Reuse of effluent water – benefits and risks

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Abstract

There is an increasing trend to require more efficient use of water resources, both in urban and rural environments. A major mechanism that can be used to achieve greater efficiencies is the reuse of water that once would have been discarded into the environment after use. The reuse of water for agricultural irrigation is often viewed as a positive means of recycling water due to the potential large volumes of water that can be used. Recycled water can have the advantage of being a constant, reliable water source and reduces the amount of water extracted from the environment. In addition, in some cases treatment requirements may be need to be less than for water used in an urban environment due to less potential human contact. There are concerns and unknowns, however, about the impact of the quality of the recycled water, both on the crop itself and on the end users of the crops. Water quality issues that can create real or perceived problems in agriculture include nutrient and sodium concentrations, heavy metals, and the presence of contaminants such as human and animal pathogens, pharmaceuticals and endocrine disruptors. Social attitudes to the use of crops that have been irrigated with recycled waters and the resulting impact on market value of crops are also a major consideration. This paper will discuss the benefits from using different types of recycled water and outline the current knowledge and opinions relating to risks such as water quality issues.

Keywords

Wastewater, recycling, soil, contaminants, pathogens, irrigation

Introduction

Increasing efficiencies in crop management and the continuing increases in crop yields has increased demands on water resources for irrigation purposes. Effluents are reused for irrigation purposes in many countries around the world on all of the populated continents (USEPA 1992). A number of these countries have developed guidelines that give quality criteria and advice on how effluents should reused for irrigation purposes. Examples of these guidelines are summarised in the USEPA guidelines for water reuse manual (USEPA 1992).

In many regions of the world, this has placed severe strains on existing resources with resulting environmental impacts. An example is in Perth, Australia where the major drinking water aquifer is being depleted by a combination of uses as a public drinking water source, horticultural irrigation and the positioning of pine plantations of large area of the mound (WA State Water Strategy 2002). Saudi Arabia is another example of a country with demonstrated impacts on natural water resources due to increasing demands on groundwater by the agricultural sector (Bushnak 2002). Large decreases in groundwater levels (up to 200m in some places) have been observed due to over extraction. In a number of countries, for example Australia, this has been compounded by prolonged periods of drought or seasons of low rainfall. In addition, predicted climate impacts from global warming also point to further stresses on water resources, thus reducing the amount of water available for both irrigation and the environment.

There are a range of mechanisms that can be used to reduce the pressure on fresh water resources for irrigation use. One possible mechanism is the recycling of wastewaters and drainage water that can be used in the place of other fresh water sources for irrigation. Types of wastewaters used for recycling include treated and untreated sewage effluent (Asano *et al*. 1996, Haarhoff & Van der Merwe 1996, Shereif *et al*. 1995), storm water runoff (Asano *et al*. 1996, Dillon *et al*. 1994), domestic greywater (Anderson 1996), and industrial wastewater (Asano *et al*. 1996, Guillaume & Xanthoulis 1996). For the purposes of this paper all of these water types are considered effluents which have the capacity to be reused. These different water types, however, can vary in quality and in the contaminants that could be potentially present. The quality and contaminants present will also impact on the level of treatment required, which in turn impacts on the economic viability of reusing the various wastewaters.

Environmental Benefits of Reusing Effluent Water

The reuse of water is just one source of water that has potential for use in an agricultural setting. Reused water does, however, have a major advantage in that it is usually a constant and reliable supply, particularly with sources such as treated sewage effluent or industrial discharges. As well as being a constant source of water, many waters suitable for reuse are produced in large volumes, which if not used would be merely discharged into the environment. It is well known that discharge of effluents, treated or non-treated, into the environment, particularly natural water bodies such as lakes, rivers and the coastal marine environments can cause severe degradation of these water ways. The degradation is often related to the presence of organic and inorganic nutrients which can cause problems such as eutrophication and algal blooms. Reusing these discharged effluents can have a significant impact on reducing or completely removing the impact of these effluents from receiving environments. In addition, the reuse of wastewaters for purposes such as agricultural irrigation reduces the amount of water that needs to be extracted from environmental water sources (Gregory 2000, USEPA 1992).

