832R92004

U.S. Environmental Protection Agency
Office of Wastewater Enforcement and Compliance
Washington, D.C.

Ultraviolet Disinfection Technology Assessment

September, 1992

NOTICE

This document has been reviewed by the U.S. Environmental Protection Agency and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ACKNOWLEDGEMENT

This report was prepared by O. Karl Scheible, with assistance from Ashok Gupta and Dennis Scannel, all of HydroQual, Inc. Wendy Bell, OWEC, Washington, D.C. was the U.S. Environmental Protection Agency Project Officer. The assistance provided by the operators and owners of the plants described in this report is acknowledged with appreciation.

The cooperation and assistance provided by the manufactures of Ultraviolet equipment was helpful and appreciated.

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This report was prepared by HydroQual, Inc. in fulfillment of Contract 68-08-0023. It was prepared by O. Karl Scheible, with assistance from Ashok Gupta and Dennis Scannell, all of HydroQual. Wendy Bell, OWEC, Washington, D.C. was the Project Officer for the U.S. Environmental Protection Agency. The assistance provided by the operators and owners of the plants described in this report is acknowledged with appreciation.

The cooperation and assistance provided by the manufacturers of UV equipment, in particular Trojan Technologies, Fisher and Porter, Katadyn, Aquionics and Ultradynamics, was helpful and appreciated.

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BACKGROUND AND OBJECTIVES

Ultraviolet (UV) disinfection systems are being widely considered for application to treated wastewaters, for both new plants and retrofitting existing plants in lieu of conventional chlorination facilities. The technology is relatively new, with most systems installed over the past three to four years. It has generally been successful, although there had been many problems with the systems installed in the early to mid-eighties. Subsequent "second generation" designs have resolved many of the earlier issues, resulting in a higher degree of reliability and a more rapid acceptance of the technology. These use modular, open-channel configurations in place of the fixed, closed shell arrangements typical of the earlier designs.

The USEPA Design Manual for Municipal Wastewater Disinfection (1) was published in 1986; the evolution to the newer open-channel configurations began only shortly before this. Although the Manual points to the advantages of the open-channel configuration, it does not adequately address their design and operation and maintenance (O and M) aspects, since there was little direct experience with the systems at the time. New design, performance, operation and maintenance information is being developed from recent full-scale applications. These data need to be disseminated to the engineering and owner/operator communities.

This report provides an assessment of the UV process, focusing on the newer designs that utilize open-channel, modular configurations. It is a part of the Office of Wastewater Enforcement and Compliance's (OWEC) program to provide technical assistance to reviewing agencies and local governments in the area of municipal wastewater treatment, by evaluating specific technologies and reporting on their capabilities and limitations.

Information was compiled from the EPA, Regional and State offices, literature, equipment manufacturers, and wastewater treatment plant personnel.

The report presents an assessment of the status of the technology relative to the type and size of UV facilities that are currently operating, and discusses the trends in system design, configuration and operations. The design and operation of selected plants are reviewed; this information and current practices are then summarized to give a perspective of key considerations that should be incorporated into the design of UV facilities. Finally, a review of costs associated with the construction and operation of UV systems is presented, based on data generated from this assessment.

FINDINGS

Thirty plants, covering a range of design flow ratings and UV open-channel configurations were evaluated. All are operating successfully, and are in compliance with their permits, which typically address fecal coliforms. A high level of satisfaction with the system operation and performance was noted by the facility operators.

All the plants accomplish nitrification, by design or by the circumstance of low loading. Improved disinfection performance is influenced by this higher degree of treatment. Minimal coliform densities are observed after UV in wastewaters with BOD/TSS levels less than 10 mg/L. Elevated effluent densities (but still well within permit) are noted at BOD/TSS levels greater than 10 mg/L.

Limited redundancy and system flexibility was noted for the majority of plants. Most plants, in particular the small systems, had single channels, precluding shutdown of a channel for repair/maintenance. Flexibility should be incorporated to a greater degree, including multichannel, multibanking configurations.

System control is kept simple. Automatic flow pacing is incorporated into the larger multichannel, multibank systems; control is flow-paced on a manual basis at several plants. The tendency at the smaller plant (average design flow less than 1.0 mgd) is to have 100 percent of the system in operation at all times.

A downstream mechanical level control gate is the preferred method to maintain liquid level in the UV channel, and it is generally successful. However, it has a specific operating range. Plants with very low flow periods (or no flow) may best be served by using adjustable weirs/weir launders for level control. This may be the case with small systems.

A screen/bar screen is an appropriate device to have immediately upstream. This serves to remove debris and algal mats from the wastewater and prevent them from catching onto the lamp modules.

Sizing of the UV system was somewhat consistent. This ranged between 0.5 and 1.5 KW (of UV output at 253.7 nm) per mgd of peak design flow, with a mean of 1 KW/mgd. This is equivalent to approximately 37 long lamps or 74 short lamps. This estimate should be applied only to advanced secondary effluents, and to plants with a peak to average flow ratio less than 2.5.

Lamps show an extended operating life. Operation greater than 14,000 hours can be expected. The criterion generally followed for lamp replacement is increasing fecal coliform density, although some plants will replace the lamps on a routine fixed time basis (7,500 to 10,000 hours).

Insufficient experience exists to assess replacement cycles for ballast and quartz sleeves. A 10 year cycle has been suggested.

Cleaning the quartz surfaces is a key element of UV O&M. Removal of the modules is appropriate and is practiced by most plants, particularly those using the horizontal lamp modules. In-place chemical recirculation is practiced less frequently, typically with vertical lamp module systems.

Dip tanks are a convenience and assist in cleaning modules removed from the channel. At minimum, a hanging rack should be provided to hold removed modules.

A variety of cleaning agents are used, typically site specific or provided by the manufacturer. Citric acid and Lime-Away^R are used most frequently. Commercial detergents and dilute acids are also used.

The frequency of cleaning varies widely from weekly to yearly, with a median of monthly. This is site specific. Fecal coliform density is typically used as the criterion for cleaning.

The labor requirement for smaller plants is estimated at 180 hours/year/100 lamps. Approximately one-third of this is associated with cleaning activities. For larger plants (greater than 150 lamps) the O&M labor is approximately 115 hours/year/100 lamp, with about one-half attributable to cleaning tasks.

The installed costs for UV systems were estimated to be $48,800/UV KW for systems with less than 100 lamps and $39,000/UV KW for larger systems (a UV KW is the power output at 253.7nm). These are screening estimates only and may vary considerably on a site by site basis. When considered on the basis of flow for advanced secondary plants, these costs range from $78,000 to $97,600 per mgd of average design flow for larger (greater than 1.5 mgd) to smaller plants.

Operation and maintenance costs are site specific and will vary regionally with respect to rates. For screening purposes, annual costs (exclusive of amortization) are estimated to be $3,300 to $3,800/UV KW/yr. This is equivalent to $6,500 to $7,500/year/mgd of average design flow.

CONCLUSIONS

Ultraviolet disinfection is now being widely applied to wastewaters, with greater than 500 operating facilities, as compared to an estimated 50 facilities in 1984. Whereas closed shell and pipe systems were typical in the early to mid-eighties, the modular, gravity flow, open-channel systems now comprise essentially all new installations. The configuration is found in greater than two thirds of active plants, as compared to less than five percent in 1985. It is comprised of horizontally or vertically placed lamp modules, placed in open, relatively narrow channels, with the lamps fully submerged in the wastewater. Horizontal systems represent approximately 85 percent of the open channel facilities.

The UV source used with essentially all systems is the low pressure mercury arc lamp. Alternate lamps are being actively investigated and are in use at several operating plants. These include medium pressure lamps and modifications of the conventional low pressure lamps. A recent advance has been the introduction of an efficient electronic ballast, which is lighter and is incorporated into the modules themselves.

UV is effective and has been demonstrated to be capable of meeting existing disinfection criteria. This includes secondary fecal coliform limits (200 fecal coliforms/100 mL) and shellfish limits (14 fecal coliforms/100 mL). An exception may be the California total coliform limit of 2.2 per 100 mL for discharge to shellfish waters. Filtration is generally required if UV is to meet the lower shellfish standards.

Alternate indicators have been incorporated into EPA disinfection guidelines and are being written into permits in a number of states. These are 126 E. Coli per 100 mL or 33 enterococci per 100 mL for freshwater, and 35 enterococci per 100 mL for marine waters. Recent studies have indicated that the design sizing requirements for these indicators is similar to those for fecal coliforms. Caution should be used, however, particularly when modifying permits for existing UV facilities. A plant that readily meets fecal coliform requirements can have difficulty meeting enterococcus limits under similar operating conditions.

Photoreactivation is a necessary factor to consider when sizing UV systems on the basis of total or fecal coliforms and E. Coli. An average maximum level of repair demonstrated from several studies is a 1.5 log increase. Enterococci do not have the ability to repair.

Hydraulic design is a key factor in the operation of UV systems. Plug flow conditions with minimal dispersion must be maintained. This is best done by using narrow channels relative to their length (to yield an aspect ratio greater than 15), having two banks in series when using horizontal lamp systems and a minimum of four banks in series with vertical lamp systems. Straightline approach and exit conditions should be maintained, with adequate upstream and downstream distances from the lamp batteries.

Headlosses are relatively low through current system configurations under normal design velocities. Care should be taken to account for upstream devices such as stilling plates and screens, and the downstream level control device when estimating overall headloss. The total headloss through the UV lamp portion of the reactor should be held to less than three inches at peak instantaneous (hourly) flow.

Design sizing should be on the basis of peak requirements (e.g. maximum daily, maximum 7-day, etc.) for disinfection. Hydraulic design is based on peak hourly flow, reflecting diurnal variation. Wastewater parameters used for design are the initial bacterial density, the UV transmittance of the wastewater (at 253.7 nm) and suspended solids. Design sizing should be based on the assumption that the peak occurrences for these parameters and flow are coincident.

RECOMMENDATIONS

There should be additional evaluation of the impact that alternate indicators have on the design and performance of UV systems. In particular, this should address plants that are or will be required to incorporate either E. Coli or enterococcus into their discharge permit.

Application of open-channel, modular, gravity flow UV systems should be encouraged for wastewater disinfection. The design implications of recent advances in system design, in particular the high intensity lamps, should be assessed. This would address potential applications and include a comparison to the conventional systems.

Continued effort should be made to determine the impact of photoreactivation on design and the degree to which this phenomenon affects receiving waters. This would best be addressed in comparison to after growth associated with chlorination/dechlorination.

SECTION 1.

ASSESSMENT OF THE UV DISINFECTION PROCESS ELEMENTS

This section briefly describes the UV disinfection process and its application to treated wastewaters. It then presents the equipment configurations that have been and are being used for wastewater applications, and addresses related process considerations and the design protocols currently in use.

1.1 UV DISINFECTION

The inactivation of microorganisms by ultraviolet radiation is a physical process, relying on the photochemical changes brought about when far-UV radiation is absorbed by the genetic material of the cell (deoxyribonucleic acid, or DNA). The wavelengths for optimum effectiveness correspond, as expected, to the maximum absorption spectrum for nucleic acids, between 250 and 265 nanometers (nm).

The inactivation mechanism is well understood for UV radiation. The reader is referred to other source material for more detailed discussions of the mechanism (1,2,3,4,5). Specifically, the most common pathway involves the dimerization of adjacent thymine monomers on a DNA strand. If many dimers are formed by exposure to UV radiation, cell replication becomes very difficult. Thus, although the cell is not "killed" by exposure to UV, it is effectively inactivated because of its inability to replicate.

1.1.1 Source of UV Radiation

The low pressure mercury arc lamp is very efficient in generating UV light within the optimal germicidal wavelength range. It is an electric discharge lamp that generates light by transforming electrical energy into the kinetic energy of moving electrons; this is converted to radiation by a collision process. Mercury vapor, kept at an optimum pressure in the presence of a rare gas (typically argon), is a very efficient emitter of light at 253.7 nm. The lower the vapor pressure of mercury in an electric discharge, the greater the intensity of the mercury resonance line at 253.7 nm. Exploiting this fact, construction of the low-pressure mercury arc lamp yields an output that is nearly monochromatic in its radiation at 253.7 nm. Thirty-five to forty percent of the input energy is converted to light, and approximately eighty-five percent of this light is at the wavelength of 253.7 nm.

These low-pressure lamps comprise the source of UV energy in effectively all systems installed today. The lamps are long thin tubes, 1.5 to 2.0 cm in diameter. Standard lengths are 91.4 cm (36 inches) and 162.6 cm (64 inches), with active mercury arc lengths of 76.2 cm (30 inches) and 147.3 cm (58 inches), respectively. The longer length lamps are typically used, except in small systems. They are more cost effective than the shorter lamps; although they have effectively twice the UV output, they are usually only 30 to 60 percent more in cost.

Some wastewater applications exist that use alternate UV sources, although they all still rely on the basic mercury vapor electric discharge concept. Medium to high pressure mercury lamps have significantly higher UV intensities and have a broader spectrum of output than the low pressure units. A study by Whitby and Engler (6) demonstrated that the germicidal effectiveness of a 2,000 watt (W) medium pressure lamp was 14.2 times that of a 60 W conventional low pressure lamp, based on the ability to achieve a 3-Log reduction in a primary effluent. The single lamp experiments suggest that the total number of lamps required for a given application can be reduced by a factor of up to 10 if medium pressure lamps were used. This would result in potentially significant savings in capital costs and area requirements, an important advantage for large systems.

There are medium pressure lamp systems in the U.S. for the disinfection of treated municipal effluents, including the Lewisburg (1 mgd) and Hillsboro (4 mgd) Ohio plants (7). These systems are operated under pressure, which would be impractical on a large scale. Uncertainties remain with the use of medium pressure systems, reflecting the very limited direct experience with wastewater applications. The costs of the lamps themselves are much higher than the low pressure lamps; they are also less efficient and thus require more power. Heat output is greater and can impose design problems relating to heat transfer. Power supply requirements are more complex and because of their shorter length and fractional second exposure times, hydraulic design becomes a critical issue when attempting to maintain plug flow conditions.

Modifications of conventional low pressure lamps are being developed, with some resultant in-field applications. A facility in Cuxhaven, Germany uses a high intensity lamp similar to the medium pressure lamps (8). Its energy conversion is more efficient, however, similar to conventional low pressure lamps. The lamps are u-shape, vertically oriented in the water, with an open-channel layout. There is a heat dissipation contact spot with the quartz enclosure that is used to remove the high heat load associated with these lamps. Another alternate lamp is a conventional lamp that is flattened in order to increase the emission from the mercury vapor, yielding higher intensities (9). A plant in Baldwin, Florida was installed with these lamps, although equipment problems have prevented an assessment of its performance.

A recent development has been the use of an alternate electronic ballast. A ballast is required to counter the inherently unstable negative volt-ampere characteristic of electric discharge arc lamps. In nearly all existing installations conventional 2-lamp lead-lag type coil ballasts are used. The electronic ballasts offer the advantage of being lighter and have the ability to adjust the input voltage (dimming). Because of their lighter weight (approximately one-third that of the coil ballasts), the ballasts are incorporated into the lamp modules themselves, as opposed to the large cabinets used for the coil ballasts. This has allowed a potentially significant cost savings. There is limited in-field experience with these modules; a full-scale operating unit is located at Camp Quin-Mo-Lac in Ontario for beach water control, with approximately three months operation. A 14.6 mgd wastewater plant was commissioned in April 1991 at St. George de Beeauce, Quebec, and several facilities in the design/bid/construct stage anticipate using these modules with the electronic ballasts (10).

Overall, UV equipment for treated wastewater disinfection will likely continue to be dominated by the conventional low pressure mercury arc lamps. They are efficient, cost-effective, and are appropriate to a wide spectrum of applications. The alternate lamps, particularly the medium pressure units, continue to be investigated and applied on a limited basis. Their likely application will be with large plants and in cases of low-grade, high volume waters such as combined sewer overflows (CSO) and stormwaters.

1.1.2 UV Effectiveness

The effectiveness of UV in the inactivation of microorganisms is well documented. Generally, UV is the most effective of the standard disinfection processes when applied to bacteria and viruses. Effectiveness increases with decreasing complexity of the organism and with decreasing cell wall thickness. Thus, viruses are particularly sensitive to UV, more so than to chlorine or other oxidants. On the other hand, higher organisms are less sensitive; in these cases chlorine is the preferred disinfecting agent. This is demonstrated in recent research regarding the Safe Drinking Water Act rules on drinking water disinfection. UV has limited cysticidal ability, and is not applicable to Giardia Lambia disinfection (11,12).

Most National Pollutant Discharge Elimination Permits (NPDES) require disinfection, with limits set on the basis of fecal coliform. There are variations from state to state, relative to the requirement for disinfection (water use guidelines, seasonal disinfection, etc), indicators, and indicator limits. UV disinfection is capable of meeting these standards in most cases:

Secondary Treatment	Maximum 30-day Fecal coliform < 200 per 100 mL
	Maximum 7-day Fecal Coliform < 400 per 100 mL
Shellfish Waters	Maximum 30-day fecal coliform < 14 per 100 mL

These are geometric means. In some cases total coliform limits are incorporated into the permit, such as 70 per 100 mL for shellfish waters. The higher limits can be met by UV with adequate clarification prior to discharge.

Suspended solids concentrations that are consistently greater than 25 mg/L may prevent the UV system from meeting the 200/400 fecal coliforms limits. Solids tend to occlude bacteria from exposure to UV. California limits total coliform to 2.2 per 100 mL for discharges to shellfish waters or impounded water bodies. UV has not been demonstrated to be capable of meeting these levels on a consistent basis in a treated wastewater matrix. The shellfish limits (14 per 100 mL) that are more typically used in various states can be met with tertiary filtration prior to UV.

1.1.3 Alternate Indicators

A major policy change in disinfection regulation has been the suggested use of E. Coli and/or enterococcus as disinfection indicators in lieu of total or fecal coliforms. The prevailing fecal coliform limits have been criticized because available epidemiological evidence does not support their use, and because the fecal coliform group can itself contain bacteria that are not necessarily associated with fecal contamination. Studies have shown that E. Coli and enterococci are better able to predict the incidence of swimming related gastroenteritis than either total or fecal coliforms (13). The USEPA "Ambient Water Quality Criteria for Bacteria" (14) recommends use of the E. Coli and/or enterococcus as pathogen indicators in recreational waters.

EPA guidance states that E. Coli not exceed 126 per 100 mL (geometric mean) in freshwater, or that enterococci not exceed 33 per 100 mL. Enterococcus limits (35 per 100 mL) are recommended for marine waters. Several states are moving toward the use of these standards, although all states that have bacteriological standards continue to use fecal and/or total coliforms as indicators. The state of New Jersey has begun to incorporate enterococci into all permits, as they are renewed. The limits are 32.5 per 100 mL on a 7-day average (GM) basis and 60 per 100 mL as a maximum value. Note that discharges to shellfish waters still require compliance with U.S. Food and Drug Administration (FDA) fecal coliform standards.

Movement to alternate indicators has raised concern over the adequacy of UV design sizing criteria relative to standard fecal coliform requirements. If UV facilities have been sized and installed on the basis of fecal coliform limits, the question is weather the system would also be able to meet enterococcus and/or E. Coli standards. Direct pilot studies have been conducted to address this, including an EPA funded study (15) at the Rehoboth Beach Water Pollution Control Plant (WPCP) in Delaware, and a recent pilot study (16) at the LOTT WPCP in Olympia, Washington.

The Rehoboth Beach WPCP is an oxidation ditch facility with nitrification and tertiary microscreens. The plant has an average design flow of 3.4 mgd; during the 1989 study, the average flow was 1.7 mgd. Table 1-1 presents a summary of effluent data representing the summer period in 1989. The plant produces a high quality effluent, with an average BOD_5 and TSS of 5.2 and 6.1 mg/L, respectively. The average and 95 percentile values are also reported for total and fecal coliforms, E. coli, and enterococcus. Total coliforms were typically 6.5 times the fecal coliforms in the treated effluent (before UV). Enterococci and E.coli densities were significantly lower than the fecal coliforms (at ratios of 0.04 and 0.13, respectively). These ratios increased substantially after UV treatment, particularly for the enterococci (1.3) and E. Coli (0.7), suggesting a lower sensitivity to UV for these groups.

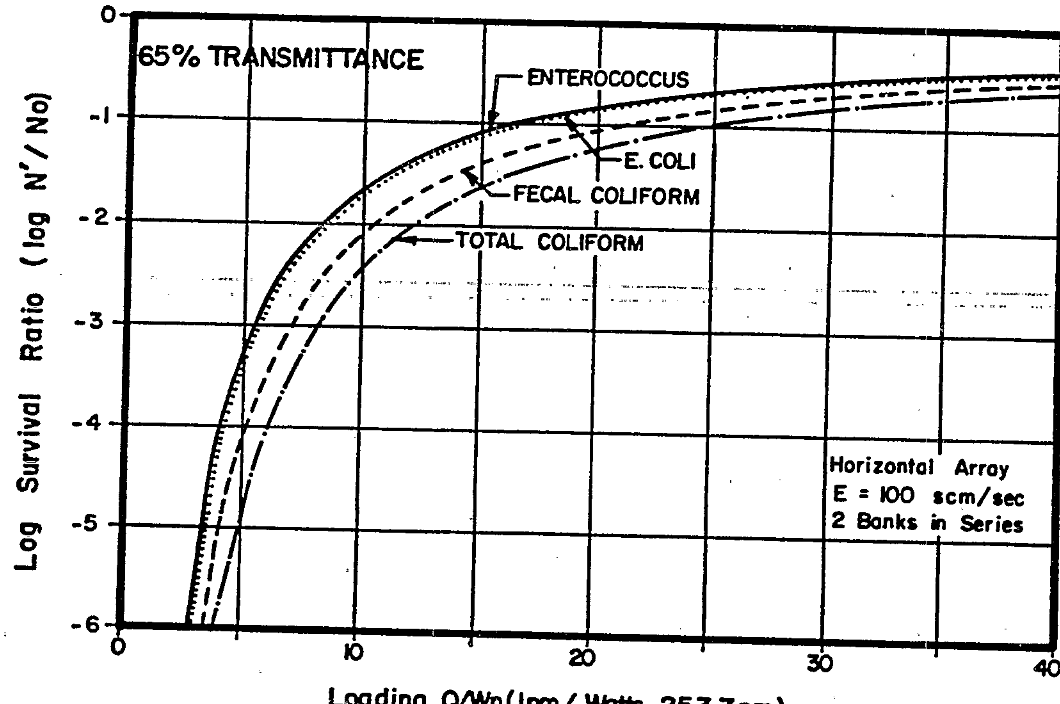
Figure 1-1 presents design curves developed from the Rehoboth Beach pilot data that reflect this lower observed UV sensitivity. The log survival ratio (N'/N_0) is shown as a function of the system loading (liters per minute/UV Watt, Lpm/UV W). From this figure one can estimate that the maximum allowable loading to achieve a 4-log reduction of enterococcus or E. coli would be approximately three-quarters the maximum allowable loading for a similar reduction in fecal coliforms. The loading for total coliforms is approximately 1.15 times that of the fecal coliforms for a 4-log reduction. This means that a larger size UV system would be necessary to accomplish equivalent reductions for enterococcus and E. Coli. However, because the initial densities are substantially lower than the fecal coliforms, the actual sizing requirements are smaller.

