Chapter 17
Use of Recycled Water for Irrigation of Open Spaces: Benefits and Risks

Muhammad Muhitur Rahman, Dharma Hagare, and Basant Maheshwari

Abstract The supply and sustainable use of recycled water may play an important role in enhancing urban water supplies in many water-scarce parts of industrialised countries like Australia because of the reduced treatment cost relative to seawater desalination and imported surface water. One such reuse option includes application of recycled water in the irrigation of urban open spaces. In 2009–2010, in Australia, the state-wide average of recycled water use in urban irrigation was 27.2% and the nation-wide average was 14% of the total recycled water produced. In Sydney, New South Wales (NSW) approximately 3.8 GL of recycled water is used for irrigating sports fields, golf courses, parks, landscapes and racecourses and, by 2015, it is expected that the recycled water will meet 12% of the total water demand in greater Sydney. Despite significant benefits of recycled water, there are several concerns related to environmental and health risks. If not properly managed, recycled water could deteriorate soil health in terms of increased salinity and sodicity, heavy metal accumulation and decreased hydraulic conductivity of soil. However, there are tools to reduce risks due to urban irrigation using recycled water; such as, national and state-wide standards of recycled water quality for urban irrigation, sustainable urban water management strategy and the pollutant control framework. In this chapter, recycled water usage for urban open space irrigation was discussed in the international and national contexts. Also, benefits and risks associated with recycled water usage in open space irrigation were examined and possible control measures were discussed.

Keywords Recycled water • Irrigation • Urban open spaces • Water quality • Environmental risk

M.M. Rahman (✉) • D. Hagare
School of Computing, Engineering and Mathematics, Western Sydney University,
Locked Bag 1797, Penrith, NSW 1797, Australia
e-mail: muhit.rahman@westernsydney.edu.au; d.hagare@uws.edu.au

B. Maheshwari
School of Science and Health, Western Sydney University,
Hawkesbury Campus, Locked Bag 1797, Penrith, NSW 2751, Australia
e-mail: b.maheshwari@westernsydney.edu.au
17.1 Introduction

Recycling is one of the viable options to attain sustainable management of wastewater. The merits of recycled water are diverse and include reducing pressure on existing fresh water supplies, minimising effluent disposal to surface or coastal waters and provisioning a constant volume of water other than rainfall-dependant sources (Chen et al. 2012). The supply and use of recycled water may play an important role in enhancing urban water supplies in many water-scarce parts of industrialised countries because of its reduced treatment cost relative to seawater desalination and imported surface water. The technological improvement and economic affordability of wastewater treatment has made wastewater recycling a reality and broadened the most sustainable use of recycled water. One such reuse option includes the application of recycled water in the irrigation of urban open spaces.

Recycled water is the treated wastewater after removing solids and certain impurities. Characteristics of recycled water depend on its source, treatment level and geographic location. Recycled water characteristics can be classified according to its physical, chemical and biological aspect. The biological aspect is important when health effects are considered. Otherwise, physical and chemical characteristics are crucial to understand the environmental effects of using recycled water. Important recycled water characteristics are pH, total dissolved solids (TDS), salinity, sodium adsorption ratio (SAR) and heavy metals. These parameters directly influence the salt accumulation in the soil and also the sodicity and its effect on soil.

17.1.1 Characteristics of Recycled Water for Using in Irrigation

Various domestic and commercial activities at the source of wastewater generation contribute towards elevated levels of salt in wastewater. In other words, composition of recycled water depends on the original composition of the municipal water supply and nature of residential and commercial communities contributing to the wastewater, and varies from community to community. In the conventional wastewater treatment process, the majority of mineral salts pass through the wastewater treatment system unaffected, unless reverse osmosis is used as one of the treatment processes (Aiello et al. 2007; Rebhun 2004). Hence, in most cases recycled water exhibits relatively higher amounts of salts, chemical contaminants and pathogens (in secondary treated recycled water) that are potentially detrimental to soils or plant growth and pose a risk to the environment and public health. According to DEC (2004), recycled water for irrigation is classified as low, medium and high strength based on the concentrations of nitrogen, phosphorus, BOD$_5$, TDS and other potential contaminants (Table 17.1). It is expected that for a certain class of recycled water strength, all the constituents fall within the given range. However, the strength of recycled water to be used in urban irrigation should also agree with plant type,
In Australia, in most of the cases, recycled water is tertiary treated before using it in urban irrigation. As shown in Table 17.2, data collected from Sydney Water shows levels of different contaminants in the recycled water are within the range of Australian Standards for urban irrigation. Amounts of contaminants present in the recycled water of some overseas countries are also highlighted in Table 17.2. Data presented in the table reveals the wide range of contaminants present in recycled water. This is because of the variability in community and water usage pattern based on geographical position, as discussed earlier. However, some contaminants (such as, electrical conductivity and TDS) shown in the table are significantly higher than drinking water standards. According to NRMMC-EPHC-AMC (2006), electrical conductivity (EC), TDS, Na\(^+\) and Cl\(^-\) are 0.1 dS/month, <500 mg/L, 180 mg/L and 250 mg/L, respectively in town (drinking) water. In addition, higher levels of certain anions and cations are also observed in recycled water. The impact of higher amounts of salt in recycled water used for irrigation is discussed in Sect. 17.4.

### Table 17.1 Classification of recycled water for irrigation according to its strength (Dec 2004)

| Parameters                  | Strength of recycled water (mg/L) |
|-----------------------------|-----------------------------------|
|                             | Low  | Medium | High         |
| TDS                         | <600 | 600–1000 | 1000–2500   |
| Total nitrogen              | <50  | 50–100  | >100         |
| Total phosphorus            | <10  | 10–20   | >20          |
| BOD\(_3\)                   | <40  | 40–1500 | >1500        |
| Metals, pesticides          | Five times the value mentioned in ANZECC and ARMCANZ (2000) is considered as high strength |
| Grease and oil              | >1500 mg/L is considered as high strength |

tolerance of the plant to contaminants, site characteristics, management of the site such as water balance for the site, relevant environmental objectives for any receiving water, existing ambient water quality and conditions under which a discharge is likely to occur.

In Australia, in most of the cases, recycled water is tertiary treated before using it in urban irrigation. As shown in Table 17.2, data collected from Sydney Water shows levels of different contaminants in the recycled water are within the range of Australian Standards for urban irrigation. Amounts of contaminants present in the recycled water of some overseas countries are also highlighted in Table 17.2. Data presented in the table reveals the wide range of contaminants present in recycled water. This is because of the variability in community and water usage pattern based on geographical position, as discussed earlier. However, some contaminants (such as, electrical conductivity and TDS) shown in the table are significantly higher than drinking water standards. According to NRMMC-EPHC-AMC (2006), electrical conductivity (EC), TDS, Na\(^+\) and Cl\(^-\) are 0.1 dS/month, <500 mg/L, 180 mg/L and 250 mg/L, respectively in town (drinking) water. In addition, higher levels of certain anions and cations are also observed in recycled water. The impact of higher amounts of salt in recycled water used for irrigation is discussed in Sect. 17.4.

