UV: NOT JUST FOR CRYPTOSPORIDIUM ANYMORE

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ABSTRACT

In North America, most UV disinfection installations at drinking water treatment plants have been designed to address the threat of Cryptosporidium, which has been the focus of new surface water treatment requirements. There have been several UV projects implemented to address other treatment objectives as well. Several of these applications are summarized in this paper.

Key words: UV disinfection; multiple disinfection barriers; Cryptosporidium inactivation; virus inactivation; DBP reduction

INTRODUCTION

Since 2000, the implementation of ultraviolet (UV) disinfection has grown rapidly in North America, with most North American installations focused on *Cryptosporidium* inactivation in response to the United States Environmental Protection Agency's (USEPA's) Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). Many drinking water utilities have implemented UV disinfection, although not explicitly required to by the LT2ESWTR. These utilities have focused on UV systems as part of a multiple barrier treatment train, in which the UV system serves as a barrier for Cryptosporidium, while also addressing other system-specific treatment objectives. In selecting UV to address site-specific treatment objectives, several unique UV applications have been implemented.

These novel UV applications for drinking water treatment include:

- UV disinfection for virus inactivation credit at two operating water treatment plants in Cedar Rapids, IA, as necessitated by the presence of ammonia in the raw water.
- UV disinfection for *Giardia* inactivation credit to reduce free chlorine contact time and minimize disinfection by-product (DBP) formation in Poughkeepsie, NY, and Ketchikan, AK. The Poughkeepsie facility has been operating since 2005, while Ketchikan's system began receiving disinfection credit in 2011.
- UV disinfection for pathogen disinfection in backwash recycle flows in Fort Collins, CO. This facility has been operating since 2003.
- High-dose UV advanced oxidation for contaminant destruction in Aurora, CO, with the application point following clarification and before biological filtration. Facility commissioning occurred in late 2010, and the system is now operating.

RESULTS AND DISCUSSION

In North America, UV disinfection has been installed at water treatment plants (WTPs) by utilities with the objective of achieving regulatory compliance. The USEPA's LT2ESWTR addresses the need for *Cryptosporidium* removal and/or inactivation for unfiltered systems that meet the USEPA filtration avoidance criteria, uncovered reservoirs, and filtration plants in higher bins (meaning higher risk of *Cryptosporidium* in the source water). UV disinfection is acknowledged as typically representing the most cost-effective approach for *Cryptosporidium*, and the USEPA estimated that 503 to 979 WTPs will be required to implement UV disinfection in response to the LT2ESWTR (USEPA, 2006).

In addition to utilities that implement UV disinfection to meet regulatory requirements, many utilities have implemented UV disinfection generally to increase finished water quality and improve public health protection. In several cases, utilities have identified site-specific treatment objectives for the application of UV systems. Several applications of UV to achieve site-specific treatment objectives are reviewed in the following sections.

UV for virus inactivation credit

The City of Cedar Rapids. IA, USA had a unique drinking water problem. They could not get enough disinfection credit to meet regulatory requirements for virus reduction because of the presence of naturally occurring ammonia in their source water. Due to the presence of ammonia, Cedar Rapids uses chloramine as its primary disinfectant, not free chlorine. Consequently, the plants would have inadequate disinfectant contact time during cold water periods of the year under high flow rate conditions. After an extensive evaluation of alternatives, UV disinfection was selected to allow the City to meet its disinfection requirements.

The City of Cedar Rapids owns and operates two conventional water treatment plants, the J Avenue WTP and the Northwest WTP. The plants treat groundwater from alluvial wells along the Cedar River with aeration, lime softening, recarbonation, filtration and chloramine disinfection. Recently, several wells were designated as groundwater under the direct influence of surface water. As a result, both plants were required to comply with the USEPA Surface Water Treatment Rule (SWTR) regulations by July 2010.

Both water plants can currently meet SWTR regulations for *Cryptosporidium* and *Giardia*. However, with the available chloramine contact time, disinfection regulations for viruses cannot be met during periods of cold water and higher plant flow rates. To meet disinfection regulations for viruses under all plant operating conditions, UV disinfection was selected as an additional disinfectant barrier for the Cedar Rapids water treatment process.

