Evolution of Tertiary Treatment Requirements in California

Takashi Asano, David Richard, Ronald W. Crites, George Tchobanoglous

The worst drought in North America in 50 years was quite evident in California in 1991. The 5 consecutive years of drought and the resulting emergency water conservation measures have cut agricultural water supplies as much as 75% and severely reduced many urban and industrial water supplies. As the demand for water increases, so does the importance of wastewater reclamation and reuse in water resources planning; by allowing a water agency to supplement water needs with reclaimed water, the water supply becomes more reliable.

Reclaimed water is right on the doorstep of the urban environment and can, even in drought years, replace potable water for nonpotable and subpotable water uses (see Box *Wastewater Reclamation and Reuse Defined*).

The desirability and benefit of water reuse have been well established in the public policy arena. For example, in the California State Water Code it is noted that "the State undertake all possible steps to encourage development of water reclamation facilities so that reclaimed water may be made available to help meet the growing water requirements of the State." It is further noted in the code that using potable water for landscape irrigation is a "waste and unreasonable use" of water when reclaimed water is available and can be used safely.

The rationale for existing and proposed wastewater reclamation and reuse regulations in California is clear-cut and wastewater reclamation technologies make compliance possible.

Wastewater Reclamation and Reuse Defined

Wastewater reclamation is the treatment or processing of wastewater to make it reusable, and water reuse is the use of treated wastewater for a beneficial use such as agricultural irrigation. In addition, direct wastewater reuse requires pipes or other conveyance facilities for delivering reclaimed water. Indirect reuse, through discharge of an effluent to a receiving water for assimilation and withdrawals downstream, is recognized to be important but does not constitute planned water reuse. In contrast to direct water reuse, water recycling normally involves only one use or user and the effluent from the user is captured and redirected back into that use scheme. In this context, water recycling is predominantly practiced in industry, such as the pulp and paper industry.

RECLAMATION AND REUSE

As the demand for water has increased, the number of wastewater reclamation and reuse facilities has increased. A 1987 survey conducted by the California State Water Resources Control Board identified more than 200 wastewater reclamation plants and 854 water reuse areas that processed and used approximately 330×10^6 m^3/yr (267,000 ac-ft/yr or 238 mgd) of reclaimed water. The State Water Conservation Coalition and a special task force have projected that 1×10^9 m^3/yr (827,000 ac-ft/yr or 738 mgd) of reclaimed water will be used by the year 2000 to augment the state's water supply.

There are seven municipal wastewater reuse categories (Table 1); however, most reclaimed water is being used in four categories: agricultural irrigation, landscape irrigation, groundwater recharge, and industrial reuse. Among these, landscape irrigation and groundwater recharge have been the most rapidly growing categories of reclaimed water use.

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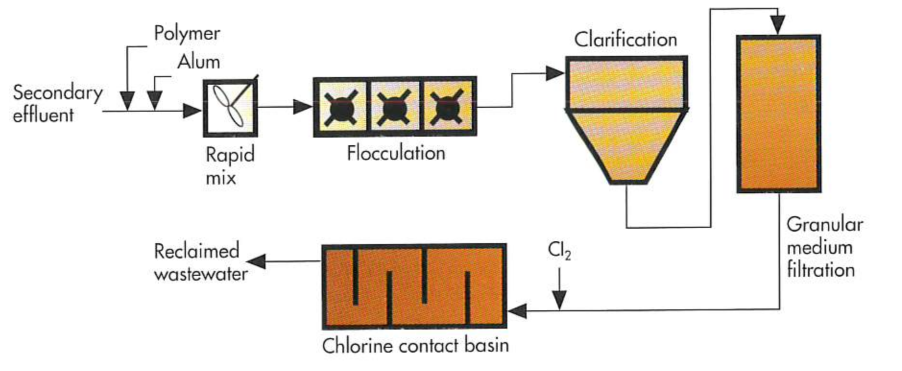
Reclaimed water may soon replace potable water for nonpotable and subpotable water uses.

