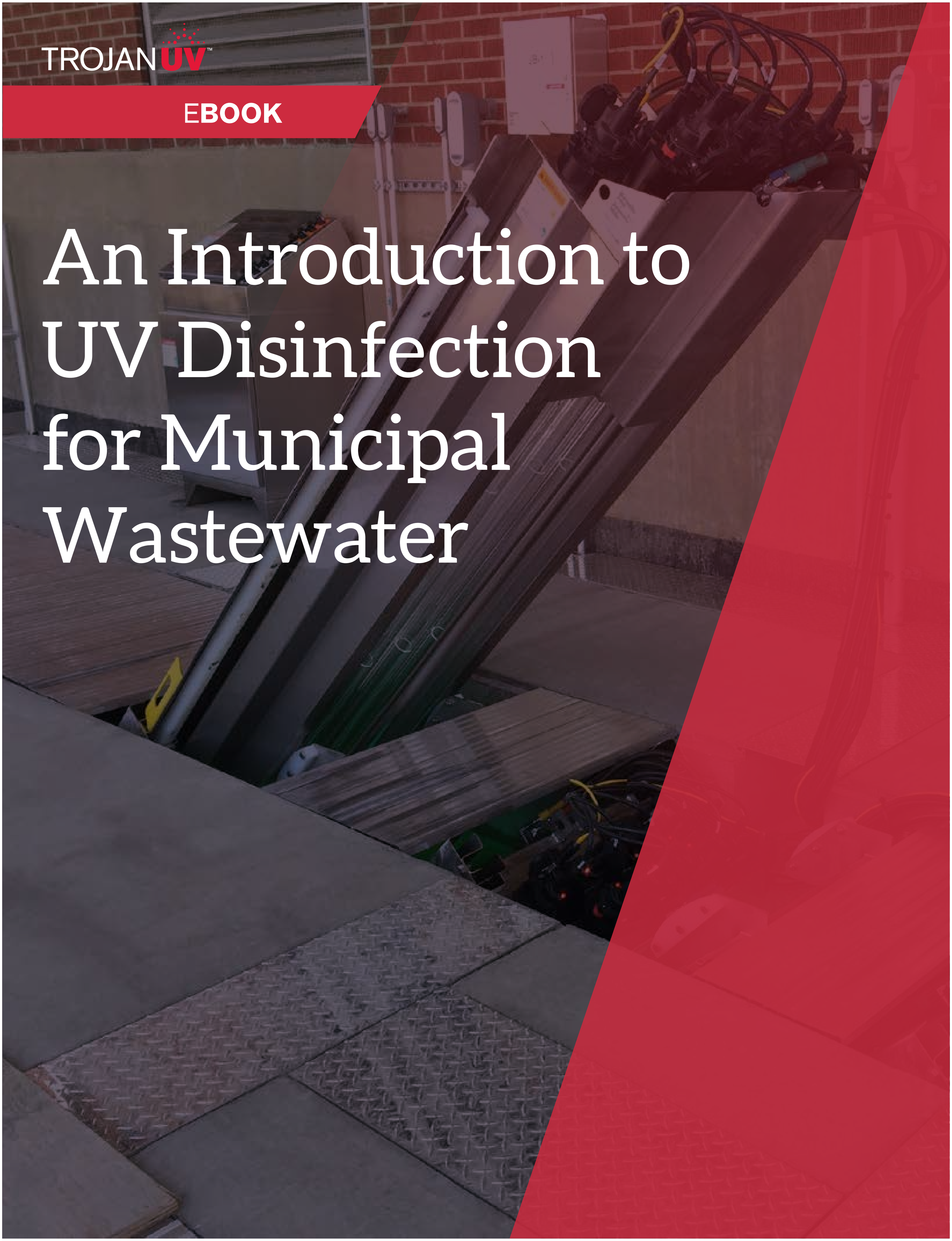
TROJAN UV

EBOOK

An Introduction to UV Disinfection for Municipal Wastewater



We developed this eBook to give you the information you need to know about UV disinfection for municipal wastewater. It's chock-full of insight and answers many frequently asked questions, such as:

- Why does wastewater need to be disinfected?
- What is ultraviolet (UV) light?
- What happens to microorganisms when they are exposed to germicidal wavelengths of UV light?
- How does UV light disinfect wastewater?
- How long has UV been used as a disinfection method?
- What are the different types of UV lamps?
- How does UV differ from chemical disinfection?
- What are the safety advantages of UV?
- What are the cost advantages of UV?

Are you currently disinfecting with chlorine and are wondering why you'd ever convert to UV?
Well, then this eBook is for you.

