Recycled Water Irrigation in Australia

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Abstract

Access to water has been identified as one of the most limiting factors to economic growth in Australia's horticultural sector. Water reclaimed from wastewater (sewage) is being increasingly recognised as an important resource, and the agricultural sector is currently the largest consumer of this resource. An overview of the Australian experience of using reclaimed wastewater to grow horticultural crops is presented in this chapter. The wastewater treatment process and governing regulations are discussed in relation to risk minimisation practices which ensure that this resource is used in a sustainable manner without impacting adversely on human health or the environment. A case study covering the socio-economic and environmental implications of recycled water irrigation is also presented.

Keywords

Wastewater • Agriculture • Irrigation • Water recycling • Water treatment • Nutrients • Contaminants • Sodicity • Salinity • Best practice management

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1 Introduction

In Australia, the agricultural sector occupies approximately 54 % of the land and is the largest consumer of water. In 2008–2009, the total water use by the agricultural sector was 6,696 GL, 47 % of the total for Australia. In the northern regions where rainfall is more reliable, the predominant enterprises are beef cattle grazing, sugar and tropical fruit farming. In the south where summers are generally dry, dry land cereal farming, sheep grazing and dairy farming (in areas of higher rainfall) predominate (ABS 2010a). Whilst the gross value of irrigated agricultural production in 2006–2007 was 34 % of the total gross value of agricultural production, irrigated farmland represents only 1 % of the total land used for agriculture; most of this land is within the confines of the Murray-Darling Basin (ABS 2010a).

Policy changes to return environmental flows to the rivers, coupled with 8–10 years of drought, have seen water allocations decline, placing increasing pressure on irrigators. Despite water conservation steps across several states which have seen a 43 % reduction in water consumption throughout the country over the period of the drought (from 24,909 GL in 2000–2001 to 14,101 GL in 2008–2009), irrigators are still challenged with ongoing reductions in water allocations (ABS 2010b). In the face of these shortages, water reclaimed from wastewater is being increasingly recognised as an important resource which provides benefits for the community and the environment by increasing available water resources, returning critical environmental flows to failing waterways and decreasing nutrient and contaminant loads to surface and coastal waters.

"Treated" sewage water (commonly known as wastewater, recycled water or reclaimed water) has been underutilised in Australia, although increases in its reuse have been seen since the mid-1990s (Anderson and Davis 2006). There has been a steady increase in the volume of water reuse in agriculture, and currently around 11.5 % of total wastewater generated is reused (ABS 2010b). Although agriculture uses the largest amount of recycled water (103 GL/year), this represents only 1 % of the total volume of water used by the agricultural sector (ABS 2010b). Figure 1 shows both the distribution of reuse water consumption throughout the agricultural

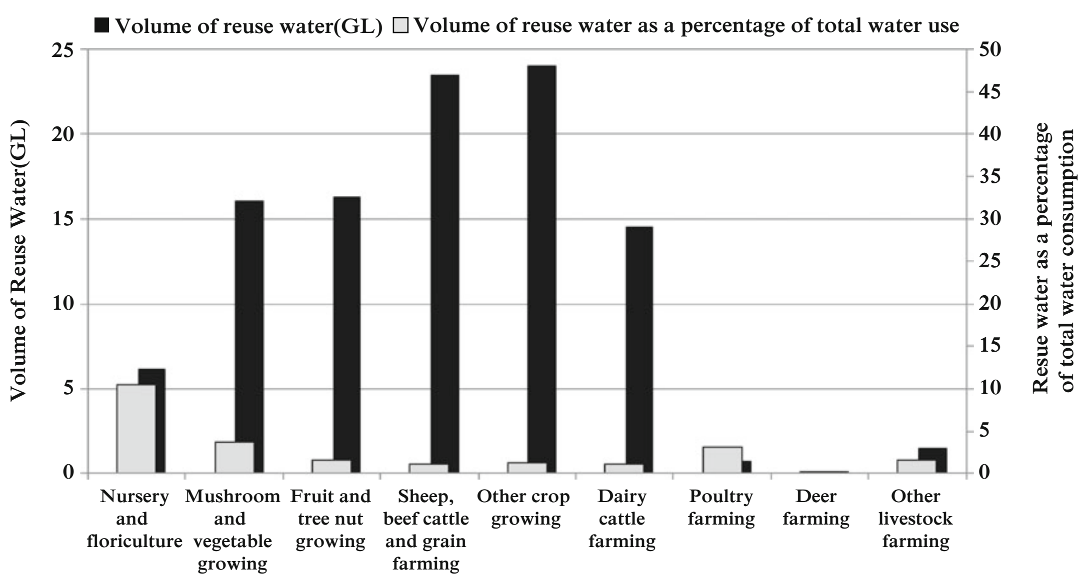

Fig. 1 Reuse water consumption within the Australian agricultural sector and as a percentage of total water consumption (From ABS 2010b)

