



April 28, 2009
7233B.00

Mr. Steve Gittings
Deputy Director/Wastewater
City of Stockton
2500 Navy Drive
Stockton CA 95206-1191

Subject: UV Design Summary
City of Stockton, California

Dear Steve:

Carollo appreciates the City of Stockton's participation in the research and validation of ultraviolet light (UV) disinfection technologies and the City's willingness to host the recent UV pilot at the wastewater treatment plant (WWTP). This letter summarizes the results of the UV pilot for disinfection of the City's wastewater effluent. This letter also presents information on the implementation of UV at the WWTP by summarizing UV design criteria, details on the appropriate UV equipment sizes for the WWTP and the cost estimates for three UV manufacturers. We have also summarized the disinfection-by-product (DBPs) data collected by the City during the UV pilot.

SUMMARY OF FINDINGS

Overall, the finding of the UV pilot at the City of Stockton's WWTP were: 1) UV can effectively meet the City's NPDES limit for total coliform (2.2 MPN/100 ml), 2) Collecting additional data on UV transmittance and performing additional dose/response tests to refine the dose required can result in reduced size requirements and cost savings for a UV system, and 3) disinfection with UV results in less formation of DBPs than the existing chlorination system.

For the cost analysis, the Calgon reactor that was pilot tested at Stockton appears to be measurably less expensive than other reactors.

BACKGROUND

Effluent Limitations

The City was issued a new NPDES discharge permit in October 2008. This permit established lower limits for several disinfection-by-products that the City was having difficulty meeting. UV disinfection is an alternative to the existing gaseous chlorine system used for disinfection. Table

1 lists the important effluent limitations (NPDES Permit Number CA 0079138, Order Number R5-2008-0154).

| Effluent Limitations (NPDES Permit Number CA 0079138) | Constituent (Units) | Total Coliform (MPN/100 ml) | Turbidity Avg (NTU) | NH ₃ -N (mg/L) | Bromo dichloro methane (ug/L) | Dibromo chloro methane (ug/L) | Cyanide (ug/L) |
|---|---------------------|-----------------------------|---|---------------------------|-------------------------------|-------------------------------|----------------|
| | Monthly Average | | | | 2 | 6.8 | 5 |
| Weekly Average | | 2.2 (median) | | | | | |
| Daily Average | | | 2 | | | | |
| Daily Maximum | | 23 | 5 no more than 5% of the time, 10 maximum | 5 | 20 | 16 | 9 |
| Instantaneous Maximum | | 240 | | | | | |

UV Effectiveness Against Microorganisms

UV disinfection is an established water and wastewater disinfection method with broad applications. By introducing errors into the microorganism's DNA, UV disables the organism's ability to self-replicate. Since UV penetrates cell membranes and virus capsids of different physiologies, it has been found to be much more broadly effective than chemical disinfectants, such as chlorine. For instance, 4-log inactivation of E. coli bacteria and pathenogenic protozoa such as Giardia lamblia and Cryptosporidium parvum can be achieved with a UV dose of less than 10 mJ/cm². The concentration of infectious viruses, such as coxsackievirus B5 and hepatitis A, can be reduced by 4 logs by a UV dose of less than 30 mJ/cm². Poliovirus type 1, which was used in the Pomona virus study that served as the basis for the 5-log virus removal standard for CDPH's Title 22 certification for reclaimed water disinfection, is reduced by 99.99 percent after a UV dose of less than 30 mJ/cm².

(All data taken from Table A.2 in the UV Disinfection Guidance Manual from the EPA's Long Term 2 Enhanced Surface Water Treatment Rule, which describes the UV pathogenic microorganisms in drinking water. The sensitivities of these microbes is translatable to wastewater applications.)"

UV DESIGN CRITERIA

UV design is based upon two critical parameters, the design UV transmittance (UVT) and the design UV dose, as summarized below.

Ultraviolet Light Transmittance

UVT is the measurement of the percentage of light, at 254 nanometers (nm), that is transmitted through one centimeter of water. UVT impacts the cost to implement a UV system, not the effectiveness of UV. Waters with reduced UVT values will often be cost-prohibitive for installation even though UV may effectively disinfect.