Figure 1—Full Treatment



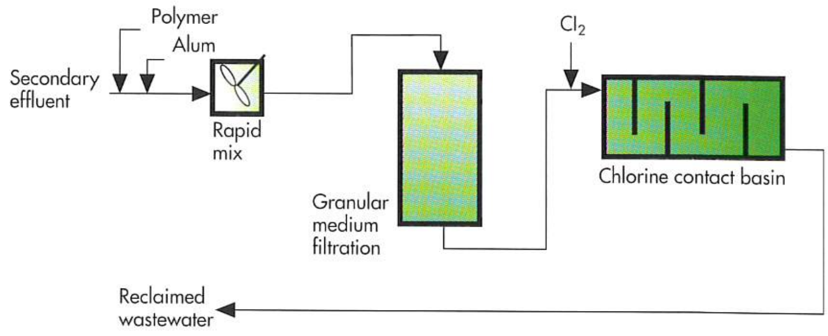
WASTEWATER RECLAMATION CRITERIA

The Wastewater Reclamation Criteria are California regulations designed to protect public health and ensure safety in wastewater reclamation and reuse practices. These criteria were established by California's Department of Health Services (DHS) and are often referred to as Title 22 regulations.

Nine regional water-quality control boards in the state are responsible for enforcing the criteria by issuing permits for wastewater discharges and wastewater reclamation. Wastewater treatment levels, operational reliability, and water-quality monitoring and compliance are specified in the criteria, and the water reuse requirements may be incorporated as parts of the wastewater discharge or reclamation permits. The current criteria, which were last revised in 1978, contain water reuse applications for irrigation of food crops and fodder, fiber, and seed crops; recreational impoundments; and groundwater recharge. The existing criteria do not address new uses such as toilet flushing in office buildings and are not developed fully for some existing water reuse applications such as groundwater recharge.

The effects of physical and chemical factors on nonpotable applications such as crop irrigation have been studied and, for the most part, appropriate water-quality criteria have been established (see Box *Early Wastewater Reuse Regulations*). Conversely, health-related microbiological limits are more difficult to quantify, as evidenced by widely varying regulations and criteria adopted in different states and countries. For example, the World Health Organization's report, *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture*, was issued in 1989 as the mini-

Figure 2—Contact Filtration

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mum guide mainly for developing countries where financial resources are limited and appropriate technologies include wastewater lagoons. California's Wastewater Reclamation Criteria are much more stringent, requiring extensive wastewater treatment, frequent water-quality monitoring, and strict use-area controls.

Enteric virus concern in water reuse. Of the known waterborne pathogens, enteric viruses have been considered most critical in wastewater reuse in California because of the possibility of infection in low doses and the difficulty of routinely examining reclaimed wastewater for their presence. Thus, essentially virus-free effluent using the full treatment process is deemed necessary by DHS for reclaimed wastewater applications with higher potential exposures such as food crops eaten raw, school yards, and recreational impoundments with unrestricted uses.

TERTIARY TREATMENT FOR WATER REUSE

Tertiary filtration has been used as a polishing step in wastewater treatment. This process effectively removes wastewater particles, thus increasing disinfection efficiency, and aesthetically enhances the water. Currently, there are more than 40 tertiary treatment facilities operating in California to help meet the most stringent water-quality requirement of producing an essentially virus-free effluent.

Full-treatment process. The most stringent treatment process specified in the criteria is the full treatment process (Figure 1). Although this process is often economically feasible, it is costly because of the expenses associated with coagulant chemicals—typically 50 to 125 mg/L alum and 0.2 mg/L anionic polymer—sludge handling, and tertiary sedimentation tanks. Thus, efforts have been directed toward developing less costly tertiary treatment alternatives that produce effluent quality comparable to that of the full treatment process.