CH2M HILL completed the study, design, and construction management of the UV disinfection projects for the 40 mgd (151 MLD) J Avenue lime softening plant and the 20 mgd (76 MLD) Northwest lime softening plant, which is expandable to 40 mgd (151 MLD). The project included retrofitting UV disinfection into the two existing water treatment plants. Both medium- and low-pressure high output UV reactors were evaluated at several potential UV sites. Impacts on existing facilities, operational access, hydraulics, and future plant improvements were considered in determining the optimum UV facility location at each facility. Extensive hydraulic and site location issues were also evaluated.

This was one of the first projects designed for virus inactivation with UV light, and design occurred prior to the release of EPA's Final UV Disinfection Guidance Manual (UVDGM). Therefore, early stages of the project included a UV demonstration project to determine the water quality impacts of UV on chloraminated water containing nitrate. A 6-mgd UV system was designed and constructed to serve a specific service area of the distribution system. Water quality in the distribution system was monitored for one year, indicating no detrimental impact of UV disinfection on the water quality. The study also involved collimated beam testing for adenovirus and MS-2 bacteriophage inactivation on Cedar Rapids water at various locations, with and without the presence of chloramines.

Through workshops with the Iowa Department of Natural Resources (DNR) and the City, additional virus disinfection credit was granted by the Iowa DNR based on the low filter turbidity and high softening pH at the two plants. The UV disinfection system was designed to provide an additional 0.5 log inactivation of viruses with a minimum operating UV dose (i.e., an MS2 reduction equivalent dose, or RED) of about 45 to 50 mJ/cm^2 This dose incorporates the UV dose of 39 mJ/cm^2 for 0.5-log virus inactivation from the LT2ESWTR, and the validation factor for the full-scale UV reactor. For virus inactivation, the RED bias is much smaller than it is with MS2 validation for *Giardia* or *Cryptosporidium* inactivation. In the future, the recent research results demonstrating the ability of medium-pressure UV disinfection to achieve higher levels of virus inactivation (Linden et al., 2007) may be discussed with the DNR.

The UV system design included the flexibility to expand the system in the future (e.g., additional lamps per UV reactor and/or additional UV reactors in series) for advanced oxidation to control future contaminants (e.g., NDMA). Due to competitive pricing from the UV manufacturer, the City purchased the 'future' UV reactors for the Northwest plant with the intent to use redundant UV reactors to achieve higher log virus inactivation. This will help to reduce reliance on chloramines for primary disinfection and can achieve greater than 2-log virus inactivation with UV alone under many plant operating conditions.

At the Northwest plant, the UV facility was located hydraulically between the filter effluent control weir upstream and the chloramine contact tank effluent control weir downstream. At the J Avenue plant, the UV facility was located hydraulically between the filter clearwell upstream and the finished water reservoir downstream. Water flows by gravity through the UV facility and is then pumped to the chloramine contact tank and high service pump station reservoir.

The project also included the design and construction of a chloramine contact tank and high service pump station at the J Avenue treatment plant. Total UV facility construction costs for both treatment plants were about $13 million, including about $1.9 million (USD) for City pre-purchase of eight UV reactors. Construction began in the summer of 2007; start-up began in 2009 at the Northwest treatment plant, and in 2010 at the J Avenue plant.

Cedar Rapids' project represents one example of using UV disinfection to achieve virus inactivation. UV disinfection may have applicability for virus inactivation for systems with challenging chlorine contact time conditions, due to ammonia present in the source water, no available contact tank, or very rapid formation of disinfection by-products during free chlorine contact.

UV for DBP reduction

Poughkeepsie, NY, USA

Since 1872, when the City of Poughkeepsie, NY, USA, became the first community in the United States to filter its

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Figure 1. *Poughkeepsie UV Disinfection System*

water, Poughkeepsie has a long tradition of producing a high quality drinking water that meets the needs of its customers. The goals of the UV disinfection project were to upgrade the existing water treatment plant, constructed in 1962, by providing treatment facilities necessary to comply with current and future drinking water regulations and to increase the treatment capacity from 16.0 mgd (61 MLD) to 19.3 mgd (73 MLD). The facility treats surface water from the Hudson River.

