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Municipal Wastewater Reuse

Selected Readings On Water Reuse

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MUNICIPAL WASTEWATER REUSE: SELECTED READINGS ON WATER REUSE

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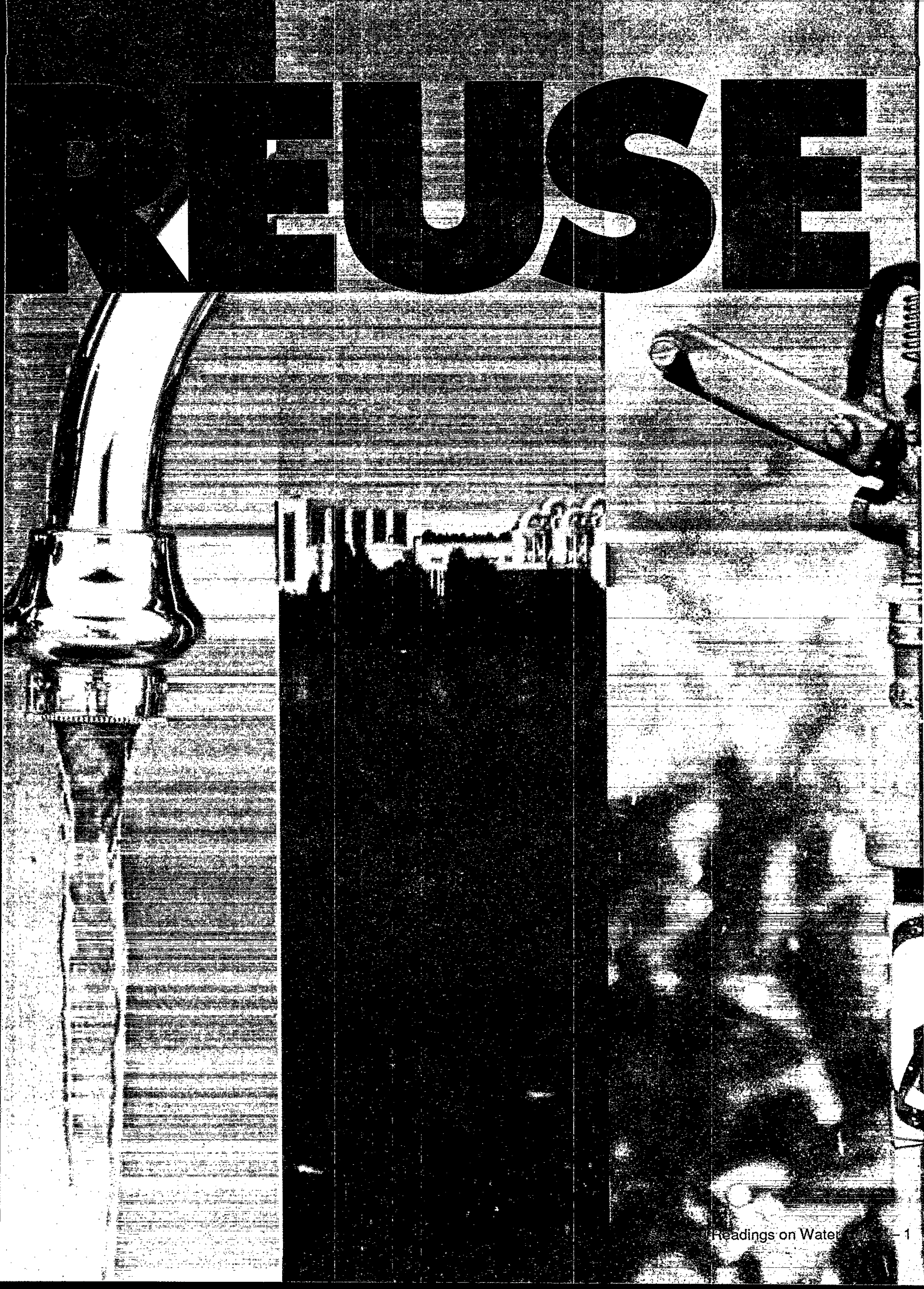
s document contains reprints of the following articles from the Water Pollution Control Federation's Water Environment echnology Journal:

REUSE



WPCF's Committment to Water Reuse—Completing the Cycle

This month marks the twenty-fifth anniversary of the establishment of WPCF's Water Reuse Committee. During the last 25 years WPCF, through this committee, has committed programs that promote and aid in the development of water reuse technology. In this anniversary year, coincidentally, WPCF received an EPA grant to publish information on water reuse as section in four issues of *Water Environment & Technology*, beginning with this October issue.

EPA representatives, speaking at the WPCF Annual Conference held in San Francisco, 1989, affirmed WPCF's position on water reuse, "Effluent reuse is a resource management option whose time has come. EPA encourages the reuse of treated wastewater effluents because of the great potential for resource recovery and for pollution minimization." In the presentation, EPA representatives affirmed, also, that reuse projects can be difficult to implement. Thus, in these *WE&T* sections, experts in the field describe successful projects and provide guidance to those who may be considering or are involved in managing water reuse and reclamation projects.

Many of the contributors to this EPA-funded project are WPCF Water Reuse Committee members. Along with the committee's long range plan, their contributions demonstrate that the Water Reuse Committee is more active than ever. For example, as part of its long range plan, the committee is focusing on the need for national water reuse standards or guidelines. As chairman and member of this committee, I share my colleague's enthusiasm for a project of such scope.

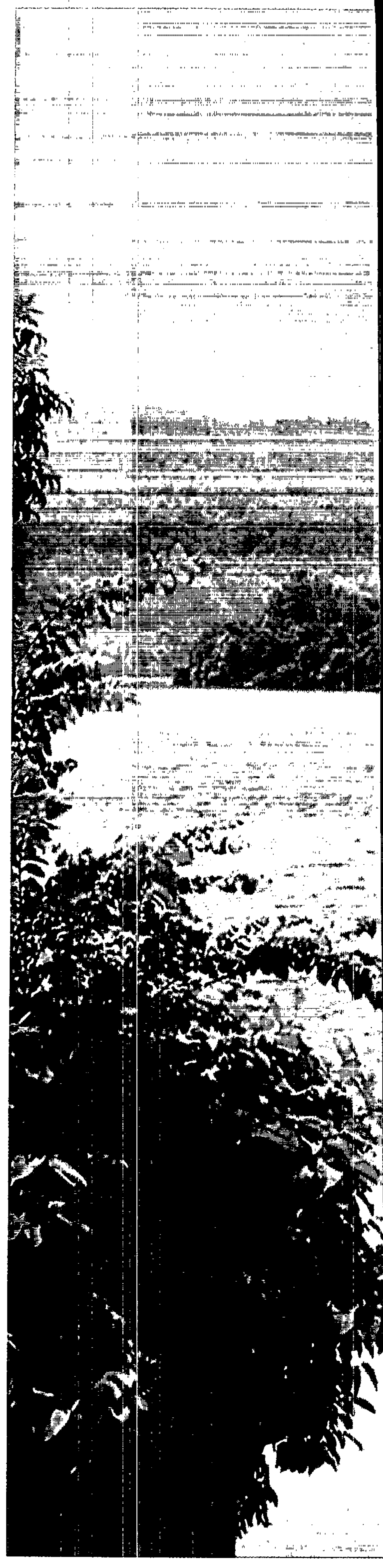
With this project, WPCF hopes to focus attention of its members on what can be accomplished, today, in recovering wastewater and what is needed to meet the growing public expectation for renewable resources in the future.

Ron Young
Chairman, WPCF Water Reuse Committee

On the Cover and In this Issue:

Officials and engineers are becoming increasingly concerned over the clean water supply. Thus, wastewater reclamation plants have been designed and more are being planned in areas where the water supply is diminishing or where demand is greater than supply. The Upper Occoquan Reclamation Plant, Centreville, Va., is one such plant that discharges treated wastewater, that meets stringent discharge permit limits, into a drinking water source; it's design and operation was the model for the Abilene, Tex., Reclamation Project Plan, whose story is told in this WE&T inset. The Abilene, Tex., Reclamation Plant, when completed, will discharge its effluent to the Lake Fort Phantom Hill reservoir.

One acceptable reuse of wastewater is irrigation. (The picutre of the spicket spraying water was taken by Carl Morrison). A recent poll of 1102 residents of California showed that a vast majority—89% of the polled residents—felt that reclaimed water would be safe for outdoor uses. Public attitudes and issues on wastewater reuse will be covered in a future inset.



GUIDELINES FOR DEVELOPING A PROJECT

Raymond R. Longoria, David C. Lewis, and Dwayne Hargesheimer

Today's technology provides a variety of water reclamation/reuse techniques to help meet the growing demand for high-quality, treated water. An organized management strategy is necessary to completely evaluate available options and select the proper approach. A four-phase planning effort was used in the development of a water reclamation/reuse project initiated in 1988 to indirectly augment potable water supplies for Abilene, Tex., by increasing the flows into the surface water supply reservoir. The four work phases focused on project definition and formation, creation of baseline data, treatment process evaluation and selection, and implementation.

Under this management approach, each phase is nearly independent, with distinct orientation meetings and schedules. The information generated from the major tasks in each phase is assembled in separate technical memoranda (TM) that deal with specific issues, focusing the approach.

Each phase ends in an intensive 1- to 2-day project team meeting followed by a coordination meeting with the owner (in this case, officials from the city of Abilene) and a public advisory committee. Thus, each TM can be drafted, reviewed by the project team, reviewed with the owner, modified, and then prepared in final form before the next phase begins.

Together, the TMs form a comprehensive report. During the final phase, they are condensed, providing the basis for the summary report. This report, a concise, 40- to 60-page account of the key project issues, is intended for a broad and often non-technical audience. All of the elements of the project are assembled into two volumes: the summary report and an appendix containing TMs (Table 1).

PHASE 1: PROJECT DEFINITION AND FORMATION

Phase 1 involves formation of the project team, including a public advisory committee (PAC), and requires the project team to develop, in detail, the specific goals and objectives of the project.

Establishing a team. In addition to the owner, engineers, and a PAC, the project team might include environmental scientists, virologists, epidemiologists, the owner's financial consultant, a water rights attorney, a public relations consultant, agronomists, economists, and other specialists.

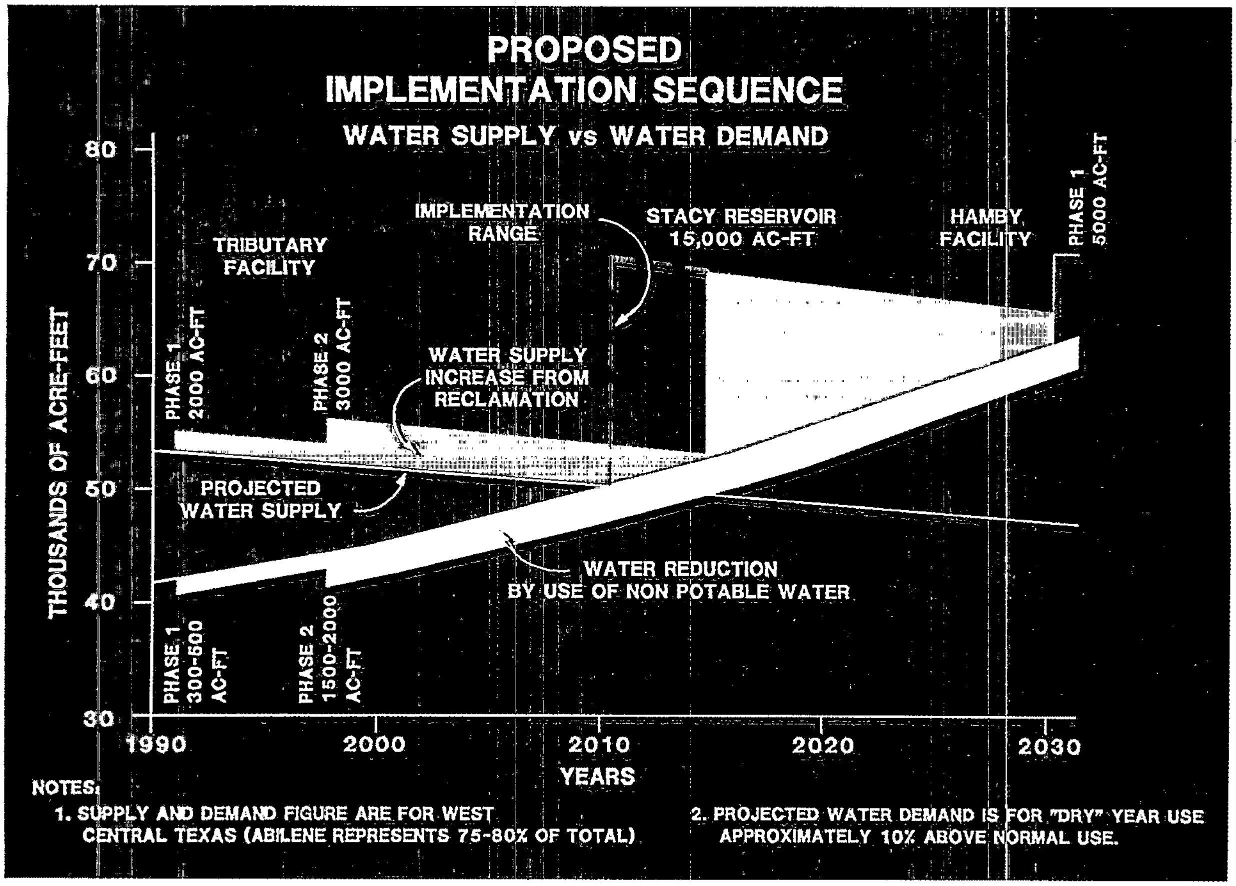
Despite all the technological and economic elements that comprise a water-reclamation research project, it is foremost a public involvement project requiring unwavering public support to be successful. Therefore, the PAC, as an advisory group of local citizens with scientific and non-scientific backgrounds, is vital to project success. PAC candidates should have good communication skills and a history of sound judgment, open-mindedness, and public activity. It is likely—and possibly preferable—that the PAC members will not be familiar with wastewater treatment technologies. They should be introduced to current technology through visits to successful full-scale reuse/reclamation projects.

