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# Greenhouse and Nursery Sanitation: Irrigation Water and Equipment

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## The Importance of Good Sanitation

Proper attention to greenhouse and nursery sanitation is essential to reducing disease and pest outbreaks. In a 2019 survey of nursery growers on O‘ahu Island, pest and disease management was listed as the number one bottleneck to increased productivity. Diseases and pests can arrive through irrigation sources, soil and soilless media, plants, equipment, tools, growing containers, and human workers and visitors. Introduction of pathogens can also occur passively from the ecosystem surrounding the greenhouse, nursery, and plants on the perimeters of properties. Continual sanitation helps prevent outbreaks over the long term. While continual sanitation may seem like a waste of money and labor, the continuous positive effects on pest-control costs outweigh the recurring costs of maintenance sanitation.

This publication addresses **irrigation water and equipment sanitation**.

## Irrigation Water

Cleaning and sterilizing irrigation water is a priority for growers, especially in Hawai‘i where growers are sometimes using rainwater catchment and surface water sources. Pathogens from irrigation water include fungi and fungi-like organisms, bacteria, viruses, and nematodes (Stewart-Wade 2011). Water sources can also accrue algae, microbes, and sediments that will clog expensive irrigation equipment.

Surface water that was collected generally has higher microbial populations than well or municipal water (Raudales et al. 2017). Growers who are not using municipal water sources should be more attentive to irrigation contamination. Municipal water sources can also be susceptible to pathogen introduction, such as when there are leaks in lines or a backflow preventer is not used, allowing contaminated water to flow back into the irrigation system. While there are no current industry or regulatory standards on how often to test irrigation water, it should be done on a recurring basis. This is because testing water is a snapshot in time and only tells you what was in the water sample at the time of testing. As of 2019, there was no sanctioned organization in place for testing irrigation water for plant pathogens in Hawai‘i. Contact your local Cooperative Extension Service office to determine the best strategy for testing your irrigation water.

All treatment methods come with certain advantages and disadvantages relating to efficacy, cost, maintenance, infrastructure requirements, and toxicity, as well as their effect on the microbial communities in the water supply. These are all considerations when deciding which sanitation method to use. The remainder of this paper will discuss these treatment methods.

### *Cultural Methods*

**Prevention**

The first step to managing contamination of irrigation water is prevention. Steps should be taken to prevent soil and plant debris from entering irrigation infrastructure. Use barriers, screens, and/or films and keep the perimeters of water sources free and clear of debris. Pathogens can be introduced on the bodies of animals, so also take measures to reduce the possibility of animals coming in contact with water sources. Prevent any debris that does get into water sources from entering irrigation equipment. Allowing time for sedimentation to occur is one method. This will allow debris and pathogens to settle at the bottom of the reservoir. Larger particles and microbes take several hours to settle. Smaller microbes and particles require up to 48 hours to settle. Many viruses and bacteria are too small to gravity settle but are often associated with larger aggregates which may help with settling. Ensure outlet pipes for pumping systems are not at a depth or location that will cause uptake of settled or floating debris. Use proper filters for intakes and pumps. Water can also be stored for a period of time before using to allow for the lifespan of short-lived pathogens to expire (Van Kuik 1992). This time period is highly dependent on the pathogen. Some fungi like Fusarium, Pythium, and Phytophthora have spores that can survive months without contact to plant material, and the bacteria Ralstonia has been observed as still viable even after a year of starvation (Alvarez et al. 2008).