At the LOTT wastewater treatment plant in Olympia, Washington, both fecal coliforms and enterococcus were investigated as part of a pilot study for design of the UV system. In this case the ratio of enterococcus to fecal

TABLE 1-1. WASTEWATER CHARACTERISTICS AT REHOBOTH BEACH, DELAWARE (REFERENCE 15)

	Average	95 percentile[(1)]
Flow	1.74	2.56
Effluent		
BOD_5 (mg/L)	5.2	21.6
TSS (mg/L)	6.1	10.2
%Transmittance at 253.7 nm (T)[(2)]	69.8	74.1 (10% - 68%)
%Transmittance at 253.7 nm (F)[(2)]	71.7	77.7 (10% - 68%)
Total Coliform (100 mL^{-1})	182,400	700,000
Fecal Coliform (100 mL^{-1})	28,200	200,000
Entercoccus (100 mL^{-1})	1,140	13,700
E. Coli (100 mL^{-1})	3,600	73,200
Ratio to Fecal Coliform		
Influent (to UV)		
Total Coliform	6.5	
Enterococcus	0.04	
E. Coli	0.13	
Effluent (from UV)		
Total Coliform	5.4	
Enterococcus	1.3	
E. Coli	0.7	

(1)95 percent of data have a value equal to or less than this value
(2)T - total (unfiltered); F - Filtered (Filtrate)



Q/Wn vs. Log Survival Ratio (log N'/N_0)

Figure 1-1
Performance - Loading Curves Developed for Rehoboth Beach UV System (15)

coliform averaged approximately 0.145, with mean values of 14000 and 96500 per 100 mL, respectively. This ratio increased to 0.95 after UV treatment, again indicating a lower sensitivity to UV. When the design sizing requirements to meet the 30-day limits of 200 fecal coliforms or 35 enterococci per 100 mL were compared, the enterococci limits were found to be the controlling factor, although the margin was rather narrow. A total of 1,030 lamps were estimated for enterococci disinfection versus 943 lamps for the fecal coliforms. LOTT will not have enterococci limits in their permit.

A third, most recent example of the enterococcus versus fecal coliform issue can be found with the Northwest Bergen County Treatment Plant in Waldwick, New Jersey (17). This is a retrofitted plant that was designed to meet fecal coliform limits (200/400). Its permit was recently changed to include enterococcus at an average limit of 32.5 per 100 mL and a maximum of 60 per 100 mL. Although the facility had been consistently meeting the fecal coliform limits, even under design flow conditions (approximately 12 to 14 mgd) extraordinary measures were needed to assure compliance with the enterococci limits. This included replacement of the lamps with new lamps, a task that will be done routinely after only 7,500 operating hours. This will substantially increase the UV system's operating costs.

The initial work at Rehoboth Beach suggested that imposition of the alternate indicators would not adversely affect the sizing requirements of UV systems to meet permit limits, nor would it compromise the ability of existing facilities to meet permit limits. It appears, however, that this may be an unknown, and one that is largely dependent on the specific site and its wastewater characteristics. Caution must be used when sizing for enterococcus (and/or E. coli) disinfection, or when modifying the permit requirements of plants already designed to meet fecal coliform limits.

1.1.4 Photoreactivation

The damage caused by exposure to UV can, to a limited extent, be repaired, depending on the environmental conditions and the specific organisms. The phenomenon is well understood and documented by extensive research (1, 18, 19,). Two mechanisms are identified. The most dominant is a catalyzed enzymatic repair requiring concurrent or subsequent exposure to light in the visible range of 310 to 490 nm. The second is a dark repair involving cleavage enzymes that clip out the dimerized nucleotides. Not all microbial organisms exhibit the ability to accomplish this repair. Of the groups often addressed by wastewater discharge permitting activities, the coliforms (total and fecal) and the E. Coli will photorepair. Enterococcus will not. Viruses do not have this ability, except when in a host cell that can repair.

Data on the photoreactivation of bacteria in treated wastewater have generally been generated on the basis of the static bottle test. In this procedure, the UV exposed sample is measured immediately for bacterial density, and is also split in to two bottles; one is opaque to visible light, while the second is transparent to visible light. These are then exposed to sunlight for one to two hours and the bacterial density is measured. The increased level measured in the "light" bottle is attributed to the repair of UV damaged organisms upon exposure to sunlight. Note that exposure to interior fluorescent or incandescent light will yield lower results than when measured with sunlight (16).

There are seasonal influences, likely due to light intensity, temperature and cloud cover. Maximum repair occurs during summer months. The repair mechanism has been shown, using the bottle technique, to result in a 1 to 2.5 log increase in fecal coliform, total coliform and E. coli (1,15,16) while the enterococci do not repair (15,16). It is suggested that a mean repair level of 1.5 log should be anticipated as the maximum increase after UV exposure.

One should note that these are maximum levels, estimated under optimal conditions for photoreactivation. These do not necessarily correspond to conditions extant in the UV channel, the plant outfall and the receiving stream. One has the discretion to consider partial photoreactivation when determining performance requirements for design sizing. Thus if a three-log kill is necessary for system performance, one would conservatively design by assuming maximum photoreactivation and size for a 4.5 log reduction.

1.2 HYDRAULIC DESIGN CONSIDERATIONS

Considerable performance problems occurred with the older, closed shell systems, often due to ineffective hydraulic design. The move to the open-channel, modular system configuration has positively influenced good hydraulic design. For UV disinfection this requires long, narrow channels with approach and exit conditions that are conducive to the desired plug flow, minimal dispersion behavior.

Two banks of horizontal lamp UV modules placed in series are typical of new designs. The channel width should be kept low, such that the aspect ratio is greater than 15 (ratio of the length to the hydraulic radius). Similar calculations should be done in configuring the vertical lamp modules. Retrofitting existing chlorine contact chambers often leads to excessively wide channels; it is best to consider splitting the channel with narrow walls along the length.

Straightline approach and exit conditions should be maintained. Upstream, a perforated stilling plate can be installed, if there is sufficient head available, to distribute the flow/velocity evenly along the cross-sectional plane of the channel. General practice places this approximately four feet upstream of the first lamp battery. Otherwise, the channel should have an undisturbed straightline approach two to three lamp lengths in distance. There should be a sufficient distance between lamp banks (two to four feet) and two to three lamp lengths between the last bank and the downstream level control device.

Scheible[20] reported the hydraulic analysis of a UV system in West Virginia that demonstrated the importance of channel hydraulic design. An open-channel, horizontal lamp unit, it was designed with over-under-over baffles in the approach channel to break the velocity of the pumped influent. The system was unable to meet fecal coliform limits, however. A residence time distribution (RTD) analysis showed very high dispersion, with an E estimate to be greater than 2,000 cm^2/sec (reference the EPA Design Manual, 1). The Morrill Dispersion Index (the ratio of t_{90}/t_{10}) ranged between 2.2 and 6.4.

Ideally, the target for these two parameters should be an E less than 100 cm^2/sec and a Morrill number less than 2.0. Mixing was occurring in the reactor, preventing effective disinfection; this was found to be caused by the disturbed flow in the approach section of the channel. The baffles were removed and a stilling plate was installed. A subsequent RTD analysis showed an E less than 100 cm^2/sec and a Morrill Dispersion Index less than 2.0, indicating that good plug flow hydraulic behavior had been achieved.

Good design practice should entail multichannel configuration, enabling the flexibility of altering the number of channels in service as a function of flow. The individual channels should be operated at a rate greater than 70 percent of its design flow. The channels should also be hydraulically independent; this can be accomplished with equivalent stilling plates at the head of each channel, or with overflow weirs.

Headlosses are relatively low through current system configurations. Design velocities are typically 1.0 to 2.0 fps and should not exceed 2.5 fps. Care should be taken to account for upstream devices such as stilling plates and screens and the downstream level control device when estimating overall headloss. The total headloss through the UV lamp portion of reactor, inclusive of all stages, should be held to less than three inches at the peak design (hourly) flow.

1.3 ULTRAVIOLET DISINFECTION COSTS

Cost information was assembled from several sources: manufacturer's equipment and major component replacement costs; bid quotes for specific installations; and actual costs data from existing UV facilities. There were a total of 35 plants for which cost information was available to some degree; these do not correspond fully to the 30 plant survey presented in Section 3. The following discussions present the capital and operational and maintenance (O&M) cost estimates. Understand that these are meant for use in screening the expected costs for a UV application. Site specific considerations are critical and will affect any cost estimate for the installation and operation of a UV disinfection system. The costs provided in the following discussions should be assumed to have a range of plus or minus 35 percent. The estimates have been normalized to 1990.

1.3.1 Capital Costs

1.3.1.1 Equipment Costs

The installed costs of UV systems are generally dominated by the equipment costs. These include:

- UV modules with lamps and quartz sleeves;
- module support racks;
- level control device;
- instrumentation and control panels;
- power supply distribution/ballasts;
- cables/cableways, and
- spare parts inventory.

There is an economy of scale, although this was found to be divided to two distinct sizes: systems with less than 100 lamps and those with greater than 100 lamps.

The costs were normalized to the available power at 253.7 nm. Thus, standard 58 inch arc lamps have a rated UV output of 26.7 watts at 253.7 nm; if a particularly system has 100 lamps, its total available UV output is 2,670 watts, or 2.67 KW. Conversely, one KW at 253.7 mn is equivalent to 37 standard long lamps (58 inch arc) or 75 short lamps (30 inch are).

The average equipment cost (1990) for small systems (< 100 lamps) was found to be $29,700 per UV KW. These are based on 18 plants ranging in sized from 24 to 76 lamps. The costs for systems greater in size than 100 lamps tended to have a narrow range. Those systems with 100 to 500 lamps (2.67 to 13.35 KW) had an average equipment cost of $23,500 per KW at 253.7 nm. This decreased to an average of $20,500 per UV KW for systems having more than 500 lamps. The mean cost of all systems with greater than 100 lamps was $22,000 per UV KW.

1.3.1.2 Construction Costs

Construction costs include the concrete open channel structures to support the UV systems, influent and effluent channel structures, utilities, flow diversion gates for each channel, grating, accessory equipment/structure, and engineering. A building is not included in the installed costs. For small systems (less than 100 lamps) the construction costs averaged $29,100 per UV KW. This decreased to approximately $17,000 per UV KW for plants greater than 100 lamps in size. One should again note that these costs, exclusive of the UV equipment, are very site dependent and can vary widely due to conditions unique to a given site. Overall, the construction costs tend to be equivalent, on average, to 100 percent of the equipment cost for small systems and 75 percent of the equipment cost for systems greater than 100 lamps.

1.3.1.3 Total Installed Costs

The capital costs (1990) associated with the installation of UV systems are summarized as follows:

System Size	Equipment	Construction	Total
< 100 lamps	$29,700/UV KW	$29,100/UV KW	$48,800/UV KW
> 100 lamps	$22,000/UV KW	$17,000/UV KW	$39,000/UV KW

The total available UV KW provided for a given plant is dependent upon the plant size, wastewater quality, performance requirements and degree of redundancy. As such, it is difficult and not wholly appropriate to relate a general cost to the size of the treatment plant. However, to gain a perspective, Section 3 finds that the average design size of an open-channel, modular UV system is approximately 1 KW at 253.7 nm/mgd peak design flow for advanced secondary to tertiary plants having peak to average flow ratios less than 2.5. This is equivalent to approximately 37 lamps per mgd of peak design flow. If we were to assume a peak to average ratio of 2.0, the number of lamps per 1 mgd of average design flow is 74; or an available UV output of 2 KW per mgd of average design flow. Given the "small" versus "large" division of 100 lamps, the small plant would have a design average flow of less than 1.5 mgd, with a total installed cost of $97,600 per mgd. "Larger" plants with a design average flow greater than 1.5 mgd would have an installed cost of approximately $78,000/mgd.

1.3.2 O&M Costs

The major elements in the costs for the operation and maintenance of UV systems are parts replacement, power and labor. Experiences from 30 selected plants are discussed in Section 3 for open channel, modular systems; these were factored into the estimates of O&M costs. Again, as with the capital costs estimates, the O&M costs are estimated for screening purposes; actual costs will vary depending on specific site conditions.

1.3.2.1 Parts Replacement

The key components that require periodic replacement are the lamps, quartz sleeves, and ballasts. The cost of these items vary widely and from equipment manufacturer to manufacturer. It is suggested that an owner pursue lamp manufacturers and/or bidding in quantity, particularly with larger systems. This will be especially effective in the purchase of lamps. For purposes of this analysis, the following unit pricing is assumed (based on the use of standard 58 inch arc length lamps):

Lamps	$60
Quartz Sleeve	$50
Ballast	$80

The replacement cycle per lamp is presumed to be every 12,500 hours of operation (1.4 years). System utilization is 40 percent; this means that an average of 40 percent of the lamps in a system are on at a given time. Furthermore, year-round operation is presumed. A life cycle of 10 years is presumed for the quartz and ballasts. To account for miscellaneous parts replacement/repair, an additional cost equivalent to two percent of the equipment capital cost is assumed as an annual cost.

Normalizing this to available UV output at 253.7 nm:

- Lamps: $\frac{37 \text{ lamps}}{\text{UV KW}} \times \frac{0.4}{1.5 \text{ years}} \times \frac{\$60}{\text{lamp}}$ = \$592/UV KW/year

- Ballast (at one per two lamps):

  $\frac{37 \text{ lamps}}{\text{UV KW x 2 lamps/ballast}} \times \frac{\$80}{\text{ballast}} \times \frac{1}{10 \text{ years}}$ = \$148/UV KW/year

- Quartz: $\frac{37 \text{ lamps}}{\text{UV KW}} \times \frac{1}{10 \text{ years}} \times \frac{\$50}{\text{quartz}}$ = \$185/UV KW/year

- Miscellaneous Parts/Repair:
  at 2 percent Equipment Cost/Year x \$22,000/UV KW = \$440/UV KW/year.

The total annual (1990) parts replacement costs are thus estimated to be \$1,365/UV KW/year.

1.3.2.2 Power Costs

Power costs will obviously be dependent on the unit rate per KW/hr, a value that is highly dependent on the regional location of the plant. For purposes of this analysis, an average rate of \$0.08/KWhr is used. The power draw for a UV system using the long standard lamp is typically between 90 and 100 W/lamp. This accounts for the full draw of the system, including instrumentation, control, lamps and ballast losses. A value of 100 W/lamp is used for this calculation, or 3.7 KW/KW at 254.7 nm. The annual system utilization assumed for lamp replacement is then used to estimate the annual power costs:

$$\frac{3.7 \text{ KW}}{\text{UV KW power}} \times \frac{0.4}{\text{year}} \times \frac{\$0.08}{\text{KW hr}} \times \frac{8,760 \text{ hrs}}{\text{year}} = \$1,040/\text{year/UV KW}$$

Thus the annual power cost is estimated to be approximately \$1,040/UV KW/year, based on the operating assumptions and rates discussed earlier.

1.3.2.3 Labor Costs

The labor requirements will be site specific, focusing primarily on parts replacement, general maintenance and monitoring, and cleaning. Estimates for these labor elements are discussed in Section 3. The total O&M labor requirement, exclusive of cleaning, was estimated to be 120 hrs/year/100 lamps for smaller systems and 55 hrs/year/100 lamps for larger systems.

Cleaning requirements are highly site specific, both in frequency and the level of effort required. For the 30 plants (Section 3) the median frequency and hours per cycle were 12/year and 5 hours/cycle/100 lamps; this yields a median of 60 hrs/year/100 lamps. Adding this to the labor estimates discussed earlier, the total labor is 115 hrs/year/100 lamps to 180 hours/year/100 lamps for large and small systems, respectively. When normalized to KW at 253.7 nm, these values are 43 and 67 hours/year/KW.

A labor cost of $20/hr is assumed, encompassing direct salary, fringe benefit costs and other related administrative costs. This too is a rate that will vary regionally and must be adjusted accordingly for specific site estimates. Based on these rates, however, the annual labor cost for operation and maintenance of the UV system is $860 to $1,340/UV KW, depending on system size.

1.3.2.4 <u>Summary of O&M Costs</u>

In summary, the annual costs (exclusive of capital cost amortization) for operation and maintenance are:

Part Replacement	$1,365/UV KW/year
Power	$1,040/UV KW/year
Labor	<u>$860 to $1,340/UV KW/year</u>
Total	$3,265 to $3,745/UV KW/year

The reader is cautioned, of course, that these are based on specific assumptions regarding rates and operating conditions. These would necessarily be adjusted by factors known for the site. Overall, these estimates are sufficient for screening the annual costs associated with UV. Considering the same assumptions used earlier in assessing capital costs (peak to average ratio of 2.0 for an advanced secondary to tertiary facility), the annual costs translate to $6,500 to $7,500/year/mgd of average design flow for large and small systems, respectively.

SECTION 2.

STATUS OF UV SYSTEMS AND EQUIPMENT CONFIGURATIONS

This section presents a brief overview of the types of UV systems that are being used for wastewater disinfection. The distribution of systems is then given regarding size and type, location, and the trend in the types of systems finding favor for wastewater applications.

2.1 SYSTEM CONFIGURATIONS

There are several ways in which UV reactors have been configured for the disinfection of treated wastewaters. The design intent must be to minimize the loss of UV energy and to maintain a minimum exposure time for all elements of the wastewater passing through the reactor. This requires close contact of the wastewater with the UV source, and plug flow conditions within the reactor itself.

The configuration has evolved, depending during the first generation of systems on the closed shell, fixed lamp systems. These gave way to open-channel units that were modular in design, with open access to the lamp assemblies. Closed shell reactors are arranged such that the lamps (within their individual quartz enclosures) are held in a fixed position inside the reactor, in full contact with the wastewater. The centerline spacing is typically 8 to 12 cm for the lamps, with the flow directed parallel to the lamps. The reactors are typically gravity flow, with piped inlet and outlet. Because of the higher velocities at the entrance and exit points, and the change in direction required at each point, these units tend to exhibit a high degree of dispersion, affecting disinfection performance. The closed shell configuration also provides poor access to the lamps and quartz for maintenance and repair. These types of units tended to dominate the market through the mid-eighties, but very few are being currently specified.

A "non-contact" configuration uses Teflon pipes to carry the liquid. These are thin-walled, and transparent to the 253.7 nm wavelength. The Teflon tubes are surrounded by unsheathed lamps. The hydraulic behavior of these units is good, simulating pipe flow. The energy utilization tends to be low, however, when compared to the submerged quartz systems. Experience with these units was generally difficult, due to serious fabrication problems, difficult maintenance, and poor accessibility. These units are not specified any longer for wastewater applications.

The open-channel configuration relies on submerging the lamps in the wastewater in an open channel. An earlier design used a fixed lamp reactor in which the entire lamp battery was installed in the channel, with the flow perpendicular to the lamps. These too suffered problems with fabrication difficulties, poor accessibility to the lamp battery, and poor maintenance. These fixed open-channel systems are no longer used.

The newer "second-generation" open channel systems use modular designs in which quartz-sheathed lamp assemblies are fabricated in multi-lamp modules; these are then hung in an open-channel, using as many modules as is necessary for the specific application. Multi-channel configurations can be used, often with two or more banks of lamps placed in series within a channel. The open-channel modular design is best suited to UV process design and represents state-of-the-art for UV systems.

The lamp modules are designed such that they can be placed either horizontally or vertically into the channel. Figure 2-1 presents a schematic of a horizontally configured module. These typically have eight lamps per module, although smaller systems may use modules with six of four lamps. Package plant units are typically designed with 2-lamp modules. The Neuse River Plant in North Carolina will use 16-lamp modules. Variations of the module itself are provided by various manufactures, although each follows the basic concept shown on Figure 2-1.

Vertical lamp modules typically contain 28 lamps. A schematic is provided on Figure 2-2. The quartz sleeves are closed at the lower end and open in the

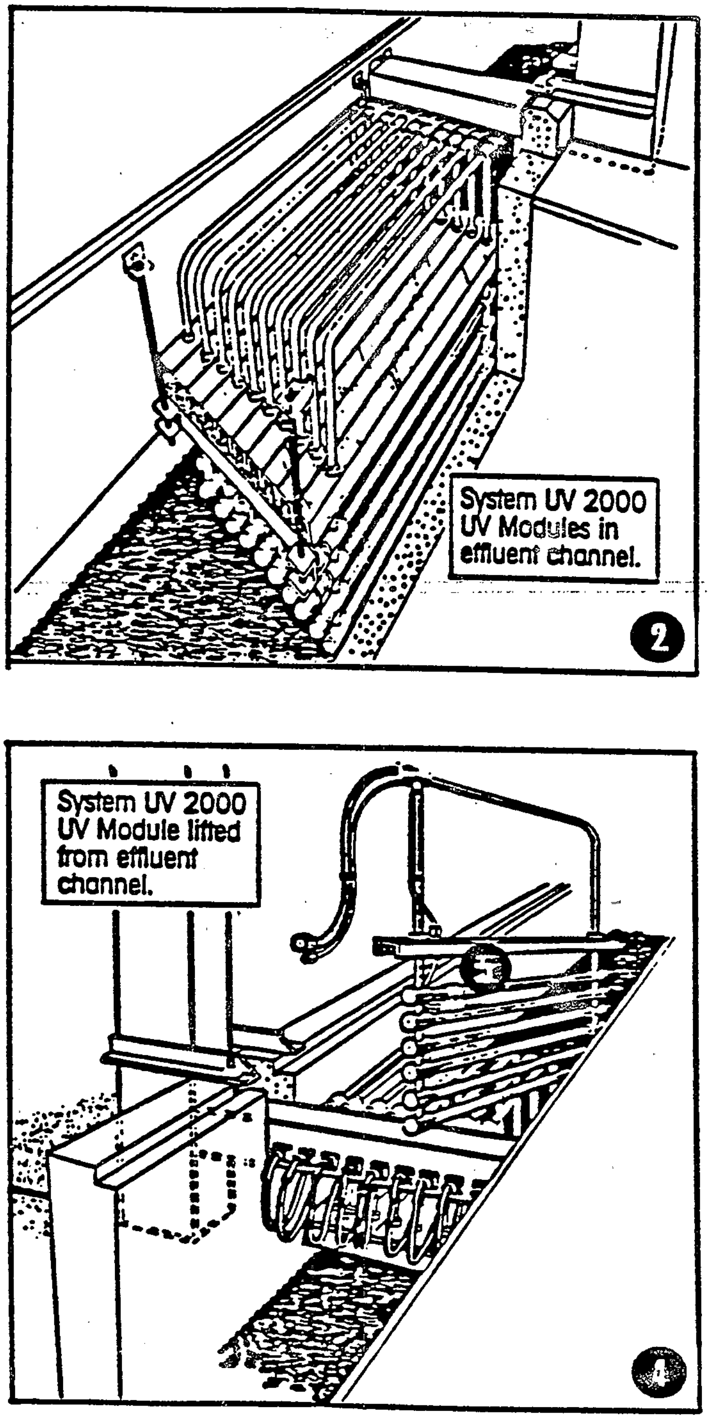


Figure 2-1 Schematic of Open Channel, Modular UV System
Using Horizontally Placed Lamps
(Courtesy of Trojan Technologies, Inc. London, Ontario, Canada)

