City of Snohomish

Peracetic Acid Testing Report

REVISED

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CITY OF SNOHOMISH
PERACETIC ACID TESTING REPORT
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CHAPTER 1
INTRODUCTION

BACKGROUND

The City of Snohomish (City) currently operates a four-stage lagoon wastewater treatment plant (WWTP), which was retrofitted with a submerged fixed-film (SFF) media system in 2012. The WWTP also includes influent pumping and flow measurement, screening, addition of supplemental alkalinity, effluent filtration, and chlorine disinfection followed by dechlorination.

The four aerated lagoons at the WWTP are part of a hybrid lagoon process called a dual-powered flow-through lagoon system, which combines aspects of suspended growth and facultative treatment. The first lagoon is a form of low-rate, suspended-growth treatment, with a normal volume of approximately 10 million gallons. Three partially mixed facultative lagoons in series follow the first lagoon, providing a normal volume of approximately 3.5 million gallons each. These three facultative lagoons provide additional biological treatment, as well as settling, storage, and digestion of solids. Additionally, each of these three lagoons has been retrofitted with 18 submerged fixed-film (SFF) media modules for enhanced treatment. The SFF media modules provide a surface for growth of biomass to increase the population of microorganisms in the lagoons, particularly nitrifying organisms, thereby increasing the effectiveness for treatment of ammonia and 5-day carbonaceous biochemical oxygen demand ($CBOD_5$).

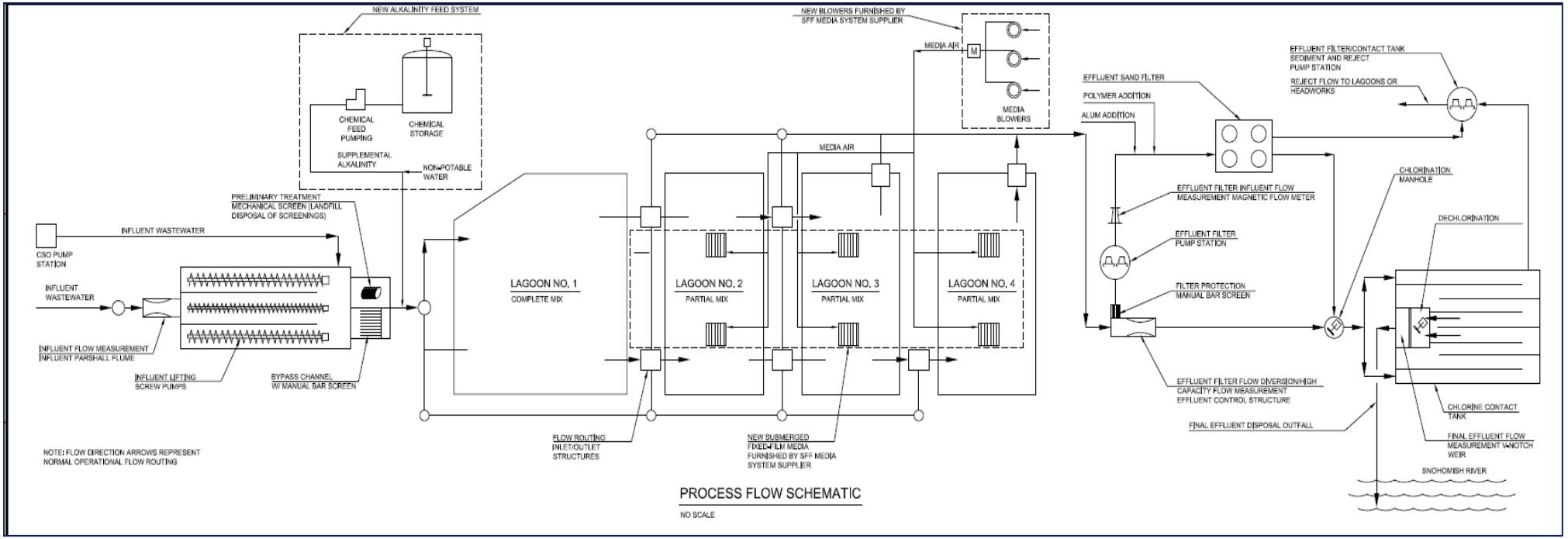
Following treatment in the lagoons, effluent is normally pumped to an effluent filtration process consisting of upflow deep bed sand filters with continuous backwash and then flows by gravity to the disinfection system. Effluent flow in excess of the filters' capacity flows by gravity directly to the disinfection system. The disinfection system uses chlorine gas that is mixed with the effluent in a chlorination manhole upstream of the chlorine contact tank. Sulfur dioxide gas is mixed with the effluent near the end of the chlorine contact tank to reduce the chlorine residual prior to discharge into the Snohomish River. A schematic of the WWTP is shown in Figure 1-1.

If the City were to continue disinfection with chlorine gas and dechlorination with sulfur dioxide, a number of improvements would be required to improve safety, replace aging equipment and comply with current codes. Additionally, the City would prefer a system that is simpler and deals with transporting, handling and storing fewer and less hazardous chemicals. For these reasons, the City decided to conduct testing of peracetic acid (PAA) at the WWTP.

CHEMISTRY OF PAA

PAA is a strong oxidant that has been growing in acceptance as a more potent, yet environmentally friendly, alternative to chlorine gas and sodium hypochlorite. PAA has been approved by the United States Environmental Protection Agency (EPA) specifically as a wastewater disinfectant. Because PAA is a stronger oxidant than chlorine, it requires a significantly lower dose and less contact time to achieve the same level of disinfection. Because PAA does not form disinfection byproducts and diminishes quickly, residual PAA does not increase effluent toxicity as does residual chlorine, except if there is an unusually high PAA residual (typically greater than 1 milligram per liter [mg/L]). As a result, use of PAA yields a lower risk to water quality with respect to effluent toxicity. In the event of a high residual, the effluent can be quenched with sodium bisulfite or sulfur dioxide to reduce the residual, similar to dechlorination of effluent.

FIGURE 1-1: WWTP SCHEMATIC



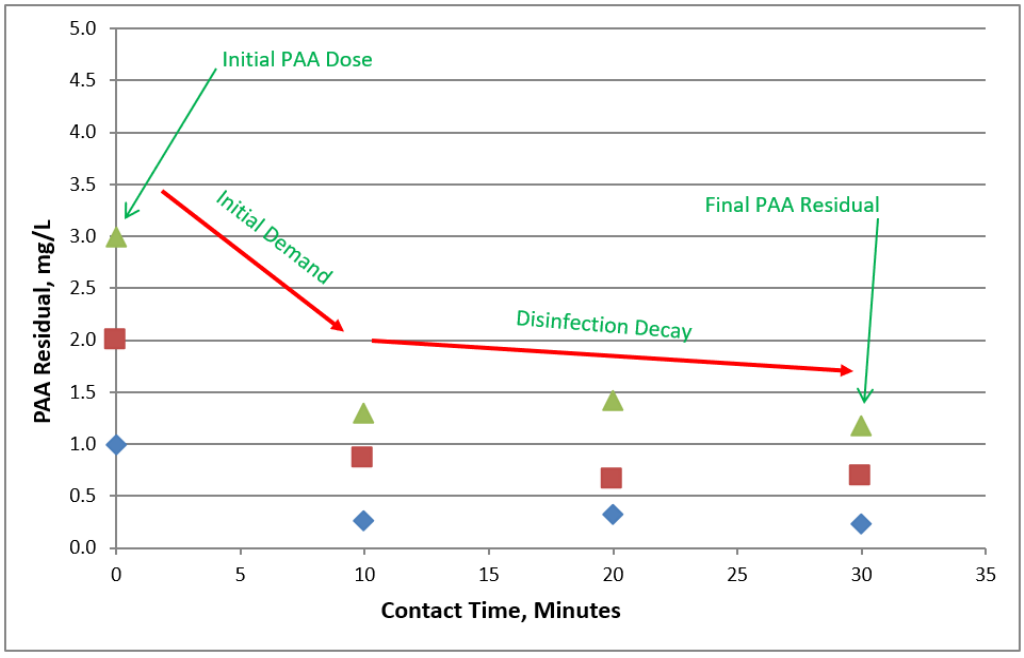
Source: *City of Snohomish Preliminary Submerged Fixed-Film Media Performance Assessment Report* (Kennedy/Jenks, December 2013)

PAA is a clear, colorless liquid with a very low freezing point. The addition of stabilizers to prevent degradation means that it can be stored for a year and experience less than 1 percent decrease in activity. The primary advantages of PAA versus disinfection with various forms of chlorine include:

- No formation of disinfection by products
- Quenching typically not required unless an unusually high dose is required, thereby yielding a relatively high residual
- Longer shelf life compared to sodium hypochlorite
- Less contact time required (typically one-half to one-third compared to chlorine)
- Residual diminishes very quickly
- PAA vendors indicate impacts on effluent pH and $CBOD_5$ are not significant (NOTE: Observations during testing support this assumption, but it is also acknowledged that other applications with higher doses and/or flows (resulting in greater use of PAA) could potentially observe a measurable impact to pH and $CBOD_5$).
- Does not react with ammonia or organic nitrogen (i.e., no breakpoint)

When PAA is added to the effluent, there is an initial demand that must be overcome before disinfection can occur, which can be affected by the amount of $CBOD_5$ present in the effluent. The initial demand is quickly consumed and the remaining residual decays over time as disinfection occurs. The rate of decay can be affected by a variety of factors such as total suspended solids (TSS) or bacterial counts. Figure 1-2 below shows dose response curves from bench scale testing of WWTP effluent conducted in January 2015 for three different PAA doses. If a curve were drawn connecting these points, the area under the curve would be the "CT" value, which is the product of the residual concentration (C) and the time of exposure (T) to that residual concentration.

FIGURE 1-2: PAA DOSE-RESPONSE CURVES



PAA is manufactured by adding hydrogen peroxide (H2O2) to acetic acid (CH3CO2H) to form PAA (CH3CO3H) and water (H2O):

$$H_2O_2 + CH_3CO_2H \leftrightarrow CH_3CO_3H + H_2O$$

Not all of the acetic acid and hydrogen peroxide react to form PAA, so there is also some amount of these chemicals remaining in the PAA solution. The hydrogen peroxide acts as an additional disinfectant, while the remaining acetic acid will register as CBOD5. The most common formulations of PAA solution include 15% or 22% PAA, though formulations with 5% and 12% PAA have also been used in some applications. The primary advantage of the 15% PAA solution is that although there is less PAA, there is a greater amount of hydrogen peroxide and less acetic acid. Because hydrogen peroxide is also an oxidant, having greater amounts of hydrogen peroxide can help offset consumption of PAA from the initial demand, leaving more for disinfection. Conversely, because acetic acid contributes to CBOD5, having greater amounts of acetic acid could increase the CBOD5, thereby reducing the dissolved oxygen and increasing consumption of hydrogen peroxide. The increased hydrogen peroxide consumption could then result in less offset of the initial PAA demand, and so perhaps require a slightly higher PAA dose.

Solutions with 15% PAA typically contain about 40% water, 30-35% acetic acid and 10-15% hydrogen peroxide. Solutions with 22% PAA typically contain about 55% water, 45% acetic acid and 5% hydrogen peroxide. So, a higher concentration PAA solution typically contains less hydrogen peroxide and more acetic acid. This means that the higher concentration of 22% PAA solution requires less volume of chemical to provide the same dose as with a 15% PAA solution. However, the required PAA dose of 22% solution could be slightly higher because the higher percentage of acetic acid may reduce the amount of hydrogen peroxide available to offset the initial demand. However, given the small PAA doses typically required to achieve satisfactory disinfection (typically requiring a dose of around 1 mg/L), the impact of the amount of acetic acid and hydrogen peroxide may not be significant for many applications.

PURPOSE

The purpose of this report is to summarize and evaluate data collected from testing of PAA at the City's WWTP between July 13, 2017 and April 9, 2018. Because PAA has not been previously approved by the Washington State Department of Ecology (Ecology) for disinfection of effluent from a municipal WWTP and is not identified as a disinfection technology in the Criteria for Sewage Works Design (Ecology, August 2008) or "Orange Book", it is considered new and developmental technology, as defined by Section G1-5.4.1 of the Orange Book. As such, the technology must first be thoroughly tested in a full-scale or representative pilot installation before approval can be given for construction and installation of the technology. This report is being submitted to Ecology for review and approval in accordance with the requirements for new/developmental technology. Upon approval of this report, the City intends to proceed with development of plans and specifications for implementation of a permanent PAA system.

ORGANIZATION

This report consists of six sections as follows:

- **Chapter 1 – Introduction**.
- **Chapter 2 – Peracetic Acid System**. Discusses the PAA system used for testing.

- **Chapter 3 – Testing Objectives and Protocol.** Discusses the testing objectives of establishing efficacy of the technology for this application, determining appropriate dosing rates and locations, and assessing the impacts of the two primary PAA formulations and reviews the testing protocol used to assess achievement of these objectives.
- **Chapter 4 – Analysis of Results.** Presents a summary of data collected during testing, interprets trends and evaluates performance in comparison to identified objectives.
- **Chapter 5 – Conclusions, Recommendations & Design Considerations.** Offers conclusions based on analysis of results, recommendations for implementation and important considerations for design.

CHAPTER 2
PERACETIC ACID SYSTEM

This Chapter discusses the components and function of the PAA system utilized for testing. Although this system is not identical to what would be proposed for a permanent installation, it is similar in all critical aspects.

PAA SYSTEM COMPONENTS

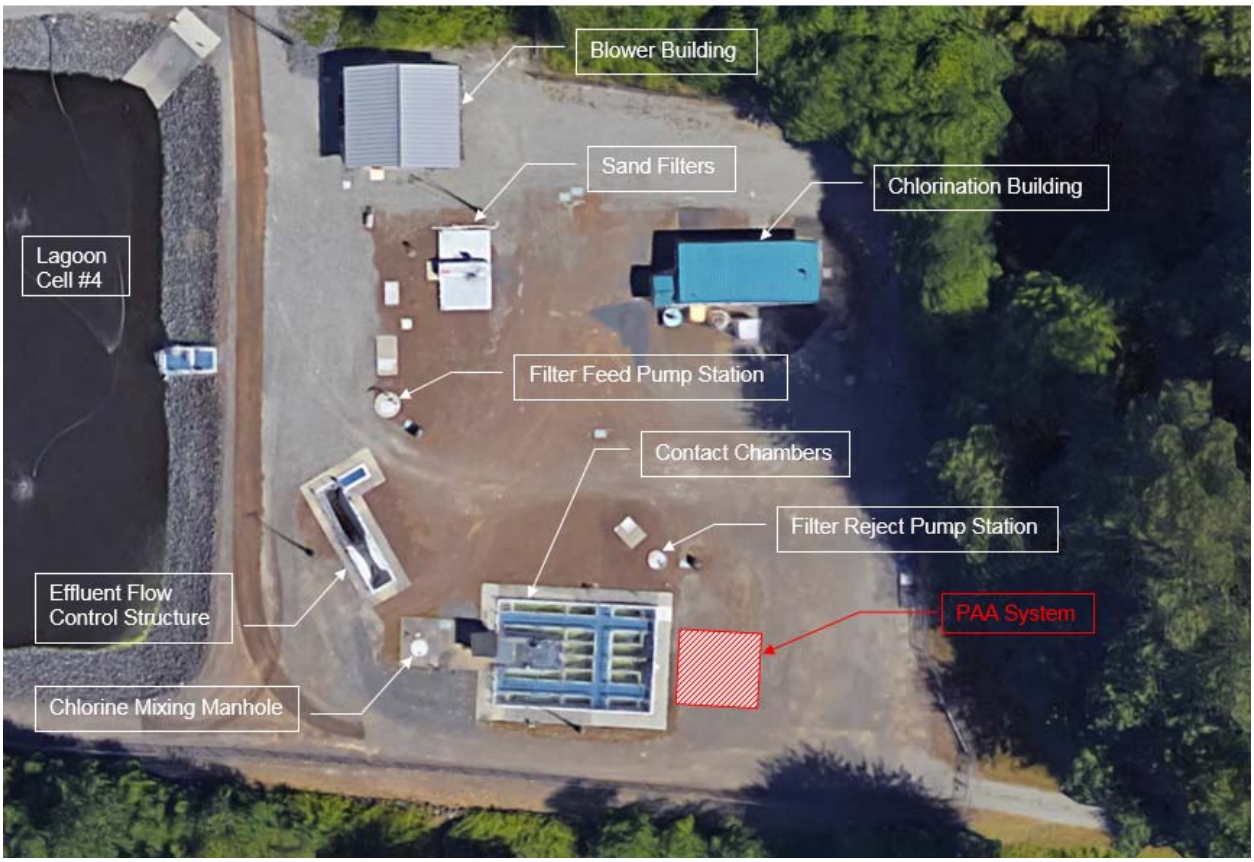
The City contracted with a vendor to provide both the PAA system and the PAA chemical for testing. The PAA system consisted of the following primary components:

- Metering pump skid
- Controllers
- PAA probes
- Chemical diffusers
- Chemical containment

The metering pump skid, PAA totes and containment berm were located outdoors under a tent adjacent to the east side of the chlorine contact tank (CCT), as shown in Figure 2-1 and Figure 2-2. The tent provided protection from rain and also blocked ultraviolet rays that can cause PAA to degrade. The metering pump skid was located in its own weatherproof enclosure with integral containment. The PAA totes were placed in the containment berm using a forklift to contain any accidental release of the chemical. Because PAA doses were small, each 300-gallon tote lasted about one month. At least two totes were kept on site so that when one was near empty the City would have a second tote available for use while a new tote was on order.

