Bayonne, NJ Combined Sewer Overflow Treatment Demonstration Project: Preliminary Disinfection Results

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ABSTRACT

A CSO pilot treatment program has been completed in Bayonne, New Jersey. The project focused on verifying performance of selected technologies for TSS removal and disinfection under field conditions. Following pretreatment for TSS removal in several alternative processes, the effluent was disinfected with peracetic acid (PAA) or ultraviolet (UV) light utilizing low-pressure and medium-pressure lamps. The test units had a design capacity of between 189 and 3,785 L/min (50 to 1,000 gpm) and were fed from an extensive CSO catchment area. PAA effectiveness was a function of the dose applied as normalized by COD for E. coli, fecal coliforms and Enterococci. Three (3) log reduction (deactivation) was achieved, on average, at 0.010 mg/L PAA dose per mg/L of COD present. Similar deactivation was achieved by UV dose of 25 mJ/cm^2 for low-pressure UV system and by 40 mJ/cm^2 for medium-pressure system.

KEYWORDS: Combined sewer overflow, CSO, peracetic acid, PAA disinfection, UV disinfection

INTRODUCTION

Bayonne Municipal Utilities Authority (BMUA), NJ, completed a Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) in 2006, as required by the New Jersey CSO Master General Permit. The LTCP evaluated a variety of technologies and methodologies for addressing combined sewer flows. Rapid treatment for TSS and disinfection at remote end-of-pipe facilities was included as a required element in the LTCP. Due to a lack of independent information, data from individual manufacturers was used as the basis for conceptual sizing of the required facilities. At the time a recommendation was made to validate selected manufacture's data prior to full scale implementation.

The BMUA retained Mott MacDonald as the Project Manager to develop, coordinate, and conduct this wet weather demonstration project and to publish the data for general use within the industry. The project was undertaken jointly by the BMUA, with grants from the NJDEP and EPA. A Technical Advisory Committee (TAC), and a Project Oversight Committee (POC) were formed, to review and comment on the means, methods, results, and conclusions of the project.

The goal and objective of the project was to develop scientifically valid performance data obtained under field conditions to evaluate the effectiveness of CSO treatment technologies and to gain an improved understanding of their potential use as satellite, end-of-pipe water treatment for CSO wet weather discharges. In addition to performance evaluation, aspects such as unit's reliability, scalability, anticipated capital and O&M costs, efficiency, and startup procedures were of interest.

TESTED TECHNOLOGIES

A solicitation for qualifications was published and various suppliers of wastewater and stormwater equipment responded offering hydrodynamic and gravimetric separators, filters, medium and low pressure ultraviolet disinfection devices and chemical disinfection units. The primary evaluation criteria for the units were; suitability for remote satellite facilities, documented performance, ease of operation, maintenance requirements, footprint and cost. The technologies selected for the demonstration project included the following existing available manufactured systems:

- Hydro International’s Storm King® with Swirl Cleanse
- Terre Kleen TK-09
- WETTCO’s Flex Filter™
- PeraGreen’s INJEXX™ Per Acetic Acid (PAA) unit (Figure 1)
- Trojan’s UV30000Plus™ (Figure 2)
- Aquionics Inline 250+W Medium Pressure UV (Figure 3)

Figure 1. Peracetic acid Peragreen INJEXX system on project site

Figure 2. Trojan UV3000 unit on project site

Figure 3. Aquionics UV 250+W unit on project site

The BMUA Oak Street Pumping Station was selected as the study location since its drainage area encompassed the entire City, the site provided adequate room, included a wet weather CSO discharge of up to 40 mgd, and provided consistent and extended CSO overflow periods.

The pilot facilities were laid out and designed to maximize flexibility in testing various configurations of TSS removal and disinfection units. Flow to each unit was controlled and measured so that it could be varied from storm to storm but held relative constant during any one storm. Figure 4 provides the aerial view of the completed pilot plant site, while Figure 5 shows the schematic layout of the pilot units and sampling locations.

Figure 4. Aerial view of the assembled pilot plant

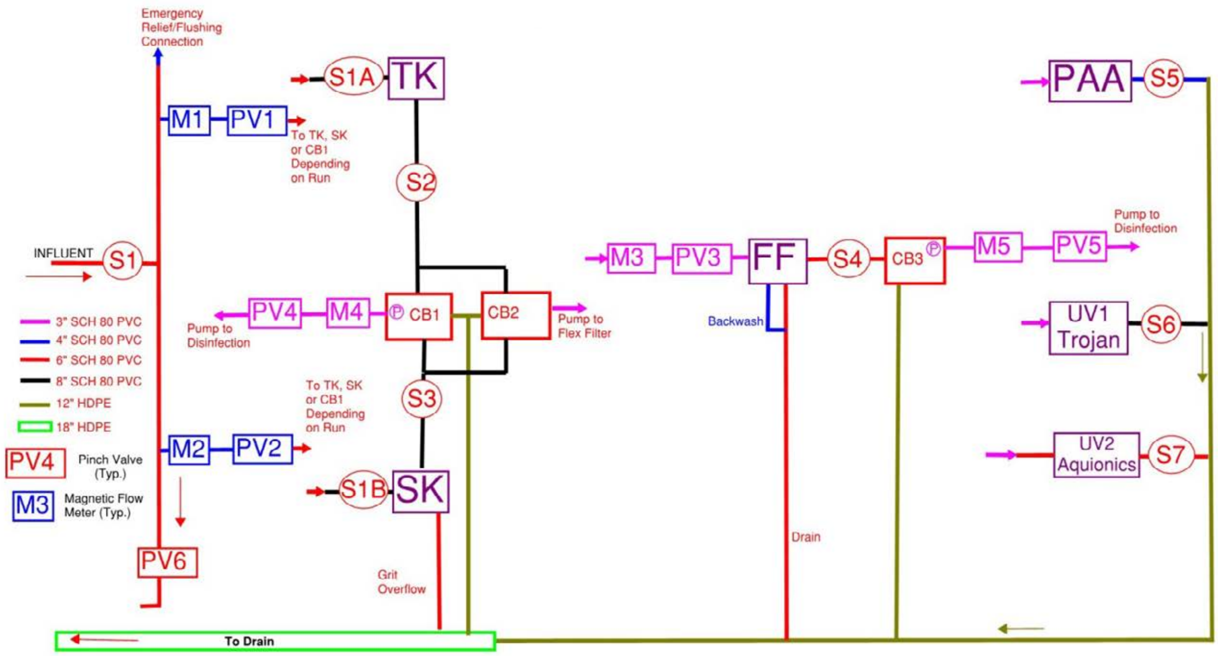

Figure 5. Schematics of the pilot plant layout and sampling locations

Testing Program

The project was initiated in the fall of 2014 with four (4) storm events (Test Runs) monitoring completed before a winter break. Testing resumed in the spring of 2015 but due to unusually dry weather and scheduling conflicts only 3 additional Test Runs were successfully completed by the end of September 2015. In order to complete the planned total of 9 sampling events, the program of “live” storm/overflow events was complemented by 2 events where regular BMUA sewage was diluted with groundwater to simulate the CSO discharge.

During each Test Run grab samples were obtained at 20 minute intervals for up to 4 hours at key influent and effluent locations and analyzed for appropriate water quality parameters. Analytical program included analysis (on selected samples, as appropriate) for the following parameters: TSS, VSS, soluble and total $CBOD_5$, COD, TOC, temperature, pH, turbidity and DO. Influent and effluent from disinfection units were analyzed for E. coli, fecal coliforms and Enterococci, as well as for UV transmittance and residual PAA, as applicable. Additionally, raw wastewater was tested at 60 minute intervals for settleable TSS and VSS utilizing the 60 minute Standard Methods gravimetric procedure.

