Non-potable urban water reuse - a case of Japanese water recycling

● Serious efforts to reuse municipal wastewater in Japan began in 1964 in response to severe droughts that had occurred across much of the country. Here, **MASASHI OGOSHI, YUTAKA SUZUKI** and **TAKASHI ASANO** review the progress that has been made since and the different ways reuse is helping ease pressure on supplies.

Photo Credit: TMG

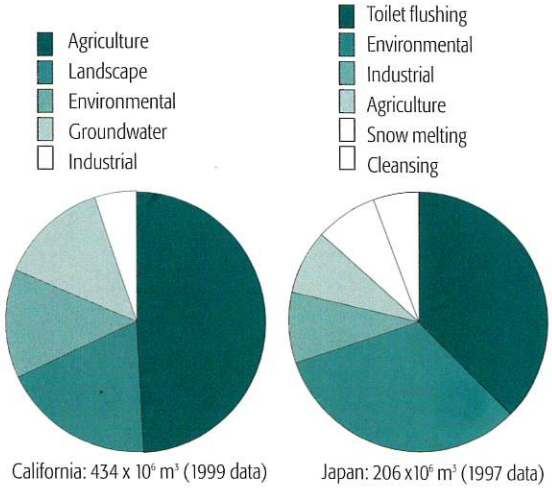
In contrast to wastewater reclamation and reuse practice in many other countries, where agricultural and landscape irrigation is the main application, water reuse in Japan is emphatically directed towards non-potable urban applications such as toilet flushing, environmental water, in-stream flow augmentation, and industrial reuse. Even though Japan has a mean annual precipitation of 1714mm and hundreds of dams and reservoirs, frequent and severe droughts have occurred over wide regions. Because of its rapid economic growth and the concentration of its population in urban areas, water demand in large cities has stretched the reliability of water supply systems and necessitated developing new water resources, with considerable economic and environmental costs. To alleviate these situations, water reuse has been championed and implemented in many cities in Japan.

Since the post-Second World War construction booms of the late 1950s, the government of Japan has invested heavily in building the nation's infrastructures, including flood control, drainage and sewerage systems, water and wastewater treatment facilities, environmental protection and the creation of water amenities in the urban environment. In particular, concentrated investment in the 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 was spent in the 1997 fiscal year on the planning and construction of 2585 sewerage systems and wastewater treatment facilities, amounting to about 0.7% of the Japanese gross national product (GNP).

The earliest planned wastewater reclamation and reuse started in 1951 as an experimental project to supply industrial water for a paper manufacturing mill in Tokyo from a nearby wastewater treatment plant. Serious wastewater reuse efforts, however, started in 1964, a year before the Tokyo summer Olympics, in response to the severe droughts that had occurred across much of Japan. Even though increasing numbers of dams and reservoirs had been constructed in the intervening years, water demand due to rapid economic growth and population concentrations in large cities had stressed the reliability of their supply systems. For example, in 1978, the prolonged drought 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.

By 1997, 163 publicly owned wastewater treatment plants (POTWs) in Japan provided water reclamation and reuse across 192 areas. In addition, 1475 on-site individual building and block-wide water reclamation and reuse systems provided toilet flushing water in commercial buildings and apartment complexes, and water for landscaping. As shown in Table 1, the annual volume of reclaimed water use was approximately 206 million cubic metres (Japan Sewage Works Association, 1998; National Land Agency, 1998). It must be noted that, unlike many other countries where agricultural irrigation is the dominant water reuse application, the water reuse practised in Japan has been for definitely non-potable urban water applications. Also, augmenting in-stream flows and providing environmental water to restore aquatic amenities in the urban environment is characteristic of recent

Figure 1 Comparison of water reuse in California and Japan.



RIGHT: Moat of the Osaka Castle filled with reclaimed water (Credit: M Ogoshi)

trends in large volume reclaimed water use under Ministry of Construction funding. Reclaimed water is considered as dependable new water in the urban environment, where water is needed most and priced highest. In addition, small agricultural and fishing villages are eligible to receive government subsidies for wastewater treatment and water reuse from other ministries, such as the Ministry of Agriculture and Fisheries.

Figure 1 shows a comparison of water reuse in California and in Japan. As noted earlier, water reuse in Japan is decisively oriented towards urban reuse applications. The majority of wastewater reuse in most other countries is for irrigation - for example, 68% of total water reuse in California (against approximately 16% in Japan) is for agricultural and landscape irrigation (Asano, 1998; State of California, 1999).

Water reuse schemes

In line with the water resources management policies of Japan, local governments have carried out most of the planned wastewater reclamation and reuse projects, which are often subsidised by Ministry of Construction funding. For example, in the periods of industrial expansion in 1960s, the Tokyo metropolitan government promoted industrial water supplies using reclaimed municipal wastewater to prevent over-abstraction of groundwater in the coastal areas of the Tokyo Bay. In other cities, wastewater reclamation was promoted as a positive image of environmental protection resulting from the construction of sewerage and wastewater treatment facilities (see Table 1). Reclaimed water has been promoted by those municipalities as a safe, dependable, and aesthetically pleasing new water resource for water 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 on a watershed scale.

