	3.3	0	4.8-7.0
11	50-200-50	19	< 1	< 0.1	> 95%	4.7	0	5.6-6.9
Suppl. 1	150	23	1	< 0.1	96%	No data	No data	4.8-7.0
Suppl. 2	200	26	3	< 0.1	88%	0	0	4.4-6.8
Suppl. 3	100	34	1	< 0.1	97%	No data	No data	4.6-6.6
Suppl. 4	100	No data	No data	< 0.1	NA	No data	No data	5.0-6.9
Range	50-200	21-69	<1-3	<0.1	88-99%	0-13	0-0.1	4.5-8.5
Permit Reqmnt.	NA	NA	NA	NA	>50%	<400	<0.3	6.0-9.0

TSS Removal

The TSS removal efficiencies from the pilot test runs were far greater than the 50 percent requirement in all runs, ranging from 88 percent to 100 percent.

Fecal Coliform

Fecal coliform bacteria analyses in the effluent during pilot testing yielded results lower than the required monthly geometric mean less than 400 MPN/100 mL, ranging from 0 to 13 MPN/100 mL.

Settleable Solids

Except for Test Run 4, which had an effluent settleable solids measurement of 0.1 mL/L/hour, all other effluent settleable solids results were 0 mL/L/hour; all results are below the maximum of 0.3 mL/L/hour annual average limit for settleable solids.

pH

Because alum coagulant consumes alkalinity, the pH of the treated water decreased to lower than 6.0 during several test runs due to the combination of high coagulant dosing and low influent water alkalinity. Section 4.5.2 has a discussion about pH adjustment.

4.1.4.2 Other Parameters

In addition to the regulatory requirements listed in the preceding subsection, the Ovivo RapidStorm Treatment System can remove other constituents from CSO wastewater. King County is required to monitor priority pollutants in CSO effluent, including arsenic, copper, lead, nickel, and zinc. Total phosphorus and total Kjeldahl nitrogen (TKN) are also monitored through the treatment process.

Table 4-13 summarizes results of these constituents from the four performance test runs during pilot testing. Analytical data of other metals tested during the performance tests are shown in Appendix D.

Average removal efficiencies of the constituents in Table 4-13 show excellent removal (greater than 90 percent) for copper, lead, and total phosphorus and varying degrees of removal for other constituents. Because copper, lead, nickel, and zinc solubilities are pH-dependent, their removal efficiencies are expected to vary with pH. However, no relationship between higher pH and higher removal efficiencies for these metals can be established from the pilot testing data. This is likely due to the relatively narrow pH range for this data set. The calculated negative removals observed for nickel in Test Run 6 were based on differences in analytical results between the influent and effluent of 0.02 and 0.08 µg/L. Such differences between the influent and effluent nickel concentrations may be attributed to analytical precision or to small variations in the nickel concentrations as a function of time rather than the treatment process increasing the nickel concentration during Test Run 6.

Table 4-13. Summary of Arsenic, Copper, Lead, Nickel, Zinc, Total Phosphorus, and TKN Removal Results

			Date and Test Run							
			10/1/2020, Test Run 3		10/1/2020, Test Run 6			10/22/2020, Test Run 10		10/23/2020, Test Run 10	Minimum/ Average/ Maximum Removal %
		Time:	**730-740**	**1200-1210**	**730**	**1310**	**1705**	**930**	**1330**	**900**	
Parameter	**Location**	**pH:**	**7.5**	**6.8**	**6.6**	**6.8**	**6.5**	**6.8**	**6.7**	**6.0**	
Arsenic	INF (µg/L)		1.78	1.9	1.68	2.38	1.43	1.10	1.12	1.63	42.2/55.1/60.8%
	EFF (µg/L)		0.83	0.913	0.800	0.961	0.826	0.438	0.439	0.644	
		Removal %:	53.4%	51.9%	52.4%	59.6%	42.2%	60.2%	60.8%	60.5%	
Copper	INF (µg/L)		25.6	23.5	30.3	26.6	16	10.5	8.09	20.5	86.7/90.6/93.3%
	EFF (µg/L)		2.14	2.17	2.04	2.31	1.5	1.4	0.91	1.7	
		Removal %:	91.6%	90.8%	93.3%	91.3%	90.6%	86.7%	88.8%	91.7%	
Lead	INF (µg/L)		1.56	1.77	1.58	2.07	1.16	0.651	0.695	1.12	88.4/93.5/100.0%
	EFF (µg/L)		0.16	0.13	0.14	0.11	0.1	0	0	0.13	
		Removal %:	89.7%	92.7%	91.1%	94.7%	91.4%	100.0%	100.0%	88.4%	
Nickel	INF (µg/L)		3.37	2.94	2.94	3.02	1.70	0.935	0.968	2.91	-4.7/10.3/19.5%
	EFF (µg/L)		2.94	2.49	2.96	2.43	1.78	0.855	0.846	2.35	
		Removal %:	12.8%	15.3%	-0.7%	19.5%	-4.7%	8.6%	12.6%	19.2%	
Zinc	INF (µg/L)		59.3	50.3	53.5	63.1	36.7	19.5	20	45.6	62.4/70.3/78.9%
	EFF (µg/L)		22.3	14.6	13.7	13.3	10.6	5.37	6.47	16.2	
		Removal %:	62.4%	71.0%	74.4%	78.9%	71.1%	72.5%	67.7%	64.5%	
Total Phosphorus	INF (mg/L)		4.17	3.76	4.19	4.56	2.79	1.51	1.36	4.02	95.2/98.4/100.0%
	EFF (mg/L)		0.20	0.10	0	0	0	0.04	0.02	0.04	
		Removal %:	95.2%	97.3%	100.0%	100.0%	100.0%	97.4%	98.5%	99.0%	
TKN	INF (mg/L)		37.61	38.40	37.81	40.75	23.28	11.75	10.53	32.99	-2.7/15.4/29.7%
	EFF (mg/L)		31.64	31.64	31.93	30.50	23.91	10.68	9.15	23.19	
		Removal %:	15.9%	17.6%	15.6%	25.2%	-2.7%	9.1%	13.1%	29.7%	

Higher alum coagulant dosing is expected to improve phosphorus and arsenic removal via adsorption of phosphorus and arsenic oxyanions by aluminum hydroxide. However, no relationship between alum dosing and total phosphorus removal was established from the pilot data. This was likely because total phosphorus removal averaged 98.4 percent during pilot testing with ≤ 0.2 mg/L total phosphorus in the effluent, so there was little room for differentiation of results between the test runs. Arsenic removal was higher in Test Run 10 when the Al:TSS ratio was 0.6 than in Test Runs 3 and 6, when the Al:TSS ratio was 0.4. Arsenic removal averaged 60.5 percent in Test Run 10, whereas the average arsenic removal was 51.9 percent for Test Runs 3 and 6.

There was marginal (average 15.4 percent) TKN removal. The ammonia/ammonium portion of TKN is highly soluble in water and not expected to be removed well by alum coagulation and filtration. The observed TKN removal can be attributed to fractions of reduced nitrogen organic compounds such as proteins, peptides, and amino acids that can be removed more readily than ammonia/ammonium.

4.1.5 Other Data

4.1.5.1 Effluent Chlorine (Cl_2) Demand

The chlorine demand was measured in grab samples in the effluent for most of the test runs. Results ranged from a low of 0.19 mg/L to a high of 2.83 mg/L, with an average of 1.24 mg/L. The data are shown in Table 4-14

Table 4-14. Summary of Effluent Chlorine Demands from Test Runs

Test Run	Effluent Chlorine Demand (mg/L)
1	2.83
2	1.34
3	1.04
4	0.73
5	0.87
6	1.61
7	0.19
8	0.79
9	0.62
10	0.79
11	1.61
Supplemental Test Run 2	0.84
Minimum	0.19
Average	1.24
Maximum	2.83

There is some correlation between effluent TOC and effluent chlorine demand (Figure 4-9) and poor correlation between effluent COD and effluent chlorine demand (Figure 4-10).

Poor correlations between effluent COD and effluent chlorine demand can be explained by the fact that the dichromate reagent used in COD analyses is a much stronger oxidant than chlorine, so many substances that are oxidized by dichromate in the COD analyses do not exert a chlorine demand.

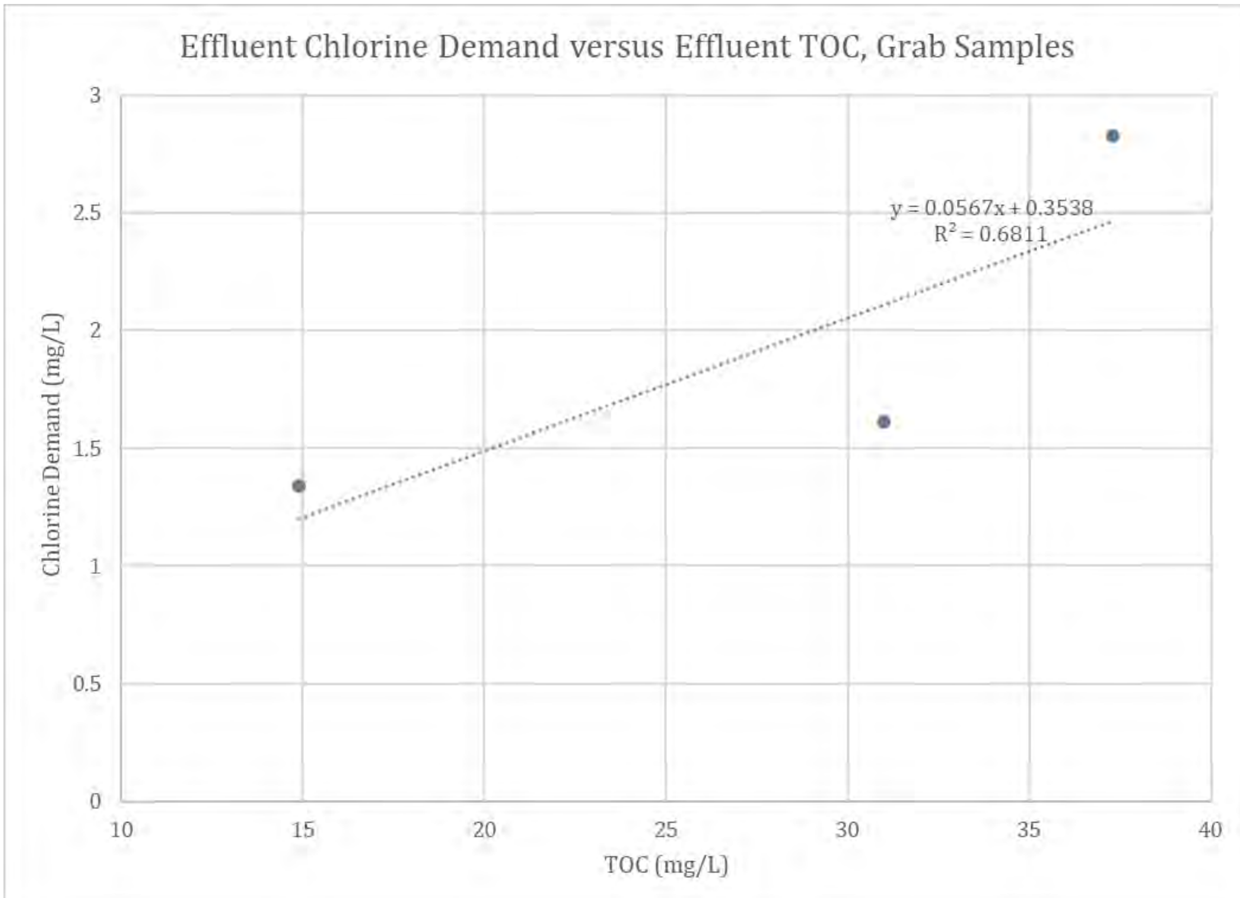


Figure 4-9. Effluent Chlorine Demand vs. Effluent TOC

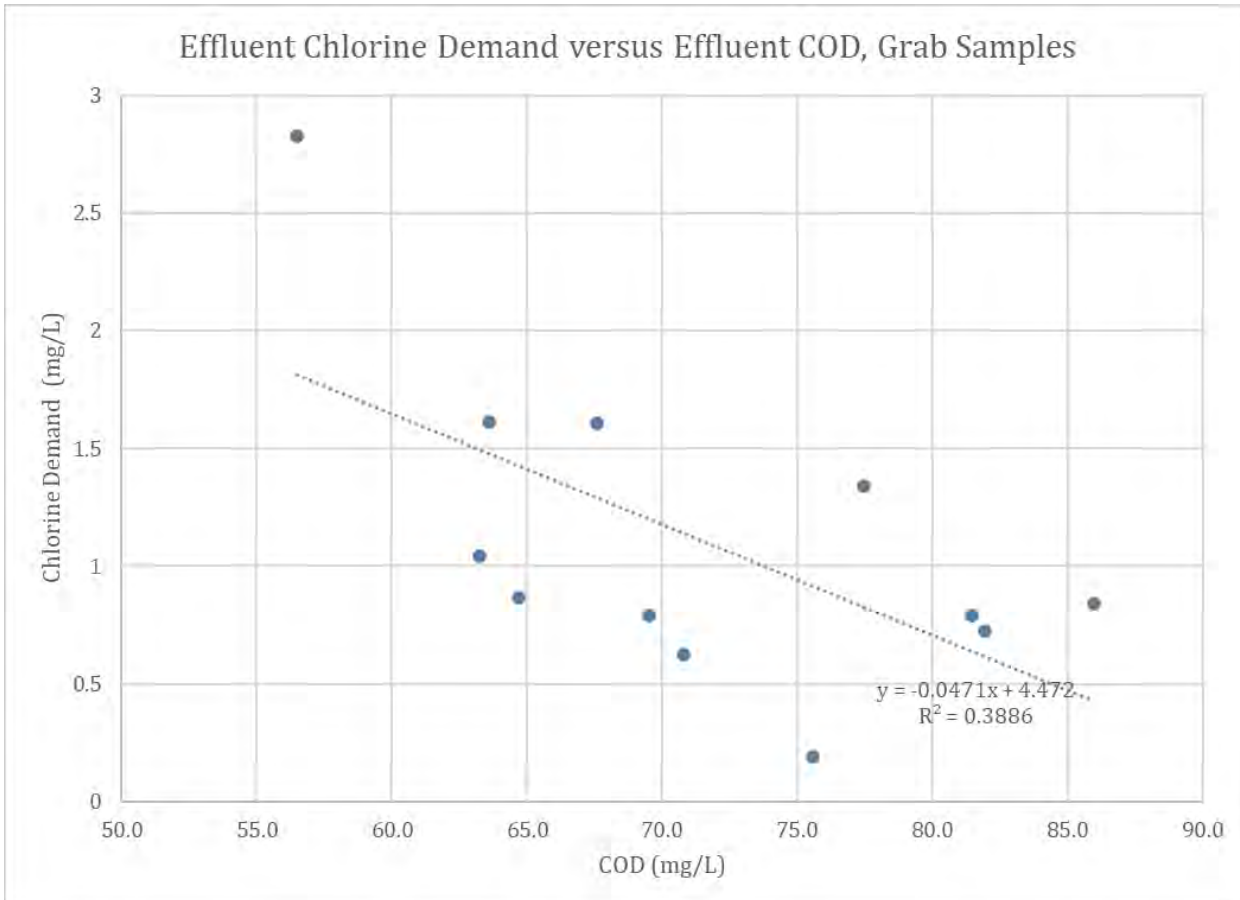


Figure 4-10. Effluent Chlorine Demand vs. Effluent COD

4.1.5.2 Effluent UV Transmittance (percent)

UV absorbance at 254 nm can be used as a surrogate for estimating the concentration of organic compounds. The UV absorbance at 254 nm in the effluent was measured in composite samples for most of the test runs. These measurements were converted to UV transmittance (percent) data. Results showed a minimum UV transmittance at 254 nm of 56.5 percent, average UV transmittance of 72.9 percent, and maximum UV transmittance of 86.0 percent (Figure 4-11).