The design of a UV system is typically based on the lower 10th percentile UVT value so as to provide a system that conservatively meets dose and coliform targets under average conditions and marginally meets dose and coliform targets under stressed (low UVT and peak flow) conditions. Figure 1 shows a probability plot of the UVT data collected during the Calgon UV pilot study overseen by Carollo. Figure 1 shows that lower 10th percentile UVT value is 70 percent. What cannot be determined from the limited UVT data is the diurnal and seasonal variability because the UVT data is collected over a short period (01/8/2009 - 01/20/2009) of time. Therefore, to account for potential diurnal and seasonal water quality variability, the UV design will be based upon a UVT of 65 percent.

As UVT is important criteria for sizing the UV system, Carollo suggests that the City of Stockton install an online UVT meter. One potential meter, the *Real UVT Online* meter, will cost about \$5,295.00 and the automatic chemical cleaning for *Real UVT Online* will cost about \$795.00. The above quotes were provided by Real Tech Incorporation on April 1, 2009. Collection of additional UVT data at the plant could potentially allow for a future reduction in UV sizing and cost.

UV Dose

The determination of the proper UV dose to meet permit requirements is critical. For some water qualities there is no UV dose that can be effective, while for other water qualities UV is extremely effective at a low dose.

For Stockton, filtered effluent samples were analyzed for fecal coliform and total coliform at UV doses ranging from 60 to 110 millijoules per square centimeter (mJ/cm^2). The results showed that UV disinfection can achieve a non-detect level of fecal and total coliform for a dose of $60 \text{ mJ}/\text{cm}^2$ as shown in Figure 2 and Figure 3, respectively. It is likely that a further reduced dose will also be effective and additional benchtop UV testing is recommended to refine this dose value. For this cost analysis, the UV disinfection systems are based upon three different UV doses (50, 70, and $110 \text{ mJ}/\text{cm}^2$). The highest UV dose shown is the appropriate UV dose, with

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some conservatism, that is required for UV disinfection for wastewater reuse applications. For river discharge applications that require 2.2 MPN/100mL total coliform, lesser dose values can be used.

