A grower guide

Soft Fruit

Water harvesting and recycling in soft fruit

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Contents

Introduction

The UK soft fruit industry is increasingly producing fruit in container grown systems, including bags, buckets and troughs. These are typically irrigated through spaghetti drip type irrigation systems.

Growers are under increasing pressure to reduce the quantities of water they use due to rising costs of mains water, reduced availability of water in certain parts of the country and changes to legislation governing abstraction from rivers. Growers are also trying to reduce the volume of 'run-off' water from container grown crops, both to reduce the risk of soil erosion and groundwater pollution.

For all of these reasons, there is a growing interest in the installation of water recycling systems on soft fruit farms.

Some soft fruit growers have already installed systems, while considerable experience of water recycling has already been gained in the ornamental plant industry.

This guide has been produced to inform soft fruit growers of the different systems for capturing water, how to assess its quality and how to deal with contamination before it is re-used. To help growers, a number of case studies are provided to offer examples of how some soft fruit and hardy nursery stock producers have already implemented water recycling systems in their businesses. Examples are also included from the Netherlands, where considerable expertise has already been developed.

Water collection systems

Rainwater harvesting from roofs (Image 1) provides an excellent source of high quality water that growers are entitled to collect without an abstraction licence, provided it is contained within pipe work or impermeably lined channels or ditches and does not run through the soil. All modern glasshouse units are equipped to collect water in this way but until recently it was not possible for field producers to capture water from the multi-bay polythene tunnels universally used in current production systems. However, recent developments in tunnel design now make roof water harvesting possible.

Collection of run-off water from substrate grown fruit crops is not yet widely adopted in the UK but the gutter systems currently employed as crop supports would lend themselves to run-off collection. In the Netherlands, it has been obligatory to collect crop run-off water for some time and more recently Belgium has followed suit.

1. **Roof water collection reservoir on a strawberry farm in the Netherlands, with separate sections for roof water and drainage water**

Roof water collection

Many glasshouse units are already equipped to collect roof water. Depending on the topography of the site, the down pipes feed into a collection sump (often a prefabricated concrete chamber). The chamber is emptied by means of a submersible pump controlled by a float switch and pumped to a main storage reservoir or prefabricated tank. For some sites where there is sufficient fall in relation to the storage reservoir, the down pipes can feed directly into drainage pipes running directly to the storage reservoir without the need for an intermediate sump. There should be sufficient capacity in the drainage pipes and collection sump to cope with rainfall of 15mm per hour or 150m^3/hr/ha for up to two hours. It is possible to experience more intense rainfall but to cope with that would require excess capacity in storage and drainage pipes that would not normally be needed. Ideally, the main storage reservoir would be of sufficient capacity to hold a winter's rainfall which can be calculated from meteorological office historical records of monthly rainfall (October – March) for the locality (1mm/ha = 10m^3).

Unlike glasshouse sites, field sites using multi-bay tunnels equipped with gutters (Images 2 and 3) may not have been designed with water collection in mind. Although sites can rely on downpipes installed solely at the end, ideally for long tunnels, downpipes should be installed every 50m. The downpipes can be run into underground drainage pipes which either feed into collection lagoons or, if there is insufficient space or suitable topography, underground prefabricated plastic tanks. Where the site is suitable, the water can run directly into the main farm reservoir. As with the glasshouse systems, there should be sufficient capacity to cope with rainfall of 15mm per hour or 150m^3/hr/ha for up to two hours. Where the area of tunnel is large (eg distances of >200m from down pipe to storage lagoon) and the potential water flow too great for the capacity of standard 150mm underground drainage pipes, water could be channelled through shallow plastic lined open gullies (Image 4).

2. **Gutter equipped multi-bay tunnel with automatic venting**

3. Gutter detail

4. Shallow lined gullies to channel water from multi-bay tunnels not equipped with underground drainage pipes

It is generally more cost effective to have a collection lagoon of large capacity that can be emptied slowly over a 24 hour period by a pump rated at 25-30m^3/hr, than rely on a small collection sump that has to be emptied rapidly by a more powerful pump. The larger pumps require a higher rated electricity supply that can be very expensive to install over longer distances.

Where multi-bay polythene tunnels with gutters remain clad throughout the year, it is possible to collect winter rainfall. The amount of winter rainfall that can potentially be collected, can be estimated from the area and the typical rainfall volume from October-March (1mm = 10m^3/ha). The efficiency of collection can be taken to be 70% of the potential, allowing for losses due to evaporation and inefficiency of collection. During the growing season (April-September), the potential collection efficiency could be reduced to 25% at times if the tunnels are not provided with automatic ventilation. With manual venting, some rainwater will be lost if the covers are left open during rainfall (for example, after cropping). However, with rapid automatic ventilation (Image 5) the efficiency will be kept close to 70% as the tunnel covers will always close when rainfall is detected.

Where tunnels are not equipped with gutters, it is still possible to collect some rainfall from the leg rows when the tunnels are still clad, using a system of shallow plastic lined gullies. This system also serves a useful purpose for draining excess water away from the edge rows.

5. Automatic venting enables the maximum amount of rainwater to be collected

Substrate run-off collection

The collection of strawberry crop run-off water is possible through the gutters that are commonly used to support substrate bags, troughs or pots on table top strawberry systems, provided they have not been pre-drilled (Image 6). In glasshouses, the troughs are typically drained into a collecting gutter which runs at right angles to the crop at the gable end of the house (Image 7), eventually draining into an underground collecting sump, normally situated at the corner of the house.

6. Typical gutter system equipped for drainage water collection

7. Collection gutter at end of row

For table top systems in multi-bay tunnels, access is required to each alleyway so each gutter should be drained with an individual down hose (proprietary fittings are available from the gutter suppliers) to underground collecting pipes (Image 8). The run-off water can be collected in underground prefabricated plastic storage tanks or, if there is space, a lined collection pond. Whichever method is used for collection, the water will then need to be pumped to a run-off water storage tank or reservoir ready for sterilisation by whatever method is chosen, followed by feeding into the main irrigation system at an appropriate rate.

Where space is limited, the substrate run-off and roof water could be collected into the same collection lagoon. However, there will then be a need to sterilise a greater quantity of water than would otherwise be the case.

The amount of crop run-off water that might be collected can be calculated as a percentage of the normal amount of irrigation applied. A typical irrigation figure for intensive strawberries, where the tables are cropped throughout the year at 10 plants/m row (7,000m row/ha) is 3,500m^3/ha/year. Assuming 10% of the water is collected as run-off, the amount of water collected will be 350m^3/ha/year. The daily maximum is likely to be 3.5m^3/ha/day. It should be noted that the potential water volumes and flows are considerably less than those to be dealt with in roof water collection.

At present, the production of cane fruit and blueberries in individual pots or troughs which stand on plastic ground cover on the ground, does not readily lend itself to collection of run-off and these crops tend to be subject to less irrigation excess. Theoretically, however, the pots could be stood on wide gutters or on raised beds with a slope of 1% to 2% with inset drainage pipes, in order to collect run-off.

The different options for collecting and treating water from glasshouse and tunnel production are represented in Diagrams 1-3.

8. End cap and downpipe for gutter systems in multi-bay tunnels

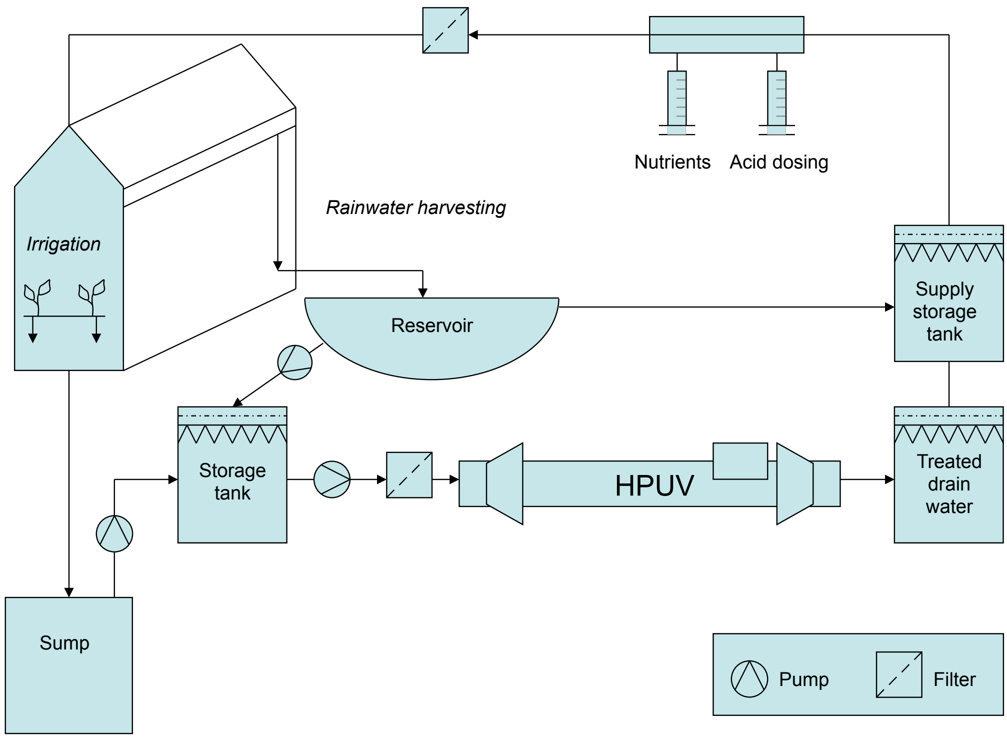

Diagram 1. Glasshouse-type system

- Roof water collection into external reservoir. Borehole input into reservoir if required
- Substrate run-off collection into sunken sumps under the glasshouse, then pumped to the storage tank.
- From storage tank, water is pumped through a filter to the HPUV unit (with some clean water added from the lagoon to dilute if necessary) to the 2nd storage tank (sterilised drain water).
- From the sterilised drain water storage tank into the main supply tank from the lagoon to acid injection and feed injection, then through filters to nursery.

