Urban Water Reuse Handbook

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Chapter 18

Water Reuse Environmental Benefits

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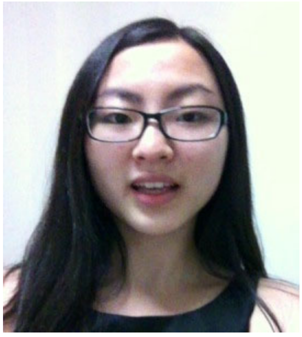

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Preface

With the socioeconomic development and population increase, freshwater consumption has increased beyond sustainable levels in many parts of the world. To combat with water scarcity issues and environmental related problems, recycled water has been increasingly considered as an important alternative water resource. It can provide a viable opportunity to supplement existing freshwater supplies, alleviate contaminant loads exerting by effluent discharge, augment and/or improve the stream flow and wetland, etc. This chapter examines the alternative water resources and identifies the importance as well as historical and current development of water reuse. It focuses on the environmental benefits associated with various recycled water applications. The illustrated case studies of recycled water in a number of countries, including Australia, Japan, the U.S., Europe and the Middle East, could be good examples for the future projects. Notably, there is also a potential to exploit and develop new end uses of recycled water further in both urban and rural areas. This can contribute largely to freshwater savings, wastewater reduction and water sustainability.

18.1 Introduction

Freshwater has become a scarce and overexploited natural resource in many parts of the world [34]. It has been recognized as a critical global issue and may become the most strategic resource in many areas, especially the arid and semi-arid regions. According to the International Water Management Institute's report, Australia, California, the Middle East, and the Mediterranean have been regarded as high water stress regions [26]. Likewise, the situation of water pollution and over-extraction in Asia and Africa is far from optimistic. Within the next decades, due to continuous economic and population growth, climate change, rapid urbanization and deteriorating water quality, water scarcity is likely to be a big constraint to the future food security and environmental sustainability [22,45]. The scientific definitions of water scarcity concepts include [38]: *Water scarcity* is the general collective term when water is scarce for whatever reason. *Water stress* is linked to difficulties in water use due to accessibility or mobilization problems (e.g., water infrastructures, flow control, costs). Normally, the use-to-availability ratio with values larger than 40%, denote high water stress. *Water shortage* refers to population-driven physical shortage of water when seen in relation to principal water requirements:

- Green water shortage, relating to deficiency in relation to crop water requirements;
- Blue water shortage, when the number of people competing for a limited resource quantity, i.e., water crowding is "high" (1,000-1,700 cubic meters per year supply per person shows water stress; less than 1,000 cubic meters per year supply per person indicates extreme water scarcity) [38,51].

By 2025, it is projected that, assuming current consumption patterns continue, at least 3.5 billion people or 48% of the world's population, will live in water-stressed river basins. Of these, 2.4 billion will live under high water stress conditions [52,53]. Moreover, water quality deterioration has been widely observed in rural and urban areas through Africa, Asia and Latin America [44]. More than 2.6 billion people (42% of the total population) lack access to basic sanitation facilities at present and are exposed to contaminated water sources which contain excessive chemical compounds and high concentration of pathogens (e.g., parasites, bacteria and viruses) [43].

18.2 Coping with freshwater scarcity by water reuse

To meet the future water and food demand, some countries have increasingly recognized the significance of water conservation and water demand management as a long-term water supply strategy. Additionally, other sustainable management solutions and technological options in driving green growth for augmenting existing water supplies should be considered, including the exploitation of alternative water resources and the identification of the significance of water recycling and reuse.

18.2.1 Alternative water resources

With traditional water resources (e.g., surface water and groundwater) being depleted, it is essential to look for alternative water resources to meet the current water demand. The alternatives may include the capture and use of rainwater and stormwater as well as the exploitation of greywater, desalinated water and recycled water.