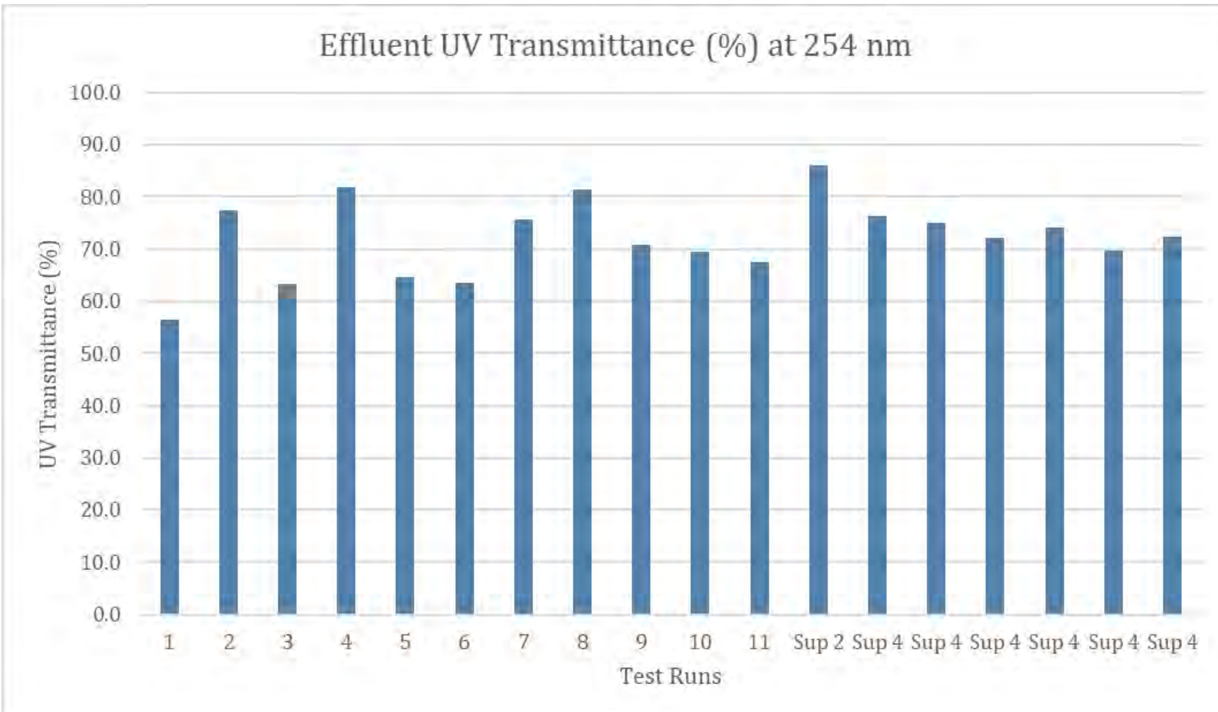


Figure 4-11. Effluent UV Transmittance at 254 nm

4.1.5.3 Hexane Extractable Material

The influent and effluent hexane extractable material (HEM) were measured for the performance tests (Test Runs 3, 6, and 10). HEM represents hydrophobic compounds that are extracted into n-hexane and serve as an analytical surrogate for fats, oils, and grease (FOG) in wastewater. HEM is an important value to track in the analyses because FOG can contribute to membrane fouling. Influent HEM values for these performance tests ranged from 20.1 to 23.9 mg/L; effluent HEM values ranged from 1.4 to 1.6 mg/L. The HEM removal percentages were 92.5 percent to 93.9 percent, indicating good HEM removal under the conditions tested.

4.1.5.4 Alkalinity

Influent total alkalinity ranged from 60 to 193 mg/L as $CaCO_3$, with an average of 128 mg/L as $CaCO_3$. Influent alkalinity is important to consider when using a coagulant such as alum to mitigate membrane fouling. This is because alum consumes alkalinity at a rate of 5.6 mg/L total alkalinity (as $CaCO_3$) per mg/L of alum (as Al) dosed. This ratio is based on each aluminum ion hydrolyzing to generate three hydronium ions.

Effluent alkalinity data ranged from 3.0 to 131 mg/L as $CaCO_3$, with an average of 64.9 mg/L as $CaCO_3$. The calculated alkalinity consumption from using alum coagulation ranged from 29 to 116 mg/L as $CaCO_3$, with an average alkalinity consumption of 68 mg/L as $CaCO_3$.

The observed alkalinity consumption was compared with the expected alkalinity consumption for the tests based on influent TSS meter readings and the set Al:TSS ratio during the testing. The results are presented in Table 4-15.

Table 4-15. Observed and Theoretical Alkalinity Consumption

Test	Time	Influent TSS (Meter, mg/L)	Alum dosage (mg/L as Al)	Alkalinity (mg/L as $CaCO_3$)		Alkalinity Consumption			Effluent pH
				Influent	Effluent	Observed (mg/L as $CaCO_3$)	Theoretical (mg/L as $CaCO_3$)	Relative Percent Difference (%)	
1	11:05	59	24	193	131	62	134	72%	6.9
2	10:30	25	10	105	63	42	56	28%	6.6
3	Composite	55	22	193	98	95	123	26%	6.7
4	14:00-14:17	19	8	83	54	29	45	37%	6.9
5	11:00	49	19	187	71	116	106	7%	6.8
6	Composite	41	16	186	85	101	90	10%	6.9
7	925	26	10	137	93	44	56	27%	6.9
8	10:35-10:45	35	21	60	3	57	118	70%	4.6
9	11:30-11:40	24	14	117	53	64	78	23%	6.8
10	Composite	68	41	140	26	114	224	66%	5.9
11	9:30	12	7	64	33	31	39	22%	6.6
Suppl. 2	10:00	28	17	76	36	40	95	79%	6.8

For most of the test runs, the observed alkalinity consumption was lower than the theoretical alkalinity consumption. For Test Run 8, this discrepancy can possibly be explained by the fact that the acidity generated from adding alum coagulant not only went into consuming bicarbonate alkalinity to near non-detectable alkalinity concentrations and contributed to decreasing the pH to less than 5. However, for most of the test runs, the difference in observed versus theoretical alkalinity consumption may be explained by lower-than-expected alum coagulant strength during the test runs.

4.2 Summary of Data Analysis

4.2.1 Correlations Between Influent TSS and Other Parameters

The process and performance tests used influent TSS readings from the in-line TSS meter to set alum coagulant dosage based on pilot testing in 2017 in Austin, Texas, where the BOD:TSS ratio was established and used to define the Al:TSS dose ratio for coagulant dosing control. The theory is that there are correlations between influent TSS concentration and the concentration of organic compounds that can foul the SiC membrane. This section reviews correlations from pilot testing influent data between TSS from in-line TSS meter readings and TOC, COD, BOD, and UV absorbance at 254 nm. Correlation between influent TSS meter readings and laboratory TSS analyses is also discussed.

4.2.1.1 TOC and TSS

Figure 4-12 shows the correlation between influent TOC and TSS concentrations. In this analysis, influent TOC data from grab samples are associated with influent TSS data from the in-line probe at the same time that the grab samples were collected. Influent TOC composite samples are correlated with the average in-line influent TSS readings from the time period, with an average ratio of 0.99 TOC to TSS.

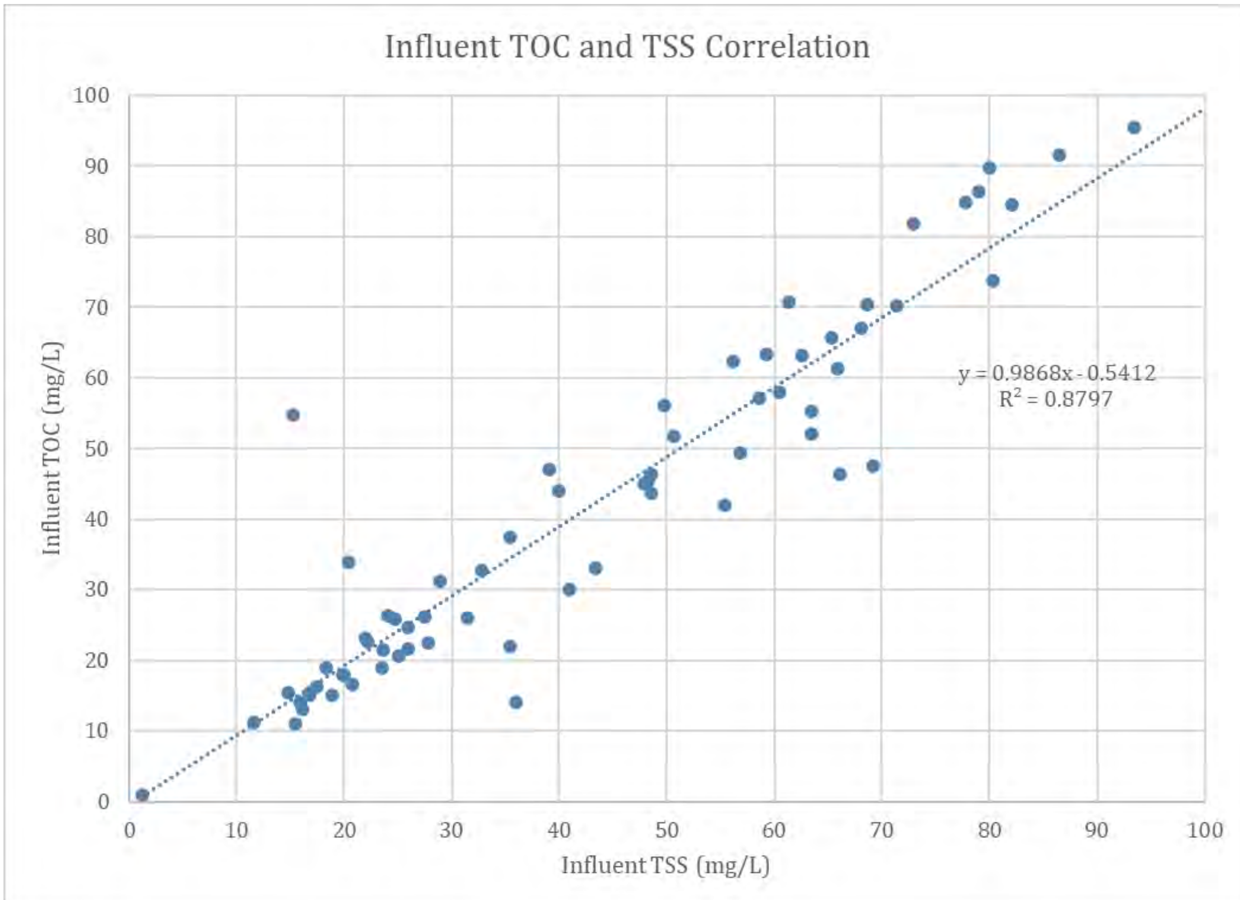


Figure 4-12. Influent TOC to TSS Correlation

4.2.1.2 COD and TSS

Figure 4-13 shows the correlation between influent COD and TSS concentrations. In this analysis, influent COD data from grab samples are associated with influent TSS data from the in-line probe at the same time that the grab samples were collected. Influent COD composite samples are correlated with the average in-line influent TSS readings from the time period, with an average ratio of 3.5 COD to TSS.

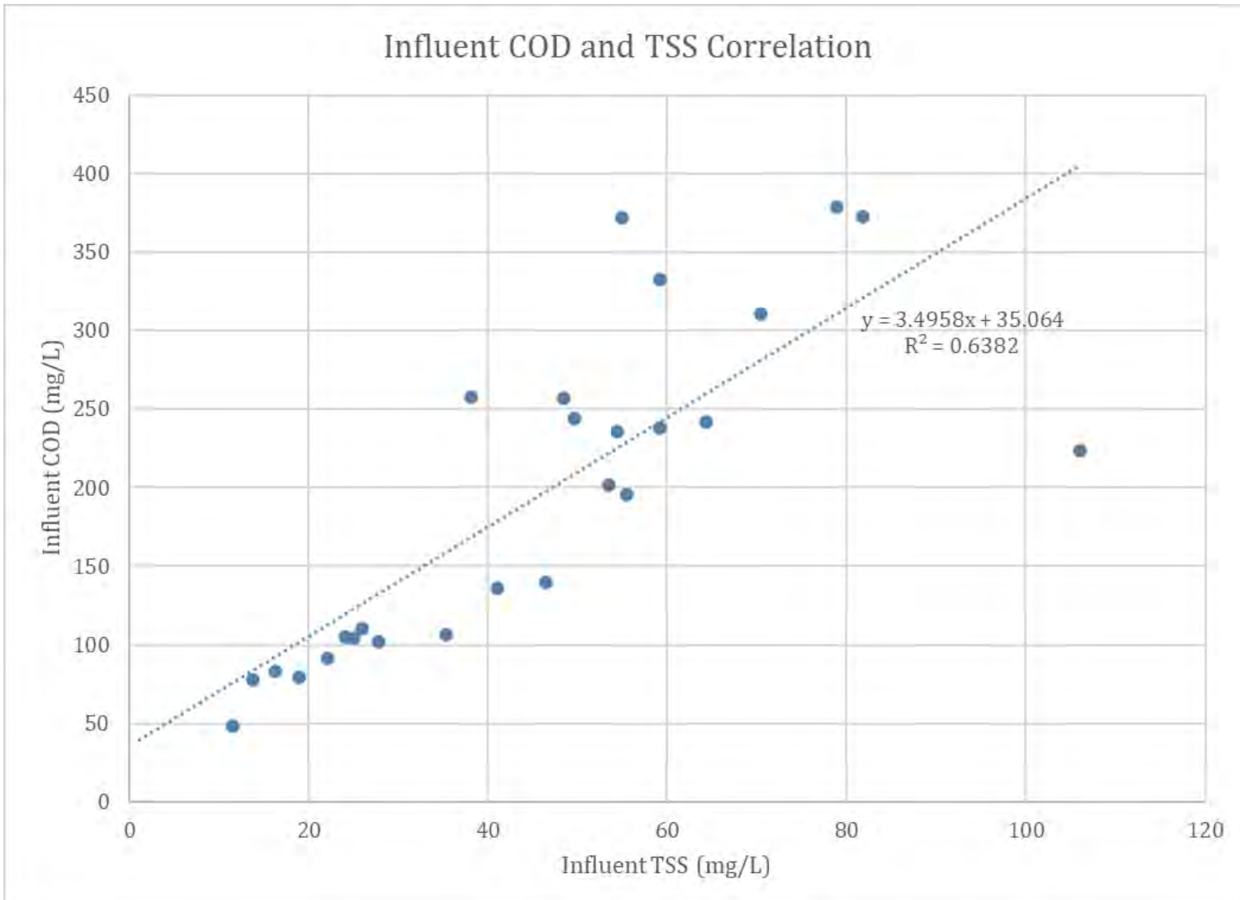


Figure 4-13. Influent COD to TSS Correlation

4.2.1.3 BOD and TSS

Figure 4-14 shows the correlation between influent BOD and TSS concentrations. In this analysis, influent BOD data from grab samples are associated with influent TSS data from the in-line probe at the same time that the grab samples were collected. Influent BOD composite samples are correlated with the average in-line influent TSS readings from the time period, with an average ratio of 1.2 BOD to TSS.