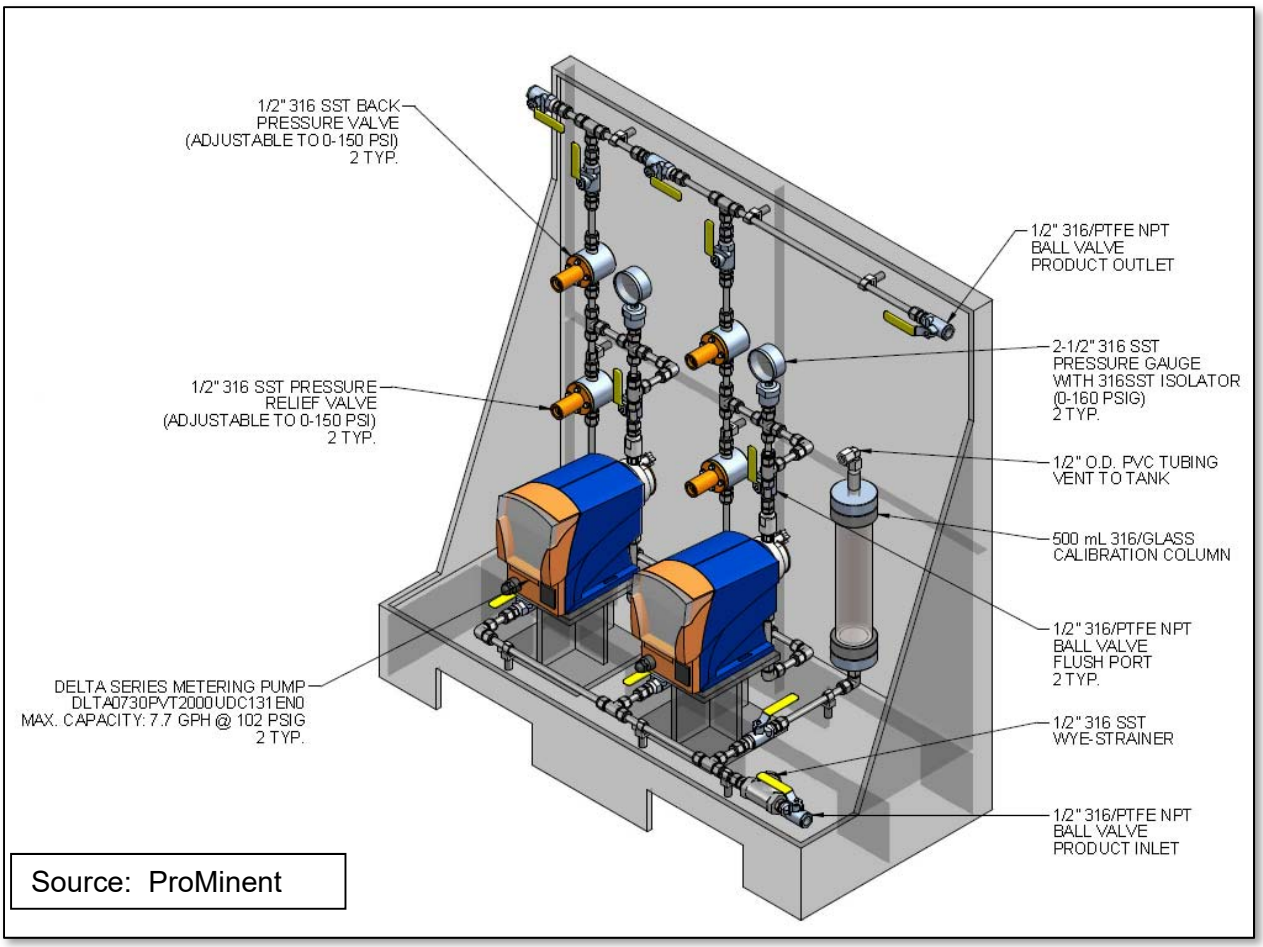
FIGURE 2-1: PAA SYSTEM SETUP

FIGURE 2-2: PAA SYSTEM LOCATION



The metering pump skid included one duty and one standby metering pump (see Figure 2-3). Each pump was sized to deliver at least twice the maximum PAA dose anticipated to be necessary at the current peak day flow, such that only one metering pump was required to run at any given time. Each metering pump was capable of receiving an analog input signal to automatically adjust the dose in response to set control parameters. Additionally, the metering pumps were equipped with pressure relief valves, leak detection, pressure gauges and a calibration column for protection, monitoring and verification of metering pump performance.

FIGURE 2-3: METERING PUMP SKID LAYOUT



The vendor provided piping and tubing to connect the PAA tote to the metering pump skid and to convey PAA discharged from the metering pump skid to the contact chambers. The vendor also provided diffusers for injection of PAA and PAA probes and analyzers to monitor PAA residual.

The CCT is divided into two chlorine contact chambers that operate in parallel. Flow from the chlorine mixing manhole is split evenly between the two contact chambers and then recombines in a common channel just prior to discharge. Due to leakage along the divider wall, both contact chambers are always in service. This leakage issue would be repaired, along with other minor non-structural cracks, as part of implementing a permanent PAA system to maximize flexibility and improve redundancy. Three PAA injection points were located in each contact chamber (see Figure 2-4). One injection point was located in the 2nd pass, one in the 3rd pass, and one in the final (4th) pass of each contact chamber providing three sets of injection points. Initially, one set of diffusers was provided that could be moved between the sets of injection points. This allowed the injection at one of three different locations in each contact chamber. Subsequently, a diffuser was provided for every injection point to make switching between injection locations simpler. Additionally, the existing induction mixer in the chlorine mixing manhole was used as a fourth injection point prior to flow being split between the two contact chambers.

FIGURE 2-4: PAA INJECTION LOCATIONS IN THE CCT

During testing, the different injection points provided a range of theoretical contact times as shown in Table 2-1. Theoretical contact times varied widely due to the wide variation in flows between the wet and dry weather seasons.

TABLE 2-1
THEORETICAL CONTACT TIMES DURING TESTING

Injection Location	Range of Calculated Contact Times
Chlorine Mixing Manhole	35.2 to 302.3 minutes
2nd Pass	Not Used
3rd Pass	22.9 to 76.1 minutes
Final Pass	6.4 to 16.2 minutes

The diffusers are oriented vertically and have perforations along its length below the water surface for dispersal of PAA. PAA discharge from the metering pump is introduced into a continuous stream of non-potable water to provide a dilute solution of PAA with greater volume for effective dispersal. However, during testing it was suggested by the PAA supplier that the chlorine in the non-potable water could be diluting the PAA strength. The City subsequently dosed the neat PAA solution (not diluted with non-potable water) directly into the chlorine mixing

manhole by dripping it into the manhole and using the existing induction mixer to disperse it. The City subsequently noted a reduction in the PAA dose of about one-third, suggesting that the presence of chlorine was reducing the PAA strength. This could be avoided in a permanent installation by either injecting the PAA as a neat solution or using effluent (which would not be chlorinated) as dilution water, which would also avoid having to pay for non-potable water supplied from the City's water system.

The orientation and length of the piping from where the PAA solution splits off to the individual injection points are identical to promote an even split of the solution between the two contact chambers. Non-potable water was provided from a nearby yard hydrant. Because PAA is not compatible with PVC, all piping and tubing carrying PAA was stainless steel and Teflon.

The existing chlorination and dechlorination equipment remained in place and connected to the extent possible such that operation of this equipment could be quickly restored at the conclusion of testing or sooner had there been any serious issues with the PAA system, which there was not.

PAA SYSTEM CONTROLS

To simplify setup of the PAA system for testing and minimize cost, the vendor provided two small controllers, rather than providing a custom control panel with programmable logic controller (PLC) or modifying the City's existing PLC in the nearby Chlorination Building for control of the PAA system. However, implementation of a permanent system will involve modifications to the existing PLC for control of the PAA system for improved integration, monitoring and control. The two small controllers received analog input signals for PAA residual from two PAA probes (provided by the vendor) and for effluent flow signal from the PLC in the Chlorination Building (wired by the City). One of the controllers output an analog signal to the metering pumps for control of the PAA dose. Additionally, five discrete signals and one analog signal were wired to the existing PLC in the Chlorination Building for monitoring. The five discrete signals included a shared pump alarm signal, High PAA residual, Low PAA residual, High-High PAA residual and Low-Low PAA residual. The analog signal was for monitoring the final PAA residual. Because of the issues with the PAA probes discussed below, real-time monitoring of PAA residual was not reliable and the City instead relied on analysis of daily grab samples for monitoring and control adjustments. Had any alarm conditions occurred that could not be immediately addressed, the City had the capability to remotely close the CCT outlet gates to cease discharge to the Snohomish River until the issue was resolved. There were not any instances during the test period that required this action.

The two PAA probes were used to measure the initial PAA residual a short distance downstream of the injection point (following reduction from the initial demand) and final PAA residual just prior to discharge into the outfall. The two probes were installed in one of the contact chambers, with the assumption that residuals in the parallel chamber would be very similar as they operate under very similar conditions. These PAA residual measurements were intended to be used both for monitoring and calculating a CT value for control. The CT value would be calculated by averaging the initial and final PAA residual and multiplying that value by estimated contact time (based on the known volume of the contact chambers, number of contact chambers in service and dosing location). The PAA dose would be automatically adjusted to maintain a target CT value as the flow (i.e., contact time) and PAA residuals changed over time. Controlling based on a target CT value was intended to provide more consistent effluent quality and more cost-effective use of chemical compared to either flow-paced dosing or maintaining a target residual measurement.

PAA RESIDUAL MONITORING

Throughout the testing period, the vendor experimented with different probes and probe configurations. Two different probes manufactured by ProMinent and one manufactured by ATI were utilized at different points during testing. The probes were initially installed in one of the contact chambers, and later moved outside of the contact chambers in a flow-through configuration with a continuous sample stream. The timeline of the various probes and configurations is as follows:

- Installed initial probes provided by ProMinent in the channels of one of the contact chambers at startup.
- After a few weeks of testing, the membranes on the probes were replaced with a different type that were intended to improve the ability to read low residuals.
- After about a month of testing, the probes were moved out of the channels and the sample pumps normally used for the chlorine analyzers were re-plumbed to provide a sample stream to the probes in the flow-through configuration. It was believed that the low velocity of water in the channels may have increased plugging of the membrane.
- After nearly two months of testing, programming of the controllers was modified to allow flow-paced dose control, since control based on CT could not be enabled due to issues with the probes consistently and reliably monitoring PAA residual. Prior to this, the City had controlled the PAA dose by manually adjusting the speed of the metering pump.
- After about three months of testing, new probes from ProMinent and ATI were installed. These probes were intended to provide better accuracy of measurement at low residual concentrations. Initially the ATI probe seemed to perform reasonably well, but could not consistently maintain accuracy. It appeared that this could have been caused by air collecting at the probe, but this could not be confirmed. After the manufacturer's allowed trial period, the ATI probe was returned. The second ProMinent probe did not appear to perform any better than the initial ProMinent probe.
- About a month before testing was completed, a new holder for the ProMinent probe was provided with a weir configuration that was intended to reduce fouling and extend the life of the membrane cap. It had been noted previously that performance of the probe was improved for a period of time following replacement of the membrane cap and subsequent recalibration. Although this probe configuration performed better, by the time the probe readings were stabilized there was only two weeks remaining in the testing period, which was not sufficient time to assess whether this probe configuration would provide accurate and reliable readings.
- During the last few days of testing, the City utilized an existing chlorine analyzer to monitor PAA residual, since it utilizes the same DPD method as used to measure PAA residual in the grab samples. The City reported that readings from the chlorine residual analyzer appeared to track with grab sample measurements based on a simple single-point calibration about as well as the PAA probes. Perhaps with two-point calibration the accuracy could be improved and with a permanent system the PLC could be used to apply the conversion factor for reporting PAA residual.

Based upon these experiences with monitoring PAA residual, the permanent installation will be designed with the intent of having flow-paced PAA dose control and utilizing daily PAA residual grab samples to adjust the target dose. However, the design will also allow for incorporating PAA residual monitoring and CT control should a sufficiently accurate and reliable PAA residual

probe and configuration be identified through further investigation. Upon installation and startup of a permanent PAA system, the City will have the opportunity to further test PAA probe types/configurations and experiment with using their chlorine residual analyzers for monitoring PAA residual. In addition to the ProMinent probe and modified holder that showed some success at the end of testing, the City could also try the ATI probe again in a configuration that eliminates the air entrapment issue it had during the previous trial. The City indicated that positioning the probe at an angle appeared as though it could resolve the issue with air entrapment for the ATI probe. Even if it is determined that sufficiently accurate residual monitoring cannot be achieved for control of the system, residual monitoring could still be useful for alarming if it is determined that a reasonable level of accuracy could be maintained. This application is not the only one to have difficulties with achieving reliable and accurate measurement of PAA residual. The Tri-City Water Pollution Control Plant in Clackamas County, Oregon has also not found a successful method of PAA residual measurement for use with their PAA system.

CHAPTER 3
TESTING OBJECTIVES AND PROTOCOL

This Chapter discusses the testing objectives of establishing efficacy of the technology for this application, determining appropriate dosing rates and locations, and assessing the impacts of the two primary PAA formulations and reviews the testing protocol used to assess achievement of these objectives.

EFFICACY OF PAA

The purpose of this objective is to prove that PAA is capable of achieving the necessary levels of disinfection to comply with current National Pollutant Discharge Elimination System (NPDES) permit limits for fecal coliform. Initially, a conservatively high PAA dose (average of 2.1 mg/L through the first month of testing) was applied to maintain a significant residual (the initial PAA residual averaged about 0.5 mg/L through the first month of testing) and ensure adequate disinfection from the beginning. Prior bench scale tests suggested a dose of 1.0 to 1.5 mg/L yielding a predicted residual of 0.3 to 0.5 mg/L. The conservatively high dose applied for the first month of testing was purposefully higher than the dose thought to be required for disinfection while maintaining a PAA residual below 1.0 mg/L in accordance with the NPDES permit.

PAA DOSING

The purpose of this objective is to confirm that the PAA dose required to achieve adequate disinfection will be cost-effective compared to alternative methods of disinfection. Once the efficacy of PAA was demonstrated, the dose was reduced to levels that were still capable of meeting the target monthly geometric mean for effluent fecal coliform of 50 colony forming units per 100 milliliters (CFU/100 mL), while decreasing the volume of PAA used. The target disinfection level is one-quarter of the permitted limit of 200 CFU/100 mL. This allows a substantial factor of safety to accommodate a sudden change of conditions, failure of equipment, or other unforeseen circumstances and affords the operators time to react if not operating in a fully automated control mode. Additionally, data collected on PAA dose, contact time and effluent fecal coliform concentrations were used to assess CT values that would achieve the target disinfection level. As discussed previously, controlling PAA dose based on a target CT value would facilitate a more cost-effective use of PAA. As flows decrease and contact time increases, the PAA dose can similarly decrease to maintain the same target CT value. This reduces PAA use compared to control based on a flow-paced target dose. It is expected that CT control would also provide more stability in performance of the PAA system. Based on results of prior bench scale tests, it appears that a CT value between 40 and 60 is necessary to achieve effluent fecal coliform below 50 CFU/100 mL. However, control based on CT necessitates accurate and reliable monitoring of PAA residual, which would need to be confirmed subsequent to implementation of a permanent PAA system as discussed previously.

PAA INJECTION LOCATION

The purpose of this objective is to determine the necessary contact time to achieve adequate disinfection and how seasonal variations in flow affect the injection location for efficient disinfection. PAA was initially injected at the existing chlorine mixing manhole just upstream of the CCT to ensure sufficient contact time for disinfection. Flow from the chlorine mixing manhole is split evenly between the two contact chambers in the CCT and then recombines in a common channel just prior to discharge. The injection location was subsequently adjusted among the four different locations provided to achieve sufficient contact time for disinfection while maintaining a

measurable final residual. If the contact time is too short, sufficient disinfection will not occur. If the contact time is too long, use of PAA may become excessive to maintain a measurable final residual because of its rapid decay rate. As seasonal changes in flow occurred, additional changes in the injection location were made to maintain efficient disinfection. For a permanent installation, solenoid valves could be utilized to automate switching between injection locations based on flow. Additionally, the number of contact chambers in service could also be automated based on flow by retrofitting actuators on the CCT inlet gates and utilizing existing actuators on the CCT outlet gates.

COMPARISON OF PAA FORMULATIONS

The purpose of this objective is to compare performance of the PAA system under similar circumstances using the two different PAA formulations. Through the prior objectives, the City used the 15% PAA formulation. Once PAA dosing and injection locations had been investigated and system performance optimized to the extent practical, the PAA system was operated for a few more weeks to establish a baseline for comparison using the 15% PAA formulation. The City then changed to using the 22% PAA formulation for a period of about one month. Both prior to and during testing of the 22% PAA formulation, which occurred in the middle of the wet weather season, the injection location remained at the chlorine mixing manhole.

TESTING PROTOCOL

As discussed in the *City of Snohomish Peracetic Acid Engineering Report* (July 2016, BHC Consultants) a full-scale test of PAA was necessary to produce meaningful and useful results, as it was concluded a pilot-scale test would not produce results that would translate accurately to a full-scale application.

The testing period was planned to have a duration of 6 to 9 months. This would allow sufficient time to complete the testing protocol and also operate the PAA system under seasonal variations in effluent quality and quantity. During the wet weather season, flows are higher due to substantial increases in I&I (primarily from the combined sewer system), effluent temperatures are lower, and aeration of the SFF media modules is cycled to save energy. The higher flows mean only a portion of the effluent flow is filtered through the existing sand filters, resulting in higher effluent TSS. The cycled aeration of the SFF media modules and lower temperatures result in less nitrification occurring in the lagoons. Additionally, the lower temperatures inhibit growth of algae and duck weed in the lagoons. During the dry weather season, flows are lower due to reduced I&I, effluent temperatures are higher, and aeration of the SFF media modules is constant. The lower flows mean that normally all of the effluent flow is filtered through the existing sand filters, resulting in lower effluent TSS. Constant aeration of the SFF media modules and higher temperatures result in the effluent being fully nitrified. Additionally, the higher temperatures tend to encourage growth of algae and duck weed in the lagoons. However, the ultrasonic transducers installed in Lagoons No. 2, 3 and 4 help mitigate algae growth in those lagoon cells.

The testing protocol originally proposed in the *City of Snohomish Peracetic Acid Engineering Report* (July 2016, BHC Consultants) and the actual testing protocol conducted are shown in Table 3-1. The actual testing protocol deviated from the proposed protocol due to inability to establish reliable and accurate online residual PAA monitoring. Although all of the main objectives were accomplished after about 6-1/2 months of testing, the testing period was extended to a full nine months in an effort to test an alternate PAA probe configuration and also gather additional data for analysis.

TABLE 3-1
PROPOSED AND ACTUAL TESTING PROTOCOLS

Objective	Originally Proposed		Actual	
	Testing Item	Duration	Testing Item	Duration
Efficacy of PAA	PAA Pilot System Setup and Training	1 week	PAA System Setup and Training (7/10/17-7/14/17)	1 week
	PAA Pilot System Startup and Troubleshooting	1 week	PAA System Startup & Troubleshoot PAA Probes (7/14/17 – 9/3/17)	7 weeks (ended with flow-paced dosing)
	Dosing based on PAA residual	4 weeks	Verifying effective disinfection with PAA (7/17/17 – 9/3/17)	7 weeks (resolving PAA probe issues)
PAA Dosing Rate	Dosing based on target CT value	4 weeks	Flow-paced dosing set point manually adjusted per residual (twice daily grabs) (9/4/17 – 10/8/17)	5 weeks
PAA Dosing Location	Adjust PAA dosing locations	2 weeks	Adjust PAA injection location for dry weather (7/31/17 – 9/3/17)	5 weeks (changed location twice)
	Reassess target CT value	2 weeks	N/A (only using flow-paced dosing, not CT control)	0 weeks
	Repeat dose location and CT adjustments if necessary		Adjust PAA injection location for wet weather (10/16/17 – 11/12/17)	4 weeks (changed location twice)
	Seasonal dose adjustment	4 weeks	Seasonal dose adjustment (10/16/17 – 11/12/17)	4 weeks (concurrent w/ location changes)
Comparison of PAA Formulations	Establish baseline with initial formulation	4 weeks	Establish baseline with initial formulation (11/13/17 – 12/12/17)	4½ weeks
	Reassess target CT with alternate formulation	2 weeks	Reassess dose with alternate formulation (12/13/17 – 12/27/17)	2 weeks
	Establish baseline with alternate formulation	4 weeks	Establish baseline with alternate formulation (12/28/17 – 1/25/18)	4 weeks
	Decommissioning	1 week	N/A (moved to later)	
Test Alternate PAA Probe Configuration	N/A	0 weeks	Collect additional data and test alternate probe configuration (1/26/18 – 4/9/18)	10½ weeks
	N/A	0 weeks	Decommissioning (4/6/18 – 4/10/18)	½ week

SAMPLING AND LABORATORY TESTING SCHEDULE

A summary of the sampling and laboratory testing implemented to collect data for evaluating performance and efficiency of the PAA system in relation to achieving the testing objectives is provided in Table 3-2 below. All laboratory analyses will be performed in accordance with the latest version of the Standard Methods for the Examination of Water and Wastewater.

