Water reuse in Japan

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Abstract Even though Japan has mean annual precipitation of 1,714 mm and hundreds of dams and reservoirs constructed, frequent and severe droughts have occurred in wide regions of the country. Because of rapid economic growth and concentrations of population in urban areas, water demands in large cities have stressed reliability of water supply systems and necessitated the development of new water resources with considerable economic and environmental costs. To alleviate these situations, wastewater reclamation and reuse have been implemented widely in major cities. This paper summarizes the current status of water reuse in Japan and discusses dominant uses of reclaimed water, emphasizing non-potable urban applications such as toilet flushing, industrial reuse, and environmental water.

Keywords Environmental water; Japan; reclaimed water; water quality; wastewater; water reuse

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Introduction

Since the post-World War II construction booms in the late 1950s, the Government of Japan has heavily invested in building the National infrastructure, which includes flood control, drainage and sewerage systems, water and wastewater treatment facilities, environmental protection and creation of water “amenities” in the urban environment. In particular, the concentrated investment for extensive construction of sewerage systems and municipal wastewater treatment facilities started around 1958, and rapid growth followed. According to the most recent statistics, approximately 28 billion U.S. dollars were spent in 1997 fiscal year for planning and construction of 2,585 sewerage systems and wastewater treatment facilities, which amounted to approximately 0.7 percent of the Japanese Gross National Product (GNP).

The earliest planned wastewater reclamation and reuse started in 1951 as an experimental work for supplying industrial water for a paper-manufacturing mill in Tokyo from nearby wastewater treatment plant. Serious wastewater reuse efforts, however, started in 1964; the year of Tokyo Summer Olympics, in response to the severe droughts that occurred in wide regions of Japan. Even though increasing numbers of dams and reservoirs have been constructed in the intervening years, water demands in large cities have stressed the reliability of water supply systems due to rapid economic growth and the concentrations of population in the large cities. For example, in 1978, prolonged drought conditions in Fukuoka City (current population: 1.3 million) in the northern Kyushu Island forced the citizens to accept serious water supply limitations for 283 days.

In 1997, 163 publicly owned wastewater treatment plants (POTWs) in Japan provided water reclamation and reuse in 192 use areas. In addition, 1,475 on-site individual building and block-wide water reclamation and reuse systems provided toilet flushing water in commercial buildings and apartment complexes, as well as waters for landscaping. Table 1 shows the current status of water reuse in Japan. The annual volume of reclaimed water use was approximately 206 × 10^6 m^3 (Japan Sewage Works Assoc., 1998; National Land Agency, 1998). It must be noted that, in contrast to many other countries where agricultural irrigation is a dominant water reuse application, the water reuse practiced in Japan has decisively been non-potable urban water applications. Also, providing in-stream flow needs and environmental water for restoring "aquatic amenities" in the urban environment characterizes recent trends in large-volume reclaimed water use, under the Ministry of Construction funding. Thus, reclaimed water is considered as dependable "new water" in the urban environment where water is needed the most and priced the highest. Furthermore, small agricultural and fishing villages have been eligible for receiving government subsidies for wastewater treatment and water reuse from other ministries, such as the Ministry of Agriculture and Fisheries.

Figure 1 compares water reuse in California and Japan. As noted earlier, water reuse in Japan is decisively orientated towards urban reuse applications. In contrast, the majority of wastewater reuse in most other countries is for irrigation; for example, 68 percent of the total water reuse in California (*vs*. approximately 16 percent in Japan) is for agricultural and landscape irrigation (Asano, 1998; State of California, 1999).

Water reuse schemes

In concert with the water resources management policies of Japan, local governments have undertaken most planned wastewater reclamation and reuse projects, which are often subsidized by the Ministry of Construction funding. For example, in the periods of industrial expansion in the 1960s, the Tokyo Metropolitan Government promoted industrial water supplies with reclaimed municipal wastewater to prevent over-drafting of groundwater in the coastal areas of the Tokyo Bay. In other cities, wastewater reclamation was promoted as a resultant positive image of environmental protection provided by the construction of sewerage and wastewater treatment facilities (*cf*. Table 1). Reclaimed water has been promoted by those municipalities as a safe, dependable, and esthetically accepted "new" water resource for providing waters for toilet flushing, in-stream flow needs, urban "aquatic amenities", and restoration of the environment. Figure 2 shows several water reuse schemes ranging from incidental water reuse to highly managed water reuse in a watershed scale.