Wastewaters can often contain significant concentrations of organic and inorganic nutrients for example nitrogen and phosphate. There is potential for these nutrients present in recycled water to be used as a fertiliser source when the water is recycled as an irrigation source for agriculture. Soil microorganisms have been observed to have increased metabolic activity when sewage effluent is used for irrigation (Ramirez-Fuetes *et al.* 2002, Meli *et al.* 2002).

Potential Risks from Using Recycled Water

There have been a number of risk factors identified for using reused waters for purposes such as agricultural irrigation. Some risk factors are short term and vary in severity depending on the potential for human, animal or environmental contact (eg, microbial pathogens), while others have longer term impacts which increase with continued use of recycled water (eg, saline effects on soil).

Pathogens

The most common human microbial pathogens found in recycled water are enteric in origin. Enteric pathogens enter the environment in the faeces of infected hosts and can enter water either directly through defecation into water, contamination with sewage effluent or from run-off from soil and other land surfaces (Feachem *et al.* 1983).

The types of enteric pathogens that can be found in water include viruses, bacteria, protozoa and helminths. The risk of water-borne infection from any of these pathogens can be reliant on a range of factors including pathogen numbers and dispersion in water, the infective dose required and the susceptibility of an exposed population, the chance of faecal contamination of the water and amount of treatment undertaken before potential exposure to the water (Haas *et al.* 1999).

Viruses

Enteric viruses are the smallest of the pathogens found in water. They are all obligate intercellular parasites that require the infection of host cells of a suitable host and then force the host cell to produce multiple copies of the virus (Toze 1997). This lack of ability to self-replicate means that viruses are present in water as inactive particles.

The majority of these viruses can be commonly detected in faecal contaminated water, for example sewage effluent, however, the wild type of poliovirus has been eradicated in developed nations such as

Australia due to widespread vaccination (Ward *et al.* 1993). Most enteric viruses have a narrow host range meaning that most viruses of interest in recycled water only infect humans (Haas *et al.* 1999). This means that only human faecal contamination of water need be considered a concern for viral infection of humans. Conversely, water borne human viruses are rarely a problem for other animals.

Bacteria

Bacteria are the most common of the microbial pathogens found in recycled waters (Toze 1999). There are a wide range of bacterial pathogens and opportunistic pathogens which can be detected in wastewaters. Many of the bacterial pathogens are enteric in origin, however, bacterial pathogens which cause non-enteric illnesses (e.g., *Legionella* spp., *Mycobacterium* spp., and *Leptospira*) have also been detected in wastewaters (Fliermans 1996, Neuman *et al*. 1997, Wilson and Fujioka 1995). Bacterial pathogens are metabolically active microorganisms that are capable of self-replication and are therefore, theoretically capable of replicating in the environment. In reality, however, these introduced pathogens are prevented from doing so by environmental pressures (Toze and Hanna 2002). Like other enteric pathogens, a common mode of transmission is via contaminated water and food and by direct person to person contact (Haas *et al.* 1999). A number of these bacterial pathogens can also infect, or be carried by wild and domestic animals.

Protozoa

Enteric protozoan pathogens are unicellular eucaryotes which are obligate parasites. Outside of an infected host they persist as dormant stages known as cysts or oocysts. There are several protozoan pathogens which have been isolated from wastewater and recycled water sources (Gennaccaro *et al.* 2003). The most common detected are *Entamoeba histolytica, Giardia intestinalis* (formerly known as *Giardia lamblia*), and *Cryptosporidium parvum* (Toze 1997).

Infection from all three of these protozoan pathogens can occur after consumption of food or water contaminated with the (oo)cysts or through person to person contact (Carey *et al.* 2004). *Giardia* and *Cryptosporidium* are ubiquitous in fresh and estuarine waters and have been detected in numerous countries around the globe (Ferguson *et al*. 1996, Haas and Rose 1996, Ho *et al*. 1995, Kfir *et al*. 1995, Wallis *et al*. 1996). *E. histolytica* can be detected in all parts of the world, although it is more prevalent in tropical regions (Feachem *et al*. 1983). Like with the bacterial pathogens, various domestic and wild animals can be a source of these protozoa and be infected by them.