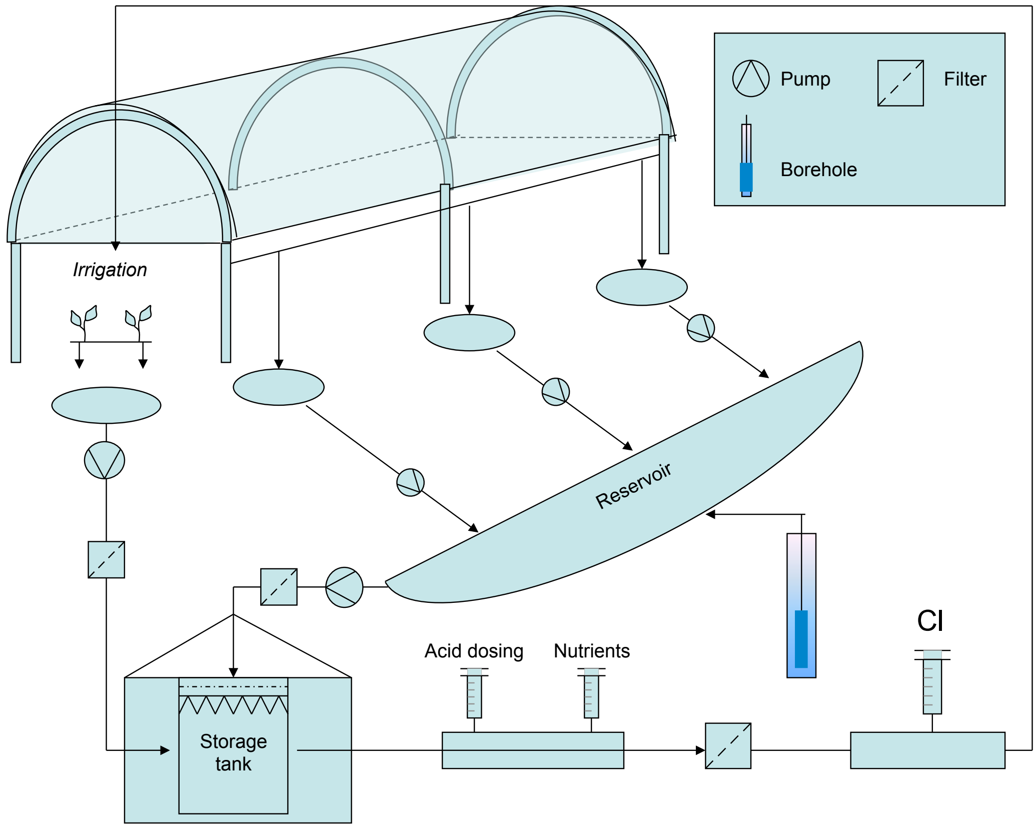

Diagram 2. Large scale tunnel water collection and run-off collection, chlorine sterilised

- Roof water from tunnels runs off into collection ponds, then is it pumped to the main reservoir, which is also filled from a borehole. Run-off water from the collection pond is pumped to a smaller storage tank by the main pumphouse . The larger storage tank by the main pump house holds acidified water, filled from the reservoir and run-off water. Water from this tank then goes through a final pH adjustment, feed injection, filtration then chlorination, then to the plant beds.

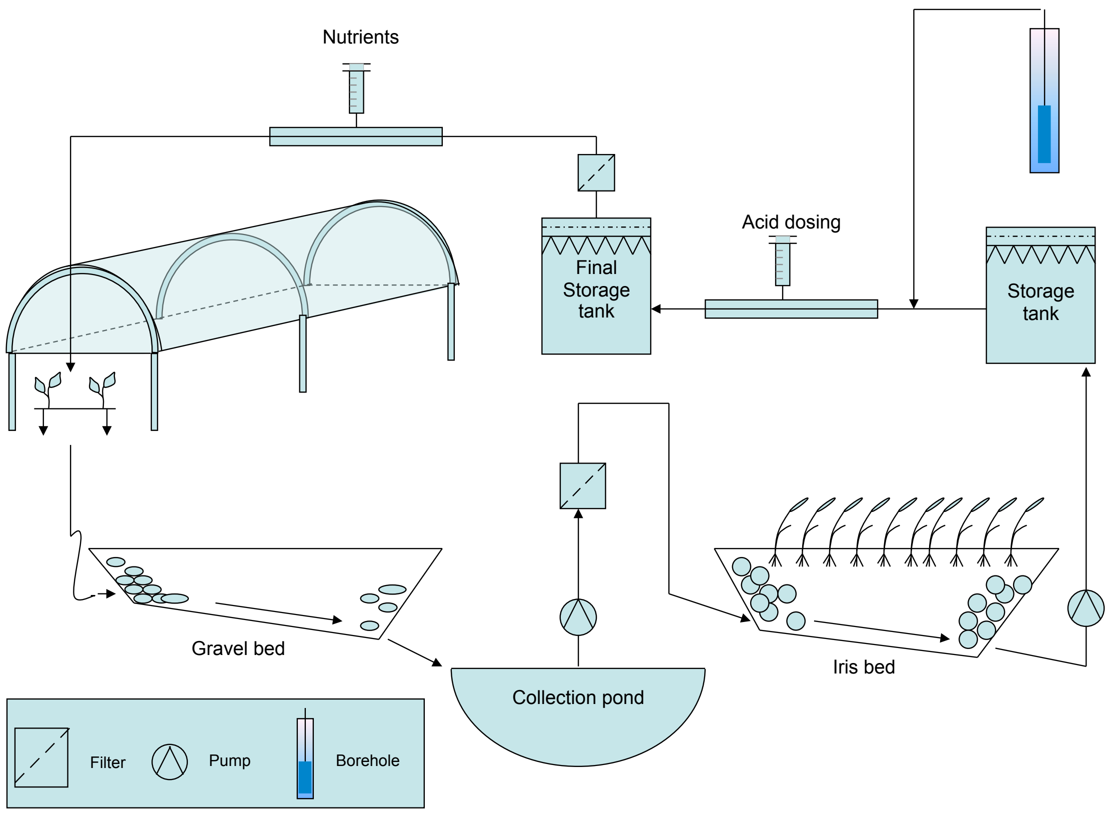

Diagram 3. Biological system for run-off water

- Substrate run-off water runs through a gravel bed into a collection pond under gravity. From there it is pumped and filtered to the top of the iris bed, passed through the bed and is pumped to a storage tank holding cleaned water. Fed by a control valve and topped up by a mains water supply or borehole, it goes through an acid injection into a final storage tank. From here, it is pumped through the feed dosing to the plant beds.

Assessment and decontamination

Main considerations

Harvested water, whether it is collected from tunnel/glasshouse roofs or from substrate run-off, will have a different chemical composition from the normal farm supply and in some cases will be contaminated with both solid and biological contaminants.

Roof water

Roof water is likely to be of relatively good quality, with a low pH and soluble mineral content. The main problems arise where glasshouse roofs are not kept clean or are shaded by trees, with plant material, moss and algae allowed to build up. In such situations, physical contaminants, algae and even pathogenic fungi can be found, although this is relatively rare. Care should be taken to avoid using roof water from areas near to boiler chimneys in case toxic oil or soot deposits are washed into the collecting tanks.

Water from multi-bay tunnels will be relatively clean as the plastic covers are unlikely to build up deposits of plant or algal material, provided it is collected via closed pipework. Any contamination is more likely to come from blown in material and algae build up in the gutters or through any open channels. However, where harvested water is collected through field drains or open ditches where contamination with soil water is possible, there is a clear risk of contamination with plant pathogens.

Substrate run-off water

Substrate run-off water is likely to be of relatively poor quality with a high pH and soluble mineral content, including chloride and sulphates, in addition to the risk of plant pathogens and other phytotoxins. There could also be physical contaminants such as particles from the substrate, algae and other material blown into the collecting gutters.

Growers should be aware of the risks associated with collecting and recycling water and be prepared to set up a system for monitoring and assessing the contaminants and ensuring that facilities are in place to deal with each of them.

Physical contaminants

The irrigation systems for substrate-grown soft fruit crops will inevitably have existing filtration systems in place to deal with solid mineral contaminants such as sand and silt and the larger biological contaminants such as algae and bacterial slime (Image 9). However, the use of roof or run-off water could introduce a different type and level of physical contamination, coming either from the catchment gutters, or through the catchment sumps or run-off ponds. If a problem is identified, it is generally better to deal with it in stages, starting as close to the source as possible with additional filtration, rather than relying on existing systems.