Are you already disinfecting with UV and want to learn more about how it works?
This eBook is perfect for you too!

Even if you're just looking for some general information about UV and wastewater disinfection, you're in the right place.

Ready? Okay, let's go!

WHY DOES WASTEWATER NEED TO BE DISINFECTED?

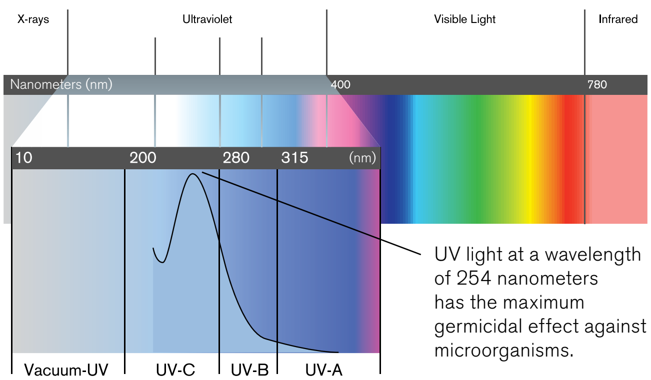
The final treatment step in municipal wastewater treatment is the disinfection process. Disinfection is required to reduce and destroy the bacteria, virus and protozoa populations in the wastewater before discharge into the receiving body of water. The disinfection of wastewater is critical to the protection of public health and the environment.

Growing awareness of the long-term public safety and environmental costs of chemical wastewater disinfection has led the industry to adopt inherently safer alternatives such as UV.

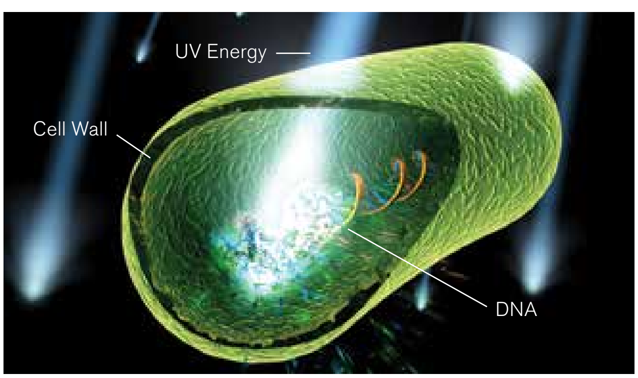
There are over 11,000 TrojanUV municipal installations throughout the world – these installations help safeguard municipal drinking water and disinfect wastewater against harmful microorganisms, viruses and contaminants.

WHAT IS ULTRAVIOLET (UV) LIGHT & HOW DOES IT DISINFECT?

UV light is a form of light that is invisible to the human eye. It occupies the portion of the electromagnetic spectrum between X-rays and visible light. The sun emits ultraviolet light; however, much of it is absorbed by the earth's ozone layer.



UV is an effective, safe and environmentally friendly way to disinfect wastewater. Unlike chemical disinfection in which substantial contact tanks and time are needed, UV light provides rapid, effective inactivation of microorganisms through a physical process. When bacteria, viruses and protozoa are exposed to germicidal wavelengths of UV light, they are instantaneously rendered incapable of reproducing and infecting. The process adds nothing to the water but UV light, has no impact on chemical composition or dissolved oxygen content, and does not create disinfection by-products.



Rendering of UV energy damaging a microorganism's DNA.

Microorganisms are inactivated by UV light as a result of damage to nucleic acids. The high energy associated with short wavelength UV energy, primarily at 254 nm, is absorbed by cellular RNA and DNA. This absorption of UV energy forms new bonds between adjacent nucleotides, creating double bonds or dimers. Dimerization of adjacent molecules, particularly thymine, is the most common photochemical damage. Formation of numerous thymine dimers in the DNA of bacteria and viruses prevents replication.

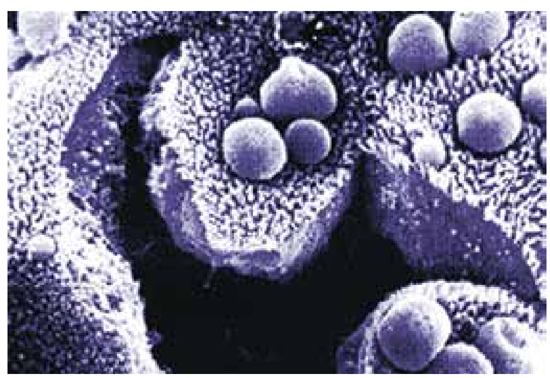
CAN ORGANISMS BE REPAIRED?