TABLE 3-2
SAMPLING AND LABORATORY TESTING SCHEDULE

Sample Location	Sample Type	Analysis	Frequency	Notes
Lagoon 4 Effluent	Grab	Fecal Coliform	2 / week	1
		pH	2 / week	1,2
		$CBOD_5$	1 / week	1
		Dissolved Oxygen	2 / week	1, 2
Filtered Effluent	Grab	Filtered Feed Flow	Continuous	1
		Fecal Coliform	2 / week	1
		pH	2 / week	1,2
		$CBOD_5$	1 / week	1
		Dissolved Oxygen	2 / week	1, 2
WWTP Effluent	24-Hour Composite	Effluent Flow	Continuous	
		Temperature	Continuous	
		$CBOD_5$	2 / week	
		TSS	2 / week	
		Ammonia-N	2 / week	
		WET Testing (Acute)	2 / Test Period	3
		WET Testing (Chronic)	2 / Test Period	3
	Grab	Initial PAA Residual	Daily	4
		Final PAA Residual	Daily	4
		Fecal Coliform	5 / week	5
		pH	Daily	
		Dissolved Oxygen	2 / week	
PAA System	Grab	PAA Pump Speed	Daily	
		PAA Dose (Calculated)	Daily	

Notes:
1) Measurements for non-filtered lagoon effluent and filtered effluent will be proportioned based on flow to determine a representative water quality for flow entering the disinfection process.
2) Dissolved oxygen and pH will be measured with handheld meters.
3) Perform one set of WET tests (acute and chronic) with 15% PAA and a second with 22% PAA (the City intends to try both formulations during the pilot study).
4) After the first two months of testing when it was determined the PAA probes may not produce accurate and reliable measurements for the remainder of the test period and manually adjusted flow-paced dose control was implemented in place of CT based control, the City began performing daily PAA residual measurements on grab samples.
5) Although only required to sample and test for fecal coliform twice per week, the City typically does so 5 times per week, except for holidays that occur on a week day.

Both acute and chronic whole effluent toxicity (WET) testing were performed twice during the testing period. The initial set of WET tests were conducted not long after a representative dose was established following the initial conservative dose. A second set of WET tests were conducted when the PAA formulation was changed and a baseline for that formulation had been established.

The method used for testing PAA residual in the grab samples followed Standard Method "4500-Cl^- G-2000. DPD Colorimetric," as outlined in the *Standard Methods for the* Examination of Water and Wastewater, except for two changes. The PAA vendor (EnviroTech) indicated a shorter wait time should be utilized (chlorine wait time is 3 minutes and for PAA 30 seconds is recommended) and a factor of 1.07 applied to the results. The kit employed for this testing method can be used in the field, which is important because PAA residual dissipates quickly. The PAA vendor recommend using the test kit with a handheld colorimetric meter to allow measurement of PAA residual immediately following sample collection for accurate results. The PAA vendor also indicated that EPA has not settled on an approved testing method for PAA, because PAA does not rank high enough in the "dangerous chemical" category. So, there is no method under 40 CFR 136 that applies to PAA, including the method used. However, the method used does follow a recognized Standard Method, such that the test results will be reliable and repeatable. A summary of all of the test methods that were used and the associated method detection limit (MDL) is provided in Table 3-3 below.

TABLE 3-3
SAMPLE TESTING METHODS

Parameter Tested	Standard Method	MDL
pH	4500-H^+ B-2000	0 - 14
$CBOD_5$	5210 B-2001	2.0 mg/L
Fecal Coliform	9222 D-1997	1 CFU/100 mL
Ammonia-Nitrogen	4500-NH_3 D-1997	0.1 mg/L
TSS	2540 D-1997	2 mg/L
Peracetic Acid	Hach Method 10290	0.05 mg/L

As indicated in Table 3-3, Hach Method 10290 is used to measure PAA residual in grab samples. According to Hach, potential interferences include chlorine, chloramines, ozone, manganese, chromium, bromine, chlorine dioxide, excessively high or low pH, or excessive hardness. Of these, only hardness is a potential concern, as effluent pH consistently remains near neutral, but alkalinity is added to the process to support nitrification. Effluent hardness should be periodically checked to ensure it is below 250 mg/L as $CaCO_3$. The most recent monitoring has indicated effluent alkalinity below 150 mg/L as $CaCO_3$.

CHAPTER 4
ANALYSIS OF RESULTS

This Chapter presents a summary of data collected during testing, interprets trends in the data and evaluates performance in comparison to identified objectives.

EVALUATION PARAMETERS

Evaluation of the effectiveness and efficiency of PAA is based upon meeting associated limits in the current NPDES permit and target levels fecal coliform and PAA dose, which are summarized in Table 4-1. The target PAA dose is based upon achieving annual operation and maintenance (O&M) costs that are comparable to other alternatives to chlorine gas that have been considered (e.g., delivered sodium hypochlorite and onsite generation of sodium hypochlorite). As mentioned previously, the target fecal coliform level is well below the permitted value to provide a factor of safety for a sudden change of conditions, failure of equipment, or other unforeseen circumstances.

TABLE 4-1
SUMMARY OF PERFORMANCE EVALUATION CRITERIA

Parameter	Value
Target Average PAA Dose	1.0 mg/L
Target Fecal Coliform Monthly Geometric Mean	50 CFU/100 mL
Permitted Fecal Coliform 7-Day Geometric Mean	≤ 400 CFU/100 mL
Permitted Fecal Coliform Monthly Geometric Mean	≤ 200 CFU/100 mL
Maximum Permitted Effluent PAA Residual	1 mg/L
Permitted Effluent pH	6.2 – 9.0

PRE-DISINFECTION EFFLUENT

The quantity and quality of the effluent prior to disinfection through the testing period are summarized in Table 4-2. The order-of-magnitude difference between the minimum and maximum daily flow is due to normal seasonal variation and high infiltration and inflow that occurs in the portion of the collection system that has combined storm and sanitary sewers. Similarly, these large fluctuations in flow and the resulting fluctuations in retention time within the lagoons likely account for much of the wide variation in pre-disinfection fecal coliform concentrations.

The pre-disinfection effluent quality data shown in Table 4-2 represent weighted averages between effluent from Lagoon 4 and filtered effluent. Since the existing effluent filters were limited to a capacity of approximately 0.9 MGD during the testing period, the different effluent quality measurements for the Lagoon 4 effluent and filtered effluent were weighted by the amount of flow from each and averaged to develop a value representative of the combined effluent prior to disinfection.

TABLE 4-2
PRE-DISINFECTION EFFLUENT QUANTITY AND QUALITY DURING TESTING

Parameter	Value
Minimum Daily Effluent Flow	0.56 MGD
Average Effluent Flow	1.52 MGD
Maximum Month Effluent Flow	2.55 MGD
Maximum Daily Flow	5.29 MGD
Minimum Fecal Coliform	6 CFU/100 mL
10th Percentile Fecal Coliform	97 CFU/100 mL
Average Fecal Coliform	2,548 CFU/100 mL
90th Percentile Fecal Coliform	5,380 CFU/100 mL
Maximum Fecal Coliform	34,792 CFU/100 mL
Minimum $CBOD_5$	2.0 mg/L
10th Percentile $CBOD_5$	3.0 mg/L
Average $CBOD_5$	6.6 mg/L
90th Percentile $CBOD_5$	10.7 mg/L
Maximum $CBOD_5$	14.5 mg/L
Minimum pH	6.51
10th Percentile pH	7.27
Average pH	7.49
90th Percentile pH	7.74
Maximum pH	7.84
Minimum Dissolved Oxygen	3.8 mg/L
Average Dissolved Oxygen	7.1 mg/L
Maximum Dissolved Oxygen	10.6 mg/L
Minimum Temperature	5.4 °C
Average Temperature	13.4 °C
Maximum Temperature	26.3 °C

POST-DISINFECTION EFFLUENT

The final effluent quality (post-disinfection) throughout the testing period is summarized in Table 4-3. The pH always remained within the permitted range and final PAA residual never closely approached or exceeded the permitted limit of 1 mg/L. Of all the final effluent fecal coliform measurements, 90 percent were at or below 83 CFU/100 mL and 77 percent were at or below 50 CFU/100 mL. The final effluent was always well below the permitted monthly average 5-day carbonaceous biochemical oxygen demand ($CBOD_5$) of 30 mg/L and 96 percent of all final effluent total suspended solids (TSS) measurements were at or below the permitted monthly average TSS concentration of 30 mg/L. Only 3 of the 72 measurements for final effluent TSS exceeded 30 mg/L, though the monthly averages remained significantly below the permit limit.

TABLE 4-3
POST-DISINFECTION EFFLUENT QUALITY DURING TESTING

Parameter	Value
Minimum Fecal Coliform	2 CFU/100 mL
10th Percentile Fecal Coliform	3 CFU/100 mL
Average Fecal Coliform	43 CFU/100 mL
90th Percentile Fecal Coliform	83 CFU/100 mL
Maximum Fecal Coliform	667 CFU/100 mL
Minimum PAA Residual	0.02 mg/L
10th Percentile PAA Residual	0.07 mg/L
Average PAA Residual	0.20 mg/L
90th Percentile PAA Residual	0.33 mg/L
Maximum PAA Residual	0.68 mg/L
Minimum pH	6.97
10th Percentile pH	7.34
Average pH	7.52
90th Percentile pH	7.74
Maximum pH	7.92
Minimum $CBOD_5$	2.0 mg/L
10th Percentile $CBOD_5$	4.0 mg/L
Average $CBOD_5$	7.1 mg/L
90th Percentile $CBOD_5$	12.0 mg/L
Maximum $CBOD_5$	16.0 mg/L
Minimum TSS	2.0 mg/L
10th Percentile TSS	3.1 mg/L
Average TSS	11.3 mg/L
90th Percentile TSS	20.0 mg/L
Maximum TSS	34.0 mg/L
Minimum Dissolved Oxygen	6.5 mg/L
Average Dissolved Oxygen	8.4 mg/L
Maximum Dissolved Oxygen	10.8 mg/L

As shown in Figure 4-1, the final effluent (post-disinfection) pH was always between 7 and 8 (except for one day that had a final effluent pH of 6.97). Early in the testing period when the PAA dose was high, there was at times a noticeable drop between the pre- and post-disinfection pH of up to 0.3. However, following that early period, after which lower doses were generally applied, the difference between the pre- and post-disinfection pH was generally not significant. There were a few instances where the pre-disinfection pH was noticeably lower than the post-disinfection pH. It is unclear if this could have been related to process conditions or due to a few non-representative samples. Although it appears that the low pH measurements coincide with low level in the lagoons, it is not exactly known how that might have impacted pH.

FIGURE 4-1: PRE- AND POST-DISINFECTION PH

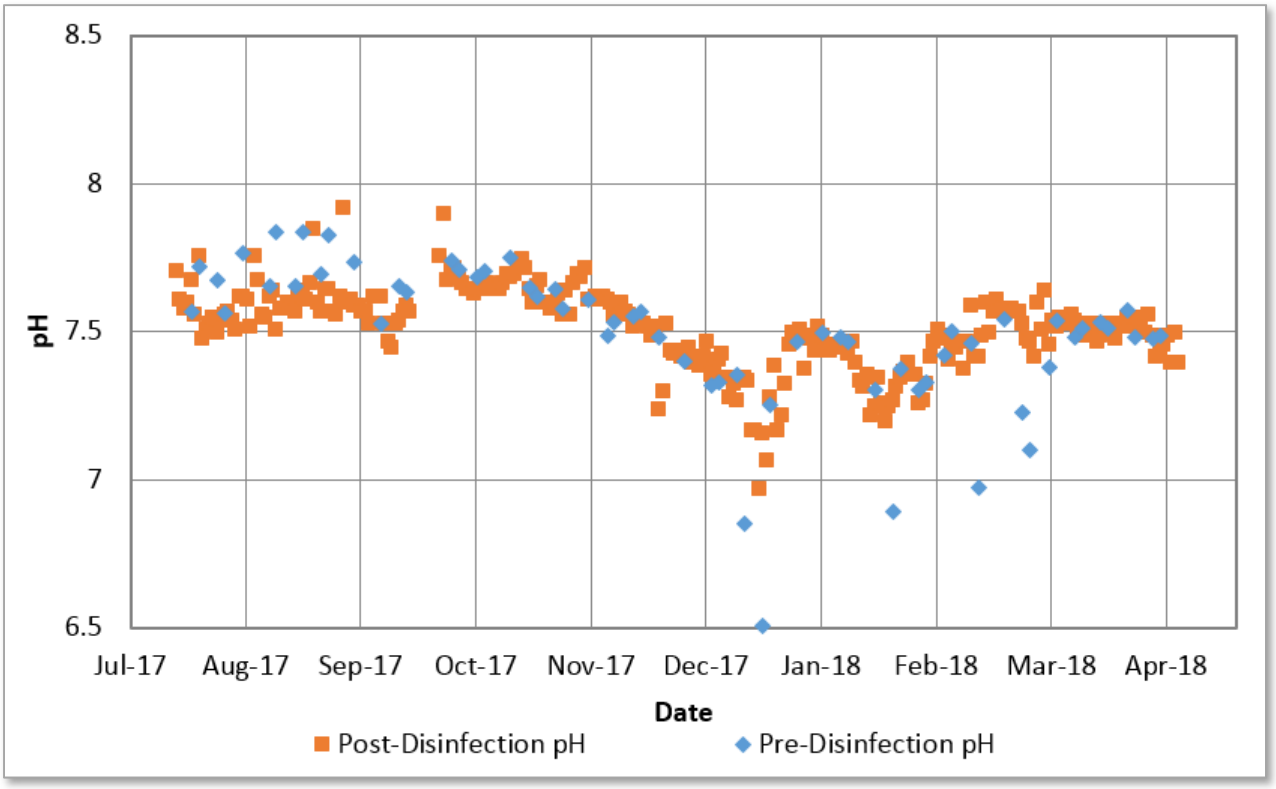


Figure 4-2 compares TSS and fecal coliform concentrations in the final effluent. As shown in Figure 4-2, the trendline has a low correlation coefficient that indicates a relatively small correlation between TSS and fecal coliform concentrations in the final effluent that is not greatly significant. Figure 4-3 compares pre- and post-disinfection $CBOD_5$. It appears during the first two months when the PAA dose was higher compared to the rest of the testing period that acetic acid in the PAA solution could have added to the $CBOD_5$. There is no way to determine for sure the small increase in effluent $CBOD_5$ is attributed to acetic acid in the PAA solution. However, it appears that later during periods of lower dose there is generally less increase between the pre- and post-disinfection $CBOD_5$ suggesting that likely some of that increase was due to the acetic acid. Because even at high PAA doses the potential impact was relatively small (about a 2 mg/L increase in $CBOD_5$) and the effluent $CBOD_5$ remained well below the permit limit throughout the testing period, the potential added $CBOD_5$ from the PAA solution is not of significant concern.

FIGURE 4-2: FINAL EFFLUENT TSS VS. FINAL EFFLUENT FECAL COLIFORM

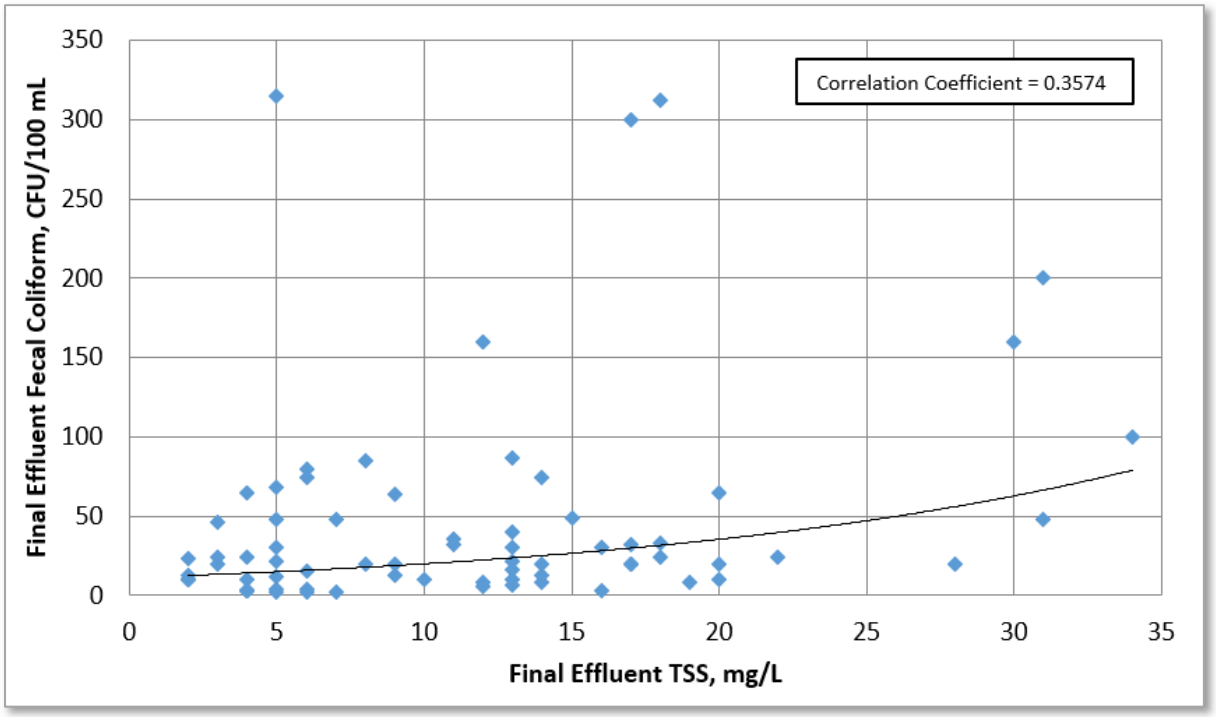
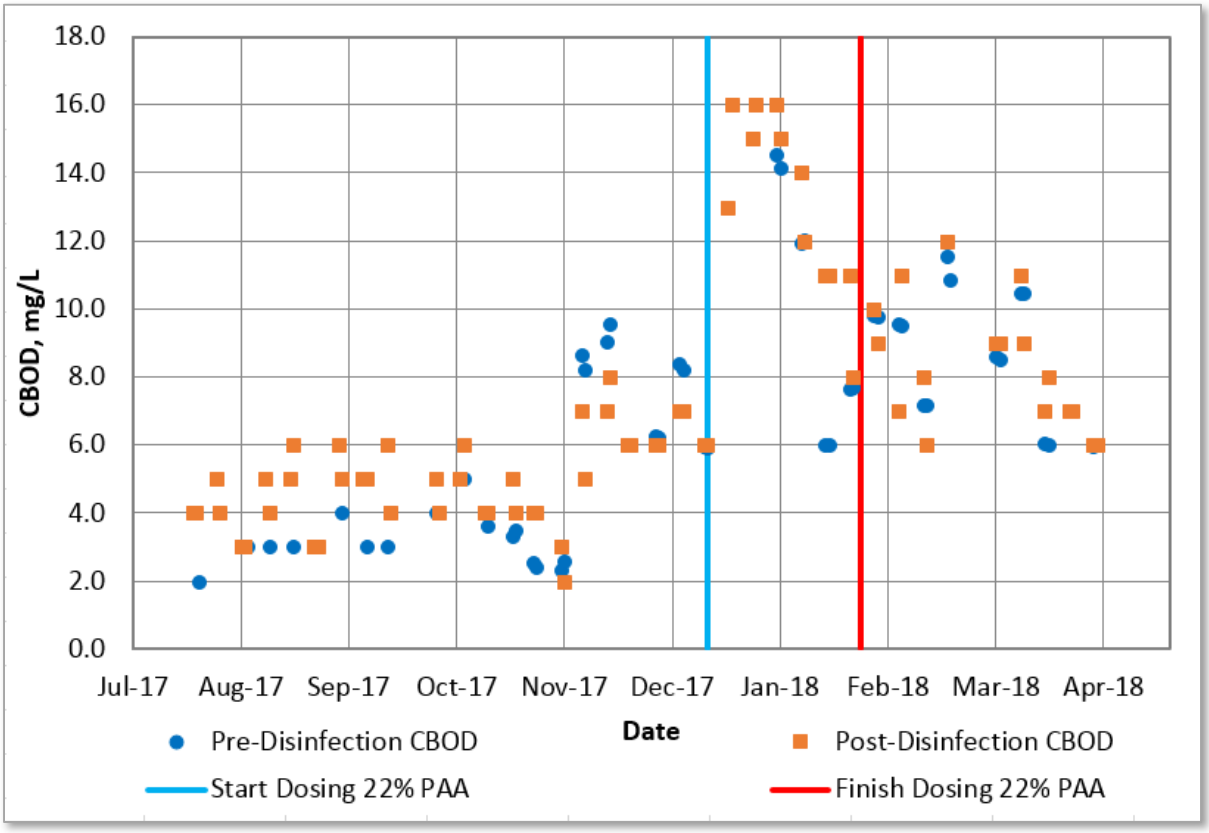


FIGURE 4-3: PRE- AND POST-DISINFECTION CBOD5



EFFICACY OF PAA

A summary of final effluent fecal coliform throughout the testing period is shown in Table 4-4. No data is shown for the 10th week (September 15, 2017 through September 21, 2017), because no effluent was discharged during this time period due to planned annual maintenance activities. Flow was attenuated in the lagoons during performance of the maintenance activities.