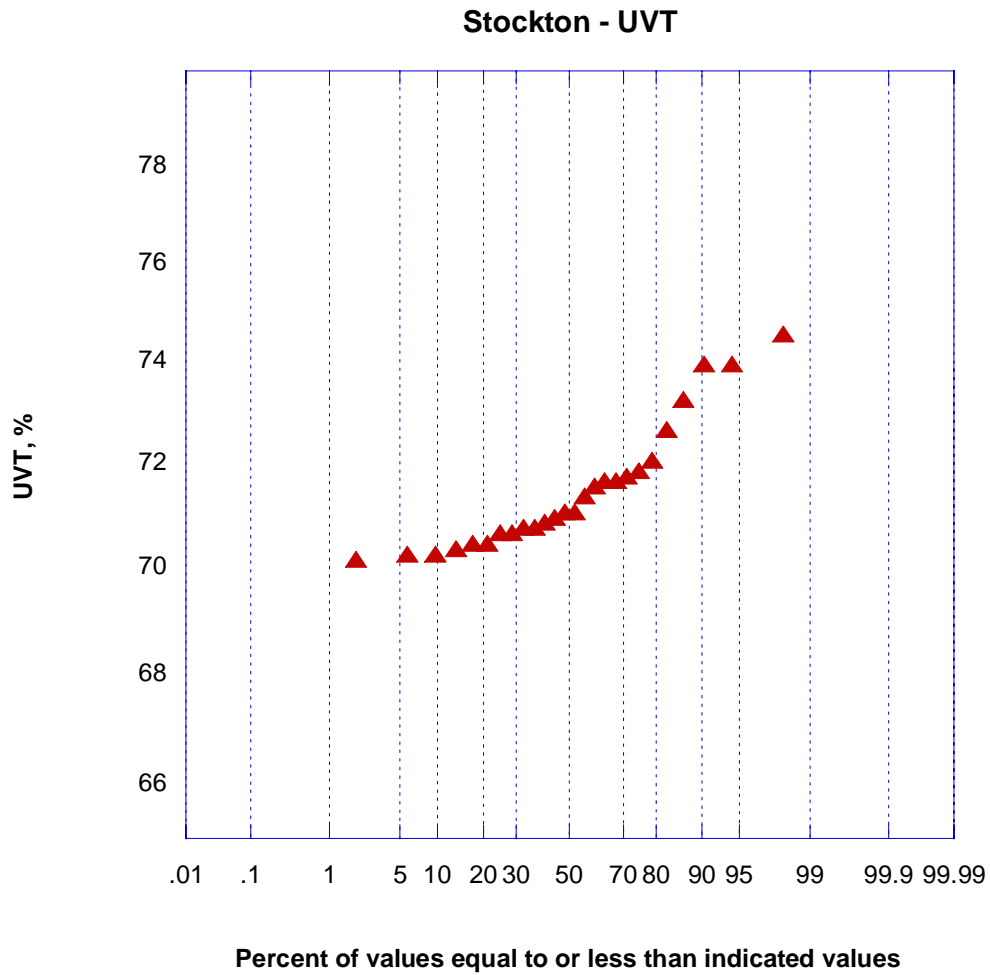


Figure 1. Probability plot of UVT

Fecal Coliform vs UV Dose

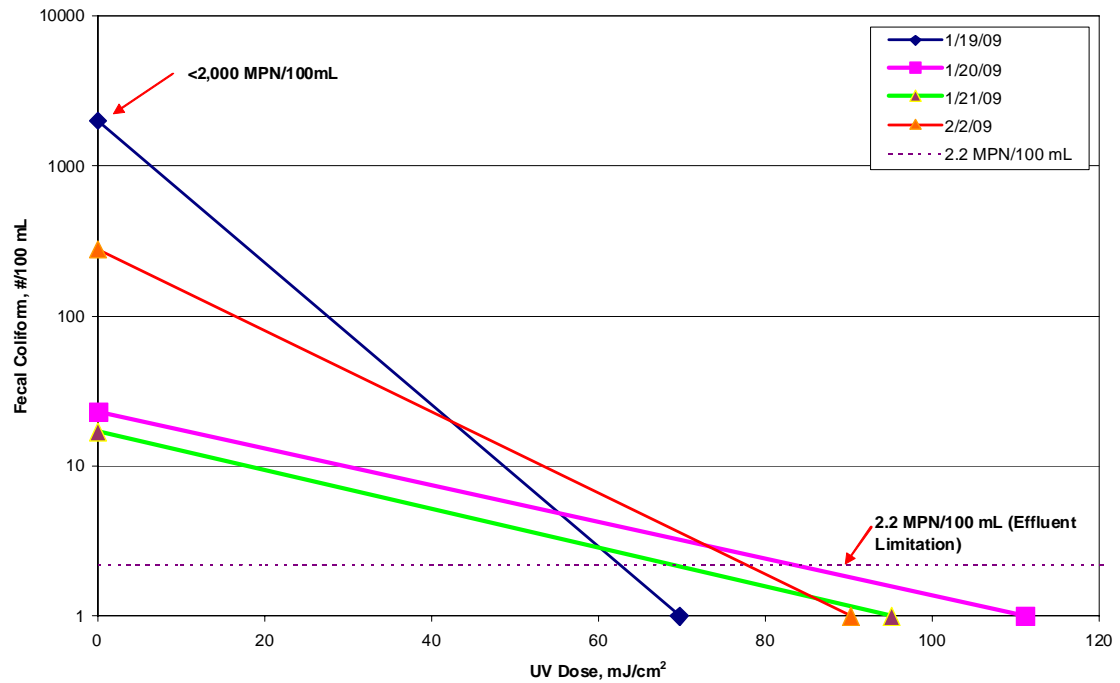


Figure 2. Fecal Coliform Response to UV Dose.

