A Comparison of Proven Water Disinfestation Systems for Production Nurseries

WHY DISINFESTATION IS IMPORTANT:

Good quality water is essential for producing healthy, vigorous plant growth. Production nurseries commonly use surface water (creeks, rivers, dams, etc) and many recycle irrigation water. Recycling conserves water and prevents the escape of nutrients and pesticides into waterways, but also increases the chance of spreading pathogens recirculated in irrigation water. Pathogens can potentially build up to high levels in dams and tanks and provide an avenue for repeated infestations that can devastate nursery crops.

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Many pathogens can be spread in irrigation water including, but not limited to: *Phytophthora*, *Pythium*, *Fusarium*, *Calonectria* (also known as *Cylindrocladium*), *Verticillium*, *Thielaviopsis* (previously *Chalara*), *Rhizoctonia*, plant parasitic nematodes and bacterial wilt. These are serious pathogens of nursery stock that can cause root rot, wilt, damping-off, lack of vigour, unthriftiness, decline and death. In most cases, once plants are infected the pathogen cannot be eradicated and will remain with the plant for its lifetime. Infected plants that appear healthy at point of sale may decline and die months or years later (even if fungicides have been applied in the production nursery). Disease prevention makes far better economic sense than disease 'curative' programs. Therefore, potentially contaminated water must be disinfested before use as irrigation water to ensure it does not become a delivery system for plant pathogens.

WATER SOURCES THAT MUST BE DISINFESTED

Surface water sources such as rivers, creeks, dams and uncovered reservoirs are almost always contaminated with species of *Phytophthora* and *Pythium* and should be disinfested before use in irrigation, wash down of equipment and washing of bare rooted stock. Only reticulated town water and water from deep bores are considered suitable for irrigating nursery stock without disinfestation treatment, provided this water is stored carefully (covered) and not contaminated prior to use. In theory, water collected from a clean roof may also be considered suitable for irrigating nursery stock without disinfestation. However, this relies on continued cleanliness of the roof, i.e. it must be completely free of organic debris. In reality, therefore, few rooves can be considered 'clean'.

WHEN TO DISINFEST

Water sourced from a surface supply (i.e. creek, river, dam, etc.) needs to be disinfested before use in irrigation. Testing for *Phytophthora* can be achieved by baiting, as indicated in Appendix 2.8 of the NIASA BMP Guidelines. However, this only detects *Phytophthora* and will not detect fungal, bacterial or nematode pathogens. Therefore if water is stored for significant intervals it should be managed appropriately to maintain quality and stop contamination with organic matter that could be infested with pathogens (for more details see below). If stored water becomes contaminated it is recommended to re-disinfest the water prior to use.

EFFECTIVE DISINFESTATION SYSTEMS

There are several systems available for effectively disinfesting irrigation water recognised under industry best practice programs. Water treatment systems differ in installation costs, operating costs, mode of action, space requirements, water volume/flow rate treated, raw water quality requirements, sensitivity of the crop, worker safety, and environmental concerns. No single system is best for all production nurseries. In general, a combination of pre-filtration with chemical, membrane or biological treatments is essential to ensure a high degree of efficacy at an appropriate cost. There are five main considerations to produce an effective treatment system.

1. The first consideration is **placement of the pump inlet in the reservoir** as this can influence the uptake of plant pathogens in irrigation water. Studies show placement of the irrigation pump inlet as far away as possible from the source of runoff (e.g. drains flowing into a dam), and at half the depth of the reservoir (i.e. avoiding the surface and bottom), had the least *Phytophthora* uptake. Reducing the inoculum load that the disinfestation system must treat reduces risk of failure.
2. The second consideration is **pre-filtration**. Suspended solids (such as soil and organic matter) in the water reduce the effectiveness of some disinfestation treatments and can plug up irrigation emitters. Course pre-filtration will normally remove particles down to approximately 40–100 µm. There is a wide range of pre-filtration techniques available. The most frequently used in production nursery systems are screen filters and pressurised media filters. The specific type of pre-filtration employed will depend on the raw water quality and the disinfestation method to be used. For example, high levels of organic matter in the water deactivates chlorine reducing its efficacy. Similarly, high turbidity can cause UV treatment to be ineffective; water must have high clarity for UV to be effective.