Table 1 provides a summary of test equipment configuration and flows for each of the Test Runs. As can be seen, in all test runs the disinfection step was preceded by a TSS removal step(s). The sole exception was test run 7, where raw CSO influent was subjected to PAA disinfection.

Table 1. Summary of equipment set-up for individual Test Runs

Run No.	Date		Train 1			Train 2			Not Used	Comments
1	10/4/2014	Equipment	SK	FF	PAA	TK		AQ	TR	SK and TK screens plugged; FF backwashed once; influent screen plugged limiting flow to 50 gpm occasionally; PAA initially not fed, then overdosed
		Flow (gpm)	500	150	50	500		150		
2	10/16/2014	Equipment	TK	FF	AQ	SK	TR		PAA	SK screen manually cleaned; TK fed w/o screen; FF fed with a pump with a screen which was periodically manually cleaned; FF backwashed twice
		Flow (gpm)	300	150	120	300	150			
3	10/22/2014	Equipment	TK	AQ		SK	FF	PAA	Trojan	Limited sampling for PAA; TK and SK functioned w/o plugging; FF fed with a pump with a screen which was periodically manually cleaned; no backwash on FF;
		Flow (gpm)	600	160		400	100	40		
4	11/6/2014	Equipment	TK	PAA		SK	FF	TR	AQ	SK screen was plugging and was periodically manually cleaned; TK water level overtopped internal weir; FF operated with a pump w/o screen, backwashed 4 times for ~ 35 minutes; PAA dose erratic due to oversized pump
		Flow (gpm)	400	50		600	150	130		
5	7/30/2015	Equipment	TK	FF	TR	SK	PAA		AQ	SK screen was plugging and was periodically manually cleaned; TK water level overtopped internal weir; FF operated backwashed 3 times for ~ 35 minutes; PAA off for first sample.
		Flow (gpm)	550-375	150	130	450-300	100			
6	8/11/2015	Equipment	TK	PAA		SK	FF	AQ	TR	SK screen was plugging and was periodically manually cleaned; FF operated backwashed 3 times for ~ 35 minutes; PAA Tank volume restored to 300 gal; AQ "Water too hot" alarm
		Flow (gpm)	300-200	105		300-200	160-140	140-100		
7	9/10/2015	Equipment	PAA			SK	TR		FF, AQ	SK screen was plugging and was periodically manually cleaned; FF not working; PAA influent samples taken from CB-3
		Flow (gpm)	100			400-345	150			
8	10/15/2015	Equipment	SK	FF	AQ	SK	PAA		TK, TR	Wedge wire screen on SK, plugged and was periodically cleaned; FF backwashed 2 times for ~ 35 minutes; Could not achieve PAA residual
		Flow (gpm)	475-710	150	130	475-710	100			
9	10/27/2015	Equipment	TK	FF	TR	TK	PAA		SK, AQ	Unusual "sludge blanket" on FF filter media, Could not achieve PAA residual
		Flow (gpm)	900-850	145	140-100	900-850	61-105			

DISINFECTION WITH PAA

Overview of Testing Procedures

A 12% solution of PAA (Proxitane WW-12) with a specific density of 1.11 g/mL was used during all runs. The volume of the PAA reactor tank initially provided by the supplier was 1,136 L (300 gallons). It was temporarily reduced to 568 L (150 gallons) by internal overflow modifications for Test Runs 3 and 4, before being restored to 1,136 L for the Test Run 5 and all subsequent Runs. The design flow rate of wastewater varied between 95 and 189 L/min (25 to 50 gpm) for the initial Test Runs, before being set at 189 L/min for Run 5 and all subsequent Runs. The resulting design hydraulic retention time (HRT) for all sampling events is provided in Table 2 and it varied from 3 to 6 minutes, with HRT standardized at 3 minutes after the Run 4. The wastewater flow rate to the PAA unit fluctuated to some degree during each Test Run in response to hydraulic head and other factors, and these variations were taken into account during the analysis of individual data sets.

PAA solution was initially pumped into the PAA reactor system by a dosing pump with 22.7 L/day (6 gpd) flow rate. The initial results indicated that the resulting dose was too high and that it was difficult to adjust the pump dosing rate to smaller flow rate with a stable output. Consequently, starting with the Test Run 5, with a smaller, 11.4 L/day (3 gpd) dosing pump was utilized. During the Test Runs the dosing pump settings (stroke and speed) were adjusted in response to the results of the PAA residual field measurement. The objective was to maintain the PAA residual in the range 1 to 2 mg/L, but this was difficult to accomplish in real time, with limited ability to conduct frequent grab sampling and measurements for adjustments.

Summary of Conditions During Test Runs

A summary of the operating conditions for all Test Runs with PAA is provided in Table 2, which lists information such as the pretreatment unit used, average PAA dose and measured residual, HRT and average water quality parameters, including feed (or influent) concentration of pathogen indicators. The average performance results in terms of log reduction of pathogen indicators are also provided. Due to large variability in the wastewater quality and in the PAA dose delivered within some of the Test Runs, these average performance data for individual Test Runs are listed for general information and are not further discussed or correlated. The subsequent analysis focuses on data sets from individual sampling events on corresponding samples collected during all Test Runs.

Table 2. Summary of the operating conditions for all Test Runs with peracetic acid

Storm #	PAA													
	Source of Influent	Design Flow, gpm	Average PAA Dose Applied, mg/L	Average PAA Residual Measured, mg/L	Design Hydraulic Retention Time, min	Average TSS in Influent to PAA, mg/L	Average Soluble $CBOD_5$ in Influent to PAA, mg/L	Average COD in Influent to PAA, mg/L	Geo. Mean in Feed			Average Log Reduction		
									E. Coli	Fecal coliform	Entero-cocci	E. Coli	Fecal coliform	Entero-cocci
1	FF	50	6.9	1.50	6	128	6.3	321	835,970	5,527,250	303,650	2.46	1.48	2.26
3	FF	40	0.56	1.05	4	12.1	28.3	113	688,520	3,041,255	748,488	3.78	0.73	0.91
4	TK	20	1.7	1.13	7.5	417	20.7	417	1,976,300	3,312,149	1,230,198	1.06	0.62	0.88
5	SK	50	1.7	1.82	3	225	22.1	364	1,176,657	8,318,359	370,081	1.87	2.15	1.07
6	TK	100	2.8	1.09	3	235	13.1	350	1,537,320	1,246,712	502,264	2.96	2.61	2.29
7	Raw	100	2	0.92	3	137	30.4	254	2,518,877	27,478,039	1,303,941	2.83	2.45	2.24
8	SK	100	2.8	0.00	3	90.3	53.8	312	4,339,314	2,991,547	1,327,225	0.18	0.72	-0.08
9	TK	100	2.8	0.18	3	113	48.2	342	4,428,413	1,949,520	1,375,294	0.65	0.25	-0.11

NOTE: For calculating Log Reduction for pathogen indicators, results reported as "less then" were interpreted as 1/2 of the detection level.

During the simulated Test Runs 8 and 9 influent wastewater was generated by mixing groundwater from the underground tankage at the site (former primary clarifiers) with raw wastewater at an approximate ratio of 1:1. Unfortunately, during these Tests Runs no measurable PAA residual was achieved, despite the fact that the PAA feed pump was operating at full capacity. Accordingly, little or no reduction in density of the bacteria during these Runs was observed across the PAA unit (Table 2).