Photochemical damage caused by UV may be repaired by some organisms if the UV dose is too low via photoreactivation or dark repair. However, studies have shown that there is little to no potential for photoreactivation at doses higher than 12 mJ/cm^2. In fact, it has been shown that some organisms, like *Cryptosporidium*, do not exhibit any evidence of repair under light and dark conditions following low-pressure or medium-pressure lamp irradiation at UV doses as low as 3 mJ/cm^2.

That's why it's critical that UV systems be designed with enough UV dose to ensure cellular damage cannot be repaired. Sizing of a system should be based on bioassay validation (field testing) to ensure proper disinfection.

CHLORINE-RESISTANT PROTOZOA

UV offers a key advantage over chlorine-based disinfection, due to its ability to inactivate protozoa that threaten public health – most notably *Cryptosporidium* and *Giardia*. The release of these harmful microorganisms into receiving lakes and rivers by wastewater facilities utilizing chlorine disinfection increases the potential of contamination in communities that rely on these same bodies of water for their drinking water source and recreational use.



Cryptosporidium protozoan under a microscope.

THE HISTORY OF UV DISINFECTION

The application of UV as a simple and effective technology for water purification began in Marseilles, France in 1910. About that same time, chlorination was emerging in the United States as the primary means of eliminating microbial contaminants in drinking water.

In the early 20th century, the focus on wastewater treatment was essentially non-existent – being governed by the simple belief that the "solution to pollution is dilution." Over time, chlorination was adopted for the disinfection of treated wastewater. However, it was not until the Federal Water Pollution Control Act of 1972 that regulations were put into effect to establish standards for wastewater treatment and the quality of effluent discharged into the environment.

Chlorination addressed a fundamental requirement of wastewater disinfection – the destruction of pathogenic microorganisms that had the potential to cause human infection. But in the 1960's and 1970's, evidence of the detrimental effects of chemical treatment was mounting. Regulators recognized that destruction of microbial contaminants must be balanced with the impact of treatment on receiving waters. The long-term effects of chlorination, namely the creation of toxic disinfection by-products, had serious environmental and public health consequences. Alternatives were needed.

In 1976, the Environmental Protection Agency (USEPA) began to introduce limits on the levels of chlorine discharged with treated wastewater. In response, some facilities installed dechlorination equipment to reduce residual chlorine levels. Others sought technologies that would address the new discharge regulations, as well as eliminate the significant dangers to their staff and surrounding communities associated with transporting, handling, and storing gaseous chlorine at their treatment plants.

These regulatory drivers accelerated the development and adoption of UV light for wastewater treatment. Unlike facilities using gaseous chlorine, plants that employed UV disinfection would not be burdened by the costs of compliance with national and state fire safety codes for secondary containment of chlorine gas releases, local emergency response plans, and community right-to-know protocols.

WHAT IS DECHLORINATION?

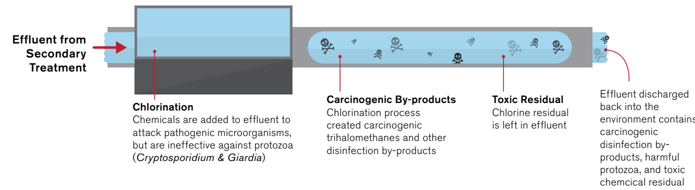
The dechlorination process typically involves the use of sulphur dioxide (SO_2), a corrosive gas that can cause eye and throat irritations at small concentrations, and a suffocating effect at higher exposure levels. As a result, it too requires special safety provisions for handling, storage, and emergency response training. Increasingly, sodium bisulfite ($NaHSO_3$) is being used as an alternative to sulphur dioxide.

In the final step of a treatment process using chlorine disinfection, gaseous sulphur dioxide is injected into the wastewater in a dechlorination basin. To adequately eliminate residual chlorine, it must be thoroughly mixed and requires contact time with the effluent of approximately one minute.

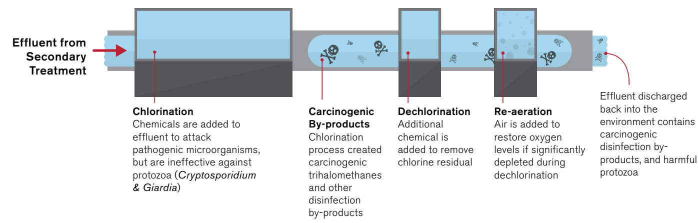
Precise dosing of sulphur dioxide is essential to achieve the desired result. Overdosing can result in the formation of sulfites, and lower the dissolved oxygen content and pH level of the effluent. If too much oxygen is depleted, the water must be re-aerated prior to discharge.

Although this process reduces chlorine compounds, scientific studies suggest that sensitive aquatic life are adversely affected by wastewater that has undergone chemical disinfection and dechlorination.

