Horticulture Innovation Australia

Final Report

Confirmation of ultra filtration as a viable low cost water disinfection and nutrient solution recycling option

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Primary Principles

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VG13052

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Summary

The aim of project VG13052 was to confirm the practical and economic feasibility of ultra-filtration as a technology for nutrient solution disinfection. This information is highly relevant and valuable to all hydroponic vegetable growers in Australia.

The capture and reuse of nutrient solution run-off not only improves water and fertiliser efficiency and therefore improved profitability, but consequently has significant environmental benefits too. A pathogen free source of water is critical to efficient and cost effective greenhouse and hydroponic production as well as the reuse of run-off water, which makes investment in reliable water disinfection essential. There are a number of disinfection technologies, yet high costs, inconsistent results and the use of chemicals are obstacles to widespread industry adoption of improved practices.

Key activities and corresponding outputs of this project have included a technical presentation at the peak national industry conference and an explanatory article in leading industry media. Extensive efficacy research trials have been completed as a key component of the methodology used in this project and this research has determined that while ultrafiltration currently offers a good option for removal of fungal pathogens, it currently does not provide adequate retention of key bacterial pathogens. Project activities have also included research into the detection levels of target pathogens in water and confirmation that the nutrient profile in hydroponic solutions is not adversely impacted by ultrafiltration.

Comprehensive benefit cost analysis has illustrated that there is almost no reasonable economic situation in which a hydroponic cucumber enterprise would not be significantly better off by implementing closed hydroponics with an ultrafiltration disinfection system. Detailed tabulated economic scenarios have been produced and published online (https://sites.google.com/site/sustainablehydroponics) to enable growers to make a preliminary assessment of how such an investment could benefit their enterprise. The project website has been established to provide a central information hub for growers to access information about the project, research findings and financial evaluation, as well to participate in an ongoing benchmarking survey about water disinfection. The project website continues to be available, post project.

Over the first monitoring period, the online benchmark survey found that only one third of enterprises are currently disinfecting water. Eighty percent of those not using a disinfection system are presently considering doing so. At the outset of this project, it was anticipated that as many as 100 enterprises may be encouraged to adopt disinfection technology, and if confirmed as reliable, adopt fine pore filtration for this purpose. Current results of the survey indicate that some 18% (equivalent to approximately 115 operators in Australia) are looking at ultrafiltration in the near future. This feedback indicates that the project is well on its way to facilitating the adoption of closed system hydroponics and ultrafiltration disinfection in 100 Australian enterprises.

This project has been able to evaluate and demonstrate the opportunities for closed system hydroponics and increased run-off targets and clearly shows the merit of investment in water disinfection. Overall, the economic viability of closed system hydroponics with disinfection is confirmed.

Keywords

Ultrafiltration; Hydroponics; PrimaryPrinciples; Controlled Environment Horticulture; Disinfection; Water Treatment; Cucumber; Greenhouse; Fusarium; Closed hydroponics

Introduction

The future of farming is efficiency, reliability and productivity and without question, protected cropping – in all its guises – is integral to this future. How this industry uses water and fertilisers and extracts maximum value from these precious resources will determine the viability, the sustainability, indeed the profitability of protected cropping. This project directly linked to the industry strategic priority to improve farm productivity, resource use and management. The capacity for an intensive vegetable enterprise to reduce fertiliser and water use and benefit financially from this opportunity is significant.

Hydroponics is a highly efficient horticultural production method, requiring significantly less space, water and fertiliser than soil based production to produce an equivalent yield of high quality, safe fresh produce. Greenhouse hydroponics is currently the most water and fertiliser efficient commercial vegetable production method. It is a high input/high output system that requires relatively large quantities of clean water even though the volume required per unit of product is substantially lower than other horticultural systems. A typical operation may have an approximate water requirement of 20ML/hectare/year. In many peri-urban areas where this industry is most prevalent, the cost of water can be in the order of $40,000 per annum. Besides the direct financial cost of this input for some enterprises, availability and subsequently the efficient use of this valuable resource is paramount in all production areas in Australia.

A closed hydroponic system, in which nutrient solution run-off is reused, further improves water and fertiliser efficiency. Savings can be up to 40% over the fundamentally high efficiency of a standard flow-through system. Despite the well-established productivity and efficiency dividends of closed hydroponics, more than half of the Australian industry does not currently make the most of reusing nutrient solutions. There are many reasons, though the most common reason for a hydroponic system not to be reusing nutrient solution is typically due to the risk of disease and the costs involved in minimising this risk.

A pathogen free source of water is essential to efficient and cost effective hydroponic production. Most sources of water are inherently a risk, with high quality bore water being the only natural source generally considered pathogen free. Any water that has contact with soil, dust or plant material is a pathogen risk. Even roof captured rain water can be contaminated with soil borne pathogens resulting from dust and plant debris on rooves and in gutters. All water used in a greenhouse hydroponic system must be pathogen free.

When water is reused, the potential for pathogens to spread and infect crops rises significantly. The increased risk of disease is a critical issue for closed hydroponics. In some situations, a potential additional challenge to the reuse of water is ensuring crop nutrition remains optimal.

There are a number of methods for disinfecting nutrient solutions (and water generally) including ultraviolet radiation, heat, slow sand filtration and a number of chemicals including ozone, chlorine and hydrogen peroxide. [An overview of the main methods is provided in the next section]. Investing in these treatment methods can be relatively expensive, particularly for smaller enterprises and a few of the treatment options have some negative consequences or limitations. Each has advantages and disadvantages. Fischer et al (2005) produced a list of eleven treatments for greenhouse irrigation water and identified a challenge or problem associated with each of them. Fine pore filtration was not included.

Various papers and publications have been produced in the past few decades that outline or describe the merits of various disinfection options [including van Os, E (2007); Nursery Papers: 1996#005, 1997#008 and 1999#003; Newman, S (2004); Runia, W (1995)]. The literature has two commonalities. The first is that the problem is significant and second, that there is no clear assessment of low pressure ultrafiltration as a potential low cost and reliable disinfection option.

Filtration has long been recognised as being an ideal disinfection option provided a filter can screen to sufficiently small size to remove the target pathogen and yet not get blocked up. Until recently, clogging in filters has been a 'deal breaker'. A preliminary assessment of ultra-membrane filtration undertaken as a sideline to a water efficiency program in NSW, indicated that filter technology may have developed to a point where it could not only reliably remove key pathogens but not suffer the historical blockage issues associated with fine pore filtration. A previous industry project (National greenhouse waste-water recycling project – VG09073) provided a series of workshops held around Australia to support growers with knowledge and skills for using closed hydroponics and commercially available disinfection technologies. However, this project did not undertake work to establish the financial viability or reliability of water disinfection technologies for small to medium enterprises, nor did it assess ultrafiltration as a cost effective option.

The aim of this Horticulture Innovation Australia project was to confirm whether ultrafiltration offers a practical and feasible means of nutrient solution disinfection for growers of hydroponic vegetables, particularly with respect to the economic viability and reliability for small to medium enterprises which currently comprise some 70 – 85% of the Australian levy paying greenhouse industry. Larger operators can already financially justify the use of high-end UV and even heat treatment technologies.

The project objective was to undertake comprehensive pathology and performance trials on ultrafiltration and evaluate the benefit to cost of these types of disinfection systems. In particular, to (i) test the efficacy of an ultrafilter (0.04µm nominal pore size) in the removal of *Fusarium* and *Pythium* and also to test the efficacy with respect to bacterial pathogens, such as *Clavibacter michiganensis* spp*. michiganensis* (*Cmm*); (ii) confirm nil adverse impact of ultrafilter on nutrient profile of filtrate; (iii) test reliability of ultrafilters with varied water quality and (iv) quantify typical purchase, installation, operating and maintenance costs to assess the economic benefit of ultrafiltration disinfection of hydroponic run-off water as a part of a closed hydroponic production system.

Common disinfection methods

There are many sources of published and online information – technical and commercial literature – that describe the suite of disinfection processes more fully and so only an overview of the main methods are included here in order to provide context to the aim of this project: to confirm whether ultrafiltration is a viable option for hydroponic vegetable growers.

Ultrafiltration

Filtration offers a direct, mechanical (physical) means to remove pathogens from recycled water. For many enterprises, this makes for a simpler management task. Every greenhouse or hydroponic manager will already be using some form of filtration so using this technology for disinfestation of water for use in the crop is not a big step.

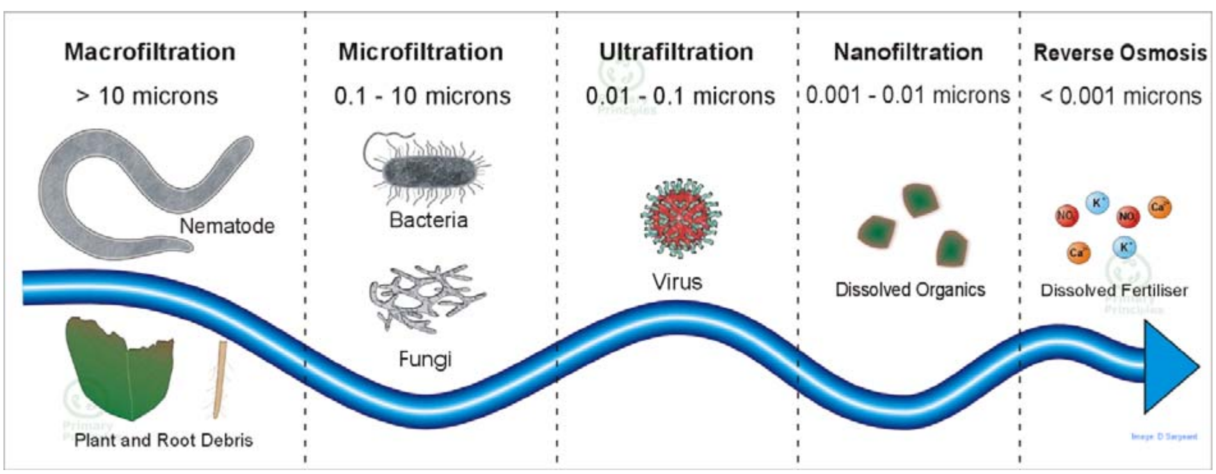


Figure 1: Illustration of the various grades and nomenclature of fine pore filtration

Ultrafiltration generally refers to the removal of contaminants from 0.01 to 0.1 micrometres. Bacteria (~0.2 micrometres) and fungi (~0.5 micrometres) should be removed from water at this level of filtration and some virus may also be removed from water with ultrafiltration. Dissolved nutrients, however, are not removed with ultrafiltration which makes it an ideal option for hydroponics.

Fungi and bacteria are the primary pathogens that most hydroponic managers need to remove. Currently, the removal of viruses from water is not a critical requirement for Australian vegetable growers, though this is likely to change in the near future, particularly with the recent determination that Cucumber Green Mottle Mosaic Virus is now established in the Northern Territory. These microorganisms might also be removed by ultrafiltration or nanofiltration.

Biofiltration

Slow sand filtration is a relatively low operating cost option for water disinfection, however due to the slow treatment rate of this type of filter, quite large systems can be required to process sufficient volumes of water. This can mean fairly significant capital costs and a relatively large area of space are needed. A range of substrates (not just sand) can be used in this type of filter, and getting the design right is critical. Maintenance is also essential in these systems.

Another form of biological filter that can potentially be used for water disinfection is a wetland or reed bed. These systems (natural and constructed) have typically be used for removing nutrients from waste water but there is also scope for pathogen removal, though more information is needed to ensure efficacy as a disinfection option. While there are simple and cost effective ways of constructing wetlands and reed beds, adequate design is essential.

Chemical disinfection

Chemical disinfection is any treatment method where an active compound is used to destroy or denature microorganisms. Generally, some form of fine filtration is necessary prior to chemical disinfection to ensure that the chemicals work reliably. There are a range of oxidising agents. Chlorine is the most commonly used. A disadvantage with many chemical treatments is that the chemical cannot discriminate between plant pathogens, other organic material and critically, plant roots. This means that in order to effectively kill the pathogen, a sufficient dose is required to compensate for the overall organic load in the water.

Unfortunately, for some chemicals a concentration high enough to be effective will also generally cause some level of damage to plants. Consequently, chemical disinfection is often better suited to batch treatment of water in order to use sufficient concentrations and provide required contact times to be effective, yet avoid damaging plant roots. Batch treatment is quite reasonable for treating new water but disinfecting nutrient run-off within a production cycle, though possible, can be impractical in many enterprises.

Sodium hypochlorite is relatively cheap and easy to use in batch treatments but chlorine is corrosive to equipment, dangerous to use and will add unwanted sodium into the system (Calcium hypochlorite can be substituted to avoid a build up of the sodium, though it is usually a little more expensive.)

Chlorine dioxide is more expensive to set up (in terms of dosing equipment) but offers a more stable form of chlorine which is less affected by residual organic matter. As a result this form of chlorine is more commonly used for in-line dosing, though it is important to find a dose rate that provides sufficient benefit without causing an unacceptable level of damage to plant roots.

Other chemical options that work in a similar way to chlorine are iodine and bromine. These three chemicals are all known as halogens.

Ozone is another oxidising chemical used in disinfection. If correct dosing can be reliably and consistently achieved, this chemical provides a potentially feasible treatment option. Reliable equipment to generate, dissolve and monitor ozone in the nutrient solution however, can be complicated and expensive. As with the halogens, chemical residues in the nutrient solution can adversely affect plants. There can also be potential workplace health and safety issues that need to be addressed when generating ozone.

Hydrogen peroxide is one of the few chemical treatments that does not generally pose a problem with damaging residues in the nutrient solution. This compound breaks down rapidly into oxygen and water, however if high concentrations do come into contact with plant roots, like all oxidising chemicals, it will attack plant cells as well as microorganisms. There are potential safety and security issues with the storage and use of hydrogen peroxide which have to be considered.

Peracetic acid is a chemical which produces hydrogen peroxide and acetic acid in water, eventually breaking down to water, oxygen and carbon dioxide. This chemical is often used as a disinfectant in the food processing industry. In general, acids and alkalis can be used to create changes in the pH of the water to provide fairly good levels of disinfection as many microorganisms are susceptible to very high or very low pH. A disadvantage of this treatment option is that the pH of the water would have to be readjusted to suit the crop prior to use. This also means that acids and alkalis are only really suitable to batch treatment systems. The pH of the treated water as well as the type of acid/alkalis used may impact on the nutrients in the hydroponic solution.

Another less well known chemical disinfection method uses copper and silver ions. This is quite old and nicely simple technology, though there seems to be little reliable data on its efficacy with the exception of treating for some fungal pathogens such as *Pythium* and *Phytophthora*. The risk of copper toxicity must be considered. A concentration of copper ions in the order of 0.2 – 0.4 mg/L might be expected to be used for disinfection, however copper levels around 0.1 mg/L would be likely to have a detrimental effect on root growth in some crops. Another limitation is that because copper ionisation does not degrade organic matter, this treatment option would be expected to have limited efficacy on pathogens protected within organic material. Another potential problem is that in water containing high levels of dissolved solids (such as a hydroponic nutrient solution), silver is likely to precipitate.

Thermal disinfection

Heat treating water is a well-established, reliable and highly effective method of disinfection. The standard approach has been to heat water to 95°C for 30 seconds, while there is also an indication that heating water to 83°C for 3 minutes is also effective against key target pathogens and this lower temperature would reduce costs and, particularly improve feasibility for hydroponic managers operating in warmer climates where there is less emphasis on generating heat over the full course of the production cycle, such as in much of Australia.

Heating water has a relatively high operating cost and the equipment is quite expensive. It is also reasonable to assume that the cost of energy will rise significantly over time and so this needs to be taken into consideration with this disinfection method. In colder climates, the cost of thermal disinfection can typically be substantially absorbed within the crop heating costs and thus does not add an extra operating cost onto the business. There may be opportunities using solar energy to pre-heat if not fully disinfect water at a lower cost.

Ironically, cooling the nutrient solution after treatment prior to reuse may be a practical problem in warmer regions that places a limitation of the feasibility of thermal disinfection for some hydroponic managers.

Ultraviolet (UV) radiation

Ultraviolet (UV) radiation is an established and proven disinfection technique, however in many systems there can be reliability issues relating to water quality and dosage rates. The suitability and sizing of different UV units is extremely variable. High water turbidity and discolouration can significantly reduce UV transmission through the water and therefore the efficacy. UV radiation also has some effect on the nutrient profile in a hydroponic solution. It is possible to manage these issues though they may add to the costs and overall management task required of the hydroponic manager.

The UV dose is dependent on radiation intensity and contact time. (This is similar to chemical treatments which are dependent on concentration and contact time). Some UV lamps available do not specify the intensity of radiation generated, while others specify dosage rates that fall below the minimum that has been shown to be required to kill key plant pathogens even in water with a high UV transmittance (very clear water). An added complication is that there remains a discrepancy in the recommended effective dose rates for some pathogens.

In using UV radiation for water disinfection, it is essential that the UV transmissivity of the water to be treated is known and maintained consistently at a high level. Many UV units require transmission rates above 60%, some even 75%. In a hydroponic enterprise, however, transmissivity of water can and usually does, vary. Tannins leached from many of the commonly used organic substrates can adversely affect UV transmission. As a starting point, the transparency of water to be treated must be at least 20% if a high pressure, high power UV unit is used or 75% for a standard output UV unit. A hydroponic manager needs to have a way to monitor the water transparency. A 10% decrease in UV transmittance (in the order of 5 NTU) can double the required size of a UV treatment system.

Recycled hydroponic nutrient solution will also often contain levels of iron and manganese that will further reduce the effective UV dose rate.

Automated high pressure ultraviolet disinfection systems are used successfully in some large scale commercial greenhouses, especially where low or no tannin producing substrates are used. Automated systems can adjust for changing water quality (up to a limit) and some models self-clean the UV lamp. These systems offer a reliable and practical method of disinfection, though small and medium sized operations need to carefully consider the financial feasibility.

Figure 1: One of the ultrafiltration test units used in the research trials

Project methodology and activities

This project comprised two main components. The first component was the series of replicated trials to assess the efficacy and overall performance of the ultrafiltration. The efficacy trials used both controlled laboratory conditions as well as 'real world' farm water samples to determine the efficacy and reliability of the ultrafiltration in removing key water borne pathogens of greenhouse crops. The use of two research trial methodologies was fundamental to determining an accurate assessment of this technology as it applies to real farm situations, and the trial replication used throughout the project is essential to ensuring growers can have confidence in the results. The controlled laboratory trials enable a reliable and repeatable investigation as to the capacity of this method of disinfection to achieve the required results. The use of farm run-off water in additional assessments provides a 'real world' evaluation of performance and allows for the impact of key variables of water quality which are excluded from laboratory trials.

A further research component of this project involved validating the sensitivity of detection of the target pathogens in water. This research is a precursor to being able to reliably detect pathogens present in farm water samples. The capacity to detect target pathogens in water (particularly at low levels) is a critical gap in preventative and integrated disease management. Presently, managers are detecting the presence of pathogens through disease expression in the crop. Reliable detection at low concentrations enables managers to identify early entry of pathogens into the production system and also system breaches such as a failure in disinfection. Early detection of pathogens generally increases the range of management options available, improving the success of intervention as well as generating better economic, safety and environmental outcomes.

The second part of the project was to evaluate the economic viability of the ultrafiltration. Detailed costs of installation and operation of the ultrafiltration system were collated to establish the benefit to cost of an investment in this type of technology.

Complementary activities were also conducted to ensure a full and proper technology assessment. These included (i) analysis of the impact of ultrafiltration on water ion (nutrient) content, (ii) water volume assessment using greenhouse reuse water to determine maintenance and cleaning schedules and (iii) online survey of disinfection systems and satisfaction.

Efficacy trials

A series of replicated disinfection trials were conducted under controlled conditions to determine the efficiency or otherwise of a commercially available ultrafiltration unit. In these series of trials, water solutions with known concentrations of test organisms as well as farm run-off samples, were prepared and passed, under sanitary conditions, through ultrafilters. The basic replicated trial process is illustrated in figure 2. Further trials were conducted using farm run-off water. These samples were collected from operational greenhouses during the cropping period. A bias selection process was used for farm sites, with properties suspected of having target pathogens, or with a known history of target diseases, confidentially chosen for evaluation of the disinfection units.

In all trials, samples were collected of the unfiltered solutions (the "positive control") and from the filtrate (filtered solutions) from each of the test units in each assessment. These samples were then analysed in the laboratory to determine the presence or otherwise of the test organisms. The specific methodologies followed are described for each assessment.

In the course of the trials, four different fine pore filter systems were used – A, B, C and D. Numbers beside the type identifier indicate that there is more than one of the same type of this filter unit is used in the trials. In all, eight separate ultrafilter units were used during the trials. More detail about these filter units is included in the Evaluation and Discussion section of this report.

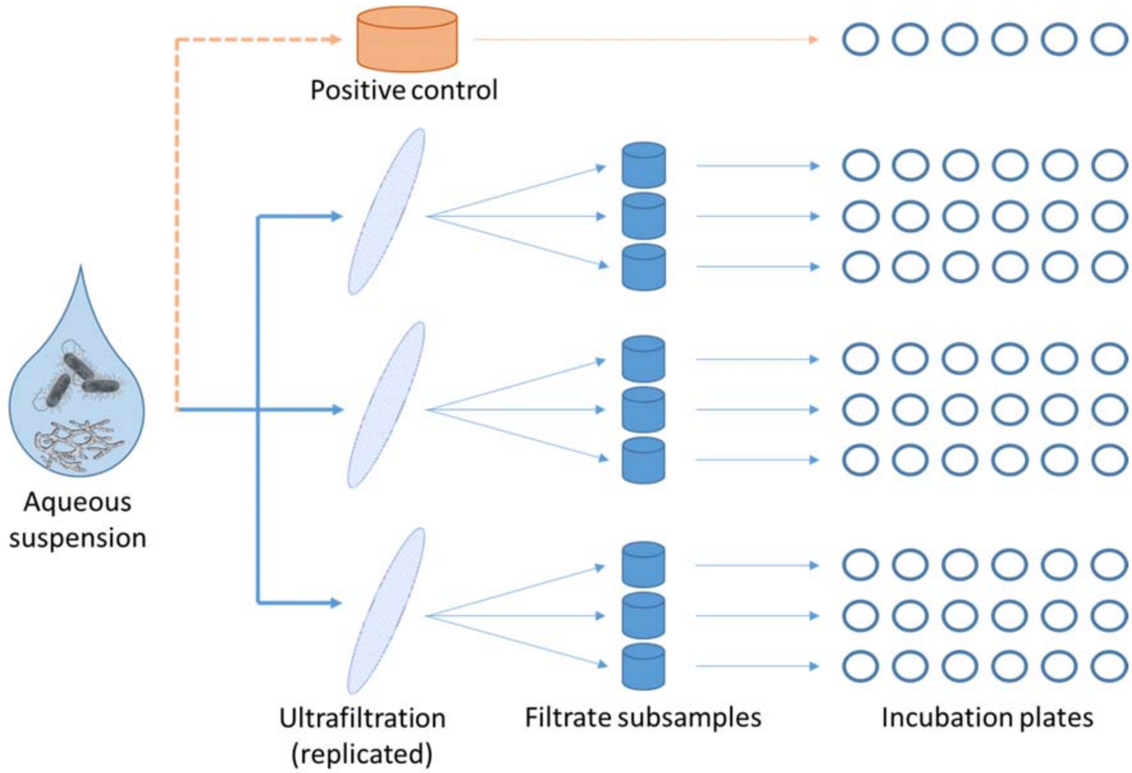


Figure 2: Illustration of the basic replicated research process used in ultrafiltration efficacy trials

Ultrafilter Assessment – *Fusarium oxysporum*

Method:

An aqueous solution containing macroconidia and microconidia of the fungal pathogen *Fusarium oxysporum* was made up from agar cultures. The colonized agar in petri plates was blended in sterile water and filtered through two layers of cheesecloth to remove hyphal fragments. Fungal conidial concentration was estimated using a haemocytometer under a light microscope. The inoculum solution was made up to one litre with a conidial count of 4.8 x 10^8. This inoculum was then poured into a drum and made up to 200L giving a final concentration of 2,400 conidia/mL. The solution was agitated to thoroughly mix and suspend the fungal spores and an aliquot (1L) was taken for a positive control check. The solution in the drum was then pumped through the ultrafilter unit (Type A) and five 20L samples of the filtrate captured in buckets which were lidded and taken back to the laboratory.

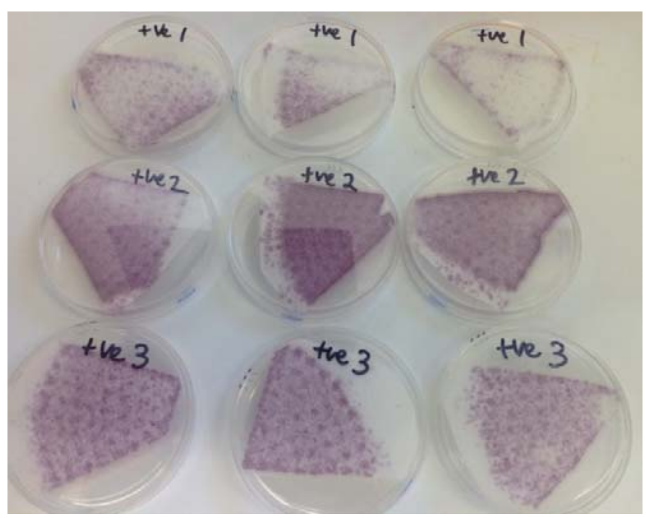


Figure 3: Positive control (unfiltered) samples showing typical purple growth of F. oxysporum.

Each of the ultrafilter filtrate samples was passed through a Whatman No42 filter paper in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. When the filtering was ceased, the filter papers were aseptically cut into pieces and placed on ¼-strength potato dextrose agar media (¼PDA) which were then placed in an incubator at 25°C. The same filtering process was also applied to the 1L positive control solution. A sample from the Whatman filtrate was also collected, centrifuged at 5,000 rpm for 5 minutes, re-suspended in 1 mL and spread plated to ¼PDA as a check that all conidia had been captured. After 24h the filter paper was removed and plates allowed to incubate for a further 3 days. They were checked regularly for growth.

Results:

No *Fusarium oxysporum* colonies were detected on the agar media suggesting that the ultrafilter units successfully removed the fungal conidia from the test solution. The positive control plates (figure 3) were covered in purple fungal *F. oxysporum* colonies confirming that the inoculum was both present and viable prior to the filtration process.

Ultrafilter Assessment – *Fusarium oxysporum* (reduced concentration)

Method:

An aqueous solution containing macroconidia and microconidia of the fungal pathogen *Fusarium oxysporum* was made up from agar cultures. The colonized agar in petri plates was blended in sterile water and filtered through two layers of cheesecloth to remove hyphal fragments. Fungal conidial concentration was estimated using a haemocytometer under a light microscope. The inoculum solution was made up to one litre and then this inoculum was poured into a drum and made up to 200L giving a final concentration of 100 conidia/mL. The solution was agitated to thoroughly mix and suspend the fungal spores and an aliquot (1L) was taken for a positive control check. The solution in the drum was then pumped through the ultrafilter unit (Type A) and five 20L samples of the filtrate captured in buckets which were lidded and taken back to the laboratory.

