Water Reclamation Plants Need Complete Reliability

by Takashi Asano and Kurt L. Wassermann

Wastewater reclamation plants have got to produce consistently acceptable effluent* where reclaimed water is supplied directly to a user without benefit of the assimilative capacity of an intermediate receiving water.

There are two types of reliability that can affect the performance of a wastewater reclamation plant:

1. That dependent on mechanical breakdown, design deficiencies, and process or operational failure
2. That relating to in-plant treatment inconsistency, even though a wastewater reclamation plant is properly designed, operated, and maintained

Most frequently cited as the leading causes of poor plant performance are operation and maintenance (O & M). Hegg et al[1] identified 70 different factors that might contribute to poor plant operation **(Table 1).** The implication of this finding is that additional training of plant operators is necessary. This can best be accomplished with technical training and assistance.

*Plant reliability is the key to consistent quality and may be defined as "the probability that a plant will meet an established standard over a specific operating time."

It is also evident that many of the present performance †problems lie beyond the plant operations personnel in the process design area **(Table 1)** and exclude O & M problems and in-plant treatment variability (mainly of diurnal or seasonal nature).

Effluent variability: If a measurement is repeated many times under essentially the same conditions, the observed values will be distributed at random to both sides of an average because of uncontrollable errors. The shape of the curve is defined by two well-known statistical parameters: (1) the mean of observations and (2) the standard deviation. Many measurements of pollutants both in wastewater and sludge have been shown to fit a prevalent statistical (normal) distribution when the logarithms of the observed values are plotted against frequency of their occurrence. [3-6]

A baseline for evaluating treatment-plant performance has been established by Hovey et al.[7]

†Performance requirements are imposed on all municipal wastewater treatment plants by state and federal regulations. The EPA's secondary treatment[2] regulations represent minimal requirements for discharge to surface waters. State regulatory agencies often impose more stringent requirements.

Table 1

Ranking of Factors Limiting Plant Performance (After Hegg et. al)[1]

Rank	Factors	Times Occurred	Times Ranked No. 1
1.	Operator application of concepts and testing to process control	28	6
2.	Wastewater treatment understanding	20	4
3.	Technical guidance	17	5
4.	Process control testing	21	0
5.	Sludge wasting capability	18	3
6.	Process flexibiity	16	2
7.	Process controllability	20	0
8.	Clarifier (secondary)	11	2
9.	Sludge treatment	15	0
9.	Aerator	9	2
28.	Working conditions	7	0
28.	Pay (operators)	5	0
32.	Equipment malfunction	4	1

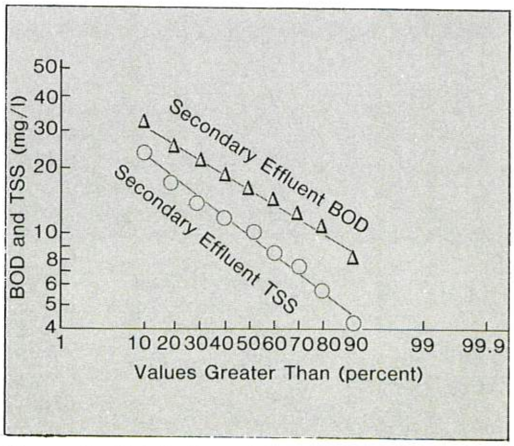


Figure 1. Distribution of Log Effluent Concentrations for Activated-Sludge Plants Designed to Meet EPA Secondary Treatment Requirements (After Ongerth[8]).

Reprinted from WATER & SEWAGE WORKS, September, 1979

He selected 20 well-operated activated-sludge plants throughout the U.S. ranging in size from 0.59 MGD (2,233 m^3/day) to 333 MGD (1.26 x 10^6 m^3/day). The distributions of daily-average, 7-day-average, and 30-day-average effluent concentrations were presented with respect to the distributions of effluent BOD_5 and total suspended solids (TSS) required for compliance with EPA secondary-treatment standards.

Ongerth[8] plotted the observations as a log-normal distribution **(Figure 1).** Activated-sludge-process effluent BOD might be expected to be slightly more stable than effluent TSS, as indicated by the relative slopes of the distributions. Activated-sludge treatment plants designed to meet EPA treatment requirements (monthly arithmetic mean BOD and TSS values of 30 mg/l), may be expected to run with an annual geometric mean for BOD_5 slightly higher than the annual geometric mean TSS concentration: approximately 15 mg/l BOD_5 versus 10 mg/l TSS.

Data by Hinrichs[9] **(Figure 2)** show BOD_5 effluent performance is relatively stable, even though conventional activated-sludge plants may be overloaded (actual flow/design flow > 1.0). In fact, for the over-designed plants, BOD_5 effluent concentrations tend to fluctuate more than for an under-designed plant. The effect of hydraulic overloadings on a secondary clarifier is shown by fluctuating suspended-solids concentrations for values of actual flow/design <1.0 **(Figure 3).** Other data by Hinrichs show the performance of different types of activated sludge plants **(Table 2).**

Reliability of advance wastewater-treatment plants: The degree of treatment and reliability requirements necessary for a treatment plant will depend on the uses of its recycled water. Five categories for reuse have been identified in a descending order of anticipated applications.