The *Ovivo CSO Pilot King County Preliminary Test Report* (Ovivo 2020) used historical data from Elliott West solids return data to estimate BOD:TSS ratio probabilities. Based on the analyses, Ovivo's preliminary recommendation for alum dosing was a dosing ratio of 0.4 mg aluminum (Al) per 1.0 mg of TSS, which would be applicable for BOD:TSS ratios up to 2.38. Under those recommendations, if the BOD:TSS ratio exceeds 2.38, a higher Al:TSS ratio should be used. Table 4-16 shows the BOD:TSS ratios during the pilot test runs. Table 4-16 shows influent TSS meter and BOD data from the process and performance pilot testing, along with calculated BOD/TSS ratios from the data.

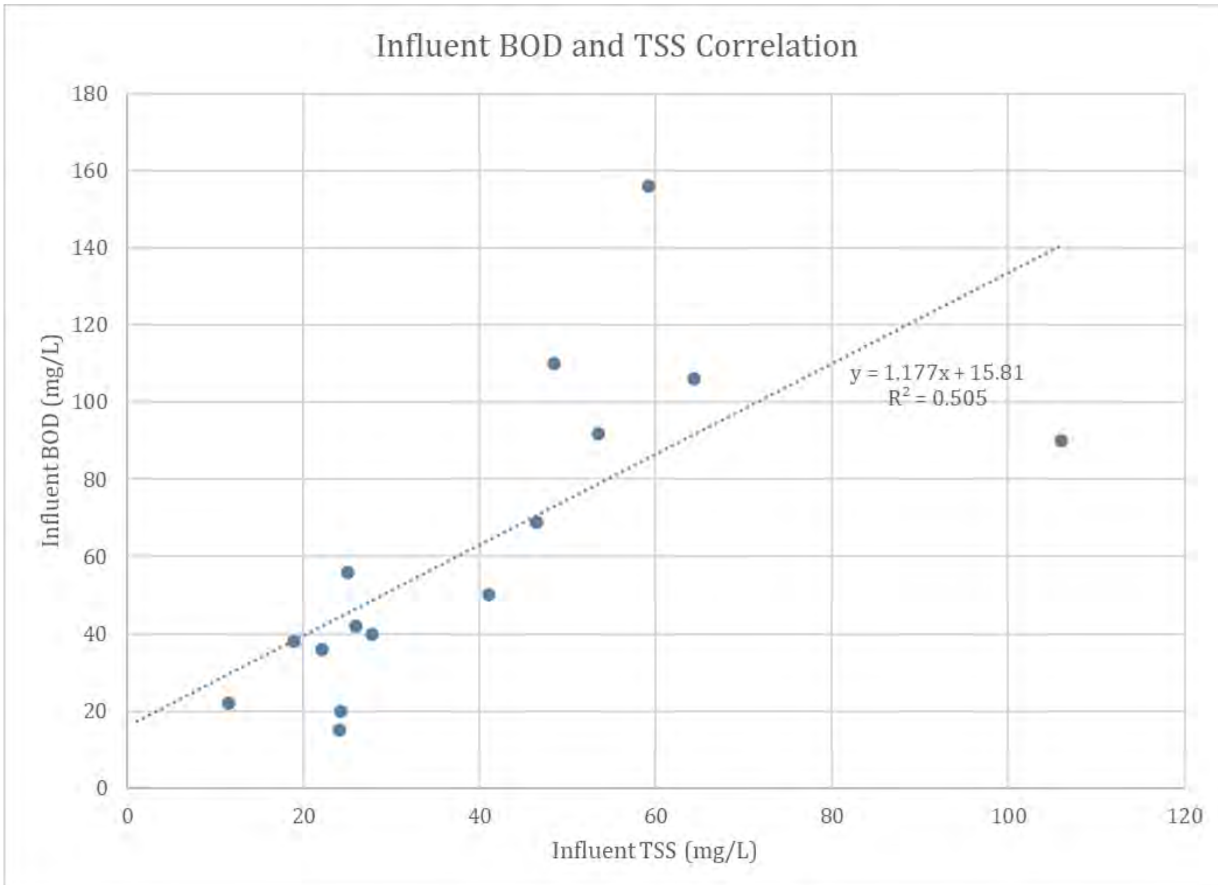


Figure 4-14. Influent BOD to TSS Correlation

Table 4-16. Influent TSS, BOD, and BOD:TSS Ratios

Test	TSS (mg/L)	BOD (mg/L)	BOD:TSS Ratio
1	59.2	156	2.63
2	25.0	56	2.24
4	18.9	38	2.01
	24.2	20	0.83
5	48.5	110	2.27
	64.3	106	1.65
7	25.9	42	1.62
8	41.0	50	1.22
9	24.1	15	0.62
	53.6	92	1.72
10	106.1	90	0.85
11	11.6	22	1.90
	46.4	69	1.49
Supplemental Test 2	27.8	40	1.44
	22.1	36	1.63

4.2.1.4 UV Absorbance (254 nm) and TSS

UV absorbance at 254 nm can be used as a surrogate for measuring the concentration of organic compounds. In Supplemental Test 4, the influent UV absorbance was measured and compared with influent TSS concentrations measured by the influent TSS meter. Figure 4-15 shows the correlation between influent UV absorbance and influent TSS concentrations There was excellent correlation between influent UV absorbance at 254 nm and influent TSS concentrations. Albeit based on a very limited data set, this correlation suggests that using influent TSS measurements from the in-line TSS meter as a coagulant dose control strategy to mitigate membrane fouling due to organic compounds is a valid approach.

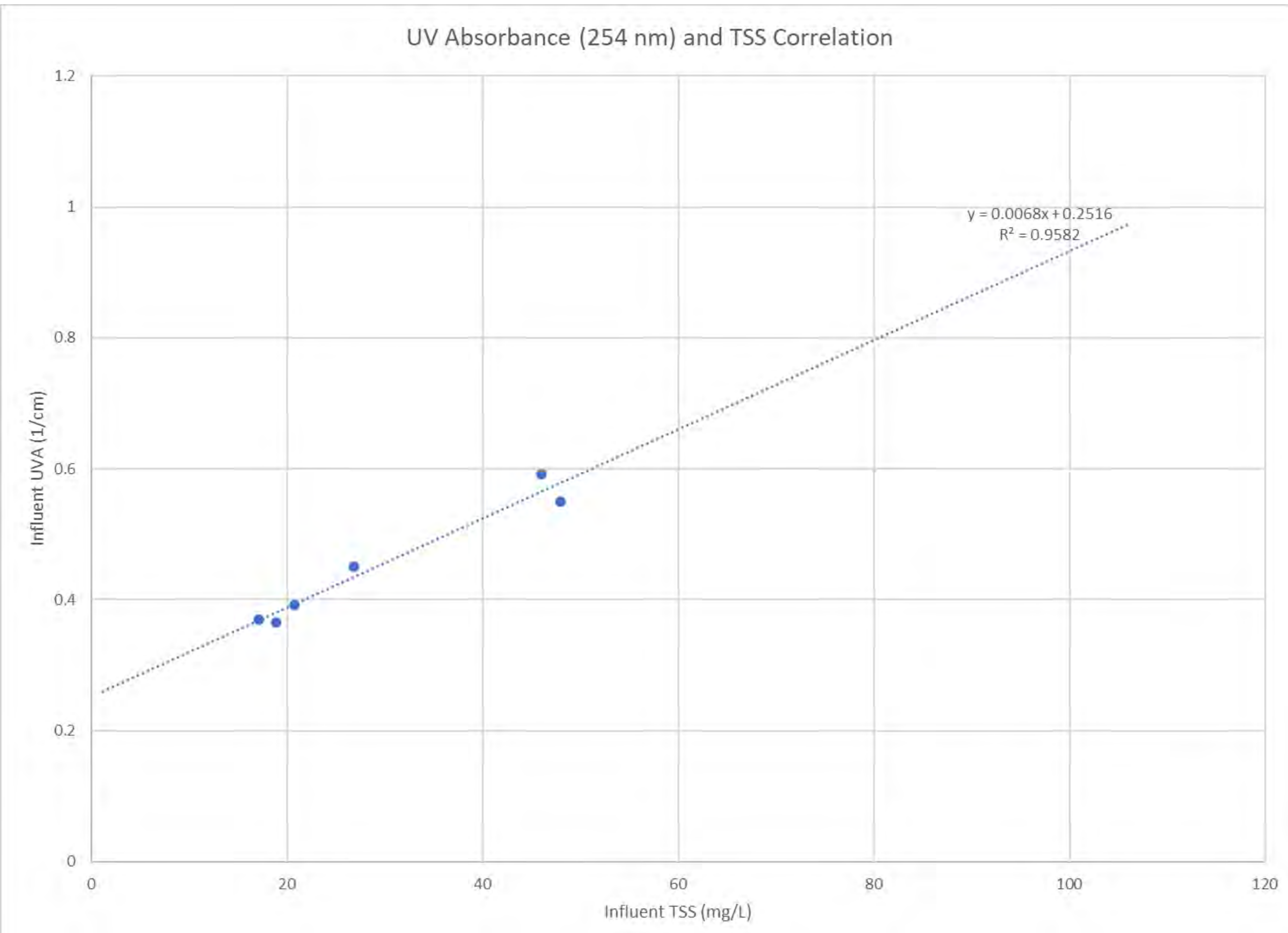


Figure 4-15. Influent UV Absorbance (254 nm) to TSS Correlation

4.2.1.5 Influent TSS Meter Readings and Laboratory TSS Analyses

Figure 4-16 shows the correlation between influent TSS meter readings and laboratory TSS analyses. The laboratory TSS data consist of both grab and composite samples. For grab samples, influent TSS meter readings at the same time are compared. For composite samples, average influent TSS meter readings from the time period are used for comparison.

Table 4-17 shows the TSS laboratory data compared to in-line meter readings and their ratios and relative percent differences.

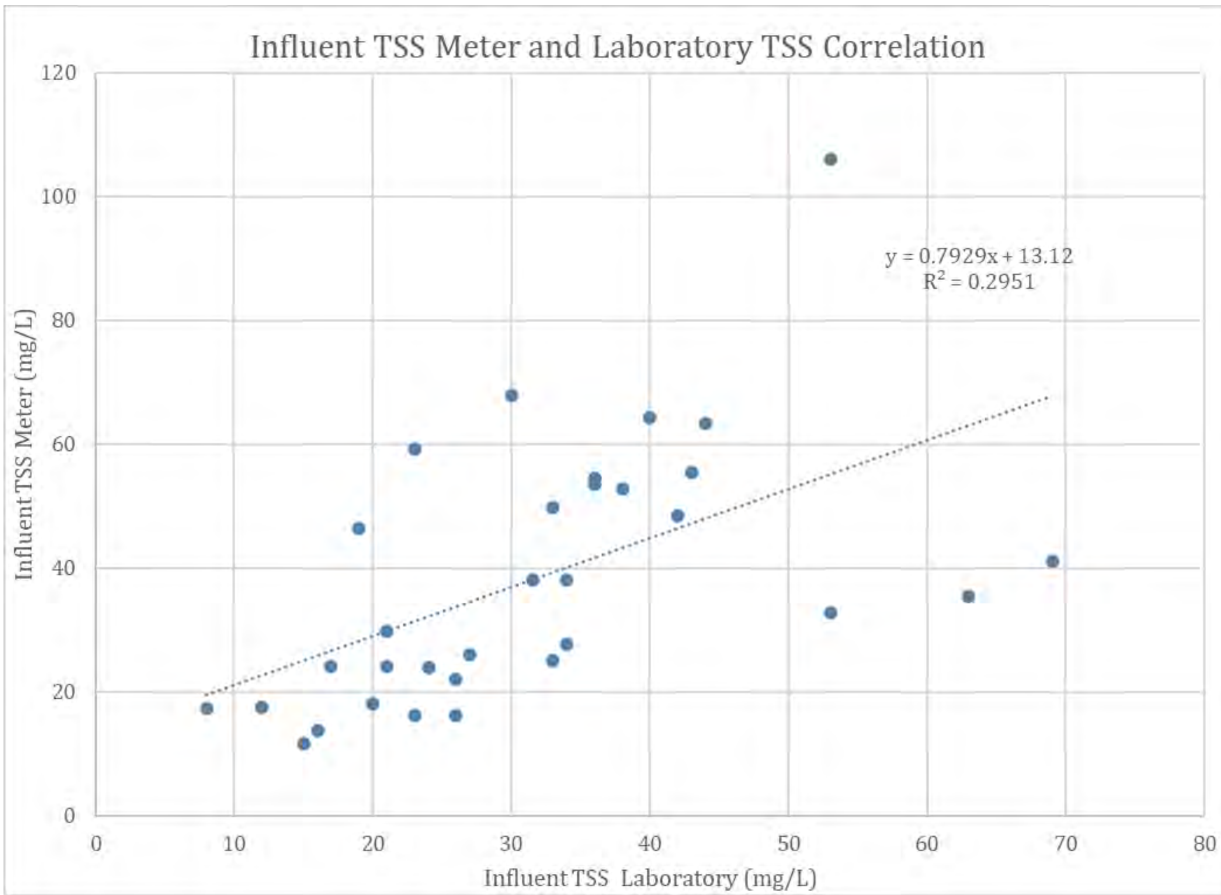


Figure 4-16. Influent TSS Meter vs. Laboratory Measurements

Table 4-17. TSS Data Comparison

Test Run	Sampling Time	TSS Influent Laboratory (mg/L)	TSS Influent Meter (mg/L)	Laboratory/Meter Ratio	Relative Percent Difference
1	1105	23	59.21	0.39	88%
2	835	44	63.48	0.69	36%
2	1030	33	25.03	1.32	27%
2	1130	17	24.11	0.71	35%
2	1430	20	18.01	1.11	10%
2	1730	8	17.40	0.46	74%
3	1000	38	52.80	0.72	33%
4	1400-1417	24	24.00	1.00	0%
5	1100	42	48.53	0.87	14%
6	1310	53	32.76	1.62	47%
7	925	27	25.94	1.04	4%
8	1035-1045	63	35.40	1.78	56%
9	1130-1140	21	24.11	0.87	14%
10	1330	12	17.50	0.69	37%
11	930	15	11.6	1.29	26%
Suppl 1	1200-1205	16	13.73	1.17	15%
Suppl 2	1000	34	27.77	1.22	20%
Suppl 3	1100-1105	34	38.15	0.89	12%
	Average:	**29**	**31**	**0.99**	**30%**