The PAC's charter is to provide guidance to the project team and to express the community's interests in the project. It should also choose the appropriate level of public participation. For example, the Abilene PAC recommended that the project team provide it with regular project updates, hold informal meetings with it frequently, and hold only one formal public meeting. This was designed to allow the PAC to disseminate accurate information to the public and channel citizens' concerns back to the project team.

Raising issues and forming goals. The PAC should identify,

Table 1—Titles of Technical Memoranda for the Abilene Project

Research Project Objective, Goals and Approach
Public Advisory Committee Activities and Meetings
Baseline Data Development
Water-Quality Assessment
Lake Fort Phantom Hill - Water Quality Studies
Water-Quality Criteria and Goals
Process Selections, Conceptual Designs and Preliminary Cost Options
Process Selection, Sizing and Location
Bench-Scale Study - High Lime and Alum Coagulation
Bench-Scale Study - Nitrification/Denitrification
Recommended Plan
Evaluation of Financing Options
Non-potable Water System



with the project team, the project goals, objectives, and key issues and approve of the technical experts selected to address those issues. Once the basic project structure is in place, the project team assembles for a 2-day meeting.

The meeting begins with a clear restatement of the goals, which are usually established well before the first project team meeting (see Box). Part of the first day is set aside for "brainstorming," while the remainder of the meeting is focused to refine the issues and statement of objectives, to establish relative levels of importance, and prepare the draft TMs.

The project team should plan to address key issues identified by the PAC promptly, to the satisfaction of the PAC. Timely issue resolution will improve the chances of public acceptance. The Abilene PAC narrowed the key issues to two questions: "Is water reclamation needed? Is water reclamation safe?"

Goals and Objectives

- Plan, test, and verify the feasibility of reclaiming water from wastewater
- Provide a meaningful increase in water supply
- Prevent adverse effects on water quality in Lake Fort Phantom Hill that would limit its potential uses
- Comply with state and federal water-quality regulations on wastewater effluent discharges
- Provide a source of drinking water of equal or higher quality than that currently produced
- Maintain or enhance the aesthetic conditions of waters in Lake Fort Phantom Hill
- Reduce or prevent increases in public-health risks associated with the potable water supply and the wastewater treatment and disposal method
- Recommend implementation of water reclamation only if it is shown to be economically favorable
- Select treatment technology consistent with the city's operations and maintenance capabilities
- Investigate non-potable water reuse options to reduce demands on the potable water supply
- Secure public involvement and participation in the development and execution of the project

CREATION OF BASELINE DATA

In Phase 2, the project team compiles fact sheets of relevant baseline information on a specific subject. The fact sheets, no more than 3 pages long, are incorporated in a single document—the baseline data TM. For the Abilene project, fact sheets summarized data on existing and projected population, reservoir models, historical water quality, potable water production and use, wastewater flows and quality, wastewater treatment plant capacity, water treatment plant capacity, water rights, climatological data, and water conservation measures. These data are used to evaluate the need for water reclamation and the adequacy of potential treatment processes and to provide a context within which alternatives are considered.

Sources of historical water-quality data and water quality model calibra-

Table 2—Phase 2 Monitoring Progam: Water Quality Parameters

Algal identification	Methylene blue active substances (MBAS)
Alkalinity	Nitrate-N
Aluminum	Nitrite-N
Ammonia	Nitrogen, total Kjeldahl
Arsenic	Pesticide scan
Barium	Phosphorus
Biochemical oxygen demand	Potassium
Boron	Selenium
Bromide	Silica
Cadmium	Silver
Calcium	Sodium
Chloride	Standard plate count
Chlorophyll *a*	Strontium
Chromium	Sulfate
Cobalt	Temperature
Color	Threshold odor
Copper	Total dissolved solids (TDS)
Cyanide	Total hardness
Dissolved oxygen	Total organic carbon
Fecal coliform	Total organic halogens
Fecal streptococcus	Total suspended solids (TSS)
Fluoride	Total trihalomethanes (THM)
Iodide	Total THM forming potential
Iron	Turbidity
Lead	Virus
Magnesium	Volatile organic carbon
Manganese	Zinc
Mercury	

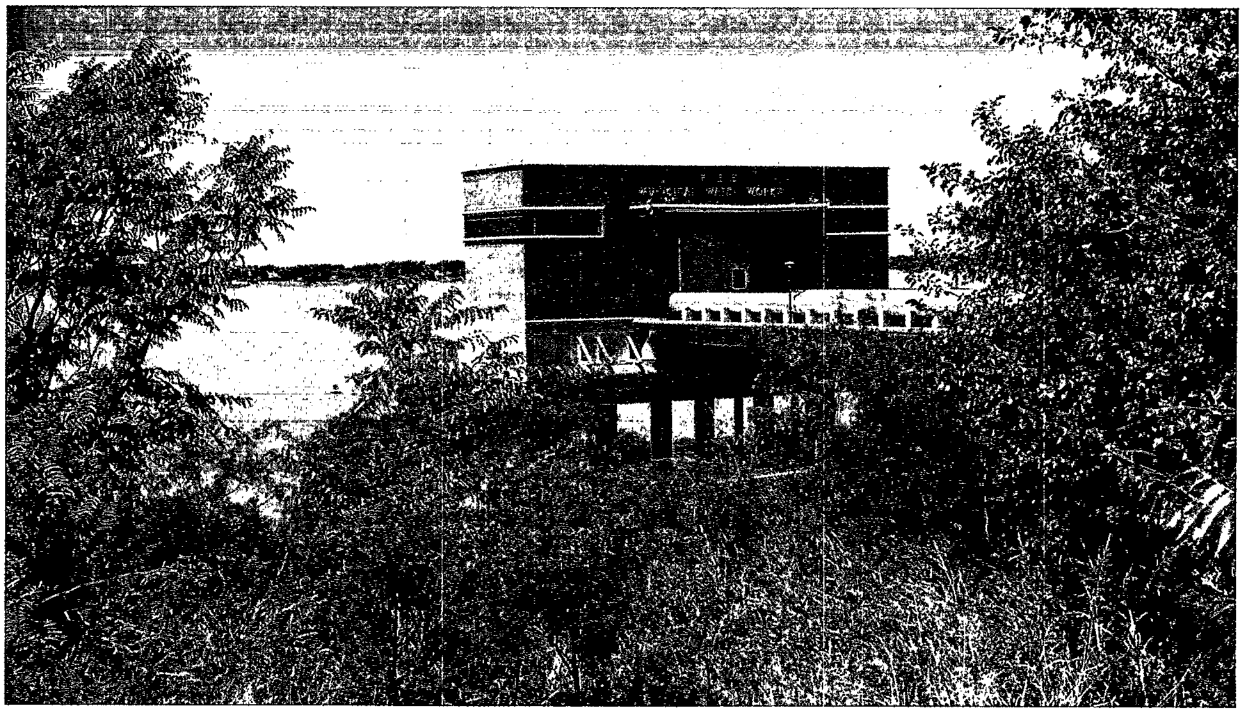
tion information include the owner, state regulatory agencies, the U.S. Geological Survey, and other users of water bodies, such as power plants or park and wildlife departments.

Because available data may be incomplete or of questionable validity, supplemental data should be acquired. An intensive water-quality monitoring program, specifically designed for the project, should be established early on in the project or, if possible, before the project is started. Monitoring for a full year, including hot, cold, dry, and wet seasons, should be conducted. Several parameters should be monitored (Table 2) and samples should be taken from at least two points in the reservoir and at least one spot in each major tributary feeding the reservoir. A sample should also be drawn from the existing wastewater treatment plant effluent.

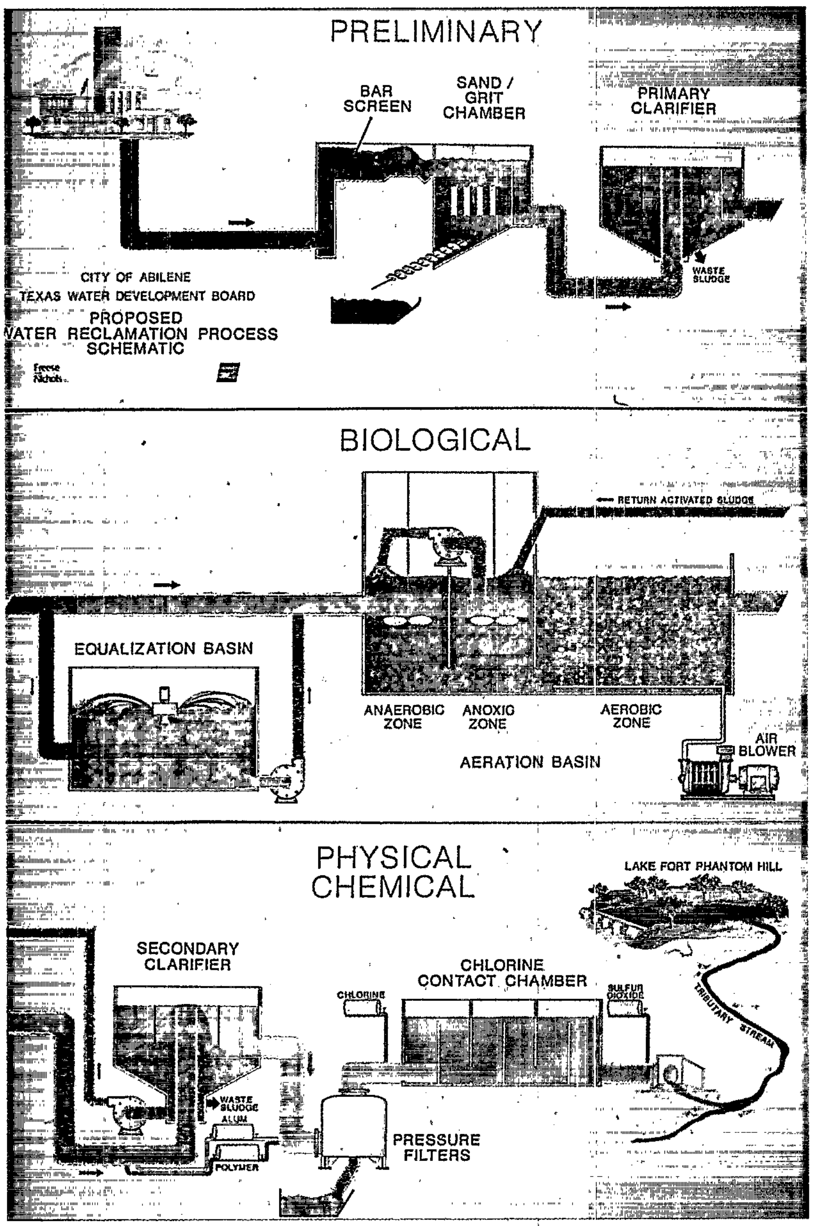
Because unexpected areas of concern may arise, the monitoring budget should contain contingency funds. Special testing was required on the Abilene project after the project team determined that *Giardia lamblia* and *Cryptosporidium* sp. could be present.

PROCESS EVALUATION AND SELECTION

In Phase 3, fundamental technical information is developed. Water-



Lake Fort Phantom Hill will received reclaimed effluent from the Abilene, Tx., wastewater treatment plant when the project is completed.



quality standards are identified, computer modeling is conducted to determine the impact of the standards on the receiving water, and treatment alternatives are developed and evaluated.

The establishment of appropriate water-quality standards for treated effluents and receiving streams is crucial. Numerous federal and state regulations must be considered, and other regional and local water-quality regulations may be applicable.

Water-quality modeling for the receiving water begins with these standards. The project team uses the computer model to evaluate the discharge effects on the reservoir at various flows and degrees of treatment. For modeling, the recommended minimum flow is a flow that would increase the lake's volume by approximately 5 to 10%. This water supply increase should produce a measurable positive or negative impact on the lake water quality. The maximum flow should be based on a projection of the practical limit of wastewater that would be available for reclamation during the study period.

For treatment levels, one set of model parameters should be set equal to the normal effluent discharge permit requirements of the receiving stream. One or two other sets that meet more and less stringent water-quality requirements also should be selected.

In the Abilene project (Table 3), one effluent set represented the reasonable best practical treatment level obtainable by current treatment processes (Row A in the table) and another set represented the treatment to maintain the state's water-quality standards (Row C). Row B represented the highest treatment level obtainable without chemical coagulation. The project team used the U.S. Army Corps of Engineers River and Reservoir Water Quality Model with flow values that ranged from 3 to 17 mgd under conditions of a 2-year critical drought period.

The water-quality standards review and the water-quality modeling results reveal the appropriate effluent quality criteria and allow selection of appropriate treatment processes. Specific effluent criteria will be required for the different reclaimed water uses proposed in the water reclamation plan. This could include reclaimed water used for irrigation, discharged to a tributary stream of the reservoir, and discharged directly to the reservoir (Tables 4 and 5).

