

City of Memphis Maynard C. Stiles Wastewater Treatment Plant Disinfection Improvements

Full-scale PAA Pilot Study Summary August 1, 2015

Background

The objective of the full-scale peracetic acid (PAA) pilot study was to identify the best disinfection control strategy to achieve compliance with the future National Pollutant Discharge Elimination System (NPDES) permit disinfection limits under varying flows and effluent water quality conditions. The Pilot Study Work Plan, previously developed and approved in 2014, included a description of Dose Control Strategy, Phases of Testing, Data Analysis, Pilot Study Management, and Additional Industrial User Testing to be conducted. This summary report provides an overview of the results from the five Phases of Testing conducted at the M.C. Stiles wastewater treatment plant (WWTP).

Pilot Objective

The objective of the full-scale pilot study was to identify the best disinfection control strategy to achieve compliance with the future NPDES permit disinfection limits under varying flows and influent quality conditions.

Dose Control Strategy

The pilot was conducted in five phases. Phases 1 through 4 included development of information on the best means of providing dose control. Phase 5 was used to demonstrate the efficacy of the final process control algorithm. Data collected during the pilot was used to update the final design of the dose control for the full-scale system design:

Phase 1: Assessment of Influent Quality Indicators

During this phase, four (4) influent quality indicator candidates were evaluated with the objective of selecting two parameters to be tested at full scale in a feed-forward process control strategy. The four indicator candidates were:

- Chemical Oxygen Demand, COD
- Color, PtCo Units
- UV Transmittance @ 254nm, UVT
- Oxidation/Reduction Potential, ORP

Phase 2: Evaluation of Feed Forward Control Strategy with Indicator Candidate A

During this phase, the disinfectant dose was automatically controlled based on flow (flow pacing) and the best influent quality indicator from Phase 1 (demand pacing), assuming that at least one PAA demand peak will be observed during this period.

Phase 3: Evaluation of Feed Forward Control Strategy with Indicator Candidate B

During this phase, the disinfectant dose was automatically controlled based on flow (flow pacing) and the second best influent quality indicator from Phase 1 (demand pacing), assuming that at least one PAA demand peak will be observed during this period.

Phase 4: Data Collection for Calibration of Set Point Values

Data from Phases 2 and 3 were compared to select the best performing process control strategy (most precise control of dose in response to flow and demand changes). The selected control strategy was run during Phase 4 to perform model calibration (adjusting coefficients of control algorithm) and definition of process control set points.

Phase 5: Process Demonstration

A final process demonstration was conducted during Phase 5, collecting field data to demonstrate compliance with daily maximum and monthly geometric mean disinfection criteria as well as maximum effluent PAA residual limit (2 ppm) to be required by State Regulatory Agencies. During this phase, the dosing of VigorOx WWT II was automatically controlled based on both flow and demand pacing.

Project Implementation

The wastewater from the north and south sides of the WWTP meet and discharge into the mixing compartment at the head of the existing contact tank. The combined flow is split into two parallel, serpentine contact channels. Pre-disinfection water quality was assessed at the head of the disinfection channel that was not receiving PAA. The following water quality parameters were measured continuously on-line, as follows:

- Color - ChemScan UV-3151 series flow-thru sensor
- Chemical Oxygen Demand (COD) - YSI CarboVis 701 submersible probe
- UV Transmittance (UVT) - YSI CarboVis 701 submersible probe
- Oxidation-Reduction Potential - ORP Prominent submersible Dulcotest Probe

PAA residuals were measured throughout the disinfection channel by three separate, Ducotest Amperometric PAA sensors, P1, P2 and P3, as shown in Figure 1. Bacterial samples were also collected at several locations throughout the basin during testing, with locations also shown in Figure 1.

