Wastewater reclamation and reuse

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Pockets of inadequate water supply represent a serious contemporary concern for the water industry. Several factors have contributed to the problem. Contamination has forced the closure of many well fields across the country, straining the water supply from alternative sources. Droughts, such as the ones in the Western States in 1976–77, the New York City metropolitan area in 1985, and in the Southeast in 1986, have exacerbated water problems in areas where water supply has been especially sensitive to local variations in precipitation. Probably the number one cause of inadequate water supply, though, has been uneven distribution of population. Continued population growth in semi-arid and arid regions of this country has forced water suppliers into more difficult water development.[1] To meet the demands placed on them by contamination, periodic droughts, and continued growth, water suppliers are faced with three major tasks: developing new water sources, protecting current sources, and implementing water conservation measures such as wastewater reclamation and reuse.

This review continues the Literature Review reorganization instituted in 1984. The intention is to devote this section to the unique aspects of wastewater reclamation and reuse concentrating on the "big picture" developments and technologies that contributed more to water supply benefits than pollution control purposes. Thus, several topics that may be considered as wastewater reclamation and reuse will appear in other review sections in this issue. Specifically, references on agricultural and landscape irrigation are covered in detail in the review on "Land Application of Wastewater." Wastewater treatment techniques commonly used in wastewater reclamation and reuse can be found in the various treatment sections in this issue. All industrial water recycling and reuse references have been covered in the appropriate industrial waste review. Exceptions are reuse applications for multiple industries or for miscellaneous industries not explicitly covered in the industrial waste reviews. Also included in this review is the topic of water reuse for groundwater recharge. Finally, references relating to health effects appear in the review under "Health Effects Associated with Wastewater Treatment, Disposal, and Reuse."

GENERAL

The major event in wastewater reclamation and reuse activities was the Water Reuse Symposium IV held in Denver, Colo., August 2–7, 1987. The proceedings will be published in 1988 and, therefore, reviewed in the next Literature Review issue.[2] The Water Reuse Committee of the American Water Works Association issued a white paper on the national research needs for water reuse.[3] Both potable and non-potable reuse needs were discussed.

The International Association on Water Pollution Research and Control (IAWPRC) headquartered in London, England, instituted a Specialist Group on Wastewater Reclamation and Reuse to promote international research and technology transfer on the subject.[4] *GeoJournal*[5] published a special issue on water and agriculture in which irrigation with saline water and reclaimed municipal wastewater were discussed. Crook and Okun[6] advocated water reclamation for non-potable reuse in municipalities. A variety of wastewater reuse techniques in arid regions of developing countries were investigated emphasizing unsophisticated treatment methods.[7] The importance of sewage effluent as a water resource was discussed and factors affecting its use were outlined with examples of successful reuse projects.[8] A technique was developed in South Africa[9] to depict the extent, relative severity, and location of the areas most affected by the drought of the early 1980s that had a significant bearing on water resources planning in that country.

The Water Re-Use Promotion Center of Japan issued an annual report with profiles and technical information on Japanese research and manufacturing companies.[10] "Developing World Water"[11] covered a number of water related topics including wastewater reclamation and reuse for developing countries. American Water Works Association Research Foundation published three issues of "Water Reuse Newsletter,"[12] reporting on the subject from various information sources.

WATER REUSE PLANNING

Wasterhoff and Berkum[13] discussed future water needs based on population and land use projections as well as evaluations of existing surface or groundwater systems, which included water conservation and wastewater reuse in augmenting available supplies. A water resources audit was presented to help small and intermediate-sized municipalities identify available water resources, isolate problem areas, set goals, and develop management strategies stressing water conservation and reuse.[14]

A historical review of wastewater treatment and disposal practice in New Zealand was presented which covered a wide range of topics, including financial investment in treatment, legislative changes, public perception, and innovative advances in treatment.[15] In South Africa, as the availability of water became an increasingly critical factor, it was important to safeguard its valuable resources to improve treatment and disposal facilities, minimize the pollution threat, and maximize water reclamation and reuse.[16] Rebhun *et al.*[17] reported that any regional or interregional reclamation scheme in semi-arid areas must include, in addition to conventional wastewater treatment facilities, conveyance pipelines and seasonal storage.