The project included upgrades to several facilities that were reaching the end of their useful life, such as the filtration system, solids contact clarifier mechanisms, and high-pressure pumps. Prior to beginning the detailed design of the plant, CH2M HILL worked with plant staff to perform both pilot scale and full scale testing of the existing treatment processes to confirm that the existing solids contact clarifiers could process the higher design flows required for this project. Alternative coagulants were also studied with the goal of improving cold water coagulation performance and reducing sludge production. Based upon this testing, the plant switched their primary coagulant from alum to polyaluminum chloride.

A new multiple barrier disinfection strategy was implemented as part of the project. The project implemented a combination of free chlorine and UV light for primary disinfection, followed by monochloramine for residual disinfection on startup in 2006. The addition of UV disinfection facilities downstream of the existing filters enhanced the existing disinfection system by increasing its effectiveness against a wider variety of microbes of concern, while also reducing the formation of DBPs associated with free chlorine primary disinfection. The lack of a finished water clearwell downstream of the filters and the need to provide adequate disinfection contact time for microbial inactivation had historically limited the plants ability to control DBPs. The addition of UV disinfection downstream of the filters allowed the point of chlorine addition to be shifted from the upstream end of the sedimentation basins to the downstream end.

The addition of UV disinfection also allowed the role of free chorine disinfection to be changed from primary Giardia disinfection to virus disinfection. Viruses are easily inactivated with free chlorine within a short contact time, such as the detention time within the existing filter boxes. UV disinfection is well suited to inactivate all other microbes of concern, including *Cryptosporidium* and *Giardia*, and was installed in the limited space available in the existing WTP filter pipe gallery.

Work associated with the design and construction of the new UV disinfection system included preparation of evaluated bid type procurement documents for UV disinfection equipment, as well as drawings and specifications that defined how to confirm the specified performance of the disinfection system via full-scale, third party validation testing. Throughout the project, CH2M HILL worked closely with the State of New York Department of Health to ensure that the installed UV disinfection system met their design and performance requirements and was eligible for full disinfection credit once installed and tested.

For Poughkeepsie, the implementation of UV disinfection provided enhanced disinfection capabilities, allowed a reduction in free chlorine contact time prior to ammonia addition, and helped to reduce the levels of regulated DBPs that formed during treatment.

UV disinfection was implemented with one dedicated medium-pressure UV reactor for each of 6 granular media filters, as shown in **Figure 1**. Each filter and reactor can treat up to 4.5 mgd (17 MLD). The design UV dose was 40 mJ/cm^2 based on the MS2 RED at the end of lamp life, peak flow, and design UV transmittance of 88 percent. Key design elements included fitting UV disinfection within the plant hydraulic profile and filter pipe gallery constraints.

UV for DBP reduction Ketchikan Public Utilities,
Ketchikan, AK, USA

On completion and startup of the 2011 construction, the Ketchikan Public Utilities (KPU) water treatment system treats unfiltered surface water with free chlorine for virus inactivation, UV disinfection for *Giardia* and *Cryptosporidium* inactivation, and monochloramine for distribution system residual disinfection. The average daily flow is 4.1 mgd (15.5 MLD) and the maximum daily flow is 12 mgd (45 MLD). The design capacity of the UV Disinfection and Chloramination Facility is 15 mgd (57 MLD).

KPU installed UV disinfection, as shown in **Figure 2**, and chloramination in response to USEPA regulations that address the public health risk posed by pathogens and DBPs in drinking water. The UV disinfection system installed by KPU is credited with 3-log inactivation of *Cryptosporidium* and *Giardia* credit according to the EPA.

Figure 2. *KPU's UV Disinfection System*

UV disinfection and chloramination provide the following benefits to KPU customers:

- Reduced pathogen risk from *Cryptosporidium, Giardia* and many other protozoan, bacterial, and viral pathogens
- Provision of a second treatment barrier to pathogens resistant to chlorine disinfection
- Reduced formation of DBPs
- Improved public health protection

Free chlorine is used for virus inactivation, so it is added to the system upstream of the UV reactors. UV disinfection reduces the chlorine residual, with the rate of chlorine reduction proportional to the chlorine dose and applied UV dose. Therefore, at very low flows, additional chlorine must be added to achieve the desired chlorine residual for the point of ammonia application for chloramine formation.