Each of the ultrafilter filtrate samples was passed through a 0.2µm Millipore filter paper in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. When the filtering was ceased, the filter papers were aseptically cut into pieces and placed on ¼-strength potato dextrose agar media (¼PDA) which were then placed in an incubator at 25°C. The same filtering process was also applied to the 1L positive control solution. A sample from the 0.2µm Millipore filtrate was also collected, centrifuged at 5,000 rpm for 5 minutes, re-suspended in 1 mL and spread plated to ¼PDA as a check that all conidia had been captured. After 24h the filter paper was removed and plates allowed to incubate for a further 3 days. They were checked regularly for growth.

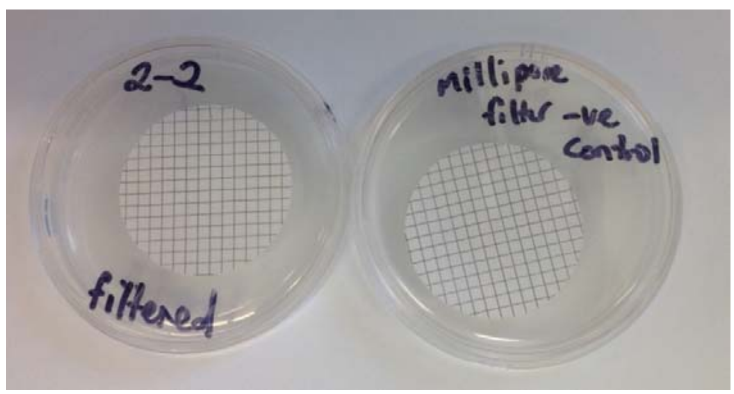


Figure 4: Millipore filters with ultrafilter treated F. oxysporum suspension (left) showing no fungal growth

Results:

No *Fusarium oxysporum* was detected on filters (figure 4) suggesting that the ultrafilter units successfully removed fungal conidia from the inoculum solutions.

Ultrafilter Assessment – *Fusarium oxysporum*

Method:

An aqueous solution containing macroconidia and microconidia of the fungal pathogen *Fusarium oxysporum* was made up from agar cultures. The colonized agar in petri plates was blended in sterile water and filtered through two layers of cheesecloth to remove hyphal fragments. Fungal conidial concentration was estimated using a haemocytometer under a light microscope. The inoculum solution was made up to one litre and then this inoculum was poured into a drum and made up to 200L giving a final concentration of 100 conidia/mL.

The solution was agitated to thoroughly mix and suspend the fungal spores and an aliquot (1L) was taken for a positive control check. The solution in the drum was then pumped through the ultrafilter unit (Type A) and five 20L samples of the filtrate captured in buckets which were lidded and taken back to the laboratory.

Each of the ultrafilter filtrate samples was passed through a Whatman No42 filter paper in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. When the filtering was ceased, the filter papers were aseptically cut into pieces and placed on ¼-strength potato dextrose agar media (¼PDA) which were then placed in an incubator at 25°C. The same filtering process was also applied to the 1L positive control solution. A sample from the Whatman filtrate was also collected, centrifuged at 5,000 rpm for 5 minutes, re-suspended in 1 mL and spread plated to ¼PDA as a check that all conidia had been captured. After 24h the filter paper was removed and plates allowed to incubate for a further 3 days. They were checked regularly for growth.

Results:

No *Fusarium oxysporum* was detected on filters (figure 5, left and centre) suggesting that the ultrafilter units successfully removed fungal conidia from the inoculum solutions. Some isolated contaminants (not *F. oxysporum*) were found on filtrate sample plates. These are expected to be have been airborne microorganisms. Sanitation and aseptic processes were reviewed for subsequent trials.

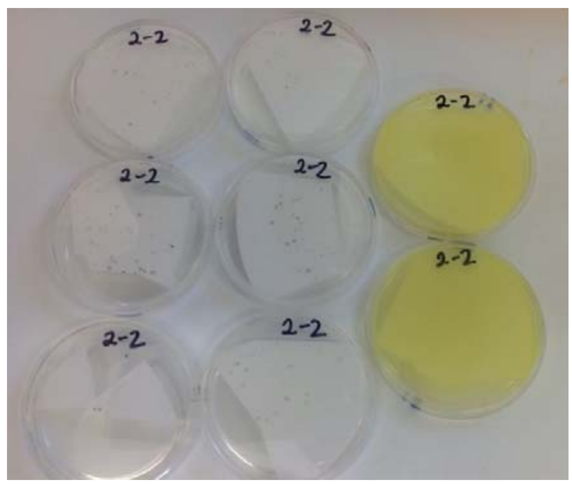


Figure 5: Whatman #42 filter papers showing some isolated contaminants but no Fusarium (left and centre) and bacterial growth (right).

Ultrafilter Assessment – *Pseudomonas syringae*

Method:

An aqueous suspension of *Pseudomonas syringae* was made up from agar cultures and passed through the ultrafilter unit (Type A) and 5 x 20L samples of the filtrate was captured in buckets which were lidded and taken back to the laboratory.

Each of the ultrafilter filtrate samples was passed through a Whatman No42 filter paper in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. When the filtering was ceased, the filter papers were aseptically removed and placed into sterile petri plates.

Results:

Bacteria were consistently recovered (figure 5, right) from all the water samples suggesting that the ultrafiltration units did not achieve the desired level of filtration and did not perform to their 0.04µm specifications.

Ultrafilter Assessment – *Pythium* spp

Method:

An aqueous solution containing different *Pythium* propagules (oospores, hyphal fragments; hyphal swellings, sporangia, motile zoospores & encysted zoospores) was made up from agar cultures of the following species: *P. irregulare*; *P. spinosum*; and *P. dissotochum*. The colonized agar in petri plates was blended in sterile water and filtered through two layers of cheesecloth to remove larger hyphal fragments. Fungal propagule concentration was estimated using a haemocytometer under a light microscope. The inoculum solution was made up to one litre with a propagule count of 2×10^7. This inoculum was then poured into a drum and made up to 200L giving a final concentration of 100 cfu/mL. The solution was agitated to thoroughly mix and suspend the fungal spores and an aliquot (1L) was taken for a positive control check. The solution in the drum was then pumped through a single ultrafilter unit (Type A) and three 20L samples of the filtrate captured in buckets which were lidded and taken back to the laboratory.

Each of the ultrafilter filtrate samples was passed through a Whatman No42 filter paper in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. When the filtering was ceased, the filter papers were aseptically cut into pieces and placed on semi-selective agar medium plates (potato carrot agar media amended with rifampicin and pimaricin [=*PAR* medium]) which were then placed in an incubator at 25°C. After 24h the filter papers were removed and plates allowed to incubate for a further 3 days. The same filtering process was also applied to 600mL of the positive control solution. The remaining 400mL was divided evenly between 3 beakers and *PAR* agar blocks (5 x 1.2cm squares) were placed into each, covered with foil and left at room temperature overnight. The following morning they were removed, plated onto *PAR* media and incubated at 25°C. They were checked regularly for growth.

Results:

No typical *Pythium* spp. colonies were detected on the agar plates suggesting that the ultrafilter unit successfully removed the fungal propagules from the test solution. The positive control plates were covered in white *Pythium* colonies confirming that the inoculum was both present and viable prior to the filtration process. Similarly the media baits plates returned positive results for *Pythium*. Plates were checked by light microscopy and confirmed to be typical morphology of *Pythium* species.

Ultrafilter Assessment – *Pythium dissotochum*

Method:

An aqueous solution containing *Pythium dissotochum* propagules (oospores, hyphal fragments; hyphal swellings, sporangia, motile zoospores & encysted zoospores) was made up from agar cultures. The colonized agar in petri plates was blended in sterile water and filtered through two layers of cheesecloth to remove larger hyphal fragments. Fungal propagule concentration was estimated using a haemocytometer under a light microscope. The inoculum solution was made up to one litre with a propagule count of 2×10^7. This inoculum was then poured into a drum and made up to 200L giving a final concentration of 100 cfu/mL. The solution was agitated to thoroughly mix and suspend the fungal spores and an aliquot (1L) was taken for a positive control check. The solution in the drum was then pumped through each of three ultrafilter units and three 20L samples of the filtrate captured in buckets which were lidded and taken back to the laboratory.

Each of the ultrafilter filtrate samples was passed through a Whatman No42 filter paper in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. When the filtering was ceased, the filter papers were aseptically cut into pieces and placed on semi-selective agar medium plates (potato carrot agar media amended with rifampicin and pimaricin [=*PAR* medium]) which were then placed in an incubator at 25°C. After 24h the filter papers were removed and plates allowed to incubate for a further 3 days. The same filtering process was also applied to 600mL of the positive control solution. The remaining 400mL was divided evenly between 3 beakers and *PAR* agar blocks (5 x 1.2cm squares) were placed into each, covered with foil and left at room temperature overnight. The following morning they were removed, plated onto *PAR* media and incubated at 25°C. They were checked regularly for growth.

Results:

No *Pythium* was detected on filters suggesting that the 3 ultrafilter units successfully removed fungal propagules from the inoculum solutions.

Ultrafilter Assessment – *Pythium* spp

Method:

A water sample (>100L) was collected from a sump tank on a cucumber greenhouse enterprise to test the removal of *Pythium* spp. The solution was agitated thoroughly and an aliquot (1L) was taken for the positive control checks. The solution in the drum was then pumped through a single ultrafilter unit (type A) and three 20L samples of the filtrate captured in buckets which were lidded and taken back to the laboratory.

Each of the ultrafilter filtrate samples was passed through a Whatman No42 filter paper in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. When the filtering was ceased, the filter papers were aseptically cut into pieces and placed on semi-selective agar medium plates (potato carrot agar media amended with rifampicin and pimaricin [*PAR* medium]) which were then placed in an incubator at 25°C. After 24h the filter papers were removed and plates allowed to incubate for a further 3 days. The same filtering process was also applied to 600mL of the positive control solution. The remaining 400mL was divided evenly between 3 beakers and *PAR* agar blocks (5 x 1.2cm squares) were placed into each, covered with foil and left at room temperature overnight. The following morning they were removed, plated onto *PAR* media and incubated at 25°C. They were checked regularly for growth.

Results:

The pre-filtered water samples (positive controls) were positive for the target pathogen. *Pythium* spp was eliminated from the three filtered water subsamples.

Ultrafilter Assessment – *Clavibacter michiganensis* spp *michiganensis*

Method:

An aqueous solution containing *Clavibacter michiganensis* spp*. michiganensis* (*Cmm*) was made up from agar cultures. The *Cmm* culture was grown on KB medium for 7 days at 25°C. Just prior to the filter tests plates were irrigated each with 10mL of sterile water and a glass rod used to make a bacterial suspension, that were then decanted into 1L flasks. It was estimated that each flask contained 10^7 *Cmm*/mL. Each of the 3 x 200L source tank was then inoculated with 1L of the *Cmm* suspension (final concentration of *Cmm* was 5,000/mL) and the ultrafilter units switched on in succession to collect the 3 x 20L sub-samples from each unit.

Each of the ultrafilter filtrate samples was passed through a 0.2µ Millipore filter in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. After water had passed through the Millipore filters, the disks were aseptically removed, placed onto KB media containing 100ppm cyclohexamide and 30ppm rifampicin and incubated at 25°C overnight. The following day disks were removed and placed into sterile petri plates, irrigated with 10mL sterile water and immuno-test

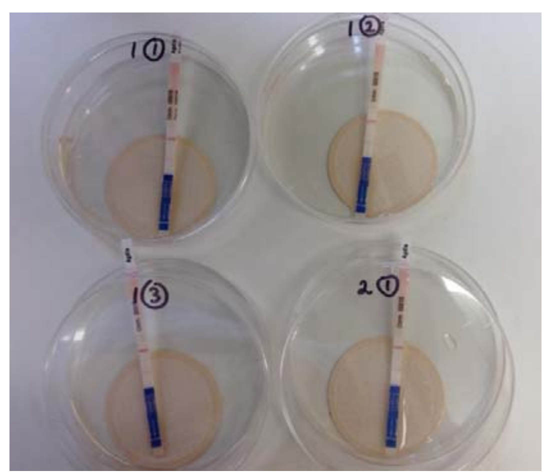


Figure 6: Millipore filters with positive immuno-test strips (2 red bands) indicating that Cmm was present in filtered water.

strips (Agdia Inc, USA) used to determine if detectable *Cmm* was present. KB plates were incubated for a further 2-3 days, irrigated and tested as above.

Results:

Clavibacter michiganensis spp*. michiganensis* (*Cmm*) was detected (figure 6) on Millipore filters from 3 water sub-samples of each of the 3 ultrafilter units suggesting that the units did not achieve the desired level of filtration and did not perform to their 0.04 µ specifications.

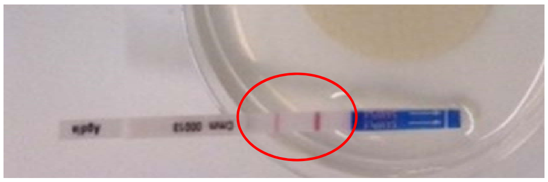


Figure 7: Immuno-test strip showing a positive result for Cmm indicated by 2 red bands (circled). A negative result has only 1 red band.

Ultrafilter Assessment – *Pythium and Fusarium* spp

Method:

A water sample (>100L) was collected from a sump tank on a tomato and cucumber greenhouse enterprise to test the removal of two target pathogens, *Pythium* and *Fusarium* spp. The solution was agitated to thoroughly and an aliquot (1L) was taken for a positive control check. The solution in the drum was then pumped through a single ultrafilter unit (Type A) and three 20L samples of the filtrate captured in buckets which were lidded and taken back to the laboratory.

Each of the ultrafilter filtrate samples was passed through a Whatman No42 filter paper in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. When the filtering was ceased, the filter papers were aseptically cut into pieces and placed on semi-selective agar medium plates (potato carrot agar media amended with rifampicin and pimaricin [*PAR* medium]) which were then placed in an incubator at 25^{o}C. After 24h the filter papers were removed and plates allowed to incubate for a further 3 days. The same filtering process was also applied to 600mL of the positive control solution. The remaining 400mL was divided evenly between 3 beakers and *PAR* agar blocks (5 x 1.2cm squares) were placed into each, covered with foil and left at room temperature overnight. The following morning they were removed, plated onto *PAR* media and incubated at 25^{o}C. They were checked regularly for growth.

Results:

The pre-filtered water samples were positive for both pathogens. Again *Pythium* spp. were eliminated from the three filtered water subsamples. Isolated colonies (1 – 2) of *Fusarium oxysporum* were recovered from each of the subsamples. The very small numbers suggests contamination rather than a filter breach.

Ultrafilter Assessment – *Clavibacter michiganensis* spp *michiganensis*

Method:

An aqueous solution containing *Clavibacter michiganensis* spp*. michiganensis* (*Cmm*) was made up from agar cultures. The *Cmm* culture was grown on KB medium for 7 days at 25^{o}C. Just prior to the filter tests plates were irrigated each with 10mL of sterile water and a glass rod used to make a bacterial suspension, that were then decanted into 1L flasks. It was estimated that each flask contained 10^7 *Cmm*/mL. Each of the 3 x 200L source tank was then inoculated with 1L of the *Cmm* suspension (final concentration of *Cmm* was 5,000/mL) and the ultrafilter units (Type A) switched on in succession to collect the 3 x 20L sub-samples from each unit.

Each of the ultrafilter filtrate samples was passed through a 0.2µ Millipore filter in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. After water had passed through the Millipore filters, the disks were aseptically removed, placed onto KB media containing 100ppm cyclohexamide and 30ppm rifampicin and incubated at 25°C overnight. The following day disks were removed and placed into sterile petri plates, irrigated with 10mL sterile water and immuno-test strips (Agdia Inc, USA) used to determine if detectable *Cmm* was present. KB plates were incubated for a further 2-3 days, irrigated and tested as above.

Figure 8: Millipore filter set-up for detecting bacterial cells.

Results:

Clavibacter michiganensis spp. *michiganensis* (*Cmm*) was detected on Millipore filters from 3 water sub-samples of each of the 3 ultrafilter units suggesting that the units did not achieve the desired level of filtration and did not perform to their 0.04 µ specifications.

Ultrafilter Assessment – *Clavibacter michiganensis* spp *michiganensis*

Method:

An aqueous solution containing *Clavibacter michiganensis* spp. *michiganensis* (*Cmm*) was made up from agar cultures. The *Cmm* culture was grown on KB medium for 7 days at 25°C. Just prior to the filter tests plates were irrigated each with 10mL of sterile water and a glass rod used to make a bacterial suspension, that were then decanted into 1L flasks. It was estimated that each flask contained 10^7 *Cmm*/mL. A 200L source tank was then inoculated with 1L of the *Cmm* suspension (final concentration of *Cmm* was 5,000/mL) and different ultrafilter unit (Type B) was switched on and the 3 x 20L filtrate sub-samples were collected.

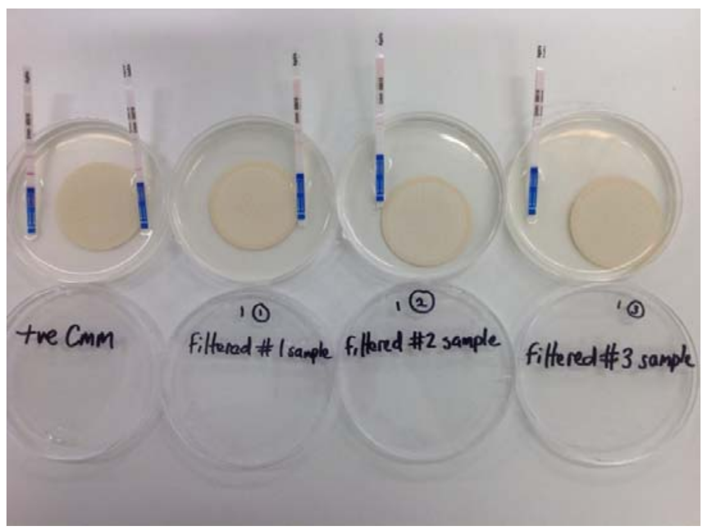


Figure 9: Millipore filter disks with negative immuno-test strips (1 red band) indicating Cmm was not present in the filtered water. Positive control sample (2 red bands) shown on left.

Each of the ultrafilter filtrate samples was passed through a 0.2µ Millipore filter in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. After water had passed through the Millipore filters, the disks were aseptically removed, placed onto KB media containing 100ppm cyclohexamide and 30ppm rifampicin and incubated at 25°C overnight. The following day disks were removed and placed into sterile petri plates, irrigated with 10mL sterile water and immuno-test strips (Agdia Inc, USA) used to determine if detectable *Cmm* was present. KB plates were incubated for a further 2-3 days, irrigated and tested as above.

Results:

No *Clavibacter michiganensis* spp. *michiganensis* (*Cmm*) was detected from the 3 water sub-samples on Millipore filters (figure 9) suggesting that the ultrafilter successfully removed detectable bacteria from the water.

Ultrafilter Assessment – *Clavibacter michiganensis* spp *michiganensis*

Method:

An aqueous solution containing *Clavibacter michiganensis* spp*. michiganensis* (*Cmm*) was made up from agar cultures. The *Cmm* culture was grown on KB medium for 7 days at 25°C. Just prior to the filter tests plates were irrigated each with 10mL of sterile water and a glass rod used to make a bacterial suspension, that were then decanted into 1L flasks. It was estimated that each flask contained 10^7 *Cmm*/mL. A 200L source tank was then inoculated with 1L of the *Cmm* suspension (final concentration of *Cmm* was 5,000/mL) and different ultrafilter unit (Type B) was switched on and the 3 x 20L filtrate sub-samples were collected.

Each of the ultrafilter filtrate samples was passed through a 0.2µ Millipore filter in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. After water had passed through the Millipore filters, the disks were aseptically removed, placed onto KB media containing 100ppm cyclohexamide and 30ppm rifampicin and incubated at 25°C overnight. The following day disks were removed and placed into sterile petri plates, irrigated with 10mL sterile water and immuno-test strips (Agdia Inc, USA) used to determine if detectable *Cmm* was present. KB plates were incubated for a further 2-3 days, irrigated and tested as above.

Results:

Clavibacter michiganensis spp*. michiganensis* (*Cmm*) was detected from the 3 water sub-samples on Millipore filters suggesting that the unit did not achieve the desired level of filtration and did not perform to its 0.04 µ specifications.

Ultrafilter Assessment – *Clavibacter michiganensis* spp *michiganensis*

Method:

An aqueous solution containing *Clavibacter michiganensis* spp*. michiganensis* (*Cmm*) was made up from agar cultures. The *Cmm* culture was grown on KB medium for 7 days at 25°C. Just prior to the filter tests plates were irrigated each with 10mL of sterile water and a glass rod used to make a bacterial suspension, that were then decanted into 1L flasks. It was estimated that each flask contained 10^7 *Cmm*/mL. A 200L source tank was then inoculated with 1L of the *Cmm* suspension (final concentration of *Cmm* was 5,000/mL) and the ultrafilter unit (Unit B) was switched on and 3 x 20L filtrate sub-samples were collected.

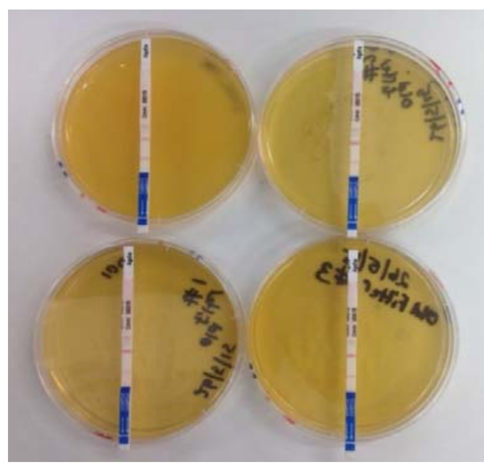


Figure 10: Bacterial suspensions from KB plates and immuno-test strips showing positive result for Cmm (2 red bands) indicating bacteria present in filtered water.

Each of the ultrafilter filtrate samples was passed through a 0.2µ Millipore filter in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. After water had passed through the Millipore filters, the disks were aseptically removed, placed onto KB media containing 100ppm cyclohexamide and 30ppm rifampicin and incubated at 25°C overnight. The following day disks were removed and placed into sterile petri plates, irrigated with 10mL sterile water and immuno-test strips (Agdia Inc, USA) used to determine if detectable *Cmm* was present. KB plates were incubated for a further 2-3 days, irrigated and tested as above.

Results:

Clavibacter michiganensis spp*. michiganensis* (*Cmm*) was detected from the 3 water sub-samples on Millipore filters suggesting that the unit did not achieve the desired level of filtration and did not perform to its 0.04 µ specifications (figure 10).

Ultrafilter Assessment – *Clavibacter michiganensis* spp *michiganensis*

Method:

An aqueous solution containing *Clavibacter michiganensis* spp. *michiganensis* (*Cmm*) was made up from agar cultures. The *Cmm* culture was grown on KB medium for 7 days at 25^{o}C. Just prior to the filter tests plates were irrigated each with 10mL of sterile water and a glass rod used to make a bacterial suspension, that were then decanted into 1L flasks. It was estimated that each flask contained 10^7 *Cmm*/mL. A 20L source tank was then inoculated with 1L of the *Cmm* suspension (final concentration of *Cmm* was 5,000/mL) and the ultrafilter units (Type C) were used and 3 x 1L filtrate sub-samples collected. The reduced volumes of water filtered and sampled were used because these ultrafilters were prototypes and approximately 1/10th the size and were run at only half the pressure of the other ultrafilters used (Types A and B). Subsequently, the flow rate of Type C was estimated to be 200ml/minute compared with 1.7L/minute of the other types.

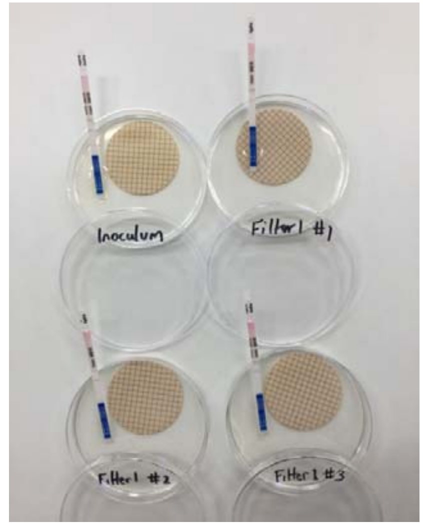


Figure 11: Millipore filter disks with negative immuno-test strips (1 red band) indicating that Cmm was not present in the filtered water. The positive control (top left) shows 2 red bands indicating presence of Cmm.

Each of the ultrafilter filtrate samples was passed through a 0.2µ Millipore filter in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. After water had passed through the Millipore filters, the disks were aseptically removed, placed onto KB media containing 100ppm cyclohexamide and 30ppm rifampicin and incubated at 25^{o}C overnight. The following day disks were removed and placed into sterile petri plates, irrigated with 10mL sterile water and immuno-test strips (Agdia Inc, USA) used to determine if detectable *Cmm* was present. KB plates were incubated for a further 2-3 days, irrigated and tested as above.

Results:

Clavibacter michiganensis spp. *michiganensis* (*Cmm*) was not detected from the 3 water sub-samples on Millipore filters from either unit suggesting that they achieved the desired level of filtration (figure 11).

Ultrafilter Assessment – *Clavibacter michiganensis* spp *michiganensis*

Method:

An aqueous solution containing *Clavibacter michiganensis* spp. *michiganensis* (*Cmm*) was made up from agar cultures. The *Cmm* culture was grown on KB medium for 7 days at 25^{o}C. Just prior to the filter tests plates were irrigated each with 10mL of sterile water and a glass rod used to make a bacterial suspension, that were then decanted into 1L flasks. It was estimated that each flask contained 10^7 *Cmm*/mL. A 20L source tank was then inoculated with 1L of the *Cmm* suspension (final concentration of *Cmm* was 5,000/mL) and two ultrafilter units (Type C) were used and 3 x 1L filtrate sub-samples collected from each. Each of the ultrafilter filtrate samples was passed through a 0.2µ Millipore filter in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. After water had passed through the Millipore filters, the disks were aseptically removed, placed onto KB media containing 100ppm cyclohexamide and 30ppm rifampicin and incubated at 25^{o}C overnight. The following day disks were removed and placed into sterile petri plates, irrigated with 10mL sterile water and immuno-test strips (Agdia Inc, USA) used to determine if detectable *Cmm* was present. KB plates were incubated for a further 2-3 days, irrigated and tested as above.

Results:

Clavibacter michiganensis spp. *michiganensis* (*Cmm*) was detected from the one sample from the first filter unit (Unit C1) and the from two samples from the second filter (Unit C2) on Millipore filters. The low intensity of the positive reaction on the *Cmm* test strip when applied directly to the Millipore filter (figure 12, left) suggests that the bacterial concentration was low compared with the unfiltered sample. However, after incubation and cultural enrichment on the agar medium, the positive reactions were much stronger confirming the results.