   As a general rule, total suspended solids should be less than 20mg/L for those treatment types influenced by the presence of suspended solids. Consequently, a pre-filtration step is often employed to remove materials such as remnants of growing media, algae and plant debris from the water prior to the actual disinfestation treatment.
3. **Raw water chemistry** also influences the effectiveness of several disinfestation treatments and needs to be taken into consideration. The main factors that can

influence disinfestation systems are pH, electrical conductivity (EC) and concentration of certain nutrients and metal ions. Where the system is sensitive to nutrients (e.g. chlorine) it is important to inject water-soluble fertilisers after there is sufficient contact time to disinfest pathogens from the water.

The sanitising activity of chlorine is also strongly dependant on pH. For water treated with either calcium hypochlorite or sodium hypochlorite, the optimal pH range is 5.5–7.5. Above 7.5, most of the chlorine would be in the form of hypochlorite, a weak sanitiser. Between pH 5.5–7.5, chlorine would be in the form of hypochlorous acid (HOCl) and is 20 to 30 times more effective than the hypochlorite form. For example, at pH 6.0, 96% of the solution is in the HOCl form, the most active and desired state for disinfestation. But if the pH increases to 7.0, only 73% is as HOCl; at pH 8.0 it reduces further to 22% and at pH 8.5 only 7% is present as HOCl.

Surface capture water in Australia tends to have a high pH and may therefore need adjusting prior to treatment.

4. Each system has a different **mode of action**, i.e. they kill or remove pathogens in different ways. These need to be understood in detail prior to installation to ensure they are always effective. System failure can allow pathogens to be spread through the nursery that may cause plants to become unsaleable. The more commonly employed systems are discussed here, covering an overview of how the system works, advantages and disadvantages and the costs of each system (Table 1). All the systems currently approved for use under the NIASA guidelines are discussed. These include chlorination, chloro-bromination, chlorine dioxide, ozone, iodine, ultraviolet light, ultrafiltration, slow sand/Rockwool filtration. In addition, bromine and activated hydrogen peroxide are also covered.

   Other systems not discussed in this factsheet may disinfest pathogens from water. Such systems should be investigated in detail before purchase. Evaluate data and research the efficacy of the system disinfesting multiple plant pathogens and their ability to do so with varied water quality parameters (preferably including those present at your production nursery). *Do not purchase a system from a company that is unwilling to provide data/research backing up their product's ability to disinfest plant pathogens from irrigation water. Data presented based on water used for post-harvest treatments, hydroponics or other activities, other than irrigation, must be treated with scepticism and extensively investigated before purchase and installation.*

5. Regardless of the system used, disinfested water must be **stored hygienically**. Put in place systems to prevent and protect water from becoming infested with organic matter and plant pathogens. In particular, stop soil, plant debris, dust and animals entering water storage facilities. Inspect storage facilities regularly to confirm that they are still hygienic and clean. If tanks are regularly becoming dirty, evaluate how they are becoming contaminated and rectify.

   High light intensity across Australia (particularly in QLD, WA and NT) causes significant algal build up when using fibreglass or polythene tanks (even black polythene) due to the transmission of light that encourages algal growth. If algae occur in storage tanks on a regular basis, consider options that completely block light from the tank, e.g. metal tanks, opaque tanks designed to block light. It may also be possible to retrofit tanks to reduce light permeability.

   If water is recycled, care must be taken in managing water quality (e.g. pH/EC, nitrate, phosphate and potassium) to avoid algal blooms. Aeration in dams adds dissolved oxygen to the water promoting aerobic bacteria that decompose organic matter that may be present. Aeration also reduces thermal stratification that can increase anaerobic bacteria in the bottom layers of the storages (which can affect water pH). For more information on management of recycled water refer to the Water Management Best Management Practice Guidelines.

Each system is slightly different and understanding the basic principles influencing water disinfestation (points 1–5 above) are important when it comes to installing the right system for your nursery. Detailed knowledge of your specific system is invaluable so water quality can be monitored and kept within optimal parameters for consistent disinfestation.

WATER DISINFESTATION TECHNOLOGIES

As indicated above, all water disinfestation techniques have different properties, killing or removing plant pathogens in different ways. In this section an overview of the disinfestation mode of action is provided. Table 1 summarises details on the activity, relative cost, recommended dose and advantages and disadvantages of each treatment (pages 6–8).