1. Land application (irrigation)

Table 2

Performance of Various Activated Sludge Processes (After Hinrichs)[9]

Process	Percent of Time Less than or Equal to 30 mg/l BOD_5	SS	Percent of Time Less than or Equal to 40 mg/l BOD_5	SS
Conventional activated sludge	73	79	89	94
Contact stabilization	96	77	99	88
Extended aeration	93	94	98	97

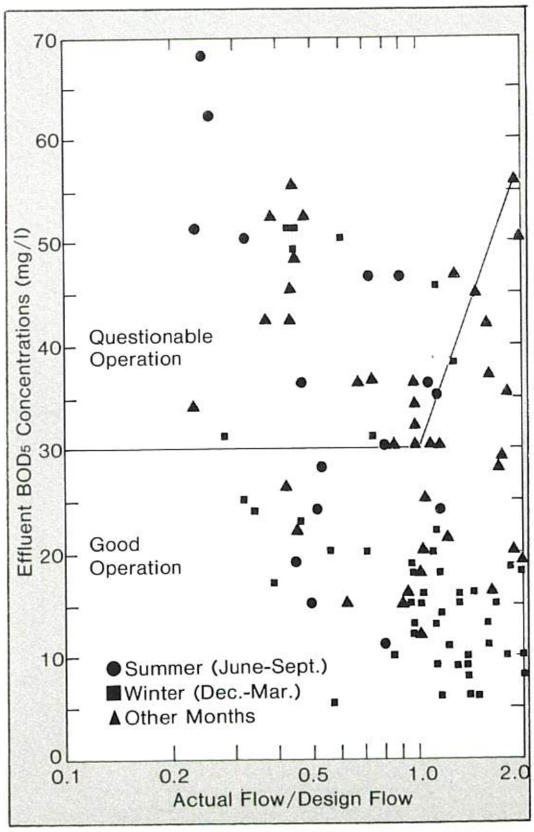
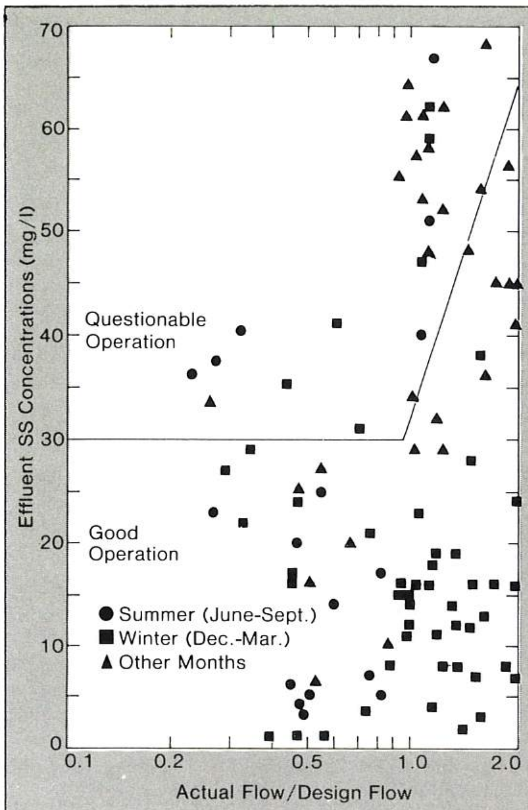
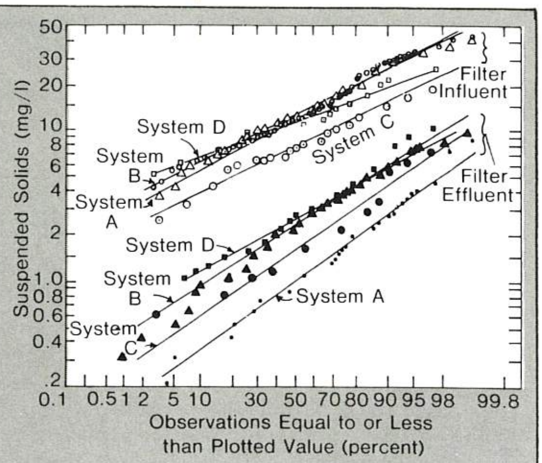
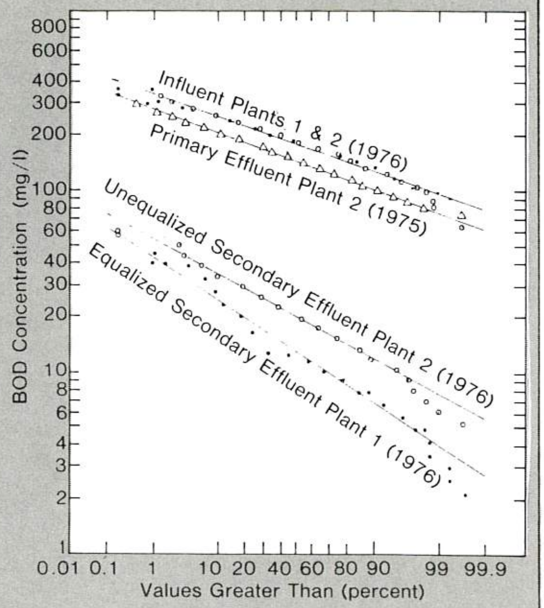


Figure 2. Conventional Activated Sludge BOD_5 (After Hinrichs[9]).







