Water Treatment Guide for Greenhouses & Nurseries

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Section 1: Introduction

Water is an important resource on the farm, so managing water to limit waste is a priority. Proactively dealing with the water at your operation can help you manage immediate risks to the surrounding environment. It will also help to minimize risks that may affect the long-term success of your farm such as maintaining access to water in times of shortage. Acting ahead of any changes in water regulation allows operators to focus on other aspects of their business and reduce the risk of fines or other regulatory activity.

While water is managed differently depending on your type of farming operation, all farms need to consider how water use efficiency can be improved to keep their operations sustainable. After doing an assessment[1] on the farm of how water is currently managed, the next step in improving water quality can be a challenging one. There are many choices for technologies to treat water, and the range of suggestions that come from suppliers and consultants can make it difficult to decide on how to improve water quality to best meet the farm's needs.

Completing an initial water assessment on your farm is an important first step – use the guide![1]

Greenhouse and nursery operations are faced with additional challenges as they often have a range of production systems requiring unique solutions:

- Water used in production (operational water) at some facilities may be re-used, while at other farms the infrastructure is lacking to collect, treat and re-use water
- Concerns regarding water quality and plant pathogens
- Capital costs for water treatment and storage systems as well as their ongoing operation and maintenance
- Space (footprint) needed for a treatment system and potential loss of production area
- Site restrictions by limiting factors such as depth of the water table and surrounding infrastructure
- Specific water quality concerns (e.g. selected elements such as aluminum, salt levels, plant growth regulators, pesticides, and/or microbial contaminants).

This document aims to:

1. Provide a navigation tool for greenhouse and nursery facilities to identify potential and appropriate solutions for water management/treatment
2. Encourage producers to strive for incremental and continuous improvements in managing on-farm water.

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[1] Best Management Practices and Self-Assessment – Water and Fertilizer Use for Outdoor Container Production. 2016. Ontario Ministry of Agriculture Food & Rural Affairs. Publication #: BMP28E. Available through Ontario.ca/publications.

Best Management Practices & Self-Assessment for Water and Fertilizer Use in Greenhouse Floriculture Production. 2018. Ontario Ministry of Agriculture Food & Rural Affairs. Available through Ontario.ca/publications.

Self-Assessment and Best Management Practices for Water and Fertilizer Use in Greenhouse Vegetable Production. 2013. Ontario Ministry of Agriculture Food & Rural Affairs. Available through Ontario.ca/publications.

Canada-Ontario Environmental Farm Plan. Available through Ontario Soil & Crop Improvement Association, www.ontariosoilcrop.org

To achieve these aims, this Guidance Document was designed to help farmers navigate their options for improving water quality, answering questions such as:

- How do I start?
- How do I decide if I should dispose of my water or re-use it?
- Why do I need to improve my water quality?
- What are the potential risks with my water?
- How do I decide which technology (treatment/management solution) to choose?

The information in this guidance document focuses on environmentally sustainable farming practices for improving water quality, but investing in a water treatment solution is not a requirement for any farm. This guidance document is a summary of technologies currently available for managing and treating water on-farm, and provides examples of case studies taken from farms that have dealt with water management issues that may be similar to those faced by other producers. The examples provided should facilitate a platform for discussions with consultants, industry experts, and government extension specialists to determine the best solution for a particular operation.

Note that farm owners must ensure that all necessary permits from the relevant authorities (e.g. provincial and federal ministries, local Conservation Authorities, regional municipalities, etc.), are in place for the technologies in this guide. **This document does not address legal requirements for managing farm water.** Check with your relevant agricultural commodity organization for an overview of any requirements you may be required to meet.

One final note: As water management remains an important issue for all horticultural producers, more solutions will continue to be developed in the future which may not be reflected in this guide.

Section 2: First Steps

Before proceeding with this document, the self-assessment guides (see Footnote[1]) should be filled out by farmers intending to address water quality and management. These guides address pre- and post-production waters, and help farms to prioritize their water management needs. This guidance document is the next step – determining how to address areas that need improvement in water management, and how to decide which Best Management Practice(s) (BMPs) and treatment technologies are appropriate to implement.

Characterize and measure all farm water flows

- Go back to the farm 'map' created through the self-assessment process
- Determine where water enters the property, where water is generated/changed/used during production, then where each of those waters go (a consultant can assist with this process)
- Identify any sensitive land features to watch for (wells, streams, rivers, shallow aquifers, ponds, septic beds, woodlots)
- Identify risk points for water movement off the farm, including:
    - Points for soluble and particulate phosphorus loss and nitrogen loss to surface water or groundwater
    - Direct discharge, groundwater discharge, pond overflow, return tank overflow
    - Note that soil type and soil infiltration rate will influence surface and groundwater impacts
- Identify infrastructure (piping/plumbing, storage, space, etc.) that can be utilized for managing or treating water
- Measure water volumes and flows **in *and* out**. The following factors will come into the calculation of water volumes that the treatment system will need to handle. Consider the variations in water use caused by factors such as:
    - Seasonality (potted/container versus transplant production, irrigation requirements and optimum leaching rates, changes in water quantity and required treatment rates)
    - Production cycles and crop variations (transplants versus mature plants, changes in irrigation required and leachate volumes)
    - Range of irrigation systems used (leachate rates vary by type)
    - Plans for expansion or downsizing of the operation (volumes required for storage)
    - Plans for renovation within short-medium term (impact on volumes, down-time duration)
- Estimate of water use and operational[2] water volumes (see Appendix A for sample calculations for a typical operation)

The following figures are *examples* from greenhouses and a container nursery operation. The figures illustrate the variation in water use/consumption over the year. Every farm will have a unique 'pattern' of water use through the year, and this will be directly correlated to how much water will need to be managed or treated for potential re-use or discharge. Understanding how much and when these waters are generated is critical to determining how to manage them. A worksheet is provided in Appendix A to calculate and summarize farm-specific data on water quality and volumes.

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[2] **Operational water**: any water flowing from, in, through, or around the production areas, other than stormwater, collected or not. In addition, any water that may be generated through a process at the facility. Examples would include nutrient feedwater, filter backwash, boiler flue condensate, etc. Modified from:
Majsztrik, J.C., R.T. Fernandez, P.R. Fisher, D.R. Hitchcock, J. Lee-Cox, J.S. Owen Jr., L.R. Oki and S.A. White., 2017. Water use and treatment in container-grown specialty crop production: A review. Water Air Soil Pollut. 2017;228(4):151. doi: 10.1007/s11270-017-3272-1. Epub 2017 Mar 21. https://www.ncbi.nlm.nih.gov/pubmed/28386151

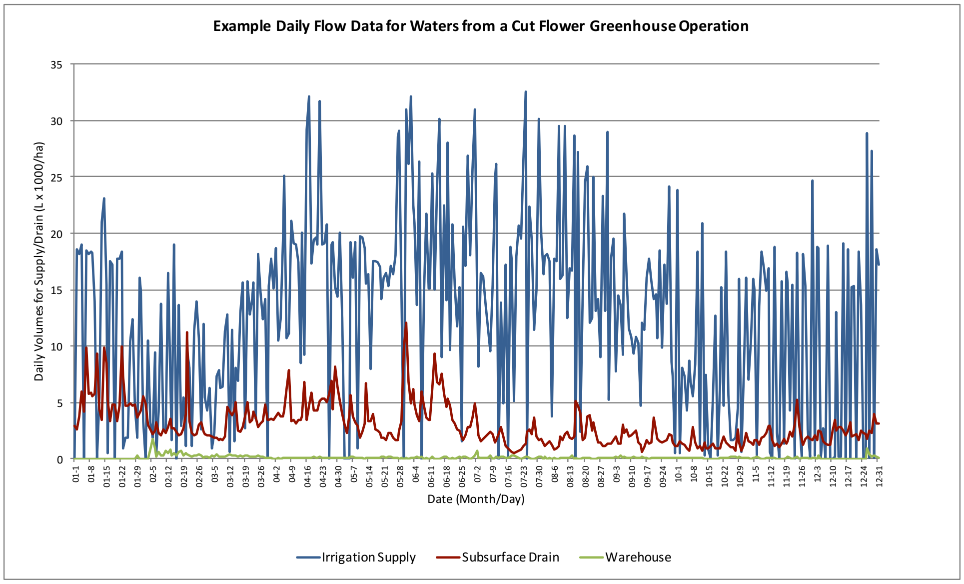

Figure 2.1. *Floriculture greenhouse growing cut flowers* – with fairly even production through the year, this cut flower greenhouse has relatively stable water needs throughout the year. By using low-volume drip tape to apply irrigation/nutrient water, the volume of water returning for treatment averages around 2500L per day (2.5 m^3). The amount of water generated in the warehouse (boiler discharge and cut flower pail water) is negligible, and can usually be combined with the subsurface drain water for treatment. Note that not all cut flower operations will have similar trends or actual flow rates.

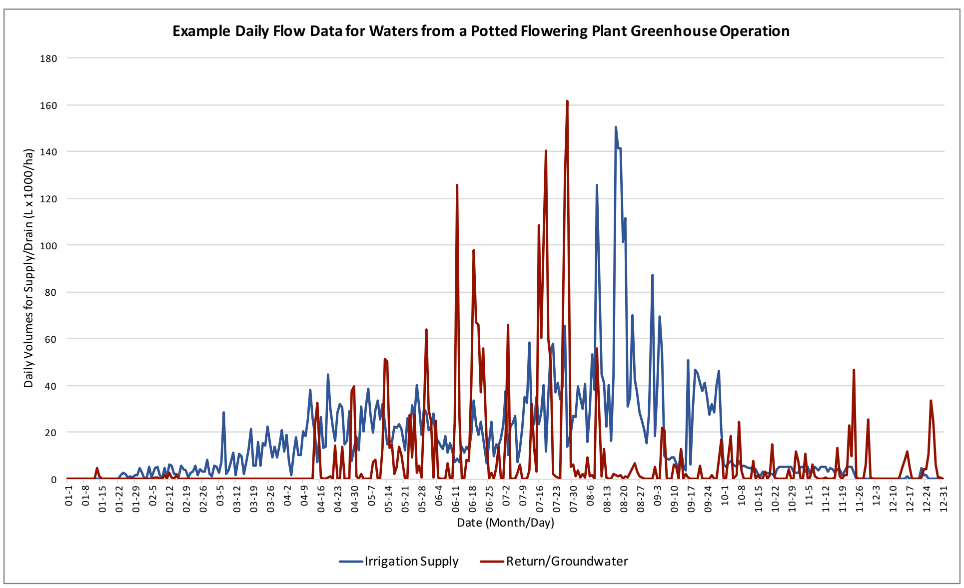

Figure 2.2. *Greenhouse operation growing potted flowering plants* – production levels vary significantly through the year, with peak production often in the spring and fall (crop dependent). The levels of leachate vary depending on the amount of greenhouse in production, but are further complicated by changing irrigation systems (misting in propagation, switching to drip stakes/trough/flood floor as crops mature) as well as by groundwater that reaches the subsurface drains under this greenhouse during rainstorms. Not all potted plant growers will have a similar pattern – every floriculture greenhouse has a range of crops and growing cycles, a range of irrigation systems, and the infrastructure will be different.

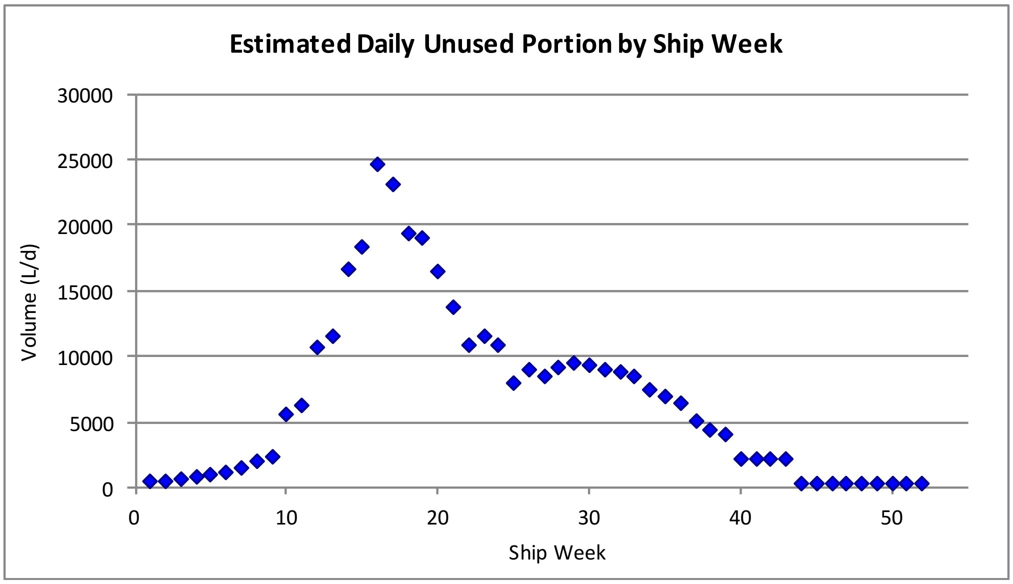

Figure 2.3. *Generic floriculture greenhouse operation* – If you don't have flow meters on your irrigation and discharge lines, it's not possible to get the level of detail as is seen in Figures 2.1 & 2.2. However, by combining production area (either in weeks or months) with average irrigation and leachate/discharge volumes from simple collection tests, it is possible to estimate volumes of water that need to be managed for re-use or discharge.

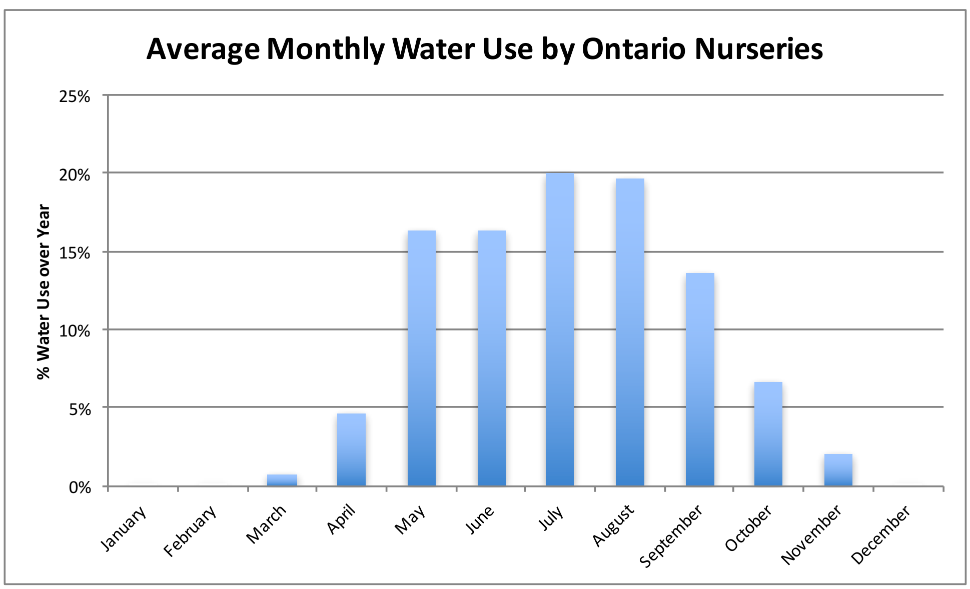

Figure 2.4. *Nursery container operation* – Outdoor production is limited to spring through fall, and irrigation supply levels vary widely depending on the crop mix, stage of growth, and weather. Generally, all the water that doesn't infiltrate the potted plants or the surrounding land becomes surface runoff and is collected in a catch basin or swale/ditch system. This entire volume of runoff water would need to be managed if considering treatment. It is possible to treat this water, but it means taking into account

potential stormwater volumes and pulses of runoff water inputs, as well as how to maintain the treatment system through the winter.

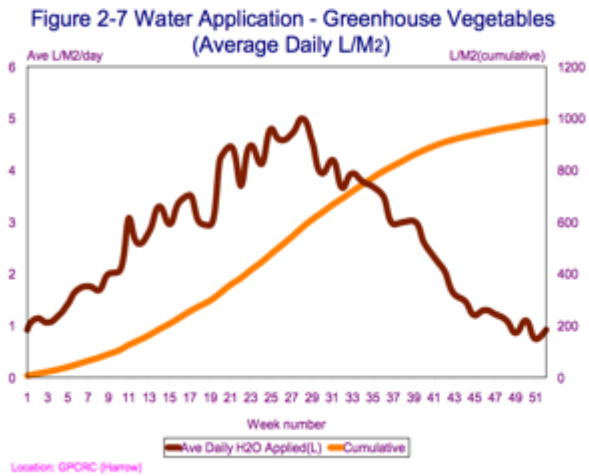

Figure 2.5. *Greenhouse vegetable production*[3] – The water supply volumes for vegetable greenhouse production depend on the crop in production (tomato, pepper, cucumber), as will the potential return volumes through the facility's recirculation system. Again, it is important to apply what you know about your crop, irrigation volumes, and return volumes to estimate the amount of water that needs treatment.

The importance of determining the volume of water being applied compared to water that could potentially be recovered and re-used cannot be overstated. Water Smart[4] studies performed by Farm & Food Care through 2015-2017 demonstrated that the first goal is to optimize water use efficiencies, and then deal with the remaining water. From the farm's perspective, it makes sense to optimize water and nutrient use efficiencies prior to designing a treatment system. For example: decreasing irrigation volumes by grouping plants by water needs, implementing cyclic irrigation, optimizing irrigation uniformity, installing a closed-loop table washer or cart irrigation system, or installing low-volume drippers will result in operational water to manage or treat. If stormwater is separated from farm-generated water, then there is also less water to treat or manage, and the water volumes that need treatment will be more predictable.

The smaller the volume that needs to be treated, the smaller the treatment system needs to be and the less it will cost!

Assess what is needed:

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[3] Growing Greenhouse Vegetables in Ontario, 2011. Ontario Ministry of Agriculture and Rural Affairs. Publication 836. Available through Ontario.ca/publications.

[4] Farm & Food Care Ontario. Water Smart Farming Project. http://www.farmfoodcareon.org/farming-and-the-environment/water/water-smart-farming-project/

What are the priorities for the facility? A summary of the farm's needs should be completed before considering treatment options.

- Does the farm need more water? I.e. is there an advantage to capturing water and re-using it?
- Where and when does the farm need water? Certain crops, times of year?
- On which crops can treated/recycled water be used?
- Can the burden on a critical water supply be lessened so it's available for when it's really needed?
- Is a short-term or long-term solution needed?
- Are there specific requirements or restrictions that need to be addressed (e.g. regulatory requirements)?

How much roof water can be collected at the facility?

Average rainfall in Niagara is 950mm per year, runoff from a greenhouse roof should yield 950 L/m^2/year

Benchmark: 1mm of rainfall = 1L/sqm = 10 cu meter/ha (or 1" of rainfall on a 1-acre greenhouse = approximately 25,000 gallons of water)

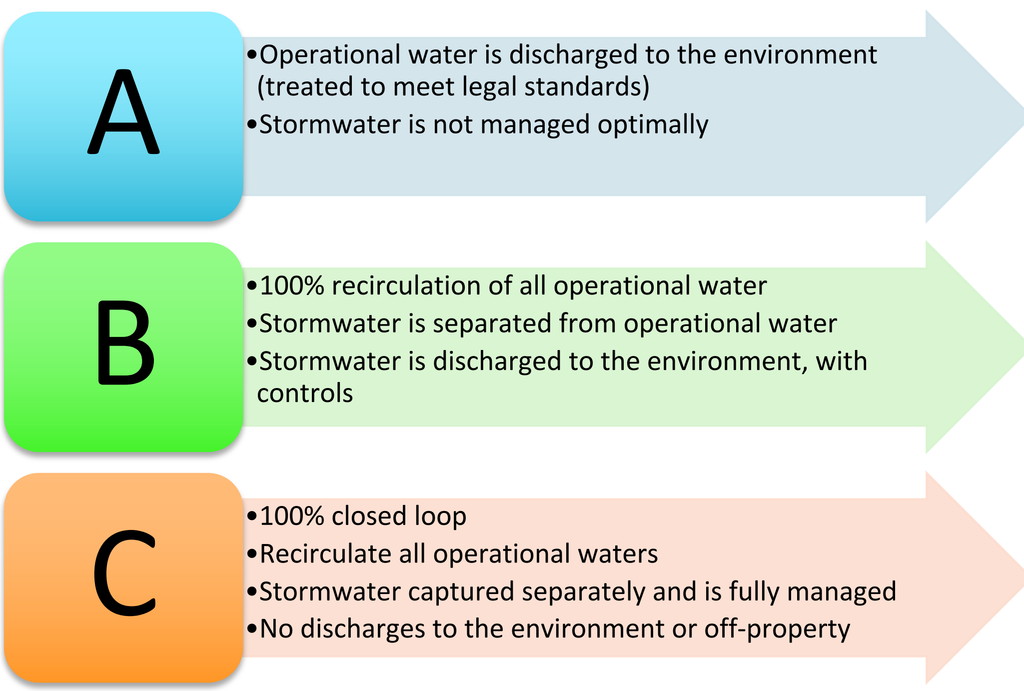

Figure 2.6. *Options in Water Management* – Any one of these options may work for your operation. The "A" option is a reasonable option for some facilities, but may require additional regulatory burden, while the "B" option is more common for the sector. From an environmental perspective, zero discharge (Option C) to the environment is ideal, but this is not always practical for the facility depending on the infrastructure. The key is to manage your water, and minimize how much water needs treatment. In the case studies (Section 3), look for the symbols for A, B, or C to see which option the farm chose.