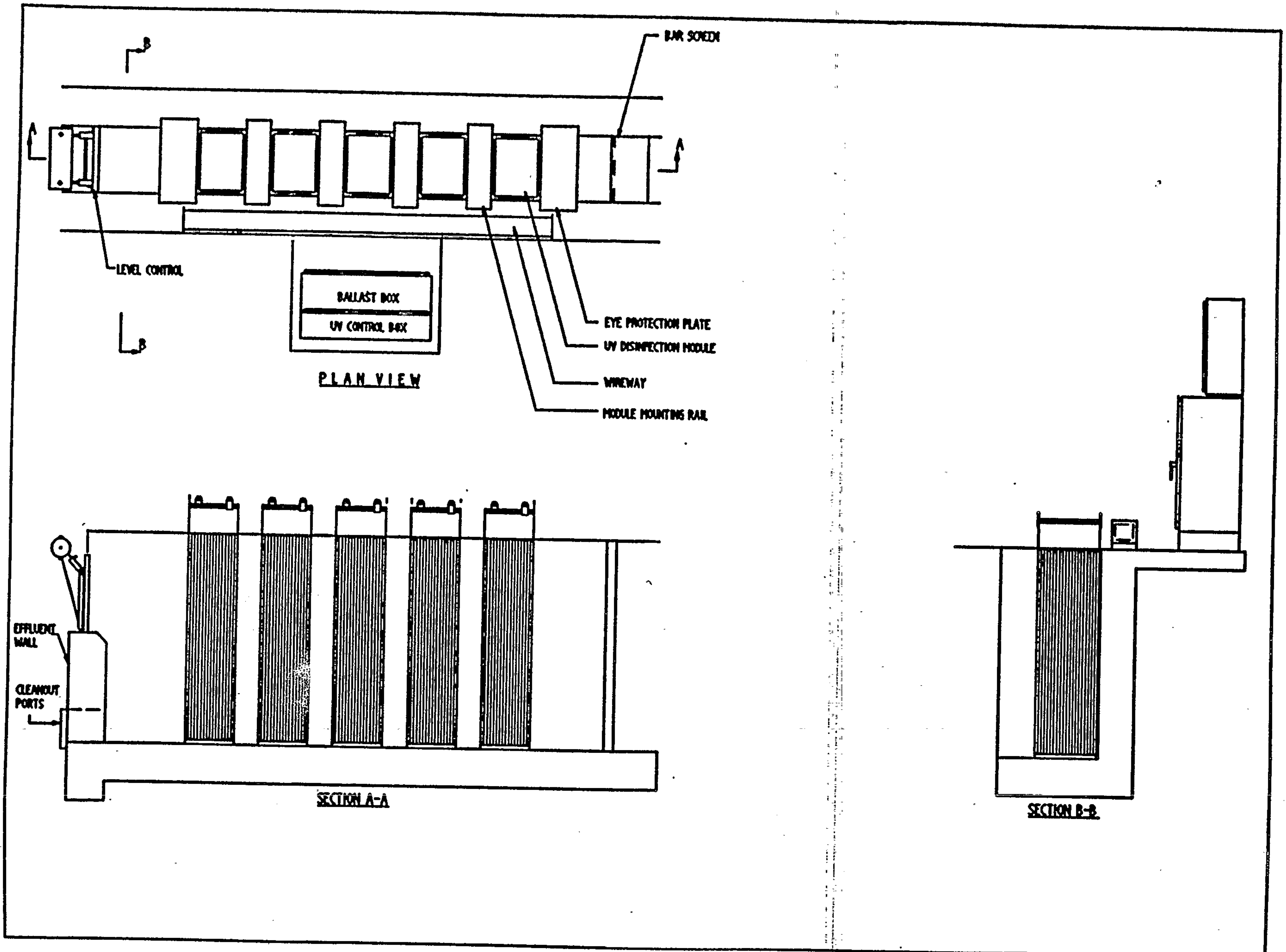


Figure 2-2 Typical Single Channel UV Disinfection Equipment Layout (Courtesy of Katadyn Systems, Inc., Bedford Hills, N.Y.)

access box at the top. The lamps can be slipped in and out of the quartz by opening the box, and are either 36 inch or 64 inch; the majority of vertical lamp systems used the longer lamps. The quartz are secured at the bottom by a grid box with rubber grommets to hold the quartz sleeve in place.

2.2 UV SYSTEMS IN THE UNITED STATES

Table 2-1 presents the number of UV systems operating in the U.S. by region and state. This list was complied from existing records and manufacturers lists. It is not all-inclusive, although it is likely within 50 to 100 plants of the total though 1990. The purpose is to show the extent of systems and the trend of installation through the country. There are also an estimated 100 to 200 facilities in the planning, design/construct phase.

The total number of plants listed is 424; the actual number of facilities under a complete census is likely between 500 and 600 facilities. UV systems are noted for 42 of the 50 states. As indicated by Table 2-1 the major fraction of operating facilities is in the eastern portion of the country. Regions 1 through 5 comprise approximately 70 percent of the systems. Region 3 has the most facilities, dominated by Maryland, Virginia and West Virginia. UV applications are least prevalent in the western regions of the country.

2.3 TYPES OF SYSTEMS

Table 2-2 gives the distribution of the various configurations operating within the United States. This also shows a similar analysis conducted in 1984(1). In the 6 years since, the number of operating plants has increased ten-fold.

In 1984, a survey identified 53 operating plants. Most were small; 80 percent had design flows less than 1 mgd. Nearly a third were the non-contact teflon units and half were closed shell reactors. The remainder were open-channel designs, but only one of these used a modular approach.

TABLE 2-1. UV SYSTEMS IN THE UNITED STATES

Region	Number of Operating Plants
Region 1: 23 facilities	
Connecticut	5
Massachusetts	3
Maine	4
New Hampshire	4
Vermont	7
Region 2: 38 facilities	
New Jersey	12
New York	26
Region 3: 98 facilities	
Delaware	4
Maryland	30
Pennsylvania	13
Virginia	21
West Virginia	30
Region 4: 44 facilities	
Alabama	11
Florida	1
Georgia	3
Kentucky	6
Mississippi	5
North Carolina	12
South Carolina	3
Tennessee	3
Region 5: 86 facilities	
Illinois	2
Indiana	15
Michigan	22
Minnesota	6
Ohio	20
Wisconsin	19
Region 6: 50 facilities	
Arkansas	19
Louisiana	10
Oklahoma	9
Texas	2

TABLE 2-1. UV SYSTEMS IN THE UNITED STATES (Continued)

	Number of Operating Plants
Region 7: 44 facilities	
Iowa	9
Kansas	4
Missouri	29
Nebraska	2
Region 8: 25 facilities	
Colorado	7
Montana	6
Utah	6
Wyoming	6
Region 9: 7 facilities	
Arizona	5
California	2
Region 10: 9 facilities	
Alaska	1
Idaho	8

TABLE 2-2. STATUS OF UV APPLICATIONS TO WASTEWATER

Year	1984	1990
Number of Plants	50 to 60	500 to 600
Flows < 1.0 mgd	80%	50%
1-20 mgd	20%	47%
> 20	-	3%
Closed Shell	49%	25%
Teflon	35%	7%
Open Channel	8%	66%
Horizontal	(100%)	(85%)
Vertical	-	(15%)
Other	8%	2%

In 1990, with a ten-fold increase in plants, there were more larger plants. Approximately half have design flows greater than 1 mgd, with several greater than 20 mgd. No new Teflon systems are being installed; these represent only approximately seven percent of the operating plants. Closed-shells systems are being installed at a low rate, with very few being considered for new applications. Approximately, 25 percent of operating systems are closed shell configurations. A small number of plants (two percent) comprise other designs, including the older fixed open-channel units and the new medium pressure (four systems) or alternate lamp systems.

The field is now dominated by the modular open-channel designs, comprising approximately two-thirds of operating systems. Nearly all new installations use these configurations. Approximately 85 percent of these systems utilize the horizontal lamp modules.

SECTION 3.

EVALUATION OF SELECTED OPERATING UV DISINFECTION FACILITIES

A total of 30 plants were selected for a detailed assessment of their design, operation and maintenance. Only those with open-channel configurations were chosen, in keeping with the focus of this evaluation. A random selection was made, constrained by the desire to have plants of varying size, alternate system designs, and representation by several manufacturers. The information was compiled through the summer of 1990 on the basis of supplier data and direct contact with the plant owner, operator, and/or engineer. The thirty plants are identified by their location:

Alabama	Athens Ozark Waldron
Colorado	Gunnison
Delaware	Bridgewater
Indiana	East Chicago
Kansas	Olathe
Kentucky	Cave City
Maryland	Edgewater Jessup Clearsprings
Louisiana	Abbeville Olla
New Hampshire	Hanover
New Jersey	New Providence
Oklahoma	Okmulgee Dewey Owasso
Pennsylvania	Highspire Willow Grove Warminster

Tennessee	Collierville
Virginia	Accomac Stoney Creek
West Virginia	Petersburg White Sulphur Springs Williamson

3.1 DESIGN AND PERFORMANCE OF THE SELECTED PLANTS

The following discussions present an overview of the selected plants with respect to their size, the type of treatment processes they use, and a description of the type and size of the UV systems. The actual performance of the plants relative to their permit requirements is then presented.

3.1.1 Description of the Selected Plants with Open-Channel UV Systems

Table 3-1 lists the selected plants, the facility contact, a summary of the treatment plant unit operations, and the type of UV disinfection system used by the facility. The flow rating is shown on the basis of peak design, average design and current average flow. Note that UV systems are generally designed on the basis of peak flow. The average design flow ranges from 0.2 mgd (Clearsprings) to 15.0 mgd (East Chicago). The ratio of the peak design to average design flow rate is typically between 1.5 and 3.0. The highest ratio is at Olathe (4.0). Two plants (Dakota City and Jessup) have flow equalization. The lower ratios are generally associated with the smaller plants.

Eleven of the selected plants have design average flows of 1.0 mgd or less. For convenience, these are separated to Group A:

Waldron	Leadwood
Bridgeville	Olla
Dakota City	Dewey
Cave City	Stoney Creek
Edgewater	Petersburg
Clearsprings	

TABLE 3-1. DESCRIPTION OF SELECTED PLANTS WITH OPEN-CHANNEL UV SYSTEMS

Plant	Contact/ Telephone No.	Flow (mgd)[a] Design Peak Design Avg Current Avg	Treatment: Preliminary/ Primary	Treatment: Secondary	Treatment: Advanced	UV Disinfection: Type	UV Disinfection: Supplier	UV Disinfection: Startup Year	UV Disinfection: Comments
Group A: Average Design Flow ≤1.0 mgd									
1. Waldron, AL	James Kimmons (501) 637-4828	1.2 1.0 0.8 (80%)	Bar Screen	Extended Aeration (Oxidation Ditch)	Sand Filtration	OC-H New	Trojan	1988	Flooding at 1.5 mgd (high I/I)
2. Bridgeville, DE	John Lascomb (302) 337-7843	1.2 0.8 0.2 (25%)	Screen Grit Removal	RBC	Sand Filtration	OC-H New	Arlat	9/88	Dissatisfied with high O&M costs
3. Dakota City, IA	Dan Hansen (515) 332-1023	0.3 (Avg) 0.25 (Current 83%)	Flow Equaliz. Bar Screen Grit Removal	Extended Aeration	Nitrification	OC-V New	Ultradyn	9/89	Has mechanical wiper
4. Cave City, KY	Steve Jolly (502) 773-2416	1.5 0.6 0.3 (50%)	Bar Screen Grit Chamber	Oxidation Ditch	Nitrification	OC-H New	F and P	2/90	Sludge Age 45-90 days
5. Edgewater, MD	Greg Schwartz (301) 956-2939								Constructed Wetlands/Total land treatment UV applied intermediate and final at process location
(Mayo #1)		0.5 (Des. Avg) 0.08 (Current Avg) (16%)		Sand Filtration Emergent Wetland/ Marsh	Nitrification Denitrification	OC-H New	Trojan	3/89	
(Mayo #2)		0.5 (Des. Avg) 0.08 (Current Avg) (16%)	Mayo #1[b]	Peat Wetland	Phosphorus	OC-H New	Trojan	3/83	
6. Clearsprings, MD	William Dean (301) 842-2672	0.4 0.2 0.1 (50%)	None	Oxidation Ditch	Filtration Post Aeration	OC-H Retrofit	Trojan	1987	System rebuilt in 8/88 10-15 day sludge age
7. Leadwood, MO	Carl Scott (314) 562-7082	1.5 0.5 0.15 (30%)	Grinder Pump	Extended Aeration (oxidation ditch)	None	OC-H New	Trojan	5/87	Sludge age ~ 20-30 days
8. Olla, LA	Jack Gough (318) 495-5151	0.3 (Des. Avg) 0.3 (Current Avg) (100%)	None	Aquaculture Pond (Water Hyacinths)	None	OC-H New	Katadyn	10/89	
9. Dewey, OK	Bobby McGonigal (918) 534-2847	1.1 0.4 0.22 (55%)	Bar Screen Grinder Pump	Oxidation Ditch	None	OC-H New	Trojan	3/88	
10. Stoney Creek, VA	Rodney McClair (703) 856-2741	1.5 0.6 0.35 (60%)	Screening	Activated Sludge	Post Aeration	OC-V New	Katadyn	8/88	
11. Petersburg, WV	Lloyd Brightwell (304) 257-1127	1.8 0.6 0.4 - 0.6 (83%)	Comminuter Bar Screen Grit Chamber	Oxidation Ditch	None	OC-H New	Trojan	9/87	

a() denotes current average flow as a percent of the design average capacity
b flow from the May 1 plant enters Mayo 2

TABLE 3-1. DESCRIPTION OF SELECTED PLANTS WITH OPEN-CHANNEL UV SYSTEMS (Continued)

Plant	Contact/ Telephone No.	Flow (mgd)[a] Design Peak Design Avg Current Avg	Treatment: Preliminary/ Primary	Treatment: Secondary	Treatment: Advanced	UV Disinfection: Type	UV Disinfection: Supplier	UV Disinfection: Startup Year	UV Disinfection: Comments
Group B: Average Design Flow >1.0, <3.0 mgd									
12. Ozark, AL	Joe Wainwright (205) 774-8447	5.25 2.1 0.9 (43%)	Screens Grit chamber	2 stage Trickling Filtration	Nitrification Post Aeration	OC-V New	Katadyn	7/87	Flooding of UV system at 3.5 mgd
13. Jessup, MD	Luther Imller (301) 799-7339	1.6 (Des. Avg) 1.1 (Current Avg) (70%)	Flow Equaliz. Primary Clar.	Act Sludge Nitrification and Denitrification	Filtration	OC-H New	Trojan	5/88	30-day sludge age
14. Lebanon, MO	Scott Schumate (417) 532-2156	3.5 2.3 2.1 (91%)	Comminuter	Oxidation Ditch	Filtration	OC-H Retrofit	Katadyn	1/89	Serious startup problems (electrical and hydraulic) Rebuilt in 12/89. Sludge age 7-15 days
15. Abbeville, LA	Ronda Huffines (318) 898-4257	4.5 1.6 2.1 (130%)	Bar Screens Grit Chamber	Oxidation Ditch Boat Clarifier	Nitrification	OC-H New	Arlat	3/89	Sludge age 25 days, I/I problems
16. Hanover, NH	Don Elder (603) 643-2362	7.0 2.3 1.3 (57%)	Bar Screens Grit Chamber Primary Clar.	Activated Sludge	None	OC-H New	Trojan	9/88	6.5 day sludge age
17. New Providence, NJ	Dan Ranick (201) 665-1077	6.0 (2.0) 0.5 (25%)	Comminuter Primary Clar.	2 trickling filters in series	Nitrification	OC-H Retrofit	F and P	4/89	All equipment replaced by Fisher & Porter (originally supplied by Arlat)
18. Owasso, OK	Charles Nicholson (918) 272-4338	3.0 2.3 1.25 (54%)	Bar Screen Grit Removal	Oxidation Ditch	Nitrification	OC-V New	Katadyn	6/88	
19. Highspire, PA	Dennis Bailey (717) 939-6204	3.8 2.0 1.0 (50%)	Bar Screen Grit Removal Primary Clarifier	Activated Sludge	None	OC-V New	Katadyn	4/88	Sludge Age ~ 4 to 5 days
20. Accomac, VA	J. Eichelberger (804) 787-2700 (804) 787-5210	2.9 2.35 2.2 (94%)	Static Screen Anaerobic Lagoon	Extended Aeration	Post Aeration	OC-H New	Trojan	1/87	
21. White Sulphur Springs, WV	Bob Pack (304) 536-3416	4.0 1.6 1.1 (70%)	Grit Removal Mechanical Screens	Extended Aeration	None	OC-H New	Trojan	1/89	
22. Williamson, WV	Earl Duba (304) 235-3719	(5.0) 3.0 1.0 (33%)	Comminuter Grit Removal	Contact Stabilization	Step Aeration	OC-H New	Arlat	10/87	

TABLE 3-1. DESCRIPTION OF SELECTED PLANTS WITH OPEN-CHANNEL UV SYSTEMS (Continued)

Plant	Contact/ Telephone No.	Flow (mgd)[a] Design Peak Design Avg Current Avg	Treatment: Preliminary/ Primary	Treatment: Secondary	Treatment: Advanced	UV Disinfection: Type	UV Disinfection: Supplier	UV Disinfection: Startup Year	UV Disinfection: Comments
Group C: Average Design Flow >3.0 mgd									
23. Athens, AL	John Custed (205) 233-8774	13.0 7.0 6.75(96%)	Bar Screen Aer. grit chamber Primary Clarifier	Trickling Filter Clarifier Activated Sludge (Oxidation Ditch)	Nitrification	OC-H New	Trojan	10/88	
24. Gunnison, CO	Don Allred (303) 641-6416	6.7 4.2 1.0 (24%)	Bar Screen Grit Removal	Extended Aeration (Oxidation Ditch)	None	OC-V New	Katadyn	9/87	3rd Channel constructed at later date, 2 channels unable to affect kill.
25. East Chicago, IN	Peter Baranyan (219) 391-8466 13.8 (92%)	36 15 13.8 (92%)	Bar Screen Grit Removal	Oxidation Ditch	Filtration	OC-H Retrofit	Katadyn	3/89	30 day sludge age
26. Olathe, KS	Tim Kurkowski (915) 764-0648	25 6.4 1.7 (27%)	Bar Screen Grit Chamber Primary Clarifier	2-stage Trickling Filter	Post Aeration Nitrification	OC-H Retrofit	Trojan	6/88	Startup problems in level control-adjusted weight setting
27. Okmulgee, OK	Tim Boone (918) 756-2740	( ) 5.0 Des. Avg 2.7 (54%)	Bar Screen Grit Removal	ABF (Biological Filters), Extended aeration activated sludge	2 Stage Nitrification	OC-V New	Katadyn	2/89	Sludge age 15 days, Seasonal nitrification
28. Willow Grove, PA	John Gehris (215) 659-1463	17.5 7.0 6.9 (98%)	Bar Screen Grinder Grit Removal Primary Clarifier	Single Step Nitrification/ Extended Aeration	Nitrification	OC-H Retrofit	Trojan	11/88	
29. Warminster, PA	Ron Frickler (215) 675-6113	16.0 8.1 5.5 (62%)	Bar Screen/Shred Grit Removal Primary Clarifier	Modified Aeration	Phosphorus and Ammonia	OC-H Retrofit	Trojan	1988	
30. Collierville, TN	Terry Williams	7.0 3.5 1.8 (51%)	Bar Screens Grit Removal	Extended Aeration, Oxidation Ditch	None	OC-V Retrofit	Katadyn	1/88	Sludge age 18-20 days

All of these accomplish nitrification a minimum, with tertiary filtration at three of the plants (Waldron, Bridgeville, and Clearsprings). Except for two of these smaller plants, they use oxidation ditch/extended aeration activated sludge treatment technologies. The two are the Edgewater plant (wetlands) and Olla (aquaculture pond for water hyacinths). Except for the Edgewater and Clearspring plants all practice some form of screening and grit removal upstream of the biological system. Note that the Edgewater plant has UV disinfection at an intermediate point and at the final effluent in the constructed wetlands system.

The UV systems for these smaller plants were started in 1987 or later, with the most recent startup in 1990 for the Cave City plant. Only one was a retrofit (Clearsprings). Two of the plants (Dakota City and Stoney Creek) use the vertical lamp configuration, one of which (Dakota City) is equipped with a mechanical wiper. The others use the horizontal lamp placement configuration. The Waldron plant has had problems with flooding due to high I/I input, well above the design peak flow. Three of the plants are well under design capacity at this point: Bridgeville (25 percent), Edgewater (16 percent), and Leadwood (30 percent). Four are at approximately one-half their design capacity: Cave City, Clearsprings, Dewey and Stoney Creek. The remainder (Waldron, Dakota City, Olla and Petersburg) are at or near capacity.

Eleven of the selected plants have design average flows between 1 and 3.0 mgd (these are shown as Group B on Table 6-1):

Ozark	Owasso
Jessup	Highspire
Lebanon	Accomac
Abbeville	White Sulphur Springs
Hanover	Williamson
New Providence	

The facilities were constructed 1987 through 1989. Two were retrofits (Lebanon and New Providence). The New Providence plant was originally equipped with an Arlat system; this was replaced with equipment by Fisher and Porter in 1990. The plants all provide for nitrification; two are two-stage trickling filter plants (Ozark and New Providence) and the rest are oxidation ditch and/or extended aeration configurations of the activated sludge process. Two of these have tertiary filtration (Jessup and Lebanon).

Three of the UV systems use the vertical lamp configuration (Ozark, Owasso and Highspire). The Ozark units have hydraulic problems, with flooding occurring at flows greater than 3.5 mgd, which is still well below the peak design flow of 5.25 mgd. The Lebanon plant had serious startup problems relating to electrical and hydraulic design; the units were subsequently rebuilt in late 1989. Except for the New Providence plant (25 percent) these plants are at or above 50 percent of their average design flow capacity. Due to high I/I conditions, the Abbeville plant experiences flow greater than design.

The remaining eight plants (Group C) have design flows greater than 3.0 mgd, with the largest being East Chicago (15 mgd):

Athens	Okmulgee
Gunnison	Willow Grove
East Chicago	Warminster
Olathe	Collierville

The plants all have nitrification capabilities using extended aeration activated sludge systems, except Athens, Olathe and Okmulgee which have two stage fixed-film or fixed-film/activated sludge configurations. Five of the eight UV systems are retrofitted into the old chlorine contact chambers. Three (Athens, Gunnison and Okmulgee) are new systems. All were installed 1987 through 1989; three are vertical lamp units (Gunnison, Okmulgee and Collierville). Note that in Gunnison a third channel had to be added when the two existing channels were unable to meet effluent limits. There was a problem with the level control gate at Olathe during startup; this was corrected by adjustment of the weights on the mechanical gate. Two of these plants are well below their design capacity: Gunnison and Olathe (approximately 25 percent), while three (East Chicago, Willow Grove, and Athens) are greater than 90 percent of their design capacity. The remaining 3 are near the 50 percent capacity point.

Overall, of the 30 plants selected for evaluation, all are designed to treat to nitrification levels at a minimum, and several have tertiary filtration. These conditions suggest that, in general, the facilities using UV have advanced secondary or tertiary processes, yielding effluents that are especially conducive to the application of UV. Eight of the plants use the vertical lamp configuration, somewhat higher in proportion to the horizontal configuration than is apparent in the overall census. Eight of the 30 are facilities that have retrofitted their UV systems into existing chlorine contact chambers, a procedure that is becoming popular with larger facilities, and plants that are being upgraded.