UV for backwash recycle treatment in *Fort Collins, CO*

In 2003, Fort Collins Utilities, working with CH2M HILL and Hydro Construction Co., Inc., implemented a UV disinfection system for treatment of filter backwash recycle flows at the existing 87-mgd (329 MLD) conventional water treatment plant. This innovative project was among the first of its kind,

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taking advantage of the disinfection effectiveness of UV treatment to conserve water and save money for Fort Collins' customers.

Because of it simplicity, low costs, and outstanding capability for pathogen disinfection, UV disinfection was implemented for treatment of the filter backwash washwater. The project consisted of new piping to divert the washwater decanted from the existing washwater lagoons, a variable speed pump station, pipeline, and medium pressure UV reactor, flow meter, and power supply. The system was sized to recycle and treat flows up to 3 mgd, which allowed capture of at least 90 percent of the flow that was previously discharged to the Pleasant Valley Lake and Canal system.

Prior to this project, as part of Fort Collins Utilities' potable water treatment process, filter backwash water was discharged to local surface water ponds. The USEPA and State of Colorado allow either recycle or discharge of the spent backwash water. Rather than discharge the backwash water, Fort Collins Utilities elected to begin recycling the backwash water for the following reasons:

- Two of the previous treatment trains were replaced with more efficient and reliable treatment processes that were able to appropriately handle and treat the recycle flow stream.
- On-going drought conditions necessitated that Fort Collins Utilities examine every option to increase its water supply. Backwash water recycling significantly reduced raw water requirements, in a timely fashion, with minimal impact to customers.

During the two years prior to this project, approximately 1,800 acre-feet of washwater were discharged annually. For Fort Collins Utilities to have an equivalent amount of source water to treat, the washwater lost to discharge could be replaced through purchase of Colorado Big Thompson (CBT) Project units, at costs in the tens of millions of dollars. The total project cost for treatment of the backwash recycle flow stream was approximately $1.5 million (USD).

CH2M HILL designed the treatment system for the backwash water before it is recycled to the upstream end of the Water Treatment Facility. Some pathogens have been detected in Fort Collins Poudre River supply prior to treatment, and several alternatives were considered for reuse of the backwash water. Of the alternatives considered, UV disinfection was selected because of its capability to disinfect pathogens including *Giardia, Cryptosporidium,* and enteric viruses. UV was also the most cost-effective alternative evaluated.

Fort Collins Utilities UV disinfection system was designed with a design UV dose of 40 mJ/cm² (based on an MS2 RED) for a flow rate of 3.0 mgd (11.4 MLD). In addition, the design provided the capability to double the capacity or disinfection capability in the future. A process flow schematic of the system is shown in **Figure 3.**

The UV disinfection system has been operating since 2003, and since start-up, it has enabled backwash recycling of 2.7 billion gallons of water, which otherwise would have been discharged. Fort Collins Utilities has produced an average of 23.5 mgd (89 MLD) over this same time period, meaning that UV disinfection has been used to recycle 4.5 percent of the plant flow over its 7 years of operation. The UV system has provided regular, trouble-free operation during this time, and Fort Collins Utilities has 'peace of mind' regarding the potential recycling of pathogens. Water is only recycled if the UV system is operational.

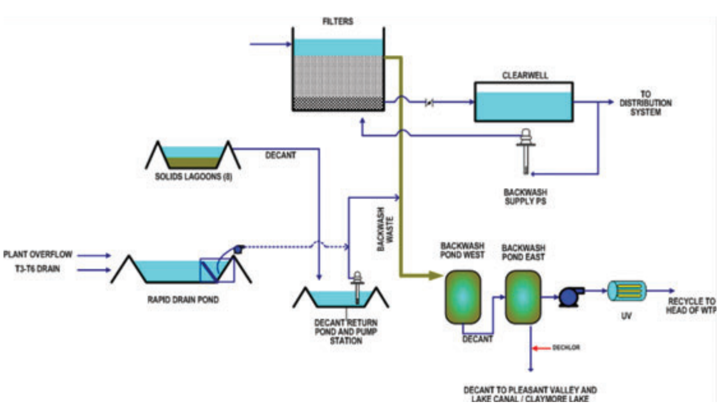

Figure 3. *Fort Collins Utilities Process Flow Schematic*

UV advanced oxidation to destroy emerging contaminants

As described by Swaim (2008), the City of Aurora, CO, is constructing a new water delivery and purification system known as the Prairie Waters Project. This $750 million USD project will increase Aurora's water supply by 20%, and will utilize a unique combination of natural and man-made purification systems to meet Aurora's stringent water quality goals. A critical component of this multiple purification system is the Peter Binney Water Purification Facility (PBWPF). The PBWPF includes a UV advanced oxidation process (AOP) as part of a multiple barrier approach to purification of South Platte River water, as shown in **Figure 4.**

