Quality Wash Water for Carrots and Other Vegetables

Martin Mebalds and Andrew Hamilton

Department of Primary Industries, Victoria

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Final Report for HAL Project VG99005

Quality wash water for carrots and other vegetables: insurance for clean food and minimising environmental impact

Horticulture Australia

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This publication reports the research and extension program which addressed the lack of information and treatment protocols for the safe re-use of vegetable wash water on farm.

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December 2002

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Media Summary

This project has found that if basic precautions are adopted, waste water from vegetable washing sheds can be re-used, saving many millions of litres of water annually. It is estimated that 4.4 million ML of water is used in Australia every year for washing vegetables, yet very few growers are willing to re-use the water for fear that it may contain plant pathogens, human pathogens such as *E. coli* or significant residues of agrochemicals. Growers are most concerned about the re-use of waste water used to remove soil from root crops as it is highly coloured and often produces foul odours.

Australia-wide surveys of vegetable farm waste-water derived from washing root crops showed that there were very few cases of excessive agrochemical residues but there was a slight increase in levels of plant pathogens, *E. coli,* nitrates and phosphorus. The water was shown to be unsuitable for discharge into rivers and streams but could be treated economically and effectively on farm for re-use. The most common agrochemical residues were residual pre-emergent herbicides. Consideration should be given to recent herbicide application history and if recent applications were made, then the water should be tested for herbicide residue concentrations. In some instances, excessive linuron levels in waste water had the potential to harm sensitive crops.

A set of guidelines were developed to assist growers in designing effective waste water treatment systems to remove excess organic matter, plant and human pathogens and nutrients. Safe re-use of waste water has the benefit of reducing farm costs and the requirement of water from rivers and bores.

A system of settling pits and ponds can adequately reduce excessive loads of organic matter provided that the capacity of the system can allow for a sufficient holding time to improve water quality. However, some larger packing houses have insufficient holding capacity in their settling ponds to cope with the volumes of water used by the washing system. The end result is thus little improvement of water quality after settlement pond treatment. Improvements in waste water treatment such as aeration and constructed wetland treatment may overcome the short-comings of existing water treatment methods for the removal of organic matter and nutrients.

If waste water is to be re-used to wash harvested crops, it should be disinfested considering it is highly likely to have elevated levels of human pathogens. The waste water is highly coloured and so is unsuitable for disinfestation by UV light, however, micro-organisms in the water may be best controlled using chlorine dioxide, which works more effectively than other forms of chlorine treatments in water with high levels of organic matter.

Technical Summary

Washing vegetables is an essential part of the postharvest treatment to remove soil adhering to root vegetables and to clean the product ready for sale. It has been estimated that Australia-wide, the process requires 4.4 million megalitres of water annually. Wash water re-use has the potential to significantly reduce the demand for water from our rivers and catchments and to alleviate water restrictions in our drier vegetable producing regions. Saving water has a direct financial benefit to growers in lower water costs and in having the ability to utilise waste water for washing soil off product or for irrigation. The re-use of waste water has not been widely practiced due to fears that the water could harm the crop by recirculating plant pathogens or because the water may be contaminated with agrochemicals or excessive salts.

This project examined the quality of water used for washing vegetables before and after the washing process and examined treatment methods aimed at improving water quality to a standard suitable for re-use on farm. Guidelines were produced for safe waste water re-use on farm.

A survey of waste vegetable wash water showed that field and postharvest pathogens were present in wash water. There was some risk that water reuse for washing or irrigation could redistribute the spores of pathogens either on product after harvest or on growing plants in the field. The survey also showed that coliform bacteria, including *E. coli* were sometimes found in source waters, including dams, bores and rivers such as the Murray River. The coliform bacteria concentrations in the wash waters were generally very high in waste water and may present a hazard to the consumer if not rinsed off in a final rinse. However, the presence of these bacteria in the waste water indicates that higher numbers of bacteria are being washed from soil encrusted root crops and that residual wash water on product would contain far fewer bacteria than the soil it replaced. The final rinse in chlorinated water immediately after the soil removal process generally removes most of the remaining bacteria. The concentrations of bacteria found in wash water (0-2,800 *E.coli*.100 mL^{-1} and $0 - 6.8 \times 10^6$ coliforms.100 mL^{-1}) exceed WHO guidelines of $<10^3$ faecal coliforms. 100 mL^{-1}) for the re-use of treated water on vegetable crops. Wash water should therefore undergo a form of treatment to reduce bacterial numbers before re-use either for irrigation or for use in the soil removal step in product washing. The waste water is highly coloured and so is unsuitable for disinfestation by UV light, however, microbes in the water may be best controlled using chlorine dioxide which works better in water with high levels of organic matter than other chlorine treatments.