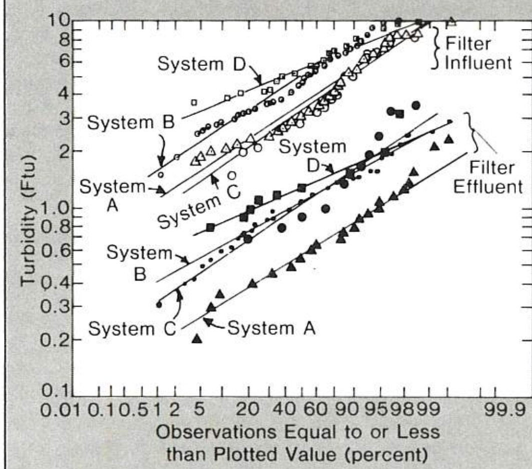


Figure 3. Conventional Activated Sludge Suspended Solids (After Hinrichs[9]). (Top left)

Figure 4. Frequency Distributions of Filter Influent and Effluent Turbidity (After Pomona Virus Study[11]). (Left)

Figure 5. Frequency Distributions of Filter Influent and Effluent Suspended Solids (After Pomona Virus Study[11]). (Top right)

Figure 6. Distribution of TSS Concentrations, Ypsilanti Township, Michigan, 1976 (After Ongerth[8]). (Above)

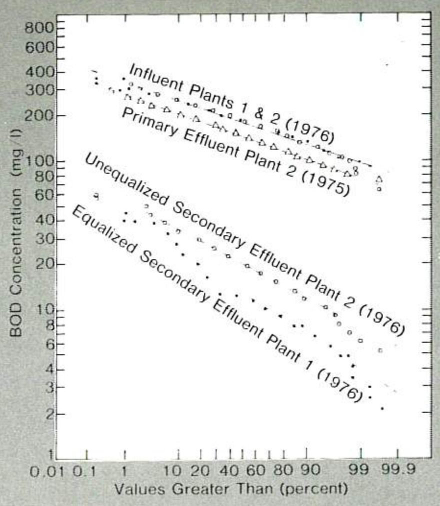
2. Impoundment for recreational facilities
3. Industrial-process-water cooling
4. Groundwater recharge
5. Direct consumptive use

California's wastewater reclamation criteria[10] require a treatment system consisting of coagulation, flocculation, sedimentation, filtration, and disinfection (system A), for landscape- and recreational-water reuse applications involving human contact and for spray irrigation of food crops. The intent of these criteria is to limit human exposure to waterborne viruses. It is generally believed that to achieve good disinfection, the effluent from a wastewater treatment plant must be low in suspended solids and turbidity.

The Pomona virus study conducted by the sanitation districts of Los Angeles County provides a baseline evaluation of treatment system capability with respect to turbidity and suspended solids **(Figures 4 and 5).**

For example, system A produces an effluent suspended-solids concentration of less than or equal to 2.0 mg/l approximately 85 percent of the time and less than or equal to 1.0 mg/l 50 percent of the time. Although this system is costly with respect to both capital and operating expenses, its performance and reliability are unquestionably superior to the alternative systems evaluated. System B (low-dose alum coagulation, filtration, disinfection) or system C (carbon adsorption, disinfection, carbon adsorption), however, are more cost-effective than system A for treatment of secondary effluent.[11]

It appears (based on experiments with clarified tertiary effluents conducted at Pomona) that



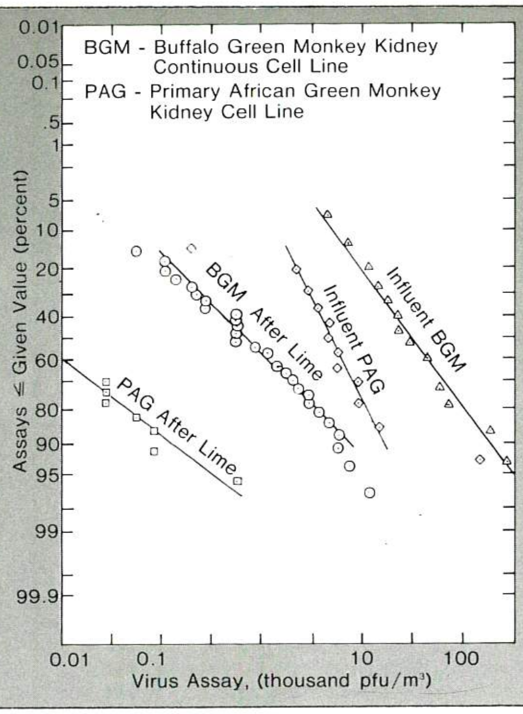


Figure 7. Distribution of BOD Concentrations, Ypsilanti Township, Michigan, 1976 (After Ongerth[8]). (Above)
Figure 8. Probability Plot of Virus Assay Levels (After McCarty et al[13]). (Right)

satisfaction of the stringent 2.2 MPN/100 ml coliform standard coincides with the degree of virus removal attainable through system A.

Ongerth[8] reported the effects of an in-line equalization system on the performance of TSS and BOD concentrations from the activated-sludge process **(Figures 6 and 7).** Plant No. 1 **[4.0 MGD (15,140 m³/day)] was equipped with an in-line equalization basin for diurnal flow smoothing, and plant No. 2 [4.0 MGD (15,140 m³/day)] had no equalization. The observed difference between TSS performance levels of equalized and unequalized plants was neglible (Figure 6).**

The flow-equalized plant, however, did have a lower concentration of effluent BOD than **did the unequalized flow** plant, the difference in mean values being approximately 7 mg/l. Variability of the equalized performance was slightly greater than that of the unequalized performance, as shown by the approximately 20 percent difference in log standard deviations.

