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The role of satellite and decentralized strategies in water resources management

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Abstract

Existing and projected water shortages and related factors have helped focus attention on the need for water reuse. With recent technological advances in wastewater treatment, it is now possible to produce reclaimed water of any quality. Thus, the use of reclaimed water will depend on the reuse opportunities and the cost of the required infrastructure. Historically, centralized wastewater treatment facilities have served the needs of organized societies since the mid 1800s. However, as there are limited options for expansion of most existing centralized facilities, the use of satellite and decentralized wastewater management systems offers significant advantages including being close both to the source of wastewater generation and to potential water reuse applications. The comparative advantages of satellite and decentralized wastewater management systems for a number of water reuse applications are presented and discussed in this paper. Selected case studies are presented to demonstrate the utility of satellite and decentralized wastewater management. Specific issues associated with the application of such systems in existing and in new developments are examined and discussed.

Keywords: Wastewater; Water management; Water reuse; Recycling; Satellite system; Decentralized system

1. Introduction

Centralized water and wastewater treatment facilities have been of critical importance in the management of the water resources of modern societies. The basic idea behind the use of centralized water treatment is that relatively high quality water from various natural sources can be treated to an even higher quality for distribution and use. In an opposite manner, wastewater from numerous individual sources is collected and transported to a centralized location for treatment and dispersal to the environment and/or reuse. Although centralized facilities for water and wastewater have served society well, new approaches are needed as a result of population growth, the concomitant increase in agricultural use of water, and the need to develop more sustainable approaches to water resources management. The use of satellite and decentralized approaches for the management of water and wastewater can play an important role in the future of water resources management. While both water and wastewater are of importance, the focus of this paper is on the role of satellite and decentralized strategies in water resources management, including a discussion of the rationale for the uses of such systems, reuse opportunities for reclaimed water, the types of systems, several case studies to illustrate various applications, and some lessons learned.

2. Rationale for the use of satellite and decentralized facilities

While centralized facilities have been in common use since the mid 1800s for wastewater management, it has become

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increasingly clear in recent years that continued dependence solely on such facilities may not be optimal with respect to sustainable water resources management and especially so in water short areas. Concerns with the continued use of centralized facilities include the following.

2.1. Capacity limitations

Historically, wastewater collection and treatment systems were designed to handle wastewater flows generated within the urban core areas, typically at the lowest point that would drain by gravity near a point of discharge, typically a water body. It is fair to say that the early planners could not have anticipated the unprecedented growth that has occurred in most modern cities. As cities have continued to grow, many centralized wastewater management systems have become overloaded. Further, because residential and commercial development has surrounded many treatment facilities that were once located in remote areas, area for expansion is now limited or non-existent. Also, because of development, the opportunity to reuse significant amounts of water is limited or non-existent. Expansion of existing collection system components which would involve disruptions in the flow of traffic and other public activities is not viewed favorably by most municipal governments and the populous. As a consequence of growth and development and constructability issues, planners are now being forced to evaluate a number of alternatives for the future development of wastewater management facilities including the use of satellite and decentralized facilities, as discussed in this paper.

2.2. Increased population growth

As cities have continued to grow, so has the demand for potable water. In many locations in the world, the readily available potable water supplies (both surface and groundwater) have been utilized to their sustainable limits, and beyond. If wastewater were reclaimed and reused it would provide a stable sustainable source of water. The use of satellite and decentralized facilities for the reclamation of wastewater for a variety of reuse applications would reduce the demand on potable water supplies.

2.3. Sustainable use of water

As the true value of water is only now understood and appreciated more fully, it has become increasingly clear that this resource must be used sustainably if the quality of life that has evolved over the last century is to continue. Further, as effluent discharge limits become more stringent, treated effluent is of a quality that can be used directly in a number of reuse applications.

2.4. Water shortages due to changes in global cycles

In the past few years, water shortages have also been experienced as a result of changing global water cycles. Extended drought periods have been experienced in many parts of the world. Here again, the use of reclaimed water could help to offset water shortages. The problem is compounded further by the unpredictable effects of global warming.

2.5. Homeland security and disaster mitigation

In the world today, centralized wastewater treatment systems can be potential targets for terrorist activities, as the destruction of wastewater treatment facilities could have severe impacts on the public health and on the environment. Natural disasters, such as earthquakes or floods, can also have severe impacts to the civic life if wastewater treatment plants are centralized. The use of satellite and decentralized facilities can be used to reduce the impact associated with such events.

To deal with the issues cited above, the utilization of satellite and decentralized strategies are examined further in the remainder of this paper.

3. Water reuse

If satellite and decentralized wastewater management facilities are to be used to reduce the demand for potable water, there should be opportunities to use the reclaimed water from these facilities. Water reuse opportunities and water quality requirements are considered below.

3.1. Reuse opportunities

Reclaimed water can be used in a number of applications; principal applications are summarized in Table 1. The reuse applications listed in Table 1 have been arranged by the quantity of reclaimed water now recycled, although the specific order may vary depending on local reuse opportunities. Although indirect potable reuse, through groundwater recharge and surface water augmentation, and direct potable reuse account for only a small percentage of the reclaimed water that is now used, it is inevitable, as will be discussed subsequently, that these uses will become dominant in the future.