4.2.1.6 Implications of Differences in Influent TSS Readings for Coagulant Dosing Strategy

Differences between the in-line meter TSS readings and laboratory TSS analytical data may be due to inherent challenges involved in sampling and analyzing TSS for relatively low TSS concentrations. The poor correlation between in-line TSS meter readings and laboratory TSS analytical data could potentially introduce a source of error on coagulant dosing when influent in-line TSS meter readings are used to determine coagulant dosage if the poor correlation is due to inaccuracies in the influent in-line TSS meter readings. However, data from the process and performance pilot testing are inconclusive regarding whether inaccurate influent in-line TSS meter readings or laboratory analytical data are responsible for the poor correlation between the two data sets.

If it is assumed that coagulant dosing should correlate with influent TOC (using influent TSS as a surrogate for coagulant dosing) to mitigate membrane fouling, then using the in-line TSS probe readings as a coagulant dosing control strategy can be justified because of the good correlation between the two (Figure 4-12). Conversely, there was poor correlation between TOC and laboratory TSS data from the influent (Figure 4-17).

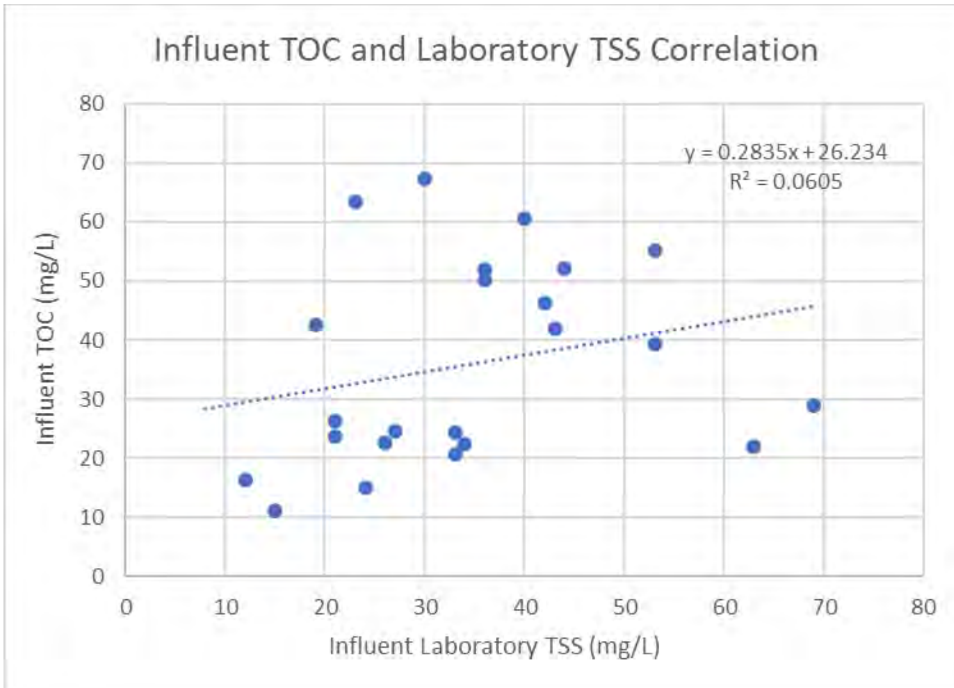


Figure 4-17. Influent TOC vs. Influent Laboratory TSS Measurements

4.2.1.7 Summary of TSS Correlations

For the influent samples taken during the process and performance pilot testing, the correlation between influent TSS meter readings and BOD (Figure 4-9) is poor compared to the correlation between influent TSS meter readings and TOC (Figure 4-12). All but one of the calculated BOD:TSS ratios in Table 4-16 was lower than 2.38, but many runs benefitted from an Al:TSS ratio higher than 0.4, as determined by the TMP rise rates. Therefore, it is suggested that the BOD:TSS ratio guideline of 2.38 be revised in favor of a TOC-based correlation with influent TSS meter readings. Not only would using a TSS:TOC relationship be more accurate based on TSS:TOC correlations from the pilot testing data, but use of estimated TOC concentrations to guide coagulant dosing is also grounded in theoretical considerations regarding fouling of membranes by organic compounds.

4.3 Comparison with Existing Manufacturer’s Design Criteria

This section compares the existing manufacturer’s design criteria with parameters tested or observed during the process and performance testing. The parameters listed under the subsection titled Adherence are meant to confirm performance at the conditions tested, not at conditions beyond what was tested. Certain parameters listed under the subsection titled Departures, such as basin TSS, are similarly meant to identify parameters tested that were different from the manufacturer’s design criteria. They do not imply that test results confirmed lack of performance to the design criteria.

4.3.1 Adherence

4.3.1.1 Peak Flux Rates

The maximum allowable flux specifications shown in Table 4-1 have been confirmed from the pilot testing data using primary effluent and primary effluent diluted with potable water.

4.3.1.2 Coagulant Type (Alum)

The pilot testing confirmed that alum (aluminum sulfate) can be used to mitigate membrane fouling. The alum used in the pilot testing contained 4.1 percent by weight aluminum.

4.3.1.3 Operating Temperature

All of the process and performance tests were done at water temperatures above 10 degrees C, the stated minimum operating temperature in Ovivo's design criteria. The tests were not conducted to show performance down to 10 degrees C, however, and did not necessarily show adherence to performance down to the stated minimum operating temperature.

4.3.1.4 CIP

The design criterion for CIPs is a minimum of 4 hours of soak duration. These CIPs were performed between test runs and successfully restored membrane function. CIP dosing was confirmed. Short, 30-minute soak duration CIPs performed during the failure tests demonstrated that shorter CIPs were sufficient to restore membrane function under the fouling circumstances encountered.

4.3.1.5 Backwash Operating Parameters

Backwash operating parameters of once every 15 minutes, 60 second durations, and backwash flow rate of 2X permeate flux were confirmed during process and performance testing.

4.3.1.6 Air Scour Rate

The air scour rate of 35 scfm per stack was confirmed during process and performance testing.

4.3.2 Departures

4.3.2.1 Coagulant Dosing

Data from the pilot test showed that for the primary effluent and primary effluent/potable water mixtures that were tested, the alum coagulant dosing rate should be set higher than the preliminary design criterion of 0.4 Al:TSS dose ratio as a function of the BOD:TSS ratio. As noted in Section 4.2.1.3, all but one of the calculated BOD:TSS ratios in Table 4-16 was lower than 2.38, but many runs benefitted from an Al:TSS dose ratio higher than 0.4.

4.3.2.2 Basin TSS

The basin TSS levels never reached the stated maximum basin TSS concentration of 6,000 mg/L during process and performance pilot testing due to loss of solids from backwashing. The maximum basin TSS reached during pilot testing was 1,530 mg/L during Supplemental Test Run 3. Because of this, the process and performance pilot testing did not determine whether the equipment could perform at a maximum basin TSS concentration of 6,000 mg/L. And the performance of the pilot unit was not tested against the basin TSS as a variable due to the limitations of the pilot.

4.3.2.3 Basin HRT

The basin hydraulic retention time (HRT) design is 20 minutes, which on the pilot unit used for these tests was based on 200 gpm permeate flow and 100 gfd instantaneous flux when all of the membrane stacks were used. Because membrane stacks were taken offline to achieve flux rates greater than 100 gfd during the pilot testing while maintaining approximately 200 gpm or lower permeate flow rates in the pilot unit, shorter HRTs that would occur at higher flux rates in a full-scale facility were not tested during the process and performance pilot testing.

4.3.3 Other Observations/Considerations

When using alum as the coagulant, pH adjustment will be necessary at times when the combination of alum coagulant dosage, influent pH, and influent alkalinity lead to effluent pH values lower than the required instantaneous minimum pH of 6 for discharge. As summarized in Table 4-12, the pH dropped below 6 in 10 of the test runs.

4.4 Comparison of Results to Anticipated Regulatory Requirements/Objectives

4.4.1 Adherence

4.4.1.1 Requirements

As summarized in Section 4.1.4, pilot testing results showed adherence to the following regulatory requirements:

- TSS removal percentage
- Effluent fecal coliform count
- Effluent settleable solids
- Improved settleable solids value compared to current CSO treatment

4.4.2 Departures

4.4.2.1 pH

After Test Run 1, the pilot testing did not use sodium hydroxide (caustic soda) to control the pH. As a result, many test runs had treated water pH lower than the minimum discharge pH of 6.0. A pH control and caustic soda dosing strategy is proposed to address this issue for full-scale applications.

4.5 Preliminary Design and Operation Criteria

As discussed in the preceding sections, the design and operations criteria should be reexamined and revised by Ovivo, as necessary, based on the process and performance pilot testing data and data analyses. Chapter 5 addresses details of the preliminary design and operation criteria for full-scale implementation. Major items identified from the pilot testing are listed below.

4.5.1 Coagulant Dosing

The process and performance pilot testing confirmed that alum is an effective coagulant for mitigating membrane fouling. It is suggested that the Al:TSS ratio be increased to above the current recommended 0.4 Al:TSS dose ratio based on influent TSS meter readings. In addition to increasing the aluminum dose linearly to correspond to higher influent TOC concentrations (as estimated using influent TSS meter readings as a surrogate), results from the pilot testing suggest that a higher Al:TSS dose ratio at higher influent TSS/TOC concentrations would also improve fouling mitigation. Further evaluation of the coagulant dosing strategy as related to the use of the influent TSS meter readings is recommended due to the discrepancies between the influent TSS meter readings and laboratory TSS analyses as reviewed in Section 4.2.1.5.

4.5.2 pH Control

Because alum consumes alkalinity, the pH dropped to below the required effluent discharge pH of 6.0 on many occasions during the pilot testing. pH control, likely using sodium hydroxide (caustic soda) would be necessary. pH control can be implemented either upstream or downstream of the membranes. The advantage of adding caustic upstream of the membranes is that no additional reaction tank may be necessary to ensure sufficient reaction time to meet effluent limit of pH 6 or above. However, although the results were inconclusive, there was evidence from Test Run 1 during the process and performance testing that caustic addition upstream of the membrane system contributed to more rapid membrane fouling. Therefore, adding caustic soda upstream of the coagulant feed point and membranes may require additional mixing to mitigate adverse impacts to the membrane. The downside of pH control downstream of the membranes is that an additional reaction tank would be required to ensure compliance with pH in the effluent. For a design flow rate of 250 million gallons per day in a system, a reaction tank with a design HRT of 5 minutes would be approximately 870,000 gallons in size. Additional chemical storage would be required whether pH control is implemented upstream of downstream of the membranes.

4.5.3 Instantaneous Flux Specifications

The instantaneous flux specifications shown in Table 4-1 have been confirmed.

4.5.4 Operating Parameters

Operating parameters such as basin TSS and basin HRT should be reexamined based on the pilot testing results.

4.5.5 Chemical Cleaning/Membrane Recovery

CIP specifications should be reexamined based on the pilot testing results. As discussed in Section 4.3.1.4 and shown in Sections 3.8.5 and 3.9.5, 30-minute soak CIPs were sufficient to restore membrane function under the fouling circumstances encountered. So, it may be possible for CIPs to be performed at shorter than the 4-hour manufacturer's design criterion when necessary and still achieve adequate membrane recovery. If the standard CIP fails to restore the membrane to baseline flux values, the strength of the chemical cleaning reagents can be increased, and/or the duration of the CIP soaks can be lengthened to increase the effectiveness of the cleanings. Another strategy is to increase the temperature of the CIP cleaning solutions. If it is suspected that inorganic scaling is responsible for most of the observed fouling, citric acid cleaning should be employed before caustic soda and sodium hypochlorite CIP. Another possible regimen to increase membrane cleaning effectiveness is to add a surfactant or surfactants to the cleaning solution if organic fouling is suspected to be the main driver of reduced membrane permeability. Membrane CIP improvements and membrane warranties would be the responsibility of the membrane provider.

4.5.6 Summary

Table 4-18 summarizes manufacturer's design criteria tested during process and performance testing and whether testing results showed compliance with the criteria.

Table 4-18. Summary of Manufacturer's Design Criteria and Compliance from Process and Performance Testing

Parameter	Manufacturer's Design Criteria	Compliance
Peak Flux Rates	Peak Day 100 gfd Peak 16-hour 125 gfd Peak 12-hour 150 gfd Peak 8-hour 175 gfd Peak 4-hour 200 gfd Peak hour 225 gfd	Yes
Coagulant Type	Alum	Yes
Coagulant Dosing Strategy	0.4 Al:TSS dose ratio when BOD:TSS ratio <2.38	No
Operating Temperature	Down to 10 degrees Celsius	Inconclusive
CIP	4 hours	Yes
Backwashing	Every 15 minutes, 60 second durations, 2X permeate flux rate	Yes
Air Scouring	35 scfm per stack	Yes
Basin TSS	Up to 6,000 mg/L	Inconclusive
Basin HRT	20 minutes	Inconclusive

5. IMPLEMENTATION

This chapter combines the information learned from the preliminary tests and the process and performance pilot tests to establish a set of defined criteria and to outline criteria that still need to be developed. The criteria are to be used to develop a full-scale facility for treating CSO wastewater that better meets performance criteria and permit limitations.

