One aspect of beet armyworm behavior that can be exploited to curb infestations is adult flight activity. Pheromone traps, an effective way to monitor beet armyworm populations, have shown that population density fluctuates with seasonal temperature patterns; infestations are more prevalent during the summer, when temperatures are high. Pheromone traps may also provide early warning of an infestation, preventing an outbreak if control is successful.

Laboratory assays indicated that the beet armyworm can develop resistance to Lannate. A Florida (FL) strain was shown to be moderately resistant to Lannate, and evidence indicates that resistance may still be increasing. Resistance to Lannate in the California strain (GR), however, could not be detected. Several steps can be taken to suppress the development of resistance: (1) insecticide rotation, (2) localized treatment of infestations, and (3) use of microbial agents.

There are presently several insecticides registered for use against the beet armyworm on ornamentals in California, including Dursban, Lannate, and Pounce. Each may be incorporated into the present chemical control program and used on a rotational basis. A rotation scheme of this nature will prevent the beet armyworm from being repeatedly exposed to a single insecticide, a situation conducive to the rapid development of insecticide resistance.

Another measure that may deter development of resistance is localized treatment of infestations. Beet armyworm infestations are often clumped or aggregated, apparently because of the egg-laying patterns of the adult female. Treatments confined to these areas reduce the amount of insecticide needed and preserve natural enemies, as well as reducing resistance development.

Bacillus thuringiensis compounds hold great potential for control of lepidopterous pests. In addition to the conventional broad-spectrum insecticides used against the beet armyworm, the inclusion of BT compounds in a control program may delay the occurrence of resistance. BT has a different mode of action, which may help to decrease the probability of resistance development. Furthermore, BT is virtually nontoxic to mammals, very compatible with most natural enemies, and relatively harmless to plants. BT is registered for this use on ornamentals. Thuringiensin, however, is not currently registered.

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Activated sludge, secondary treatment of municipal wastewater.

Using reclaimed municipal wastewater for irrigation

Takashi Asano □ G. Stuart Pettygrove

The risks are proportional to the degree of human contact and the adequacy and reliability of treatment.

Land application of municipal wastewater is a well-established practice in many arid and semiarid regions of the world. In some regions, 70 to 85 percent of such water is used for agricultural and landscape irrigation. As demand for water increases in this country, irrigation with reclaimed municipal wastewater has become a logical and important component of total water resource planning and development.

In California, about 220,000 acre-feet of municipal wastewater from 240 cities and towns are used each year, principally for agricultural and landscape irrigation. In addition, about 610,000 acre-feet per year of treated wastewater is incidentally reused after it is discharged and enters surface or ground waters. Over half of the intentionally reclaimed municipal wastewater (57 percent) is used to irrigate fodder, fiber, and seed crops, a use not requiring a high degree of treatment. About 7 percent is used to irrigate orchard, vine, and other food crops. Irrigation of golf courses and landscape areas makes use of about 14 percent of reclaimed wastewater each year, and these uses are increasing.

There are several reasons for the growing use of reclaimed municipal wastewater, including: (1) the lack of fresh water at a competitive price; (2) the potential use of plant nutrients in reclaimed municipal wastewater; (3) the availability of high-quality effluents; (4) a need to establish comprehensive water resource planning, including water conservation and reuse; and (5) the avoidance of more stringent water pollution control requirements, including advanced wastewater treatment facilities at municipalities.

Although irrigation with municipal wastewater is in itself an effective form of wastewater treatment, some additional treatment must be made before such water can be used for agricultural or landscape irrigation. The degree of treatment is an important factor in the planning, design, and management of wastewater irrigation systems. Preapplication treatment is necessary to protect public health, to prevent nuisance conditions during application and storage, and to prevent damage to crops, soils, and groundwater.