Generally, the plants vary in their capacity relative to design. About a third each are at approximately 25 percent, 50 percent, or 100 percent of their design capacity.

3.1.2 Description of the UV Systems at the Selected Plants

Table 3-2 is a summary of the UV installations at each of the selected plants. This is divided into the same groupings as shown on Table 3-1. The descriptors include the type of configuration, the number of channels and banks of lamps (that are placed in series in a given channel), the design flow per channel and the level of redundancy. The next three columns give the number of modules and lamps per channel, the size lamps that are used, and the total size of the system with respect to the number of lamps and the equivalent UV output at 253.7 nm. The lamps are 1.47m (58 inch) or 0.76m (30 inch) in size. Several ratios are then given to compare and assess the sizing characteristics of each plant. These include the ratios of flow per lamp and the flow per killowatt (kW) in units of gpm and Lpm per kW, based on the peak design flow.

All of the smaller plants (Group A) are designed with one channel. Of the two vertical lamp systems, the Dakota City plant has one bank of modules and the Stoney Creek is divided into four banks in series. Three of the plants with horizontal configurations have only one bank of lamps (Clearsprings, Leadwood, and Dewey), effectively precluding standby and flexibility for shutdowns and repair. The remaining six smaller plants have two banks in

TABLE 3-2. DESCRIPTION OF UV SYSTEMS AT SELECTED PLANTS

Plant	Type	Number of Channels	Number of Banks	Design Peak Flow per Channel	Redundancy At Peak %	No. of Modules Per Channel	No. of Lamps per Channel/Arc Size	Total* Number of Lamps/ Total KW_{UV}	Ratio Peak Q per Lamp (gpm/lamp)	Ratio Peak Q per UV power (mgd/KW_{UV})	Ratio Peak Q per UV Watt (Lpm/W_n)	Comments
Group A: Average Design Flow ≤1.0 mgd												
1. Waldron, AL	OC-H	1	2	1.2 (each bank)	100.0	14	56 58"	56 1.5	29.8	1.58	4.42	Each bank designed for maximum flow
2. Bridgeville, DE	OC-V	1	2	1.2	0%	20	120 58"	120 3.2	6.9	0.38	0.98	Full system (2 banks) at peak flow. High cost, $200/lamp and quartz
3. Dakota City, IA	OC-V	1	1	0.3	0%	1	38 30"	38 0.5	5.48	0.6	1.54	Full system on at all times
4. Cave City, KY	OC-H	1	2	1.5	0%	16	64 58"	64 1.7	16.3	0.88	2.31	Have Cl_2 as backup (haven't used it). Module leaks/kicks out breakers. One bank normally operated.
5. Edgewater, MD (Mayo #1)	OC-H	1	2	0.5	0%	5	40 58"	40 1.07	8.7	0.47	1.23	Two systems: before and after peat wetland
(Mayo #2)	OC-H	1	2	0.5	0%	10	80 58"	80 2.14	4.35	0.24	0.61	
6. Clearsprings, MD	OC-H	1	1	0.4	0%	8	32 58"	32 0.85	8.7	0.47	1.23	Full system in operation; no standby
7. Leadwood, MO	OC-H	1	1	1.5	0%	6	24 30"	24 0.32	43.4	5.0	12.0	Full system in operation; no standby
8. Olla, LA	OC-H	1	2	0.5/bank	100%	1	72 58"	72 1.9	19.3	1.12	2.73	1 bank designed for full flow
9. Dewey, OK	OC-H	1	1	1.1	0	6	48 58"	48 1.3	15.9	0.86	2.26	minor electrical problems; corrected
10. Stoney Creek, VA	OC-V	1	4	1.5	0	28	112 30	112 1.5	9.30	1.0	2.61	Minor electrical problems corrected
11. Petersburg, WV	OC-H	1	2	1.8/bank	100%	20	80 58"	80 2.1	31.2	1.69	4.44	Minor hydraulic problems corrected
Group B: Average Design Flow >1.0, <3.0 mgd												
12. Ozark, AL	OC-V	2	-	2.63	0%	6	168 30"	336 4.54	10.9	1.16	3.05	-
13. Jessup, MD	OC-H	1	2	1.6	100%	12	72 30"	72 0.97	30.8	1.65	8.55	One bank in operation at all times; 1 standby

*Based on 26.7 Watts/58" Arc and 13.5 Watts/30" Arc (at 253.7 nm)

TABLE 3-2. DESCRIPTION OF UV SYSTEMS AT SELECTED PLANTS
(Continued)

Plant	Type	Number of Channels	Number of Banks	Design Peak Flow per Channel	Redundancy At Peak %	No. of Modules Per Channel	No. of Lamps per Channel/Arc Size	Total* Number of Lamps/ Total KW_{UV}	Ratio Peak Q per Lamp (gpm/lamp)	Ratio Peak Q per UV power (mgd/KW_{UV})	Ratio Peak Q per UV Watt (Lpm/W_n)	Comments
14. Lebanon, MO	OC-H	1	2	3.5	0%	20	160 58"	160 4.27	15.2	0.82	2.15	Down for 9 months due to problems; rebuilt in December 1989
15. Abbeville, LA	OC-H	1	2	4.5	0	28	196 58"	196 5.2	15.9	0.86	2.25	2 banks/first 4 lamps on all times; top 3 on with increased flow
16. Hanover, NH	OC-H	1	2	7.0	0	40	320 58"	320 8.5	15.2	0.82	2.15	Full system in operation; no standby
17. New Providence NJ	OC-H	3	2	2.0	0	18	108 58"	324 8.7	12.9	0.69	1.83	4th channel available f[illegible] equipment
18. Owasso, OK	OC-V	2	3	1.5	0	3	84 30"	168 2.3	6.2	1.32	1.74	no startup problems
19. Highspire, PA	OC-V	1	4	3.8	0	10	252 30'	252 3.4	10.5	1.11	2.93	1st bank has 7 modules; 2nd, 3rd and 4th banks have 2 modules each
20. Accomac, VA	OC-H	1	1	2.9	0	14	112 58'	112 3.0	18.0	0.96	2.54	Plant has equalization basin, still has chlorination as backup
21. White Sulphur Springs, WV	OC-H	1	2	1.6	0	22	176 58"	176 4.7	6.3	0.85	2.24	No startup problems
22. Williamson, WV	OC-H	1	1	3.0	0	20	120 58"	120 3.2	17.4	0.93	2.46	Major hydraulic problems during first 18 months of operation - corrected
Group C: Average Design Flow >3.0 mgd												
23. Athens, AL	OC-H	1	2	13.0 (each bank)	100.0	36	576 58"	576 15.4	31.4	1.68	4.46	Each bank designed for maximum flow
24. Gunnison, CO	OC-V	3	2	2.24	0%	6	168 30"	504 6.8	9.23	0.98	2.6	3 channels for peak flow; normally 2 channels in operation
25. East Chicago, IN	OC-H	2	2	18	0%	82	656 58"	1312 35.0	19.0	1.03	2.7	Second bank on after 16 mgd
26. Olathe, KS	OC-H	2	2	12.5	0%	18	144 58"	288 7.7	30.1	3.25	4.27	Full system at peak Q. Normal (<3.4 mgd): 1 bank on

TABLE 3-2. DESCRIPTION OF UV SYSTEMS AT SELECTED PLANTS
(Continued)

Plant	Type	Number of Channels	Number of Banks	Design Peak Flow per Channel	Redundancy At Peak %	No. of Modules Per Channel	No. of Lamps per Channel/Arc Size	Total* Number of Lamps/ Total KW_{UV}	Ratio Peak Q per Lamp (gpm/lamp)	Ratio Peak Q per UV power (mgd/KW_{UV})	Ratio Peak Q per UV Watt (Lpm/W_n)	Comments
27. Okmulgee, OK	OC-V	2	3	2.5	0	7	196 30"	394 5.3	4.4	0.47	1.23	startup problems with venting panels and effluent gate - corrected
28. Willow Grove, PA	OC-H	1	2	17.5	0	96	768 58"	768 20.5	15.8	0.85	2.24	UV system was retrofitted in the chlorine contact tank
29. Warminster, PA	OC-H	1	2	16.0	0	44	352 58'	704 18.8	15.8	0.85	2.23	Electrical problems mostly corrected, flooding conditions due to poor hydraulic design - corrected
30. Collierville, TN	OC-V	2	4	3.5	0	4	112 58"	224 6.0	21.7	1.17	3.07	No startup problem

series, three of which (Waldron, Olla, and Petersburg) are sized such that a single bank will disinfect at peak flow (100 percent redundancy). Having at least two banks allows for shutdown/repair of one bank, while still maintaining disinfection capabilities. Channel repairs are not possible without bypassing, given only one channel; disinfection would not be possible under these bypassing circumstances.

The design loadings vary from 0.38 mgd per kW (Bridgeville) to 5.0 mgd per kW (Leadwood). The higher value appears to be an aberration; the loading values typically fall between 0.4 and 1.7. The average was 1.27 mgd per kW, or 0.91 mgd per kW without the Leadwood plant. This is also equivalent to 1.1 kW/mgd. The last column lists the loading in terms of the rated flow per unit UV watt; this averaged (without the Leadwood plant) approximately 2.4 Lpm per UV Watt. Note that the power ratings are based on rated nominal UV (at 253.7 um) output for low pressure mercury arc lamps; this is 26.7 watts per 1.47 m lamp and 13.5 watts per 0.75 m lamp.

Several plants in this group experienced minor electrical problems, primarily during startup, which were eventually corrected. The Bridgeville operators complained of high costs associated with the lamps and quartz replacements. This is a system installed by Arlat that requires shipment of the modules back to the factory for replacement of the parts, effectively at a rate of approximately $200 per lamp. This is excessive, and is not comparable to any of the other manufacturers. The Cave City plant has a backup chlorination unit in the case of UV failure; they have not had to use it to date. Note that there were some difficulties with the quartz/lamp seals to the module frames, resulting in leakage and kickout of the respective breaker. This has been corrected by the manufacturer.

The moderate sized plants in Group B also are primarily limited to a single channel to handle peak flow. Three of the 11 have 2 or more channels (Ozark, New Providence, and Owasso). Only Jessup has redundancy, whereby one of the two banks is capable of handling the peak condition. Each plant except for Accomac and Williamson has two or more banks within a channel that are operated according to flow. The Accomac plant has equalization and is equipped with a backup chlorination unit. The Williamson plant has a unit that allows for variable water levels in the channel; with increasing flow (and level), additional rows of lamps are activated. This unit had serious hydraulic problems of mixing and shortcircuiting caused by improperly designed upstream baffles. These were replaced by an upstream stilling plate that corrected the problem and allowed the plant to be in compliance. The Lebanon plant had to be rebuilt due to electrical problems and excessive lamp failures. The channel was also modified to correct upstream flooding problems. Brought back on-line in late 1989, it has since been operating successfully.

The system sizing for these plants appears to be more consistent than observed for the smaller plants. The range is between 0.7 and 1.65 mgd per kW, with an average of 1.0 mgd/kW. This is equivalent to a loading of 2.6 Lpm/W.

The third grouping, comprising plants with design average flows of greater than 3.0 mgd, have systems with one to three channels. Three of the plants have only one channel. These are Athens, Willow Grove and Warminster; Athens is designed to have one of its two lamp banks fully redundant under peak loading. Note that Willow Grove and Warminster are both retrofits. The remaining plants have two channels, except for Gunnison, which has three. The horizontal lamp units all have two banks in series in each channel; the vertical lamp units vary from two to four banks in series. Problems were noted at two of the plants (Okmulgee and Warminster) relating to electrical and hydraulic difficulties; these were corrected.

The size of the systems range between 0.5 and 1.68 mgd/kW, except for Olathe which is designed at a loading of 3.25 mgd/kW. Similar to the Leadwood plant in Group A, the Olathe plant is an outlier. Both plants have high peak to average flow ratios (4.0 and 3.0 for Olathe and Leadwood, respectively), which likely means that the systems were designed for a value less than peak (e.g. 7-day average) for disinfection purposes. Without Olathe, the average design loading is 1.0 mgd/kW. This is equivalent to 2.6 Lpm/W.

Overall, the selected plants show a certain consistency in their configurations. One to three channels are used, with a single channel in the smaller plants and the multiple channels found with the larger plants. Most of the larger systems have some flexibility in operating banks of lamps within the channel, although this is not always the case. Redundancy to any degree is not typical; only 5 of the 30 plants have redundant systems, and 4 of these are with the smaller plants. Flexibility appears to be limited, with little ability to isolate a portion of the system for repair or replacement. Bypasses were not evident with most plants, suggesting a difficulty with repairing/shutting down channels when only one channel exists.

Sizing of the units appears to be relatively consistent, falling between 0.5 and 1.7 mgd/kW, with an average essentially equivalent to 1.0 mgd/kW. This is demonstrated in Figure 3-1, which presents the peak design flow of the plant as a function of the total UV power (kW at 253.7 nm) of the UV system. There is some scatter, particularly with the outliers discussed earlier (Leadwood and Olathe), but the slope of the relationship closely approximates 1.0. Thus, a rough sizing estimate can be made for a given plant by assuming 1 kW of UV output for each mgd of peak design flow. This would be for advanced secondary plants, and peak to average flow ratios less than 2.5. The 1.0 kW is the nominal UV output, equivalent to approximately 37 long lamps (1.47 m or 58 inch arc length) or 74 short lamps (0.75 m or 30 inch arc length). Such an approximation should only be used in screening type assessments and should not serve as a final design sizing parameter. Note also that redundancy or standby capabilities would be added to this estimate.

3.1.3 Summary of Performance and Permit Requirements at the Selected Plants

Table 3-3 presents permit and effluent data for each of the selected plants. The UV system is first reiterated in terms of type, size, and year of startup. The permit requirements are then summarized with respect to the BOD, TSS, nitrogen, and bacterial limits. The current quality of the effluents is then summarized, addressing these four parameters. Note that these data reflect the six months prior to the summer of 1990. If appropriate, the permit description includes seasonal requirements, particularly with respect to nitrogen control and disinfection.

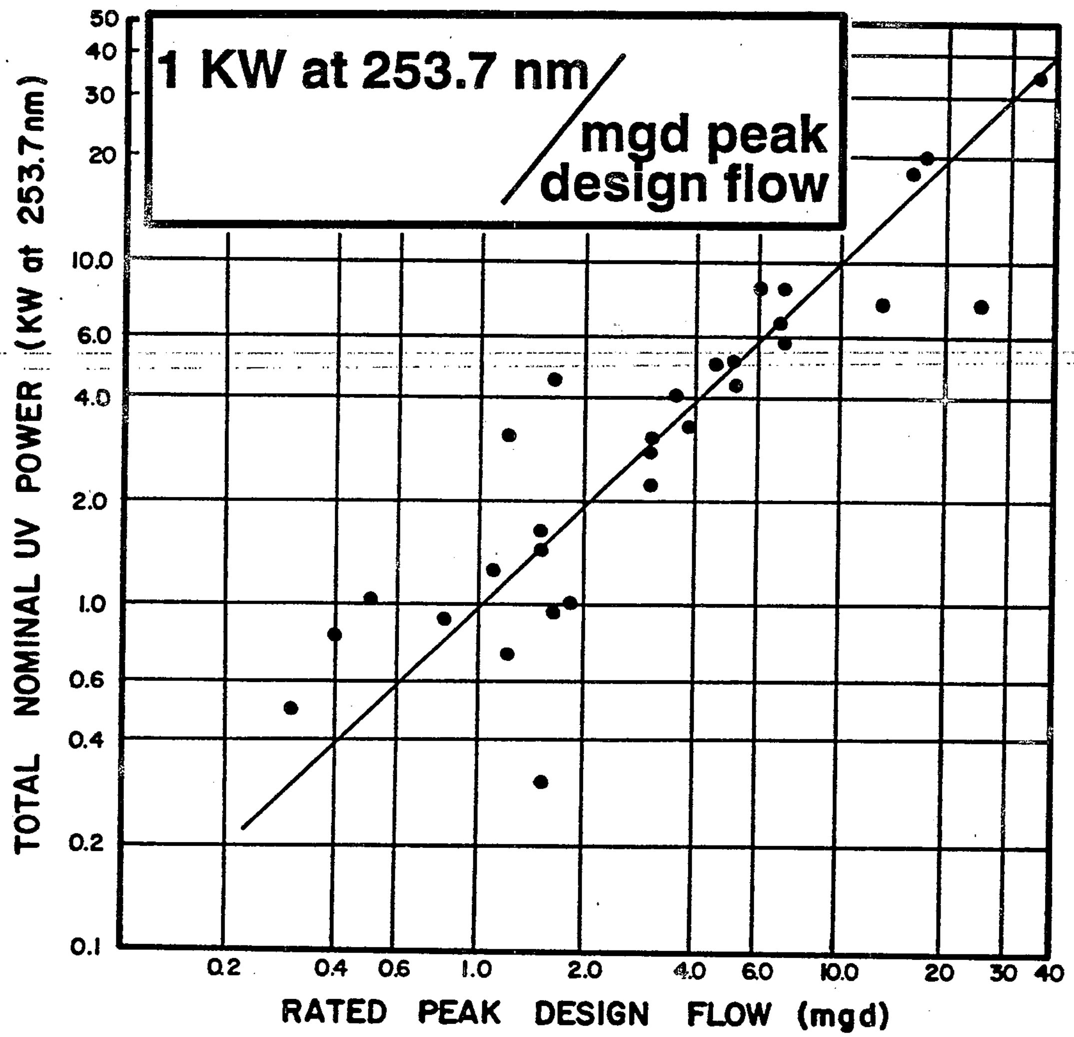


Figure 3-1
UV System Sizing for Selected Plants as a Function of Peak Design Flow

TABLE 3-3. SUMMARY OF PERMIT REQUIREMENTS AND PERFORMANCE AT SELECTED PLANTS

Plant	UV System Type No. of Lamps Startup	Permit BOD (mg/L)	Permit TSS (mg/L)	Permit NH_3-N (mg/L)	Permit Bacterial ($100mL^{-1}$)	Current (Average) BOD (mg/L)	Current (Average) TSS (mg/L)	Current (Average) NH_3-N (mg/L)	Current (Average) Bacterial ($100\ mL^{-1}$)	Comments
Group A: Average Design Flow ≤ 1.0 mgd										
1. Waldron, AR	OC-H 56 1987	22 (7d) 15 (30d)	45 (7d) 30 (30d)	3.0 (7d) 2.0 (30d)	No limit					
2. Bridgeville, DE	OC-H 120 1988	45 (7d) 30 (30d)	30 (7d) 15 (30d)	June - Oct TKN 9 (30d)	Fecal Coliform 200 (30d)	6.1	3.7	TKN 3.8 (30d) (June - Oct)	25 Fecal Coliform	Seasonal Nitrification; Preference for Cl_2 or Br_2 due to costs
3. Dakota City, IA	OC-V 38 1989	45 (7d) 25 (30d)	45 (7d) 30 (30d)	-	Fecal Coliform 200 (30d)	<10	13 - 15	-	160 - 180 Fecal Coliform	Seasonal Disinfection (April - Oct)
4. Cave City, KY	OC-H 64 1990	45 30	45 30		Fecal Coliform 400 (7d) 200 (30d)	5	3	-	<10 Fecal Coliform	Plant Nitrifies
5. Edgewater, MD (Mayo 1 and 2)	OC-H 120 1989	30 (7d) 20 (30d)	45 (7d) 30 (30d)	May - Oct TKN 15 (7d) 10 (30d)	Fecal Coliform 14 (30d)	6.1	4.7	TKN 0.9	1.8 Fecal Coliform	
6. Clearsprings, MD	OC-H 32 1988	30 (7d) 25 (30d)	30 (7d) 25 (30d)	Apr - Oct TKN 27 (7d) 18 (30d)	Fecal Coliform 200 (30d)	<10	<10	-	<2 Fecal Coliform	Seasonal Nitrogen Removal
7. Leadwood, MO	OC-H 24 1988	45 (7d) 30 (30d)	45 (7d) 30 (30d)	-	Fecal Coliform 400 (7d) 200 (30d)	7 - 14	4 - 10	-	<1 Fecal Coliform	Seasonal Disinfection (Apr - Oct)
8. Olla, LA	OC-H 72 1989	20 (30d)	10(30d)	-	Fecal Coliform 25 (30d)	5	0.5	-	< 1 Fecal Coliform	
9. Dewey, OK	OC-H 48 1988	20 (30d)	30 (30d)	-	Fecal Coliform 400 (7d) 200 (30d)	<20	78	-	31 Fecal Coliform	Clarifier washout causing TSS exceed-ances
10. Stoney Creek, VA	OC-V 112 1988	Summer 13 (30d) Winter 30 (30d)	30 (30d)	-	Fecal Coliform 400 (7d) 200 (30d)	4	5	-	10 - 40 Fecal Coliform	
11. Petersburg, WV	OC-H 80 1987	30 (30d)	30 (30d)	15 (30d)	Fecal Coliform 200 (30d)	<10	<10	<0.01	<20 Fecal Coliform	

TABLE 3-3. SUMMARY OF PERMIT REQUIREMENTS AND PERFORMANCE AT SELECTED PLANTS (Continued)

Plant	UV System Type No. of Lamps Startup	Permit BOD (mg/L)	Permit TSS (mg/L)	Permit NH_3-N (mg/L)	Permit Bacterial ($100mL^{-1}$)	Current (Average) BOD (mg/L)	Current (Average) TSS (mg/L)	Current (Average) NH_3-N (mg/L)	Current (Average) Bacterial ($100\ mL^{-1}$)	Comments
Group B: Average Design Flow >1.0, <3.0 mgd										
12. Ozark, AL	OC-V 336 1987	Apr - Oct 45 (7d) 25 (30d) Nov - Mar 45 (7d) 35 (30d)	37.5 (7d) 25 (30d) Apr - Oct 45 (7d) 45 (30d)	Apr - Oct 7.5 (7d) 5.0 (30d) Nov - Mar No limits	Year-round Fecal Coliform 2,000 (7d) 1,000 (30d)	16	20	0.4 (when 2nd stage operating)	<100 with nitrification 700-800 without nitrification	Seasonal Nitrification
13. Jessup, MD	OC-H 72 1988	Apr - Oct 26 (7d) 17 (30d)	26 (7d) 17 (30d)	TKN 4 (7d) 3 (30d)	Fecal Coliform 200 (30d)	<3	<3	<1 TKN	<4 Fecal Coliform	Seasonal Nitrogen Removal
14. Lebanon, MO	OC-H 160 1989	10 (30d)	15 (30d)	-	Fecal Coliform 400 (30d) 1,000 (daily)	-	-		-	Meeting permit
15. Abbeville, LA	OC-H 196 1989	Apr - Oct 21 (daily) 10 (30d)	Apr - Oct 21 (daily) 10 (30d)	Apr - Oct 10 (daily) 5 (30d)	Apr - Oct Fecal Coliform 400 (7d) 200 (30d)	4	8	1 - 2	<1 Fecal Coliform	Seasonal nitrification; I/I cause washout & FC exceedance
16. Hanover, NH	OC-H 320 1988	45 (7d) 30 (30d)	45 (7d) 30 (30d)	-	Total coliform 240 (not to exceed)	<30	<10	-	Total Coliform 200 - 220	Influent Coliform averages 29,000, problems with permit at higher solids
17. New Providence, NJ	OC-H 324 1989	24 (7d) 16 (30d)	24 (7d) 16 (30d)	May - Oct 6 (7d) 4 (30d)	Fecal Coliform 400 (7d) 200 (30d)	10 - 20	5 - 15	1 - 2	100 Fecal Coliform	Seasonal nitrification; variability with Eff fecal coliforms
18. Owasso, OK	OC-V 168 1988	30 (7d) 20 (30d)	45 (7d) 30 (30d)	-	Fecal Coliform 400 (7d) 200 (30d)	10	10.1	-	< 5 Fecal Coliform	-
19. Highspire, PA	OC-V 252 1988	45 (7d) 30 (30d)	45 (7d) 30 (30d)	-	Fecal Coliform 200 (30d)	<10	<10	-	30 - 40 Fecal Coliform	-
20. Accomac, VA	OC-H 112 1987	May - Oct 15 (7d) 30 (30d)	May - Oct 15 (7d) 30 (30d)	-	Fecal Coliform 200 (30d)	<10	<15	-	<100 Fecal Coliform	-
21. White Sulphur Springs, WV	OC-H 176 1989	30 (30d)	30 (30d)	15 (30d)	Fecal Coliform 200 (30d)	5 - 8	3 - 5	<1	0 - 10 Fecal Coliform	-
22. Williamson, WV	OC-H 120 1987	30 (30d)	30 (30d)	18 (30d)	Fecal Coliform 200 (30d)	15.9	11.5	-	45 Fecal Coliform	-