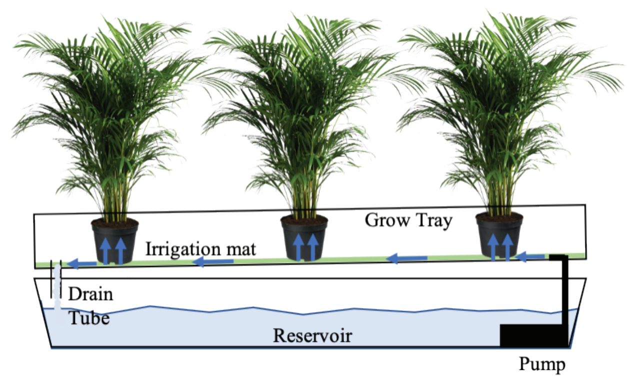


**Figure 1. Diagram of an ebb-and-flow irrigation system. A pump moves the nutrient solution from the reservoir into the growing tray. The solution moves through the irrigation mat into the pots through holes in the bottom of the pots. After a specified time, the water is drained out of the growing tray back to the reservoir.**

**Watering habits and inoculum reduction**

Irrigation practices and timing can reduce the propagation and spread of inoculum. Trickle and drip irrigation minimize excess water by reducing runoff of irrigation water which may contain disease propagules from the soil it filtered through (Hong and Moorman 2005). Irrigating more often and for longer periods of time will also hasten the spread of disease through irrigation systems and the nursery. Irrigating at night will also cause disease to spread faster and cause disease onset to occur earlier than daytime irrigation. Water is evaporated slower at night, which leads to longer time of exposure of standing water on plant tissue and other surfaces. If this water is contaminated, this can lead to more exposure to pathogens. Increasing soluble salts in irrigation water can reduce the spread of disease as well; for example, irrigation water with an electrical conductivity of 2.2 mS cm-1 reduced Phytophthora cryptogea infestation by 13.5% (Thinggaard and Anderson 1995). Understanding the salt tolerance of the crops being grown is important when employing this strategy.

***Physical Methods***

**Barriers**

Fiber mats and films can reduce the spread of pathogens. These can be used in ebb-and-flow systems (Figure 1), which work by recirculating irrigation water. In these systems, the plants grow on benches or floors in trays that are periodically flooded and drained after a specified period of time. Ebb-and-flow systems are popular worldwide because of the reduction in watering labor and the conservation of recycled water and nutrient solutions associated with them, though these systems are not yet common in Hawai‘i. The use of irrigation mats in ebb-and-flow systems can reduce pathogen movement by providing a physical barrier for pathogens as water moves through the system (van der Gaag et al. 2001).

**Filtration**

Filtration is one of the more commonly used methods for removing pathogens from irrigation water because it is one of the most reliable and inexpensive preventative methods. Filtration can be divided into slow and rapid methods. Slow filtration is a low-tech method, and a system can be built by someone with even limited knowledge of construction: chemicals are not used, and there is no need for pH adjustment.

The most common form of slow filtration is slow sand filtration (SSF) (Figure 2), which works by forming a biofilm that acts as a filter along with the sand itself. SSF was found to be successful in controlling fungi and fungi-like species in nursery conditions (Kubiak et al. 2015), as well as other microbes and nematodes. SSF is not completely effective in removing nematodes in irrigation water, though (Van Os et al. 1999). One issue