sector and the reuse water consumption as a percentage of total water use for each enterprise type. Whilst beef, sheep and grain production use the largest volume of reuse water, it amounts to only 1 % of this industries' total water use (ABS 2010b). Horticulture and floriculture use the greatest amount as a proportion of total water use (10 %), followed by vegetable and mushroom production (4 %). This may be a reflection of the relative proximity of these industries to major wastewater treatment plants which supply the majority of reuse water and are located in proximity to densely populated urban areas.

2 Wastewater Treatment and Public Health

2.1 Wastewater Treatment

Untreated wastewater originates from domestic households, commercial premises and industrial activities. It does not include storm water which is the rainfall run-off from sealed surfaces including roofs and roads. It typically consists of 99.9 % water and 0.1 % impurities which include: dissolved and suspended organics, pathogens, nutrients, trace elements, salts, refractory organics, priority pollutants and heavy metal(loid)s. Varying degrees of treatment can be applied to remove or reduce these contaminants in wastewater. The aim of wastewater treatment is to produce water which is fit for purpose, i.e. when used as intended will not threaten human health or degrade the receiving environment. The extent of treatment required is usually regulated by Public Health or Environmental Protection Authorities.

Wastewater reclamation processes are traditionally grouped into preliminary, primary, secondary and tertiary treatment processes though it is possible to find significant overlap at wastewater treatment plants. At the preliminary stage, large debris and finer abrasive material are removed to prevent damage to downstream equipment. In the primary processes, sedimentation is used to remove approximately 65 % of the solid content of raw sewage and approximately 35 % of the biochemical oxygen demand (BOD). Sedimentation also removes a proportion of the heavy metal(loid)s which, being mainly cations, bind to negatively charged organic matter and clay particles. In secondary processes, bacteria remove soluble and colloidal wastes by assimilating organic matter to form new microbial biomass and by producing gas through the use of organic matter for endogenous respiration. Tertiary processes such as nutrient removal, filtration and disinfection are employed as an additional step to achieve sufficient removal of coliforms, parasites, salts, trace organics and heavy metal(loid)s to make the water suitable for unrestricted irrigation of food crops. These steps can be carried out concomitantly with earlier processes and include nutrient removal through precipitation (as in the case of phosphorus-P) and gaseous emission (as in the case of nitrogen-N though denitrification), and disinfection by UV light, chlorine or ozone reduces the number of pathogens present in the waste stream by inactivation.

2.2 Governance and Quality Requirements of Reclaimed Water Use

Regulations governing the use of reclaimed water are not uniform throughout Australia; each state and territory has responsibility for managing natural resources and public health in their jurisdiction. Legislation for wastewater reuse is covered by acts relating to food safety, public health and/or environmental protection. As such the state Public Health Authority and/or Environmental Protection Agency have responsibility for policing reclaimed water reuse.

Many states require enterprises which irrigate with reclaimed wastewater or supply reclaimed wastewater for the purpose of irrigation to produce and adhere to environmental (irrigation) management plans and/or user agreements. The plans should include a study of the irrigation site characteristics and justify how the wastewater will be applied so that its use will not threaten human health or adversely impact on the receiving environment. The need for user agreements to ensure wastewater is being utilised in the

Table 1 Water quality standards and applications for water classes A–D in South Australia