The most commonly found pesticides in wash waters surveyed were chlorpyriphos, prometryn, linuron and endosulphan. Of these, chlorpyriphos and linuron were the only chemicals found to be in a significantly higher concentration than source water. Pesticide levels were generally well below those which would be likely to cause the product to exceed maximum residue limits or to be of concern if the water were to be released into streams. However, in some cases, the concentration of linuron in the wash water was so high that carrot, lettuce and tomato crops would have been adversely affected. Adoption of low cost technologies such as horizontal flow constructed wetlands may be an efficient, cost effective method of reducing agrochemical, nutrient, and coliform bacteria concentrations in agricultural wastewater.

Treatment of water in settling pond systems did not significantly reduce the nutrient concentrations in water so additional treatments would be required if the water were to be discharged. Re-use of treated waste water for irrigation however, is practicable as the salt

concentrations were generally not likely to be harmful to crops such as carrots, although there were exceptions, and some crops are much more sensitive to salt than carrots. Generally salt levels in source and treated water did not vary greatly and were not affected by treatment in settling ponds. Where know salt concentrations in source water is close to the limit tolerated by crops, then waste water from washing should be carefully monitored for salinity before re-use.

There were very low concentrations of plant pathogens in the waste water, however, they were more numerous than in source waters. If waste water is being considered for crop irrigation then it should be monitored on a regular basis for the presence of plant pathogens. Where plant pathogens in waste water are of concern, water sanitation systems suited to high organic matter load should be considered.

Introduction

Vegetable growers face increasing pressures of decreasing water allocations, increasing charges for water and higher levels of accountability for environmental impact of their farming operations by councils, state EPAs and by the general community.

The importance of reducing the contamination of surface and ground waters from agrochemicals is recognised worldwide (Holt 2000,Yuones and Galal-Gorchev 2000) and in Australia (ARMCANZ and ANZECC 1995), but is of particular concern to rural communities who depend on these water sources for their drinking water. Furthermore, overseas buyers are increasingly concerned that the product they buy has been produced in a way that has minimal environmental impact. In Australia, reduced environmental flows of water and degraded water quality have major environmental impacts. In this context, the safe re-use of wash water would help to alleviate these concerns. It has been estimated from growers statements on water use per tonne of product, that 4.42 million megalitres of water is used per annum to wash vegetables. One of the larger growers uses 320,000 L water/week washing root vegetable crops. Recycling this quantity of water will have a significant impact on water use efficiency on farm, with less water required from Australia's river systems and underground water supplies.

The re-use of water used to wash soil off vegetables has been practiced by many in the industry where water is scarce for many years, however the build up of colour and development of unpleasant odours restricts this practice and discourages others from re-using this water. There is a lack of detailed knowledge of the changes in water quality parameters once it has been used to remove soil from vegetables. There is no information on the effectiveness of existing vegetable industry water treatment practices in removing organic matter and other undesirable components of waste wash water

Washing root crops such as carrots, parsnips and potatoes results in rapid deterioration of water quality. The waste water carries away not only soil but organic matter, spores and mycelium of fungi, bacteria, traces of nutrients, salts and chemical residues that are associated with the crop. The high load of organic matter begins to break down through microbial action, depleting oxygen in the water. In the absence of dissolved oxygen, anaerobic fermentation begins, causing the evolution of unpleasant smelling gases such as hydrogen sulphide (Wensloff 1998, Gross 1995). Growers have tried to overcome the problems associated with re-use of this water by installing relatively inexpensive systems of settlement pits, screens and settlement ponds where heavier material is allowed to settle out and lighter plant material is trapped by screens.

A further discouragement for water re-use is the fear that the water is not fit for the soil removal process or for irrigation onto crops because it may contain excessive agrochemicals, human or plant pathogens washed from diseased plants or contaminated soil. Similar concerns have recently been expressed about the use of recycled water in Queensland (Higgins *et al.* 2002). Blumenthal *et al.* (2000) however have recently reviewed, from a human health perspective, the WHO guidelines for the safe re-use of wastewater in agriculture. They present clear guidelines for the maximum allowable concentrations of coliforms and *E. coli* present in waste water for different crops. Studies had shown that consumers who ate raw vegetables irrigated with 10^4 faecal coliforms (FC)/100 mL did not develop infection with diarrhoeal disease or *E. coli* related diseases and this water was considered acceptable for use on root crops.

Water treatment options

The aim of water treatment is to improve water quality parameters (chemical and microbial) to a level where the water is fit for its intended use. The extent of water re-use on farm therefore will depend on the cost of treatments for the removal of organic matter, excessive residues of agrochemicals and nutrients, and the removal of bacteria and fungi which may compromise the safety of the crop in ground, of the harvested vegetables and of agricultural workers or consumers.

Removal of organic matter may be achieved in a variety of ways:

- by trapping particulates with screens and filters or break down and removal with the use of settlement in ponds and dams (Kolarik and Booker 1995, Gross 1995, Clear water solutions 1998);
- constructed wetlands (Headley *et al.* 2001);
- aerobic (Torrijos and Moletta 1997) and anaerobic microbial breakdown (Rintala and Lepistö 1997, Di Bernardino *et al.* 2000).