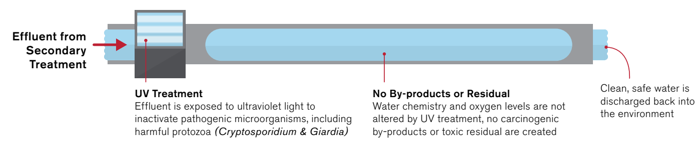
Chemical Disinfection



Chemical Disinfection with Dechlorination



UV Disinfection



In the late 1970's, the USEPA's Innovative and Alternative (I&A) Technology program helped fund several full-scale UV systems.

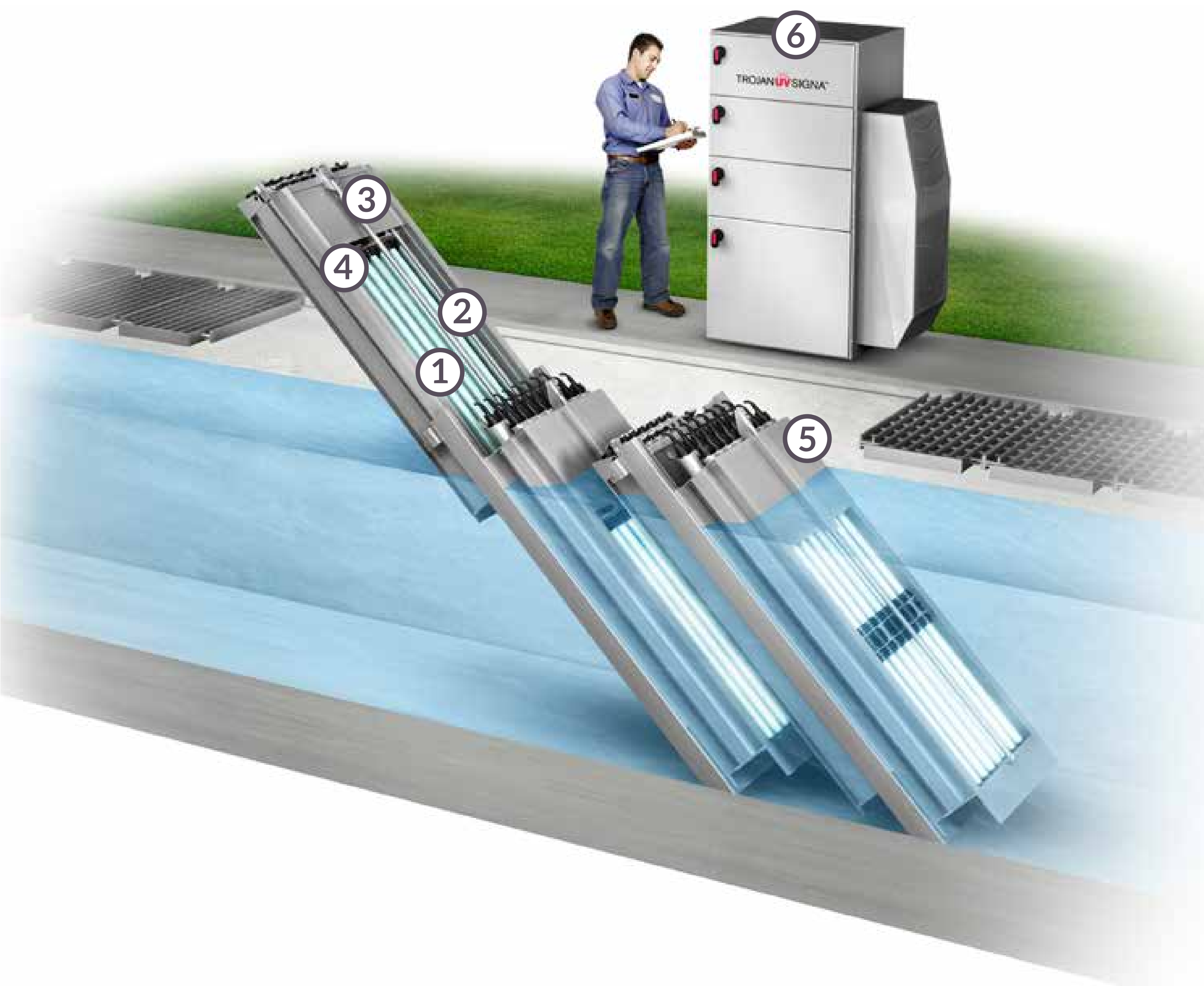
The success of these installations demonstrated that UV light was a viable treatment technology that provided highly effective disinfection without creating by-products. It was a clean and safe alternative to chemical treatment.