- Desalinated water, i.e. saline water is separated into two parts using different forms of energy in desalination technologies; the potable water with a low concentration of dissolved salts is produced in one part, in the other part, the brine concentrate is collected which has a much higher concentration of dissolved salts than the original feed water [14,41];
- Greywater, it refers to urban wastewater that includes water from household kitchen sinks, dishwashers, showers, baths, hand basins, and laundry machines but excludes any input from toilets [29, 37]; generally, it is less polluted and low in contaminating pathogens, nitrogen, suspended solids and turbidity compared with municipal and industrial wastewaters [17]; greywater can be used immediately or treated and stored, the applications include irrigation, toilet flushing and other purposes [30];
- Rainwater and stormwater, which can be harvested and treated locally; the harvested water can be used in place of drinking water in many functional areas for different purposes, including toilets, gardens, fire fighting, cooling towers and manufacturing;
- Recycled water, i.e. former wastewater that has been treated to remove solids and certain impurities; it is intended to be used for non-potable uses (e.g., irrigation, industrial uses, recreational and environmental purposes, toilet flushing, car washing, dust control and fire suppression); with more advanced treatment, it can be used for indirect potable reuse (i.e. discharge into a water body before being used in the potable water system) [4,24];

18.2.2 Importance of water reuse

The current severe water supply and demand situations have forced many water authorities and local councils to increasingly consider recycled water as a supplementary water supply [4]. This resource can help to alleviate the pressure on existing water supplies while protect remaining water bodies from being polluted [24]. A distinct benefit of recycled water is the reliability of water supply all through the year for both household and local industries, which is available even in a drought. This is superior to rainfall-dependent water supplies (e.g., rainwater and stormwater) that are vulnerable to drought and infrastructure delivery problems. Ensuring water supply reliability supports the public health, quality of life and the economic sustainability of the region. Moreover, COF [19] has conducted a comparison between water recycling (Eastern Treatment Plant) and desalination (Wonthaggi) projects, which are both designed to deliver a similar volume of potable water to the city of Melbourne, Australia. With advanced water treatment facilities (e.g., biological filters, reverse osmosis (RO), and UV disinfection systems), both of the options can supply clean water of potable water quality. It was found that the capital cost of the water recycling approach is only $1.86 billion, compared with $3.1 billion of the desalination approach. Besides, the treatment energy cost is only 10% of desalination. With respect to environmental considerations, water recycling also produces lower CO_2 equivalent gas emission and less end of ocean outfall discharge. Likewise, Pasqualino [35] also showed that replacing potable and desalinated water by recycled water for non-potable purposes (e.g., irrigation, industry, urban cleaning and fire fighting) could result in lower environmental impacts in terms of acidification potential, global warming potential and eutrophication potential.

Moreover, compared to other water resources, recycled water can contribute to a considerable wastewater reduction through reduced effluent discharges to the aquatic environment. It can also introduce some economic benefits to local government or private sectors. For instance, in

Australia, irrigating vineyards at McLaren Vale with recycled water which contains some amount of nutrients has already brought $120 million to the South Australia government [20]. To some extent, excessive costs on water infrastructure and energy consumption could be avoided as well [1,24]. Furthermore, when bringing recycled water and other water resources together in management, the ecological footprint of water, sewage and drainage system could be potentially reduced by over 25% [2]. In a broader sense, water management can be further incorporated into climate change adaptation and environmental sustainable development [5,18].

18.2.3 Historical and current development of water reuse

The modern birth of recycled water application was in the mid-19th century along with the prosperity of wastewater treatment technologies. Before 1990s, 70% of reused wastewater was processed to a secondary treatment level by conventional activated sludge (CAS) methods and the effluent was only suitable for agricultural uses in less developed areas. With the rapid development of advanced wastewater treatment technologies such as membrane filtration in the last 10 to 15 years, the application of recycled water has been broadened from non-potable uses (e.g., irrigation, industry, environmental flow and residential uses) to indirect and direct potable reuses. Currently, thousands of water recycling schemes and pilot studies are being carried out worldwide with many more in the planning and construction stages [17,39]. The global water reuse capacity is projected to rise from 33.7 GL/d in 2010 to 54.5 GL/d in 2015 [36].

In developed countries, especially the cities and regions where freshwater resources are approaching the sustainable limit, recycled water would continue to be an important alternative water resource, especially for non-potable purposes [17]. More stringent water treatment standard (e.g., tertiary treatment and additional nutrient removal) is expected to be required in most recycled water schemes. As highly advanced technologies are available for producing clean water from wastewater without adverse health effects, the focus of motivating water reuse should shift away from technological issues to environmental, social and economic concerns [48]. While agricultural and industrial purposes are presently the dominant end uses of recycled water, urban and residential applications such as landscape irrigation, toilet flushing and car washing, are experiencing rapid development, the amount of which are likely to be as high as or much higher than that of agricultural irrigation schemes [10]. High value end uses with potential close human contact such as groundwater recharge and indirect potable reuse would be promising but still somewhat ambiguous due to strong public misgivings [18].