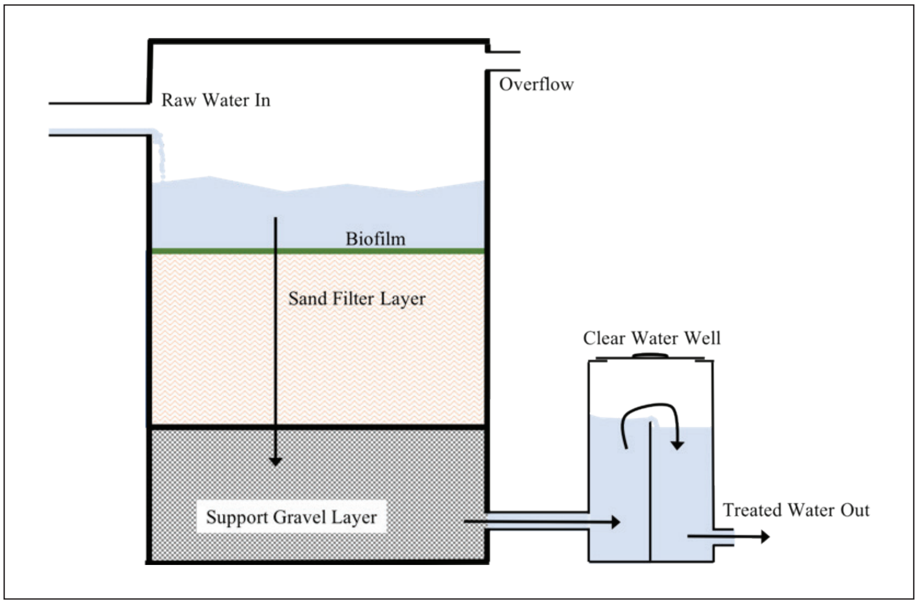


**Figure 2. Diagram of a slow sand-filtration water-treatment system. Water enters the system and is filtered through a biofilm and then a sand filter before moving through a layer of gravel to a clear water well where it can be stored for use.**

related to filtration is the large size of the infrastructure required. Efficacy depends on the size of the system and the sand particle size, as well as on the temperature and the microbial populations in the sand media. Alternative media in slow-filter systems include rockwool, pumice, and volcanic ash or grain.

Rapid filtration is generally 20 to 50 times faster than slow filtration but tends to be less effective at removing pathogens. This method is effective for pre-treatment filtration of water prior to disinfection.

Membrane filters can be used to filter pathogens from irrigation water. Membrane filters can remove particles sizes smaller than 0.1 nm, smaller than any pathogen. These systems are expensive to install and maintain and rely on high energy use for pumping. Membrane filters with a pore size of 0.01 mm can remove fungi and bacteria, while those with a pore size as large as 0.05 mm can remove fungi (Tu and Hardwood 2005).

Other less expensive and energy-consuming filter types include mesh filters, wound filter cartridges, pleated polyester filters, carbon filter cartridges, polypropylene disc filters, and activated carbon filter cartridges. These filters will screen out debris and solids including algae and fine silt at the smallest opening sizes. These filters will not be relatively effective in filtering out pathogens already in irrigation water, but they do eliminate debris that can clog irrigation and act as environments for pathogens and inoculum to survive.

## Heat

Heat is another method for disinfesting irrigation water. The most common method requires water to pass through heat exchangers that raise the temperature to 95°C (203°F) for 30 seconds for control of viruses (Newman 2004), and 60°C (140°F) for 2 minutes for elimination of fungi, fungi-like organisms, bacteria, and nematodes (Runia and Amsing 2001). Nematodes were completely controlled at temperatures of 45°C (113°F) for 30 minutes (Hallmann et al. 2005). This method requires high energy costs and large infrastructure but is effective in controlling plant-pathogenic organisms. One issue related to using heat exchangers is the build-up of calcium on the metal surface as well as the need for expensive corrosion-free metals that will not cause toxicity in irrigation water. This process requires natural gas as a fuel and can use between 270 and 350 $ft^3$ of fuel per 100 gallons of water. Heat treatment will also eliminate beneficial microbes, potentially disrupting the microbial community and allowing for the uninhibited growth of pathogenic organisms.

**Ultraviolet light**

Ultraviolet (UV) light treatment is commonly used for water treatment, including the elimination of pathogenic organisms. A UV dose of 100 mJ/cm$^2$ is recommended for killing pathogenic fungi. A dose of 250 mJ/cm$^2$ is recommended to eliminate any and all organisms, including difficult-to-kill viruses (Runia 1995). UV systems tend to be costly and require maintenance and replacement of expensive UV lamps. Like heat treatment, UV treatment will also eliminate beneficial microbes and can disrupt the microbial community of irrigation water.

**Other**

Other physical methods, including sonication, pressure, and electrostatic precipitation, are available and being researched for disinfestation of irrigation water but are not common.

***Chemical Methods***

Chemical treatments can be effective methods for controlling pathogens when combined with filtration methods. Eliminating solids in irrigation water will reduce the chemical demand of the water. Nutrients should not be added to irrigation water in combination with chemical treatments, since certain nutrient solutions will interact negatively with chemical disinfectants. The two treatments should occur separately from each other and clean water should be run through the irrigation lines to clear them before the other application occurs. It is very important to also consider phytotoxicity in chemical treatments. The phytotoxicity of the chemicals described below on plants commonly grown in Hawai‘i is not fully understood, and caution should be taken when using a new chemical treatment in irrigation water. The following chemicals are considered pesticides by the Environmental Protection Agency and are regulated under the Worker Protection Standard.