Helminths

Helminths (nematodes and tape worms) are common intestinal parasites which are transmitted the faecal-oral route (Toze 1997). Some of these parasites require an intermediate host for development prior to becoming infectious for humans. These helminths that have complex life cycles requiring development in a secondary host are rarely a concern in recycled water. Helminth parasites commonly detected in wastewaters that are of significant health risk in reused waters include the round worm (*Ascaris lumbricoides*), the hook worm (*Ancylostoma duodenale* or *Necator americanus*), and the whip worm (*Trichuris trichiura*). These helminths have a simple life cycle with no intermediate hosts and are capable of causing infection via the faecal-oral route (Toze 1997).

The presence of microbial pathogens in reused water, particularly when sourced from sewage effluent is arguably the major concern for health regulators, farmers and the general public. One of the major sources of helminth infections around the world is the use of raw or partially-treated sewage effluent and sludge for the irrigation of food crops (WHO 1989). In Mexico, farmer workers and their children that work in fields irrigated with untreated sewage effluent have been found to have a greater prevalence of round worm infection than the general population (Peasey *et al.* 2000). The authors found that infection rates, particularly for adults, decreased with treatment of the sewage effluent with infection rates decreasing at a rate that could be linked to the level of treatment. Peasey *et al.* (2000) also found that the consumption of raw vegetables (such as carrots, cauliflower, lettuce and cucumber) irrigated with partially treated sewage effluent did not confer any greater prevalence of infection from any age group to the general population.

Public and commercial concern does exist regarding pathogens through the use of recycled water and biosolids on cereal crops (Crute *et al.* 2004). It should be expected, however, that if there is a reduction of risk for the consumption of raw vegetables irrigated with partially treated effluent, then it can be surmised that grain crops irrigated with treated recycled waters would have even less risk from microbial pathogens. Even more specifically, grains are commonly processed further before they are consumed by humans which decreases the human health risk even further. Little is known, however, about the risk to domestic grazing animals that may be fed this grain unprocessed as a stock feed source. It is acknowledged that more scientific research is needed to confirm this lack of confirmatory information and funding is being provided to undertake this research (Crute *et al.* 2004).

Trace Organics and Heavy Metals

While many countries (for example Australia and the USA) have guidelines for use of reused water (NH&MRC 1999, USEPA 1992), these guidelines tend to focus on the health or environmental risk from microbial pathogens and nutrients. Very little is mentioned regarding the potential presence of trace contaminants apart from heavy metals and some brief mention on disinfection-byproducts and pharmaceutically-active compounds (eg, USEPA 1992). There is concern about the potential health and environmental impacts by the compounds if they survive treatment processes, are able to accumulate in the environment and enter the food chain.

Heavy metals are easily and efficiently removed during common treatment processes and the majority of heavy metal concentrations in raw sewage end up in the biosolid fraction of the treatment process with very low heavy metal concentrations present in the treated effluents (Sheikh *et al.* 1987). Thus, heavy metals are of little concern for irrigation of crops when using treated effluents as a source of recycled water. If the source for the recycled water is from an industrial source or is less treated than normal then the influence of heavy metals would need to be considered. Heavy metals that are present in effluents used for irrigation tend to accumulate in the soils where there is a potential that they could become bioavailable for crops. Angelova *et al.* (2004) observed that fibre crops such as flax and cotton did take up heavy metals when grown in heavily contaminated soils, however the concentrations detected in the leaves and seeds was only a small percentage of the concentration present in the soil. Fazeli *et al.* (1998) examined the uptake of heavy metals by rice grown in paddies irrigated with untreated effluent from a paper mill. They also determined that the uptake of the metals in the seeds was much less than was present in the effluent or the soil. They concluded, however, the levels in the seeds could still be a health risk for people whose major part of the diet was rice. Ofosu-Asiedu *et al.* (1999) examined the uptake of heavy metals by crops irrigated with domestic and industrial wastewater. They found that the levels in the crops irrigated with this water was similar to background environmental levels and thus posed no health risks.