Demonstrating effectiveness. In selecting alternative treatment process configurations, the project team should give preference to ones currently in use elsewhere. The PAC can be more confident in support of the project if members have visited a successful project that uses the same process scheme.

Regardless of other treatment processes, bench-scale tests should be conducted for key process parameters to demonstrate to the public that a process successful in other areas of the country is equally successful under local conditions. For example, the water-quality model for the Abilene project indicated sensitivity to phosphorous and nitrates. High lime coagulation bench-scale tests demonstrated that phosphorous could be removed adequately within a range of dosages, while nitrification/denitrification rate tests determined the appropriate design criteria.

The project team reviews the process alternatives (Tables 6, 7, and 8), prepares a detailed analysis of the advantages and disadvantages of each, selects a process, and then prepares a detailed description of the selected process.

During this phase, the project team should meet twice, once to address the water-quality standards and once to evaluate the process alternatives.

Table 3—Sample of Water-Quality Modeling Values

Effluent Set	Degree of Treatment BOD5	TSS	ortho-Phosphate	Ammonia	Nitrate
A	3.0	1.0	0.2	2.0	10.0
B	5.0	5.0	2.0	3.0	25.0
C	10.0	15.0	10.0	3.0	25.0

Table 4—Recommended Reclamation Levels for Irrigationa

Contaminant	Levels for controlled access	Levels for limited control access areas
Biochemical oxygen demand (BOD), mg/L	20	20
Total suspended solids (TSS), mg/L	20	20
Chlorine residual	1.0	not specified
Fecal coliform, per 100 mL	100	not specified
Total coliform, per 100 mL	not specified	2.2
Turbidity, NTU	not specified	2

[a] Levels at the time when the Abilene project was being planned.

Table 5—Recommended Reclamation Level for Supply Augmentation

Contaminant or Quality	Quantity	Flow, mgd
BOD, mg/L	5	
Turbidity, NTU	2	
Ammonia nitrogen, mg/L	2	
Nitrate/nitrite nitrogen, mg/L	20	<3
	10	>3
Total phosphorus	2.0	<3
	0.2	>3
Dissolved oxygen	>5.0	

IMPLEMENTATION

By the onset of the fourth phase, the major TMs are completed, and the project team should be ready to draft the summary report. In this final phase, the recommended treatment plan and other infrastructure requirements are combined in a comprehensive water reclamation plan. Non-potable water system or water conservation plans should also be incorporated into the reclamation plan during this phase.

The implementation phase should delineate the needed system improvements, establish an implementation schedule, develop a water supply *vs.* demand curve, enumerate costs, and identify any non-structural requirements. In addition to the treatment units, implementation plans should include the required wastewater collection system improvements and the pumping and non-potable water distribution system requirements.

The implementation schedule and the supply *vs.* demand curve should complement one another. The existing supply *vs.* demand conditions are used to determine when improvements will be needed and to develop an implementation schedule. The changes in the supply *vs.* demand curve caused by system improvements are then observable in a modified supply *vs.* demand curve (see Figure).

At this stage, estimated costs should be considered in planning budget estimates, which will be used to establish project financing needs, and should provide adequately for contingencies. In addition to overall capital costs and annualized costs, the project dollars should be expressed in terms of cost per volume (dollars/1000 gal) and cost for developing a water supply in terms of volume per year (dollars/ac-ft•yr). These figures would be compared to conventional surface water supply project costs.

Non-structural (management and operations) needs, which are addressed in this phase, include water rights, water-quality monitoring, financing, and public information. Because water rights to reclaimed wastewater have become complex, a water rights attorney should be retained to prepare a position paper on the owner's legal authority for reuse of wastewater to supplement surface water sources.

Monitoring for ongoing evaluation. The water-quality monitoring program should be continued through Phase 4 to provide data needed to evaluate the impact of the reuse improvements. The program, however, could be scaled back. Locations, both within the reservoir and on its tributaries, should continue to be sampled. While sampling and testing of the more sensitive parameters should be stepped up, many parameters repeatedly shown to be below detection limits or well within criteria can be tested less frequently or eliminated from the monitoring program.

Testing should involve a local university or some other independent agency to increase the likelihood of public acceptance. A technical committee could be appointed to review the water-quality data.

Financing and public acceptance. Financing options for a reclamation project are similar to those for conventional wastewater treatment systems. Reclamation projects also may qualify for funding from programs geared toward water supply development. Additionally, most non-potable water supply system improvements will benefit specific entities that should be asked to assist in financing the non-potable system improvements.

In general, the public perception of water reuse is positive as long as a project is presented using the proper approach. Because the connection between wastewater and water is not one that the public desires to make, asking the public to accept wastewater as a water source is a "difficult sell."

It normally requires a public information and relations campaign to convince the public to accept this concept. The development of a public information and acceptance program should begin with the study and continue throughout the implementation phase. There are several approaches and the owner's public information staff should develop and direct the public acceptance program. ■

Raymond R. Longoria is an engineer with Freese and Nichols, Inc., in Fort Worth, Tex.; David C. Lewis is an engineer with CH2M Hill in Austin, Tex.; and Dwayne Hargesheimer is the director of the water utility department of the city of Abilene, Tex.

Table 6—Four Treatment Process Alternatives: System Train

High-Lime	Alum and biophosphorus removal
Activated sludge	Activated sludge
Nitrification	Nitrification
Denitrification	Biological phosphorus removal
Clarification	Coagulation
High-lime	Filtration
Recarbonation	Clarification
Filtration	Filtration
Chlorination	Break-point chlorination
Post aeration	Post aeration
Alum	**Nitrification**
Activated sludge	Activated sludge
Nitrification	Nitrification
Denitrification	Biological phosphorus removal
Coagulation	Clarification
Chemical phosphorus removal	Filtration
Clarification	Chlorination
Filtration	Post aeration and force main
Break-point chlorination	
Post aeration	

Table 7—Treatment Alternative Design (and Average) Operating Conditions

Effluent quality, mg/L	Treatment Type			
	High-Lime	Alum	Alum and biological phosphorus removal	Nitrification
BOD	5.0 (2.0)	5.0 (2.0)	5.0 (2.0)	5.0 (3.0)
TSS	5.0 (1.0)	5.0 (2.0)	5.0 (1.0)	5.0 (5.0)
TKN	2.0 (1.0)	2.0 (0.1)	2.0 (0.1)	2.0 (1.5)
Nitrate	10.0 (5-7)	10.0 (5-7)	15-20(15-20)	15-20(15-20)
Phosphorus	0.2 (0.1)	0.2 (0.15)	0.2 (0.15)	2.0 (2.0)
Dissolved oxygen	5.0 (6.0)	6.0 (6.0)	5.0 (6.0)	5.0 (6.0)
Coliform, per 100 mL	2.2 (2.0)	2.2 (ND)[a]	2.2 (ND)	200.0 (100)
Turbidity, NTU	2.0 (1.0)	2.0 (1.0)	2.0 (1.0)	NA[b] (4-10)

[a] Not detected.
[b] Not applicable.

Table 8—Preliminary Cost Data for Abilene, Tex., Reuse Project

Cost, million dollars	Treatment Type			
	High-Lime	Alum	Alum and biological phosphorus removal	Nitrification[a]
Capital	13.41	11.26	10.12	11.58
Operations and maintenance	0.70	0.56	0.46	0.35
Equivalent annual[b]	2.09	1.73	1.51	1.55

[a] Includes construction of pump station and force main to pump beyond reservoir during droughts.
[b] Based on 20 years at 8% interest.

Keys to Better Water Quality

Larger populations and a higher standard of living require more water—from all available resources—to satisfy domestic and industrial needs. Unfortunately, growth and population increases have generally been associated with water-quality deterioration. The quality of many of Earth's surface supplies will continue to show deterioration until, at some point, planned reuse and its associated treatment process will offer a higher-quality product than conventional treatment. Thus, the key to dealing with water-resource problems will lie in our ability to extend and augment existing supplies through various reclamation processes. Success in water-reuse technology will probably depend on our ability to communicate and apply the technological advances that are achieved.

The government's role should be to coordinate research and demonstration projects and promulgate controlling rules and regulations. Over ten government agencies have some interest in water reuse and recycling. For the sake of efficiency and sound management, one agency should coordinate and manage all reuse research and demonstration projects.

About this section

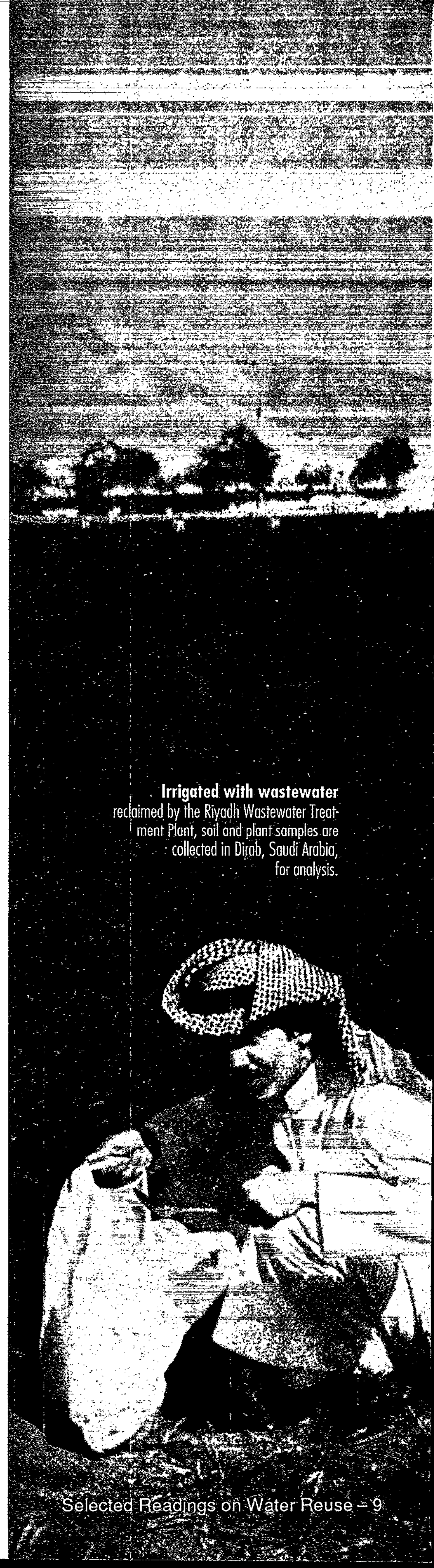
This is the second installment in a series devoted to the subject of water reuse. Installments were scheduled for publication in four issues of Water Environment & Technology. The publication of these insets was made possible by a grant from the Environmental Protection Agency.

Last month WE&T published an article on planning a reclamation project. This month WE&T focuses on the worldwide status of wastewater reclamation. The trends in reuse in developing countries, in the arid Middle East, and in the U.S. are described. Papers on reclamation and reuse of wastewater that were featured in several sessions of the recent Conserv 90 are also summarized in an article.

Public participation is necessary during each step of reuse programs: the public should not be expected to automatically understand and support reuse projects and, although increasingly recognized as a significant natural resource, reuse or disposal of wastewater will continue to receive greater scrutiny. The public's role can be one of a supporting partner or major antagonist. The difference seems to be involvement by the public—local and national—in all parts of the reuse effort.

Water reuse began out of necessity brought about by expanding industries, ever-increasing populations, and the need for larger volumes of water to support growing agricultural needs. As mankind approaches the 21st century with a world population projected to nearly double by the year 2000, it is realistic to project that, without significant change, existing water resources will be taxed beyond our current abilities to satisfy demand. The role of water reuse must therefore, be expanded.

Kenneth J. Miller
Vice President and Director
Water Supply and Treatment
CH2M Hill
Denver, Colo.



Irrigated with wastewater reclaimed by the Riyadh Wastewater Treatment Plant, soil and plant samples are collected in Dirab, Saudi Arabia, for analysis.

Conserv 90 brings together experts on water reuse

Conserv 90 was conceived in the wake of the 1988 drought that devastated the country and raised concerns about water supply and use. Conserv 90 is a joint effort of the American Society of Civil Engineers, American Water Resources Association, American Water Works Association, and the National Water Well Association. The theme of Conserv 90, which was held in Phoenix, Ariz., in August, was "Offering Water Supply Solutions for the 1990s." This summarizes the session Effluent Reuse.

EFFLUENT REUSE

Water reclamation and reuse is taking on added significance in a climate in which increased community development is putting a lot of pressure on water resources and sewer services.

To minimize subsurface discharge of wastewater in an arid rural area of poor drainage not served by public sewer services, a new 800-student high school in a rural Texas school district included an on-site advanced treatment system that included the use of reclaimed water for flushing toilets. This system reduced wastewater discharge by 85%.

In Houston, Tex., a sewer moratorium imposed on a high-growth area meant that all new construction projects could discharge no more than 1600 gpd/ac of property. High property values could not be supported by the level of development which the discharge limit imposed. As a solution, a construction project of the Alliance Bank and Trust Company included an on-site wastewater treatment and recycling system with water conservation plumbing fixtures. When fully completed, the 200,000-sq-ft building will discharge only 1000 gpd.