It is important to identify the nature, size and number of particles in the water so that the most appropriate filtration system is used (Table 1).

Large particles such as sand, silt, clay, peat and coir fibres cause premature blocking of the fine filtration units and may therefore require pre-filtration for initial removal. **Hydrocyclones** are ideal for this purpose but **disc filters** (see below) are sometimes used. Although less effective, they are a cheaper option. For the larger biological contaminants (algae, bacterial slime, moss and weed seeds) which may occur in collection ponds, a self-cleaning suction filter can be fitted to the pump suction pipe.

9. Algae build up causing dripper blockage

For the smaller particles which are very problematic for blocking the nozzles of drip irrigation systems, **fast sand filters**, **disc filters** or **screen filters** are employed.

Screen or **mesh** filters are widely used in the UK. Water passes through a fine mesh and particles are caught in it. The holes in the mesh should be smaller than the smallest nozzle in the irrigation system; any particle that does pass through the filter should be small enough to pass all the way around the system without causing a blockage. For drip irrigation, a mesh with a minimum hole size of 100µm should be used. Over time, filters become blocked and will require cleaning to increase the flow of water around the system. Large mesh filters, positioned upstream of the main filter, will catch larger particles and reduce the frequency of cleaning.

Disc filters (Image 10) are a series of grooves through which water percolates, catching the particles in the flow. They can be employed for removal of both large and small particles and require less water for backwashing and cleaning than other filters. They are increasingly used in irrigation systems both for this reason and also because they are relatively economical.

10. Disc filter array at Haygrove Farms

Table 1. Recommended filter types according to contamination

Contamination	Hydrocyclone	Sand or media filter	Disc filter	Auto screen filter
Soil particles				
Low (<50mg/L)	✓✓✓			✓
High (>50mg/L)	✓✓✓	✓✓		✓
Suspended solids				
Low (<50mg/L)		✓✓✓	✓✓	✓
High (>50mg/L)		✓✓✓	✓✓	
Algae				
Low (<50mg/L)		✓✓	✓✓✓	✓
High (>50mg/L)		✓✓✓	✓✓	✓

Table prepared from information in 'Water quality and treatment systems' by John Adlam.

Fast sand filters (Image 11) have been widely used in the past and can be particularly effective in removing biological contaminants such as algae. However, they are less effective in dealing with heavy levels of contamination, requiring frequent backwashing.

11. Fast sand filter

Plant pathogens

When using substrate run-off water and occasionally with roof water, there is a risk of circulating plant diseases in the recycled water. For soft fruit crops grown in substrate, the main risk is from *Phytophthora* diseases which are spread by zoospores and are readily carried in the water supply. For example, strawberries are susceptible to *Phytophthora cactorum* causing crown rot and *Phytophthora fragariae* causing red core. Raspberries are susceptible to *Phytophthora rubi* causing root rot. Note that although wilt caused by *Verticillium dahliae* is common in strawberries and some raspberry varieties, the disease does not form motile zoospores, making it less likely to spread in the water supply. Similarly, water borne virus is not thought to be a problem in substrate-grown soft fruit.

To some extent the potential risk can be avoided by using run-off water on different crops to that from which it was collected. For example, run-off water from strawberries can be safely used on raspberries. Although both are susceptible to *Phytophthora*, it is generally accepted that the species and subspecies concerned are different and do not cross infect.

Molecular methods (such as PCR) are increasingly being used to identify the different species and subspecies infecting different host plants. Pathogens such as *Fusarium, Verticillium, Pythium, Botrytis, Thielaviopsis* and *Rhizoctonia* can be carried in water as spores or mycelium and are not host specific.

It is also worthwhile testing the water for the presence of fungal pathogens, whether it is rainwater from roofs or run-off water. There are companies which offer a testing service which will quantify the level of pathogen spores present (see Further information section). A decision can then be made on the need for decontamination. It should be noted that current testing methods rely on detecting the presence of zoospores in the water sample either by culturing or DNA based methods. In practice the concentration of these zoospores can be very low and unevenly distributed. The use of baits to actively attract zoospores and improve reliability of testing has been developed in the nursery sector. However, the pathogens *P. rubi* and *P. fragariae* require specific baits. Root material of strawberry and raspberry can be used as baits but it is difficult to obtain root material guaranteed to be free of the pathogens. Practical alternatives have yet to be developed.

Viruses and fungal disease spores are too small to be removed by normal physical filtration methods. There are a number of methods available which vary in space required, initial capital cost, running cost and efficacy.

Slow sand filtration

Slow sand filters (Image 12 overleaf) harbour beneficial microbial populations and water passes through a gelatinous film on the surface of the sand during filtration.

12. Slow sand filter installed at tray plant producer Avoird Trayplants in the Netherlands. The filter is contained in the left of the three tanks – the two tanks to the right are used for treated water

Where water is heavily contaminated, pre-filtration is essential to remove large particles prior to passing through the sand filter. Water is pumped through a coarse filter, such as a parabolic screen, to remove solid debris such as leaves and fruit and then upwards into the filtration system. The weight of water above the top of the sand layer pressurises the system. Water typically flows through the slow sand filter at a rate of 100mm/hour, sometimes more if good quality sand is used. The volume per hour in cubic metres can be calculated by multiplying the flow rate (~100mm) by the surface area of the filter (m^2). A submersible pump is used to move water from the gravel underdrain at the bottom of the filter into a storage tank.

The frequency of cleaning required varies but may be monthly or bi-monthly. The water level is dropped to below the sand and the top layer of sand is scraped off.

For more information on slow sand filtration see the HDC grower guide *Slow sand filtration – A flexible, economic biofiltration method for cleaning irrigation water*, which summarises research funded by MAFF (now Defra) and HDC (HNS 88).

Advantages of slow sand filters

- Environmentally friendly.
- Particularly effective against *Phytophthora* and *Pythium.*

Disadvantages of slow sand filters

- Upkeep – they need to be cleaned as the surface becomes clogged. This can be a very time consuming process, depending on the level of contamination.

UV sterilisation

Microorganisms, such as bacteria, fungi, viruses and nematodes, are inactivated when they absorb ultraviolet (UV) radiation. The most effective wavelength is 264nm. UV sterilisation (Image 13) has been particularly popular for glasshouse systems but could be employed elsewhere.

13. Priva Vialux UV sterilisation rig

The system

A 2-3cm water film passes through a radiation chamber which is fitted with a UV lamp. As UV waves travel through the water, pathogens are inactivated. The effectiveness of sterilisation depends on the UV dose applied; the dose (mJ/cm^2) depends on UV intensity (mW/cm^2) and exposure time. A dose of 60-80mJ/cm^2 is considered sufficient to sterilise run-off water for re-use in strawberry production. The more sophisticated UV sterilisation systems automatically monitor the UV dose experienced by the water and prevent inadequately sterilised water from entering the irrigation system. Water flow, UV intensity and dilution can all be adjusted automatically to cope with different water quality and ensure adequate sterilisation.

The T10 value is the percentage of UV radiation (254nm) transmitted through 10mm of water. For UV to be an effective steriliser, water should have a T10 of 15 or above. Organic material, nitrates and iron chelates all absorb UV radiation. Run-off water from substrates such as fresh coir can be particularly turbid (T10 of 10-40) and may require blending with clear water (eg roof water) to raise the T10 value to 15 or more for effective sterilisation. Many coir supplies are pre-rinsed with a buffer solution which reduces the problem of turbidity in the run-off. It is also possible to specify extra pre-rinsing.

Water entering the radiation chamber should have no more than 5mg solids/litre. Suitable pre-treatments include fast sand filtration systems and self-cleaning screen filters (25µm).

UV lamps may be high or low pressure. The appropriate choice depends on peak flow rate and microbiological load. Low pressure lamps deliver one wavelength (254nm) of radiation at ~0.2kW. High pressure lamps deliver higher flux over a broader spectrum of wavelengths at higher power (up to 12kW). These high pressure lamps have greater germicidal activity in turbid water but at the cost of additional electrical input, higher running temperature, lower efficiency conversion to UV-C and shorter lifetime.

Advantages of UV sterilisation

- Effective against fungi, bacteria, viruses and nematodes – including *Phytophthora, Pythium* and *Rhizoctonia.*
- Water composition, pH and temperature are unchanged.
- No chemical inputs – environmentally friendly.

- Short residence time in the chamber, no heating and cooling time.
- Compact.
- Low maintenance.

Disadvantages of UV sterilisation

- Pre-filtration required.
- Continuous supply of electricity required making it expensive to run.
- At high pH (usually above pH 6), the quartz tube becomes contaminated with lime scale – the more sophisticated systems have an automatic self cleaning facility.
- No residual disinfectant.

Examples of UV lamps

Vialux from Priva available in three sizes: 6, 9 or 12kW bulbs.

Pasteurisation

Pasteurisation is mainly employed in glasshouse units (Image 14) where it is considered an alternative to UV sterilisation. Some units employ heat from the main nursery heating supply while others are self-contained with inbuilt burners.

14. Pasteurisation unit installed on a glasshouse salad nursery, the Netherlands

Microorganisms are inactivated at high temperatures. For adequate sterilisation, water must be heated to 95°C for 30 seconds or to 85°C for 180 seconds.