Apart from heavy metals, most of the concern and public comments regarding trace contaminants revolve around pharmaceutically-active compounds (PhAC), endocrine disrupting compounds (EDC) and disinfection-byproducts (DBP). These PhACs and EDCs originate either from industrial or domestic sources while DBPs are a byproduct usually formed from the chlorination during and post treatment of reused water. As DBPs are not known to be a potential carcinogen for animals they will not be discussed here. These chemicals tend to be present at very low concentrations in the treated reused water (generally in the range of ng/L) as well as requiring the ingestion of large doses over long time periods to produce any clinical effect. That said, it is an area of concern from health officials and the public, and there have been documented cases of environmental impacts from these trace compounds.

Endocrine Disrupting Chemicals

EDCs are compounds outside of an organism which can impact on the structure and function of an organism's endocrine system causing effects on the organism or its progeny (Lim *et al.* 2000) Known EDCs that can be found in wastewaters and the environment include the estradiol compounds commonly found in the contraceptive pill, phytoestrogens, pesticides, industrial chemicals such as Bisphenol A and nonyl Phenol, and heavy metals (Lintelmann *et al.* 2003). Untreated sewage effluent is a major source of these compounds and contains higher concentrations than most other water sources.

While EDCs are present in untreated sewage effluent in concentrations much lower than natural hormones within the body and many have endocrine capabilities than are up to several thousand times less than natural hormones. Secondary treatment of sewage effluent is recognised to remove the majority of these chemicals from the effluent (Staples 1998, Wang *et al.* 2003). The low concentrations of endocrine disrupting chemicals in treated recycled water and the potential short environmental half lives of these compounds means that there is virtually no risk for EDC relating to using recycled water for crop irrigation.

While the health impacts for humans is considered low to negligible due to the very low concentrations in treated effluent, it has been demonstrated that wildlife that are in constant or near constant contact with water receiving treated effluent and other EDC-containing waters (eg, alligators in Florida and riverine fish in the UK) can be impacted (Guillette *et al.* 1994, Jobling *et al* 1998). The Floridian alligators were found to suffer from problems relating to the size and development of male gonads in Juvenile male alligators which was related to the presence of estrogenic-like compounds in the Florida everglades (Guillette *et al.* 1994). Joblin *et al.* (1998) observed that there was in increase in intersexuality of riverine fish which was linked to the presence of EDCs in UK water ways.

Pharmaceutically-Active Compounds

The majority of PhACs detected in environmental waters and waste waters are drugs used for a variety of therapeutic uses for both humans and animals. Examples include analgesics such as Ibuprofen, caffeine, antiepiletics, cholesterol reducing drugs such as atorvastatin (common brand name Lipitor), antibiotics and antidepressants. These drugs and other chemicals can enter the environment from a range of sources but one of the most common routes is through treated and untreated sewage effluent.

Similar to the issue with endocrine disrupting chemicals, these PhACs are found more commonly in sewage effluent than in other recycled waters meaning that more care would be needed with recycled water sources from sewage effluent. Some of these chemicals are easily removed during sewage treatment and environmental processes (Andreozzi *et al.* 2002, Buser *et al.* 1999), while others are more persistent (Ternes *et al.* 2002, Drewes 2004). Regardless, the concentrations of these chemicals in treated effluents is much lower than the concentrations used in the drugs and personal care products and thus should be considered of little health risk even if taken up by crops. One of the major concerns relating to PhACs is the development of antibiotic resistance in soil and water microorganisms due to the discharge of antibiotics into the environment (Guardabassi *et al.* 1998).