**Chlorine**

Chlorine is commonly used as a chemical means for disinfestation. Liquid chlorine is the most common form, but solid and gaseous chlorines are options as well.

**Table 1. Rates of chlorine in different chemical formulations for common pathogens based on mortality studies.**

| Pathogen | Rate | Time | Notes | Source |
|---|---|---|---|---|
| Virus (CLSV)[1] | 4 ppm hypochlorous acid | 30 min | 100% mortality | Rosner et al. 2006 |
| Algae (Ux, Mm, As, and Pm)[2] | 5 ppm chlorine dioxide | 30 min | High level of control | Junli et al. 1997 |
| Bacteria (Ps, Ea)[3] | 0.25 ppm chlorine dioxide | Daily | 2.28-fold (Ps) and 2.5-fold (Ea) | Truchado et al. 2018 |
| Fusarium (Conidia) | 2.5 ppm chlorine dioxide | 5 min | >90% mortality | Copes et al. 2004 |
| Fusarium (Chlamydospores) | 50 ppm chlorine dioxide | 5 min | 40% mortatlity | Wick 2010 |
| Phytophthora | 2.6 ppm chlorine dioxide | 2 min | Zoospores | Mebalds et al. 1995 |
| Xanthomonas | 3 ppm chlorine dioxide | Daily | >90% mortality | Krathausen et al. 2011 |
| Rhizoctonia | 4 ppm hypochlorous acid | 0.5 min | Over 50% mortality | Cayanan et al. 2009 |
| Nematode | 50 ppm hypochlorous acid | 11 min | No notes | Grech & Rijkenberg 1992 |

[1]CLSV= Cucumber leaf spot virus; [2]Ux=Ulothrix, Mm=Microphorimidum, As=Ankistrodesmus, and Pm=Phorimidium
[3]Ps=Pseudomonas, Ea=Enterobacteria

Chlorine forms hypochlorous acid in water, and this is the compound that disrupts microbial functioning. At different concentrations, chlorine is effective at controlling fungi and fungi-like organisms, bacteria, and viruses. A concentration of 4 ppm chlorine has been effective for eliminating all of these pathogens to some success (Hong 2001, Poncet et al. 2001, Rosner et al. 2006). The pH of irrigation water is an important consideration in the use of chlorine. At high pH, hypochlorous acid becomes ineffective at disinfesting. At pH 6, chlorine is at its peak activity, and as pH increases it becomes less active, up to pH 10, at which chlorine is completely ineffective. pH testing and acidification to pH of 6 will be necessary if chlorine is used to disinfest irrigation water (Shield 2001).

Chlorine concentrations must be monitored routinely, and proper chlorine levels must be maintained. The following steps should be taken for monitoring chlorine levels:

- Decide which dose response to apply to a system. Avoid going above 5 ppm total chlorine or 2 ppm free chlorine. Table 1 provides a general reference of some tested rates for different pathogens.
- Acquire a reliable chlorine meter that tests for total and free chlorine levels.
- Invest in a reliable inline dosage system. Just pouring chlorine into reservoirs is an inaccurate method for applying chlorine to irrigation water.

Chlorine is relatively inexpensive to establish as a practice, but the delivery system requires regular maintenance. It does have the added benefit of eliminating algae and other microbial life that can clog irrigation. A disadvantage of chlorine is that the harmful byproducts that can be created are hazardous to humans and the environment if large amounts are released. When chlorine reacts with nitrogen in water, it becomes ineffective at disinfesting.