Similarly, on-site treatment and use of reclaimed water greatly reduced the wastewater discharges of the Squibb Corp. building in Montgomery Township, N.J., near Princeton, that does not have public sewer services. The system has enabled the township to control growth and avoid unwanted sewer infrastructure expenses while maintaining environmental goals.

In conservation-conscious Santa Monica, Calif., a 1.3-mil sq-ft complex consisting of four buildings for office and retail space is, when completed, expected to produce only 40,000 gpd as opposed to an expected 70,000 gpd. The reason: low flush toilets and other water conserving fixtures, on-site treatment and reclamation for landscape irrigation.

A successful on-site wastewater treatment system like those described above typically consists of on-line flow equalization and emergency storage tanks, biological nitrification and denitrification, membrane filtration, activated carbon, and disinfection. Membrane filtration is used to clarify biological process solids down to a particle size of about .005 μ. Granular activated carbon is used for color removal and is a backup for organic carbon removal. Typical removal rates are: biochemical oxygen demand (BOD) and total suspended solids (TSS) ≤ 5 mg/L, turbidity ≤ 0.5 NTU, total coliform ≤ 2.2/100 mL.

Factors inhibiting the wider practice of on-site reclamation and recycling include lack of state regulations, lack of standards for reclaimed water quality, and ambiguous plumbing codes.

In another paper, a project in Beaufort County near Hilton Head Island, S.C., which is experiencing rapid population growth, is described. To accommodate this growth, the Beaufort-Jaspar Water and Sewer Authority is planning two wastewater treatment plants which would be designed to produce effluent that could be applied to area golf courses. Also, the authority has been investigating the development of a wet-weather discharge system that would combine the flows of both plants and distribute the treated effluent to a forested floodplain wetland. The wetland would provide additional treatment while protecting the adjacent tidal freshwater river.

In the rural areas of Brevard County, Fla., reclamation is a necessity in light of the growth of the county along the coast. Just completed is the South Central Regional Wastewater System which will serve a 25-sq mile area of the mainland and will provide total reuse of effluent. It consists of four pumping stations, several miles of force main, a 3-mgd plant, and effluent reuse for irrigation of sod farms. The county has also decided to provide filtration and high-level disinfection because the effluent will eventually be extended to irrigation of public contact areas.

Venice, Fla., which has a critical water supply problem and a high growth rate, is constructing a new plant, the East Side WWTP, which will provide advanced secondary treatment to produce reclaimed water suitable for urban irrigation. The reclaimed effluent must meet state standards for public access irrigation: 20 mg/L BOD, 5 mg/L TSS and no detectable fecal coliforms. Nutrients are not regulated because their presence in irrigation water is beneficial as a fertilizer. The reclaimed water will greatly reduce pressure on local aquifers which have been the source of golf course irrigated water.

One of the most water conservation-conscious states is Arizona, where Tucson and Phoenix have developed elaborate reclamation systems for golf course and other forms of irrigation. Reclamation takes great pressure off of the groundwater supplies in a state that is heavily agricultural.

Meanwhile, in Southern California, where the water supplies are under great stress, the Irvine Ranch Water District has expanded its 15-year-old reclamation system to include nonpublic-contact use of reclaimed water for office and other highrise buildings. Feasibility studies began in 1987 for a dual-distribution system that delivers potable water and reclaimed wastewater to these sites. Pipes and fixtures are color-coded to allow easy distinction. Almost all of the hurdles, from testing to design approval, have been surmounted and officials announce that the system will be in actual operation in a building soon.

Also in Southern California, a blend of groundwater and highly treated wastewater is being injected underground to stem saltwater intrusion that has resulted from groundwater overdrafting.

–Alan B. Nichols, senior staff writer for Water Environment & Technology.

Above: **In Dariyah, Saudi Arabia,** palm trees and fodder crops grow where land was irrigated with reclaimed wastewater. Below Right: **Plants in this Dirab, Saudi Arabia,** greenhouse are watered with wastewater reclaimed by the Riyadh Wastewater Treatment Plant.

Water Reuse in Riyadh, Saudi Arabia

Riyadh, the capital of Saudi Arabia, is nestled in the central part of the arid Najd highlands. Its location, combined with a population that has nearly tripled to almost 2 million people over the last 10 years, guarantees water shortages and necessitates water reclamation. In the city, there are approximately 30 projects involving water reuse. Industrial and agricultural programs rely on effluent from the Riyadh Wastewater Treatment Plant (RWWTP).

The first stage of the RWWTP began operations in 1976 with a capacity of 40,000 m^3/day (10.6 mgd) to serve a population of 160,000 persons. Because of the city's rapid growth, the plant was almost immediately overloaded, and plans were quickly made to expand the facility. By 1980 the plant's capacity was expanded to 80,000 m^3/d (21.2 mgd), and, in 1983, the second stage of development was completed giving the site an average daily capacity of 200,000 m^3/d (52.8 mgd). The collection system uses 1980 km (1228 miles) of lines and no lift stations. Greater collection-line depths are tolerated in order to avoid lift-station operation and maintenance costs.

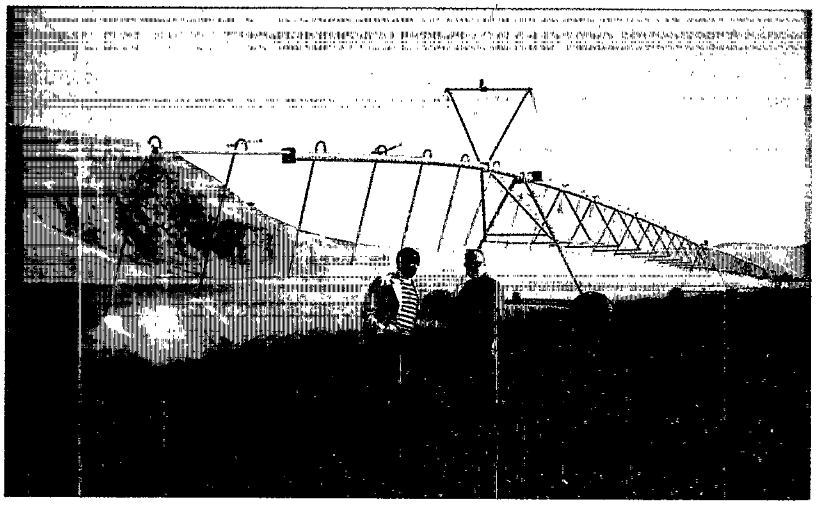
The plant, which provides preliminary, primary, secondary, and chlorination treatment, is a high-rate trickling filter system with random-fill plastic media, followed by two aerated lagoons, and finally chlorination.

Sludge treatment is achieved by anaerobic digestion, followed by sand drying beds. The dried sludge is hauled away by farmers who use the material as a soil conditioner or additive.

Plans have been completed to provide tertiary treatment of the wastewater; this will be gravity sand filtration of the final effluent.

Riyadh WWTP Influent and Effluent Composition

Constituent	Concentration, mg/L	
	Influent	Effluent
Total dissolved solids	1300	1200
Suspended solids	250	40
Settleable solids (ml/L)	3	ND
BOD_5, 20°	250	45
Chemical oxygen demand (COD)	450	100
Ammonia-nitrogen	25	25
Nitrate-nitrogen	-	< 1
Phosphates	10	7
Chlorides	180	160
Alkalinity	240	200
Grease	100	10
Temperature, °C	29	27
Free available chlorine	0.0	0.8
Total chlorine residual	0.0	4.0
pH	7.3	7.4
Dissolved oxygen	0	5
Total coliform	$< 10^6$/mL	50 to100/100 mL



A center pivot irrigation system sprays reclaimed wastewater on crops in Dirab, Saudi Arabia.

REUSE PRACTICES

The Petromin Oil Refinery uses some 20,000 m^3/d (5.3 mgd) of RWWTP's effluent. About 75% is treated to produce high-quality boiler feed water, while the balance is treated and used for crude oil desalting and cooling water and is also available for fire fighting should that prove necessary.

About 3600 m^3/d (0.9mgd) of effluent is used for landscape irrigation at the RWWTP. The grassed areas are aerial-spray irrigated while the shrubs and flowers are flood irrigated. Areas adjacent to the housing and main offices at the plant are watered with potable water to prevent any unwarranted use of the effluent.

The largest portion of the plant's effluent is pumped to Dirab and Dariyah for agricultural irrigation. The pumping station at Riyadh has a capacity of 120,000 m^3/d (31.7 mgd) with an on-line storage of 300,000 m^3/d (79.3 mgd). The transmission line to Dariyah, which has a capacity of 200,000 m3/d (52.8 mgd), is 50 km (31 miles) long and 800 mm (41.5 in.) in diameter. The transmission line to the Dirab irrigation site is 55 km (34 miles) long and 1000 mm (39.4 in.) in diameter.

MEETING STANDARDS AND DEMANDS

In 1985, 92,000 m^3/d (24 mgd) of RWWTP effluent was pumped to Dirab and spread generally over 2000 ha (5,000 acre) The farms at Dirab average around 65 ha (106 ac.) in size and the main crops are wheat, fodder, and vegetables. In 1985, 70,400 m^3/d (19 mgd) of RWWTP effluent was pumped to Dariyah. The farms at Dariyah average about 15 ha (37 acre) and the main crops are date palms, fruit trees, vegetables, and fodder.

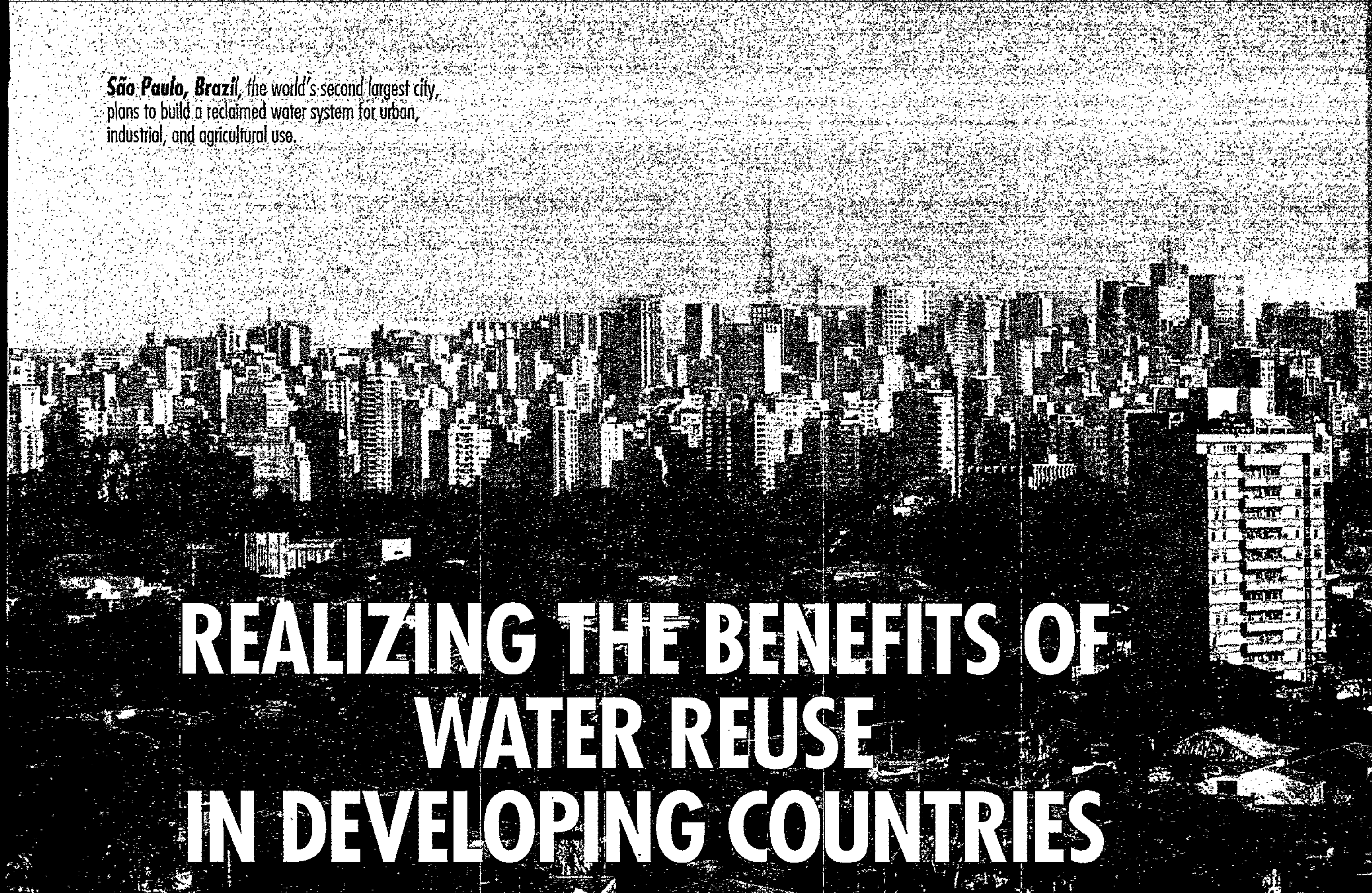
The irrigation water has made it possible to more than double the land under cultivation at Dirab; as in the past, the wells at Dirab used for irrigation would be dry during the summer months. Also, the nutrients in the effluent (see Table), especially nitrogen and phosphorus, reduce the need for fertilizers, thus, reducing costs, and substantial savings are being realized. Farmers are also using treated sludge from the plant as a soil conditioner.