Alternative tertiary treatment process. An alternative treatment process was studied at the Sanitation Districts of Los Angeles County's Pomona Research Facility during 1976-77. The study compared the virus removal capabilities of an alternative tertiary process—contact filtration (Figure 2)—to the specified full-treatment process.

When high chlorine residuals of approximately 10 mg/L were used, there was no difference in the overall removal or inactivation of the seeded poliovirus between the full treatment process and the contact filtration process. When low chlorine residuals of approximately 5 mg/L were applied, a slight difference in removal was observed—5.2 log removal versus 4.7 log removal. (The log removal refers to the fraction of poliodifferent wastewater treatment, recharge methods, and retention times. With the proposed regulations, virus removal or inactivation on the order of 20 logs is expected with some combination of wastewater treatment, passage through the unsaturated zone, and underground storage. Under these circumstances, the risk of infection as a result of the groundwater recharge operations with reclaimed municipal wastewater is considered negligible.

The proposed groundwater recharge regulations are intended to control the concentration of organics in domestic water supply wells. Unregulated organic chemicals, those with no established maximum contaminant level (MCL), and unidentified organic chemicals are of special concern. A total organic carbon (TOC) of 1 mg/L was chosen as a treatment performance standard to represent the maximum allowable concentration of unregulated organics in extracted well water. In the proposed regulations, the removal of organic substances beyond that provided by secondary treatment may be required when the extracted water contains a significant proportion of reclaimed wastewater, as shown in Table 2. Organics removal may be accomplished using activated carbon and membrane separation processes such as reverse osmosis or any demonstrated alternative.

Table 2—Proposed Maximum Allowable Organics Concentration

Percent reclaimed wastewater in groundwater	Maximum organic carbon in wastewater, mg/L	
	Surface spreading	Direct injection
0 to 20	20	5
21 to 25	16	4
26 to 30	12	3
31 to 35	10	3
36 to 45	8	2
46 to 50	6	2

COST OF WASTEWATER RECLAMATION AND REUSE

Reported total annualized wastewater reclamation costs range from \$0.16/m^3 (\$200/ac-ft) to almost \$1.05/m^3 (\$1300/ac-ft). Therefore, it is important when comparing costs that assumptions and factors associated with wastewater reclamation and reuse costs be understood correctly.

A 1991 cost study indicated that the incremental life cycle cost for a 18×10^3-m^3/d (5-mgd) tertiary filtration plant to produce reclaimed water ranged from \$0.2/m^3 (\$244/ac-ft) for the full-treatment process to \$0.07 to \$0.08/m^3 (\$88 to \$101/ac-ft) for the alternative filtration processes. The ratio of full-treatment cost to direct or contact filtration cost ranged from 2.0 to 2.4 for capital cost, 3.9 to 5.6 for operations and maintenance (O & M) cost, and 2.4 to 2.9 for total life cycle cost for the treatment capacities ranging from 3.8×10^3 to 38×10^3 m^3/d (1 to 10 mgd). Economies of scale are not present for facilities less than 3.8×10^3 m^3/d (1 mgd). One factor that significantly affects cost is the degree to which available capacity in the treatment plant is used. Irrigation, the primary reclaimed water use, drops off significantly during the winter. Maximum use can be achieved by seasonal effluent storage, obtaining a mix of reclaimed water uses to reduce seasonal peaking factors, or using alternative water supplies for supplementing peak water demands.

The distribution system for reclaimed water is the principal cost of most reuse projects. Recent experience in California indicates that approximately \$3 million in capital cost are required for new distribution systems including pumping stations for each 1.2×10^6 m^3/yr (1000 ac-ft/yr) of reclaimed water. Assuming a facility life of 20 years and a 9% interest rate, the amortized cost of the distribution systems for reclaimed water is around \$0.24/m^3 (\$300/ac-ft), excluding O & M costs.