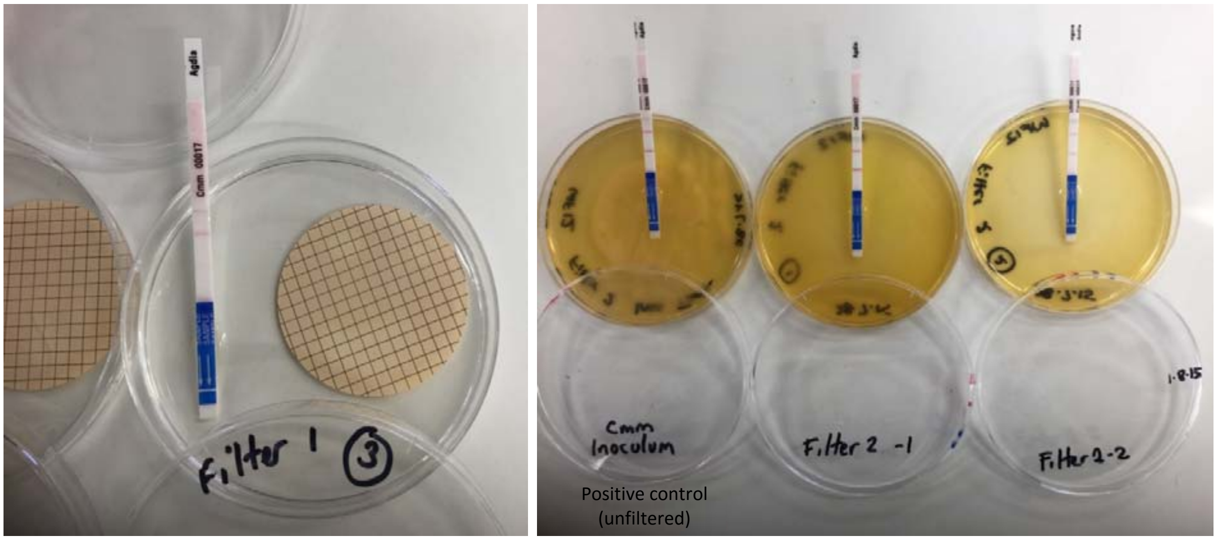


Figure 12: Millipore filter disks showing positive immuno-test strips indicating Cmm is present in filtered water. The positive reaction is weak when tested directly (left image). Reaction is more intense after incubation (right image)

Ultrafilter Assessment – *Clavibacter michiganensis* spp *michiganensis*

Method:

An aqueous solution containing *Clavibacter michiganensis* spp*. michiganensis* (*Cmm*) was made up from agar cultures. The *Cmm* culture was grown on KB medium for 7 days at 25°C. Just prior to the filter tests plates were irrigated each with 10mL of sterile water and a glass rod used to make a bacterial suspension, that were then decanted into 1L flasks. It was estimated that each flask contained 10^7 *Cmm*/mL. A 20L source tank was then inoculated with 1L of the *Cmm* suspension (final concentration of *Cmm* was 5,000/mL) and two ultrafilter units (Type C) were used and 3 x 1L filtrate sub-samples collected from each. Each of the ultrafilter filtrate samples was passed through a 0.2µ Millipore filter in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. After water had passed through the Millipore filters, the disks were aseptically removed, placed onto KB media containing 100ppm cyclohexamide and 30ppm rifampicin and incubated at 25°C overnight. The following day disks were removed and placed into sterile petri plates, irrigated with 10mL sterile water and immuno-test strips (Agdia Inc, USA) used to determine if detectable *Cmm* was present. KB plates were incubated for a further 2 – 3 days, irrigated and tested as above.

Results:

Clavibacter michiganensis spp*. michiganensis* (*Cmm*) was detected from all three sub-samples from both filter units. Again the *Cmm* test strips developed lower intensity positive bands (figure 13) compared with the unfiltered water positive reactions. This suggests that the filteres are retaining a significant proportion of the bacteria, but not all.

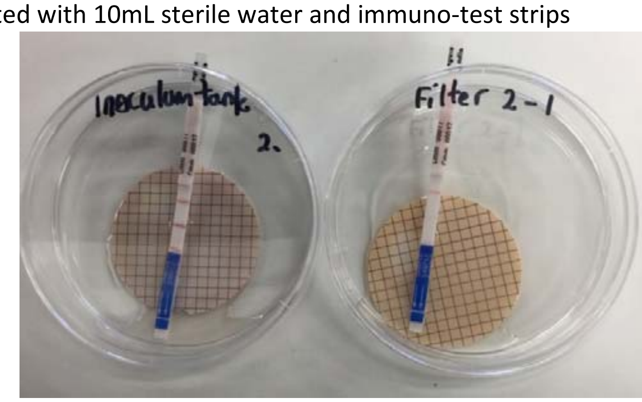


Figure 13: Millipore filter disks indicating present of Cmm. The filtered water (right) has a much weaker positive result compared with the control (left).

Ultrafilter Assessment – *Clavibacter michiganensis* spp *michiganensis*

Method:

An aqueous solution containing *Clavibacter michiganensis* spp. *michiganensis* (*Cmm*) was made up from agar cultures. The *Cmm* culture was grown on KB medium for 7 days at 25°C. Just prior to the filter tests plates were irrigated each with 10mL of sterile water and a glass rod used to make a bacterial suspension, that were then decanted into 1L flasks. It was estimated that each flask contained 10^7 *Cmm*/mL. A 20L source tank was then inoculated with 1L of the *Cmm* suspension (final concentration of *Cmm* was 5,000/mL) and two ultrafilter units (Type D) were used and 3 x 1L filtrate sub-samples collected from each. Each of the ultrafilter filtrate samples was passed through a 0.2µ Millipore filter in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. After water had passed through the Millipore filters, the disks were aseptically removed, placed onto KB media containing 100ppm cyclohexamide and 30ppm rifampicin and incubated at 25°C overnight. The following day disks were removed and placed into sterile petri plates, irrigated with 10mL sterile water and immuno-test strips (Agdia Inc, USA) used to determine if detectable *Cmm* was present. KB plates were incubated for a further 2 – 3 days, irrigated and tested as above.

Results:

Clavibacter michiganensis spp. *michiganensis* (*Cmm*) was detected from all three sub-samples from both filter units. Again the *Cmm* test strips developed lower intensity positive bands compared with the unfiltered water positive reactions.

Ultrafilter Assessment – *Clavibacter michiganensis* spp *michiganensis*

Method:

An aqueous solution containing *Clavibacter michiganensis* spp. *michiganensis* (*Cmm*) was made up from agar cultures. The *Cmm* culture was grown on KB medium for 7 days at 25°C. Just prior to the filter tests plates were irrigated each with 10mL of sterile water and a glass rod used to make a bacterial suspension, that were then decanted into 1L flasks. It was estimated that each flask contained 10^7 *Cmm*/mL. A 20L source tank was then inoculated with 1L of the *Cmm* suspension (final concentration of *Cmm* was 5,000/mL) and two ultrafilter units (type D) were used and 3 x 1L filtrate sub-samples collected from each. Each of the ultrafilter filtrate samples was passed through a 0.2µ Millipore filter in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. After water had passed through the Millipore filters, the disks were aseptically removed, placed onto KB media containing 100ppm cyclohexamide and 30ppm rifampicin and incubated at 25°C overnight. The following day, disks were removed and placed into sterile petri plates, irrigated with 10mL sterile water and immuno-test strips (Agdia Inc, USA) used to determine if detectable *Cmm* was present. KB plates were incubated for a further 2 – 3 days, irrigated and tested as above.

Results:

Clavibacter michiganensis spp. *michiganensis* (*Cmm*) was detected from all three sub-samples from the filter unit suggesting that the unit failed to eliminate this bacterium.

Ultrafilter Assessment – *Fusarium spp*

Method:

A water sample (>100L) was collected from a sump tank on a tomato and cucumber greenhouse enterprise to test the removal of *Fusarium* spp. The solution was agitated thoroughly and a 1 litre aliquot was taken for the positive control checks. The solution in the drum was then pumped through a single ultrafilter unit (Type A) and three 20L samples of the filtrate captured in buckets which were lidded and taken back to the laboratory.

Each of the ultrafilter filtrate samples was passed through a Whatman No42 filter paper in a Büchner funnel (diameter 15cm) that sat upon an Erlenmeyer flask with a vacuum attachment. When the filtering was ceased, the filter papers were aseptically cut into pieces and placed on semi-selective agar medium plates (potato carrot agar media amended with rifampicin and pimaricin [*PAR* medium]) which were then placed in an incubator at 25°C. After 24h the filter papers were removed and plates allowed to incubate for a further 3 days. The same filtering process was also applied to 600mL of the positive control solution. The remaining 400mL was divided evenly between 3 beakers and *PAR* agar blocks (5 x 1.2cm squares) were placed into each, covered with foil and left at room temperature overnight. The following morning they were removed, plated onto *PAR* media and incubated at 25°C. They were checked regularly for growth.

Results:

The pre-filtered water samples (positive controls) were positive for the target pathogen. *Fusarium* spp was eliminated from the one filtered water subsamples.

Figure 14: Technician pouring filtered water into Büchner funnel with Whatman No 42 filter paper used for fungal and oomycete detection.

Sensitivity validation

Additional research trials were conducted to determine the sensitivity (dilution end-point detection limits) of laboratory assays for *Fusarium oxysporum f.sp. cucumerinum*, *Pythium aphanidermatum* and *Clavibacter michiganensis* ssp. *michiganensis (Cmm)*.

1. *Fusarium oxysporum* dilution end-point

Method:

Cultures of *Fusarium oxysporum* were grown on ¼ PDA for 7 – 10 days under light to allow conidia formation. The conidia were then harvested by flooding the plate, scratching the surface with a sterile glass rod and filtering the conidia through sterile muslin cloth to remove mycelium debris. The conidial concentrations (cells/mL) were quantified using a haemocytometer.

The conidial concentration was then adjusted to make up 1L of deionised water with a conidial concentration of 10^7 conidia/L. Serial dilutions (1:10) were then set up using 1L bottles. This was achieved by adding 100mL spore suspensions to 900mL deionised water, mixing and drawing a 100mL aliquot and continuing dilutions. Dilutions were made from 10^7 conidia/L to a dilution end-point.

Using aseptic technique, each of the 1L conidia suspensions was passed through a Whatman No 42 (2.5 µm pore size). The filter paper was then cut into segments and plated out onto ¼ PDA amended with 100 ppm novobiocin. The plates were incubated for 3 days under lights before enumerating colonies.

Results:

The dilution end-point was not reached when the spore concentration was as little as one in 10 litres of water (table A, Rep 1). Taking the two replicates together it could be concluded that the detection limit for this fungus is at or below one spore per litre.

Table A: Detected colony forming units (CFU) on agar media from serial dilutions of Fusarium oxysporum conidia

Estimated *Fusarium oxysporum* conidia/L	CFU detected (Rep 1)	CFU detected (Rep 2)
10^7	>300	>300
10^6	>300	>300
10^5	>300	>300
10^4	>300	>300
10^3	112	>300
10^2	36	109
10	3	18
1	23	9
0.1	2	0

2. *Pythium aphanidermatum* dilution end-point

Method:

Subcultures of *Pythium* isolate were plated onto 10% V8 agar. These were then incubated at 25°C in the dark for 3 to 5 days. Agar plugs (3 x 3 mm) were then taken from the actively growing region, or edge, of the V8 culture and placed onto a prepared miracloth disc on fresh 10% V8 agar.

These were then Incubated in the dark at 25°C for a further 5 to 14 days, or until the miracloth disc was covered with mycelium, at which time, the miracloth was transferred to a sterile 250mL Erlenmyer flask containing 100 mL of 5% clarified V8 juice broth and incubated overnight on an orbital shaker (90 rpm) at 24°C under light.

Decanted The 5% V8 broth was decanted, leaving the miracloth in the flask. The miracloth disc was then rinsed four times at 15 minute intervals with 100 mL mineral salt solution (MSS) and incubated again in 100 mL of mineral salts solution overnight at 24°C in the orbital shaker (90 rpm) under light.

The miracloth was then transferred to a sterile Petri dish and sterile distilled water added to only just cover the miracloth. This was then incubated for 5 minutes at 4°C and then left on the bench to allow release of zoospores. The zoospore concentration (cells/mL) was quantified using a haemocytometer.

The zoospore concentration was then adjusted to make up 1L deionised water with an initial zoospore concentration of 10^5 zoospores/L.

Serial dilutions (1:10) were then set up using 1L bottles. One in ten dilutions were made by mixing and adding 100mL to 900mL deionised water, mixing and continuing with dilutions to 0 zoospores/L (= possible 1 zoospore/10L).

Using aseptic technique, each of the 1L zoospore suspensions were passed through a Whatman No 42 (2.5 µm pore size). The filter paper was cut into segments and plated out onto Pythium selective media. The plates were incubated for 2 days in the dark before enumerating colonies. Plates that contained too many Colony forming units (CFU) to count were marked as greater than 300 CFU.

Results:

The dilution end-point was not reached even when theoretical zoospore concentrations were as little as one in a litre of water (table B). These results suggest detection would still be possible at an equivalent concentration of one zoospore in 10 litres.

Table B: Detected colony forming units (CFU) on agar media from serial dilutions of zoospores of Pythium aphanidermatum

P. aphanidermatum **zoospores/L**	**CFU detected (Rep 1)**	**CFU detected (Rep 2)**
100 000	>300	>300
10 000	>300	>300
1000	>300	>300
100	186	136
10	24	29
1	15	8

3. *Clavibacter michiganensis* ssp. *michiganensis* dilution end-point

Method:

Clavibacter michiganensis ssp. *michiganensis (Cmm)* was grown on KB agar plates at 25°C for 48 hours. A single colony was then transferred with a loop into 10 mL of liquid Luria-Bertani (LB) medium and shaken at 150 rpm at room temperature for 16 hours.

The bacterial cells were collected by centrifuging 1 mL of culture at 9.727G at 4°C for 5 minutes. The supernatant was removed and the pellet was resuspended in 1 mL of sterile water. The bacterial concentration was estimated by enumerating bacteria using the haemocytometer.

Ten-fold serial suspensions were made up in 1L sterile deionised water (from 10^7 – 0 cells/L).

Spread plates were made to enumerate the concentration of bacteria in the 1L serial dilutions by pipetting 100 µL of each dilution on KB media and spreading the aliquot with sterile glass beads. Plates were incubated for 4 days.

The 1L bacterial suspensions were then filtered through 0.2µm Millipore filters and the Millipore filters were placed onto KB agar and incubated in the dark. Filters were removed after 48 hours and plates were further incubated for 4 days in the dark at room temperature.

The detection of the bacteria from each dilution series was marked as either positive or negative. This observation was made due to the shape of the filter paper that made counting of each CFU inaccurate.

Results:

In all three experiments *Cmm* was detected at below 5 CFU per litre of water (tables C and D). The results of the initial experiment suggest that the limit of detection may be an order of magnitude lower.

Table C: Detected bacterial colony forming units (CFU) on agar media from serial dilutions of Clavibacter michiganensis ssp. michiganensis (Cmm)

***Cmm* cells/L**	**CFU (Rep1)**
10^7	>300
10^6	>300
10^5	>300
10^4	>300
10^3	58
10^2	0
10	22
1	18
0.1	1

Table D: Detected bacterial colonies on agar media from serial dilutions of Clavibacter michiganensis ssp. michiganensis (Cmm)

Estimated cells/L	**Replicate 1**		**Replicate 2**	
	Actual Cells/L	Detection of *Cmm*	Actual Cells/L	Detection of *Cmm*
10^7	37 000 000	+	42 000 000	+
10^6	3 700 000	+	4 200 000	+
10^5	370 000	+	420 000	+
10^4	37 000	+	42 000	+
10^3	3700	+	4200	+
10^2	370	+	420	+
10	37	+	42	+
1	3.7	+	4.2	+
0.1	0	-	0	-

Water nutrient analysis

A secondary challenge for hydroponic managers when recirculating nutrient solutions, is proper maintenance of the nutrient balance. Although this is not a significant hurdle, it can pose difficulties in some production systems and for less experienced growers. Additionally, when run-off water is treated by some disinfection methods, the disinfection process can further impact on the returned nutrient solution.

Many chemical treatments can affect pH and managers using chlorine need to ensure that sodium chloride is replaced with calcium chloride when water is to be recirculated to avoid the accumulation of sodium in the nutrient solution. Ozone will break down chelates and therefore affect the availability of elements like iron and manganese, so these need to be monitored and adjusted. Iron availability can also be affected by ultraviolet radiation. Biological filtration can initially deplete key nutrients. Use of these disinfection options requires routine nutrient chemical analysis and adjustment to ensure elements are not limiting.

A key advantage of ultrafiltration is that this disinfection process does not impact on the nutrient balance of the solution. The only effect is the reduction in turbidity of water as the fine pore filter readily removes organic matter such as root debris and algae as well as suspended solids. Ultrafiltration can vastly enhance the efficacy of other disinfection technologies such as ultraviolet radiation and all oxidising treatments. Table E presents typical nutrient solution analyses showing water before and after treatment with ultrafiltration. Water nutrient analyses were conducted to confirm that the impact of this disinfection technology is benign. The only effect of filtration was the reduced turbidity of the water. There was no change to the nutrient profile.

Water volume assessment

Ultrafiltration units were operated continuously (with automated preset backwashing cycles and manual cleaning) at two farm sites for extended periods drawing and processing water from an unlined dam used to collected greenhouse run-off (Site A) and drawing and processing water from a sump tank within a greenhouse (Site B). These tests were conducted to determine the likely working life of the membranes. Water pressure and flow rates were observed to detect reduced performance which would indicate blockage.

No permanent decline in membrane or filter performance was detected. In the primary economic analyses, it was assumed that membranes would not need to be replaced over the economic assessment period.

Table E: Water nutrient analyses showing typical nutrient solution pre and post treatment with ultrafiltration

Analysis	Method^	Unit	Limit of reporting	Pre-filter	Post-filter
Sample preparation	APHA 3030B				
pH	APHA 4500 H+-B	pH units	0.04	6.4	6.4
Electrical Conductivity	APHA 2510 B	uS/cm	10	2000	2000
Total Alkalinity	APHA 2320 B	mg/L $CaCO_3$	14	45	45
Chloride (potentiometric)	APHA 4.51 4500-D	mg/L	7	40	41
Hardness		mg/L $CaCO_3$	1	600	600
Calcium Carbonate Saturation Index	R&H N1a			-1.3	-1.2
Sodium Adsorption Ratio	R&H M1a			0.40	0.40
Turbidity	APHA 2130	NTU	0.07	3.3	1.8
Dissolved Elements and Metals by ICP-AES	USEPA 6010				
Total Nitrogen		mg/L	0.08	170	170
Total Phosphorous		mg/L	0.03	38	38
Aluminium		mg/L	0.05	<0.05	0.05
Arsenic		mg/L	0.05	<0.05	<0.05
Boron		mg/L	0.04	0.12	0.12
Calcium		mg/L	0.03	170	170
Cadmium		mg/L	0.002	<0.002	0.002
Cobalt		mg/L	0.004	<0.004	<0.004
Chromium		mg/L	0.005	<0.005	<0.005
Copper		mg/L	0.004	0.13	0.12
Iron		mg/L	0.003	1.8	1.8
Potassium		mg/L	0.06	170	160
Magnesium		mg/L	0.006	45	45
Manganese		mg/L	0.001	0.18	0.17
Molybdenum		mg/L	0.003	0.069	0.066
Sodium		mg/L	0.05	23	23
Nickel		mg/L	0.007	<0.007	<0.007
Phosphorous		mg/L	0.03	41	41
Lead		mg/L	0.02	<0.02	<0.02
Sulphur		mg/L	0.06	58	57
Selenium		mg/L	0.04	<0.04	<0.04
Zinc		mg/L	0.008	0.15	0.15

^ R&H ~ Rayment & Higginson (1992); USEPA ~ United States Environmental Protection Agency
Methods 140 &153 are based on APHA 4500-NO_3 I;
Methods 160 & 161 are based on APHA 4500-P G

Economic evaluation

The overall economic feasibility of disinfection technologies is strongly correlated to the volume of water being treated and this is no different with ultrafiltration, though potentially lower upfront costs for smaller treatment capacities does provide an improved scenario for small to medium enterprises. At large scales of operation, the financial viability of water disinfection (with a range of treatment options that are available) and closed hydroponics is clear. The in-field practical performance of a relevant disinfection system remains the key parameter. The economic analyses in this project has been based on the reliability determined by the research trials.

A comprehensive tabulation of a range of economic and enterprise scale scenarios has been prepared to provide a ready reckoner for hydroponic managers in order to quickly assess the potential of ultrafiltration relevant to their circumstances. Obviously, businesses still need to undertake a more detailed assessment specific to their enterprise prior to making an investment, but these scenarios enable a reliable, preliminary budget and evaluation resource. These benefit cost analysis tables are published on the project website and have been included in appendix 1.

Key considerations being used include the size of enterprise and the volume of water to be treated (and recovered), the discount rate of interest that reflects the potential change in the value of money over time as well as the starting cost and potential rate of inflation of primary inputs – electricity, labour, fertilisers, cleaning chemicals and water. Day to day use and 'real world' assessment of commercially available ultrafiltration systems shows that general maintenance and repairs are negligible, though with all technology and utilities a consideration for breakdown and failure is prudent and is included in all the analyses.

Four distinct economic environments (coupled with 3 different interest rates) are also used to provide relevancy of the benefit to cost analyses to variable real-world conditions. Essentially, the net value of an investment can pivot on the potential changes in the value of benefits and/or changes in value of costs. Analyses in this project have considered situations in which both the value of benefits and costs are low, both the value of benefits and costs are high and where one or other of the benefit or costs are high or low respectively.

The full suite of benefit cost analyses are tabulated in the appendix and are available online. The financial viability of closed system hydroponics for the production of cucumber with ultrafiltration disinfection is excellent. Some additional examples to illustrate variations in key parameter are included below.

Interest rates

Three interest rates are used to encompass the potential variability in economic conditions. A low rate of 2.5%, a medium rate of 5.0% and a high rate of 7.5% were selected. The interest rate accounts for the increasing cost of money over time (inflation) and is used to determine the value of the investment in *present* dollars. Effectively this illustrates the total cost of the investment, if it was fully paid, now. Valuing the investment in today's dollars enables fair comparison to be made of the benefits and costs across different investment options.

Benefits and costs

For all the economic assessments, benefits and costs are considered to be either 'high' or 'low', resulting in four potential base economic situations. These are listed in table F. High (or low) conditions reflect both the estimated initial value as well as the forecast rate of inflation. Initial values and forecast inflation rates have been determined from a composite of data (collected directly from growers or suppliers, and from economic forecasts – particularly for inflation rates such as for electricity prices). The range of values were collated and reasonable 'high' and 'low' values were subjectively selected. The intention of the economic assumptions is to ensure a reasonable likelihood, but with a slight conservative bias to test the economic merit of an investment in this technology. Benefits are slightly downplayed, whilst potential costs are rounded up.

Table F: Summary of the key benefit and cost assumptions used in benefit to cost analyses

Input (benefit or cost)	High value scenarios		Low value scenarios	
	Initial cost	Assume annual rate of increase	Initial cost	Assume annual rate of increase
Water	\$2.00 / kilolitre	2.0%	\$1.00 / kL	1.5%
Fertiliser	\$3.50 / kilolitre	5.0%	\$2.20 / kL	3.0%
Labour	\$25.00 / hour	1.5%	\$17.00 / hr	1.0%
Electricity	\$0.50 / kWh	5.0%	\$0.30 / kWh	2.5%
Cleaning chemicals	\$0.40 / cycle	3.0%	\$0.30 / cycle	2.0%
General maintenance and repairs	0.5%	-	0.5%	-

The key benefits used in these economic assessments are the value of water and fertiliser. Both of these are significant inputs into a hydroponic vegetable growing enterprise and the costs of these to an enterprise are directly related to the scale of the enterprise, the management practices of the enterprise and the level of recycling used. Subsequently, more efficient use of these key inputs by way of reuse of nutrient loaded hydroponic run-off forms the base economic benefits of disinfecting and recycling water.

Vignette 1: Example typical scenario

Assuming a 5000m^2 production area, with a 30% run-off target (and 95% recovery) that treats all water, in a low cost, low benefit (refer to table F) economic environment with a 2.5% rate of interest, the overall investment in today's dollars would be \$35,707.81 over 5 years. The payback period, (not including any actual yield increase attributable to the investment) is just 2.67 years. The return on investment is 39.67%.

This means that for every dollar spent, just under \$1.40 is returned. Over 10 years, which reflects a reasonable operating life of the disinfection system, the return on investment is almost 96%.

Water

Water is costed at \$2.00 per kilolitre for high benefit scenarios. This is relatively expensive water but is the approximate typical value of municipal water supplies across the country. A significant number of enterprises in peri-urban areas rely on town water supplies for much, if not all greenhouse water requirements. Municipal water supplies are already treated and can be considered free of plant pathogens – provided the water does not come into contact with soil, dust or plant material prior to use. Subsequently, in enterprises which use relatively expensive municipal water supplies, new water does not have to be disinfected thus reducing the potential size of a disinfection unit, however, the run-off water has a more significant value and contributes considerably to the economic benefits of disinfection and closed system hydroponics.

Farms that have access to other sources of water including ground water, surface capture and/or rain capture can have substantially different costs for water. Generally, the costs of these water supplies are less than municipal water and therefore, the potential economic benefit of recycling water is reduced. However, with the exception of ground water, all sources of untreated water have an element of pathogen risk due to contamination by soil, dust or plant material. Consequently, in most enterprises, disinfection of the new water is required. In the benefit cost analyses, water is valued at $1.00 per kilolitre in low value scenarios. This valuation encompasses the typical costs of pumping and storing water.

Ultrafiltration, as for all filters, requires a periodic backwash and cleaning process. In the ultrafilters used in this project, an allocation of 5 kilolitres per annum is used for backwashing. This water is not reused and is assumed to go to waste.

Additionally, the rate of water capture is assumed to be imperfect with a 5% loss included in all scenarios.

Since the feasibility of closed system hydroponics and therefore disinfection technology is closely related to the volume of water being treated, separate analysis of the benefit to cost ratio is undertaken for three different situations. In the first scenario, only run-off water is treated. In the second scenario, all water, that is, new water and recycled water is treated. In the third scenario, recovery of water is assumed to be 75%. This encompasses the supposed standard 5% loss (for example due to leaks, spillage and other use) and a deliberate 'bleed' of a further 20% of water. In some enterprises, water quality and/or the accumulation of sodium in recycled water necessitates a proportion of water to be discharged and new water added.

Fertiliser

Fertiliser in hydroponics is a significant input cost. For this project, the value of fertiliser is calculated from a range of commercially used nutrient recipes for vegetable production to determine a relevant cost of the fertiliser in a kilolitre of nutrient solution. The upper and lower valuations were rounded and used as the assumed fertiliser values for the high value ($3.50/kL) and low value ($2.20/kL) scenarios, respectively. The amount and therefore value of fertiliser is directly proportional to the volume of run-off water that is captured, treated and reused. Larger enterprises and higher rates of run-off significantly increase the cost, and therefore the potential saving that can be realised with a closed system of hydroponics.