Chlorine dioxide is a more powerful treatment option than chlorine but has shown inconsistent ability to control fungi and fungi-like organisms across the board, when compared to chlorine. While it is more effective in controlling some organisms, it does not have better general control. One benefit of chlorine dioxide is that it is not negatively affected by high pH (Stewart-Wade 2011). The optimum range for chlorine dioxide in treating pathogens is 0.25 to 3 ppm (Fisher 2011). Nematodes have been shown to be tolerant of chlorine up to 50 ppm for 11 minutes (Grech & Rijkenberg 1992). Chlorine dioxide is most easily applied as a solid tablet that is dissolved into a water supply which is then used as irrigation water, but this requires continual purchasing and application of tablets. Tablets are best used for shock treatment for one-time removal of pathogens. On-site chlorine dioxide production systems are an option but cost more up front to install but over time would save on recurring costs for everyday sanitation.

**Bromine**

Bromine works like chlorine in disinfesting irrigation water (at concentrations around 30 ppm) but is less affected by high pH levels of the irrigation water, with efficacy still occurring at a pH of 8.5. Bromine does react with nitrogen like chlorine but is still effective as a disinfectant. Also, bromine has very little phytotoxicity to plants even at concentrations of 100 ppm (Austin, 1989). Bromine also forms byproducts that are hazardous to humans and the environment.

**Chlorine–bromine**

Chlorine–bromine combinations, at recommended concentrations of between 5 and 15 ppm, are also an option (Cunningham and Taverner 2002). Costs and labor involved with chlorine–bromine treatments are similar to those of chlorine treatment systems. There is limited knowledge on phytotoxicity of chlorine–bromine combinations.

**Hydrogen peroxide**

Hydrogen peroxide requires higher concentrations than other oxidizers. Recommendations are around 2000 ppm, or a little over 2 gallons for every 100 gallons of irrigation water (Newman 2004). Hydrogen peroxide is known to have phytotoxic effects and can also degrade greenhouse plastics. This is an issue because at the concentration rates required for control, the hydrogen may not be fully broken down into oxygen and water before it enters the nursery or environment. Combinations of hydrogen peroxide and peracetic acid (see below for a fuller discussion of peracetic acid) are available in products like ZeroTol 2.0 (hydrogen peroxide 27.1%, peracetic acid 2%) and Sanidate 12.0 (hydrogen peroxide 18.5%, peracetic acid 12.0%). The recommended rate for 100% kill of all organisms is 500 ppm or higher for ZeroTol 2.0 and 200 ppm or higher for Sanidate 12.0 (Elmer 2008).

**Iodine**

Iodine is effective against fungal organisms at concentrations as low as 0.7 ppm but is not effective against viruses (Runia 1995). Iodine treatment systems are expensive, due to their computer-based automated dosing, in which iodine is automatically dosed and then filtered out of the irrigation water. This filtering can also remove needed nutrients and also leads to higher and more technical maintenance costs. Iodine systems are safer and have less phytotoxic potential than other chemical treatments.

**Ozone**

Ozone is a strong oxidizer and disinfectant. It is effective against all pathogenic organisms, depending on concentration and length of exposure (Runia 1995). Ozone treatments systems are costly, though, and ozone treatments require low-pH and relatively pure irrigation water to be effective.

**Surfactants and film-forming polymers**

Surfactants and film-forming polymers (FFPs) have been effective in controlling disease-causing organisms in irrigation systems by breaking down the cell walls of these organisms (Peterson et al. 2019). These chemicals are best used in small irrigation and hydroponic systems but are not feasible for larger irrigation systems. The most feasible use of surfactants and FFPs to control diseases spread by irrigation water is to apply them as a preventative on crop plants before irrigation (Peterson et al. 2019). Surfactants and FFPs can be applied to plants and act as a protective barrier against fungi and fungi-like organisms and bacteria.

**Peroxyacetic acid**

Peroxyacetic acid or peracetic acid (PAA) becomes hydrogen peroxide and acetic acid when introduced to irrigation water and has shown efficacy in disease control. It has a low chance of phytotoxicity and further degrades into water and oxygen, leading to little risk due to the lower concentration of hydrogen peroxide produced in the process. PAA concentration rates range from 10 ppm to 80ppm for fungi, bacteria, and nematodes and up to 400 ppm for viruses (Fisher 2011, Runia 1995).