Nutrients

A major contaminant type commonly found in wastewater is organic and inorganic nutrients. The most common organic nutrient is dissolved organic carbon (DOC). DOC can take various forms depending on the source of the wastewater. The source of the organic carbon can also influence the bioavailability of the nutrient. For example DOC from drainage water would be likely to be more recalcitrant than DOC present in the effluent from a sewage treatment plant or from a food processing plant. It has been noted that the organic carbon present in recycled water can stimulate the activity of the soil microorganisms (Ramirez-Fuentes *et al.* 2002). Magesan *et al.* (2000) noted that the organic and inorganic nutrients in treated effluent that had a high carbon to nitrogen ratio stimulated the soil microorganisms which, in turn, decreased the hydraulic conductivity of the irrigated soil. The microorganisms in this study reduced the hydraulic conductivity in the soil by excess cell growth and the production of biofilm structures, both of which would have clogged up the pore spaces between the soil particles. In a different study Sheikh *et al.* (1987) observed that salad crops irrigated with the treated effluent, which had raised concentrations of inorganic nutrients, produced higher yields than similar crops irrigated with groundwater. Chakrabarti (1995) observed that rice crops gave a higher yield when irrigated with raw or partially diluted sewage effluent compared to unamended groundwater. In the same study Chakrabarti noted that initially the rice did better if a fertiliser was used in conjunction with the sewage effluent but this requirement for additional nutrients decreased over time due to accumulation of nutrients, particularly nitrogen, in the soil.

Evidently, while the additional nutrients can be a bonus as additional fertiliser, excess nutrients, particularly carbon and nitrogen, can have an adverse effect through excessive microbial activity and growth. Thus, care needs to be taken in the concentrations of nutrients in the recycled water to avoid detrimental impacts the porosity of soils.

Salinity

The physical characteristics of recycled water can have an impact on the environment in which it is used. Physical characteristics of interest can include pH, dissolved oxygen and suspended solids, but by far the most important, especially for water that is to be used for irrigation purposes, is the salinity of the recycled water, in particular the concentrations of sodium. Sodium and other forms of salinity are the most persistent in recycled water and are among the most difficult to remove from water usually requiring the use of expensive cation exchange resins or reverse osmosis membranes. These treatment regimes are commonly only used for the production of high quality recycled water which will provide a high return for the company providing the treatment water (eg, potable water or low TDS industrial water). Such treatment practices and high water quality requirements are rarely practical or economic for crop and pasture irrigation, thus other management mechanisms need to be employed.

The salinity of recycled water can impact both on the soil itself, as well as influencing the growth of the crops being irrigated. Salinity in the form of sodium can directly effect soil properties through the phenomena of swelling and dispersion (Halliwell *et al.* 2001). These effects occur as sodium, which is a positively charged cation, interact with the negatively charged layers (known as platelets) of clay particles. As sodium concentrations increase, the electrophoretic mobility of the clay platelets increases resulting in swelling dispersion of the clay particles thus impacting on soil permeability (Halliwell *et al.* 2001). This effect of increasing sodium concentrations on clay is not uniform, however and can vary between soils with similar soil characteristics (Balks *et al.* 1998). The reasons for these variations are complex and involve competing properties including soil texture and mineralogy, bulk density, pH, mechanical stresses and aggregate binding agents such as iron, aluminium oxides and organic matter (Halliwell *et al.* 1998). These effects and some of the consequences are portrayed in Figure 1 and much greater detail that is beyond this paper can be obtained in the papers by Balks *et al.* (1998), Halliwell *et al.* (2001) and Surapaneni and Olsson (2002).

One of the major impacts on the soil is the reduction of hydraulic conductivity. This can impact on the ability of water to infiltrate into the soil profile (with subsequent surface ponding problems) and thus, reduce the water availability to irrigated crops. As discussed above, salinisation of soil through the application of irrigation water will high salinity and the subsequent effect on clay in the soil is one mechanism that reduces the hydraulic conductivity. Other wastewater characteristics that have been identified to reduce hydraulic conductivity include the present of suspended solids (Magesan *et al.* 2000), nutrients which cause excess growth of microorganisms in the soil (Magesan *et al.* 1999) or interaction of dissolved organic matter with the soil profile (Tarchitzky *et al.* 1999).