Class	Applications	Microbiological criteria	Chemical/physical criteria
A	Primary contact recreation	<10 *Escherichia coli*/100 mL	Turbidity ≤2 NTU
	Residential non-potable	Specific removal of viruses, protozoa and Helminths may be required	BOD <20 mg/L
	Unrestricted crop irrigation		Chemical content to match use
	Dust suppression with unrestricted access		
	Municipal use with public access		
B	Secondary Contact recreation	<100 *Escherichia coli*/100 mL	BOD <20 mg/L
	Restricted crop irrigation	Specific removal of viruses, protozoa and Helminths may be required	Suspended Solids <30 mg/L
	Irrigation of pasture and fodder for grazing animals		Chemical content to match use
	Dust suppression with restricted access		
	Municipal use with restricted access		
C	Passive recreation	<1000 *Escherichia coli*/100 mL	BOD <20 mg/L
	Municipal use with restricted access	Specific removal of viruses, protozoa and Helminths may be required	Suspended Solids <30 mg/L
	Restricted crop irrigation		Chemical content to match use
	Irrigation of pasture and fodder for grazing animals		
D	Restricted crop irrigation	<10000 *Escherichia coli*/100 mL	Chemical content to match use
	Irrigation for turf production	Helminths may need to be considered for pasture and fodder	
	Silviculture		

Source: DOH and EPA (1999); *NTU* Nephelometric Turbidity Units

approved manner varies across the jurisdictions as do the requirements for ongoing monitoring, audits and reviews. The extent of the relevant authorities' ongoing involvement in a scheme depends on its size, the risk associated with reuse and sensitivity of the receiving area.

Currently each state authority holds the responsibility for defining the quality of water that can be used to irrigate fruits/vegetables; guidelines for reclaimed water use exist in each state and territory (Power 2010). Recycled water guidelines set targets for removal of pathogens, nutrients, toxicants and salts. Health-based targets receive the greatest emphasis, and microbial contaminants present the greatest risk to human health; studies have shown that in achieving targets for pathogen removal, the chemical hazards which threaten human health are also reduced to acceptable levels.

Both the National and State guidelines for recycled water use were until recent times based around matching defined classes of water (based largely on their pathogen burden, biochemical oxygen demand and turbidity) with preapproved uses (Table 1). The highest quality A^+ recycled water could be used in residential dual reticulation systems, and the lowest classes, C or D, could only be used for irrigation of nonfood crops, e.g. instant turf, woodlots and flowers.

In 2006, in the face of increasing pressure on freshwater resources, the National Water Quality Management Strategy *Australian Guidelines for Water Recycling*: *Managing Health and Environmental Risks* (AGWR) was released (NRMMCEP and HCAHMC 2006). The AGWR was produced in an effort to establish consistent standards for reclaimed water schemes across the country and to introduce the risk management framework promoted by the *World Health Organization's Guidelines for Drinking-water Quality* (WHO 2008).

The AGWR does away with the class-based system and advocates a risk assessment-based approach. Each scheme is individually assessed; water quality targets, treatment processes and additional preventative measures are tailored to produce a safety level consistent with the proposed end use of the reclaimed water. The emphasis is no longer on end of line testing but on developing a multi-barrier approach to reduce risk to an acceptable level known as the "tolerable risk". The risk assessment is carried out largely in relation to hazards to human health, and in this regard microbial pathogens are the greatest threat (NRMMCEP and HCAHMC 2006). The AGWR national guidelines are not mandatory, and several states have elected not to adopt the new approach at this point in time (Power 2010).

3 Key Environmental Hazards

The contaminants in reclaimed water that present the greatest risk to the receiving environment include boron (B), cadmium (Cd), chlorine (Cl) and disinfection residuals, N, P, Sodium (Na) and Chloride.

3.1 Nutrients

Human and domestic wastes contribute large amounts of N and P to sewage. Only 50 % of the N and 60 % of the P are removed during treatment so the concentration of these major nutrients still remains higher in treated sewage than in irrigation water from other sources (Kelly et al. 2006).

Whilst the use of treated wastewater can benefit crop nutrient management, application in excess can be detrimental to both crops and the local environment. The nutrient load supplied to a crop is determined by the nutrient concentration of the reclaimed water and the irrigation depth (Kelly et al. 2006). Table 2 outlines the macronutrient uptake of a range of vegetables and the nutrient load supplied by an irrigation depth of 1,000 mm from wastewater which is treated to a tertiary level; the data demonstrates that at this level of irrigation, some nutrients would be supplied in excess of requirements, thereby likely to result in the loss of nutrients through leaching and surface run-off.

Nitrate is the most mobile form in soil and can be subject to leaching if nitrate and water are applied in excess of the plants' needs, this is a particular risk in colder, wetter seasons where plant growth is slow (Kelly et al. 2006). Nitrate can reach surface waters through run-off, contaminate groundwater and impact on public health if the water is used as a potable resource and potentially cause eutrophication of groundwater-dependent ecosystems.