The tentative Saudi Arabian Water Quality Standards for unrestricted agricultural irrigation are 10 mg/L for 5-day biochemical oxygen demand (BOD_5) and 10 mg/L for suspended solids. The effluent does not meet the tentative standards, but, as soon as the tertiary plant is completed, there should be little difficulty in producing an effluent that meets these requirements. However, overloading, also, presents problems.

Wastewater flows to the RWWTP have been increasing dramatically, and at present the flows are over 330,000 m^3/d (87 mgd). Plans have been completed and construction is presently underway on a new, 200,000 m^3/d (52.8 mgd) plant located just to the north of the existing plant.

The new plant will also provide preliminary, primary, secondary, and tertiary treatment. The secondary treatment process, however, will be an activated sludge system incorporating a nitrification-denitrification process, and tertiary treatment will consist of sand filtration and chlorination.

–James M. Chansler, Wastewater Management Division, Broward County Office of Environmental Services, Pompano Beach, Fla.; Donald R. Rowe, Larox Research Corporation, Bowling Green, Ky.; Khaled Al-Dhowalia, Civil Engineering Department, King Saud University, Riyadh, Saudi Arabia; and Alan Whitehead, Riyadh Water and Sewerage Authority, Riyadh, Saudi Arabia.



São Paulo, Brazil, the world's second largest city, plans to build a reclaimed water system for urban, industrial, and agricultural use.

Daniel A. Okun

REALIZING THE BENEFITS OF WATER REUSE IN DEVELOPING COUNTRIES

Daniel A. Okun

The proportion of the world's population living in urban areas is rapidly increasing, especially in developing countries in Asia, Africa, and Latin America. In 1950, only New York and London had populations exceeding 10 million; by 1975, the number of "megacities" had grown to seven, including three in developing countries. By the year 2000, forecasts indicate that there will be some 25 of these huge population centers, with 20 in developing countries.

Inevitably, the water-supply demands of growing urban regions will outstrip available water resources, especially in developing countries. As a result, large industrial, commercial, and residential developments often develop their own supplies— frequently by tapping local groundwater—without adequate planning or government supervision. This causes problems such as land subsidence and saltwater intrusion.

Also, because of water shortages, water service in most urban areas of developing countries is intermittent, allowing the distribution system to be contaminated by infiltration of contaminated groundwater, posing a serious threat to public health. Water reclamation, by reducing the demand on the potable supply, may help maintain water pressure.

The location of burgeoning urban centers creates other problems. About half of all megacities and most secondary cities are inland, in areas where there is insufficient water for the disposal and dilution of their increasing wastewater flows.

In industrialized countries, the practice of water reclamation for nonpotable purposes has been increasingly relied on to provide a new source of water to meet urban needs. For cities in developing areas, water reclamation has the potential to reduce the magnitude of inevitable problems by providing additional water while at the same time reducing the amount of wastewater that must be discharged.

As in recent water and wastewater planning efforts for municipalities in Florida, California, and the southwest U.S., engineers formulating plans for cities in developing countries should assess the potential for integrating water-supply and sewerage-system planning to maximize the benefits that water reclamation can provide.

PLANNING CONSIDERATIONS

The costs of developing new water resources for urban areas are high—much higher in constant dollars than the costs of developing existing sources because the latter were the lowest-cost options when they were selected. Thus, water reclamation, by substituting nonpotable for potable water where feasible, may be a more attractive alternative. Also, for inland cities where wastewater treatment costs are high because of the need to protect downstream water quality, water reclamation for reuse may well be economically attractive.

Direct potable reuse should not be considered because it is not yet proven or acceptable, nor is it likely to be in the current planning horizon. Moreover, because of the frequent occurrence of water-borne infectious diseases in the developing world, the risks of transmitting cholera, typhoid, and dysentery through reclaimed water are far greater than in the industrialized world, where these diseases have virtually been eliminated.

Groundwater recharge, a form of indirect potable reuse, is also constrained by public-health uncertainties. Agricultural reuse, which is widely practiced throughout the world, should not be a prime consideration for urban planners because the water is far more valuable in urban use. In the early stages of a water-reclamation project, providing reclaimed water to nearby agricultural lands may be attractive. However, as the metropolitan area expands, displacing agriculture, the reclaimed water would be shifted to urban uses. Also, irrigation is a consumptive use, whereas many other nonpotable uses, such as industrial processing and toilet flushing, permit another cycle of reuse.

For a water-reclamation program to be instituted, urban areas must be sewered. In developing countries, while 50% to 80% of urban areas are provided with water service, only 10% to 50% are provided with sewerage. Programs to increase urban sewerage service now have a high priority, but systems intended for water reclamation should be planned differently than conventional systems designed to discharge wastewater to a receiving body of water.

WATER QUALITY FOR REUSE

In urban settings, because significant numbers of people could potentially be exposed to nonpotable reclaimed water used for landscape irrigation, industrial purposes, toilet flushing, and many other uses, there must be no hazard. The most important water-quality objective is that the water must be adequately disinfected, and a chlorine residual should always be present. Also, the water must be clear, colorless, and odorless; otherwise, it would be aesthetically unacceptable.

Research by the Los Angeles County Sanitation Districts[1] has demonstrated that a high-quality secondary effluent, treated with small doses of either coagulant, polymer, or both; direct conventional sand filtration; and chlorine disinfection can easily and continuously provide a satisfactory product. The design, operational, and quality parameters that have been adopted in California are shown in Table 1. These criteria, which may be modified for cities in developing countries, are best determined by pilot studies.

Reclamation plants differ from typical wastewater treatment plants, which are built to treat and discharge effluent to receiving waters, in several ways. The location of the plant is primarily influenced by potential markets for the reclaimed water, rather than the service area's topography or the location of the receiving water. The sludge that is produced is not necessarily treated at the reclamation plant because it may be returned to the sewer for treatment and disposal at another plant. The amount of wastewater treated at the reclamation plant depends on the demand for reclaimed water; the remainder of the wastewater may travel to another plant for disposal. Finally, and perhaps most importantly, the effluent is a marketable product and should be treated as such: quantity and quality are important if customers are to be satisfied.

Therefore, reclamation plants are designed for reliability, with duplicate units, standby power sources, and continuous on-line monitoring of effluent turbidity and chlorine residual, as well as monitoring for chlorine residual on the distribution system.

Table 1—California Criteria for Urban Nonpotable Reuse

Parameter	Criteria
Coagulant (alum, polymer)	Required unless effluent turbidity <5 NTU
Rapid mix	High energy
Filter media	Anthracite and sand
Effective media size	
Anthracite	1.0 to 1.2 mm
Sand	0.55 to 0.6 mm
Filter bed depth	0.92 m (3 ft)
Filter loading rate	12 m/h (5 gpm/sq ft)
Chlorine residual	Minimum of 5 mg/L after 2 hours
Chlorine contact time	2 hours
Chlorine chamber	40:1 (length:width or depth)
Coliform bacteria, MPN	
7-day median	2.2/100 mL
maximum	23/100 mL
Filter effluent turbidity, 24-hour average	2 NTU

NONPOTABLE REUSE PROGRAMS

Water-reuse programs in the industrialized world are instructive in gauging the chances for success in the developing world. The widest experience with water reclamation and nonpotable reuse is in the U.S., not only in the arid Southwest but also in humid Florida; in Singapore, where, despite extraordinarily high precipitation, water resources are limited; in Israel, where innovative reuse practices have a long history; in the oil-rich countries of the Middle East, where 1 L of fresh water may cost more than 1 L of petrol, and costly desalination practices are common along with high-tech systems of reclamation; and in the resort islands of the West Indies where the value of fresh water for tourism also justifies the high cost of reclamation.

A typical approach involves the reclamation of wastewater for a single large user, such as a program initiated in Baltimore, Md., in 1942. About 4.5 m^3/s (100 mgd) of effluent from the city's Back River activated-sludge plant was chlorinated and conveyed 7.2 km (4.5 miles) through a 2.44-m (96-in.) pipeline to the Sparrows Point plant operated by Bethlehem Steel Co. This is generally the way reuse begins in many urban centers.

Power plants with evaporative cooling towers are large users of reclaimed water. A 58-km (36-mile) transmission main was installed in 1982 to carry secondary effluent from Phoenix, Ariz., to a 3.9-m^3/s (90-mgd) reclamation plant at the Palo Verde nuclear power station. At the plant, biological nitrification (on trickling filters), lime-soda softening, coagulation, dual-media filtration, and chlorination are provided to meet the special water-quality requirements of cooling towers. A large Phoenix developer who needed the water for a housing and commercial development sued the city for making this agreement, illustrating the value of reclaimed water.

A growing practice involves the use of dual-distribution systems—one for potable water and the other for nonpotable purposes. The first system was installed in 1926 in Grand Canyon Village, Ariz., where scarce drinking water is pumped from a spring near the bottom of the canyon about 1 km below. Reclaimed wastewater is used in the village for most nonpotable purposes, including extensive landscape irrigation and toilet flushing.

The Irvine Ranch Water District in southern California initiated wastewater reclamation using a dual system, mainly for urban irrigation as an alternative to ocean disposal of effluent. However, even when the requirement for secondary treatment for ocean discharge was waived, it was determined that reclaimed water service was about 33% less expensive than drawing additional potable water from the local water supplier. Consequently, all new development in the district is provided with a dual system, and this is being extended to high-rise office buildings for toilet flushing. Currently, about 25% of all the water used in Irvine is nonpotable water produced by its reclamation plant. The district hopes to provide about 0.6 m^3/s (13 mgd) of reclaimed water to its customers by the year 2000.[2]

An important feature of reclamation programs, as illustrated by those of the Los Angeles County Sanitation Districts, is that the reclamation plants are located far up on the sewerage network, near the markets for reclaimed water. The plants do not treat the sludge produced; it goes back into the sewerage system to be treated at a plant near the point of wastewater disposal. This is also the practice in Irvine and other reclamation plants in Orange County, Calif.

The largest dual system in operation began to be retrofitted in St. Petersburg, Fla., in 1977. One major reason for installing the dual system was because the cost of treatment for reclamation was considerably less than the cost to provide the advanced wastewater treatment that is required for discharge to Tampa Bay and the Gulf of Mexico. Another major benefit evolved from the city's reliance on a groundwater source for potable water that is limited and located a considerable distance away.

The city provides an annual average total water supply of about 2.7 m^3/s (60 mgd). About 0.9 m^3/s (20 mgd) of this is reclaimed water, which goes to some 6000 customers, including about 5650 residential users and 250 commercial, industrial, and other users. This represents only a small fraction of the potential market, which is being serviced as rapidly as facilities can be provided. The city has experienced about 10% growth since 1976, without any increase in potable water demand, because of its successful water-reclamation program.

The Japanese have confronted problems similar to those facing the developing world. In Japan, a relatively small portion of urban areas—about 40%—is sewered while the entire country has serious water-supply shortages because of its very high population density.[3]

Water reclamation was first practiced in Japan through recycling. Reclamation plants were built "on-site," primarily for toilet flushing in large buildings. Emphasis is now shifting to reclamation at municipal publicly owned treatment works (POTWs). The country currently uses about 3.2 m^3/s (72 mgd) of reclaimed water from POTWs (Table 2). Up to now, the reclamation plants installed at POTWs have been small—generally about 0.05 m^3/s (1.0 mgd)—and less than 1% of all wastewater is reclaimed, but plans are underway to extensively increase such reuse.

About 1.3 m^3/s (30 mgd) is used in buildings (Table 3). In Tokyo, the use of reclaimed water for toilet flushing is mandated in buildings larger than 10,000 m^2 (100,000 sq ft). The many diverse uses of reclaimed water in urban dual systems in Japan are shown in Table 4. Because of the heavily urban setting, landscape irrigation is far less important than in the U.S.

In Singapore, secondary wastewater is discharged to the ocean through outfalls. At one location, effluent is intercepted, filtered, and chlorinated at a 0.5-m^3/s (10-mgd) plant to provide water to an industrial park. This program has been extended to provide water for flush toilets for some 25,000 residents in 12-story apartment buildings.

Throughout the world, dual distribution systems are proliferating, speeded up by policies adopted by states in the U.S. and governments elsewhere. An important feature of all these reclamation systems is that customers pay for the reclaimed water, but generally at a price significantly less than for fresh water.

REUSE PLANNING

Cities in the industrialized world have a major advantage in initiating reclamation programs: they already have the necessary sewerage systems and secondary treatment plants. However, this is not always positive, as treatment plants are typically situated to minimize treatment and disposal costs. Consequently, plants are generally at a low elevation, located a great distance from reuse markets. Also, the costs to retrofit streets and buildings in developed urban areas to add a new service may be prohibitive.

In developing countries, on the other hand, the investment in urban infrastructure is so far short of the need that the costs of conventional and dual systems may not be so different; with a dual system, the savings incurred in avoiding the need to exploit an additional water supply may, in fact, offset the cost differential. If the initial cost for needed facilities is too great to be borne, which is generally the case in developing countries, at least the planning might be done to facilitate reclamation and reuse in the future. Further, an important feature of reclamation is that it can be staged, with reclaimed water being introduced into the system in small, affordable increments.