3.2. Water quality requirements

By employing the appropriate wastewater treatment technology, it is now possible to produce any quality of reclaimed water, including direct potable use (see Table 1). A variety of technical, economic, and environmental criteria may be used to decide which of the available reuse opportunities may be selected. Typical water qualities that are now achievable with various types of treatment are reported in Table 2. Additional details on treatment processes can be found in Asano et al. (2007) and Tchobanoglous et al. (2003).

4. Types of satellite and decentralized systems and infrastructure requirements

The characteristics of *satellite* systems (also known as distributed systems), which may be considered as an integral part of a centralized treatment system and of *decentralized* systems

Table 1
Reuse opportunities for reclaimed water[a]

Reuse application	Remarks
Agricultural irrigation	Controlled agricultural irrigation is by far the most popular water reuse application in the world. The type of soil, the kind of cultivations, the type of the irrigation system, the climatic conditions and the local legislation define the minimum reclaimed water characteristics, and consequently the appropriate treatment practices (Lazarova and Asano, 2004; Pettygrove and Asano, 1985)
Landscape irrigation	Reclaimed water is used extensively for landscape irrigation applications, such as irrigation of parks, golf courses, green parts in residential areas, cemeteries, roadside plantings and meridians (Gill and Rainville, 1994)
Industrial applications	Reclaimed water is extensively used for cooling power plants, oil refineries and manufacturing facilities (Asano et al., 1988; Mann and Liu, 1999)
Urban non-irrigation applications	Fire protection, air conditioning cooling, toilet and urinal flushing, as well for car and commercial laundering are examples of urban non-irrigation applications. The amount of reclaimed water used for urban applications is generally small, compared with the previously described reclaimed water applications (Lazarova et al., 2003; Yamagata et al., 2002)
Environmental and recreational applications	Water enhancement in wetlands, and in wildlife habitats, the enrichment of water flows in rivers during the dry season, and the creation of lakes and ponds for recreational use are examples of environmental and recreational applications. Reclaimed water has also been used in erosion and sedimentation control (Crites et al., 2006; Crites and Tchobanoglous, 1998)
Groundwater recharge (indirect potable reuse)	Reclaimed water has been used for *groundwater recharge* to restore the groundwater levels and to control saltwater or blackish water intrusion to fresh water aquifer (Asano, 1985; Bouwer, 1991)
Surface water augmentation (indirect potable reuse)	The introduction of highly treated water into the existing water supply reservoirs for blending with other surface waters
Direct potable uses	The only documented direct potable reuse application is the case of the water plant at the capital of Namibia, Windhoek, where tertiary treated wastewater undergoes RO treatment, and then it is blended with treated surface water, before it is fed to the water distribution system (Harrhoff and Van der Merwe, 1996)

[a] Adapted in part from Asano et al. (2007).

Table 2
Typical range of effluent quality after removal of residual particulate matter[a]

Constituent	Unit	Range of effluent quality after indicated treatment				
		Conventional activated sludge[b]	Conventional activated sludge with filtration[b]	Activated sludge with BNR and filtration[c]	Membrane bioreactor	Activated sludge with BNR[c], followed by MF, RO and AOP[d]
Total suspended solids (TSS)	mg/L	5–25	2–8	1–4	≤1	<0.01
Colloidal solids	mg/L	5–25	5–20	1–5	0–4	<0.01
Biochemical oxygen demand (BOD)	mg/L	5–30	<5–20	1–5	<5–10	<1
Chemical oxygen demand (COD)	mg/L	40–80	30–70	20–30	<30–40	10–50[e]
Total organic carbon (TOC)	mg/L	10–40	15–30	1–5	5–10	<0.5
Ammonia nitrogen	mg N/L	1–10	1–6	1–2	<1–5	<0.5
Nitrate nitrogen	mg N/L	20–30	20–30	1–10	<10[f]	<0.5
Nitrite nitrogen	mg N/L	0 to Trace	0 to Trace	0.001–0.1	0 to Trace	Trace
Total nitrogen	mg N/L	15–35	15–35	2–5	<10[f]	<1.0
Total phosphorus	mg P/L	4–10	4–8	≤2	4–10	<0.1
Turbidity	NTU	2–15	0.5–4	0.3–2	≤1	≤0.1
Volatile organic compounds (VOCs)	μg/L	10–40	10–40	10–20	10–20	<10
Metals	mg/L	1–1.5	1–1.4	1–1.5	Trace	<0.005
Surfactants	mg/L	0.5–2	0.5–1.5	0.1–1	0.1–0.5	<0.01
Totals dissolved solids (TDS)	mg/L	500–700	500–700	500–700	500–700	20–40
Trace constituents[g]	μg/L	5–40	5–30	5–30	0.5–20	<10
Total coliform	No./100 mL	10^4–10^5	10^3–10^5	10^4–10^5	<100	<1
Protozoan cysts and oocysts	No./100 mL	10^1–10^2	0–10	0–1	0–1	<1
Viruses	PFU/100 mL[h]	10^1–10^3	10^1–10^3	10^1–10^3	10^0–10^3	<1

[a] Adapted in part from Asano et al. (2007).
[b] Conventional activated sludge is defined as activated sludge treatment with nitrification.
[c] BNR is defined as biological nutrient removal for the removal of nitrogen and phosphorus.
[d] MF: microfiltration, RO: reverse osmosis, AOP: advance oxidation process.
[e] μg/L.
[f] With anoxic stage.
[g] For example, prescription and non-prescription drugs.
[h] Plaque forming units.