Closed-loop water recycling systems

Individual building water recycling systems. Individual wastewater reclamation and reuse take place, mainly, for toilet flushing in the same site such as in a large office building or an apartment complex with an on-site wastewater treatment plant. In some cities such as Tokyo and Fukuoka, a dual distribution system is mandated for newly constructed buildings of certain floor space, generally greater than 3,000–5,000 m^2 and/or installed water supply pipe diameter of greater than 50 mm. The reason for this requirement is that local water supply facilities, trunk sewer mains, pumping and wastewater treatment facilities are

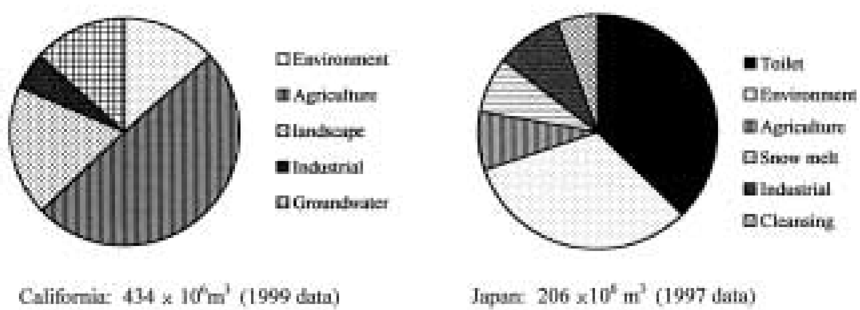

Figure 1 Comparison of water reuse in California and Japan

Table 1 Current status of water reuse in Japan*

Application	Objectives and motivation	Number of POTWs and on-site treatment facilities	Annual volume of use ($\times 10^6 m^3$)
Toilet flushing: From POTWs From on-site	Water conservation and wastewater flow reduction, providing capacity for expansion in build-up areas	36 1,475	3.0 71
Environmental water	In-stream flow needs, urban "water amenities", publicity for successful environmental protection by POTWs	55	63.9
Agricultural irrigation	Dependable water supply	16	15.9
Snow melting	Snow clearing on streets and roads	24	15.3
Industrial water	Dependable less costly water supply	6	12.6
Cleansing water	Dependable less costly water supply	49	11.2
Cooling water	Dependable less costly water supply, environmental protection	20	4.8
Dilution water	Night soil treatment	13	4.1
Tree planting	Dependable less costly water supply	90	0.5
Others	e.g., Dust control in construction site	47	3.6
Sub-total	POTWs	192	135
	On-site	1,475**	71
Total		1,667***	206

*Compiled from the published data from the Japan Sewage Works Assoc., 1998; and the National Land Agency, 1998

**On-site individual building and block-wide water recycling system were not reported by the Ministry of Construction (MOC) statistics, because they are not publicly owned treatment works (POTWs) funded by the MOC

***Due to the multiple use areas from the same POTW and the on-site wastewater reuse, total number of the use areas is reported to be over 1,830

limited and cannot accommodate increased water supply demands and wastewater flows and treatment in rapidly growing cities.

Block-wide water recycling system. Several buildings were connected together to a block-wide wastewater treatment facility and their reclaimed water distributed back to the buildings via block-wide urban distribution pipelines, mainly for toilet flushing. As shown in Table 1, the total number of installations of individual and block-wide water recycling systems was 1,475 and the annual volume of reclaimed water use was approximately $71 \times 10^6 m^3$ (National Land Agency, 1998). Typical wastewater treatment trains consist of a membrane separation activated sludge process (membrane bioreactor), because of the small footprint required for on-site installation, followed by disinfection.

The water recycling systems discussed above are implemented in a relatively small scale such as in a single building or several buildings forming a block-wide water recycling system without the benefit of public sewerage systems.

Large-area water recycling systems. Large-area water recycling systems are generally assisted by the Ministry of Construction (MOC) subsidies up to 50 percent of the capital costs, and implemented via public sewerage system and POTW. Tertiary or advanced wastewater treatment processes are normally employed for further treatment prior to water reuse. The reclaimed water is distributed through a network of pipelines to large water reuse areas.