OXIDISING AGENTS

There are many treatment technologies that can oxidise organic matter. These include chlorine (in the form of sodium hypochlorite and calcium hypochlorite), bromine, chloro-bromine, chlorine dioxide, activated peroxygen and ozone. Oxidising agents react with chemical groups on organic matter, changing the chemical structure of this material. Organic matter includes peat, algae, bacteria, plant debris and pathogens. Plant pathogens and algae are killed after exposure to the oxidising agent if it is present at a certain concentration over a certain duration. The oxidising agent, however, can be depleted by organic matter in the water. Therefore, it is critical that water is pre-filtered before it is treated with oxidising agents. Oxidising agents also react with iron and other metals reducing their effectiveness.

Inline chlorination unit.

CHLORINE (AS HYPOCHLOROUS ACID)

Chlorine is added to water as either sodium hypochlorite or calcium hypochlorite. The chlorine reacts with the water by hydrolysis to form hypochlorous acid — the main active ingredient in chlorination. Chlorine residual levels for effective water treatment need to be maintained between 2–3ppm for a minimum contact time of 20 minutes at pH 5.5–7.5. Some isolates of the same species can be more tolerant of Chlorine and will require higher ppm and longer contact times. Also, different lifestages of fungi can be more tolerant, for example *Phytophthora* sporangia and mycelium requires greater doses and or contact times than zoospores. Therefore, whenever possible, increase contact times to achieve greater pathogen mortality. This will also lower the risk of phytotoxicity (which can occur at concentrations greater than 2ppm).

These products also oxidise fertiliser salts including micronutrients, using up the chlorine in the process. This is why fertiliser must be added after disinfestation, never before.

BROMINE

Bromine is a member of the same family as chlorine and has a similar action in disinfesting water but greater effective pH range (up to pH 9), shorter contact time (5–35ppm residual for 10 minutes contact time) and is effective against a broader range of pathogens. In addition, by-products are less persistent and non-toxic to plants compared with chlorine, even at high levels. It is also not effected by nitrogen products. However, this method can be difficult to use, in particular maintaining a constant concentration over days when using a high flow rate.

CHLORO-BROMINATION

Chloro-bromination is a combination of bromine and chlorine giving improved effectiveness over chlorine or bromine alone. It only requires 3ppm residual for 8 minutes contact at pH 5.5–9.0.

CHLORINE DIOXIDE

Chlorine dioxide is highly effective for disinfesting a range of plant pathogens over a broad pH range, up to pH10, and requires only a 3ppm residual for 8 minutes. It is over 10 times more soluble in cold water than chlorine and is a more selective oxidiser than chlorine, not reacting as much to the organic matter, so a lower dosage rate can be used to achieve an active residual disinfectant.

OZONE

Ozone works well against all pathogens including viruses. Though in water with high pH, organic matter, nitrite, manganese, iron or bicarbonate concentrations, it is not as effective as other oxidisers. Ozone does not mix easily in water, therefore either an intensive recirculating storage or tumble system is required. A residual dose of 1.4 ppm for 16 minutes contact is required, but it can be difficult to regulate this concentration due to its activity with other compounds.

ACTIVATED PEROXYGEN

Activated peroxygen (hydrogen peroxide) is a strong oxidiser, but compared to ozone, requires higher concentrations and longer exposure times to achieve the same disinfection (e.g. 200 ppm for 24 hours to kill *Fusarium* spores). Efficacy is improved by adding activators, but still limited by high levels of organic matter. This treatment has potential environmental and occupational health and safety hazards as residual hydrogen peroxide can have mutagenic, phytotoxic and corrosive effects. There are a number of active ingredients that can be used in this treatment method; peroxyacetic acid is a more effective biocide than hydrogen peroxide alone.