Headley *et al.* (2001) found that the removal efficiency for phosphorous and nitrogen was increased with increasing retention time. A hydraulic retention time (HRT) of 5 days, 86% of all nitrogen and phosphorous was removed from nutrient rich runoff from a nursery. Industrial style batch reactors may also be used to reduce organic matter in farm waste waters. Torijos and Moletta (1997) developed a relatively inexpensive sequencing batch reactor which can reduce Biological Oxygen Demand (BOD_5) by 97.5% from highly polluted winery waste water. The system is suitable for small operators in terms of cost and management. The costs of the processes per megalitre of water vary greatly, depending on the cost of equipment, infrastructure and running costs.

Removal of 85–94% of enteric bacteria from waste water was achieved using surface flow constructed wetlands (Perkins and Hunter 2000) and efficiency of removal was inversely proportional to the flow rate or retention time in the system. Furthermore, Perkins and Hunter (2000) found that when flow rates became excessive, the wetlands became inefficient at removing bacteria. The findings of Headley *et al.* (2001) and Perkins and Hunter (2000) have immediate implications for growers who want to install water treatment ponds or wetlands. They must ensure that they have sufficient capacity in their settling pond/wetland systems to adequately retain the volume of waste water flowing from the washing facility for a minimum retention time (eg 3 days), otherwise the system will fail. Where high volumes of water are processed during the harvest season, aeration of wastewater in settling ponds will accelerate breakdown of organic matter (Wensloff 1998).

A part of this project was to examine the efficiency of existing water treatment systems for the removal of agrochemicals and harmful microbes, and to consider cost effective methods to improve the treatment of water on farm.

References

Agriculture and Resource Management Council of Australia and New Zealand & Australian New Zealand Environment and Conservation Council (1995) National water quality management strategy: Guidelines for groundwater protection in Australia. ARMCANZ & ANZECC, Canberra.

Blumenthal, U.J. Peasey, A., Ruiz-Palacios, G. and Mara, D.D (2000) Guidelines for wastewater re-use in agriculture and aquaculture: recommended revisions based on new research evidence Task No: 68 Part 1. London School of Hygiene & Tropical Medicine, UK Internet: http://www.lboro.ac.uk/well/

Technology Transfer

During the course of the project the information gathered on water quality, treatment and re-use was delivered to a wide range of audiences and in a range of media.

Conferences:

The results of our work were reported at 'Carrot Conference Australia' in Perth
Presentation: Hamilton, A. and Mebalds, M.I. (2000)The potential for recycling carrot wash water- water quality considerations

Fresh Conference: The Future in Food Safety and Processing Technologies for Value-added Horticultural Products Melbourne, 2001
Presentation Mebalds, M.I. (2001) Methods for the disinfestation of irrigation water.

Posters:

Hamilton, A. (2000) Coliform bacteria detected in carrot wash water.
Mebalds, M.I. (2000) The plant pathogenic fungi in carrot wash water and settling pond discharge

Articles in Industry Publications:

Two articles have been written for
Good Fruit and Vegetables Vol. 11, No. 2, p. 50 and
Good Fruit and Vegetables January 2001 issue.

Newsletters, *In the Wash*, This newsletter covers research findings and directions for both our project and the clean and safe handling systems for vegetables and tomatoes project (VX99004)

Grower workshops

The first vegetable grower workshop was held near Clyde, Victoria on 26 April 2002. The workshops were designed to deliver a 15 minute talk on Clean and Safe Handling Systems (VX99004) and a further 15 minute talk on recycling wash water (VG99005). A question time of approximately 30 minutes was then used to answer questions and concerns regarding the material presented. After a short break, demonstrations on water testing for turbidity and electrical conductivity using growers' water was used to develop further discussion on the implications of the test results on the most appropriate methods of water quality improvement and disinfestation.

A further demonstration on chlorination and the draw-down effect of various vegetables was held to illustrate the variability of chlorine demand and the importance of monitoring of disinfectant concentrations.

A Field Day notebook incorporating presentations and water treatment guidelines (Appendix 1) was produced and distributed to all participants. Further copies of the field day notebook were given to state vegetable IDOs for distribution.

Patrick Ulloa, the Victorian Vegetable Industry Development Officer, arranged the workshop with growers. It was attended by approximately 15 grower families representing the major vegetable growers on the Mornington Peninsula.

Further, Gatton Field Days at Gatton, Qld. were attended on 7, 8 and 9th May 2002 where a display booth was established with information on the project including a Power point presentation of results, Field day notes were distributed to interested vegetable growers and the project outcomes discussed.

A trip along the Murray River region from Swan Hill to Mildura by Sally-Ann Henderson, Martin Mebalds and Andrew Hamilton included visits to all the major carrot growers of the region where they explained the results of the project to growers.

Grower workshops were also held in Virginia, South Australia on 26 June, Yanco on 20 June and Cowra, New South Wales on 30th July Bundaberg Queensland on 18th June 2002. A further workshop for carrot growers was held in Perth on 4th October 2002.