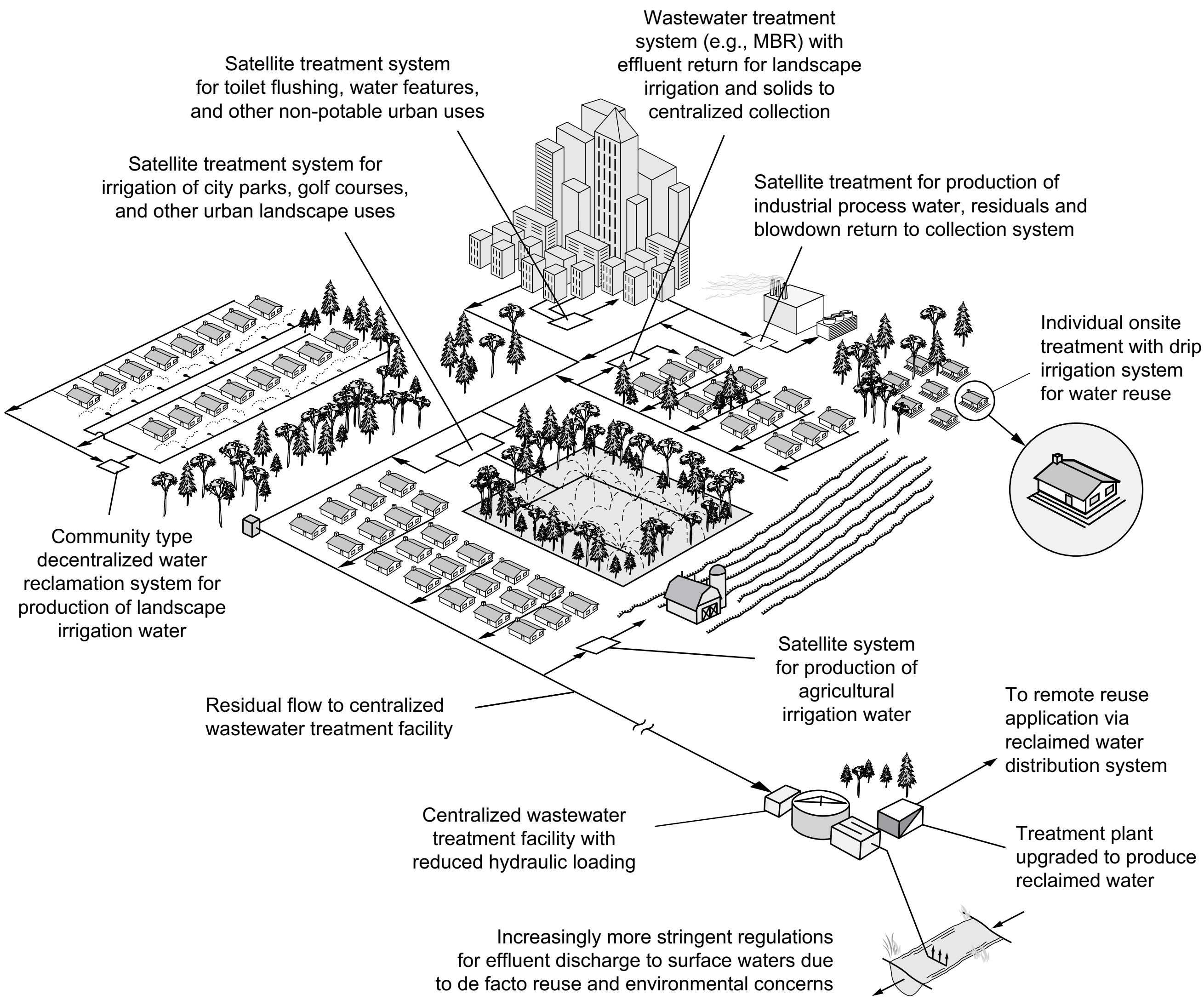

Fig. 1. Illustration of the applications for satellite and decentralized reclamation facilities in densely populated areas (adapted from Asano et al., 2007).

which are self-sufficient treatment systems are illustrated on Fig. 1 and described below. The necessary infrastructure requirements are also considered.

4.1. Satellite systems

Satellite wastewater treatment systems, located generally in the upper portions of the wastewater collection system, usually lack solids processing facilities. Solids generated from these facilities are returned to the collection system for processing at a centralized treatment plant. Apart of the obvious utility for water reuse, the satellite treatment systems may also be used to reduce wastewater flows to the centralized facilities, or as means to eliminate or reduce discharges to impacted receiving water bodies. Three types of satellite systems illustrated on Fig. 2 are described below.

4.1.1. Interception type

In the interception systems (see Fig. 2a), wastewater is intercepted before reaching the collection system, diverted to a satellite system for treatment, and reused locally for applications such as toilet and urinal flushing, localized landscaping, including water features, and cooling water in high rise commercial or residential buildings.