### 17.2 Current Status of Use of Recycled Water for Urban Irrigation

Urban irrigation with recycled water helps to attain water sustainability, which subsequently leads a city to grow as a liveable city. Knowledge of the current status of recycled water use in urban irrigation in the context of geographical distribution is important to understand and improve the use and quality of recycled water in urban irrigation. In this section recycled water use in urban irrigation practiced in different developed countries is reviewed. Later, the current status of using recycled water in urban irrigation in Sydney and overall Australia is discussed.
Recycled water use in urban irrigation is gaining popularity throughout the world as an alternate to using fresh water. Currently, most of the developed countries have availed themselves of the use of recycled water as an indicator of water sustainability. In the implementation of recycled water in urban irrigation, guidelines developed by World Health Organization (WHO) and United States Environmental Protection Agency (USEPA) are mostly followed by different countries. Australia, many Middle Eastern and Mediterranean European countries, and many states of

### Table 17.2  Key characteristics of recycled water for irrigation

| Parameter                      | Unit   | Recycled water characteristics (International) | Recycled water characteristics (Australian) | Recycled water standard for irrigation (Australian) |
|--------------------------------|--------|-----------------------------------------------|---------------------------------------------|---------------------------------------------------|
| Total Salinity, EC             | dS/m   | 0.51–2.7                                       | 0.803                                       | 0.65–1.3d                                         |
| Total dissolved solids (TDS)   | mg/l   | 358–1800                                       | 495                                         | 600–1000f                                         |
| Sodium adsorption ratio (SAR)  |        | 1.9–11                                         | 5.4                                         | 10–18f                                           |
| BOD5                           | mg/l   | 6–13.2                                         | <2                                          | 40–1500f                                          |
| Aluminum                       | mg/l   | 0.0–0.17                                       | 0.033                                       | 5                                                |
| Arsenic                        | mg/l   | 0.00062–0.005                                  | <0.001                                     | 0.1                                              |
| Boron                          | mg/l   | 0.0005–0.00118                                 | 0.048                                       | 0.5                                              |
| Cadmium                        | mg/l   | 0–0.22                                         | 0                                           | 0.01                                             |
| Cobalt                         | mg/l   | 0.001–4.8                                      | 0.001                                       | 0.05                                             |
| Copper                         | mg/l   | 0.00273–5.76                                   | 0.001                                       | 0.2                                              |
| Iron                           | mg/l   | 0.103–25.7                                     | 0.026                                       | 0.2                                              |
| Lead                           | mg/l   | 0–0.2                                         | <0.001                                     | 2                                                |
| Manganese                      | mg/l   | 0.003–7.35                                     | 0.039                                       | 0.2                                              |
| Molybdenum                     | mg/l   | 0.004–0.004                                    | <0.001                                     | 0.01                                             |
| Nickel                         | mg/l   | 0.003–3.05                                     | 0.003                                       | 0.2                                              |
| Selenium                       | mg/l   | 0.053–0.053                                    | <0.005                                     | 0.02                                             |
| Zinc                           | mg/l   | 0.035–2.2                                      | 0.033                                       | 2                                                |
| Sodium                         | mg/l   | 84.9–350                                       | 96                                          | 230–460f                                          |
| Chloride                       | mg/l   | 43.9–564.4                                     | 113                                         | 350–700f                                          |
| Total N                        | mg/l   | 8.6–11.71                                      | 5.8                                         | 5–50                                             |
| Total P                        | mg/l   | 0.6–11.1                                       | 0.021                                       | 0.5–10f                                          |

a. Adrover et al. (2010) and Dikinya and Areola (2010)
b. Treated by Sydney water (2011–2012); data collected by personal communication
c. DEC (2004)
d. Water salinity rating: low
e. For moderately tolerant plant, i.e. lucerne
f. Total P loads in wastewater from intensive animal industries are likely to vary between 10 and 500 mg/L
United States of America (USA) also have water reuse guidelines or regulations (Anderson 2003; Exall 2004; Sato et al. 2013; Angelakis and Gikas 2014).

In USA, 41 states have set guidelines for using recycled water for urban irrigation. It includes unrestricted and restricted irrigation in 28 and 34 states, respectively (Feigin et al. 1991). Typically, secondary treatment and disinfection is the minimum level of treatment required for unrestricted irrigation of urban landscapes. However, in some cases, additional treatment including coagulation, oxidation, and filtration are practiced (Feigin et al. 1991). In Florida, USA, in 2005, 462 golf courses, covering over 56,000 acres of land, were irrigated with recycled water. Recycled water was also used to irrigate gardens of 201,465 residences, 572 parks and 251 schools (Haering et al. 2009). According to Olivieri et al. (2014), in California, the state wide survey indicated that use of recycled water increased 2.2 times (from 400 to 862 Mm$^3$/year) within two decades (from 1989 to 2009). About 37% of the produced recycled water was used in agricultural purpose and about 17% was used for landscape irrigation. In southern California, recycled water was used for irrigating mainly golf courses and lawns. An extensive survey conducted by Tanji and Grattan (2007) shows that in 2002, on average 21.1% of total recycled water was used for landscape irrigation. However, the proportion of total recycled water used for landscape irrigation in 2003 in southern California were 17% in the Los Angeles region, 34% in the Santa Ana region, 78% in the San Diego region and 34% in the San Francisco Bay region. The authors emphasise that there is potential to use the recycled water in landscape irrigation in arid and densely populated areas, such as the Los Angeles basin. It was proposed to replace the currently used fresh water with recycled water in irrigating golf courses, lawns, trees, shrubs, ground covers, vines, ornamental plants and flowers.

In Canada, although few have been reported in the literature (Exall 2004), recycled water is being used for irrigating golf courses and municipal lands in many regions. CWRS (1999) reported that over 200 golf courses used recycled water for irrigation. Among them three were in Alberta, three in British Columbia, two in Ontario and one in Nova Scotia. The irrigation was mainly conducted from April to October. In the golf courses of Alberta, 114,000–150,000 m$^3$/season of recycled water was used; in British Columbia it was 150,000 m$^3$/season and in Nova Scotia 250,000 m$^3$/season.

In Europe, a considerable development of using recycled water occurred in the coastline and islands of the semi-arid southern regions, and in the highly urbanised areas of the wetter northern regions (Bixio et al. 2006). About 70% of the wastewater generated in Europe is recycled (Sato et al. 2013). The use of recycled water was quite different between these two regions. In southern Europe, for example, recycled water was used for agricultural irrigation and for urban or environmental applications, whereas, in northern Europe, the uses were mainly for urban or environmental applications, or industrial purposes (Angelakis and Gikas 2014). Recycled water use in urban environmental applications is shown in Fig. 17.1 for different countries in Europe. As shown in the figure, many of the European countries are currently meeting 30% or more of their urban irrigation demand from recycled water.
In Australia, different states developed their own approaches to manage recycled water. Australia was established with a 3 tier government system, namely, a federal government, 6 states and 2 territory governments, and about 700 local governments (Radcliffe 2010). The management of public open spaces are under the jurisdiction of local governments. The local governments receive the recycled water from state owned wastewater treatment facilities. Wastewater reuse for the purpose of irrigation of agricultural crops, amenity planting and recreational facilities started in the late 1990s (Radcliffe 2010). Until the 1990s no major Australian city had advanced sewage treatment other than secondary treatment and some cities were still piping primary treated effluent into high energy coastlines and relying on dispersion. In 1999, the largest water recycling project commenced in Australia. This is the Virginia Pipeline Scheme where 22,000 ML of advanced treated recycled water had been contracted from the Bolivar STP near Adelaide, South Australia to irrigate market gardens on the Northern Adelaide Plains (Dillon 2000). At present, a national guideline for recycled water quality and end uses, *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks* developed in 2006, provides a generic framework for the management of recycled water (NRMMC-EPHC-AMC 2006).

The overall picture of wastewater recycling is promising for different capital cities in Australia. Table 17.3 shows the amount of recycled water as a percent of total sewage produced for five major cities of Australia (Radcliffe 2010). As shown in the table the recycling of wastewater rose sharply between 2001–2002 and 2007–2008 in the case of Melbourne and Adelaide. On the other hand for cities Sydney,
Brisbane and Perth only marginal increases were recorded. However, as per the author, all these cities have set some targets to achieve in the coming years from 2007 to 2008.