Comparatively, in less developed countries, owing to technical and economic constraints, a large proportion of water reuse activities still involve secondary wastewater treatment. There would be a tendency in recycled water market towards higher level of treatment. With respect to end uses, apart from agricultural irrigation that will continue to be the major user of recycled water, other agricultural activities such as livestock consumption, using recycled water, can be beneficial to alleviate freshwater stress and maintain economic development. According to these recent trends in both developed and developing areas [17], current end uses are mostly limited to a few non-potable purposes. To meet aggressive water recycling targets, beyond the implementation of more recycled water schemes, the development of new end uses might be prospective and should be realized accordingly [18].

18.3 Environmental benefits of water reuse

18.3.1 Freshwater savings

Recycled water can satisfy many water demands, as long as it is adequately treated to ensure water quality appropriate for the use. In the U.S., recycled water reuse accounts for 15% of the total water consumption, which is tantamount to save approximately 6.4 Gigalitres per day (GL/d) of fresh water [17]. Generally, the advanced treatment is required where there is a greater chance of human exposure to the water. When the water is not properly treated, health problems could arise from being exposed to recycled water which might contain disease-causing organisms or other contaminants. Table 18.1 illustrates the possible recycled water end use categories associated with different treatment levels [47].

Insert Table 18.1 here

Notably, agricultural irrigation currently represents the largest use of recycled water throughout the world. In Australia, there are about 270 different agricultural irrigation schemes across the country, using 45-126 GL of recycled water per year. Nonetheless, considering the annual total water consumption in agriculture (6240 GL in 2011–12), the contribution of recycled water was still small, which only accounted for 2% [8]. If higher amount of recycled water can be properly reused, considerable freshwater savings would be achieved, especially in intensive farming systems. It is worth noting that the Shoalhaven Water's Reclaimed Water Management Scheme in New South Wales (4 GL/year) has converted the region from dry land to dairy farm without introducing extra charge and environmental problems. Besides, the Wider Bay Water recycling scheme in rural Queensland, which used recycled water on 400 Ha sugar cane in 2007 has resulted in the highest producing property in the district [9]. Moreover, landscape irrigation is the second largest user of recycled water in the world currently despite that the particular water demand varies greatly by geographical location, season, plants and soil properties. The specific applications include the golf course uses, public parks, schools and playgrounds uses, and residential area landscape uses. A successful example is the Darwin Golf Course in Tasmania, Australia, where 450 Megalitres per year (ML/year) of effluent provided by Darwin Golf Course Sewage Treatment Plant (STP) has well connected with the golf course irrigation. Part of effluent sent to golf course pond can be further utilized in sport field such as Marrara Sports Complex, thereby great water saving can be achieved [9,17].

Apart from irrigation purposes, recycled water has also been successfully applied to industrial sectors which become the third biggest contributor to recycled water consumption recently. The major categories associated with substantial water consumption include cooling water, boiler feed water and industrial process water [17]. With respect to cooling water, the thermal power generation plants of MahaGenco Company at Koradi and Khaparkheda, India, reuse 110 ML/day of treated water for cooling purposes predominantly. This has become India’s largest water reuse project and the company is going to use treated water constantly for the next 30 years, which will directly benefit 1 million people due to significant amount of freshwater savings [46]. In pulp and paper mill industry, the Mondi Paper Company in Durban, South Africa, uses 47.5 ML/day of recycled water from the Durban Water Recycling Plant. As a result, great water savings in Mondi have been achieved and the water tariff has been reduced by 44% [50].

As for metallurgical industry, the Port Kembla Steelworks in Australia, which belongs to BlueScope Steel Company, used 20 ML/day of recycled water from the Wollongong STP. The project has reduced the Port Kembla Steelworks' freshwater use by more than 50%. The new partnership with Sydney Water will further reduce the draw on freshwater from Avon Dam from 37 ML/day to 17 ML/day [13]. Similarly, the Port Kembla Coal Terminal also receives recycled water from the Wollongong STP and has been using it for dust suppression since 2009, reducing 70% of freshwater consumption [17]. Regarding the food processing industry, Matsumura and Mierzwa [31] reviewed water reuse for non-potable applications in poultry processing plant in Brazil. They found that prechiller effluent including continuous discharged effluent and batch discharged effluent could be reused during chilling processes or for other non-potable applications after UF. The water from gizzard machine was able to be reused in inedible viscera flume as cascade water without pre-treatment. Besides, wastewater from thawing process and filer wash process might also be reused after filtration. By adopting water reuse programs, freshwater consumption was reportedly reduced by 21.9%.