Understand the water quality issues at the facility:

Now that you've decided if you are going to re-use all or a portion of your water or discharge it, the next step is understanding what's in your pre-treatment water. The most important considerations for growers when it comes to water quality are risk of pathogens, followed by parameters/nutrients that may limit or affect growth, and then contaminants that can impact the irrigation system. To know which water quality issue may be the most significant for an operation, monitoring and water quality testing is critical.

- Monitor for key parameters:
  - Nutrients or specific elements of concern (e.g. aluminum, salts, alkalinity, etc.)
  - EC
  - pH
  - Microbial populations (plant pathogens: bacteria, fungi, etc.)
  - Agrochemicals – pesticides, growth regulators, residual disinfectants
  - Particulates
  - Other (e.g. tannins, disinfectants, etc.)
- Monitor critical locations/sources:
  - Water source(s), pre- and- post treatment if there is treatment
  - Coming off the production area
  - Storage systems
  - Recirculated water (Pre- and post- treatment)
- Monitor at frequencies that relate to the level of risk:
  - Throughout production cycle
  - Changes in source water quality
  - Various crop sensitivities (crop type and stage)
  - Consider labour availability and level of commitment possible

It can take time to go through the steps of monitoring water quality at an operation, and there is previous research on water quality of operational waters for horticultural operations that can be used as a general reference. However, before applying water (treated or not) to a crop, facilities are **strongly** recommended to perform water quality testing. Additional information on testing and benchmark water quality data can be found in Appendix B of this guide or the characterization study by the Soil Resource Group[5].

Next Steps (i.e. making decisions):

Now that quantity and quality of the water at the facility have been determined – what has to be changed to ensure the water meets your needs? Depending on what's in your water, various approaches can be taken. See Figure 2.7 for a flow-chart of the decision process.

Pathogen loading from return water can be managed in a number of ways without installing specialized treatments, for example by using multiple reservoirs as the pathogen risk actually decreases as water passes from one chamber to the next. Increasing the distance or travel time between the chambers further improves the water quality since there is more 'retention time' for settling to occur and survival of pathogens decreases. Managing the pump intake depth and location within the reservoir can also

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[5] Greenhouse Process Water Quality and Quantity Characterization Analysis. Final Report 2012. The Ontario Greenhouse Alliance. Prepared by The Soil Resource Group, Guelph, ON.

decrease pathogen and sediment inputs to the next step in production[6]. If growing on the ground, ensure that there is sufficient grade or the base drains well to minimize standing water under containers.

Specific elements or parameters can be managed to an extent without employing technologies, for example by selecting optimal water sources, working with specialists to fine-tune the fertilizer choices for crops, developing systems for blending fresh water with return water and applying higher risk water onto more mature/less sensitive crops, etc.

However, there may be waters that need various levels of treatment, from very simple to complex systems. At this point, how does a farmer go about deciding which technology(ies) might work?

1. Complete Sections 1 and 2 of this guide and the associated worksheets (Appendix A)
2. Review Section 3 and the example questions and case studies that were designed to illustrate how some farms went through the process of deciding on an appropriate technology
3. If the case studies provided are not applicable, contact local specialists to bridge the gap between Sections 2 and 4 (i.e. get through the decision process)

Finally, it is important to keep track of if a treatment system is performing properly. The final section of this guidance document includes information on how to carry out an in-house monitoring program.

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[6] Hong, C.X. and G.W. Moorman, 2005. Plant pathogens in irrigation water: challenges and opportunities. Reviews in Plant Sciences, **24**(3): 189-208. Available online at: https://s3.amazonaws.com/academia.edu.documents/44485922/Plant_Pathogens_in_Irrigation_Water_Chal20160406-1246-3uwd27.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1521738948&Signature=zoNiO%2FUCgrioKE%2B04SIs%2FTjOKRk%3D&response-content-disposition=inline%3B%20filename%3DPlant_Pathogens_in_Irrigation_Water_Chal.pdf

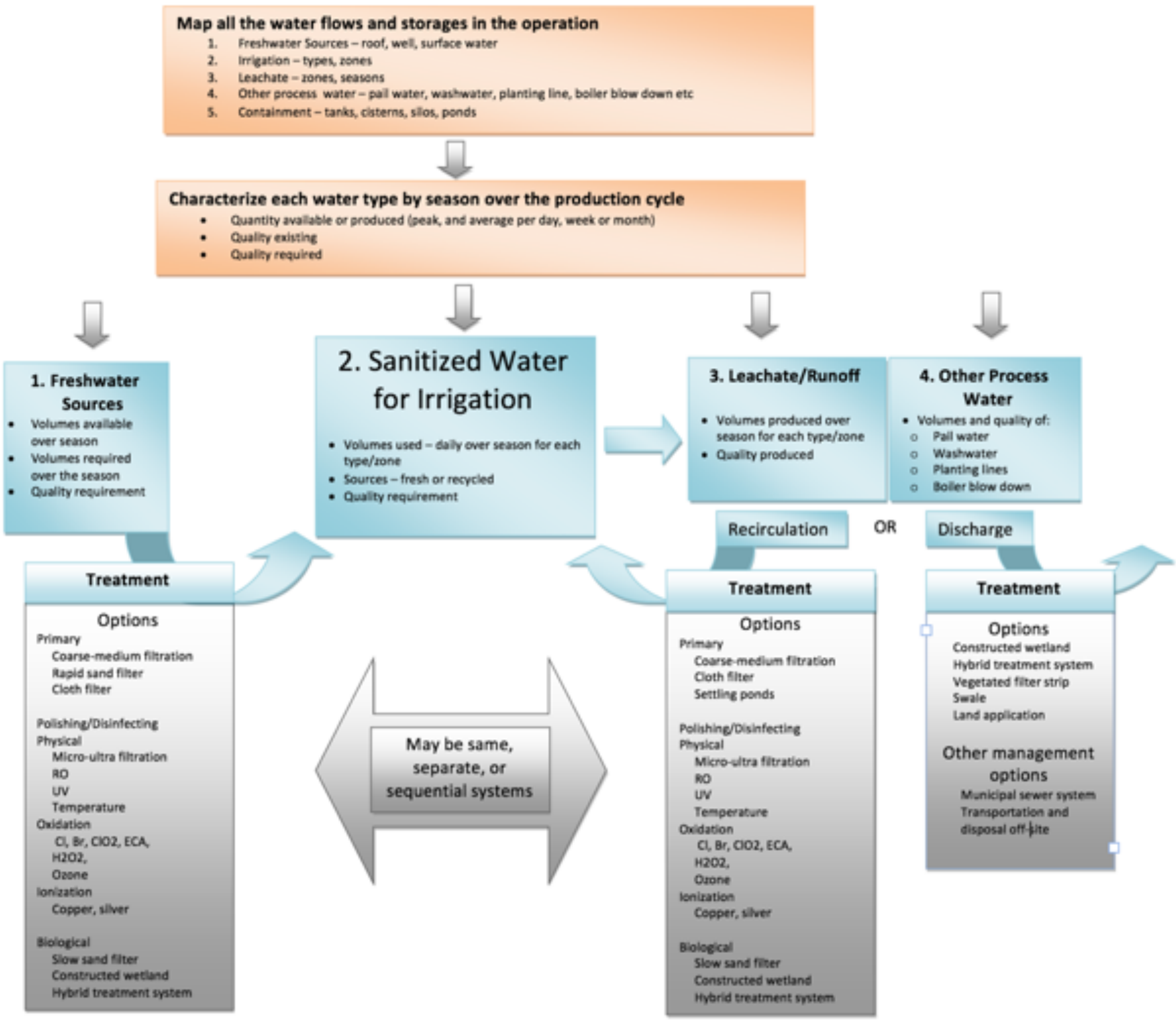

Figure 2.7. Decision tree to illustrate the process for determining how to manage farm water.

Section 3: Case Studies of Various Treatment Options

This section includes examples of how some farms started the process of determining how to treat their water and what information they needed to get to that point. This section focuses on the decision-making process; details of the technologies and treatments are presented in Section 4. A local specialist/consultant may be able provide information or examples beyond the scope of the case studies presented here. A blank template, similar in appearance to the case studies, can be found in Appendix C.

Key questions in the decision-making process:

1. What is the most pressing concern (i.e. the key driver)? Pathogen removal? Water quality to meet allowable discharge targets? Water quality to allow for recirculation/re-use? Polishing step to remove colour or particular contaminant so that other GH systems can function?
2. Production area by ship week? Overall size of operation?
3. Crop (area/percentage) by ship week?
4. Irrigation system(s) in place, where, when used?
5. Crop sensitivities? Special needs?
6. Which water types need to be treated?
7. Facility layout, footprint availability, outdoor/geographical considerations
8. Any infrastructure complications? (e.g. cross connections, long distances, etc.)
9. Future expansion plans?
10. Budget? Three parts: isolate/bring waters to one point, treatment, and storage

Remember - use the worksheets generated in Appendix A when answering these questions!

Case studies included in this section:

#1. Floriculture Greenhouse – Hybrid Treatment System (HTS)
#2. Container Nursery – Hybrid Treatment System (HTS)
#3. Floriculture Greenhouse – Woodchip Bioreactor
#4. Floriculture Greenhouse – Constructed Wetland
#5. Floriculture Greenhouse – Vegetative Filter Strip (VFS)
#6. Floriculture Greenhouse – Electro-Chemical Activation (ECA)

Case Study #1	Floriculture Greenhouse – Treating Operational Waters with HTS
Concerns/Drivers	○ Under pressure to address nutrient discharges to nearby surface water ○ Loss of valuable nutrients ○ Concern over potential spread of pathogens to plants and costs for treatment if recycling the water
Farm information - details of seasonality, irrigation methods, water sources, what waters need treating, budget, etc.	○ Production area/volumes: • For each zone, determined weekly volume applied and leached/lost to determine water volume that could be collected and re-used or discharged (analysis of water flows was not a quick process!) • Flows: 300-25,000L/day anticipated, not consistent over time • Peak flows April-June, a lower peak in August-September (but year-round flow present) ○ Range and timing of irrigation systems used for each crop & in each zone: combination of mist, sprinkler, boom, drip, capillary mat, hand ○ Crop sensitivity: Propagation can only use groundwater, recirculation and roof water can be used on more tolerant crops ○ Range of waters to treat include: nutrient leachate, cart/shipping water, subsurface drains, floor drains ○ Additional challenges: Many cross-connections with stormwater, requires a lot of effort to isolate operational water ○ Land area available: ~0.25 hectare outdoors, but extremely limited indoor space ○ Future expansion plans: additional greenhouse ranges planned ○ Budget: separate budget needed for a) isolating and collecting all greenhouse operational waters ($ not reported), and b) treatment ($50k target)
Decision Process	○ If recycling: • Needed low pathogen risk • Accept cleaned/stripped water (would prefer to keep nutrients), could work with slightly elevated alkalinity ○ If discharging: • Would mean a more intensive permit process • Water needs to meet ministry targets ○ The treatment system must: • Have simple maintenance system, low operating costs • Be cost-effective treatment • Want ‘green’ technology ○ Treatments eligible for government cost-share funding ○ Treatment options include: • Traditional water treatment – UV, ECA, Chlorine (range of forms) • Vegetative Filter Strip (needs ministry permit) • Land Application (needs Plan/approvals) • Hybrid Treatment System (HTS)

Final Stage of the Decision Process **B**	○ Evaluation of regulatory controls on each option – with complete recirculation, traditional water treatments & HTS had no required ministry approvals ○ Costing of traditional water treatments compared to HTS (similar) ○ Capital (install) cost for treatment system based on daily design flow: for this site: $2.4 per L/day treatment capacity ○ HTS could be designed to handle the flows and fluctuations over the year ○ Opportunity to try completely novel treatment system (HTS) with a dedicated team of research scientists to oversee design/install/performance was the deciding factor ○ Water quality from HTS system suitable for irrigation, especially if being blended with fresh nutrient solution ○ Ultimate decision: to treat and recirculate/reuse the water ○ For more info on Hybrid Treatment Systems see Section 4
Benefits to date	○ Completely recirculate all greenhouse/nutrient water (none is discharged), so there are no nutrients going out into environment ○ Capturing additional water means less water-taking ○ Thinking about this process encouraged the farm to participate in Farm & Food Care's Water Smart study, further improving their water use efficiency ○ Treated water not used on propagation area, but rest of farm can use the water ○ Fertilizer savings still to be determined (new system)

Figure 3.1 Hybrid Treatment System with woodchip cell in the background, and pea gravel and filter sand cells in the foreground.

Case Study #2	**Container Nursery – Treating Surface Runoff Waters with HTS**
Concerns/Drivers	○ Desire to improve water quality ○ Concern with potential for recycling pathogens through main irrigation water source
Farm information - details of seasonality, irrigation methods, water sources, what waters need treating, budget, etc.	○ Production area/volumes: • Determined irrigation schedule (7-10am most mornings through growing season) • Estimated volume applied (~100,000L/d) • Estimated surface runoff based on 60% potential recapture from applied volumes ○ Irrigation scheduling and precipitation impacts? • Estimated precipitation volumes (200,000L/d average rainfall event) • Large fluctuations possible during storm events ○ General water quality of surface runoff: some particulate, low level nutrients ○ Main challenges: weather, sizing of unit, managing the variability in flows ○ Layout/footprint: area available for an in-ground treatment system, but want to use the surface area for growing (~1 hectare) ○ Future expansion plans not applicable ○ Budget: separate budget needed for: a) electrical/grading, and b) treatment
Decision Process	○ Both recycling AND discharging the water: • Needed low pathogen risk • Water needs to meet ministry targets • Accept cleaned/stripped water (would prefer to keep nutrients), could work with slightly elevated alkalinity • Creation of ‘sewage works’ means a more intensive permit process for the discharge ○ The treatment system must: • Have simple maintenance system, low operating costs • Be cost-effective treatment • Want ‘green’ technology ○ Treatments eligible for government cost-share funding ○ Treatment options include: • Vegetative Filter Strip (needs ministry permit) • Land Application (needs Plan/approvals) • Hybrid Treatment System (HTS)
Final Stage of the Decision Process **A**	○ Evaluation of regulatory controls on each option – all options require ministry approvals ○ Opportunity to try completely novel treatment system (HTS) with a dedicated team of research scientists to oversee design/install/performance was the deciding factor ○ HTS could be designed to handle the flows and fluctuations over the year

	○ Capital (install) cost for treatment system based on daily design flow: for this site: $1.4 per L/day treatment capacity ○ For more info on Hybrid Treatment Systems see Section 4
Benefits to date	○ Surface runoff is cleaned to acceptable standards ○ Option to treat water stored in their pond (i.e. cycle it through the treatment and back into the storage system) ○ Enhanced investigations into improving their water use efficiency ○ Entire farm can use the treated water ○ No loss of production area

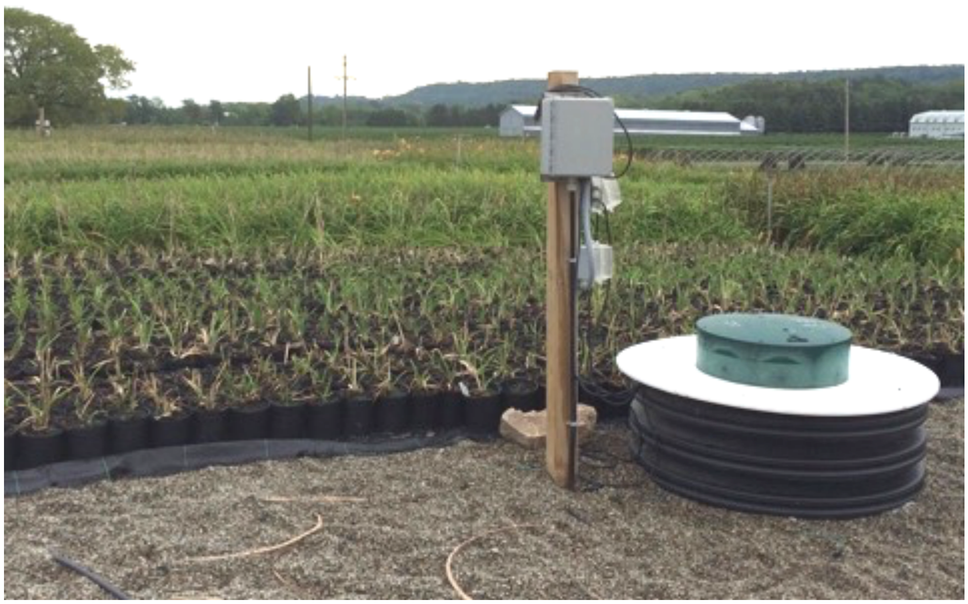
Figure 3.2 Hybrid Treatment System underneath growing area.