As with water recovery, the rate of water capture and therefore fertiliser, is assumed to be imperfect with a 5% loss included in the two situations where (i) all water is treated and (ii) only run-off water is treated. A third situation has also been included in which recovery of water and fertiliser is assumed to be 75%.

Labour

Labour is required in the installation and general maintenance of a disinfection unit, as for any piece of equipment. The assumed labour input reflects only the labour attributed to the specific task of the ultrafiltration disinfection system. The number of hours used in the benefit cost analyses is based on time taken to fully install a system including trenching, tank bases and all plumbing and fittings (in year 1) and the time required for each cleaning cycle required for the life of the economic analysis. The cleaning cycle is rounded out to 1 labour hour per cycle. The number of cleaning cycles is determined by the volume of water treated. In all scenarios, it is assumed that the respective treatment unit is operated at maximum capacity and 55 cleaning cycles per annum are required.

Electricity

The pump and ultrafilter as a unit draw a little over 11.5kWh per day. Although in situ, less electricity may be required depending on the capacity of the unit and the volume of water to be disinfected, in all scenarios, it is assumed that the respective treatment unit is operated at maximum capacity. The cost of power has been calculated as a fixed price per kilowatt-hour (kWh). This calculation considered fixed connection costs plus expected daily 24 hour per unit costs based on pricing periods (for example, peak, shoulder and off-peak) and the duration of these each day. The values used in the benefit to cost analyses are based on a collation of different locations and a 'high' and 'low' value selected subjectively from these ranges.

It should be noted that electricity pricing is highly variable between regions, selected pricing plans and quantity of power purchased or used. The high ($0.50/kWh) and low ($0.30/kWh) assumed values have been selected to reflect a reasonable cost for a typical enterprise.

The annual rate of price increase in electricity is potentially quite significant. A number of energy price forecasts over the next 10 years were collated to establish a fair value. It is important to recognise that these values could be significantly more or less than the values used in the analyses. The selected 'high' value of 5% closely aligns with a bulk of energy price forecasts for the near future. The 'low' value of 2.5% increase in prices is more reflective of the average forecast rise in electricity costs.

Cleaning chemicals

All filters require some form of backwash and cleaning process. The ultrafilters used in this project utilise a periodic cleaning process using chlorine and citric acid. Although very small quantities of these chemicals are required, the costs have been included for completeness.

Maintenance and repairs

Day to day use and 'real world' assessment of commercially available ultrafiltration systems as part of this project showed that general maintenance and repairs are negligible, though with all technology and utilities a consideration for breakdown and failure is prudent. As a result a maintenance cost of 0.5% of the initial purchase price is included in all the analyses.

At the outset of this research program, it was anticipated that membranes would need to be replaced periodically. Initially this was expected to be every 2 – 5 years but operation of the trial units showed no deterioration in performance, provided the scheduled backwashing and cleaning cycles are followed. The added costs of replacing membranes is minor and so the benefit to cost analyses have not included any additional specific cost of membranes in the 10 year economic period. Instead, the general maintenance and repair allocation of 0.5% of the initial capital cost is included in all assessments. This would readily cover the replacement of membranes, if necessary. However, to illustrate the potential economic effect should membranes require regular replacement and so deemed a fixed cost, some example additional scenarios have been included (vignette 2).

Vignette 2: Example typical scenario with scheduled replacement of membranes

Assuming a 5000m^2 production area, with a 30% run-off target (and 95% recovery) that treats all water, in a low cost, low benefit (refer to table F) economic environment with a 2.5% rate of interest, the overall investment in today's dollars would be $35707.81 over 5 years. The payback period, (not including any actual yield increase attributable to the investment) is just 2.67 years. The return on investment is 39.67%. Over 10 years, the return on investment is almost 96%.

a) if the membranes are replaced every 5 years, the financial impact would be negligible with the return on investment over 10 years slipping only slightly to 93.4%.

b) if it assumed that the membranes actually need to be replaced annually, the payback period moves out by just 4 months and the return on investment over 5 years is still very worthwhile at 28.2%.

c) membranes would need to be replaced with new every 2 months before the cost would render a negative return.

Even under a high cost, low benefit economic situation (refer to table F), annual replacement of the membranes would still be a positive investment, with a payback period of 4.61 years and a return on investment of 3.17% over 5 years.

Disease

Originally the potential benefit of disease was included in the economic analysis. However, while anecdotally it is estimated that some 10% of crop productivity is lost due to subclinical and/or delayed control of disease (and not including major outbreaks), the inherent and unknown variability between enterprises and even between crops or seasons makes addition of this benefit potentially misleading. Subsequently, the actual benefit of reduced disease has been excluded from main scenarios.

The importance of this omission is that the real world benefits gained through any type of effective disinfection of water are likely to be greater than that suggested by the completed benefit cost analyses. This means that the calculated payback periods are likely to be shorter and the returns greater (vignette 3). In vignette 4, although a high cost, low benefit situation is assumed and a conservative base yield and price are considered, the potential gains through rising yield are substantial.

Vignette 3: Example typical scenario with increased yield due to disease suppression

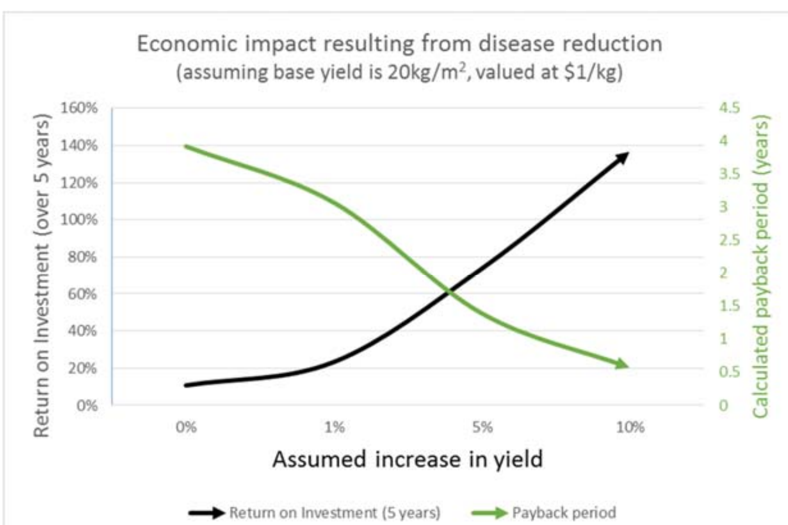
Assuming a 5000m^2 production area, with a 30% run-off target (and 95% recovery) that treats all water, in a low cost, low benefit (refer to table F) economic environment with a 2.5% rate of interest, the overall investment in today's dollars would be $35707.81 over 5 years. The payback period, (not including any actual yield increase attributable to the investment) is just 2.67 years. The return on investment is 39.67%.

If this enterprise has a yield of 20kg/m^2 and farm gate price of $1.00/kg, a 10% gain in yield resulting from less disease pressure would shorten the payback period by 6 months and increase the 5 year return on investment to 55.48%. This could apply to an enterprise currently recirculating nutrient solution and not using any form of disinfection of the reused water, or it could apply to an enterprise using dam water without disinfection, for example.

Vignette 4: Example high cost scenario with increased yield due to disease suppression

Assuming a 5000m^2 production area, with a 30% run-off target (and 95% recovery) that treats all water, in a high cost, low benefit (refer to table F) economic environment with a 2.5% rate of interest, the overall investment in today's dollars would be $44,944.69 over 5 years. The payback period, (not including any actual yield increase attributable to the investment) is 3.92 years. The return on investment is 10.96%.

Assuming that this enterprise has a yield of 20kg/m^2 and farm gate price of $1.00/kg, the potential benefits arising from an increasing gain in yield resulting from less disease pressure has dramatic impact on both the payback period and the 5 year return on investment as illustrated by the following graph.



Although taken out of the general economic evaluations due to the difficulty in establishing a fair value, the value of disease suppression or elimination is a primary benefit of disinfection and cannot be disregarded. Even at a conservative yield and farm gate price of product, excluding the benefits of water and fertiliser recovery, a yield gain of just 6.4% would be sufficient economic reason to invest in disinfection of new water as presented in vignette 5.

Vignette 5: Example typical scenario with increased yield due to disease suppression, no water recovery

Assuming a 5000m^2 production area, and no water reuse (no recovery of water or fertiliser) that treats new water only, in a low cost, low benefit (refer to table F) economic environment with a 2.5% rate of interest, the overall investment in today's dollars would be $35707.81 over 5 years.

If this enterprise has a yield of 20kg/m^2 and farm gate price of $1.00/kg, a 6.4% gain in yield resulting from less disease pressure would have a payback period under 5 years and a return on investment to 1.19%.

If the farm gate price is $1.50/kg, realisation of only a 4.25% yield gain would be necessary to justify the investment in disinfection of the water.

If this enterprise has a yield of 30kg/m^2 and farm gate price of $1.50/kg, a 2.9% gain in yield resulting from less disease pressure would have a payback period of just 4.68 years.

Scale of operation

One of the dominating reasons for ultrafiltration disinfection compared with other non-chemical disinfection technologies, is that the capital investment is typically lower, which is a critical factor for smaller farms. The size of the enterprise and the volume of water being disinfected and recovered has a substantial bearing on the economic viability of closed system hydroponics and water disinfection. The principal benefits are the value of water and, even more so, the value of fertiliser in the water. An important consideration is that the water and fertiliser 'value' is realised through reuse and so an enterprise that treats all water requires and larger treatment capacity yet the clearest benefit is proportional only to the run-off volume and recovery rate of water.

Note, as mentioned previously, the economic value of reduced disease is also a substantial benefit but is potentially so significant and variable between enterprises, crops and even seasons, that it has been omitted from the economic analyses to provide clarity and fair comparison.

As the volume of water and nutrient solution run-off increase, the purchase and installation costs of the treatment unit also rises and occurs in steps as the capacity of a unit is reached and a larger treatment capacity if required. As a result, when treatment volume only just exceeds treatment capacity, the economic viability is most at risk. This is readily noticeable in the tabulated economic assessments (provided in the appendix). In these situations, it may be more profitable to reduce the recovery rate of water, than to upgrade the treatment capacity. Alternatively, investing in a larger system may be prudent if an expansion in production is planned in the near future. Vignette 6 illustrates the impact of enterprise scale.

The investment in a closed system for larger enterprises is resoundingly beneficial. For a smaller enterprise, the volume of water treated and the target run-off volume are significant factors.

In the tabulated economic analyses, three water reuse situations are evaluated. An enterprise is assumed to treat all water (for example, a farm using surface water and recycling), or treat only the run-off water (for example, a farm using good quality ground water and recycling), or treat run-off only less a 20% discharge, that is a lower recovery rate (for example, a farm using Municipal water and recycling with proportional discharge to waste in order to manage sodium accumulation). The impact of this variation, again using the 'standard' scenario is illustrated in vignette 7.

Vignette 6: Example typical scenario with changes in enterprise size

Assuming a 5000m^2 production area, with a 30% run-off target (and 95% recovery) that treats all water, in a low cost, low benefit (refer to table F) economic environment with a 2.5% rate of interest, the overall investment in today's dollars would be $35707.81 over 5 years. The payback period, (not including any actual yield increase attributable to the investment) is just 2.67 years. The return on investment is 39.67%.

If this enterprise was only 2500m^2, the overall investment in today's dollars would drop to $28,831.03 over 5 years, but the payback period, (not including any actual yield increase attributable to the investment) would blow out to 6.97 years. This results in a negative return on investment over the 5 years, though is still a very viable investment when a 10 year horizon is considered. The return on investment over 10 years is a very healthy 15.20%.

Alternatively, if the enterprise was a full hectare (10000m^2), a much larger treatment capacity would be required increasing the overall investment in today's dollars to $50,082.35 over 5 years. With the much greater volume of reuse water and therefore larger financial benefits due to water and fertiliser savings, the return on investment over the 5 years is 99.16%. For every dollar spent, this investment would return almost $2.00. This investment, at this scale, would pay for itself in a little over 18 months.

Vignette 7: Example typical scenario with different water treatment objectives

Assuming a 5000m^2 production area, with a 30% run-off target (and 95% recovery) that treats all water, in a low cost, low benefit (refer to table F) economic environment with a 2.5% rate of interest, the overall investment in today's dollars would be $35707.81 over 5 years. The payback period, (not including any actual yield increase attributable to the investment) is just 2.67 years. The return on investment is 39.67%.

If this enterprise, only treated the run-off water, a smaller disinfection system would be suitable and the overall cost in today's dollars would be $28,831.03 over 5 years. Because the recovered water and fertiliser are the key financial benefit (excluding the benefit of disease suppression), the breakeven point falls to just 1.55 years and the return on investment calculated over 5 years, almost doubles, to 72.98%.

If however, the third situation exists and the enterprise disinfects only the run-off water but also has to discharge 20% to waste giving a recovery rate of 75%, the payback period is 2.58 years and the ROI over 5 years, is 36.56%. This is still a potentially profitable option.

Maximising the recovery rate of run-off water is an important consideration as it directly affects the economics of a closed hydroponic system. Consequently, run-off recovery should be a key aspect of farm planning. In the above example, if the recovery rate of run-off fell to just 50%, the investment would take an extra 3.6 years before it paid for itself.

Finally, for most situations in Australia, crop productivity and effective hydroponic management are generally improved with higher run-off targets. However, for a majority of enterprises, high water and fertiliser costs constrain run-off management decisions. Closed system hydroponics, with high water recovery and reliable disinfection of water can result in a significantly better financial position. The run-off target pursued in an enterprise can have a significant impact on the volume of water and fertiliser used and thus, potentially recovered. In addition to improved crop management options, increasing the target run-off percentage directly affects the required treatment capacity and therefore has financial implications. Interestingly, in a situation where the new water must be disinfected (for example, dam water is used), increasing the run-off to obtain better crop management outcomes, would actually improve the economic viability of the disinfection system (vignette 8).

Vignette 8: Example typical scenario with different run-off targets

Assuming a 5000m^2 production area, with a 30% run-off target (and 95% recovery) that treats all water, in a low cost, low benefit (refer to table F) economic environment with a 2.5% rate of interest, the overall investment in today's dollars would be $35707.81 over 5 years. The payback period, (not including any actual yield increase attributable to the investment) is just 2.67 years. The return on investment is 39.67%.

If this enterprise, only had a 10% run-off target, but still needed to treat all water (for example, the farm uses surface water), the same size disinfection system would be required but because the recovered water and fertiliser are the key financial benefit (excluding the benefit of disease suppression), the investment would be non-viable.

If however, the run-off target was increased to 20%, the specific investment in the disinfection system would become economic in its own right, with the payback period being 5.74 years.

A farm using a 40% run-off target, would have a payback period of just 18 months and a return on investment of 86.22% over 5 years.

If the same enterprise was considered, but new water did not need to be disinfected so only run-off is treated (95% recovery), the investment would break even at a run-off level of 18%. If the recovery rate of water fell below 69%, however, this investment would become unviable (given a 10 year investment period), illustrating the importance of water efficiency in parts of an enterprise.

Monitoring and evaluation

Two elements of monitoring and evaluation were planned and implemented as part of this project. Monitoring and evaluation of the research component was embedded in the replicated trial program developed from the outset of this project. Results (both expected and unexpected) were tested and retested. Rigorous scientific method ensured a robust monitoring regime for the technical trials.

The second component of monitoring and evaluation addresses the uptake of closed system hydroponics, disinfection and reuse of nutrient run-off and in particular, adoption of fine pore filtration as a disinfection tool. This is ongoing as it cannot be completed within the project period, but has been instigated by way of the project portal and online survey. Within the timeframe of this project, benchmark data has been collected and a process set up to continue to gather information after the project has formally concluded. This information will be periodically published online for up to 36 months and provides a continued monitoring of the relevant impact of this research and economic analysis and overall industry awareness. Early monitoring results are included in the sections 'Information and technology transfer', 'Disinfection systems and satisfaction' and 'Outcomes'.

Information and technology transfer

The initial online benchmark survey found that only one third of enterprises are currently disinfecting water. Eighty percent of those not using a disinfection system are presently considering doing so. At the outset of this project, it was anticipated that as many as 100 enterprises may be encouraged to adopt disinfection technology, and if confirmed as reliable, adopt fine pore filtration for this purpose. Current results of the survey indicate that some 18% (equivalent to approximately 115 operators in Australia) are looking at ultrafiltration in the near future.

Principally this project sought to address three research questions in order to confirm whether or not ultrafiltration is a suitable investment option for hydroponic vegetable growers implementing improved management practices. The primary technology transfer strategy placed central to this project and trial plan was the establishment of baseline and reliable information about the technical and economic performance of ultrafiltration (and to some extent, all disinfection technologies). This has been achieved.

This information and learning has been broadcast to the greenhouse hydroponic industry via a technical presentation at the peak industry body conference in 2015, as well as being distributed in print via a 6 page spread in the leading industry publication, *Practical Hydroponics & Greenhouses*. This article was also picked up and promoted globally through the online industry newsletter, *Hortidaily.com*. Information about the project, the trial results and the economic analyses have also been made available online, through the project specific webpage – https://sites.google.com/site/sustainablehydroponics. A further print article in *Vegenotes* will follow, with the content already received. An industry organised field day (NSW mid-north coast) focused on a commercial cucumber enterprise which has implemented closed system hydroponics using ultrafiltration following the dissemination and publication of results from this project, demonstrating a broadening of the awareness of these improved practices and technology.

The target audience for this project is two-fold. The key audience are existing and potential greenhouse hydroponic growers (up to 1200 enterprises). Currently the majority of small to medium hydroponic vegetable enterprises in Australia still employ flow-through hydroponic systems and/or practice periodic discharge of nutrient solutions. Whilst these production systems are highly efficient and productive when compared to field based production, significant improvement in resource efficiency and sustainability can still be achieved.

Although the research focus has been on ultrafiltration as this is a resurgent technology and has the potential to provide a lower cost option in closed system hydroponics, an underlying component of information and technology transfer in this project is the increased knowledge about and ongoing implementation of closed systems. All water used in a greenhouse and/or hydroponic production system needs to be pathogen free in order to fully capitalise on the economic and environmental opportunities of protected cropping. The adoption of reliable disinfection of water in protected horticulture remains a critical step in the development and capacity building of this sector of the vegetable industry.

Not only have the trials and economic analyses conducted in this project provided a clearer understanding of the current status of ultrafiltration, but these analyses demonstrate the significant advantage that closed hydroponics with water disinfection provides.

The secondary audience that has been integrated into the technology transfer reach of this project in order to enhance the longer term outcomes for industry, are the various equipment resellers and suppliers. Hydroponics is an equipment centric industry and this strategy ensures that growers will have continued exposure to knowledge and technology concerning disinfection and ultrafiltration. Commercial opportunities are available to all industry equipment suppliers. The information generated in this project has been made freely available and was widely sourced at the industry conference. It provides commercial suppliers with confidence in the relevant technologies as well as enabling them to provide advice and service backed by independent analysis.

Critical success factor

At the outset of this project and research program, the trial results were defined as a critical success factor. Preliminary tests indicated that this technology could remove pathogens from water and that these filters do not have maintenance or failure problems of other filter systems. The objective of the project was to test this and confirm this type of treatment option as a viable tool for industry. With all research, there is a chance that the results will not be as expected. This would clearly impact on the adoption strategy and outcomes. While the benefit to cost analyses demonstrate a substantial value in the implementation of disinfection of reused water with ultrafiltration, the pathology results were mixed. The fine pore filters tested were highly effective against fungal pathogens but shown to be less reliable in the removal of bacterial pathogens. This result dampens the broader industry potential as growers of Solanaceous crops would still benefit from a secondary disinfection technology, but the primary project target – hydroponic cucumber growers – have gained a proven treatment option. Overall, the economic value of water disinfection and closed system hydroponics is resounding.

Based on the results of this project, the only true impediment to industry adoption is the individual financial situation of growers as to whether they have the cash flow to invest in disinfection. The economic analyses demonstrate that the financial viability of disinfection and reuse of the nutrient run-off is unquestionable.

Disinfection systems and satisfaction

In conjunction with a presentation (Appendix 2) and workshop at the 2015 Protected Cropping Australia biannual industry conference, an online survey was developed to gather feedback from industry about current use of disinfection technologies and also a measure of satisfaction. While this process cannot provide definitive data, it does provide an excellent insight into this area that has not previously been investigated. This information also provides a useful benchmark for future assessment of interest and adoption of ultrafiltration or other disinfection technologies. Of the 142 complete responses (148 received between July 2015 and June 2016), 52% were indicated to be in Australia.

Currently Ultraviolet radiation (UV) is the most widely used method of disinfection in hydroponics (figure 15) with almost a third of respondents who currently disinfect water using this technology. It is worth noting that only one third of respondents indicate that they are currently using any form of water disinfection, however 80% of these respondents plan to install a disinfection system in the near future.

The next most popular system currently used is ozone with just under a quarter of respondents, followed by chlorine treatment which is being used by 17% of respondents. None of the respondents currently use ultrafiltration, however some 11% of operations do use biofiltration such as slow sand filtration.

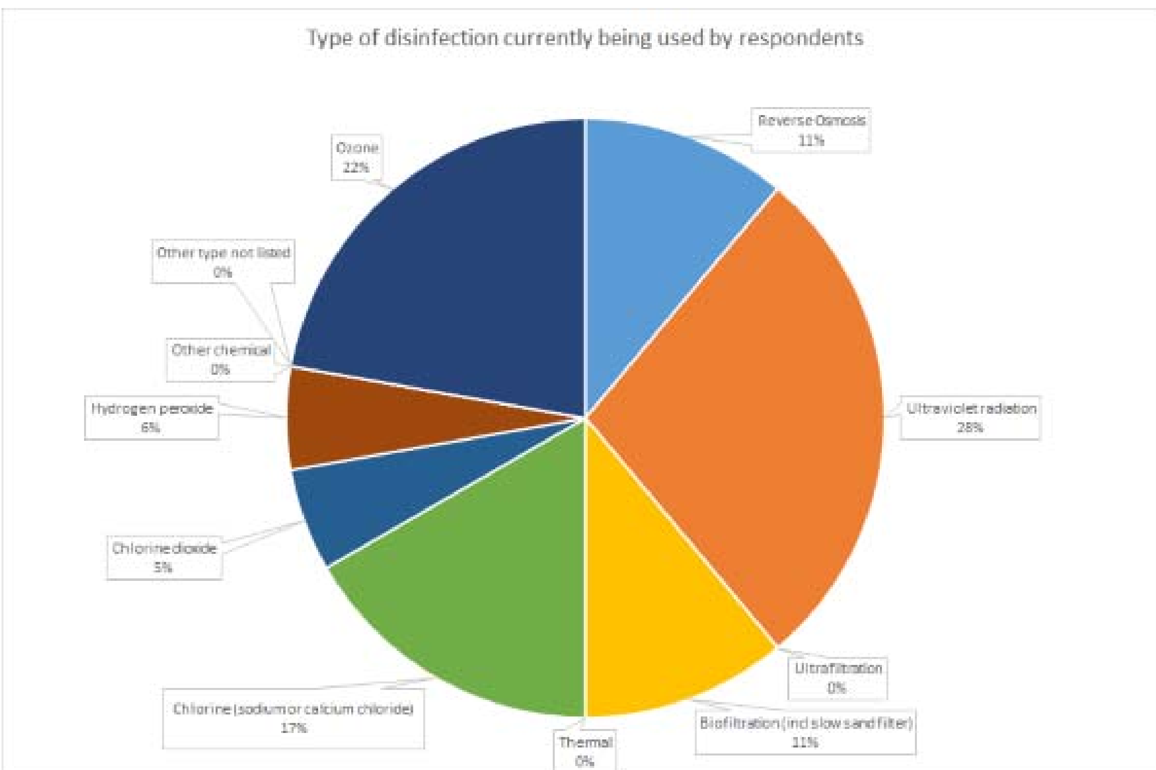


Figure 15: Type of water disinfection system currently being used in hydroponics

Of the people planning on a installing disinfection system in the near future, ultraviolet radiation is again the most popular choice (37%) whilst chemical options such as ozone and chlorine and chlorine dioxide may be becoming less popular. Almost 20% of respondents indicate that they are looking at ultrafiltration as a preferred option making it the second most popular choice.

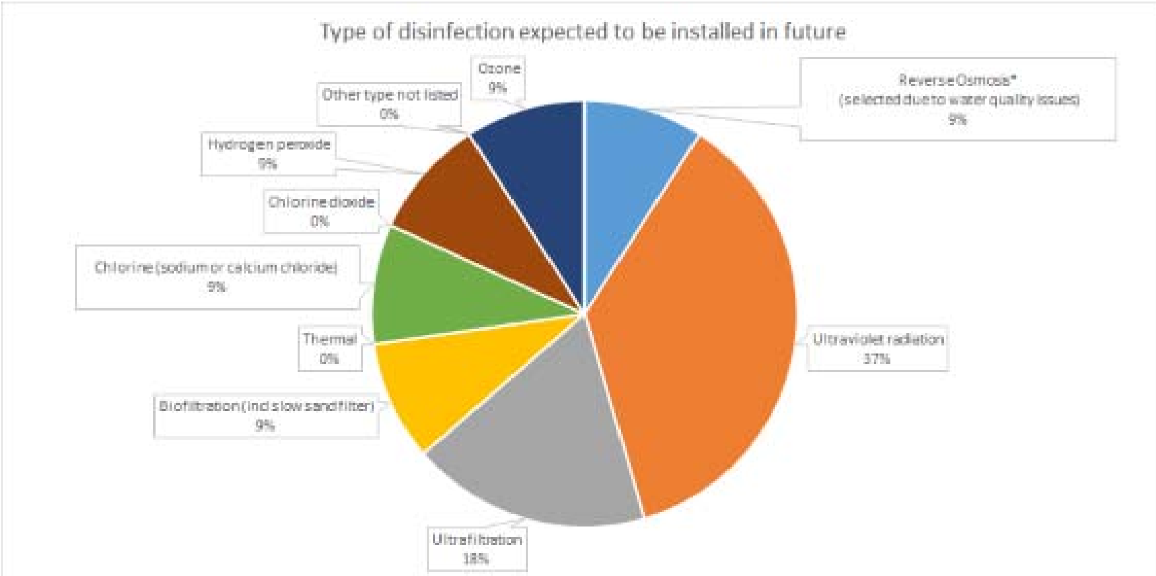


Figure 16: Type of water disinfection system planned to be used in the near future

Current satisfaction with water disinfection is a particular concern and was a key reason for ensuring that this project rigorously tested real world experience. Forty percent of survey respondents using a disinfection system indicated that they had checked their treated water and found target pathogens. A further 10% of respondents suspected that their treated water contained pathogens but could not confirm it. Another 15% of enterprises had not checked. These results (figure 17) suggest that almost half, and

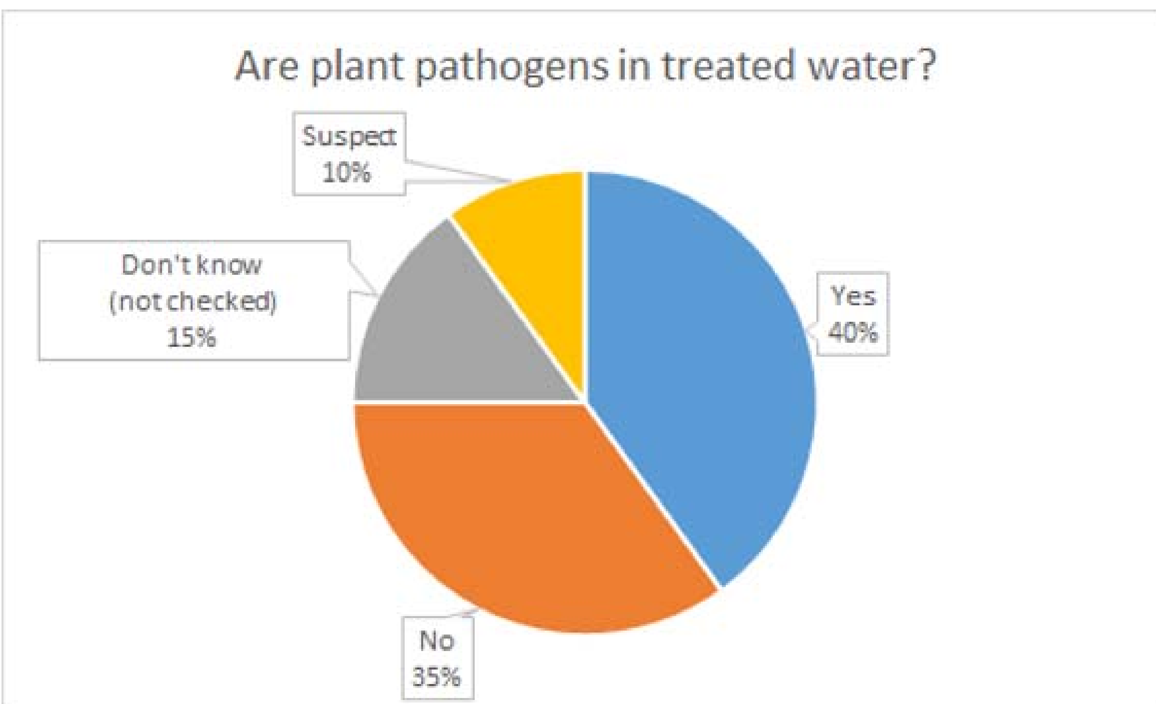


Figure 17: Relative performance of treatment options in providing disinfection

possibly more disinfection systems currently in use are not adequately removing target pathogens from the water.