TABLE 4-4
SUMMARY OF FINAL EFFLUENT FECAL COLIFORM DURING TESTING PERIOD

Time Period		Geometric Mean CFU/100 mL		Time Period		Geometric Mean CFU/100 mL	
Month	Week	Month	Week	Month	Week	Month	Week
Jul	1	2	2	Dec	21	31	27
	2		2		22		25
	3		2		23		10
Aug	4	6	2		24		38
	5		2		25		127
	6		10	Jan	26	30	52
	7		11		27		26
Sep	8	32	20		28		9
	9		13		29		26
	10		N/A	Feb	30	62	91
	11		31		31		59
Oct	12	40	70		32		46
	13		59		33		249
	14		43	Mar	34	14	13
	15		31		35		12
	16		44		36		19
Nov	17	19	24		37		10
	18		46		38		23
	19		6	Apr	39	52	52
	20		15				

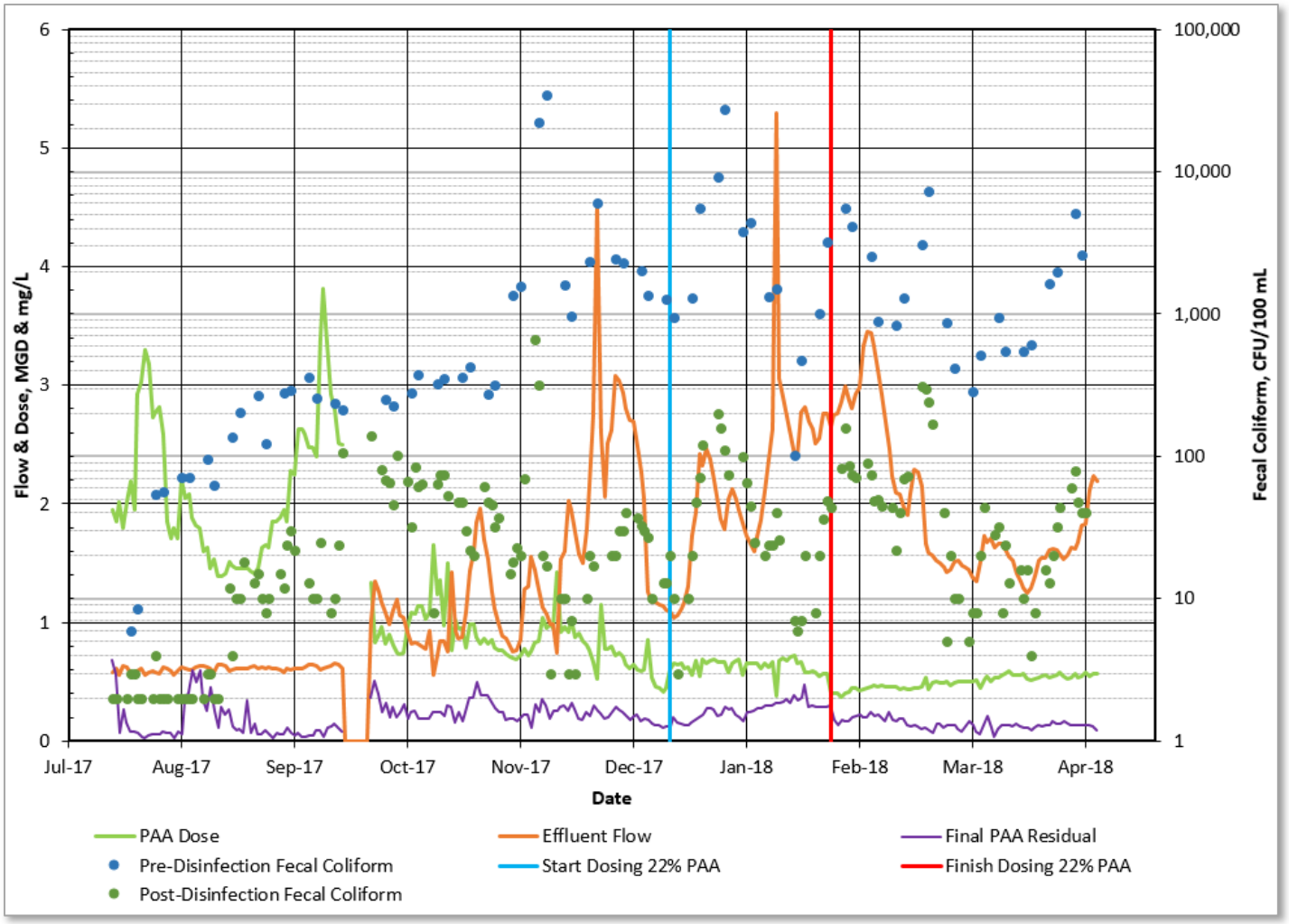
The geometric means for every month and every week of the testing period were significantly below permitted limits. Only February 2018 had a monthly geometric mean significantly above the target of 50 CFU/100 mL. This appears to be due to a lagoon turnover event in late February that resulted in temporarily elevated effluent TSS and fecal coliform counts. As this turnover event was not anticipated, the PAA dose was not adjusted. This illustrates the benefit of targeting a low fecal coliform count, as even with this sudden change in effluent quality the resulting monthly and weekly geometric means were still well below the permit limits.

PAA DOSING

A comparison of effluent flow, PAA dose and pre- and post-disinfection fecal coliform concentrations are shown in Figure 4-4 below. As would be expected, when effluent flow is low and essentially all effluent is filtered, the pre-disinfection fecal coliform concentrations are lower,

which also generally yields lower post-disinfection fecal coliform concentrations. As evident in the Figure 4-4, the dry weather low flow period transitioned to the higher flow wet weather period around mid-October for the duration of testing.

FIGURE 4-4: TESTING PERIOD EFFLUENT FLOW, PAA DOSE & RESIDUAL AND FECAL COLIFORM



As mentioned earlier, the PAA dose was initially intentionally high (average over 2 mg/L) for the first few weeks of testing and then was gradually reduced. At the beginning of August 2017, the injection location was moved from the chlorine mixing manhole to the 3rd pass in the contact chambers and then to the final pass by the end of August, which significantly reduced the contact time. This reduction in contact time, plus increasing pre-disinfection fecal coliform concentrations, precipitated an increasing trend in the PAA dose but improved the ability to maintain a measurable final PAA residual. Following the shutdown of discharge for annual maintenance activities, the dose was reduced significantly, which increased the post-disinfection fecal coliform concentrations. However, the increased fecal coliform concentrations were still well within the permit limits and yielded a higher PAA residual. By the middle of October 2017, the injection location was moved back to the 3rd pass and then to the chlorine mixing manhole after the first week of November 2017. This was done to provide more contact time in response to increasing effluent flows and increasing pre-disinfection fecal coliform concentrations. This

additional contact time avoided an increase in the PAA dose while maintaining a measurable residual and decreasing post-disinfection fecal coliform concentrations, even as pre-disinfection fecal coliform concentrations increased.

Throughout the entire testing period, the PAA dose averaged 1.0 mg/L. Ignoring the first 4 weeks of testing when the PAA dose was intentionally high, the average PAA dose for the remainder of the testing period was approximately 0.9 mg/L. After further optimization and eliminating chlorine interference from carrier water, the average dose during the wet weather period was 0.6 mg/L with a dose between 0.4 and 0.9 mg/L 90% of the time. All of these values are at or below the target dose of 1.0 mg/L for PAA to be cost competitive with other disinfection technologies being considered. It appeared that chlorine in the non-potable carrier water was diluting the strength of the PAA. Had this been accounted for throughout the entire testing period the overall average PAA dose would likely have been lower. Because it took the entire low flow dry weather period to run through the test protocol for PAA dose and injection locations, it is not possible to infer from the data what optimal operations would have looked like during this period.

Plots of final effluent (post-disinfection) fecal coliform versus PAA dose and contact time are shown in Figure 4-5 and 4-6. Each plot includes a trendline and indicates the associated correlation coefficient for that trendline. The correlation coefficients for both plots are similar and neither indicates a particularly strong correlation, though some level of correlation is evident. This is due to the fact that multiple variables effect effluent fecal coliform, particularly PAA dose, contact time and pre-disinfection fecal coliform concentration. The plots shown in Figures 4-5 and 4-6 consider only one of those variables. A plot of CT value versus log reduction in fecal coliform is shown in Figure 4-7. The trendline for this plot has a higher correlation coefficient because it considers all 3 of the primary variables previously mentioned.

FIGURE 4-5: PAA DOSE VS. FINAL EFFLUENT FECAL COLIFORM

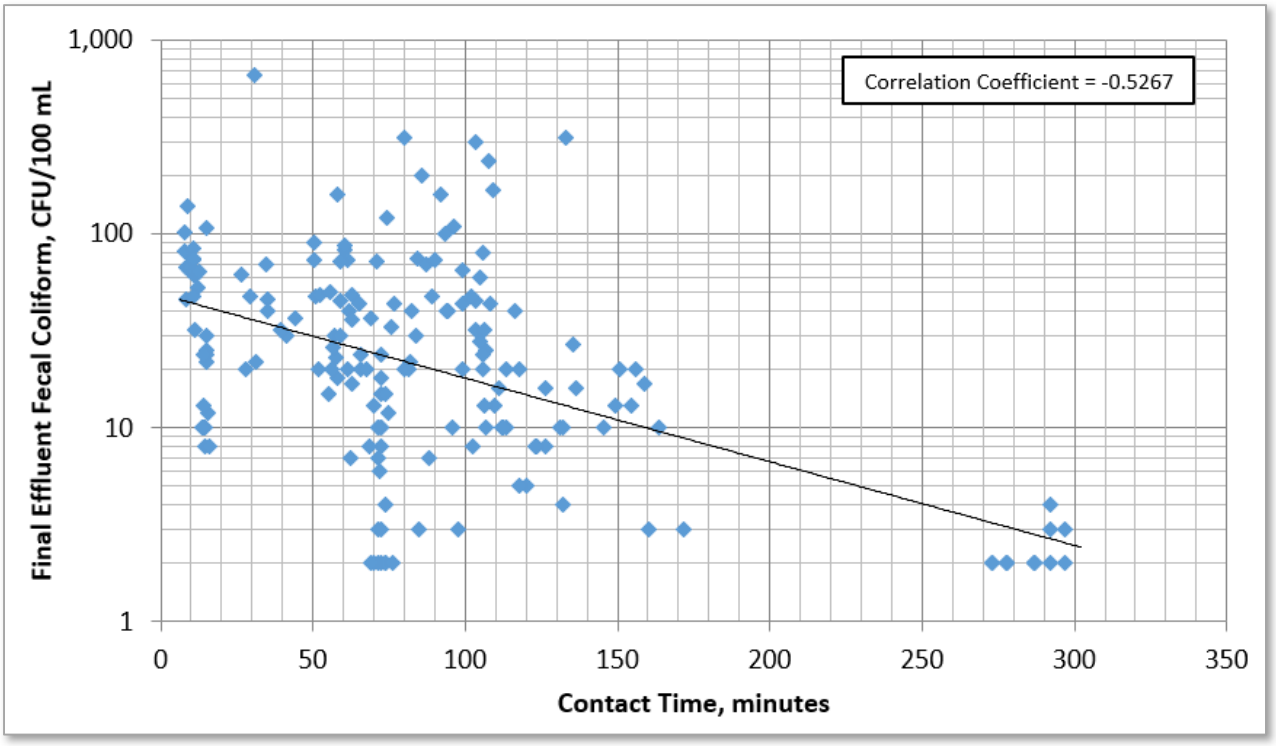


FIGURE 4-6: CONTACT TIME VS. FINAL EFFLUENT FECAL COLIFORM

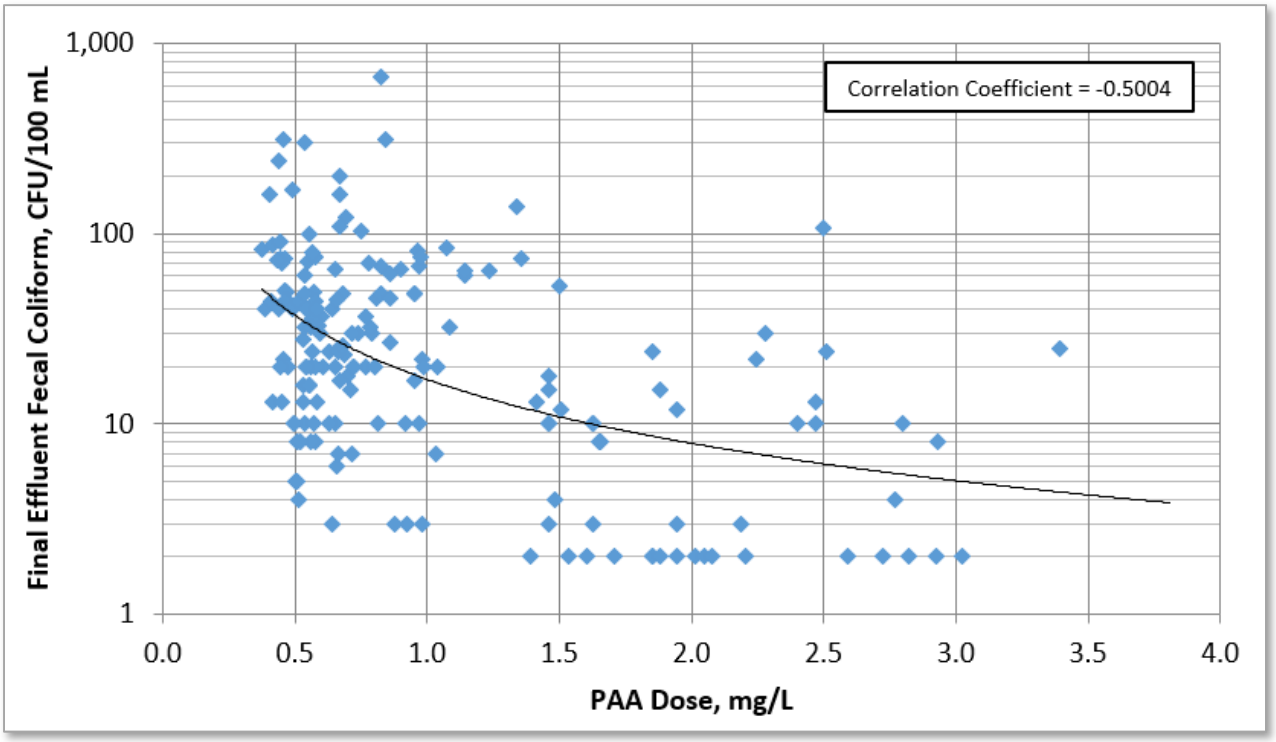
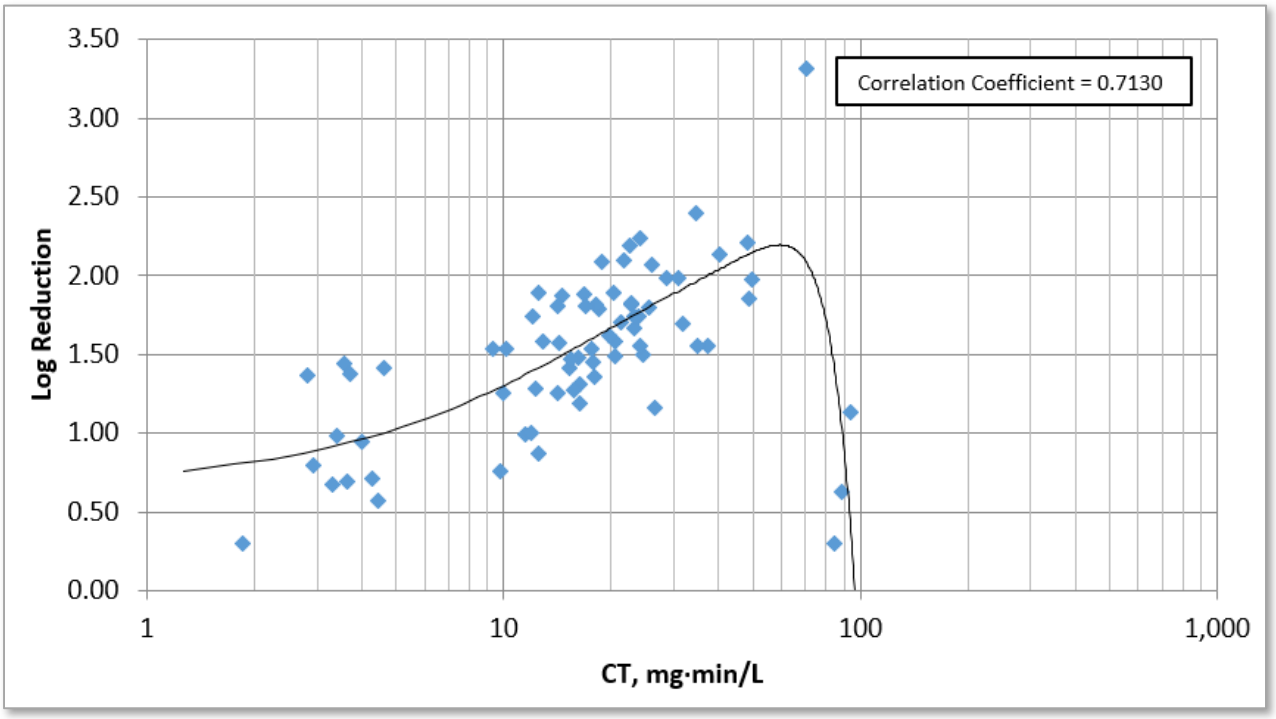
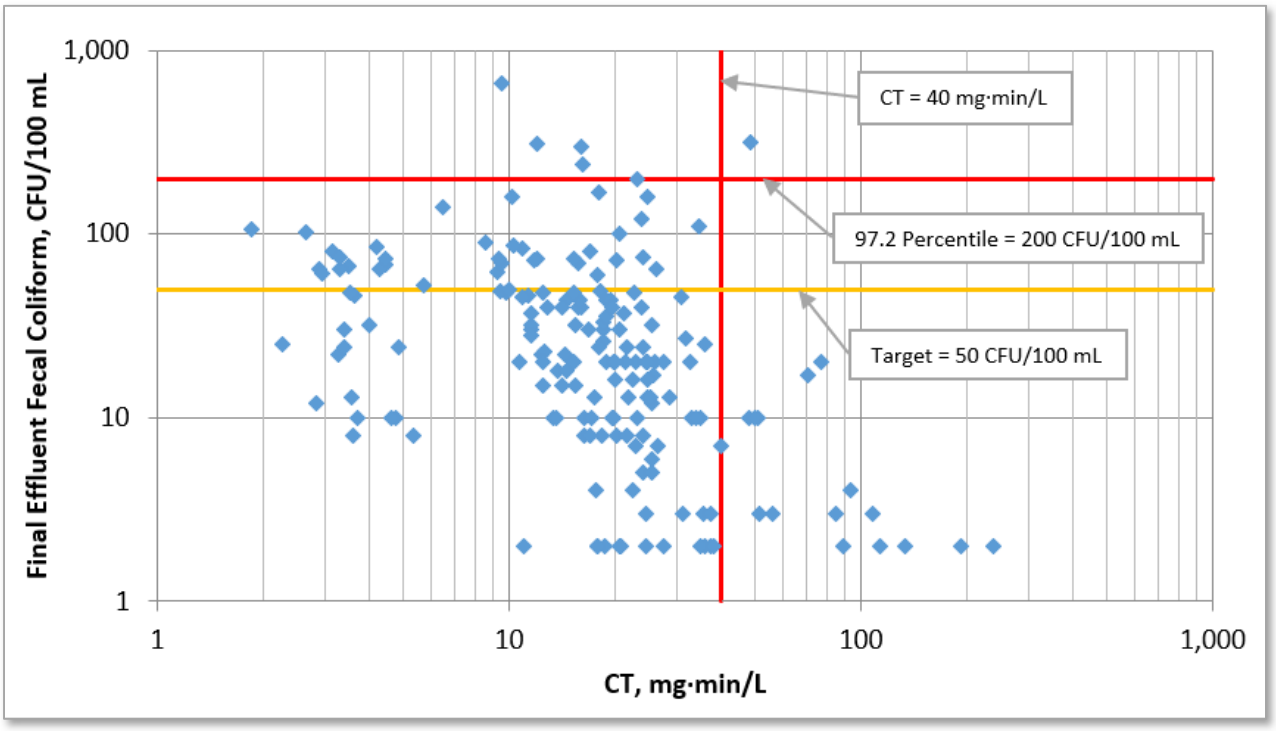