Recommendations

Scientific

The project examined a range of existing water treatment strategies, as it was considered that an evaluation of the existing facilities has not been previously assessed. Once treatment strategies have been examined and analysed, recommendations could be made to improve water treatment processes within the vegetable industry. This approach has the best chance of adoption, as modifications of existing technologies are less expensive than installing new facilities. The pond systems were shown to reduce organic matter content if they were not overloaded with large volumes of wash water, reducing hydraulic retention time. The systems have a capability to reduce agrochemical concentrations in water however, in practice, there was little beneficial effect in existing systems when overloaded.

Further work needs to be undertaken in studying alternative and complimentary water treatment systems that may overcome current system inadequacies. In particular, extra aeration of water in settling ponds, and the addition of subsurface or surface horizontal constructed wetlands similar to those developed by Headley *et al.* (2001), have the potential to further reduce nitrates, phosphates, agrochemical concentrations and coliform bacteria levels with minimal additional cost. Further work on irrigation of crops with waste water over a period of years would help resolve the issue of cumulative effect of introduction of a range of pathogens at low concentration and plant disease development.

Industry

A draft of the Guidelines for the re-use of waste water from vegetable washing was distributed to all vegetable IDOs in 2001 for comment and feed back. Once comments were received, the guidelines were then incorporated into the field day notes and are presented in Appendix 1.

Acknowledgments

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Many growers supported the project but in particular we are indebted to Mr Rocky Lamatina who provided advice and support for the project in the development stage.

We acknowledge the support of Dr Elaine Davison for the provision of *Pythium* cultures and the identification of isolates from waste water. Dr Davison and Dr Alan McKay also helped collecting water samples, arranged a grower's seminar in Perth and showed us carrot farms in the region.

We thank Fawzia Tawfik and Maresa Connell of the State Chemistry Laboratories, Werribee for her work on agrochemical detection in all water samples. I would like to acknowledge the work done by our collaborators in this national project. Their work was a key to the projects success.

The Industry Development Officers in each state contributed to the project, in particular Patrick Ulloa (Victoria) who helped with grower meetings and our technology transfer plan.

NSW Vegetable IDO Dr Alison Anderson assisted in planning the grower workshop in Cowra and provided transport from Sydney. Craig Feutrill SA Vegetable IDO organised the Virginia grower workshop. Judy Skilton, Executive Officer, Bundaberg Fruit & Vegetable Growers helped with the Bundaberg workshop. SallyAnn Henderson provided transport and drove us to carrot growers along the Murray River from Swan Hill to Mildura.

Dr Alison Anderson, NSW vegetable IDO and Joe Napoli of the Lachlan Valley Horticultural Network helped to organised the Cowra workshop and Samantha Hertiage and Julia Telford vegetable IDOs for Queensland help organise the Bundaburg workshop. The grower workshops were held in conjunction with a Mr Paul Harrup and Dr Robert Holmes who presented finding of their work on Clean and Safe Handling Systems for Vegetables and consequently, we shared the work load associated with the technology transfer package.

This project was largely dependant on the good will of the participating vegetable growers for access to farms and samples of their source and waste waters and to those that allowed detailed analysis of the performance of their waste water treatment systems. We thank all participating growers. Confidentiality agreements prevent me from naming them however, their participation was vital for the advancement of the industry through research and especially for the development of methods for the conservation of water within the vegetable industry.

If I have inadvertently left anyone out who should be acknowledged, I apologise. This project was a large team effort where all who participated showed enthusiasm and generosity of time and effort. Thank you.

Appendix I

Guidelines for the re-use of waste-water from vegetable washing

Why re-use vegetable waste-water?

In Australia each year about 4.42 million ML of water are used to wash carrots. In some instances this water is re-used for washing, and often it is disposed of by using it to irrigate crops, although sometimes it is simply flooded onto to uncropped land.

Re-use of waste-water from vegetable washing is particularly important in drier areas where water is a highly valued resource, both environmentally and economically. For example, in the Sunraysia district of Northern Victoria, growers obtain their water from the Murray River. This river and its catchment have been under considerable pressure, and balancing the competing demands of agriculture and the environment is a topic of considerable debate. Growers pay to use this water; thus there are both economic and environmental incentives for its efficient use.

In our study of the quality of waste-water from the vegetable washing process, we used the carrot industry as a model. This industry uses particularly large volumes of water because soil has to be washed off the produce. The resulting 'dirty' waste-water can contain pathogens and is sometimes difficult to disinfect if highly loaded with organic matter. Thus, the carrot washing process can be seen as a worse case scenario when it comes to the quality of vegetable washing waste-water.

In these guidelines the following issues will be addressed:

1) potential spread of post-harvest diseases through the re-use of waste-water;
2) crop health issues related to the disposal of waste-water by means of crop irrigation;
3) potential food safety issues arising from re-use of vegetable waste-water;
4) methods of treating vegetable waste-water for re-use;
5) environmentally safe disposal of vegetable waste-water.

Contamination of food

Agrochemical residues

All of the agrochemicals in Table 1 were more frequently detected in waste-waters than source waters, suggesting that they entered the waste-water as a result of the soil removal process.