Closed-loop water recycling systems

Individual building recycling systems

Individual wastewater reclamation and reuse is mainly for toilet flushing on individual sites, such as in large office buildings or apartment complexes with an on-site wastewater treatment plant. In some cities such as Tokyo and Fukuoka, dual distribution systems are mandated for newly constructed buildings of a certain floor area, generally greater than 3,000 - 5,000 m^2 and/or with an installed water supply pipe diameter greater than 50mm. The reason for this requirement is that local water supply facilities, trunk sewer mains, pumping and wastewater treatment facilities are limited and cannot accommodate increased water supply demands and wastewater flows and treatment in large cities.

Block-wide water recycling systems

In these systems, several buildings are connected 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, there were 1475 installations of individual and block-wide water recycling systems in total and the annual volume of reclaimed water used was approximately 71 million cubic metres (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 on a relatively small scale, such as in a single building or several buildings to form a block-wide water recycling system without the benefit of public sewerage systems.

Open-loop water recycling systems

Large area water recycling systems

Large area water recycling systems are generally aided by Ministry of Construction (MOC) subsidies of up

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 (x $10^6 m^3$)
Toilet flushing	Water conservation and wastewater flow reduction, providing capacity for expansion in build-up areas		
- from POTWs		36	3.0
- from on-site		1,475	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 Association, 1998; and the National Land Agency, 1998.

** On-site individual building and block-wide water recycling systems were not reported in 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, the total number of use areas is reported to be over 1,830.

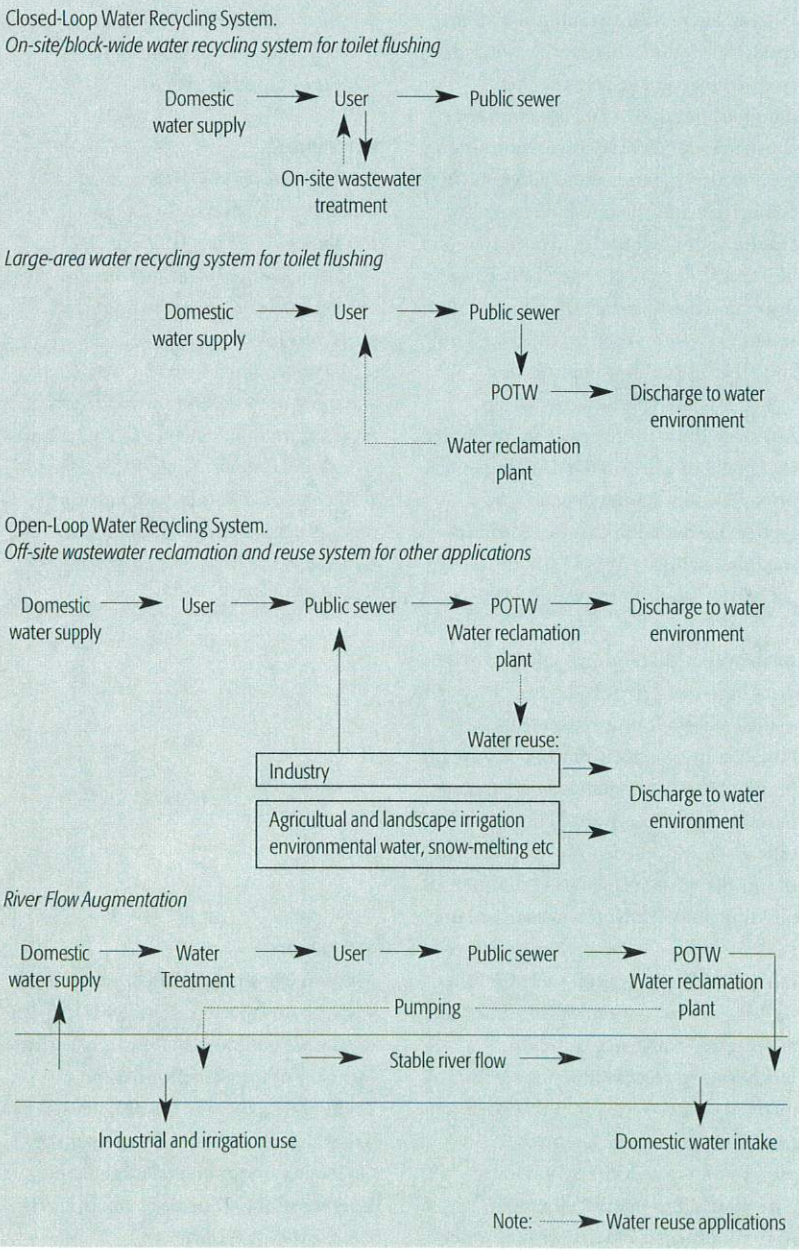
to 50% of the capital costs, and are implemented via the public sewerage system and POTWs. Tertiary or advanced wastewater treatment processes are normally used for further treatment prior to water reuse. The reclaimed water is distributed through a network of pipelines to large water reuse areas.