The survey has now been reset and remains active online so that it can provide a benchmark measure of change over the next 12 – 36 months. The concluding results will be published online, on the project website.

Outputs

This project set out to deliver several key outputs, all of which have now been achieved. An online project portal has been developed to ensure all growers have ready access to project results and general information about disinfection and closed system hydroponics, when they want it. This website also provides a capture point for ongoing survey of the industry with respect to current practices and near future intentions about disinfection systems, as well as delivery of the findings. This output has been developed to extend industry awareness and learning beyond the project timespan.

The main output of this project (presented in this report) has been extensive trial results showing the successful removal of target fungal pathogens from water and a cautionary finding about the less reliable removal of bacterial pathogens, contrary to technical theory.

Comprehensive benefit cost analyses have illustrated that ultrafiltration and water disinfection in hydroponic cucumber production is demonstrably viable across a wide range of economic conditions and assumptions.

Broad industry dissemination of project developments has been accomplished through technical conference presentation, published industry media and continues to be made available through a dedicated website and ultimately, by way of this report.

A factsheet presenting the overall findings in terms of efficacy and financial benefit and a factsheet explaining closed system hydroponics and the installation of this type of treatment unit in a closed hydroponic system distributed at the Protected Cropping Australia conference in 2015 have also been made freely available online. These resources have also been offered for publication in the PCA newsletter, *Soilless*.

Additionally, a field day organised by Coffs Harbour Landcare took place on the 25th May, 2016. This site is a greenhouse hydroponic cucumber farm which has installed an ultrafiltration disinfection unit as part of a closed hydroponics system. This grower had been following the project trials and economic analyses and subsequently selected this technology for his enterprise. This event was an excellent forum for promotion of the results of this project and enabled local farmers, many of whom are growing cucumbers hydroponically, to see ultrafiltration technology in situ, learn about the technology and understand the opportunities disinfection of nutrient solutions provides, by way of closed system hydroponics.

Outcomes

There are two primary outcomes targeted with this project. The first is to facilitate awareness in the greenhouse hydroponic industry of ultra-filtration as an option for disinfecting source water and recycled nutrient solution. The pathway to this outcome has involved the comprehensive testing and reporting of research trials into the efficacy and general performance of ultrafiltration and the determination and delivery of extensive benefit to cost analysis of the economic merit of disinfection, closed system hydroponics and ultrafiltration.

Survey results to date show two important shifts in industry awareness. The first result indicates that while only one third of industry respondents were using disinfection in their production systems, 80% of those not currently disinfecting water, identify that they are presently considering installing some form of disinfection technology. Secondly, from an initial zero base, the interest in ultrafiltration has now been reported to be at 18% of intended installations. This change over the latter half of the project period illustrates a positive gain in awareness and excellent progress in the achievement of this outcome. The online survey has been reset and will now be used to gauge further changes in awareness, now that the trials and economic analyses are complete.

The second targeted outcome encompasses adoption. This is a more complex objective as there are numerous and variable barriers to adoption of any new practice or technology. It is also a medium term outcome and cannot be confined to a short project horizon. There were two principal adoption barriers with regards to ultrafiltration disinfection identified in the initial development of this project. The first was awareness of the technology. It is clear that this barrier has now been somewhat addressed and continues to be. The second key barrier is financial. Many small to medium growers need to assess new equipment investments very carefully. This key strategy to deliver on this outcome was to produce comprehensive benefit cost analyses of the technology to provide industry with a robust decision support. These analyses have been completed and made extensively available to industry directly through conference and industry networks and this report, as well as online.

From this project, it has been found that there is almost no reasonable economic circumstance in which investment in reliable disinfection technology and reuse of nutrient solution run-off, is not a viable and profitable option for hydroponic vegetable growers. This clear economic evaluation of water disinfection and reuse provides significant lessening of these financial adoption barriers. As the key impediment, the delivery of this outcome, (that is, implementation of water disinfection by up to 100 enterprises) has been well positioned for achievement over the next 3 – 5 years as proposed. The online survey and website will be used to monitor and report this progress.

The disappointing efficacy results with respect to bacterial pathogens is expected to have a dampening effect on the adoption of ultrafiltration due to the number of hydroponic enterprises that include Solanaceous crops within their production programs. However, the relative ease with which ultrafiltration can be synergistically coupled with secondary treatment options such as lower cost ultraviolet radiation to provide more reliable results for small to medium operators, may offset this limitation. Notwithstanding, the overall implementation of disinfection technology (not necessarily ultrafiltration) in the longer term is enhanced by the outputs of this project and progress is already shown by the benchmarking survey results to date.

The implementation of any type of disinfection technology and successful treatment and reuse of nutrient loaded run-off water is a significant benefit both economically and environmentally, for the hydroponic vegetable industry. Closed system hydroponics has been clearly shown to vastly improve potential financial returns and greatly increase resource efficiency, particularly with respect to fertiliser use.

An additional outcome achieved in this project has been the development of detection sensitivity of key pathogens in water. This research was found to be necessary in order to determine the reliability and capacity of the ultrafiltration research trials but now also provides a better understanding of the levels of pathogen detection possible from farm water samples. Going forward, this work will contribute to more effective diagnostics of disease on vegetable farms and provide industry with an improved audit tool for disinfection and sanitation processes and equipment.

Finally, it is worth noting that the longer term environmental benefits of closed system hydroponics (and therefore the use of disinfection of reuse water) can be quite significant. Though not a described intended outcome of this project, a typical 1 hectare enterprise operating with a 20% daily run-off target would recapture almost 470kg of nitrogen and just over 100kg of phosphorous annually.

Evaluation and discussion

There is almost no reasonable economic situation in which a hydroponic cucumber enterprise would not be significantly better off by implementing closed hydroponics with an ultrafiltration disinfection system. This project, with the rigorous technology evaluation and comprehensive economic analyses bears considerable relevance and value to the industry. A typical Australian hydroponic cucumber enterprise could save upwards of $10,000 per year just by capturing and reusing run-off water. A greenhouse hydroponic enterprise currently using untreated water, could add more than $11,000 per annum to revenue, simply by disinfecting the source water and reducing the underlying impact of disease.

A disease free source of water is critical to efficient and cost effective hydroponic production. Furthermore, a closed hydroponic system, in which nutrient solution run-off is reused, improves water (and fertiliser) efficiency by up to 40% over open systems but increases the potential spread of pathogens. Some 65% of the more common pathogens of hydroponic cucumber production can be spread through water, making the reuse of the nutrient run-off a high disease risk. Any source of water that has contact with soil or plant material is potentially a disease risk and needs to be disinfected before it is used in the greenhouse or hydroponic system. In a typical greenhouse vegetable enterprise, up to 10% of potential income is lost through disease – and this does not include losses from a major disease outbreak.

There are several disinfection technologies including ultraviolet radiation (UV), heat and chemical disinfection (such as chlorine or ozone) but high costs, inconsistent results and the use of chemicals are obstacles to wide-spread industry adoption of improved practices.

This project, through replicated trials and detailed economic analyses, has found that ultrafiltration is a cost effective and viable disinfection system for cucumber growers. Replicated trials, with different ultrafilter units, repeatedly demonstrated successful removal of key target fungal pathogens, *Fusarium oxysporum* and *Pythium* spp.

Overall this project has achieved what was intended, though some of the research results were unexpected and disappointing. The failure of the ultrafilters to reliably remove bacteria was unexpected, but sound scientific method and replication was used in all assessments and so this work must conclude that this technology is not currently suitable for use in cropping situations with significant bacterial pathogens.

Given these results, the appropriateness of the scientific method followed in this project has proven to be paramount. Replication of filter efficacy trials were designed into the project methodology to ensure confidence in the results and this project has subsequently demonstrated the critical value of replication in applied research programs. Without this replication and without repetition of some of these trials, very different conclusions could have been drawn.

The unexpected results also necessitated an extension of the laboratory trials. Additional ultrafiltration membranes were sourced and acquired and extra trials were conducted. These additional activities were incorporated into the existing project budget and plan.

It is important to note that the once the initial filters (specified in micrometres) that were selected as being suitable for this research program were demonstrated to be ineffective, additional membranes specified in Daltons (100kDa) were imported from Europe. The trials were repeated and these membranes were also found to be ineffective. Another set of membranes with a 50% reduction in pore size (50kDa) were then imported. These too, failed to retain the test bacteria, though there was indication of a lower concentration of bacteria in the filtrate. The research program was terminated at this stage as it was extending beyond the scope of the project.

Filtration occurs from the outer surface of the ultrafilter membranes as filtered water moves to the hollow inner core. Particles too large to pass through the fine pores are held on the outside of the fiber walls. Backwashing, initiated automatically after a set interval, takes a couple of minutes. In the systems trialed, clean backwash water and air are used to scour the membrane surface and this material is then discharged from the system. Over the course of a year, approximately 5000 litres of water are required for backwashing. Periodically, a chemical cleaning process is used to further remove any material attached to the membrane surface. For the trials and economic assessments, this cleaning cycle occurred slightly more than once per week, resulting in 55 cleaning cycles per year. Small quantities of sodium hypochlorite and citric acid are used in this process. Overall, this task takes approximately 1 hour.

Ultrafilter type A was selected as the primary unit for this project as it is commercially available and its specifications suited the technical requirements of the project objectives. Type B is an older version of the Type A filter. It was originally used in a farm water efficiency program prior to this project and had shown reliable performance in disinfecting hydroponic run-off water of both fungal and bacterial pathogens. It was brought into this project after early replicated results with the Type A filter indicated that bacteria were not being removed from the filtrate. After continued poor results in the removal of bacteria, new filter membranes were imported from Germany (Type C). The technical specifications of these membranes (100kDa) again exceeded the theoretical requirements of the project trials. These membranes were set up in a test unit. Again, failure of the ultrafilter to remove bacteria led to the fourth type, Type D being used. These membranes were of a much smaller pore size (50kDa) and were again imported from Germany as membranes and set up into test units for the trials.

Filtration ultimately is based on the notion of particle size, however, there are different methods of specification which cannot be readily converted. Types A and B are commercially available ultrafilter set ups with a nominal pore size of 0.04 micrometres which is a unit of length. The maximum pore size of these membrane filters is specified at 0.1 micrometres, which is still half the size of the expected smallest dimension of the target bacteria. Systems C and D are specified in kiloDaltons, which is a measure of mass. Table G illustrates the non-lineal relationship between Daltons and micrometres. The relative position of the test membranes have been included in the table.

Table G: Relative values of two common measures of particle size as used in filtration

Micrometer (um)	kiloDalton
0.0015	5
0.0025	10
0.004	Filter D (50)
	Filter C (100)
0.01	200
0.02	500
Filters A & B (0.04)	
0.1	1000

Fusarium oxysporum was selected as the primary model pathogen for use in the trials as this fungal pathogen can be very damaging and difficult to control once it enters a hydroponic cucumber enterprise. Three species of *Pythium* were also assessed in separate trials. Concentrated suspensions containing the fungal pathogens were prepared and pumped through replicated ultrafiltration units. A series of samples of the filtrate, as well as a positive control sample (the unfiltered solution) were then screened in the laboratory. The smallest elements of *Fusarium* spp (microconidia) measure in at around 2 – 3 µm and macroconidia at 3 – 4.5 µm, in their smallest dimension.

Suspensions of the bacterial pathogen *Clavibacter michiganensis* spp *michiganensis* (Cmm) were also tested. The aim of these additional trials was to determine whether these ultrafiltration units could also be used in situations where bacterial pathogens are a primary concern. *Clavibacter* is a rod shaped bacterium around 0.5 – 1.0 µm in length and the diameter (or width) exceeds 0.2 micrometres. The smallest bacteria known are 0.2 – 0.3 µm by 0.5 – 2.0 µm which would suggest that the largest of the filter membranes trialed should retain all bacteria.

The mixed results obtained in the trials, while disappointing are also of enormous protective value to industry as this project has been able to qualify the circumstances and technical performance of ultrafiltration. This could otherwise result in a significant cost to growers should they invest in a disinfection system that is unreliable. Contrary to technical and commercial literature and equipment specifications that would suggest that even the smallest bacterial pathogens would be retained by the filter, these trials conducted in an independent laboratory do not uphold this expectation.

From this research, we can conclude that this technology is not currently suitable for use in cropping situations with significant bacterial pathogens, unless it were coupled with as secondary treatment option such as ultraviolet radiation. It is important to note the use of ultrafiltration will substantially enhance the efficacy of UV treatment and potentially enable managers to install lower power, lower cost units. Another point of note is that the general economic evaluations show that for a typical enterprise, a significant increase in capital expenditure above that required for ultrafiltration alone, could still be financially viable.

Subsequently, this project has also provided an invaluable cautionary finding for growers looking to options for water disinfection. Industry experience has shown that some methods of water disinfection can be unreliable and, particularly for smaller farms, can be cost prohibitive. Interestingly, the unreliability factor is also borne out in the responses to the online survey conducted as an ongoing part of this project. Up to half of the disinfection systems being used (all types), do not have the users' complete confidence that they are reliably treating the water.

The research activities encompassing the efficacy trials, the sensitivity of detection trials, nutrient testing and filter volume assessments have all been highly valuable in addressing the project objectives and delivering results. The nutrient testing and water volume testing were only minor components and were included by way of completeness. The results directly matched expectation.

The sensitivity of detection trials were not originally planned, but early project discussions regarding the reliability and general parameters of laboratory results led to the need to test the base level at which the project would be able to detect pathogens. Subsequently, this additional research component was undertaken. This work provides significant benchmark research in diagnostics and opens the way for industry to better understand disease risk in the production system and importantly, offers a high accuracy means to conduct reliable pathology audits on water sources, within production systems and, critically of disinfection and treatment processes.

As a research based project, delivery of information to industry had a planned delayed start. Once the main findings were established, delivery of outputs began in earnest with a three point strategy. A project webpage was set up to provide a single reference point for the project, general information about disinfection and ultrafiltration and as a hub for the results as they came to hand. A limitation of this webpage has been that no visitor counter is installed, which means that an accurate assessment of the number of people accessing project information is not available. Interestingly, the webpage is also used as the capture and delivery point for the benchmark survey, so response to that survey does provide a partial indicator.

A technical presentation at the peak industry conference was made. This conference had some 400 delegates and was also widely reported in industry media. Coupled with this presentation was an invitation to participants to go online to the project portal for further information and to complete the survey. In the first stage of the survey, 148 responses were collected, though 6 of these were incomplete. Just over half of the respondents were from Australia, making them part of the project target audience. The presentation has since been uploaded to the project portal, though again with no visitor counter, it is unknown what level of website traffic has visited this output.

The third element of information delivery and industry engagement was a media article and was prepared as a follow-up to the conference talk. This tactic is a common marketing approach that builds awareness and knowledge. The article was published in *Practical Hydroponics & Greenhouses* magazine which is an industry leading publication, now exclusively online and distributed globally. The daily global horticulture newsfeed *Hortidaily.com* also picked up this article.

Principally, monitoring in this project consists of two discrete parts. Monitoring of the research trials is embedded into the scientific methodology. The trials have shown that the focus technology – ultrafiltration – is an excellent option for hydroponic growers that have significant fungal pathogen risks. Growers who have significant bacterial pathogen risks may need to couple ultrafiltration with a secondary treatment process for reliable results.

Monitoring of industry awareness and adoption are the second part. The online benchmark survey is the basis of this task. Awareness can be monitored by way of the benchmark survey respondents. From a zero base, ultrafiltration was identified as the intended disinfection option by 18% of respondents in the first monitoring period (2015/2016). Directly, this represents that 25 enterprises (13 in Australia) are looking to install ultrafiltration. Indirectly, this result represents around 115 Australian hydroponics growers from a nil base [Assumes 1200 enterprises, 80% of those not currently using disinfection] are currently planning for ultrafiltration. At a minimum, this monitoring shows that awareness in the Australian hydroponic vegetable industry has increased significantly since the start of this project. Additional subjective review of awareness can also be derived from the fact that the PCA conference in 2015 had over 400 delegates. These people would have become more aware of ultrafiltration simply by being exposed to information and discussion at the event. Furthermore, the *Practical Hydroponics & Greenhouses* is well established as the premier resource for industry news and information in the Australian hydroponics industry and is now offered as a free digital publication to a global readership.

The second target outcome is to facilitate the adoption of closed system hydroponics with disinfection in 100 enterprises over the next 5 years. The first stage monitoring period would suggest that this outcome is well on the way to completion. Monitoring, however, will continue after the formal end of this project via the project portal and the industry survey. The second monitoring period is underway and will continue post project, with results reported on the webpage and in industry media.

A key point of learning from this project has been the reminder that research does not always deliver the expected result. This emphasises the importance that all projects with research trials, including applied research and especially, technology assessments, need to include replication and good scientific methods, as was done in the development and delivery of this project.

Conclusion

Trials were undertaken to confirm that ultrafiltration technology can reliably remove key pathogens from the run-off water and benefit cost analyses were conducted to assess the potential economic value to cucumber growers under different scenarios.

Replicated trials have demonstrated that ultrafiltration is a highly effective disinfection option in situations where fungal pathogens are the target. The technology is affordable and has been shown to offer an effective and financially viable means of treating water and recycled nutrient solutions for the reliable control of critical fungal pathogens. Subsequently, this technology could be of great value to specialist hydroponic cucumber growers.

For most situations in Australia, crop productivity and effective hydroponic management are commonly improved with the opportunity to use higher run-off targets. However, for a majority of enterprises, high water and fertiliser costs constrain run-off management decisions. Closed system hydroponics, with high water recovery and reliable disinfection of water can provide better crop management opportunities, better resource efficiencies, improved environmental outcomes and result in a significantly better financial position. This project has been able to evaluate and demonstrate the opportunities for closed system hydroponics and increased run-off targets and clearly shows the merit of investment in water disinfection. Overall, the economic viability of closed system hydroponics with disinfection is confirmed.

The project webpage, https://sites.google.com/site/sustainablehydroponics continues to be available, post project.

Recommendations

Hydroponic growers should undertake a pathology audit of their water supplies (including treated water) used in the production system, including for irrigation, cooling and cleaning.

> From extensive industry experience, unmanaged (and commonly unobserved) disease can account for a 10% loss in yield in a typical greenhouse hydroponic crop. With some 65% of key pathogens potentially spread in water, disease in hydroponics can be a significant drain on enterprise productivity and profitability. Furthermore, reliability of disinfection systems can be uncertain with as many as half industry survey respondents confirming or suspecting their disinfection system is not working effectively. The trials in this project repeatedly showed that membrane filters which are specified to retain bacteria, may not necessarily do so.

The vegetable industry should consider completing an independent pathology assessment of a number of current disinfection systems being used across the industry (potentially also including postharvest treatments).

> With as many as half industry survey respondents confirming or suspecting that their currently used disinfection system is not working effectively and with the replicated trials in this project showing inadequate performance of ultrafiltration with respect to bacterial pathogens, it would be prudent to ensure that the technologies industry are investing in, are meeting specification and expectations. If such a program is implemented, duplicate water samples should be analysed through at least two different laboratories.

Horticulture Innovation Australia should endeavor to promote closed systems with water disinfection in respect to future publications or media that HIA or its partners have a stake in.

> This project has confirmed the economic argument in favour of closed system hydroponics. The environmental benefits of improved water and fertiliser efficiency are already well established. Closed system hydroponics with disinfection should be considered the current practice benchmark for this industry.

Hydroponic growers should consider utilising two disinfection technologies in series (such as ultrafiltration followed by UV or ozone) to reduce the risk of pathogen spread to as close to zero as is possible.

> Given the possibility that some disinfection technologies may not be performing as reliably as expected, statistically, the implementation of two treatment processes in series would render the risk of disease passing through the disinfection process, close to zero. Based on the benefit to cost analyses conducted in this project, it is reasonable to expect that such a measure is still likely to have a positive return on investment.

All hydroponic growers, not already utilizing a closed hydroponic system, should endeavor to implement a closed hydroponic system with water disinfection.

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Intellectual Property / Commercialisation

No commercial IP generated. The technology being tested already exists in commercial business. The problem being addressed is that there was no proof that it will do the job. Access to equipment and product was obtained commercially.

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Appendix 1 – Tabulated benefit to cost analyses of ultrafiltration

The following tables have been compiled to provide a comprehensive review of the financial viability of ultrafiltration disinfection in a closed hydroponics cucumber enterprise, given a range of economic conditions and water use scenarios.

Results in each table are listed in columns for eight (8) different scales of production, from 2500m^2 up to 1 hectare (10000m^2). Across the tables, results are listed for four (4) different levels of daily run-off.

The estimated total investment cost is displayed in *today's* dollars and includes the initial purchase and installation as well as running costs over 5 years. The payback period is an estimate of how long the investment will take to pay for itself. For these tables, a payback period greater than 10 years is considered to be "uneconomic". It is important to note that this is not necessarily the case and that you may have a longer investment horizon.

Growers can obtain a Benefit to Cost Analysis (BCA) estimate based on their own specific values via the project webpage portal: https://sites.google.com/site/sustainablehydroponics

The calculated Return on Investment (ROI) is provided for both a 5 year and a 10 year period. A ROI greater than zero indicates that the investment is likely to be economically viable over the nominated period. A negative return on investment (shown in red) indicates that the investment has not 'paid for itself ' within the nominated time period. For example, in a scenario where the payback period is 6 years, the ROI will be negative over a 5 year timeframe and positive over 10 years.

A ROI of 10% over 5 years indicates that for every dollar invested during this period, the effective return (fertiliser and water savings) would be $1.10.

Scenario: Treating run-off water only. Low ‘BENEFIT’ (fertiliser and water) values; low ‘COST’ (energy and labour) values*									
Interest (discount) rate	**2.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	7.0 years	3.7 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-13.51%	15.32%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	15.20%	53.60%
Estimated total investment cost (present value^ over 5 years)		$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03
	Payback period	>10 years	>10 years	8.3 years	6.0 years	4.6 years	3.7 years	1.6 years	0.8 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-19.28%	-7.74%	3.79%	15.32%	72.98%	130.64%
	ROI over 10yrs	uneconomic	uneconomic	7.52%	22.88%	38.24%	53.60%	130.39%	207.19%
Estimated total investment cost (present value^ over 5 years)		$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03
	Payback period	7.0 years	4.6 years	3.3 years	2.5 years	2.0 years	1.6 years	0.5 years	0.6 years
30% Target run-off	ROI over 5yrs	-13.51%	3.79%	21.09%	38.38%	55.68%	72.98%	159.47%	179.33%
	ROI over 10yrs	15.20%	38.24%	61.28%	84.32%	107.35%	130.39%	245.59%	291.77%
Estimated total investment cost (present value^ over 5 years)		$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$35707.81	$35707.81
	Payback period	3.7 years	2.5 years	1.8 years	1.3 years	1.0 years	0.8 years	0.6 years	0.1 years
40% Target run-off	ROI over 5yrs	15.32%	38.38%	61.45%	84.51%	107.58%	130.64%	179.33%	272.45%
	ROI over 10yrs	53.60%	84.32%	115.03%	145.75%	176.47%	207.19%	291.77%	422.36%

*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1.0%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost.