In Australia, there are prescribed levels for acceptable concentrations of agrochemicals in food—'The Food Standards Code' (National Food Authority 2001). The maximum residue limits (MRLs, maximum level of a chemical which is permitted to be present in food) of the most frequently detected agrochemicals in our survey are presented below.

Table 1. Maximum Residue Limits for some of the most commonly encountered agrochemicals in carrot waste-water. nsg = no specific guideline, therefore there must be no detectable residue in the product; * = all vegetables except asparagus, brassica vegetables, cassava, potato and tomato; ** = all vegetables except carrot, common bean (dry), lupin (dry), mung bean (dry), onion (bulb), potato, soya bean (dry), sweet corn (corn-on-the cob) and sweet potato.

conc. = μg/g	linuron	chlorpyrifos	prometryn	total endosulphan
carrot	nsg	nsg	nsg	200
brassica vegetables	nsg	500	nsg	nsg
asparagus	nsg	50	nsg	nsg
vegetables	50	10*	100	2000**

In our survey, most source and waste-waters contained few agrochemicals, and those that were present were typically found in very low concentrations. However, it is not possible from this information to determine if the low levels detected in the waste-water would lead to levels in the vegetable (e.g. carrot) in excess of the Food Standards Code levels, although specific studies would be need to confirm this. The four most commonly encountered agrochemicals were linuron, chlorpyrifos, prometryn and endosulphan sulphate.

Potential for spread of human pathogens

The presence of human pathogens in vegetable waste-waters was not measured directly in our study. Rather, we used an indicator bacterium, *Eschericia coli*. *E. coli* belongs to a group of bacteria known as thermotolerant coliforms. Thermotolerant coliforms, including *E. coli*, are common in the gut of warm-blooded animals. Hence, their presence suggests that there is the potential for other pathogens to be present. According to the 'Guidelines for on-farm food safety for fresh produce' (Agriculture, Fisheries and Forestry – Australia 2001) the concentration of thermotolerant coliforms in farm irrigation water should not exceed 1000 cfu (colony forming units) / 100 mL, and the concentration of *E. coli* in produce should not exceed 20 cfu / g of produce. In our survey, we frequently found that in the waste-water the concentration of *E. coli* alone exceeded this recommended guideline for total thermotolerant coliforms.

Crop protection

Plant Pathogens

One of the primary concerns related to re-using vegetable washing wastewater for irrigation is that the practice may spread plant pathogens throughout a farm. If soil is washed off carrots from a diseased patch of ground, and this waste-water is used to irrigate various parts of the farm, then these pathogens can spread to previously uninfected areas.

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality—henceforth referred to as 'Australian and New Zealand Water Guidelines'— (ANZECC & ARMCANZ 2000) have identified an urgent need for future research into the development of guidelines for acceptable levels of plant pathogens in irrigation water, particularly in intensive agricultural and horticultural industries where wastewaters are re-used. In our study we have taken the first step by identifying the most common plant pathogens found in vegetable wastewater.

In our survey of operations throughout Australia, wastewater was found to contain about ten times more fungi than source water. However, only some of these were potential plant pathogens. A list of the potential pathogens isolated, and the frequency at which they were found in source and waste-waters, is presented in Table 2. *Pythium*, the causative agent of cavity spot, was rarely isolated, although it was only found in waste-water.

Table 2. Potentially pathogenic fungi to carrots found in source and waste-waters. PH = potential postharvest pathogen; P = laboratory tests demonstrated these isolates to be pathogenic to carrots.

Fungus	disease	% source	% waste
Alternaria alternata[P]	potential PH pathogen	19	46
Aspergillus niger	black mould rot	31	46
Fusarium sporotrichioides[P]	PH pathogen	0	4
Pythium spp[P].	cavity spot	4	15
Rhizoctonia solani	field root rot	8	0
Rhizopus stolonifer	rhizopus rot, minor PH rot	4	8

Because of the frequent presence of pathogens in waste-water, if this water is to be re-used then in most instances some form of treatment and disinfection will need to be applied. This treatment will not necessarily need to remove all plant pathogens, especially if the product is passed through a final disinfection rinse (e.g. chlorine). A reasonable objective would be to get the recycled water to a quality, with respect to plant pathogens, similar to that of water sourced from rivers and bores.

Agrochemicals in irrigation water

If waste-water is to be re-used for irrigation then we need to know if it contains any herbicides in concentrations that may be toxic to crop plants. Linuron is a herbicide that is commonly used for the control of weeds in carrots and other vegetable crops, and we frequently detected it in carrot waste-waters.

There are no Australian guidelines for the concentration of linuron, or any of the other agrochemicals we surveyed, in irrigation waters. However, in the Australian and New Zealand Water Guidelines (ANZECC & ARMCANZ 2000) interim guidelines are provided for the levels of several other herbicides for various crops.