Furthermore, other applications on residential and/or commercial purposes (e.g., fire protection, toilet flushing, car washing, gardening and clothes washing) are being widely practiced. By constructing dual-reticulation pipe systems for water supply in several urban residential areas, substantial water saving has been achieved in many developed countries, including Australia, Japan, the U.S., the UK and Germany [6]. In Australia, one representative example is the Water Reclamation and Management Scheme (WRAMS) in Sydney Olympic Park. It has extended the urban water recycling concepts to integrated water management by incorporating both stormwater and recycled water in recycled water delivery systems. The novel stormwater reservoir design enabled stormwater from the Olympic Park and excess secondary effluent from STP to be stored and regulated so that the subsequent WRP can be operated at any rate to cope with large events. Up to 7 ML/day of recycled water under MF, UV and super-chlorination was used for toilet flushing and open space area irrigation at sporting venues in Olympic Park, saving 850 ML/year of Sydney's freshwater supply. The additional recycled water also served 2000 residential houses in Newington in terms of toilet flushing and garden watering. Recently, the end uses have been expanded to over eleven types, including swimming pool filter backwash and ornamental fountains [15].

In addition to centralized dual pipe systems, in the U.S., the first large-scale onsite water recycling system was conducted at Solaire building (293-unit) in New York City. The wastewater treatment system, located in the basement, uses membrane bioreactor and UV disinfection to treat more than 95 ML/d of wastewater, of which 34 ML/d is for toilet flushing, 43.5 ML/d is used as makeup water for the building's cooling towers and 22.7 ML/d is for landscape irrigation. The system has reduced the freshwater and energy consumption by 75% and 35% respectively [3]. Remarkably, some sustainable management or control approaches (e.g., selection of advanced irrigation methods, adoption of additional treatment methods, and/or increase of capital and maintenance costs) in existing or future recycling schemes can be carried out to reduce the freshwater consumption and overall environmental footprint further.

18.3.2 Pollution load reduction

In some cases, the main impetus for water reuse comes not from a water supply need, but from a need to eliminate or decrease environmental loads exerting by effluent discharge to the ocean, an estuary, or a stream [47]. This strength of recycled water is fairly distinct as many studies have already demonstrated massive adverse effects on aquatic sensitive ecosystems from wastewater effluent in terms of nutrients pollution, temperature disturbance and salinity increase. For instance, the Rouse Hill Water Recycling Scheme, located at north-western Sydney, is one of the most successful schemes in Australia. The primary objective of the scheme is to reduce the nutrient loads on the Hawkesbury-Nepean River system which caused by the discharge of treated wastewater. It started in 2001 and uses up to 2.2 GL/year of recycled water, serving over 19,000 homes. At the same time, it also helps to care for the environment and reduce impacts on waterways. The amount of treated wastewater discharged to the Hawkesbury-Nepean River has been largely reduced. In 2009, the upgrade of the plant enables up to 4.7 GL/year of wastewater to be recycled for residential use and can eventually serve 36,000 homes in the area [32]. Besides, the Illawarra wastewater recycling plant in Wollongong, Australia, is one of the most advanced coastal treatment plants in the world. The project was designed to improve water quality at Illawarra beaches, particularly those near STPs and supply high-quality recycled water for industrial reuse. Presently, the plant adopts microfiltration and RO technologies to recycle 20 ML/day of sewage for reuse by BlueScope Steel at Port Kembla. The scheme facilitates protection of coastal waters, reduction of impact on sensitive marine ecosystems and minimization of the effluents’ negative impacts when released to the environment [49].