**Other**

Electrochemically activated water (ECA-water) is an older technology that has become more popular in recent years. ECA-water production requires the purchase of an expensive device, but production costs are low, and only 8 ppm of ECA-water is required for control. Electrochemical disinfection has been used widely to control human pathogens in vegetable production (Gil et al. 2015) and has recently been tested and found successful in inactivating viruses in irrigation water (Brandte et al. 2016). There are multiple other chemical options being researched for use in controlling pathogens in irrigation water, including fungicides, carbon dioxide, acid-electrolyzed water, and ionization (Sewart Wade 2011). These options, though simple to install, are not well studied, and they have not been used widely in greenhouse or nursery operations.

### *Biological Methods*

**Biological control agents**

Beneficial microbes can act as disease suppressors in the context of treating irrigation water, either through competition for resources, parasitism, or induced resistance in the plants. This method of control has many challenges, the most important of which are stability and reliability. It is difficult to develop formulations and application rates for live populations to suppress a large population of disease-causing organisms. The current best management practice is to promote beneficial microorganisms by not overusing pesticides and sterilization methods. For example, soil sterilization led to higher disease presence in potting media due to repopulation of the media with infested irrigation water and the lack of beneficial organisms to aid in disease suppression (Strong et al. 1997).

The inoculation of sterilized environments with beneficial microorganisms has been suggested as an addition to sterilization programs in nursery and greenhouses, but this is an understudied area. Constructed wetlands are another option, for operations with the available space. Wetlands are low maintenance but have varied and understudied efficacy in controlling pathogens; for instance, they have been effective in removing fungal pathogens (Huett 2002) through interactions between the wetland substrate, microorganisms, and wetland plants. Wetlands also have the advantage of providing space to grow aquatic plants for extra income.

## Equipment Sanitation

Maintaining and sanitizing irrigation equipment is another important factor in keeping irrigation systems free of disease-causing organisms and debris that can clog irrigation lines. A pH above 6.0 in irrigation water can lead to precipitation of minerals like calcium and magnesium carbonates. These carbonates can clog emitters and lead to irregular irrigation for drip emitters (Fig. 3). Avoiding high pH and EC will help keep these deposits from building up. Nitric, sulfuric, or phosphoric acid flushes can be used to clear these clogs. Lines should be flushed with regular water after an acid flush.

Irrigation equipment should be kept off the ground and benches where it can become infested with pathogens due to splashing water or movement through wind, plant material, or other tools that come in contact with the irrigation equipment. Hoses and irrigation equipment not in use should be cleaned and dried and stored off the ground and outside of the greenhouse. Hoses in use should be hung off the ground, and hand-watering wands should be hung above and out of the way of plant material. Pathogen-transmitting insects may seek the water in irrigation equipment and cause infestation. Fixing leaking irrigation equipment and reducing populations of insects that can transmit disease-causing pathogens will reduce the chance of this.

## Summary

Irrigation water and equipment sanitation starts with understanding your water quality. Preventing debris and pathogens from entering the system and filtering the solids from the water are essential to maintain irrigation systems. Physical, chemical, and biological water-treatment systems are available. The treatment method depends on the water quality entering the system and the types of pathogens to be treated as well as economic, maintenance, and toxicity considerations. For more information on appropriate irrigation system disinfestation, contact your local Cooperative Extension Service office. Table 2, supplied at the end of this document, serves as an easy-to-reference guide to all the methods discussed above and includes information about each method.

**Figure 3. Example of a dirty irrigation head. The algal and mineral growth on this equipment can harbor disease and decrease the efficiency of the irrigation.**

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## Disclaimer

The pesticides mentioned are provided as suggestions for selecting suitable controls and should not be considered to be recommendations. The pesticide label is the law. Read it before purchasing a pesticide to ensure that it is registered for your intended use. Carefully read the label entirely before use and follow its instructions.