Reclaimed water quality

The quality of reclaimed water depends to a great extent on the quality of the municipal water supply, the nature of the wastes added during use, and the degree of treatment the wastewater receives (see fig. 1). Wastewater quality data routinely measured and reported at treatment plants mostly pertain to biochemical oxygen demand and suspended solids that are of interest in water pollution control. In contrast, the water quality characteristics of greatest importance in irrigation use — the salt content and concentration of specific chemical elements that affect plant growth or soil permeability — are not routinely measured. Consequently, it is often necessary to sample and analyze the wastewater for those constituents to determine its suitability for agricultural and landscape irrigation (table 1).

Evaluation of quality

Historically, the quality of irrigation water has been determined by the quantity and kind of salt present. As salinity in the reclaimed wastewater increases above a certain level, the probability of soil, water, and cropping problems also increases. Potential problems are related to the total salt content, to the types of salt, or to excessive concentrations of one or more elements. These problems are no different from those caused by salinity or specific ions in fresh water and are of concern only if they restrict the use of the water or require special management to maintain acceptable crop growth and yields. For irrigation with reclaimed wastewater, therefore, the suitability of a water is judged against the level of management needed to cope successfully with the water-related problems that are expected to develop during use.

The approach often used is to present water quality guidelines that stress the management needed to successfully use irrigation water of a certain quality. Such guidelines are given in table 2, developed by R. S. Ayers and D. W. Westcot (FAO Irrigation and Drainage Paper 29, "Water Quality for Agriculture," 1985) and Westcot and Ayers ("Irrigation Water Quality Criteria" in *Irrigation with Reclaimed Municipal Wastewater — A Guidance Manual*, G. S. Pettygrove and T. Asano [editors], Lewis Publishers, Inc., Chelsea, Michigan, 1985).

Salinity

Salinity, measured by electrical conductivity, is the single most important factor in determining the suitability of a water for irrigation. Plant damage from both salinity and specific ion concentration is usually tied closely to an increase in salinity. Establishing a net downward movement of water and salt through the root zone is the only practical way to manage a salinity problem. Under such conditions, good drainage is essential to allow a continuous movement of water and salt below the root zone. Long-term use of reclaimed wastewater for irrigation is not possible without adequate drainage.

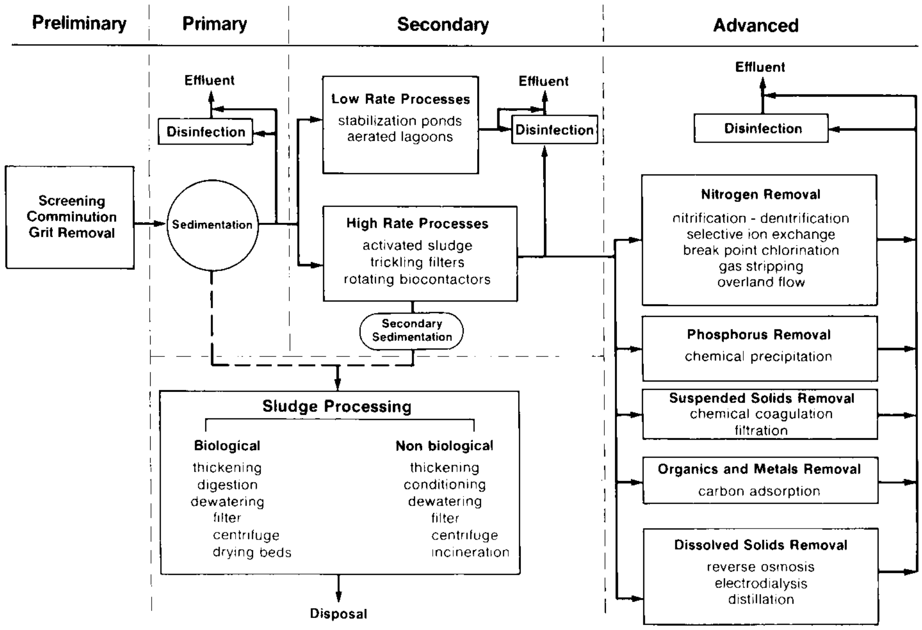

Fig. 1. Generalized flow sheet for municipal wastewater treatment and use for irrigation.