Total Coliform vs UV Dose

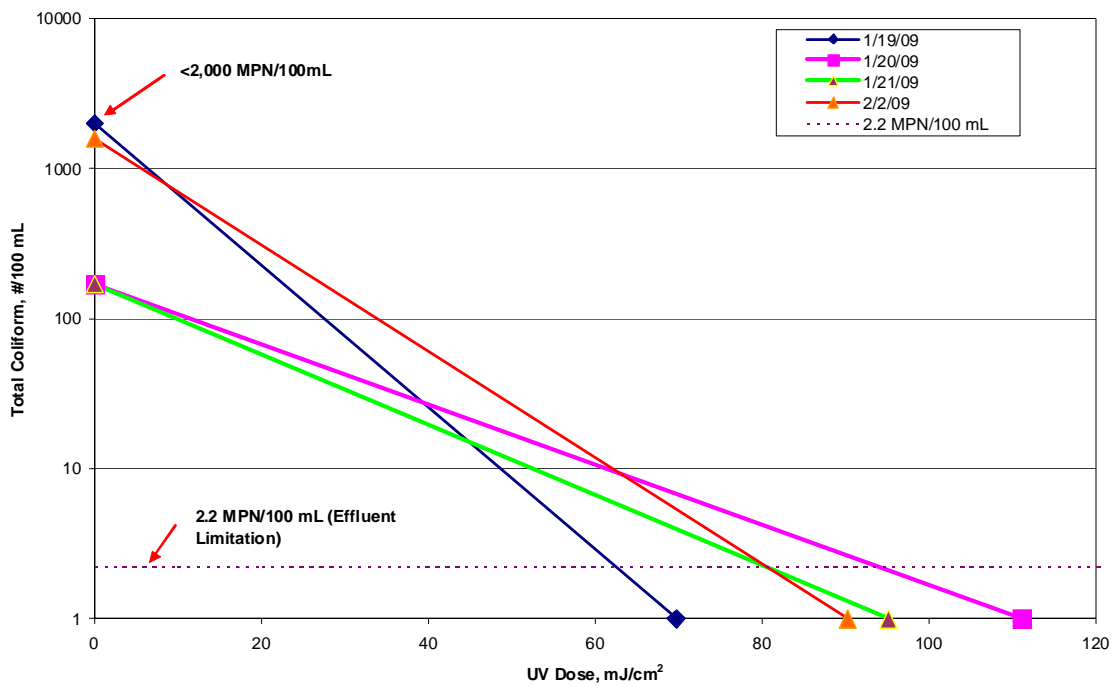


Figure 3. Total Coliform Response to UV Dose.

The cost estimate presented in this UV memo is limited in nature due to the limited amount of testing performed for this project. For sizing UV disinfection systems at Stockton, detailed benchtop testing to refine the UV design dose is highly recommended. BioVir Laboratories can be utilized for performing the collimated beam testing. Past projects with BioVir Laboratories demonstrate that it will cost about \$500 per collimated beam test. Carollo recommends that plant effluent samples should be collected weekly for a period of two months to obtain substantial UV dose/response data. If the City of Stockton proceeds with the collimated beam study, BioVir laboratory will send the coolers and sampling bottles to the sampling team in Stockton. Carollo would be happy to assist with this matter.

UV REACTORS AND COSTS

Three UV systems were evaluated for this project, the Aquionics 18000+, the Trojan UV3000Plus, and the Calgon C³-500, as reviewed below.

Aquionics 18000+

The Aquionics 18000+ system uses 5,780-watt medium pressure high output (MPHO) lamps and the lamps are oriented perpendicular to the bulk flow. The Aquionics 18000+ system has 18 lamps per reactor, with multiple reactor trains required for this project. Due to high intensity of MPHO UV lamps, there is a significant reduction in the number of lamps required to achieve disinfection compared to other UV technologies. The Aquionics 18000+ consists of an in-vessel system and designed to operate with two reactors in series for UV doses of 110 and 70 mJ/cm². Aquionics 18000+ system is designed to operate with one reactor in series for UV dose of 50 mJ/cm².