A possible explanation of this lack of PAA residual is an accelerated degradation of PAA caused by high salinity. Such effects were reported by Liu *et al.* (2014), where 1% and 3% sea water solutions were found to significantly accelerate degradation of PAA solutions, resulting in half-life times of 30 to 60 minutes. In tests on undiluted seawater Howarth (2003) found half-life of PAA to be 12 to 30 minutes, depending on the initial PAA concentration. Since the pilot test site is adjacent to coastline, groundwater in the underground tanks could have been contaminated with intruding seawater. During the Test Run 9 conductivity of the simulated wastewater was measured at 4.2 uS/cm, which is consistent with about 10% contribution of seawater. Subsequent test of the groundwater from the underground tanks confirmed that contamination, with the TDS measured there at 4,630 mg/L. Even though the contact time in the Test Runs 8 and 9 was only 3 minutes, the high salinity in our simulated wastewater was likely contributing to the accelerated decay of the PAA and the lack of residual.

The relatively high soluble $CBOD_5$ in the simulated wastewater (Table 1) could have been another factor in the lack of a measured PAA residual in Test Runs 8 and 9.

In any case, due to the lack of PAA residual and meaningful log removal, the results of PAA disinfection tests for the Test Runs 8 and 9 were excluded from further analysis.

Table 3 provides a brief summary of pathogen indicator data from all valid individual sampling events in the Test Runs 1 through 7 indicating that the average log reduction was in the range 1.7 to 2.3 logs for all three indicators. In contrast, in HDR (2014) study on wet weather primary effluent it was found that higher PAA and chlorine residual is required to inactivate E. coli and Enterococci to its potential regulatory limits than is required for fecal coliform. The specific log reductions were not identified in that study, but from the graphical presentation of the data it appears that at about 3 mg/L PAA residual and 15 min. contact time the log reduction for fecal coliform averaged 2.5 to 3, while it was approximately 2 for E. coli and Enterococci. Similarly, in WERF (2005) study on wet weather plant influent (corresponding to CSO) chlorine and chlorine dioxide were most effective against fecal coliform and least effective against E. coli, although the overall removals were better than in the current study.

Table 3. Summary of Pathogen Indicator Data for PAA Tests

Pathogen Indicator	Initial Count Range (cfu/100 mL)	Average Log Reduction
E. coli	5.2E+05 to 4.9E+06	2.3
Fecal coliform	6.0E+05 to 5.5E+07	2.0
Enterococcus	4.0E+04 to 2.1E+06	1.7

The lower removals demonstrated during the current program are likely related to a relatively low PAA dose applied (Table 2), which generally was under 3 mg/L (targeting 1 to 2 mg/L residual) and shorter contact time. This compares to order of magnitude larger dose of chlorine in the WERF (2005) study (8.5 to 28 mg/L range).

Discussion of the Results

Initially, all valid data sets from individual sampling events during Test Runs 1 through 7 were analyzed to determine correlation between disinfection effectiveness and the applied PAA dose or PAA residual, including data normalized by contact time. The obtained correlations were not satisfactory.

Subsequently, the applied PAA dose was normalized with respect to COD by dividing the dose by COD measured in the corresponding wastewater sample. The normalized dose correlates quite well with the log reduction for all three pathogen indicators (Figures 6 through 8). The only significant outliers are 3 data points for fecal coliforms for the Test Run 1, where a number of interferences and out of range results were reported by the laboratory.