In the pasteurisation unit, water enters the first chamber and heat is transferred from the outgoing solution to the incoming solution. In the second chamber, water is heated to the preset temperature by an external heat source. As water exits the system, heat is transferred to incoming water.

Calcium can precipitate on heat exchange plates so it is recommended that pH is adjusted to ~4.5 prior to pasteurisation.

Approximately 1.25m^3 of gas will be required to sterilise 1,000 litres of re-circulated nutrient solution. Pasteurisation units will typically process 1,500-50,000 litres of water per hour. A pasteurisation unit capable of processing 10,000 litres per hour is generally considered to be adequate for a six hectare site.

Advantages of pasteurisation

- Effective against fungi, bacteria, viruses and nematodes.
- Water composition, pH and temperature are unchanged.
- Turbidity of water does not affect effectiveness of treatment, pre-filtration may not be required and water run-off from a range of different substrates may be sterilised.
- No chemical inputs – environmentally friendly.

Disadvantages of pasteurisation

- Very expensive to install.
- No residual disinfectant.
- Energy intensive.
- Heating and cooling time.
- Oxygenation of water will be reduced.

Examples of pasteurisation unit

Van Dijk Heating in the Netherlands manufactures the ECOSTER drain water disinfector. Units range in capacity from 1,500-50,000 litres per hour and can be used in combination with a natural gas burner or electric heating elements.

Chlorination

Chlorine is regularly used as a disinfectant in water treatment. Two forms are commonly used including chlorine dioxide (Image 15), which is generated *in situ* and injected as a solution, there is a proprietary system available and sodium hypochlorite (Image 16 overleaf) which is injected as a liquid, using an electrical powered variable speed injection pump – a range of equipment is available. In both cases, hypochlorous acid is formed in the water, which is an effective disinfectant.

15. Chlorine dioxide generator and injection unit at Haygrove Farms

16. Sodium hypochlorite liquid injection using a metering pump at New Forest Fruit Company

Chlorine concentration must be high enough to inactivate pathogens but not so high as to be toxic to the crop. The chlorine left in the system once all microorganisms have been destroyed is referred to as free chlorine. A free chlorine concentration of 1ppm at the far end of the irrigation line should be adequate.

The rig will be set up to monitor the free chlorine concentration in the system and automatically adjust the chlorine injection rate accordingly. Generally, a higher concentration of chlorine is needed in the summer than in the winter as a result of increased pathogen activity at higher temperatures. Typically, a concentration of 7-8ppm will need to be injected in the winter and 12-15ppm in the summer. It is also necessary to regularly check the free chlorine level at the farthest end of the irrigation system using a test kit.

Hypochlorous acid is most effective at low pH. Therefore, ideally, acid injection should occur prior to chlorine injection. Under acidic conditions, soluble iron is oxidised and precipitates. The solid iron particles formed may need to be removed by filtration.

Advantages of chlorination

- Cheap - £3,000 for a 50m^3/hour capacity system injecting sodium hypochlorite.
- Growers report no change in mineral quality, pH or electrical conductivity and no adverse effect on the crop at 1-1.5ppm.
- Residual disinfectant activity; free chlorine remains active in the irrigation water and will continue to have an effect (including on algae) as the water travels around the system.

Disadvantages of chlorination

- Chlorine is a hazardous material and care is needed in handling, piping and storing. Chlorine solutions have to be held in a separate cage outside of the main pump house.
- Pre-filtration required.
- Not regarded as environmentally friendly.
- May not control viruses although not a problem in soft fruit.

Ozone

Like chlorine, ozone is a powerful oxidising agent which inactivates microorganisms. Ozone gas is generated *in situ* and bubbled through water. Ozone is converted to oxygen during the process and, unlike chlorine, leaves no residual chemical in the water. It does not provide residual disinfectant activity.

For optimum performance, water should be pH 4-4.5. For effective sterilisation, 8.73g ozone per 1,000 litres of water per hour is needed. In Europe, 764mV is required.

Ozone sterilisation systems are not readily available in the UK and the process is more expensive to run than heat pasteurisation.

Advantages of ozone

- Effective against viruses, bacteria and fungi.
- Ozone is not corrosive.
- No hazardous chemicals used.
- Environmentally friendly.

Disadvantages of ozone

- Very expensive to install.
- Not readily available in UK, no technical backup.
- No residual disinfectant.

Copper ioniser

Copper has natural fungicidal properties and is effective against a range of pathogens including *Phytophthora* and *Pythium*. When an electrical current is passed through copper electrodes, copper ions are formed in solution. Copper ions attach to, disrupt and kill pathogens.

The copper ionisation system consists of a control box, a water flow meter and two or more copper electrodes. The system (Image 17) measures water flow and adjusts electrical conductivity to maintain a preset concentration of copper ions. Copper concentrations of 0.5-1ppm are sufficient to control fungal root pathogens such as *Phytophthora* and *Pythium*. Copper electrodes usually need replacing every one to two years.

17. Aquahort copper ioniser installed on a Danish pot plant nursery

Although the system was proven to be very effective for control of *Phytophthora* and *Pythium* in HDC project HNS 142, the systems are relatively expensive and have not been taken up by the nursery stock or fruit industry in the UK. There are, however, two installations being used successfully for strawberry production by growers in the north of the Netherlands. So far, at these sites there have been no problems with a build up of copper either in the strawberry foliage or in the growing media.

Advantages of copper ionisers

- Effective against fungi and bacteria.
- Relatively unaffected by organic matter and particles in water.
- Copper ions remain in the water and provide residual disinfectant activity (including against algae).
- Equipment is compact.

Disadvantages of copper ionisers

- Moderately expensive to install and run.
- Limited track record of use in fruit production.
- Not environmentally friendly.

Other biological systems

Apart from slow sand filters, reed beds, gravel beds and iris beds can all be used to filter water. These systems have been adopted in nursery stock production to clean up run-off from container beds that may be contaminated with nutrients and pesticides. There is little experience of using them for soft fruit production but there is potential, as the major disease risk, *Phytophthora* species, is similar in both sectors.

Typically, a two stage process is adopted with water from the collection pond passing initially by gravity, either through a *Phragmites australis* reed bed or a gravel bed.

Much of the cleaning occurs at this stage through root activity of the reeds and microbial activity in the root zone. *Phragmites australis* transfers oxygen from its leaves down to its roots, encouraging the growth of microorganisms in the bed. These microorganisms colonise gravel, soil and plant roots and feed on contaminants present in the water. The reeds will take up some of the nutrients in solution.

There are many different *Phragmites australis* species which vary in their growing habit and tolerance to different chemicals.

The reeds are typically planted in gravel ridges in a butyl rubber or clay lined basin with water flowing by gravity through the basin (Image 18). In a vertical flow bed, water is delivered over the surface of the bed and flows vertically through it. In a horizontal flow bed, water is delivered at one end and flows horizontally through the system. In the UK, water usually flows through the bed itself, below the surface of the gravel. Any dead reeds should be regularly removed. After some years the reeds can become too dense, impeding the water flow and requiring thinning out. Reed beds have a limited lifespan and may need replacing seven to ten years after installation.

An alternative system that has proved effective with less maintenance has been a gravel bed (Image 19), which appears to operate biologically in a similar way to a slow sand filter. Gravel beds consist of long butyl rubber lined channels, typically 1.2m deep, containing stone. The water is fed in at the bottom of the bed through a slotted drainage pipe laid at the bottom in an S formation running up and down the bed. Water is drawn off by gravity at the far end of the bed. The system should initially be primed with beneficial microbes such as *Bacillus* species.

18. Reedbed at John Richards Nursery

19. Small gravel bed at Lowaters Nursery, with plastic cover pulled back to show gravel

The second stage of the process for final cleaning is an iris bed (Image 20 overleaf) where the water runs through 1m deep channels with *Iris pseudacorus* grown in trays suspended or floating on the water. The water surface is normally kept covered to avoid further contamination by wind blown material. A further adaption is inclusion of shallow cascades for oxygenation and solarising. As with reed beds, the iris can eventually become too dense and require replacement.

20. Iris bed on a nursery in the Netherlands

21. Valves for switching and blending water sources at De Jong BV

Advantages of biological systems

- Environmentally friendly.
- Bio-active water may be less susceptible to re-infection than water treated using chemical and physical methods.
- Low running costs.

Disadvantages of biological systems

- Reeds can grow excessively and deciduous material tends to blow around.
- Takes up a lot of space.
- Moderate capital costs.
- Upkeep, some maintenance needed.
- Reed beds can freeze in cold weather and an alternative water treatment would be required.

Nutrients

In recirculation systems, nutrients present in run-off water are reapplied to the crop. Growers report fertiliser savings of up to 40% compared to run-to-waste systems. Unless it has been cleaned through a biological system, the Electrical Conductivity (EC) of the run-off water will probably be higher than the input feed and some nutrients, in particular chlorides and sulphates, tend to accumulate in recirculated water. While EC probes can be used to measure EC on site, more thorough nutrient analyses require laboratory analysis. Water samples should be sent off every one to two weeks for analysis. The nutrient feed can then be adjusted to take account of the nutrients already present in the run-off water and avoid excessive levels of particular elements. Table 2 provides a list of the maximum recorded analyses for electrical conductivity, bicarbonate hardness and a range of mineral concentrations, above which crop damage or other adverse effects may occur.