4.1.2. Extraction type

In the extraction type of satellite systems (see Fig. 2b), wastewater is literally mined from the collection system en route to the central treatment plant; typical applications of extraction type satellite systems include: park or green-belt irrigation, water reuse in high rise commercial or residential buildings, and cooling tower applications. Indirect potable reuse through groundwater recharge has become an alternative option in many locations.

4.1.3. Upstream type

The upstream type of systems (see Fig. 2c) typically is used to treat wastewater generated at the outskirts of a centralized collection system, where there is an increased demand for reclaimed water for suburban park and meridian strip irrigation.

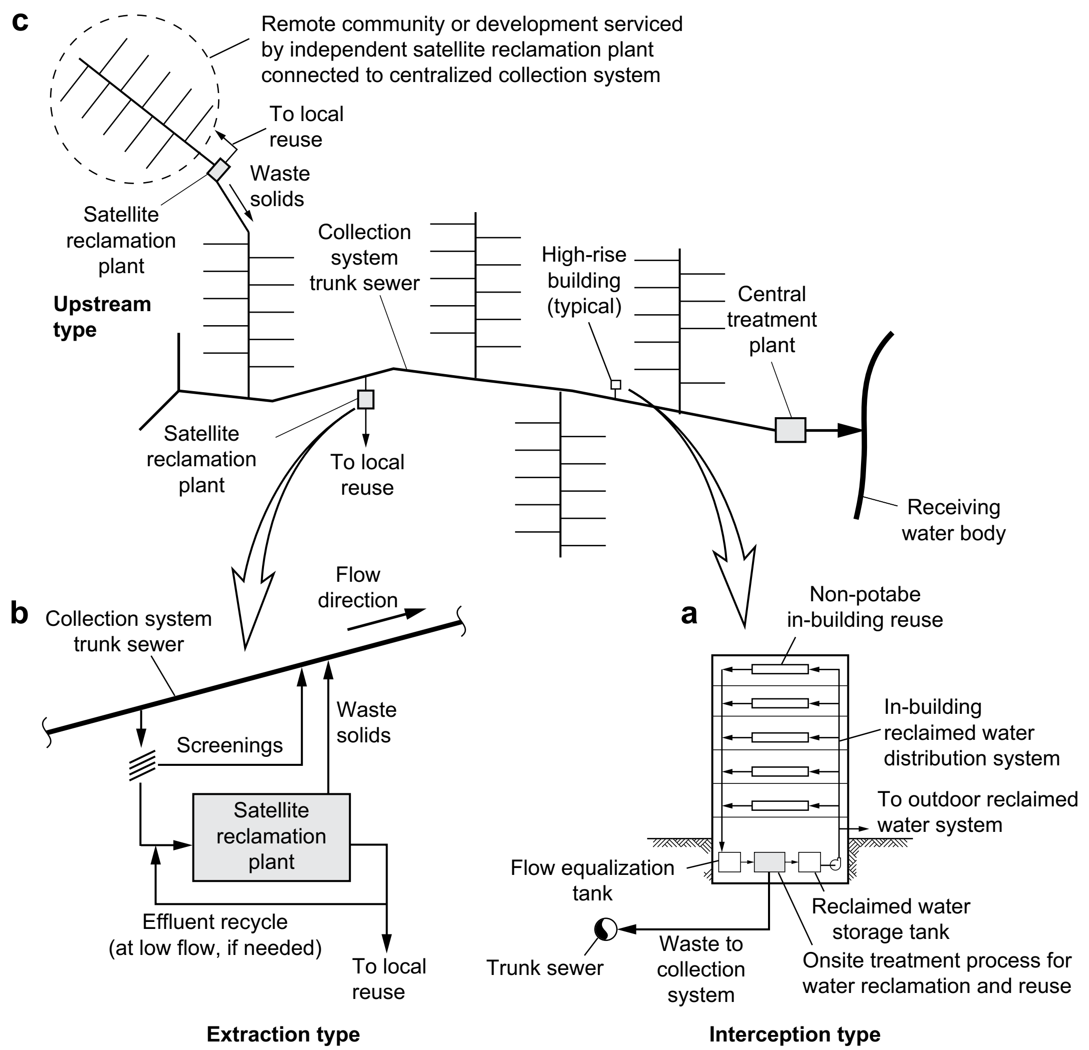

Fig. 2. Schematic illustration of three types of satellite water reclamation and reuse systems: (a) interception type, (b) extraction type, and (c) upstream type (adapted from Asano et al., 2007).

Upstream plants can also be used for indirect potable reuse through groundwater recharge and surface water irrigation. Where groundwater recharge or surface water augmentation is used, a fixed amount of reclaimed water can be recycled without the need for storage facilities. Water reclamation in these locations can contribute significantly to downstream flow reduction.