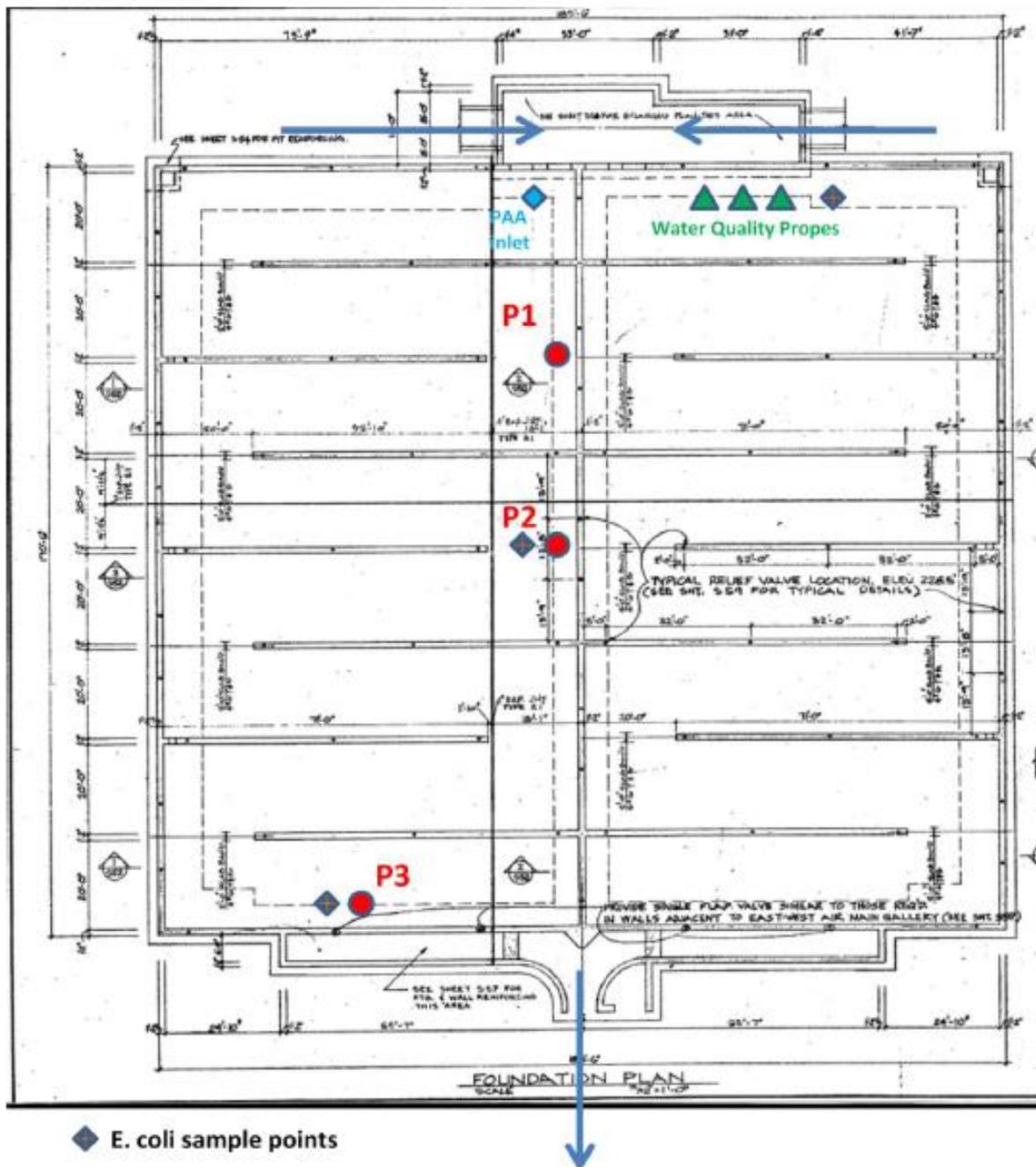


Figure 1. Water quality monitoring and sampling locations in disinfection contact tank.

Pilot Testing Results

Results of pilot testing are summarized by Phase in the following sections. The results for each Phase were evaluated using regression analyses to determine the best fit among the water quality parameters, PAA residual and microbial reductions to determine parameters for process control. The best correlation (as determined by regression analysis) was selected in each Phase by considering the lowest deviation in the curve fit and the steepest slope that would provide the greatest sensitivity for process control.

Phase 1 Results

Phase I was implemented from December 5 – 15, 2014 and during this period, PAA was fed using dose pacing. The PAA dose was initially set at 10 ppm; and was increased to 15 ppm on December 11 at 8:10 am. Results of effluent color and COD collected during Phase 1 are provided in Figure 2; results of UVT and ORP are provided in Figure 3. The PAA residuals at P2 and P3 were near the detection limit of the analyzer throughout the phase and are not shown; as a result, the analysis of Phase 1 data is based on the residuals reported at P1, which are shown in Figure 4 along with *E. coli* results. Based on the initial results of Phase 1, the following recommendations were provided for future Phases of work:

- UVT is not a good process control parameter because of the small range of values that are measured; additionally, UVT values are near zero when color is high, so scaling for process control is limited at these ranges and this parameter will be eliminated from further testing.
- ORP has limited applicability because it could not be correlated to disinfection performance; therefore this parameter will not be carried forward into future phases of testing.
- Color and COD were both readily correlated to disinfection performance; these parameters will be carried into Phase 2 and 3 of testing.
- Because there is no statistical difference in the *E. coli* results between samples collected at P2 and P3, the *E. coli* sampling location located at P2 will be relocated to the P1 location commencing in Phase 2, which will allow additional information to be collected on disinfection kinetics.

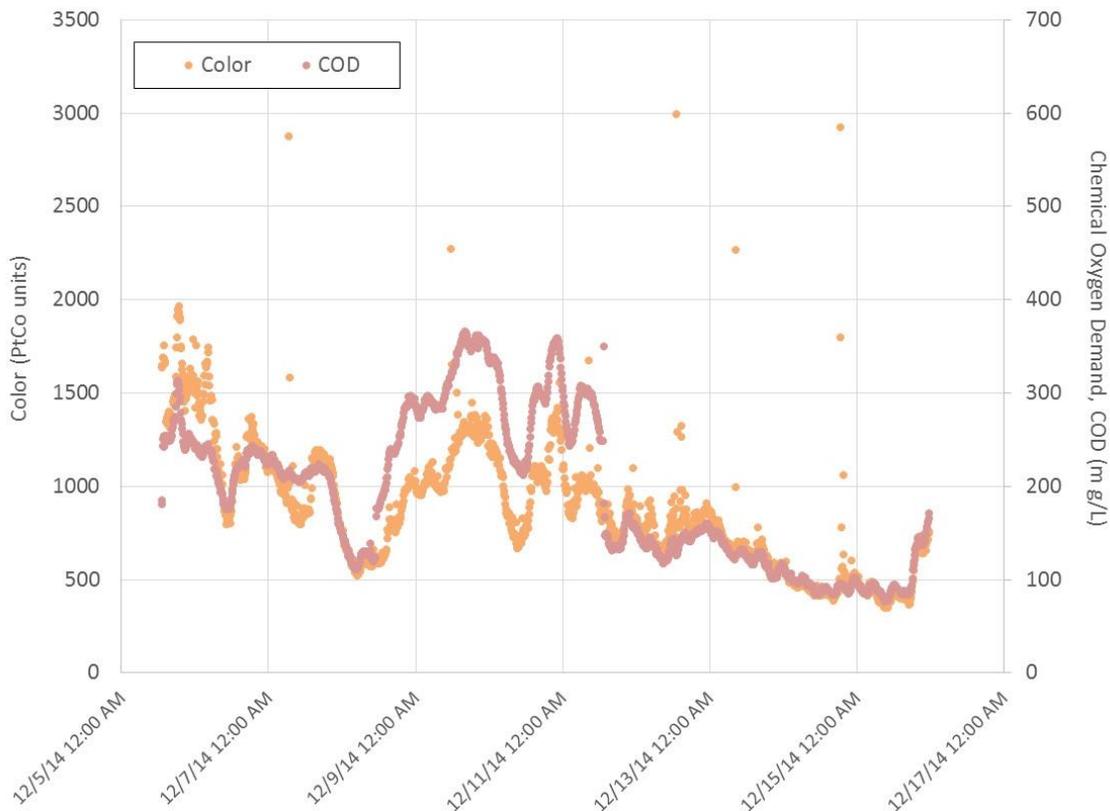


Figure 2. Color and COD measurements during Phase 1.