Chemical names and trade names are included as a convenience to the reader. Their use in this publication does not imply endorsement, nor discrimination against similar products or services not mentioned. Individuals who use chemicals are responsible for ensuring that the intended use complies with current regulations and conforms to the product label. Be sure to obtain current information about usage and examine a current product label before applying any chemical. For assistance, contact your state pesticide-regulating authority.

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**Table 2. Summary of treatment methods for disinfesting water**

| Treatment | Advantages | Disadvantages | Cost[1] | |
|---|---|---|---|---|
| | | | Capital | Operate[2] |
| **Filtration** | | | | |
| Slow sand filtration | Simple<br>Low hazard<br>Not phytotoxic<br>Not affected by $H_2O$ properties | Large infrastructure<br>High maintenance<br>Efficacy breakdown | $$ | $ |
| Membranes | Low hazard<br>Not phytotoxic<br>Not affected by $H_2O$ properties | High maintenance<br>Clogging<br>Requires pre-filtration | $$–$$$ | $$ |
| **Physical** | | | | |
| Heat | Low hazard<br>Not phytotoxic<br>Not affected by $H_2O$ properties | Corrosive<br>Need to cool $H_2O$ | $$–$$$ | $$–$$$ |
| UV Light | Low hazard<br>Low phytotoxicity | Bulb replacement affected by solids<br>Requires pre-filtration | $$–$$$ | $ |
| Sonication | Low hazard<br>Not phytotoxic | Lack of research<br>Inefficient | $$$ | $$$ |
| Pressure | Low hazard<br>Not phytotoxic | Lack of research | $$–$$$ | $–$$ |

**Table 2. Summary of treatment methods for disinfesting water**

| Treatment | Advantages | Disadvantages | Cost[1] | |
|---|---|---|---|---|
| | | | Capital | Operate[2] |
| **Chemical** | | | | |
| Chlorine | Simple<br>Highly effective<br>Well used and understood | Corrosive<br>Dosing required<br>Requires pre-filtration | $–$$ | $–$$ |
| Bromine | Not phytotoxic<br>Broad pH range | Hazardous<br>Dosing required<br>Requires pre-filtration | $–$$ | $–$$ |
| Chlorine–bromine | Broad pH range<br>Broad efficacy range | Hazardous<br>Corrosive<br>Dosing required<br>Requires pre-filtration | $–$$ | $–$$ |
| Hydrogen peroxide | Simple<br>Well used and understood | Hazardous<br>Corrosive<br>Dosing required<br>Requires pre-filtration | $ | $$ |
| Iodine | Not phytotoxic | Hazardous<br>Corrosive<br>High maintenance<br>Dosing required | $$–$$$ | $$$ |
| Ozone | Low hazard<br>Can break down pesticides | Corrosive<br>Dosing required<br>Requires pre-filtration | $$$ | $$ |
| Surfactants and film-forming polymers | Simple<br>Low phytotoxicity<br>Low hazard | Lack of research | $ | $ |
| Peroxyacetic acid | Low hazard<br>Low phytotoxicity | Lack of research<br>Dosing required<br>Requires pre-filtration | $–$$ | $–$$ |
| Fungicides | Simple<br>Well studied | Hazardous<br>Requires pre-filtration | $–$$ | $–$$ |
| Carbon dioxide | Simple<br>Low hazard<br>Not phytotoxic | Lack of research<br>Requires pre-filtration | $$ | $$ |
| Acid-electrolyzed water | Simple<br>No phytotoxicity<br>No hazard | Lack of research<br>Requires pre-filtration | $–$$ | $–$$ |
| Ionization | Simple<br>Long-lasting equipment | Lack of research<br>Requires pre-filtration | $–$$ | $ |

**Table 2. Summary of treatment methods for disinfesting water**

| Treatment | Advantages | Disadvantages | Cost[1] | |
|---|---|---|---|---|
| | | | Capital | Operate[2] |
| **Biological** | | | | |
| Biological agents | Low hazard<br>Not phytotoxic | Low stability and reliability | $–$$ | $ |
| Wetland | Low hazard<br>Not phytotoxic<br>Low maintenance | Large infrastructure | $$–$$$ | $ |