FIGURE 4-7: CT VS. LOG REDUCTION OF FECAL COLIFORM



The stronger correlation identified in Figure 4-7 above suggests that the CT value, which factors both PAA dose and contact time, would likely be a better control variable compared to either PAA dose or contact time individually. As shown in Figure 4-8 below, a CT value of 40 mg•min/L or greater was able to consistently maintain final effluent fecal coliform concentrations below the target concentration of 50 CFU/100 mL, except for one instance when pre-disinfection fecal coliform concentrations spiked to the highest level measured during the testing period. This coincides with a relatively rapid drop in temperature and a likely lagoon turnover event. Additionally, it should be noted that Figure 4-7 above shows a drop in the log reduction for fecal coliform at CT values above 70 mg•min/L. Although excessive contact time could result in regrowth after much of the PAA residual has dissipated, these low values all occurred in the first few weeks of testing when flows were very low and pre-disinfection fecal coliform concentrations were also very low. Therefore, it is more likely attributed to the fact that the initial concentrations were very low, such that even a low log removal still resulted in very low fecal coliform concentrations in the final effluent. However, a maximum CT value of 60 mg•min/L is suggested to avoid excessive contact time and potential regrowth.

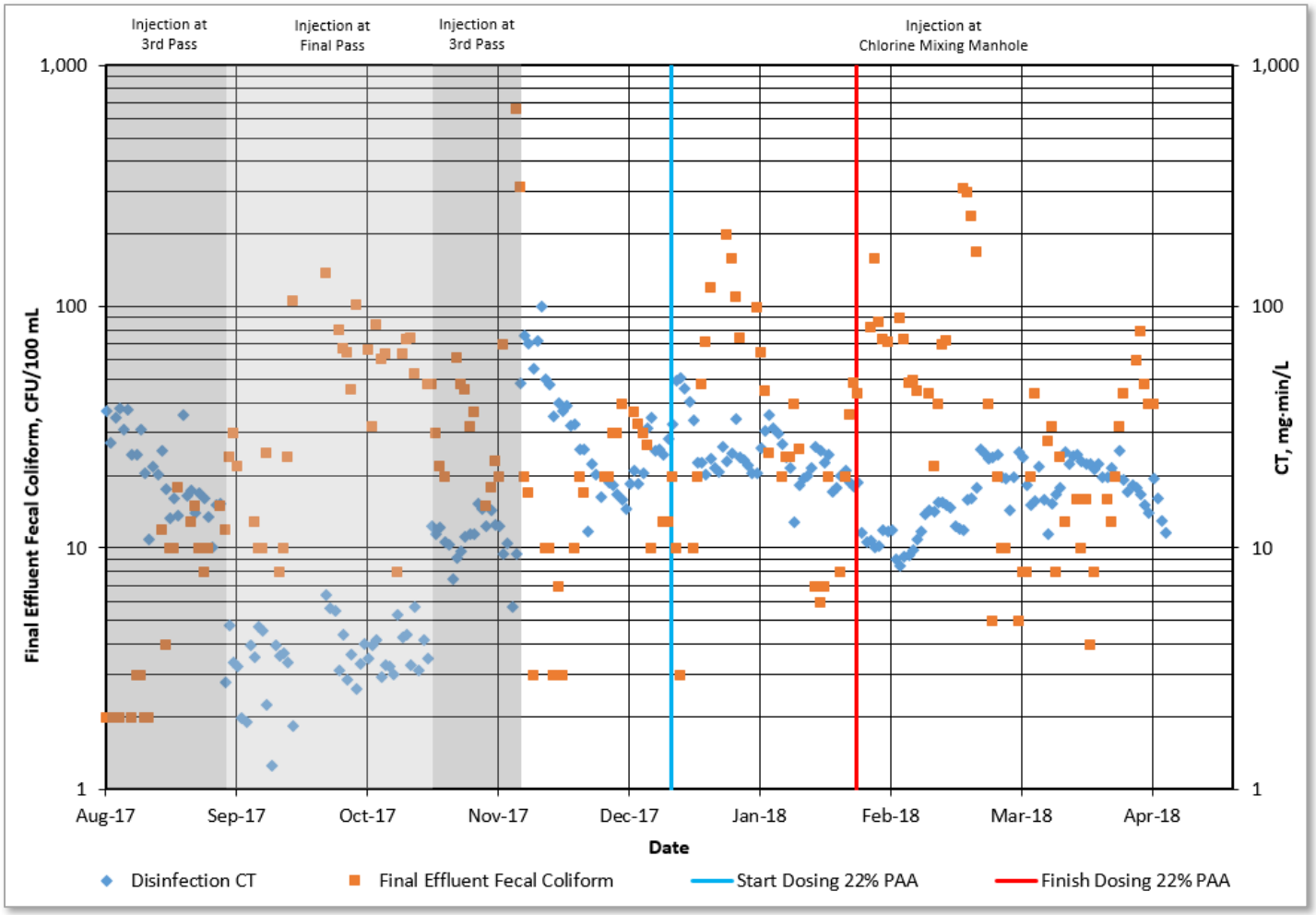
FIGURE 4-8: CT VS. FINAL EFFLUENT FECAL COLIFORM



PAA INJECTION LOCATION

The final effluent (post-disinfection) fecal coliform and CT value for the testing period are shown in Figure 4-9. Figure 4-9 excludes data prior to August 2017 when the PAA dose was conservatively high and the contact time was very high with PAA injected at the chlorine mixing manhole under low dry weather flows. Based on the results of the testing and observations made, the City anticipates that the injection location will be changed seasonally and the PAA dose will remain within a relatively consistent range year-round, likely on the order of 0.5 to 1.5 mg/L. If the required dose nears the limits of the target range, the injection location would be changed accordingly.

FIGURE 4-9: FINAL EFFLUENT FECAL COLIFORM AND CT TREND



As is expected, there is generally an inverse relationship between the CT value and final effluent fecal coliform concentration. As discussed previously, CT is a product of the contact time and the average of the initial and final PAA residuals. Samples for measuring the initial PAA residual were collected a short distance after the injection location, which accounted for a reduction in the residual due to the initial demand. The 2nd pass location was not utilized during the testing period. As shown in Figure 4-9, CT values ranged from less than 2 to a little over 100 mg•min/L. A brief summary of performance at each injection location (excluding initial use of the chlorine mixing manhole injection location from 7/13/17 to 7/31/17 due to excessive contact time) is as follows:

- 3rd Pass, 8/1/17 to 8/28/17 (Dry Weather) – CT values generally varied between 10 and 40 mg•min/L producing an average effluent fecal coliform concentration under 10 CFU/100 mL.
- Final Pass, 8/29/17 to 9/14/17 (Dry Weather) – CT values generally ranged between 2 and 5 mg•min/L producing an average effluent fecal coliform concentration under 20 CFU/100 mL.
- No Effluent Discharge 9/15/17 to 9/21/17 – Annual maintenance activities performed.

- Final Pass, 9/22 to 10/16/17 (Transition from Dry to Wet Weather) – CT values generally ranged between 3 and 6 mg•min/L producing an average effluent fecal coliform concentration around 70 CFU/100 mL.
- 3rd Pass, 10/17/17 to 11/6/17 (Transition from Dry to Wet Weather) – CT values generally ranged between 10 and 20 mg•min/L producing an average effluent fecal coliform concentration around 40 CFU/100 mL.
- Chlorine Mixing Manhole, 11/7/17 to 4/9/18 (Wet Weather) – CT values generally ranged between 10 and 40 mg•min/L producing an average effluent fecal coliform concentration under 50 CFU/100 mL.

The injection locations used for testing were limited to those that would be easily accessible and facilitate installation of the simplified diffuser setup used for testing. For the permanent installation, improvements could be made to facilitate more optimal placement of injection locations. For example, based on results of testing, the final pass injection location should be moved further upstream to provide more contact time, as the resulting CT values for the test period were too low to reliably achieve the target final effluent fecal coliform concentration of 50 CFU/100 mL.

Injection locations should be positioned to facilitate a target range of CT values based on overlapping flow ranges. For instance, flow ranges and injection locations could be set to target CT values of 20 to 60 mg•min/L. This would provide an average CT value of about 40 mg•min/L that should reliably achieve the target final effluent fecal coliform concentration of 50 CFU/100 mL without allowing contact times that are excessive or too short for any injection location. Adjustable flow ranges would be programmed into the PLC so that when flows exceeded the set range solenoid valves would be automatically activated to change injection to the next upstream location or when flows were below the range to change injection to the next downstream location.

COMPARISON OF PAA FORMULATIONS

The vendor charged about 20% more for the same quantity (300 gallons) of 22% PAA solution, compared to the price for 15% PAA solution. The City was interested in evaluating whether the purported benefits of the 22% PAA solution were worth the extra cost. A summary comparison of results for the two PAA solutions is shown in Table 4-5. This compares use of 22% PAA solution with use of 15% PAA solution both before and after. These periods of comparison all occurred during wet weather conditions with periods of similar average flows.

Although the average daily cost of 15% PAA for the prior period was about a 34% greater compared to the average daily cost of 22% PAA, the 15% PAA dose was higher and yielded a significantly average concentration for final effluent fecal coliform. Conversely, the average daily cost of 15% PAA for the period after was a little less compared to that for 22% PAA, but it had a significantly lower average dose and higher average concentration for final effluent fecal coliform. Based on these results, it is expected that to achieve similar results as with the 22% PAA solution, the 15% PAA solution would have a similar dose at perhaps a slightly greater expense. Assuming an average dose of 1.0 mg/L and at the current average annual flow of about 1.3 MGD, the average rate of use for 15% and 22% PAA solutions would be approximately 7.7 and 5.3 gallons per day, respectively. This would equate to a daily cost of $79.00 for 15% PAA and $66.14 for 22% PAA, or about $28,840 and $24,140 annually, respectively. As the annual cost difference is less than $5,000, which is not insignificant, but not large enough to select the 22% formulation over the 15% formulation if there are other benefits to the 15% formulation.

TABLE 4-5
COMPARISON OF PAA FORMULATIONS

Parameter	15% PAA Before	22% PAA	15% PAA After
Dates	**11/13/17 – 12/12/17**	**12/13/17 – 1/25/18**	**1/26/18 – 2/27/18**
Avg. PAA Dose, mg/L	0.72	0.63	0.45
Avg. Flow, MGD	2.13	2.19	2.43
Avg. PAA Dose, gpd	9.14	5.59	6.38
PAA Cost, $/gal	$10.26	$12.48	$10.26
Avg. Daily PAA Cost, $	$93.78	$69.76	$65.46
Avg. Initial PAA Residual, mg/L	0.39	0.34	0.20
Avg. Final PAA Residual, mg/L	0.22	0.26	0.17
Final Effluent Fecal Coliform Geometric Mean, CFU/100 mL	19	47	62

Figure 4-10 and Figure 4-11 below compare log reduction in fecal coliform versus CT for the 15% and 22% PAA formulations, respectively. Based on this comparison, it appears 15% PAA may produce a slightly higher log reduction at the same CT, which could be attributed to the higher concentration of hydrogen peroxide in the 15% PAA formulation.

FIGURE 4-10: CT VS. LOG REDUCTION OF FECAL COLIFORM FOR 15% PAA

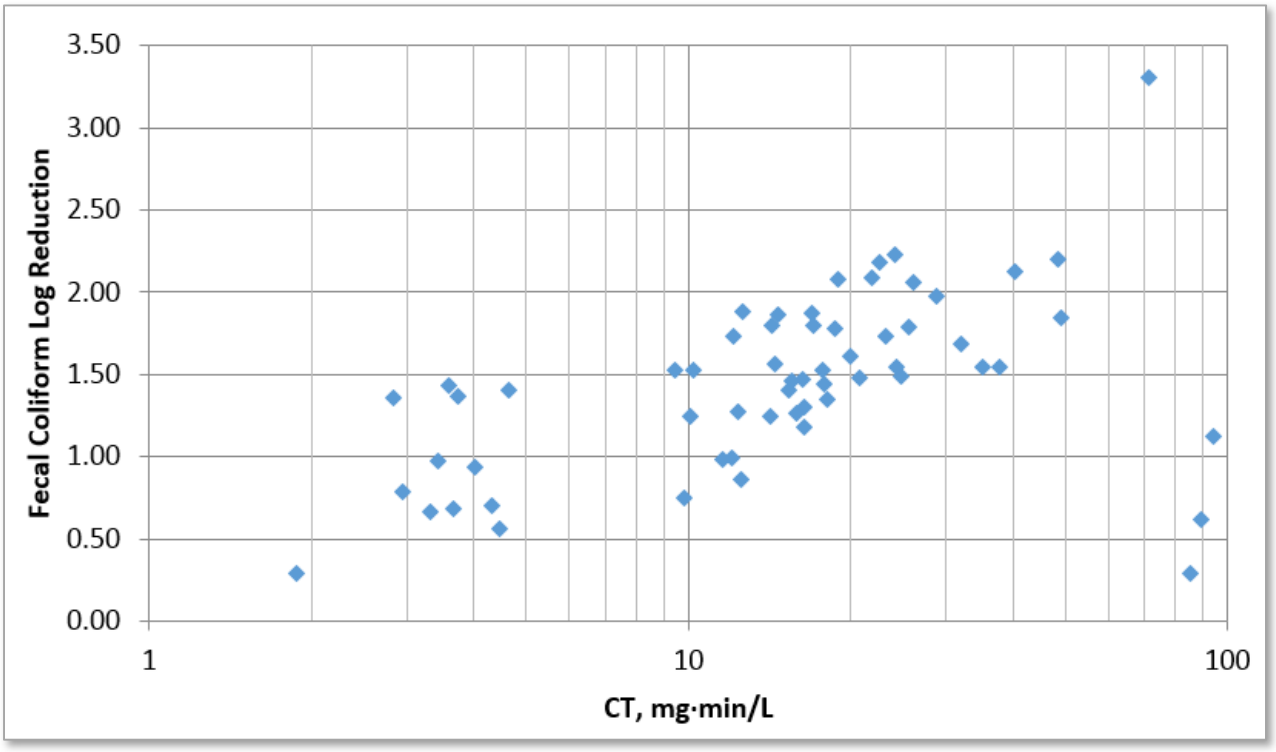
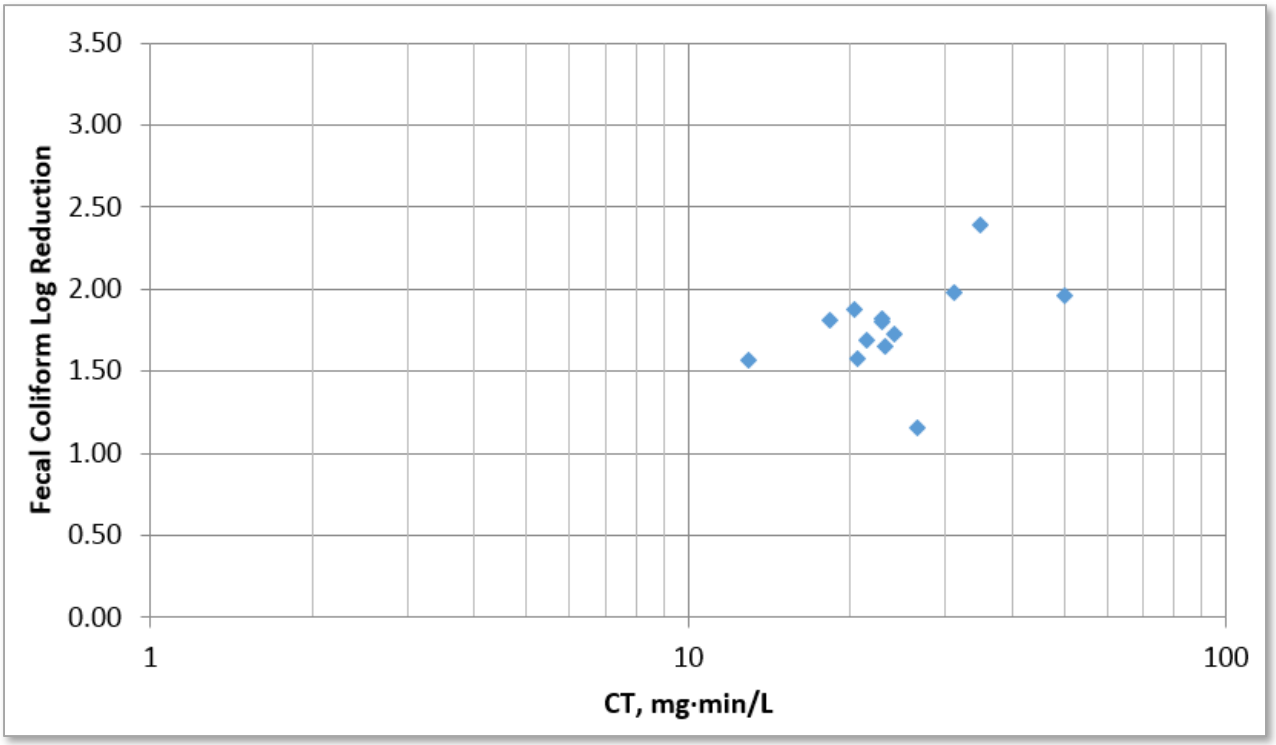


FIGURE 4-11: CT VS. LOG REDUCTION OF FECAL COLIFORM FOR 22% PAA



Similarly, it appears that the 15% PAA formulation may have been capable of achieving similar levels of disinfection at a slightly lower dose. Figure 4-12 and Figure 4-13 below show final effluent fecal coliform concentrations versus PAA dose for the 15% and 22% PAA formulations, respectively.