Australia has some of the oldest and least fertile soils in the world; therefore, the P in waste water is generally of great benefit to crops in Australia. Reclaimed wastewater typically con-

Table 2 Crop macronutrient uptake and supply in reclaimed water (kg/ha)

		Nutrient contents (kg/ha)				
Crop	Typical yield (t/ha)	N	P	K	Ca	Mg
Cabbage	50	147	24	147	36	13
Capsicum	20	41	4	69	52	7
Carrot	44	210	19	270	175	10
Cauliflower	50	181	28	225	127	18
Celery	190	308	97	700	290	38
Cucumber	18	66	12	120	34	8
Lettuce	50	100	18	180	10	3
Potato	40	264	23	310	66	21
Tomato	194	572	133	856	348	87
Reclaimed water[a]	1,000 mm	82	11.5	468	399	308

Source: Kelly et al. (2006)
[a]Nutrients applied in 1,000 mm from the Virginia Pipeline Scheme, South Australia

tains less than 3 mg/L of soluble P, which rapidly becomes adsorbed to soil particles after irrigation (Kelly et al. 2006). When plant demand is low, P accumulation and immobilisation in the soil is more likely than leaching or over-fertilisation; the exception is in sandy soils where there is some risk of leaching (Kelly et al. 2006). The main concerns associated with P are its potential toxicity to Australian natives which has evolved on our low P soils and run-off or accidental discharges to water bodies leading to eutrophication (NRMMCEP and HCAHMC 2006).

3.2 Heavy Metal(loid)s

Most heavy metal(loid)s are very effectively removed from wastewater in the treatment process so that their levels are very low in reclaimed water. Boron and Cd are the only two heavy metal(loid)s included in the list of key environmental hazards in the current Australian Guidelines for Water Recycling – they are not as readily separated from reclaimed water during standard treatment (NRMMCEP and HCAHMC 2006).

Metal(loid)s partition to the biosolids formed during sedimentation processes because their ionic nature causes them to sorb strongly to charged organic matter and clays (Unkovich et al. 2006). At low levels some heavy metal(loid)s are considered as micronutrients, but above plant requirements foliar application can produce phytotoxicity (Bolan et al. 2011). By virtue of their persistent nature, they can also accumulate in the soil, thereby resulting in soil biota toxicity, phytotoxicity through root uptake and entry into the food chain leading to negative impacts on food quality and human health.

Boron is not retained in biosolids because it exists as an uncharged species within the normal pH range of wastewater and thus remains in the reclaimed water. Boron is a micronutrient at very low levels; it has a narrow safety margin and, if leaching fractions are insufficient, it can accumulate in the soil profile and cause a reduction in yield and also phytotoxicity in sensitive species (Unkovich et al. 2006).

Cadmium presents the highest health risk of all the heavy metal(loid)s in reclaimed water; it is loosely bound to soil and will cause phytotoxicity at relatively low levels; it is a particular threat to humans and animals because toxicity occurs at a lower threshold than for plants. Consequently, there are national and international schemes to monitor the Cd concentration in foods (Unkovich et al. 2006).

3.3 Organic Contaminants

Three main groups of organic contaminants are found in reclaimed wastewater (GuangGuo 2006; Müller et al. 2007) that include (1) natural organic matter (NOM) which consists of refractory molecules like fulvic and humic acids; (2) disinfection by-products which are formed during chlorination and (3) synthetic organic compounds including pesticides, organohalothanes, phthalates, aromatic hydrocarbons, surfactants, endocrine disrupting chemicals (EDCs), pharmaceuticals and personal care products.

Although NOM can induce putrefaction in stored reclaimed water by depleting oxygen, there is little concern with discharging NOM onto agricultural land because it should eventually be broken down by the natural microbial populations (GuangGuo 2006). Disinfection by-products (DBP) can be formed by the reaction of chlorine with NOM (Singer 1999). Trihalomethanes are the most well known of the DBPs which are considered carcinogenic, mutagenic and clastogenic (Kim and Clevenger 2007). Synthetic organic compounds represent a wide range of chemicals. Some are susceptible to wastewater treatment processes whilst others fall into the group of stable organics which may remain in very small amounts in reclaimed water. Many have been implicated as EDCs which interfere with normal hormone communication systems; they impact adversely on growth, reproduction and development. There is limited data on their presence in wastewater, and due to their potential to cause adverse environmental and human health impacts, further monitoring and research are warranted (Holmes et al. 2010).