FUTURE DIRECTIONS

California has a long history of wastewater reclamation and reuse and more than 200 wastewater reclamation plants have been operating successfully, reclaiming more than 400×10^6 m^3/yr (325,000 ac-ft/yr) of municipal wastewater. Wastewater reclamation and reuse criteria are being reviewed by committees organized by DHS, and expanded water reuse regulations are being formulated. The existing and proposed wastewater reclamation criteria are the culmination of sound public health practices, engineering experience, economics, and public acceptance based on the long and successful water reuse practices in California. ■

Takashi Asano and George Tchobanoglous are with the Department of Civil Engineering, University of California at Davis. David Richard and Ronald W. Crites are with Nolte and Associates in Sacramento, Calif.

Early Wastewater Reuse Regulations

In many ways, since turn of the century, California has been the vanguard of wastewater reclamation and reuse. The first wastewater reuse regulations were promulgated in 1918 pertaining to irrigating crops with sewage effluents. These regulations prohibited the use of raw sewage, septic or Imhoff tank effluents, or water polluted by "such sewage for the irrigation of tomatoes, celery, lettuce, berries, and other garden truck crops eaten raw by human beings." In 1949, the state legislature enacted legislation assigning to the Department of Water Resources responsibility for conducting surveys and investigations relating to water reclamation for beneficial purposes. California wastewater reuse regulations have been developed progressively during the past 50 years.

In the mid-1970s, increased concern about the presence of pathogens in treated effluents prompted the adoption of tertiary wastewater treatment consisting of coagulation, flocculation, sedimentation, filtration, and disinfection for wastewater reclamation and reuse in the urban environment. Several less-stringent and less-costly wastewater treatment processes are permitted in the criteria for the uses involving limited human contact, such as irrigation of fodder, fiber, and seed crops.

REFERENCES

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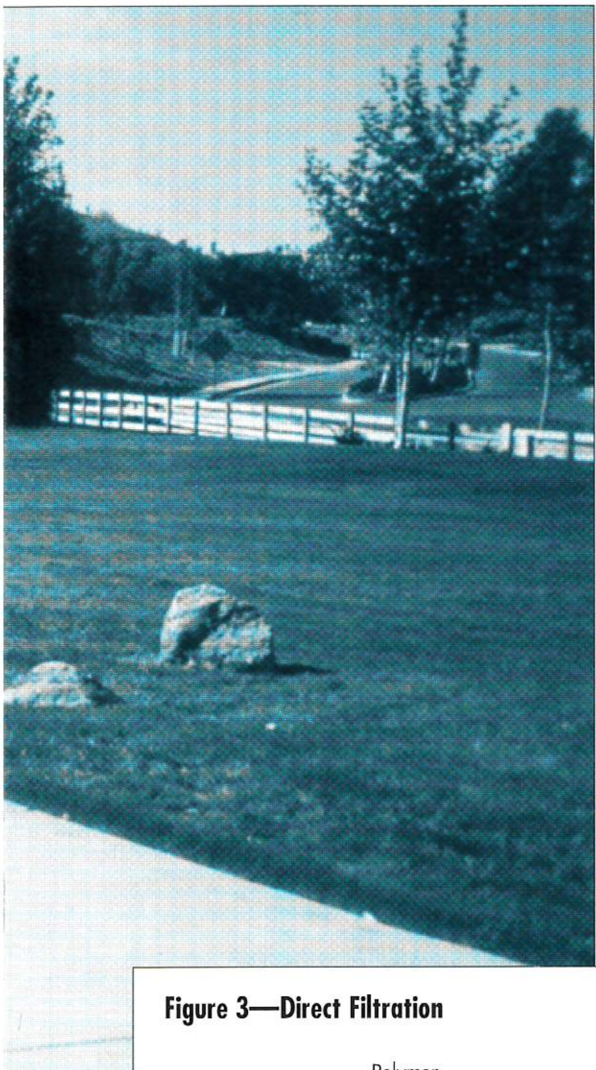
virus remaining after treatment; thus, one log removal is equivalent to 90% removal and five log removal is 99.999%.) The public health significance of this slight difference is not known.