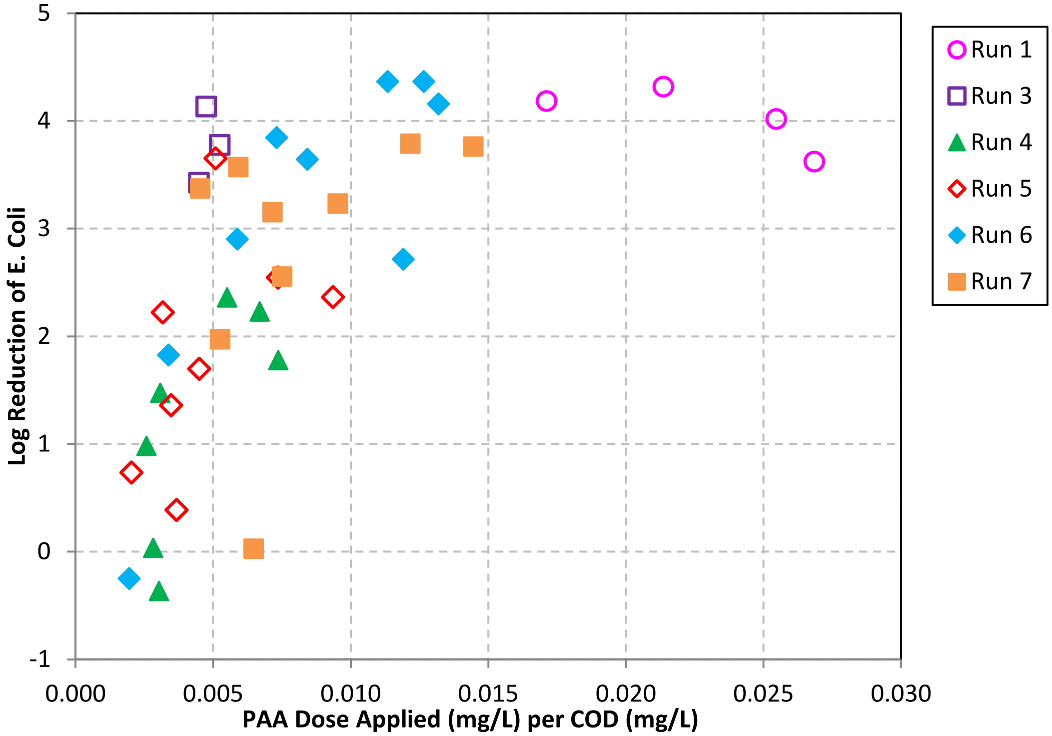

Figure 6. PAA Dose per COD vs Log Reduction of E. Coli

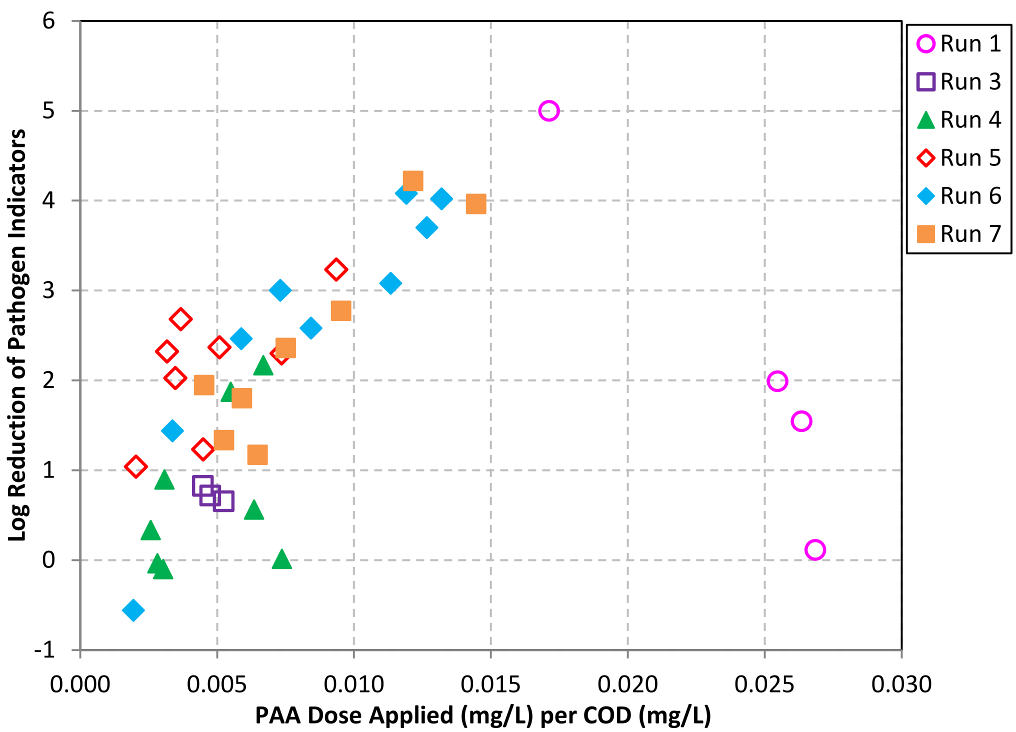

Figure 7. PAA Dose per COD vs Log Reduction of fecal coliforms

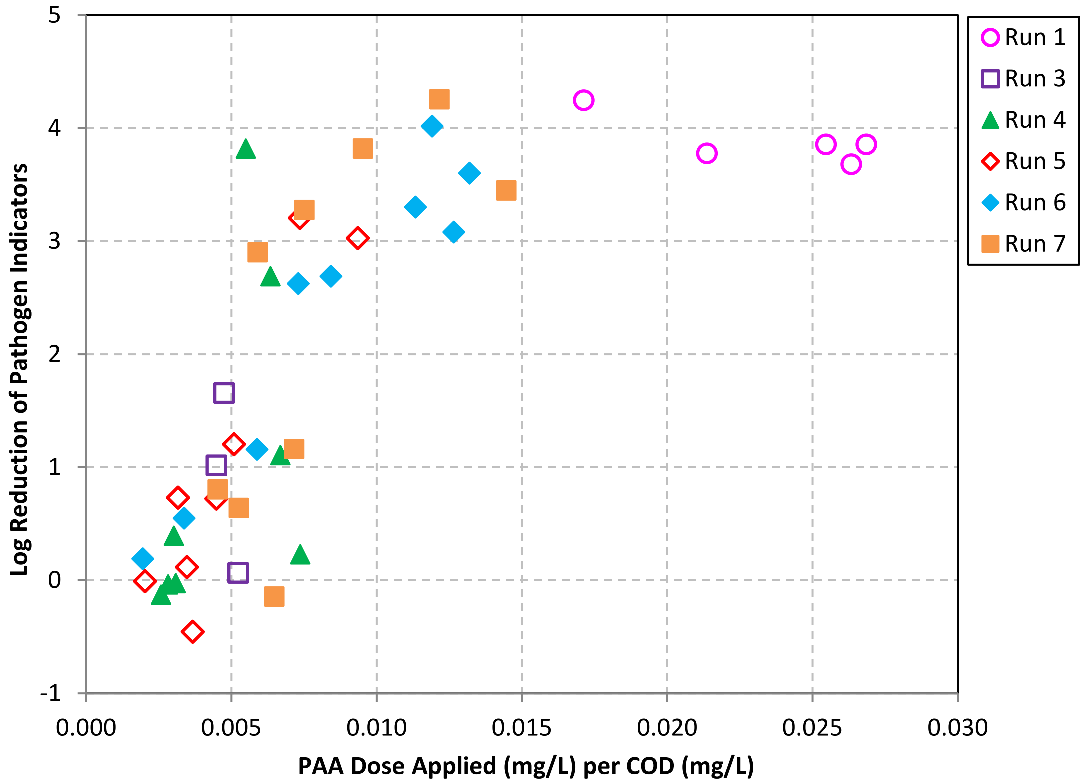

Figure 8. PAA Dose per COD vs Log Reduction of Enterococci

Figure 9 provides data from all Test Runs consolidated for each of the 3 pathogen indicators, with the exception of the 3 outlying data points for fecal coliforms. Best fit logarithmic regressions lines shown on this graph indicate a very good fit, with better than 99% confidence level (considering value of the R^2 and number of data points).

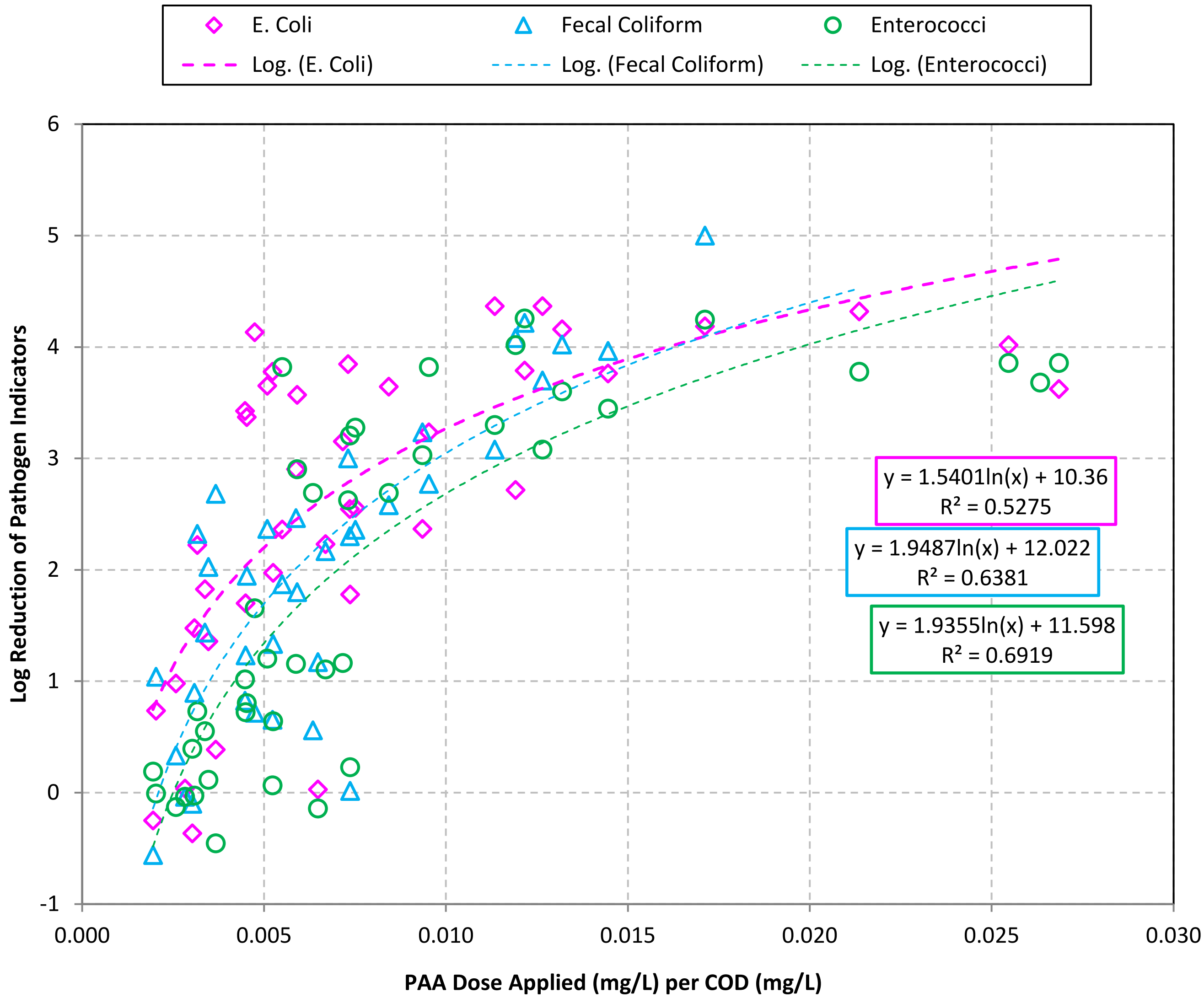

Figure 9. PAA Dose per COD vs Log Reduction of Pathogen Indicators

From Figure 9 it could be inferred that PAA dose of 0.01 mg/L of PAA per mg/L of COD typically results in 3 log reduction of fecal coliforms, with slightly higher effectiveness for E. coli and slightly lower for Enterococci. Increasing the relative dose to above 0.015 mg/L of PAA per mg/L of COD increased log reduction to 4, although data in that range are too limited to allow for a firm conclusion. Further increase of the PAA dose appeared to have limited effect on further increasing reduction of the bacterial densities, based on very limited data.