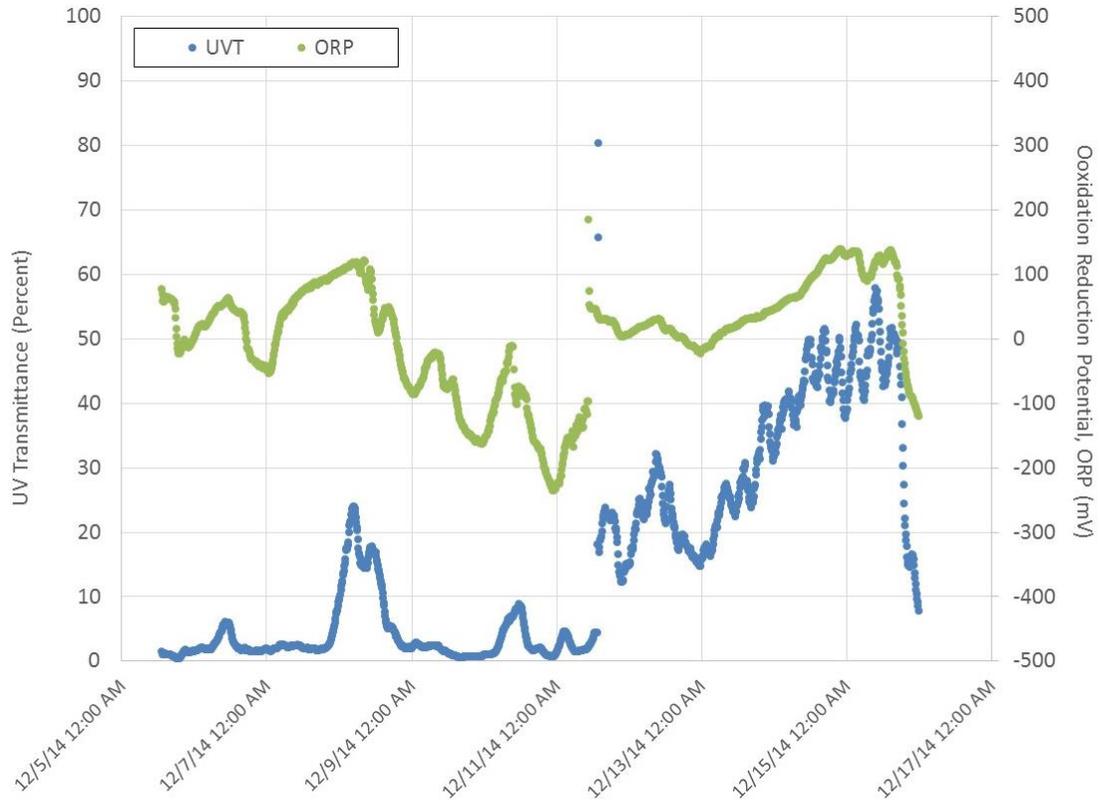


Figure 3. UVT and ORP measurements during Phase 1.



Figure 4. PAA residual at P1 and *E. coli* measurements during Phase 1.

Phase 2 Results

Phase 2 commenced on January 7, 2015 at 8 am, using wastewater color as the feed-forward parameter for the dosing scheme. The initial Phase 2 set point for PAA was established at 10 ppm; as color increased, the dose was increased based on the correlation developed from data collected during Phase 1 to test the feed forward algorithm that was developed. Testing continued through January 17, 2015. Data for PAA dose was plotted along with effluent color, and PAA residual measured at Probe 1, and is provided in Figure 5. The PAA residuals at P2 and P3 were near the detection limit of the analyzer throughout the phase and are not shown; as a result, the analysis of Phase 2 data is based on the residuals reported at P1, which are shown in Figure 6 along with *E. coli* results.

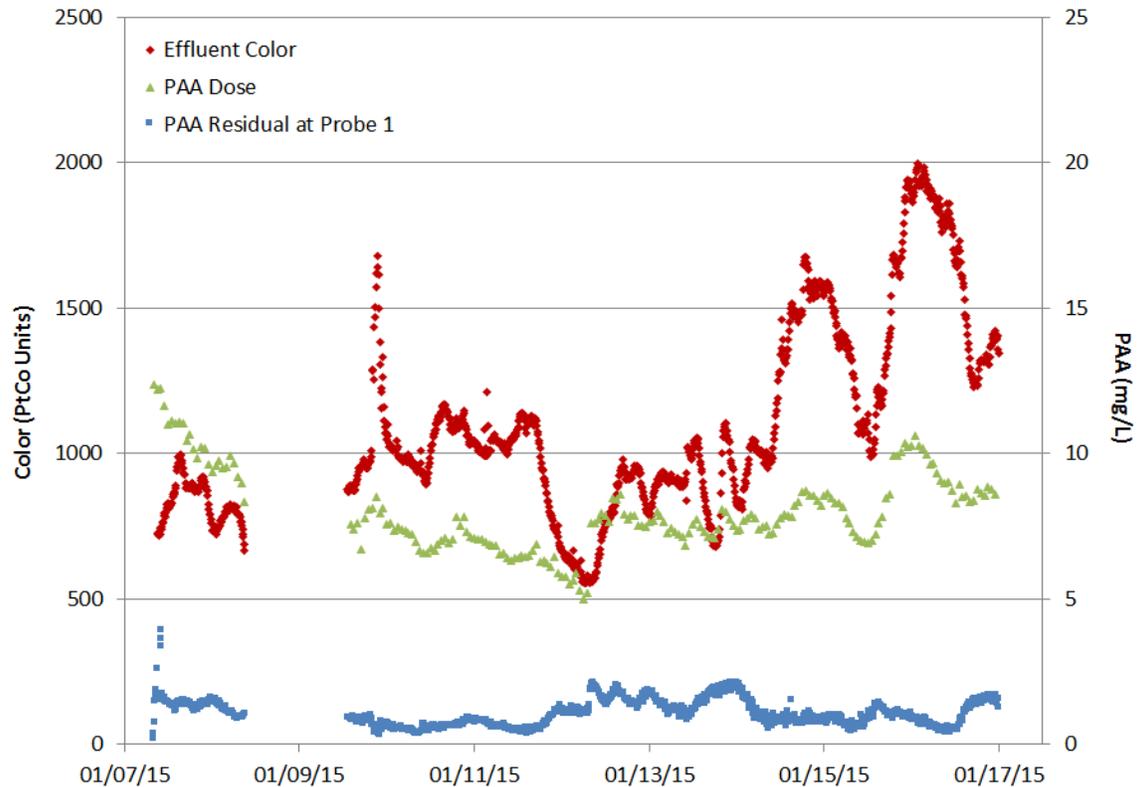


Figure 5. Color and PAA residual measurements during Phase 2.