Since the ultimate goal of wastewater reclamation and reuse is to create a new source of water supply, the meaning of the term "health hazard" or "health risk" needs to be rethought. There is sufficient historical evidence to show that a significant risk of contracting an infectious disease exists when ingestion of untreated or insufficiently treated municipal wastewater occurs. The only reported viral diseases to result from exposure to sewage-contaminated water, however, have been hepatitis A and gastroenteritis.[12]

Water Factory 21, operated by the Orange County Water District, is a 15-MGD (56,775-m³/day) advanced wastewater-treatment plant designed to improve the quality of biologically treated municipal wastewater that is injected underground to maintain a seawater intrusion barrier. McCarty et al[13] reported results of native virus tests on trickling filter and chemical clarifier effluents **(Figure 8).** Although the connection between these isolated viruses and human disease is not well understood, it appears that these viruses can be eliminated to a great extent through lime treatment at high pH. ■ u-7

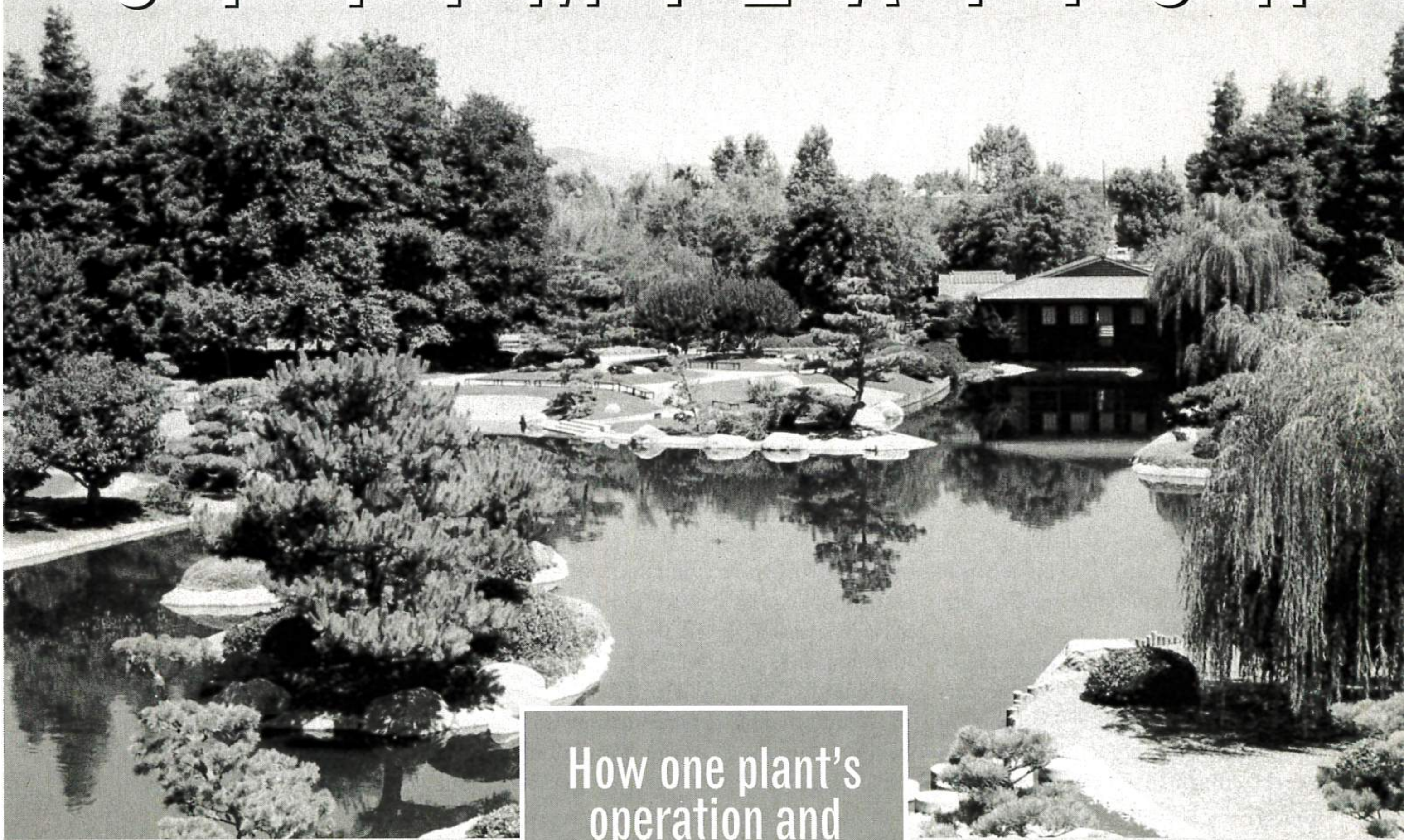
About the Authors
Takashi Asano and Kurt L. Wassermann are water reclamation specialist and chief, respectively, for the Office of Water Recycling, California State Water Resources Control Board, Sacramento, California.