In 1986, the USEPA Design Manual: Municipal Wastewater Disinfection was published. It included comprehensive pilot data on UV systems and design guidelines for the application of this rapidly growing technology.

Today, roughly 50% of the wastewater in North America is treated with UV. This includes new plants as well as existing ones that have converted from chlorine.

WHAT A UV DISINFECTION SYSTEM LOOKS LIKE

UV wastewater disinfection uses a fundamentally different process than chemical-based systems and does not require large contact tanks. Instead, the clarified wastewater is directed through open channels where it flows past a series of ultraviolet lights that are submerged in the effluent. As bacteria and other microorganisms in the water flow past the array of UV lamps, they are exposed to ultraviolet energy and instantly inactivated – rendering them unable to infect or threaten public health and the environment.



1 Lamps

UV lamps, like fluorescent lamps, contain ionized gas mixtures that conduct electricity. When voltage is applied to the lamp's electrodes, an electrical arc is created causing the lamp to illuminate.

2 Lamp Sleeves

The UV lamps are housed in protective quartz sleeves that allow UV energy to be emitted into the water.

3 UV Intensity Sensor

The UV intensity sensor provides real-time monitoring of UV lamp output to ensure that specified UV levels are maintained.

4 Sleeve Cleaning System

Over time, exposure to the clarified wastewater can result in the quartz lamp sleeves becoming fouled, thereby limiting the output of UV energy. To prevent this build-up from occurring, and maximize system efficiency, many UV disinfection systems are equipped with automatic sleeve wiping/cleaning.

5 UV Banks or Modules

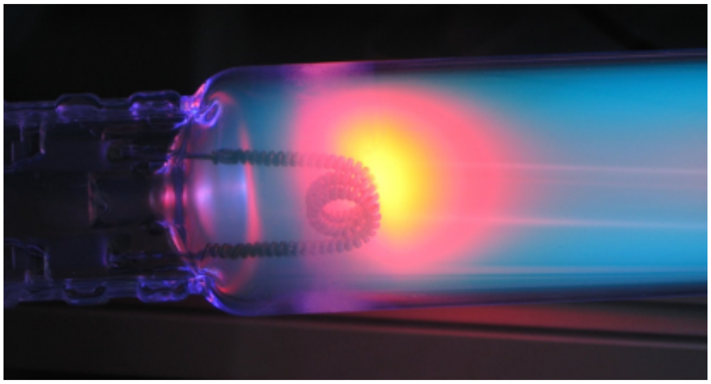
Modern UV systems use stainless steel banks or modules containing the UV lamps, lamp sleeves, wiring and, in some instances, the lamp drivers that regulate power to the lamps. The lower portion of the modules containing the lamps is submerged into the clarified wastewater to allow the wastewater to be illuminated with UV light.

6 System Controller

Modern UV systems include microprocessor-based control systems that vary the output of the UV lamps based on the volume and conditions of the wastewater they are disinfecting. These are linked into the main control systems of the treatment plant and permit remote monitoring of the UV system's performance.

THESE AREN'T YOUR ORDINARY LAMPS

A UV lamp is quite different than your standard incandescent light bulb. Yes, electricity is still passed through a tungsten filament which heats up, but that energy "excites" a very small amount of mercury vapor contained in the lamp. It is the mercury vapor that glows and emits the UV light.



TrojanUV Solo Lamp starting up.

Low-pressure lamps are extremely efficient and have a longer life. Medium-pressure lamps have higher UV output and power consumption but are more compact and can have less head loss.

In recent years, new lamp technology that combines the best features of both low- and medium-pressure lamps has been introduced. Thanks to this advanced technology, UV systems have become much more compact, efficient, and easier to install and maintain.

Lamp Spacing

UV banks and modules should be designed to optimize the number of UV lamps required to provide a specific dose with the necessary hydraulic capacity. The hydraulic characteristics require turbulent flow with mixing and minimal head loss. Lamp spacing is designed to optimize the water layer around the quartz sleeve and to provide the maximum average intensity, while minimizing the potential of short-circuiting.

UV Transmittance (UVT)

UVT is the ratio of light entering the water to that exiting the water. Simply put, water with high UVT (e.g., 90%) is relatively clear, allowing more UV light to reach the organisms you are trying to treat. As water quality decreases, the UVT is reduced (e.g., 50%) which in turn reduces the amount of UV light that can penetrate and provide treatment.

Lamp Aging

As lamps age, the amount of UV output decreases. The number of on/off cycles of the lamp also contributes to the decay in output of the lamp. UV systems should be designed to deliver the required UV dose at the end of lamp life (EOLL) to ensure proper disinfection before lamp replacement. EOLL should also be independently validated to guarantee the system meets disinfection requirements.