4.2. Decentralized systems

Decentralized treatment plants can be used for wastewater treatment generated from an individual isolated house to a cluster of houses or to a subdivision (see Fig. 3a). Decentralized systems may also be used for the treatment of wastewater generated at universities campuses, or by isolated commercial, industrial and agricultural facilities. In all the above cases, reclaimed water is utilized typically at the vicinity of wastewater generation. Decentralized wastewater treatment systems usually are not linked to a central sewer wastewater collection system network and to a centralized treatment plant, however, in some occasions they may be connected with a centralized plant. Solids accumulated in cluster and decentralized systems are discharged on a periodic basis to a centralized collection system. An example of an MBR (membrane bioreactor) activated sludge plant for an isolated subdivision is shown in Fig. 3b.

4.3. Infrastructure requirements

Regardless of the reuse application some form of infrastructure will be required with satellite and decentralized systems. Depending on the reuse application the required infrastructure facilities include the wastewater diversion or collection system, the inflow or outflow flow equalization facilities, the reclaimed water distribution system, including in- or off-line storage facilities, if required.

Infrastructure requirements will vary depending on the reuse applications (Table 3). For example, for seasonal applications such as irrigation of golf courses, in addition to treatment and distribution system requirements, storage facilities may be required if a fixed amount of water is to be recycled to justify the cost of the treatment facilities. Wastewater

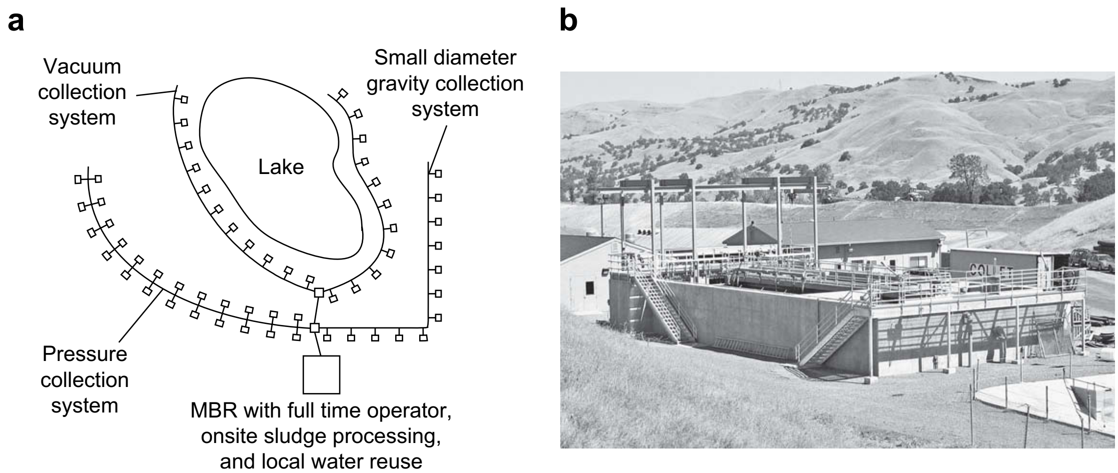

Fig. 3. Typical example of system for housing development or small community: (a) schematic diagram illustrating different types of collection systems and (b) typical small MBR (membrane bioreactor) activated sludge treatment facility used for small decentralized developments (adapted from Asano et al., 2007).

equalization may be needed if large variations in the incoming flow are expected. In most cases, reclaimed water storage facilities are usually required to balance the daily rate of water production with the rate of water demand. Sufficient quantities of reclaimed water have to be stored in the cases that water utilization follows a seasonal pattern, such as the irrigation of golf courses. Seasonal variations of the demand of reclaimed water may impose the need for large storage capacities. In such cases storage of reclaimed water in groundwater aquifers and potable water storage reservoirs will be more cost effective. If reclaimed water is to be used in new residential developments for non-potable reuse applications, such as landscape watering, consideration should be given to installing a separate reclaimed water distribution system (e.g. dual piping system) during the construction phase (see Fig. 4). Retrofitting and existing residential or commercial development has proven to be far expensive to be viable economically.

5. Case studies

Two case studies are presented to illustrate the use of satellite and decentralized systems. Additional examples, along with the case studies discussed below, are presented in Table 4. In addition, global positioning coordinates for water reuse facilities are given in Table 4 to enable viewing of these facilities in their natural setting.

5.1. City of Upland, California, USA: A satellite system to recover water for golf course irrigation

The City of Upland, located at the west end of San Bernardino County, is served by a centralized wastewater treatment system. In early 1980s, when the construction of a large residential area had been finished, the town was facing two major issues: limited collection system interceptor capacity and limited groundwater supply. The last issue was an important constraint to the decision of constructing a golf course within the city limits. Both problems were overcome successfully by the use of an extraction type satellite system for the production of reclaimed water. Thus, the Upland Hills Country Club Golf Course, which opened its gates in 1981, has had an abundant supply of reclaimed water.