The main uses of reclaimed water are for toilet flushing and environmental water, but there are other uses such as irrigation and snow melting. This type of large scale water reuse schemes has been increasing with showcase installations such as the Tokyo Metropolitan Government (Shinjuku Sub-Center, Ariake District, Shinagawa Station East Side District,

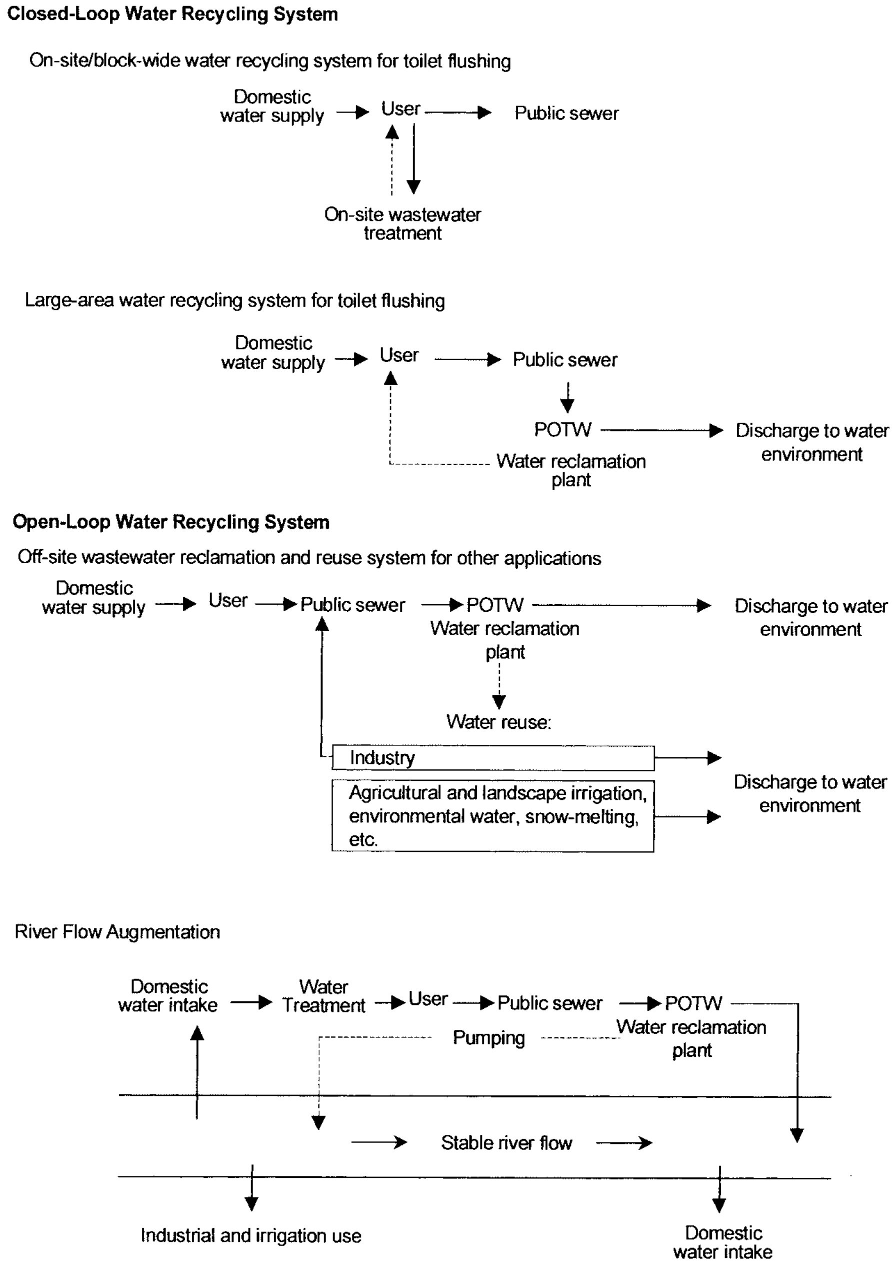

Figure 2 Water recycling system schemes used in Japan

and Osaki Station East District), and Fukuoka and Nagoya Cities. There are other large-scale water recycling systems constructed in the Makuhari New Town in Chiba Prefecture, Hamamatsu City, and Kobe City (the Rokko Island, and the Port Island Water Reuse Projects).