Specific ion toxicity

Toxicity occurs when a specific ion is taken up by the plant and accumulates in amounts that result in damage or reduced yield. The ions of most concern in wastewater are sodium, chloride, and boron. The most prevalent toxicity from the use of reclaimed municipal wastewater is caused by boron originating from discharges of household detergents or from industrial plants. Chloride and sodium also increase during domestic use of water, especially where water softeners are used. With sensitive crops, toxicity is difficult to correct without changing the crop or the water supply. The problem is usually accentuated by hot and dry weather.

Soil permeability

Besides its direct effect on the plant, sodium in irrigation water may affect soil structure, reducing the rate at which water can move into the soil as well as soil aeration capacity. If the infiltration rate is greatly decreased, it may be impossible to supply the plant with enough water for good growth. In addition, reclaimed wastewater irrigation systems are frequently on less desirable soils or those already having soil permeability and management problems. It may be necessary in this case to modify soil profiles by excavating and rearranging the affected land.

A permeability problem usually occurs in the surface layer of the soil and is mainly related to a relatively high sodium or very low calcium content in the soil or in the applied water. At a given sodium adsorption ratio (SAR), the infiltration

TABLE 1. Laboratory analyses needed to evaluate common irrigation water quality problems

Measurement	Symbol	Unit	Range in irrigation water
Salinity			
Salt content:			
Electrical conductivity	EC_w	mmho/cm or dS/m	0.1 - 3
Total dissolved solids	TDS	mg/L	10 - 2,000
Cations and anions:			
Calcium	Ca^{2+}	meq/L	0.2 - 20
Magnesium	Mg^{2+}	meq/L	0.1 - 5
Sodium	NA^{+}	meq/L	0.1 - 40
Carbonate	CO_3^{2-}	meq/L	0 - 0.1
Bicarbonate	$HC0_3^{-}$	meq/L	0.1 - 10
Chloride	Cl^{-}	meq/L	0.1 - 30
Sulfate	$S0_4^{2-}$	meq/L	0 - 20
Miscellaneous			
Boron	B	mg/L	0.1 - 2.0
pH (hydrogen ion activity)	pH	unit	6.5 - 8.5
Sodium adsorption ratio	SAR or R_{Na}	—	0.1 - 15

rate increases or decreases with the salinity level. Therefore, SAR and electrical conductivity of applied water (EC_w) should be used in combination to evaluate the potential permeability problem (see table 2).

Reclaimed municipal wastewaters are normally high enough in both salt and calcium, and there is little concern for the water dissolving and leaching too much calcium from the soil surface. Sometimes reclaimed wastewaters are relatively high in sodium; the resulting high SAR is a major concern in planning wastewater irrigation projects.

Nutrients

The nutrients in reclaimed municipal wastewater provide fertilizer value to crops or landscapes but in certain instances are in excess of plant needs and cause excessive vegetative growth, delayed or uneven maturity, or reduced quality. Nutrients occurring in significant quantities include nitrogen and phosphorus, and occasionally potassium, zinc, boron, and sulfur.

The most beneficial and the most frequently excessive nutrient in reclaimed municipal wastewater is nitrogen. Treated wastewater typically contains 90 pounds per acre-foot (33 mg/L) of total nitrogen. Most of this is in the ammonium or quickly available organic form, with little present as nitrate. The actual economic value of the nitrogen depends on amount of water applied, crop requirement, and other factors; in many situations, the reclaimed water contains at least the total crop requirement for nitrogen as well as for several other elements.

Miscellaneous problems

Clogging problems with sprinkler and drip irrigation systems have been reported. Slimes and bacteria in the sprinkler head, emitter orifice, or supply line cause plugging, as do heavy concentrations of algae and suspended solids. The most frequent clogging problems occur with drip irrigation systems. From the standpoint of public health, however, such systems are often considered ideal, because they are totally closed and avoid the problems of worker safety and spray drift.

Excessive residual chlorine in treated effluent due to chlorine disinfection causes plant damage when sprinklers are used, and the effluent is sprinkled on foliage. Residual chlorine at less that 1 mg/L should not affect plant foliage, but when it exceeds 5 mg/L, severe plant damage can occur.