Quartz Sleeve Cleanliness

As mentioned earlier, each UV lamp is typically enclosed in a quartz sleeve to insulate them from the water. Quartz is used because it is transparent to UV light. An accumulation of inorganic and organic solids on the quartz sleeve, also known as fouling, decreases the intensity of UV light that can enter the surrounding water.

UV lamps in TrojanUV systems are enclosed in a quartz sleeve to insulate them from the water. ActiClean™ is our patented dual-action sleeve cleaning system that uses mechanical wiping in conjunction with ActiClean Gel contained within wiper canisters surrounding the quartz sleeves.

The fouling rate is site-specific, varies with treatment process, and may be more rapid in the presence of high concentrations of iron, calcium and magnesium ions. Other variables like water quality, temperature, velocity, and chemicals can affect sleeve fouling. In general, the fouling rate on the quartz sleeve is unpredictable, but can be prevented through a sleeve cleaning system or manually cleaning the sleeves with chemicals.

THE DIFFERENCES BETWEEN UV & CHLORINE DISINFECTION

UV is a very cost-effective and a reliable technology that protects the public against pathogenic microorganisms, including protozoa, bacteria, and viruses. Chemical disinfection using chlorine is also effective against these pathogens; however, there are pathogens such as *Cryptosporidium* and *Giardia* which are chlorine-resistant but can be disinfected by UV light.

Unlike chemical approaches to water disinfection, UV provides rapid, effective inactivation of microorganisms through a physical process. The retention time required to achieve disinfection ranges from a few seconds compared to several (>30) minutes for chlorine disinfection. This eliminates the need for large chlorine contact chambers, thereby reducing the required footprint and cost of installation.

	Chlorine Disinfection	UV Disinfection
No Disinfection By-products (DBP's)	✖	✔
No Chemical Residue	✖	✔
No Community Safety Risks	✖	✔
Effective Against *Cryptosporidium* and *Giardia*	✖	✔
Well-Suited for Changing Regulations	✖	✔

Safety

Chlorine is a highly toxic chemical that must be transported and handled with extreme caution. It is stored under pressure in large tanks and is released into the wastewater as a gas. It is a strong oxidizing agent that can be extremely dangerous to humans. If chlorine gas is inhaled, it comes in contact with moisture inside the lungs and converts to hydrochlorous acid. The resulting damage to the respiratory system can be permanent or fatal.

Disinfection with hypochlorite typically takes the form of sodium hypochlorite, which is a diluted liquid or solid form of chlorine that is mixed with sodium. It is a clear, yellow liquid that is corrosive, not unlike liquid bleach. Because it is diluted, it is not as volatile or toxic as chlorine gas – nor does its release have the same disastrous potential. It is typically purchased and delivered to the treatment plant in large volumes, or can be created on-site using a concentrated solution and mixing and pumping equipment.

The safety risks for operating a UV system, although low, are related to operator exposure to high levels of UV light and possible electrical hazards. The exposure to UV light is very low given that UV light is shielded from operators by channel grating and light locks. As well, there are lock-outs in the power cabinets to ensure power is off, and lock-out/tag-out occurs when servicing a UV system.