Water recovery rate: 95%

Scenario: Treating run-off water only. Low 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	**5.0% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	7.7 years	3.9 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-16.28%	11.63%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	9.75%	46.33%
Estimated total investment cost (present value^ over 5 years)		$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02
	Payback period	>10 years	>10 years	9.3 years	6.6 years	5.0 years	3.9 years	1.6 years	0.8 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-21.86%	-10.70%	0.46%	11.63%	67.44%	123.25%
	ROI over 10yrs	uneconomic	uneconomic	2.43%	17.07%	31.70%	46.33%	119.50%	192.67%
Estimated total investment cost (present value^ over 5 years)		$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$34940.00
	Payback period	7.7 years	5.0 years	3.5 years	2.6 years	2.0 years	1.6 years	0.5 years	0.6 years
30% Target run-off	ROI over 5yrs	-16.28%	0.46%	17.21%	33.95%	20.70%	67.44%	151.16%	89.97%
	ROI over 10yrs	9.75%	31.70%	53.65%	75.60%	97.55%	119.50%	229.25%	152.25%
Estimated total investment cost (present value^ over 5 years)		$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$34940.00	$34940.00
	Payback period	3.9 years	2.6 years	1.9 years	1.4 years	1.0 years	0.8 years	0.6 years	0.1 years
40% Target run-off	ROI over 5yrs	11.63%	33.95%	56.28%	78.60%	100.93%	123.25%	169.03%	258.70%
	ROI over 10yrs	46.33%	75.60%	104.87%	134.13%	163.40%	192.67%	269.47%	392.63%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1.0%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating run-off water only. Low ‘BENEFIT’ (fertiliser and water) values; low ‘COST’ (energy and labour) values*									
Interest (discount) rate	**7.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	8.7 years	4.2 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-18.89%	8.15%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	4.61%	39.48%
Estimated total investment cost (present value^ over 5 years)		$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37
	Payback period	>10 years	>10 years	>10 years	7.3 years	5.4 years	4.2 years	1.7 years	0.8 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	-13.48%	-2.67%	8.15%	62.22%	116.29%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	11.58%	25.53%	39.48%	109.22%	178.96%
Estimated total investment cost (present value^ over 5 years)		$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$34252.15
	Payback period	8.7 years	5.4 years	3.7 years	2.8 years	2.1 years	1.7 years	0.5 years	0.6 years
30% Target run-off	ROI over 5yrs	-18.89%	-2.67%	13.55%	29.77%	46.00%	62.22%	143.33%	159.40%
	ROI over 10yrs	4.61%	25.53%	46.46%	67.38%	88.30%	109.22%	213.83%	248.84%
Estimated total investment cost (present value^ over 5 years)		$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$34252.15	$34252.15
	Payback period	4.2 years	2.8 years	1.9 years	1.4 years	1.1 years	0.8 years	0.6 years	0.1 years
40% Target run-off	ROI over 5yrs	8.15%	29.77%	51.40%	73.03%	94.66%	116.29%	159.40%	245.87%
	ROI over 10yrs	39.48%	67.38%	95.27%	123.17%	151.07%	178.96%	248.84%	365.12%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1.0%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating all water (run-off and new water). Low 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	**2.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$28831.03	$35707.81	$35707.81	$35707.81	$35707.81	$35707.81	$43607.09	$50082.35
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
Estimated total investment cost (present value^ over 5 years)		$28831.03	$35707.81	$35707.81	$35707.81	$35707.81	$35707.81	$43607.09	$50082.35
	Payback period	>10 years	>10 years	>10 years	9.1 years	7.1 years	5.7 years	4.0 years	3.1 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	-25.51%	-16.20%	-6.89%	14.37%	32.77%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	4.47%	17.53%	30.59%	67.17%	98.96%
Estimated total investment cost (present value^ over 5 years)		$28831.03	$35707.81	$35707.81	$35707.81	$35707.81	$35707.81	$43607.09	$50082.35
	Payback period	7.0 years	7.1 years	5.2 years	4.1 years	3.3 years	2.7 years	2.0 years	1.5 years
30% Target run-off	ROI over 5yrs	-13.51%	-16.20%	-2.23%	11.73%	25.70%	39.67%	71.55%	99.16%
	ROI over 10yrs	15.20%	17.53%	37.12%	56.71%	76.29%	95.88%	150.76%	198.44%
Estimated total investment cost (present value^ over 5 years)		$28831.03	$35707.81	$35707.81	$35707.81	$35707.81	$35707.81	$43607.09	$50082.35
	Payback period	3.7 years	4.1 years	3.0 years	2.4 years	1.9 years	1.5 years	1.1 years	0.8 years
40% Target run-off	ROI over 5yrs	15.32%	11.73%	30.36%	48.98%	67.60%	86.22%	128.73%	165.55%
	ROI over 10yrs	53.60%	56.71%	82.82%	108.94%	135.06%	161.18%	234.34%	297.92%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1.0%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating all water (run-off and new water). Low 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	**5.0% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$28069.02	$34940.00	$34940.00	$34940.00	$34940.00	$34940.00	$42833.73	$49303.81
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
Estimated total investment cost (present value^ over 5 years)		$28069.02	$34940.00	$34940.00	$34940.00	$34940.00	$34940.00	$42833.73	$49303.81
	Payback period	>10 years	>10 years	>10 years	>10 years	7.9 years	6.3 years	4.2 years	2.8 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	-19.29%	-10.32%	9.72%	38.29%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	10.84%	23.16%	56.33%	95.31%
Estimated total investment cost (present value^ over 5 years)		$28069.02	$34940.00	$34940.00	$34940.00	$34940.00	$34940.00	$42833.73	$49303.81
	Payback period	7.7 years	7.9 years	5.7years	4.3 years	3.4 years	2.8 years	2.0 years	1.6 years
30% Target run-off	ROI over 5yrs	-16.28%	-19.29%	-5.84%	7.61%	21.06%	34.51%	64.59%	90.65%
	ROI over 10yrs	9.75%	10.84%	29.31%	47.79%	66.23%	84.74%	134.50%	177.64%
Estimated total investment cost (present value^ over 5 years)		$28069.02	$34940.00	$34940.00	$34940.00	$34940.00	$34940.00	$42833.73	$49303.81
	Payback period	3.9 years	4.3 years	3.2 years	2.5 years	2.0 years	1.6 years	1.1 years	0.9 years
40% Target run-off	ROI over 5yrs	11.63%	7.61%	25.55%	43.48%	61.42%	79.35%	119.45%	154.20%
	ROI over 10yrs	46.33%	47.79%	72.42%	97.05%	121.68%	146.31%	212.67%	270.19%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1.0%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating all water (run-off and new water). Low 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	**7.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$27386.37	$34252.15	$34252.15	$34252.15	$34252.15	$34252.15	$42140.91	$48606.34
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
Estimated total investment cost (present value^ over 5 years)		$27386.37	$34252.15	$34252.15	$34252.15	$34252.15	$34252.15	$42140.91	$48606.34
	Payback period	>10 years	>10 years	>10 years	>10 years	8.9 years	6.9 years	4.5 years	3.5 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	-22.18%	-13.53%	5.42%	21.87%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	4.65%	16.28%	46.46%	72.59%
Estimated total investment cost (present value^ over 5 years)		$27386.37	$34252.15	$34252.15	$34252.15	$34252.15	$34252.15	$42140.91	$48606.34
	Payback period	8.7 years	8.9 years	6.2 years	4.6 years	3.6 years	2.9 years	2.1 years	1.7 years
30% Target run-off	ROI over 5yrs	-18.89%	-22.18%	-9.21%	3.76%	16.73%	29.70%	58.13%	82.80%
	ROI over 10yrs	4.61%	4.65%	22.09%	39.54%	56.98%	74.42%	119.70%	158.89%
Estimated total investment cost (present value^ over 5 years)		$27386.37	$34252.15	$34252.15	$34252.15	$34252.15	$34252.15	$42140.91	$48606.34
	Payback period	4.2 years	4.6 years	3.4 years	2.6 years	2.0 years	1.6 years	1.2 years	0.9 years
40% Target run-off	ROI over 5yrs	8.15%	3.76%	21.06%	38.35%	55.64%	72.94%	110.84%	143.73%
	ROI over 10yrs	39.48%	39.54%	62.79%	86.05%	109.30%	132.56%	192.93%	245.19%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1.0%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating run-off water only (and discharging 20%). Low 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	2.5% pa	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	6.2 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-8.96%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	21.26%
Estimated total investment cost (present value^ over 5 years)		$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03
	Payback period	>10 years	>10 years	>10 years	>10 years	8.0 years	6.2 years	2.6 years	1.4 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	-18.06%	-8.96%	36.56%	82.09%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	9.13%	21.26%	81.89%	142.52%
Estimated total investment cost (present value^ over 5 years)		$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$35707.81
	Payback period	>10 years	8.0 years	5.5 years	4.1 years	3.2 years	2.6 years	1.0 years	1.1 years
30% Target run-off	ROI over 5yrs	uneconomic	-18.06%	-4.41%	9.25%	22.91%	36.56%	104.85%	120.53%
	ROI over 10yrs	uneconomic	9.13%	27.32%	45.51%	63.70%	81.89%	172.84%	209.29%
Estimated total investment cost (present value^ over 5 years)		$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$28831.03	$35707.81	$35707.81
	Payback period	6.2 years	4.1 years	3.0 years	2.3 years	1.8 years	1.4 years	1.1 years	0.5 years
40% Target run-off	ROI over 5yrs	-8.96%	9.25%	27.46%	45.67%	63.88%	82.09%	120.53%	194.04%
	ROI over 10yrs	21.26%	45.51%	69.76%	94.02%	118.27%	142.52%	209.29%	312.39%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1.0%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 75%									

Scenario: Treating run-off water only (and discharging 20%). Low ‘BENEFIT’ (fertiliser and water) values; low ‘COST’ (energy and labour) values*									
Interest (discount) rate	**5.0% pa**	Size of cucumber enterprise							
		2500 m²	3000 m²	3500 m²	4000 m²	4500 m²	5000 m²	7500 m²	10000 m²
Estimated total investment cost (present value^ over 5 years)		$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	6.8 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-11.87%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	15.53%
Estimated total investment cost (present value^ over 5 years)		$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02
	Payback period	>10 years	>10 years	>10 years	>10 years	9.0 years	6.82 years	2.7 years	1.4 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	-20.69%	-11.87%	32.19%	76.25%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	3.97%	15.53%	73.29%	131.05%
Estimated total investment cost (present value^ over 5 years)		$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$34940.00
	Payback period	>10 years	9.0 years	6.0 years	4.4 years	3.4 years	2.7 years	1.1 years	1.1 years
30% Target run-off	ROI over 5yrs	uneconomic	-20.69%	-7.47%	5.75%	18.97%	32.19%	98.29%	112.39%
	ROI over 10yrs	uneconomic	3.97%	21.30%	38.63%	55.96%	73.29%	159.93%	191.69%
Estimated total investment cost (present value^ over 5 years)		$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$28069.02	$34940.00	$34940.00
	Payback period	6.8 years	4.4 years	3.1 years	2.4 years	1.8 years	1.4 years	1.1 years	0.5 years
40% Target run-off	ROI over 5yrs	-11.87%	5.75%	23.38%	41.00%	58.63%	76.25%	112.39%	183.19%
	ROI over 10yrs	15.53%	38.63%	61.74%	84.84%	107.95%	131.05%	191.69%	288.92%

*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1.0%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost.

Water recovery rate: 75%

Scenario: Treating run-off water only (and discharging 20%). Low 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	**7.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	7.5 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-14.62%
	ROI over 10 yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	10.12%
Estimated total investment cost (present value^ over 5 years)		$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	7.5 years	2.8 years	1.5 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-14.62%	28.07%	70.76%
	ROI over 10 yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	10.12%	65.17%	120.23%
Estimated total investment cost (present value^ over 5 years)		$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$34252.15
	Payback period	>10 years	>10 years	6.6 years	4.7 years	4.0 years	2.8 years	1.1 years	1.1 years
30% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-10.35%	2.45%	15.26%	28.07%	92.10%	104.79%
	ROI over 10 yrs	uneconomic	uneconomic	15.62%	32.14%	48.66%	65.17%	147.76%	175.40%
Estimated total investment cost (present value^ over 5 years)		$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$27386.37	$34252.15	$34252.15
	Payback period	7.5 years	4.7 years	3.3 years	2.5 years	1.9 years	1.5 years	1.1 years	0.5 years
40% Target run-off	ROI over 5yrs	-14.62%	2.45%	19.53%	36.60%	53.68%	70.76%	104.79%	173.06%
	ROI over 10 yrs	10.12%	32.14%	54.16%	76.19%	98.12%	120.23%	175.40%	267.20%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1.0%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 75%									

Scenario: Treating run-off water only. Low 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**2.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	7.7 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-12.66%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	6.66%
Estimated total investment cost (present value^ over 5 years)		$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	7.7 years	2.4 years	1.2 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-12.66%	31.01%	74.68%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	6.66%	60.00%	113.33%
Estimated total investment cost (present value^ over 5 years)		$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$44944.69
	Payback period	>10 years	>10 years	6.5 years	4.4 years	3.2 years	2.4 years	0.8 years	0.8 years
30% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-8.29%	4.81%	17.91%	31.01%	96.51%	121.93%
	ROI over 10yrs	uneconomic	uneconomic	12.00%	28.00%	44.00%	60.00%	140.00%	185.11%
Estimated total investment cost (present value^ over 5 years)		$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$44944.69
	Payback period	7.7 years	4.4 years	2.9 years	2.1 years	1.5 years	1.2 years	0.8 years	0.2 years
40% Target run-off	ROI over 5yrs	-12.66%	4.81%	22.27%	39.74%	57.21%	74.68%	121.93%	195.90%
	ROI over 10yrs	6.66%	28.00%	49.33%	70.66%	92.00%	113.33%	185.11%	280.15%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating run-off water only. Low 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**5.0% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	8.8 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-14.85%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	3.14%
Estimated total investment cost (present value^ over 5 years)		$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	8.8 years	2.6 years	1.2 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-14.85%	27.72%	70.30%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	3.14%	54.72%	106.29%
Estimated total investment cost (present value^ over 5 years)		$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$43668.87
	Payback period	>10 years	>10 years	7.2 years	4.7 years	3.4 years	2.6 years	0.8 years	0.8 years
30% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-10.59%	2.18%	14.95%	27.72%	91.58%	115.25%
	ROI over 10yrs	uneconomic	uneconomic	8.30%	23.77%	39.24%	54.72%	132.07%	173.19%
Estimated total investment cost (present value^ over 5 years)		$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$43668.87	$43668.87
	Payback period	8.8 years	4.7 years	3.1 years	2.2 years	1.6 years	1.2 years	0.8 years	0.2 years
40% Target run-off	ROI over 5yrs	-14.85%	2.18%	19.21%	36.24%	53.27%	70.30%	115.25%	187.00%
	ROI over 10yrs	3.14%	23.77%	44.40%	65.03%	85.66%	106.29%	173.19%	264.26%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost.									
Water recovery rate: 95%									

Scenario: Treating run-off water only. Low 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	7.5% pa	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
Estimated total investment cost (present value^ over 5 years)		$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	2.7 years	1.2 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	24.58%	66.10%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	49.57%	99.42%
Estimated total investment cost (present value^ over 5 years)		$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$42526.56
	Payback period	>10 years	>10 years	8.2 years	5.1 years	3.6 years	2.7 years	0.9 years	0.8 years
30% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-12.80%	-0.34%	12.12%	24.58%	86.87%	108.93%
	ROI over 10yrs	uneconomic	uneconomic	4.70%	19.65%	34.61%	49.57%	124.35%	161.79%
Estimated total investment cost (present value^ over 5 years)		$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$42526.56
	Payback period	>10 years	5.1 years	3.2 years	2.3 years	1.6 years	1.2 years	0.8 years	0.3 years
40% Target run-off	ROI over 5yrs	uneconomic	-0.34%	16.27%	32.88%	49.49%	66.10%	108.93%	178.58%
	ROI over 10yrs	uneconomic	19.65%	39.60%	59.54%	79.48%	99.42%	161.79%	249.06%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating all water (run-off and new water). Low 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**2.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$38067.91	$44944.69	$44944.69	$44944.69	$44944.69	$44944.69	$52843.97	$59319.23
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
Estimated total investment cost (present value^ over 5 years)		$38067.91	$44944.69	$44944.69	$44944.69	$44944.69	$44944.69	$52843.97	$59319.23
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	5.7 years	4.0 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-5.62%	12.10%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	26.72%	54.84%
Estimated total investment cost (present value^ over 5 years)		$38067.91	$44944.69	$44944.69	$44944.69	$44944.69	$44944.69	$52843.97	$59319.23
	Payback period	>10 years	>10 years	>10 years	6.8 years	5.0 years	3.9 years	2.5 years	1.9 years
30% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	-11.23%	-0.13%	10.96%	41.56%	68.15%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	14.04%	28.30%	42.56%	90.08%	132.25%
Estimated total investment cost (present value^ over 5 years)		$38067.91	$44944.69	$44944.69	$44944.69	$44944.69	$44944.69	$52843.97	$59319.23
	Payback period	7.7 years	6.8 years	4.6 years	3.4 years	2.6 years	2.1 years	1.4 years	1.0 years
40% Target run-off	ROI over 5yrs	-12.66%	-11.23%	3.57%	18.36%	33.16%	47.95%	88.75%	124.20%
	ROI over 10yrs	6.66%	14.04%	33.05%	52.06%	71.07%	90.07%	153.43%	209.67%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating all water (run-off and new water). Low 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**5.0% pa**	Size of cucumber enterprise							
		2500 m²	3000 m²	3500 m²	4000 m²	4500 m²	5000 m²	7500 m²	10000 m²
Estimated total investment cost (present value^ over 5 years)		$36797.89	$43668.87	$43668.87	$43668.87	$43668.87	$43668.87	$51562.60	$58032.68
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
Estimated total investment cost (present value^ over 5 years)		$36797.89	$43668.87	$43668.87	$43668.87	$43668.87	$43668.87	$51562.60	$58032.68
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	6.2 years	4.3 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-8.85%	7.98%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	20.42%	46.34%
Estimated total investment cost (present value^ over 5 years)		$36797.89	$43668.87	$43668.87	$43668.87	$43668.87	$43668.87	$51562.60	$58032.68
	Payback period	>10 years	>10 years	>10 years	7.5 years	5.4 years	4.2 years	2.6 years	1.9 years
30% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	-13.90%	-3.14%	7.63%	36.72%	61.97%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	9.28%	22.94%	36.60%	80.63%	119.51%
Estimated total investment cost (present value^ over 5 years)		$36797.89	$43668.87	$43668.87	$43668.87	$43668.87	$43668.87	$51562.60	$58032.68
	Payback period	8.8 years	7.5 years	4.9 years	3.6 years	2.7 years	2.2 years	1.4 years	1.0 years
40% Target run-off	ROI over 5yrs	-14.85%	-13.90%	0.45%	14.80%	29.15%	43.50%	82.30%	115.97%
	ROI over 10yrs	3.14%	9.28%	27.49%	45.70%	63.92%	82.13%	140.84%	192.68%

*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost.

Water recovery rate: 95%

Scenario: Treating all water (run-off and new water). Low 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**7.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$35660.78	$42526.56	$42526.56	$42526.56	$42526.56	$42526.56	$50415.32	$56880.75
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
Estimated total investment cost (present value^ over 5 years)		$35660.78	$42526.56	$42526.56	$42526.56	$42526.56	$42526.56	$50415.32	$56880.75
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	6.8 years	4.6 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-11.88%	4.14%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	14.50%	38.43%
Estimated total investment cost (present value^ over 5 years)		$35660.78	$42526.56	$42526.56	$42526.56	$42526.56	$42526.56	$50415.32	$56880.75
	Payback period	>10 years	>10 years	>10 years	8.5 years	5.9 years	4.5 years	2.7 years	2.0 years
30% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	-16.43%	-5.98%	4.47%	32.18%	56.21%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	4.72%	17.81%	30.90%	71.74%	107.65%
Estimated total investment cost (present value^ over 5 years)		$35660.78	$42526.56	$42526.56	$42526.56	$42526.56	$42526.56	$50415.32	$56880.75
	Payback period	>10 years	8.5 years	5.4 years	3.8 years	2.9 years	2.3 years	1.5 years	1.1 years
40% Target run-off	ROI over 5yrs	uneconomic	-16.43%	-2.50%	11.43%	25.36%	39.29%	76.24%	108.28%
	ROI over 10yrs	uneconomic	4.72%	22.17%	39.62%	57.08%	74.53%	128.99%	176.87%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating run-off water only (and discharging 20%). Low 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	2.5% pa	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
Estimated total investment cost (present value^ over 5 years)		$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	4.5 years	2.2 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	3.43%	37.90%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	26.31%	68.42%
Estimated total investment cost (present value^ over 5 years)		$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91
	Payback period	>10 years	>10 years	>10 years	9.6 years	6.2 years	4.5 years	1.6 years	1.4 years
30% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	-17.26%	-6.91%	3.43%	55.14%	75.21%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	1.05%	13.68%	26.31%	89.47%	125.09%
Estimated total investment cost (present value^ over 5 years)		$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91	$38067.91
	Payback period	>10 years	9.6 years	5.6 years	3.8 years	2.8 years	2.2 years	1.4 years	0.7 years
40% Target run-off	ROI over 5yrs	uneconomic	-17.26%	-3.47%	10.32%	24.11%	37.90%	75.21%	133.61%
	ROI over 10yrs	uneconomic	1.05%	17.89%	34.73%	51.58%	68.42%	125.09%	200.12%

*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost.

Water recovery rate: 75%

Scenario: Treating run-off water only (and discharging 20%). Low 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**5.0% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
Estimated total investment cost (present value^ over 5 years)		$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	4.9 years	2.2 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	0.83%	34.44%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	22.14%	62.86%
Estimated total investment cost (present value^ over 5 years)		$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$43668.87
	Payback period	>10 years	>10 years	>10 years	>10 years	6.9 years	4.9 years	1.7 years	1.5 years
30% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	-9.25%	0.83%	51.25%	69.94%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	9.93%	22.14%	83.22%	115.68%
Estimated total investment cost (present value^ over 5 years)		$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$36797.89	$43668.87
	Payback period	>10 years	>10 years	6.1 years	4.0 years	2.9 years	2.2 years	1.5 years	0.7 years
40% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-5.89%	7.56%	21.00%	34.44%	69.94%	126.58%
	ROI over 10yrs	uneconomic	uneconomic	14.00%	30.29%	46.57%	62.86%	115.68%	187.57%
*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost.									
Water recovery rate: 75%									

Scenario: Treating run-off water only (and discharging 20%). Low 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	7.5% pa	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
	ROI over 10 yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic
Estimated total investment cost (present value^ over 5 years)		$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	5.3 years	2.3 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-1.65%	31.14%
	ROI over 10 yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	18.08%	57.44%
Estimated total investment cost (present value^ over 5 years)		$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$42526.56
	Payback period	>10 years	>10 years	>10 years	>10 years	7.7 years	5.3 years	1.7 years	1.5 years
30% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	-11.48%	-1.65%	47.53%	64.95%
	ROI over 10 yrs	uneconomic	uneconomic	uneconomic	uneconomic	6.27%	18.08%	77.12%	106.68%
Estimated total investment cost (present value^ over 5 years)		$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$35660.78	$42526.56	$42526.56
	Payback period	>10 years	>10 years	6.7 years	4.3 years	3.1 years	2.3 years	1.5 years	0.7 years
40% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-8.21%	4.91%	18.02%	31.14%	64.95%	119.93%
	ROI over 10 yrs	uneconomic	uneconomic	10.21%	25.95%	41.70%	57.44%	106.68%	175.57%

*Assumed costs: Fertiliser: $2.20/kL, increasing at 3%pa; Water: $1.00/kL, increasing at 1.5%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost.

Water recovery rate: 75%

Scenario: Treating run-off water only. High 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	**2.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00
	Payback period	>10 years	>10 years	>10 years	7.7 years	6.0 years	4.8 years	2.1 years	1.1 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	-18.26%	-8.04%	2.17%	53.26%	104.35%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	11.69%	25.66%	39.62%	109.43%	179.23%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00
	Payback period	4.8 years	3.3 years	2.4 years	1.8 years	1.4 years	1.1 years	0.3 years	immediate
20% Target run-off	ROI over 5yrs	2.17%	22.61%	43.04%	63.48%	83.91%	104.35%	206.52%	308.70%
	ROI over 10yrs	39.62%	67.54%	95.46%	123.39%	151.31%	179.23%	318.85%	458.47%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$35737.75
	Payback period	2.1 years	1.4 years	1.0 years	0.7 years	0.5 years	0.3 years	immediate	immediate
30% Target run-off	ROI over 5yrs	53.26%	83.91%	114.57%	145.22%	175.87%	206.52%	359.78%	394.82%
	ROI over 10yrs	109.43%	151.31%	193.20%	235.08%	276.97%	318.85%	528.28%	611.88%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$35737.75	$35737.75
	Payback period	1.1 years	0.7 years	0.4 years	0.2 years	<1.0 mth	immediate	immediate	immediate
40% Target run-off	ROI over 5yrs	104.35%	145.22%	186.09%	226.96%	267.83%	308.70%	394.82%	559.76%
	ROI over 10yrs	179.23%	235.08%	290.93%	346.77%	402.62%	458.47%	611.88%	849.17%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost.									
Water recovery rate: 95%									

Scenario: Treating run-off water only. High ‘BENEFIT’ (fertiliser and water) values; low ‘COST’ (energy and labour) values*									
Interest (discount) rate	5.0% pa	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13
	Payback period	>10 years	>10 years	>10 years	8.6 years	6.5 years	5.1 years	2.2 years	1.1 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	-20.94%	-11.06%	-1.18%	48.23%	97.64%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	6.15%	19.42%	32.69%	99.03%	165.37%
Estimated total investment cost (present value^ over 5 years)		$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13
	Payback period	5.1 years	3.5 years	2.5 years	1.9 years	1.5 years	1.1 years	0.3 years	immediate
20% Target run-off	ROI over 5yrs	-1.18%	18.59%	38.35%	58.11%	77.88%	97.64%	196.46%	295.28%
	ROI over 10yrs	32.69%	59.22%	85.76%	112.30%	138.84%	165.37%	298.06%	430.75%
Estimated total investment cost (present value^ over 5 years)		$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$34968.22
	Payback period	2.2 years	1.5 years	1.0 years	0.7 years	0.5 years	0.3 years	immediate	immediate
30% Target run-off	ROI over 5yrs	48.23%	77.88%	107.52%	137.17%	166.82%	196.46%	344.69%	376.18%
	ROI over 10yrs	99.03%	138.84%	178.64%	218.45%	258.26%	298.06%	497.09%	569.73%
Estimated total investment cost (present value^ over 5 years)		$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$34968.22	$34968.22
	Payback period	1.1 years	0.7 years	0.4 years	0.2 years	<1.0 mth	immediate	immediate	immediate
40% Target run-off	ROI over 5yrs	97.64%	137.17%	176.70%	216.23%	255.76%	295.28%	376.18%	534.91%
	ROI over 10yrs	165.37%	218.45%	271.52%	324.60%	377.67%	430.75%	569.73%	792.98%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating run-off water only. High 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	7.5% pa	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71
	Payback period	>10 years	>10 years	>10 years	9.8 years	7.2 years	5.5 years	2.3 years	1.2 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	-23.47%	-13.90%	-4.34%	43.49%	91.32%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	0.94%	13.55%	26.17%	89.26%	152.34%
Estimated total investment cost (present value^ over 5 years)		$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71
	Payback period	5.5 years	3.7 years	2.6 years	2.0 years	1.5 years	1.2 years	0.3 years	immediate
20% Target run-off	ROI over 5yrs	-4.34%	14.79%	33.93%	53.06%	72.19%	91.32%	186.99%	282.65%
	ROI over 10yrs	26.17%	51.41%	76.64%	101.87%	127.11%	152.34%	278.51%	404.68%
Estimated total investment cost (present value^ over 5 years)		$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$34278.82
	Payback period	2.3 years	1.5 years	1.0 years	0.7 years	0.5 years	0.3 years	immediate	immediate
30% Target run-off	ROI over 5yrs	43.49%	72.19%	100.89%	129.59%	158.29%	186.99%	330.48%	358.79%
	ROI over 10yrs	89.26%	127.11%	164.96%	202.81%	240.66%	278.51%	467.77%	530.84%
Estimated total investment cost (present value^ over 5 years)		$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$34278.82	$34278.82
	Payback period	1.2 years	0.7 years	0.4 years	0.2 years	<1.0 mth	immediate	immediate	immediate
40% Target run-off	ROI over 5yrs	91.32%	129.59%	167.85%	206.12%	244.38%	282.65%	358.79%	511.72%
	ROI over 10yrs	152.34%	202.81%	253.28%	303.75%	354.22%	404.68%	530.84%	741.12%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost.									
Water recovery rate: 95%									