REFERENCES

1. Hegg, B. A., K. L. Rakness and J. R. Schultz. "Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance." *Journal WPCF*, Vol. 50 (March 1978).
2. Federal Register, EPA Secondary Treatment Information, Vol. 38 (August 17, 1973).
3. Dixon, W. J. and F. J. Massey Jr. *Introduction to Statistical Analysis*, New York, McGraw-Hill Inc. (1969).
4. Aitchison, J. and J. A. C. Brown. *The Lognormal Distribution* London, Cambridge University Press (1957).
5. Young, J. C., et al. "Packed Bed Reactors for Secondary Effluent BOD and Ammonia Removal" *JWPFC*, 47, 46-56, (1975).
6. Dean R. B. and S. L. Forsythe. "Estimating the Reliabiity of Advanced Waste Treatment," *Water & Sewage Works* (June/July 1976).
7. Hovey, W. H., et al. "Optional Size of Regional Wastewater Treatment Plants," Water Resources Center, University of California, Davis; Contribution No. 161 (January 1977).
8. Ongerth, J. E. "Flow Equalization—Evaluation of Applications in Municipal Wastewater Treatment," Office of Research and Development, U.S. EPA, Cincinnati, Ohio.
9. Hinrichs, D. J. "Estimation of Effluent Limitations to be Expected from Properly Operated and Maintained Treatment Works," U.S. EPA, Permits Division, Office of Water Enforcement, Washington, DC.
10. California Administration Code, Title 22, Division 4, "Environmental Health: Wastewater Reclamation Criteria" (1978).
11. Sanitation Districts of Los Angeles County, "Pomona Virus Study - Final Report," California State Water Resources Control Board (June 1977).
12. Akin, E. W., et al. "Health Hazards Associated with Wastewater Effluents and Sludge: Microbiological Considerations" in Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges (Sagik, B. P. and C. A. Sorber, Ed.), The Center for Applied Research and Technology, The University of Texas at San Antonio, Texas (1978).
13. McCarty, P. L., et al. "Water Factory 21: Inorganic, Organic, and Biological Quality of Reclaimed Wastewater and Plant Performance," Technical Report No. 226, Department of Civil Engineering, Stanford University (January 1978).

Reuse

OPTIMIZATION



Kris Flaig

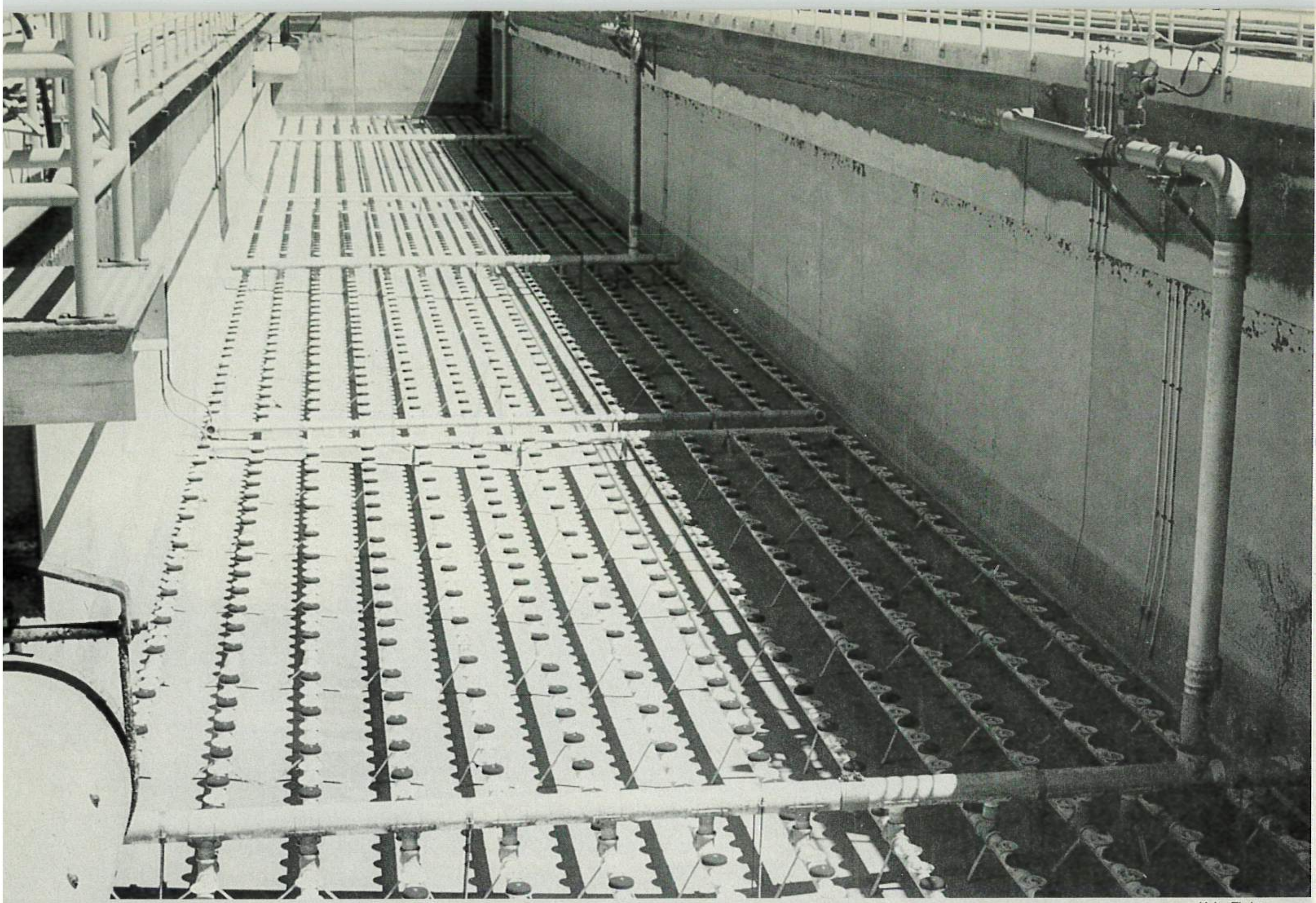
The popular Japanese Garden in Los Angeles, Calif., receives recycled water from the Donald C. Tillman Water Reclamation Plant. Soon, much of the plant's effluent will be used for direct groundwater recharge.