ULTRAVIOLET LIGHT DISINFECTION

Overview of Testing Procedures

Two UV disinfection units were tested during the demonstration project: a low-pressure, high-intensity Trojan UV3000Plus model, and a medium-pressure, high-intensity Aquionics UV 250+W model. The units supplied by the manufacturer were rated as follows:

- Trojan: maximum hydraulic capacity of 946 L/min (250 gpm). No further specifications, such as acceptable UV transmittance (UVT) range, were provided,
- Aquionics: flow range 379 – 1,136 L/min (100 - 300 gpm) at 45 to 65% UVT.

In the case of the Aquionics unit the specified flow range was designed to provide a minimum UV dose of 30 mJ/cm^2 under the above listed conditions. The 65% is a typical minimum value of UVT found in secondary effluents and is a standard design value for UV disinfections systems aimed at three to four log reduction of pathogen indicators (HydroQual, 2006). The unit's flow rating decreased to 397 L/min (100 gpm) at UVT values of 45% in order to achieve the same UV dose.

Summary of Conditions During Test Runs

A summary of the operating conditions for all Test Runs utilizing either UV disinfection unit is provided in Table 4. Table 4 lists information such as the pretreatment unit used, average water quality parameters, including average count of pathogen indicators in the influent. The average performance results in terms of log reduction of pathogen indicators are also provided. The water quality parameters were measured in the effluent from the upstream TSS removal unit. Due to large variability in the wastewater quality during the individual the Test Runs, these average performance data are listed for general information only and are not further discussed or correlated. The subsequent discussion and analysis of the results is based on sets of individual data collected during all Test Runs.

Table 4. Summary of conditions during UV disinfection Test Runs

Storm #	UV Disinfection											
	Source of Influent	UV Unit Type (Trojan or Aqu-ionics)	Design Flow, gpm	Trans-mittance %	Average TSS in Influent to UV, mg/L	Average Soluble $CBOD_5$ in Influent to UV, mg/L	Geo. Mean in Feed			Average Log Reduction		
							E. Coli	Fecal coliform	Entero-cocci	E. Coli	Fecal coliform	Entero-cocci
1	TK	A	200	16.8	199	9.9	784,244	7,316,329	636,498	1.25	1.35	1.15
2	SK	T	150	44.8	196	6.9	493,504	1,934,295	364,299	2.31	2.87	1.91
	FF	A	120	62.8	9.9	5.1	300,370	726,924	235,048	2.27	2.48	1.91
3	TK	A	160	27.0	97	31	889,599	5,664,802	886,950	1.51	1.83	1.14
4	FF	T	130	27.1	31	16.2	1,281,190	1,602,734	742,545	2.29	2.30	1.76
5	FF	T	130	39.6	29.2	21.9	522,495	3,944,017	287,200	2.27	3.40	1.98
6	FF	A	130	40.1	27.8	13.4	1,150,762	907,888	342,454	1.89	1.52	1.07
7	SK	T	150	23.8	118	28.4	2,468,098	21,815,203	1,262,797	1.42	1.98	1.27
8	FF	A	130	25.9	28	41.3	3,393,289	1,455,492	1,019,468	0.94	1.38	0.73
9	FF	T	130	27.0	37.9	39	3,425,122	2,288,616	1,349,306	1.23	1.53	1.27

NOTE: For calculating Log Reduction for pathogen indicators, results reported as "less then" were interpreted as 1/2 of the detection level.

Discussion of the Results

Table 5 provides a summary of pathogen indicator data from all valid individual UV sampling events. From these data it is apparent that UV was most effective in inactivation of fecal coliforms, while least effective in inactivation of Enterococci. These results are consistent with the data reported in WERF (2005) study on wet weather plant influent (corresponding to CSO), although the overall removals were better than reported below. This is undoubtedly due to the much lower UV dose applied in the current study, as discussed below.

Table 5. Summary of Pathogen Indicator Data for UV Tests

Pathogen Indicator	UV Unit	Initial Count Range (cfu/100 mL)	Average Log Reduction
E. coli	Trojan	1.2E+05 to 4.6E+06	1.9
	Aquionics	8.0E+04 to 5.3E+06	1.5
Fecal coliform	Trojan	5.0E+05 to 3.9E+07	2.4
	Aquionics	1.2E+05 to 2.8E+07	1.7
Enterococcus	Trojan	1.2E+05 to 2.1E+06	1.6
	Aquionics	6.4E+04 to 1.7E+06	1.2

During each individual sampling event involving UV disinfection units (typically every 20 minutes), the value of the UVT of incoming wastewater was measured. These discrete UVT values, together with the actual wastewater flow at the time of sampling, were provided to the UV units' manufacturers. Based on this information and results of validation tests for their equipment, the units' suppliers calculated the irradiation power delivered during each sampling event. For several sampling events with particularly low transmittance, the calculated dose is an approximation, as the parameters were outside of the validated range.

Figure 10 illustrates log reduction of E. coli recorded in all individual samples during all Test Runs as a function of the calculated UV dose, separately for Trojan and Aquionics units. Figures 11 and 12 provide the same information for fecal coliforms and Enterococci, respectively.

Inspection of Figures 10, 11 and 12 indicate an expected trend of increasing log reduction of pathogen indicators as UV dose increases. Despite the ostensibly low values of correlation coefficients (R^2) shown on these figures, the correlations (forced through the origin) are statistically significant at 99% confidence level for 4 out of 6 data sets, with the remaining 2 being at 95% level. This is due to the relatively large number of data points available for these correlations.