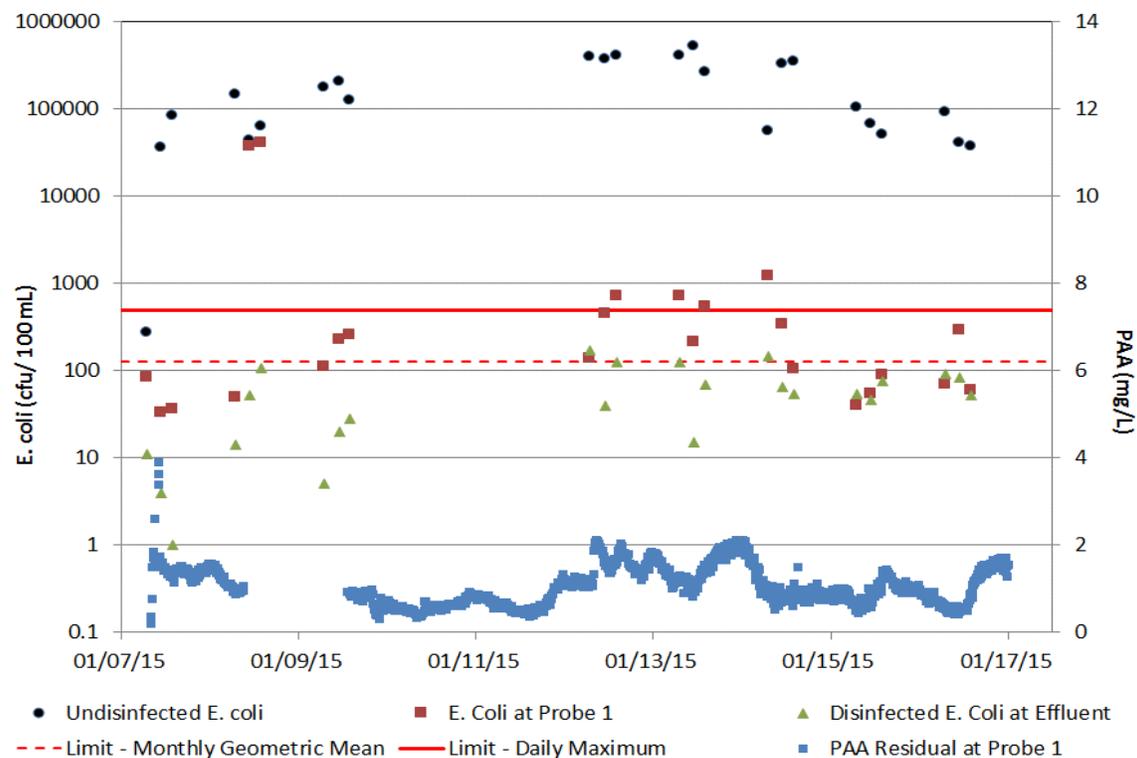


Figure 6. *E. coli* results and PAA residual measurements at Probe 1 during Phase 2.

It is of note that during Phase 2, the data logger stopped recording from January 8, 2015, 9:10 am to January 9, 2015, 1:00 pm; the cause is not known, however, this gap in the data did not alter the conclusions drawn from Phase 2. Additionally, in Figure 5, a jump in the PAA dose may be noted on January 12, 2015; this was a planned increase in PAA dose halfway through the study.

Results of the bacteria testing showed that color was a good feed forward parameter for managing disinfection process control. All but two samples were below the monthly geometric mean limit for *E. coli*; additionally, all samples were below the maximum daily limit, thus test data would meet compliance requirements. The *E. coli* data at Probe 1 showed that in most cases, the majority of the disinfection is accomplished in the first few minutes of contact; however, it was necessary to provide additional contact time to achieve disinfection to meet permit requirements.

In addition to the online color data collected on the undisinfected effluent, grab samples were also collected at the influent (at the location of the water quality probes) and at the effluent of the contact basin (near Probe 3) for laboratory measurements of apparent and true color. Apparent color is the direct color reading of the sample, while true color represents the results of the filtered sample. Data for these daily grab samples is summarized in Table 1. It is of note that on average, throughout the treatment in Phase 2 of testing, that the PAA reduced the color of the effluent by approximately 100 Platinum-Cobalt (PtCo) units. It was not anticipated that PAA would have a significant impact on effluent color; this is a secondary benefit of PAA for disinfection at the Stiles WWTP.

Table 1. Summary of daily apparent and true color data collected from grab samples

Date	Apparent Color (PtCo units)			True (filtered) Color (PtCo units)		
	Untreated flow	PAA treated flow	Difference	Untreated flow	PAA treated flow	Difference
01/08/15	467	394	-73	336	269	-67
01/09/15	908	844	-64	802	624	-178
01/10/15	1264	1124	-140	870	696	-174
01/11/15	1208	1148	-60	824	696	-128
01/12/15	960	760	-200	508	396	-112
01/13/15	1000	872	-128	520	460	-60
01/14/15	1252	1056	-196	770	624	-146
01/15/15	850	626	-224	354	255	-99
01/16/15	572	550	-22	1392	1220	-172
01/17/15	686	646	-40	151	133	-18
01/18/15	500	498	-2	149	112	-37
Average Color Reduction			-104			

Based on the results of this Phase of testing, as anticipated from data collected during Phase 1, color was readily correlated to disinfection performance. Phase 2 demonstrated that color provided excellent process control for the disinfection process. In addition, results from daily grab samples for color at the influent and effluent of the contact basin showed that PAA notably reduced the color of the effluent which is an unanticipated secondary benefit of PAA for disinfection at the Stiles WWTP.

Phase 3 Results

Phase 3 was initiated on January 19, 2015 and concluded on January 28, 2015. Data for PAA dose was plotted along with effluent COD, and PAA residual measured at Probe 1, and is provided in Figure 7. The PAA residuals at P2 and P3 were near the detection limit of the analyzer throughout the phase and are not shown; as a result, the analysis of Phase 3 data is based on the residuals reported at P1, which are shown in Figure 8 along with *E. coli* results.