Dilution is the normal option to manage the concentration of these nutrients (Image 21). The process can be controlled automatically with the more sophisticated fertigation rigs available. A maximum EC of $0.9mSm^{-3}$ can be set, but if there is a plentiful supply of clean low EC water available for dilution (eg roof water), a greater dilution would be preferable for strawberries and raspberries.

In theory, nanofiltration or reverse osmosis rigs (Image 22) could be used to remove excess nutrients from run-off water, but such equipment is expensive to install and run and there are only a few installations in horticulture in the UK. A possible reason for their lack of popularity is the fact that water yield might only be 40% of the input, the remainder being in the form of a concentrated waste that has to be disposed of. The pH of the run-off water could also be higher than the desired level. However, all of the water should subsequently pass through the acidification rig with the pH automatically adjusted.

22. Reverse osmosis rig installed at New Farm Produce, Staffordshire

Table 2 Water mineral analysis – suitability of water sources for use in irrigation of strawberries

Parameter	Maximum	Notes
Electrical Conductivity (EC) (uS, 20°C)	900	• When the EC of the source water is high, it is difficult to add sufficient fertiliser to produce a satisfactory feed without an excessively high EC
Bicarbonate Hardness, mg/L	240	• High levels are often associated with high pH, which can in turn lead to low availability of Fe and P and the formation of insoluble precipitates which block drippers • Higher levels can be allowed but the amount of acid required to reduce the level to the recommended 50mg/L can lead to nutrient imbalances
Nitrate (NO_3) N, mg/L	50	• High levels can cause excessive growth, particularly where further N has to be added for acidification
Ammonium (NH_4) N, mg/L	21	• Higher levels can occur in feed solutions for substrate crops, particularly for everbearer cultivars with a higher N requirement • Excess levels limit Ca uptake and affect fruit firmness and colour
Potassium (K), mg/L	-	• Excessively high levels are unlikely to be encountered
Phosphorous (P), mg/L	-	• Excessively high levels are unlikely to be encountered
Calcium (Ca), mg/L	-	• Excessively high levels are unlikely to be encountered
Magnesium (Mg), mg/L	-	• Excessively high levels are unlikely to be encountered
Sulphate (SO_4), mg/L	144	• High levels are not normally damaging through sulphur toxicity, but can contribute to excessively high EC
Sodium (Na), mg/L	35-72	• Substrate grown crops are most susceptible • Excess causes scorch of petioles and sepals and yield reduction at higher levels
Chloride (Cl), mg/L	52-140	• Higher levels (towards the upper limits) acceptable for soil grown crops on trickle irrigation • Excess causes damage to roots and yield reduction but level depends on climate, substrate and plant type
Boron (B), mg/L	0.22-0.33	• Some authorities suggest <0.22 for substrate crops
Iron (Fe), mg/L	1.0	• High levels of iron in source water can lead to oxides forming, which will block drippers • Feed solutions for substrate crops use iron chelates and can have higher levels (<1.7)
Manganese (Mn), mg/L	27.0	
Zinc (Zn), mg/L	0.35	• Some authorities suggest a higher limit, up to 1.3, can be allowed for substrate crops • At very high levels, leaf toxicity symptoms can be seen
Copper (Cu), mg/L	0.5	• General recommendation, not specific to strawberries
Molybdenum (Mo), mg/L	0.1	
Aluminium (Al), mg/L	2.0	• General recommendation, not specific to strawberries
Fluoride (Fl, mg/L	1.0	• General recommendation, not specific to strawberries
Silicon (Si), mg/L	22.0	• Excess causes albino fruits and reduced yield

Case studies

To provide practical examples of the range of water recycling systems already being adopted in soft fruit and hardy ornamental production and how they are being implemented, the HDC funded the author John Atwood to travel and study a number of production sites and nurseries in the UK and the Netherlands. The following case studies have been produced as a result.

Re-use of strawberry substrate run-off water on different crops and rainwater harvesting (Soft fruit grower in South East England)

A large soft fruit business in the south east of England is finding that a combination of rainwater harvesting, collection of irrigation run-off and recirculation has significantly reduced reliance on mains water and provides a quarter of the water required for production.

At the site, 10ha of multi-bay tunnels have been fitted with guttering in the leg rows to create large scale rainwater harvesting and storage in reservoirs. Alongside this, a further 2.5ha of table top strawberries grown in coir bags has been fitted with hanging gutters. Water draining directly from the strawberries is collected in these gutters, which are a maximum length of 120m. They are carefully installed so there is an adequate fall to allow a natural flow of water. Once collected from the gutters, the water moves underground in buried pipes. It is then passed through manual screen filters of 100µm to remove plant and substrate debris from the water and stored in a buried 20m^3 tank. Run-off irrigation water, filtered in this way, has been successfully used to irrigate other crops on site. For example, run-off water from strawberry production has been applied, without sterilisation, to trees grown in soil and raspberries in substrate, after blending with fresh water and adjusting pH and feed concentration. A modest saving in fertiliser required for the second crop has been made.

At this site, water is drawn from a variety of sources including mains, rivers, stream-fed winter fill reservoirs and borehole. The rain water harvesting and run-off collection currently accounts for 25% but plans are in place to extend the area currently utilising both of these strategies, investing in further reservoirs and storage tanks. This alongside investment into a UV filter to sterilise collected water, could represent significant water and fertiliser savings on site and allow recirculation of water within the strawberry crop. Pathogen testing of reservoir water occurs annually on site, but may be required more frequently if recirculation of water within the strawberry crop is to be considered safe due to the threat of *Phytophthora* species.

Water harvesting – soft fruit (Soft fruit grower in the east of England)

In a soft fruit business based in the east of England, water availability has always been a limiting factor. They are totally dependent on a mains water supply which is limited and expensive. It is impossible to obtain a licence for a borehole at the site and the water quality from the dyke system is too saline for use on strawberries, even if a licence were available for abstraction.

Rainwater harvesting has offered a way forward for the farm, although it has not proved cheap. A 1.2ha block of Haygrove 'Greenhouse Range' tunnels equipped with gutters and automatic venting was erected in 2012 (Image 23). The tunnel covers are kept on throughout the winter (this particular field is well sheltered) and water is collected in metal gutters which feed into a 10m^3 sump, a prefabricated plastic tank installed below ground level to one side of the tunnel bock. A lack of space meant that there was no room to dig a collection pond and the sump had to be relatively small (Image 24).

23. Multi-bay tunnel equipped with gutters and automatic venting

24. In order to provide space for the sump, part of a windbreak had to be removed

Because of the small sump size, in order to cope with rainfall events of up to 15mm/hr, two relatively powerful pumps (7 hp) are used to rapidly transfer water into the 3,500m^3 main farm reservoir. These can clear the sump within a few minutes. However, having two pumps of this rating did require a relatively expensive electricity supply.

In 2012, 3,200m^3 of rainwater was harvested from the block, a little less than 90% of the calculated potential for the area, given the rainfall records for the months collected. One advantage has been the very good quality of the water.

Water harvesting, recycling and chlorination – soft fruit (Haygrove Farms Ltd)

Haygrove's site near Ledbury is now nearly self-sufficient in water, due to their large scale investment in rainwater capture and recycling. The innovative soft fruit and cherry enterprise operates from several sites in the UK and South Africa, alongside a worldwide polytunnel business.

The Haygrove patented polytunnel guttering system is a relatively new concept and was installed at the Ledbury site three years ago in a drive towards water self-sufficiency. The initial designs for rainwater harvesting employed plastic and fabric guttering but are now being superseded with an all metal design which is less liable to flexing and leakage. The gutters are installed in the Y-shaped leg structures which support the tunnel system (Image 25). About half of the site's 40ha of tunnels now have gutters.

25. Metal gutters are cut and installed in Y-shaped legs to harvest rainwater between multi-bay tunnels

Downpipes from the gutters connect to an underground pipework system which feeds directly into one of five reservoirs recently constructed or expanded. All reservoirs (Image 26)are clay-lined, the largest of which can accommodate 24,000m^3 of water. Three of the reservoirs are arranged in a cascade and are connected by silways (Image 27).

26. One of the three main reservoirs at Haygrove Farms situated in the valley bottom

27. Silway used to connect cascading reservoirs at Haygrove Farms

Only the permanent covered crops such as raspberries and strawberries are equipped with gutter tunnels. Half of the tunnel area is without gutters, for crops such as cherries, which are left uncovered for part of the year. The non-gutter tunnels are, however, equipped with leg row lined trenches which feed into poly lined open low trenches (Image 28) which in turn feed into one or other of the reservoirs. Some water collected on stretches of gutter equipped tunnels also drains into low trenches rather than pipe work to avoid overloading the capacity of the pipe work system.

28. Typical low trenches used at Haygrove Farms to feed water into reservoirs

From the reservoirs, water is acid treated and pumped through a single disc (mesh) filter into a galvanised 250m^3 storage tank.

In the next treatment stage, water is nutrient injected, fed through six double disc filters and treated with chlorine. A Xziox system injects chlorine dioxide into the water, leaving 0.3-0.4ppm residual chlorine in solution. The Xziox system was installed initially to reduce problems with *Phytophthora,* which was becoming a problem in the raspberry crop and may have resulted from contaminated groundwater entering the reservoir system. Since installing the system, the problem has been eliminated and the farm is also now able to cope with potentially contaminated recycled water without additional investment in treatment processes.