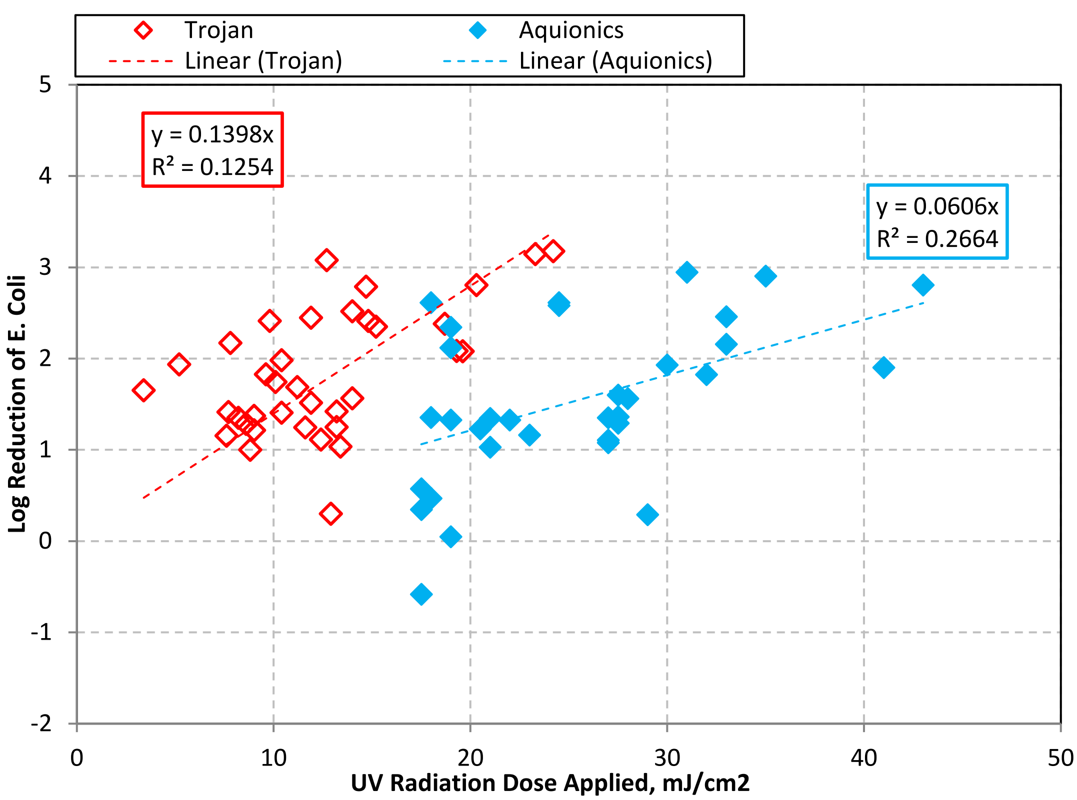

Figure 10. UV dose applied vs log reduction of E. Coli

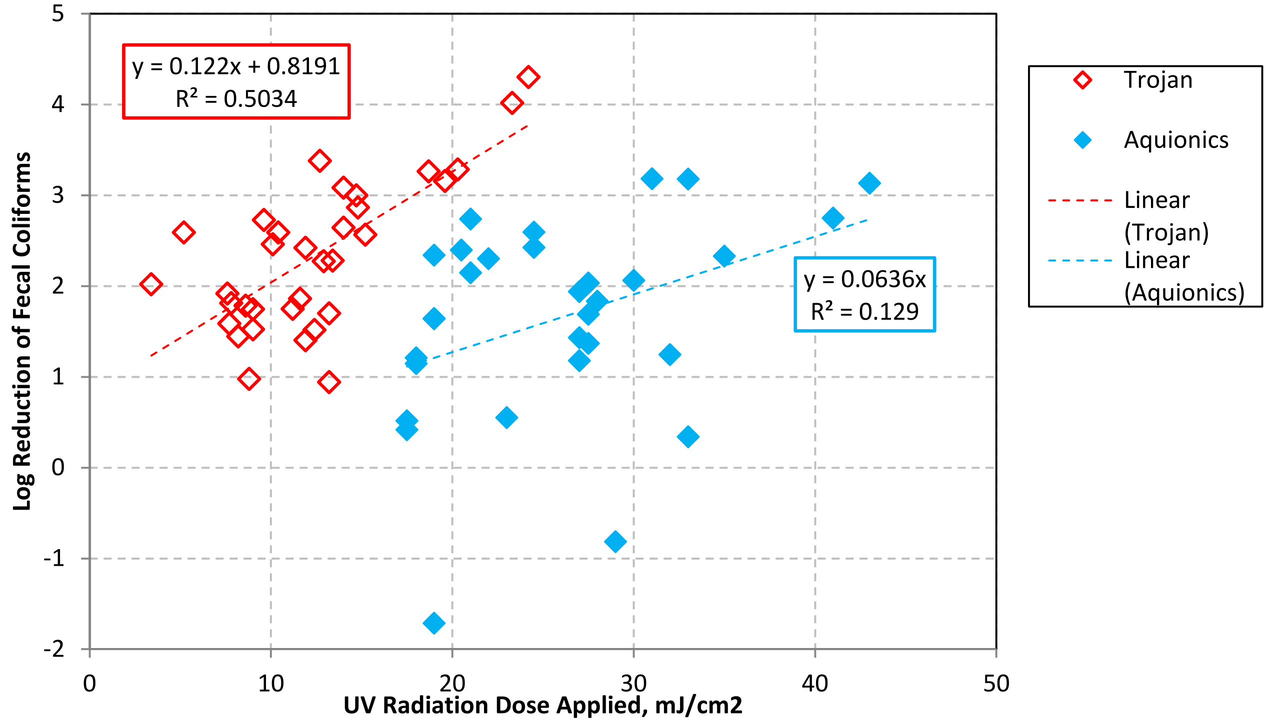

Figure 11. UV dose applied vs log reduction of fecal coliforms

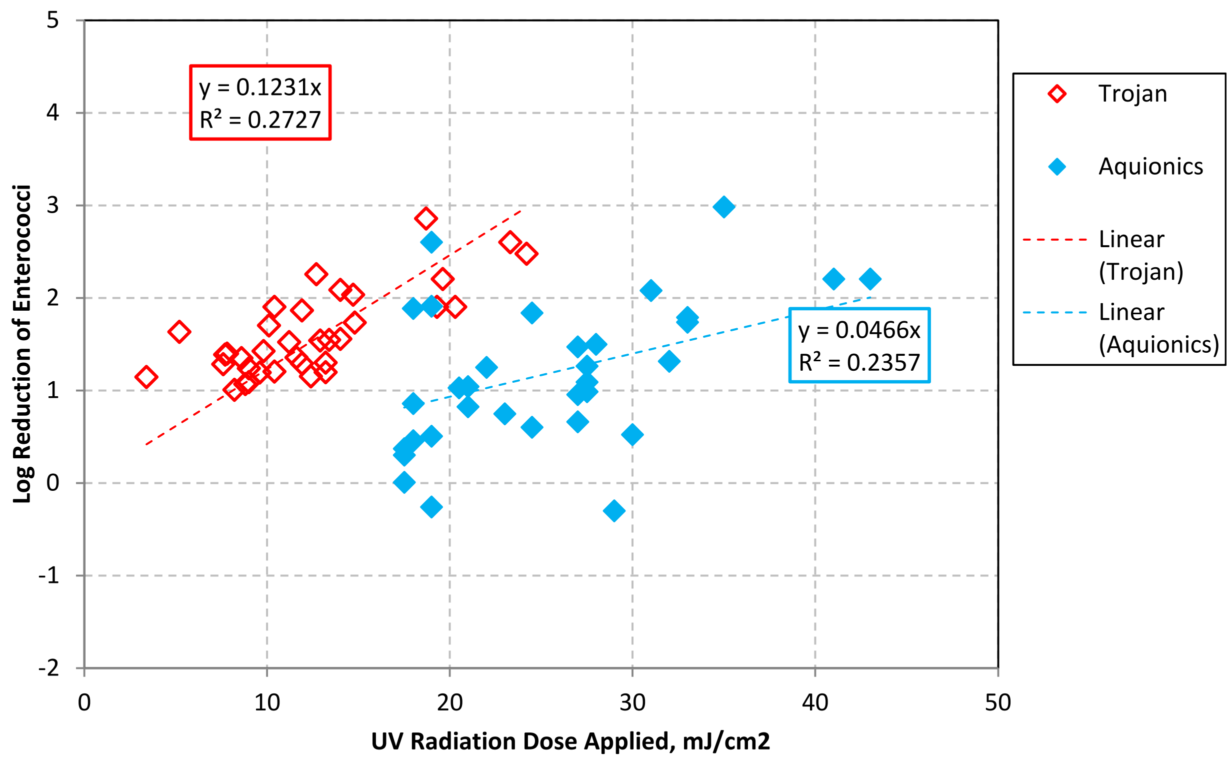

Figure 12. UV dose applied vs log reduction of Enterococci

Attempts to further improve the resulting correlations by normalizing the UV dose by COD were not successful. It is assumed that this is because the organic strength of the wastewater, as measured by COD, is already factored into the UV dose calculation by independent measurement of the transmittance.