TABLE 3-3. SUMMARY OF PERMIT REQUIREMENTS AND PERFORMANCE AT SELECTED PLANTS (Continued)

Plant	UV System Type No. of Lamps Startup	Permit BOD (mg/L)	Permit TSS (mg/L)	Permit NH_3-N (mg/L)	Permit Bacterial ($100mL^{-1}$)	Current (Average) BOD (mg/L)	Current (Average) TSS (mg/L)	Current (Average) NH_3-N (mg/L)	Current (Average) Bacterial ($100\ mL^{-1}$)	Comments
Group C: Average Design Flow >3.0 mgd										
23. Athens, AL	OC-H 576 1988	June - Nov 25 (7d) 15 (30d) Dec - June 27 (7d) 18 (30d)	45 (7d) 30 (30d)	June - Nov 1.5 (7d) 1.0 (30d) Dec - June 7.5 (7) 5.0 (30d)	Fecal Coliform 2,000 (7d) 1,000 (30d)	8.0	13.0	2.4	Fecal Coliform 324	Seasonal Nitrification; 15-18 day sludge age; Minor hardware and wiring problems on startup
24. Gunnison, CO	OC-V 504 1987	45 (7d) 30 (30d)	45 (7d) 30 (30d)	No limit	Fecal Coliform 12,000 (7d) 6,000 (30d)	<10	<10	-	<200 Fecal Coliform	20 day sludge age
25. East Chicago, IN	OC-H 1312 1989	10.7 (7d) 7.1 (30d)	12.8 (7d) 8.5 (30d)	6 (daily) 1.5 (30d)	Apr - Oct Fecal Coliform 400 (7d) 200 (30d)	1.7	5.2	-	12 Fecal Coliform	Seasonal Disinfection Inf FC - 3,000 Avg - 17,000 Maximum
26. Olathe, KS	OC-H 288 1988	45 (7d) 30 (30d)	45 (7d) 30 (30d)	2 (summer) 6 (winter)	Fecal Coliform 400 (7d) 200 (30d)	12 - 17	6 - 12	0.8	<10 Fecal Coliform	Out of spec first 10 mos. Changed bulbs-OK now.
27. Okmulgee, OK	OC-V 394 1989	15 (7d) 10 (30d)	23 (7d) 15 (30d)	6 (7d) 4 (30d)	Fecal Coliform 400 (7 day) 200 (30 day)	<10	7 - 12	<1	<200 Fecal Coliform	-
28. Willow Grove, PA	OC-H 768 1988	May - Oct 23 (7d) 15 (30d)	45 (7d) 30 (30d)	May - Oct 3 (7d) 2 (30d)	Fecal Coliform 200 (30d)/1000 or less 10% of month	5 - 10	10	0.5	Meeting Criteria Fecal Coliform	-
29. Warminster, PA	OC-H 704 1988	May - Oct 23 (7d) 15 (30d)	45 (7d) 30 (30d)	May - Oct 0.5 (7d) 1.0 (30d)	Fecal Coliform 200 (30d)	5	<10	1.09	43 Fecal Coliform	-
30. Collierville, TN	OC-V 224 1988	40 (7d) 30 (30d)	40 (7d) 30 (30d)	-	Fecal Coliform 200 (30d)	10	4 - 10	-	3 - 10 Fecal Coliform	18 - 20 day sludge age

The permit requirements vary widely, ranging from secondary levels of BOD and TSS (i.e. 30/30) to advanced secondary with ammonia removal or some form of nitrogen control, particularly on a seasonal basis. Eighteen of the plants have requirements greater than secondary levels; almost all the plants accomplish some degree of nitrification because they are low-loaded systems (extended aeration, oxidation ditches, two-stage biosystems, etc.). This is evident from the consistently low levels of BOD and TSS (and nitrogen in cases where it is measured) in the treated effluents.

All except two plants have fecal coliforms as the primary indicator. Waldron has no limit, while the Hanover permit is written on the basis of total coliforms. The Hanover plant has a not-to-exceed total coliform limit of 240/100mL, which is restrictive and somewhat analogous to the shellfish limit of 14 fecal coliforms per 100 mL. The effluent has been close to this limit, varying between 200 and 220/100mL. The plant is at approximately 60 percent capacity and keeps both banks of lamps on in its single channel. It is not clear that the facility will be able to stay in compliance as it approaches design conditions.

The Lebanon plant must comply with a 30-day maximum average of 400 fecal coliforms/100 mL and a single point maximum of 1000 FC/100mL. The facility is meeting its requirements, and is currently at effectively full capacity. Recall from Tables 3-1 and 3-2 that this was a retrofit that had to be rebuilt in late 1989. Two plants, Edgewater and Olla, have low fecal coliform limits of 14 and 25 FC/100 mL (30-d maximum average), respectively. Each is producing a high quality effluent with fecal coliforms less than 2/100 mL.

The large majority of plants are required to meet standard secondary limits of 200/400 on a 30-d/7-d basis. All are meeting their permit requirements, although a number of plants tend to have significant effluent densities. The Dakota City plant measures fecal coliform densities only slightly less than permit, ranging between 160 and 180 FC/100 mL. It is at approximately 85 percent capacity and may require enhancement of its UV system. The New Providence plant is at only 25 percent capacity, but is measuring higher and variable levels in its effluent. Similarly, Dewey, Stoney Creek, Highspire, and Williamson are measuring elevated levels (but within limits) in the disinfected effluent.

Several plants have high permitted fecal coliforms levels. These are Athens, Gunnison and Ozark; the 30-d limit for the Gunnison plant is 6,000 FC/100 mL, while it is 1000 FC/100 mL for the other two plants. In each case, the UV systems are in compliance. At Ozark, only seasonal nitrification is required. Fecal Coliforms are typically less than 100/100ml when the plant is nitrifying, but rise to 700 to 800 FC/100mL when the plant is not nitrifying. This is due to the increased quality of the nitrified effluent, reflected by higher UV transmittances and lower initial coliform densities.

3.1.4 Design Sizing and Performance Summary for the Selected Plants

Table 3-4 is presented as a summary of the design sizing and performance record for each of the selected plants. This information is drawn from Tables 3-1, 3-2 and 3-3, and presents the size of the treatment facility, the configuration of the UV system, its size, and the quality of the effluent relative to BOD, TSS, nitrogen and coliforms. Each of the plants is generating a quality effluent and is in compliance with its permit. Those that are accomplishing a high degree of nitrification are also discharging minimal levels of coliform. In cases where the BOD and TSS levels tend to be at levels greater than 10 mg/L, the effluent coliform levels also tend to be more pronounced, with measureable densities between 10 and 200 FC/100 mL.

UV disinfection efficiency is very dependent upon the quality of the effluent generated by the upstream processes. As higher levels of treatment are accomplished, the UV process is more efficient, resulting in the need for less hardware, or providing for a greater factor of safety. Thus nitrification, denitrification, filtration and other tertiary processes that are added to conventional secondary treatment operations are particularly conducive to assuring the success of the UV process. The impact on water quality is generally represented by lower coliform densities, increased sensitivity of the bacteria to UV, and increased UV transmissibility at 253.7nm by the wastewater. An interesting observation made from this assessment was

TABLE 3-4. SUMMARY OF DESIGN SIZING/PERFORMANCE CHARACTERISTICS FOR SELECTED PLANTS

Plant	Peak Design Flow (mgd)	Peak to[h] Average Ratio	% Cap	Permit[a] Limit ($100mL^{-1}$)	UV System: Type	UV System: Number Channels	UV System: Number Banks	UV System: Design Peak Loading (mgd/kW)	Effluent Quality[c]: Typical Level (mg/L): BOD	Typical Level (mg/L): TSS	Typical Level (mg/L): NH_3-N	Bacterial[d] ($100mL^{-1}$)
1. Waldron, AL	1.0	1.2	80	None	H	1	2	1.58	-	-	-	-
2. Bridgeville, DE	1.2	1.5	25	200	V	1	2	0.38	6	4	3.8 (TKN)	25
3. Dakota City, IA	0.5	1.0E	83	200	V	1	1	0.6	<10	13-15	-	160-180
4. Cave City, KY	1.5	2.5	50	200	H	1	2	0.88	5	3	-	<10
5. Edgewater, MD	0.5	1.0E	16	14	H	1	2	0.47	6	5	0.9 (TKN)	1.8
6. Clearsprings, MD	0.4	2.0	50	200	H	1	1	0.47	<10	<10	-	<2
7. Leadwood, MO	1.5	3.0	30	200	H	1	1	5.0	7-14	4-10	-	<1
8. Olla, LA	0.3	1.0	100	25	H	1	2	1.12	5	0.5	-	<1
9. Dewey, OK	1.1	2.75	55	200	H	1	1	0.86	<20	78	-	31
10. Stoney Creek, VA	1.5	2.5	60	200	V	1	4	1.0	4	5	-	10-40
11. Petersburg, WV	1.8	3.0	83	200	H	1	2	1.69	<10	<10	<0.1	<20
12. Ozark, AL	5.25	2.5	43	1,000	V	2	-	1.16	16	20	0.4	<100[e]
13. Jessup, MD	1.6	1.0E	70	200	H	1	2	1.65	<3	<3	<1TKN	<4
14. Lebanon, MO	3.5	1.5	91	400	H	1	2	0.82	-	-	-	In Comp[f]
15. Abbeville, LA	4.5	2.75	130	200	H	1	2	0.86	4	8	1-2	<
16. Hanover, NH	7.0	3.0	57	240 TC[b]	H	1	2	0.82	<30	<10	-	200-220[g]
17. New Providence, NJ	6.0	3.0	25	200	H	3	2	0.69	10-20	5-15	1-2	<100
18. Owasso, OK	3.0	1.25	54	200	V	2	3	1.32	10	10.1	-	<5
19. Highspire, PA	3.8	1.9	50	200	V	1	4	1.11	<10	<10	-	30-40
20. Accomoc, VA	2.9	1.25	94	200	H	1	1	0.96	<10	<15	-	<100
21. White Sulphur Springs, WV	4.0	2.5	70	200	H	1	2	0.85	5-8	3-5	<1	<10
22. Williamson, WV	5.0	1.7	33	200	H	1	1	0.93	16	11	-	45
23. Athens, AL	13.0	1.9	96	1,000	H	1	2	1.68	8	13	2.4	324
24. Gunnison, CO	6.7	1.6	24	6,000	V	3	2	0.98	<10	<10	-	<200
25. East Chicago, IL	36.0	2.4	92	200	H	2	2	1.03	1.7	5.2	-	12
26. Olathe, KS	25.0	4.0	27	200	H	2	2	3.25	12-17	6-12	0.8	<10
27. Okmulgee, OK	5.0	Average	54	200	V	2	3	0.47	<10	7-12	<1	<200
28. Willow Grove, PA	17.5	2.5	98	300	H	1	2	0.85	5-10	10	0.5	In comp[f]
29. Warminster, PA	16.0	2.0	62	200	H	1	2	0.85	5	<10	1.1	43
30. Collierville, TN	7.0	2.0	51	200	V	2	4	1.17	10	4-10	-	3.10

(a)Fecal coliform, unless otherwise noted. 30-d average is shown, unless noted otherwise. See Table C for full permit description.
(b)Total coliform; value is not to exceed, any sampling.
(c)Average levels typical of performance. Based on discussion with operators.
(d)Fecal coliform, unless otherwise noted.
(e)Levels when second stage nitrification in operation. FC levels increase to 700 to 800 FC/100 L without nitrification.
(f)Data not available. Stated to be in compliance.
(g)Total Coliform.
(h)E designates plants with equalization.

the lack of any data regarding the incoming coliform densities and the transmissibility of the effluent. The plants did not measure these parameters, even in cases where there may have been difficulties and the data could be used for troubleshooting.

3.2 EVALUATION OF THE OPERATION AND MAINTENANCE OF UV SYSTEMS

The review of the selected plants entailed an assessment of the O and M practices associated with the disinfection system. This was based on discussions with the plant operators and focused primarily on the routine maintenance tasks of parts replacement and system cleaning. Some discussion also addressed any difficulties encountered with the system, the methods used for system control, upstream screening devices, and routine safety practices. The first part of the following section will focus on operations; cleaning practices will be addressed separately.

3.2.1 Summary of O and M Practices at Selected Plants

Table 3-5 presents a summary of information relating to O and M of the selected UV systems, exclusive of cleaning activities. First the type of unit and its size are reiterated, including the startup year, for each of the thirty plants. This is the same information from Tables 3-1 and 3-2. The next series of columns presents the rate of replacement for the lamps, quartz and ballasts, the estimated labor associated with this task, and the criteria used to initiate lamp replacement. The replacement cycle could be estimated fairly well for the lamps. It is based on the operators criteria for replacement and accounts for seasonal/year-round use of the system, and the probable system utilization rate. Thus if the system is operated on the basis of flow, the utilization would be approximately 50 percent; this would increase up to 75 to 100 percent if the system was operated manually and was basically kept in full operation as a matter of convenience or to assure compliance.

As shown on Table 3-5, the lamp replacement rate varies from 25 to 50 percent per year. Exceptions are the Williamson and Dakota City plants. These replace the full inventory of lamps after 7,500 hours operation, which is the

TABLE 3-5. SUMMARY OF O AND M PRACTICES AT SELECTED PLANTS

Plant	UV System Type No. of Lamps Startup	Replacements[(a)] Lamps/Quartz/Ballast Rate (% year)	Est Labor Hrs Year	Lamp Criteria	Other[(b)] O&M Hrs/Year	Total O & M Time Hrs/Year/100 Lamps	Upstream of UV Unit	Level Control	System Control	Other Comments
Group A: Average Design Flow ≤1.0 mgd										
1. Waldron, AR	OC-H 56 1988	(50)/(10)/(10)	15	Failure	60	134	No screen	Level control gate	Manual	Debris from bypass caused breakage. Some problem with quartz seals. Glasses gloves; no formal safety.
2. Bridgeville, DE	OC-H 120 1988	50/50/10	10	Increasing Coliform	60	60	No screen	Fixed weir	Manual	Modules returned to vendor for replacement of lamps/ quartz, both units kept in operation.
3. Dakota City, IA	OC-V 38 1989	50/(10)/(10)	10	Yearly (7,500 hrs)	30	105	No screen	Automatic control gate	100% system on (Manual)	Use glasses; signs posted.
4. Cave City, KY	OC-H 64 1990	(50)/(10)/(10)	25	Coliform/ Failure	35	94	1/2" bar screen	Level control weir	Manual	Screen not effective. Problems with level gate; keep closed at all times; 1 person replaces parts; glasses/long sleeves.
5. Edgewater, MD Mayo #1	OC-H 40 1989	(50)/(10)/(10)	30	Coliform/ Failure	30	50	No screen	Level control gates	All lamps kept on (manual)	Intermittent flow (pumped). Gates leak during no flow, difficult to maintain level; use goggles; shields not effective. O-rings should be replaced with lamps.
Mayo #2	OC-H 80 1989									
6. Clearsprings, MD	OC-H 32 1988	(50)/(10)/(10)	10	Failure	60	220	Filtered	Level control gate	Manual - full system	Have not replaced lamps yet since 8/88, ~14,000 hrs.
7. Leadwood, MO	OC-H 24 1988	(25)/(10)/(10)	10	Failure	60	290	No screen	Level control gate	Manual-continuous for all lamps	Goggles used
8. Olla, LA	OC-H 72 1989	25/10/10	5	Failure	60	90	No screen (plan to install one)	level control gate	2nd unit on Q> 0.58, unable to handle hydraulically	Leaves a problem, installed 1/4" plastic mesh screen. Some breakage, handling alternate banks. Use same lamps ~6,000 hrs. Eye injuries, now use goggles.

(a) when shown in parenthesis, it is an estimate, and not based on current practice at the plant.
(b) system checks, sampling, routine maintenance other than cleaning and lamp replacement.

TABLE 3-5. SUMMARY OF O AND M PRACTICES AT SELECTED PLANTS
(Continued)

Plant	UV System Type No. of Lamps Startup	Replacements(a) Lamps/Quartz/Ballast Rate (% year)	Est Labor Hrs Year	Lamp Criteria	Other(b) O&M Hrs/Year	Total O & M Time Hrs/Year/100 Lamps	Upstream of UV Unit	Level Control	System Control	Other Comments
9. Dewey, OK	OC-H 48 1988	50/10/10	10	Failure	30	85	No screen	Level control gate	Manual, full system in operation	Difficult access to modules; have original lamps (~14000 hrs); cable harness replaced; UV goggles not worn.
10. Stoney Creek, VA	OC-V 112 1988	50/10/10	14	Coliform	50	57	Bar Screen	Weir	Manual, Based on flow	Still has the original lamps. Occasional breakage during cleaning and handling; safety glasses; signs posted.
11. Petersburg, WV	OC-H 80 1987	25/10/10	5	Failure	45	63	No Screen	Level control gate	No system control	Debris is not a problem. All lamps on continuously. Use welder's glasses. Signs posted.
Group B: Average Design Flow >1.0, <3.0 mgd										
12. Ozark, AL	OC-V 336 1987	38/(10)/(10)	50	10,000 hr	200	74	2" screens	5' fixed weir, had to lower	1st 3 modules on at all times. Flow paced on 2nd three.	Debris - no problem. Grease buildup on quartz. Pacing not used, all lamps left on. Weir adjusted to prevent flooding.
13. Jessup, MD	OC-H 72 1988	(25)/(10)/(10)	15	Coliform	180	270	No screen (filtered)	Level control gate	Manual - alternate 1 unit each week	Haven't replaced lamps yet ~8,000 hrs operation. Cables showing corrosion. Difficult to replace lamps. Goggles/signs/gloves.
14. Lebanon, MO	OC-H 160 1989	(50)/(10)/(10)	30	Failure	60	56	No screen (filtered)	Level Gate	Manual-both banks on continuous	9 months down due to electrical and hydraulic problem. Rebuilt 12/89; Corrected problems. Flood gate at Q >3.0 mgd. Goggles/signs
15. Abbeville, LA	OC-H 196 1989	(50)/(10)/(10)	30	Failure/ Coliform	150	92	No screen	Fixed Weir	Level sensor turns on top lamps	Short bulb life initially, replaced bulbs; problem with debris, especially during high flow; replaced level gate with weir; worm wheels holding bulbs are corroding; difficult to change lamps-high costs. Use goggles. High headloss.

TABLE 3-5. SUMMARY OF O AND M PRACTICES AT SELECTED PLANTS (Continued)

Plant	UV System Type No. of Lamps Startup	Replacements[(a)] Lamps/Quartz/Ballast Rate (% year)	Est Labor Hrs Year	Lamp Criteria	Other[(b)] O&M Hrs/Year	Total O & M Time Hrs/Year/100 Lamps	Upstream of UV Unit	Level Control	System Control	Other Comments
16. Hanover, NH	OC-H 320 1988	(50)/10/10	80	Failure/ Coliform	80	50	No screen	Level control gate	Manual, full system in operation at all times	Have not changed lamps yet ~14,000 hrs; replaced starters/breakers; plugs get moist, replaced 12 in 18 months.
17. New Providence, NJ	OC-H 324 1989	25/10/10	60	Failure/ Coliform	80	45	No screen	Replacing motorized gate with mechanical gate	Flow paced 0-0.5 1 bank, 1 channel 0.5-2 1 channel, 2 bank, >2 - new channels	Breakage is significant from handling; effluent motorized gates did not work, replaced with Emil gates; poor access to modules; leaf problems into quartz racks, need a screen; several electrical/parts problems, equipment replaced by Fisher & Porter
18. Owasso, OK	OC-V 168 1988	50/10/10	10	Coliform	60	42	Screen (1/4" mesh)	Manual Adjust. weir	Automatic 4 of 6 modules at Q>1 mgd	Replaced all lamps at 10,000 hrs (high coliform); goggles and posted signs
19. Highspire, PA	OC-V 252 1988	50/10/10	30	Coliform	125	62	Screen (1/4" mesh)	Weir	Automatic Q>1 mgd, 2nd bank, Q>2 mgd, 3rd bank, Q>3 mgd, 4th bank comes in operation	Lamps were changed after 17,000 hrs of operation time, approx 2 yrs service, because coliform index started going up.
20. Accomac, VA	OC-H 112 1987	60/10/10	16	Failure	50	59	Grating	Weir	No control	Problem with algae build-up and rats. Some breakage problem during cleanup. UV safety glasses. All lamps on all time. No system control.
21. White Sulphur Springs, WV	OC-H 176 1989	50/10/10	20	Coliform	80	57	No Screen	Level control gate	No system control	Debris is not a problem. Easy access to modules. All lamps on continuously. Still has the original lamps.
22. Williamson, WV	OC-H 120 1987	100/10/10	25	Coliform	55	67	No Screen	Fixed Weir	Automatic, depending on flow.	Debris is a problem. All lamps were replaced after 7500 operating hours (approx. 1 yr service). Electrical Problem with cabinets; replaced wiring.