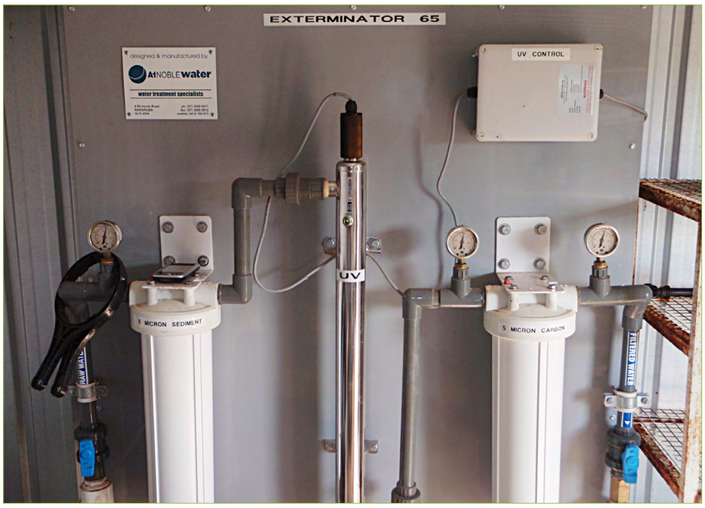
OTHER CHEMICAL TREATMENTS

IODINE

The chemical iodine disrupts cell function by replacing chemicals necessary for the pathogen to thrive with iodine ions. Water is passed through a series of iodine filters, exposing plant pathogens to iodine. A 5ppm residual with 30 minutes contact time is required, but is effective over a broad range of pH, EC levels and organic loads. The iodine dose adjusts automatically according to the organic load of the water and after treatment iodine residues are removed using anion-exchange resin.

ULTRAFILTRATION (MICROFILTRATION)

The system involves selective filtration based on filter pore size, generally about 0.01 to 1 micron in size. This process removes plant pathogens (including viruses), suspended solids and high molecular weight polymers. This system must be used in conjunction with pre-filtration to remove larger particles at 10 microns, as finer filters are easily clogged. The system is not affected by nutrient chemistry and has no chemicals that can cause phytotoxicity. Membranes require backwashing and will require replacement after long use.



UV water disinfestation unit. Source NGIQ

Microfiltration system showing the volume of material filtered.

ULTRAVIOLET LIGHT (UV)

Water in tubular chambers is exposed to UV radiation that kills living cells (including pathogens) by disrupting their DNA. Since there are no chemical residues, it is considered environmentally friendly. The treatment is not pH sensitive but is highly dependent on water turbidity, which needs to be less than 2 NTU (nephelometric turbidity units). Particulates in the water disperse light, reducing the effectiveness of UV radiation. Pre-filtration of the water to less than 25 microns is essential as it must be free of suspended materials, tannins, iron and manganese. Water must have a high UV transmission (> 60% UV transmission after filtration) and 80mJ/cm^2 eliminates most pathogens.

SLOW FILTRATION (SLOW SAND FILTERS OR SLOW FLOW FILTERS)

This is a low technology approach for disinfesting water. It has been extremely effective in eliminating *Phytophthora* from recirculating water in commercial production nurseries. The process uses both physical and biological processes to filter and break down organic matter, as well as kill pathogenic bacteria and fungi. Sand of specific grades act as the physical filter and a biofilm crust that develops on the surface of the sand filter acts as the biological component which is made up of beneficial microbes capable of killing plant pathogens. Rockwool can be used instead of sand, but it must be granulated premium superflock rockwool. While the biofilm layer is important for the functioning of the filter, it must be maintained to a certain size or the filter can become clogged. Slow filtration systems must not be allowed to dry out or heat up and pre-filtering is necessary to remove algae and silt. A flow rate of 100L/hr/m^2 should be used often requiring storage of the clean filtered water in tanks.

FURTHER READING:

- NIASA Best Management Practice Guidelines
- Water Management Best Management Practice Guidelines
- Numerous irrigation factsheets on the Nursery Production FMS website
- Many nursery papers are also available on various disinfestation systems and irrigation water management

This document was prepared by Sarah Dodd and Andrew Manners (Agri-science Queensland, Department of Agriculture and Fisheries, Ecosciences Precinct, GPO Box 267, Brisbane QLD 4001) as part of the nursery levy and Hort Innovation funded project 'Building the resilience and on-farm biosecurity capacity of the Australian production nursery industry (NY15002)' in 2020. Thanks go to Marcus van Heijst from Priva for comments and feedback on Table 1 and John McDonald (GIA) for helpful suggestions that improved this document. All photos by DAF, unless otherwise stated.