Inspection of Figures 10, 11 and 12 indicates that the Trojan UV unit performed better than the Aquionics UV unit at the same calculated UV dose. It is not clear if the disparity in performance is a result of systemic difference in the validation procedure and effective dose calculation performed by different manufacturers, or if it is also related to the lower efficiency in generation of UV in the germicidal range by the polychromatic medium pressure lamps as compared to the relatively monochromatic low pressure lamps.

The most obvious observation is that the relatively low log reduction of bacterial densities achieved by the UV units is the inadequate UV dose caused by frequently very low transmittance of the wastewater. This can be most readily inspected on Figure 13, where the expected, strong relationship between the wastewater TSS and transmittance is evident. Figure 14 presents the same data grouped by the Test Run. The transmittance ranged from single digits to 60%, with majority clustered in the 20 to 50% range. These low transmittance values are consistent with expectations. For example, transmittance of primary effluent is quoted to be in 20 to 50% range in Metcalf & Eddy/AEOCOM, (2014). HDR (2014) report on wet weather primary effluent found the UTV values to be somewhat higher, in the range from 40 to 60%.

It is clear that the flow rating of the supplied UV units was suitable for a typical, secondary effluent application, without taking into account the expected, significantly worse quality of the CSO effluent. As a result, the applied dose for the Trojan UV unit never exceeded 25 mJ/cm^2 and was below 45 mJ/cm^2 for the Aquionics unit. This is contrasted with much higher effective UV dose applied during the wet weather tests reported by WERF (2005) report, when it ranged from 65 to 220 mJ/cm^2.

Subsequent Figures indicate that correlation between UVT and total $CBOD_5$ (Figure 15) and COD (Figure 16), are even better than with TSS, attesting to the contribution of soluble organics to the UV absorbance.