Scenario: Treating all water (run-off and new water). High 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	**2.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$28846.00	$35737.75	$35737.75	$35737.75	$35737.75	$35737.75	$43652.01	$50142.24
	Payback period	>10 years	>10 years	>10 years	>10 years	8.8 years	7.1 years	4.9 years	3.9 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	-25.78%	-17.53%	1.28%	17.56%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	6.78%	18.65%	51.83%	80.65%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$35737.75	$35737.75	$35737.75	$35737.75	$35737.75	$43652.01	$50142.24
	Payback period	4.8 years	5.1 years	3.9 years	3.0 years	2.5 years	2.0 years	1.5 years	1.2 years
20% Target run-off	ROI over 5yrs	2.17%	-1.04%	15.46%	31.95%	48.45%	64.94%	102.56%	135.12%
	ROI over 10yrs	39.62%	42.38%	66.10%	89.83%	113.56%	137.29%	203.67%	261.31%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$35737.75	$35737.75	$35737.75	$35737.75	$35737.75	$43652.01	$50142.24
	Payback period	2.1 years	2.5 years	1.8 years	1.4 years	1.1 years	0.8 years	0.6 years	0.4 years
30% Target run-off	ROI over 5yrs	53.56%	48.45%	73.19%	97.93%	122.67%	147.41%	203.83%	252.67%
	ROI over 10yrs	109.43%	113.56%	149.16%	184.75%	220.34%	255.94%	355.50%	441.96%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$35737.75	$35737.75	$35737.75	$35737.75	$35737.75	$43652.01	$50142.24
	Payback period	1.1 years	1.4 years	1.0 years	0.7 years	0.5 years	0.3 years	0.1 years	<1.0 mth
40% Target run-off	ROI over 5yrs	104.35%	97.93%	130.92%	163.91%	196.89%	229.88%	305.11%	370.23%
	ROI over 10yrs	179.23%	184.75%	232.21%	279.67%	327.13%	374.58%	507.33%	622.61%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating all water (run-off and new water). High 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	**5.0% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$28083.13	$34968.22	$34968.22	$34968.22	$34968.22	$34968.22	$42876.06	$49360.24
	Payback period	>10 years	>10 years	>10 years	>10 years	9.9 years	7.9 years	5.3 years	4.1 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	-28.57%	-20.64%	-2.91%	12.45%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	0.46%	11.62%	41.65%	67.67%
Estimated total investment cost (present value^ over 5 years)		$28083.13	$34968.22	$34968.22	$34968.22	$34968.22	$34968.22	$42876.06	$49360.24
	Payback period	5.1 years	5.5 years	4.1 years	3.2 years	2.6 years	2.1 years	1.5 years	1.2 years
20% Target run-off	ROI over 5yrs	-1.18%	-4.76%	11.11%	26.98%	42.85%	58.73%	94.18%	124.89%
	ROI over 10yrs	32.69%	33.95%	56.27%	78.60%	100.92%	123.24%	183.30%	235.33%
Estimated total investment cost (present value^ over 5 years)		$28083.13	$34968.22	$34968.22	$34968.22	$34968.22	$34968.22	$42876.06	$49360.24
	Payback period	2.2 years	2.6 years	1.9 years	1.4 years	1.1 years	0.9 years	0.6 years	0.4 years
30% Target run-off	ROI over 5yrs	48.23%	42.85%	66.66%	90.47%	114.28%	138.09%	191.27%	237.34%
	ROI over 10yrs	99.03%	100.92%	134.41%	167.89%	201.38%	234.87%	324.95%	403.00%
Estimated total investment cost (present value^ over 5 years)		$28083.13	$34968.22	$34968.22	$34968.22	$34968.22	$34968.22	$42876.06	$49360.24
	Payback period	1.1 years	1.4 years	1.0 years	0.7 years	0.5 years	0.3 years	0.1 years	<1.0 mth
40% Target run-off	ROI over 5yrs	97.64%	90.47%	122.22%	153.96%	185.71%	217.45%	288.36%	349.79%
	ROI over 10yrs	165.37%	167.89%	212.54%	257.19%	301.84%	346.49%	466.60%	570.66%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost.									
Water recovery rate: 95%									

Scenario: Treating all water (run-off and new water). High 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	**7.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$27399.71	$34278.82	$34278.82	$34278.82	$34278.82	$34278.82	$42180.92	$48659.68
10% Target run-off	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	8.9 years	5.7 years	4.4 years
	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-23.54%	-6.79%	7.73%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	5.15%	32.40%	55.98%
Estimated total investment cost (present value^ over 5 years)		$27399.71	$34278.82	$34278.82	$34278.82	$34278.82	$34278.82	$42180.92	$48659.68
20% Target run-off	Payback period	5.5 years	6.0 years	4.4 years	3.4 years	2.7 years	2.2 years	1.6 years	1.2 years
	ROI over 5yrs	-4.34%	-8.24%	7.05%	22.34%	37.64%	52.93%	86.42%	115.47%
	ROI over 10yrs	26.17%	26.17%	47.20%	68.22%	89.25%	110.28%	164.79%	211.96%
Estimated total investment cost (present value^ over 5 years)		$27399.71	$34278.82	$34278.82	$34278.82	$34278.82	$34278.82	$42180.92	$48659.68
30% Target run-off	Payback period	2.3 years	2.7 years	2.0 years	1.5 years	1.1 years	0.9 years	0.6 years	0.4 years
	ROI over 5yrs	43.49%	37.64%	60.58%	83.52%	106.45%	129.39%	179.63%	223.20%
	ROI over 10yrs	89.26%	89.25%	120.79%	152.34%	183.88%	215.42%	297.19%	367.94%
Estimated total investment cost (present value^ over 5 years)		$27399.71	$34278.82	$34278.82	$34278.82	$34278.82	$34278.82	$42180.92	$48659.68
40% Target run-off	Payback period	1.2 years	1.5 years	1.1 years	0.7 years	0.5 years	0.3 years	0.2 years	<1.0 mth
	ROI over 5yrs	91.32%	83.52%	114.10%	144.69%	175.27%	205.86%	272.84%	330.93%
	ROI over 10yrs	152.34%	152.34%	194.39%	236.45%	278.51%	320.56%	429.59%	523.92%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating run-off water only (and discharging 20%). High 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	2.5% pa	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	8.0 years	3.4 years	1.9 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-19.34%	21.00%	61.33%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	10.22%	65.34%	120.45%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00
	Payback period	8.0 years	5.4 years	3.9 years	3.0 years	2.3 years	1.9 years	0.7 years	0.2 years
20% Target run-off	ROI over 5yrs	-19.34%	-3.20%	12.93%	29.06%	45.19%	61.33%	141.99%	222.66%
	ROI over 10yrs	10.22%	32.27%	54.31%	76.36%	98.40%	120.45%	230.67%	340.90%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$35737.75
	Payback period	3.4 years	2.3 years	1.7 years	1.3 years	0.9 years	0.7 years	0.1 years	0.1 years
30% Target run-off	ROI over 5yrs	21.00%	45.19%	69.39%	93.59%	117.79%	141.99%	262.99%	290.65%
	ROI over 10yrs	65.34%	98.40%	131.47%	164.54%	197.60%	230.67%	396.01%	462.01%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$35737.75	$35737.75
	Payback period	1.9 years	1.3 years	0.9 years	0.6 years	0.4 years	0.2 years	0.1 years	immediate
40% Target run-off	ROI over 5yrs	61.33%	93.59%	125.86%	158.12%	190.39%	222.66%	290.65%	420.87%
	ROI over 10yrs	120.45%	164.54%	208.63%	252.72%	296.81%	340.90%	462.01%	649.34%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost.									
Water recovery rate: 75%									

Scenario: Treating run-off water only (and discharging 20%). High 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	**5.0% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	8.9 years	3.6 years	2.0 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-21.98%	17.02%	56.03%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	4.75%	57.13%	109.51%
Estimated total investment cost (present value^ over 5 years)		$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13
	Payback period	8.9 years	5.8 years	4.1 years	3.1 years	2.4 years	2.0 years	0.7 years	0.2 years
20% Target run-off	ROI over 5yrs	-21.98%	-6.38%	9.22%	24.83%	40.43%	56.03%	134.05%	212.07%
	ROI over 10yrs	4.75%	25.70%	46.65%	67.60%	88.56%	109.51%	214.26%	319.01%
Estimated total investment cost (present value^ over 5 years)		$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$34968.22
	Payback period	3.6 years	2.4 years	1.8 years	1.3 years	1.0 years	0.7 years	0.1 years	0.1 years
30% Target run-off	ROI over 5yrs	17.02%	40.43%	63.83%	87.24%	110.64%	134.05%	251.07%	275.93%
	ROI over 10yrs	57.13%	88.56%	119.98%	151.41%	182.83%	214.26%	371.39%	428.74%
Estimated total investment cost (present value^ over 5 years)		$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$28083.13	$34968.22	$34968.22
	Payback period	2.0 years	1.3 years	0.9 years	0.6 years	0.4 years	0.2 years	0.1 years	immediate
40% Target run-off	ROI over 5yrs	56.03%	87.24%	118.45%	149.65%	180.86%	212.07%	275.93%	401.24%
	ROI over 10yrs	109.51%	151.41%	193.31%	235.21%	277.11%	319.01%	428.74%	604.98%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost.									
Water recovery rate: 75%									

Scenario: Treating run-off water only (and discharging 20%). High 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	7.5% pa	Size of cucumber enterprise							
		2500 m²	3000 m²	3500 m²	4000 m²	4500 m²	5000 m²	7500 m²	10000 m²
Estimated total investment cost (present value^ over 5 years)		$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	3.8 years	2.0 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	13.28%	51.05%
	ROI over 10 yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	49.41%	99.22%
Estimated total investment cost (present value^ over 5 years)		$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71
	Payback period	>10 years	6.3 years	4.4 years	3.3 years	2.6 years	2.0 years	0.7 years	0.2 years
20% Target run-off	ROI over 5yrs	uneconomic	-9.37%	5.73%	20.84%	35.94%	51.05%	126.57%	202.09%
	ROI over 10 yrs	uneconomic	19.53%	39.45%	59.37%	79.30%	99.22%	198.83%	298.43%
Estimated total investment cost (present value^ over 5 years)		$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$34278.82
	Payback period	3.8 years	2.6 years	1.8 years	1.3 years	1.0 years	0.7 years	0.1 years	0.1 years
30% Target run-off	ROI over 5yrs	13.28%	35.94%	58.60%	81.25%	103.91%	126.57%	239.85%	262.20%
	ROI over 10 yrs	49.41%	79.30%	109.18%	139.06%	168.94%	198.83%	348.24%	398.03%
Estimated total investment cost (present value^ over 5 years)		$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$27399.71	$34278.82	$34278.82
	Payback period	2.0 years	1.3 years	0.9 years	0.6 years	0.4 years	0.2 years	0.1 years	immediate
40% Target run-off	ROI over 5yrs	51.05%	81.25%	111.46%	141.67%	171.88%	202.09%	262.20%	382.94%
	ROI over 10 yrs	99.22%	139.06%	178.90%	218.75%	258.59%	298.43%	398.03%	564.04%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost.									
Water recovery rate: 75%									

Scenario: Treating run-off water only. High 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**2.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	3.4 years	1.7 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	16.09%	54.78%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	45.47%	93.95%
Estimated total investment cost (present value^ over 5 years)		$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88
	Payback period	>10 years	6.2 years	4.1 years	2.9 years	2.2 years	1.7 years	0.5 years	0.1 years
20% Target run-off	ROI over 5yrs	uneconomic	-7.13%	8.35%	23.83%	39.31%	54.78%	132.18%	209.57%
	ROI over 10yrs	uneconomic	16.37%	35.77%	55.16%	74.56%	93.95%	190.93%	287.91%
Estimated total investment cost (present value^ over 5 years)		$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$44974.63
	Payback period	3.4 years	2.2 years	1.5 years	1.0 years	0.7 years	0.5 years	immediate	immediate
30% Target run-off	ROI over 5yrs	16.09%	39.39%	62.52%	85.74%	108.96%	132.18%	248.26%	293.20%
	ROI over 10yrs	45.47%	74.56%	103.65%	132.74%	161.84%	190.93%	336.40%	418.24%
Estimated total investment cost (present value^ over 5 years)		$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$44974.63	$44974.63
	Payback period	1.7 years	1.0 years	0.7 years	0.4 years	0.2 years	0.1 years	immediate	immediate
40% Target run-off	ROI over 5yrs	54.78%	85.74%	116.70%	147.65%	178.61%	209.57%	293.20%	424.26%
	ROI over 10yrs	93.95%	132.74%	171.54%	210.33%	249.12%	287.91%	418.24%	590.98%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating run-off water only. High 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**5.0% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	3.6 years	1.7 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	13.08%	50.78%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	40.32%	87.09%
Estimated total investment cost (present value^ over 5 years)		$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00
	Payback period	>10 years	6.7 years	4.3 years	3.1 years	2.3 years	1.7 years	0.5 years	0.1 years
20% Target run-off	ROI over 5yrs	uneconomic	-9.53%	5.54%	20.62%	35.70%	50.78%	126.17%	201.55%
	ROI over 10yrs	uneconomic	12.25%	30.96%	49.67%	68.38%	87.09%	180.63%	274.17%
Estimated total investment cost (present value^ over 5 years)		$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00
	Payback period	3.6 years	2.3 years	1.5 years	1.1 years	0.8 years	0.5 years	immediate	immediate
30% Target run-off	ROI over 5yrs	13.08%	35.70%	58.32%	80.93%	103.55%	126.17%	239.25%	281.06%
	ROI over 10yrs	40.32%	68.38%	96.44%	124.50%	152.57%	180.63%	320.95%	395.36%
Estimated total investment cost (present value^ over 5 years)		$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00
	Payback period	1.7 years	1.1 years	0.7 years	0.4 years	0.2 years	0.1 years	immediate	immediate
40% Target run-off	ROI over 5yrs	50.78%	80.93%	111.09%	141.24%	171.40%	201.55%	281.06%	408.08%
	ROI over 10yrs	87.09%	124.50%	161.92%	199.34%	236.76%	274.17%	395.36%	560.48%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating run-off water only. High ‘BENEFIT’ (fertiliser and water) values; high ‘COST’ (energy and labour) values*									
Interest (discount) rate	**7.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	3.8 years	1.8 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	10.21%	46.95%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	35.32%	80.43%
Estimated total investment cost (present value^ over 5 years)		$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12
	Payback period	>10 years	7.5 years	4.6 years	3.2 years	2.4 years	1.8 years	0.5 years	0.1 years
20% Target run-off	ROI over 5yrs	uneconomic	-11.83%	2.86%	17.56%	32.25%	46.95%	120.42%	193.90%
	ROI over 10yrs	uneconomic	8.26%	26.30%	44.34%	62.38%	80.43%	170.64%	260.85%
Estimated total investment cost (present value^ over 5 years)		$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$42553.24
	Payback period	3.8 years	2.4 years	1.6 years	1.1 years	0.8 years	0.5 years	immediate	immediate
30% Target run-off	ROI over 5yrs	10.21%	32.25%	54.30%	76.34%	98.38%	120.42%	230.63%	269.58%
	ROI over 10yrs	35.32%	62.38%	89.45%	116.51%	143.57%	170.64%	305.96%	373.55%
Estimated total investment cost (present value^ over 5 years)		$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$42533.24	$42533.24
	Payback period	1.8 years	1.1 years	0.7 years	0.4 years	0.2 years	0.1 years	immediate	immediate
40% Target run-off	ROI over 5yrs	46.95%	76.34%	105.73%	135.12%	164.51%	193.90%	269.58%	392.77%
	ROI over 10yrs	80.43%	116.51%	152.60%	188.68%	224.77%	260.85%	373.55%	531.40%

*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost.

Water recovery rate: 95%

Scenario: Treating all water (run-off and new water). High 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**2.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$38082.88	$44974.63	$44974.63	$44974.63	$44974.63	$44974.63	$52888.88	$59379.11
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	7.2 years	5.1 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-16.41%	-0.73%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	15.13%	40.64%
Estimated total investment cost (present value^ over 5 years)		$38082.88	$44974.63	$44974.63	$44974.63	$44974.63	$44974.63	$52888.88	$59379.11
	Payback period	>10 years	9.0 years	6.1 years	4.5 years	3.5 years	2.8 years	1.8 years	1.4 years
20% Target run-off	ROI over 5yrs	uneconomic	-21.36%	-8.25%	4.85%	17.96%	31.07%	67.18%	98.54%
	ROI over 10yrs	uneconomic	3.65%	20.92%	38.20%	55.47%	72.75%	130.26%	181.29%
Estimated total investment cost (present value^ over 5 years)		$38082.88	$44974.63	$44974.63	$44974.63	$44974.63	$44974.63	$52888.88	$59379.11
	Payback period	3.4 years	3.5 years	2.5 years	1.9 years	1.5 years	1.1 years	0.7 years	0.5 years
30% Target run-off	ROI over 5yrs	16.09%	17.96%	37.62%	57.28%	76.94%	96.60%	150.77%	197.81%
	ROI over 10yrs	45.47%	55.47%	81.38%	107.30%	133.21%	159.12%	245.40%	321.93%
Estimated total investment cost (present value^ over 5 years)		$38082.88	$44974.63	$44974.63	$44974.63	$44974.63	$44974.63	$52888.88	$59379.11
	Payback period	1.7 years	1.9 years	1.3 years	1.0 years	0.7 years	0.5 years	0.2 years	0.1 years
40% Target run-off	ROI over 5yrs	54.78%	57.28%	83.49%	109.71%	135.92%	162.13%	234.36%	297.08%
	ROI over 10yrs	93.95%	107.30%	141.84%	176.39%	210.94%	245.49%	360.53%	462.58%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%									

Scenario: Treating all water (run-off and new water). Low 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	**5.0% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$36812.00	$43697.09	$43697.09	$43697.09	$43697.09	$43697.09	$51604.93	$58089.11
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	8.0 years	5.5 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-19.33%	-4.45%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	9.14%	32.16%
Estimated total investment cost (present value^ over 5 years)		$36812.00	$43697.09	$43697.09	$43697.09	$43697.09	$43697.09	$51604.93	$58089.11
	Payback period	>10 years	>10 years	6.7 years	4.8 years	3.7 years	2.9 years	1.9 years	1.4 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-11.09%	1.62%	14.32%	27.02%	61.33%	91.10%
	ROI over 10yrs	uneconomic	uneconomic	15.58%	32.10%	48.61%	65.12%	118.29%	165.21%
Estimated total investment cost (present value^ over 5 years)		$36812.00	$43697.09	$43697.09	$43697.09	$43697.09	$43697.09	$51604.93	$58089.11
	Payback period	3.6 years	3.7 years	2.6 years	2.0 years	1.5 years	1.2 years	0.7 years	0.5 years
30% Target run-off	ROI over 5yrs	13.08%	14.32%	33.37%	52.42%	71.48%	90.53%	142.00%	186.65%
	ROI over 10yrs	40.32%	48.61%	73.37%	98.14%	122.91%	147.68%	227.43%	297.82%
Estimated total investment cost (present value^ over 5 years)		$36812.00	$43697.09	$43697.09	$43697.09	$43697.09	$43697.09	$51604.93	$58089.11
	Payback period	1.7 years	2.0 years	1.4 years	1.0 years	0.7 years	0.5 years	0.2 years	0.1 years
40% Target run-off	ROI over 5yrs	50.78%	52.42%	77.83%	103.23%	128.64%	154.04%	222.67%	282.20%
	ROI over 10yrs	87.09%	98.14%	131.17%	164.19%	197.21%	230.24%	336.58%	430.43%

*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost.

Water recovery rate: 95%

Scenario: Treating all water (run-off and new water). High 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**7.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$35674.12	$42553.24	$42553.24	$42553.24	$42553.24	$42553.24	$50455.33	$56934.09
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	9.1 years	5.9 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-22.08%	-7.92%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	3.53%	25.15%
Estimated total investment cost (present value^ over 5 years)		$35674.12	$42553.24	$42553.24	$42553.24	$42553.24	$42553.24	$50455.33	$56934.09
	Payback period	>10 years	>10 years	7.4 years	5.2 years	3.9 years	3.1 years	2.0 years	1.5 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-13.77%	-1.45%	10.87%	23.19%	55.85%	84.15%
	ROI over 10yrs	uneconomic	uneconomic	10.49%	26.28%	42.06%	57.85%	107.06%	150.29%
Estimated total investment cost (present value^ over 5 years)		$35674.12	$42553.24	$42553.24	$42553.24	$42553.24	$42553.24	$50455.33	$56934.09
	Payback period	3.8 years	3.9 years	2.8 years	2.0 years	1.5 years	1.2 years	0.8 years	0.5 years
30% Target run-off	ROI over 5yrs	10.21%	10.87%	29.35%	47.83%	66.31%	84.79%	133.77%	176.23%
	ROI over 10yrs	35.32%	42.06%	65.74%	89.42%	113.10%	136.77%	210.59%	275.44%
Estimated total investment cost (present value^ over 5 years)		$35674.12	$42553.24	$42553.24	$42553.24	$42553.24	$42553.24	$50455.33	$56934.09
	Payback period	1.8 years	2.0 years	1.4 years	1.0 years	0.7 years	0.5 years	0.2 years	0.1 years
40% Target run-off	ROI over 5yrs	46.95%	47.83%	72.47%	97.11%	121.75%	146.39%	211.70%	268.30%
	ROI over 10yrs	80.43%	89.42%	120.99%	152.56%	184.13%	215.70%	314.11%	400.58%

*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost.

Water recovery rate: 95%

Scenario: Treating run-off water only (and discharging 20%). High 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**2.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	6.4 years	3.0 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-8.35%	22.20%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	14.82%	53.12%
Estimated total investment cost (present value^ over 5 years)		$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88
	Payback period	>10 years	>10 years	7.9 years	5.3 years	3.9 years	3.0 years	1.1 years	0.4 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-14.46%	-2.24%	9.98%	22.20%	83.30%	144.40%
	ROI over 10yrs	uneconomic	uneconomic	7.19%	22.50%	37.81%	53.12%	129.68%	206.24%
Estimated total investment cost (present value^ over 5 years)		$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$44974.63
	Payback period	6.4 years	3.9 years	2.7 years	1.9 years	1.4 years	1.1 years	0.2 years	0.2 years
30% Target run-off	ROI over 5yrs	-8.35%	9.98%	28.31%	46.64%	64.97%	83.30%	174.95%	210.42%
	ROI over 10yrs	14.84%	37.81%	60.78%	83.75%	106.71%	129.68%	244.52%	309.14%
Estimated total investment cost (present value^ over 5 years)		$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$38082.88	$44974.63	$44974.63
	Payback period	3.0 years	1.9 years	1.3 years	0.9 years	0.6 years	0.4 years	0.2 years	immediate
40% Target run-off	ROI over 5yrs	22.20%	46.64%	71.08%	95.52%	119.96%	144.40%	210.42%	313.89%
	ROI over 10yrs	53.12%	83.75%	114.37%	144.99%	175.62%	206.24%	309.14%	445.51%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 75%									

Scenario: Treating run-off water only (and discharging 20%). Low 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	5.0% pa	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	7.0 years	3.2 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-10.72%	19.03%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	10.78%	47.70%
Estimated total investment cost (present value^ over 5 years)		$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00
	Payback period	>10 years	>10 years	8.9 years	5.8 years	4.1 years	3.2 years	1.1 years	0.4 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	-16.68%	-4.77%	7.13%	19.03%	78.55%	138.07%
	ROI over 10yrs	uneconomic	uneconomic	3.39%	18.16%	32.93%	47.70%	121.55%	195.40%
Estimated total investment cost (present value^ over 5 years)		$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$43697.09
	Payback period	7.0 years	4.1 years	2.8 years	2.0 years	1.5 years	1.1 years	0.2 years	0.2 years
30% Target run-off	ROI over 5yrs	-10.72%	7.13%	24.99%	42.84%	60.70%	78.55%	167.83%	200.84%
	ROI over 10yrs	10.78%	32.93%	55.09%	77.24%	99.40%	121.55%	232.33%	291.07%
Estimated total investment cost (present value^ over 5 years)		$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$36812.00	$43697.09	$43697.09
	Payback period	3.2 years	2.0 years	1.3 years	0.9 years	0.6 years	0.4 years	0.2 years	immediate
40% Target run-off	ROI over 5yrs	19.03%	42.84%	66.65%	90.46%	114.26%	138.07%	200.84%	301.12%
	ROI over 10yrs	47.70%	77.24%	106.78%	136.32%	165.86%	195.40%	291.07%	421.43%
*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 75%									

Scenario: Treating run-off water only (and discharging 20%). High 'BENEFIT' (fertiliser and water) values; high 'COST' (energy and labour) values*									
Interest (discount) rate	**7.5% pa**	Size of cucumber enterprise							
		2500 m^2	3000 m^2	3500 m^2	4000 m^2	4500 m^2	5000 m^2	7500 m^2	10000 m^2
Estimated total investment cost (present value^ over 5 years)		$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12
	Payback period	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	7.8 years	3.3 years
10% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	-12.99%	16.01%
	ROI over 10 yrs	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	uneconomic	6.83%	42.44%
Estimated total investment cost (present value^ over 5 years)		$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12
	Payback period	>10 years	>10 years	>10 years	6.3 years	4.4 years	3.3 years	1.1 years	0.4 years
20% Target run-off	ROI over 5yrs	uneconomic	uneconomic	uneconomic	-7.19%	4.41%	16.01%	74.02%	132.02%
	ROI over 10 yrs	uneconomic	uneconomic	uneconomic	13.95%	28.20%	42.44%	113.66%	184.88%
Estimated total investment cost (present value^ over 5 years)		$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$42553.24
	Payback period	7.8 years	4.4 years	2.9 years	2.1 years	1.5 years	1.1 years	0.2 years	0.2 years
30% Target run-off	ROI over 5yrs	-12.99%	4.41%	21.81%	39.21%	56.62%	74.02%	161.03%	191.77%
	ROI over 10 yrs	6.83%	28.20%	49.56%	70.93%	92.30%	113.66%	220.49%	273.86%
Estimated total investment cost (present value^ over 5 years)		$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$35674.12	$42553.24	$42553.24
	Payback period	3.3 years	2.1 years	1.4 years	1.0 years	0.7 years	0.4 years	0.2 years	immediate
40% Target run-off	ROI over 5yrs	16.01%	39.21%	62.42%	85.62%	108.82%	132.02%	191.77%	289.03%
	ROI over 10 yrs	42.44%	70.93%	99.42%	127.91%	156.39%	184.88%	273.86%	398.47%

*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.40/cycle, increasing at 3%pa; Labour: $25/hr, increasing at 1.5%pa; Electricity: $0.50/kWh, increasing at 5%pa; General maintenance and repairs: 0.5% of purchase cost.

Water recovery rate: 75%

Appendix 2 – Water Futures – the wash up on ultrafiltration for water disinfection in hydroponics

The following are reproduced slides from the technical presentation delivered at the Protected Cropping Australia 2015 industry conference.