Water quality case studies

We have used a brief report of case studies by Ayers and Tanji (see table 3) to guide the reader through some of the detailed irrigation water quality criteria presented in table 2. Table 3 contains chemical analyses of representative waters in California: relatively unpolluted water from the Sacramento River at Keswick; a moderately saline groundwater from Vernalis in San Joaquin County; and two treated municipal wastewater effluents from Fresno and Bakersfield.

The Fresno municipal wastewater treatment plant is designed for 60 million gallons per day (mgd) and is now operating at 38 mgd. Land treatment of effluent includes both percolation ponds (900 acres) with 21 recovery pumps for export of recovered water, and a 600-acre on-site farm using effluent directly for irrigation. Crops grown with both direct effluent delivery and percolated-recovered water include cotton, corn, alfalfa, almonds, sorghum, beans for seed, wine grapes, and winter cereals.

The Bakersfield treatment plant #2 is designed for 19 mgd and is now operating at 7 to 16 mgd. It provides primary treatment followed by aerated lagoons covering 51 acres and reservoirs to provide up to 90 days of storage if needed. The effluent is used to supply 5,100 acres of cropland with a 55-inch depth of water. Crops grown include cotton, corn, alfalfa, sorghum, rice and irrigated pasture. Effluent is blended with low-nitrogen water to control growth of nitrogen-sensitive crops such as cotton.

The quality of reclaimed water from Fresno and Bakersfield can be evaluated by following the guidelines in table 2. Although the water quality is such that "slight" to "moderate" permeability, toxicity, and miscellaneous problems can be expected from use of these two wastewaters, Ayers and Tanji concluded that good normal farming practices used in the area should allow full production of adapted crops. Table 4 summarizes their evaluation of the suitability of reclaimed wastewater for irrigation.

Health and regulatory considerations

There is some risk of human exposure to pathogens in every wastewater reclamation and reuse operation, but the health concern is in proportion to the degree of human contact with the reclaimed water and the adequacy and reliability of the treatment processes (fig. 1).

TABLE 2. Guidelines for interpretation of water quality for irrigation (after Westcot and Ayers)

Potential irrigation problem	Units	Degree of restriction on use: None	Slight to moderate	Severe
Salinity (Affects crop water availability)				
EC_w	dS/M or mmho/cm	< 0.7	< 0.7 - 3.0	> 3.0
TDS	mg/L	<450	450 - 2,000	>2,000
Permeability (Affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)				
SAR = 0 - 3		and EC_w = >0.7	0.7 - 0.2	< 0.2
= 3 - 6		= >1.2	1.2 - 0.3	< 0.3
= 6 - 12		= >1.9	1.9 - 0.5	< 0.5
= 12 - 20		= >2.9	2.9 - 1.3	< 1.3
= 20 - 40		= >5.0	5.0 - 2.9	< 2.9
Specific ion toxicity (Affects sensitive crops)				
Sodium (Na)				
Surface irrigation	SAR	< 3	3 - 9	> 9
Sprinkler irrigation	meq/L	< 3	> 3	
	mg/L	< 70	> 70	
Chloride (Cl)				
Surface irrigation	meq/L	< 4	4 - 10	> 10
	mg/L	<140	140 - 350	> 350
Sprinkler irrigation	meq/L	< 3	> 3	
	mg/L	<100	> 100	
Boron (B)	mg/L	< 0.7	0.7 - 3.0	> 3.0
Miscellaneous effects (Affects susceptible crops)				
Nitrogen (total-N)	mg/L	< 5	5 - 30	> 30
Bicarbonate (HCO_3) (Overhead sprinkling only)	meq/L	< 1.5	1.5 - 8.5	> 8.5
	mg/L	< 90	90 - 500	500
pH	unit		------normal range 6.5 - 8.4------	
Residual chlorine (Overhead sprinkling only)	mg/L	< 1.0	1.0 - 5.0	> 5.0

A secondary clarifier in which sludge settles before effluent undergoes dual-media filtration.