In Australia, most of the recycled water is reused in agriculture. In 2004, irrigated agriculture accounted for approximately 67% of Australia’s total water usage. Nearly 50% of the water used for irrigating pasture and fodder crops, and 13% used for horticulture and viticulture (vegetables = 4%, fruit = 5%, grapevines = 4%) (Hamilton et al. 2005). In 2009–2010, 37% of recycled water was used in agriculture followed by sewerage and drainage services, which used 30%. Distribution of other sectors is shown in Fig. 17.2a. It is interesting to see that the purpose for which recycled water is used in 2009–2010 (ABS 2012) has been considerably changed than it was in 1993–1997 (Dillon 2000). This includes reducing the reuse of recycled water in mining from 32 to 3%, and increasing the sewerage and drainage services from 3% to 30%. The reason of this change may be because of discrepancies in the definition of sectors when calculating the reuse of recycled water (Hamilton et al. 2005). For example, according to the Australian Bureau of Statistics (ABS 2006, 2010, 2012), the ‘effluent’ is estimated as all regulated discharge from the water supply, sewerage, and drainage industries. Thus, some of these discharges would be non-sewage effluent. In practice, ‘effluent’ refers to treated sewage only. Thus some of the changes in the recycled water use can be attributed to the differences in methods of calculation. Nevertheless, the data in Fig. 17.2 appears to indicate that lately more and more recycled water is being used for irrigating open and agricultural fields.

In the case of using recycled water for urban irrigation, there are significant differences in reuse between states, with NSW, Victoria and Queensland using higher amount compared to other states and territories (Table 17.4). It is evident from the table that in 2004–2005 to 2008–2009, state-wide average of recycled water use in urban irrigation was 30% of the total, which is 28.9 and 26.7% for the whole Australia; in 2009–2010, state-wide average was 27.2% and the nation-wide average was 14% of the total recycled water. In 2009–2010, in the Australian Capital Territory (ACT) usage of urban irrigation (GL/year) is reduced compared to other reported years. Again the “% usage of total water” shows significantly low, because other sectoral use of recycled water, such as “sewerage and drainage services” increased significantly (from 3.9 GL/year in 2008–2009 to 30.8 GL/year in 2009–2010).

### Table 17.3 Percentage of water recycled in major cities in Australia (After Radcliffe 2010)

| Major city | 2001–2002 | 2005–2006 | 2007–2008 | Stated objectives on 2003 |
|------------|-----------|-----------|-----------|--------------------------|
| Sydney     | 2.3       | 3.5       | 4.4       | 10% recycling by 2020    |
| Melbourne  | 2.0       | 14.3      | 23.2      | 20% recycling by 2010    |
| Brisbane   | 6.0       | 4.8       | 6.3       | 17% recycling by 2010    |
| Adelaide   | 11.1      | 18.1      | 30.6      | 33% recycling by 2025    |
| Perth      | 3.3       | 5.3       | 6.4       | 20% recycling by 2012    |
In Sydney recycled water has been used for irrigation since 1960s. In 2011, Sydney Water supplied about 3.8 GL of recycled water for irrigating farms, sports fields, golf courses, parks, landscapes and racecourses and by 2015, it is expected that the recycled water will meet 12% of total water demand in greater Sydney (Sydney Water 2013). It seems that Sydney has improved the recycling target from its objective stated on 2003 (Table 17.3). Thus the increasing use of recycled water, particularly for irrigating urban open spaces, in the place of fresh water, is one of the important goals of the local and state governments to achieve sustainable

![Fig. 17.2](image-url) Sectoral distribution of recycled water use in Australia in (a) 2009–2010 (ABS 2012) and (b) 1993–1997 (Dillon 2000)

### 17.2.3 In Sydney

In Sydney recycled water has been used for irrigation since 1960s. In 2011, Sydney Water supplied about 3.8 GL of recycled water for irrigating farms, sports fields, golf courses, parks, landscapes and racecourses and by 2015, it is expected that the recycled water will meet 12% of total water demand in greater Sydney (Sydney Water 2013). It seems that Sydney has improved the recycling target from its objective stated on 2003 (Table 17.3). Thus the increasing use of recycled water, particularly for irrigating urban open spaces, in the place of fresh water, is one of the important goals of the local and state governments to achieve sustainable
management of water. About 1 GL of recycled water per annum is used in Sydney and Illawarra for irrigating farms, golf courses, sports fields, parks and a racecourse (Sydney Water 2011). Overall, as per 2011 data, Sydney Water operates 17 recycled water schemes. These include the residential dual reticulation scheme at Rouse Hill; the Wollongong Recycled Water Scheme that supplies recycled water for industrial and irrigation use; and other schemes that supply recycled water for use in agriculture and on playing fields and golf courses.

The amount of recycled water used in greater Sydney varies, depending on the weather. The application rates as well as number of years of irrigation of some of the fields in Sydney are listed in Table 17.5. Past and projected scenarios of recycled water use for different sectors in Sydney are shown in Fig. 17.3. According to the Metropolitan Water Directorate (2014), in mid-2010, use of recycled water was saving about 33 GL of water that might otherwise come from drinking water supplies. Implementation of the Replacement Flows Project at St Marys from October 2010 increased recycling by 18 GL/year and by 2030 it is projected that 100 GL of water will be recycled each year.

### Table 17.4
Annual volume and percent use of recycled water (of total produced recycled water) in urban irrigation (ABS 2006, 2010, 2012)

| States and territories | 2004–2005 GL/year | % of total | 2008–2009 GL/year | % of total | 2009–2010 GL/year | % of total |
|------------------------|------------------|-----------|------------------|-----------|------------------|-----------|
| NSW                    | 9.76             | 19.61     | 11.69            | 18.74     | 15.68            | 12.37     |
| VIC                    | 24.30            | 34.88     | 32.88            | 33.60     | 9.88             | 10.10     |
| QLD                    | 15.67            | 35.02     | 8.60             | 20.21     | 16.64            | 27.16     |
| SA                     | 1.48             | 7.24      | 5.29             | 18.26     | 2.95             | 9.21      |
| WA                     | 6.62             | 43.38     | 9.37             | 50.23     | 3.37             | 19.26     |
| TAS                    | 0.45             | 10.53     | 0.52             | 8.04      | 2.62             | 40.34     |
| NT                     | 1.33             | 71.98     | 1.55             | 83.82     | 1.22             | 99.03     |
| ACT                    | 0.56             | 25.35     | 0.32             | 7.66      | 0.15             | 0.49      |
| Australia              | 60.13            | 28.88     | 70.22            | 26.71     | 52.50            | 14.04     |

### Table 17.5
Application rate of recycled water for urban open space irrigation (Sydney Water 2010)

| Name of the site/field | Number of years of irrigation | Application rate (AR, ML/ha/year) |
|------------------------|-------------------------------|----------------------------------|
| Nepean Rugby Park      | 17                            | 2.50                             |
| Ashlar Golf Club       | 37                            | 4.50                             |
| Dunheved Golf Club     | 11                            | 1.05                             |
| Castle Hill Golf Club  | 28                            | 2.07                             |
| Kiama Golf Club        | 13                            | 5.11                             |
| Liverpool Golf Club    | 7                             | 2.53                             |
| Richmond Golf Club     | 51                            | 3.52                             |
| UWS Hawkesbury Campus  | 51                            | 1.12                             |
| Warwick farm racecourse| 31                            | 0.60                             |
Benefits of using recycled water in urban irrigation are its availability year round and the presence of some organic material and nutrients which are beneficial to plant growth. Different communities, local governments and policy makers tend to use recycled water for beneficial purposes (such as urban irrigation, and environmental flows) rather than disposing it in the ocean. However, benefits from recycled water still depend on its efficient management for irrigation scheme. Apparent benefits of using recycled water for irrigation are detailed in the following sections.

17.3 Benefits of Using Recycled Water in Irrigation

Benefits of using recycled water in urban irrigation are its availability year round and the presence of some organic material and nutrients which are beneficial to plant growth. Different communities, local governments and policy makers tend to use recycled water for beneficial purposes (such as urban irrigation, and environmental flows) rather than disposing it in the ocean. However, benefits from recycled water still depend on its efficient management for irrigation scheme. Apparent benefits of using recycled water for irrigation are detailed in the following sections.