How one plant's operation and equipment changes produced a consistent reuse-quality effluent

Kris Flaig, Mark Starr, Bob Birk, George Tchobanoglous, and Takashi Asano

The largest recycling project undertaken by the City of Los Angeles, Calif., will use up to 8.9 mgd (33 700 m^3/d) of effluent from the Donald C. Tillman Water Reclamation Plant. Currently, most of the plant's effluent is used to irrigate golf courses and replenish Balboa Lake and the Los Angeles River. But soon, much of the flow will be diverted to the Hansen Spreading Grounds for groundwater recharge.

The Tillman plant provides hydraulic relief to the collection system located upstream of the much-larger Hyperion Treatment Plant. The activated sludge plant was designed originally to process domestic, commercial,



Kris Flaig

To supply air to specific parts of the aeration tanks, maintenance staff thinned out domes in certain areas.

and industrial wastewater (see figure, *Plant Schematic*, p. 23). Influent loads consist of 280 mg/L of biochemical oxygen demand and 300 mg/L of total suspended solids.

Because of modifications made to equipment and operational procedures, the plant has been able to demonstrate to regulatory agencies that its effluent is of consistently high quality and worthy of being used for groundwater recharge.

Secondary Treatment

After primary clarification, flow splits into two treatment phases of secondary treatment, which comprises 18 300-ft (91-m) activated sludge aeration basins followed by 44 final sedimentation tanks. Waste activated sludge is returned to the collection system for treatment at the Hyperion plant.

To improve biological processes, the return activated sludge (RAS) pumping rate and air flowrate were increased. Increasing the RAS rate lowered the sludge blanket level in secondary clarifiers, resulting in a shorter period of oxygen deprivation for bacteria. Increasing the air flowrate raised the dissolved oxygen (DO) level in aeration tanks from 1 to 2 mg/L.

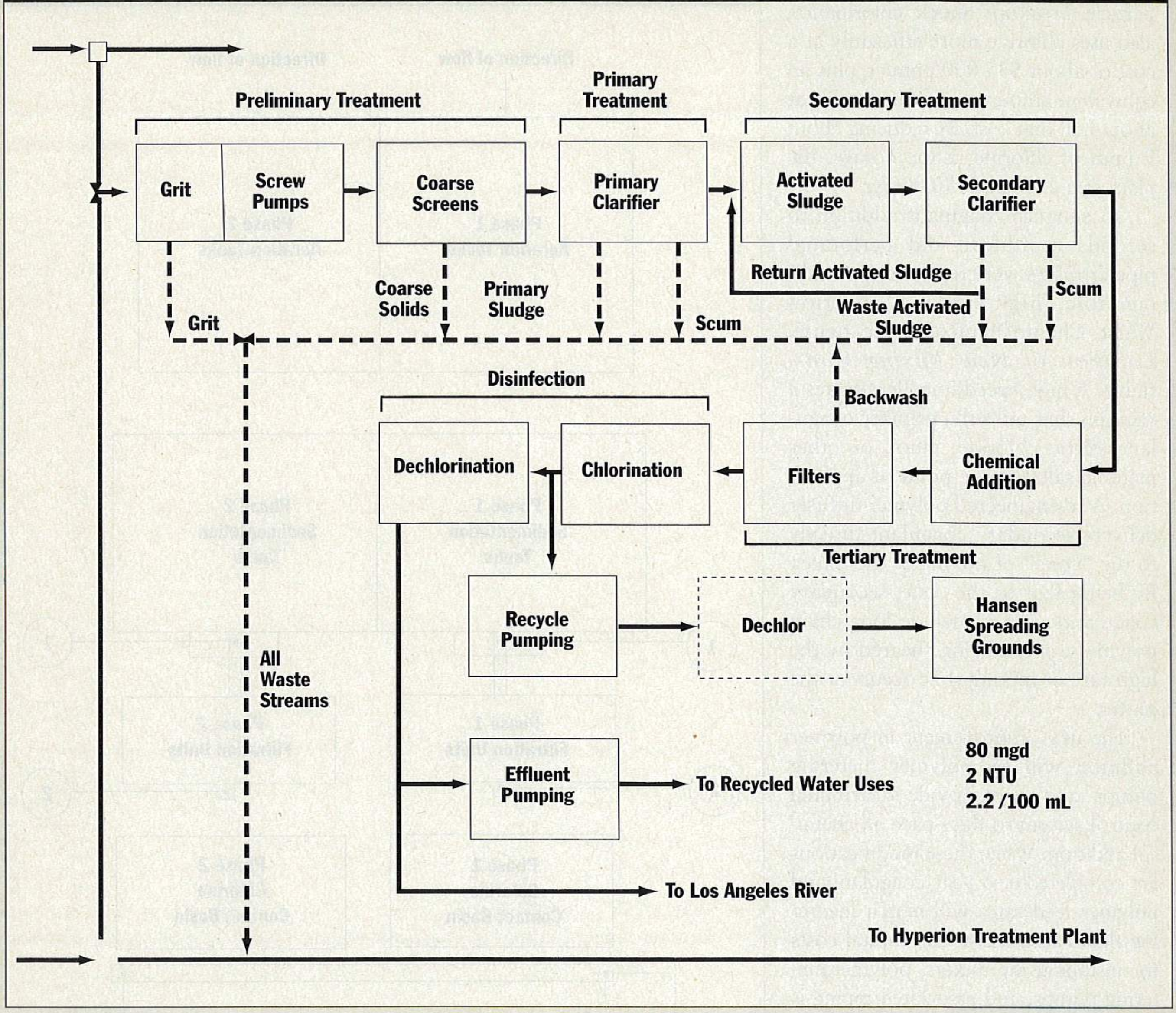
Aeration tank detention time was reduced to avoid nitrite formation, which interferes with effective chlorination. In addition, DO control was automated by reconfiguring the plant computer and purchasing more DO probes. Now, air valves to each aeration tank automatically control DO, ensuring adequate levels throughout the day and better efficiency.