5.1 Final Design Criteria

The process and performance pilot testing generally confirmed the design criteria developed by Ovivo, as presented in Section 3.1.11 of this document (Table 3-3 through Table 3-7). Two of the manufacturer's criteria may need to be modified:

- As explained in Chapter 4, the process and performance pilot tests suggest the need for a higher value of Al:TSS ratio than the manufacturer's recommendation of 0.4. The TMP rise rate was lowest for an Al:TSS ratio of 0.6 and acceptable for an Al:TSS ratio of 0.5. Increasing the ratio will have an impact on the coagulant storage volume required. More discussion of this issue is in Section 5.3.3.
- Ovivo indicates a maximum suspended solids level of 6,000 mg/L in the basin prior to wasting, but closer examination of the preliminary testing data suggests that value may be too high. More discussion of this issue is in Section 5.4.2.

5.2 Lessons Learned and Innovations

5.2.1 Air Entrainment

Air entrainment regularly interfered with the permeate flow meter and startup turbidity readings in the pilot testing (readings were elevated due to entrained air). The impact to the flow meter was critical since it made it very difficult to control the permeate pumps. Ovivo installed an air removal system to help reduce the entrained air, but this solution was hampered by the elevation of the permeate header pipe. Both the pipe location and size of air removal system will need to be determined during full scale design.

5.2.2 Wasting

An automated wasting valve was added to allow better control of wasting of excess solids. During pilot operation the automated valve was never used. During preliminary testing, it was found that the rate of TMP increase accelerated at TSS >6,000 mg/L, so Ovivo set the wasting valve to open when TSS reached this level. Since TSS never got that high during testing, it never opened. See further discussion of solids buildup in Section 5.4.2.

5.2.3 Scum and Foam

There was significant scum and foam during the operation of the pilot. It is not known whether this was due to the use of primary effluent as a surrogate for CSO wastewater. A scum trough and spill box were installed and were only marginally helpful in removing foam and scum. In a full-scale facility, with access to permeate water, sprays along with a floating scum removal unit may be more helpful in keeping foam under control and cleaning the membranes after an event has ended.

5.2.4 Instrumentation and Control

The process and performance pilot testing implemented instrumentation and control as follows:

- A TSS probe was used to measure the influent TSS, which was used for controlling the dosing of coagulant. The probe's readings did not match the lab results for TSS. The TSS measurement on a full-scale facility would need to be designed to provide accurate measurements with a high correlation to lab-tested TSS. TSS measurement would have to be reliable to provide consistent TSS-based coagulant dosing.
- A second TSS probe installed in the membrane basin monitored solids buildup and control wasting.
- An influent organics/UV absorbance probe (Hach UVAS) was installed to see whether organics data (Parameter SAC254) could be useful for dosing control. There was a definite correlation between this organic/UV absorbance parameter and TSS.
- A number of significant PLC programming changes were made after the pilot unit arrived. No dry testing of the programming was completed for the pilot. A full-scale facility would require dry testing before controls are shipped to the site.
- Local data logging as a backup was implemented because of poor remote access connectivity for data storage by OVIVO. This was due, in part, to poor cellular service at the West Point facility.

In a full-scale facility, it would be good to include similar monitoring efforts. Given that the technology has been only proven at a pilot scale, collection of additional data will provide more insights to how best to operate the technology. Additional monitoring could include the following:

- BOD/COD using spectral-type probe.
- Alkalinity and pH, especially if alum is used.

5.3 Design Considerations

5.3.1 Chemical Addition

The process requires the addition of a coagulant, which, according to Ovivo, binds small organics that can foul the membrane and allow higher flux rates and run times. Alum was the primary coagulant, but ACH was also tested. Jar testing suggested that ACH would be an effective coagulant. During preliminary testing, it was discovered that ACH has to be operated in a very narrow dose range, with significant and persistent fouling of the membrane if ACH is overdosed.

When alum, or other coagulant that consumes alkalinity, is used, pH control must be considered. During the process and performance pilot testing, the pH deviated periodically below the effluent limit of 6.0. Alum consumes alkalinity, so alkalinity adjustment will be required. Alkalinity adjustment could be done before or after the process. There might be better control of the process if it were done post membrane, which would eliminate any lag in chemical addition. King County has expressed concern with adding the chemical after the process because of the limited feedback time for control, though adjustment is completed after the coagulation and filtration process in many water treatment applications. Variations of the flow will have to be considered in the design process.

Caustic is often used for alkalinity adjustment, but it presents many issues related to safety and handling. Magnesium hydroxide is another chemical used for alkalinity adjustment in many wastewater treatment applications. Calcium carbonate has been used in Europe but not extensively in the United States. Calcium carbonate can be provided in a liquid slurry that is much safer and more cost effective than caustic or magnesium hydroxide. Both magnesium hydroxide and calcium carbonate require constant and periodic mixing respectively

5.3.2 Mixing Post Coagulant Injection

It became apparent during the preliminary testing that mixing was needed after introduction of coagulant, so it was provided for the process and performance testing. An in-line static mixer was used, but it is not known if this is the best method of mixing. Ovivo established that alum requires less mixing energy than ACH, as stated in the preliminary testing report:

> *"Mixing energy proved critical for ACH while alum was less dependent on high mixing energy. An in-line static mixer was determined to provide the best mixing conditions."*

Currently, Ovivo's criteria identify an in-line static mixer for mixing. This may not be practical for large CSO flows or flows in a channel. Coagulation mixing methods for a full-scale application may include the following:

- Hydraulic mixing would be similar to the in-line mixer used in the process and performance testing. Sufficient velocity is needed to mix the coagulant with the influent. Baffles or other structures could be used to create the mixing energy.
- Mechanical mixing using a tank with a paddle or propeller is common in water treatment applications.
- Diffuser mixing uses a distribution grid placed in a tank, with the coagulant injected at all depths through the grid. The large grid allows dispersion of the coagulant and mixing occurs quickly.
- Pumped blenders add the coagulant directly to the water being treated through a diffuser in a pipe.

The type of mixing in a full-scale facility would depend on the area available and existing layout. To allow for sufficient mixing, the process should be sufficiently sized. This may require multiple basins depending on the range of flow.

5.3.3 Dosing Control

The measurement of TSS was used for coagulant dosing control as outlined in Ovivo's preliminary testing report:

> *"Total suspended solids (TSS) was identified as a possible surrogate for biochemical oxygen demand (BOD) of the CSO water. Ideally, BOD and/or COD represent the ideal variable for coagulant dosing control if it could be measured reliably and accurately in real time. However, on-line measurement of BOD and/or COD in CSO applications has yet to be demonstrated hence the need to find an applicable surrogate for coagulant dose control. Under dry weather conditions at WPTP, the ratio of BOD to TSS remains fairly constant so a*

> *TSS-based dosing strategy is able to ensure a minimum ratio of coagulant to organic material (i.e., BOD) is maintained. Since water quality can vary during a storm event at the County's CSO facilities, it is important to have a TSS-based dosing strategy that can compensate for changes in BOD-to-TSS ratios."*

Ovivo's dosing strategy is to maintain an Al:TSS ratio of 0.4 or greater unless the BOD:TSS ratio is greater than 2.38; for higher BOD:TSS ratios, the AL:BOD ratio needs to be 0.17 or greater. This condition was experienced during Run 1 when the BOD:TSS exceeded 2.38. The coagulant dosage was adjusted upward after a higher-than-expected TMP increase was identified. The increase in coagulant dosage resulted in a reduction in the TMP rise rate.

There are monitors that use optical indirect measurement for on-line measurement of BOD in the influent, but they are expensive for a pilot application. An example is the s::can unit that is being successfully used for influent monitoring at wastewater treatment plant facilities. A full-scale facility CSO treatment facility could have this type of monitoring if it is determined that BOD is the best parameter to use. BOD is a good parameter for wastewater applications, but for CSOs with significant inorganic suspended solids, there is a question as to whether BOD or TSS is the best parameter to use for pacing coagulant. TSS appeared to work most of the time in the process and performance pilot test. It is unknown whether it is an optimal use of coagulant.

More work could be done to examine other means of dosing control. In water treatment, both TOC and UV absorbance are used to dose coagulant. The data provided by the Hach UVAS instrument indicates potential use in a future dosing strategy. In addition, zeta potential might be a method to both control dosage and observe optimization.

5.3.4 Storage Requirements

This technology has three chemical storage requirements: coagulant, CIP chemicals, and alkalinity adjustment.

5.3.4.1 Alum

The volume of alum required to treat 1 million gallons, based on the typical range of CSO TSS, is shown in Table 5-1 for dosages of 0.4 Al:TSS, 0.5 Al:TSS, and 0.6 Al:TSS. If the requirement is to treat 100 million gallons per day for a 24-hour period, the required coagulant storage for the various TSS levels would be 100 times the volume listed in Table 5-1.

Table 5-1. Storage per 1 Million Gallons Treated

	Volume Alum (gallons – 8.3%)		
TSS (mg/L)	**0.4 Al:TSS**	**0.5 Al:TSS**	**0.6 AL:TSS**
70	514	642	770
50	367	458	550
30	220	275	330

5.3.4.2 Alkalinity Adjustment

Since 1 mg/L of alum will consume 0.5 mg/L of alkalinity as CaCO3, alkalinity adjustment will be required. Depressed pH values were observed in a number of the process and performance pilot runs. If alum is used, additional chemical storage will be needed. The volume of caustic needed to replace the alkalinity lost due to the alum would be approximately 40 percent of the volume of alum used. Actual need will depend on available alkalinity in the influent waste stream.

5.3.4.3 CIP Chemicals

CIP chemicals are not anticipated to require significant space on a plant site. Based on the rates provided by OVIVO, it is anticipated that 54 gallons of sodium hypochlorite and 27 gallons of sodium hydroxide would be needed per 1 million gallons per day of capacity (design flux rate of 100 gfd).

5.3.5 Cleaning

5.3.5.1 Cleaning in Place

It was determined during preliminary testing that, for a full-scale design, the permeability during the chemical fill sequence and after CIP backwash can be used to determine whether the CIP fully recovered the membranes. It would be important to have the ability to determine the success of a CIP in a full-scale application. Target permeability post cleaning was not a focus of the pilot and should be determined for a full-scale facility

It was determined that chlorine combined with caustic provides effective and reliable cleaning when using alum. Using ACH instead of alum requires a more extensive cleaning protocol, especially if the ACH is overdosed.

5.3.5.2 Basin Cleaning

Basin cleaning was not addressed during the pilot project. The pilot unit included a bell-shaped device that Ovivo calls a flushing device. The device provides dirty water to flush debris from the floor of the unit, but it does not clean the membranes if foam and scum have attached to them as the basin is drained. During a CIP, the membranes are backflushed which may help remove some of the scum that may have attached to the surface. It may be better to use the supply of permeate, which is much cleaner water, for both backflushing the membranes and membrane surface cleaning. Spray nozzles could be positioned above the membranes to wash any residuals from the surface of the membrane. Permeate could also be used in a flushing device, such as a tipping bucket, to flush any solids on the floor of the basin.

5.4 Criteria Not Addressed During Pilot

There are a number of elements essential to the process that were not evaluated during the pilot. This section discusses those items that will need to be addressed for any full-scale application.

5.4.1 Screening

The process and performance pilot tests used a wedge-wire-type screen with mechanical brushes on the inlet and outlet sides and 6 by 6 mm openings. This is a reject-type screen that requires the rejected material to be directed back to the interceptor. The testing did not address whether this is the best approach for screening. At some CSO locations, it may be better to remove the debris from the influent stream instead of putting it back into the sewer and potentially overloading the downstream headworks.

The size of the screen is critical. With a membrane application, it is important to remove materials that could block or clog the space between the membranes. The spacing between the membranes in the module is 6.7 mm, which is why a 6-mm screen was using for the pilot testing.

5.4.2 Solids Buildup

Ovivo specified a maximum suspended solids level of 6,000 mg/L in the membrane tank before wasting must be initiated, with the solids sent back to the main interceptor.

In Run 14 in the preliminary testing, a change in TMP rise rate occurred at a basin suspended solids level between 5,000 and 5,500 mg/L TSS. During the short testing completed in Austin, a noticeable change in the TMP rise rate was observed at a suspended solids concentration of about 4,000 mg/L. The testing in Austin was completed at similar air scour and flux rates used for the pilot.

Solids concentration can have an impact on the performance of the membrane, so wasting of solids may need to be initiated at lower basin TSS levels, especially during high flows with high flux rates.

5.4.3 Membrane Integrity

The pilot testing did not include examination of the membranes after the testing was complete to investigate membrane and integrated piping integrity.

Ovivo has stated that turbidity results are the best indicator of membrane integrity. Turbidity is used for membrane integrity monitoring.

The RapidStorm pilot was equipped with a turbidimeter that provides instantaneous readings. Turbidimeter readings above 0.1 NTU may indicate a leak in the submerged piping and membranes or trapped air that is causing false high NTU readings. Results of effluent fecal bacteria testing would also help assess system integrity.

In the testing at Austin prior to the work at King County, a 5-gallon bucket of coarse sand was added to the pilot unit. Ovivo examined the membranes under a microscope after testing was completed and indicated that there was no evidence of abrasion or wear to the membranes.

No continuous monitoring other than turbidity have been identified that could confirm integrity of the connections, O-rings, and piping associated with the membrane. It would be prudent to develop testing protocols in the event that elevated turbidity values (turbidity spikes) are encountered.

5.4.4 Maintenance Considerations

Maintenance considerations were not part of the pilot work but will be important for a full-scale facility. These considerations should address the following:

- Instrumentation – calibration and cleaning:
  - TSS probes
  - Turbidity monitors

  - pH probe
  - Flow meters
  - Temperature probes
  - BOD and/or TOC probe(s)
  - Other potential instrumentation
- Level sensors:
  - Process tanks
  - Permeate storage
  - Mixing tank
  - Chemical storage
- Pressure sensors – critical for flux determination and rate of fouling
- Mixing tank:
  - Maintenance of mechanical mixer(s)
  - Draining post event
- Tank/membrane cleaning post events:
  - Tank cleaning (i.e., tipping bucket) – maintaining mechanisms
  - Membrane cleaning (residual scum removal) – cleaning nozzles
  - Valves associated with permeate used for cleaning
- Equipment:
  - Membranes
  - Air scour blowers
  - Permeate pumps
  - Chemical feed pumps
  - Influent screens

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Appendix A

Ovivo Pilot Process and Performance Plan

Appendix C. Process and Performance Test Plan – West Point TP Pilot

Revised Version – 9 August 2020

This was originally prepared as Appendix C to the Testing Plan submitted December 28, 2018.