At-a-glance Safety Comparison

	Chlorine Gas	Sodium Hypochlorite	UV Disinfection
Community Safety	Chlorine gas is delivered to the treatment plant by truck or train. Chlorine gas has a ten-mile kill-zone placing the entire delivery route at risk.	Sodium hypochlorite has a limited shelf life, requiring frequent transporting and delivery of the corrosive substance.	UV disinfection is a chemical-free process that eliminates the need to transport and store dangerous chlorine. Disinfection with UV light poses no safety threat to the surrounding communities.
Employee Safety	Chlorine gas is toxic and must be handled with extreme caution. Training programs and certifications must be in place and routinely practiced and updated.	Sodium hypochlorite is corrosive and harmful if ingested or inhaled. It must be handled and stored with caution. Containment and leak protection equipment must be in place.	Employee working conditions are significantly improved. Operators are not required to handle hazardous, toxic chemicals.
Public Health Protection	Use of chlorine for disinfection creates carcinogenic by-products. These by-products, when released into the environment, can find their way into downstream drinking water supplies.	Disinfection with chlorine-based Sodium hypochlorite also produces carcinogenic by-products. Dechlorination does not remove or reduce these by-products.	UV disinfection produces no harmful by-products and does not alter or impact the quality of downstream receiving waters.
Treatment Performance	*Cryptosporidium* and *Giardia* are virtually unaffected by chlorine. In the past decade, these emerging pathogens have caused fatalities and disease outbreaks affecting hundreds of thousands of people.	*Cryptosporidium* and *Giardia* are virtually unaffected by chlorine. In the past decade, these emerging pathogens have caused fatalities and disease outbreaks affecting hundreds of thousands of people.	UV disinfection is highly effective against a wide range of pathogens, including chlorine resistant organisms such as *Cryptosporidium* and *Giardia.* The use of UV at wastewater treatment plants provides an additional level of protection for downstream drinking water supplies.
Environmental Impacts	Chlorine is extremely toxic to aquatic life. Dechlorinating (removing residual chlorine) requires the addition of a second chemical, which subsequently depletes dissolved oxygen that is essential for the survival of aquatic life.	Dechlorination is also required when using sodium hypochlorite for treatment. This process is often followed by a third step to add oxygen back to the water, increasing the cost and complexity of the treatment system.	UV disinfection does not add anything to the water, other than light. As a result, the receiving waters, aquatic life and wetlands rebound and flourish following the conversion of chemical disinfection to UV treatment.
Changing Regulations	Regulations are becoming increasingly stringent in order to limit the amount of chemicals and disinfection by-products leaving the wastewater treatment plant. Regulations for the protection of communities and employees will continue to become more stringent, increasing administration and other "hidden" costs.	Regulations are becoming increasingly stringent in order to limit the amount of chemicals and disinfection by-products leaving the wastewater treatment plant. As a result, the operation of chemical-based treatment systems will continue to become more costly and complex.	UV is well suited to meet current and future regulations. The process is safe, simple and straightforward to administer and implement.

Costs

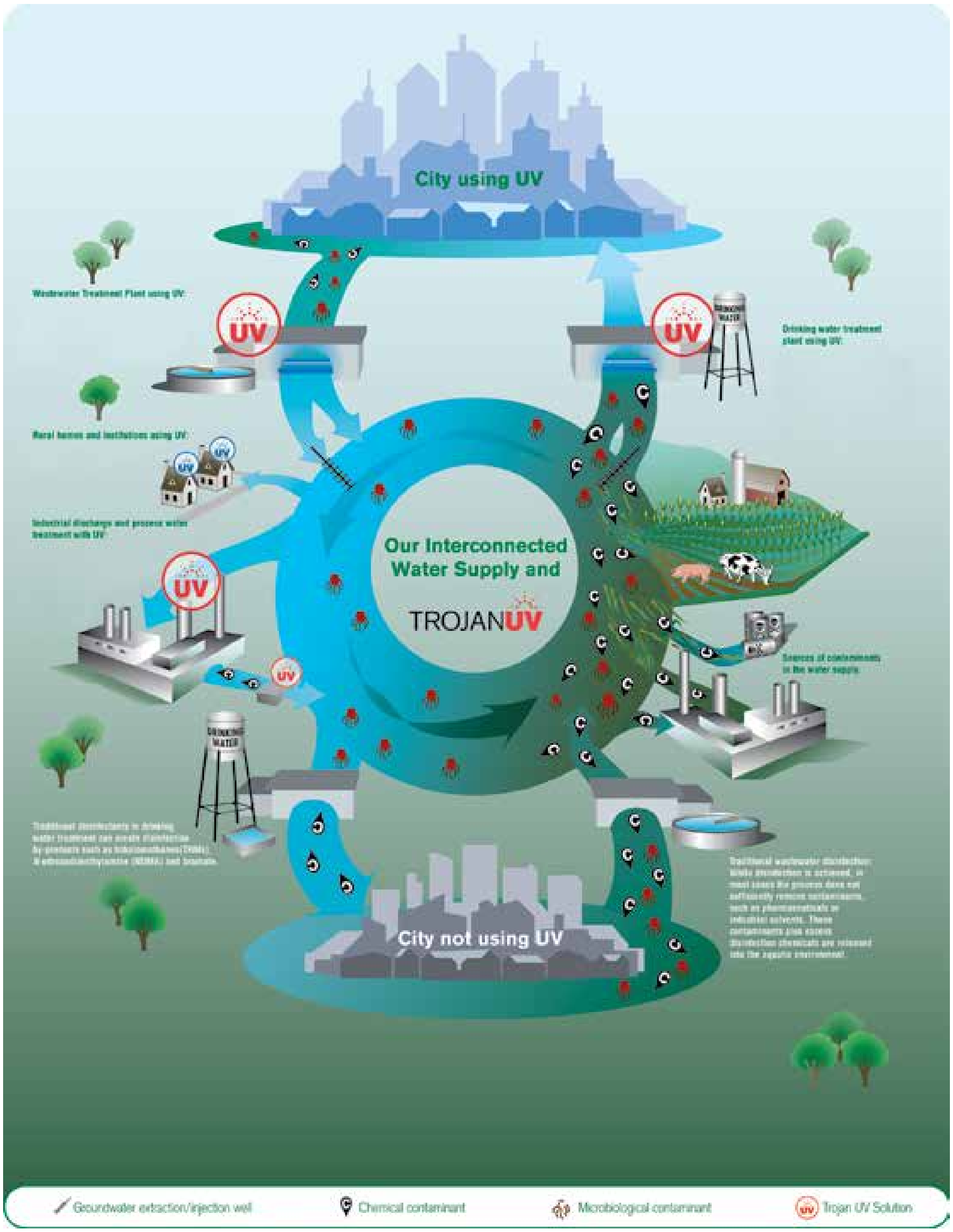
The initial capital expense and the operating expenses over a finite length of time (typically 20 years) can be added together to determine the total cost of implementation. This analysis is called a Life Cycle Cost analysis or an Investment Return Analysis. When combined with an evaluation of qualitative factors, including the safety benefits, the decision maker can then select the most appropriate treatment process for their application.