TABLE 3-5. SUMMARY OF O AND M PRACTICES AT SELECTED PLANTS
(Continued)

Plant	UV System Type No. of Lamps Startup	Replacements(a) Lamps/Quartz/Ballast Rate (% year)	Est Labor Hrs Year	Lamp Criteria	Other(b) O&M Hrs/Year	Total O & M Time Hrs/Year/100 Lamps	Upstream of UV Unit	Level Control	System Control	Other Comments
Group C: Average Design Flow >3.0 mgd										
23. Athens, AL	OC-H 576 1988	50/(10)/(10)	130	Failure	300	75	No upstream screens 20' approach to 1st Bank	Level Control Gate	One bank on at all times	Sloughed material catches on modules (increased h_L) Good approach to unit lamps. Safety interlock. Glasses generally worn. Minor replacement of cables /fans wiring. Some breakage - handling.
24. Gunnison, CO	OC-V 504 1987	(33)/(10)/(10)	65	Failure	300	72	Bar screen before UV	Manually adjustable weir	Manual operation for each channel	Flooding problem with 2 channels, needed 3rd channel. Lamps have greater than 10,000 hrs. Safety goggles, signs posted.
25. East Chicago, IN	OC-H 1312 1989	(30)/(10)/(10)	85.0	Failure	900	75	No screen	Level control gate	Flow Paced: <18 mgd, 1 bank (2 channel); >18 mgd 2 banks, 2 channels	Operated for ~1 year; will continue until lamps fail before replacement, bad O-ring seals-corrected.
26. Olathe, KS	OC-H 288 1988	67/(10)/(10)	40	Coliform/ Failure	150	66	No screen	Level control gate	Flow paced: <3.4 mgd:1st Bank, 2 channel; >3.4 mgd, 1st and 2nd bank both channels	Replaced lamps at ~10,000 hrs in order to improve performance. No problem with debris. UV glasses/ shield; signs posted.
27. Okmulgee, OK	OC-V 394 1989	25/10/10	50	Failure	160	53	Screen	Motorized gate replaced by adj. weir	Manual (auto not used)	Screen removes algae; have not replaced lamps (~5000 hrs) (may replace 1 channel at 7500), use WQ meters; should have stand-by power; safety training/ goggles, clothing.
28. Willow Grove, PA	OC-H 768 1988	25/10/10	45	Failure	350	52	No screen	Level control gate	Q>9 mgd, 2nd bank is brought on manually	Algae build up is problem, at present flow pacing is done manually although designed for automatic.
29. Warminster, PA	OC-H 704 1988	50/10/10	75	Coliform	320	56	No screen	Level control gate	Q>7 mgd, 2nd bank comes in operation	No problems with debris. UV safety glasses, signs posted.

TABLE 3-5. SUMMARY OF O AND M PRACTICES AT SELECTED PLANTS
(Continued)

Plant	UV System Type No. of Lamps Startup	Replacements(a) Lamps/Quartz/Ballast Rate (% year)	Replacements(a) Est Labor Hrs Year	Replacements(a) Lamp Criteria	Other(b) O&M Hrs/Year	Total O & M Time Hrs/Year/100 Lamps	Upstream of UV Unit	Level Control	System Control	Other Comments
30. Collierville, TN	OC-V 224 1988	50/10/10	16	Failure	100	56	No screen	Weir	Q>3.5 mgd, 2nd bank in each channel comes in operation	No problem with debris. Easy access to modules.

operating life generally stated by the lamp manufacturers. This is equivalent to a rate of greater than 100 percent per year if year-round disinfection is practiced. Olathe and Owasso replaced their lamps after 10,000 hours of operation in order to improve performance. Ozark has a fixed 10,000 hour replacement cycle. In general, however, one can expect to get greater than 12,000 hours of operation from the conventional low pressure lamps, when used in the submerged, open-channel configuration. Gunnison has greater than 10,000 hours; Clearsprings, Dewey and Hanover each have greater than 14,000 hours operation; and Highspire replaced their lamps after 17,000 hours operation, at which point the coliform levels had begun to increase.

Three of the plants have units supplied by Arlat. These require a high level of effort to replace the lamps, using clips and heat-shrink seals; in some cases it requires that the modules be returned to the factory for replacement. This has been found to cause excessive costs, as cited by the operators at Bridgeville, Abbeville, and Williamson. A fourth plant (New Providence) had originally been using Arlat equipment; this was replaced with a Fisher and Porter system in 1990.

The criterion for failure is generally lamp failure and or increasing coliform densities (except at those plants with fixed operating cycles, as discussed earlier). Generally, its appears that the latter condition would be the final trigger. The high operating life cycles that are being obtained suggest that the lamps will not fail (i.e. electrode failure, shutoff); rather, their output will deteriorate to such a degree that there is insufficient germicidal energy for effective disinfection. The lamps are replaced at this point to restore the system efficiency. For design purposes, a reasonable estimate of operating life would be 14,000 hours; thus the replacement rate in a system with year-round disinfection, and an average 50 percent utilization, would be approximately 30 percent per year:

((8,760 hours/year)/(14,000 hours/lamp)) x 50 percent - 31.2 percent

With the smaller systems, and to a lesser extent the larger plants, it appears that the tendency is to operate the full system (75 to 100 percent utilization) at all times instead of controlling it on the basis of flow. This would increase the replacement rate for the above example to 50 to 60 percent per year. If disinfection is required on a seasonal basis the replacement rate is reduced to 25 to 30 percent per year.

Regarding the quartz sleeves and the ballasts, it is not possible to make a direct assessment of their expected life cycle. The experience with full scale systems, particularly with respect to the open channel submerged units, is limited, covering a period of approximately five years. This is not sufficient to evaluate in-field experience for long-term replacement rates of the quartz and ballasts. Many of the replacements currently reported by operators have been due to breakage and electrical wiring failures, reasons that do not speak to the degradation or failure of the components themselves.

The quartz will degrade due to solarization of the quartz structure, resulting in a cloudiness of the quartz and a loss of transmissibility. Abrasion of the surface due to long-term exposure to the wastewater is also a contributing factor to their deterioration. There is no current feedback on replacement of the quartz for these reasons. At this point, an estimate that may be appropriate is a replacement rate of 10 years, to account for minimal breakage and for deterioration of the quartz.

Similarly, there is little experience with ballast failures and replacement rates. Earlier failures have been attributed to improper electrical design and the lack of proper ventilation in the ballast cabinets. These difficulties appear to have been corrected, although there are still reports of electrical problems with a few installations upon startup. This was the case with the Lebanon, Abbeville, Hanover, Williamson, and Athens systems. Ballasts are expected to have long lives, particularly based on the experiences with those found in normal fluorescent lighting fixtures. For purposes of life cycle assessments with UV disinfection systems, a 10 year replacement period is suggested.

The effort required for replacement of these key components (largely the lamps themselves) is relatively low. The estimates shown on Table 3-5 are based on discussions with the plant operators and their estimate of time requirements over specific calender periods for changing lamps, with some allowance for occasional replacement of ballasts and quartz sleeves. This is also shown on Figure 3-2, which presents the hours spent per year against the number of lamps that would be replaced per year. The mean is 0.4 hours per lamp, or 24 minutes per year. There is significant variability, with the rate ranging from approximately 10 minutes to 50 minutes per lamp. Note that this is total labor, even if two people are engaged in the activity (which tends to be typical).

This analysis can be used in screening the labor and parts replacement costs for UV systems. One should be careful to acknowledge how the system will likely be operated in terms of utilization; recall that the tendency is to have much of the system on at a given time, regardless of the flow. Also account for the year-round versus seasonal disinfection requirements. Note also that these charges could be incurred in discrete intervals, rather than be spread out somewhat evenly over a period of time. This results from the likelihood that the operators will replace all the lamps at once, triggered by the overall operating time and a decrease in disinfection efficiency, as discussed earlier.

A second labor factor is presented on Table 3-5. This is an estimate of the time required, on a yearly basis, for activities other than replacement of the lamps/quartz/ballasts and cleaning. These would include system monitoring and sampling, area maintenance, component repair/replacement, etc. This tends to be a factor of two to six times the amount of time estimated for the replacement of key components. When added to the parts replacement activities, the total time required outside of routine cleaning needs (discussed in a later section) is estimated. These data are shown on Table 3-5 and plotted on Figure 3-3, which presents the total hours per year as a function of the system size. There is some scatter, particularly with the smaller plants. For the 14 plants with less than 150 lamps, the mean labor requirement was 120 hours per 100 lamps. The equivalent mean for plants with more than 150 lamps was 55 hours/100 lamps.

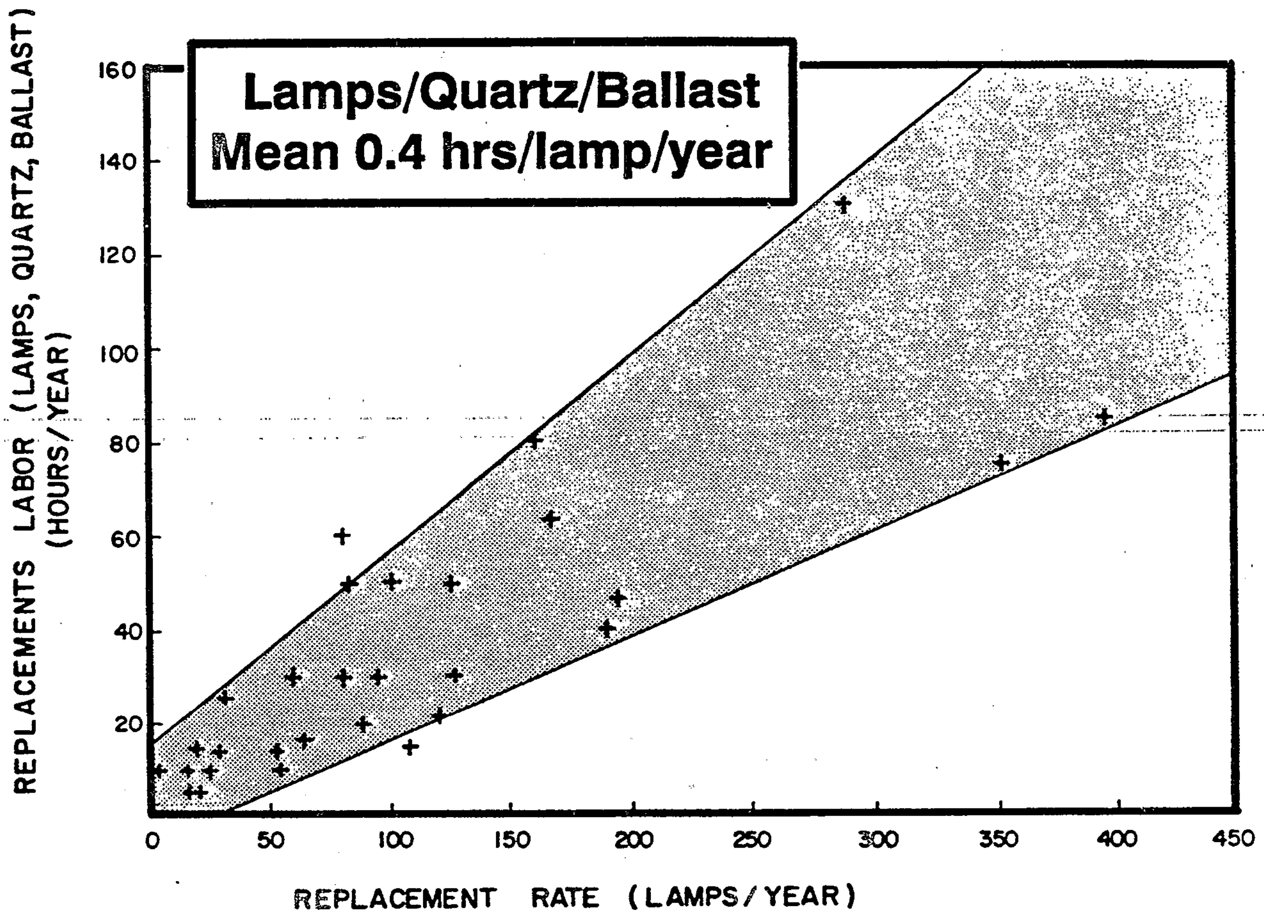


Figure 3-2
Labor Requirements for Replacement of Lamps/Ballasts/Quartz

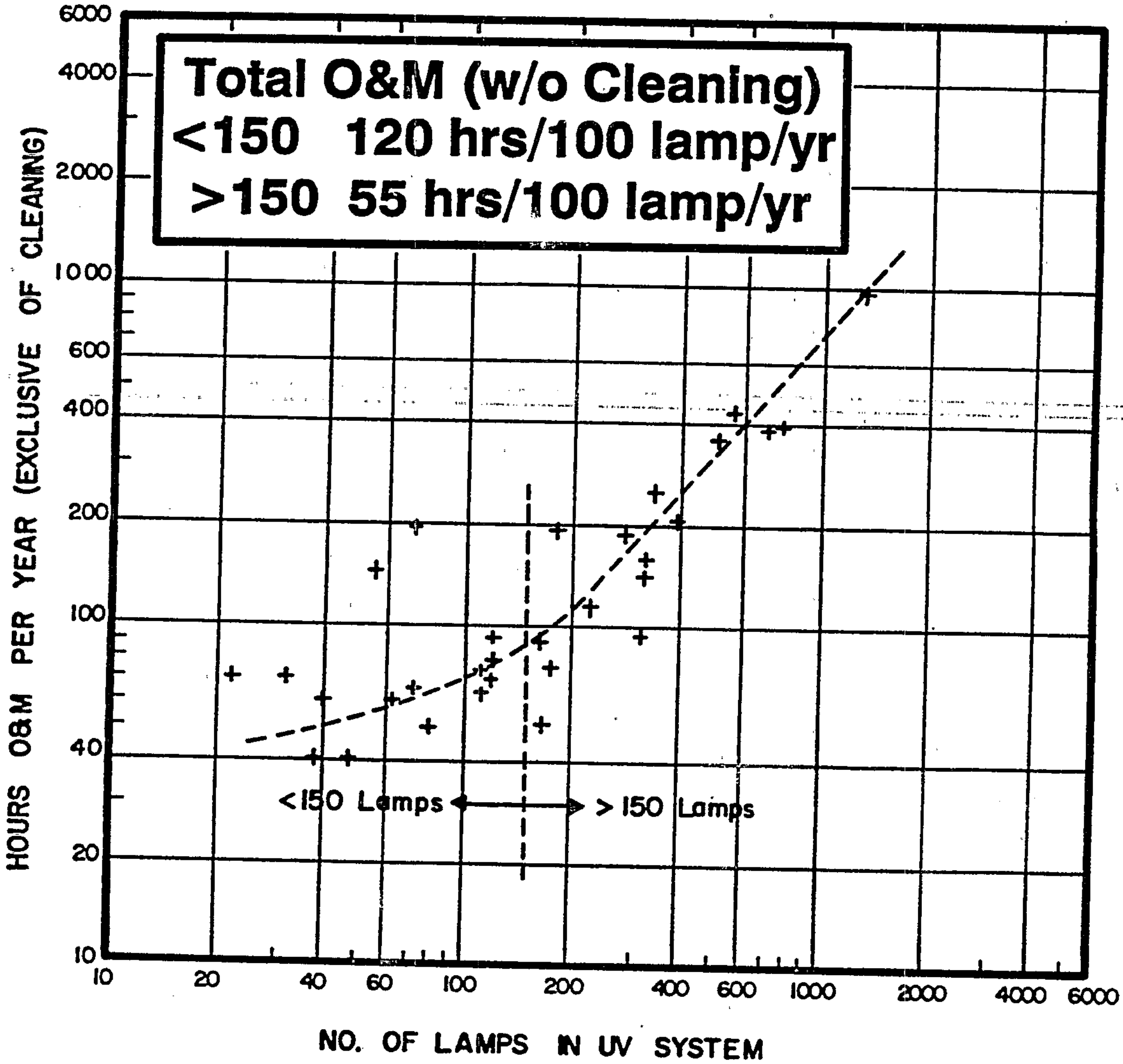


Figure 3-3
Estimate of O&M Labor (Exclusive of Cleaning)

The next series of columns on Table 3-5 addresses upstream protection for the lamps, level control devices, and the method used for system control. Upstream devices such as screens are used to protect the lamp battery from debris that may reach the UV system and cause damage to the quartz/lamp assemblies. Other problems occur from algae sloughing off the clarifiers and leaves falling into the channels; these catch on the lamp modules and accumulate, creating additional head loss problems and maintenance tasks. From Table 3-5, three of the plants are noted to have filters (Clearsprings, Jessup and Lebanon); these are installed for tertiary solids removal and will also effectively remove unwanted material from the flow-stream. The plants report no difficulties with debris in the UV channel.

One plant (Accomac) has a grating placed upstream of the UV units. This is effective in removing debris, but the operators do note that algal mats are still able to pass through and cause problems with the UV units. Seven plants have either bar or mesh screens, ranging in size from one-quarter inch to 2 inch openings (Cave City, Gunnison, Stoney Creek, Ozark, Owasso, Highspire, and Okmulgee). These all report no problems with debris or sloughed material fouling the UV modules. Okmulgee reports that the screen is very effective in removing algal mats from the wastestream. All of these devices are cleaned manually.

Of the remaining 19 of the 30 selected plants, 12 report that they have no problems relating to debris or sloughed material. The other seven state that they do, however. The Waldron plant has experienced breakage of the quartz from debris entering the unit during periods of bypass. At both Olla and New Providence, leaves tend to enter the channel and accumulate on the modules. Olla is installing a screen. Abbeville receives excess debris during high flow periods; this problem is also reported by the Williamson plant. Both the Athens and Willow Grove facilities complain of algae sloughing from clarifier and channel walls and accumulating on the lead module frames.

Overall it appears that the installation of an upstream screening device is an option that most plants do not choose. From this assessment, however, it also appears that it is most appropriate to have one in place. These can be simple, large-mesh (0.5 inch) screens (stainless steel), that can be slipped in and out of the channel manually for cleaning on a frequent basis. This will save considerable labor if the alternate is to clean the debris attached to the individual modules. An alternate device that may be more convenient to the operator would be a bar screen that can be raked (a moving mesh or bar screen that is self-cleaning would not be cost-effective); this would still have to be removed periodically for a thorough cleaning. Note that it is important to remember that these devices, particularly as they accumulate material, will impose a headloss; this must be accounted for when considering the hydraulic design of the facility.

A critical operating requirement is that the water level in the channel must be kept fairly constant. If it fluctuates widely (greater than plus or minus one inch from the control level), several problems can occur. In horizontal systems the top row of lamps can either be exposed or the depth of water above this row can become so great that disinfecting effectiveness of the unit is compromised. In vertical units this same problem occurs, except that the top portion of each lamp is affected. In the Arlat systems, the water level was allowed to vary, using a fixed dowstream weir; in this case a level sensor would turn on successive horizontal rows of lamps (Bridgeville, Abbeville and Williamson). In this way the exposed lamps would not be operating. Adjustable weirs have also been used, with motorized actuators that respond to level sensors. These are used at Cave City. Manually adjustable weirs are used at Ozark, Highspire, Accomac, Owasso, Gunnison, and Collierville.

The remaining plants all use a mechanical level control gate to maintain the desired level. These rely on field setting and adjustment of the counter-weights to assure the proper level control over a range of flow rates. They have generally been very successful and comprise the dominant method for level control in open-channel systems. Problems are noted, however, at low flows and at plants that have no flow at times. The gates will oscillate and cause wide fluctuations in level. They are not designed to be watertight and will allow the channel to drain during periods of very low or no flow.

The method of level control should be carefully considered in the design of a facility. The mechanical gates would be the preferred device in most cases, particularly larger systems in which multiple channels are used and the channel velocities can be maintained within a reasonable operating range. If there are low flow periods (or no flow), fixed weirs may be more appropriate. Sufficient weir length must be provided, however, to avoid excessive level fluctuation. This can be accomplished by using serpentine weirs and weir launders. An alternative is to use a motorized adjustable weir slaved to a level sensor.

System control has generally been kept simple with the newer open channel UV units. This has been limited to pacing the operation of multiple channels and banks to the flow rate. This is typical of the larger plants. In this evaluation, 11 of the plants practice automatic flow pacing (Olla, Ozark, Abbeville, New Providence, Owasso, Highspire, Williamson, East Chicago, Olathe, Warminster and Collierville). Except for Olla, all have design average flows greater than 1.0 mgd. The Okmulgee plant has automatic flow pacing capabilities, but prefers to keep the system on manual control.

Of the 19 plants that are controlled on a manual basis, only 11 of these attempt to vary the number of lamps in operation as a function of the flow to the lamps. Thus, as an example, Willow Grove will operate with one bank on (there is only one channel), and bring the second bank into service when the flow exceeds 7 mgd. The remaining 8 plants simply operate with 100 percent of the lamps on at all times (Dakota City, Edgewater, Clearsprings, Leadwood, Dewey, Petersburg, Hanover and White Sulfur Springs).

The manner in which the UV system is controlled should be a function of the type and size of plant. Above all, it should be kept simple; the objective is to conserve the operating life of the lamps (and the associated power utilization). This becomes increasingly important with the larger plants (greater than 150 to 200 lamp systems), and more practical. With the small plants, it may be best to have the full system in operation, exclusive of the redundant units incorporated into the design. Manual control and flexibility should be available as the system increases in size, enabling the operator to bring portions of the system (i.e. channels and banks) into and out of operation as a function of flow and performance. Automating this activity becomes advantageous as the system becomes larger, using multiple channels.

Safety is important in the operation of UV systems, centering primarily on protection from exposure to UV radiation. This affects the eyes with a temporary condition known as conjunctivitus, or "welder's flash", that can last for several days, causing a painful burning sensation. Bare skin will also be burned upon exposure to UV at these wavelengths. Exposure risk is generally minimal, as long as the operating lamps are submerged and the lamp batteries are shielded. The danger arises if the lamps are operated in air; this should never be necessary except under extraordinary circumstances. Systems should be equipped with safety interlocks that shut off operating modules if they are removed from the channel. Electrical hazards are minimized by the inclusion of ground fault interruption circuitry with each operating module. This feature is typically standard with current systems and should be a requirement with all specified systems.

The precautions against exposure to UV radiation are straightforward. UV blocking glasses, with side shields, should be worn at all times in the general area. One plant reported that the shields were ineffective and switched to goggles for full protection. Exposure of skin should be minimized, using long sleeved shirts and buttoned necks, as examples. Signs should also be posted near the equipment and in the general area that warn of the hazard and instruct the use of glasses, at a minimum. Of the selected plants, most all required and actively used eye protection, generally preferring goggles. One plant imposed stricter rules after an eye injury had occurred. Signs are also posted in several of the plants. Specific training is not typical, except that which is given by the equipment manufacturer during startup, and this does not always occur. At best, safety issues and training relating to the UV system should be be incorporated into the plant's normal safety program.

3.2.2 Summary of UV Cleaning Practices at Selected Plants

Maintaining the quartz surfaces is a critical element in the successful operation and performance of the UV process. This is a simple task, entailing routine cleaning of the quartz sleeves with a standard agent. It is one that has at times been overlooked, however, resulting in apparent failure of the UV process because the quartz surfaces have become fouled and have lost their transmissibility. The fouling is most often due to the deposition of inorganics such as calcium or magnesium carbonates and iron. Greases or biological films can also adhere to the surface. The key task is to anticipate this and to have a fixed protocol for maintenance of the quartz surfaces.

The key elements of cleaning open-channel systems entail isolation of the modules (either in or out of the channel), selection of a cleaning agent, development of a method, the time required to accomplish the task, and the criteria that trigger the need for cleaning. These factors were reviewed for each of the selected plants and are summarized on Table 3-6. The assessment showed considerable variability among the plants, making each case somewhat unique. Essentially all are successful, using methods that are relatively simple, easily applied, and which fit specifically to the conditions of the facility. This is a marked improvement from the earlier system configurations using closed shell, fixed in-channel, and teflon pipe designs (20). These systems suffered serious problems relating to the ability to keep the quartz or teflon surfaces clean and the access to the quartz for such maintenance tasks.