Case Study #3	**Floriculture Greenhouse – Treating Operational Waters with a Woodchip Bioreactor**
Concerns/Drivers	○ Concern over potential spread of pathogens to plants and costs for treatment if recycling the water ○ Under pressure to address nutrient discharges to nearby surface water ○ From the outset, decided to recirculate 100% of operational waters
Farm information - details of seasonality, irrigation methods, water sources, what waters need treating, budget, etc.	○ Production area/volumes: • Estimated daily water volumes that would be collected and re-used: • Flows: 25,000L/day max. anticipated, not consistent over time • Peak flows April-June, a lower peak in August-September (but year-round flow present) • Range of waters to treat: nutrient leachate, subsurface drains • Range of irrigation methods, but mostly flood floors ○ Land area available limited (~0.1 hectare) ○ Limited outdoor area, but extremely limited indoor space ○ Future expansion plans: maybe additional flood floors ○ Additional challenges: • Crop sensitivity: Propagation uses groundwater only, recirculation and storm water on more tolerant crops • Groundwater can enter subsurface drain system during big storms
Decision Process	○ To recycle: • Needed low pathogen risk • Accept cleaned/stripped water (would prefer to keep nutrients) ○ The treatment system must: • Have simple maintenance system, low operating costs • Be cost-effective treatment • Want 'green' technology ○ Treatments are eligible for government cost-share funding ○ Treatment options include: • Traditional water treatment – UV, ECA, Chlorine (range of forms) • Vegetative Filter Strip (needs ministry permit) • Land Application (needs Plan/approvals) • Constructed wetland or novel technology option of using woodchips (at the time, HTS did not exist) ○ Design needs to handle the flows and fluctuations over the year ○ Budget: separate budget needed for a) isolating and collecting all greenhouse operational waters ($ not reported), and b) treatment ($20k target)
Final Stage of the Decision Process **B**	○ Evaluation of regulatory controls on each option – preferred no required ministry approvals ○ Woodchip bioreactor system was priced similarly to traditional water treatments ○ Capital (install) cost for treatment system based on estimated daily design flow: for this site: $0.64/L treatment capacity ○ Designed to handle the flows and fluctuations over the year

	○ Opportunity to try completely novel treatment system (woodchip bioreactor) with a dedicated team of research scientists to oversee design/install/performance was the deciding factor ○ Water quality from the treatment system suitable for irrigation, especially if being blended with fresh nutrient solution ○ For more info on Woodchip Bioreactors see Section 4
Benefits to date	○ Completely recirculate all greenhouse/nutrient water (none is discharged), so there are no operational waters going out into environment ○ System has been working consistently for a number of years ○ Pathogen removal excellent ○ Capturing additional water means less water-taking ○ Thinking about this process encouraged the farm to participate in Farm & Food Care's Water Smart study, further improving their water use efficiency ○ Treated water not used for propagation, but treated water used on all other crops ○ Continue to use ECA water treatment and PRIVA Vialux UV treatment in the greenhouse in addition to the woodchip bioreactor

Figure 3.3 Woodchip Denitrification Bioreactor

Case Study #4	Floriculture Greenhouse – Treating Nutrient Feedwater with Combined Constructed Wetland & UV Technologies
Concerns/Drivers	○ Operation previously recirculating some nutrient feedwater ○ Ultraviolet sanitation system not working well due to contaminants in water ○ Critical to ensure water is free of pathogens ○ Desire to keep valuable nutrients ○ Want to manage high volumes of irrigation water
Farm information - details of seasonality, irrigation methods, water sources, what waters need treating, budget, etc.	○ Volumes/production: • Cut flower, hydroponic production system • Main period of need for managing volumes is winter-spring • Estimated total volumes (daily average, peak) based on applied • Volumes: weekly production (# units/week, and volume/unit), (consider refresh volumes and what gets used by the plant) • High volumes moving through • Added floor drain and other greenhouse waters to the return water, so need to treat a mix of waters ○ Existing treatment: hydrogen peroxide and UV for sanitation ○ Additional challenges to address: • Need to ensure that no PGR's from other crops could be recirculated to the cut flowers • The water that's generated has colour & turbidity contaminants • Always difficult when retrofitting – want to do it right but also to utilize what they had – had to consider water lines, tanks, bypasses • Require 'polished' (i.e. clear and colourless) water for existing UV system to work optimally (to get sufficient volume through) ○ Land area available (~0.5 hectare) ○ The treatment system must: • Have simple maintenance system, low operating costs • Be cost-effective ○ Treatments should be eligible for government cost-share funding ○ Treatment options include: • Constructed wetland • Sand filter ○ Budget consideration: isolating/re-routing waters, treatment system, and storage requirements
Decision Process	○ Farm reviewed treatment options available: • Heat pasteurization –natural gas costs were uncertain • Ozone options at the time were limited • Constructed wetland – could be effective for polishing water • Sand filters – may be part of the solution, but colour still an issue and concerned that particulates may clog it (high maintenance) ○ Farm looked to other growers for ideas, went to research talks & grower days ○ Big take-home message from Paul Fisher (University of Florida, cleanwater3.org) – not one technology will solve it all – a whole integrated approach across the facility is needed

	○ Had to include other operational waters into the system, not just recirculated nutrient feedwater – increasing pressure from environmental ministry
Final Stage of the Decision Process **B**	○ Decided to install constructed wetland, but after adding greenhouse operational waters there was more particulate to deal with ○ Installed filter cloth at time of constructed wetland install, but using a lot of cloth ○ Subsequently added a settling pond to remove extra solids, then water goes through the cloth filter before going through the constructed wetland ○ For more info on Constructed Wetlands see Section 4
Benefits to date	○ Ongoing pathogen testing confirms system is effective, although regular maintenance is required ○ Overall capital treatment costs = approximately $3 per L/d treatment capacity (settling pond/wetland combined) ○ The UV system combined with hydrogen peroxide is now working well (optimal volumes treated) for sanitation; the settling pond, constructed wetland and cloth filter system ensures the water reaching the final stage of treatment is suitable – the water is polished properly and then sanitized ○ Minimal maintenance of UV needed, it’s functioning well ○ Cloth filter use at least 10x less than before the settling pond ○ Expect algae issues in the settling pond in upcoming seasons, and will have to address that

Figure 3.4 Settling Ponds and Constructed Wetland

Case Study #5	**Floriculture Greenhouse – Managing Operational Waters with a Vegetative Filter Strip**
Concerns/Drivers	○ Need to manage operational water discharging from the greenhouse ○ Prepared to get ministry approvals as necessary
Farm information - details of seasonality, irrigation methods, water sources, what waters need treating, budget, etc.	○ Production area/volumes: • Minimal volumes, estimated initially, confirmed through collection measurements • ○ Piping/isolation of irrigation leachate already completed, discharge went directly onto grass outside the greenhouse ○ Estimate required storage – based on volumes generated per day at peak ○ Layout/Footprint: approximately 0.5 hectares available outdoors ○ Estimated volumes per day, and storage needed ○ No future expansion plans ○ Budget extremely limited (small facility)
Decision Process	○ Limited options for recycling due to age of facility • Obtain permit for discharge (requires treatment and permit) • Re-use would require sanitation treatment and substantial plumbing system upgrades ○ If discharging: • Would mean a more intensive permit process • Water needs to meet ministry targets ○ The treatment system must: • Have simple maintenance system, low operating costs • Be cost-effective treatment • Want 'green' technology ○ Treatment options include: • Vegetative Filter Strip (needs ministry permit) • Direct Discharge (needs treatment before permit would be granted) ○ Budget of $ to purchase tank and plumbing system, grade lot (minimal lot preparation required)
Final Stage of the Decision Process **B**	○ Design engineers calculated an 8000L tank was required to manage the volumes, and calculated the appropriate flows and area of land required ○ 1% slope over a 1,000m^2 area was sufficient ○ Designed for zero discharge at the end of the system, so no physical discharge occurs off property ○ ○ ○ For more info on Vegetative Filter Strips see Section 4
Benefits to date	○ No water has been observed to flow beyond the Vegetated Filter Strip (i.e. there is zero discharge) ○ All the operational waters are managed

<table>
<tr><th>Case Study #6</th><th>Floriculture Greenhouse Propagators – Pathogen Control using ECA</th></tr>
<tr><td>Concerns/Drivers</td><td>○ Primary concern is having pathogen control for propagation
○ Also looking to recycle their irrigation water, so want pathogen control on the recirculated water to be consistent and effective
○ Had existing treatment system (hydrogen peroxide) but it was not consistent when they irrigated through their mist system</td></tr>
<tr><td>Farm information - details of seasonality, irrigation methods, water sources, what waters need treating, budget, etc.</td><td>○ Production area/volumes:
• overall production over the year is 70% full, late Dec to Jan pretty low (~20%) then gradually climbs up to 100% by late-February to end of May, then scales back, then fall program starts picking up again
• $/sq ft is crucial (cost of equipment) but so is impact of clean water on plant
• treating the return water from irrigation/fertilizer, plus are also treating the town water – so not worried about source/supply
○ Range and timing of irrigation systems used for each crop & in each zone: mist, sprinkler, boom, drip, capillary mat, hand
○ Estimate required storage dependent on system chosen
○ Range of waters to be treated by the system (various operational waters)
○ Additional challenges:
• no really fussy crops, but the propagation area must receive consistent, high-quality water
• Feb-May is critical time for super-clean water, but still want to recycle and have clean water all year so it can always be used
○ Layout/Footprint: minimal space available inside
○ Future expansion plans: add additional greenhouse/property
○ Budget limited (< $100K)</td></tr>
<tr><td>Decision Process</td><td>○ Want to recycle:
• Need consistently low pathogen risk
• Prefer to keep nutrients
○ The treatment system must:
• Work consistently
• Be cost-effective for multiple locations/zones
○ Sales people came through and made suggestions – e.g. soluble copper, ozonator, chlorine dioxide, ECA
• Copper – tried soluble copper before, not 100% satisfied, good control on fungi but not full sanitation achieved
• Ozone – costly, limitation was that would need 4 units – so only really value for locations where irrigation system is all connected as one
• ECA – had possibilities, ability to inject in multiple places, should be cost effective but some learning curve associated with it
○ Looking for a solution that could address needs at multiple locations
○ Ozone out of budget, ECA within budget</td></tr>
</table>

	○ Layout/Footprint: ECA unit itself is 6-8' tall, 3-4 feet by 3-4', plus storage tank (sized based on need); it was a bonus that they didn't need to have multiple locations and big footprint
Final Stage of the Decision Process **B**	○ Final decision – went with ECA system since the product can be injected at multiple sites (including new greenhouse operation) and enough evidence it will perform as required ○ Injecting after filter cloth/at that point there is a flow meter before it goes into feed tanks (could have chosen to inject as it goes out to crop) ○ Didn't need to get special pump set ○ Expect learning curve, close monitoring until system has been in place for a while ○ Moderate-High capital cost ($~50K), but can generate own product on-site
Benefits to date	○ Low operating costs – recurring costs are the KCl (but it's minimal) and unit runs 1-2hours/night, hydro basically like that of a lightbulb ○ Seeing better roots – really enhances growth/health, ○ Works well for pathogen control, not perfect but fewer disease instances observed ○ Possible to get an Argus/Priva sensor or get manual calibration/testing materials to ensure levels are right ○ Seems to have a shelf life, but can generate on demand so it works out ○ Doing in-house testing to see if everything is really working ○ ~75% satisfied with the system – but would any system ever get to 100%?
Additional comments from the owner:	○ Can't just set it up and walk away ○ Check levels frequently, especially when starting up system ○ Use computer control system or check levels manually ○ Ensure concentration is stable, injected levels are where you want them, ○ If recycling then really need to know volumes out versus coming back to know if injecting enough or too much ○ Once lines are clean then maybe levels need to come down accordingly in the level applied (so stay on top of PPM to make sure they're right – check weekly or so) ○ If not recycling – maybe rely on municipal water just for prop, then maybe don't need to invest the same ○ Storage/shelf life important – get the right size tank for generated product ○ With ANY treatment – make sure it's working on a regular basis, monthly is probably not enough (maybe ECA or injected chemical type things needs MORE than that – weekly or semimonthly) ○ ECA may work better for operations with high volumes (like a hydroponics operation) ○ Legal issue – There is an application submitted to Health Canada to allow for chlorination using KCl instead of NaCl, expected approval by end of 2018

Section 4: Treatment options and their key parameters

This section presents a list of technologies and/or management treatment processes designed to improve water quality. This list is not exhaustive, but provides an overview of commonly used technologies in horticulture. Information from Section 2 and 3 of this document should prepare growers for which treatments to focus on based on their needs and existing situation. The list is broken up into types of treatment: physical, chemical, biological, and combinations of these three.

The information compiled here is not exhaustive but provides an overview of key points to be aware of before engaging a contractor or sales person regarding installation of treatment system. BE INFORMED ahead of time – it will save you money!

Before going further – read this notice!
The following section contains brief summaries of the main methods used to treat water, particularly in recirculating systems. While the summaries below aim to provide a quick synopsis of the mode of action, operational considerations, and advantages and limitation of each group of technologies, there are many resources where additional information can be found. For example:

The **Back Pocket Grower** at http://backpocketgrower.com/ provides details on the efficacy of the range of treatment systems/chemicals on 30 specific genera of plant pathogens or groups of organisms. As a bonus, it also has other interactive tools for irrigation solution chemistry, substrate volumes, production budgets, production guides for 75 crops, as well as training videos on propagation, substrates, irrigation and water quality, and links to on-line certificate courses.

CleanWater3: Treatment Technologies. http://watereducationalliance.org/keyinfo.asp

Sign up for newsletters from the **CleanWater3** website: http://cleanwater3.org/newsletters.asp to receive up to date information on water management and treatment related issues.

More details on the mode of action, efficacy and costs of treatment systems can be found at Dr. Youbin Zheng's **University of Guelph** interactive website: http://www.greenhouse-management.com/greenhouse_management/irrigation_water_greenhouses/disinfestation_greenhouse_irrigation_water.htm.

A further on-line resource is the **Pacific Northwest Plant Disease Management Handbook**: Treating irrigation water to eliminate water molds https://pnwhandbooks.org/node/291/print.

What is in this chapter?

Disinfection usually involves at least 2 steps: pre-treatment/pre-filtration to remove organic and inorganic debris (plant material, sediment, algae etc.), followed by a sanitation step. Pre-treatment improves the performance of the final (usually costlier) disinfection process by removing material that would otherwise interfere or clog up the final treatment. Treatment systems have been divided up into the following categories: physical, chemical, and biological. Several systems are a combination of two or more of those processes. Selected parameters for the range of treatment systems are summarized in Table 4.1.

Physical
Remove contaminants either by separating them out of the water passing through the treatment system or by killing organisms in the water without removing them from the system. These treatment methods generally do not have a residual treatment effect on the irrigation system itself and are not useful for reducing biofilms and preventing clogging. There should be no phytotoxic effects.

- Filtration – from sand separators to reverse osmosis
- Rapid media filtration - rapid sand, greensand, activated carbon
- Ultraviolet irradiation
- Heat treatment (pasteurization)

Chemical
Chemical treatment systems function by damaging cell membranes and/or internal cell organs, causing organism death. Unlike physical systems, in a properly operated system there are

residual chemicals to increase the dose-response time of the treatment system, and prevent biofilm buildup in the irrigation lines.

- Oxidizing agents
    - Chlorine & Bromine – oxidation to destroy organisms such as algae, fungi and bacteria
        1. Sodium hypochlorite (liquid; bleach)
        2. Calcium hypochlorite (solid); 60-70% available Cl
        3. Chlorine gas
        4. Chlorine dioxide
        5. Electro-Chemical Activation (ECA)
        6. Bromine
    - Hydrogen Peroxide, Peroxyacetic acid
    - Ozone
- Combined Physical and/or Chemical: Advanced Oxidation
- Copper and Silver
    - Copper ionization
    - Copper salts
    - Copper / spin-out fabric liner
    - Silver

Biological

Biological treatment systems generally combine a number of treatment processes: physical separation, competition by other organisms, or creating an environment that does not favour pathogen survival. Often these systems can provide nutrient removal as well, and serve as methods for dealing with water that cannot be recirculated. NOTE: Most of these are outdoor systems, and biological systems are responsive to temperature. Therefore, special considerations may need to be incorporated in the design such as insulation or covering.

- Slow media filters and fluidized beds
- Constructed wetlands
- Wood chip denitrification bioreactors
- Hybrid treatment systems
- Bioswales
- Vegetated filter strips
- Land application

Table 4.1 Summary of the selection criteria for water quality treatment systems

Category	Technology	Treatment Range					Pre-treatment required?	Phytotoxic Residuals?	Footprint	Costs		Page reference
		Solids/ organic material	Pathogens	Nutrients: N	Nutrients: P	Agri-chemicals				Capital	Operating	
Physical	Filtration - coarse	√	No	No	No	No	No	No	Small - medium	$-$$	$	28-31
	Filtration- micro	√	√	R/O	R/O	R/O or nano-	Yes	No	Medium	$$-$$$	$$	28-31
	Rapid media filters	√	No	No	Media dependent	Media dependent	Coarse	No	Small	$-$$	$	32-33
	UV	No	√	No	No	No	Yes	Few	Small	$$-$$$	$	34-35
	Heat	No	√	No	No	No	No	No	Medium	$$$	$$$	36-37
Chemical	Chlorine	√	√	No	No	Some	Yes	Phytotoxic	Small	$-$$	$-$$	37-40
	Chlorine dioxide	√	√	No	No	Some	Yes	Phytotoxic	Small	$-$$	$-$$	37-40
	ECA	√	√	No	No	Some	Yes	Phytotoxic	Small	$$	$-$$	37-40
	Bromine	√	√	No	No	Some	Yes	Phytotoxic	Small	$-$$	$-$$	37-40
	Hydrogen peroxide	√	√	No	No	Some	Yes	No	Small	$-$$	S-$$	41-42
	Ozone	√	√	No	No	Some	Yes	No	Medium	$$$	SS	43-44
	Advanced oxidation	√	√	No	No	Some	Yes	No	Medium	$$$	$$$	45
	Copper; Silver	No	√	No	No	No	Yes	Possible	Small	$$	$$	46-47
Biological	Slow filters & fluidized beds	√	√	No	No	Possible	Coarse	No	Medium	$$	$	48-50
	Constructed wetlands	√	Variable	√	Variable	√	Coarse	No	Small-large	$$-$$$	$	51-52
	Woodchip Bioreactors	√	√	√	Some	Likely	Coarse	No	Medium	$-SS	$	53-54
	Hybrid Treatment Systems	√	√	√	√	Likely	Coarse	No	Medium	SS-$$$	$	55-58
	Bioswales	√	Variable	√	Variable	Potentially	Coarse	No	Medium	$-SS	$	59-61
	Vegetated Filter Strip	√	Zero discharge				Coarse	No	Medium	$	$	62-63
	Land Application	√	√	√	√	√	No	No	Storage	$	$	64-65

Physical: Filtration

There is a wide variety of filter systems used to remove contaminants from either source water or water recovered for reuse in recirculating systems. Often filters are used as a pre-treatment step prior to other physical disinfection systems such as UV that require relatively clear water in order to perform optimally or chemical disinfection where organic materials can tie up the active disinfection component. Ideally total suspended solids should be less than 20 mg/L. Coarse materials can rapidly clog filtration systems designed to remove finer particles (e.g. microfiltration) and should be removed first to increase the efficiency and longevity of a more expensive downstream filtration system. The capital and operating costs of filtration systems generally increases with decreasing pore size, from very low for in-line screens ($0.02/1000 gal) to very high for nano- and ultra-filtration ($1.75/1000 gal)[1], so a multistage filtration will be cost-effective in the end.

The chart below indicates the type of materials that can pass through or be retained on specific filter systems (modified from: https://www.safewater.org/fact-sheets-1/2017/1/23/ultrafiltrationnanoandro.

Figure 4.1 Physical filtration capabilities matrix.

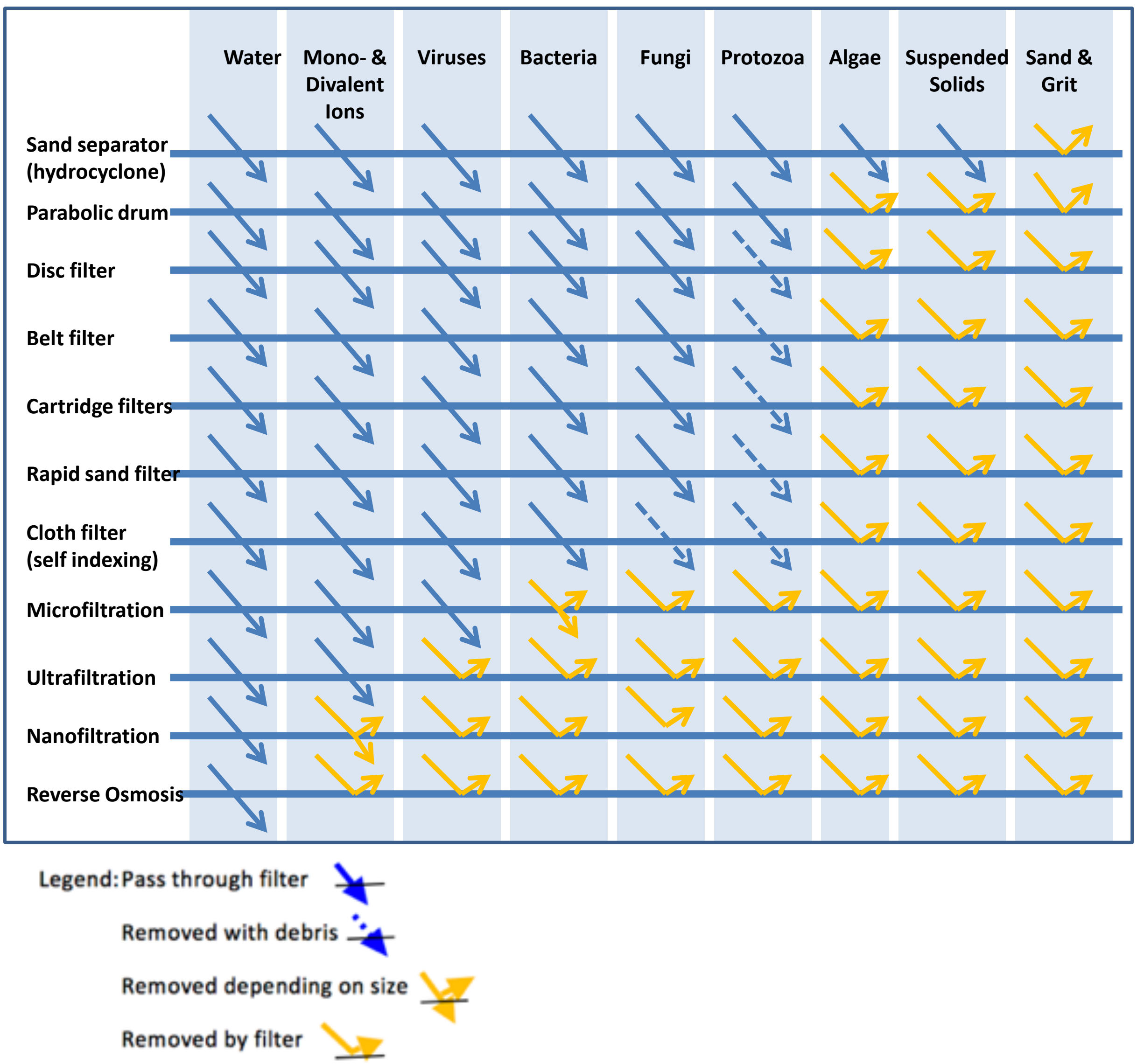

Table 4.2 The following table briefly describes the principles of operation of the various commonly used filter types, contaminants removed, advantages and limitations of the filter, and suitable waters for treatment.