There were two disruptions in the data collection during Phase 3. The first occurred during the period from January 22, 2015 at 8:20 am to 6:30 pm when the PLC went inoperative due to a spurious signal being sent to the control algorithm; this programming issue was corrected and would not occur again. The second disruption occurred during a loss of power to the plant from January 22, 2015 at 9:40 pm to January 23, 2015 at 7:30 am. The loss of plant power caused a fault in the PAA dosing pump, requiring a manual restart which did not occur until the morning of January 23. Both disruptions caused a loss in monitoring data and disruption of PAA addition to the disinfection channel. While reducing the overall amount of data for analysis, the loss of data does not impact conclusions drawn from Phase 3. Considering the design implications gained from the trial, the loss of PAA addition to the disinfection channel, resulting in loss of microbial control during the power outage will be taken into consideration during full scale implementation (for example, this system should be designed with an uninterruptible power supply that is adequate until power can be restored to the system).

Results of bacteria testing showed that COD was an adequate feed forward parameter for managing disinfection process control. With the initial PAA setpoint, in general, effluent *E. coli* concentrations met the 126 cfu/100 mL criteria. Exceptions included the first *E. coli* value at the beginning of Phase 3, which was attributed to a non-equilibrated condition at the time of the sample collection. In addition, *E. coli* values above the treatment target were also observed when PAA addition was disrupted due to the PLC error and the power outage. Finally, when the PAA setpoint dose was lowered during the second half of

Phase 3, *E. coli* concentrations generally did not meet the disinfection criteria, indicating that a higher set point used in this half of the study is needed to meet disinfection compliance.

Based on the results of the Phase 3 testing, as anticipated from data collected during Phase 1, COD could be correlated to disinfection performance and while not as sensitive as color, could be used as a feed forward parameter for process control of disinfection.

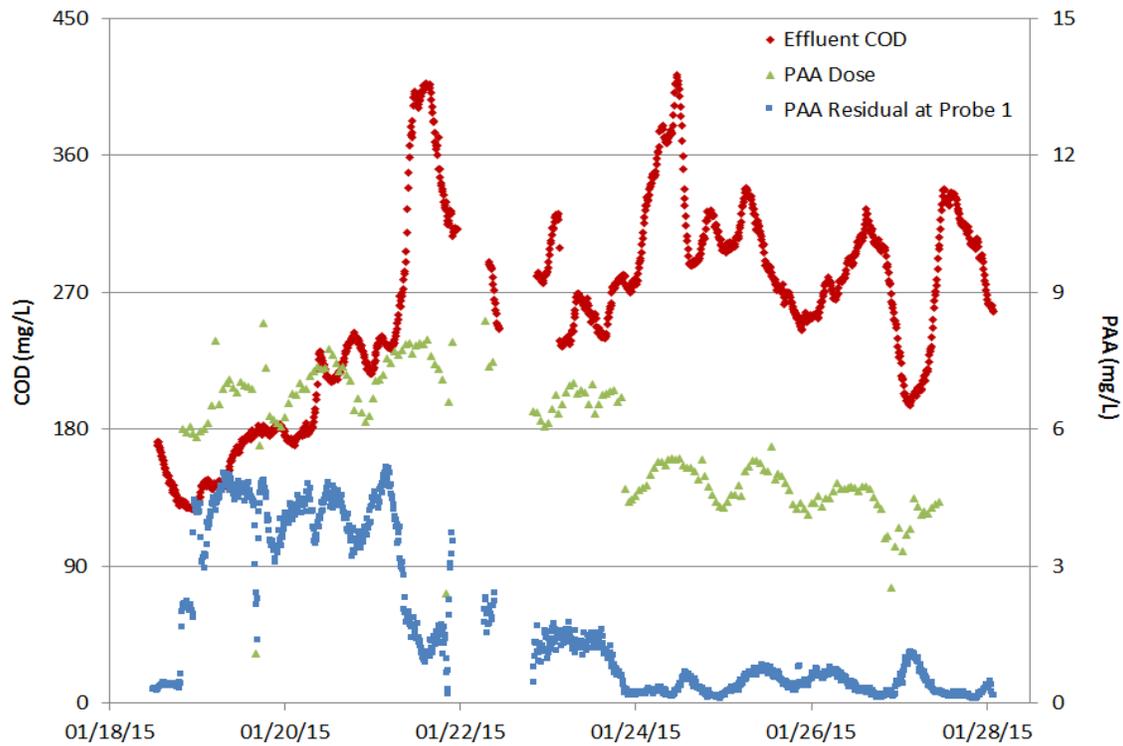


Figure 7. COD and PAA residual measurements during Phase 3.