APPENDIX C. PROCESS AND PERFORMANCE TEST PLAN – WEST POINT TP PILOT

1. INTRODUCTION

1.1 BACKGROUND

King County is investigating additional combined sewer overflow (CSO) treatment options to improve the quality of the discharge from its CSO treatment facilities, to meet or exceed Washington State Department of Ecology (Ecology) and U.S. Environmental Protection Agency consent decree requirements associated with the County CSO Program. Tetra Tech and Parametrix are evaluating a new technology for King County CSO treatment that uses a physical chemical coagulation filtration process incorporating aluminum coagulation and a silicon carbide (SiC) membrane filter. The technology produces high-quality effluent and could be used to treat some or all of the flow from a CSO site prior to discharge into surface water. In addition, the technology has a small footprint that could be placed on a restricted site.

The technology system, developed by Ovivo, is called the RapidStorm Treatment System. It utilizes a SiC membrane and is designed for treatment of CSOs and sanitary sewer overflows (SSOs). It is patterned after Ovivo's stormBLOX, which utilizes a polymeric membrane technology in a side-stream process to treat raw sewage during wet-weather flows at membrane bioreactor treatment plants to Class A reclaimed standards. Ovivo claims that RapidStorm Treatment System can be activated rapidly during wet weather to treat CSO and SSO flows.

King County, Tetra Tech, and Parametrix participated in Ovivo's performance tests, using the new treatment technology to treat simulated CSO and SSO discharges. The performance testing was conducted over three days in October 2017 using various test scenarios at a pilot treatment plant in Austin, Texas. The results are described in the report titled *Alternative CSO Treatment Technology; Ovivo stormBLOX Manufacturer Testing and Evaluation* (Tetra Tech and Parametrix, December 20, 2017).

Based on the positive results of the performance testing conducted in Austin Texas by Ovivo in 2017, King County has commissioned the construction of a 200 gallon per minute[1](gpm) pilot treatment plant. King County planned a long-term pilot test of the new treatment technology at the West Point Treatment Plant (TP). The pilot testing will use the Ovivo SiC membrane technology to treat West Point TP primary effluent (PE) as a surrogate

[1] Pilot plant capacity is 200 gallons per minute at a flux of 100 gallons per square foot per day (gfd).

test water with properties similar to combined sewage (CS). The pilot testing at the West Point TP consists of three phases:

- **Bench-scale Tests**: In preparation for the pilot testing, King County conducted bench-scale tests at the West Point TP using a single SiC membrane plate. The bench-scale testing investigated different coagulants, cleaning chemicals, and dosing rates for the membranes. The results of this bench-scale testing informed the development of the next two phases of testing at the West Point TP.

- **Preliminary Tests:** A series of preliminary tests was conducted by King County and Ovivo using the 200 gpm pilot treatment plant at the West Point TP to establish the key design criteria for the SiC membrane technology. The results of the preliminary tests informed the development of the last phase of testing at the West Point TP. A Preliminary Test Report is under development by Ovivo for King County as of the time of the writing of this appendix.

- **Process and Performance Tests:** The testing and sampling plan is the last phase of pilot testing at the West Point TP and is described in this appendix. The Process and Performance testing will be conducted with the 200 gpm pilot treatment plant to confirm the key design criteria established by Ovivo and to measure other performance attributes of the technology. The Process and Performance testing is scheduled to begin in May of 2020 subject to the State of Washington "Stay Home, Stay Healthy Order."

Based on the results of the pilot testing at the West Point TP, the pilot treatment plant would be considered for installation at the Elliot West CSO TP on Elliot Avenue West in Seattle for further pilot testing on CSO discharges. Proposed test runs, sampling, and water quality analysis for that pilot testing at the Elliott West CSO TP are summarized in this appendix's companion document, *King County Pilot Testing of Ovivo Membrane Treatment of Combined Sewer Overflows – Testing Plan* (December 2018).

1.2 OBJECTIVES

The purpose of the Process and Performance pilot test runs at the West Point TP is to build a baseline of knowledge and experience with the RapidStorm Treatment System, in preparation for the potential pilot test at Elliott West CSO TP. Since the RapidStorm Treatment System process is still an early-stage technology, the pilot tests at West Point TP and Elliott West CSO TP will help to confirm several of the key design criteria that were defined by Ovivo in the preliminary testing at West Point TP.

Conducting the Process and Performance pilot test runs at the West Point TP provides several benefits versus starting the pilot at the Elliott West CSO TP, including the following:

- A continual supply of low total suspended solids (TSS) water (primary effluent).

- Convenient access for King County engineering, operations, and laboratory staff.

- Operational control to conduct tests according to staff schedules, instead of waiting on weather.

Although there may be some differences in untreated water quality and system performance between West Point TP and Elliott West CSO TP, King County anticipates that the West Point TP test runs will provide useful information that will address pilot program objectives, reducing the operational "learning curve" during future piloting at a wet-weather facility.

Therefore, the Process and Performance testing objectives for the West Point TP pilot test runs are similar to the objectives for the pilot at the Elliott West CSO TP. These objectives include:

1. Confirm coagulant type and dose on pilot.
2. Confirm manufacturer’s criteria.
3. Support a request for manufacturer’s approval of modified design criteria based upon these pilot test results. The manufacturer must be willing to guarantee a set of design conditions for full-scale installation.
4. Demonstrate the performance of advanced treatment, with a view to meeting permit requirements.
5. Simulate system failure modes to evaluate recovery procedures.

Design criteria for the RapidStorm Treatment System include the following:

- Screening and pretreatment requirements.
- Coagulant type, mixing, dose, and dynamic dosing strategy.
- Membrane flux.
- Air scour rate.
- Backwash flux, interval, and duration.
- Maximum total suspended solids in membrane tank.
- Wasting flow, interval, and duration.
- Cleaning chemical, concentration, and soak time.

Design criteria will be documented in Ovivo’s Preliminary Test Report to King County.

Additional objectives for pilot testing are described in Section 4.

2. PROCESS AND PERFORMANCE PILOT TESTING

2.1 INTRODUCTION

King County has contracted with Ovivo to provide the RapidStorm Treatment System pilot treatment plant for pilot testing. Process and Performance pilot testing data will be used to help accomplish the objectives defined in Section 1.2. This section describes the proposed testing runs, sampling and sampling locations, roles and responsibilities, and data management.

This Process and Performance pilot plan provides general directives for testing. Ovivo will provide equipment control narratives, and detailed operations and maintenance procedures to King County.

2.2 SCHEDULING

Scheduling for the Process and Performance pilot testing is to be determined as of May 2020 subject to the State of Washington "Stay Home, Stay Healthy Order." Tests will be conducted according to the following assumptions:

1. All test runs will be conducted at West Point wastewater treatment plant using primary effluent (PE) or diluted PE with hydrant water.
2. Typically run two (2) pilot test runs each week.
3. Test runs shall be conducted each Tuesday and Thursday, with cleaning on Wednesday.
4. Weekly data review meetings shall be conducted each Friday.

2.3 PROPOSED TEST RUNS TO MEET OBJECTIVES

Testing objectives for the Process and Performance pilot testing pertain to water quality performance and provide a basis to support full-scale project planning. The objectives establish testing that is critical to the potential design of a full-scale facility. The following are summaries of proposed Process and Performance tests for the West Point TP pilot plan, with more details in Table 2-1 (page 8):

- Confirm performance, dosing rates, and dosing control of the preferred coagulant (aluminum chlorohydrate [ACH]) or alum for all test runs.
- Run 1: Evaluate technology design criteria by running at steady-state flux operation with constant influent conditions as a process test.
- Run 2: Evaluate performance on variable water quality at steady-state flux operation as a process test.
- Run 3: Evaluate technology treatment performance at steady-state flux operation with constant influent conditions as a performance test.

- Run 4: Evaluate peak flux by running PE + dilution from 100 to 200 gallons per square foot per day (gfd) in 25 gfd increments and back down from 200 gfd to 100 gfd.
- Run 5: Evaluate operation with variable flux and water quality using a front-loaded (200 -50 gfd) hydrograph in a process test.
- Run 6: Evaluate performance with variable flux and water quality with a back-loaded (50 – 200 gfd) hydrograph.
- Run 7: Test system response (impact and recovery) to equipment failure by adjusting coagulant dosing.
- Run 8: Test system response (impact and recovery) to equipment failure by adjusting air scouring or backwash.
- Run 9: Test 24-hour hydrograph operation by implementing a middle-loaded hydrograph with peak flux of 200 gfd.
- Run 10: Performance test of a 24-hour hydrograph operation by implementing a variable hydrograph to simulate discharge from Elliott West CSO TP facility (200 gfd maximum flux, 50 gfd minimum flux).
- Run 11: Test operation under disruption by cycling On/Off to mimic back-to-back events and assess the tolerance of the system to rapid startups and shutdowns.
- Run 12: Evaluate long-term clean-in-place (CIP) effectiveness by using clean water to run after CIP using sodium hypochlorite and sodium hydroxide.
- For storm events (with a trigger of >175 MGD in the West Point TP effluent), front-loaded and back-loaded hydrographs same as Run 5 and Run 6, respectively, will be run. Another proposed test for a storm event would be to cycle the pilot between On/Off to mimic back-to-back events.

➢ During a storm event, the pilot test should start 1 hour after the flow passes the trigger level. This will allow many of the “first-flush” solids to pass through the clarifier.

The following tests for the West Point TP pilot are proposed as supplemental test runs that could be explored:

- Test a range of backwash design criteria to better sustain membrane performance, potentially prolonging available runtime between chemical cleanings.
- Test a range of chemical cleaning design criteria to potentially recover membrane performance more quickly or using less chemical; potential benefits could include reducing required treatment footprint for redundant membranes and chemical storage.
- Test a range of air scour design criteria to “intensify” treatment through higher air scour rates, potentially increasing system robustness by reducing the rate flux decline or allowing the system to handle higher fluxes or higher tank TSS levels for short durations.
- Evaluate the maximum run time achievable before needing to conduct a CIP.
- Synthesize the lessons learned from prior tests in a hydrograph simulation test to simulate performance under anticipated non-steady state operation.

The proposed pilot tests described above are summarized in Table 2-1 (page 8). King County staff will conduct water quality sampling and analysis according to two different plans—process and performance—as indicated for each individual test run in Table 2-1. Sampling and analysis plans are discussed further in Section 2.4.3

The Process Sampling and Analysis Plan (in Table 2-4 on page 16) represents a baseline level of sampling that will be performed for each test. The Performance Sampling and Analysis Plan (Table 2-5 on page 17) represents a more intensive level of sampling designed to demonstrate the water quality performance of RapidStorm Treatment System across a broad range of water quality parameters.

The hydrographs for Test Runs 5, 6, 9, and 10 were developed to cover a range of conditions experienced at Elliott West CSO TP and other King County CSO facilities. These tests will help determine how sensitive the system is to different storm patterns. The front-loaded hydrograph and middle-loaded hydrograph represent variations on typical single-peak storm events, such as those from April 14, 2018, and February 12, 2016, respectively. The back-loaded hydrograph represents what we expect to be the worst-case scenario because the system will experience the highest flows when it has already experienced fouling. The spiky hydrograph represents multiple-peak storms, such as that seen at Elliott West CSO TP on October 13, 2016.

In all tests, the pilot should not be shut down prematurely if a failure is imminent. The pilot will automatically shut down when it reaches the high transmembrane pressure (TMP) threshold, which Ovivo indicates will not damage the system. Letting the pilot run until this point will provide valuable information on the recovery after failure events.

Table 2-1. West Point Process and Performance Pilot Test Runs

Purpose	Run #		Test Date	Influent Water Source	Flux Rate (gfd)	Wasting Rate	Air Scour, Total (scfm)	Backwash Frequency (minutes)	Run Duration (hours)	SAP Type	Notes
Required Test Runs											
1. Confirm Technology Design Criteria.	1		TBD	PE	100	basin < 6,000 mg/L	105	15	24	Process Test	Steady-state flux operation - constant influent conditions
2. Confirm Performance on Variable Water Quality.	2		TBD	PE + Dilution	100	basin < 6,000 mg/L	105	15	12	Process Test	Steady-state flux operation - variable influent conditions with decreasing influent strength, to be detailed in individual test run package
3. Confirm Technology Treatment Performance.	3		TBD	PE	100	basin < 6,000 mg/L	105	15	10	Performance Test	Steady-state flux operation - constant influent conditions
4. Confirm peak flux.	4		TBD	PE + Dilution	varies	basin < 6,000 mg/L	105	15	10	Process Test	Confirmation of peak flux range - 100 to 200 (25 gfd increments walk up and down)
5. Confirm Operation with Variable flux and water quality.	5		TBD	PE + Dilution	hydrograph	basin < 6,000 mg/L	105	15	24	Process Test	Hydrograph 1 - front loaded hydrograph (200 gfd - 50 gfd) same set of flux conditions as preliminary testing hydrograph
6. Confirm Performance with Variable flux and water quality.	6		TBD	PE + Dilution	hydrograph	basin < 6,000 mg/L	105	15	12	Performance Test	Hydrograph 2 - back loaded hydrograph (50 gfd to 200 gfd) with 12-hour duration, to be detailed in individual test run package
7. Test System Failure and Recovery	7		TBD	PE	100	basin < 6,000 mg/L	105	15	varies	Process Test	System response (impact and recovery) to equipment failure – loss of coagulant
8. Test System Failure and Recovery.	8		TBD	PE	100	basin < 6,000 mg/L	varies	varies	varies	Process Test	System response (impact and recovery) to equipment failure – loss of air scour or backwash
9. Test 24 hour hydrograph operation.	9		TBD	PE + Dilution	hydrograph	basin < 6,000 mg/L	105	15	24	Process Test	Hydrograph 3 – middle-loaded hydrograph with peak flux of 200 gfd, to be detailed in individual test run package
10. Confirm 24 hour performance with variable conditions.	10		TBD	PE + Dilution	hydrograph	basin < 6,000 mg/L	105	15	24	Performance Test	Hydrograph 4 - variable hydrograph to simulate actual discharge from Elliott West CSO TP facility (200 gfd maximum flux - 50 gfd minimum flux), to be detailed in individual test run package
11. Test operation under disruption.	11		TBD	PE + Dilution	hydrograph	basin < 6,000 mg/L	105	15	12	Process Test	Pilot cycled ON/OFF to mimic back-to-back events - Hydrograph TBD
12. Confirm long term CIP effectiveness.	12		TBD	clean water	100	n/a	105	15	6	Process Test	Clean water test to document CIP efficiency - no coagulant addition
Storm Event Test Runs (trigger = West Point effluent flow > 175 MGD)											
Items 1-5 and 7 above	x		unknown	PE + Dilution	hydrograph	basin < 6,000 mg/L	105	15	24	Performance Test	Hydrograph 1 - front-loaded hydrograph (200 gfd - 50 gfd) same set of flux conditions as preliminary testing hydrograph
	x		unknown	PE + Dilution	hydrograph	basin < 6,000 mg/L	105	15	24	Process Test	Hydrograph 2 – back-loaded hydrograph (50 gfd to 200 gfd) with 12-hour duration, to be detailed in individual test run package
	x		unknown	PE + Dilution	hydrograph	basin < 6,000 mg/L	105	15	12	Process Test	Pilot cycled ON/OFF to mimic back-to-back events - Hydrograph TBD
Supplemental Test Runs											
Items 1-6 above	x		TBD	PE	100	basin < 6,000 mg/L	varies	varies	10	Process Test	Optimization - backwash
	x		TBD	PE	100	basin < 6,000 mg/L	varies	varies	10	Process Test	Optimization - air scour
	x		TBD	PE	TBD	basin < 6,000 mg/L	TBD	TBD	10	Process Test	Testing of modified design criteria (based on results from early test results)
	x		TBD	PE	100	basin < 6,000 mg/L	105	15	24+	Process Test	Maximum run time prior to CIP

2.4 TESTING AND SAMPLING LOCATIONS

This section summarizes the data parameters that will be collected during Process and Performance pilot testing through online performance monitoring and water quality sampling. It includes sampling points, operational parameters, and water quality parameters to be collected. In general, planned water quality sampling (parameters/methods, frequency, and sample type) is designed to use the permit limits and monitoring requirements of King County's NPDES Permit No. WA0029181 at the Elliott West CSO TP as guidance. All pilot operational parameters will be measured by an online meter or analyzer included with the pilot skid. This operational data will be recorded by the pilot data logger. Water quality parameters will be collected via sampling during all test runs.