A purported benefit of 15% PAA is that it contains less acetic acid, which can elevate levels of $CBOD_5$ in the effluent. Plots of the change in net oxygen demand and $CBOD_5$ versus PAA dose are shown in Figures 4-14 and 4-15 for the 15% and 22% PAA formulations, respectively. The change in $CBOD_5$ is the difference between the $CBOD_5$ prior to disinfection and in the final effluent following disinfection, where a positive value means $CBOD_5$ increased and a negative value means $CBOD_5$ decreased. The change in net oxygen demand is the change in $CBOD_5$ minus the change in dissolved oxygen, where the change in dissolved oxygen is the difference between the values prior to disinfection and in the final effluent following disinfection. Net oxygen demand accounts for the impact due to fluctuations in dissolved oxygen in addition to $CBOD_5$. A negative net oxygen demand means demand decreased and a positive value means the net oxygen demand increased.

FIGURE 4-12: 15% PAA DOSE VS. FINAL EFFLUENT FECAL COLIFORM

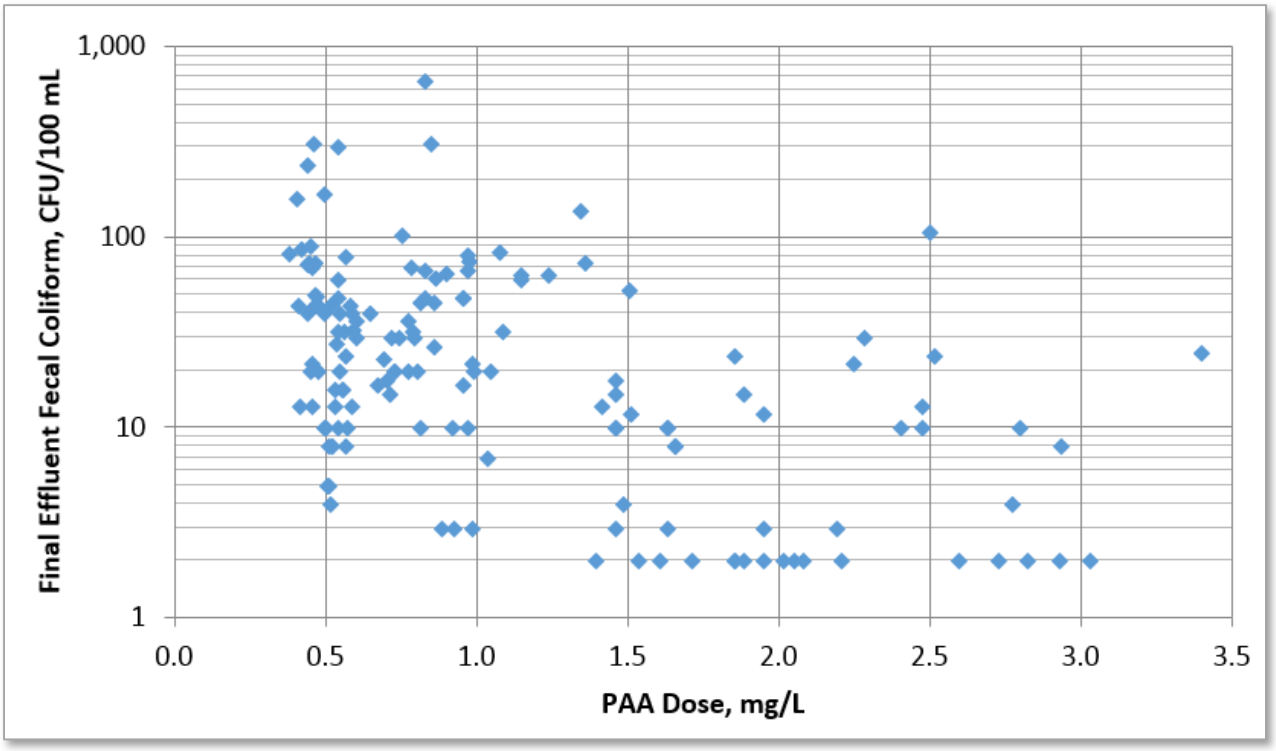


FIGURE 4-13: 22% PAA DOSE VS. FINAL EFFLUENT FECAL COLIFORM

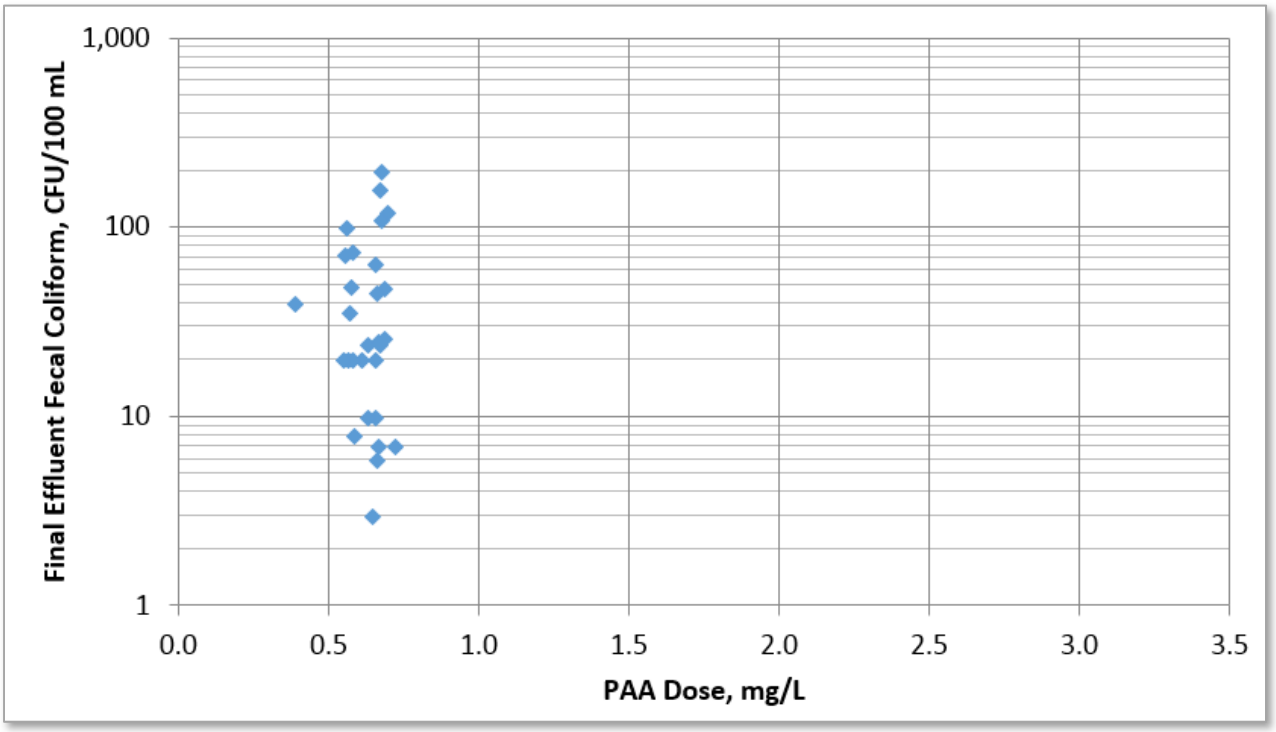


FIGURE 4-14: NET OXYGEN DEMAND & $CBOD_5$ CHANGE VERSUS 15% PAA DOSE

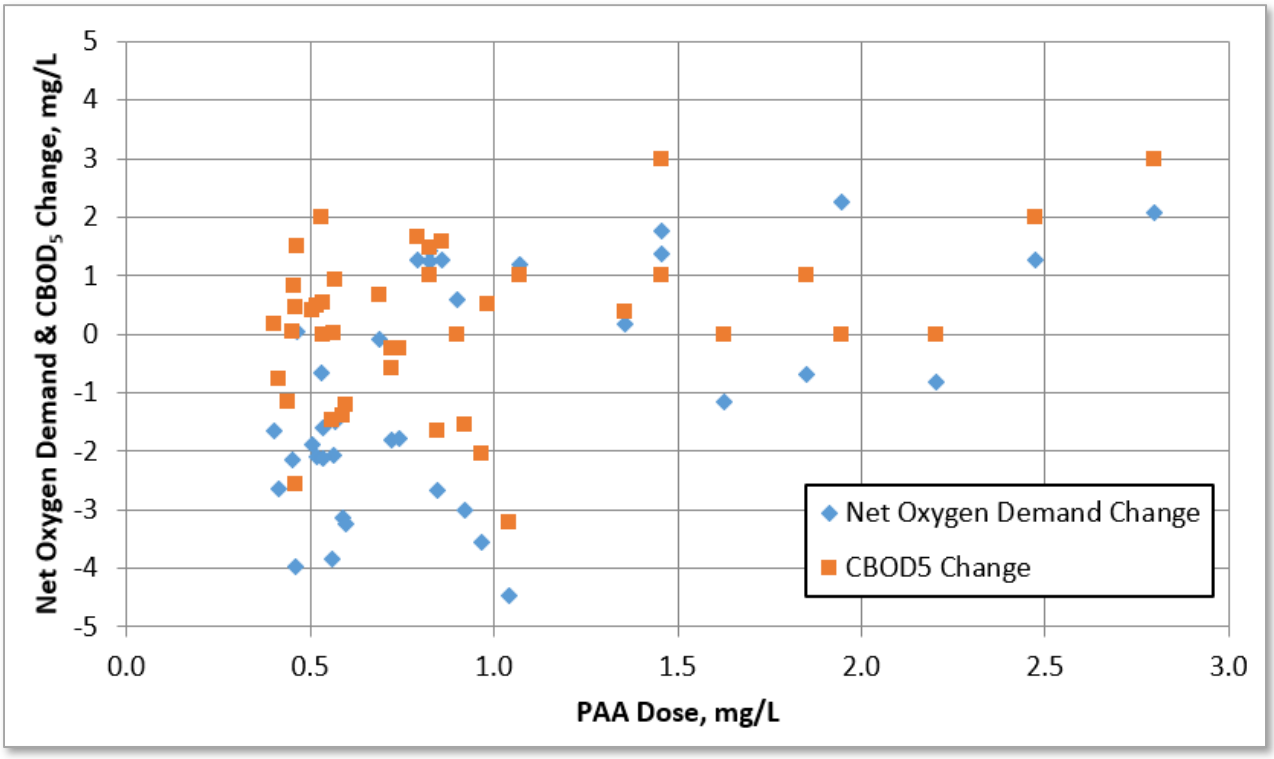
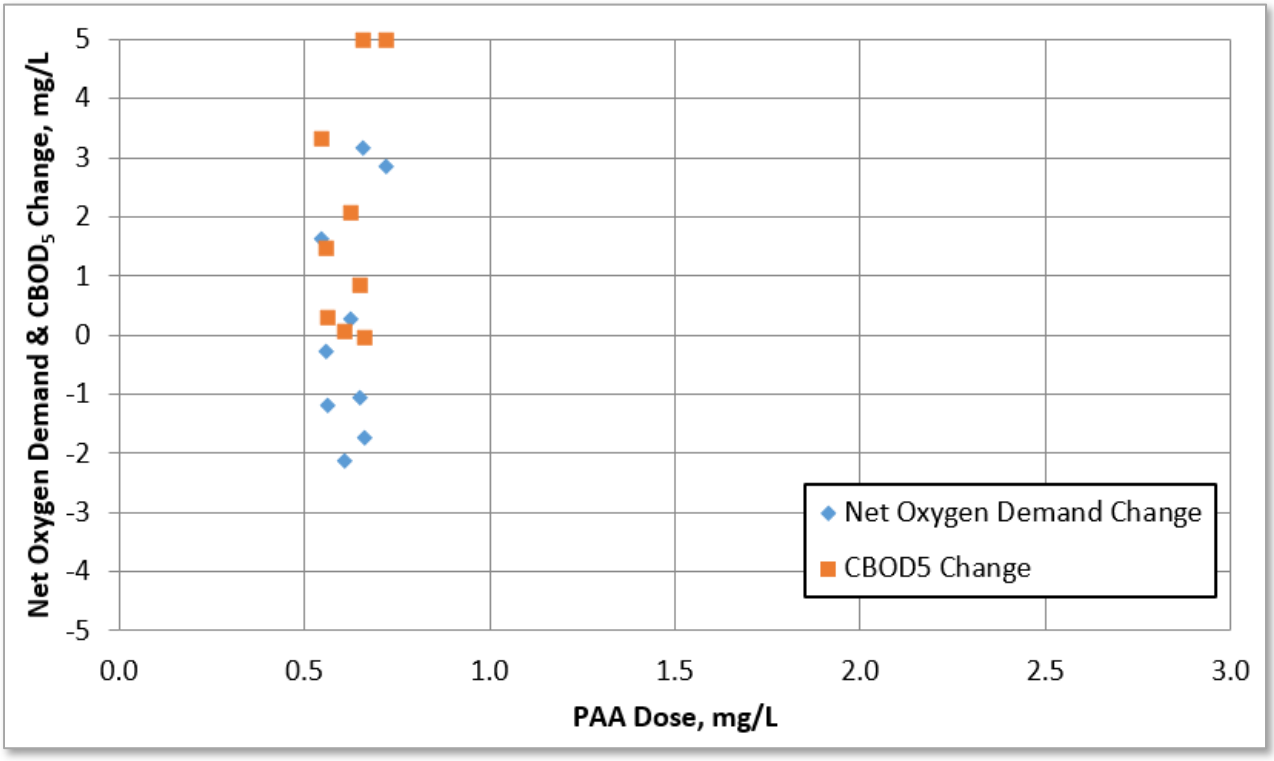


FIGURE 4-15: NET OXYGEN DEMAND & $CBOD_5$ CHANGE VERSUS 22% PAA DOSE



Based on a comparison of Figure 4-14 and Figure 4-15, it appears that the 15% PAA formulation may have resulted in a somewhat lower change in net oxygen demand at similar doses compared to the 22% PAA. It is possible this could be due to higher levels of acetic acid in the 22% PAA formulation. Furthermore, it appears that a higher PAA dose in general may have a greater chance of yielding an increase in $CBOD_5$ and net oxygen demand. As shown previously in Figure 4-3, the contribution from the acetic acid perhaps accounts for up to 2 mg/L of additional $CBOD_5$ at high PAA doses. It appears that with the 22% formulation, the change in CBOD5 could be up to 3 mg/L higher than with the 15% formulation. However, at these levels neither is a concern for NPDES permit compliance.

Considering that 22% PAA solution is a little more cost-effective per pound of active PAA, but 15% PAA solution may require a slightly lower dose and CT value to achieve similar levels of disinfection (likely due to higher concentrations of hydrogen peroxide) and may contribute less to elevated effluent $CBOD_5$ (due to lower concentrations of acetic acid), the small cost savings with 22% PAA are likely largely offset by these small advantages of 15% PAA. Therefore, it is recommended that the City select the PAA formulation and vendor based on convenience and competitive pricing. Because the PAA system can easily utilize either formulation, there is no reason the City can't change vendors or formulations as pricing and availability changes.

Although testing at the City's WWTP did not appear to demonstrate a significant advantage for either formulation, this may not be the case for all applications. This application used relatively small quantities of PAA because of the pre-disinfection fecal coliform concentrations from the lagoon process and the relatively low flows often received by the WWTP. There are many facilities that have processes producing higher pre-disinfection fecal coliform concentrations and operating at substantially higher flows that would likely utilize much greater quantities of PAA. In such instances, those facilities might notice some significant difference between different formulations. Furthermore, this testing is specific to the particular formulations tested. Formulations from other vendors may have differences that also contribute to some noticeable changes in results. Therefore, conclusions drawn about the two formulations used in this testing should only be considered applicable to this particular facility.

CHAPTER 5
CONCLUSIONS, RECOMMENDATIONS & DESIGN CONSIDERATIONS

This Chapter offers conclusions based on analysis of testing data, recommendations for implementation and a summary of important considerations for design.

CONCLUSIONS

The following conclusions are made based on evaluation of the testing data:

- PAA is capable of effectively disinfecting the effluent to meet the NPDES permit limits and achieve a lower level of disinfection that provides a factor of safety to accommodate sudden changes in effluent quality, equipment failures and other unforeseen circumstances.
- In general, the PAA system will be operating in a similar fashion as the existing chlorination system as it pertains to adjusting the dose with variations in flow and effluent quality. The PAA dose will be adjusted as needed to maintain sufficient disinfection based on monitoring of effluent fecal coliform and PAA residual. As with chlorination, typical fluctuations in pH and temperature do not significantly impact the efficiency of disinfection with PAA. Unlike chlorine, PAA is not subject to nitrite-lock and does not react with ammonia, which provides improved stability of performance and more consistent dosing.
- As with chlorine, PAA must be well mixed for effective disinfection. This requires diffusers with carrier water and/or mechanical mixing to properly disperse the chemical.
- Three different PAA dose control methods could be suitable for this application: manual control of the PAA dose by adjusting pump speed locally, flow-paced dosing requiring the operator to set a target PAA dose, and CT control wherein the operator sets a target CT and the dose automatically is adjusted based on measured residual and calculated contact time to maintain the target CT.
- An average PAA dose of about 1.0 mg/L is capable of meeting the target monthly geometric mean for fecal coliform of 50 CFU/100 mL. This average PAA dose results in competitive O&M costs with other disinfection technologies that were considered for replacement of chlorine gas disinfection. This comparison is documented in the forthcoming *2017 General Sewer Plan and Wastewater Facilities Plan*.
- In general, a CT of 40 mg•min/L appears to be sufficient to consistently and reliably achieve effluent fecal coliform concentrations of 50 CFU/100 mL or less and provide sufficient safety factor to accommodate sudden changes in effluent quality, equipment failures and other unforeseen circumstances while also avoiding potential for regrowth due to excessive contact time and diminished PAA residual.
- Having multiple PAA injection locations ensures that an adequate CT value can be maintained under seasonal changes in effluent quality and quantity.
- The injection locations should be optimized to target a CT range of 20 to 60 mg•min/L based on the anticipated range of PAA doses and contact time associated with adjustable and overlapping flow ranges among the injection locations.
- The 22% PAA solution is a little more cost-effective per pound of active PAA, but the 15% PAA solution may require a slightly lower dose and CT value to achieve similar levels of

disinfection and may contribute less to elevated effluent $CBOD_5$, such that the small cost savings of the 22% PAA solution are likely largely offset by these small advantages of the 15% PAA solution.

RECOMMENDATIONS

Based on successful completion of PAA testing and the conclusions noted above, it is recommended that a permanent PAA system be implemented to replace the existing chlorine gas disinfection system. As noted in the forthcoming *2017 General Sewer Plan and Wastewater Facilities Plan*, PAA has similar O&M costs, lower capital cost and lower 20-year life cycle cost compared to other viable disinfection technologies considered. The following additional recommendations are made when considering design of a new permanent PAA system:

- Continue targeting monthly geometric mean of 50 CFU/100 mL to ensure sufficient factor of safety to accommodate sudden changes in effluent quality, equipment failures and other unforeseen circumstances.
- Effluent hardness should continue to be periodically checked to ensure it is maintained below 250 mg/L as $CaCO_3$, as it has been in the past, so that it does not interfere with PAA testing.
- Either inject PAA as a neat solution or use effluent (which would not be chlorinated) as dilution water to avoid diluting the strength of the PAA solution and also avoid having to pay for non-potable water supplied from the City's water system.
- Injection locations should be set with programmed adjustable and overlapping flow ranges to target CT values of 20 to 60 mg•min/L. This would provide an average CT value of about 40 mg•min/L that should reliably achieve the target final effluent fecal coliform concentration of 50 CFU/100 mL without allowing contact times that are excessive or too short for any injection location. When flows exceeded the set range, solenoid valves would be automatically activated to change injection to the next upstream location or to the next downstream location, when flows were below the range.
- Because there does not appear to be a significant advantage of either PAA formulation, the City should select the PAA formulation and vendor based on convenience and competitive pricing. Based on current pricing, it would appear that the 15% PAA formulation is more cost-effective. Because the PAA system can easily utilize either formulation, there is no reason the City can't change vendors or formulations as pricing and availability changes.
- The permanent PAA system should be designed with the ability to operate under CT control, in addition to a flow-paced PAA dose set point. After the new system is operational, the City should continue experimenting with the ProMinent probe and modified holder that showed some success at the end of testing, as well as possibly testing the ATI probe in a configuration that eliminates the air entrapment issue it had during the previous trial. If it is determined that sufficiently accurate residual monitoring cannot be achieved for control of the system, consider a use limited to alarming if it is determined that a reasonable level of accuracy could be maintained.