Besides making process changes, the plant also began dedicating staff to maintenance tasks, such as weekly DO probe cleaning and calibration and DO profile evaluation. Staff also removed, bleached, acid-washed, and reinstalled more than 50 000 aeration domes and the associated piping in an ambitious project that took more than 4000 hours. Inspection and cleaning now are performed periodically to maintain optimum aeration. During routine maintenance, aeration domes are placed in specific areas so air reaches areas in the tank where it is needed most.

The entire skimming system was replaced to correct dead zones in the secondary clarifier. The replacement included brushes on collection gear to sweep pockets on the tank bottoms.

The diffuser grid pattern also was optimized over a 2-year period to supply air to specific parts of the aeration tanks. To address this, aeration domes would be added or reconfigured selectively during routine maintenance, at a cost of $21 000.

Plant Schematic



Tertiary Treatment

Chemicals are added to secondary effluent prior to direct filtration by 16 Hardinge traveling-bridge automatic backwash filters. Each of the two tertiary phases has eight filtration basins. Phase 1 monomedia filters are filled with 16 in. (40 cm) of silica sand while Phase 2 dual-media filters contain 8 in. (20 cm) of anthracite on 8 in. of silica sand. Despite their differences in media, no significant difference in performance has been observed between the two filter types.

Filter rehabilitation and other modifications significantly reduced final effluent turbidity. First, a contractor removed the sand, replaced porous plates, recaulked the system, and replaced media in half the Phase 2 filter basins after an inspection uncovered a construction failure. The remaining filters were refurbished shortly after.

Second, filter cleaning was changed from continuous chlorination to periodic, or "shock," chlorination. Continuous chlorination at higher concentrations tends to break apart flocculated particles, resulting in high turbidity. But shock chlorination is performed one filter at a time and cleans build-up without causing widespread particle breakup. Shock chlorination also uses chlorine more efficiently at a cost of about $35 000/ppm/yr, plus an equivalent amount of sulfur dioxide at about half that cost. By reducing about 9 ppm of chlorine in the dosage, the plant saved about $450 000/yr.

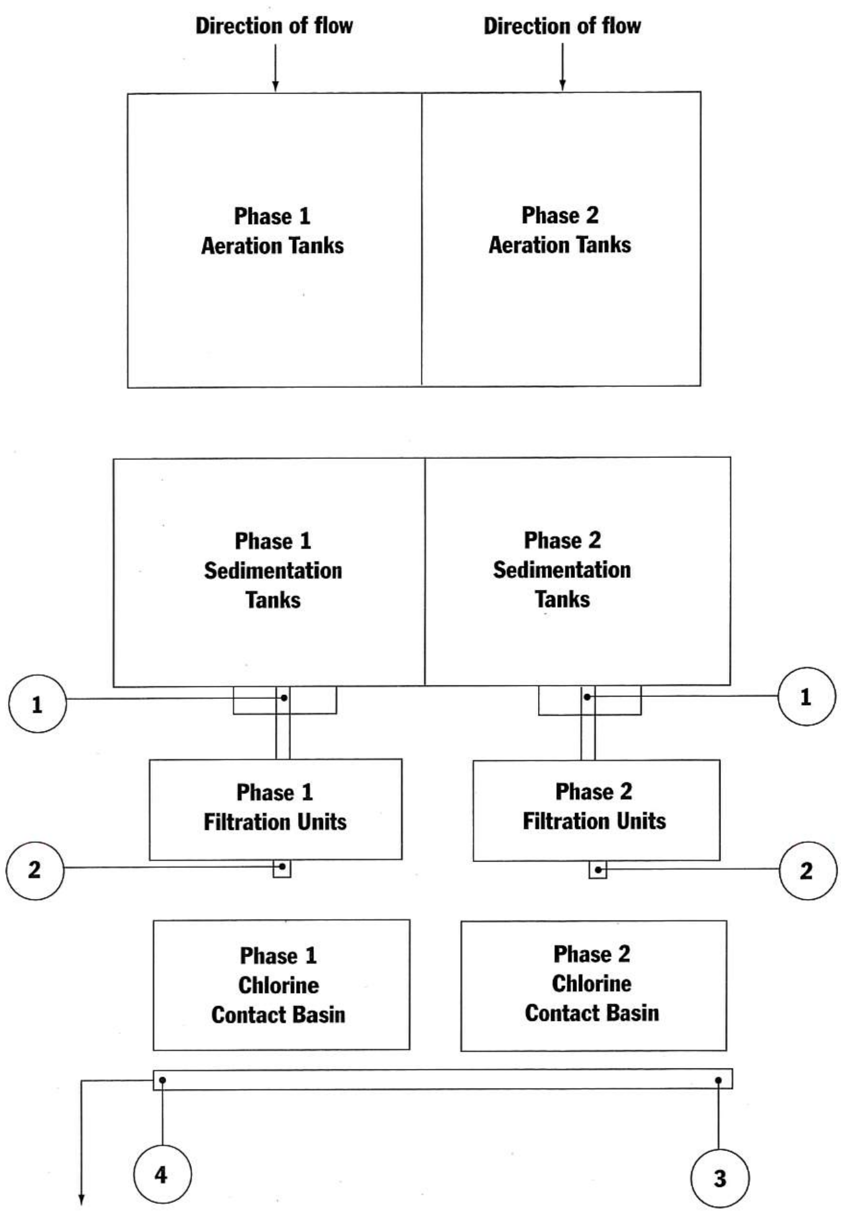
To enhance coagulant addition to secondary effluent, old perforated pipe diffusers were replaced with submersible, high-energy, induction Water Champ™ mixers (see figure, *Location of New Mixing Units,* right). A high-speed impeller creates a vacuum that pulls the primary coagulant (ferric chloride, alum, or other metallic salts) to the point of application. A re-engineered polymer diffuser delivers secondary coagulant directly to the "cone" of mixing in the mixer. By being sent to the cone, secondary coagulants, which include long-chain polymers, avoid being sheared by the high rate of mixing that occurs at the center.