MUNICIPAL WASTEWATER REUSE

Asano and Pettygrove[18] reviewed water quality aspects of irrigation with reclaimed municipal wastewater in which different waters were compared for suitability for irrigation. The 5-year field results of the Monterey Wastewater Reclamation Study for Agriculture (MWRSA)[19,20] in California were published with special reference to the irrigation of vegetable crops eaten raw. No adverse health and/or agronomical effects were found in the MWRSA with the tertiary treated effluents from Castroville, Calif. In Berlin-Ruleben, Fed. Rep. of Germany, the elimination of human viruses was studied in an advanced wastewater treatment plant. Polio virus and Rotavirus suspensions were seeded and the results showed 90 to 95% removal without ozonation and 99.9% removal with ozonation.[21] Ellis[22] investigated the viability of slow sand filtration and obtained the results indicating the removal of at least 90% of SS, more than 65% of the remaining BOD, and over 95% of the coliform organisms. Possible guidelines for establishing water quality criteria for wastewater reuse for irrigation in the Kingdom of Saudi Arabia were discussed in light of the experiments conducted at a farm at the University of Petroleum and Minerals.[23]

Denver's potable water reuse demonstration plant was designed to convert secondary municipal wastewater effluent into potable water through highly sophisticated advanced wastewater treatment systems. The technical issues addressed included product quality and consumer safety, treatment cost evaluations, and regulatory agency endorsement; non-technical issues involved public education and acceptance.[24] In Israel, agricultural irrigation was considered the most economical way to dispose of municipal wastewater. However, because of the location of the irrigated areas, energy expenses for effluent transport were the important consideration.[25] The domestic sewage of the city of Beer-Sheva, Israel, was treated in a series of facultative ponds and applied via sprinkler and trickle irrigation systems to cotton, wheat, alfalfa, and corn with excellent results.[26]

GROUNDWATER RECHARGE

General discussions on conjunctive use and artificial recharge of groundwater were presented.[27] The physical and chemical processes during percolation of treated wastewater were studied in the vicinity of Johannesburg, South Africa.[28]

The use of advanced wastewater treatment for the purpose of groundwater recharge was investigated at the Berlin Water Works in the Fed. Rep. of Germany.[29] By using both instrumental and sensory detection methods, it was shown that alum coagulation/sand filtration had no significant effect on the off-flavor compounds in the raw water samples. However, all related compounds were substantially reduced during artificial groundwater recharge.[30]

The potential for artificial groundwater recharge by continuous flooding of dormant grapevines was evaluated in the San Joaquin Valley, Calif., using the cultivar Thompson Seedless.[31] Hamlin[32] found groundwater recharge by injection of reclaimed water was a feasible method of improving groundwater quality in the shallow aquifer system in the Palo Alto Baylands along the San Francisco Bay. In Kissimmee, Fla.,[33] a force main will transport treated effluent to a rapid infiltration site 22.4 Km from the town for disposal and some reuse at a golf course.

Physical and biological clogging during artificial recharge was studied with an experimental model.[34] Fairchild[35] covered a wide range of topics including groundwater usage, agricultural chemicals, other pollution sources, and protection and management. American Society of Civil engineers published the third edition of "Ground Water Management"[36] in which planning and implementation of groundwater management plans were discussed.

INDUSTRIAL WATER RECYCLING AND REUSE

In a fertilizer company in Gujarat, India, water conservation, recycling, and reuse were implemented because of water shortage.[37] To detect and maintain control over contaminants in recycled white water, an instrument-based retention control strategy was developed for a modern paper machine.[38] The 320-MW coal-fired Holcomb Station of the Sunflower Electric Cooperative in Kansas maintained a zero-discharge water balance since 1983. Cooling tower blowdown was reduced to the minimum through high cycles of concentration and recycled water was used in flue gas desulfurization and bottom ash and coal-handling requirements.[39]

Laboratory studies were conducted to determine the effectiveness of waste pickle liquor in removal of phosphorus from municipal wastewater and to ascertain which process variables had an effect on phosphorus removal.[40] Biological decomposition of trace organic compounds was investigated to apply to the reclamation system of the rinse water recovered from the semiconductor manufacturing process.[41]

TECHNOLOGY DEVELOPMENT

An instruction was issued for a system designed to recycle water used in military field showers located in water-short areas of the world. It also identified water quality test requirements and procedures to be used when recycling shower wastewater and examined the health implications associated with recycled water.[42] Water used during current and previous space missions has been either carried or made aloft. Future human space endeavors will require some form of water reclamation and recycling, but there is little experience in the U. S. space program.[43]

The performance of *Lemna gibba,* a duckweed species, as a domestic wastewater stripper was evaluated.[44] The effluent met irrigation criteria; protein yield of the duckweed reached 12 ton/ha per year. The nutrient film technique, gravel bed hydroponics, and root zone biotechnology have been promoted as appropriate for wastewater renovation. However, outdoor study in a semitropical setting, using a proven wastewater renovation crop species, *Brachiaria mutica,* demonstrated that it was not possible to maintain continuous horizontal flow regime and wastewater

renovation was no better than existing technologies, such as effluent irrigation.[45] An investigation of the feasibility of using reclaimed wastewater in concrete mixes revealed a 15% increase in 28-day strength compared to those cured in potable water.[46]

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