DESIGN CONSIDERATIONS

Table 5-1 below summarizes important design criteria based on the above conclusions and recommendations.

TABLE 5-1
DESIGN CRITERIA SUMMARY

Parameter	Value
Design Average Annual Flow, MGD	2.0
Design Peak Flow, MGD	9.4
Design CT, mg•min/L	20 - 60
Design PAA Dose, mg/L	0.5 – 2.0
Target PAA Residual, mg/L	0.2
Target Effluent Fecal Coliform, CFU/100 mL	50
PAA Formulation	15% or 22%
Number of PAA Injection Points	4(a)
Minimum Number of PAA Totes	2 (1 duty/1 standby)
Tote Volume, gallons	300
Tote Average Duration of Use, days	25(b)
Number of PAA Dosing Pumps	2 (1 duty/1 standby)
PAA Dosing Pump Type	Diaphragm(c)
Minimum Pump Capacity, gph	2.5(d)
Number of Induction Mixers	1(e)
Induction Mixer Type	Submersible(f)
Minimum Induction Mixer Size, HP	2.0

Notes:
(a) Similar locations as for testing using diffusers with carrier water, except a mechanical induction mixer may be utilized at the mixing manhole.
(b) Based on PAA dose of 1.0 mg/L at design average annual flow.
(c) Stainless steel and Teflon wetted parts. Peristaltic pump may be considered instead if tubing suitably compatible with PAA is confirmed.
(d) Yields PAA dose of 1.0 mg/L at design peak flow.
(e) Standby unit not needed, as other injection points can be utilized if mixer fails.
(f) Stainless steel materials

Reliability and Redundancy

As noted in Table 5-1 above, there will be a standby dosing pump and standby tote available. If the duty pump fails, the standby pump will be automatically started. The standby tote will allow the operator to switch totes for uninterrupted supply while awaiting delivery of a new tote. Each tote is expected to last about 1 month and can be stored for up to one year without significant degradation of the chemical. The system will have 4 different injection points, one associated with each pass of each contact chamber, where the mixing manhole serves as the injection location for the first pass of both contact chambers. If there is an issue with any one injection location, the other three will still be available for use.

Flow metering will be provided to verify that the proper dose is being delivered. As mentioned previously, assuming a PAA probe demonstrates sufficient accuracy and repeatability, PAA residual monitoring will be used to monitor the initial and final PAA residual and ensure that the residual is not too high or too low. Both the flow metering a residual monitoring would be utilized to trigger alarms if the PAA dose or residual is out of range. Additionally, the automated contact chamber outlet valves can be closed if issues arise with the PAA system that cannot be

immediately resolved and flow can be allowed to attenuate in the lagoons until the issue is corrected or temporary measures (e.g., manual control) are implemented.

Safety

In accordance with NFPA 704, PAA is a level 3 health hazard and classified as both an oxidizer and corrosive. The PAA will be stored in a new pre-engineered metal building constructed on a concrete slab, which will also house the PAA dosing system and an air gap pumping system for non-potable water supply at the south end of the WWTP. Due to the relatively small size and configuration of the PAA system, the City prefers a pre-engineered metal building, rather than a concrete masonry building. The building will protect the stored PAA from prolonged exposure to sunlight and extreme temperatures. In accordance with the International Fire Code, the following features will be included in the design for safe storage, handling and use of PAA:

- Automatic sprinkler system
- Minimum 1-hour fire resistance rating for the building
- Secondary containment for the PAA totes and dosing pumps
- Smoke detection
- Continuous ventilation at minimum 1 cfm per square foot of area
- Backup power for uninterrupted service of safety devices, as well as uninterrupted operation of the PAA system for continuous disinfection
- Backflow prevention, shutoff valves and pressure safety valves
- Leak detection and alarming
- Hazard identification signs

In addition to the above requirements of the International Fire Code, an emergency eyewash/shower will be provided in the building along with a spill containment kit and appropriate personal protective equipment. Furthermore, all materials in contact with neat PAA will be either Type 316 stainless steel or Teflon for chemical compatibility and to avoid leakage or spills due to degradation of materials.

Other Design Considerations

The following are additional considerations to be made and elements to be included during design of the PAA system.

- Existing CCT: The existing CCT requires minor repairs and recoating of the interior concrete surfaces. Repairs would consist of filling non-structural cracks to maintain structural integrity and eliminate potential for leakage in the divider wall between the two chambers, such that one chamber can be completely isolated for maintenance.
- Existing Chlorination and Dechlorination Systems: The existing gas chlorination system will be demolished with implementation of the proposed PAA system. It was originally planned that the existing sulfur dioxide system would be retained to quench potentially high PAA residuals in the effluent. However, considering the consistently low PAA residuals observed during testing, the City will also consider removal of the sulfur dioxide system. If the sulfur dioxide system is removed, provisions for dosing liquid sodium bisulfite could be provided instead if ever high PAA doses and high PAA residuals were required. If the existing sulfur dioxide system is retained, the existing gas storage room and control room would continue to be used for storage of sulfur dioxide gas and makeup

of sulfur dioxide solution. The existing chlorine gas valve shutoff system and vacuum alarm switches would be repurposed for the existing sulfur dioxide system. Although the installation of an automatic valve shutoff system may negate the need for a gas scrubber, it is assumed that the existing scrubber would also be rehabilitated and reused for scrubbing sulfur dioxide gas. These options will be examined further during design.

- Pipeline Ventilation and Air Binding: Because the PAA solution does off-gas (the PAA itself does not, but the acetic acid in the solution does), the PAA system used during testing included venting, a piping arrangement to keep the pumps primed and the pumps had automated degassing. As a result, air binding was not an issue during testing. Proper venting of high points will also be necessary in the design. Additionally, a foot valve should be provided on the suction line and the suction lift should be minimized to reduce potential for loss of prime.
- Dosing Pump Selection: If a suitable hose material is confirmed, peristaltic pumps should be considered in place of diaphragm pumps as they are self-priming. If a peristaltic pump is utilized, it must be sized appropriately with sufficient turndown while avoiding high rotational speeds to minimize mechanical wear on the tubing. If diaphragm pumps are used, they need to have automated degassing, as was used during testing.
- Electrical Supply: Changes to the electrical load would include installation of two fractional horsepower metering pumps, and installation of a new panelboard to serve lighting and HVAC loads associated with the new building. This would likely increase the total horsepower draw an equivalent of about 5 horsepower. This would necessitate some modifications to EMCC2, such as adding a breaker to a spare bucket in EMCC2 for service to a new panelboard that would provide power to the metering pumps and HVAC and lighting for the new building.
- Automated Valves: Retrofitting electric actuators on the CCT inlet gates, along with the outlet gates that are already automated, would allow one of the CCT chambers to be remotely isolated and automatically taken out of or put into service to maintain a target CT value. Additionally, solenoid valves could be used to automatically switch the injection point to maintain the target CT and allow the operator to remotely change the injection point. If the required dose to maintain the target CT nears the limits of the target dose range, the injection location would be changed accordingly. One or both of these measures could be included the automated CT control method to further optimize efficiency of the process.

APPENDIX A

TESTING DATA

Date	Lagoon 4 Grabs				Filtered Effluent Grabs (Sand Filter)					Effluent 24-Hr Composite					Effluent Grabs					PAA
	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Filter Feed Flow	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Effluent Flow	Temp	CBOD	TSS	Ammonia-N	Initial PAA Residual	Final PAA Residual	Fecal Coliform	pH	Dissolved Oxygen	Pump Speed
	CFU/100 mL		mg/L	mg/L	MGD	CFU/100 mL		mg/L	mg/L	MGD	°C	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100 mL		mg/L	%
7/13/2017						23	7.72			0.58	24.8				0.64	0.68	2	7.71		10.0%
7/14/2017										0.61	24.6				1.15	0.56	2	7.61		10.0%
7/15/2017										0.56	24.7				1.12	0.07		7.58		10.0%
7/16/2017										0.63	24.4				0.07	0.27		7.60		10.0%
7/17/2017	50	7.68								0.62	24.4				0.67	0.16	2	7.68		11.0%
7/18/2017				8.86	0.57	6	7.57		6.72	0.57	24.5	4	4	0.1	0.49	0.08	3	7.56	7.94	11.0%
7/19/2017	38	8.01	4	10.10						0.58	24.7	4	4	0.1	0.66	0.08	3	7.76	7.85	10.0%
7/20/2017					0.58	8	7.72	2	6.77	0.59	24.3				0.55	0.07	2	7.48	8.13	15.0%
7/21/2017										0.61	24.1				0.22	0.04	2	7.51		16.0%
7/22/2017										0.56	24.7				1.20	0.02		7.53		16.0%
7/23/2017										0.58	24.9				0.67	0.05		7.55		16.0%
7/24/2017	76	7.81								0.59	25.2				0.07	0.06	2	7.50		14.0%
7/25/2017			3	8.88	0.58	54	7.68		7.24	0.58	25.5	5	6	0.1	0.58	0.06	4	7.54	8.06	14.0%
7/26/2017	58	7.92		8.39				2	7.12	0.57	25.6	4	5	0.1	0.06	0.06	2	7.56	8.07	
7/27/2017					0.61	56	7.56			0.62	24.9				7.9	0.08	2	7.57		
7/28/2017										0.61	24.5				2.1	0.07	2	7.54		10.0%
7/29/2017										0.59	24.7				4.6	0.07		7.51		9.0%
7/30/2017										0.56	24.9				5.4	0.03		7.62		
7/31/2017	125	7.90								0.59	25.1				3.6	0.08	2	7.62		
8/1/2017			7	8.72	0.62	72	7.77	3	7.22	0.62	25.3	3	6	0.04	0.99	0.06	2	7.61	8.03	12.0%
8/2/2017	203	7.98	7	9.52	0.61				7.51	0.61	25.5	3	7	0.04	0.42	0.34	2	7.52	8.3	11.0%
8/3/2017					0.61	74	7.78	3		0.60	25.9				0.54	0.41	2	7.76		
8/4/2017										0.60	26.3				0.44	0.6	2	7.68		10.0%
8/5/2017										0.62	26.0				0.38	0.5		7.56		10.0%
8/6/2017										0.63	25.6				0.48	0.6		7.55		10.0%
8/7/2017	107	8.2								0.63	25.6				0.35	0.35	2	7.62		9.0%
8/8/2017			9	10.33	0.61	95	7.65		7.76	0.62	25.6	5	4	0.02	0.43	0.26	3	7.64	7.65	9.0%
8/9/2017	125	8.14		10.89	0.58			3	7.88	0.61	25.7	4	4	0.04	0.41	0.45	3	7.51	7.66	8.0%
8/10/2017					0.56	60	7.83			0.58	25.8				0.28	0.26	2	7.58		8.0%
8/11/2017										0.64	25.6				0.21	0.11	2	7.58		8.0%
8/12/2017										0.64	25.1				0.35	0.29		7.60		8.0%
8/13/2017										0.63	24.5				0.36	0.22		7.58		8.0%
8/14/2017	220	7.95								0.59	23.6				0.41	0.27	12	7.57		
8/15/2017			7	8.71	0.6	136	7.66		6.86	0.60	23.5	5	5	0.1	0.36	0.12	4	7.64	8.06	8.0%
8/16/2017	240	8.08		8.87	0.59			3	6.69	0.61	23.2	6	2	0.1	0.28	0.09	10	7.62	7.99	8.0%
8/17/2017					0.61	203	7.84			0.61	23.4				0.35	0.1	10	7.61		8.0%
8/18/2017										0.61	23.5				0.31	0.07	18	7.67		8.0%
8/19/2017										0.61	23.4				0.66	0.34		7.85		8.0%
8/20/2017										0.62	23.2				0.4	0.07		7.60		8.0%
8/21/2017	285	8.19								0.63	23.2				0.35	0.15	13	7.57		8.0%
8/22/2017			4	9.23	0.61	270	7.7		6.95	0.61	23.6	3	6	0.1	0.33	0.06	15	7.65	7.87	8.0%
8/23/2017	450	7.99		8.15	0.61			3	6.20	0.62	23.8	3	2	0.1	0.42	0.06	10	7.65	7.39	9.0%
8/24/2017					0.61	123	7.83			0.61	23.1				0.36	0.09	8	7.57		9.0%
8/25/2017										0.62	22.8				0.32	0.06	10	7.56		9.0%
8/26/2017										0.61	22.8				0.26	0.02		7.62		10.0%
8/27/2017										0.61	23.1				0.35	0.07		7.92		10.0%
8/28/2017	540	8.02								0.60	23.4				0.36	0.06	15	7.60		10.0%
8/29/2017			6	8.30	0.6	290	7.78		6.07	0.58	23.6	6	5	0.1	0.3	0.06	12	7.61	7.73	10.0%
8/30/2017	710	7.96		8.05	0.59			4	5.89	0.61	23.1	5	3	0.1	0.54	0.11	24	7.59	7.65	10.0%
8/31/2017					0.6	290	7.74			0.60	23.3				0.38	0.07	30	7.59		12.0%
9/1/2017										0.61	23.3				0.39	0.05	22	7.57		12.0%
9/2/2017										0.61	23.5				0.20	0.07		7.57		14.0%

Date	Lagoon 4 Grabs				Filtered Effluent Grabs (Sand Filter)					Effluent 24-Hr Composite					Effluent Grabs					PAA
	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Filter Feed Flow	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Effluent Flow	Temp	CBOD	TSS	Ammonia-N	Initial PAA Residual	Final PAA Residual	Fecal Coliform	pH	Dissolved Oxygen	Pump Speed
	CFU/100 mL		mg/L	mg/L	MGD	CFU/100 mL		mg/L	mg/L	MGD	°C	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100 mL		mg/L	%
9/3/2017										0.61	23.7				0.22	0.04		7.53		14.0%
9/4/2017										0.62	23.6				0.51	0.04		7.62		14.0%
9/5/2017				8.62	0.6	393	7.61		6.94	0.65	23.4	5	2	0.1	0.46	0.05	13	7.62	7.70	14.0%
9/6/2017	580	7.71		8.38	0.59			3	6.88	0.65	23.3	5	4	0.1	0.63	0.05	10	7.62	7.76	14.0%
9/7/2017					0.56	220	7.51			0.63	23.0				0.55	0.09	10	7.53		13.2%
9/8/2017										0.60	22.6				0.21	0.09	25	7.47		17.6%
9/9/2017										0.61	22.2				0.13	0.04		7.45		20.0%
9/10/2017										0.62	21.8				0.44	0.11		7.53		18.0%
9/11/2017	372	7.86								0.63	21.6				0.38	0.12	8	7.54		16.0%
9/12/2017				8.69	0.6	222	7.64	3	7.48	0.66	21.6	6	2	0.1	0.39	0.15	10	7.57	8.50	16.0%
9/13/2017	465	7.62	4	8.66	0.6				8.13	0.64	21.1	4	4	0.1	0.37	0.11	24	7.59	8.50	14.0%
9/14/2017					0.59	204	7.64			0.61	20.8				0.17	0.08	107	7.57		
9/15/2017										0.00										
9/16/2017										0.00										
9/17/2017										0.00										
9/18/2017	401	7.8		10.43						0.00										
9/19/2017				10.11						0.00										
9/20/2017	367	7.8								0.00										
9/21/2017										0.00										
9/22/2017										1.02	22.6				1.09	0.36	139	7.76		12.0%
9/23/2017										1.35	18.0				1.18	0.51		7.90		10.0%
9/24/2017										1.26	18.1				1.13	0.40		7.68		10.0%
9/25/2017	420	7.84								1.17	18.0				0.57	0.24	81	7.71		10.0%
9/26/2017				10.51	0.76	181	7.70	4	10.01	1.08	18.4	5	5	0.1	0.73	0.32	68	7.72	9.73	8.0%
9/27/2017	259	7.73	4	10.13	0.76				10.26	0.99	18.6	4	4	0.1	0.43	0.20	65	7.69	9.64	8.0%
9/28/2017					0.77	216	7.71			1.10	19.3				0.59	0.29	46	7.67		8.0%
9/29/2017										1.19	18.4				0.49	0.20	103	7.65		8.0%
9/30/2017										1.06	18.0				0.53	0.25		7.65		
10/1/2017										1.04	17.8				0.61	0.31		7.63		
10/2/2017	349	7.68			0.81					0.92	17.5				0.52	0.19	67	7.65		8.0%
10/3/2017				10.47	0.8	279	7.69		9.40	0.82	17.1	5	11	0.1	0.48	0.24	32	7.65	9.85	8.0%
10/4/2017	378	7.71	5	9.94					9.35	0.83	16.7	6	8	0.1	0.51	0.26	85	7.65	9.76	8.0%
10/5/2017						384	7.7			0.82	16.5				0.34	0.19	61	7.67		8.4%
10/6/2017										0.80	16.1				0.39	0.19	64	7.65		8.2%
10/7/2017										0.78	15.8				0.37	0.19		7.66		7.3%
10/8/2017										0.93	15.7				0.43	0.19		7.65		9.0%
10/9/2017	327	7.76								0.56	15.4				0.41	0.25	8	7.67		8.3%
10/10/2017		7.80		10.59						0.72	15.0	4	9	0.1	0.43	0.25	64	7.70	10.43	8.0%
10/11/2017	340	7.74	3	10.31	0.51				10.28	0.84	15.4	4	6	0.1	0.58	0.24	74	7.69	10.51	10.1%
10/12/2017					0.57	357	7.76			0.84	14.0				0.40	0.21	75	7.70		7.4%
10/13/2017										0.76	13.5				0.66	0.30	53	7.74		10.1%
10/14/2017										1.42	13.3				0.69	0.29		7.75		9.7%
10/15/2017										0.93	13.1				0.70	0.16		7.72		8.5%
10/16/2017	357	7.67								0.86	13.1				0.42	0.25	48	7.65		7.4%
10/17/2017				10.89	0.65	361	7.65		10.30	0.87	12.9				0.32	0.17	48	7.60	10.66	
10/18/2017	430	7.57	4	10.68	0.71				10.07	1.08	12.6	5	5	0.1	0.32	0.24	30	7.66	10.66	7.7%
10/19/2017					0.73	421	7.67	3		1.43	12.5	4	5	0.1	0.43	0.36	22	7.68		12.3%
10/20/2017										1.59	12.2				0.39	0.37	20	7.60		
10/21/2017										1.84	11.7				0.36	0.50		7.60		14.0%
10/22/2017										1.96	12.2				0.27	0.39		7.58		14.0%
10/23/2017	282	7.64								1.70	12.6				0.31	0.39	62	7.60		12.8%
10/24/2017				10.80	0.72	265	7.66	2	10.07	1.53	12.8	4	5	0.1	0.28	0.39	48	7.63	10.69	11.1%