METHOD OF TREATMENT	PRINCIPLES OF OPERATION	Target contaminants, Advantages and Limitations	Target Water to Treat
Sand separator (hydrocyclone)	• Uses centrifugal forces to separate sand and other solid material out of water	• Rapid removal of large amounts of soil, sand and large particles as a pre-filtration step • Prevents clogging of pipes, sprinklers etc. • Some versions used to take out coagulated/ flocculated fine organic materials	• Source water (river, lake, pond)
Rotating drum filter	• Water is passed through a rotating screen which separates debris from water; screen continually sprayed to clean	• Large amounts of organic and inorganic debris	• Processing water • Source water (river, lake, pond)
Parabolic screen	• Screen with a parabolic curve to separates dirt and large particulates from water • Dirt slides down and off the screen to a collection point, while the cleaned water passes through the screen. • Rapid and semi self-cleaning	• Good pre-filter step • No moving parts or energy requirement	• Return irrigation water • Wash water
Rapid sand filter	• Sand bed over gravel used for removal of coarse particles from water • Either gravity or pressure fed • Cleaned by backwashing	• Removes organic material/debris • Water with minimal levels of algae or biofilms • Effective pre-treatment of water prior to disinfection processes • Management of dirty backwash required • Other media such as pumice also used with improved performance	• Source water (river, lake, pond)
Media filters: (see following section for details)	• Selective removal of chemicals based on the filter media • Cleaned by backwashing	• Greensand: removal of iron and manganese • Activated carbon: removal of organic compounds such as pesticides and plant growth regulators (PGRs)	• Source water (river, lake, pond) • Return water in recycling systems
Disk filter (10-20um)	• Several stacked, flat, grooved disks • Water forced under pressure around the disks and through the grooves to remove the filtered material • Cleaned by backwashing	• Removal of organic matter • Not for water high in sand or large particles • Management of dirty backwash required	• Source water (river, lake, pond)

Cloth filter (self-indexing)	• Removal of fine material • Filter cloth advances based on the water flow through the filter • Dirt is removed as a cake along with the spent filter	• Various pore sizes available for the cloth from 10 to 200 microns	• Source water (river, lake, pond) • Return irrigation water • Wash water
Cartridge filters	• Removal of specific material depending on the cartridge material	Specific for material to be removed • Non-reactive materials: Sand, scale, lime, rust, fine particles • Stainless steel: sand, scale, rust • Pleated cartridge filters: sand, scale, rust • Activated carbon: smell, colour, taste, pesticides, chlorine, organic compounds • Oil-block absorptive media: oils	• Source water (river, lake, pond) • Return water in recycling systems
Hollow fibre membrane filtration systems	• Hollow fibre membrane systems with selected pore size for pathogen removal (see below) • Dirty water filtered from the outside through the membrane into the hollow fibre core; cleaned water flows out of the fibres to clean water storage • Vacuum driven • Can be in-line or in-tank • Requires periodic backwash	• Not in general use for greenhouse but systems used for municipal treatment • Automated backwash cycle • Small footprint • Systems can be installed inside return tank; treated water sent to clean water tank • Small volume of backwash to be managed (<0.2% in pilot[6]) • Systems have been trialed in Ontario (University of Guelph, H. Zhou)	• Pretreated source water and return water in recirculating systems
Microfiltration	• Low pressure removal of particles from approx. 0.1 to 10 micron in size	• Particles, sediment, algae, fungus, bacteria • A pre-filtration step for nano-filtration and reverse osmosis	• Pretreated source water and return water in recirculating systems
Ultrafiltration	• Selective filtration based on pore size • Removal of particles from approx. 0.01 to 1 micron in size (small colloids and viruses) • Does not affect the nutrient chemistry	• Pathogen removal including viruses, bacteria, fungi • Suspended solids and high molecular weight polymers • Relatively inexpensive on small scale but can become costly depending on level of automation. • Membrane requires backwashing • Will require replacement after long use (membranes are recycled) • Not generally in use in greenhouse systems yet	• Pretreated source water and return water in recirculating systems
Nanofiltration	• Removal of particles from approx. 0.001 to 0.01 micron in size	• Disinfection and partial demineralization • Removal of pesticides depending on molecular size	• Pretreated source water and return water in

	• High pressure filtration through nanometer size cylindrical pores • Removal of larger molecules such as pesticides etc.	• High cost and maintenance • Requires pre-treatment to improve efficiency • Not generally used in greenhouse systems yet	recirculating systems
Reverse osmosis	• High pressure is used to force the source water through a filter retaining the contaminants on one side of the filter in a concentrated “brine” and pure water on the other	• Very clean water is produced • Removes low molecular weight compounds • Removes salts, sugars, metals, pesticides, nutrients etc. as well as pathogens • A large amount of concentrated “brine” to be managed, • High capital cost • Requires pre-treatment to improve efficiency • When used for recycling over a prolonged time, can cause some nutrient deficiencies	• Pretreated source water and return water in recirculating systems

References and Resources:
1. Raudales, R. et al., 2017. The cost of filtration. https://gpnmag.com/article/the-cost-of-filtration/
2. Cleanwater3 website: http://cleanwater3.org/
3. Zheng, Y. Greenhouse and Nursery Water Treatment Information System: Particle and debris removal. http://www.ces.uoguelph.ca/water/debris.shtml
4. Safe Drinking Water Foundation, Ultrafiltration, Nanofiltration and Reverse Osmosis. https://www.safewater.org/fact-sheets-1/2017/1/23/ultrafiltrationnanoandro
5. Clearstream Inc.: http://www.clearstream.ca/media_filters.htm
6. Lenntech: Water Treatment Solutions. https://www.lenntech.com/systems/
7. Ohtani, T. et al., 2000. Development of a membrane disinfection system for closed hydroponics in a greenhouse. J. Agric. Engng Res., **77**(2):227-232

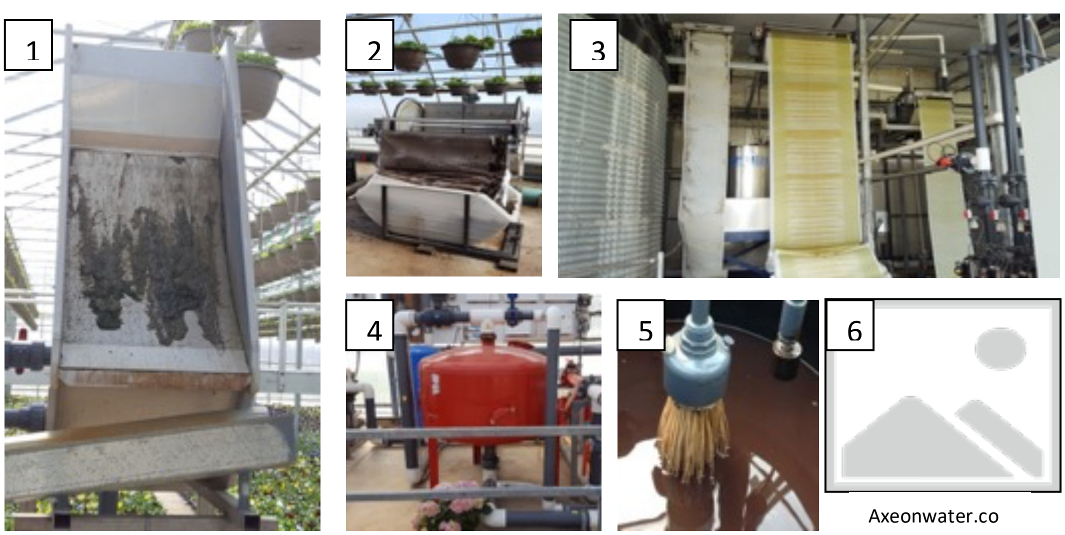

Figure 4.2 Filter technology range (1-parabolic screen filter, 2 - small scale cloth filter, 3 - large scale cloth filters, 4 - rapid sand filter, 5 - pilot scale hollow fibre filter, 6 - reverse osmosis)

Physical-Chemical: Rapid media filters

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
√	Media dependent	No	Media dependent	Media dependent	Media dependent	No	$-$$	$-$$

Rapid Sand Filter

- Physically removes particulate organic matter and debris, but the media is chemically neutral.
- Systems vary widely in size and configuration, but the most common type for greenhouse use is the 'squat' tank containing a layer of sand over gravel (Figure 4.3, 4.4)[1].
- Has backwash systems to clean and prevent clogging, and the backwash must be dealt with appropriately.

Greensand

- Greensand filter media has a coating of manganese oxide which oxidizes iron, manganese(II), and/or hydrogen sulphide in water[2].
- The most common configuration is the standard tall tank with backwash.

Granulated Activated Carbon

Mode of Action

- Granulated activated carbon (GAC) is produced by charring (burning under low oxygen conditions) which creates a porous material with high reactive internal surface area.
- It can be used for the removal of organic contaminants, including pesticides and plant growth regulators (PGRs), as well as chlorides etc generated from recirculating water.

Design and Operational Considerations

- Installation costs similar to rapid sand filter, but the media will require regeneration to maintain efficiency, therefore operating costs will be higher
- Since it is difficult to know when it is losing efficiency it should be replaced regularly based on design criteria – water volume x typical contaminant concentration
- Regeneration can be done on-site or under service agreement with supplier

Advantages and Limitations

- Requires pre-filtration to prevent clogging and improve efficiency
- Can also remove micronutrients so test to ensure adequate supply to crop

Other Media Filters

- A range of media exist for removing specific contaminants from water. Some are shown in Figure 4.5.

References and Further Reading

1. https://www.sswm.info/sites/default/files/toolbox/WHO%201996%20Closed%20filter.jpg
2. https://www.wwdmag.com/arsenic/greensand-process-removes-iron-manganese-arsenic-groundwater
3. Majsztrik, J. and S.A. White, 2017. Water quality quest. Nursery Management, Sept 2017. http://magazine.nurserymag.com/article/september-2017/water-quality-quest.aspx

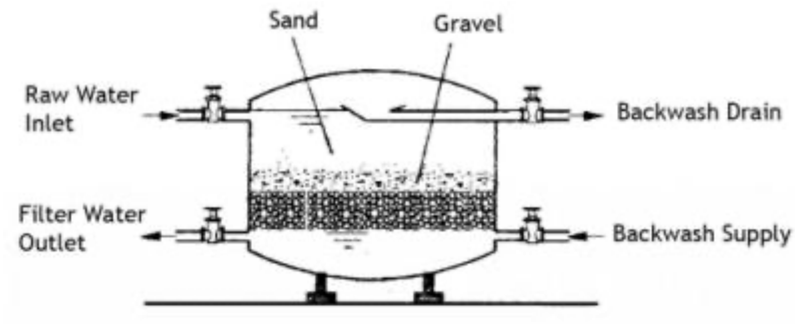

Figure 4.3 Rapid Sand Filter; from:
https://www.sswm.info/sites/default/files/toolbox/WHO%201996%20Closed%20filter.jpg

Figure 4.4 Rapid sand filters at two commercial greenhouse operations

Figure 4.5 Media used for specific contaminant removal, from:
http://batterywaterplant.com/images/iron_removal_chemicals.jpg

Physical: Ultraviolet (UV) Irradiation

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
		Broad spectrum		√	Yes	Possible	$$-$$$	$

Mode of Action

- In-line treatment that uses Ultraviolet-C (UV-C) radiation at 254nm wavelength to damage DNA and prevent reproduction of micro-organisms
- Disinfection rate depends on the exposure "time x radiation intensity" (dose); however, note that some DNA repair and regrowth can occur with low radiation intensities (e.g. 3mJ/cm^2)

Design and Operational Considerations

- Effective UV dose varies between organisms:
    - Bacteria: 3.5 to 26.5 mJ/cm^2
    - Fungal propagules: 10-70mJ/cm^2; recommended to run at 100 mJ/cm^2
    - Viral: 100-277mJ/cm^2; recommended to run at 250 mJ/cm^2
    - Nematodes (100 mJ/cm^2 to prevent root infection, and 500 mJ/cm^2 for organism death)
    - For more information see Reference 1-3
- UV dose achieved depends on: strength of UV lamps, transmission through the water, flow rate, and thickness and turbulence of the water layer
- Pre-filtration to less than 25 microns is essential because water clarity is critical for effective treatment; any solids or coloured dissolved molecules block the UV radiation from reaching the target organisms; water turbidity should be less than 2NTU (nephelometric turbidity units) for proper treatment
- High, medium and low-pressure lamps versus power consumption:
    - low pressure lamps produce a more precise wavelength (254nm) whereas medium and high-pressure lamps produce a broader spectrum of wavelengths (180-400nm). For destruction of DNA, the 254nm is most effective and the conversion of power to UV-C wavelengths is about 30-35%; however, they are limited to a relatively low UV output and therefore relatively low flow rates[4]
    - medium and high-pressure lamps (broad spectrum) require more energy to produce the same level of 254nm radiation (and therefore disinfection rate) compared to low pressure lamps (about 15% power to UV-C wavelengths) and are therefore less energy efficient[4]
    - however, broad spectrum radiation also allows for inactivation of organisms through some protein /enzyme degradation as well as DNA destruction and may be preferable for some organisms (e.g. viruses)[5]
    - broad spectrum radiation may enhance the destruction of other contaminants such as pesticides
- Information required for sizing: peak flow; sample for free transmission test; target microorganisms and the required treatment level[4]
- Regular maintenance required to remove biofilm from lamps, and replace ageing lamps which loose efficacy

Advantages and Limitations

- Not corrosive or pH dependent, and leaves no residuals in the treated water
- Chemicals are not required so there is no risk of phyto- or human toxicity
- Does not require large amount of space
- Flow rate can be adjusted to improve effective dose
- Built-in monitoring and cleaning features in modern systems
- Systems for low flow rates are cheaper to install than other physical methods
- Can be combined with other systems such as peroxide and/or ozone for advanced oxidation treatment

- High capital cost especially for large systems
- Significant servicing and maintenance is required, but much can be done in-house
- Efficacy reduced with:
  - high organic matter; requires pre-filter to remove plant debris and particles to reduce turbidity
  - Iron buildup; bulb requires acid washing
- Can destroy iron chelates so chelated iron may need to be readjusted in the irrigation solution to prevent iron chlorosis in the crop
- High doses may generate free radicals and may impact plants receiving the treated water

Figure 4.6 Ultra violet treatment systems

References and Resources

1. Majsztrik, J. and S.A. White, 2017. Successful sanitation. Nursery Management http://magazine.nurserymag.com/article/october-2017/successful-sanitation.aspx
2. BackPocketGrower.org for efficacy of the range of treatment systems/chemicals on 30 specific genera of plant pathogens or groups of organisms: http://backpocketgrower.org/waterbornesolutions.asp
3. Zheng, Y. et al. Water Treatment Information System found at http://www.watereducationalliance.org/
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Physical: Heat treatment (pasteurization)

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
		Broad spectrum			Not required	no	$$$	$$$

Mode of Action

- Pasteurization is the inactivation of organisms by applying heat at temperatures below the boiling point (as opposed to sterilization which is heat treatment above the boiling point under pressure)
- Inactivation is based on a "temperature X time" dose relationship: e.g. 95°C for 30 seconds, 90°C for 2 minutes, 85°C for 3 minutes

Design and Operational Considerations

- The required dose is specific for each organism: most commonly run at 95°C for 30 seconds to treat all pathogens; less time required for many bacteria and fungi, but viruses have a longer dose requirement
- Generally, requires 1GJ to treat 10m^3 of water, but 60°C for 2 minutes has been recommended to reduce energy input by 42% but still achieve substantial treatment levels[2]
- Treated water needs to be cooled prior to irrigation, therefore a holding tank is required
- To improve efficiency, a heat exchanger is used to transfer the heat from the treated water to the cold untreated water
- Must be built of corrosion-free materials, i.e. not copper or zinc which can be toxic to plants

Advantages and Limitations

- Simple, effective, generally broad spectrum, and long-proven technology
- Can be built to handle high flow rates with computerized control and monitoring systems
- Chemicals are not required so there is no risk of phyto- or human toxicity
- Does not require pre-filtration, however residual organic matter after treatment can allow rapid re-colonization post treatment
- Heat does not interfere with nutrients

- Generally, not cost effective for large volumes of water; capital cost can be expensive; high operating costs in terms of power requirement
- Depending on the hardness of the water source, scaling can be a problem in the heat exchangers, but is reduced at lower temperatures, or by lowering the pH of the source water to 4 with nitric acid.

References and Resources

1. Zheng et al Water Treatment Information Systems website http://www.ces.uoguelph.ca/water/PATHOGEN/HeatTreatment.pdf
2. Pettitt, T. 2003. Developments in pathogen removal from recycled water: Proceedings - International Fertiliser Society, **531**:1-20. https://www.researchgate.net/publication/262565677_Fertigation_Developments_in_pathogen_removal_from_recycled_water

Chemical: Oxidation - Halides (Chloride and Bromide)

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
	√	Broad spectrum		√	yes	Phytotoxic	\$-\$\$	\$-\$\$

Unlike physical methods, chemical methods continue to act in the irrigation system and can assist in reducing biofilm buildup. However, note that chemicals also kill beneficial organisms and potentially reduce competition and inherent resistance to pathogens within the whole production system when used at high levels.

Prior to chemical treatment, the water should be pre-filtered to remove suspended solids, organic matter and the solids-associated microbial population, and lower the chemical demand for disinfection. Similarly, nutrients should be added after chemical disinfection (allowing for reaction time) because some chemicals can react with nutrients such as ammonia.[5]

1. Chlorine

Mode of Action

- Free residual chlorine, resulting from chlorine products dissolved in water, is highly oxidizing and damages the outer membranes and structures of algae, fungi and bacteria.
- Chlorine breaks down to hypochlorous acid (HOCl; strong oxidizer) and hypochlorite (OCl^-; weak sanitizer).
- The most common form in the industry is sodium hypochlorite (liquid; bleach).
- Calcium hypochlorite (solid; 60-70% available Cl^-) is safer than many other forms, but more expensive.

Design and Operational Considerations

- Efficacy is pH dependent: HOCl concentrations are highest at pH 5-6 and as pH increases hypochlorous converts to hypochlorite which is less effective, therefore acidification may be necessary prior to chlorination.
- Recommended level of free chlorine is 0.5-2ppm at the end of the irrigation system
- Effective chlorine dose (concentration x time) depends on the target organism: e.g. 2 mg/L free chlorine for 2 min will eliminate oomycete zoospores but 4 mg/L for 8 minutes is needed for oomycete sporangia, 8 mg/L for 5 minutes for *Fusarium oxysporum*, 10 mg/L for 10 minutes for *Rhizoctonia solani* (see References 1-3 for more information).
- Over- and under-dosing is easily done if levels of organic matter and nutrients in the solutions treated fluctuate widely.
- Need to monitor chlorine demand in order to maintain a residual level of free chlorine.
- Effective concentration for some pathogens may exceed the phytotoxic level for some crops. Therefore, increased holding times or aeration to allow more free chlorine to gas off, treatment through activated carbon, or addition of sodium sulphite or sodium metabisulphite to deactivate the chlorine before irrigation may be required.