In free draining soils, if the hydraulic conductivity is not reduced, then there is the possibility of movement of salt through the soil profile into unconfined aquifers (Bond 1998). The quality of the reused effluent, soil characteristics and initial quality of the receiving groundwater all are important factors in determining the extent to which salt reaches and impacts the quality of the groundwater. If the groundwater already is saline or has a high salt concentration then additional salt entering the groundwater from the soil will have limited impact (Bond 1998). Where groundwater has lower salt concentrations, the impact of some additional salt may not be considered too adverse if the extent of groundwater movement is limited, the groundwater is not used for any other nearby purposes (eg, drinking water supplies), or the groundwater does not have discharge zones where the salt can discharge into rivers and other surface water bodies (Bond 1998). Thus while the addition of salt to groundwater is often inevitable, this impact needs to be weighed up in consideration with all risks and benefits relating to effluent reuse.

The other issue relating to elevated sodium levels in recycled waters, particularly effluents such as treated sewage is the effect the sodium has on crops irrigated with this water. Grain crops such as wheat have been observed to be more resistant to saline irrigation of soils with less drop in yields over a wide range of electrical conductivities compared with other more sensitive crops (Katerji *et al.* 2003). Other cereals such as maize were less resistant to increases in salinity with large reductions in yield with increases in salinity (from electrical conductivity values of 2 dS/m up to 7 dS/m). Katerji *et al.* (2003) also noted that the soils type could influence yield with loamy soil having a greater yield than clay soils irrigated with water that had similar salinities. Asch *et al.* (2000) noted that a water salinity of 3.5 dS/m had a significant impact on the yield of rice with a decrease in grain yield compared to rice cultivars irrigated with fresher river water (0.5 – 0.9 dS/m).

Effluents commonly used for reuse purposes, for example treated sewage effluent, can often have electrical conductivities less than 1 dS/m (Balks *et al.*1998, Malkawi and Mohammad 2003). In these cases, the salinity of the water is usually not a problem for crops and good crop yields have been observed (Hussain and Al-Saati 1999). Increases in soil salinity due to the sodium accumulation in the soil can be more problematic (Surapaneni and Olsson 2002) which requires increased soil management practices for example, leaching the sodium from the soil structure by periodic irrigation with water with a lower salinity.