In any event, it is clear that the traditional practice of considering sewerage separately from water supply is inappropriate. With the difficulties inherent in financing systems in developing countries, planners can lower costs by considering water reclamation in initial planning stages and by

Table 2—Uses of Reclaimed Water in Japan

Category	Percent of total	Amount, m³/s (mgd)
Nonpotable in dual systems	40	1.3 (29)
Industrial	29	0.9 (21)
Agricultural	15	0.5 (11)
Stream flow augmentation	12	0.4 (8)
Snow removal	4	0.1 (3)
Total	100	3.2 (72)

Table 3—Buildings Using Reclaimed Water in Japan

Type	Percent
Schools	18
Office buildings	17
Public halls	9
Factories	8
Hotels	4
Others (residences, shopping centers, etc.)	44
Total	100

Table 4—Uses of Reclaimed Water in Dual Systems in Japan

Use	Percent
Toilet flushing	37
Cooling water	9
Landscape irrigation	15
Car washing	7
Washing and cleansing	16
Flow augmentation	6
Other	10
Total	100

situating plants in appropriate areas. In developing countries, where the impetus for reuse comes from water resource needs, the plants should be located upstream on the sewerage system, nearer the potential markets. This has a further advantage in that reclaimed water that is not sold can help sustain the flow in urban streams that would otherwise run dry.

Another characteristic of cities in developing countries is that storm drainage is inadequate, and stormwater management programs might be somewhat different if reclamation is being considered. Depending on local circumstances, stormwater may be stored and then fed into the reclamation system.

EXPERIENCES IN DEVELOPING COUNTRIES

Water reuse in urban areas in developing countries has generally been unplanned and indirect. In Bogota, Colombia, for example, the city installed a good sewerage system, but the sewers discharge untreated wastewater to the Rio Bogota. Water is taken from the heavily polluted river to irrigate market crops, with inevitable negative health consequences, particularly to unwary visitors.

The city of São Paulo in Brazil is illustrative of large, rapidly growing urban areas that confront water shortages while planning extensions to their sewerage systems and wastewater treatment plants. A 3.5-m³/s (80-mgd) module of a secondary treatment plant went into operation in 1988 in the western part of the city in the vicinity of rapidly growing urban and industrial areas. The quality of the effluent was so high that pilot-plant studies were initiated to determine whether coagulation, sedimentation, and sand filtration would produce an effluent that would meet quality requirements for urban reuse.

The research results were so encouraging that São Paulo is now surveying industry requirements for nonpotable water. Paper and chemical plants are the largest water users. Other uses, such as seasonal landscape and local market crop irrigation and toilet flushing in the large office and residential buildings that characterize São Paulo, are also being evaluated. Further pilot-plant studies are being undertaken to develop design criteria for reclamation, with the aim of eliminating the sedimentation step, which sharply reduces coagulant dosages.

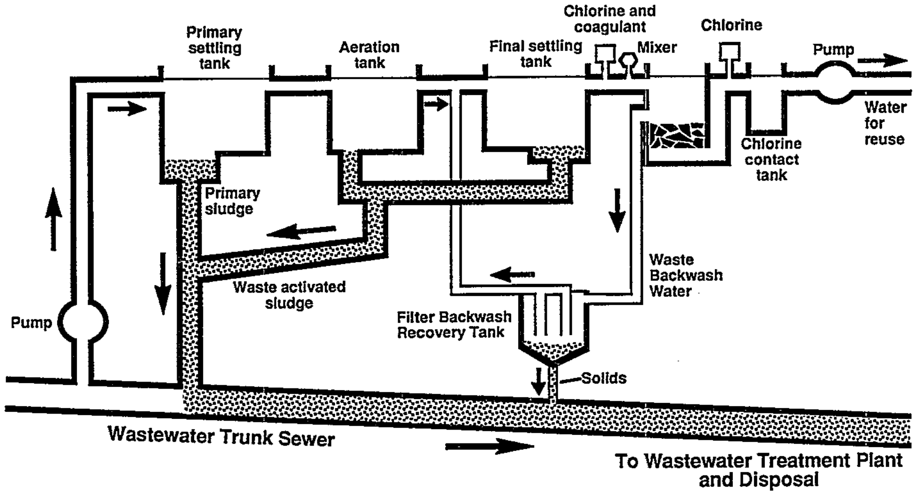
The Beijing-Tianjin region of China, with a total area of 28,000 km² (11,000 sq miles) and a population of about 18 million, 60% of which is urban, provides another example of the potential for reuse. In 1984, water allocations totaled about 200 m³/s (4500 mgd)—about 65% for agriculture and 35% for industrial and domestic use.[4] Studies showed that the most economical source of additional water for the region would be through reclamation of wastewater for agricultural, industrial, and domestic uses with the recognition that, over time, the reclaimed water for agriculture would be switched to urban and industrial use.

The major problem is that much of the region's population is not yet served by sewerage, and that only about 10% and 20% of the municipal wastewater in Beijing and Tianjin, respectively, receives treatment. Projects for urban sewerage, wastewater treatment, and water reclamation and reuse are underway. It is expected that a total of about 25 m³/s (600 mgd) will be available for nonpotable reuse in 2000.

The practice of nonpotable reuse will also be valuable in the arid Middle East and North Africa. Other than in oil-rich countries, the focus has been on reclamation of urban wastewater for agriculture. Reclamation in the region has followed the pattern elsewhere, where farmers take water from polluted drains and rivers that would be dry most of the year except for the wastewater. This focus is understandable, as the traditional priority use for fresh water in arid areas has been agriculture. However, it is now being recognized that in many countries in this region, urban and industrial demands for water may constitute 30 to 45% of the total demand, representing a substantial need, but also providing a potential source of reclaimed water.

Plans for Jordan exemplify the new approach to water reclamation. About 70% of the population is urban, and this percentage is growing. The portion of total water demand for urban and industrial use is expected to increase from about

Figure 1: Typical Flow Diagram for Los Angeles County Sanitation Districts Reclamation Plant.



25% today to about 45% in 25 years, with a commensurate drop in agricultural allocations. Because sewerage in urban areas is expected to increase over the next 10 years from about 45% to 85%, the strategy is to use the increased volume of urban effluent to provide reclaimed water for agriculture, releasing fresh water now going to agriculture for use in the cities and in industry.

Unfortunately, in Jordan and elsewhere in the region, there are many issues that are not yet being examined. The potential exists for better use of very limited freshwater supplies by using reclaimed water for nonpotable purposes in urban areas, stretching the existing freshwater resources to serve a much greater population. Otherwise, the only additional sources of water would be new dams and reservoirs that would be extremely costly and of questionable political feasibility. Most of the reclaimed water, after being used to meet industrial, toilet flushing, and other nonconsumptive demands, could be reclaimed for agricultural use.

Because the value of water in urban and industrial uses is much greater than in agriculture, the cost-recovery potential to municipalities providing the reclamation service gives better assurance that the system will be properly managed than if the reclaimed water were used solely for agriculture, where cost recovery is far less likely. Furthermore, providing a nonpotable water distribution system in urban areas in Jordan is more feasible than in many countries because more than a third of the urban population is not yet served with piped water—a service that does have a high priority for the future.

MEETING MANY NEEDS

For the protection of the public health and the conservation of water resources in the developing world, sewerage and wastewater treatment must be provided, reclaimed water quality must be monitored and, most importantly, the use of the water must be metered, charged for, and regulated. If reclaimed water is considered a resource rather than a waste, a potential for cost recovery exists. Only with cost recovery will a reclamation program be sustainable.

Urban areas throughout the world, and especially in the developing countries of Asia, Africa, and Latin America, are growing rapidly, and many cities are facing water shortages. The reuse of wastewater for agriculture is widely practiced in the developing world, but it is often unplanned and unregulated, posing major threats to the public health of farmers and those using the crops. Even if agricultural practices can be improved—and they should be—the advantages of reclaiming water for urban and industrial uses are many.

The principal impetus is the shortage of water. Those responsible for planning or engineering water-resource, sewerage, or pollution-control projects in urban areas of developing countries should assess the potential for water reclamation for nonpotable urban and industrial reuse as well as agricultural reuse. If capital investments for additional water-resource development are imminent, the option of water reclamation should be evaluated. If reclamation for reuse is feasible, either immediately or in the future, the design of the sewerage system and the situating of water reclamation plants should be undertaken to minimize costs.

Daniel A. Okun is Kenan professor emeritus of environmental engineering at the University of North Carolina in Chapel Hill and is a consultant with Camp, Dresser and McKee, Inc.

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REFERENCES

1. "Pomona Virus Study, Final Report." Los Angeles County Sanitation Districts, California Water Resources Control Board, Sacramento, Calif. (1977).
2. Young, R. E., *et al.*, "Wastewater Reclamation—Is it Cost Effective? Irvine Ranch Water District—A Case Study." Proc. Water Reuse Symposium IV, AWWA Research Foundation, Denver, Colo., 55 (1987).
3. Murakami, K., "Wastewater Reclamation and Reuse in Japan." Pro. 26th Annual Tech. Conf., International Session, Japan Sewage Works Assn., Tokyo, 43 (1989).
4. "Water Resources Policy and Management for the Beijing-Tianjin Region." State Science and Technology Commission, Beijing, and Environment and Policy Inst., East-West Center, Honolulu (1988).

U.S. WATER REUSE: CURRENT STATUS AND FUTURE TRENDS

Kenneth J. Miller

The hydrologic cycle represents the ultimate water-reuse process: the finite amount of water on the planet undergoes continuous use and regeneration while travelling through the various stages of the hydrologic continuum. Today, the world's rising population and its concurrent increase in industrialization have outpaced the slow-moving natural cycle. Many areas already face severe water shortages, and things are only going to get worse. To meet the growing demand for water, the pace of regeneration and subsequent reuse must be accelerated.

Planned, unplanned, direct, and indirect water reuse have been practiced for over 2000 years. Unfortunately, water-reuse technology has been negatively affected by the public's reticence to accept historical and existing reclamation practices. The best example that supports this claim is the water-supply industry in the U.S. There are very few surface-water bodies in the U.S. that do not receive wastewater discharges from the upstream municipalities and industries. In fact, by the early 1950s, nearly all surface-water and some groundwater supplies showed evidence of man's industrial and municipal wastes. The public does not want to hear this, however, and when a water reuse project is proposed, the initial public reaction is generally negative.

Notwithstanding the sentiment of the consuming public, indirect and direct reuse has been contributing to our recreational and agricultural water, aquifer recharge, and potable water supply for more years than we care to acknowledge.

Agricultural irrigation in Santa Rosa, Calif., reclaims 16 mil. gal of wastewater a day.

BENEFITS OF WASTEWATER RECLAMATION

Benefits attributable to wastewater reclamation generally fall into two categories: supplementing available resources and pollution abatement. Water reclamation and reuse supplement or enlarge what may otherwise be a fixed quantity of water available for use in a given area.

The quality of water required for various uses often dictates the most desirable form of reclamation and reuse. For example, water for most agricultural uses and many industrial uses need not be of as high a quality as that used for human consumption. In such cases, water reclamation through crop irrigation and use of treated effluents for industrial purposes may relieve the burden of supplying these needs with high-quality potable water. Artificial recharge of groundwater, either by injection or spreading of reclaimed water is often possible in areas that depend largely on groundwater sources. This also results in augmenting the available source by essentially "banking" reclaimed water in the subsurface against the time when withdrawal of groundwater exceeds natural recharge.

Finally, in areas where sufficient potable water is not available, highly purified reclaimed water can be recycled into the potable water system. This should not be implemented without considerable research covering all possible effects. It is not, however, an action without precedent; direct or semi-direct domestic recycling is now being practiced in some areas of the world and will undoubtedly become more widespread.

The other major pollution abatement benefit of water reuse and reclamation involves the removal of more pollutants than conventional secondary waste treatment processes can accomplish. Generally, the quality standards for water reuse are such that some additional waste treatment is necessary to reduce oxygen demand; nutrient content; avoid undesirable algal growths; remove suspended solids, color, taste, odor, and refractory materials; and remove or inactivate potential disease-causing organisms.

In the U.S. today, water reuse practices can be broken down into the following categories: indirect potable reuse, agricultural reuse, urban landscape irrigation, industrial reuse, groundwater recharge, and potable reuse demonstration.

Table 1—Agricultural Reuse Statistics

Agricultural Reuse Statistics

Leesburg, Fla.	
maximum reuse volume:	3 mgd (3400 ac-ft/yr)
irrigation area:	330 ac of total 915-ac site
reservoir capacity:	10 mil. gal
pumping station capacity:	6400 gpm
irrigation pipeline:	44,000 ft
irrigation guns/gun spray rate:	83/620 gpm
Maui, Hawaii	
maximum reuse volume:	4 mgd (4500ac-ft/yr)
irrigation area:	400 ac
distribution system type:	3 side-wheel roll systems
distribution distance:	960 ft
Sonora, Calif.	
reservoir capacity:	1800 ac-ft
distribution system:	9 miles
number of release points:	19
irrigation area:	1300 ac
flow rate, per release point:	100 to 1300 gpm

INDIRECT POTABLE REUSE

Indirect potable reuse is practiced by nearly all communities dependent on surface water. The difference from city to city can, in several instances, be quantified by the dilution factor. The classic case in the U.S. is the Upper Occoquan Sewage Authority (UOSA) that provides potable water to the suburbs of Washington, D.C.

The 9.8-bil.-gal Occoquan Reservoir—the principal water supply in Northern Virginia—serves more than 660,000 people. In the 1960s, before the formation of UOSA in 1971, discharges of conventionally treated wastewater deteriorated the reservoir's water quality. To reverse this trend, the Virginia State Water Control Board adopted a comprehensive policy that required construction of a highly sophisticated, regional, advanced wastewater reclamation plant to replace the 11 largest existing secondary treatment plants, and to reclaim the wastewater as a water resource.