Advantages and Limitations

- Low cost for installation and operation
- Easy to operate and control

- Effective in pathogen disinfection
- Use of chlorine can produce long-lived by-products that are potentially detrimental to human and environmental health (e.g. trihalomethanes)

2. Chlorine gas

- Direct injection of chlorine gas into water to form HOCl and HCl
- Mode of action and operational considerations are the same as for sodium and calcium hypochlorite systems
- Cheapest, but has the highest associated work safety risks
- Chlorine gas is toxic to both humans and plants

3. Chlorine dioxide (ClO_2)

Mode of Action

- Uses sodium chlorite ($NaClO_2$) for the electrochemical generation of ClO_2
- The most effective chlorine treatment method over a wide range of pH (4-10) and contact times
- 2X more powerful than chlorine
- Does not hydrolyze in water and does not react with nitrogen compounds[3]

Design and Operational Considerations

- Must be generated on-site
- Optimum pH range of the water to be treated is 4-8.4
- 0.5ppm for 2 min will control oomycete zoospores
- *Fusarium, Cylindrocladium, Alternaria* and *Botrytis* require much longer contact time, and control was less effective (see References 1-3 for more information)
- Can be applied continuously at low concentrations (0.25mg/L) for water treatment
- Can be used as a shock treatment to remove biofilms (20-50mg/L)

Advantages and Limitations

- Rapid kill time
- Generally low phytotoxicity[2]
- Works over a range of pHs (4-10)
- Efficacy is reduced by organic matter and nutrients
- Not stable and has to be produced and used on-site

Figure 4.7 ClO_2 injector system

4. Electro-Chemical-Activation (ECA)

Note: ECA water is also known as **electrolyzed water; electro-activated water, electrolyzed oxidizing (EO) water**

Mode of Action

- This technology works by passing a salt solution (potassium chloride; KCl) through a module with two electrodes, across which there is a direct electrical current.

- KCl brine solution is electrolyzed, producing chlorine gas (Cl_2) and oxygen (O_2) at the positive electrode (anode). Cl_2 dissolves in the water to form hypochlorous acid (HClO; active chlorine) and hydrochloric acid (HCl; also anti-microbial). Potassium hydroxide (KOH; detergent) and hydrogen gas (H_2) form at the negative electrode (cathode). (H_2) escapes into the outside air.

Design and Operational Considerations

- Generated on-site, or the concentrated solution may be brought from off-site and injected into irrigation system
- KCl is preferred over sodium chloride (NaCl) in horticulture to avoid the build-up of Na in recirculating systems
- Peak HOCl concentration is produced around pH 5.5-6.0
- System requires soft water, so municipal or well water may need pre-treatment

Advantages and Limitations

- Provides consistent performance
- Eliminates biofilms in irrigation lines and pipes
- Increases O_2 to water and plant roots
- Higher strength solutions can be used for sanitizing trays, irrigation lines etc.
- Generated on site thus no storage requirement for strong oxidizing agents
- Concentrate can be transported for use at other locations/facilities, but if brought in from an off-site location monitor free chlorine levels as solution strength will decrease over time

Figure 4.8 Electro-chemical-activation (ECA) system

5. Bromine

- Chemistry similar to chlorine
- Can be used at lower concentrations
- Relative efficacy is organism specific – provides better control of some organisms such as *Botrytis, Fusarium and Rhizoctonia* and others, but poorer for *Alternaria* [5]
- Can be combined with chlorine to broaden effectiveness
- Lower phytotoxicity than chlorine
- Residuals less persistent than those of chlorine, but can still occur in the presence of organic matter

References and Resources

1. BackPocketGrower.org for efficacy of the range of treatment systems/chemicals on 30 specific genera of plant pathogens or groups of organisms: http://backpocketgrower.org/waterbornesolutions.asp
2. Raudales et al., 2014. Control of waterborne microbes in irrigation: A review. Agricultural Water Management **143**:9-28.

3. Zheng et al Water Treatment Information Systems website http://www.ces.uoguelph.ca/water/about.shtml
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Chemical: Oxidation - Hydrogen peroxide (H_2O_2) and Peroxyacetic acid (PAA)

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
	√	Broad spectrum		√	yes	No phytotoxic	$	$$

Hydrogen Peroxide (H_2O_2)

Mode of Action

- H_2O_2 can be used alone or in the presence of an organic acid such acetic acid to form more stable and effective sanitizing agents[1]
- In presence of metal ions, it breaks into a reactive hydroxyl radical (OH^-) which is a strong oxidizer
- Efficacy is dose dependent (concentration X exposure time)

Design and Operational Considerations

- Can be used to provide continuous disinfection or as a shock treatment to remove biofilms depending on the dose and residual concentration measured at the furthest point from the injection system – See Table 4.3
- Also used for cleaning cisterns; residual concentrations in storage tanks should ideally be at 2-3ppm[3]
- For efficiency, pre-filtration to remove particulate organic matter is recommended

Advantages and Limitations

- Highly efficient
- Low capital investment
- Requires higher concentrations and longer exposure times than ozone to disinfect
- No long-term or harmful environmental residues
- Increases oxygen supply to roots, but can cause root damage at high concentrations
- Mn and Fe will oxidize and precipitate out; may need to increase micronutrients in solution
- Long term use can degrade plastics

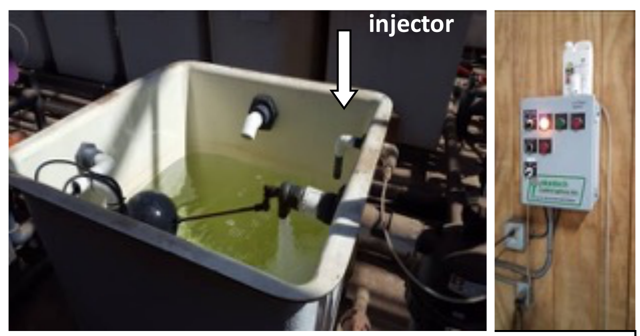

Figure 4.9 Hydrogen peroxide (H_2O_2) mix tank and injection system installed at a flower greenhouse

Table 4.3 [2]

Recommended levels of hydrogen peroxide concentration before and after injection

Dosage of hydrogen peroxide (measurements taken at the furthest point from injection)

Injection method/purpose	Injected concentration (ppm)	Residual concentration (ppm)*
Continuous injection	<50	0.5
Selective injection	50-100	2-3
Annual maintenance treatment of the irrigation system	200-500	8-10

Peroxyacetic acid/peracetic acid (PAA)[4,5]

Mode of Action

- Dissociates into hydrogen peroxide and acetic acid in water
- Used alone or in conjunction with H_2O_2
- Used as a surface disinfectant, or shock or maintenance treatment for cleaning irrigation lines

Design and Operational Considerations

- More stable than pure H_2O_2 and has longer residual effect/prolonged disinfection activity
- Most effective at <pH 7; can reduce alkalinity

Advantages and Limitations

- No toxic residuals to plants or environment
- Enhanced oxygen to plant roots
- Requires pre-filtration – organic matter reduces effectiveness
- More expensive than other chemicals
- Corrosive and requires appropriate handling

References and Resources

1. Raudales et al., 2014. Control of waterborne microbes in irrigation: A review. Agricultural Water Management **143**:9-28.
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5. Zheng, Y. et al. Water Treatment Information System found at http://www.watereducationalliance.org/

Chemical: Oxidation - Ozone

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
	√	Broad spectrum		√	yes	No phytotoxic	$$$	$$

Mode of Action

- Ozone (O_3) is an unstable form of oxygen gas, which rapidly decomposes to oxygen (O_2) and a free O^- radical that damages cell membranes, causing death.
- Formed by using electricity to split oxygen to form ozone, and diffusing it into the water in a contact vessel
- Ozone has twice the oxidation potential of chlorine.
- Efficacy is based on dose response (O_3 concentration x exposure time).

Design and Operational Considerations

- Very unstable, therefore needs to be produced on-site
- Wide range of dose response for different pathogens: bacteria (0.5mg/L for 1 min) oomycetes (0.8mg/L for 8 min), fungi (0.7mg/L for 16 min) and viruses (7.9mg/L for 75 min)[1] (see Reference 2 for more information)
- A residual concentration of <1mg/L recommended to avoid phytotoxicity in the crop [1]
- O_3 requirement is based on the oxidation-reduction potential (ORP) level in the water, can fluctuate daily between 1 and 10g/m^3/hr, and will require 0.6kWhr/m^3 treated based on 10g/m^3/hr. This level will keep irrigation system clean (J. Oosterveld, pers. comm.)

Advantages and Limitations

- Breaks down organic chemicals such as pesticides and PGRs as well as disinfecting
- Eliminates biofilms in irrigation lines and pipes
- Not affected by pH (but high pH can reduce the lifespan of the system)
- No toxic residuals
- Increases oxygen to plants
- Cost effective for large operations
- Continuous treatment in recirculating systems

- High capital investment and maintenance cost
- Pre-filtration required: efficacy reduced or electricity consumption high when water/solution contains high organic matter and bicarbonates
- Reacts with bicarbonates, sulphides, ammonia and nitrites reducing efficiency
- Mn and Fe precipitate out; may need to increase micronutrients in feed solution
- Chelators degraded and need to be replaced

Figure 4.10 Ozone system installed at a vegetable greenhouse

References and Resources

1. Raudales et al., 2014. Control of waterborne microbes in irrigation: A review. Agricultural Water Management **143**:9-28.
2. BackPocketGrower.org for efficacy of the range of treatment systems/chemicals on 30 specific genera of plant pathogens or groups of organisms: http://backpocketgrower.org/waterbornesolutions.asp

Combined Physical and/or Chemical: Advanced Oxidation

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
	√	Broad spectrum		√	Yes	No	$$$	$$$

Advanced oxidation is the combination of 2 or more oxidizing treatments that improve the efficiency of individual treatments, or increases the effectiveness on recalcitrant organic molecules or pathogens. The major disadvantage to these systems is the increasing cost as treatment systems are combined.

- Hydrogen peroxide and UV
  - H_2O_2 injected just prior to UV treatment
  - UV breaks the bonds of the oxygen and produces hydroxyl radicals which are very strong oxidizing agents $2\ O_3 + H_2O_2 \rightarrow 2OH^- + 3\ O_2$
  - Reduces the energy required for UV irradiation alone to achieve the same level of disinfection
  - Concentrations critical – excess peroxide reduces UV efficiency and results in residual phytotoxic levels of H_2O_2

- Hydrogen peroxide and ozone
  - Mixing H_2O_2 with ozone accelerates the production of hydroxyl radicals and increases the disinfection rate
  - Ozone is added prior to hydrogen peroxide
  - Carbonates and bicarbonates impact the performance of the system[1]

- Ozone and UV
  - High concentrations of organics in recirculation water have high UV absorbance and reduce the efficiency of UV disinfection
  - Treating with ozone prior to the UV step breaks down the organics and improves UV efficiency; having a recirculating system increases the contact time with UV and O_3 and improves the performance[1]
  - Ozone followed by UV also produces free hydroxyl radicals from any residual O_3 in the water

- Combinations of these treatments with other oxidation processes is the subject of much on-going research (e.g. Ozone, UV and H_2O_2)

References and Resources

Feng, W. et al., 2015. Advanced Oxidation Processes for treatment of organics in recirculation greenhouse nutrient feedwater, WAMQI Project 26, Final Report. http://www.farmfoodcareon.org/wp-content/uploads/2016/04/WAMQI-finalreport16.pdf

Chemical: Copper and Silver

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
		Algal, fungal, bacterial		√		Excess copper or silver ions	$$	$$

Copper ionization

Mode of Action

- A direct current is applied across copper electrodes to electrolytically generate copper ions
- Copper is an essential plant nutrient but at high levels binds to proteins and disrupts normal microbial cell functions
- Ionization increases the effectiveness of copper compared to copper salts at a given concentration[1]

Design and Operational Considerations

- Treatment with 0.28-4 mg/L is generally effective for sanitation[4]; time-dose response appears to be important, and increasing exposure time greatly improves effectiveness
- 2mg/L resulted in >99% control of total yeast & mold, but control of bacterial pathogens may require higher doses or exposure time[1]
- Critical levels (i.e. time-dose) are available for many pathogens, algae, and crops (see References 5 and 6)
- Safe up to 2 mg/L Cu^{2+} in the irrigation water for most crops, but phytotoxicity can occur and should be determined on test plants prior to use; for example, 1 mg/L in greenhouse cucumber and tomato production and 0.55 mg/L for sweet pepper production is recommended when rockwool is used as growing substrate (Khosla, pers. comm.).

Figure 4.11: Copper Ionization systems (Aqua-Hort), vertical and horizontal under bench installations

Advantages and Limitations

- Cost effective
- Particularly effective for algae
- Activity is only marginally affected by organic matter
- Does not remove particle, organic matter and nutrients
- Efficacy reduced in the presence of iron chelates compared to iron salts[1,2] (copper displaces iron in the chelates, and is therefore no longer active in solution)
- Copper can accumulate in the recycling system

Copper salts

- Supply of Cu ions to solution as a sulphate or nitrate salt, but appear to be less effective than ionized copper. For example, 0.28ppm Cu^{2+} salts required to reduce disease incidence compared to 0.07ppm ionized Cu[1]
- Shown to be more effective at higher ECs (2.2mS/cm compared to 1.5mS/cm)[2]

Copper /spin out fabric bed liners

- A novel use of copper to control disease is the use of Spin-out ® fabric - a latex polymer formulation of $CuOH_2$ – to prevent *Phytophthora* root rot from spreading within a recirculating nursery system.
- The material was originally developed as a paint layer to stop roots growing through capillary matting and to encourage adventitious root growth in the containers but may be useful as site specific management (spot treatment)[7]

Silver

- Silver ions can be very effective at low concentrations, or increase effectiveness of copper[8] (Raudales et al 2014) but are less commonly used
- Effective sanitation concentration range is 0.07-0.5ppm silver[4]

References and Resources

1. Mohammad-Pour, G.S. et al. 2011. Efficacy of copper sanitizers in sub-irrigation tanks. Proc. Floa. State Hort. Soc. **124**:281-284
2. Toppe, B. and K. Thinggaard, 2000. Influence of Copper ion concentration and electrical conductivity of the nutrient solution on *Phytophthora cinnamomi* in ivy grown in ebb-and-flow systems. J. Phytopathology **148**:579-585.
3. Toppe, B. and K. Thinggaard, 1998. Prevention of Phytophthora root rot in *Gerbera* by increasing copper ion concentration in the nutrient solution. European Journal of Plant Pathology **104**:359-366.
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Biological and Physical: Slow filters & fluidized bed reactors

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
√	√	Broad spectrum	Some		Pre-filter	No phytotoxic	$$	$

Slow Sand Filters

Mode of Action

- Based on slow mechanical filtration through a thick sand bed, enhanced by the build-up of a "biological layer" (*Schumutzdecke*) at the surface of the filter which facilitates the breakdown of organic matter and suppression of pathogens by natural flora (Fig 4.12)
- Biofilm of suppressive organisms builds up on the sand grains and adds to removal efficiency

Design and Operational Considerations

- System consists of a collection tank for feed water, housing container, sand filter bed (1m); (2 recommended), gravel support filter bed and collection tank, and water layer with constantly maintained head (1m); gravity driven operation
- Requires fine (<0.3mm diameter), round, homogeneous sand[1]
- Usually 0.4-1.5m deep; increasing depth increases effectiveness, and allows for periodic removal of the top layer to prevent clogging – generally construction in lined pits or corrugated steel water tanks; sized for operation
- Temperatures should be greater than 15°C for microbial activity, therefore for year-round functioning, may be necessary to have it inside
- Novel horizontal slow flow sand filters have been shown to be effective at pathogen removal in a closed-loop full scale nursery operation (Figure 4.13)

- Finest grade sand fractions and granulated rockwool are most effective at controlling disease such as *Phytophthora, Pythium* and *Fusarium*; viruses are also removed after an initial lag period[6] but information for the greenhouse/nursery industries is limited
- Filters with a flow rate of 100-300L/hr/m^2 of surface area have shown to be the most effective for pathogen removal rate [3]

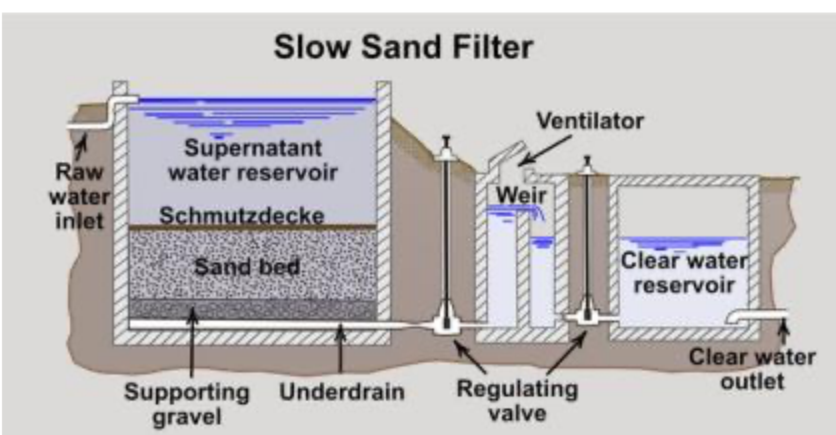

Figure 4.12 Typical slow sand filter design. https://www.aggman.com/green-aggregates-and-water-purification/

Benefits and Limitations

- Reliable and effective method with low capital investment
- Some part of the natural microflora retained and can improve disease suppressiveness of the irrigation water
- No harmful residuals and does not substantially alter the nutrient, pH or electrical conductivity of the water

- Does not remove all pathogens and is based on a living system where there are microbes present in the solution
- Effectiveness is a compromise between flow rate and efficacy
- Subject to clogging and maintenance required to remove and replace top 1-3cm layer
- Pre-filtration reduces the frequency of clogging
- Requires more space relative to other systems (1-acre operation requires 25m^2 at 2.5m^3/hr)
- Alternate designs have been described that may reduce some of the drawbacks, for example the horizontal flow slow sand filter shown in Figure 4.13

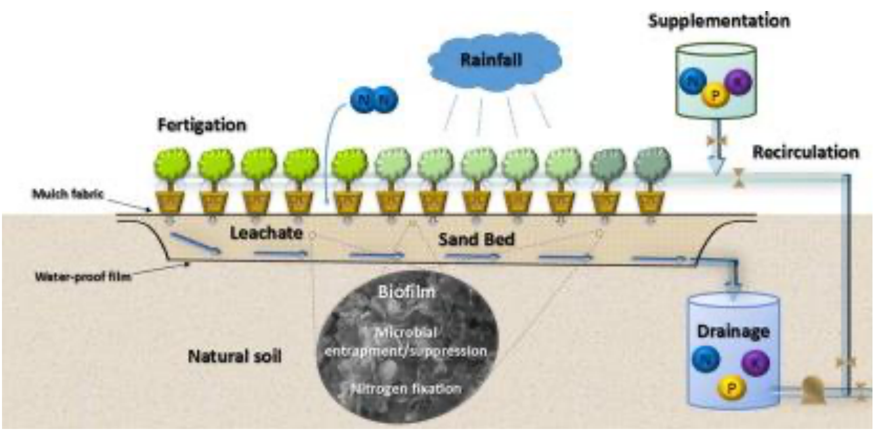

Figure 4.13 Slow filters with alternative media types.
https://www.sciencedirect.com/science/article/pii/S0048969717310732

Alternative media for slow filters

Rockwool
- Established the same way as the slow sand filters (Stewart-Wade. 2011)
- Does not require a supporting gravel layer
- Lower specific density (by 10X) than sand therefore easier to construct
- Clogs less therefore less maintenance (does not require regular removal of top layer)
- Possibly more effective at removing *Fusarium* (Grodan claim)
- More expensive than sand

Lava rock; pumice granules (fluidized bed)
- Lava rock is very porous which provides a large surface area for beneficial bacteria to proliferate. The bacteria, in turn, break down fungal spores, algae and slime
- The granules are submerged in a layer of water; a strong air stream moves the granules and provides oxygen to stimulate biological activity
- Low maintenance and operating cost

- Can handle faster flows than sand filtration therefore requires less space
- Can treat larger volume at a faster rate
- Removes *Pythium* and *Phytophthora*, and 98% of *Fusarium* and tobacco mosaic virus (*TMV*)
- Filter requires less maintenance than a slow sand filter
- Requires a large area
- 3X more expensive than sand
- Not effective for all pathogens

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6. Oki et al., 2017. Elimination of Tobacco mosaic virus from irrigation runoff using slow sand filtration. Scientia Horticulturae **217**:107-113
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Biological-Physical: Constructed Wetlands

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
√	tannins	variable	√	√	beneficial	no	$$-$$$	$

Modes of Action

- Filter solids
- Reduction of nutrients through uptake and removal by plants (if harvested) and utilization by microbial components in the root/media or sediment matrix
- Removal of pesticides through microbial processes (depends on class of pesticide)