Open-loop water recycling systems

Off-site water recycling systems for other applications. The off-site water recycling system is an open loop system in which reclaimed water is supplied to off-site locations such as industries, agricultural lands, aesthetic and environmental uses, and snow-melting facilities. The used waters are not generally returned to POTW, and discharged to the environment. There are hundreds of such installations in Japan and major categories of water reuse were reported in Table 1.

Water reuse for in-stream flow augmentation. In this water reuse scheme, reclaimed water is pumped from POTW to the point of introduction to a stream or river to augment various in-stream flow needs. The reclaimed water is introduced to the point in the river where upstream water extractions reduced stream flow, substantially. The examples include the Ara River bordering the Metropolitan Tokyo and Saitama Prefecture, the Naka River and the Mikasa River in Fukuoka Prefecture, and the Ina River boarding Hyogo and Osaka Prefectures. These examples are mainly related to municipal wastewater reuse in urban areas. In addition, water recycling in industries is widely practiced in Japan and, in some industrial categories, in-house water recycling ratio approaches 90 percent. Wastewater reclamation and reuse in small agricultural and fishing villages have also been eligible for receiving government subsidies from other ministries, rather than the Ministry of Construction.

Reclaimed water quality criteria

As in other countries, the most critical issues concerning reclaimed water quality are protection of public health. Although there have been no uniformly enforceable national water quality standards for wastewater reclamation and reuse, various Japanese ministries have established applicable reclaimed water quality criteria. Table 2 summarizes such reclaimed water quality criteria for toilet flushing, landscape irrigation, and environmental water. The water quality criteria for toilet flushing were established jointly by the Ministries of Construction, Health and Welfare, and International Trade and Industry in 1981.

Water reuse case studies

In this section, examples of large-area water recycling systems that characterize the Japanese wastewater reclamation and reuse are presented. Table 3 shows three examples of the large-area urban water recycling systems for toilet flushing, irrigation of parks, and cleansing. The water quality data and reclaimed water price are also given. The treatment trains include tertiary treatment consisting of chemical coagulation, granular-medium filtration, ozonation, and chlorine disinfection.

Discussions

In Japan, most surface water rights have been historically allocated for irrigation of rice fields, and water transfers among different water right holders are inflexible and thus rarely

Table 2 Reclaimed water quality criteria for toilet flushing, landscape irrigation, and environmental water applied in Japan

	Parameters	Toilet flushing water	Landscape irrigation	Environmental water
Criteria	Total coliform bacteria (CFU/mL)	≤10*	Not detected	Not detected
	Residual chlorine (combined), mg/L	Trace amount	≥0.4	–
Guidelines	Appearance	Not unpleasant	Not unpleasant	Not unpleasant
	Turbidity, unit	–	–	≤10
	BOD, mg/L	–	–	≤10
	Odor	Not unpleasant	Not unpleasant	Not unpleasant
	pH, unit	5.8–8.6	5.8–8.6	5.8–8.6

*This is equivalent to 1,000 CFU/100 mL. Note that California's Wastewater Reclamation Criteria (Title 22) is 2.2/100 mL total coliforms occurred. In recent years, several options related to comprehensive water resources management have been investigated in the context of watershed management. Water use efficiency is relatively low because of seasonal heavy rainfalls in typhoon and monsoon seasons and the mountainous topographical limitations where rivers flow rapidly to the oceans.

In these physical and cultural circumstances, water reclamation and reuse are viewed in Japan as “new” water resource located right at the doorstep of the urban areas. Because of rapid urban sprawl in many cities and subsequent construction of sewers and flood control channels, many small urban streams have been in neglect and most aquatic environments degraded. Thus, in recent years, restoration of the water environment and “aquatic amenities” using reclaimed water have been promoted by the Ministry of Construction and several municipalities as positive results of the investments made in sewerage and wastewater treatment facilities.

Water reuse for environmental purposes can be characterized as follows: (1) reclaimed water is treated by tertiary treatment consisting of chemical coagulation, granular-medium filtration, and often ozonation to remove color and musty odor, (2) reclaimed water is normally transported a short distance from POTWs to a point of discharge, (3) unlike large-scale toilet flushing, no complex pipeline networks are employed, (4) maintenance work is normally conducted by POTW’s personnel; thus, keeping O&M costs low. Furthermore, aquatic parks or water gardens are often located near or within the POTW, so that the cost of water reuse can be much lower than using conventional potable water supply.