TABLE 3. Analyses of representative waters in California

Constituent	Surface water Sacramento River Keswick May 1978	Groundwater Vernalis area San Joaquin Co. June 1979	Wastewater effluent Fresno May 1978	Wastewater effluent Bakersfield (date unknown)
Electrical conductivity (dS/M)	0.11	1.25	0.69	0.77
pH	7.1	7.7	8.6	7.0
Calcium (meq/L)	0.50	5.0	1.2	2.35
Magnesium (meq/L)	0.41	2.72	1.05	0.41
Sodium (meq/L)	0.26	4.00	3.48	4.74
Potassium (meq/L)	0.04	0.10	0.35	0.66
Sodium adsorption ratio (SAR)	0.4	2.0	3.3	4.0
Bicarbonate (meq/L)	0.69	3.11	3.87	3.57
Sulfate (meq/L)	0.15	2.29	—	1.29
Chloride (meq/L)	0.06	5.63	1.97	3.01
Nitrate + ammonia-N (mg/L)	0.08	5.9	14 (TKN)*	0.5(NO_3-N)
Boron (mg/L)	—	1.4	0.43	0.38
Total dissolved solids (mg/L) (From EC × 640 TDS)	72	800	442	477
Arsenic (mg/L)			<0.002	
Cadmium (mg/L)			<0.002	<0.01
Chromium (mg/L)			<0.02	
Lead (mg/L)			<0.05	

SOURCE: R.S. Ayers and K. Tanji. 1981. "Agronomic Aspects of Crop Irrigation with Wastewater," Proceedings of the Specialty Conference, Water Forum '81. American Society of Civil Engineers.
*TKN = total Kjeldahl nitrogen.

TABLE 4. Evaluation for the suitability of reclaimed wastewater for irrigation (after Ayers and Tanji)

Problem area	Degree of problem: Fresno	Degree of problem: Bakersfield
Salinity	No problem	No problem
Permeability	Slight	Slight
Toxicity (To sensitive crops only)		
Sodium		
Surface irrigation	Slight	No problem
Sprinkler irrigation	Slight to moderate	Slight to moderate
Chloride		
Surface irrigation	No problem	No problem
Sprinkler irrigation	No problem	No problem
Boron	No problem	No problem
Heavy metals	No problem	No problem
Miscellaneous (Susceptible crops only)		
Nitrogen	Slight to moderate	—
Bicarbonate	Slight to moderate	Slight to moderate

The contaminants in reclaimed water that are of health significance may be classified as biological and chemical agents. For most of the uses of reclaimed water, pathogenic organisms pose the greatest health risks, and water quality standards for pollution control are properly directed at these agents. Bacterial pathogens, helminths, protozoa, and viruses are removed in wastewater treatment processes in varying degrees. The most important treatment process from the standpoint of pathogen destruction is chlorine disinfection. The inactivation of viruses by chlorine is, however, highly variable.

To protect public health without unnecessarily discouraging wastewater reclamation and reuse, many regulations include water quality standards and requirements for treatment, sampling and monitoring, treatment plant operations, and treatment process reliability. To minimize health risks and aesthetic problems, tight controls are imposed on the delivery and use of reclaimed water after it leaves the treatment facility. Regulations for a specific irrigation use are based on the expected degree of contact with the reclaimed water and the intended use of the irrigated crops.

Conclusions

Land application of municipal wastewater is common in many regions of the world. According to a 1984 California State Department of Health Services survey, approximately 220,000 acre-feet of municipal wastewater are reclaimed annually in California by 240 wastewater treatment plants that supply water to more than 380 users.

One approach to evaluating the suitability of reclaimed wastewater is to consider it the same as any other freshwater source and appraise its suitability for irrigation using the criteria in table 2. These criteria, when applied to the reclaimed water quality of Fresno and Bakersfield, suggest that there will be no serious potential agronomic or public health problems in the use of reclaimed municipal wastewater from those cities. In fact, both projects have been operated for many years with few problems stemming from poor water quality.

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