TABLE 1. COMPARISON OF COMMON WATER DISINFESTATION SYSTEMS

TREATMENT	HOW IT WORKS	RELATIVE COST	EFFECTIVE APPLICATION	ADVANTAGES	DISADVANTAGES
SODIUM HYPOCHLORITE	Oxidising agent	Low	2–3 ppm residual Cl for 20 mins contact at pH 5.5–7.5	• Highly effective, stable residual that keeps disinfesting • Cleans out algal and bacterial slime • Relatively safe and non-phytotoxic • Precipitates iron and manganese • Chemical readily available and relatively cheap • Test kits inexpensive • Equipment costs relatively inexpensive	• pH to be monitored and adjusted within small range (5.5–7.5) • Highly corrosive and an irritant at high concentration so requires careful handling • Injection equipment requires regular maintenance • Requires pre-filtration as Cl rapidly used up by impurities • Requires regular testing (weekly) of residual chlorine • Requires storage tank to achieve contact time and residual (in-line systems must still achieve required contact time and residual) • Limited shelf life (1 month), reduced by sunlight and heat • Never combine with fertilisers or other chemicals containing ammonium • Problematic for water with › 0.5ppm iron due to iron precipitation (settling) — consideration required in managing precipitated iron • Not effective against all plant pathogens
CALCIUM HYPOCHLORITE	Oxidising agent	Low	2–3 ppm residual Cl for 20 minutes contact at pH 5.5–7.5	As per sodium hypochlorite, plus: • Available Cl about 65% › sodium hypochlorite • Less phytotoxic and corrosive to pipes and equipment than sodium hypochlorite. • As CaOCL, Calcium is available for plant uptake • Maintains its stability and efficacy during storage better than sodium hypochlorite	As per sodium hypochlorite, plus: • Insoluble components (calcium carbonate) at higher concentrations • Can be a hazard if subjected to heat or stored in or near an easily oxidized organic material or in metal. • Calcium hypochlorite costs more than sodium hypochlorite
CHLORINE DIOXIDE	Oxidising agent	Moderate	3 ppm residual for 8 minutes contact at pH 5–10	• Potent oxidant (more than 2x as strong an oxidant as Cl) • Not effected by nitrogenous compounds • Effective at broader pH (‹10), good for Australian production nurseries with high water pH • Requires shorter contact time • Residual activity is longer than Cl • Effective against a broad range of pathogens	• Human health and environmental hazards • Unstable gas that must be generated onsite with specialised equipment • Equipment is relatively expensive • Equipment requires regular maintenance • Requires accurate and regular testing of residual level • High residual levels can be toxic to plants • Does not have efficacy against all plant pathogens or life stages • Stock solution should be used within 15 days to minimise loss due to volatilisation
BROMINE	Oxidising agent	Moderate	5–35 ppm residual for 10 mins contact at pH 5.5–9.0	• Compared to chlorine: still effective at higher pH (‹ 9), effective against a broader range of pathogens, by-products are less persistent, non-toxic to plants, even at high levels. • Not effected by nitrogen products • Not toxic to plants even at high levels	• By-products with human health and environmental hazards • Less soluble than chlorine • Can be difficult to maintain a constant concentration over days at a high flow rate. • Significant efficacy variation (ppm) across the various key plant pathogens based on a standard contact time
CHLORO-BROMINATION	Oxidising agent	Low	3 ppm residual for 8 mins contact at pH 5.5–9.0	• Improved effectiveness over bromine or chlorine alone • More effective at higher pH compared with Cl • Relatively inexpensive • Setup costs are moderate • Weekly testing of residual levels is relatively simple and inexpensive	• Corrosive • Requires two injectors and stock tanks so increased equipment costs • Requires storage tank to achieve contact time • pH requires monitoring and may need adjusting • Does not have efficacy against all plant pathogens or life stages