Wastewater is mined on its way to the centralized treatment, and is directed to a satellite treatment system were it undergoes full treatment to produce Title 22 water (State of

Table 3
Infrastructure requirements for seasonal and year-round reuse applications[a]

Seasonal reuse	
Agricultural irrigation	Pumping station, force main to point of use, distribution system, winter storage
Landscape irrigation	Pumping station, dual distribution system if reclaimed water is used
Golf course irrigation	Pumping station, dual distribution system if reclaimed water is used, local storage facilities
Residential reuse for lawn irrigation	Pumping station, dual distribution system if reclaimed water is used, local storage facilities
Lakes and recreational enhancement	Pumping station, dual distribution system if reclaimed water is used, local storage facilities
Year-round reuse	
Industrial cooling	Pumping station, facilities for handling of cooling water blowdown
Groundwater recharge (indirect potable reuse)	Pumping station, recharge basins or injection wells
Surface water augmentation (indirect potable reuse)	Pumping, force main from treatment facility to storage reservoir, diffuser for injection into reservoir
Commercial toilet flushing	Dual plumbing system, storage facilities, additional disinfection facilities

[a] Wastewater treatment facilities for both, satellite and decentralized plants, and extraction facilities for satellite plants are *de facto* requirements for any kind of application.

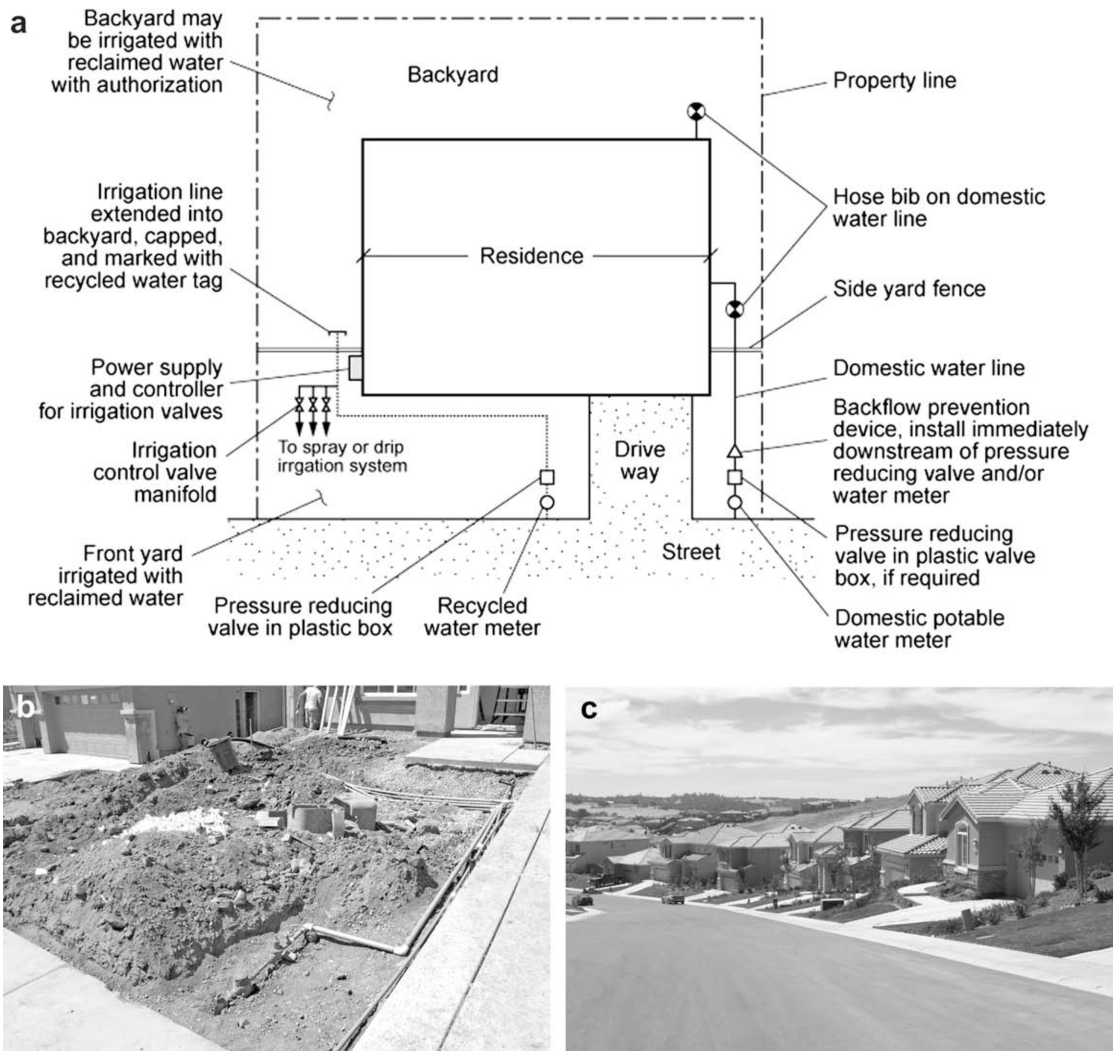

Fig. 4. Typical residential development served with dual plumbing in Serrano, El Dorado County, California (coordinates: 38.678 N, 121.054 W): (a) layout of a dual plumbing system for an individual residence, (b) reclaimed water plumbing system being installed at a residence as shown in (a) above, and (c) view of typical developed home sites with front and back yards irrigated with reclaimed water (adapted from Asano et al., 2007).