Date	Lagoon 4 Grabs				Filtered Effluent Grabs (Sand Filter)					Effluent 24-Hr Composite					Effluent Grabs					PAA
	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Filter Feed Flow	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Effluent Flow	Temp	CBOD	TSS	Ammonia-N	Initial PAA Residual	Final PAA Residual	Fecal Coliform	pH	Dissolved Oxygen	Pump Speed
	CFU/100 mL		mg/L	mg/L	MGD	CFU/100 mL		mg/L	mg/L	MGD	°C	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100 mL		mg/L	%
10/25/2017	285	7.41	3	10.43	0.72				9.63	1.26	12.6	4	3	0.1	0.31	0.33	46	7.56	10.28	9.7%
10/26/2017					0.74	331	7.67			1.12	13.0				0.30	0.28	32	7.64		7.9%
10/27/2017										1.00	13.1				0.28	0.24	37	7.56		7.0%
10/28/2017										0.89	13.1				0.37	0.25		7.67		6.3%
10/29/2017										0.86	12.8				0.39	0.18		7.70		5.8%
10/30/2017	1110	7.67								0.80	12.8				0.26	0.19	15	7.69		5.3%
10/31/2017				10.71	0.90	1315	7.71		10.08	0.76	12.6				0.31	0.19	18	7.72	10.76	5.0%
11/1/2017	2300	7.62	4	10.28	0.64				9.68	0.77	12.0	3	2	0.1	0.27	0.17	23	7.61	10.52	5.0%
11/2/2017					0.60	1250	7.61	2		0.85	11.7	2	3	0.1	0.28	0.20	20	7.61		
11/3/2017										1.28	10.9				0.33	0.22	70	7.62		8.9%
11/4/2017										1.30	10.0				0.40	0.22		7.61		8.4%
11/5/2017										1.55	9.4				0.29	0.11		7.62		10.4%
11/6/2017	20000	7.28								1.45	9.0				0.31	0.31	667	7.61		10.6%
11/7/2017				10.17	0.75	24000	7.64	7	9.42	1.28	8.3	7	5	3.7	0.48	0.25	315	7.60	10.74	9.6%
11/8/2017	73000	7.55	11	10.04	0.79				9.33	1.13	8.3	5	8	4.6	0.67	0.35	20	7.56	10.81	10.4%
11/9/2017					0.79	21250	7.53			1.07	8.4				0.59	0.30	17	7.59		9.1%
11/10/2017										0.99	8.7				0.46	0.19	3	7.60		8.7%
11/11/2017										0.98	8.6				0.58	0.26		7.57		8.4%
11/12/2017										0.74	8.8				0.63	0.26		7.56		9.4%
11/13/2017	2500	7.57								1.53	9.1				0.62	0.29	10	7.52		12.3%
11/14/2017				8.92	0.78	667	7.54	7	7.96	1.60	9.1	7	10	9.9	0.60	0.30	10	7.54	9.96	13.5%
11/15/2017	940	7.57	11	8.70	0.74				7.35	2.03	9.2	8	16	11	0.58	0.26	3	7.53	9.67	16.2%
11/16/2017					0.74	1000	7.57			1.95	9.1				0.59	0.32	7	7.53		17.4%
11/17/2017										1.76	9.4				0.52	0.25	3	7.52		13.5%
11/18/2017										1.58	9.4				0.54	0.19		7.49		12.5%
11/19/2017										1.50	9.2				0.39	0.18		7.52		11.2%
11/20/2017	1800	7.48								1.79	9.2	6	20	11.5	0.45	0.24	10	7.24		12.7%
11/21/2017				8.03	0.77	3367	7.49		5.89	2.15	9.4	6	17	11.5	0.44	0.21	20	7.30	8.49	14.4%
11/22/2017	6000	7.51		7.72	0.82				5.92	2.75	10.4				0.52	0.30	17	7.53	8.71	16.0%
11/23/2017										4.50	10.8				0.35	0.26		7.44		20.1%
11/24/2017										2.60	10.9				0.45	0.23		7.43		32.0%
11/25/2017										2.06	10.8				0.30	0.19		7.43		13.9%
11/26/2017										2.51	10.9				0.28	0.20		7.42		
11/27/2017	2600	7.43								2.62	10.8				0.36	0.24	20	7.44		18.1%
11/28/2017				6.96	0.77	2000	7.33	4	4.44	3.08	10.5	6	14	8.0	0.38	0.29	20	7.45	7.88	19.2%
11/29/2017	2300	7.44	7	7.02	0.77				4.41	3.04	10.2	6	16	7.7	0.38	0.27	30	7.40	7.91	19.4%
11/30/2017										2.94	10.0				0.32	0.25	30	7.42		18.1%
12/1/2017										2.80	9.8				0.31	0.21	40	7.39		15.6%
12/2/2017										2.71	9.4				0.28	0.18		7.42		14.5%
12/3/2017										2.70	9.3				0.37	0.21		7.47		15.1%
12/4/2017	2400	7.32								2.49	9.1				0.39	0.22	37	7.36		13.0%
12/5/2017				7.28	0.73	1200	7.33	5	4.03	2.27	8.8	7	18	8	0.32	0.17	33	7.38	7.99	11.7%
12/6/2017	1500	7.43	10	7.32	0.73				4.17	2.05	8.3	7	13	7.9	0.30	0.19	30	7.41	8.22	10.8%
12/7/2017					0.66	1200	7.24			1.26	8.0				0.29	0.18	27	7.43		9.6%
12/8/2017										1.17	7.3				0.33	0.15	10	7.35		5.8%
12/9/2017										1.17	6.8				0.22	0.13		7.28		5.0%
12/10/2017										1.15	6.5				0.22	0.13		7.33		4.9%
12/11/2017	1400	7.35								1.14	6.1				0.22	0.11	13	7.27		4.5%
12/12/2017				9.05	0.75	1200	7.36	5	5.64	1.1	5.8	6	14	8	0.25	0.12	13	7.35	8.91	4.7%
12/13/2017	1300	7.44	8	8.98	0.75				5.83	1.09	5.6	6	17	8.2	0.30	0.12	20	7.35	9.00	4.4%
12/14/2017					0.75	800	6.63			1.04	5.4				0.41	0.20	10	7.34		4.5%
12/15/2017										1.06	5.4				0.48	0.16	3	7.17		4.6%

Date	Lagoon 4 Grabs				Filtered Effluent Grabs (Sand Filter)					Effluent 24-Hr Composite					Effluent Grabs					PAA
	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Filter Feed Flow	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Effluent Flow	Temp	CBOD	TSS	Ammonia-N	Initial PAA Residual	Final PAA Residual	Fecal Coliform	pH	Dissolved Oxygen	Pump Speed
	CFU/100 mL		mg/L	mg/L	MGD	CFU/100 mL		mg/L	mg/L	MGD	°C	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100 mL		mg/L	%
12/16/2017										1.12	5.6				0.46	0.15		7.17		4.8%
12/17/2017										1.17	6.2				0.43	0.13		6.97		4.7%
12/18/2017	1300	6.60								1.3	6.4				0.39	0.13	10	7.16		5.3%
12/19/2017				8.32	0.72	1300	6.39		3.67	1.73	6.7	13	28	11.1	0.30	0.16	20	7.07	7.59	6.2%
12/20/2017	5250	7.28		7.93	0.72				4.11	1.93	6.8	16	31	11.8	0.33	0.18	48	7.28	8.39	8.2%
12/21/2017					0.75	6300	7.21			2.42	6.5				0.37	0.20	72	7.39		8.3%
12/22/2017										2.32	6.5				0.42	0.22	121	7.17		9.9%
12/23/2017										2.46	6.2				0.34	0.28		7.22		10.0%
12/24/2017										2.38	5.7				0.30	0.28		7.33		10.0%
12/25/2017										2.2	5.5				0.41	0.27		7.46		9.3%
12/26/2017				8.88	0.77	24000	7.54		6.16	2.01	5.6	15	31	9.6	0.33	0.21	200	7.50	9.19	8.4%
12/27/2017	34000	7.49		8.80	0.8				5.80	1.87	5.5	16	30	9.2	0.32	0.22	160	7.49	9.21	7.8%
12/28/2017					0.82	20250	7.45			1.78	5.9				0.43	0.29	110	7.51		7.5%
12/29/2017										2.04	6.4				0.30	0.27	75	7.38		7.4%
12/30/2017										2.12	6.5				0.30	0.28		7.49		8.7%
12/31/2017										2.04	6.6				0.31	0.22		7.48		8.6%
1/1/2018										1.95	6.3				0.27	0.20		7.44		8.4%
1/2/2018				7.67	0.76	9300		11	4.62	1.84	6.0	16	34	9.8	0.27	0.17	100	7.52	8.17	6.5%
1/3/2018	6000	7.55	17	7.87	0.82				4.36	1.73	6.0	15	20	9.7	0.28	0.25	65	7.49	8.11	7.1%
1/4/2018					0.84	2800	7.45			1.66	6.1				0.35	0.25	45	7.44		6.9%
1/5/2018										1.60	6.6				0.41	0.26	25	7.44		6.7%
1/6/2018										1.72	6.9				0.36	0.28		7.46		7.1%
1/7/2018										1.86	7.0				0.37	0.28		7.45		7.2%
1/8/2018	1800	7.53								2.10	7.5				0.37	0.30	20	7.46		8.5%
1/9/2018				6.80	0.84	450	7.4	10	3.31	2.37	7.7	14	18	11.6	0.36	0.30	24	7.46	7.37	9.2%
1/10/2018	1700	7.49	13	6.64	0.84				3.02	2.63	7.9	12	22	11.6	0.36	0.30	24	7.43	7.16	10.7%
1/11/2018					0.86	600	7.37			5.29	8.3				0.41	0.32	40	7.47		12.4%
1/12/2018										3.06	8.7				0.33	0.32	26	7.40		12.7%
1/13/2018										2.90	9.0				0.33	0.33		7.34		12.3%
1/14/2018										2.74	8.9				0.29	0.35		7.32		11.3%
1/15/2018										2.57	8.9				0.33	0.32		7.36		11.2%
1/16/2018		7.19		7.15	0.82	300	7.15	6	1.91	2.41	9.3	11	13	8.4	0.35	0.39	7	7.22	7.53	10.6%
1/17/2018	600	7.35	6	7.11	0.83				3.35	2.40	9.2	11	12	8.3	0.37	0.34	6	7.25	7.63	9.7%
1/18/2018					0.83	167	7.21			2.77	9.1				0.36	0.37	7	7.35		11.2%
1/19/2018										2.82	8.9				0.33	0.47	20	7.26		10.0%
1/20/2018										2.69	8.7				0.25	0.29		7.20		9.6%
1/21/2018										2.63	8.6				0.25	0.30		7.25		9.6%
1/22/2018	810	6.68								2.51	8.3				0.30	0.29	8	7.27		9.0%
1/23/2018				7.69	0.84	1400	7.33	7	3.73	2.55	8.0	11	20	8.8	0.34	0.29	20	7.32	8.09	8.6%
1/24/2018	3000	7.41	8	7.67	0.84				3.76	2.76	8.0	8	11	9	0.31	0.29	36	7.35	7.95	9.6%
1/25/2018					0.83	3800	7.3			2.76	7.8				0.29	0.29	49	7.37		9.7%
1/26/2018										2.65	7.6				0.28	0.30	44	7.40		9.6%
1/27/2018										2.75	7.7				0.19	0.18		7.36		9.8%
1/28/2018										2.76	7.9				0.20	0.14		7.36		9.8%
1/29/2018	5500	7.35								2.86	8.2				0.18	0.18	83	7.26		9.5%
1/30/2018				7.80	0.88	5500	7.2	7	3.63	2.99	8.4	10	12	8.1	0.18	0.17	160	7.27	8.40	10.6%
1/31/2018	4300	7.35	11	7.67	0.88				3.3	2.87	8.3	9	13	8.1	0.17	0.17	87	7.33	8.21	10.5%
2/1/2018					0.88	3700	7.29			2.81	8.3				0.19	0.20	74	7.42		11.0%
2/2/2018										2.93	8.8				0.19	0.21	72	7.47		11.6%
2/3/2018										2.98	9.1				0.19	0.22		7.51		11.2%
2/4/2018										3.33	9.5				0.15	0.20		7.48		12.8%
2/5/2018	2900	7.45								3.45	9.7				0.14	0.20	90	7.49		13.4%

Date	Lagoon 4 Grabs				Filtered Effluent Grabs (Sand Filter)					Effluent 24-Hr Composite					Effluent Grabs					PAA
	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Filter Feed Flow	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Effluent Flow	Temp	CBOD	TSS	Ammonia-N	Initial PAA Residual	Final PAA Residual	Fecal Coliform	pH	Dissolved Oxygen	Pump Speed
	CFU/100 mL		mg/L	mg/L	MGD	CFU/100 mL		mg/L	mg/L	MGD	°C	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100 mL		mg/L	%
2/6/2018				7.26	0.83	1400	7.34	5	3.23	3.44	9.8	7	14	7.2	0.12	0.25	74	7.41	7.70	13.8%
2/7/2018	1100	7.55	11	7.31	0.83				3.09	3.33	10	11	15	7	0.15	0.21	49	7.45	7.70	13.5%
2/8/2018					0.83	320	7.39			3.13	10.1				0.14	0.22	50	7.45		12.7%
2/9/2018										2.93	10				0.17	0.20	45	7.47		12.0%
2/10/2018										2.7	9.8				0.20	0.17		7.38		10.9%
2/11/2018										2.47	9.4				0.16	0.24		7.47		10.0%
2/12/2018	840	7.53								2.24	9.1				0.2	0.18	44	7.59		9.2%
2/13/2018				7.65	0.87	810	7.37	6	2.7	2.09	8.5	8	13	7.1	0.18	0.17	22	7.42	7.93	8.5%
2/14/2018	930	7.13	8	8	0.87				2.46	2.08	8.1	6	13	7.5	0.19	0.19	40	7.42	8.14	8.2%
2/15/2018					0.87	1800	6.79			1.97	8				0.17	0.19	70	7.49		8.0%
2/16/2018										1.91	7.9				0.20	0.14	73	7.60		7.5%
2/17/2018										2.08	8.1				0.24	0.12		7.50		8.1%
2/18/2018										2.29	8				0.20	0.13		7.57		9.2%
2/19/2018										2.27	7.6				0.20	0.12		7.61		9.1%
2/20/2018				8.12	0.88	7600	7.49	8	4	2.15	7.2	12	18	9.4	0.20	0.10	312	7.57	8.13	8.8%
2/21/2018	8500	7.61	14	8.08	0.87				3.68	1.66	6.6	12	17	9.3	0.20	0.11	300	7.58	8.43	8.0%
2/22/2018					0.87	6300	7.49			1.59	6.5				0.21	0.09	240	7.58		6.4%
2/23/2018										1.57	5.7				0.26	0.07	170	7.58		7.0%
2/24/2018										1.52	5.9				0.31	0.15		7.57		6.9%
2/25/2018										1.5	5.9				0.29	0.15		7.57		6.7%
2/26/2018	1700	7.63								1.47	6.1				0.30	0.11	40	7.53		6.6%
2/27/2018				8.44	0.87	340	6.98		3.36	1.42	6.2	10	13	9.4	0.26	0.14	5	7.48	8.40	6.5%
2/28/2018	530	7.21		8.39	0.87				3.07	1.45	6.4	10	14	9.8	0.29	0.13	20	7.47	8.37	6.3%
3/1/2018					0.87	340	7.03			1.51	7.1				0.22	0.13	10	7.42		6.8%
3/2/2018										1.52	7.2				0.25	0.1	10	7.60		6.9%
3/3/2018										1.48	7.7				0.17	0.08		7.51		6.8%
3/4/2018										1.47	7.7				0.22	0.12		7.64		6.7%
3/5/2018	380	7.31								1.45	8.1				0.26	0.17	5	7.46		6.7%
3/6/2018				7.26	0.83	220	7.43	7	3.17	1.38	8.7	9	12	13.2	0.26	0.13	8	7.54	7.09	6.4%
3/7/2018	470	7.56	11	7.23	0.84				3.31	1.35	8.6	9	19	13.3	0.21	0.08	8	7.52	7.37	6.4%
3/8/2018					0.77	560	7.52			1.51	8.6				0.21	0.06	20	7.55		6.2%
3/9/2018										1.73	9.2				0.19	0.13	44	7.54		8.0%
3/10/2018										1.68	9.5				0.22	0.21		7.53		8.2%
3/11/2018										1.71	10.0				0.21	0.11		7.56		7.8%
3/12/2018	1100	7.56								1.63	10.6				0.18	0.04	28	7.54		7.8%
3/13/2018				6.01	0.89	810	7.42	10	3.16	1.66	10.7	11	17	14.7	0.2	0.1	32	7.51	6.61	8.0%
3/14/2018	850	7.58	11	5.95	0.88				2.96	1.67	10.9	9	14	14.3	0.2	0.13	8	7.53	6.75	8.4%
3/15/2018					0.88	300	7.46			1.62	11.1				0.21	0.13	24	7.49		8.2%
3/16/2018										1.56	11.4				0.33	0.13	13	7.50		8.2%
3/17/2018										1.52	11.3				0.28	0.12		7.53		7.6%
3/18/2018										1.41	11.4				0.25	0.15		7.47		7.1%
3/19/2018	740	7.6								1.35	11.6				0.27	0.12	16	7.49		6.8%
3/20/2018				6.2	0.83	440	7.5	5	3.15	1.29	12.1	7	13	15.6	0.24	0.11	10	7.52	6.65	6.7%
3/21/2018	970	7.59	8	6.09	0.83				2.7	1.25	12.0	8	13	15.9	0.22	0.11	16	7.53	6.50	6.1%
3/22/2018					0.82	410	7.47			1.29	11.7				0.25	0.09	4	7.53		6.1%
3/23/2018										1.39	10.9				0.24	0.11	8	7.48		6.6%
3/24/2018										1.52	10.9				0.27	0.13		7.53		7.4%
3/25/2018										1.54	10.8				0.24	0.12		7.52		7.6%
3/26/2018	1800	7.61								1.54	10.2				0.22	0.14	16	7.55		7.7%
3/27/2018				7.17	0.88	1500	7.15		3.01	1.61	10.0	7	9	14.9	0.27	0.14	13	7.52	7.34	7.7%
3/28/2018	2600	7.52		7.23	0.88				2.62	1.62	10.4	7	9	13.9	0.21	0.17	20	7.55	7.18	7.9%
3/29/2018					0.88	1500	7.46			1.61	10.6				0.33	0.15	32	7.55		8.1%

Date	Lagoon 4 Grabs				Filtered Effluent Grabs (Sand Filter)					Effluent 24-Hr Composite					Effluent Grabs					PAA
	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Filter Feed Flow	Fecal Coliform	pH	CBOD	Dissolved Oxygen	Effluent Flow	Temp	CBOD	TSS	Ammonia-N	Initial PAA Residual	Final PAA Residual	Fecal Coliform	pH	Dissolved Oxygen	Pump Speed
	CFU/100 mL		mg/L	mg/L	MGD	CFU/100 mL		mg/L	mg/L	MGD	°C	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100 mL		mg/L	%
3/30/2018										1.58	11.1				0.21	0.15	44	7.54		8.2%
3/31/2018										1.53	11.9				0.14	0.17		7.50		7.5%
4/1/2018										1.57	11.5				0.19	0.15		7.56		7.4%
4/2/2018	5100	7.55								1.63	11.3				0.2	0.14	60	7.49		7.9%
4/3/2018				6.9	0.83	5100	7.41	5	3.09	1.62	11.4	6	6	10.4	0.18	0.14	80	7.42	7.03	8.2%
4/4/2018	3000	7.56	7	6.65	0.83				2.95	1.68	11.1	6	7	9.7	0.17	0.13	48	7.43	6.93	8.1%
4/5/2018					0.83	2100	7.41			1.82	11.1				0.16	0.14	40	7.46		8.8%
4/6/2018										1.83	12				0.29	0.13	40	7.49		9.5%
4/7/2018										2.11	12.2				0.27	0.13		7.4		10.2%
4/8/2018										2.23	11.9				0.22	0.12		7.5		11.1%
4/9/2018										2.19	12.8				0.21	0.09		7.4		10.9%