The next improvement in polymer addition will be polymer metering pumps and a plantwide distributed control system to flow-pace all chemical addition. When these modifications are completed next year, coagulant and polymer feed rates will match incoming flows accurately. The capital costs for installing the mixers, polymer-metering pumps, and associated piping is $210 000.

Disinfection Modifications

The previous disinfection system used high-pressure effluent to transport chlorine through a diffuser pipe and into a channel between the filters and chlorine contact tanks. Flow-induced turbulence would disperse the solution throughout the effluent channel.

Location of New Mixing Units



1. Mixer installation for coagulant injection
2. Mixer installation for disinfectant injection (chlorine)
3. Mixer installation for dechlorination (sulfur dioxide)
4. Mixer installation for dechlorination trim system (sodium bisulfite)

To improve mixing and optimize use of free chlorine for the "initial kill," the pipe has been replaced by submerged-induction 20-hp (15-kW) mixers. The mixers shear chlorine gas into tiny bubbles, which diffuse into the flow stream at up to 60 ft/s (18 m/s). Two chlorine contact tanks for each phase provide more than 2 hours of contact time before Phase 1 and 2 effluents are combined in the final effluent channel.

A new two-stage dechlorination system consists of a primary (sulfur dioxide) application point followed by a secondary, or trim (sodium bisulfite), application point, as shown in the figure on p. 24 (*Location of New Mixing Units*). A similar system has been installed at the Balboa Pumping Plant, which pumps recycled flow to the Hansen Spreading Grounds; it is the key to providing the approved amount of chlorine residual and controlling off-spec product water.

The final effluent channel was widened from 5 to 10 ft (1.5 to 3 m) to increase detention time. Channel widening had the added benefit of providing a single sample-location point for combined phase flows. The previous dechlorination system provided only one monitoring opportunity, which often resulted in higher chemical use.

The total capital budget for the chlorination and dechlorination improvements project was $3.2 million. Tracer test results indicate that the chlorine contact tanks are well-designed, minimize short-circuiting, and maximize plug-flow mixing.

Secondary Improvements Significant

After 4 years, it is evident that modifications to secondary processes have improved treatment as much as modifications to tertiary processes. Meeting the standard of 5 nephelometric turbidity units (NTUs) for filter influent was much easier after secondary process modifications. A better influent, in turn, enabled the plant to easily meet the 2-NTU filter effluent standard. All modifications demonstrated that the plant could produce a high-quality effluent consistently for recycling purposes, particularly groundwater recharge.

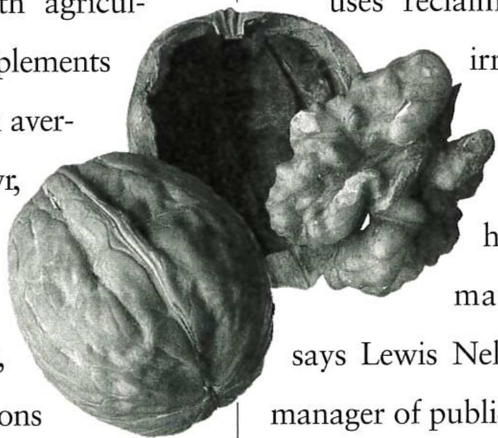
*Kris Flaig is a sanitary engineering associate in the Regulatory Affairs Division, **Mark Starr** is a sanitary engineer in the Regulatory Affairs Division, and **Bob Birk** is a plant manager for the Bureau of Sanitation in Los Angeles, Calif. **George Tchobanoglous** and **Takashi Asano** are internationally recognized consultants and professors emeritus at the University of California at Davis.*

FROM SOUP TO WALNUTS

A reuse project solves discharge problems and preserves community character

Mary DeSena

What preserves green space, maintains zoning compatible with agricultural land, supplements city revenues an average $500 000/yr, protects valuable groundwater resources, and saves millions of dollars in wastewater treatment facility expansion?



In the central California town of Visalia, the answer is water reuse. The town's project, which uses reclaimed water to irrigate a city-owned walnut orchard, has provided many benefits, says Lewis Nelson, Visalia's manager of public works, who was in charge of implementing the project.

"It's a win-win-win solution to a number of problems we were facing," Nelson says.

Several Benefits

When an insurance company offered the orchard for sale, it proposed rezoning the area for industrial development. The community objected to rezoning, and the city purchased the 900-ac (360-ha) property, intending to preserve the area's agricultural character and buffer the nearby wastewater treatment plant from surrounding areas.

However, the soil in the orchard was not suitable for a walnut grove, as large areas of the property had poor perme-

Lewis R. Nelson, City of Visalia (Calif.) Public Works

Standpipes over irrigation lines deliver effluent to the walnut orchard.