17.3.1 Water Security

Water security can be defined as making sure that all water users get continuous access to a suitable quality of water (Productivity Commission 2011). In a country like Australia, where sources of water varies because of variable rainfall and inflows to river, alternate sources of water are needed to ensure water security. According to the Productivity Commission (2011), the following actions may increase water security in Australia:

- Building wastewater recycling plants, desalination plants or dams that will add to available water,
• Developing regulatory options so that the users, such as irrigators, may purchase irrigation water in an easy and efficient manner, and
• Reducing water consumption through demand management activities, such as water restrictions or community campaigns to preserve water.

On the basis of the above three actions, recycled water might be a viable source for agriculture near urban areas, which has the advantage of flowing uniformly throughout the year and being relatively consistent in quality. Also, if the recycled water can be stored during winter this can represent a valuable economic commodity (Dillon 2000).

As discussed earlier, New South Wales, Australia has progressed well with the recycling of treated wastewater for urban irrigation (Table 17.4). For a clear picture of how much potable water can be saved by replacing it with recycled water, the irrigation approach for golf courses can be discussed. Maintaining a quality golf course includes the maintenance of good quality landscapes which includes fairways and surrounding roughs. Unlike trees and shrubs, turf grasses have very little capacity to store water and withstand periods of drought. Golf course turf usually needs water applied at least twice per week in the summer. Any deficit in rainfall must be supplemented with irrigation. A typical golf course requires 378.5–3,785 m$^3$ of water per week in summer to maintain healthy vegetation. The hilly terrain and irregular shape of golf course makes applying water and water retention, and irrigation uniformity difficult. Water audits performed across the country suggest that many golf courses use 20–50\% more irrigation water than necessary (Alliance for water efficiency 2014). Therefore, recycled water has great potential to tackle the situation in a well-managed golf course saving potable water. This is also highlighted in Table 17.5, where recycled water use in different golf courses is shown.

Besides obtaining recycled water from centralised wastewater treatment for irrigation of open spaces, sewer mining is an alternate source of recycled water. Sewer mining involves extracting the wastewater before it reaches the centralised wastewater treatment plant and treating it at a decentralised treatment facility (Water Corporation 2013). Sewer mining schemes in Sydney are producing over 1 GL of recycled water each year. With four major projects now completed and another eight under way, this alternative water source is helping save precious potable water supplies (Metropolitan Water Directorate 2014). Among the completed four projects, Pennant Hills Golf Club supplies 1 ML/year of recycled water to irrigate greens and fairways, Sydney Olympic Park Authority supplies 8 ML/year of recycled water to irrigate Sydney Olympic Park and Newington Estate, and Kogarah Council uses around 1.6 ML/year to irrigate parks, playing fields and Beverly Park Golf Course (Metropolitan Water Directorate 2014). However, for the successful implementation of sewer mining, care should be taken so that the quality of produced recycled water is inspected by regulatory agencies.
17.3.2 Nutrient Value of Recycled Water

An advantage of using recycled water for irrigation is its nutrient value comprising nitrogen (N) and phosphorus (P) (Table 17.1). While Sakadevan et al. (2000) reported an increased yield of dry matter because of recycled water irrigation, and Toze (2006) reported increased metabolic activity of soil microorganism, nutrients of recycled water have two distinct advantages:

- Controlling eutrophication of surface water; and
- Could potential supplement fertiliser required for plant growth.

Eutrophication control of surface water is indirectly related to recycled water use in irrigation. The impact is indirect, because it is compared in a manner that when nutrient rich recycled water is disposed in surface water (Greenway 2005) this may contribute to the process of eutrophication. Therefore, in agricultural areas and especially in dry climates, an alternative to the usual wastewater treatment with biological nutrient removal would be the reuse of these waters for irrigation; therefore the effective nutrient removal would occur through uptake by crops (Sala and Mujeriego 2001).

Recycled water has the potential to be used as fertiliser when used as irrigation water. Fasciolo et al. (2002) reported that average garlic yields irrigated with treated wastewater were 10% higher than those irrigated with well water. According to Vazquez-Montiel et al. (1996), yields of Maize crop increased 33% when secondary treated recycled water was used instead of fresh water. According to Sala and Mujeriego (2001), nutrient contribution in the soil increases with each application of recycled water. The greater the irrigation dose, the higher the contribution, given a certain nutrient concentration. Because of this, it is very important to generate frequent information on these nutrient contributions during the irrigation season, so that conventional fertilisers would only be applied either as a complementary source of nutrients if the irrigation could not cope with all the crop needs, or as a source of material for balancing the ratio between nutrients (Sala and Mujeriego 2001). The same study showed that in the Costa Brava area, North East Spain, where recycled water is supplied for irrigating three golf courses, information about the content of nutrients in the recycled water is generally given every month, so the users can adapt their fertilisation plans to what is being applied to the irrigation water. Table 17.6 summarises the nutrient contributions by the irrigation water on two golf courses in

| Element                      | Contribution by irrigation water | Recommended contribution | % contribution by irrigation water |
|------------------------------|----------------------------------|---------------------------|-----------------------------------|
| Nitrogen, kg N/ha.year       | 108                              | 166                       | 65                                |
| Phosphorus, kg P₂O₅/ha.year  | 121                              | 100                       | 121                               |
| Potassium, kg K₂O/ha.year    | 160                              | 166                       | 96                                |
1997 located on the Costa Brava which are using recycled water. It is clear from the table that among three nutrients, only Nitrogen should be supplied additionally as a form of fertiliser to meet the recommended need. Periodic monitoring of nutrient status in soil to avoid imbalanced nutrient supply is also highlighted by other researchers (Pedrero et al. 2010; Mohammad and Ayadi 2005; Vazquez-Montiel et al. 1996).

17.4 Risks of Using Recycled Water in Irrigation

Despite the significant benefits of recycled water, there are several concerns related to environmental and health risks. If not properly managed, irrigation induced run-off and rainfall runoff from irrigated areas may cause eutrophication of surface water. Due to increased level of salt in the recycled water there is a risk of root zone salinisation (Rahman et al. 2014a, 2015a, 2016) In addition, excessive leaching of salt from rootzone may cause an increase in contaminants in the groundwater. For restricted use of recycled water in urban recreational areas (such as golf courses), care should be taken to avoid direct human contact or limit the exposure to recycled water at the time of irrigation; for unrestricted uses (such as for irrigating landscape of parks, playgrounds and schoolyards) recycled water quality should be of relatively high quality. Opinions of the community using these recreational facilities cannot be overlooked and should be incorporated in the management plan of using recycled water for urban irrigation. Overall, concerns related to using recycled water are discussed below.

17.4.1 Soil Health

One of the major concerns related to recycled water irrigation is the increase of salinity including sodicity and bicarbonate hazards in irrigated fields. Salinity is the concentration of soluble salts in water that are measured as total dissolved solid (TDS) or electrical conductivity (EC). EC is an indirect measurement of TDS in the irrigation water or soil extract. Electrical conductivity of soil extracts can be based on a 1:5 soil:water extract ($EC_{1:5}$) or a saturation paste extract ($EC_e$). $EC_e$ is commonly used as an indicator of plant tolerances. However, because $EC_{1:5}$ are much easier to obtain, conversion factors are often used to convert soil $EC_{1:5}$ to $EC_e$.

Irrigation salinity problems are often compounded by the effects of sodium ($Na^+$) on the dispersion of soil colloids, resulting in a loss of soil structure. This phenomenon decreases the leaching potential of the salt and accelerates the build-up of salts within the rootzone. $Na^+$ also affects the saturated hydraulic conductivity. Soil colloid dispersion is affected by the ratio of $Na^+$ to the divalent cations calcium ($Ca^{2+}$)
and magnesium ($\text{Mg}^{2+}$) in the irrigation water, a ratio known as the sodium adsorption ratio (SAR), which is given by:

$$\text{SAR} = \frac{\text{[Na}^+\text{]}}{\sqrt{\left(\text{[Ca}^{2+}\text{]} + \text{[Mg}^{2+}\text{]}\right)/2}}$$

(17.1)

where, $\text{Na}^+$, $\text{Ca}^{2+}$, and $\text{Mg}^{2+}$ are in meq/L.