Criteria accompanying the policy specified treatment standards for UOSA that are among the most stringent in the U.S. Additional criteria established treatment processes deemed necessary to achieve the prescribed level of treatment. A 15-mgd treatment plant designed to meet these criteria began operation in June 1978 (see Box). The facility has performed so well that the plant's capacity has been expanded to treat 27 mgd and planning continues for further expansion to 54 mgd. Operating costs for conventional and advanced wastewater treatment are \$0.83/1000 gal to \$1.37/1000 gal.

AGRICULTURAL REUSE

To provide for its inevitable growth and to minimize impact on its natural environment, in 1970, Leesburg, Fla., began exploring ways to improve its wastewater treatment plant and to discontinue the practice of discharging effluent to Lake Griffin. Efforts culminated in an improved 3-mgd (3400 ac-ft/yr) secondary treatment plant and new wastewater reuse irrigation system, which began operation in January 1981. Effluent was diverted away from Lake Griffin by pumping 8 miles west of the plant. At this site, approximately 330 ac are irrigated with reclaimed wastewater.

This wastewater reuse irrigation system is currently the largest solid-set (fixed-gun) system in the state (Table 1). Because of the seasonally high water table, approximately 100 ac of the irrigated areas are planted with Coastal Bermuda grass, which is harvested using city-owned agricultural field machines and tractors.

Reclaiming wastewater for irrigation not only makes Maui Hawaii's first large-scale wastewater reclamation facility and new collection system a zero-discharge plant, but also converts the reclaimed wastewater into a valuable resource for the arid Kihei region. The Kihei secondary treatment plant serves Maui's southwest coast and has an average design capacity of 4 mgd (Table 1).

Designed to eventually serve a 4400-ac area, the collection system includes eight pump stations that deliver collected wastewater to the main-9-mgd pump station that delivers wastewater to the Kihei plant.

Most of the reclaimed water is used for irrigating ranch land and newly landscaped roadways. About 250,000 gpd are treated further by mixed-media filtration and chlorination to produce higher quality water for park irrigation.

A standby injection well is used

Table 2—Urban Landscape Irrigation Statistics

St. Petersburg, Fla.	
delivery volume:	68.4 mgd
distribution network:	92 miles
residential user fees:	$6/mo
industrial user fees:	$6/mo for the first ac-ft and $1.20 for each 0.5 ac-ft increment or $0.25/1000 gal ($81/ac-ft)
Tucson, Ariz.	
annual delivery volume	35,000 ac-ft/yr
demonstration delivery volume:	1000 ac-ft
spreading basin area:	3 ac
extraction well:	1 on-site
monitoring wells:	10
suction lysimeters:	6
access wells:	20
Colorado Springs, Colo.	
annual delivery volume flow design:	1000-1250 ac-ft/yr
daily flow design:	7 mgd
user fees:	$0.60/1000 gal ($196/ac-ft)
Aurora, Colo.	
golf course irrigation area:	120 ac
golf course reservoir:	6 mil. gal
plant effluent reservoir:	0.5 mil gal
annual average volume reused:	100 mil. gal
distribution pipeline:	4 miles
user fees:	$0.78/1000 gal

during the infrequent, but heavy, rainy periods. The well takes the reclaimed water through solid rock layers into a cinder layer more than 100 ft below sea level.

The unique Tuolumne County Water District in Sonora, Calif., reuse plan called for an irrigation system rather than a wastewater disposal system. Reclaimed water is delivered to individual ranchers based on a predetermined irrigation schedule, adjusted each year for cropping patterns, rainfall, and other factors. Over 30 ranchers, with a combined 1300 ac, will use the reclaimed water for irrigation. Acceptable uses of the reclaimed secondary effluent, according to the California State Department of Health, include irrigation of pasture, fodder, fiber, or seed crops, plus stock-watering and aesthetic uses where public contact is prohibited.

Each rancher signs a contract with the district to take a specified quantity of water—depending on irrigated acreage—during the April through October irrigation season. The water is free, but the rancher agrees to take the water for 20, 30, or 40 years. The contract is also binding on successive property owners. If a rancher does not take the water, the district may enter the land and apply the water as contracted. To provide system flexibility, each rancher agrees to take all water made available up to 125% of the contracted amount. At the same time, the district is obligated to make every effort to temporarily reduce the water delivered in any given year if there are cropping pattern changes.

A unique feature of the irrigation system is the automated operation of the irrigation turnouts (Table 1). Solenoid-actuated, hydraulically operated globe valves on each pipe turnout are remotely operated by command from a control panel at the Sonora Treatment Plant. Commands are transmitted by radio signals initiated on a keyboard at the treatment plant. Flow rates and totalized flows at each turnout can be displayed on a cathode ray tube (CRT) screen or line printed on command at the treatment plant control panel. The remote station transmits actual flow data to the CRT for visual confirmation.

URBAN LANDSCAPE IRRIGATION

The use of reclaimed wastewater for urban irrigation of landscaped areas is one of the fastest growing reuse types in the U.S. Many municipalities find this the easiest and least costly method of reuse. The benefits can also be great because exterior residential and commercial watering on a yearly basis can average more than 40% of a residential customer's total water consumption in arid and semiarid areas.

In St. Petersburg, Fla., which is located in a water-short region, potable water must be piped in from limited well fields located 30 to 50 miles from St. Petersburg.

In the mid-1970s, the city decided to embark on a water-reuse program to help solve its wastewater and water supply problems by constructing a limited dual distribution system (Table 2) that would provide non-potable water for irrigation of public and private properties, including golf courses, parks, school grounds, commercial and residential sites, and street medians.

Secondary wastewater treatment, including grit removal, aeration, and clarification, results in a greater than 90% reduction of biochemical oxygen demand (BOD) and total suspended solids (TSS). The wastewater is then filtered, chlorinated, and placed in a 12-hour retention area. When necessary, treated wastewater is rechlorinated. An auxiliary deep-well injection system ensures zero-discharge or reduces use during rainy periods.

The dual water system has had a profound effect upon the city's water system, reducing potable water demands by 10% to 15% of the water use in 1982 and 1983. The potable water savings in 1983 was nearly 14,700 ac-ft, saving the city thousands of dollars. Reclaimed water is sold to other city departments and to private and public entities at $6/mo.

In 1982, Tucson, Ariz., initiated a metropolitan wastewater reuse program mandating that reclaimed wastewater be used to irrigate all municipal and private golf courses, school grounds, cemeteries, and parks, as well as for other identified uses. By 1984, the Tucson Water Department was operating the first elements of a wastewater reuse treatment plant, reservoir, and transmission system. To date, $23 million has been spent on the system, and a 10-year capital development program calls for an additional $40 million to complete the system. The completed system will provide approximately 35,000 ac-ft/yr of reclaimed wastewater.

Because irrigation water demands vary as much as 400% from winter to summer, subsurface storage of reclaimed wastewater in an aquifer storage-and-recovery system was installed. A demonstration recharge project showed that effluent could be safely recharged and later recovered. The recharge system has been expanded for large-scale controlled recharge and recovery.

Colorado Springs, Colo., is located at the eastern base of the Rocky Mountains in a water-short area. To reduce dependence on water from the western slopes of the mountains, in the early 1960s the city implemented a limited dual-distribution system in which reclaimed wastewater and surface water from a nearby stream was used to meet major irrigation demands. This is one of the oldest operating systems in the U.S. in which reclaimed wastewater is used for urban landscape irrigation.

Reclaimed water, which comes from the city's secondary wastewater treatment facility, is recycled through two major distribution systems that parallel the city on the east and west sides (Table 2). Current users include parks, golf courses, cemeteries, and commercial properties. Each site must provide its own pumping to meet individual pressure requirements.

Since 1970, Aurora, Colo., has used reclaimed domestic wastewater to irrigate the Aurora Hills Golf Course (Table 2). Aurora uses an average of 100 mil. gal/yr of reclaimed wastewater pumped from the Sand Creek Wastewater Reclamation Facility to an onsite nonpotable water reservoir. In 1982, four city parks were added to the reclaimed water system, and their irrigation requires an additional 50 mil. gal/yr.

The plant uses conventional screening and grit removal followed by aeration and final clarification. A chlorine solution is added to the final clarifier effluent immediately upstream from the contact basin. From an onsite 0.5-mil.-gal reservoir, the effluent is either reused or discharged into a nearby stream. The reuse system pumps the water from the reservoir through multi-media pressure filters and a 14-in.-diameter pipeline.

In 1982, when irrigation of city parks began, the reuse facility's capacity was doubled, and the plant's effluent standards were tightened. When reclaimed water was used exclusively for golf course irrigation, the standards required a discharge limit of 30 mg/L each of BOD and TSS and 200 fecal coliform organisms/100 mL. However, because football and soccer are played at the parks—sports that promote frequent human contact with irrigated grass—the mean total coliform standard was made more stringent at 23 coliform/100 mL.

Process modifications were made to meet the proposed standards, including the addition of a flow-paced jet disinfection system to replace the old chlorine solution system. The reuse water for the park is taken directly from the line that feeds the onsite reservoir, rather than from the reservoir itself, thus maximizing the available chlorine residual. In the filter complex, a polymer-feed system was added to improve solids recovery in the pressure filters. An additional chlorine-feed system allows for post-chlorination of all reclaimed water. The 4-mile pipeline allows for an additional 80-minute contact time at peak pumping rates.

Three operational problems are currently being addressed. To alleviate problems with algal growths, which contribute to unsightly conditions and some sprinkler nozzle-clogging, algacides are used on a continuous basis. To prevent reservoir debris from causing nozzle-clogging, a self-cleaning drum strainer was installed on the pump discharge. Salt buildup in low-lying areas where ponding of surface runoff occurs is being mitigated by eliminating ponding or by seeding those low-lying areas with more salt-resistant strains of grasses.

The economics of the Sand Creek reuse program have been quite favorable for the city. In the past, an average of 100 mil. gal/yr were used for irrigation. The 1980, costs of the reuse system, including debt service of the original filtration complex and transmission line, but excluding irrigation pumping costs, averaged $0.43/1000 gal.

Since 1975, the Inverness Water and Sanitation District, Colo., has reclaimed wastewater from the commercial office park it services to irrigate the park's 18-hole, 140-ac golf course. The park, located south of Denver, will ultimately have over

Table 3—Inverness Reclaimed Wastewater Characteristics

Characteristics	Concentration
5-day BOD	20 mg/L
Total suspended solids	20 mg/L
Total dissolved solids	460 mg/L
Ammonia nitrogen	14 mg/L
Sodium	20 mg/L
Sulfur oxide	30 mg/L
pH	6.9 to 7.3
Fecal coliform	20 organisms/100 mL

Table 4—Water Factory 21 Performance and Requirements

Constituent	Secondary effluent	Blended injection water	Requirements for blended injection water
COD, mg/L	130	10	30
Methylene blue active substances, mg/L	2.7	0.08	0.05
Ammonia nitrogen, mg/L	45	0.9	1.0
Cadmium, mg/L	29	0.6	10
Chromium, mg/L	154	8.8	50
Mercury, mg/L	9	2.4	5
E-coli, MPN/100 mL	41×10^6	>2	>2
Turbidity, NTU	36	0.4	1.0

Table 5—Denver Demonstration Plant Quality Goals

Characteristic, unit of measure	Average, potable water
Turbidity	0.6
Carbon alcohol extract, mg/L	0.09
Alkalinity, mg/L as $CaCO_3$	60.0
Harmful organics	None present
Suspended solids, mg/L	0.0
Total coliform, no./100 mL	0.1
Total dissolved solids, mg/L	157.0
Fecal coliform, no./100 mL	0.0
Nitrate nitrogen, mg/L	0.3
Fecal strep, no./100 mL	0.0
Ammonia nitrogen, mg/L	0.0
Virus	None present
Total phosphate, mg/L as P	0.07
Gross metals	None harmful
Hardness, mg/L as $CaCO_3$	88.0
Taste	Unobjectionable
BOD, mg/L	<1.0
Odor	Unobjectionable
COD, mg/L	<5.0
Total organic carbon, mg/L	5 to 8
Carbon chloroform extract, mg/L	0.06

The purification process used at UOSA includes activated-sludge secondary treatment, phosphorus removal by lime coagulation, two-stage recarbonation, nitrogen removal by ion exchange, mixed-media filtration, activated-carbon adsorption, and breakpoint chlorination. Resource recovery and reuse are achieved using ion-exchange media, carbon regeneration, and organic-solids composting. The plant uses a closed-cycle ammonia stripping and adsorption process for regeneration of the ion-exchange system regenerate solution. The ammonia removal and recovery process recovers 40% ammonium sulfate solution for resale as an agricultural fertilizer. A composting system converts waste organic solids to a stable organic soil conditioner suitable for recreational land rehabilitation or agricultural use.

1000 developed acres with a projected average daily wastewater flow of 0.9 mgd. In 1984, the development averaged flows of 250,000 gpd. All wastewater flows are collected and treated onsite. The golf course uses an average of 100 mil. gal/yr; almost half this amount is reclaimed wastewater.

The park's treatment facility includes a flow equalization basin, aeration basins, secondary clarifiers, and a chlorine contact basin. Disinfection is accomplished using chlorine gas that is put into solution and mixed with the secondary effluent. At a flow rate of 250,000 gpd, a theoretical contact time of 45 minutes is provided.