In a relatively recent development, run-off water from strawberries is collected and fed into the main irrigation system at the pump house and ultimately recirculated around the crop. Strawberries are grown in coir bags on gutters (Image 29 overleaf) and run-off water is collected at the end of each row through a flexible hose pipe (Image 30 overleaf) into an underground pipe work system then into a 1m^3 LBC (liquid bulk containers) dug into the ground at intervals at the tunnel ends. The LBCs are pumped out into a tank at the pumphouse where it is fed into the main water system at around 1%. At this low level, any high conductivity in the run-off does not significantly influence the final water composition. Similarly, any potential contamination is dealt with by the existing filtration system and the routine chlorine dioxide injection.

29. Metal gutters are cut and erected to support coir bags at Haygrove Farms

30. Drain water collection from strawberry bags at Haygrove Farms

Water harvesting and recycling using UV sterilisation and pasteurisation – glasshouse strawberries (De Jong, Yong Fruit BV, the Netherlands)

Strawberry producers, Young Fruit BV, grow Elsanta and Sonata in two heated glasshouse sites near Dongen in the Netherlands (Image 31). The production is year round with two crops per plant. Four plants are planted in 5 litre pots, spaced along suspended gutters to give 10 plants per m^2. They expect yields of 1.2kg per plant in the spring and 0.8kg per plant in the autumn. Crops are provided with supplementary lighting and CO_2 injection.

31. Glasshouse strawberry production at Jong Fruit BV

As the business grew in the late 1990s, sustainable water use became more and more important. Rainwater is harvested on both sites and supplemented with sterilised drain water for irrigation. Glasshouse expansion in 1999 was only permitted by the local authority on condition that a water recirculation system was installed. For some years now in the Netherlands, it has not been permitted to discharge crop drainage water into the dykes and in 2013, similar restrictions were imposed in neighbouring Belgium. The company's smaller three hectare glasshouse uses a Vialux UV sterilisation system (Image 32) and their larger four hectare glasshouse is equipped with a Van Dijk pasteurisation unit.

32. Prima Vialux UV sterilisation unit at De Jong Fruit BV

At both sites rainwater is harvested from the entire glasshouse roof and stored in an open butyl rubber lined lagoon. At the smaller three hectare site, there is a 3,700m^3 lagoon and at the larger site, rainwater flows into a 20,000m^3 lagoon. During the summer, some water is abstracted from a borehole. Although the nursery has a reverse osmosis unit to remove ions and reduce the EC of borehole water, the high running costs make its use uneconomical. The nursery also produces tray plants on a 3.3ha field site. To avoid contamination of groundwater, field drainage water from the site is now collected, sterilised and used to irrigate the covered crops.

At both sites, plants are watered to 30% run-off and the drain water is collected. Each of the five glasshouse compartments on the smaller site has a submerged drain sump which the run-off water drains into. Water is electrically pumped out of these sumps into a 125m^3 holding tank (Image 33) prior to sterilisation. Water flows through the UV system at a constant rate and into a second 125m^3 holding tank. Sterilised water may be stored here for a number of days until needed.

33. Storage tanks for different water sources at De Jong Fruit BV

The Vialux UV system was installed in 1999 and runs at 60-80mJ/m^3. Strawberries are grown in coir that has been specially rinsed to remove loose matter and reduce browning of irrigation water. Run-off water on this site typically has a T10 value of 40, making it clear enough for effective UV sterilisation. For a short time after the UV system was installed, water was sampled weekly and sent for pathological analysis. The nursery owner was particularly worried about the spread of *Phytophthora* in the irrigation water. Over time, confidence in the system has grown and this analysis is no longer done on a routine basis.

Sterilised water is mixed with harvested rainwater to make a solution with a preset EC of ~0.4mSm^{-3}. Typically, sterilised run-off water comprises 40% irrigation water. Nutrients and acid are injected to generate a final EC of ~1.5mSm^{-3}. The grower's primary concern with the system is EC rising too high for healthy plant growth. For this reason, drain water samples are sent weekly for nutrient analysis and the feed rate is adjusted accordingly. Drain water is included in irrigation water and used throughout the production cycle, except for a four week window from fruit set through to early harvest.

At the larger site, run-off water is sterilised using a gas-powered Van Dijk pasteurisation unit that was already installed when the site was purchased. The unit uses so little gas that it doesn't register on the site's gas meter. Despite being highly effective against pathogens, pasteurisation reduces the oxygen concentration of the water and increases the temperature by ~3°C.

Looking to the future, Yong Fruit BV is investigating the potential use of hydrogen peroxide injection to remove toxic compounds which could accumulate over time in the water recirculation system. Measures such as this could ensure the long-term success of water recirculation.

Water harvesting and plans for recycling (slow sand filter being installed) – glasshouse strawberries and tray plant production (Verpaalen Aardbeien BV, Rijsbergen, the Netherlands)

A father and son partnership, this business combines both glasshouse fruit production and tray plant production. They started producing tray plants (initially 400,000 per year) for their own use and now produce an additional 1.5 million for sale, some of which are exported to the UK.

The nursery has 4ha of modern glass for strawberry production, which was completed in sections from 2004 onwards. Elsanta is the only variety used for fruit production. They plant tray plants in mid-August to crop from early October and finish at Christmas. The plants are then cropped again by heating from the end of February to crop in April-May. Half of the spring crop is produced before 1 May. The production system is typical for this area of the Netherlands, using rigid pots in suspended gutters, with 4 plants per 5 litre pot, 10 plants per metre run and 10 plants per m^2. The growing media is a 50:50 peat coco fibre mix with a small (5%) percentage of perlite added for drainage. Between the spring and autumn fruit crops, the glasshouse is used for mother plants to produce runners which are then rooted into trays outside in the 6ha tray plant unit.

The tray plant field is covered with woven black plastic ground cover over impervious plastic sheets, graded to allow water to flow into French drain-type drainage channels, which are isolated from the soil (Image 34). In this area of the Netherlands, all run-off has to be collected from substrate crops and re-used. This legislation was introduced due to high levels of dimethomorph (used routinely for *Phytophthora* control on the tray plants) being found in drainage water and contamination in the local river. Nearby Belgian growers will also be subject to the same restrictions.

34. Tray plant production field showing drainage channels

In the tray plant field there is a high level of irrigation run-off, particularly when the un-rooted runners are first inserted. Typically, 10mm of water is applied per day during the initial period to support the plants, virtually all of which runs-off. The drains run into a single 27m^3 drainage sump – a prefabricated concrete chamber. There is a submersible pump installed that can rapidly empty the chamber into the nearby drainage water reservoir, which is a section of the main nursery reservoir (Image 35).

35. Tray plant field drainage sump with submersible pump

All roof water is collected from the 4ha glasshouse block and is run into the reservoir (Image 36). Because the height of the roof is above the level of the reservoir, no pumping is necessary, provided the pipes are kept full.

36. Roof water reservoir

The nursery is also supplied by borehole water which has a low (0.3mSm^{-3}) conductivity but is high in iron. Iron is removed by aeration and sedimentation equipment.

The main reservoir has a capacity of 27,000m^3 which is mainly filled with rain water from the glasshouse roofs. There are additional 4,500m^3 separate sections for drainage water and for de-ironed borehole water.

The drainage water reservoir is filled from the tray plant field and also the glasshouse, the latter from internal sunken drainage sumps in the glasshouse, pumped out with submersible pumps. In the glasshouse, under full load, the plants can receive 1 litre per plant per day. At 30% run-off, this can potentially generate 30m^3 drainage water per ha per day. Note, this is a higher level of irrigation and run-off than is common in the UK.

At present all the drainage water is applied to a 1.5ha grass field to dispose of it. However, because of concern that this is not acceptable to the local authority, the nursery is in the process of installing a slow sand filter through which all the drainage water will pass. The slow sand filter system was chosen because of concern that the turbidity of the water would be a problem with UV light sterilization and the grower was not aware of other options.

When the sand filter is fully operational, the recycled water will be applied to the fruit crops only. At present, the grower remains concerned about hygiene aspects of using recycled water on the tray plant crops.

Water harvesting and recycling with slow sand filter – glasshouse strawberry, mother plant and strawberry tray plant production (Peter van der Avoird, Avoird Trayplant, Molenschot, the Netherlands)

Peter Van der Avoird is a strawberry tray plant producer. The business in its current form was started in 2002, when Peter took over his father's holding that was previously used for vegetable production. Strawberry tips are taken in May for everbearers and July and September for other varieties. He strongly favours production of 'fresh' everbearer plants using young material like this. The main variety for everbearer production is currently Capri.

Peter has four outdoor field sites, two for raspberry production, two for strawberry production and a 2ha glasshouse area. The run-off is not collected from the raspberry sites as the volume of water and fertiliser (N and P) applied is relatively low compared to neighbouring vegetable crops in the area, so it is not considered to be a major pollution risk.

The main 3.5ha strawberry tray field is graded and laid out with woven plastic ground cover over impermeable plastic. Overhead irrigation run-off water drains into French drains with 250mm drainage pipe which runs through a silt trap into a 5 m^3 sump. From there, it is pumped out by submersible pump to the dirty drainage water reservoir of 700m^3 (Image 37).