From an environmental point of view, among different salts in recycled water such as sodium ($\text{Na}^+$), potassium ($\text{K}^+$), calcium ($\text{Ca}^{2+}$), chloride ($\text{Cl}^-$), magnesium ($\text{Mg}^{2+}$), sulphate ($\text{SO}_4^{2-}$) and bicarbonate ($\text{HCO}_3^-$), sodium and chloride are the most important salts. This is because they are more likely to remain as ions in soil solutions and contribute to the effects of salinity. Plants are affected by salts via soil salinity (NRMMC-EPHC-AMC 2006). As water evaporates from soils or is used by the plants, salts are left behind. This phenomenon increases the concentration of salts in the soil with time, until it influences the amount of water a plant can take up from the soil due to the osmotic effect it creates.

Several studies have been reported indicating increases of salinity due to recycled water irrigation. Distinct long term effects of recycled water use in terms of salinity is observed by Dikinya and Areola (2010). After 3 years of irrigation with recycled water, the electrical conductivity in soil increased from 105.1 to 235 $\mu$S/cm (about 123% increases), cation exchange capacity (CEC) of soil decreased from 9.21 to 8.61 cmol/kg and $\text{Na}^+$ increased from 2.95 to 5.75 meq/100 g of soil. CEC is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination. Jahantigh (2008) reported a similar result of salinity increase after irrigating with recycled water for 5 years. He reported an increase of 95% (from 2.3 to 4.5 $\mu$S/cm) salinity. Klay et al. (2010) conducted a study to find out the increase of salinity due to the use of treated wastewater for irrigation. The result showed an increase of salinity with irrigation period. Data was collected at different depths and at different time periods (i.e. 3 months, 2 years, 7 years, 8 years, 12 years and 14 years). After 14 years of irrigation, the salinity increased with depth. At the top soil (0–30 cm), the salinity increased from 0.16 to 1.12 $\mu$S/cm, which is around 600% increase. Decrease of cation exchange capacity after long term irrigation was reported by Adrover et al. (2010). A total of 11% and 2% decrease in CEC was reported for the irrigation period of 20 years and 2 years respectively. Xu et al. (2010) investigated the long term effect of recycled water irrigation for up to 20 years. The authors reported that the EC values of the top soil profile varied with the time of irrigation. EC values of 51.6, 78.6, 113.2 and 122.7 $\mu$S/cm were observed for irrigation time 0, 3, 8 and 20 years of irrigation. Increase of salinity in terms of EC, $\text{Na}^+$ and $\text{Cl}^-$ are also reported by other researchers (Xu et al. 2010; Yang et al. 2006; Gloaguen et al. 2007; Leal et al. 2009; Alarcón and Pedrero 2009; Wang et al. 2003).

As with agriculture, several investigators reported the risk of accumulation of salt in open spaces because of long term irrigation with recycled water. Candela et al. (2007) investigated the effect of recycled water irrigation in a golf course in
Spain for 2 years. They observed that Na$^+ \text{ increased in the top 60 cm of soil profile due to water application and evapotranspiration. The salinisation in unsaturated zone increased by 1300 mg NaO$_2$ (Sodium superoxide) per kg and Cl$^- \text{ increased in }$

aquifer water by approximately 400 mg/year. After 4 years of investigation, to find the effects of recycled water on nine golf courses in southern Nevada, Devitt et al. (2007) reported that the soil salinity levels followed a sinusoidal seasonal curve, where 70% of all the peaks occurred in summer. So, temporal distribution has effect on the salinisation to some extent. The result indicates that the management should control the uniformity of the irrigation system and an amount of fresh water application to maintain sufficient leaching to reduce salinity.

Although the increase of soil salinity because of the treated wastewater irrigation is convincing, the phenomenon depends on variability of soil characteristics. As salts are highly soluble they infiltrate and accumulate in the deeper layer of the soil. When, the soil EC is less than the EC of recycled water, a little portion of the residual dissolved solid is accumulated on the soil particle and most of the salt is leached from soil and accumulates in the groundwater (Klay et al. 2010). The movement of soil solution depends on soil type and different hydraulic properties of soil. When comparing the salt accumulation data in fields irrigated with recycled water with that of fresh water, soil characteristics, textures, irrigation history as well as soil profiling should be consistent. Otherwise, it is very difficult to say that soil condition is directly associated with the application of treated water (Aiken 2006; Stevens et al. 2003).

Authors of this chapter conducted a laboratory scale column study to compare the salt accumulation in the soil profile due to recycled water and town water irrigations (see Rahman et al. 2014b). Soil samples were collected from two fields (D33 and Yarramundi) located in University of Western Sydney, Hawkesbury campus, Australia. Two types of soil, namely, D33 (silty loam) and Yarramundi (loamy sand) soil were used for the experiment (Fig. 17.4). The experiment was conducted for a period of 330 days. Six columns of the same dimensions were prepared for each type of soil. Three of the columns were used for recycled water application; the other three were used for town water application. Irrigation water (recycled and town water) was applied at the same frequency in respective columns, as in practice. At the end of the study period, soil samples were collected from every 5 cm of the soil profile from each of the 12 columns. The soil samples were analysed for 1:5 soil water electrical conductivity (EC$_{1:5}$) and SAR.

Results of EC$_{1:5}$ and SAR for D33 and Yarramundi columns for both recycled and town water applications are presented in Fig. 17.5. As expected, EC$_{1:5}$ (Fig. 17.5a, b) in top 0.05 m for both types of soil columns had more salt accumulation, which is because of the occurrence of more evaporation at the soil surface. Salinity in soil due to recycled water application showed higher EC$_{1:5}$ than that of town water application. D33 soil with recycled water application caused an increased accumulation of salt (in terms of EC$_{1:5}$) by about 2.5 times in the soil of upper portion of the column (0–0.05, 0.05–0.10, 0.10–0.15, 0.15–0.20 m) compared to town water application. Soil samples collected from the lower portion of the soil column (0.20–0.25, 0.25–0.30 m) showed relative salt accumulation by about 2.1 times. In the case
of Yarramundi soil, recycled water application caused salt accumulation by about 1.9 times in the soil of upper portion of the column (0–0.05, 0.05–0.10, 0.10–0.15, 0.15–0.20 m) compared to town water application. It was about 2.3 times for samples collected from the column depths of 0.2–0.3 m. In case of SAR, for D33 soil (Fig. 17.5c), recycled water caused 3.6 times more SAR in the soil of depth 0–0.2 m than the town water irrigation; SAR was 3.8 times more in the soil samples collected from the column depth of 0.2–0.3 m. In the case of Yarramundi soil, recycled water application caused 5.4 times more SAR in the soil of upper portion of the column (0–0.2 m) compared to town water application; it was about 6.5 times more for samples collected from the column depths of 0.2–0.3 m. It is clear from the above result that variability of salinity and sodicity in coarse textured soil (Yarramundi) is more when compared to fine textured soil (D33). Results from this experiment will help in understanding patterns of salt accumulation and occurrences of sodicity throughout a soil profile of these specific soil types. The results will also help to avail management options such as reduction of salinity in soil by using town water.

Fig. 17.4 Schematic of column setup to study soil salinisation due to recycled water irrigation (Rahman et al. 2014b)
Heavy metal accumulation in soil due to recycled water irrigation is another concern for the assessment of soil health. Smith et al. (1996) investigated the effect of irrigation with secondary treated municipal effluent on the accumulation of heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) for 4 and 17 years. The non-effluent irrigated area was served as the control area and provided reference concentrations to assess the extent of contamination. They concluded that irrigation with recycled water did not increase the heavy metal values and suggested that it may take between 50 and 100 years for heavy metal levels (mainly Cd) in effluent-irrigated soil to reach the threshold values (Australian guidelines) for environmental concern.