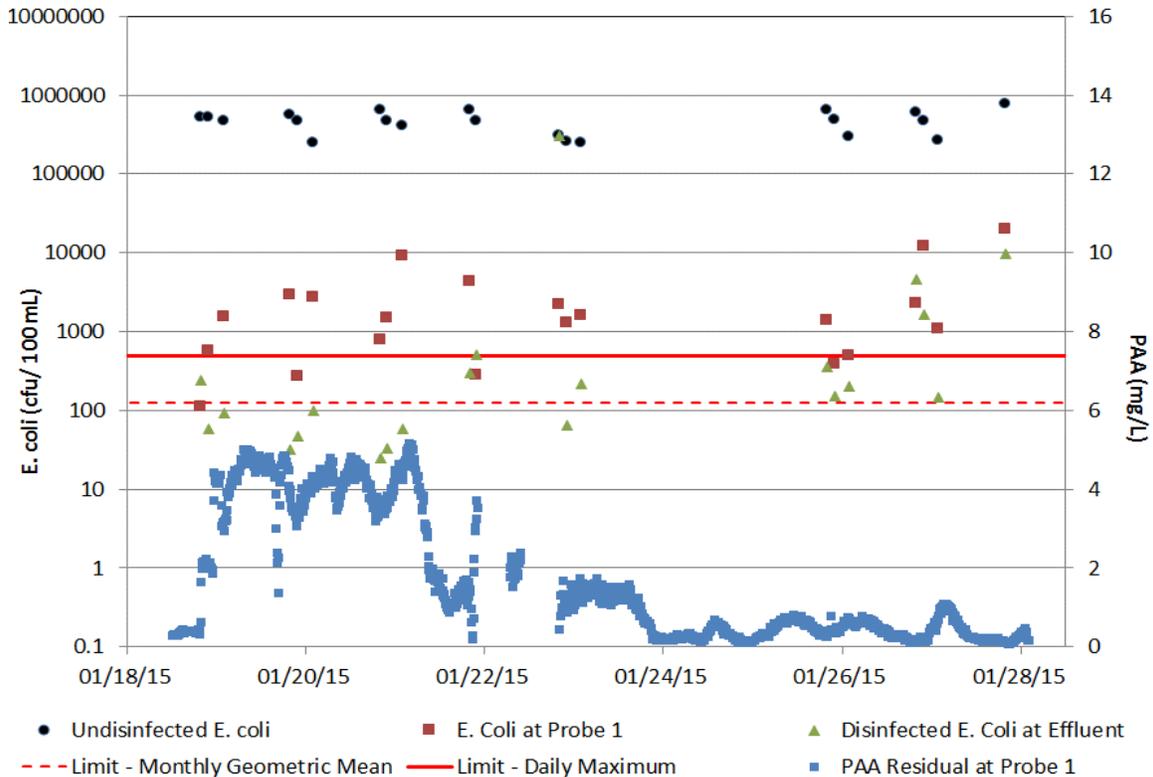


Figure 8. *E. coli* results and PAA residual measurements at Probe 1 during Phase 3.

Phase 4 Results

Phase 4 was initiated on February 3, 2015 and concluded on March 4, 2015. A new flow meter was installed on January 31, 2015 that provided improved readings, and as a result the flow based control was also improved. Based upon the results from Phases 2 and 3, effluent color was utilized in Phase 4 as it showed a more precise dose control compared to effluent COD. Data for PAA dose was plotted along with effluent color, and PAA residual measured at Probe 1, and is provided in Figure 9. The PAA residuals at P2 and P3 were periodically near the detection limit of the analyzer throughout the phase and are not shown; as a result, the analysis of Phase 4 data is based on the residuals reported at P1, which are shown in Figure 10 along with *E. coli* results.

As shown in Figure 9, there were operational disruptions in the data collection during Phase 4. The first disruption occurred late in the day on Thursday, February 19th and into the morning of February 20th, when extreme cold weather caused the effluent sample line leading to the color analyzer to freeze. As a result, color analysis and the resulting feed-forward control of PAA dosing were impaired. The second disruption occurred due to the severe cold weather resulting in interruption of deliveries of PAA. To prevent a shutdown of the study due to limited PAA, a PAA “conservation” program was initiated on Saturday, February 21st. The program consisted of reducing the PAA dose to a flow-paced 2 ppm, during periods when *E. coli* sampling was not occurring (weekends and evening hours). This reduction in off-hour PAA usage did not negatively impact *E. coli* testing or the demonstration of PAA efficacy. There were no technical issues associated with this reduction in off-hour PAA usage, and this was continued throughout the remainder of the pilot as a significant cost-savings to the City. Both interruptions are important to note so that the final engineering design will prevent these issues from occurring at full-

scale by providing freeze protection and an appropriate storage volume onsite as well as working with the chemical supplier to provide consistent product supply.

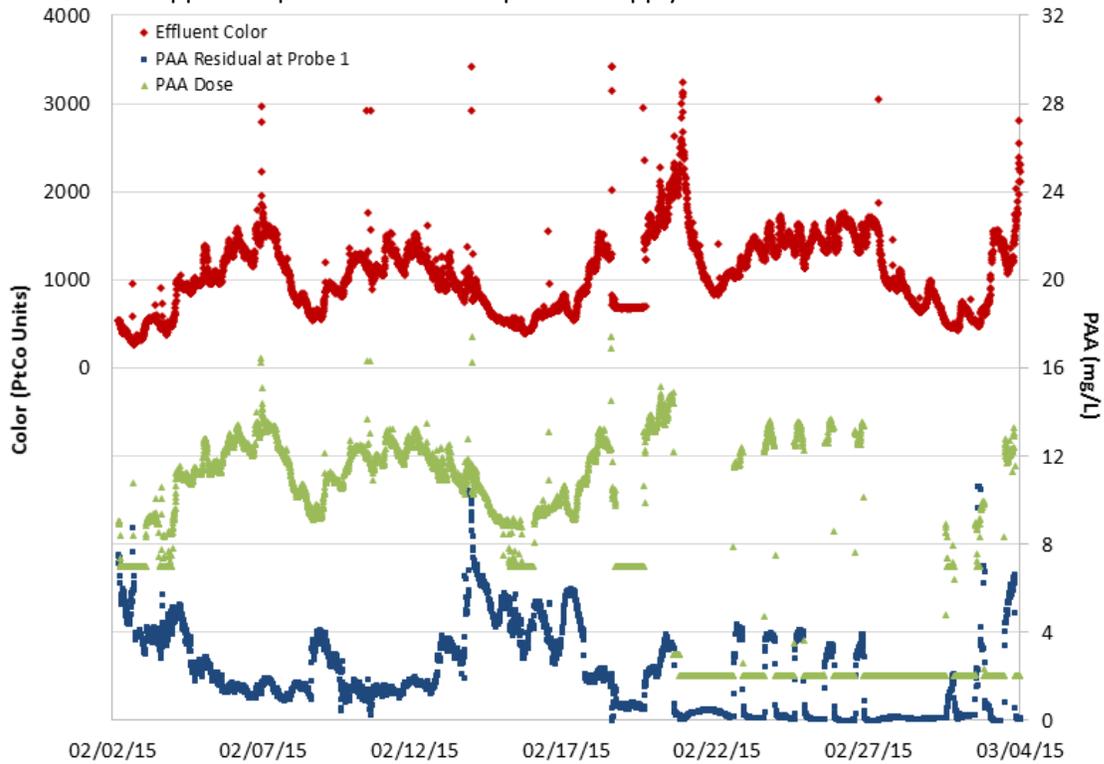
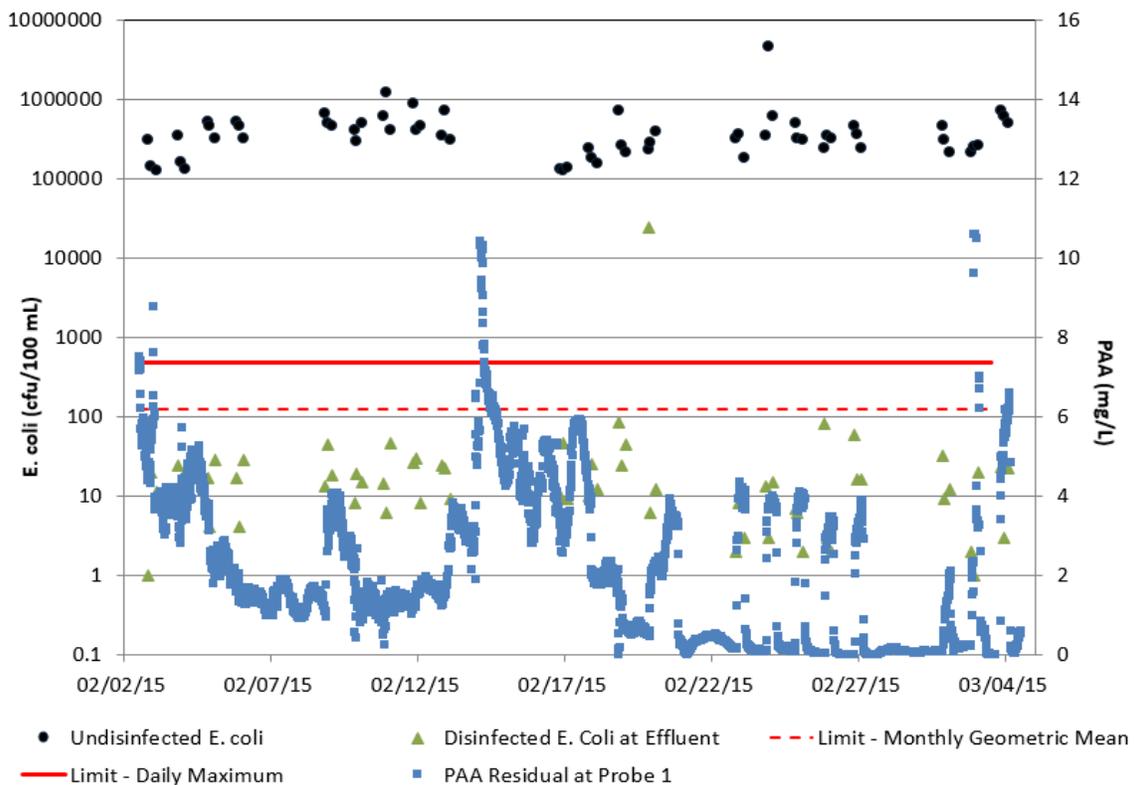