Despite the lack of official Australian guidelines, it is still important to gain some appreciation as to what acceptable levels of linuron, the most common herbicide in carrot waste-water, could be. Therefore, we look at guidelines from other countries. In a worldwide survey of regulatory agencies (Caux *et al.* 1998) found that there were no irrigation water quality guidelines for the protection of non-target (i.e. crop) plants from linuron. They developed maximum acceptable toxicant concentrations for linuron based on previously published research on the toxicity of linuron to various crops, and these can be used for vegetable production in Australia. These maximum acceptable concentrations for various vegetables are presented below (Table 3). It is important to note that even though we found linuron in almost half of the carrot waste-water samples, the concentrations were generally well below those likely to cause damage to, or reduce productivity of, carrots. The average concentration of linuron in the samples where it was detected was only 5.3 µg/L, and there was only one sample where the maximum acceptable concentration for carrots was exceeded. Nevertheless, the concentration of linuron in this sample was very high (34 µg/L), and thus it can be seen that there is the potential for toxic levels of linuron to be present in waste-water being re-used for irrigation. It should also be noted that other vegetables are much less tolerant to linuron than carrots (Table 3.). In particular, tomatoes are highly sensitive. Therefore, in some instances carrot waste-water may be able to be used to irrigate carrots but not other crops.

Table 3. Maximum acceptable concentrations of linuron in irrigation water for the protection of various crop species. From Caux *et al.* (1998). These values are based on high irrigation rates.

	maximum acceptable linuron concentration (µg/L)
carrot	12.4
lettuce	4.9
turnip	1.89
parsnip	8.9
cucumber	3.3
tomato	0.071

Salinity of recycled water used for irrigation

Salinity is a measure of the concentration of salts in either water or soil. Salinity can affect plants through either indirect means, namely the reduction in availability of water to the plant, and direct routes, such as toxicity of specific ions to the plant. The overall effect of salinity on crops is dependent on many factors including soil type, soil moisture, soil salinity and climate. For this reason, there are no specific Australian guideline levels for irrigation water salinity for crops. However, the Australian and New Zealand Water Guidelines provide methods for estimating the potential effect of saline irrigation water for a specific site. In our survey, salinity in carrot waste-water ranged from 87 to 3,000 µS/cm (average = 730 µS/cm). Soil salinities of the farms ranged from 70 to 660 µS/cm (average = 206 µS/cm). Using a formula from the Australian and New Zealand Water Guidelines for the properties investigated in our survey revealed that in nearly all circumstances the waste-water could be used for irrigation without causing salinity stress to carrots and other vegetables.

A computer program called SALT PREDICT can also be used to calculate permissible site specific irrigation salinity levels. This program takes into account many factors such as soil type, water-table depth, rainfall and irrigation rates, so a site specific threshold level for irrigation water salinity can be calculated. This software is available with the Australian and New Zealand Water Quality Guidelines and through the Queensland Department of Natural Resources. For a simple estimate of threshold salinities for various crops for three basic soil types, Table 4.2.5 in the Australian and New Zealand Water Quality Guidelines can be consulted. According to this table, irrigation water salinity for carrots should not exceed 2,200, 1,200 or 700 µS/cm for sand, loam and clay soils respectively. However, it must be recognised that these values are just estimates and do not take into account other site specific factors such as rainfall or salinity from a rising water table.

Treatment of waste-water

Chemical disinfestation

The raw waste-water from nearly all operations was too turbid (i.e. unclear) to enable effective disinfestation using standard chemical disinfectants such as chlorine (e.g. sodium hypochlorite or calcium hypochlorite). High turbidity is typically an indicator of high suspended solids organic matter in the water. This matter can bind to chlorine and thus reduce the amount available to act upon pathogenic micro-organisms. We found that passing water through a series of settling ponds (see below) reduced the turbidity substantially.

The active agent in chlorine disinfectants is hypochlorous acid. The proportion of hypochlorous acid in solution decreases with increasing pH. Thus, chlorine disinfectants are less effective at high pH levels. Only 50% of the chlorine is in the active form (hypochlorous acid) at pH 7.5, and this rapidly decreases with pH values greater than this. It therefore recommended that pH should at least be below 7.5 if hypochlorous acid based disinfectants are to be used. In our survey we found that the average pH of waste-water was 7.0 (range 6.1–7.7), with 87% of the samples being below 7.5. At pH 7 about 75 % of the chlorine is in the active form. Thus, in most situations carrot waste-water is suitable for chlorine disinfestation, provided that the turbidity has been reduced substantially. Where water pH is above 7.5, but below 8.5, then a hypochlorous/hypobromous acid mix may be more effective as a disinfectant but still has the same limitation in the presence of high levels of organic matter. Another alternative is the use of chlorine dioxide which is less affected by high levels of organic matter and is still effective at a pH of 9.5–10. Disinfection using chlorine dioxide is recommended in particular for waste/dam water if the pH is higher than 7.5.