At-a-glance Cost Comparison

Ongoing Expense	Chlorine Gas	Sodium Hypochlorite	UV Disinfection
Disinfection/ Dechlorination Chemical Supply	**$$$** Purchase and delivery of chlorine gas cylinders.	**$$$$$$** Purchase and delivery or on-site generation of hypochlorite.	**None** No chemical supply is required.
Electricity	**$** Relatively low power requirements for chlorine gas disinfection.	**$** Power is required for operating chemical feed pumps and aeration equipment (if applicable).	**$$$$** Electricity is required to power the UV lamps.
Replacement Parts	**$** Replacement parts are minimal with chemical disinfection systems.	**$** Replacement parts are minimal with chemical disinfection systems.	**$$$** Replacement parts associated with UV disinfection systems consist primarily of UV lamps.
Operator Labor	**$$$$$$** Labor required for changing chlorine cylinders, maintaining lead detection and emergency equipment, maintaining on-site chemical distribution and storage equipment.	**$$$** Labor required to maintain pumps, generators, storage tanks, water conditioning equipment, de-scaling equipment, on-site chemical distribution piping.	**$** Labor includes replacing UV lamps periodically and ensuring that quartz sleeves that house the UV lamps are kept clean.
Leak Response Requirements	**$$$$$$** Costs for responding to and repairing leaks are very high.	**$$$** Since hypochlorite is less toxic than chlorine gas, costs in this area are reduced. However, there are costs associated with containment and leak protection of the hazardous chemical.	**None** UV lamps contain a very small amount of mercury. Leak response and emergency preparedness plans are not required, however, local guidelines must be adhered to. Trojan offers a complimentary recycling program in which used lamps are picked up and shipped to an approved recycling facility.
Administration for Ensuring Regulatory Compliance	**$$$$$$** Time-intensive administration for compliance with regulated risk management plans, emergency response plans and community right-to-know programs.	**$$$** Although sodium hypochlorite is exempt from “hazardous” designation, it is unstable and corrosive. As such, procedures must be in place to ensure proper transportation, handling, storage and spill protection.	**$** Administration costs for UV are low. No special safety programs or risk mitigation plans are required.
Training	**$$$$$$** Employees must be trained on process safety management, risk management plans, and evacuation procedures in addition to routine operation of the system.	**$$$** Training programs must be in place to ensure chemicals are properly transported, stored and handled.	**$** UV equipment is simple and straight-forward to operate. No special training or certification is required for operators.

WHY COMMUNITIES DOWNSTREAM (AND WE AT TROJAN) LOVE UV

UV is the only cost-effective disinfection alternative that does not have the potential to create or release carcinogenic by-products into the environment. In addition, UV is an effective disinfectant for chlorine-resistant protozoa like *Cryptosporidium* and *Giardia*. These harmful protozoa, if untreated in effluent, can find their way into drinking water intakes located downstream of the wastewater treatment plant.



UV disinfection is a safe, simple treatment process that does not use chemicals. Wastewater disinfected with UV does not have any negative effects on receiving waters of the treatment plant. As a result, it is well suited to meet current human safety and environmental safety regulations. And as regulations continue to evolve, we believe that UV wastewater disinfection remains the most responsible choice for protecting our communities and the environment.

YOU KNOW A LOT MORE ABOUT UV NOW

Congratulations, you've made it to the end of the eBook! We trust that you found it to be insightful and informative. To further your knowledge, we encourage you to visit **www.trojanuv.com** and **www.resources.trojanuv.com**.

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