Shiratani [42] performed scenario analyses of recycling of sewage treated water into agricultural in order to reduce pollutant load discharged into the Aburagafuchi Lake in Japan. Since the lake was heavily polluted with organic matter, reducing pollutant load discharged into the lake has become the most important measure to improve the water environment. The results showed that irrigating paddy fields with the sewage-treated water could contribute to conserving water and reducing pollutant load, with reduction rate in BOD, nitrogen and phosphorus ranging from 6-36%, 16-46% and 18-51% respectively. Particularly, the results indicated that, irrigating paddy fields with the treated water during non-cropping periods and the accompanying reduction in withdrawn water from the river were more effective in reducing pollutant loads discharged into the lake.

Additionally, in the U.S., the city of San Jose began implementing the South Bay Water Recycling (SBWR) Program in order to comply with the San Jose/Santa Clara Water Pollution Control Plant (SJ/SC WPCP)'s National Pollutant Discharge Elimination System Permit. Since most of the Bay Area's treated wastewater is discharged to the San Francisco Bay which is a 303(d) listed impaired water body, the area's natural salt water marsh might be threatened. Water reuse will result in direct water quality benefits for the Bay. The project can mitigate the effluent flows from the SJ/SC WPCP, thereby reducing the load of pollutants that enter the Bay. In 2008, the SBWR program had the capacity to provide 3,363 million gallons per year of recycled water to over 500 customers for non-potable purposes, such as agriculture, industrial cooling and processing, and irrigation of golf courses, parks and schools. By avoiding the conversion of salt water marsh to brackish marsh, the habitat for two endangered species can be protected [25, 47].

Moreover, groundwater recharge with recycled water can reduce the decline of groundwater levels, dilute, filtrate and store recycled water, partially prevent saltwater intrusion and mitigate subsidence [7]. Presently, aquifer recharge with recycled water has been implemented in some areas in order to alleviate problems of falling groundwater tables. For example, in Mosman

Peninsula, Western Australia, two golf courses are impacted by saltwater intrusion into their irrigation bores. Local government and residential groundwater users have also been affected. There has been consistent demand, particularly from the Town of Mosman Park, for a good and sustainable source of water. Consequently, a pilot study named Mosman Peninsula aquifer recharge scheme has been conducted, in which the superficial aquifer on the peninsula could be used to store reclaimed water over winter for maintaining the saltwater interface as well as summer irrigation use [12].

In the U.S., one of the largest groundwater replenishment (GWR) systems in the world has been established in the Orange County Water District (OCWD), California, in 2007. The GWR system purifies highly treated wastewater through microfiltration, RO, UV disinfection, and hydrogen peroxide technologies. Half of the treated water is injected into OCWD's seawater intrusion barrier wells along the Pacific coastline, the other half is provided to groundwater spreading basins in Anaheim. The project has three growth stages with the production rate of 265, 321, and 474 ML/day in 2008, 2010, and 2020 respectively. By 2020, GWR will be capable of supplying approximately 22% of total water demand in OCWD. Other environmental benefits of GWR system include: protection from seawater intrusion, elimination of need for additional ocean outfall, improvement of groundwater quality by decreased mineral levels, more cost-effective and energy-efficient compared to water importation from northern California [33]. Similarly, in the Middle East, a groundwater recharge project for seawater intrusion barrier as well as groundwater replenishment for agricultural irrigations is presently implemented in Salalah, Oman, where 20 ML/day of tertiary treated effluent is discharged to a series of recharge wells to form a barrier against seawater intrusion [17,27].

18.3.3 Augmentation of stream flow and enhancement of wetlands

Water reuse for stream flow augmentation (where "stream" refers to, in order of decreasing flow, a river, creek, or brook) or for constructed wetlands, ponds or lakes has the potential to improve stream and wetland habitat and increase potable water supply. In contrast to traditional discharge of wastewater in which a site is selected for the purpose of disposal and any benefits are incidental, water reuse for stream flow restoration or augmentation is sited and designed to renew urban streams for environmental, ecological, societal or other community benefit [37]. Using recycled water for environmental applications may allow utilities to obtain the full benefit of current and future recycled water supplies.

An increasing number of cities are considering or implementing these projects by a variety of reasons. In Australia, 17 inland STPs in Sydney, New South Wales, discharge recycled water into the Hawkesbury-Nepean River System where water supply dams and weirs have been built in the upper catchment. To release reliable environmental flows and protect the health of the downstream river, these STPs have been upgraded to advanced tertiary standards since 2004. Typically, the new St Marys Water Recycling Plant in the west of city is now in operation as the first of its kind in the world. Tertiary treated wastewaters from the Penrith, St Marys and Quakers Hill STPs are transferred to this plant and undergone additional ultrafiltration, RO, decarbonation and disinfection processes. The recycled water is released to the Hawkesbury-Nepean River, providing 18 GL/yr of water for environmental flow regulation. This represents a very large saving of freshwater as this flow would otherwise have been provided by freshwater from the Warragamba

Dam. Until now, due to the high water quality requirement and limited exposure to the public, most of the environmental-related schemes have been successfully implemented and neither adverse environmental impacts nor human health problems have been identified [16].