Settling Ponds

A series of at least 3 settling ponds may provide an effective means of reducing the turbidity carrot waste-water, and also for removing pathogens. The size and number of settling ponds will have a critical effect on the effectiveness of the system, although it will not be feasible in most situations to conduct engineering studies to calculate optimal pond size and number. This will depend on many factors, including flow rates, pond mixing hydraulics and soil type. Nevertheless, some generalisations can be made with respect to using settling ponds to treat waste-water.

A screen trap to remove coarse material such as leafy material and broken pieces of root crops is a useful addition to any system, as this will greatly reduce the amount of organic matter entering the pond system.

The first pond in the series may become anaerobic, that is, it may lack oxygen (or have very low levels). If the organic load and throughput of the water is not matched with the size of the system, then the following ponds in a series may also become anaerobic, and this is generally undesirable for the removal of human and plant pathogens. Anaerobic ponds have a distinctive smell, similar to rotten eggs, which results from the emission of hydrogen sulphide gas. Hydrogen sulphide is produced under anaerobic conditions by bacteria in the water. A simple method for preventing a pond from becoming anaerobic is to aerate it. This may be done by pumping water from the pond, then spraying it through a fine nozzle, through the air, before returning it too the pond. Similarly, aeration of ponds can be encouraged by passing water over a rock-fall or some type of waterfall as it enters each pond.

We have studied three different sized settling ponds systems, and of these, two were highly inefficient at removing the faecal indicator bacterium *E. coli* whereas the other was reasonably efficient, although not all *E. coli* were removed. Based on these findings, it cannot be assumed that settling ponds are efficient at removing potential human pathogens, and thus disinfection should also be considered. In addition, these systems were generally only partially effective at reducing total fungal loads, and thus disinfection may also reduce the likelihood spreading post-harvest or field pathogens.

Artificial wetlands

A potential alternative to settling ponds is to pass water through artificial or constructed wetlands. This involves passing water through a series of wetlands that contain reed beds. Such systems have been demonstrated to be particularly efficient at removing nutrients from the water. Recent work in Australia has demonstrated constructed wetlands to be useful for cleaning nursery run-off water so that it can be re-used, or disposed of to the environment with greatly reduced nutrient concentrations (Headley *et al.* 2001).

Sand filters

Sand filtration may provide an additional benefit, although the degree of this benefit will depend on the quality of the final pond water. We believe that most carrot wastewaters would be too high in suspended solids to enable sand filtration without some form of initial sedimentation. The standard sand filtration system we analysed was not particularly effective at removing plant pathogenic fungi from the water. However, the effectiveness of any system will depend on flow rates and on how long it has been since the sand has been changed. Slow sand filters have previously been demonstrated as being effective at reducing loads of pathogenic fungi (Barth 1997).

Disposal of wastewater from vegetable washing: environmental considerations

Agrochemicals

According to the Victorian State Environment Protection Policy (Environment Protection Act 1970, Waters of Victoria, Schedule D, D1) 'All farm effluents from intensive animal industries, milking sheds and vegetable washing and processing shall be disposed of by land irrigation in such a manner as to preclude any polluting run-off to surface waters or pollution of groundwater.' Whilst the legislative requirements may vary slightly from one state EPA to the next, we believe that it is good practice always ultimately dispose of vegetable waste by land irrigation, particularly if it has not undergone any treatment. Direct release of waste-water to waterways, particularly without treatment, has the potential to cause environmental impacts. For example, wastewater can contain high levels of nutrients, such as nitrogen and phosphorous from fertilisers, and the addition of these nutrients to surface waters can lead to 'eutrophication'—the prolific growth of algae and aquatic plants. Eutrophication can bring about drastic changes in the structure of the natural biological community, and often results in greatly reduced biodiversity. In this project we found that in some circumstances vegetable waste-water contained levels of nutrients that were theoretically capable of causing eutrophication. The movement of nutrients into groundwaters is more likely on farms with sandy soils and with water tables close to the surface. Waste-water should be irrigated in such a way that it does not leach or pass the root zone of the crops.

Agrochemicals in waste-water also have the potential to cause environmental damage, through direct toxicity to aquatic organisms. For example, linuron, a commonly used herbicide for control of weeds in carrot production (e.g. Afolan, Dualin, Lorox, Linuron technical, Linuron 50W, Clean crop linuron, Checkmate EC herbicide), is known to be toxic to many aquatic plants and animals. This chemical was detected in about half of the waste-water samples surveyed in this project. There are no Australian guidelines for acceptable levels of linuron. Furthermore, Caux *et al.* (1998) conducted a literature search of water quality guidelines throughout the world and found that there were no specific guidelines for linuron. They developed interim Canadian Water Quality Guidelines for linuron that we can also use as a guide. According to these guidelines, for the protection of aquatic life the concentration of linuron in fresh surface waters should not exceed 7μg/L. With the exception of one sample, the concentration of linuron in carrot waste-water in this survey was 7 μg/L or less. In one circumstance a concentration of 34 μg/L was detected. However, this wastewater was not being discharged directly to surface waters. Furthermore, even in situations where this is the case, the dilution of the waste-water in the receiving water body needs to be considered.