Design and Operational Considerations

- Three main types/designs:
  - *Surface flow constructed wetlands* - collection of runoff water to a holding pond, gravity flow through multiple vegetated wetland paths and cells, and into a second stage holding/settling pond. They require a large space but have minimum engineering (Figure 4.14)
  - *Subsurface flow constructed wetlands* – collected water for treatment is pumped through 3-4 cells filled with selected media, generally gravel. They require less space but are more highly engineered (Figure 4.15)
  - *Floating wetlands* – floating cells planted with rooted wetland plants such as cattails (*Typha*), water sedge (*Carex*), or bulrush (*Scirpus*) on water bodies at least 1m deep. They can be deployed into existing ponds and deep channels (Figure 4.16)

Figure 4.14 Surface flow constructed wetland (aerial view, flow path, and collection pond)

Figure 4.15 Subsurface vertical flow wetland (construction and mature wetland; Aqua Treatment

Figure 4.16 Floating wetland modules (Phytolinks™) and deployment in a stormwater pond

/

- Removal rates of particular constituents depend primarily on:
    - Type of media: specific media can help with filtration, nutrient removal as well as Biological Oxygen Demand (BOD) removal
    - Water and oxygen levels in the media
    - Hydraulic retention time: the length of time the water to be treated spends in the wetland system
    - Temperature: wetlands perform best in the summer because microbial activity increases at higher temperatures
    - Season: some reversal of nutrient removal can occur in the winter because of release from organic matter as plants die-off if not harvested
    - Phosphorus removal efficiency decreases with the age of the wetland, which can become a net generator particularly in spring if the media becomes P saturated
- Course materials should be removed prior to treatment to prevent clogging
- All require harvesting to remove nutrients tied up in the above ground biomass

Advantages and Limitations

- Low maintenance and operational costs
- Remove multiple contaminants (suspended solids, nutrients, pesticides, BOD)
- Very good for cleaning up/polishing the water if recovery and reuse of nutrients is desirable in recirculating systems
- Suitable for open systems (release to the environment as long as standards are met) or closed systems (cleaning of water for reuse without removing all nutrients)
- Vertical subsurface flow wetlands usually perform better than surface flow wetlands in colder climates because the active part of the wetland is below ground. They are more effective at filtration and microbial processes in general and particularly in cooler months.
- Floating wetlands can be deployed into existing ponds and deep channels
- Provide wildlife habitat and may provide aesthetic enhancement to the facility

- Large space requirement depending on the design and volume of water to be treated
- May not consistently remove plant pathogens, particularly in older systems with a build up of plant material
- May need to be periodically dredged or recharged

References and Resources:

1. White, S. et al. 2011. Constructed Wetlands: A How to Guide for Nurseries. *https://www.clemson.edu/extension/horticulture/nursery/images/cws_howtoguide_small.pdf*
2. Stearman, G.K. et al 2012. Removal of nitrogen, phosphorus and prodiamine from a container nursery by a subsurface flow constructed wetland. Journal of Bioremediation & Biodegradation. Open access: https://www.omicsonline.org/removal-of-nitrogen-phosphorus-and-prodiamine-from-a-container-nursery-by-a-subsurface-flow-constructed-wetland-2155-6199.S7-002.pdf

Biological-Physical: Woodchip denitrification bioreactors

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
√	some	√	√	potentially	beneficial	no	$$	$

Mode of Action

- Woodchip denitrification bioreactors were originally designed to remove nitrate-nitrogen (NO_3-N) from runoff from agricultural fields.
- Denitrification is the process whereby, under anaerobic conditions (saturated conditions where no oxygen (O_2) is present), nitrate is converted to molecular nitrogen (N_2) which is then released into the atmosphere as nitrogen gas.
- Wood-based media provides a carbon source for the denitrifying bacteria.
- Importantly, the woodchip bioreactor can also consistently reduce fungal plant pathogens levels by over 90% (Figure 4.17)
- 50-60% of phosphorus is also removed from irrigation water if concentrations are greater than about 10mg/L.
- Investigations of removal of pesticides in woodchip bioreactors are just beginning, but the results are promising. [1]

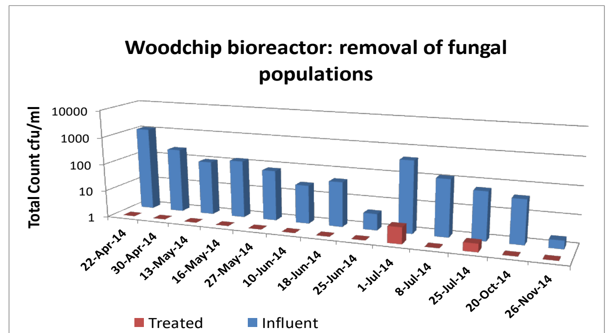


Figure 4.17 Reduction of fungi by woodchip

Design and Operational Considerations

- For horticultural operations, woodchip media is enclosed in a tank or lined in-ground pit.
- In a down-flow system, water to be treated is distributed to the top of the bioreactor unit through perforated pipes.
- Water percolates down through the media, and is collected by perforated piping, and forced up and out of the filter by hydrostatic pressure when the next pulse of water to be treated is applied to the top of the system (Figure 4.18).
- The surface may be covered with gravel or landscape cloth to prevent weed growth.

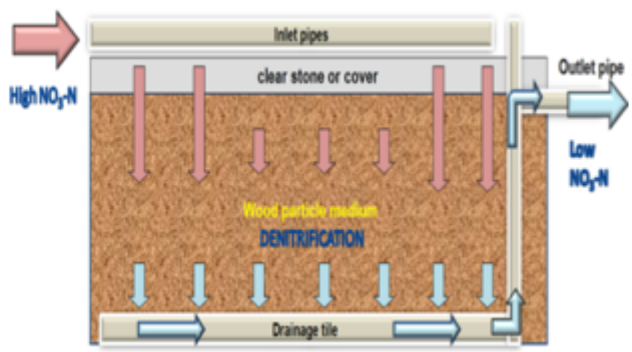


Figure 4.18 Down-flow design of woodchip

- Stages of construction of a down-flow bioreactor are shown in Figure 4.19.

- In up-flow bioreactors, water is pumped into the bottom of the unit and forced upwards through the woodchips for treatment, and flows out at the top.
- The level of nitrate removal depends on a combination of temperature and retention time (residence time of the water in the system). Summer treatment rates will be faster than in the winter months.
- A hydraulic retention time of at least 4 days is desirable, particularly if pathogen removal is important.
- Denitrification is greatly reduced at temperatures less than 10°C, so systems should be at least 1.5m (5 ft) deep to retain activity over the colder months. Pathogen removal is also better in deeper systems.

- Water to be treated should be filtered to remove large particulate matter prior to application to minimize clogging.
- A collection pond or tank for the water to be treated is desirable to provide consistent dosing of the system and optimize biofilter size and performance. This also reduces the occurrence of undesirable reactions such as the production of hydrogen sulfide or methane gasses.

Figure 4.19 Construction of a woodchip denitrification bioreactor at a flower greenhouse operation

Advantages and Limitations:

- Low maintenance and operating cost
- Estimated longevity: an existing system installed at a commercial flower greenhouse is still performing at a high level of efficacy after 10 years, with an addition of 30-50cm woodchips in year nine.
- Bicarbonates will increase in treated water; this can be reversed with acid dosing if the water is recirculated.
- Some land base is required, but the surface can be used as potted production space (avoid machinery traffic).
- Additional infrastructure includes a pre-filter and a balancing pond or tank to allow for consistent dosing.
- Too low or inconsistent dosing, or shutting down for periods of time, can result in a 'smelly' system due to the production of hydrogen sulphide. Methane (a potent greenhouse gas) production can also result with excessively long retention times.
- Note that discharges to the environment require an ECA.

References and Resources:

1. Wagner et al. 2016. Mitigation of pesticide runoff using a bioreactor in Santa Maria Valley http://www.cdpr.ca.gov/docs/emon/pubs/ehapreps/report_302_wagner.pdf
2. Woodchip Bioreactors for Nitrate in Agricultural Drainage, Christianson and Helmers, Iowa State University Extension and Outreach website PMR1008.pdf
3. Denitrifying bioreactors: An emerging best management practice to improve water quality, Lassiter and Easton, Virginia Tech Cooperative Extension Publication BSE-55P
4. https://pubs.ext.vt.edu/BSE/BSE-55/BSE-55-PDF.pdf

Biological-Physical: Hybrid Treatment Systems (HTS)

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agrichemicals			Capital	Operating
√	√	√	√	√	beneficial	no	$$-$$$	$

This is a new treatment system design for greenhouse and container nursery industries. In fact, most studies done on this type of treatment train system for removing multiple contaminants have only been carried out at the lab scale, with nitrogen and phosphorus being the primary targets[1].

Modes of Action

- HTS are combinations of woodchip denitrification bioreactors and selected mineral media cells using vertical flow constructed wetland design[2] and specific flow characteristics that function to remove plant pathogens and/or nutrients and/or excess agrichemicals including plant growth regulators (PGRs) and many pesticides
- The denitrification bioreactor cell is filled with a carbon source (generally woodchips) and is operated under constantly saturated (anoxic) conditions in which nitrate-N is converted to N_2 gas in a process called denitrification
- If operated with sufficient residence time, the woodchip cell is also very effective at removing fungal plant pathogens from irrigation water, making it an effective disinfection method
- The woodchip cell also removes PGRs and many pesticides, particularly fungicides and herbicides
- The mineral media chosen for the system serve a number of functions including: filtering solids, removal of phosphorus if required, reducing the biological oxygen demand (BOD) and increasing oxygen levels in the water coming from the woodchip cell

Construction and Operational Considerations

- HTS are designed with site-specific combination of media and flow characteristics. These design selections dictate the performance of the HTS to remove particular contaminants to meet the operation's production and environmental requirements. For example, for recovery, treatment and reuse as irrigation water, pathogen and PGR removal is critical whereas nutrient removal is not. If the water is to be released to the environment, adequate nutrient removal will be a primary consideration
- Multi-cell vertical subsurface flow wetlands provide a suitable engineering design for the HTS
- The HTS consist of multiple cells: a woodchip cell followed by one to three cells filled with the selected mineral media. (Figure 4.20)

Figure 4.20 Installation stages of HTS, showing lined cell preparation, media (woodchips in back, filter sand and pea gravel to the front) and potted plants set on top.

- The woodchip cell can be either an up-flow or down-flow design, but must always be operated under saturated conditions (anoxic; low oxygen)
- The mineral cells are operated down-flow and aerobically (draining at controlled flow rates).
- The specific design will depend on:
  - *Treatment objectives:* Water clarity (solids and/or tannin removal)? Pathogen removal? Nutrient removal, e.g. nitrogen or phosphorus? Other, e.g. aluminum or agrichemical?
  - *Daily water volume that needs to be treated (calculated or measured over the production cycle).* This requires detailed monitoring or calculations of the water leached from the production area and any other areas that produce water requiring treatment. See Section 2 and Appendix A of this document for more information. **Note: the system size (and therefore capital cost and treatment performance) depends on accurate estimates or measurements.**
  - *Potential location.* Is there space? How will the water move to and from the HTS?
- Other infrastructure may be required. For example: collection point or tank/pond for the untreated water, holding tank/pond for the treated water, piping to deliver the water to and from the HTS, electrical requirements, etc. The system can be fitted with flow meters and alarms and connected to the facility's computer control system.
- Permitting will be required if the water discharges to the environment
- Removal efficiencies of particular constituents depend primarily on:
  - Type of media: woodchips for N removal and mineral media for filtration, P removal, and BOD removal. Mineral media assessed to date include pea gravel, pea gravel/slag mix, wollastonite, filter sand, and red sand,
  - Influent pH and target component concentrations,
  - Water and oxygen levels in the media: the denitrification cell must be saturated and anaerobic at all times,
  - Hydraulic retention time (HRT): longer retention times or recirculation within the HTS increase treatment extent, and
  - Temperature: HTS perform best above 10°C (biological activity increases with temperature), particularly for the denitrification cell. However, water can still be processed through the system, particularly for recirculating systems where nutrient removal is not essential.
- A summary of ranges of removal efficiencies are shown in Table 1. Where wide ranges are shown, the variation is caused by differences in some of the factors listed above, in particular HRT, temperature, and influent concentrations. For further information on this technology see the Flowers Canada (Ontario) Inc. and Soil Resource Group project Technical Report[3]

Figure 4.21 Nursery crop covered for winter, but water still treated in the HTS

Advantages and Limitations:

- Removes multiple contaminants according to design: fungal plant pathogens, nutrients if required, pesticides, solids and BOD
- By selecting the mineral some nutrients can be retained in the water if desired (e.g.

phosphorus). However, the conditions required to remove fungal pathogens mean that nitrate-N will be removed.

- Can be operated year-round (Figure 4.21).
- Very minimal ongoing maintenance is required, but routine monitoring of pumps etc. is recommended.
- It can be linked to greenhouse control systems to facilitate monitoring.
- Requires a sufficient landbase; however, the surface can be used as potted production surface once completed (Figure 4.22). Note: no vehicle traffic should be allowed.
- Because these are new treatment systems, the longevity is not yet known. Our experience is that the woodchip denitrification cell lifespan exceeds 10 years, and is expected to last much longer. Depending on the selected media and treatment goals, the mineral cells may perform similarly.


Figure 4.22 Completed HTS with nursery crop production on surface

Table 4.4. A brief summary of removal efficiencies of various media components used in the HTS, and the performance of the permanent container nursery HTS installation.

Media or System	Influent Nutrient Concentrations	Average removal efficiency [1] (%)			
		Fungal population	NO_3-N	P	PGRs & Pesticides
Woodchip	High	Up to 99	99[2]	60	Up to 99
Woodchip	Low	Up to 99	99[2]	0	Up to 99
Pea Gravel	High or Low	0	0	40-90	0
Filter Sand	High or Low	50-90	10	10-90	short term
Wollastonite	High or Low	50-90	10	20-90	short term
Slag/Gravel	High or Low	>90	0	>90	Limited[3]
Permanent HTS – Nursery	**Low**	**96**	**81**	**69**	Yes: removal rate depends on specific chemical
Greenhouse	**Moderate**	**97**	**74**	**23**	

1. Removal efficiencies are affected by nutrient concentrations, flow rate and temperature
2. Greatly reduced performance at temperatures less than 10^{o}c
3. Only agrichemicals broken down by alkaline conditions

References and Resources:

1. Christianson, L.E. et al. 2017. Denitrifiying woodchip bioreactor and phosphorus filter pairing to minimize pollution swapping. Water Research, **121**:129-139.
2. Aqua Treatment Technologies. http://www.aqua-tt.com/
3. Flowers Canada (Ontario) Inc. and Soil Resource Group. 2018. Development of water treatment best management practices for greenhouses and nurseries in Ontario (Technical Report) (www.flowerscanadagrowers.com).

Biological-Physical: Bioretention swales, grassed swales, rain gardens

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
√	√	(√)	√	potentially	beneficial	no	$	$

Bioretention swales, grassed swales and rain gardens are generally considered *Low Impact Development (LID)* technology for stormwater management.

Modes of Action

- Bioswales are wide, shallow channels planted with grass or other vegetation that slow down, filter and carry stormwater runoff away from the site- generally from large areas with impervious surfaces such as parking lots or roadways (Figure 4.23).
- Vegetated bioswales/Bioretention swales are planted with a combination of plants, often native, that can withstand periods of extreme moisture conditions
- Grassed swales are planted with grass that is regularly mowed, but these are less effective than those planted with taller plants that can capture more debris etc.[1]
- Rain gardens are similar, but designed as small depressions, planted with native flowers, grasses and shrubs, designed to temporarily hold and soak in rain water from smaller areas such as a roof, driveway or open area. They do not carry the water away from the site (Figure 4.24).
- Nutrients and pollutants are removed through plant uptake and the activity of the microorganisms in the soil and surrounding the plant roots.

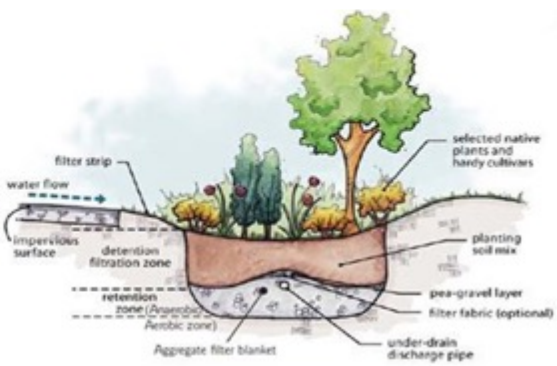


Figure 4.23 Vegetated Bioswale, *http://www.mlive.com/news/muskegon/index.ssf/2012/07/construction on whitehalls fir.html*

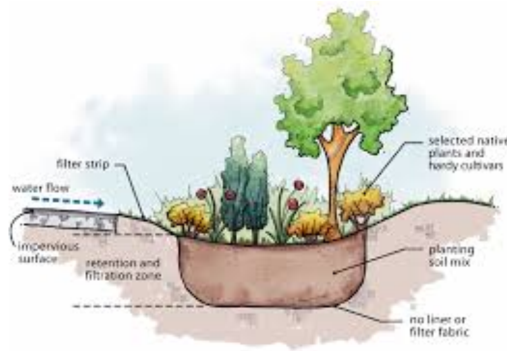


Figure 4.24 Rain Garden, *http://www.betterground.org/rain-gardens/*

Design and Operational Considerations

- Bioswales consist of the following general components:
  - Flowpaths from an impervious surface
  - Course filter of gravel or small rip rap stone to remove debris
  - Ditch of sufficient dimensions to accommodate the calculated water flows. The infiltration rate should be half an inch per hour or greater, and the sides of the slopes 5% or less. The longitudinal slope should be between 1-4%.[1]
  - Planting soil mix that will support healthy plant growth and microbial activity
  - Aggregate sub-layer to retain water and distribute it along the length of the swale,

- Often includes an under-drain discharge pipe
  - Sometimes includes check dams to increase the retention time.
- They should not be used in areas with high groundwater tables (i.e. water tables that reach the bottom of the swale[1]).
- Vegetation needs to withstand periods of both flooding and drought (Figure 4.25)
- Deep rooted varieties are better than shallow rooted species for nutrient removal, e.g. *Panicum vigatum* (switchgrass)[2], but consideration needs to be given to characteristics that may be problematic such as seed production. Avoid invasive species!
- Shallow slopes, low flow velocities and dense vegetation will all increase effectiveness.
- Note: appropriate permits will be required. Ontario has a detailed design guide for stormwater management including information on bioswales and guidance for approvals under the Ontario Water Resources Act.[3]
- The Credit Valley Conservation Authority has also produced an extensive stormwater management LID guidance document.[4]

Figure 4.25 Bioswale to manage roof stormwater runoff. The vegetation consists mainly of naturally developed water cress bed.

Advantages and Limitations:

- For a greenhouse or nursery operation, can manage parking lot stormwater separately from irrigation water avoiding petrochemical and salt contamination
- Reduce stormwater runoff volume impacts (washouts etc.)
- Cost effective way to remove pollutants and assist in groundwater recharge
- Can add aesthetic landscaping to the site (Figure 4.26)
- Can be used in conjunction with other treatment practices
- Removal rates will depend on soil type and vegetation so careful design is important
- Inspection and maintenance to ensure proper functioning of bioswales is required:
  - erosion, trash and debris, and sediment accumulation, etc caused by big storm events
  - assess and manage plants for disease, pests, and/or die-off
  - weed management

Figure 4.26 Vegetated bioswale to manage parking lot runoff.

References and Resources:

1. Caflisch, M and K. Giacalone, An Introduction to Bioswales. http://www.clemson.edu/extension/hgic/water/resources_stormwater/bioswales.html
2. Cording, A. 2016. Evaluating stormwater pollutant removal mechanisms by Bioretention in the context of climate change. Graduate College Dissertations and Thesis (PhD)

3. Ontario, 2017. https://www.ontario.ca/document/stormwater-management-planning-and-design-manual/stormwater-management-plan-and-swmp-design
4. Credit Valley Conservation Authority, 2011. Low Impact Development Stormwater Management Planning and Design Guide. https://cvc.ca/low-impact-development/low-impact-development-support/stormwater-management-lid-guidance-documents/low-impact-development-stormwater-management-planning-and-design-guide/

Biological-Physical: Vegetated Filter Strips (VFS)

Treatment Range (note: zero discharge)					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
√	√	(√)	√	potentially	beneficial	no	$	$

Modes of Action

- Vegetated Filter Strips (VFS) are engineered systems designed to encourage the complete infiltration of the water to be treated (i.e. zero discharge) into the soil.
- Contaminants are removed through settling, filtration, infiltration, percolation and absorption processes.
- Nutrients and other elements in the water are removed as the water spreads out and moves slowly and uniformly down a wide, permanently vegetated area on a gentle downslope.
- This gives time for the water to infiltrate and percolate through the soil and elements (nutrients and metals) to be trapped or sorbed by the receiving soil and/or taken up and used by vegetation.