3.4 Salinity and Sodicity

Irrigating with reclaimed water carries a risk of inducing soil salinity and/or sodicity because reclaimed water often contains high levels of salts, in particular Na (Rengasamy 2006). Soil salinity is seen when an elevated concentration of soluble salts in the soil-water solution induces osmotic stress in vegetation. Sodicity is an increase in proportion of Na relative to the divalent cations and adversely affects soil structure.

Managing soil salinity has been identified as one of the largest threats to developing a sustainable recycled water scheme (Sumner and Naidu 1998; Stevens et al. 2003). The salts which contribute to salinity include Na^+, K^+, Ca^{2+}, Cl^-, Mg^{2+}, $SO_4{}^{2-}$ and HCO_3^-, but Na^+ and Cl^- ions exert the greatest environmental impact because their solubility in water renders them more available for interactions in the soil (NRMMCEP and HCAHMC 2006).

Reclaimed water can induce soil salinity when salts become concentrated in the soil through evaporation, the principle signs of which relate to osmotic stress. Salinity reduces plant growth because the increased osmolarity makes it difficult for plants to absorb water and nutrients. In response to reduced water uptake, plants produce the hormone abscisic acid which signals stomata to close, reducing transpiration water losses. Consequently, carbon dioxide absorption is reduced and photosynthesis slows leading to lower plant growth (Hartung et al. 1999).

To prevent salt accumulation, a leaching fraction must be incorporated into the crops irrigation requirements to drive salts below the root zone. However, given climatic variations in rainfall and evaporation throughout the year, supplying the correct leaching volume can be difficult. Maintaining soil structure so that the leaching fraction can permeate the soil layers is also critical and this is complicated further by sodicity.

Reclaimed waters frequently have higher levels of Na^+ ions compared to the other cations and can induce sodicity or saline sodicity (Bond 1998). Sodicity develops when free Na^+ ions bind to the cation exchange sites on clays and by this mechanism remain in the soil whilst the other free salts are leached downwards (Sumner and Naidu 1998; Rengasamy 2006). In situations where the other free salts remain, the soil is known as saline-sodic and the soil structure remains intact.

The extent to which Na^+ ions bind to the cation exchange sites on a clay particle is determined by the ratio of Na^+ ions to Ca^{2+} and Mg^{2+} ions in the soil solution. This can be expressed either as the percentage of Na which occupies the cation exchange capacity of a clay, the exchangeable sodium percentage (ESP), or the ratio of Na^+ ions to Ca^{2+} and Mg^{2+} ions in the soil solution, the sodium adsorption ratio (SAR).

Sodic soils have poor physical characteristics because the high levels of Na^+ interfere with the structural integrity of clay particles when the soil is wetted (Laurenson et al. 2010). As a consequence, sodic soils display the typical characteristics and problems that include (Rengasamy 2006) reduced porosity and permeability, reduced infiltration and hydraulic connectivity, surface crust formation which impedes infiltration and promotes run-off and erosion, difficult to cultivate, provide an impediment to the development of a root network and expose plant roots to anoxic or waterlogged conditions and slow plant growth.

Reduced drainage can also lead to further accumulation of salts through poor downward movement of irrigation water and evaporative concentration. Clays with low hydraulic conductivity are more prone to developing sodicity because they have a low leaching fraction (Rengasamy 2006), and these soils retain water in their profile which is subjected to evaporation, leaving salts behind.

4 Management Practices

4.1 Irrigation Methods and Management

When reclaimed water is used as an irrigation source, the crop irrigation requirement must be carefully calculated to avoid the effects of hydraulic loading which include waterlogging, poor crop growth and health, mobilisation of salts and contaminants, rising water tables and run-off (NRMMCEP and HCAHMC 2006). The irrigation requirement is essentially the difference between the crop water requirements and the rainfall but also must take into account the seasonal changes in rainfall, homogeneity of water infiltration and the leaching requirement (Christen et al. 2006). Whilst leaching is often necessary to drive salts below the root zone, it is important that it is not conducted at the expense of a rising water table. A balance must be reached between the total water requirements of the crop and preserving the normal hydrologic function. Regional and local groundwater levels should be monitored so that any changes can be detected and managed appropriately.