The main uses of reclaimed water for these systems are toilet flushing and environmental water, but other uses include irrigation and melting snow. Use of this type of large scale water reuse scheme has been increasing, with showcase installations such as the Tokyo metropolitan government (Shinjuku sub-center, Ariake district, Shinagawa station east side district, and Osaki station east district), and Fukuoka and Nagoya cities. There are other large-scale water recycling systems in the Makuhari new town in Chiba prefecture, Hamamatsu city, and Kobe city (the Rokko island, and the Port island water reuse projects).

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 for off-site locations such as industries, agricultural land, aesthetic and environmental uses, and snow melting facilities. The reused waters are not generally returned to the POTW apart from some industrial wastewater, and are discharged to the environment instead.

Figure 2 Water recycling system variations practised in Japan.



Shinjuku office buildings in Tokyo where reclaimed water is used for toilet flushing (Credit: Tokyo Metropolitan Government)

There are hundreds of such installations in Japan, and major categories of water reuse are shown in Table 1.

Water reuse for in-stream flow augmentation

In these water reuse schemes, reclaimed water is pumped from a POTW to the point where it is introduced into a stream or river to augment various flow needs. The reclaimed water is introduced at the point in the river where upstream water extractions substantially reduce stream flow. 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, bordering Hyogo and Osaka prefectures. These examples mainly relate to municipal wastewater reuse in urban areas. In addition, industrial water recycling is widely practised in Japan and, in some industrial categories, the in-house water recycling ratio approaches 90%. Wastewater reclamation and reuse systems in small agricultural and fishing villages have also been eligible to receive government subsidies from other ministries, rather than the Ministry of Construction.

Reclaimed water quality criteria

As in other countries, the most critical issue relating to reclaimed water quality is the 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 reclaimed water quality criteria. Table 2 summarises 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.

Characteristics of Japanese water reuse

In Japan, most surface water rights have been historically allocated for irrigating rice fields, and water transfers among different

water right holders are inflexible and therefore have occurred only rarely. In recent years, several options for comprehensive water resource management have been investigated in the context of watershed management. Water use efficiency is relatively low because of the heavy rainfalls in the typhoon and monsoon seasons, and the mountainous topography, which means rivers flow rapidly to the oceans.

In these physical and cultural circumstances, water reclamation and reuse are viewed in Japan as 'new' water resources located right on the doorstep of the urban areas. Because of the rapid increase in urban sprawl in many cities and the subsequent construction of sewers and flood control channels, many of the small urban streams have been neglected and most aquatic environments degraded. Therefore, in recent years, the restoration of the water environment and aquatic amenities using reclaimed water have been promoted by the Ministry of Construction and a number of municipalities as positive investments in sewers and wastewater treatment facilities.

Water reuse for environmental purposes can be characterised as follows:

- reclaimed water is treated by tertiary treatment consisting of chemical coagulation, granular-medium filtration, and often ozonation to remove color and the musty smell
- reclaimed water is normally transported a short distance from POTWs to a point of discharge
- unlike large-scale toilet flushing reclaimed water distribution systems, no complex pipeline networks are employed
- maintenance work is normally conducted by POTW personnel, keeping operational and maintenance costs low.

Furthermore, an aquatic park 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.

Water reuse, with high tech wastewater treatment, for toilet flushing in large commercial buildings and apartment complexes has been the hallmark of Japan's water recycling initiatives. As shown in Table 2, the water quality criteria for this use are to have equal to or less than 1000 /100ml faecal coliforms, compared to California's 2.2/100ml for similar applications. However, the metropolitan Tokyo government has been using more stringent wastewater reclamation and reuse criteria, similar to the California's Title 22 criteria. There is an assumption that no cross-connection will occur, so no annual cross-connection inspections are required after the initial inspection after construction. There is a discussion among government agencies about adopting more comprehensive reclaimed water quality criteria 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.

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/100 ml)	≤1000	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
	Odour	Not unpleasant	Not unpleasant	Not unpleasant
	pH, unit	5.8-8.6	5.8-8.6	5.8-8.6

Water reuse in Japan is not cheap. Although the yardstick price for reclaimed water of about 80% of the drinking water price generally applies in Japan, the reported production cost for reclaimed water in Fukuoka city is \$2.01/m^3 compared to a drinking water cost 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 make a slight profit on its wastewater reclamation and reuse systems. Determined efforts by city officials were needed, however, to expand the service areas and renovate commercial buildings in the downtown areas. Judging from Fukuoka city's experience during 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 the expense of water recycling in Japan is the cost associated with the installation of dual distribution systems in buildings and for the installation of pipelines in built-up and congested areas. These reclaimed water prices reflect competition for new water resources, and these expenses are the necessary cost of doing business in highly urbanised metropolitan areas. ●

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