Rattan et al. (2005) reported an irrigation scheme in peri-urban agricultural fields irrigated for 5, 10 and 20 years with recycled water in India to investigate the heavy metal accumulation. The result is shown in Fig. 17.6. Recycled water irrigation over 20 years resulted into a significant build-up of Zn (7.4 times), Cu (5.2 times), Fe (6.5 times), Ni (3.8 times) in soils over adjacent tubewell water irrigated soils; whereas Mn was reduced by 1.8 times. Soils receiving sewage irrigation for 10 years exhibited significant increases in Zn, Fe, Ni and Pb, while only Fe in soils was positively affected by sewage irrigation for 5 years.

Similar investigations were conducted by Xu et al. (2010) where the highest levels of Cr, Cu, Ni and Zn were found at 30–40 cm horizons in plots irrigated with effluent for 8 years. In plots with irrigation lengths of 20 years, the highest concen-
Concentrations occurred at deeper depths of 40–50 cm. It was also observed that longer irrigation time (20 years) caused a decrease of metal levels in soil profiles compared with that of 8-year irrigation, which may occur because of leaching.

Among other problems of soil health due to recycled water use in irrigation is the impact on saturated hydraulic conductivity of soil. A decreased hydraulic conductivity may influence the increase of salinity. Gonçalves et al. (2007) reported that after 2 years of irrigation, the hydraulic conductivity decreased from 48 to 30.73 mm/h. Similar studies were conducted by Levy et al. (1999) and Aiello et al. (2007). Some investigators (Estevez et al. 2010) reported less or no effect of soil salinisation due to recycled water application in open spaces. However, to be on the safe side, an intensive management and long term monitoring was recommended to avoid mass loading of salt and nutrients in soil (Tanji 1997; Zhang et al. 2006).

**17.4.2 Public Health**

Probably, microbial contamination is the most discussed and researched issue relating to recycled water irrigation; one reason may be the risk of human contamination considered to be greater than that associated with chemical compound (Hamilton et al. 2005; Toze 2006; Derry et al. 2006). Potential microorganisms in recycled water include pathogens, viruses, bacteria, protozoa and helminths; they may pose risk to human health when raw vegetables irrigated with recycled water are consumed (Toze 2006). Contamination from open space irrigation may occur due to spray-drift exposure and hand to mouth exposure. Derry et al. (2006) reported a risk
of human exposure from recycled water irrigation in the campus of University of Western Sydney (UWS), Australia. The authors identified infants and young children of a day care in the campus, who sometimes visit livestock such as deer and sheep in areas irrigated with recycled water, as most susceptible to waterborne infections. The same study suggested precautionary measures including hand washing before eating food and after coming back from a field visit and using gumboots during field visits to avoid possible contamination.

In addressing the health risk from recycled water, QMRA (Quantitative Microbial Risk Assessment) models are widely used by many researchers (Donald et al. 2009; O’Ttoole et al. 2009; Hamilton et al. 2006, 2007). Hamilton et al. (2006) used QMRA for estimating the annual risk of virus infection associated with the consumption of raw vegetables irrigated with recycled water. Across the various crops, effluent qualities, and viral decay rates considered, the annual risk of infection ranged from $10^{-3}$ to $10^{-1}$ when recycled water irrigation ceased 1 day before harvest and from $10^{-9}$ to $10^{-3}$ when it ceased 2 weeks before harvest. The model presented a useful starting point for managing risk associated with spray irrigation of certain crops with recycled water. Although QMRA is considered as an essential component of microbial risk assessment of recycled water scheme, the model has some cons; it is tedious and technically demanding. This disadvantage is overcome by including another model RIRA (Recycled water irrigation risk assessment) as part of QMRA assessment process (Hamilton et al. 2007). RIRA is designed to accommodate a wide range of scenarios. The model uses pathogen specific dose-response models to calculate the annual risk of infection, when the pathogen of interest and the exposure scenario is defined. Another study addressing microbial contamination from recycled water was conducted by Donald et al. (2009). The approach provided an additional way of modelling the determinants of recycled water quality and elucidating relative influence of these determinants on a given disease (namely, gastroenteritis) outcomes. The conceptual model was comprised of six elements, i.e. recycled water and distribution pathways, exposure pathways and populations, cumulative end-user dose, identified toxicity and pathogenicity pathways, individual covariates and health endpoints. Through sensitivity analysis the authors identified three nodes that contributed most to the occurrence of gastroenteritis. These include, cumulative end user dose to pathogen, age of patients, exposure period to pathogen and quantity of pathogen intake.

17.4.3 Community Perspective

Recycled water usage schemes, because of the perceived risk, are sometimes questioned by the community associated with the scheme. There are instances, where a recycled water usage scheme was resisted by communities in Australia, USA and The Netherlands (Hurlimann and McKay 2006) resulting in the abandonment of such projects. Greater understanding of social factors in a policy context will facilitate planning and sound management of recycled water usage schemes. One suitable approach to achieve this objective is community consultation.
An assessment of risk perception related to tertiary treated recycled water usage was carried out by Derry and Attwater (2006) through a questionnaire survey at the campus of UWS, which involved 72 staff, 189 students and 72 residents. The majority of respondents (97% of staff, 91% of students and 100% of residents) considered the irrigation of grass, trees and shrubs to be acceptable, while 83% of staff and 74% of students accepted the idea of using recycled water for sports oval irrigation. The lowest acceptance was recorded for irrigating food crops (14% of staff, 24% of students and 32% of residents). When the respondents were asked about the regional planning of recycled water usage by Water Management Authority (Sydney Water), only 15% responded that they were aware. This indicates in order to reduce perception of risk associated with the use of recycled water the Authorities should focus on providing timely and accurate information, and have a process of implementation which is perceived as fair; the authors suggested signage, talks at meetings or displays at sustainability centres as an option.

Similar investigation in the regional level was conducted by Po et al. (2005) in Perth and Melbourne. Ninety three participants (one from each household) from three different socio economic groups (i.e. lower, medium and higher) were selected for a questionnaire survey. Results showed that more than 95% of participants responded that it was acceptable to use recycled water in public parks and golf courses. More than 80% agreed that it was acceptable to use recycled water for watering lawns and gardens or pasture land. At Mawson Lakes, South Australia, Hurlimann and McKay (2005) surveyed 136 households to investigate the community attitude towards the reuse of recycled water. Results showed that Mawson Lakes community was on average willing to pay $17.80 annually for a continual green appearance of public open spaces. The response of householders in a sense of the economic aspect of reuse schemes (i.e. willingness to pay) is helpful for future planning. In Sydney, Marsden Jacob Associates (2014) conducted a survey on 1240 households to investigate the economic viability of recycled water schemes. Results showed that Sydney households are on average willing to pay between $2.65 and $48.38 per year for an additional 10–40 GL per year of recycled water by 2030. However, the recycled water should be used by business, industry, Councils, or the environment (in the form of environmental flows). The survey also found that the households were less willing to pay to use the recycled water in Western Sydney homes for the purposes of toilet flushing and watering the gardens. The finding of the survey is concurrent to that of Hurlimann and McKay (2007) in that people do not like to use recycled water when the proposed use comes into personal contact.

17.5 Recycled Water Use for a Liveable City

The term ‘liveable city’ refers to the quality of life or wellbeing of its inhabitants (Johnstone et al. 2012). The liveability of a city sometimes associated with different elements that improve the quality of life including comfort, security, welfare, and sustainable water and environment. Sustainable management of urban water is
necessary to ascertain that the city would be liveable in the future. City planners and scientists should make sure that the residents will have a clean supply of water and a healthy environment in which to live. As well as the supply of water from conventional sources (i.e. surface and groundwater), it is important to establish alternate sources for an uninterrupted supply of water and sustainable usage. Recycled water usage schemes as a part of urban water management are considered to be possible options to achieve this goal.