2.4.1 Sampling Locations

Multiple adjacent sampling ports will be needed to allow for grab samples to be collected by King County, as well as for automatic samples. Operational data and water quality samples will be collected at the following sampling locations (SL) in the system (see Figure 2-1):

- (INF-SL) Pilot Influent—A sampling port on the pilot, tapping the inflow pipe to the pilot before coagulant addition
- (EFF-SL) Pilot Permeate—A sampling port on the pilot, tapping the membrane permeate pipe

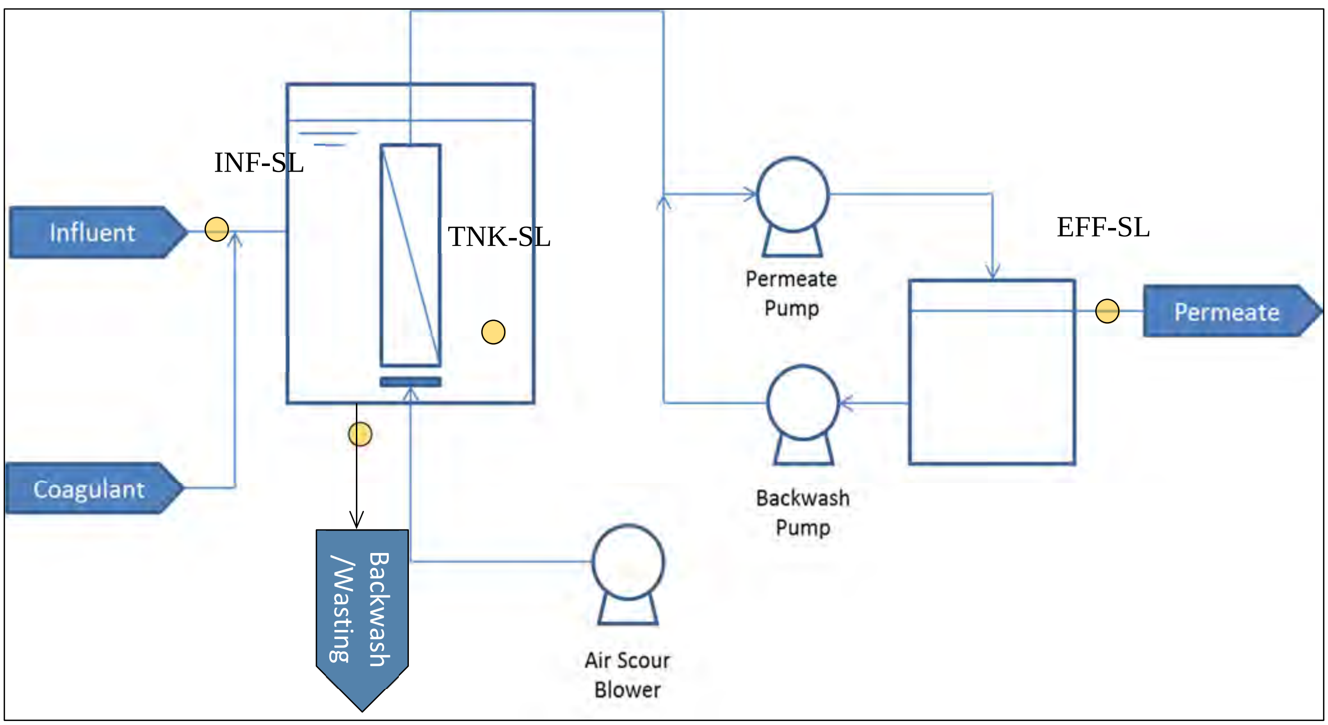

Figure 2-1. Pilot Unit Plan and Profile Drawing Schematic with Sampling Points Indicated

- (TNK-SL) Membrane Tank—A sampling port on the membrane tank, withdrawing mixed water from the feed side of the membranes

Note that the autosamplers will be kept cold with ice to preserve the quality of the samples.

2.4.2 Process Data

Operational parameters will be collected continuously through the pilot skid and will include both system settings and system performance. The pilot programmable logic controller will record operational parameters at a 10-second interval. System settings and performance parameters to be monitored are listed in Table 2-2. Influent supervisory control and data acquisition (SCADA) flow data from the West Point TP will also be collected and reviewed.

2.4.3 Water Quality Data

Water quality will be monitored through online analyzers, grab samples, and auto samplers. The water quality parameters in this sampling plan include those required under the Elliott West CSO TP permit, operationally significant parameters, and other constituents such as metals.

Online Monitoring

The pilot skid will include integrated online water quality analyzers or probes for the following parameters in the locations noted:

Table 2-2. Pilot Online Operational Monitoring Parameters

Parameter	Type	Location
Air Flow	Setting	TNK
Permeate Pump #1 Speed	Setting	Permeate Pump #1
Permeate Pump #2 Speed	Setting	Permeate Pump #2
Permeate Pump #3 Speed	Setting	Permeate Pump #3
Chemical Pump #1 Speed (& Coagulant Dosage)	Setting	Chemical Pump #1
Chemical Pump #2 Speed (& Caustic Dosage)	Setting	Chemical Pump #2
Chemical Pump #3 Speed (& Hypochlorite Dosage)	Setting	Chemical Pump #3
Chemical Pump #4 Speed (& Citric Acid Dosage)	Setting	Chemical Pump #4
Total Pilot Inflow (Influent PE & Dilution Water)	Performance	INF
Permeate Flow (& Flux)	Performance	EFF
Backwash Flow (& Flux)	Performance	BW
Transmembrane Pressure	Performance	TNK
Temperature-Corrected Permeability	Performance	TNK
Membrane Tank Level	Performance	TNK
Suction Pressure	Performance	VAC

The following online analyzers and probes are used for coagulant dosing and operating strategies during pilot testing:

- pH (effluent)
- Conductivity (in membrane tank)
- Temperature (in membrane tank)
- TSS (in influent line and membrane tank)
- Turbidity (effluent only)

While the data from these units will be captured by a data logger, King County staff will periodically check these probes/analyzers before each event and recalibrate as needed.

Online monitoring will also include logging of operational parameters via an on-board SCADA system, including at least the parameters given in Table 2-2. Ovivo will provide a remote viewing capability for the system.

Water Quality Sampling and Analysis Test Plans

One of the most important objectives of the pilot test is to determine if the RapidStorm Treatment System can effectively remove TSS and coliforms under varying influent and operating conditions. Another objective of the pilot testing is to determine if using the ceramic membrane process for treatment can yield other secondary benefits, such as removal of other constituents. The sampling and analysis test plans include tests designed to help answer if these objectives are met in the pilot testing.

King County staff will conduct water quality sampling and analysis according to two different testing objectives—process and performance—as indicated for each individual test run, as discussed in Section 2.3.1. Water quality analytical methods and containers are listed in Table 2-3 (page 13). The Process Sampling and Analysis Plan (Table 2-4 on page 16) represents a baseline level of sampling that will be performed for each test. The Performance Sampling and Analysis Plan (Table 2-5 on page 17) represents a more intensive level of sampling designed to demonstrate the water quality performance of RapidStorm Treatment System across a broad range of water quality parameters.

Sample Scheduling

The schedule of when to get grab samples and probe measurements will be listed in the test run packages prepared by the consultant team prior to each test run. In general, grab samples will be scheduled to fit the following:

- Influent samples will be grabbed shortly after process changes, so that influent water quality is measured should the system fail.
- Tank samples and effluent samples will follow influent sampling, generally after one hydraulic residence time has passed.
- Sampling will typically follow a change in the flux or dilution during a run.
- Sampling will be scheduled during what the consultants believe to be the most critical part of the test.
- Sampling of different water quality constituents will be scheduled simultaneously to get a more complete picture of the water quality at a particular instant.
- Samples of the same water quality constituent will be collected multiple times over the course of the run to cover a variety of process conditions and times.

If King County staff believe failure of the pilot is imminent, they are encouraged to condense the sample collection plan and collect the remainder of scheduled sample events before failure occurs.

Each table describes the sampling requirement for each parameter by location, indicating sample type (grab or composite), sample frequency, and composite pacing method. All composite samples will be collected using a time-based compositing method.

Table 2-3. Water Quality Analytical Methods

Analyte (Parameter)	Analytical Method	Container
Turbidity	SM2130B	
Total Suspended Solids	SM2540D	
Total Volatile Solids	SM2540E	
Chlorine Demand Test	SM4500-Cl D SM4500-Cl E	
Settleable Solids	SM2540F	
Alkalinity	SM2320B	
UV Absorbance (254)	SM5910B	125 mL amber narrow mouth glass
5-Day Biochemical Oxygen Demand (BOD5)	SM5210B	
Chemical Oxygen Demand (COD), total	Hach 8000	
Total Organic Carbon (TOC)	SM5310-B	125 mL H_3PO_4 pre-preserved amber glass
Fecal Coliform	SM9221 E2 + C (A1 MPN)	
Total Phosphorus	SM4500-P-E	
Total Kjeldahl Nitrogen	SM4500 Norg B	
Ammonia - Nitrogen	SM4500 NH3 E	
Fats, Oils, Grease	EPA 1664	1000 amber glass wide mouth (WM) bottle with H_2SO_4
Fecal Coliform	SM9221 E2 + C (A1 MPN)	125 mL sterile polypropylene bottle
Metals, Total (Ca and Mg)	EPA 200.8	500 mL WM acid washed polypropylene bottle
Hardness	EPA 200.8	calculated
Metals, Total (Priority Pollutant)	EPA 200.8	500 mL WM acid washed polypropylene bottle
Metals, Total (Mercury)	EPA 245.1 and EPA 7470A (SW-846)	500 mL WM acid washed polypropylene bottle

Process Test Sampling and Analysis Plan

The analytes included in the Process Test Sampling and Analysis Plan (Table 2-4 on page 16) are listed below with brief explanations for their usefulness:

pH – One handheld probe field measurement of the effluent pH from the effluent sample tap/sample flow "box" will be taken per test to compare against the pH probe in effluent and evaluate the extent of pH depression from coagulant addition.

Conductivity – One handheld probe field measurement of the pilot membrane tank will be tested for conductivity to compare with online conductivity measurements or used as a spot check against a conductivity standard to verify the online conductivity probe. Conductivity is a surrogate for total dissolved solids (TDS) and can be measured rapidly compared to TDS analyses. Trends in conductivity can be used to analyze for changing water chemistry.

Temperature – One handheld probe field measurement will be taken for temperature in the membrane tank to compare with online temperature measurements.

Turbidity – Turbidity data can be used as a surrogate for suspended solids, and one grab sample will be taken in the pilot effluent per test to compare with online turbidity measurements.

Total Suspended Solids (TSS) – TSS samples will be collected in the pilot influent, membrane tank, and pilot effluent. This data will help evaluate how well the pilot unit performs in acting as a barrier to suspended solids and as a comparison to Ovivo's coagulant dosing control.

Total Volatile Suspended Solids (TVSS) – TVSS are surrogates for insoluble organic matter. The ceramic membrane system is expected to remove TVSS. Samples for TVSS, like TSS, will also be collected in the pilot influent, membrane tank, and pilot influent.

Chlorine Demand Test – The chlorine demand test shows how much oxidant (specifically chlorine) demand is in the water. One chlorine demand test will be performed per test for a grab sample taken in the pilot effluent.

Settleable Solids – Settleable solids are measured as the volume of solids per liter that settle to the bottom of an Imhoff Cone. One settleable solids test will be performed per test for a grab sample taken in the pilot effluent. The results complement TSS and TVSS results, all of which when reviewed together can show how well the treatment acts as a barrier to particulates.

Alkalinity – The alkalinity measures the ability of the water to resist pH depression due to acid being added. This is a critical water chemistry parameter to evaluate the effect of coagulant dosing. Alkalinity will be measured for one composite sample per test in both the pilot influent and the pilot effluent to track the decrease in alkalinity from coagulant addition.

UV Absorbance (254) – The UV absorbance at 254 nanometers (nm) is a surrogate for the concentration of organic compounds in the water, particularly organic compounds with aromatic rings. It will be measured and reported as transmittance (in percent) at 254 nm based on the inverse relationship between absorbance and percent transmittance. One analysis will be performed per test for a composite sample in the pilot effluent.

BOD5 - The 5-day biochemical oxygen demand (BOD5) test measures the amount of oxygen consumed from microbial metabolism in a 5-day test. It is an indirect measurement of how much food is available and is metabolized by microbes. One analysis will be performed per test for a composite sample in the pilot effluent. The BOD5 data will be compared against chemical oxygen demand (COD) data to establish if there is a relationship between the two.