Water Futures

The wash up on ultrafiltration
for water disinfection in hydroponics

Primary Principles Pty Ltd

www.primaryprinciples.com.au

Background

Primary Principles Pty Ltd with the support of Horticulture Innovation Australia Ltd and the collaboration of NSW DPI is currently running a series of trials to test ultrafiltration as a viable low cost water disinfection and nutrient solution recycling option.

The objective is to confirm whether this technology is effective (and feasible) in the farm situation (including small to medium enterprises) and so provide greenhouse and hydroponic managers with another option in water disinfection.

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Mr Rene de Jong, Berghof Membrane Technology
Mr Larry James, Aqua Solutions

Horticulture Innovation Australia

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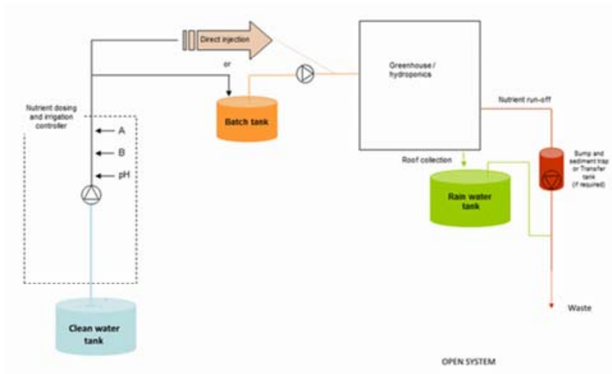
Open hydroponics

- Simple set up and management…
  - ➢Run-off might be 20, 30, 40% of the crop water demand
  - ➢Value in fertiliser and water around $4-6/kL
  - ➢Plus costs of environmental management



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Farm hygiene

- Preventing pathogens from getting into your greenhouse or hydroponic system and crop is one of the most effective methods of control.
- Considering the 20 more common pathogens of concern for greenhouse vegetable growers, 65% can be spread in water.
- Any source of water that may have contact with soil or plant material, is potentially contaminated and needs to be disinfected before use.
- The opportunity cost of diseases in greenhouse crops is around 10 - 15% of potential income.

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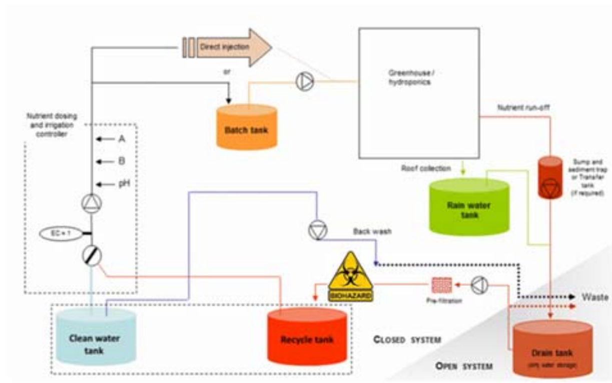
Simple reuse hydroponics

- Making more efficient use of water and fertiliser…
  - What else is in the water?



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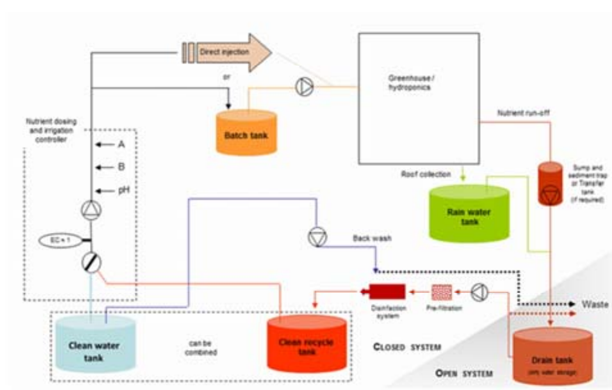
Closed hydroponics

- *ALL* water used in hydroponics and greenhouses should be disinfected
- Minimise impact on nutrient profile



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Disinfection methods

- There are three essential performance benchmarks:
  1. it has to reliably remove the target organisms,
  2. it has to be financially feasible,
  3. it has to be practical (fit in with farm operations and resources).
- There are five main categories of disinfection methods:

  Chemical disinfection
  Ultraviolet radiation (UV)
  Thermal disinfection
  Biological filtration
  Fine pore filtration

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Chemical disinfection

- Chemical disinfection is any treatment method where an active compound is used to destroy or denature microorganisms
- Chlorine (sodium/calcium hypochlorite, chlorine dioxide), Iodine and bromine, Ozone, hydrogen peroxide, peracetic acid (and acids/alkalis generally), copper and silver ions
- Dose and contact time
- Indiscriminate
- Barriers and bunkers
- Interactions and Residues

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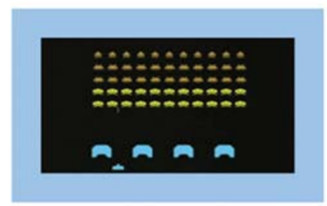
Ultraviolet radiation (UV)

- Many ways similar to chemical disinfection - an active compound used to destroy or denature microorganisms
- Established and proven technology
- Dose and contact time
- Indiscriminate
- Barriers and bunkers
- Turbidity
- Interactions



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Thermal (heat) disinfection

- Heat treating water is a well established, reliable and highly effective method of disinfection
- High energy input (and cost) more readily offset in cooler climates in which greenhouse heating is used for longer periods of the year
- Temperature and time
- Unaffected by water quality
- Residual heat

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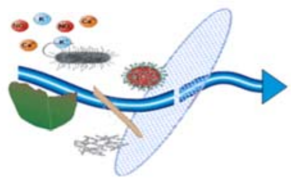
Filtration

- Filtration offers a direct, mechanical (physical) means to remove pathogens (and other materials) from water
- Biofiltration creates an environment in which beneficial or benign organisms remove pathogens (and other materials) from water



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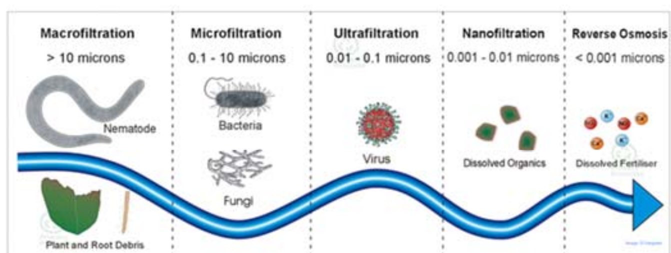
Ultrafiltration



- Removal of contaminants from 0.1 down to 0.01 microns
- Bacterial plant pathogens ≈ 0.2 microns (eg *Clavibacter*)
- Fungal plant pathogens ≈ 0.5 microns (eg *Fusarium*)
- Viral plant pathogens ≈ 0.02 microns (eg CGMMV)
- Dissolved nutrients are not removed
- Used successfully in industrial and domestic situations but on the farm…
    - plant debris, algae and other organic matter, microorganisms and exudates, substrates, size of plant pathogens

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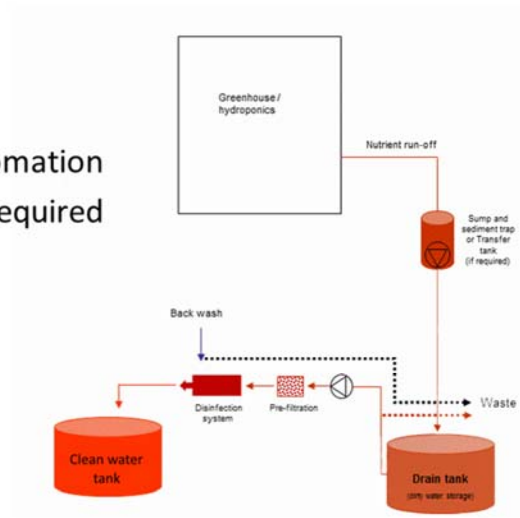
Set up

- Varies depending on existing infrastructure and level of automation
- Sizing of systems depends on required water treatment volume
- Prefiltration
- Water storage
- Backwashing
- Sensors, float valves
- Pumps



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Benefit : cost

	Up to 20kL		Up to 40kL		Up to 80kL	
Installation	$26,000		$34,000		$53,500	
Production area	0.5 ha	1 ha	0.5 ha	1 ha	0.5 ha	1 ha
Treat runoff only						
10% runoff	0.33 / 0.37	0.65 / 0.73				
20% runoff	0.65 / 0.73	1.30 / 1.46				
30% run-off	0.98 / 1.10			1.60 / 1.81		
Treat full supply						
No runoff			0.00 / 0.00			0.00 / 0.00
10% runoff			0.27 / 0.30			0.44 / 0.53
20% runoff			0.53 / 0.60			0.89 / 1.06
30% run-off			0.80 / 0.90			1.33 / 1.58

No crop saving due to less disease

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Benefit : cost

	Up to 20kL		Up to 40kL		Up to 80kL	
Installation	$26,000		$34,000		$53,500	
Production area	0.5 ha	1 ha	0.5 ha	1 ha	0.5 ha	1 ha
Treat runoff only						
10% runoff	0.62 / 0.68	1.24 / 1.36				
20% runoff	0.95 / 1.04	1.89 / 2.09				
30% run-off	1.27 / 1.41			2.08 / 2.32		
Treat full supply						
No runoff			0.24 / 0.26			0.40 / 0.45
10% runoff			0.51 / 0.56			0.85 / 0.98
20% runoff			0.77 / 0.86			1.29 / 1.51
30% run-off			1.04 / 1.16			1.73 / 2.04

1% crop saving due to less disease

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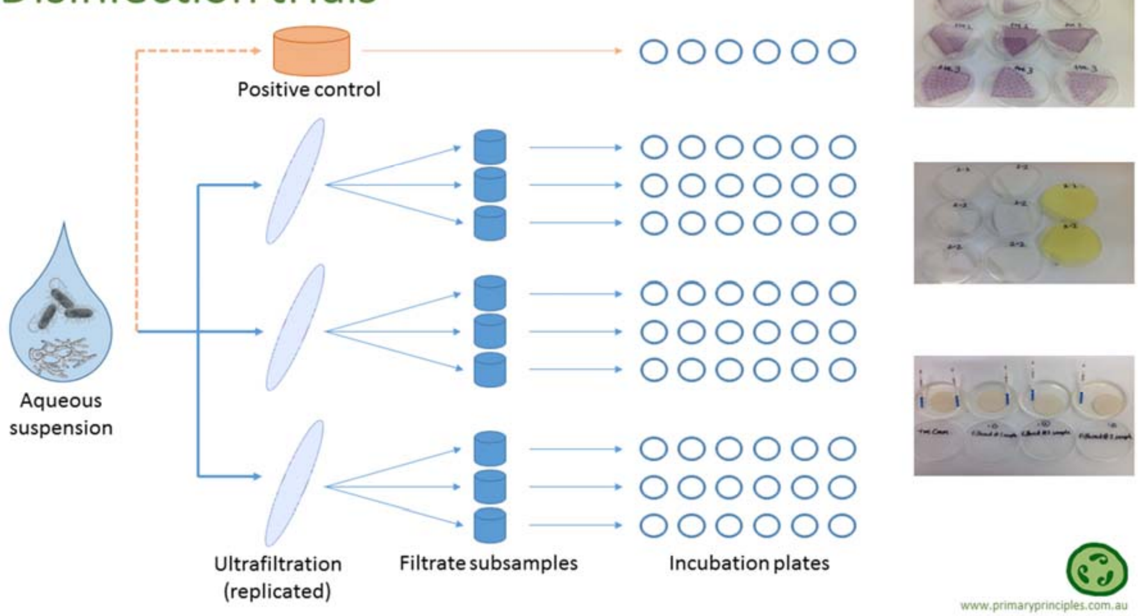
Disinfection trials



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Assessment	Filter system	Microorganism	Est. concentration	Prefilter (positive control)	Filtrate 1	Filtrate 2	Filtrate 3	Result (preliminary*)
1	A	*F. oxysporum*	2400 conidia/ml	✓	✖	✖	✖	👍
2	A	*F. oxysporum*	100 conidia/ml	✓	✖	✖	✖	👍
3	A	*F. oxysporum*	100 conidia/ml	✓	✖	✖	✖	👍
3a	A	*P. syringae*	Not estimated	✓	✓	✓	✓	👎
4	A	*Pythium spp* (*P. irregulare, P. spinosum, P. dissotochum*)	100 cfu/ml	✓	✖	✖	✖	👍
5	A	*P. dissotochum*	100 cfu/ml	✓	✖	✖	✖	👍
6	A	*C. michiganensis*	5000 Cmm/ml	✓	✓	✓	✓	👎
7	A	*C. michiganensis*	5000 Cmm/ml	✓	✓	✓	✓	👎
8	B	*C. michiganensis*	5000 Cmm/ml	✓	✖	✖	✖	👍
9	B	*C. michiganensis*	5000 Cmm/ml	✓	✓	✓	✓	👎
10	B	*C. michiganensis*	5000 Cmm/ml	✓	✓	✓	✓	👎
11	C	*C. michiganensis*	5000 Cmm/ml	✓	✖	✖	✖	👍

* Trials are incomplete. Please check with final project results prior to relying on these results

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The wash-up

- Removal of fungal pathogens is confirmed. Available technology is effective and economically feasible.
- Mixed results with the removal of bacterial pathogens.

  Further work
  - to determine reason for failure of some filtration
  - repeat tests with 'successful' membranes to confirm results
  - conduct tests with 'successful' membranes under farm conditions to confirm feasibility
  - determine detection limits to facilitate testing of farm situations.
- Ultrafiltration leaves nutrient profile of run-off water unchanged.
- Filtration systems can be readily installed;
  - in series to enhance filtration objectives
  - in parallel to increase treatment volumes
- Ultrafiltration is economically feasible from small to large water volumes

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Survey

https://sites.google.com/site/sustainablehydroponics

or google: “ultrafiltration hydroponics”

…do you have a disinfection system? what type?

how much does/did it cost to install?

how much water does it treat in 24hrs?

how much does it cost to run and maintain?

…do you know whether your disinfection system is working?

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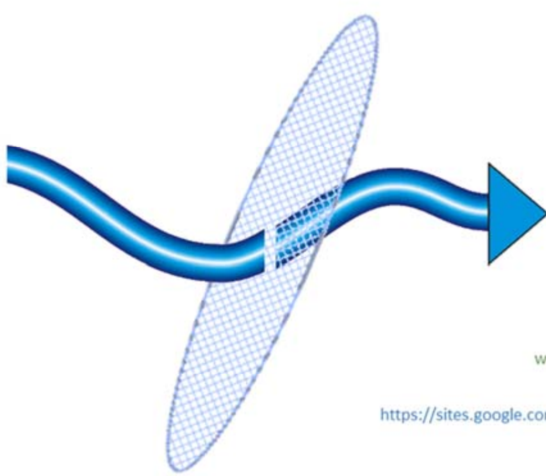

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Appendix 3 – Project grower factsheets

These awareness factsheets were produced as handouts to provide growers with some preliminary information and to increase awareness, within industry, of ultrafiltration and this project.

Closed systems

– making the most of hydroponics

Hydroponics is a highly efficient production system. An open system – one in which the nutrient solution is used only once – requires only a small fraction of the water and fertiliser that is needed in a field cropping system to produce an equivalent yield. A closed hydroponic system is even more efficient and sustainable. A closed system reuses the nutrient solution several times. The excess nutrient solution (containing fertilisers and water) that drains from the crop is collected, disinfected and reused. Reusing nutrient run-off saves thousands of dollars per year.

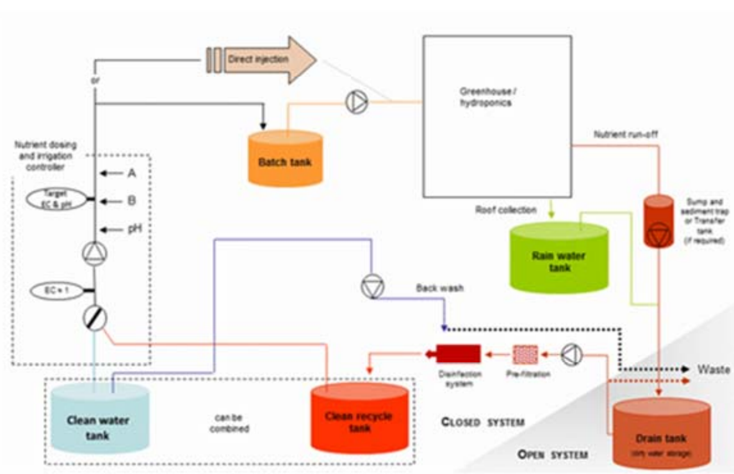
> *The nutrient run-off from one hectare of hydroponic cucumbers is worth around $15000 per year in fertiliser content alone.*

A key impediment to implementing closed hydroponics is disease. Some 65% of the more common pathogens of hydroponic vegetable production can be spread through water, making the reuse of the nutrient run-off a high disease risk. Reliable disinfection of reuse water is essential.

All hydroponic systems are basically the same – a balanced recipe of fertilisers are mixed with clean water to create a nutrient solution of known concentration, the pH may be adjusted and then this nutrient solution is irrigated to the crop.

The nutrient loaded run-off water is collected and appropriately managed and disposed. A closed hydroponic system simply adds a disinfection step (and possibly increased water storage capacity) so that this valuable waste water can be reused without risking the spread of water borne pathogens.

The disinfected reuse water is then mixed ('shandied') with new clean water. The best approach is via a 3-way proportional valve that can readily adjust the water to a target EC. Generally a target EC of 1.0 is used at this mixing stage. New fertiliser is then added to prepare the nutrient solution for irrigation to the crop.



There are 4 principle methods of disinfection – ultraviolet radiation, heat, chemical and filtration.

Ultrafiltration is an under-used technology for closed system hydroponics but it provides a relatively low cost and reliable disinfection option. It is low maintenance and readily integrated into existing farm set ups. Recent trials have shown ultrafiltration to be highly effective and feasible for hydroponic cucumber growers.

Is ultrafiltration worth the money?

Yes. The following three scenarios illustrate the returns under some potential situations.

A 2000m^2 cucumber enterprise, using municipal water so that only the run-off water needs to be treated and which has an average run-off target of 30%, would need to invest an estimated $13928.00 to install an ultrafiltration unit and reuse the run-off. The recovery rate of run-off water is expected to be 95%. The discount rate of interest is assumed to be 3%pa. Fertiliser and chemical costs are projected to increase by 3%pa, water is expected to increase by 1.5%pa and energy and labour are anticipated to increase annually by 5% and 2% respectively. General maintenance and repairs have been assumed to be as high as 3% of the unit's cost. In this scenario, the return on investment over 5 years would be 4.14% and the payback period would be just 4.5 years.

Considering the same scenario, but assuming that fertiliser does not increase in cost (the price remains the same), the investment would still breakeven at just over 5 years (the 5 year benefit to cost ratio is approximately 1).

A larger enterprise (5000m^2) with the same economic conditions (as example 1) but which has to treat all water, would need to spend an estimated $20701.50 to install an ultrafiltration unit and reuse the run-off. Again, the recovery rate of run-off water is assumed to be 95%. The larger investment reflects the increased volume of water that needs to be disinfected, however, this also results in greater fertiliser and water savings from the reuse water. In this scenario, the return over 5 years is more than double the outlay. The payback period is less than 12 months.

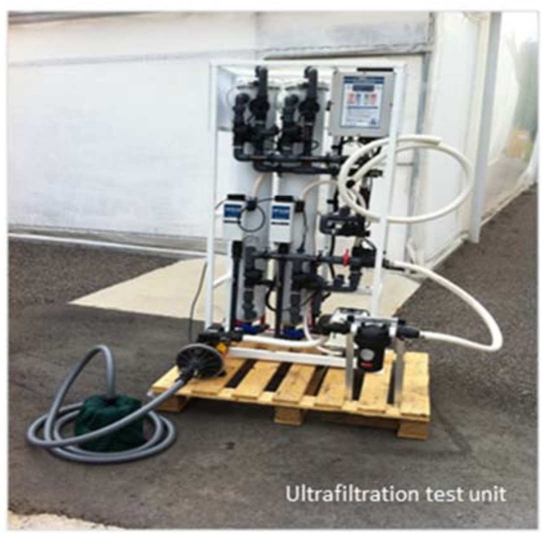
Even under fairly unlikely economic conditions, for example where energy and labour costs rise but the value of fertilisers and water remain the same, closed hydroponics is a good investment.

Added benefit

The direct economic advantage of increasing the efficiency of fertiliser and water use in the farm is well demonstrated. One of the key advantages often overlooked in considering closed hydroponics, is that the capacity to use higher run-off targets provides a grower with expanded management options.

More choices and greater flexibility in root zone management enables better responsivity to changes in growing conditions as well as the correction of problems.

Closed system hydroponics means that this flexibility can be exercised sustainably and without wasting water and fertiliser.



Ultrafiltration test unit

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Horticulture Innovation Australia

Ultrafiltration

– a disinfection option for hydroponic cucumbers

A closed hydroponic system is the most efficient and sustainable production method for many vegetables, for example cucumbers. The nutrient loaded run-off water is reused several times saving thousands of dollars per year in fertilisers and water.

Disinfection of all water sources used in hydroponics is essential for effective and sustainable management of key diseases.

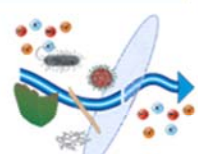
A 30% return on investment in hydroponic cucumbers

Ultrafiltration provides a relatively low cost and reliable disinfection option. It is low maintenance and readily integrated into existing farm set ups. Water volume capacity can be matched to farm needs by adding extra filter units.

Extensive benefit cost analysis (BCA) has been undertaken using a range of different economic situations based on the a series of 'high' and 'low' value benefits and costs [refer to the table below]. Different size farms and varied rates of run-off were also considered. Investment in ultrafiltration could be very worthwhile. On the example BCA table (over the back) you can easily see that as farm size and run-off levels increase, the investment gets even better. The full set of tables are available on the project webpage – https://sites.google.com/site/sustainablehydroponics

Input (benefit or cost)	High value scenarios		Low value scenarios	
	Initial cost	Assume annual rate of increase	Initial cost	Assume annual rate of increase
Water (Benefit)	$2.00 / kilolitre	2.0%	$1.00 / kL	1.5%
Fertiliser (Benefit)	$3.50 / kilolitre	5.0%	$2.20 / kL	3.0%
Labour	$25.00 / hour	1.5%	$17.00 / hr	1.0%
Electricity	$0.50 / kWh	5.0%	$0.30 / kWh	2.5%
Cleaning chemicals	$0.40 / cycle	3.0%	$0.30 / cycle	2.0%
General maintenance and repairs	0.5%	-	0.5%	-

A 3500m^2 closed hydroponic cucumber enterprise with a 40% run-off target, in a low benefit and low cost economic environment, with a 2.5% rate of interest and which disinfects all water (new and recycled), would only need to spend around $36,000 (over 5 years) on the disinfection system. This investment could pay for itself in 3 years and provide a 30% return on investment.



Primary Principles

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Scenario: Treating run-off water only. High 'BENEFIT' (fertiliser and water) values; low 'COST' (energy and labour) values*									
Interest (discount) rate	2.5% pa	Size of cucumber enterprise							
		2500 m²	3000 m²	3500 m²	4000 m²	4500 m²	5000 m²	7500 m²	10000 m²
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00
10% Target run-off	Payback period	>10 years	>10 years	>10 years	7.7 years	6.0 years	4.8 years	2.1 years	1.1 years
	ROI over 5yrs	uneconomic	uneconomic	uneconomic	-18.26%	-8.04%	2.17%	53.26%	104.35%
	ROI over 10yrs	uneconomic	uneconomic	uneconomic	11.69%	25.66%	39.62%	109.43%	179.23%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00
20% Target run-off	Payback period	4.8 years	3.3 years	2.4 years	1.8 years	1.4 years	1.1 years	0.3 years	immediate
	ROI over 5yrs	2.17%	22.61%	43.04%	63.48%	83.91%	104.35%	206.52%	308.70%
	ROI over 10yrs	39.62%	67.54%	95.46%	123.39%	151.31%	179.23%	318.85%	458.47%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$35737.75
30% Target run-off	Payback period	2.1 years	1.4 years	1.0 years	0.7 years	0.5 years	0.3 years	immediate	immediate
	ROI over 5yrs	53.26%	83.91%	114.57%	145.22%	175.87%	206.52%	359.78%	394.82%
	ROI over 10yrs	109.43%	151.31%	193.20%	235.08%	276.97%	318.85%	528.28%	611.88%
Estimated total investment cost (present value^ over 5 years)		$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$28846.00	$35737.75	$35737.75
40% Target run-off	Payback period	1.1 years	0.7 years	0.4 years	0.2 years	<1.0 mth	immediate	immediate	immediate
	ROI over 5yrs	104.35%	145.22%	186.09%	226.96%	267.83%	308.70%	394.82%	559.76%
	ROI over 10yrs	179.23%	235.08%	290.93%	346.77%	402.62%	458.47%	611.88%	849.17%

*Assumed costs: Fertiliser: $3.50/kL, increasing at 5%pa; Water: $2.00/kL, increasing at 2%pa; Cleaning chemicals: $0.30/cycle, increasing at 2%pa; Labour: $17/hr, increasing at 1%pa; Electricity: $0.30/kWh, increasing at 2.5%pa; General maintenance and repairs: 0.5% of purchase cost. Water recovery rate: 95%

Through a series of replicated research trials ultrafiltration has been found to be very effective in removing key fungal pathogens hydroponic nutrient run-off, making it a good option for hydroponic cucumber growers.

Assessment	Filter system	Microorganism	Est. concentration	Prefilter (positive control)	Filtrate 1	Filtrate 2	Filtrate 3	Result
1	A	*F. oxysporum*	2400 conidia/ml	✓	✗	✗	✗	👍
2	A	*F. oxysporum*	100 conidia/ml	✓	✗	✗	✗	👍
3	A	*F. oxysporum*	100 conidia/ml	✓	✗	✗	✗	👍
4	A	*Pythium spp* (*P. irregular, P. spinsoum, P. dissotochum*)	100 cfu/ml	✓	✗	✗	✗	👍
5	A	*P. dissotochum*	100 cfu/ml	✓	✗	✗	✗	👍

Results for bacterial pathogens are mixed so growers who need to target bacterial pathogens, need to be more cautious with this technology. Ultrafiltration can be easily coupled with other disinfection systems such as ultraviolet radiation.

Assessment	Filter system	Microorganism	Est. concentration	Prefilter (positive control)	Filtrate 1	Filtrate 2	Filtrate 3	Result
1	A	*C. michiganensis*	5000 Cmm/ml	✓	✓	✓	✓	👎
2	A	*C. michiganensis*	5000 Cmm/ml	✓	✓	✓	✓	👎
3	B	*C. michiganensis*	5000 Cmm/ml	✓	✗	✗	✗	👍
4	B	*C. michiganensis*	5000 Cmm/ml	✓	✓	✓	✓	👎
5	B	*C. michiganensis*	5000 Cmm/ml	✓	✓	✓	✓	👎
6	C	*C. michiganensis*	5000 Cmm/ml	✓	✗	✗	✗	👍