Other agrochemicals detected in wastewater samples were fenamiphos, chlorpyriphos, diazinon, dimethoate, malathion, trifluralin, dimethoate, metalaxyl, prometryn, linuro, alpha-endosulphan, beta-endosulphan and endosulphan sulphate. Of these, the most commonly detected were chlopyriphos and prometryn which were found in 38% and 27% of the waste-water samples respectively. For many of these chemicals, there are Australian and New Zealand Water Guidelines for the protection of freshwater life. These guidelines work on the concept of 'trigger values'. A trigger value represents the concentration of a chemical below which there is minimal risk that ecological damage will occur. "They indicate a risk of impact if exceeded and should 'trigger' some action..." The guidelines also define different 'levels of protection', and in this circumstance it signifies the percentage of species expected to be protected (ANZECC & ARMCANZ 2000). The trigger values for different levels of protection for the chemicals detected in our survey are presented below in Table 4.

Table 4. Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ 2000): trigger values for agrochemicals detected in carrot waste-water.

	trigger values for freshwater (μgL^{-1})			
	level of protection (% species)			
	99%	95%	90%	80%
Chlorpyrifos[B]	0.00004	0.01	0.11	1.2
Diazinon	0.00003	0.01	0.2	2
Dimethoate	0.1	0.15	0.2	0.3
Malathion	0.002	0.05	0.2	1.1
Trifluralin[B]	2.6	4.4	6	9[A]
Endosulphan[B]	0.03	0.2[A]	0.6[A]	1.8[A]

A = Figure may not protect key test species from acute toxicity (and chronic); trigger value > acute toxicity value—see Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Section 8.3.7.
B = Chemicals for which possible bio-accumulation and secondary poisoning effects should be considered.

Of the 15 agrochemicals analysed for, chlorothalonil and phorate were the only ones that were not detected in any of the 26 waste-water samples.

Physical characteristics of waste-water

Other problems associated with the disposal of vegetable wastewater are high turbidity or lack of clarity of the water. In south-eastern and south-western Australia the recommended turbidity ranges for lowland rivers are 6–50 NTU and 10–20 NTU respectively. The levels of turbidity of the waste-water in this study were clearly well in excess of these levels. Thus, if vegetable waste-water was to be discharged directly into a waterway, then this could potentially be environmentally damaging, particularly in smaller waterways where the dilution effect would be less marked.

The addition of salts to waterways can also cause environmental problems. However, in our survey we found that on average the soil removal process did not greatly increase the salinity of the water (624 µS/cm in source-water compared to 730 µS/cm in waste-water). Nevertheless, care needs to be taken when disposing of saline waste-water, regardless of the origin of the salts.

Nutrients

The waste-water from the carrot washing process generally contains high concentrations of nitrogen and phosphorus. In nature, nitrite is a transient form of nitrogen and is usually only present in very low concentrations, if at all. Many commercial fertilisers, and chicken manure, contain very high concentrations of nitrite. Nitrate was about 2.6 times more concentrated in the source-water samples than the waste-water samples. Nitrate and nitrite concentrations are often reported as oxidised nitrogen, which is basically the sum of nitrate and nitrite. In south-eastern Australia total oxidised nitrogen concentrations in lowland rivers and freshwater lakes/reservoirs should not exceed 50 and 10 µg/L respectively (ANZECC & ARMCANZ 2000). Similarly, in south-western Australia total oxidised nitrogen should not exceed 150 and 10 µg/L in lowland rivers and freshwater lakes/reservoirs respectively. The concentrations of oxidised nitrogen in the carrot waste-waters was substantially higher than these values, but the concentrations in the source water were even higher. This suggests that overall, the carrot washing process is not adding to the oxidised nitrogen loading of the water. Whether or not the nitrogen, specifically nitrite, in carrot waste-water is likely to cause eutrophication of waterways in the environment would depend on several factors. Firstly, in most situations the waste-water is not discharged directly to a waterway. By disposing of the water by land irrigation some of the nitrogen may be removed. Soil can act as a natural filter. This is another reason for encouraging waste-water disposal by land irrigation. Secondly, the degree of dilution of the waste-water needs to be taken into account.

In south-eastern Australia total phosphorus concentrations in lowland rivers and freshwater lakes/reservoirs should not exceed 50 and 10 µg/L respectively (ANZECC & ARMCANZ 2000). Similarly, in south-western Australia total phosphorus concentrations should not exceed 65 and 10 µg/L in lowland rivers and freshwater lakes/reservoirs respectively. We could only measure phosphorus concentrations in three carrot waste-water samples, due to technical reasons (too many interfering substances in the water). In theses samples the average total phosphorus and dissolved reactive phosphorus concentrations were 5,833 and 1,967 µg/L respectively. In contrast, the source-water concentrations for these samples were 6,200 and 1,533 µg/L respectively. Thus, unlike nitrogen, the concentration of total and of dissolved reactive phosphorus does not appear to change greatly as a result of the soil removal process, although further data would be needed to confirm this.

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