Table 3 Examples of large area water recycling systems

Location, Year of operation	Treatment trains	Reclaimed water quality, mg/L except coliforms, CFU/mL	Supply capacity, m^3/d, and pipelines length	Supply areas, km^2	Main water reuse application	Reclaimed water price*, $/$m^3$
Chiba Prefecture Makuhari New Center Water Recycling Project October 1989	Activated sludge process, chemical coagulation, filtration, ozonation, and chlorination	Coliforms ND**, Residual Cl_2 1.4 BOD 1, CODMn 4.8, SS 1, Color 5, Total-N 15, total-P 0.06	4,120 maximum, 2,372 average; ductile iron pipes 100–300 mm dia., and 2.76 km pipeline length	0.62, (1.10 planned)	Toilet flushing, cleansing, environmental water, convention center, commercial bldgs., hotel, parks	1.75 for commercial uses, and 0.88 for public facilities
Kobe City Rokko Island Water Recycling Project April 1986	activated sludge process, filtration, ozonation, and chlorination	Coliforms ND, residual Cl_2 0.04, BOD 5, COD 10.1, total-N 31.8, total-P 0.58	2,100 maximum, 995 daily max. and 415 daily average; vinyl-chloride and cast iron pipes 5–300 mm dia., and 6 km pipeline length	1.66	Toilet flushing, park irrigation, cleansing, commercial bldgs.,school, parks	1.67 for commercial uses, and 1.00 for individual homes and apartments
Fukuoka City Water Recycling Project June 1980	activated sludge process (AO process), filtration, ozonation, and chlorination	Coliforms ≤10, residual Cl_2 3.1, BOD 3, CODMn 7.1, SS ≤2, turbidity 1, color 4, Odor ND, PH 7.5, Total-N 20, total-P 0.97	4,500 maximum, 3,900 daily max.; mortar- or epoxy-resin coated ductile pipes 75–300 mm, and 48 km pipeline length	7.7, Reclaimed water use required if floor space ≥3,000 m^2 or water intake pipe diameter ≥50 mm	Toilet flushing, park irrigation, cleansing, Commercial bldg., parks	2.97 in 1997, and 2.99 in 1998

*Conversion rate of 120 yen/U.S.$1 was used. **ND = Not detected

Water reuse for toilet flushing in large commercial buildings and apartment complexes has been the hallmark of Japan's water recycling with high-tech wastewater treatment. As shown in Table 2, the water quality criteria used in Japan for this use are equal to or less than 1,000/100 mL fecal coliforms, compared to California's 2.2/100 mL for similar application. However, the Metropolitan Tokyo Government has been using more stringent reclaimed water criteria similar to California's Title 22 Criteria. As a matter of fact, reclaimed water quality of the selected cities, as reported in Table 3, is much higher than required in Table 2. There is an assumption that no cross-connection would occur; thus, no annual cross-connection inspections are required after the initial inspection when constructed. There is a discussion among government agencies that more comprehensive reclaimed water quality criteria be adopted in the near future to protect public health, and to enforce cross-connection inspection in commercial buildings where reclaimed water is used for toilet flushing and other in-building applications.

Water reuse in Japan is not cheap. Although the yardstick price for reclaimed water of about 80 percent of drinking water price is generally applicable, reported production cost for the reclaimed water in the Fukuoka City is \$2.01/m^3 compared to that of drinking water of \$1.88/m^3. The consumer price of reclaimed water averaged \$2.99/m^3 compared to the drinking water price of \$3.73/m^3. Even with a small margin for the reclaimed water, Fukuoka City has been able to produce a slight profit for its wastewater reclamation and reuse systems. Determined efforts by City officials were needed, however, to expand service areas and renovate commercial buildings in the downtown areas. Judging from Fukuoka City's experience of more than 20 years, water reuse for toilet flushing can be economically justified in many water-scarce urban areas. Furthermore, reclaimed water can be justified as new water for new applications such as newly created parks and playgrounds, golf courses, and "water amenities" in urban redevelopment. Another reason for expensive water recycling in Japan is the expenses associated with the installation of dual distribution systems in buildings as well as installing pipelines in built-up and congested areas. These reclaimed water prices reflect competition for new water resources and these expenses are the necessary cost for doing business in highly urbanized metropolitan areas.

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