Upstream of UV AOP, Aurora's multi-barrier purification approach includes riverbank filtration, aquifer recharge and

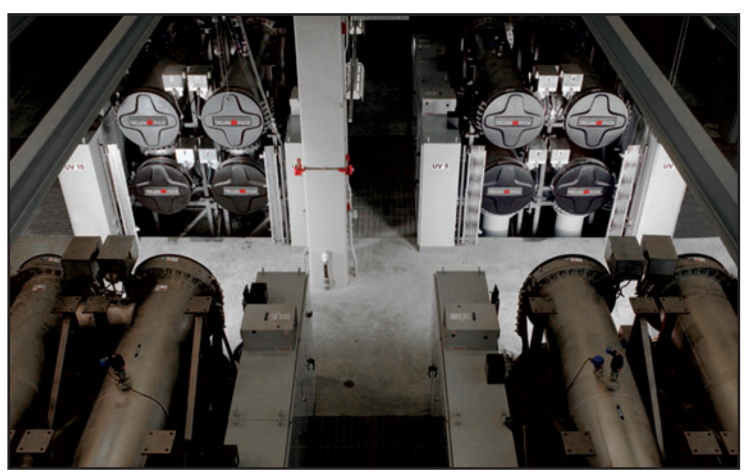

Figure 4. *UV advanced oxidation at the Peter Binney Water Purification Facility*

recovery, precipitative softening, and recarbonation. Following UV AOP, purification processes include biologically-active carbon (BAC) filtration, granular activated carbon (GAC) adsorption, blending, and final disinfection with monochloramine.

Purification alternatives for the Prairie Waters Project incorporated an AOP step, and AOP options were evaluated based on their ability to achieve the multiple objectives of providing:

1. Primary disinfection of *Cryptosporidium* and *Giardia*
2. Destruction of N-nitrosodimethylamine (NDMA) and other nitrosamines
3. Control of organics and micro-pollutants

The candidate purification processes to meet these three objectives provide both disinfection and oxidation, so they are referred to as the 'disinfection/oxidation process'. In addition, the disinfection/oxidation process must not lead to excessive formation of other by-products, such as bromate, at levels that will compromise regulatory compliance or meeting the City's goal of delivering a water that provides comparable protection of public health when compared to current water supplies.

The most viable options identified to meet the defined objectives for the disinfection/ oxidation process at the ARWPF consisted of:

1. Ozone advanced oxidation process followed by UV disinfection.
2. UV AOP.

The ozone advanced oxidation process (AOP) utilizes ozone and hydrogen peroxide addition for advanced oxidation, and UV disinfection would also be necessary for this option to provide Cryptosporidium inactivation without excessive bromate formation. This option would not provide significant destruction of NDMA.

Of these options, UV AOP was selected because of its capability of achieving all of the City's disinfection/oxidation objectives simultaneously. UV AOP offers the following benefits for the PBWPF:

- Superior disinfection capability, compared to ozone, in a single unit process.
- Destruction of NDMA.
- Advanced oxidation as part of a multiple barrier strategy for micro-pollutants.
- Minimal formation of regulated by-products such as bromate.

Additional testing and analysis was conducted to establish design criteria for UV AOP. Bench-scale testing was conducted on South Platte River water at CH2M HILL's Applied Sciences Laboratory. The water collected for this bench-scale testing was sampled from an alluvial well that Aurora operated for over 18 months to demonstrate the performance of riverbank filtration.