The pathogen content of reclaimed water is often the limiting factor with regards to irrigation method; for example, class A water can be applied to crops which are eaten raw by any irrigation method, water consistent with class B can only be used to irrigate these crops by furrow or dripper irrigation and class C must be applied by subsurface drippers. Furrow or flood irrigation has the advantage of being relatively inexpensive and low in manpower requirements, but unless it is well designed and managed, infiltration can vary greatly throughout the irrigation space. Because sprinklers commonly apply water directly on foliage, their use on produce consumed raw is limited to class A water. Even with class A water, direct ion toxicities (with saline reclaimed water) and an increased propensity to develop fungal disease can be a concern where foliar application of water occurs (Christen et al. 2006). The most efficient system with the least environmental and human risk is generally considered to be drip irrigation (Christen et al. 2006).

4.2 Best Practice Management

Best practice irrigation with reclaimed water cannot be achieved by a one-solution-fits-all approach because there are a multitude of variables which must be considered, and each enterprise is unique. Irrigation schemes using reclaimed water should be tailored to optimise the economic returns to the grower whilst also minimising the impact on the receiving environment. This can best be achieved by undertaking a comprehensive risk assessment of the whole scheme and designing an irrigation management plan to minimise the risk of adverse outcomes.

The risk assessment should be based on the potential health impacts and soil, site and wastewater characteristics as follows:

- The soil properties examined should include soil texture, topsoil depth, depth to drainage or root impeding layers, infiltration rates, soil-water holding capacity and soil chemistry.
- Site characterisation must make assessment of topography, slope, soil homogeneity, history of waste storage or disposal on site, depth to groundwater and seasonal or permanent water tables, areas of drainage hazard and separation distances from sensitive areas.
- Wastewater analysis should describe the reclaimed water with reference to total solids, suspended and volatile solids, total P, inorganic P, total N, NH_4^+-N, K, SO_4^{2-}, BOD, pH, electrical conductivity, SAR, Ca, Mg, organic C, Na and Zn.
- Potential health impacts must be addressed with the relevant state health authority.

5 Case Study: Northern Adelaide Plains Irrigation Scheme

The Northern Adelaide Plains Reclaimed Water Scheme (or Virginia Pipeline Scheme), South Australia, provides irrigation for over 20 different types of crops within an area of approximately 200 km^2 (Laurenson et al. 2010). It was the first scheme of its type in Australia and remains as one of the largest reclaimed water schemes in the southern hemisphere. It supplies approximately 180 GL of tertiary treated, class A wastewater from the Bolivar Wastewater Treatment Plant (WWTP) to horticultural growers on the Northern Adelaide Plains through more than 100 km of pipelines (Laurenson et al. 2010). In 2008, the scheme encompassed 400 connections with the capability to supply up to 105 ML/day during the peak seasons; it delivers nearly half the water required by growers at Virginia. The water is used to irrigate a wide range of fruit and vegetables which supply local and interstate markets including beans, broccoli, cabbage, capsicum, carrots, cucumber, eggplants, lettuce, melons, onions, parsnips, pears, potatoes, pumpkins, tomatoes, zucchini, nuts, olives and wine grapes (Marks and Boon 2005).

The scheme is a joint venture between the Virginia Irrigators Association (representing the growers), Water SA (the state water authority responsible for wastewater treatment) and a private company, Water Infrastructure Group, Tyco. The establishment of this scheme in 1999 was largely driven by local growers facing a shortage of irrigation water.

The Virginia Pipeline Scheme has provided a secure water resource during a period which has been one of the driest on record. In some cases, the reclaimed water has replaced groundwater resources and in others provided a water source where farmers were unable to receive a groundwater allocation. The scheme has ensured the long-term economic sustainability of Adelaide's food bowl. The recycled water is sold at a reduced rate compared to mains water. About $50 million worth of the produce grown in the area each year uses the reclaimed water. The Water Infrastructure Group translates this to a $1 billion benefit to the district over the first 10 years of the project.

Environmentally, the scheme results in 35 % of water being recycled at Bolivar WWTP, reduces the discharge of harmful nutrients into the marine environment, reduces demand for groundwater extractions and contributes to reducing South Australia's dependence on pressured surface water systems. As one proponent eloquently summed it up, "The scheme has operated for 10 years with no human health issues and no detrimental environmental impacts, proving that recycled water can provide a safe and sustainable water resource."

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