TREATMENT	HOW IT WORKS	RELATIVE COST	EFFECTIVE APPLICATION	ADVANTAGES	DISADVANTAGES
OZONE	Oxidising agent	High	1.4 ppm residual for 16 mins contact	• Less effected by pH and temperature than chlorine • Can oxidise manganese and iron compounds and many pesticides • Good activity against viruses	• Affected by variations in water. Ozone demand increases with alkalinity and the concentration of bicarbonate, iron and ammonium • Not naturally dispersed in water column therefore requires a mixing process or constant recycling through the dosing process to ensure efficacy • Potential health hazard, potentially toxic to plants • Corrosive • Unused ozone removed by carbon – adds cost • No stable residual • Generated onsite, can't be stored
ACTIVATED PEROXYGEN (HYDROGEN PEROXIDE)	Oxidising agent	Moderate	200 ppm residual for 24hrs	• Highly efficient • Low capital investment • Enhanced oxygen uptake to roots • Efficacy is improved by the addition of activators	• Requires a special injector that is resistant to very corrosive chemicals and has a very high injection ratio, or the material must be diluted before injection. • Requires relatively higher concentrations and exposure times. • Requires pre-filtration- limited by high levels of organic matter. • Hydrogen peroxide residual can be mutagenic, phytotoxic and corrosive. • Safe handling, delivery and storage can be difficult and expensive.
IODINE	Disrupts the ionic balance within cells by replacing chemicals necessary for pathogens to thrive with iodine ions.	Moderate	5 ppm residual for 30 mins.	• Automated system adjusts according to the organic load of water • Effective over broad ranges of pH, EC and organic load • Residues automatically removed	• Potential phytotoxic damage to crops at this level (5 ppm) • Potential for chemical breakdown and user difficulty • Carbon filters used to remove iodine residues also remove iron and copper leaving water deficient in these nutrients • Relatively expensive compared to chlorine
ULTRAVIOLET LIGHT	Disrupts the genetic material in the cell effectively killing it.	Low	60% UV transmittance. Radiation of 80mJ/cm² eliminates most pathogens — all fungi, bacteria, nematodes At 250mJ/cm² all viruses are also eliminated	• No chemicals, non-toxic and no residues, so it is environmentally friendly • Not pH sensitive (note, water with high bicarbonate requires pre-treatment to prevent calcium precipitation on quartz tubes) • Non-corrosive • Relatively low operating costs (power, some acid for self-cleaning of quartz tubes, lamp replacement every 16,000 hrs) • Very safe • Self-monitoring and self-cleaning systems recommended for horticultural applications	• Setup cost is higher than chlorine but less than chlorine dioxide • Water quality is critical - water must be free of suspended materials, tannins, iron and manganese • Extremely high level of pre-filtration required — 20 micron • Must be designed to match water flow rates and water quality • Destroys some iron chelate. • No ongoing residual effects downstream, i.e. pathogens are only killed when exposed to UV. The system can be offered in combination with H_2O_2 injection to provide residual activity.
ULTRAFILTRATION	Forces water through a single filter that removes pathogens	Moderate	Range between 0.01–1.0 micron membrane pore sizes	• Removes all plant pathogens including viruses • Cost effective at low flow rates • Can be automated • Environmentally friendly • No chemicals required (small quantity of Chlorine during backwash)	• High setup cost • Requires good pre-filtration– 10 micron • Higher energy costs than some other systems • Maintenance costs (membrane replacement) • Waste water from back flushing filter requires disposal

TREATMENT	HOW IT WORKS	RELATIVE COST	EFFECTIVE APPLICATION	ADVANTAGES	DISADVANTAGES
SLOW SAND FILTRATION (SSF) OR SLOW FLOW FILTRATION (SFF)	Physically and biologically filters pathogens out of the water. Antagonistic micro-organisms in the bio-filter attack and destroy plant pathogens.	Low	≤ $100 L/hr/m^2$ flow rate. The finest grade sand fractions are the most effective in filtering out pathogens	• No chemicals required — not phytotoxic • Relatively low cost construction • Low cost operation • Virtually no waste products • Environmentally friendly	• High setup costs • Light transmission through tank walls allows algal build up across the biofilm layer causing system blockages • Requires tanks that do not transmit light (e.g. metal) as many poly tanks, even black, are not effective light blockers • Large storage tanks required when irrigation demand is high • Legionella bacteria part of microflora • Occasional efficacy breakdowns • Sand is heavy — difficult to construct/relocate • Gravel layers makes for large unit • Water level maintenance in SSF is critical to effectiveness • Maintenance of the size of the biofilm layer is critical • Not available 'off the shelf' • Must not be allowed to dry out or heat up and pre-filtering is required to remove algae or silt
ROCKWOOL FILTRATION	Physically and biologically filters pathogens out of the water	Low	Granulated premium superflock rockwool is very effective in filtering out pathogens	As per SSF with the following improvements: • Less dense than sand — easier construction and relocation • Does not require gravel, smaller unit size • Much less clogging, less maintenance • More effective on certain pathogens	• High setup costs • Light transmission through tank walls allows algal build up across the biofilm layer causing system blockages • Requires tanks that do not transmit light (e.g. metal) as many poly tanks, even black, are not effective light blockers • Legionella bacteria part of microflora • Large storage tanks required when irrigation demand is high • Occasional efficacy breakdowns • Water level maintenance in the system is critical to effectiveness • Maintenance of the size of the biofilm layer is critical • Not available 'off the shelf' • Must not be allowed to dry out or heat up and pre-filtering is required to remove algae or silt • More complex system than sand