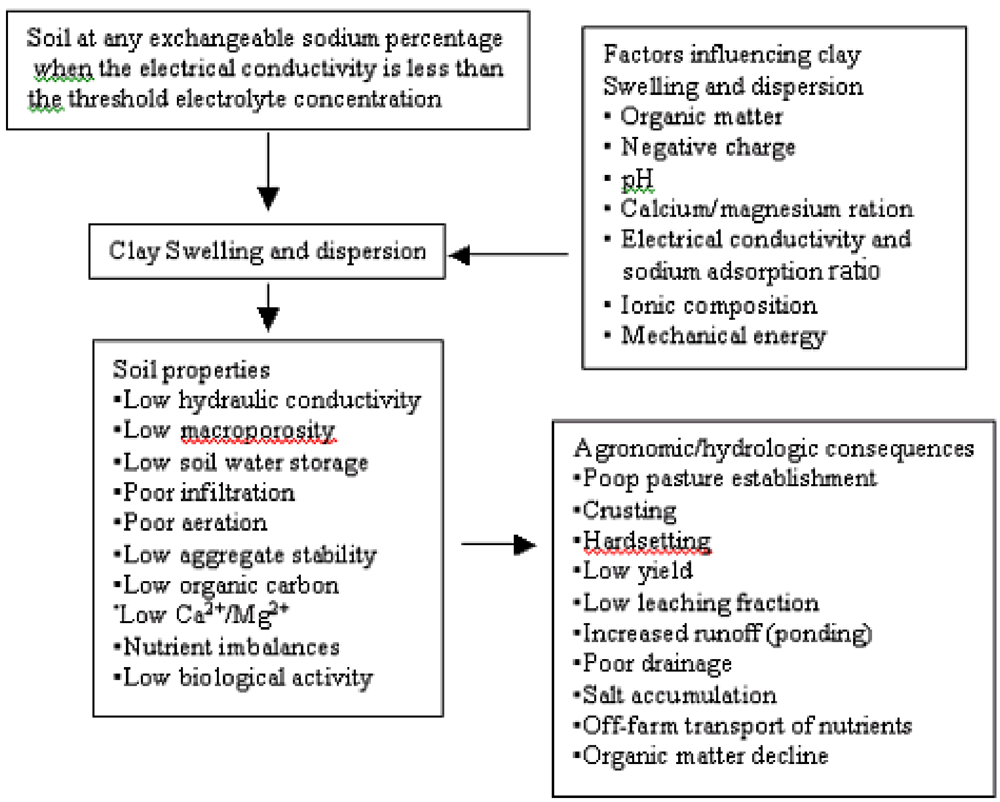

Figure 1. Development of soil problems due to changes in salinity (Surapaneni and Olsson 2002)

Public Concern

A major issue relating to all water reuse schemes is public opinion. Communities tend to be favourable in general to reusing water, in fact at times demanding that it is undertaken (eg, the Western Australia State Water Strategy (2002)). Most people, however, tend to become less favourable towards reused water as it physically comes closer to them. In other words, they are very supportive of the irrigation of public open spaces in some ill defined region, but baulk at the use of reused water in the household or when the chance of personal physical contact increases (Po *et al.* 2003, Hartley 2003).

The amount of public unease about water reuse also depends on the type of reused water and treatment levels. For example, people have much less concern about using untreated captured stormwater than they have about highly treated sewage effluent (Po *et al.* 2003). While the actual physical risk from the treated sewage effluent can be similar or less than that of untreated stormwater, the public perception (the "Yuck-factor") can lead to a belief within the community of a greater risk from the effluent (Marks 2003, Nancarrow *et al.* 2002).

It could be considered that public opinion for water reuse would be more favourable when it involves distance concepts such as crop irrigation. Consumers and exporters, however, are still concerned about the potential for negative health and environmental impacts with crops and recycled water and biosolids (Crute *et al.* 2004). More scientific research and effective communication as well as effective interaction with government agencies is needed to provide information on the merits and potential risks (or lack of) of using recycled water for the irrigation of cereal crops.

Overcoming water reuse problems (Management possibilities)

The principal mechanism for overcoming any difficulties relating to reusing water for irrigation of crops is the pre-treatment of the recycled water. As mentioned above the risk from microbial pathogens is significantly reduced with the treatment of water (Peasey *et al.* 2000). Treatment of recycled water also reduces the concentration of organic and inorganic nutrients, trace organics and heavy metals. The major contaminant that is difficult to remove from recycled water is salt and other cations and anions. The only effective treatment mechanism to remove salt molecules and ions is reverse osmosis membrane filtration. Such a high level of treatment is far too expensive to be economically viable for irrigation of crops and turf.

While it is difficult and expensive to remove salt and other recalcitrant contaminants from recycled water, they can be can be managed by effective use of the water. If the soil is porous enough and low in clay then all that is often required is monitoring that leaching of the water through the soil profile is occurring (Harris and Urie 1983). Alternatively water with a lower salinity can be blended with recycled water to reduce the concentration of salt. Another strategy that can be used is conjunctive water use. This involves leaching salt out of the soil profile by occasional irrigation of fields with a water source that has a low sodium concentration to flush accumulated salt out of the soil profile (Slavich *et al.*2002, Surapaneni and Olsson 2002).

Conclusions

The use of recycled water for the irrigation of crops has benefits in using a resource that would otherwise be discarded and wasted. Using recycled water also reduces the pressures on the environment by reducing the use of environmental waters. There are factors that need to be considered, including the presence of pathogens and chemical contaminants as well as salinity and impacts on soil structure. These can all be controlled through treatment and effective farm management practices. Ongoing research and development will also improve and increase the use of recycled water for irrigation purposes as well as increasing public confidence.

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