In-place cleaning is practiced at four of the selected plants: Dakota City, Ozark, Okmulgee, and Collierville. This involves isolating the UV system within the channel by upstream and downstream slide gates, and recirculating a cleaning solution within the UV system. Agitation is generally provided through air diffusers (perforated pipes) at the bottom of the channel. The spent cleaning solution is typically discharged back to the head end of the plant or to a tank for reuse. The in-place method is not common to the open-channel designs, except those that use the vertical lamp modules. Each of the four plants in this assessment are vertical lamp systems; note that the Dakota City plant also has a mechanical wiper.

Each of the four plants uses a citric acid solution as the cleaning agent. At Ozark, the in-place cleaning is conducted approximately once every two to three weeks (equivalent to about 21 cycles per year) by recirculating the

TABLE 3-6. SUMMARY OF UV CLEANING PRACTICES AT SELECTED PLANTS

Plant	UV System Type No. of Lamps Start Year	Equipment Description	Cleaning Agent/ Frequency/ Criteria	Hrs/ Year	Hrs/Cycle 100 Lamps	General Routine	Other Comments
Group A: Average Design Flow ≤ 1.0 mgd							
1. Waldron, AL	OC-H 56 1988	Remove modules and place on rack	Snow Bowl-Bathroom Cleaner MARC Super Str. Bowl Cleaner twice/month; routine schedule	60	4.5	Rinse with hose; wipe with sponge; rinse again	Difficult access, racks too deep; wash walls and bottom each time. Also clean when bypass is used.
2. Bridgeville, DE	OC-H 120 1988	Remove modules - hang on wall rack	Dilute HCl once/3 weeks; based on Coliform increase	45	2.2	Apply cleaner and rinse	1 person; 2 1/2 hrs each time
3. Dakota City, IA	OC-V 38 1989	Mechanical wiper and inplace recirculation	Citric acid cleaned manually once/year	10	26	Recirculate citric acid. 1/year, remove module & manually clean. Mechanical wiper operates every 6 hours.	Satisfied with wiper; have not chemically cleaned yet (8 months)
4. Cave City, KY	OC-H 64 1990	Remove Modules (getting dip tank)	HCl descaler/delimer once/month Based on kill efficiency	50	6.5	Acid descaler/delimer applied with mop; rinsed with water and dried	Difficult to clean, hope dip tanks helps.
5. Edgewater, MD Mayo #1	OC-H 40 1989	Remove modules and hang on rack	Lime-away once/2 months Based on kill efficiency	30	4.2	Apply lime-away with rag and wash down with water	Final unit (after peat) developed film (not on 1st unit). Suspect peat leaching. Peat shutdown, will start again soon
Mayo #2	OC-H 80 1989						
6. Clearsprings, MD	OC-H 72	Remove modules	Lime-away 1/month Based on coliform	50	5.8	Apply lime-away and rinse with water, 2 people used	Skim holding tank once/ day. Channel scrubbed each day. Would want a hanging rack.
7. Leadwood, MO	OC-H 24 1989	Remove modules	Lime-away once/6 weeks Routine	10	4.8	Apply lime-away and rinse	Hose out channels daily; debris hangs up on lamps; Would want a hanging rack.
8. Olla, LA	OC-H 72 1989	Remove modules	Dishwashing detergent once/2 weeks Routine schedule	120	6.4	Remove modules, spray with soap solution, wipe with towel, rinse with water	
9. Dewey, OK	OC-H 48 1988	Remove modules	Lime-away once/2 months; based on coliform	48	16.7	Rinse; wipe with lime-away and rinse again.	
10. Stoney Creek, VA	OC-V 112 1988	Remove modules	Muriatic Acid (HCl) once/month; based on coliform index	24	1.8	Remove modules by hand. Place them on rubber mat. Apply muriatic acid and rinse them with water hose	Iron content in the waste-water is high. Muriatic acid is used to remove stains from the quartz sleeve.

TABLE 3-6. SUMMARY OF UV CLEANING PRACTICES AT SELECTED PLANTS (Continued)

Plant	UV System Type No. of Lamps Start Year	Equipment Description	Cleaning Agent/ Frequency/ Criteria	Hrs/ Year	Hrs/Cycle 100 Lamps	General Routine	Other Comments
11. Petersburg, WV	OC-H 80 1987	Remove modules	Phosphoric acid once/6 months; based on coliform index	35	21.9	Remove modules by hand. Wipe the quartz sleeve with phosphoric acid and water, rinse it with water hose	Cleaning is done when coliform index exceeds 60 col/ 100 mL.
Group B: Average Design Flow >1.0, <3.0 mgd							
12. Ozark, AL	OC-V 336 1987	Inplace cleaning-recirculation pump	Citric acid once each 2 - 3 weeks (manually 1/yr); based on kill efficiency	250	4.4	Inplace circulation for approx. 4 hrs. Manually remove and clean 1 time per year	Grease on quartz. Difficult access - no work area between channels. Etching/ frosting of quartz after 2 years.
13. Jessup, MD	OC-H 72 1988	Remove modules	Dilute HCl acid 1/month Based on coliform & intensity	30	3.5	Remove modules; 1 person holds it and 2nd person wipes with dilute acid and rinses	No hanging rack
14. Lebanon, MO	OC-H 160 1989	Remove modules manually and hang on rack	Citric acid every 1 week to 1 month; Coliform based	220	6.9	Spray acid solution and rinse with water	7 to 10 quartz sleeves are broken each time cleaned.
15. Abbeville, LA	OC-H 196 1989	Remove modules and hang on rack	Mild detergent every 2 weeks to 4 weeks; Based on coliform	280	8.3	Wash with detergent and water; rinse	Use 2 people to minimize breakage
16. Hanover, NH	OC-H 320 1988	Tip up module (in-place) Remove 2 times/year	Lime-away once/week; Based on coliform	250	1.5	Apply lime-away with module raised from channel; brush and return. Remove modules 2/year	Water high in iron and manganese
17. New Providence, NJ	OC-H 324 1989	Manual removal (no rack)	Brillo/detergent once every 1-5 weeks; Based on coliform	110	11.3	Remove module, scour with brillo pad and soap, and rinse	Variable coating problem clean one channel, change lead channel
18. Owasso, OK	OC-V 168 1988	Remove modules	Lime away once/month, Based on coliform	60	3.0	Remove modules, wipe with lime-away and rinse with water	Cleaning very effective
19. Highspire, PA	OC-V 252 1988	Remove modules Dip tank	Citric Acid once/2 month; based on coliform	80	2.0	Remove module and soak in dip tank for 1/2 hr.; Rinse	Uses $FeSO_4$ for phosphorus removal; Modules are 40 lbs.
20. Accomac, VA	OC-H 112 1987	Remove modules	Dilute sulfuric acid followed by Windex, once/month (winter) and once/week (summer); based on coliform index and algae growth	100	2.5	Remove modules, apply dilute H_2SO_4, followed by Windex; wipe it and rinse.	Cleans more often in summer due to algae growth in the plant.

TABLE 3-6. SUMMARY OF UV CLEANING PRACTICES AT SELECTED PLANTS (Continued)

Plant	UV System Type No. of Lamps Start Year	Equipment Description	Cleaning Agent/ Frequency/ Criteria	Hrs/Year	Hrs/Cycle 100 Lamps	General Routine	Other Comments
21. White Sulphur Springs, WV	OC-H 176 1989	Remove modules	6% phosphoric acid solution once/6 month; based on coliform index	15	4.3	Lift the racks, put them against the wall. Apply 6% phosphoric acid solution, rinse it with water hose	Cleaning is done when coliform index exceeds 40 col/100 mL.
22. Williamson, WV	OC-H 120 1987	Remove modules	Mild citric acid solution once/3 weeks; based on coliform index	110	5.4	Remove modules by hand. Wipe the sleeve with mild solution, wash it with water hose	Entire system is cleaned same day.
Group C: Average Design Flow >3.0 mgd							
23. Athens, AL	OC-H 576 1988	Remove modules from channel (manual)	Lime-Away 3 times/year; based on coliform kill efficiency	180	10.4	One bank each time; remove module; soft cloth with agent; 1 person holds module, while other cleans and rinses. 2 people needed.	Difficult access - modules are in deep channels, install rack for modules
24. Gunnison, CO	OC-V 504 1987	Remove modules	Citric acid 2 times/year; based on Intensity meter	180	17.8	Remove modules-lift from channel; wipe with citric solution; rinse	3 people used for cleaning
25. East Chicago, IN	OC-H 1312 1989	Remove modules; Dip tanks (fits 5 modules)	Citric acid 1/year based on in-line intensity	70	5.3	Remove and put in dip tank; rinse	Adds $FeCl_3$ for phosphorus removal. Lift modules by hand, good access (15 lbs) Time: 1 hr/5 max, 2 people
26. Olathe, KS	OC-H 288 1988	Remove modules	Lime-away once/6 weeks; based on Intensity meter reading	140	5.6	Wipe with rag and lime away and then flush with water	Reduced cleaning frequency after replacing lamps
27. Okmulgee, OK	OC-V 394 1989	Inplace recirculation	Citric acid (50 lbs/cycle) weekly; routine schedule	150	0.7	In-place recirculation of citric acid solution	
28. Willow Grove, PA	OC-H 768 1988	Remove modules	Lime-away once/3 months; based on UV intensity	140	4.6	Remove modules, wipe with lime-away and rinse with water	Clean whole system at same time
29. Warminster, PA	OC-H 704 1988	Remove modules	Lime-away once/6 months; Based on UV transmission	70	5.0	Remove modules, hang and apply lime-away	Cleaning is effective
30. Collierville, TN	OC-V 224 1988	In-place cleaning	Citric Acid once/6 months; Based on coliform	20	4.5	In place cleaning; circulates citric acid and rinse afterwards	Cleans one channel at a time

solution for approximately four hours in each channel. The modules are removed once per year to manually clean the individual quartz sleeves. The facility has reported difficulties with grease deposits on the quartz, suggesting that the citric acid may not be the most appropriate cleaner, or that an additional detergent type cleaner should be used periodically. The frequency of cleaning is dictated by rises in effluent coliform densities. This is the only plant, of the thirty, that reported problems with the quartz, indicating that the sleeves showed evidence of etching and frosting (solarization) after only two years use. This is unusual, and there was no immediate explanation as to the cause of this early quartz deterioration. The operators also complained of inadequate workspace; no area was provided between the two channels, making it difficult to access the modules.

A similar procedure is used at Okmulgee and Colliervile. At Okmulgee the cleaning is done on a routine weekly basis (at 50 lbs citric acid use per cycle), while the recirulation is conducted once per six months at Collierville. As mentioned earlier, the Dakota City system is fitted with a mechanical wiper. This is not a commonly used device, particularly with the open-channel systems. The plant is satisfied with the unit, and has not had to conduct an in-place recirculation cleaning in the first eight months of operation. The operators anticipate removing the modules and cleaning them manually on a yearly basis.

Two plants use dip tanks: East Chicago and Highspire. These are also vertical lamp module systems, in which the modules are removed from the channel and placed in a tank containing a recirculating cleaning solution. In both cases, citric acid is used as the cleaning agent. The modules are allowed to soak for a period of time, then rinsed and placed back in the channel. At Highspire this is done approximately once per month, generally on the basis of rising effluent coliform densities. Note that the plant adds an iron salt for phosphorous removal, which may add to the fouling effects on the quartz. This is also the case at East Chicago, which anticipates a frequency of once per year based on limited experience (it started in 1989), using the water quality meter to determine when cleaning is necessary. The plant finds the procedure to be efficient and effective; two people are used, handling five modules at a time. The modules are lighter than earlier designs (15 pounds versus 40 pounds) and access is good.

Note that the use of dip tanks is gaining favor and is generally supplied with most new systems, including those using horizontal lamp configurations. These can be in a fixed location or rolled on wheels to each bank of modules. An example is shown on Figure 3-4 which is a sketch of a typical unit used for horizontal lamp modules. Modules are removed individually from the channel and placed in the recirculating bath. It is then hung on the rack above the tank to drain, where it can be physically wiped and/or rinsed with clean water. In certain cases, a cage system is being devised to enable removal of banks of lamps from the channel (via a moving overhead hoist) and placement in a large dip tank. This is especially useful at larger plants. At present this is planned for the Nuese River plant in Raleigh-Durham, North Carolina, and the LOTT plant in Olympia, Washington (10).

The remaining 24 selected plants rely on removal of the modules from the channel and manually cleaning them. Five of these plants have a rack to hang the modules on while the operator cleans it: Waldron, Bridgeville, Edgewater, Lebanon, and Abbeville. The others lay the modules on the floor, rest it against the wall, or have a second person hold it. Three of these plants have vertical lamp modules (Stoney Creek, Owasso, and Gunnison) which requires two people to lift the modules from the channel. At Stoney Creek, the iron content of the wastewater is relatively high, requiring monthly cleaning. The frequency is set by observation of rising coliform levels. This particular plant uses muriatic acid to remove the irons stains that deposit on the quartz surfaces; the material is applied to the quartz and then rinsed off with a water hose. At Owasso a commercial product "Lime-Away" is used. The modules are removed from the channel at a rate of once per month (based on coliform densities), the quartz are wiped with the lime-away, and the module is then rinsed with clean water. This is reported to be very effective. The Gunnison plant uses citric acid approximately twice per year, based on intensity readings. The citric acid solution is applied to the quartz and then rinsed with clean water.

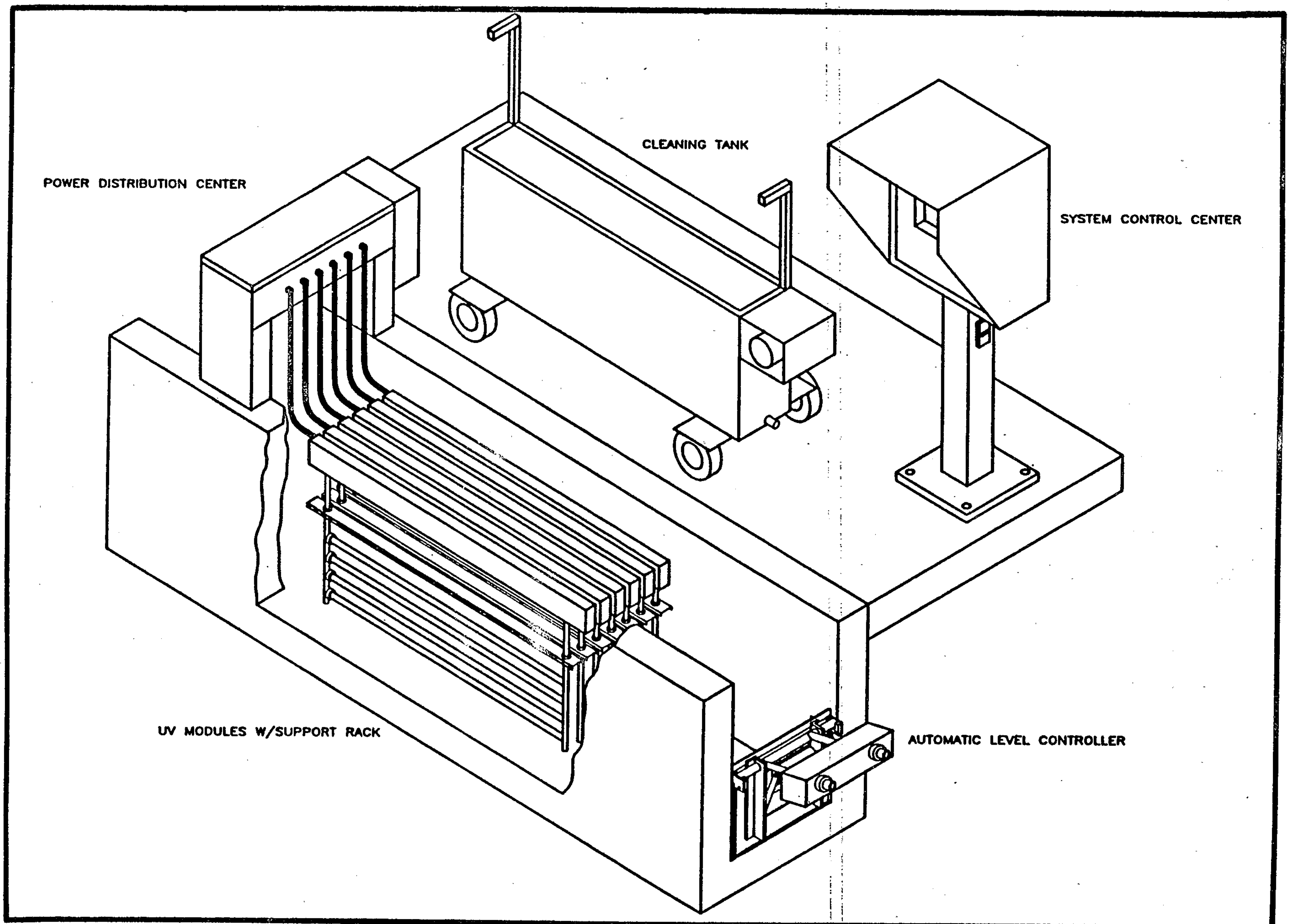


Figure 3-4
Schematic of UV Channel System Showing Cleaning Tank
(Courtesy Trojan Technologies, Inc. London, Ontario)

Waldron uses a commercial tile and bowl cleaner, cleaning on a routine twice per month frequency. They also hose down the channels each time the modules are cleaned. The modules are hung on a rack, rinsed, sponged down with the cleaner and then rinsed again. Similarly, Bridgeville and Edgewater use a rack to hang the modules, apply the cleaner and then rinse with clean water. Bridgeville does this once every three weeks (based on coliform increase), while Edgewater has a frequency of once a month (coliform kill efficiency). Bridgeville uses a dilute hydrochloric acid and Edgewater uses Lime-Away. Cave City also uses a hydrochloric acid descaler (once/month) but finds it difficult to clean the quartz surfaces. They will be getting a dip tank to improve this operation.

Clearsprings and Leadwood use Lime-Away on a frequency of once/month and once per six weeks, respectively. They also report that the channels are hosed down daily; at Leadwood debris tends to catch on the lamps, which is removed (hosed downed) daily. Both plants would like to have hanging racks to make the cleaning process more convenient. The Olla plant uses a dishwashing detergent about once every two weeks on a routine basis, spraying the quartz with the soap solution, wiping them with a towel, and then rinsing them with water. At Dewey, Lime-Away is used about once every two months, based on coliform levels.

Petersburg uses a dilute phosphoric acid solution. This is done approximately one every six months, generally based on effluent coliform densities. This is set at a limit of 60 fecal coliforms per 100 mL. At Jessup, a dilute acid is also used. One person holds the modules while a second cleans and rinses it. This is done approximately once per month, based on effluent coliform density and intensity readings.

At Hanover, the modules are tipped up, wiped and brushed with lime-away and then returned. This wastewater is high in iron and manganese, such that the modules require cleaning one per week. Twice each year the modules are removed completely for a more rigorous cleaning. The Accomac plant uses both dilute sulfuric acid and Windex to clean the quartz. This is done more frequently in the summer because of algal growth through the plant, requiring a cleaning approximately once per month. The frequency decreases to once per month during the winter. At New Providence, a scouring pad (Brillo) is used with detergent to clean the quartz surfaces. The frequency is variable, ranging from once per week to once per five weeks.

A 6 percent phosphoric acid solution is used approximately once per 6 months, based on coliform densities (when fecal coliforms exceed 40 per 100 mL). This frequency is once per three weeks at Williamson, which uses a mild acid solution. Athens uses Lime-Away, cleaning at a frequency of three times per year. This is based on coliform density. There is difficulty in accessing the modules from these deep channels. Two operators are needed; one holds the module, while the second cleans it. The operators stated a need for a hanging rack.

Olathe, Willow Grove, and Warminster all use Lime-Away, at a frequency based on intensity meter readings. This is once per six weeks, three months, and six months respectively. Each removes the modules, applies the Lime-Away with a soft cloth, and then rinses with clean water.

3.2.2.1 Frequency and Labor Requirements for Cleaning

The frequency of cleaning is highly variable, ranging from once per week to once per year. Table 3-6 presents the estimated time spent per year for cleaning the quartz, based on input from the operators. It is not appropriate to simply include this in the O&M labor requirement summarized on Figure 3-3. Rather, the time required per 100 lamps is normalized to the cycles per year, which is shown on Table 3-6.

There is no clear trend in this value relative to plant type or size. The labor requirement ranges from 0.7 to 26 hours/cycle/100 lamps. Eighty percent (24 of the 30 plants) are less than or equal to 8.3 hours/cycle/100 lamps, with a mean value of 4.3 hours/cycle/100 lamps. The remaining 6 plants range between 10.4 and 26 hours/cycle/100 lamps, with an average of 17.4 hours/cycle per 100 lamps. The overall 30 plant mean is 6.9 hours/cycle/100 lamps.

Overall, a value to 5 to 10 hours/cycle/100 lamps would appear to be appropriate for use in screening a facility labor requirement for cleaning. Actual yearly requirements will then depend on the frequency. Of the 30 plants, the median frequency was approximately one per month or 12 times per year. Using a median estimate of 5 hours/cycle/100 hours and 12 cycles per year, the yearly requirement would be 60 hours /100 lamps. When compared to the labor requirements on Figure 3-3, this is twice that of the large plants and equivalent to that of the smaller plants. Thus, the cleaning activities can comprise one-third to one-half the total labor requirement for (O&M).

3.2.2.2 Summary Assessment of Cleaning Practices

The cleaning practices, as presented in the preceding discussions is highly variable. The principle points are summarized on Table 3-7, addressing the equipment and methods used for cleaning; the cleaning agents; the criteria used for cleaning; and the resultant frequency and labor use.

The dominant practice is to remove the modules from the channel, with or without provision of a rack to hang the module. In-place recirculation or dip tanks are more typically used for the vertical lamp module systems. The standard practice for manually cleaning the units is to simply apply the cleaner onto the quartz and then rinse the module with clean water.

Citric acid and Lime-Away are typically used as cleaning agents, although several others are used including detergents and other dilute acids. There is no strict criterion that sets the type of cleaner; the manufacturer will generally recommend one or more. It becomes a matter of trial and error specific to the plant site. This is also the case with frequency; as noted, this varies widely and depends on the specific site requirements.

The criterion for cleaning is typically based on fecal coliform densities. This was the case for two-thirds of the selected plants. The remaining third was split between using the intensity meter reading, or simply setting a proscribed frequency.

TABLE 3-7. SUMMARY OF CLEANING PRACTICES FOR THE 30 SELECTED PLANTS

A. Equipment Use for Cleaning	Number of Plants	Comments
(1) In-place Recirculation	4	All vertical lamp modules; Remove once/year
(2) Mechanical Wiper	1	One of four "in-place" units
(3) Dip Tanks	2	
(4) Remove modules onto a rack	5*	
(5) Remove modules	19*	No special equipment to hold the module

*Method is to rinse, apply cleaning agent, rinse, and return to channel.