Figure 9. Color, PAA dose and PAA residual measurements during Phase 4.



● Undisinfected E. coli ▲ Disinfected E. Coli at Effluent - - - Limit - Monthly Geometric Mean
 — Limit - Daily Maximum ■ PAA Residual at Probe 1

Figure 10. *E. coli* results and PAA residual measurements at Probe 1 during Phase 4.

Results of bacteria testing in Phase 4 showed color was an excellent feed forward parameter for managing disinfection process control. Phase 4 was completed on March 4, 2015; and as shown in Figure 10, the PAA setpoint determined from previous Phases easily met the 126 cfu/100 mL criteria, except for during the first interruption when the sample line leading to the color analyzer froze. As a result, PAA dose control was switched to flow pace only at the baseline setpoint for PAA and the sample collected during this time did not meet the daily maximum limit. While this result did not meet the permit requirement, it showed the dose control algorithm using color is a highly sensitive method for managing effluent *E. coli* concentrations.

Phase 5 Results

Phase 5 was initiated on March 6, 2015 and concluded on April 4, 2015. The flow meter installed prior to Phase 4 provided stable and improved readings throughout the entirety of Phase 5; as a result, the flow based control was also stable. Data for PAA dose was plotted with effluent color, and PAA residual at Probe 1, and is shown Figure 11. The PAA residuals at P2 and P3 were periodically near the detection limit of the analyzer throughout the phase and are not shown; as a result, the analysis of Phase 5 data is based on the residuals reported at P1, which are shown in Figure 12 along with *E. coli* results.