In the U.S., Halaburka [23] assessed the economic and ecological merits of stream flow augmentation using tertiary-treated recycled water in a California coastal stream. Compared to a direct ocean outfall discharge of secondary-treated effluent with no beneficial water reuse, numerous benefits were found by inland discharge of recycled water, including recreation, aesthetics, and habitat for native or endangered species. For example, the pedestrian path following the rehabilitated section of Calera Creek provides recreational benefit to people who use it for walking, biking, bird watching and dog walking. The recreational value was estimated at $10.20 per visitor per recreation day for the base-case. The restoration also improved the aesthetics of the neighborhood, which can have a significant positive effect on housing prices. Further, the creek provides habitat for a number of native plant and animal species. The value of habitat protection can be substantial and in some cases is the most valuable ecosystem service of a stream restoration. Table 18.2 summaries other projects in the U.S. and internationally. Generally, the main motivation of these projects has been to provide necessary stream flow for ecological benefit and/or to restore an unsightly, dry or low-flow creek for aesthetic and recreational benefit in an urban or semi-urban community. Meanwhile, they can also contribute to decreased use of potable water supplies, reduced volume of wastewater discharge and outfall contaminant loads [37]. Noticeably, three common issues, namely temperature, nutrients, and trace metals and organic contaminants, are consistently associated with urban stream degradation and are key potential hindrances to the reuse of water for stream flow augmentation [11].

Insert Table 18.2 here

With respect to wetlands, they have many noteworthy functions, such as flood attenuation, wildlife and waterfowl habitat, aquifer recharge, fisheries breeding grounds and water quality enhancement. For wetlands that have been impaired or dried from water diversion, water flow can be augmented and/or enhanced with recycled water to sustain and improve the aquatic and wildlife habitat. For instance, in the U.S., recycled water from Iron Bridge Plant was supplied to a wetland, breeding hundreds of aquatic animals and plants. After that, it was further discharged into St. Johns River in Orlando, Florida [17,47].

18.4 Summary and conclusions

Water reuse has shown to be effective and successful in creating a new and reliable water supply while not compromising public health. As water demands and environmental needs grow, recycled water becomes an important water supply in many countries. An apparent environmental benefit of recycled water is to offset the use of potable water supplies (e.g., surface water or groundwater released from reservoirs or impoundments) being used for agricultural, industrial, residential and/or commercial purposes at the site. Besides, recycled water is beneficial to reduce the volume of wastewater discharge at the local rivers or ocean outfall locations, helping to minimize outfall contaminant loads and meet regulatory or permit requirements. Additionally, recycled water for stream flow augmentation and wetland enhancement applications has provided substantial recreational and aesthetic benefits to the community as well as environmental benefits to the local habitats. By working together to overcome obstacles, water reuse, along with water conservation and other sustainable water management strategies such as the development of green technologies, can facilitate to conserve our vital environment.

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Tables

Table 18.1 Types of treatment processes and suggested uses at each level of treatment

Types of treatment processes	Suggested end uses
Water collection system	—
Primary treatment sedimentation	• No uses recommended at this level
Secondary treatment: biological oxidation, disinfection	• Surface irrigation of orchards and vineyards • Nonfood crop irrigation • Restricted landscape impoundments • Groundwater recharge of non-potable aquifer • Wetlands, wildlife habitat, stream augmentation • Industrial cooling processes
Tertiary/advanced treatment: Chemical coagulation, filtration, disinfection	• Landscape and golf course irrigation • Toilet flushing • Vehicle washing • Food crop irrigation • Unrestricted recreational impoundment • Indirect potable reuse: groundwater recharge of potable aquifer and surface water reservoir augmentation