Comparative treatment studies. The Monterey, Calif., Wastewater Reclamation Study for Agriculture (MWRSA) was a 6-year (1980-86), $7.2 million field-scale project designed to evaluate the safety and feasibility of irrigating food crops—many for eating raw—with reclaimed municipal wastewater. Removing enteric viruses by direct filtration (Figure 3) and contact filtration was studied. These filtration processes are typically operated with a small quantity of alum addition in the range of 2 to 5 mg/L and chlorine disinfection with 5 to 10 mg/L chlorine dose and 1.5-hour contact time.

Enteric viruses were monitored for the presence of naturally occurring animal viruses in influents to and effluents from the full treatment process and the two alternative filtration processes. During the study period, no enteric viruses were detected in the chlorinated effluent of either the full treatment or alternative filtration processes. Totals of 186 m^3 (49,213 gal) and 160 m^3 (42,170 gal) were sampled from the full-treatment process and alternative filtration processes, respectively. The unchlorinated secondary effluent contained measurable enteric viruses 80% of the times sampled; these amounts averaged 2200 viral units (vu)/100 L with a range of 100 to 73,400 vu/100 L.

As a result of the studies, DHS adopted direct or contact filtration as an acceptable alternative, providing certain design criteria are met and, consequently, almost all tertiary treatment plants designed recently use these alternative filtration processes.

Irrigation of a park with reclaimed water in Mission Viejo, Calif.



VIRUS RISK ASSESSMENT IN WASTEWATER REUSE

Despite wide acceptance of filtration as a tertiary treatment to satisfy public health concerns for many water reuse applications, comprehensive monitoring data on treatment process reliability and enteric virus removal capabilities in wastewater treatment processes were not available when the criteria were last revised in 1978. To provide a scientific basis on which to evaluate the existing and proposed criteria, a virus risk analysis was conducted. Based on the enteric virus monitoring data from 424 secondary effluent samples and 814 tertiary effluent samples in California, risks associated with using reclaimed municipal wastewater were analyzed for golf courses, food crops, recreational impoundments, and groundwater recharge. All tertiary treatment facilities consisted of either full-treatment or alternative filtration processes.

Significant differences in terms of virus removal capabilities were not observed among the treatment processes. Virus concentrations in reclaimed water after tertiary filtration and chlorination were less than 111 vu/100 L and 99% of the time were less than the limit of detection of 1 vu/100 L. The treatment processes used were designed to meet a reclaimed water turbidity of 2 nephelometric turbidity units (NTU) and total coliform concentration of 2.2/100 mL or less, as specified in California's Wastewater Reclamation Criteria. Both processes are equally effective in virus removal and are equivalent when they are operated properly.

At an enteric virus concentration of 1 vu/100 L, annual risk of polio- and echo-virus infection from exposure to chlorinated tertiary effluent is estimated to be in the range of 10^{-2} to 10^{-4} for un-

Figure 3—Direct Filtration

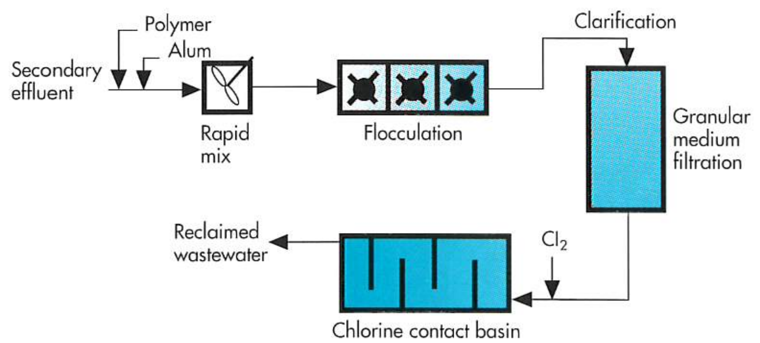


Table 1—Categories of Municipal Wastewater Reuse and Potential Constraints[a]