These tests were performed to provide information on the performance of the UV AOP. The key identified tasks related to UV AOP addressed the following:

- Assessing water quality to assist in establishing UV AOP design criteria
- Conducting tests to evaluate the removal of micro-pollutants, taste and odor causing compounds, and pathogens through the UV advanced oxidation process
- Evaluating the formation of DBPs through UV AOP
- Evaluating downstream treatment approaches for quenching the hydrogen peroxide residual
- Determining the removal of background micro-pollutants through UV AOP (and through the entire PBWPF process)

The UV AOP testing was performed using two side-by-side collimated beam devices, each utilizing a low-pressure, mercury-vapor UV lamp. For the micro-pollutant tests, NDMA, 1,4-dioxane, and atrazine were selected as the micro-pollutants of interest. These specific compounds were selected because all are of some interest in the source water, and because the destruction mechanism is different for each compound. The destruction of NDMA is dominated by photolysis, the destruction of 1,4-dioxane is due entirely to oxidation, and atrazine destruction occurs via both photolysis and oxidation. For the micro-pollutant spiking tests, a series of UV doses were applied to the spiked solution. The UV doses were selected based on target levels of NDMA destruction including 0.25-log, 0.5-log, 1.0-log, and 2.0-log.

The test results, described in detail elsewhere (Swaim et al., 2008) demonstrated that destruction of spiked NDMA occurred by photolysis, as expected, and the UV AOP performance for NDMA destruction was predictable and repeatable. In addition, at the UV doses necessary for NDMA destruction, substantial destruction of atrazine, 1,4-dioxane, and taste and odor causing compounds also occurred. For these compounds, the UV AOP performance is highly dependent on the peroxide dose. For this test, a hydrogen peroxide dose of 5 mg/L was applied, and destruction of these compounds would increase with increasing hydrogen peroxide dose. From a test with a mixture of multiple contaminants and pathogens, UV AOP provided simultaneous disinfection and destruction of micro-pollutants and other compounds of concern.

In additional treatability testing, nine nitrosamines were spiked into samples and tested using the low-pressure collimated beam UV device over a series of UV doses. The results are shown in **Figure 5.** As shown, the destruction of NDMA exceeded the destruction of the other nitrosamines tested at the same UV dose. From these results, and from sampling results (not included herein), among the nitrosamines, NDMA represented a conservative indicator,

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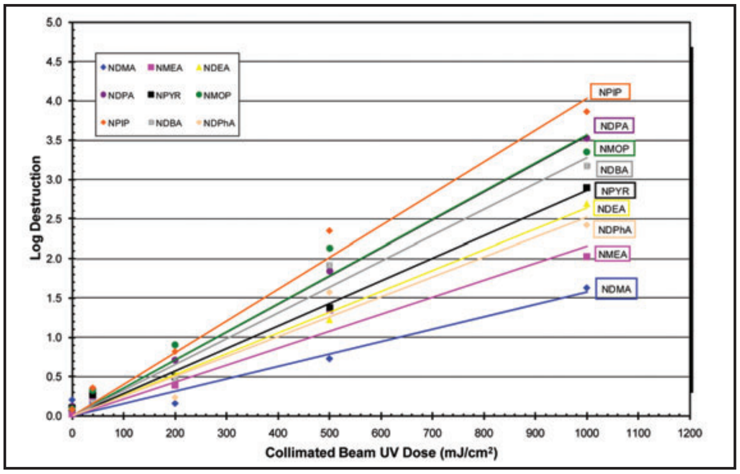

Figure 5. *Destruction of Nitrosamine Compounds by the UV AOP (Hydrogen Peroxide Dose of 5 mg/L)*

both for presence and for removal by UV photolysis.

Low-pressure, high-output UV equipment was selected for the full-scale equipment because it is most cost-effective for year-round operation. Downstream, biological filters and GAC contactors provide quenching of the remaining hydrogen peroxide residual.

Overall, UV AOP is a key component of the multiple barrier approach at Aurora Water's Peter Binney Water Purification Facility. UV AOP was selected because it met several key treatment goals and is also a sustainable treatment process, in which pollutants are destroyed, rather than transferred to a waste stream or discharged.

CONCLUSIONS

These unique UV applications encompassed treatment goals in addition to *Cryptosporidium* inactivation. These projects provide starting points for other site-specific applications of UV light at water treatment facilities.

Each of these projects required proactive communications with primacy regulators, upfront discussions with UV manufacturers, and site-specific design approaches. In addition, performance testing and validation testing approaches were developed individually for each project to ensure validated conditions extended to the intended application and to ensure that performance at each facility achieved the site-specific treatment objectives.

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