Trojan 3000+

The Trojan 3000+ system uses 240-watt low pressure high output (LPHO) lamps and the lamps are oriented parallel to the bulk flow. The Trojan 3000+ alternative consists of an open channel system with four channels in operation for UV doses of 110 and 70 mJ/cm². The Trojan 3000+ system is designed to operate with three channels for UV dose of 50 mJ/cm².

Calgon C³500

The Calgon C³500 system uses 500-watt LPHO lamps and the lamps are oriented parallel to the bulk flow. The Calgon C³500 alternative consists of an open channel system with four channels in operation for UV dose of 110 mJ/cm² and three channels for UV dose of 70 mJ/cm². The Calgon C³500 system is designed to operate with two channels for UV dose of 50 mJ/cm².

Cost Estimates

In completing the cost analysis, it was assumed that each UV design is new construction that does not require any demolition of existing structures or complicated foundation work. All buildings were also designed at grade. In addition, the following information was used to provide construction and operations and maintenance costs for the UV systems:

- Design Flow - 55 mgd;
- Average Flow - 38 mgd
- Design UVT - 65 percent;
- Average UVT - 70 percent;
- Energy Cost - \$0.12/kW-hr;
- Labor Rate - \$50/hr;
- $n = 20$ years; and
- $i = 4.5$ percent.

Design characteristics and cost estimates for each UV system are further described in Table 2. Figure 4 shows the life cycle cost comparison for three UV manufactures.

DISINFECTION-BY-PRODUCT FORMATION

One of the key compliance issues for the City in meeting the new NPDES permit is compliance with the DBPs, namely bromodichloromethane, chloroform, dibromochloromethane and cyanide. During the UV pilot at the WWTP, the City's laboratory collected samples from both the UV pilot and the existing chlorine contact channel to compare the formation of DBPs. The results of this sampling and testing is shown in Table 3. In general, the UV system showed no formation of bromodichloromethane, chloroform or dibromchloromethane above the levels in the influent, while the chlorination system formed additional concentrations for each of these constituent in every case. For cyanide, the results are less clear, however, the chlorination system appears to have formed additional cyanide more frequently than the UV system. Other studies performed on cyanide formation have found that UV at doses for disinfection, in general, does not form cyanide while chlorination does. Further testing of cyanide may be warranted to better define the formation potential.

Table 2 Disinfection Equipment Power and Cost Estimates (55 mgd Peak Flow, 38 mgd Average Flow, 65% Design UVT)

| Disinfection Equipment | Channel/Trains | Total Lamps | Number of Reactors per Channel/Train | System Footprint | Power (KW) ⁽¹⁾ | Annual Energy Cost ⁽²⁾ | Lamp Replacement Cost | Annual O&M Cost ⁽³⁾ | Equipment Cost | Construction Cost ⁽⁴⁾ | Project Cost ⁽⁵⁾ | Life Cycle Cost ⁽⁶⁾ |
|-------------------------------------|----------------|-------------|--------------------------------------|------------------|---------------------------|-----------------------------------|-----------------------|--------------------------------|----------------|----------------------------------|-----------------------------|--------------------------------|
| Dose = 110 mJ/cm² | | | | | | | | | | | | |
| Aquionics 18000+ | 15 | 540 | 2 | 104' x 90' | 1512 | \$1,589,000 | \$151,000 | \$1,791,000 | \$5,959,000 | \$18,802,000 | \$23,687,000 | \$46,988,000 |
| Trojan 3000+ | 4 | 3072 | 4 | 160' x 50' | 334 | \$351,000 | \$292,000 | \$1,072,000 | \$6,912,000 | \$21,513,000 | \$27,329,000 | \$41,276,000 |
| Calgon C ³ 500 | 4 | 1792 | 4 | 140' x 60' | 415 | \$437,000 | \$123,000 | \$811,000 | \$4,691,000 | \$15,804,000 | \$20,064,000 | \$30,615,000 |
| Dose = 70 mJ/cm² | | | | | | | | | | | | |
| Aquionics 18000+ | 9 | 324 | 2 | 104' x 55' | 1058 | \$1,120,000 | \$152,000 | \$1,314,000 | \$3,575,000 | \$11,587,000 | \$14,646,000 | \$31,741,000 |
| Trojan 3000+ | 3 | 1920 | 4 | 150' x 45' | 164 | \$172,000 | \$162,000 | \$603,000 | \$4,320,000 | \$14,255,000 | \$18,141,000 | \$25,986,000 |
| Calgon C ³ 500 | 3 | 1152 | 3 | 150' x 40' | 219 | \$231,000 | \$70,000 | \$462,000 | \$3,015,000 | \$10,776,000 | \$13,715,000 | \$19,726,000 |
| Dose = 50 mJ/cm² | | | | | | | | | | | | |
| Aquionics 18000+ | 12 | 216 | 1 | 63' x 99' | 648 | \$681,000 | \$64,900 | \$769,000 | \$2,383,000 | \$8,217,000 | \$10,422,000 | \$20,427,000 |
| Trojan 3000+ | 3 | 1296 | 3 | 36' x 150' | 113 | \$119,000 | \$109,000 | \$412,000 | \$2,916,000 | \$10,390,000 | \$13,247,000 | \$18,607,000 |
| Calgon C ³ 500 | 3 | 768 | 2 | 40' x 130' | 143 | \$150,000 | \$47,000 | \$307,000 | \$2,010,000 | \$8,038,000 | \$10,254,000 | \$14,248,000 |