Urban water management is a holistic way to design and manage urban water systems (Van der Steen 2011). Urban water management for future cities should be adopted by considering social, economic and environmental perspectives of sustainability. According to Van der Steen (2011), the increasing population of cities puts major demands on urban services, including the supply of water and the management of wastewater. Population growth and urbanisation are leading to increased demand for water and wastewater services, increased pollution, changes in land use and many other pressures (Fig. 17.7) in cities around the world. However, many cities in advanced countries like Australia have progressed significantly to overcome basic water scarcity and service issues through the adoption of sustainable technologies. According to Brown et al. (2009), the communities in ‘water sensitive cities’ would be driven by the normative values of protecting intergenerational equity with regards to natural resources and ecological integrity, as well as by concern that

![Fig. 17.7 Issues and future challenges in urban water management (After Howe et al. 2011)](image-url)
communities and environments are resilient to climate change. However before achieving the goal of becoming water sensitive, cities go through different transition phases including ‘water supply city’, ‘sewered city’, ‘drained city’, ‘waterways city’, and ‘water cycle city’ (for a review of this literature see Brown et al. 2009). The transition phases are cumulative and associated to increased level of sustainable water management.

For a sustainable water management strategy in Australia, Hurlimann (2007) proposed a Water Source Hierarchy – ‘Reduce, Reuse, Recycle, Desalination’ (Fig. 17.8). The hierarchy rates management options in order of least impact to the environment; reducing water consumption is of minimal environmental impact, reuse may have some environmental impact, increasing with recycling, then desalination which has the greatest environmental impact and should be considered as a last resort (Hurlimann 2007). The hierarchy also agrees with the recommendations proposed by the Productivity Commission (2011) to maintain water security (discussed in Sect. 17.3.1). In addition to reducing water consumption by users, controlling contaminant load at source (contributed by the user) may reduce adverse impact on the environment. Reducing contaminant load at source (i.e. source control of pollutant) is helpful to reduce pollutant load in wastewater treatment plant and in its output (i.e. recycled water). Thus the source control of pollutants (i.e. salinity) would help eliminating some risks associated with the end use of recycled water such as soil and human health risk due to recycled water irrigation in urban open spaces as discussed earlier. Rahman et al. (2015b) proposed an assessment framework to evaluate the salinity sources that may have significant impact on the rootzone salinity (in terms of total dissolved solid and sodium ion concentration) when recycled
Water is used for irrigating sporting ovals in Sydney, Australia. The framework includes four phases (Fig. 17.9):

- **Salt generation phase** – consists of domestic appliances (salt sources) that contribute towards the salt load in the wastewater.
- **Wastewater phase** – consists of various wastewater streams including different streams of grey and black water.
- **Treatment phase** – consists of the treatment plant that produces recycled water.
- **Salt accumulation phase** – includes the process of salt accumulation in the root zone due to recycled water irrigation.

Results show that by reducing the TDS load from washing machines alone by 50% reduces the TDS concentration in soil by approximately 9% and this can be increased to a 19% reduction by reducing the TDS loads from both washing machines and toilet water, simultaneously. Also observed was that using environmental friendly detergents reduce the TDS load to the laundry streams four to seven times and Na⁺ load about twice than any popular brand detergents. Moreover, using environmental friendly liquid detergents reduced the TDS load by 1.6 and Na⁺ load by 3.6 times than when using environmental friendly powder. However, the authors suggested that viability of using environmental friendly products should be considered with economic sustainability, as generally these products are more expensive than the popular brands. The study highlighted that any strategies which help in the reduction of salt in the wastewater stream from washing machines will be beneficial in managing the soil salinity as a result of recycled water use for irrigating urban open spaces.
17.6 Conclusions

This chapter highlighted the extent of use of recycled water (treated wastewater) worldwide. As discussed, use of recycled water in the irrigation of open and sports fields is increasing. Water authorities in different cities are increasingly supply the recycled water for irrigation purposes instead of simply disposing the recycled water in the ocean. In 2009–2010, in Australia, the state-wide average of recycled water use in urban irrigation was 27.2% and the nation-wide average was 14% of the total recycled water produced. In Sydney, New South Wales, it is expected that by 2015 the recycled water will meet 12% of the total water demand in greater Sydney. Several community surveys indicated the overwhelming support for use of recycled water for irrigation applications (Hurlimann and McKay 2005). This is reflected in many surveys that local communities support the usage of recycled water in irrigating open spaces and are willing to pay more for such use in extended form in the future. There are both beneficial and adverse impacts arising from the use of recycled water for irrigation. The benefits of using recycled water in urban irrigation include year round supply of irrigation water and supplement of nutrient for plant growth. Recycled water use in irrigation of urban open spaces has some negative impacts, because of the risks associated to the accumulation of salt and other unwanted contaminants in the soil. However, in advanced countries like Australia, the challenge of proper management of recycled water is undertaken and risks associated with its usage are well tackled. It is expected that recycled water use in urban areas will go beyond its conventional usage for open space irrigation including parks and recreational areas. Recycled water has the potential to irrigate urban pocket wetlands and green precincts, and other under-utilised land such as road reserve, rail corridors and road median strips. Irrigating rooftop gardens with recycled water is another application of recycled water. Major cities around the world have realised the potential for using recycled water for irrigating urban landscape. As a result, supply of recycled water for irrigation purposes will significantly increase in the near future. This necessitates the use of appropriate management practices which will protect the health of plants, soil and human beings. There is a need for considerable research in the area of development of appropriate management practices.

Open Access This chapter is distributed under the terms of the Creative Commons Attribution-Noncommercial 2.5 License (http://creativecommons.org/licenses/by-nc/2.5/) which permits any noncommercial use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.

The images or other third party material in this chapter are included in the work’s Creative Commons license, unless indicated otherwise in the credit line; if such material is not included in the work’s Creative Commons license and the respective action is not permitted by statutory regulation, users will need to obtain permission from the license holder to duplicate, adapt or reproduce the material.
References

ABS (Australian Bureau of Statistics) (2006) Water Account for Australia 2004–2005
ABS (Australian Bureau of Statistics) (2010) Water Account for Australia 2008–2009
ABS (Australian Bureau of Statistics) (2012) Water Account for Australia 2009–2010
Adrover M, Farrús E, Moy G, Vadell J (2010) Chemical properties and biological activity in soils of Mallorca following twenty years of treated wastewater irrigation. J Environ Manag 95:S188–S192
Aiello R, Cirelli GL, Consoli S (2007) Effects of reclaimed wastewater irrigation on soil and tomato fruits: a case study in Sicily (Italy). Agric Water Manag 93:65–72
Aiken JT (2006) A soil microbial response to urban wastewater application-bacterial communities and soil salinity. PhD Thesis. Western Sydney University, Sydney
Alarcón J, Pedrero F (2009) Effects of treated wastewater irrigation on lemon trees. Desalination 246:631–639
Alliance for Water Efficiency (2014) Golf course water efficiency introduction. http://www.allianceforwaterefficiency.org/golf_course.aspx. Accessed 15 Nov 2014
Anderson J (2003) The environmental benefits of water recycling and reuse. Water Sci Technol: Water Supply 3(4):1–10
Angelakis A, Gikas P (2014) Water reuse: overview of current practices and trends in the world with emphasis on EU states. Water Util J 8:67–78
ANZECC & ARMCANZ (2000) Australian and New Zealand guidelines for fresh and marine water quality. National Water Quality Management Strategy. Australian & New Zealand Environment and Conservation Council, and Agriculture and Resource Management Council of Australia and New Zealand, Australia
Bixio D, Thoeye C, De Koning J, Joksimovic D, Savic D, Wintgens T, Melin T (2006) Wastewater reuse in Europe. Desalination 187:99–101
Brown RR, Keath N, Wong THF (2009) Urban water management in cities: historical, current and future regimes. Water Sci Technol 59:5
Candela L, Fabregat S, Josa A, Suriol J, Vigués N, Mas J (2007) Assessment of soil and groundwater impacts by treated urban wastewater reuse. A case study: application in a golf course (Girona, Spain). Sci Total Environ 374:26–35
Chen Z, Ngo HH, Guo W (2012) A critical review on sustainability assessment of recycled water schemes. Sci Total Environ 426:13–31
CWRS (Centre for Water Resources Studies) (1999) Reuse of renovated municipal wastewater for golf course irrigation. Prepared for PEI Department of Technology and Environment. CWRS Internal Report No. 99–11. Dalhousie University, Halifax
DEC (Department of Environment and Conservation) (2004) Use of effluent by irrigation. http://www.water.nsw.gov.au/Urban-water/Recycling-water/Sewage
Derry C, Attwater R (2006) Risk perception relating to effluent reuse on a university campus. Water 33:57–62
Derry C, Attwater R, Booth S (2006) Rapid health-risk assessment of effluent irrigation on an Australian university campus. Int J Hyg Environ Health 209:159–171
Devitt D, Morris M, Bird R (2007) Spatial and temporal distribution of salts on fairways and greens irrigated with reuse water. Agron J 99:692
Dikinya O, Areola O (2010) Comparative analysis of heavy metal concentration in secondary treated wastewater irrigated soils cultivated by different crops. Int J Environ Sci Technol 7:337–346
Dillon P (2000) Water reuse in Australia: current status, projections and research. In: Proceedings of water recycling Australia, pp 19–20
Donald M, Cook A, Mengersen K (2009) Bayesian network for risk of diarrhea associated with the use of recycled water. Risk Anal 29:1672–1685
Estevez E, Cabrera M, Fernandez-Vera J, Hernandez-Moreno J, Mendoza-Grimon V, Palacios-Diaz MP (2010) Twenty-five years using reclaimed water to irrigate a golf course in Gran Canaria. Span J Agric Res 8:95–101