37. Tray plant production field with segregated water storage reservoir and slow sand filter installed in a galvanised circular tank

There is a main open reservoir of 2,000m^3 which is filled with roof water from the glasshouse and topped up as required with borehole water (EC 0.3mSm^{-3}), which is first de-ironed.

The regulation in this area dictates that during the first 3mm of rainfall, drainage water must be collected, after which any excess can be run into the dyke. The drainage water switching is controlled by a valve connected to a rainfall gauge. The gauge has to be reset after any spraying or fertiliser application.

Sterilisation of the dirty drain water is achieved by slow sand filter. Dirty water is first pumped through a fast sand filter to remove larger particles which would otherwise clog the slow sand filter. The slow sand filter consists of a 130m^3 metal tank (5m diameter x 2.7m depth) containing three grades of sand. Water is pumped through at a rate of 2.5m^3/hr and enters the slow sand filter through a holed pipe running across the top. Water depth is maintained at 40cm above the sand. The treated water is then pumped from the bottom of the tank into the two 130m^3 clean water tanks. Routine tests have shown the slow sand filter to be 100% effective in removing *Phytophthora, Pythium, Rhizoctonia* and *Xanthomonas*. It is not consistent in removing chemicals. Some are completely degraded while others remain. Dimethomorph remains at 80%. The effect on the EC is also minimal.

Peter uses the drainage water mainly on the heavy tray plants and finds no detrimental effect. The EC of the drain water varies from 0.2 to 1.1mSm^{-3}. *Phytophthora* levels are measured routinely every month, a service that is widely available in the Netherlands (eg BLGG, Zuidweg 42, Naldwijk).

The sand filter surface is cleaned twice a year by scraping off surface algae.

The slow sand filter method was chosen and installed two years ago because of concern over the risk from *Xanthomonas.* Wageningen University made a comparison of control methods: UV, hydrogen peroxide injection and pasteurisation. All were effective, but Peter chose slow sand filtration for reasons of cost and reliability. Hydrogen peroxide was too expensive in consumables and there was concern about effectiveness where there is a lot of organic matter in the water. UV was effective in the trials but Peter remained worried about its effectiveness on turbid water. Pastuerisation, as used by major glasshouse hydroponics salad growers, was considered too expensive.

The cost of the sand filter was 34,000€ of which 11,000€ was for the cost of sand.

Overall, Peter has been satisfied with the system and has no qualms about using the recycled water for his tray plant production. At present, the capacity of the system is inadequate to cover more than the level of recycling required under local regulations, but he is strongly considering doubling the capacity by installing another similar slow sand filter.

Reed and iris beds for treatment – particularly for *Phytophthora* species in nursery stock bed run-off (John Richards Nurseries, Worcestershire)

John Richards Nurseries is a producer of container grown trees and shrubs with both outdoor and protected crops. Owner John Richards has a keen interest in production using environmentally friendly methods.

At the nursery site in Worcestershire, drainage water from the plant standing beds is collected and treated biologically prior to recirculation. For nursery stock production as with soft fruit, the main risk in recirculated water comes from *Phytophthora* species. Although the species may be different from those encountered in fruit, the same methods of control are valid.

John originally used chlorination for water treatment but found re-infection to be a problem. Slow sand filters were considered, but a test run encountered problems with blocking. Finally, reed and iris beds were installed and have proved successful, with the re-infection problem on the beds eliminated. This is thought to be due to the beneficial biological activity resulting from the reed and iris beds.

Run-off water drains from the plant standing beds into a 1,250m^3 lagoon (Image 38). From here it is pumped into the reed bed (Image 39), entering as a fountain through a homemade venturi structure of perforated piping. The reed bed is 40 metres long, 5 metres wide and is lined with black polythene. The water level is around 0.5 metres. Norfolk reed was planted in gravel ridges at three metre intervals across its width. A drainage system was installed under the bed to stop the plastic lining from floating. Water flows by gravity through the bed then by pipe into a 25,000 m^3 clay-lined reservoir. It has been observed that storage in the reservoir is associated with a drop in alkalinity and reduction in nutrient concentration.

38. The drainage lagoon at John Richards Nursery collects run-off water from the container plant beds

39. Reed bed at John Richards Nursery

Water is then pumped out of the reservoir and flows through a self-cleaning sand filter and a bag filter before entering a 12m^3 primary storage tank. To maintain aeration, a small pump constantly circulates water in the tank. From this primary storage tank, the water is then pumped into the iris beds.

The iris beds (Image 40) comprise a linked system of six, 1 metre wide and 18 metre long beds, with the water 30cm deep, laid out side by side in a cascade. The beds themselves are completely covered in woven black plastic groundcover to stop light penetration and dust contamination. Irises are planted in exposed slabs of polystyrene with their roots submerged in the water. Shallow cascades aerate the water in the bed and water flows out of the bed through a mesh (disc) filter and into a 47m^3 storage tank, which is large enough to supply the nursery for two thirds of a day. An additional filter had to be installed due to the high number of water insects present in the iris bed.

40. Iris bed at John Richards Nursery when first installed

The reed bed cost £2,500 to install, with the nursery staff carrying out the work, while the iris bed cost £7,500 in materials and labour.

Chlorination of river and ground water sources for soft fruit production (The New Forest Fruit Company, Hampshire)

The New Forest Fruit Company grows strawberries and blueberries in soilless substrate on two sites in Hampshire. Effective sterilisation of abstracted water allows the company to irrigate without relying on a mains water supply. In 2011, chlorine injection systems were installed on both sites to sterilise water and prevent blockages in irrigation lines.

At New House, a 50 hectare site, water is abstracted from a stream through the winter months and stored in a 22,500m^3 open reservoir. This supply is supplemented with land drainage and surface water throughout the year. At the second site, at Penerley River, water is abstracted from one river throughout the year. Prior to the installation of the chlorination system, algae and bacteria were accumulating in irrigation lines and regularly causing blockages.

Sodium hypochlorite is injected (Image 41) into irrigation water using a Tekna Evo Solenoid Dosing Pump (model 803). Three units are required to service the larger 50 hectare New House site, while one unit is sufficient for the smaller Penerley River site. For effective sterilisation, there should be 1-1.5ppm residual free chlorine at the far end of the drip irrigation line. This concentration is checked weekly and the chlorine injection rate is adjusted as required. Typically, 7-8ppm must be injected in the winter and 12-15ppm is needed in the summer. This reflects the higher bacterial and algal pressure present in the warmer summer months.

41. Sodium hypochlorite injection point

Water from the reservoir has a pH of 7.5 and is injected with chlorine prior to filtration, nutrient dosing and acidification. The mineral quality of the water appears unchanged by chlorination and this is consistent with the treatment having no discernible effect on the fruit crop.

Before installing the chlorination system, to solve the algal problem, the New Forest Fruit Company tried using a supersonic vibration unit and aerating the water with sprinklers. Neither proved effective at sterilising the water, although oxygenated water seemed to improve root growth and reduce other disease problems.

While chlorination has proved an effective way of keeping irrigation lines flowing, sodium hypochlorite is a hazardous substance and must be handled with caution on the nurseries. The drums of sodium hypochlorite are kept in cages outside the pump houses and emergency shut off switches have been installed outside the pump houses so that the system can be shut off at any time.

Reed and iris beds (Lowaters Nursery, Hampshire)

Lowaters Nursery produces a wide variety of container grown plants for garden centres on a 6.5ha site in Hampshire. Harvesting rainwater and recirculating run-off water has enabled the company to irrigate without using mains water, a move that is both sustainable and economical.

A little under a third of the production site is under protection and plants are grown on capillary sand beds. Water is collected from the glasshouse roofs (Image 42) and flows through a silt trap (Image 43) into a central gravel bed (Image 44). The gravel bed is a 1 metre by 10 metre channel lined with butyl rubber laid over a geotextile. The 1.2 metre deep channel is filled with stones covered with a protective woven plastic ground cover sheet which, in turn, is weighed down with concrete slabs (Image 45). Water flows into the bed through a perforated drainage pipe laid in an S-shaped configuration. The gravel bed has a slight downward incline and water flows through the channel to the far end. Here, water is piped by gravity, into the main lagoon (Image 46).

42. Roof water is collected from glasshouses at Lowaters Nursery

43. Silt trap prior to gravel bed

44. Typical size of gravel used in gravel bed

45. Small gravel bed with woven plastic cover

46. Run-off water collection lagoon

Water sterilisation appears to be very effective. *Phytophthora* is detectable in water entering the initial silt trap from the glasshouse roofs but not in water entering the lagoon. A *Trichoderma* population has established in the gravel bed, generating bioactive water which is less liable to become re-infected with *Phytophthora*.

The main lagoon, fed with water from the gravel bed, is clay-lined and has a 1,100m^3 capacity. Additional water flows into the lagoon from a multi-span polytunnel roof and a dispatch area polytunnel. Although this water has not passed through the gravel bed, it is considered to be clean and uncontaminated. Some run-off drain water is also fed into the lagoon. Although this water is unsterilised and considered contaminated, water in the lagoon has been found to be free from contamination. The company attributes this effect to populations of beneficial microbes which have come from the gravel bed and established in the lagoon. In order to take advantage of rainfall on the site, the water level is kept quite low by pumping water out of the lagoon and into the main reservoir (Image 47).