Notes:

- (1) Power draw is based upon operational values (kW).
- (2) Annual energy cost is based upon operational values. Energy cost is based upon \$0.12 per Kw-hr.
- (3) Annual O&M cost includes energy and chemical cost.
- (4) The expected accuracy for the above estimate is +30 percent to -15 percent.
- (5) The expected accuracy for the above estimate is +30 percent to -15 percent. Total Project Cost = (Total Construction Cost) + (Engineering Services Fees) + (Owner's Reserve for Change Orders) + (Start-up, Site-visits, Performance Bond Fees)
- (6) Life Cycle Cost = 13.01 (20 years annual cost at 4.5% discount rate) *Annual O&M cost + Project Cost.

| Table 3 Summary of Disinfection-By-Product Formation | | | | | |
|--|----------|----------|----------|----------|----------|
| | 1/19/09 | 1/20/09 | 1/21/09 | 2/2/09 | 2/3/09 |
| Bromodichloromethane, µg/l | | | | | |
| Filter Effluent | J 0.4 | 1.0 | J 0.4 | ND <1.2 | ND <1.2 |
| UV effluent | J 0.45 | 1.1 | J 0.4 | ND <0.25 | ND <0.25 |
| Chlorine effluent | 3.6 | 4.1 | 4.0 | 2.7 | 2.1 |
| Chloroform, µg/l | | | | | |
| Filter Effluent | ND <0.26 | 0.9 | ND <0.26 | ND <1.3 | ND <1.3 |
| UV effluent | ND <0.26 | 1.1 | ND <0.26 | ND <0.26 | ND <0.26 |
| Chlorine effluent | 4.1 | 4.8 | 4.9 | 3.5 | 2.9 |
| Dibromochloromethane, µg/l | | | | | |
| Filter Effluent | ND <0.31 | J 0.3 | ND <0.31 | ND <1.6 | ND <1.6 |
| UV effluent | ND <0.31 | ND <0.31 | ND <0.31 | ND <0.31 | ND <0.31 |
| Chlorine effluent | 1.4 | 1.7 | 1.4 | 0.7 | 0.9 |
| Cyanide, µg/l | | | | | |
| Filter Effluent | J 2.3 | 3.4 | J 2.7 | J 0.76 | J 2.5 |
| UV effluent | J 2.7 | 6.2 | 3.3 | J 2.1 | J 2.5 |
| Chlorine effluent | 3.7 | 5.1 | 4.1 | J 2.9 | 3.3 |
| ND - Not Detected at shown detection limit | | | | | |
| J - Detected between the Method Detection Limit and the Reporting Limit; estimated value | | | | | |