Wastewater reuse category	Potential constraints
Agricultural and landscape irrigation	
crop irrigation commercial nurseries parks school yards freeway medians golf courses cemeteries greenbelts residential areas	Effects of salts on soils and crops. Public health concerns, surface and groundwater pollution, marketability of crops, and public acceptance.
Industrial reuse	
cooling boiler feed process water heavy construction	Scaling, corrosion, biological growth, and fouling; public health concerns.
Groundwater recharge	
groundwater replenishment salt water intrusion subsidence control	Potential toxicity of chemicals and pathogens.
Recreational and environmental	
lakes and ponds marsh enhancement streamflow augmentation fisheries snowmaking	Health concerns and eutrophication.
Nonpotable urban uses	
fire protection air conditioning toilet flushing	Public health, fouling, scaling, corrosion, and biological growth.
Potable reuse	
blending in water supply pipe-to-pipe water supply	Potentially toxic chemicals, public health, and public acceptance.

[a]Arranged in descending order of anticipated volume of use.

restricted recreational impoundments where swimming may take place. The probability of infection per year for a golfer who plays on the golf course irrigated with this reclaimed water is estimated to be in the range of 10^{-4} to 10^{-6}. The latter risk level is less than the limit recommended for many potable water supplies of 1 infection per 10,000 consumers per year.

In addition, the risk of infection is reduced by natural die-off of pathogens and exercising proper use-area controls, such as irrigating golf courses at night when public exposure is minimum.

PROCESS OPERATING CHARACTERISTICS

Although the effluent qualities from the treatment processes are comparable, their operating characteristics are quite different. The full-treatment process is typically operated with a 50- to125-mg/L alum dose, which produces flocs in the sweep-coagulation region, while filtration using alum doses between 5 and 10 mg/L produce flocs in the sweep and adsorption region.

The stability of low-dose alum coagulation is affected by slight changes in wastewater pH, typically pH 7 to 7.5. When using filtration with such low alum doses, pH control is essential.

To produce an essentially virus-free effluent using direct or contact filtration, the secondary effluent quality must be high. For example, to meet the stringent turbidity requirement of less than 2 NTU, the secondary effluent turbidity must be between 7 and 9 NTU, suspended solids between 14 and 22 mg/L, and chemical oxygen demand between 40 and 80 mg/L (Metcalf & Eddy, 1991). A secondary effluent turbidity value of 10 NTU is often the economic dividing line for using full treatment instead of direct or contact filtration. When secondary effluent turbidity levels are consistently above 10 NTU, secondary treatment system improvements are often considered more cost-effective than increasing chemical doses. Otherwise, the more costly full treatment process must be used, in which case wastewater reuse may be ruled out because of its cost.

When turbidity and disinfection levels are used as the indices of treatment effectiveness, effluents from well-operated activated sludge processes are superior to those from trickling filters because of the size and distribution of colloidal particles in the effluents. The average effluent turbidity of 2 NTU will be met regardless of filter types if the secondary effluent turbidity is 6 NTU or less, which is characteristic of well-operated biological secondary treatment.

PROPOSED REGULATIONS FOR GROUNDWATER RECHARGE

A large opportunity exists for groundwater recharge in California because of the need to develop additional groundwater supplies and to prevent seawater intrusion in coastal aquifers. Regulations are being developed by a committee organized by DHS to provide uniform statewide criteria on which to regulate and design groundwater recharge projects.

The overall virus removal in various groundwater recharge operations is designed to be essentially identical with

Courtesy of Nolte and Associates

Irrigation of a schoolyard with reclaimed water in Mission Viejo, Calif.