Suggested water recycling treatment and reuse

Increasing level of treatment
Increasing level of human exposure

Table 18.2 Examples of water reuse for the purpose of stream flow augmentation

Location	Wastewater treatment	Description	Motivation
San Antonio River (San Antonio, Texas), 2000-present	San Antonio Water System operates three WRCs. Dos Rios and Leon Creek WRCs are conventional activated sludge facilities. Medio Creek WRC employs an extended aeration process. Tertiary treatment includes filtration and disinfection (chlorination and dechlorination, except for Medio Creek WRC, which uses UV disinfection).	Recycled water replaces the use of groundwater for instream flow at the downtown River Walk attraction, which also flows through a city park and zoo, at three new discharge locations. Monitoring shows improved water quality and the return of sensitive, pollutant intolerant species.	By the mid-1950s, headwater reaches near downtown were dry due to groundwater pumping. Reach downstream of WWTP discharge was considered a 40-mile (64-km) "dead zone" due to poor water quality. A City water recycling goal was to improve area streams by maintaining flows.
Salado Creek (San Antonio, Texas), 2001-present		Water quality monitoring and fish surveys were conducted before and after augmentation began, and improved water quality was observed. Creek was removed from the 303(d) List of Impaired and Threatened Waterbodies for DO impairment.	See above. Impaired stream with low DO levels and occasional high fecal coliform. Community desired reliable base flow. Future discharge is under consideration at San Pedro Creek.
Bell Creek (Sequim, Washington),	Sequim WRF. Includes tertiary treatment with UV disinfection and	Recycled water is discharged to maintain benthic species and improve salmon habitat (0.06	City Council Water Reuse Task Force identified enhancement of Bell Creek as

2001-present	aeration via cascade structure.	mgd or 250 m^3/day).	the number one alternative (followed by irrigation). Flow is committed to improve salmon habitat year-round.
Hillsborough River, Tampa, Florida (not implemented)	Howard F. Curren Advanced WWTP. Proposed tertiary treatment with aeration and UV disinfection.	Tampa Bay Downstream Augmentation Project was not implemented in part due to public concerns about discharge quality, including PPCPs. Future augmentation (Alafia River) is being considered.	To use recycled water from the City of Tampa to augment river flows and allow upstream potable withdrawal to increase by an equal amount.
San Luis Obispo Creek (San Luis Obispo, California), 1994-present	San Luis Obispo WRF. Primary, secondary with nitrification, and tertiary treatment with filtration and chlorination. Dechlorination and cooling tower prior to discharge.	WRF produces 3.6 mgd (14,000 m^3/day) recycled water, of which a minimum of 1.6 mgd (6,000 m^3/day) is released to creek at historical outfall. Creek habitat depends on recycled water discharge, which dominates summer flow.	Not originally intended as environmental enhancement. Observation of improved water quality following recycled water discharge to creek and presence of endangered species led to greater use for stream flow over landscaping and industrial uses.
Tossa de Mar Creek (Tossa de Mar, Spain), 1997-present	Tossa de Mar Water Reclamation Plant (coagulation, flocculation, sedimentation, filtration, UV+chlorine disinfection).	Tertiary-treated recycled water from an artificial pond percolates through soil to the creek, preventing the creek from becoming dry in the summer and providing ecological benefits.	To use recycled water from the WWTP to establish vegetation and create a park using marginal land located between the WWTP and Tossa de Mar Creek.
Nobidome Stream (Tokyo, Japan), 1984-present	Tamagawa-Johryu WWTP includes rapid sand filtration, partial P removal; chemical coagulation and ozonation added in 1989-1991.	Recycled water is viewed as an attractive water supply for stream augmentation in urban areas, as well as for creation of artificial streams.	Once an attractive riverine area of a Tokyo suburb, the stream dried when the headwaters were diverted in 1976.
Multiple rivers (Tokyo, Japan), 1995-present	Ochiai WWTP process includes tertiary treatment by rapid sand filtration.		Low flow or dry rivers (Shibuyahawa, Furukawa, Nomikawa, and Megurogawa Rivers) due to rapid urbanization.

Abbreviations: DO = dissolved oxygen; mgd = million gallons per day; PPCPs = pharmaceuticals and personal care products; UV = ultraviolet; WRC = water recycling center; WRF = water reclamation facility; WWTP = wastewater treatment plant.

Source: Adapted from Plumlee [37], Eckhardt [21], Latino and Haggerty [28], Asano [6], Sala and de Tejada [40], Yamada [54].