Table 4
Selected examples of satellite and decentralized facilities for water reuse[a]

Location	Description
Satellite facilities	
Upland Hills Country Club Golf Course, Upland, CA (coordinates: 34.125 N, 117.641 W)	One of the earliest satellite systems involving sewer mining and treatment for golf course irrigation. System has been in operation for 25 years (Ripley, 2006) (see also Fig. 5)
Solaire residential high-rise building in New York (coordinates: 35.698 N, 139.692 W)	Wastewater is intercepted from the residences, treated highly and reused for toilet flushing and cooling water (Zavoda, 2005)
Tokyo Metropolitan Government Building, Tokyo, Japan (coordinates: 40.717 N, 74.016 W)	Wastewater, collected from high-rise buildings, is treated for toilet flushing (Maeda et al., 1996).
Decentralized facilities	
Rouse Hill, New South Wales, Australia (coordinates: 33.687 S, 150.923 E)	Reclaimed water used for a variety of non-potable uses (Cooper, 2003)
Serrano, El Dorado County, CA (coordinates: 38.678 N, 121.054 W)	Yard and community landscape irrigation with reclaimed wastewater. During the summer period the reclaimed water supply must be augmented (see also Fig. 4)
St. Petersburg, FL(coordinates: 27.827 N, 82.683 W)	Landscape irrigation from four decentralized water reclamation plants. There is a waiting list to get reclaimed water (City of St. Petersburg, 2002)

[a] Adapted from Asano et al. (2007).

Fig. 5. View of satellite treatment plant located in a housing development in Upland, CA (coordinates: 34.125 N, 117.641 W) used to supply reclaimed water for golf course irrigation (courtesy D. Ripley).

California, 2000). The plant consists of influent screening, primary sedimentation, flow equalization, and biological treatment (using three aerobic–anaerobic fixed film reactors). The effluent passes through multimedia pressure filters and is disinfected with chlorine. The biosolids are discharged to the collection system for downstream processing at the centralized treatment system. The satellite treatment system is equipped with odor control facilities, and it is entirely enclosed in a residential type building (see Fig. 5), thus causing neither visual, nor odor impacts. Ponds constructed at the golf course, are also used as reclaimed water storage reservoirs, allowing for unobstructed continuous course irrigation (Asano et al., 2007; Ripley, 2006).

5.2. Rouse Hill, New South Wales, Australia: a dual piping system for water conservation

The Rouse Hill Development Area (RHDA) is a new residential area, about 45 km northwest of Sydney. The area is located close to the Hawkesbury–Nepean River, which would have been the natural treated wastewater receiver of the RHDA. However, due to environmental concerns on the impact of the discharge of treated wastewater into the above estuary, Sydney Water (the agency which designed the sewerage and wastewater treatment system), proposed to reuse the treated water in non-potable domestic applications, such as garden irrigation, toilet flushing and car washing. As a result, a significantly smaller quantity of treated wastewater would have to be discharged into the river, with a parallel reduction in the demand for potable water. Today, more than 15,000 properties are connected to the reclaimed water system, while 10,000 more are expected to follow soon. This level of connections makes RHDA one of the largest residential areas in the world utilizing reclaimed water (Cooper, 2003).

The wastewater treatment plant of the RHDA consists of fine screens (3 mm), degritters, primary clarifiers, a compartmentalized activated sludge reactor for the removal of BOD, nitrogen, and phosphorous, flocculators, secondary clarifiers, and filters. The average dry weather inflow to the system is approximately 5600 m^3/d. Approximately 50% of the above outflow is treated in a water reclamation plant, which consists of ozonation (for virus inactivation), microfiltration, and disinfection with sodium hypochlorite. The reclaimed water is stored close to the areas of use, in three reservoirs with total capacity of 6000 m^3.

The reclaimed water flows via gravity to the end users, through an individual water distribution system. There are no connections between the potable and the reclaimed water distribution systems, whilst, the piping, plumping fittings, and taps used for reclaimed water distribution are colored lilac to distinguish them from the potable water system. Additionally, the potable water distribution system is equipped with backflow prevention devices to prevent contamination for possible cross-connections.

The demand for potable water has been reduced by approximately 35%, since the commissioning of the reclaimed water distribution system. Approximately 2000 m^3/d of potable water are currently used to supplement the demand in reclaimed water applications, thus the reclaimed water system has been scheduled to be expanded to approximately 5200 m^3/d.

6. Discussion

Because of the increased demand for high quality of water and the fixed amount of natural fresh water that is available, the need for wastewater reclamation and reuse, after appropriate treatment is a fact of life if a sustainable future is envisioned with respect to water. From a review of the data presented in Table 2 it is clear that with currently available technology, wastewater can be treated to any desired quality. Further, with technology currently under development even more improvements will be achievable. Thus, once a decision has been made to use reclaimed water the conditions under which satellite and decentralized facilities can be used effectively in both existing and new developments *vis-a-vis* indirect potable reuse must be considered.