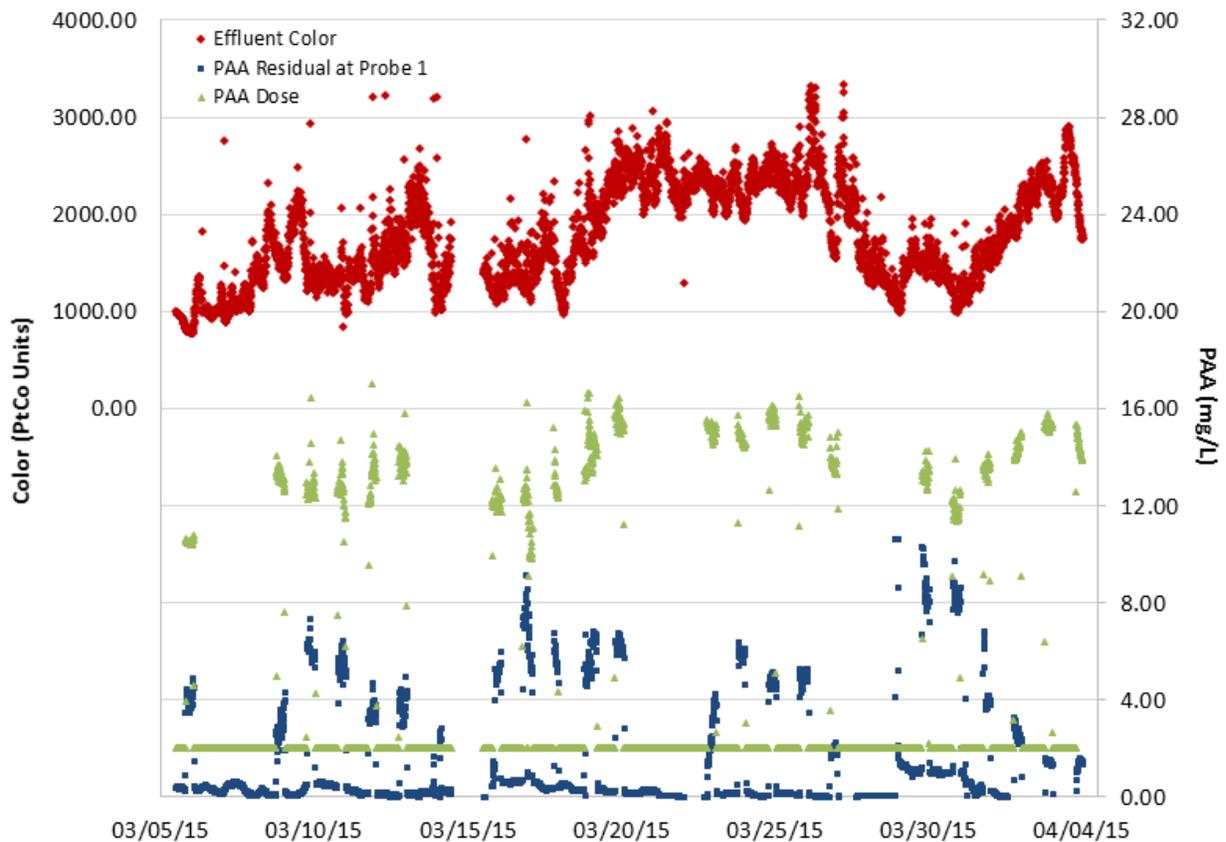


Figure 11. Color, PAA dose and PAA residual measurements during Phase 5.

As noted, a PAA “conservation” program was initiated on Saturday, February 21st, reducing the dose of to a flow-paced 2 ppm, during periods when *E. coli* sampling was not being conducted. This can be observed in Figure 11, which shows the PAA dose and residual in green and blue symbols, respectively.

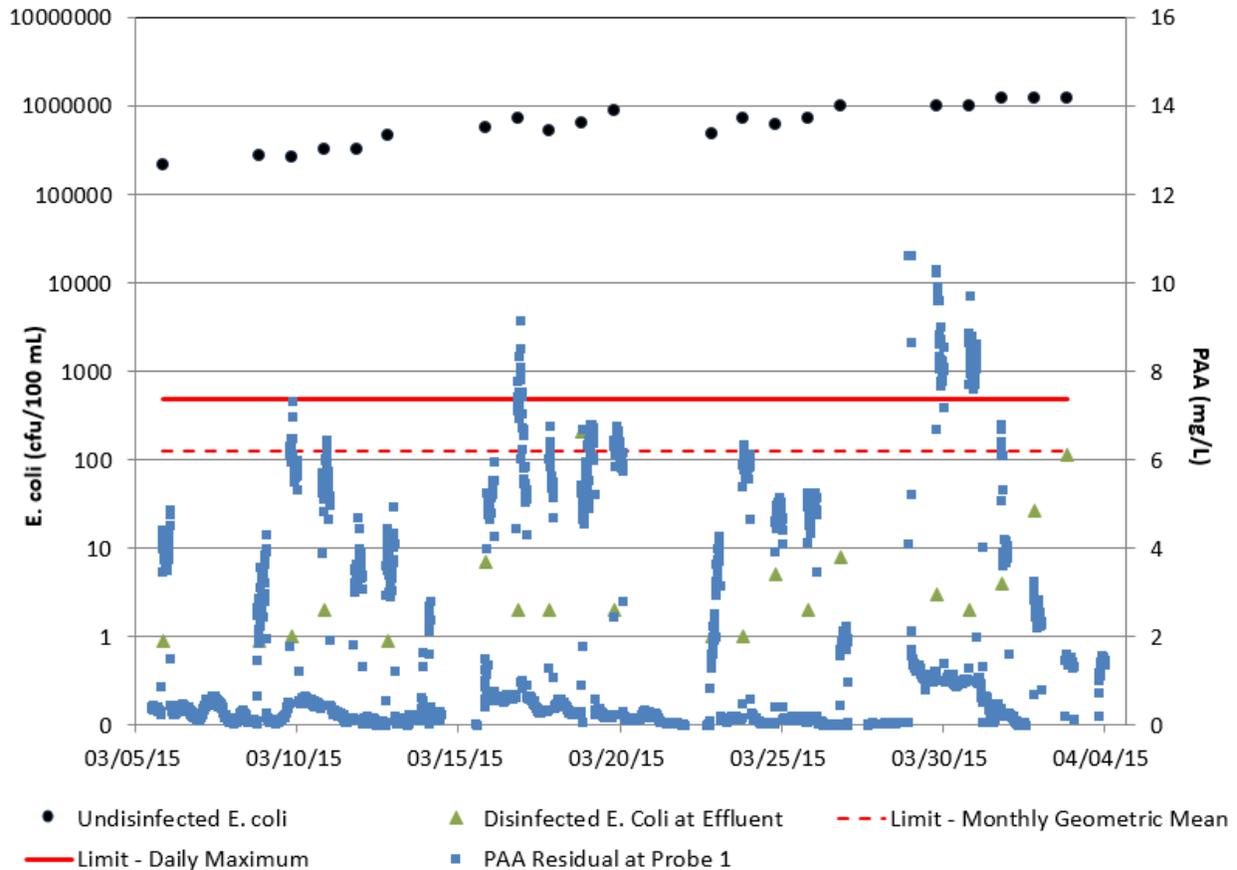


Figure 12. *E. coli* results and PAA residual measurements at Probe 1 during Phase 5.

Results of the bacteria testing in previous phases showed that color was an excellent feed forward parameter for managing disinfection process control. Phase 5 was completed on April 4, 2015; and as shown in Figure 12, the PAA setpoint determined from previous Phases met the 126 cfu/100 mL criteria except for on one day during a high color event. Even though the March 19 sample did not meet the monthly geometric mean limit, it would have still been in compliance because it was less than the maximum daily limit of 487 cfu/100 mL.

Summary and Conclusions

Based on the results of this Phase of testing, as anticipated from data collected during previous Phases, color is strongly correlated to disinfection performance. This parameter, which was also used for feed forward during Phase 4 proved to be an excellent process control parameter for managing disinfection. The entire month of Phase 5 data demonstrated that PAA fed using dose pacing with a feed forward control based on color is an optimal means of meeting disinfection compliance. Using the information collected in this study, the City will complete design of the disinfection system so that it can be put into operation to meet the compliance schedule outlined in the NPDES permit.