Exall K (2004) A review of water reuse and recycling, with reference to Canadian practice and potential: 2. Applications. Water Qual Res J Can 39(1):13–28

Fasciolo GE, Meca MI, Gabriel E, Morabito J (2002) Effects on crops of irrigation with treated municipal wastewaters. Water Sci Technol 45(1):133–138

Feigin A, Ravina I, Shalhevet J (1991) Irrigation with treated sewage effluent: management for environmental protection. Springer-Verlag, New York

Gloaguen TV, Forti M, Lucas Y, Montes CR, Goncalves RAB, Herpin U, Melfi AJ (2007) Soil solution chemistry of a Brazilian oxisol irrigated with treated sewage effluent. Agric Water Manag 88:119–131

Gonçalves RAB, Folegatti MV, Gloaguen TV, Libardi PL, Montes CR, Lucas Y, Dias CTS (2007) Hydraulic conductivity of a soil irrigated with treated sewage effluent. Geoderma 139:241–248

Greenway M (2005) The role of constructed wetlands in secondary effluent treatment and water reuse in subtropical and arid Australia. Ecol Eng 25:501–509

Haering KC, Evanylo GK, Benham B, Goatley M (2009) Virginia cooperative extension. Publication No. 452-014. https://pubs.ext.vt.edu/452/452-014/452-014_pdf.pdf

Hamilton AJ, Boland AM, Stevens D, Kelly J, Radcliffe J, Ziehl A, Paulin B (2005) Position of the Australian horticultural industry with respect to the use of reclaimed water. Agric Water Manag 71(3):181–209

Hamilton AJ, Stagnitti F, Premier R, Boland AM, Hale G (2006) Quantitative microbial risk assessment models for consumption of raw vegetables irrigated with reclaimed water. Appl Environ Microbiol 72:3284

Hamilton AJ, Stagnitti F, Kumarage SC, Premier RR (2007) Rira: a tool for conducting health risk assessments for irrigation of edible crops with recycled water. Comput Electron Agric 57:80–87

Howe CA, Butterworth J, Smout IK, Duffy AM, Vairavamoorthy K (2011) Findings from the SWITCH (Sustainable Water Management in the City of the Future) Project 2006–2011. http://www.switchurbanwater.eu/outputs/pdfs/Switch_-_Final_Report.pdf

Hurlimann A (2007) ‘Time for a water re-‘vision’. Aust J Environ Manag 14(1):14–21

Hurlimann A, McKay J (2005) Contingent valuation by the community of indirect benefits of using recycled water: an Australian case study. Water Sci Technol: Water Supply 5(3–4):95–103

Hurlimann AC, McKay JM (2006) What attributes of recycled water make it fit for residential purposes? The Mawson Lakes experience. Desalination 187:167–177

Hurlimann A, McKay J (2007) Urban Australians using recycled water for domestic non-potable use—an evaluation of the attributes price, saltiness, colour and odour using conjoint analysis. J Environ Manage 83:93–104

Jahantigh M (2008) Impact of recycled wastewater irrigation on soil chemical properties in an arid region. Pak J Biol Sci 11:2264–2268

Johnstone P, Adamowicz R, Haan FJ, Ferguson B, Wong T (2012) Liveability and water sensitive city-science-policy partnership for water sensitive cities. Cooperative Research Centre for Water Sensitive Cities, Melbourne. ISBN 978-1-921912-17-7

Klay S, Charaf A, Ayed L, Houman B, Rezgui F (2010) Effect of irrigation with treated wastewater on geochemical properties (saltiness, c, n and heavy metals) of isohumic soils (zaouit sousse perimeter, oriental tunisia). Desalination 253:180–187

Leal RMP, Herpin U, Fonseca AF, Firme LP, Montes CR, Melfi AJ (2009) Sodicity and salinity in a Brazilian oxisol cultivated with sugarcane irrigated with wastewater. Agric Water Manag 96:307–316

Levy G, Rosenthal A, Tarchitzky J, Shainberg I, Chen Y (1999) Soil hydraulic conductivity changes caused by irrigation with reclaimed waste water. J Environ Qual 28:1658–1664
Sydney Water (2010) Annual report 2010 [Online]. Available: www.sydneywater.com.au. Accessed 8 Aug 2011
Sydney Water (2011) Recycling water for irrigation [Online]. www.sydneywater.com.au. Accessed 8 Aug 2011
Sydney Water (2013) Irrigating with recycled water-Penrith City Council. Available: https://www.sydneywater.com.au/web/groups/publicwebcontent/documents/document/zgrf/mdq2/~edisp/dd_046317.pdf. Accessed 8 Dec 2013
Tanji K (1997) Irrigation with marginal quality waters: issues. J Irrig Drain Eng 123(3):165–169
Tanji KK, Grattan SR (2007) Salt management guide for landscape irrigation with recycled water in coastal southern California: a comprehensive literature review. Southern California Salinity Coalition (SCSC) and National Water Research Institute (NWRI), CA
Toze S (2006) Reuse of effluent water—benefits and risks. Agric Water Manag 80:147–159
Van der Steen P (2011) Application of sustainability indicators within the framework of Strategic Planning for Integrated Urban Water Management, UNESCO-IHE Institute for Water Education, Delft. www.switchtraining.eu/switch-resources
Vazquez-Montiel O, Horan NJ, Mara DD (1996) Management of domestic wastewater for reuse in irrigation. Water Sci Technol 33(10):355–362
Wang Z, Chang A, Wu L, Crowley D (2003) Assessing the soil quality of long-term reclaimed wastewater-irrigated cropland. Geoderma 114:261–278
Water Corporation (2013) Sewer mining-information sheet. ISBN 1740437527. https://www.watercorporation.com.au/-/media/files/residential/water%20supply%20and%20services/water%20forever%20south%20west/fact-sheet-sewer-mining-water-forever-sw.pdf
Xu J, Wu L, Chang AC, Zhang Y (2010) Impact of long-term reclaimed wastewater irrigation on agricultural soils: a preliminary assessment. J Hazard Mater 183:780–786
Yang YL, Han LB, Zhang Q, Su DR (2006) Effects of reclaimed water irrigation on the physical and chemical characteristics of saline-alkaline earth in Tianjin. J Beijing For Univ 28:85–91
Zhang HS, Zhang K, Han L, Su D, Wang N, Li Y (2006) Effects of reclaimed water irrigation on soil environment of greenbelt. J Beijing For Univ 28:78–84