6.1. Existing communities with centralized facilities

In communities with centralized treatment facilities, the use of satellite or decentralized facilities will depend on the reuse opportunities. If extensive distribution facilities will be needed from an existing treatment facility to meet seasonal uses for reclaimed water applications such as golf course and park irrigation, the cost of the distribution system will generally make the use reclaimed water prohibitively expensive, and, especially so, if winter storage is needed to achieve a fixed amount of reuse. In such situations, the use of one or more satellite treatment systems may be cost effective, especially if other year-round reuse opportunities, such as flow augmentation and other environmental uses, can be developed. Alternatively, in developed areas, the reuse of highly treated reclaimed water for indirect potable reuse through groundwater recharge or surface water augmentation will be far more cost effective. Blending high quality reclaimed water with either existing groundwater or surface water will allow for indirect potable use of the reclaimed water on a year-round basis, and will represent a constant source of additional water supply. Further, the need for a separate reclaimed water distribution system is eliminated. It must be recognized, however, that the indirect potable reuse option will be significantly more difficult to implement, especially surface water augmentation. In some locations, indirect potable reuse will not be an option, even though *de facto* indirect potable reuse is common in most streams and rivers in the United States and elsewhere.

6.2. Existing communities with centralized facilities and new developments

The opportunities for reuse in new developments are considerably greater, especially when the reuse of reclaimed water is incorporated into the planning stages. The infrastructure needed for the use of reclaimed water should preferably be incorporated into new developments during the design and implementation phases (see Fig. 4a and b). Where this practice has been followed provision for the use of reclaimed water has proven to be cost effective (see Fig. 4c). In the design of the reclaimed water facilities for new developments, the production of wastewater at the vicinity of the reuse area should take into account, with the objective of matching the production of reclaimed water with the demand for reclaimed water, thus minimizing the need for storage. With new developments there is also the opportunity to combine non-potable reuse with indirect potable reuse as noted above.

7. Conclusions

In most parts of the world, the use of reclaimed water is inevitable especially if the current standard of living is to be sustained with respect to the use of water. Because the existing treatment facilities of most large cities are located inappropriately with respect to water reuse, the use of all types of satellite and decentralized systems will become critical in the future, especially until the idea of indirect potable reuse gains wider acceptance. Ultimately, indirect potable reuse by means of groundwater recharge and surface water augmentation will be needed to optimize the use of reclaimed water, along with other localized uses.

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References

Asano, T., 1985. Artificial Recharge of Groundwater. Butterworth Publishers, Boston, MA.

Asano, T., Burton, F.L., Leverenz, R., Tchobanoglous, G., 2007. Water Reuse: Issues, Technologies, and Applications, New York.

Asano, T., Mujeriego, R., Parker, D., 1988. Evaluation of industrial cooling systems using reclaimed municipal wastewater. Water Science and Technology 20 (10), 163−174.

Bouwer, H., 1991. Role of groundwater recharge in treatment and storage of wastewater for reuse. Water Science and Technology 24 (9), 295−302.

City of St. Petersburg, 2002. Landscaping and Irrigation Requirements. December 2002, Revision, City of St. Petersburg, Development Review Services Division, St. Petersburg, FL.

Cooper, E., 2003. Rouse Hill and Picton Reuse Schemes: innovative approaches to large-scale reuse. Water Science and Technology 3 (3), 49−54.

Crites, R.W., Middlebrooks, E.J., Reed, S.D., 2006. Natural Wastewater Treatment Systems. Taylor and Francis, Boca Raton, FL.

Crites, R.W., Tchobanoglous, G., 1998. Small and Decentralized Wastewater Management Systems, New York, USA.

Gill, G., Rainville, D., 1994. Effluent for irrigation. Wastewater Reuse for Golf Course Irrigation. Lewis Publishers, Boca Raton, FL.

Harrhoff, J., Van der Merwe, B., 1996. Twenty-five years of wastewater reclamation in Windhoek, Namibia. Water Science and Technology 33 (10−11), 25−35.

Lazarova, V., Asano, T., 2004. Challenges of sustainable irrigation with recycled water. In: Lazarova, V., Bahri, A. (Eds.), Water Reuse for Irrigation: Agriculture, Landshapes, and Turf Grass. CRC Press, Boca Raton, FL, pp. 1−30.

Lazarova, V., Hills, S., Birks, R., 2003. Using recycled water for non-potable, urban uses: a review with particular reference to toilet flushing. Water Science and Technology 3 (4), 69−77.

Maeda, M., Nakada, K., Kawamoto, K., Ikeda, M., 1996. Area-wide use of reclaimed water in Tokyo, Japan. Water Science and Technology 33 (10−11), 51−57.

Mann, G.J., Liu, Y.A., 1999. Industrial Water Reuse and Wastewater Minimization. McGraw-Hill, New York.

Pettygrove, G.S., Asano, T., 1985. Irrigation with Reclaimed Municipal Wastewater: a Guidance Manual. Lewis Publishers, Chelsea, MI.

Ripley, 2006. Personal communication.

State of California, 2000. Code of Regulations, Title 22, Division 4, Chapter 3 Water Recycling Criteria, Sections 60301 et seq. Sacramento, CA.

Tchobanoglous, G., Burton, F.L., Stensel, H.D., 2003. Wastewater Engineering: Treatment and Reuse, New York.

Yamagata, H., Ogoshi, M., Suzuki, Y., Ozaki, M., Asano, T., 2002. On-site insight into reuse in Japan. Water 21 (7), 26−28.

Zavoda, M., 2005. The Solaire, a high-rise residential reuse case study. In: Proceedings, 20th Annual Water Reuse Symposium, Alexandria, VA.