Design and Operational Considerations

- A VFS consists of the following components shown in Figure 4.27:
  - A collection and temporary storage tank or holding basin (these can be located below ground outside the greenhouse or above ground within the greenhouse to continue function under winter conditions)
  - A screen to remove debris from runoff
  - A distribution system designed to provide uniform sheet flow across the width of the infiltration area. This can take several forms, for example a gravity-fed narrow lined gravel ditch or 'diaphragm' across the width of the infiltration area which spreads the influent water[2], or pump-fed perforated pipe along the width of the infiltration area Figure 4.28.

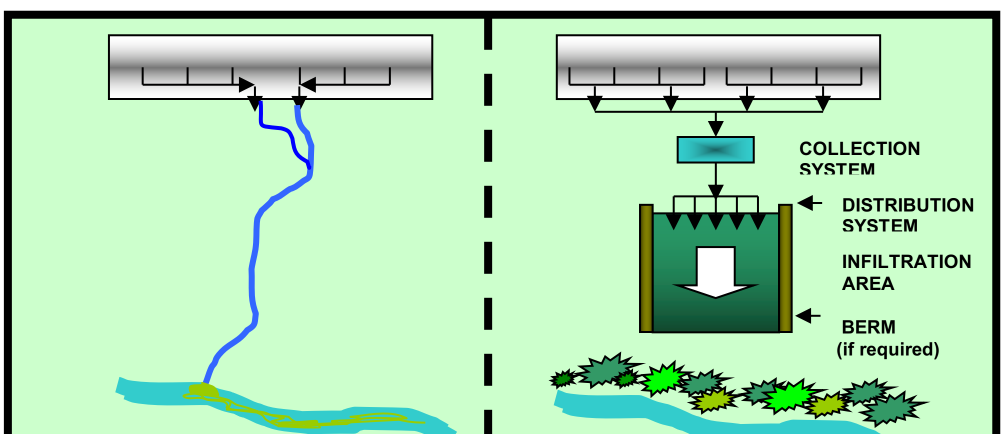


Figure 4.27 On the left, direct flowpath to surface water; on the right, engineered VFS Modified from OMAFRA, 2011. Publication 826.

  - An infiltration area of sufficient size and shape to allow for uniform and complete infiltration of applied water, (i.e. zero discharge). The area must meet the following criteria:
    - a gentle (2%-5%), consistent slope, graded to accept and manage runoff
    - densely vegetated (planted)
    - sized according to specific criteria based on soil type, infiltration rate and water volumes to be treated

- sandy-loam to loam soils perform best; sand infiltrates too fast while clay is too slow resulting in an overly large VFS or discharge out the end of the VFS
- Other Ontario regulations include:
    - Depth to groundwater must be at least 0.9m and depth to bedrock at least 0.5m for at least a 10m zone around the perimeter of the filter bed.
    - There must be at least a 50m flow path from the lower edge of the infiltration bed OR a vegetated buffer zone planted adjacent to the top of the bank of the surface water with a minimum width that is dependent on the slope of the infiltration area.
    - The VFS must not be located within 3m of field drains or within a floodplain area.
- A VFS requires an approved provincial Environmental Compliance Approval (ECA)
- To avoid saturation at the upper end of the infiltration area, water is applied at a rate that slightly exceeds the infiltration rate of the soil, thus forcing the water to move slowly down the VFS slope
- It should be mowed 3-4 times over the growing season to a) remove nutrients, b) prevent thatch build up, and c) limit the spreading of weeds. Any observed areas of settling or rilling over time should also be regraded and revegetated to prevent direct flow paths and ensure uniform flow is maintained along the VFS.
- An engineer should be consulted to properly design a vegetated filter strip.
- A detailed design manual has been produced by the Ontario Ministry of Agriculture and Rural Affairs (OMAFRA)[1]: Ontario Publication 826, and is available at http://www.omafra.gov.on.ca/english/engineer/vfss_order.htm

Advantages and Limitations:

- Requires significant land base with required slope (natural or engineered)
- Not suitable for all soil types (sands and clays)
- Seasonal only - cannot be used in winter (frozen) conditions
- Requires proper maintenance to ensure sheet flow conditions
- Requires an approved ECA

Figure 4.28 Before and after installation of a VFS at a greenhouse facility; close-up of distribution pipe

References and Resources:

1. OMAFRA 2011. Vegetated filter strip system design manual. Ontario Publication 826 Available at: http://www.omafra.gov.on.ca/english/engineer/vfss_order.htm
2. Florida Dept of Transportation, 2015. Best Maintenance Practices for Stormwater Runoff http://www.fdot.gov/maintenance/RDW/BestMaintPracticesSWRunoff.pdf
3. Zheng, Y. Greenhouse and Nursery Water Treatment Information System: http://www.ces.uoguelph.ca/water/NCR/VegetatedBuffers.pdf

Biological-Physical: Land Application of Greenhouse Nutrient Feedwater

Treatment Range					Pre-treat?	Residuals	Costs	
Solids	Organic matter	Pathogens	Nutrients	Agri-chemicals			Capital	Operating
√	√	√	√	√	no	no	$-$$	$

Greenhouse nutrient feedwater (GNF) is water that is generally rich in nutrients and has value for crop production, but has inherent risks for re-use within the greenhouse such as high salts or pathogen risk. It can be used to irrigate less sensitive alternative crops such as fruit orchards, vegetable, field, or biomass crops.

Mode of Action

- GNF is applied with conventional field irrigation application equipment. Water nutrients and other constituents are removed through the soil by infiltration, percolation and absorption processes. If vegetation is growing, nutrients and other constituents may be taken up and used by vegetation.

Legislative and Logistical Considerations

- The Greenhouse Nutrient Feedwater regulation (Ontario Regulation 300/14) under the Nutrient Management Act (NMA) is designed to regulate and permit the land application of GNF to agricultural crops.[1,2]
- To be considered GNF under the NMA, the nutrient solution must come from a closed circulation system in your greenhouse, and must not be mixed with any other material (Figure 4.29). (GNF may be mixed with liquid Agricultural Source Materials (manure) in certain circumstances.)
- In order to land apply GNF under the NMA, you must register your operation with OMAFRA.

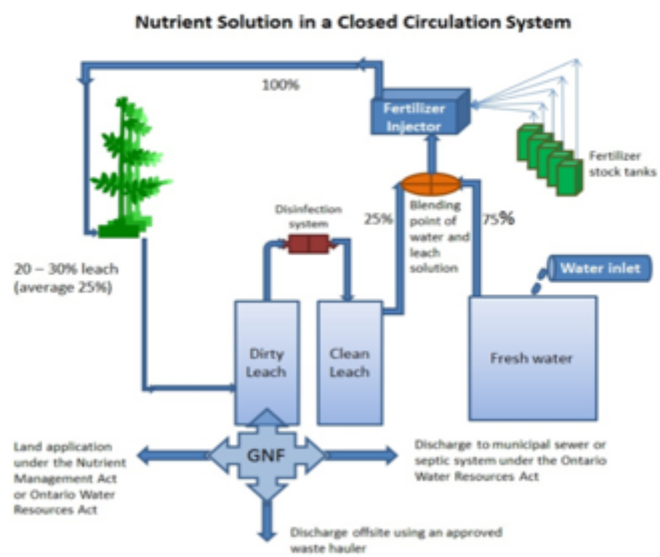


Figure 4.29 A closed circulation system. Greenhouse nutrient feedwater is the nutrient solution that is removed from the circulation system of a registered greenhouse. Taken from http://www.omafra.gov.on.ca/english/nm/regs/gnfpro/gnfreg.htm

- Land application requires a GNF Strategy (covers the generation and storage) and a GNF Plan (covers land application) if the farm generates more than 5 nutrient units (NU) to apply in any one calendar year (1 NU has a fertilizer replacement value of the lower of either 43kg N or 55kg P_2O_5). If the farm generates 5 NU or less, a simplified version of a GNF Strategy, called a GNF Document, is required, and the GNF Plan is not required. See http://www.omafra.gov.on.ca/english/nm/regs/gnfpro/gnfmantable.htm to determine the NU generated by your vegetable or flower greenhouse operation.

- GNF Strategies and Plans need to be prepared by a certified nutrient management planner or by someone from the operation who has completed the appropriate training.

- Both the GNF Strategy and Plan must include a contingency plan
- GNF Plans account for nutrient levels in the receiving soil and the applied GNF using updated NMAN software
- Maximum application rates need to be followed. There are requirements for maximum application of a range of nutrients, regulated metals, and other ions, as well as maximum application rates based on volumes applied (based on runoff potential rather than nutrient loadings).
- Application timing is generally restricted to April 1 to November 30 (crop growing season), and not on snow-covered or frozen ground. Having enough GNF storage for the winter months is necessary.
- See the OMAFRA links below for more details and contact information

Advantages and Limitations:

- Land application under the *Nutrient Management Act* (NMA) encourages best management practices, and provides valuable water with/without nutrients to local farmers.
- If orchards or fields are nearby, land application may be a simple, cost-effective option for GNF management, and has the advantage of using what would otherwise be considered waste (water and nutrients) (Figure 4.30).

- Transport distance between appropriate land base/crops and the GNF storage may be too large to be practical and economical.
- Land application may require the purchase of suitable irrigation equipment.

Figure 4.30 Irrigation of *Miscanthus* biomass crop at a container nursery operation

References and Resources:

1. OMAFRA: Applying greenhouse nutrient feedwater on agricultural land
   http://www.omafra.gov.on.ca/english/nm/regs/gnfpro/gnfland.htm
2. Greenhouse Nutrient Feedwater Regulation
   http://www.omafra.gov.on.ca/english/nm/regs/gnfpro/gnfreg.htm

Section 5: Decision made & system installed…now what?

Just as greenhouse operations routinely monitor light, temperature and humidity control equipment, the performance of the water treatment system needs to be monitored. Don't assume that because it is running, it is performing to standard! Furthermore, don't assume that, even if it is working properly, there are no microbial risks in the rest of the production area. Carry out routine maintenance following the recommendations from equipment suppliers – it sounds simple but it's easy to put off when times get busy.

A routine ***on-farm water quality monitoring program*** enables the operator to monitor water treatment system performance and assess changes in water quality throughout the whole production system and proactively manage it. It will help spot "issues" before they become "problems" that can affect the whole operation. Having the hands-on methods available also enables an operator to work backwards from a crop issue to determine the cause(s) of the problem. It may be that the issue is not from a failure within the irrigation and treatment system but the introduction of contaminated materials to the production facility (e.g. transplants, bulbs etc.). In this case it is even more critical to ensure that the treatment system is performing well to prevent the contamination from spreading.

Grower quote: "It is interesting how when one is not having troubles the tests can be like, sure do your thing, we will just sit back and watch and hopefully learn for when we need it; but, when a challenge comes, it becomes more interesting to know how and what we learned through these tests."

Ask the following questions:

- What are the primary concerns at the facility? Plant pathogens from a water source? Pathogens from recycled water? Highly sensitive crops? Introduction of disease on transplants, bulbs etc.?
- Where are the critical monitoring points? Map out the movement of water in the production system starting at the source water and following it until it is applied to the crop, where and how the leachate is collected and how is it treated after that. What other water is used that might be added to the recirculating water (wash waters, pail water, planting lines etc.)?

What to monitor:

- ***Chemical disinfectant levels***. Do this on a **daily** basis; keep records.
    - Are residual concentrations in the clean water storage tanks or cisterns at recommended levels? See http://www.ces.uoguelph.ca/water/ for concentration details.
    - Are concentrations accounting for specific crops and diseases? Use the Grower Tool: Waterborne Solutions found at http://watereducationalliance.org/gsearch.asp for recommendations.
    - Measure treatment and residual levels:
        - Test strips are cheap and quick, but subject to individual interpretation.
        - Hand held metres and colorimeters are more expensive, but more accurate.

- ***Microbial levels.*** Do this on a **weekly or biweekly** basis; keep records.
  Greenhouses and container nurseries are not sterile environments, nor should they be. Most bacteria and fungi in water samples will likely be benign or even beneficial rather than pathogenic, so the aim is to reduce the pathogen levels and reduce biofilm buildup. Substantial or sudden increases in microbial populations may signal potential problems such as treatment equipment failure, biofilm buildup, poor quality water sources, or the introduction of contaminated materials

to the production facility. Such problems need to be identified and addressed to prevent wide-spread impacts on the crop.

- 3M™ Petrifilms™ – simple and inexpensive to use on-site for routine monitoring of treatment system performance and checking for build-up of microbial contaminants throughout the system.
  - Aerobic Plate Counts – general measure of microbial water quality and risk of biofilm build-up
  - Rapid Yeast & Mold –measure of the load of fungal organisms in the system, and risk of potential build-up of pathogenic fungi in the system
  - For further information refer to the next section.
- Alternatively, there are local service providers who conducts these same tests – check in your area. Samples can be also sent out to a laboratory for routine monitoring.
- DNA Multiscans™
  - More targeted but expensive testing
  - Identifies the relative level of a range of specific plant pathogens in the system
  - Useful for diagnosing the specific risk or cause of an identified problem

Where to monitor:

- It is recommended that, at the beginning of a monitoring program, a sampling "blitz' be carried out to establish a baseline and identify critical points in the irrigation system. The routine monitoring program may include only 3- 5 sampling locations monitored on a weekly or biweekly basis.
- ***Source water.*** How clean is the water coming in and does it change over the season? And does that impact how the treatment system operates. Changing from collected roof water to creek or pond water may necessitate increased filtering or dosing or reduced flow rates to account for increases in organic matter impacts on treatment efficiency.
- ***Return water tank.*** The water quality in this tank will indicate two things: 1. changes in the overall cleanliness of the irrigation system (e.g. biofilm buildup up in tanks, troughs and piping), and 2. if changes are needed to the treatment system settings to effectively treat the return water
- ***Immediately pre- and post-treatment.*** This will verify that the treatment system is performing adequately. A reasonable goal may be to consistently reduce fungal loads by around 90% in a normally operating recirculating system, but this will be an operation specific evaluation. Work with the technology supplier and/or a consultant.
- ***Post-treatment storage tank***. Even if the treatment system is working well, water quality will decline if the storage tank is not periodically cleaned.
- ***Feed tanks.*** Small tanks may seem inconsequential, but if they are not cleaned periodically, the time and money spent on treatment prior to this step may be wasted. Check them periodically.
- ***Irrigation spray nozzles, drippers, etc.*** The most critical point in the whole system is just before the irrigation water is applied to the crop. Monitoring various locations around the greenhouse, will indicate whether or the irrigation water distribution system remains clean or if there is a biofilm buildup and maintenance is required.

When things go wrong:

- Contact your local treatment supplier or consultant, or your local OMAFRA support staff.

Hands-on microbial water quality monitoring "Tool-Kit" for greenhouses

Why monitor microbial water quality?

There are several reasons to monitor the microbial water quality throughout a greenhouse facility, but the overall goal is to **manage RISK** and prevent plant pathogens from getting into production areas. A routine monitoring program enables the operator to monitor **water treatment system performance** and assess changes in water quality throughout the **whole production system** and proactively manage it. For example, deciding when to clean out tanks, which water to use for more (or less) sensitive crops, or what level of disinfectant is needed when switching water sources (from roof water to pond water, for example).

What is described below is a **PRACTICAL** "Tool Kit" of methods growers can use in-house to track microbial water quality throughout their system. The methods were evaluated to meet the following criteria: simple and quick to do without requiring specialized skills, cheap enough to be used on a routine basis, provide a fast result relative to a diagnostics laboratory, and give sufficient information for farmers to make good decisions.

Where and when to monitor

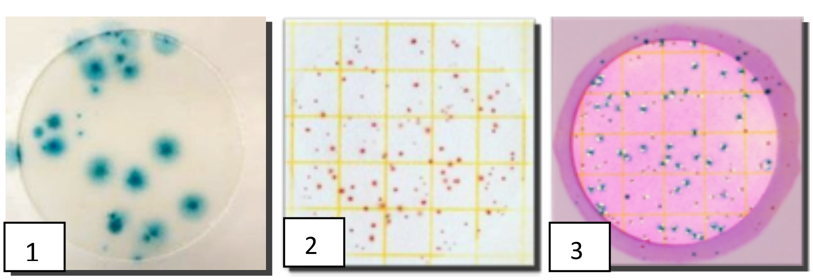
The extent and frequency of a water quality monitoring program at a facility is as individual as the facility itself, and has to fit in with the production system. Think about how the water flows in your irrigation system (even draw a diagram), and ask the following questions:

- What are your primary concerns? Plant pathogens from a water source? Pathogens from recycled water? Are there sensitive crops? Is the disinfection system(s) performing to requirements?
- Where are your critical monitoring points? For example: source water, pre- and post-treatment (immediately before and after to test performance), pre- and post-treatment storage tanks or cisterns, and don't forget about the feed tank. Remember, this is your program, so some monitoring points could be for routine monitoring, but others only for trouble shooting. It may be helpful to do more tests at the beginning and then narrow it down to a routine testing program. You may decide to do more testing in some seasons depending on your crops and expected water quality. It's your Tool-kit – make it fit the job.
- And what are the best (least busy) days to do this – make it part of your routine.

What's in the "Tool-Kit"

Three types of 3M Petrifilms are recommended as being cost and time effective:

- Rapid Yeast & Mold (RYM) – a measure of risk from fungal pathogens
- Total Aerobic Plate Count (bacterial) (AC) – general water quality; risk of biofilm development
- *E.coli* and total coliforms (EC) – for when food safety is important



3M Petrifilms:

1) Total Yeast & Mould,
2) Aerobic Plate Count,
3) *E. coli*/Total Coliform

Other useful methods in the tool kit could include:

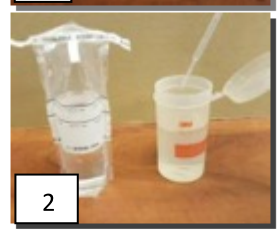
- **ImageJ** – a free downloadable program to help with counting high numbers of colonies on the Aerobic Count plate in particular.
- **DNA Multiscans®** will identify what fungal pathogens are present, but are much more expensive and do not distinguish between living and dead organisms in the sample.
- The Clean-Trace **ATP** measurements parallel the AC and RYM plate counts but are real-time measurements, and may be useful in some cases though the system is also more expensive.
- Your tool-kit should also include test strips or hand-held testers for measuring pH and disinfectants such as chlorine, chlorine dioxide, or hydrogen peroxide peracetic acid etc- whatever fits your system.

Testing Procedure

Rule # 1: Keep everything clean!

Rule # 2: Once you have figured out your method, do it the same every time!

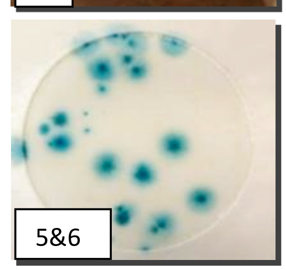
1. Sampling into a sterile sample container or whirl-pak



2. Diluting using sterile phosphate buffer if required (record the dilution factor)
3. Lift top film, drop 1 ml of sample or sample dilution on centre of bottom film

4. Roll top film back down, and use spreader to distribute the sample evenly
5. Incubate in an incubator or at room temperature 2-5 days at 20-28^{o}C (Choose a consistent incubation time and temperature that works best for your schedule. The lower the temp, the longer the incubation period needs to be.)