47. Foreground; main reservoir, background; clean water storage tank and RHS windbreak shading around iris beds

The main reservoir is butyl-lined with a 7,000m^3 capacity. Water is pumped through a venturi on its way into the reservoir which oxygenates the water. Further to this, a submersible 4m^3/hr pump forces water through a perforated scaffolding pole cross on the base of the reservoir to introduce more oxygen into the water. From here, water is pumped at a steady rate of 4m^3/hr into the iris beds.

Each of the three iris channels is 1 metre wide by 10 metres long and 1 metre deep. Floating expanded polystyrene rafts are planted with iris such that the root mat sits in the water below. Between the rafts, clear water is visible and exposed to the open air. Due to poor top growth of iris, Lowaters are considering replacing the polystyrene floats with plastic crates lined with fleece (Image 48). It is hoped that the crates could be suspended over the water, iris would grow in the fleece layer and the roots would hang down into the water underneath. Water enters and exits the iris beds at a constant rate, taking about four hours to travel from one end to the other. At the far end of the bed, a pump directs water though a disc filter and into a clean water tank.

The clean water tank is circular and galvanised. With a capacity of 300m^3, the tank could supply water for the nursery for a week. This clean water passes through a final disc filter (Image 49), before entering irrigation lines.

48. Crates of bare root Iris ready to be planted in situ to replace the EPDM rafts

49. Small disc filter for final water filtration

Further information

Suppliers of multi-bay Spanish tunnels suitable for roof water harvest

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Ledbury
HR8 2JL
Tel. 01531 633659
www.haygrove.co.uk

Pro Tech Marketing Ltd.
Unit 9, Offerton Barn Business Centre
Offerton Lane
Hindlip
Worcester
WR3 8SX
Tel. 01905 451601
www.pro-tech-marketing.co.uk

Suppliers of strawberry gutters

FormFlex – Metazet
De Lierseweg 6
2291 PD
Wateringen
The Netherlands
Tel. 0031 174 315 010
www.formflex.nl

Haygrove Ltd
Redbank
Ledbury
HR8 2JL
Tel. 01531 633659
www.haygrove.co.uk

Meteor Systems
Meteor Systems Etten-Leur
Munnikenheiweg 58
NL 4879 NG ETTEN-LEUR
Tel. (0031) 765 042 842
www.irrigation.com

Pro Tech Marketing Ltd.
Unit 9, Offerton Barn Business Centre
Offerton Lane
Hindlip
Worcester
WR3 8SX
Tel. 01905 451601
www.pro-tech-marketing.co.uk

Suppliers of ultraviolet sterilisation systems

Priva UK Ltd
34 Clarendon Road
Watford
Hertfordshire
WD17 1JJ
Tel. 01923 813480
www.priva.co.uk/

DaRo UV Systems Ltd.
Unit 1 Drury Drive,
Woodhall Business Park,
Sudbury
Suffolk
CO10 1WH
Tel. 01787 370187
www.uvwatertreatment.co.uk

ATG UV Technology
Genesis House
Richmond Hill
Pemberton
Wigan
WN5 8AA
Tel. 01942 216161
www.atguv.com/horticulture/

Suppliers of chlorine injection systems

Chlorine dioxide generating and metering equipment

Ximax water solutions
Kamera House
7 Western Gardens
Brentwood
Essex
CM14 4SP
Tel. 01277 849988
www.ximaxwatersolutions.com

Sodium hypochlorite variable speed injection pumps

Seko UK – Chemical Controls Ltd
Unit 3
Coldharbour Pinnacles Industrial Estate
Coldharbour Road
Harlow
Essex
CM19 5JH
Tel. 01279 423550
www.seko-group.com

Manufacturers/suppliers of pasteurisation units

Manufacturers of pasteurisation units

Van Dijk Heating
Regulierenring 7
3981 LA Bunnik
The Netherlands
Tel. (0031) 306 563 844
www.vandijkheating.com/en

Suppliers of pasteurisation units

C.M.W. Horticulture Ltd
Stonepit Road
South Cave
Brough
East Yorkshire
HU15 2BZ
Tel. 01430 422222
www.cmwhorticulture.co.uk

Manufacturers/suppliers of copper ionisation systems

Aqua-Hort DK
Engdalsvej 28
DK-8220 Brabrand
Denmark
Tel. (0045) 702 26 611
www.aqua-hort.dk

Suppliers of Aqua-Hort DK systems in the UK

Hortisystems UK Ltd
Sylvan Nurseries
West Chiltington Road
Pulborough
West Sussex
RH20 2PR
Tel. (01798) 815815
www.hortisystems.com

Manufacturers of nano filtration filter systems

Kirton Engineering Ltd
Old Station Road
Shepshed
Leicestershire
LE12 9NJ
Tel. 01509 504565
www.kirton.co.uk

Water testing facilities (nutrients)

Eurofins
Valiant Way
Wolverhampton
WV9 5GB
Tel. 0845 604 6740
www.eurofins.co.uk

NRM Ltd
Coopers Bridge
Braziers Lane
Bracknell
Berkshire
RG42 6NS
Tel. 01344 886338
www.nrm.uk.com

Water testing facilities (pathogens)

Matthew Goodson
Stockbridge Technology Centre Ltd.
Cawood
Selby
North Yorkshire
YO8 3TZ
Tel. 01757 268275
www.stockbridgetechnology.co.uk

Tim Pettitt
Eden Project
Bodelva
Cornwall
PL24 2SG
Tel. 01726 811911
www.edenproject.com

Design of water filtration systems

Dove Associates
Weggs Farm
Common Road
Dickleburgh
Diss
Norfolk
IP21 4PJ
Tel. 01379 741200
www.dovebugs.co.uk

Flowering plants
11–12 Homeground
Buckingham Industrial Park
Buckinghamshire
MK18 1UH
Tel. 01280 813764

Costings

To provide growers with an understanding of the typical costs involved in the water harvesting/recycling and water treatment systems included in this guide, a comprehensive series of tables and assumptions for each system have been collated. These can be found in the Appendices at the back of this guide.

Other relevant HDC publications

HDC Factsheet 15/06. *Water quality for the irrigation of ornamental crops*

HDC Grower Guide. S*low Sand Filtration: A flexible, economic bio filtration method for cleaning irrigation water*

Image credits

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Appendices

Appendix 1 – Typical cost of gutters used for water harvesting/recycling

Gutter details	Cost
Gutters suitable for water collection/recycling to support bags, to include; 1.8m steel table top legs (3m spacing), termination wire brackets, white polyester coated substrate steel gutter, leaf and truss supports and tape, end caps with down pipes	£5.16 per m
Gutters suitable for water harvesting between tunnel covers to install between 8m bays with 2.2m leg spacing to include; down pipes for end sections, steel rain gutter, end plates, rope hooks, rivets, screws and sleeves	£8,430 per ha

Appendix 2 – Cost comparison of different water treatment systems described in the guide

	Slow sand filter	UV steriliser	Chlorine dioxide	Hypochlorite	Aquahort	Treatment rates
10m^3/hr						
Equipment costs	£2,350.00	£1,973.00	£9,000.00	£1,490	£5,700.00	40m^3/day, 4hr/day, 180 days/year, 7,200m^3/yr
Running costs/year	£1,090.00	£14.74	£538.13	£394.62	£496.00	
Running costs/m^3	£0.18	£0.025	£0.20	£0.03	£0.11	
25m^3/hr						
Equipment costs	£3,000	£2,812.00	£9,000.00	£1,490.00	£8,910.00	100m^3/day, 4hr/day, 180 days/year, 18,000m^3/yr
Running costs/year	£1,090	£30.87	£1,122.66	£394.62	£1,021.00	
Running costs/m^3	£0.08	£0.015	£0.11	£0.03	£0.08	
50m^3/hr						
Equipment costs	£4,150.00	£4,912.00	£9,000.00	£1,590.00	£15,210.00	200m^3/day, 4hr/day, 180 days/year, 36,000m^3/yr
Running costs/year	£1,090.00	£40.55	£2,245.32	£789.23	£2,200.00	
Running costs/m^3	£0.04	£0.025	£0.09	£0.03	£0.08	
100m^3/hr						
Equipment costs	£5,550.00	£8,187.00	£9,000.00	£1,740.00	£15,210.00	400m^3/day, 4hr/day, 180 days/year, 72,000m^3/yr
Running costs/year	£1,090.00	£60.82	£4,490.64	£1,580.36	£3,368.00	
Running costs/m^3	£0.02	£0.041	£0.07	£0.02	£0.06	

Assumptions

Equipment costs – These costs do not include installation.

Electricity – Electricity costs assume a charge of £0.128 per kWh.

Chlorine dioxide – The costs incurred in this form of treatment assume a cost of £0.25 per litre for sodium hypochlorite and £1.00 per litre for hydrochloric acid.

Hypochlorite – sodium hypochlorite is normally supplied in a 1,000 litre intermediate bulk container (IBC), which must be stored in a bund to protect the soil from accidental leakage. It is assumed that bulk sodium hypochlorite is injected at a rate of 10ppm and costs £0.26 per litre.

Appendix 3 – Comparative operating costs/m³ for different water treatment systems