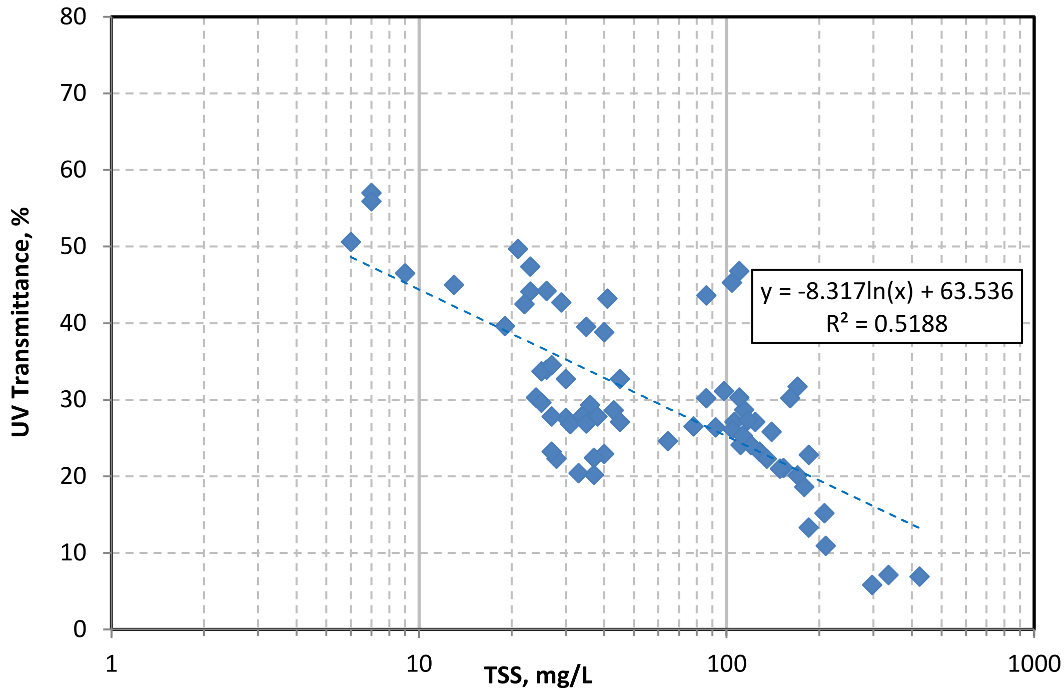

Figure 13. Effect of TSS on UV transmittance

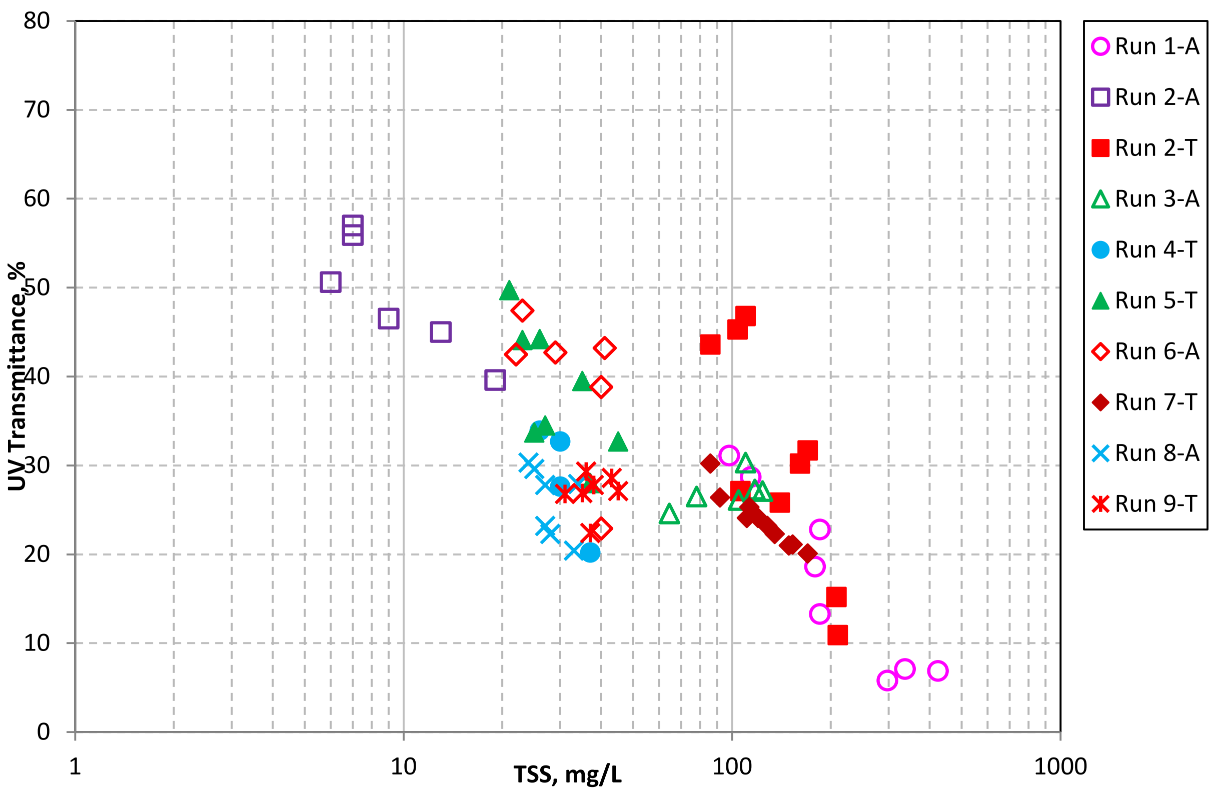

Figure 14. Effect of TSS on UV transmittance – grouped by Test Run

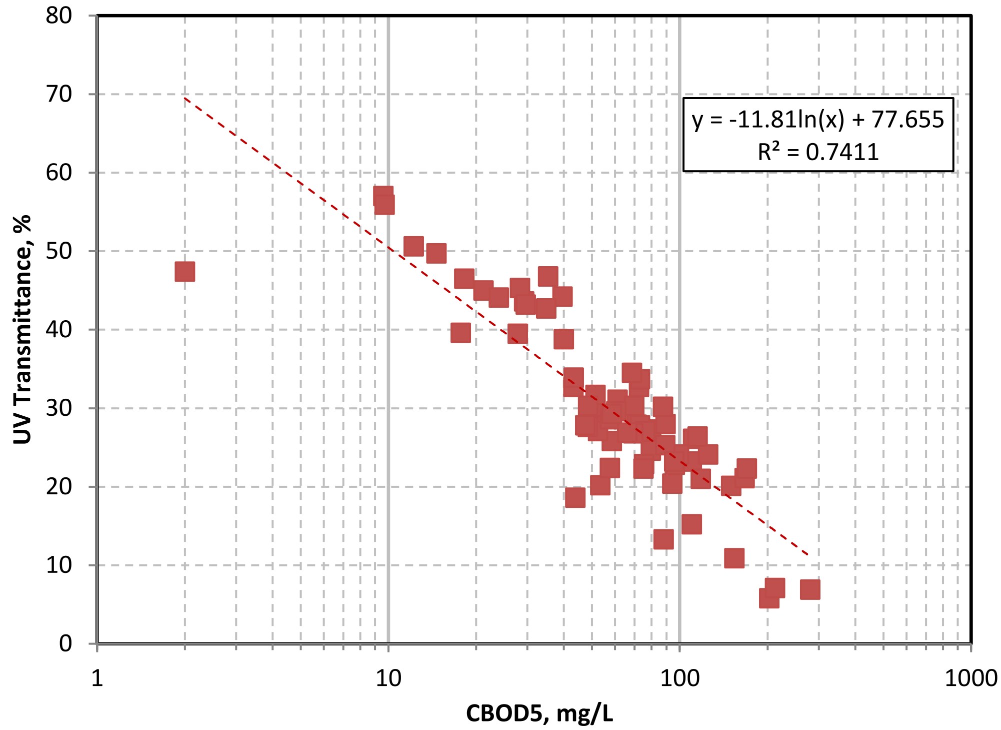

Figure 15. Effect of CBOD$_5$ on UV transmittance

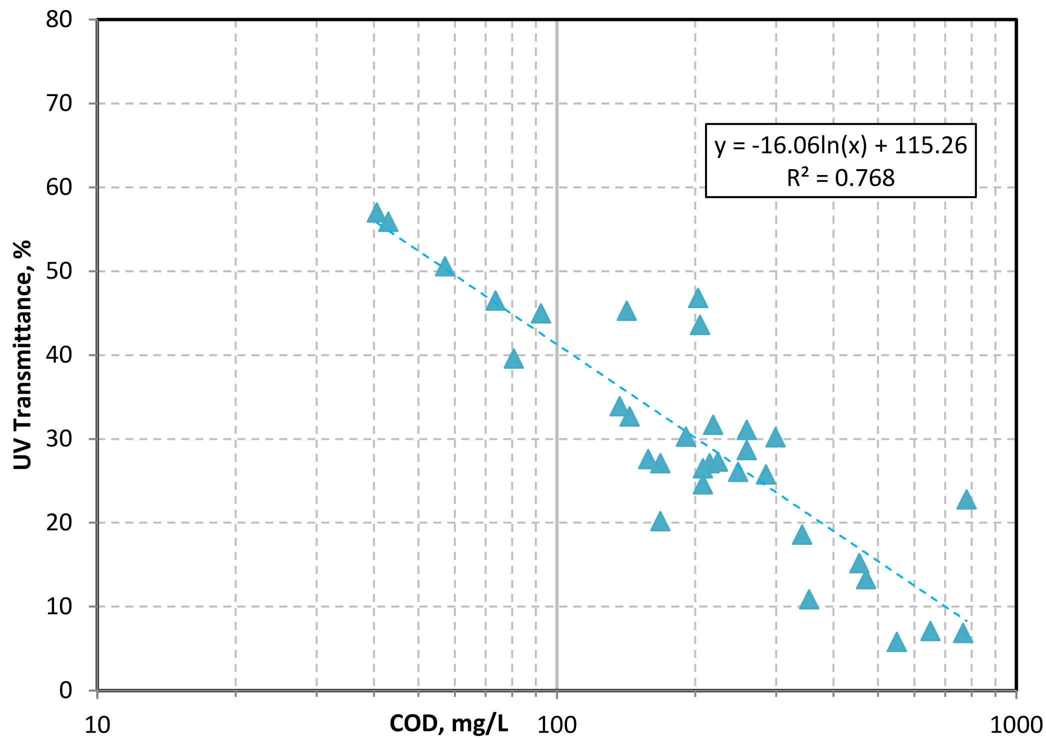

Figure 16. Effect of COD on UV transmittance

CONCLUSIONS AND RECOMMENDATIONS

PAA Disinfection Tests:

1. The most important finding from the PAA pilot study was definition of a predictive relationship between the applied dose of PAA per mg/L of COD present in the wastewater and the log reduction of pathogen indicators. PAA dose of 0.01 mg/L of PAA per mg/L of COD predicted 3 log reduction of fecal coliforms, with slightly higher effectiveness for E. coli and slightly lower for Enterococci.
2. Increasing the relative dose to above 0.015 mg/L of PAA per mg/L of COD increased log reduction to 4. Further increase of the PAA dose appeared to have limited effect on further increasing reduction of the bacterial densities, although data in that range are too limited to allow for a firm conclusion.
3. The PAA contact time and dose applied in most of the Test Runs were relatively low; nevertheless a removal of 99% (or two log) reduction of the pathogen indicator organisms was documented, on average. Higher applied dose, as modified by COD concentration, may be needed to satisfy the disinfection requirements and guidelines of many States and the Federal government.
4. Should applicability of the relationships discussed under items 1 and 2 above be confirmed at other locations, it would be desirable to adjust the PAA application rate based on both wastewater flow and organic strength. The organic strength could potentially be measured in real time by a surrogate parameter such as TOC, but this could be practical only at large sites. Alternatively, a typical COD profile of CSO discharge could be developed based on historical data and PAA dose adjusted based on that profile and instantaneous flow. Lacking this, the only available strategy to accomplish significant disinfection would be to apply a pre-set PAA dose effective at the high end of the possible COD concentrations. This, however, will result in potentially significant residual PAA concentration, which could be toxic to the aquatic life.
5. The issue of toxicity of residual PAA to aquatic life in the receiving stream is a significant issue in selection of appropriate disinfection strategy. The key consideration is to balance impact of un-disinfected, or partially disinfected, CSO discharges on the designated water uses with potential toxicity of the residual PAA to the aquatic life.
6. Use of PAA in satellite CSO locations could be complicated by a need for on-site storage of large volumes of the chemical, which requires secondary containment and appropriate safety measures.

UV Disinfection Tests:

1. The UV units tested exhibited the expected effectiveness commensurable with the modest UV dose applied, as limited by frequently very low UV transmittance of the CSO wastewater
2. The pathogen deactivation results follow the expected relationship with the applied UV irradiation dose.
3. Trojan UV3000Plus unit using low-pressure lamps required approximately 25 mJ/cm^2 irradiation energy input to achieve 3 log deactivation of pathogen indicators, on average.
4. Aquionics 250+W unit using medium-pressure lamps required approximately 40 mJ/cm^2 irradiation energy input to achieve 3 log deactivation of pathogen indicators, on average.

5. Design flow of UV equipment, when used in a "dirty water" application, must be significantly lowered (de-rated) to account for poor transmittance of the CSO wastewater treated (in the absence of adequate pre-treatment to increase UVT).
6. Wastewater transmittance showed an expected, strong correlation with water quality parameters such as TSS, $CBOD_5$ and COD.

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