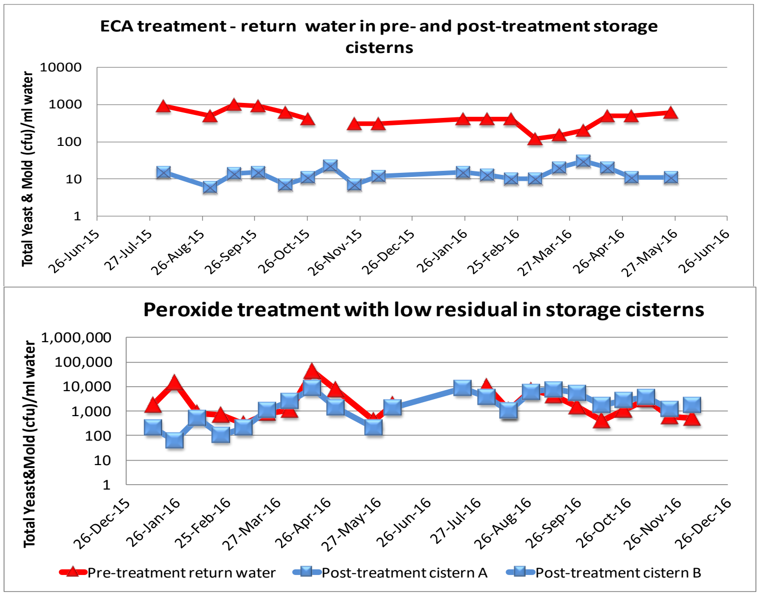
6. Count colonies (directly for a few, or using Image J or an estimate method if counts are high) and multiply by the dilution factor (if used) to get 'colony-forming units' per milliliter of sample (cfu/ml)



7. Record your data and keep track of water quality along with crop quality observations
8. Refer to the 3M Interpretation guides for Aerobic Count plate, Rapid Yeast & Mold count plate, or *E. coli*/Coliform count plate for details on procedure and interpretation.

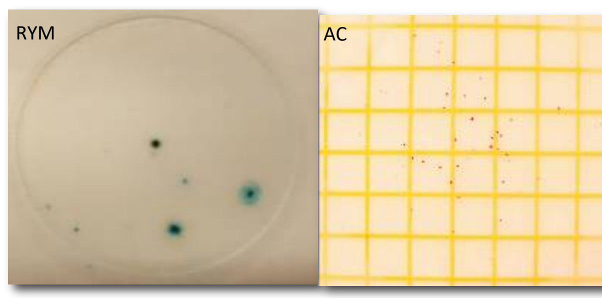
How to interpret your results

Two example sets of monitoring data from cisterns holding pre- and post- treatment water are shown below on log-scale graphs. In the first graph, the results of routine monitoring indicated that the treatment system was generally working well and consistently removed about 99% of the fungal populations. The second graph illustrates a treatment system that was not significantly or consistently reducing the population – the likely cause was low residual peroxide concentrations in the storage cistern.



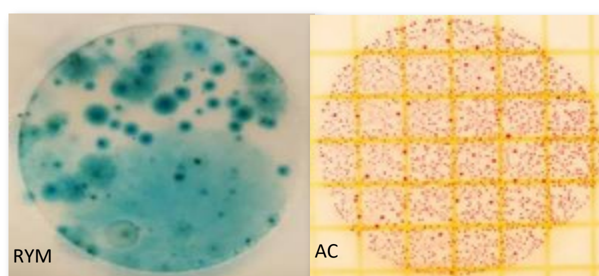
Low counts/Consistent results

- Treatment system OK
- Scouting looks OK
- Routine tracking of changes in levels with water sources changes (e.g. pond versus roof), cisterns, treatment performance etc



High counts/Inconsistent results

- Unusual spikes in data
- Send for DNA multiscan?
- Extra scouting for issues?
- Monitor extra locations to identify potential problem source?
- Check/maintain treatment equipment?
- Clean tanks (including feed)?
- Line clean out when Aerobic Plate Counts (AC) exceed 10,000cfu/ml to prevent line clogging due to biofilm build up



Further Reading and Information

Monitoring Irrigation Water for Floriculture Crops, edited by Paul Fisher, University of Florida IFAS Extension http://manatee.ifas.ufl.edu/agriculture/nursery/A-ZPubs/Monitoring_Irrigation_Water.pdf

3M™ Interpretation guides

- 3M™ Petrifilm™ Rapid Yeast and Mould Interpretation Guide http://multimedia.3m.com/mws/media/1388678O/rapid-yeast-and-mould-interpretation-guide.pdf
- 3M™ Petrifilm™ Aerobic Count Plate Interpretation Guide http://multimedia.3m.com/mws/media/236194O/petrifilm-aerobic-interpretation-guide.pdf
- 3M™ Petrifilm™ *E.coli*/Coliform Count Plate Interpretation Guide http://multimedia.3m.com/mws/media/236246O/petrifilm-ecoli-coliform-interpretation-guide.pdf

ImageJ download link: https://imagej.nih.gov/ij/download.html

Fisher, P and S. Smith, 2007. Monitoring pathogens and algae in irrigation water. http://hort.ifas.ufl.edu/yprc/resources/water/pdfs/Water%20quality%20monitoring.pdf

For more information, contact:

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Dr. Jeanine West, Water Specialist
Flowers Canada (Ontario) Inc.
jeanine@fco.ca

Flowers Canada (Ontario) Environment Resource Webpage:
https://www.flowerscanadagrowers.com/environment-water-specialist-resource-page

Supplies can be ordered from:

- Innovative Diagnostics for 3M™ supplies
- Mandel Scientific (Guelph) for dilution tubes
- Amazon.ca for most other supplies

Section 6: Helpful Resources

- FCO website with research, factsheets and sampling information: https://www.flowerscanadagrowers.com/environment-water-specialist-resource-page
- More details on the mode of action, efficacy and costs of treatment systems at http://www.greenhouse-management.com/greenhouse_management/irrigation_water_greenhouses/disinfestation_greenhouse_irrigation_water.htm.
- OMAFRA/SWIP/MOECC initiatives:
    - Vegetable and Fruit Washwater Treatment Manual, 2018. Ontario Ministry of Agriculture and Rural Affairs, Publication 854. Available through Ontario.ca/publications
    - Self-assessment guides OMAFRA:
        - Best Management Practices and Self-Assessment – Water and Fertilizer Use for Outdoor Container Production. 2016. Ontario Ministry of Agriculture Food & Rural Affairs. Publication #: BMP28E. Available through Ontario.ca/publications.
        - Best Management Practices & Self-Assessment for Water and Fertilizer Use in Greenhouse Floriculture Production. 2018. Ontario Ministry of Agriculture Food & Rural Affairs. Available through Ontario.ca/publications.
        - Self-Assessment and Best Management Practices for Water and Fertilizer Use in Greenhouse Vegetable Production. 2013. Ontario Ministry of Agriculture Food & Rural Affairs. Available through Ontario.ca/publications
- Canada-Ontario Environmental Farm Plan. Available through Ontario Soil & Crop Improvement Association at www.ontariosoilcrop.org
- Holland Marsh LSGBCUF project at http://www.hmgawater.ca/
- Farm & Food Care Water smart project at http://www.farmfoodcareon.org/farming-and-the-environment/water/water-smart-farming-project/
- Farm & Food Care WRAMI & WAMQI at http://www.farmfoodcareon.org/farming-and-the-environment/water/
- **Pacific Northwest Plant Disease Management Handbook**: Treating irrigation water to eliminate water molds https://pnwhandbooks.org/node/291/print.
- The Water Education Alliance website (Cleanwater3.org) is a great resource for water treatment and management information.
    - **CleanWater3: Treatment Technologies** at http://watereducationalliance.org/keyinfo.asp
    - Even sign up for their newsletter to receive up to date information on water management and treatment related issue at http://cleanwater3.org/newsletters.asp
    - The **Back Pocket Grower** at http://backpocketgrower.com/ provides details on the efficacy of the range of treatment systems/chemicals on 30 specific genera of plant pathogens or groups of organisms. As a bonus, it also has other interactive tools for irrigation solution chemistry, substrate volumes, production budgets, production guides for 75 crops, as well as training videos on propagation, substrates, irrigation and water quality, and links to on-line certificate courses.

Appendix A = Worksheets for calculating water use, volumes, and runoff

Worksheet 1[7]: Total Maximum Daily Water Applied

This worksheet explains how to estimate peak water use for irrigating a selected production area in one day. A peak use day is a day with high solar radiation, low relative humidity, under high temperatures. The same calculation can be used to determine the average amount of water applied daily.

To calculate the maximum water applied per day through the whole operation, consider:

- The volume of water emitted in each production area during one irrigation event
- The number of irrigation events per day
- Total area in production to be irrigated on peak use day

Tips:

Use a water meter to track output in each production area over the course of one irrigation event.

Specific crops may be irrigated several times per day, while others are not. It may be helpful to calculate irrigation volumes and events based on different production areas or crops with different requirements.

Example calculation:

Total Maximum Daily Water Applied =

Propagation Production Area [(Volume per irrigation event) x (Number of irrigation events)]

+

Stock Plant Production Area [(Volume per irrigation event) x (Number of irrigation events)]

+

Production Area [(Volume per irrigation event) x (Number of irrigation events)]

+

Finishing Area [(Volume per irrigation event) x (Number of irrigation events)]

+

Outdoor Production Area [(Volume per irrigation event) x (Number of irrigation events)]

Note: all operations will be different – consider the areas present in your operation. Other production areas may also be present and production space in use and crop needs may change depending on the season or crop stage.

Note: When calculating the volume required for an irrigation/storm water collection pond, take into consideration the average annual precipitation and historical storm events in your area.

[7] *This worksheet has been adapted from:*
Best Management Practices and Self-Assessment – Water and Fertilizer Use for Outdoor Container Production. 2016. Ontario Ministry of Agriculture Food & Rural Affairs. Publication #: BMP28E. Available through Ontario.ca/publications.

Worksheet 2[8]: Leaching Fraction for Potted Crops

Leaching fraction (LF) is commonly used to assess the irrigation efficiency of container/potted crop production. It helps to measure whether too much, or not enough irrigation water is being applied to the crop. The lower the number, the lower the volume of water being lost out the bottom of the pot. Periodically, growers may need to leach their crops (e.g. to remove an accumulation of fertilizer salts in the media). However, on average, growers are working towards minimizing percent leaching fraction.

Several unrelated factors can affect the leaching fraction data. For instance, media that is not evenly or regularly moistened tends to have dry "cracks" that channel irrigation water rapidly through the pot, exaggerating the leachate volume. Potted crops with dense or relatively tall canopies can deflect overhead irrigation water, preventing it from landing on the surface of the media of some of the pots within the irrigation zone. This deflection is determined by measuring interception area (Worksheet 3).

By knowing and paying attention to these limitations, growers can use % leaching fraction to help make decisions about irrigation scheduling to conserve water and nutrients, or to determine the volume of water that must be managed.

Example for Areas with Overhead or Drip Irrigation
To estimate the leachate volumes in a particular growing zone, choose growing areas that have crops that are similar in age, size and canopy height and size. Use 10–20 pots each for both the "interception" and the "leachate" pots in each growing area.

You will need the following for each area:
- 20-40 clean, empty pots identical to those used to grow crops in each growing area
- 20-40 small plastic bags (e.g. small garbage bags)
- 10-20 medium-sized stones or wood blocks (to lift potted plant above the base of the "leachate" pots)
- wide-mouth 1–2 L jug, graduated cylinder, flags, notebook and writing utensil

Step 1
Place 10–20 empty pots lined with an impermeable barrier (e.g. plastic bag) randomly throughout the growing area. Try to have some containers from the outer edges and middle of the area. These empty, lined pots are the "interception" pots. Only use pots identical to those used in the crop you are testing. The "interception" pot approximates how much of the overhead irrigation water actually makes it onto the surface of the media. (*Tip:* Use elastic bands to secure the impermeable barrier to the top rim of the pot if pots are placed outdoors.) For drip irrigation, place the drip stake directly into the pots and secure it with tape.

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[8] *This worksheet has been adapted from:*
Best Management Practices and Self-Assessment – Water and Fertilizer Use for Outdoor Container Production. 2016. Ontario Ministry of Agriculture Food & Rural Affairs. Publication #: BMP28E. Available through Ontario.ca/publications.

Step 2
Place 10–20 empty, lined pots directly underneath the same number of crop plant pots. Place a stone inside to give room for drainage. These pots are the “leachate” pots, and will catch the volume of water that drains from the crop pots. The “leachate” pots are identical to the crop pots and fit tightly under the crop pot. Place these crop plant + “leachate” pots beside the empty “interception” pots. (*Tip:* Flag the plants so you can find them more easily after the irrigation event.)

Step 3
After an average irrigation event, collect and measure all “leachate” and “interception” pot water volumes, and record them in a chart so you can refer back to individual pot volumes. (*Tip:* Collect water into a wide-mouthed vessel before pouring into the graduated cylinder for measurement.)

Step 4
Use the water volumes collected to calculate percent leaching fraction (%LF):

% Leaching Fraction = (“leachate” pot volumes / “interception” pot volume) x 100

Average % Leaching Fraction for the Production Area=
[Average (“leachate” pot volumes)/ Average (“interception” pot volumes)] x 100

Interpreting the results
Review the individual %LF for various pots throughout the production area. Do they differ in relation to their location? Do specific crops, spacing or pot sizes affect the results?

Guidelines for Interpreting Average Leaching Fraction:

%LF = 0–15% Very Good	**%LF = 16–25%** Good	**%LF = 26-40%** Inefficient	**%LF = >40%** Excessive
This indicates a conservative use of irrigation water.	Review crop quality, wetness of the media and any other factors that could be exaggerating %LF. Then consider reducing the length of the irrigation cycle.	Review crop quality, wetness of the media and any other factors that could be exaggerating %LF. Then consider reducing the length of the irrigation cycle.	Review crop quality, wetness of the media and any other factors that could be exaggerating %LF. Strongly consider reducing the length of the irrigation cycle.

For subirrigation systems, the total volume applied versus returns to the recirculation tank can either be metered, or the pump capacity (gallons or litres per minute) can be multiplied by the time the pump runs to estimate the flow.

Worksheet 3[9]: Interception Efficiency

Percent interception efficiency (%IE) is commonly used to describe the spacing and configuration of potted crops. It indicates the pot surface area in relation to the area of production space they are growing on. The true value of this measurement is to quantify the effective use of the production area and the efficient use of overhead-applied irrigation water. Potted crops with relatively tall or wide canopies will deflect irrigation water and prevent it from landing on the surface of the media. The higher the %IE, the lower the volume of water being lost between pots. %IE is a simple calculation based on container spacing in two directions.

By measuring %IE throughout the growing season for various crops, growers can use the data to help make decisions about irrigation to conserve water and nutrients lost through leaching, or to establish volumes of water that need to be managed for re-use or discharge.

What you will need:

• measuring tape and a notebook

Step 1. Pick your sites.

For this exercise, try to choose overhead irrigated potted crops that are similar in pot size and growth stage. By collecting %IE data on different zones or crop types, growers can obtain a more accurate estimate of the volume of water that is not reaching the plants.

Step 2. Calculate your areas.

Start by envisioning a rectangle or square that includes one quarter of each of 4 containers (see Fig. A). Measure the length and width of the rectangle that intersects with the centres of the 4 containers and record it as ground area. In staggered pot spacing, you will need to draw an imaginary vertical line to make the parallelogram into a rectangle and measure length and width (see Fig. B). These length and width dimensions will be used to calculate the area of the rectangle that reaches the centre of 4 pots. There are 4 quarters of a container surface in each rectangle, which adds up to one full container surface area. Calculate surface area (A) of one container (A= π r2) by measuring the diameter of the pot. The radius is one-half of the diameter and is used to calculate the pot surface area. If the container is square or a rectangle, simply calculate the area of the container using length x width.

Step 3. Do the calculations.

%IE = Surface area of 1 container / Rectangle area x 100

<u>Sample calculation:</u>

6 inch = 15.24 cm pots; spaced at 4 inches between pots = 10.16 cm, in each direction

(Container diameter = 15.24 cm) (r= Radius = ½ diameter = 7.62 cm)

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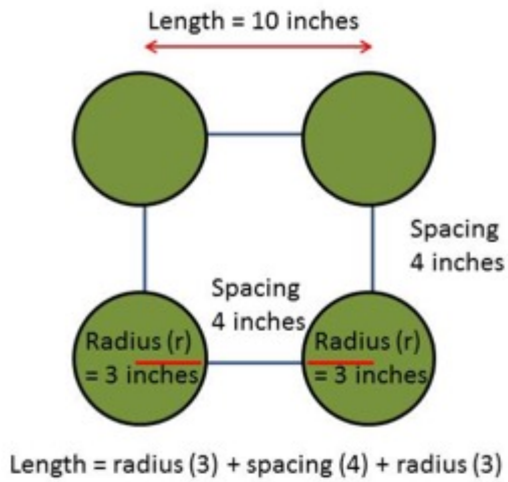
[9] *This worksheet has been adapted from:*
Best Management Practices and Self-Assessment – Water and Fertilizer Use for Outdoor Container Production. 2016. Ontario Ministry of Agriculture Food & Rural Affairs. Publication #: BMP28E. Available through Ontario.ca/publications.

Pot surface area: $A = \pi r^2 = \pi (7.62)^2 = 182.41 \text{ cm}^2$

$\%IE = (182.4 \text{ cm}^2 / 25.4\text{cm} \times 25.4\text{cm}) \times 100$
$= (182.4 \text{ cm}^2 / 645.16 \text{ cm}^2) \times 100$
$= 28.3\%$



In the case of round pots there is already a significant loss in interception, even when the crop is grown using `pot-to-pot' tight spacing.

The following table lists the maximum %IE when a crop is grown in round containers that are placed out pot-pot tight in all four directions.

Table 2. Maximum % Interception Efficiency Possible for Typical Round Containers used in Commercial Production

Pot Size (Diameter)	Pot Surface Area	Rectangle Area (pot–pot tight)	Maximum Potential %IE
4" (10.16 cm)	81.03 cm^2	10.16 x 10.16 = 103.23 cm^2	78.5%
6" (15.24 cm)	182.41 cm^2	15.24 x 15.24 = 232.26 cm^2	78.5%

Step 4. Complete this several times during the growing season for several different production zones and crops. Use the data to optimize irrigation interception efficiency.

NOTE: The volume of leachate (Leaching Fraction) plus the volume reaching the growing area (1-Interception Efficiency) per unit area is the volume of water that needs to be managed (i.e. treated, re-used or discharged).

Appendix B = Irrigation Water Quality Table

Table 2-16 from Pub 383[10]. ACCEPTABLE RANGES FOR CHEMICAL PROPERTIES OF IRRIGATION WATER These are guidelines only. Crops will vary greatly in their sensitivity to soluble salts and water chemical properties.

Chemical Property	**Acceptable Range for Most Container-Grown Woody Crops**	**Acceptable Range for Most Container-Grown Herbaceous Perennials/Greenhouse Crops**	**Acceptable for Irrigation Purposes in a Greenhouse Using Soilless Substrates (Rockwool, Oasis, Peat or Coir**
pH	5.0-7.0	5.0-7.0	5.0-7.0
EC (electrical conductivity – a measure of soluble salts)	<1.75mS/cm	<1.0mS/cm	<1
Calcium carbonates ($CaCO_3$)	<150 ppm	<120 ppm	<`120
Bicarbonates (HCO_3)	<150-200 ppm (lower if not leached with rainfall)	<100-150 ppm (lower if not leached with rainfall)	<100-150 ppm
Sodium (Na)	<70 ppm	<60 ppm	<60ppm
Chloride (Cl)	<140 ppm	<100 ppm	<100ppm
Sulphur (S)	<70 ppm	<70 ppm	<70 ppm
Sulphates (SO_4)	<200 ppm	<200 ppm	<200ppm
Iron (Fe)		<5 ppm	<5ppm
Boron (B)	<0.8 ppm	<0.5 ppm	<0.5ppm

[10] Nursery & Landscape Plant Production and IPM. 2009. Ontario Ministry of Agriculture Food & Rural Affairs. Publication #: 383.

Appendix C: Template for Decision Making

Key questions in the decision-making process:

1. What is the most pressing concern (i.e. the key driver)? Pathogen removal? Water quality to meet allowable discharge targets? Water quality to allow for recirculation/re-use? Polishing step to remove colour or particular contaminant so that other GH systems can function?
2. Production area by ship week? Overall size of operation?
3. Crop (area/percentage) by ship week?
4. Irrigation system(s) in place, where, when used?
5. Crop sensitivities? Special needs?
6. Which water types need to be treated?
7. Facility layout, footprint availability, outdoor/geographical considerations
8. Any infrastructure complications? (e.g. cross connections, long distances, etc.)
9. Future expansion plans?
10. Budget? Three parts: isolate/bring waters to one point, treatment, and storage

Steps:	**Type of Operation:**
Concerns/Drivers	○
Farm information - details of seasonality, irrigation methods, water sources, what waters need treating, budget, etc.	○
Decision Process	○
Final Stage of the Decision Process	○