TOC – Total organic carbon (TOC) measures the total organic carbon content in the water and is a good surrogate for BOD5 and COD. Samples will be taken in both the pilot influent and effluent to track TOC removal across the ceramic membrane and to establish the relationship between TOC and BOD5.

COD – Chemical oxygen demand (COD) measures the amount of oxygen demand in the water based on substances that react with dichromate. A ratio between COD and BOD5 can be established from data that is specific to a wastewater. COD analyses will be taken in both the pilot influent and effluent to track COD removal.

Fecal Coliform – One of the key goals of the pilot testing is to establish how well the ceramic membrane system removes fecal coliforms under different influent and operating conditions. Fecal coliform analyses will be performed for two grab samples in the pilot influent and four samples in the pilot effluent per test.

Performance Test Sampling and Analysis Plan

An expanded list of analytes is included in the Performance Test Sampling and Analysis Plan (Table 2-5 on page 17). Additional analytes are listed below with brief explanations for their usefulness:

Total Phosphorus – Total phosphorus (P) measures the concentration of P in the water that can potentially convert to orthophosphate. Orthophosphate is one of the nutrients responsible for eutrophication in receiving waters. In the performance testing, total phosphorus will also be measured, with three grab samples in the pilot influent and three grab samples in the pilot effluent. Aluminum coagulant addition (in the form of ACH) could remove total phosphorus, and these analyses are intended to collect data to review the extent of phosphorus removal in the performance testing.

Total Kjeldahl Nitrogen – Total Kjeldahl nitrogen (TKN) measures the amount of reduced (not nitrite and nitrate) nitrogen in the wastewater, including ammonia and organic nitrogen compounds. Organic nitrogenous compounds detected in the TKN analyses can break down into ammonia in the receiving environment and contribute to aquatic toxicity. The organic portion of TKN could possibly be removed in the ceramic membrane process. TKN will be measured in the performance testing, with three grab samples per test in the pilot influent and three grab samples per test in the pilot effluent, to examine TKN removal across the ceramic membrane process.

Ammonia Nitrogen – Ammonia contributes to aquatic toxicity. It will be measured in the performance testing, with three grab samples per test in the pilot influent and three grab samples per test in the pilot effluent. Ammonia nitrogen data will help distinguish between organic nitrogen components and ammonia in the TKN measurements.

Fats, Oils, and Grease – Fats, oils, and grease (FOG) can contribute to BOD5 and consume dissolved oxygen (DO) in the receiving environment, leading to low DO water that is deleterious to aquatic life. FOG can also cause a visible sheen on the water surface, which is unsightly and could cause public concerns. The combination of aluminum coagulation and ceramic membrane filtration could remove some FOG in the wastewater. FOG will be measured in the performance testing, with three grab samples per test in the pilot influent and three grab samples per test in the pilot effluent, to examine FOG removal across the ceramic membrane process.

Calcium and Magnesium (under Total Metals) – Calcium and magnesium contribute to total hardness. Higher total hardness concentrations can mitigate the aquatic toxicity of certain metals such as copper and cadmium in the receiving environment. Calcium and magnesium will be measured in the performance testing, with three grab samples per test in the pilot influent, three grab samples per test in the membrane tank, and three grab samples per test in the pilot effluent.

Priority Pollutant Metals (under Total Metals) – The priority pollutant metals at King County include antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), selenium (Se), silver (Ag), thallium (Tl), and zinc (Zn). One reason for testing these metals is that some of these priority pollutants can occur in the influent as colloidal particles and can be removed in the ceramic membrane process, or they can be adsorbed by the aluminum-based coagulant and removed from solution. These priority pollutant metals will be measured in the performance testing, with three grab samples per test in the pilot influent, three grab samples per test in the membrane tank, and three grab samples per test in the pilot effluent.

Mercury – Mercury is known to bind to sulfur-based compounds or adsorb to suspended solids and is often found in the particulate form in wastewaters. Particulate mercury is expected to be removed in the ceramic membrane process. As such, mercury will be measured in the performance testing, with three grab samples per test in the pilot influent, three grab samples per test in the membrane tank, and three grab samples per test in the pilot effluent.

Table 2-4. Process Test - Sampling and Analysis Plan

Analyte (Parameter)	Hold Time Limit	Sample Min. Volume Required (mL)	Turn Around Time (TAT) (days)	Location of Analysis	Location – Pilot Influent (INF) Sample Type		Sample Frequency				Location – Pilot Effluent (EFF) Sample Type		Sample Frequency				Location – Membrane Tank (TNK) Sample Type		Sample Frequency			
					Grab	Comp	Grab	Flow-Paced	Time-Paced	No. of samples per Test Run	Grab	Comp	Grab	Flow-Paced	Time-Paced	No. of Samples per Test Run	Grab	Comp	Grab	Flow-Paced	Time-Paced	No. of Samples per Test Run
pH	-		-	Field													X		1/run			1
Conductivity	-		-	Field													X		1/run			1
Temperature	-		-	Field													X		1/run			1
Turbidity	-		-	Field							X		1/run			1						
Total Suspended Solids	7 days		1	Field & WP Lab	X	X	1/run		hourly	2		X			hourly	1	X		1/run			1
Total Volatile Suspended Solids	7 days		1	WP Lab	X	X	1/run		hourly	2		X			hourly	1	X		1/run			1
Chlorine Demand Test	Within 15 minutes		1	WP Lab							X		1/run			1						
Settleable Solids	48 hours		1	WP Lab							X		1/run			1						
Alkalinity	14 days		1	WP Lab		X			hourly	1		X			hourly	1						
UV Absorbance (254)–report out in transmittance	48 hours	80mL	2	WP Lab								X			hourly	1						
5-Day Biochemical Oxygen Demand (BOD5), total	48 hours		5	WP Lab								X			hourly	1						
Total Organic Carbon (TOC), total	28 days	60mL	21	KCEL	X	X	8/run		hourly	9		X			hourly	1						
Chemical Oxygen Demand (COD), total	28 days		1	WP Lab		X			hourly	1												
Fecal Coliform	"6+2" hours	100 mL	2	WP Lab	X		2/run			2	X		4/run			4						

Table 2-5. Performance Test - Sampling and Analysis Plan

Analyte (Parameter)	Hold Time Limit	Sample Min. Volume Required (mL)	Turn Around Time (TAT) (days)	Location of Analysis	Location – Pilot Influent (INF)						Location – Pilot Effluent (EFF)						Location – Membrane Tank (TNK)					
					Sample Type		Sample Frequency			No. of samples per Test Run	Sample Type		Sample Frequency			No. of Samples per Test Run	Sample Type		Sample Frequency			No. of Samples per Test Run
					Grab	Comp	Grab	Flow-Paced	Time-Paced		Grab	Comp	Grab	Flow-Paced	Time-Paced		Grab	Comp	Grab	Flow-Paced	Time-Paced	
pH	-		-	Field													X		1/run			1
Conductivity	-		-	Field													X		1/run			1
Temperature	-		-	Field													X		1/run			1
Turbidity	-		-	Field							X		1/run			1						
Total Suspended Solids	7 days	200 mL (eff), 100 mL (inf & tnk)	1	Field & WP Lab	X	X	1/run		hourly	2		X			hourly	1	X		1/run			1
Total Volatile Suspended Solids	7 days	200 mL (eff), 100 mL (inf & tnk)	1	WP Lab	X	X	1/run		hourly	2		X			hourly	1	X		1/run			1
Chlorine Demand Test	Within 15 minutes	At least 200 mL	-	WP Lab							X		1/run			1						
Settleable Solids	48 hours	At least 250 mL	1	WP Lab							X		1/run			1						
Alkalinity	14 days	100 mL	1	WP Lab		X			hourly	1		X			hourly	1						
UV Absorbance (254)–report out in transmittance	48 hours	50-125 mL	1	WP Lab								X			hourly	1						
5-Day Biochemical Oxygen Demand (BOD5), total	48 hours	500 mL	5	WP Lab								X			hourly	1						
Total Organic Carbon (TOC), total	28 days	60 mL	21	KCEL	X	X	3/run		hourly	4		X			hourly	1						
Chemical Oxygen Demand (COD), total	28 days	100 mL	1	WP Lab		X			hourly	1												
Fecal Coliform	"6+2" hours	100 mL	2	WP Lab	X		2/run			2	X		4/run			4						
Total Phosphorus	28 days	100 mL	1	WP Lab	X		3/run			3	X		3/run			3						
Total Kjeldahl Nitrogen	28 days	500 mL	1	WP Lab	X		3/run			3	X		3/run			3						
Ammonia - Nitrogen	28 days	200 mL	1	WP Lab	X		3/run			3	X		3/run			3						
Fats, Oils, Grease	28 days	1000 mL	21	KCEL	X		3/run			3	X		3/run			3						
Metals, Total (Calcium & Magnesium) – 1 bottle for Ca/Mg, Priority Pollutant metals and Mercury.	180 days	500 mL	21	KCEL	X		3/run			3	X		3/run			3	X		3/run			3
Metals, Total (Priority Pollutant – 1 bottle for Ca/Mg, Priority Pollutant metals and Mercury.	180 days	500 mL	21	KCEL	X		3/run			3	X		3/run			3	X		3/run			3
Metals, Total (Mercury) – 1 bottle for Ca/Mg, Priority Pollutant metals and Mercury.	28 days	500 mL	21	KCEL	X		3/run			3	X		3/run			3	X		3/run			3

2.5 ROLES AND RESPONSIBILITIES

Table 2-6 lists the pilot project team members with roles and contact information. King County will be responsible for all hands-on operation of the pilot system. The sections below provide general outlines of responsibilities. Ovivo will provide detailed technical documentation, control narratives, and an operations and maintenance manual on the pilot unit to King County, backed up with 24/7 remote assistance on the pilot unit. The 24/7 support will be provided by Ovivo.

Table 2-6. West Point PT Pilot Team Members and Contact Information

Name/Org	Roles and Responsibilities	E-Mail and Telephone
Eron Jacobson King County	Project Manager	Eron.jacobson@kingcounty.gov
Christina Vanburen King County	Project Control	christina.vanburen@kingcounty.gov
Bob Bucher King County	Technology Assessment – installation, commissioning, operation, troubleshooting, data review, and decommissioning	bob.bucher@kingcounty.gov 206-477-9747
Pardi Sukapanpotharam King County	Technology Assessment – commissioning, operation, data management, and data review	Pardi.sukapanpotharam@kingcounty.gov 206-477-9783
Pedro De Arteaga King County	West Point Process – commissioning, operation, and data review	pedro.dearteaga@kingcounty.gov 206-477-9749
Jessica Tanumihardja King County	West Point Process – commissioning, operation, and data review	Jessica.tanumihardja@kingcounty.gov 206-477-1652
Karl Zimmer King County	Assistant Manager (West Offsite) – operation review	karl.zimmer@kingcounty.gov
Ellen Sisk King County	Environmental Laboratory Project Manager – SAP review, sample analysis, and data reporting	ellen.sisk@kingcounty.gov
Phuong Truong King County	West Point Process Laboratory Supervisor – SAP review, sample analysis, and data reporting	phuong.truong@kingcounty.gov
Emily Smithers King County	West Point Process – commissioning, operation, and data review	Emily.smithers@kingcounty.gov, 206.263.0194
Mike Snodgrass Ovivo	Project Engineer – commissioning, operation, data management, data review, and troubleshooting - Pilot Operations Primary Point of Contact	mike.snodgrass@ovivowater.com 805-705-1505
Ashwini Khare Ovivo	Ovivo Project Manager – Ovivo Primary Point of Contact	Ashwini.Khare@ovivowater.com 512-695-9482
Mike Ollivant Parametrix	Principal Consultant – Consultant Team Pilot Monitoring Secondary Point of Contact	mollivant@parametrix.com 253-381-9703
Doug Berschauer Parametrix	Water Technology Lead – Test plan, data review, and Lead Technical memorandum	dberschauer@parametrix.com 253-905-4281
Scott Weirich Parametrix	Process Engineer –Consultant Team Pilot Monitoring Primary Point of Contact	SWeirich@parametrix.com 253-501-5269
Marcos Lopez Tetra Tech	Principal in Charge – Consultant Team Pilot Monitoring Secondary Point of Contact	marcos.lopez@tetratech.com 206-890-0055
Grizelda Sarria Tetra Tech	Project Manager	grizelda.sarria@tetratech.com 206-883-9412
H.C. Liang Tetra Tech	Process Specialist – Lead Test Plan, data review, and technical memorandum – Consultant Team Pilot Monitoring Primary Point of Contact	hc.liang@tetratech.com 720-483-9012
Greg Brink VMS	Project Principal / Project Manager	greg@vms-inc.com 720-308-4205
Lisa Stensby VMS	Project Scheduler	lisa@vms-inc.com 503-680-9697

The consultant team will review the data generated by the pilot and meet weekly by phone with King County and Ovivo to discuss results and plan the upcoming tests.

2.5.1 Before Tests

Before tests, King County will pre-program the agreed upon operating conditions for the next test run in the pilot system settings. The pilot plant operators should check all online analyzers and recalibrate if necessary.

2.5.2 During Tests

King County should refer to the pilot operations strategy section of the June 22, 2018, technical memorandum *CSO Rapid Treatment (CSO RT) Pilot Pipe Connection Details*, considering portions relating specifically to the pilot, and not to the Elliott West CSO TP site.

2.5.3 After Tests

King County will conduct the following activities after each test run:

- While primary effluent is expected to be relatively clean, remove any screenings or other debris, if present.
- Backwash the membranes and observe performance recovery.
- Initiate a chemical clean and let soak.
- Drain cleaning solution and test permeability with clean water (*optional)* to observe performance recovery from chemical soaking.
- Turn off skid and close appropriate valves.
- Check chemical levels and replenish.
- Program settings for the next run.
- Provide a written debriefing summary of significant events from the run into the on-site operator’s log.
- Complete chain of custody forms, then pack and transport water quality samples to lab.
- Receive new sampling bottles for future runs.
- Notify project team of any noteworthy events from the run.
- Receive updated lab reports, upload to project website, and notify project team of new data.
- Upload pertinent West Point TP SCADA data to the project website (OneDrive) for the consultant team and Ovivo to review.

2.6 DATA MANAGEMENT

The following data sources will be collected and uploaded to the project website (SharePoint) as soon as they become available after each event:

- Electronic copy of water quality results and quality control from the West Point TP Process Lab and King County Environmental Lab.
- Scan of pages from on-site operational log.
- SCADA data from pilot skid (via Water Expert), with summary data graphs/charts provided by Ovivo (Mike Snodgrass).
- Influent flow SCADA data from West Point TP.

The consultant team and Ovivo will review the data on a weekly basis, and in advance of each week's meeting will send an email to the project team summarizing the most recent results and making recommendations for upcoming tests.