Stockton - UV Life Cycle Cost Comparison

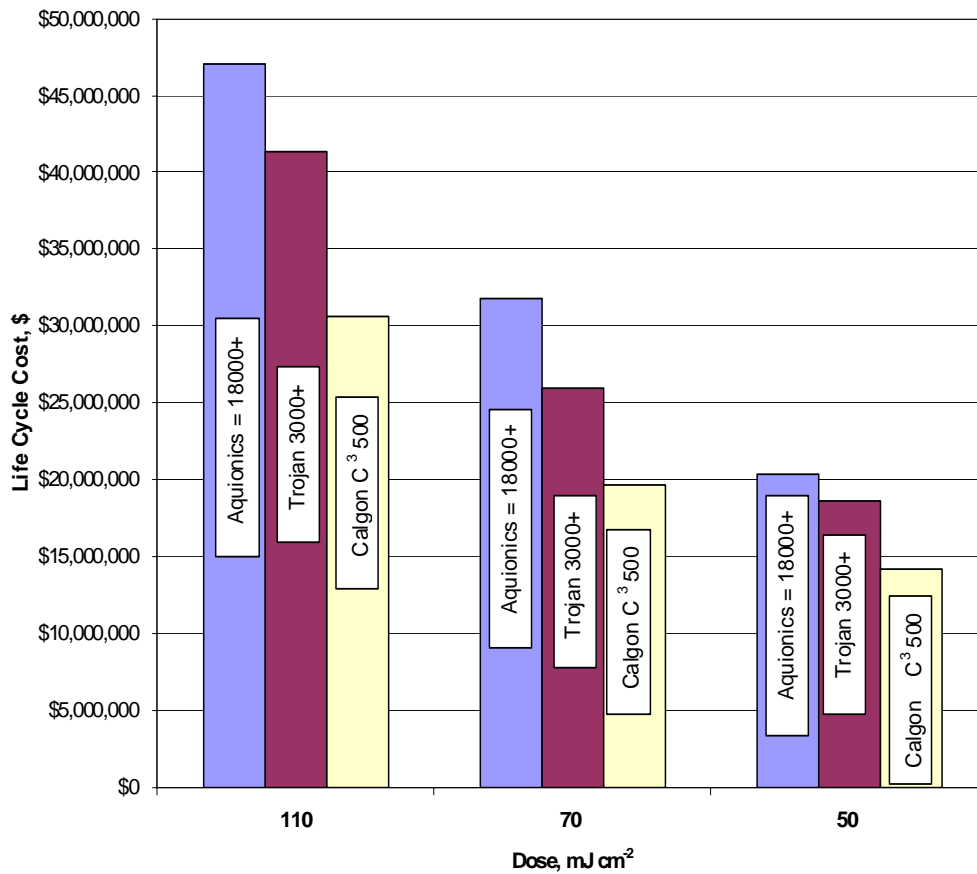


Figure 4. Life Cycle Cost of Three UV Disinfection Systems

RECOMMENDATIONS AND NEXT STEPS

Based upon the cost analysis, the Calgon C³500 reactor is the most cost effective on a project cost and net present worth basis. Further, should Stockton be able to demonstrate low effective UV dose values and/or high UVT values, UV will become even more cost efficient. Thus, the installation of an on-line and self-cleaning UVT meter and the continuation of benchtop UV dose/response testing is recommended.

Overall, the finding of the UV pilot at the City of Stockton's WWTP were: 1) UV can effectively meet the City's NPDES limit for total coliform (2.2 MPN/100 ml), 2) Collecting additional data on UV transmittance and performing additional dose/response tests to refine the dose required can result in reduced size requirements and cost savings for a UV system, and 3) disinfection with UV results in less formation of DBPs than the existing chlorination system.

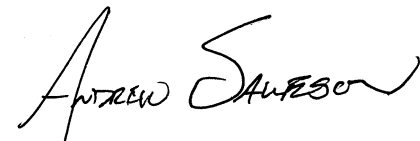
We would be happy to assist you, as needed, with the additional recommended transmittance testing or the dose/response testing. Again, we thank the City of Stockton for hosting the UV pilot and hope the information this pilot generated is helpful in determining future disinfection needs at the plant.

Sincerely,

CAROLLO ENGINEERS, P.C.



Lydia Holmes
Partner



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LH:jl