B. Cleaning Agents	Number of Plants	Comments
(1) Citric Acid	9	Two dip tanks, four in-place, three external modules
(2) Lime-Away	10	Commercial product
(3) Dilute HCI Acid	4	
(4) Detergent	3	dishwashing detergent; Windex; a plant also uses Brillo pads.
(5) Phosphoric Acid	2	
(6) Sulfuric Acid	1	
(7) Tile/Bowl Cleaner	1	Commercial product

TABLE 3-7. SUMMARY OF CLEANING PRACTICES FOR THE 30 SELECTED PLANTS (Continued)

	Number of Plants	Comments
C. Frequency (cycles)		
(1) Weekly (52/year)	2	
(2) Monthly to biweekly (12 to 26/year)	14	
(3) Six weeks to yearly (1 to 9/year)	14	
D. Labor per cycle/per 100 lamps		
(1) 1 to 10	24	mean, 4.3 hours/cycle/100 lamps
(2) greater than 10	6	mean, 17.4 hours/cycle/100 lamps
E. Criteria for Cleaning		
(1) Fecal coliform	20	
(2) Intensity meter	5	
(3) Routine	5	

In summary, the following observations are made:

- removal of the modules is appropriate and probably best for most plants. Cages are suggested for larger plants for removing bundles of lamp modules.
- moving hoists/cranes will facilitate removal of the module bundles or vertical lamp modules,
- dip tanks provide a convenience and assist in cleaning modules removed from the channel,
- in-place recirculation is effective, particularly for vertical lamp modules. Agitation should be provided during the recirculation cycle. Plant should still plan to remove the modules once per year for a rigorous cleaning.
- the cleaning agent(s) that suits the facility is dependent upon the nature of fouling. A trial and error series of test should be conducted, using readily available, off-the-shelf commercial products,
- frequency of cleaning will be dependent on the specific site requirements,
- small-scale piloting would be very effective in establishing the cleaning agents and frequency most suitable to a specific plant, and
- monitoring fecal coliforms is an effective tool for determining the need for cleaning lamps. Note that this is also used for triggering lamp replacement.

SECTION 4.

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APPENDIX A

SITE VISIT REPORTS

- NW Bergen County, Waldwick, New Jersey
- Blytheville, Arkansas
- Piggott, Arkansas
- Wallkill, New York

SITE VISIT
NORTHWEST BERGEN COUNTY WASTEWATER TREATMENT PLANT
March 2, 1990

The Town of Waldwick, New Jersey is approximately 20 miles due north of Newark, New Jersey. Mr. Dave Alvarez, the operations supervisor who has been at the plant for nine years, conducted the plant tour. It is a secondary treatment facility which employs the activated sludge process. Preliminary treatment is accomplished through screening and comminution. Primary settling is provided by three primary settling tanks; a primary sludge degritter removes inert material prior to on-site incineration. Oil and grease skimmed from the surface of the primary clarifiers are also incinerated. The activated sludge system is composed of three aeration basins, each of which has two passes, generating in the step aeration mode. Secondary clarification is provided prior to disinfection and final discharge.

Disinfection is accomplished by ultraviolet radiation. The UV disinfection system is a retrofit, with the UV equipment installed in an existing chlorine contact chamber. As shown on Figure A-1, the rear half of the chlorine contact chamber was utilized for the equipment installation. The front half provided a long straight approach channel to the UV system. The chlorine contact chamber walls were widened in order to decrease the channel width to the proper size for accommodating the UV equipment. A structure was also built over the last half of the chlorine contact chambers which fully encloses the UV equipment.

The decision to replace chlorination with ultraviolet disinfection was the result of a study which investigated several disinfection alternatives, including hydrogen peroxide, ozonation, chlorination and ultraviolet radiation. The study was conducted due to growing concerns over safety issues involved with continued use of chlorine for disinfection and the fact that dechlorination would soon be required. The Rehoboth Beach, Warminster and Willow Grove wastewater treatment plants were three of four treatment plants using ultraviolet radiation that were visited as part of the disinfection study. Ultimately UV disinfection was chosen on the basis of safety, cost and maintenance.

The disinfection unit consists of two disinfection channels, with one being totally redundant. It is an open channel design with lamps arranged horizontal and parallel to the direction of flow. The equipment was supplied by Trojan Technologies, Inc., London, Ontario, Canada. Each channel has two banks of lamps in series and is rated for 12 mgd with both banks in operation. Each bank contains 240 lamps (58 inch arc length) in 30 modules of 8 lamps/module.

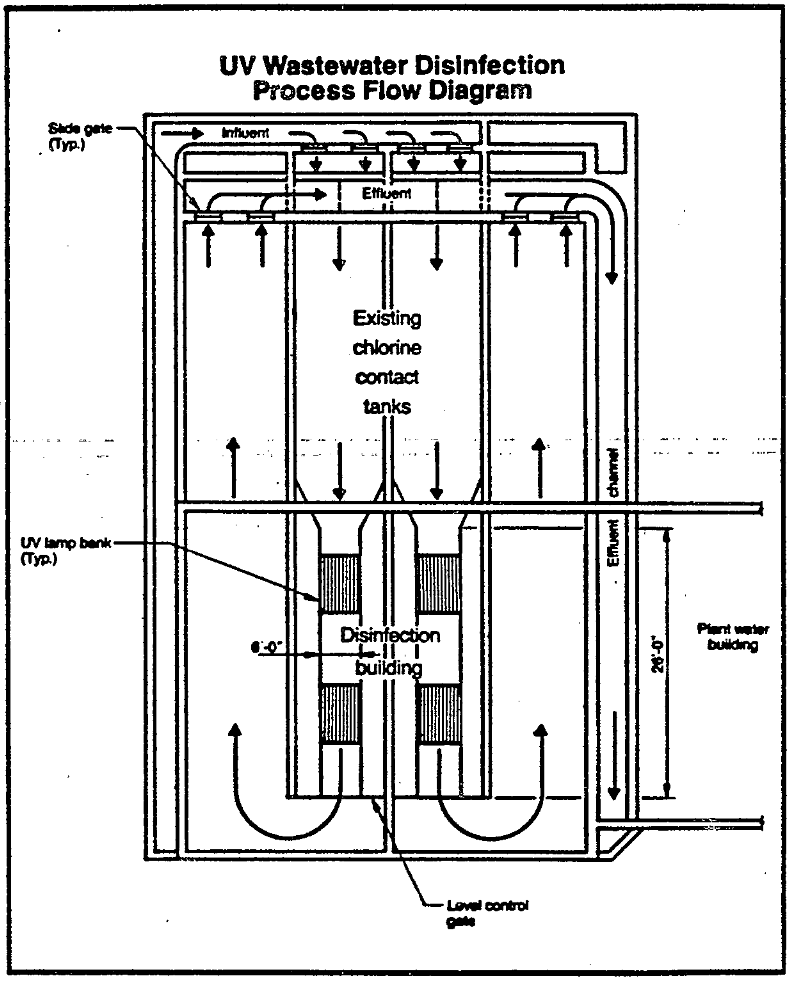
The UV system has a flow monitoring device which controls the operation of the system. The second bank of lamps is brought into service when the flow reaches 6 mgd. Once the second bank is brought into service it remains on for a minimum of two hours regardless of flow. A skimmer is provided in front of the UV inlet to prevent floating debris from fouling the lamps. A level control gate is provided on the effluent end of the disinfection channel to maintain adequate liquid level in the channel.

The control systems are housed in upright steel cabinets. One cabinet is provided for each bank of lamps. The system controls include: a lamp status display; and elapsed time indicator; and an intensity monitor. The lamp status display consists of a pattern of indicator lights arranged identical to the lamp arrangement in the channel. A lit lamp indicates that either power to the lamp has been interrupted or the lamp has burned out. The elapsed time indicator is used to record operating time and schedule maintenance, one indicator is provided for each bank of lamps. The intensity monitor displays the quantity of ultraviolet energy being delivered by the system in microwatts per square centimeter.

The lamps are cleaned on a monthly basis. A cleaning station is located in one corner of the UV building. It consists of a bermed area to contain possible spills and utilizes a stainless steel bath into which a module is placed for cleaning. A phosphoric acid solution is used for lamp cleaning. The tank is also aerated to provide agitation of the cleaning solution for improved cleaning. After cleaning, the lamps are thoroughly rinsed and then dried prior to being returned to service. Visual inspection and recording of the systems operational parameters (elapsed time, lamp status and intensity) is performed three times per day.

The plant design flow is 12 mgd; it currently averages around 10 mgd. The plant's fecal coliform limit is 200 organisms/100 mL as a 30-day average and 400 organisms/100 mL as a 7-day average. Coliform sampling is performed four days a week. The samples are generally taken during periods when the UV is under its heaviest load. UV transmittance is run along with the coliform testing. The operator reported that since the UV equipment has been installed there have been no counts over 400 organisms/100 mL and only a few occasions where the count exceeded 200 organisms/100 mL. He also added that the system has gone over its design flow several times without problems.

Plant personnel are very pleased with the system, and felt that they made the right choice by moving to UV. To this point the following benefits were reported: less intensive maintenance; no chemical costs; less safety training is required and it is less of a liability from a safety standpoint than chlorine disinfection. It was noted that a screen would be a benefit, placed upstream of the first bank of lamps. Debris tends to accumulate on the lead end of the modules.



Since only a few seconds of ultraviolet exposure are required to treat effluent, there is no need for large contact tanks. It is possible to retrofit most UV systems within existing chlorine contact tanks, like this one at Northwest Bergen County's wastewater plant.

Figure A-1 Layout of Retrofit at NW Bergen Plant
(Reference 21)

SITE VISIT
BLYTHEVILLE WASTEWATER TREATMENT PLANT TRIP REPORT
November 16, 1989

A visit was made to the Blytheville Sewer District which owns and operates three wastewater treatment plants: the Blytheville North WWTP, South WWTP and the West WWTP. Blytheville, Arkansas is located in Mississippi County and is 55 miles due north of Memphis, Tennessee. The wastewater flow to the plants is primarily domestic; all three plants process trains are essentially identical.

They are extended aeration activated sludge plants. Preliminary treatment utilizes an Aquaguard Traveling Screen screenings are shredded by grinder pumps prior to disposal. The Biolac-R extended aeration activated sludge system manufactured by the Parkson Corporation, Fort Lauderdale, Florida is used for secondary treatment.

The North plant is the smallest of the three and is designed for a flow of 0.8 mgd and a BOD loading of 1,134 lbs/day. The South and West plants handle 1.40 mgd and 1.50 mgd average flow, and BOD loadings of 3,562 lbs/day and 3,253 lbs/day, respectively. All three plants have the same discharge limits. The BOD and TSS limits are 30 mg/l as a 30-day average and 45 mg/L as a 7 day average. Coliform limits are seasonal; between October and April the limits are 1,000 fecal coliform per 100mL as a 30-day geometric mean, and 2,000 fecal coliforms per 100 mL as a 7-day geometric mean. Between May and September the limits are 200 fecal coliforms/100 mL as a 30-day geometric mean and 400 as a 7-day geometric mean.

All three plants went on-line in April, 1989. Each plant is operating at approximately half its design flow, with average effluent BODs under 15 mg/L, and average TSS levels less than 20 mg/L. There have been coliform excursions, with 7-day averages exceeding 1,000 fecal coliforms/100 mL. Plant personnel reported no major problems with the disinfection systems.

The disinfection system in each plant consists of one channel. The equipment was furnished by Ultraviolet Purification Systems (UVPS) Bedford Hills, New York (now Katadyn Ultraviolet Systems). The North plant utilizes 64 lamps (58 inch arc length). The South and West plants each use 96 lamps (58 inch arc length). Each system is eight lamps deep and arranged in 4 banks. Bank 1 consists of the bottom 5 horizontal levels of lamps, which remain on continuously. Banks 2 through 4 represent lamp levels 6, 7 and 8 respectively. These banks come on individually as the liquid level in the channel increases.

The system controls are housed in a steel cabinet adjacent to the disinfection channels. The system controls include: a lamp status display; elapsed time indicators; an analog intensity monitor and hand switches for manual control of power to each rack of lamps. The lamp status display is a clearly labeled pattern of indicator lights which matches the pattern of lamps in the disinfection channel. The indicator lights remain lit when power is being delivered to the lamp and the lamp is on. The indicator light goes out when power to a lamp is interrupted or a lamp has burned out. Elapsed time indicators are provided to record operating time and schedule maintenance for each bank of lamps. The analog intensity monitor relates the intensity of the radiation to existing wastewater conditions. It is calibrated to read 100 percent with a new lamp and clean effluent. Beneath the intensity monitor are 3 indicator lights; the red light indicates system failure; the yellow light indicates low intensity and the green light indicates safe operation. Still further below the indicator lights, there are intensity test buttons. They test the analog reading 0, 50 and 100 percent intensity.

Log books are kept at all plants; all maintenance performed and any observations made from visual inspections are recorded. Visual inspections of the UV disinfection system are made at least daily. The lamps are cleaned weekly using a soft brush and a product called Simple Green™. This product is sold in auto parts stores as a general purpose detergent and degreaser. The district had recently acquired a lamp rack tester which checks on the lamp status display.

The system should have multiple channels. As it stands now, there is no backup system to put on-line during lamp cleaning or repair and maintenance tasks. The cause of the high effluent coliform counts had not been identified. Upstream protection of the disinfection system in the form of screens may also be appropriate.

SITE VISIT
WALLKILL WASTEWATER TREATMENT PLANT
March 1, 1990

The Town of Wallkill, New York is approximately 50 miles northwest of New York City. Preliminary treatment is accomplished by comminution followed by automatic bar screening (by-pass to manual screening as a backup) and grit removal using a cyclone degritter. Primary settling tanks are not provided. Effluent from the cyclone degritter is biologically treated in oxidation ditches which operate in the extended aeration mode of the activated sludge process. Stationary surface impellar type mechanical aerators are employed for aeration requirements. Secondary settling is achieved in two secondary clarifiers. Secondary effluent flows to three UV disinfection units prior to final discharge to a nearby river.

The plant is designed for a peak flow of 10 mgd and a daily average flow of 4.0 mgd. Space is provided in all structures for additional equipment needed for expansion to 6.0 mgd. There were two permits written, both of which meet or exceed standard secondary treatment limitations. The plant was designed for nitrification and is limited to 8.1 and 5.0 mg/L of NH_3-N in the effluent for winter and summer seasons, respectively. The disinfection season runs from May 15 through October 15, limiting fecal coliform discharge to 200 organisms/100 mL as a daily average, with a maximum daily of 400 organisms/100 mL.

The plant went on-line November 16, 1989. Since startup, the average plant flow has been 2.2 mgd with a peak flow of 3.6 to 3.7 mgd. The plant has performed well in general, achieving average removals of 90 percent and 96 to 97 percent for BOD and TSS, respectively. It had experienced some problems with nitrification. The operator due to the record cold weather throughout the month of December 1989.

The UV disinfection system consists of three channels in parallel. The equipment was furnished by Arlat Technology, Bramalea, Ontario, Canada. Arlat Technology has since sold the rights of their UV disinfection business to

Fisher and Porter, Inc. Arlat, however, is responsible for the performance of the equipment and any warranty claims (should they be made) at this facility. Each unit contains 208 lamps (58 inch arc length) and is rated for 6.0 mgd. The system is an open channel design with a horizontal lamp arrangement. Slide gates located at the head of each channel are provided for flow control to the individual disinfection units. The flow passes through the channel parallel to the lamps. A level control gate is provided at the effluent end of each channel. A liquid level sensing device is also provided. This device controls operation of the lamps in rows five through eight based on height of flow in the channel (rows 1 through 4 are on continuously).

The lamps and quartz are completely sealed on either end, held in place by plastic snap grip tube clamps which are riveted to the steel lamp rack. Removal of a lamp rack automatically shuts down the power to that rack. Wiring from individual lamps is bundled together with plastic ties. Lamp wires are then connected to the main power line through plastic twist connect fittings which are spaced across the top bar of the lamp rack assembly. The main power line from each rack then runs to the main power supply and control panels. The power supply and control panels are contained in stainless steel housings which are set at grade level above the units.

Two free standing control panels are supplied for each channel. Each control panel consists of 2 sections: (1) a lower section containing line voltage power supply components; and, (2) an upper section containing low voltage and monitoring equipment. Power supply equipment located in the lower section consist of ballasts and breakers. One instant start, high power factor type ballast with auto-reset thermal protection is provided per pair of lamps. Lamps are protected by single-lamp breakers which are complemented by ground fault circuit interruptors. Upper section monitoring equipment include: LED display for monitoring lamp operation; a UV intensity monitor; and a clock for recording the hours of operation.

The lamps will be manually cleaned as needed. A steel cleaning rack is located at the edge of the channel. The lamps will be cleaned with a soft brush and a cleaning solution provided with the equipment. Cleaning frequency has not yet been established since the disinfection system had not been put on-line as yet.

UV was not originally chosen to accomplish disinfection. The original designs called for chlorination. Before formal review of the designs by the governing agency, the municipality was told the plans would not be reviewed if chlorination was specified. At that point UV was incorporated into the facility plan.

The UV system as previously mentioned has not yet been started up. The plant plans to start up the system one month prior to the beginning of the disinfection season which begins May 15, 1990. This is being done to assure the system is fully operational prior to May 15. Performance testing of the system by the contractor is scheduled for the beginning of April. The system will be tested for one month. A follow up call to the plant revealed that the testing had begun during the first week of April. The tests were being conducted on one channel with full plant flow (~2 to 2 1/2) with influent and effluent samples being taken twice daily.

Plant personnel were generally displeased with the UV system. The chief operator felt that the use of UV disinfection was forced upon him and he thinks the system will be difficult to maintain. He envisioned maintenance personnel involved in lamp cleaning on a daily basis. He also commented that the UV system was one of the most expensive pieces of equipment on the site ($400,000). His perception of lamp cleaning was greatly influenced by a nearby plant that was experiencing problems with their UV system.

General comments regarding the design and operation of the system are as follows:

1. The system should be enclosed. An enclosure would provide protection against adverse weather conditions.

2. There should be upstream protection of the UV system in the form of screens.

3. The design and construction materials used for the lamp rack are poor.

   Plastic material used for electrical connections and lamp holders is not well suited for its intended purposes. Lamp replacement would be more difficult than the manufacturer's literature would lead one to believe.

4. Baffles are not provided prior to the UV lamps. Considering the nature of the influent structure, high turbulence may result.

5. Performance testing as it was briefly described, may not be representative of the performance specifications. At 90 percent BOD removal and 96 to 97 percent TSS removal, the plant is most likely achieving far better than a 30/30 effluent which the UV performance is written on. The flow of 2 to 2 1/2 is also only 30 to 40 percent of its rated flow.

SITE VISIT
PIGGOTT WASTEWATER TREATMENT PLANT (WWTP)
November 15, 1989

A visit was made to the Piggott WWTP, Piggott, Arkansas on November 15, 1989. The plant was designed by Hildson Engineering which is located in the Memphis, Tennessee area. Piggott, Arkansas is approximately 85 miles north of Memphis, Tennessee. The plant waste flow is characterized as 100 domestic. Although the sewer district has separate sanitary and storm sewers, the plant receives significant peak flows during storm periods due to inflow/infiltration. The plant is located adjacent to a lagoon which was previously used as the sewer district's treatment facility. A section of this lagoon is used for storage during high flows.

The facility is an extended aeration activated sludge plant. Preliminary treatment consists solely of screening by an Aqua-Guard™ Traveling Screen. After screening, the influent flow is measured by a parshall flume prior to biological treatment. Biological treatment is accomplished by the Biolac-R Extended Aeration System manufactured by the Parkson Corporation, Fort Lauderdale, Florida.

The plant is designed for an average daily flow of 0.6, a loading of 1,000 lbs/day for BOD and TSS and an ammonia loading 75 lbs/day. A review of the plant's discharge monitoring report reveals a discharge limit of 30 mg/L as a daily average and 45 mg/L as a daily maximum for both BOD and TSS. Ammonia is limited to 4 mg/L and 6 mg/L May through October and 7 mg/L and 11 mg/L November through April for daily average and daily maximum limits, respectively. Seasonal limits are also written for fecal coliforms; 200 FC/L and 400 FC/L from April through September for daily average and maximum daily, respectively. October through March the daily average is 1,000 FC/L while the daily maximum is limited to 2,000 FC/L.

The plant went on-line in April 1989. Since startup the plant flow has averaged approximately 3.0 mgd. A review of recent plant data (June through

October) operating shows some problems. Although the plant met its effluent BOD limit throughout this period (averaging 21 mg/L), the effluent TSS levels are consistently above permitted levels. The average effluent TSS was 35 mg/L. The plant superintendent believes the plant effluent will improve once it gets up to its operating MLSS.

The disinfection system performance has been poor. Monthly daily maximum effluent fecal coliform counts are all above 10,000/100 mL while the daily averages for these months ranged from about 4,000 to 18,000/100 mL. This is attributed to the high effluent suspended solids, and to the inability to maintain a full complement of bulbs in operation. Although the system appeared to be fully operational at the time of the visit, the low intensity warning light was lit. The plant superintendent reported that the problems with the system have never been satisfactorily resolved.

The UV disinfection system consists of one channel, without a backup. The equipment (Model 70UV2000) was furnished by Fisher and Porter Company, Warminster, Pennsylvania. The unit contains 64 lamps (58 inch arc length) and is rated for 0.6 mgd. The system is a horizontal, open channel design. The lamps are arranged parallel to the direction of flow. They are laid out in eight modules across, and eight lamps deep. The system is equipped with an automatic control device which controls the number of lamp levels in service at any one time.

The disinfection units system controls are housed in a stainless steel control cabinet. System control included: a lamp status display; cabinet temperature display elapsed time meters; and a UV intensity monitor. The lamp status display system consists of a series of indicator lights arranged in a pattern identical to that of the UV lamps in the channel. A dim light indicates that the lamp is powered and turned on; a bright light indicates the lamp has burned out and must be replace and an unlit light indicates that the lamp is not powered and is off (this means either the main power is off or the ballast is not functioning properly). An elapsed time meter is provided for each controlled level of UV lamps. It is mounted on the face of the equipment cabinet and is used to record and schedule maintenance as well as lamp replacement. This is an important feature since different controlled levels receive varied use. The cabinet temperature monitor displays the operating temperature and will actuate a common user-accessible alarm contact when the temperature within the cabinet exceeds a user-adjustable setting. Maintenance of adequate cabinet temperature is essential to prevent electrical component damage due to overheating. A UV intensity monitor is located on the cabinet face, it consists of a digital meter which indicates the intensity of the radiation being emitted by the lamps. The intensity probe can be positioned in various locations. The intensity monitor output is a measure of the lamps output given the wastewater clarity at that time. A loss of intensity at similar wastewater conditions indicates that the lamp should be checked and/or cleaned.

The flow to the disinfection unit is discharged over the effluent weir of the polishing basin. The liquid drops 8 to 12 inches into a long straight channel which directs the flow past the UV lamps. The long straight trough allows for little turbulence and therefore the dispersion factor should be low.

The lamps are cleaned weekly with water and a soft brush. An operations manual provided by Fisher and Porter recommends a cleaning solution of citric acid or a mild detergent and water. The manual also recommends treating the lamps, after they have been cleaned, and dried, with a protective coating of an anti-fouling solution.

The system should have multiple channels. The system as it stands now has no backup system to put on-line during lamp cleaning or repair and maintenance tasks. The electrical problems responsible for preventing the system from being fully operational on a full-time basis need to be corrected. There should also be an upstream protection of the UV system in the form of screens.

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