The treatment facility's chlorinated effluent is pumped through a 4200-ft-long, 8- and 10-in.-diameter pipeline to a storage reservoir, allowing an additional contact time of 20 minutes. The storage reservoir, which is not part of the golf course, has a capacity of approximately 55 mil. gal. The reservoir is designed for an annual fill and draw; water fluctuation is approximately 20 ft. Because the reservoir receives all water from the wastewater treatment plant, it is sized to store water throughout the year, with irrigation occurring from April through October. The typical water quality of the irrigation water discharged to the reservoir is presented in Table 3.

At the pump station drawing water from the storage reservoir, chlorine may be added to the irrigation water before it is pumped to the distribution system. However, in general, the addition of chlorine is not required to meet the discharge standard of 23 fecal coliform organisms/100 mL.

Water quality at the sprinklers will generally be equal to that shown in Table 3, with the exception of TSS and fecal coliform; these values may be markedly higher because of the presence of algal blooms and wastes produced by waterfowl on the reservoir.

The average application of water to the golf course is equivalent to 0.55 mgd, with peaks of 1.4 mgd. Of the 100 mil. gal required to operate the irrigation system, the current wastewater flow provides approximately 65%, with the remaining 35% provided by the district's well. By 1987, 100% of the irrigation demands were met with reclaimed wastewater.

The 1980 costs of the reuse system, excluding debt service, but including all operation and maintenance costs of the reuse pumping systems, averaged $0.64/1000 gal. Because of the high cost of obtaining additional water for irrigation, which is estimated at over $1.00/1000 gal, the district saved over $0.36/1000 gal of water used. As the district grows, and a greater percentage of the irrigation water demand is met with reclaimed wastewater, the district will realize greater savings. Future plans for the district include irrigation of lawns and other open spaces. Plans are already underway for a complete dual distribution system. Use of the reclaimed wastewater for lawn irrigation will require additional treatment to meet the stringent water-quality standards proposed by the Colorado Department of Health.

INDUSTRIAL REUSE

There are many uses of reclaimed wastewater for industrial purposes; each use may require specific levels of treatment. In 1979, industrial reuse process flows averaged 66 mgd (73,000 ac-ft/yr), and reclaimed water for industrial cooling accounted for nearly 142 mgd (159,000 ac-ft/yr).

In the city of Tampa, Fla., a remodeled incinerator facility burns 1000 ton/day of refuse and uses approximately 1 mgd of reclaimed wastewater for cooling-water makeup. The water is pumped from the Hookers Point advanced wastewater treatment facility, 1.5 miles from the McKay Refuse-to-Energy Facility. Although the remodeling cost was $60 million, the system saves Tampa's water department over

1000 ac-ft/yr of potable water.

Water was an important raw material for the initial 200-MW stage of the R.D. Nixon Power Plant, a coal-fired, steam/electric plant near Colorado Springs, Colo. Although brackish, the well-water supply was selected to provide water to the facility. As the power plant expands, however, reclaimed water will be relied on because the well-water supply is limited. With conventional blow-down practices for cooling-water systems relying on well water, effluents from the power plant would exceed state water-quality limits for dissolved salts and metals in the small receiving stream. Thus, it was necessary to develop an effluent recovery and recycle system that would allow these supplies to be reused. The selected process recovers and recycles power plant cooling-water effluent, attaining zero discharge. Well water is softened by ion exchange; effluent is treated and recovered by flocculation, clarification, filtration, reverse osmosis, and vapor-recompression evaporation. Brine concentrates are disposed in evaporation ponds. Within the recovery system, flows range up to 1 mgd with salinities ranging from one-fifth to over five times that of seawater.

The system produces water and treats effluents for less than alternative systems using municipal wastewater or purchased water.

GROUNDWATER RECHARGE

In 1975, the Orange County Water District (OCWD) began operating a water reclamation facility—Water Factory 21—capable of reclaiming 15 mgd of secondary effluent and injecting it into the coastal aquifer to prevent seawater intrusion and to recharge the existing potable groundwater basin.

Processes similar to those used at South Lake Tahoe, Calif., along with breakpoint chlorination and reverse osmosis, were selected. This combination was chosen to help ensure a product water able to meet drinking-water standards. Blending of reclaimed wastewater with at least 50% desalinated seawater or deep well water was provided as further insurance.

Specific unit processes include lime clarification with sludge recalcining, ammonia stripping, recarbonation, breakpoint chlorination, mixed-media filtration, activated-carbon adsorption with carbon regeneration, post-chlorination, and reverse-osmosis demineralization.

The 5-mgd, high-pressure, reverse osmosis system was designed to operate in parallel with the 15-mgd activated carbon facility. Today, the activated carbon system operates in standby mode largely because of high-quality secondary effluent and because of reduced groundwater recharge needs.

Performance and treatment requirements for Water Factory 21 are shown in Table 4. Total capital and operating costs, based on 1983 dollars, were estimated to be $1510/mil. gal (491/ac-ft). The lime/reverse-osmosis process tested at Water Factory 21 offers significant potential for meeting treatment needs. The process would eliminate ammonia stripping, sand filtration, and activated-carbon adsorption and regeneration. Costs for the new low-pressure system are estimated to be $1346/mil. gal ($438/ac-ft), as compared to $1510/mil. gal ($492/ac-ft) for the Water Factory 21 treatment trains.

POTABLE REUSE DEMONSTRATION

Chanute, a relatively small community in southeast Kansas, relies entirely on the Neosho River for its water supply. Chanute maintained and operated a conventional rapid-sand-filtration plant to treat Neosho River water before it entered the city's potable water distribution system. During the years 1953 through 1957, a record drought struck the Neosho drainage basin. Flow decreased and, in early 1956, it practically ceased. Although all possible water conservation measures were instituted and flow-augmentation procedures were attempted, the water supply continued to dwindle. On October 14, 1956, without any fanfare, city officials opened a valve that permitted mixing of effluent that had received conventional secondary treatment with water stored in the Neosho River channel behind the water treatment plant impoundment dam.

The recycling process was used for a total of 5 months during the fall and winter of 1956 and 1957. During this period, treatment removed, on the average, 86% of the BOD and 76% of the chemical oxygen demand (COD) contents of the wastewater. It substantially reduced both total nitrogen and ammonia-nitrogen concentrations; detergent concentrations decreased an average of 25%. It was estimated that one complete cycle through the waste treatment and back through the water treatment required about 20 days. Thus, during the total period of time during which water recycling was practiced, the same water passed through the treatment plant approximately seven times.

The Denver Water Department is operating a 1-mgd demonstration plant that produces potable water from secondary treatment plant effluent. The need for the project grew out of the recognition that additional conventional sources, if available, might cost $5000/ac-ft to develop by the year 2000; and industrial reuse of wastewater would not substantially reduce water demands. The construction of the demonstration plant is part of a $35-million, 7-year project by the department to demonstrate that high-quality water, equal to or better than Denver's current drinking water, can be produced safely and reliably from treated wastewater treatment plant effluent. EPA is also participating in this demonstration project by contributing approximately $7 million of the total cost.

The demonstration plant cost approximately $16.2 million to build. Its capacity is 1 mgd for the initial processes through the first stage of carbon adsorption, and 0.1-mgd for the remaining processes. Water treated by this facility has undergone 5 years of extensive testing for more than 200 potential contaminants, and an exhaustive program of health-effects testing is underway.

None of the reuse water produced from this demonstration plant will be added to drinking-water supplies. It will be allocated strictly for industrial use at the Metropolitan Denver Sewage Disposal District No. 1 (MDSDD) Treatment Plant and for the extensive testing program. If the absolute dependability of this reuse facility is established, reuse may be instituted on a full-scale basis.

The treatment process was developed from information obtained from 10 years of operation of a 5-gpm pilot plant by the Denver Water Department and University of Colorado and from information gained by CH2M Hill from the design, construction, and review of the Lake Tahoe Advanced Wastewater Treatment Plant, Occoquan Advanced Wastewater Treatment Plant, and several other projects.

The MDSDD Treatment Plant is adjacent to the Denver Water Department's reuse demonstration plant. Unchlorinated secondary effluent is pumped from the treatment plant to the reuse plant. Secondary effluent enters the reuse plant at the rapid-mix basins, where lime is added and mixed with the water. Lime facilitates the removal of suspended particles, phosphorous, and some heavy metals, and aids in the destruction of viruses and most microbiological organisms. Water then flows to flocculation basins. If necessary, aluminum sulfate and polymer are added to enhance flocculation and settling characteristics.

Following flocculation, the water enters the chemical clarifiers, which remove settleable solids and reduce solids loading into the filters. The water then passes into the recarbonation basin, where carbon dioxide is added to reduce the pH to between 7 and 8, and through ballast ponds to equalize the flow to downstream processes. Pressure filters remove most of the remaining suspended particles, improving the subsequent treatment steps. The treated water then flows into the selective ion-exchange process, which removes nitrogen in the form of ammonium (NH4) from the process flow by passing the water through a naturally occurring zeolite media (clinoptilolite). Sodium chloride is added to regenerate the zeolite media. The ammonia recovery and removal system them removes the ammonium ions from the regenerate solution. Ammonium sulfate, a commercial-grade fertilizer produced as a byproduct of the system, is stored onsite and sold to reduce treatment expenses. The water then passes through first-stage carbon adsorption process. This process removes remaining dissolved organic compounds. The product water then passes through the ozonation process. Ozone oxidizes organic substances that remain after first-stage carbon adsorption and also acts as a primary disinfectant. The water then passes on to second-stage granular activated carbon treatment where the remaining organics that have been rendered more absorbable by ozone oxidation are removed. In addition, biological activity on the carbon filter is used to remove organics by biodegradation.

The demonstration plant can regenerate and store spent granular activated carbon. A fluidized bed regeneration furnace that can operate at a maximum temperature of 2000° F regenerates the carbon that has adsorbed the organics. The water then flows to the reverse-osmosis system where dissolved salts are removed back to the range of Denver's present supply. Reverse osmosis also serves as the final physical barrier to the passage of a variety of potential contaminants.

Following reverse osmosis, the water passes through an air-stripping tower that removes carbon dioxide and volatile organic compounds. The final product water is treated with either chlorine dioxide or chlorine to destroy any disease-causing organisms and provide a residual disinfectant for transmission and storage.

Recognizing that true standards for potable wastewater reuse fail to exist, the Denver Water Board elected to meet the same water quality as the potable water currently being consumed by the Denver citizens. Table 5 contains a partial list of the water-quality goals for this demonstration facility.

WATER REUSE PRACTICES IN THE FUTURE

In 1983, Tampa began a study to determine reuse alternatives for an extremely high-quality effluent from the Hooker's Point Advanced Wastewater Treatment Plant. To evaluate the effects of additional treatment on the effluent, a pilot plant has been constructed with capabilities that include pre-aeration, high-lime treatment, multi-media filtration, reverse osmosis, ultrafiltration, granular activated carbon, and disinfection.

A research program has been designed to determine the health risks associated with reuse of the pilot-plant product water as a component blended into a raw potable water supply.

The ultimate goal of the Tampa Water Resources Recovery Project is to treat an advanced wastewater treated effluent to potable quality. The final product will be placed into the Tampa bypass canal to recharge an adjacent aquifer and then flow into the Hillsboro River upstream of a raw water intake. To date, water-quality parameters of the treated water exceed those of the river water.

Surface supplies, while improving, may never be swimmable and fishable, if indeed they ever were, and groundwaters are showing evidence of man's encroachment and of his industrial renaissance. The quality of many surface supplies, like that of the Hillsboro River, will continue to deteriorate until planned reuse and its associated treatment process will offer a higher-quality product than conventional treatment. The need for ever-improving advanced wastewater treatment processes and recycling technology will continue to grow worldwide as the population increases and the standard of living of the third-world developing nations begins to improve. The key to our success in dealing with the water-resource problems will lie in our ability to extend and augment existing supplies through various reclamation processes.

The task of applying current state-of-the-art in water reuse will tax the ingenuity of all sectors of our society, not just the water-supply community. Research and demonstration projects will be required. Moreover, water reuse will not be limited by the ability to successfully treat wastewater, but by the costs associated with the construction and operation of the treatment. Water quality standards will be required to process or recycle water to qualities that will be desired; conceivably, five or six water quality standards for agricultural use, alone, could be developed. In addition to effluent discharge standards, standards which relate directly to industrial needs are likely to be promulgated.

Water reuse in both the U.S. and worldwide will inevitably increase as existing water supplies are incapable of meeting future demand brought about by increasing world populations and industrialization. The municipal, industrial, and agricultural demands will, thus, have to be met and, this prospect, thereby, clearly reveals the need for expanded water reuse research in the 21st century.

Kenneth J. Miller is vice president and director of water engineering with CH2M HILL Consulting Engineers in Denver, Colo. This updated report was reprinted for 1987 Annual Conference Proceedings, American Water Works Association, Denver Colo.

)n-Site Wastewater (eclamation and Recycling

John Irwin

With the onset of the 1990s, many communities and townıips have been strugling with the problem of roviding for increasing esidential and commeriàl growth at a time /hen water resources are ıore scarce and envionmental capacity to dequately manage /astes is severely limited. 'his is evidenced by the ıovement in many owns and states to adopt ew standards for water onservation in plumbing fixtures. It is also videnced by the significant number of ommunities that have imposed sewer ıoratoriums or sewer-capacity restrictions. 'inding additional water supplies and exanding wastewater treatment plant caacity is expensive, sometimes impractical, nd, at best, involves long-range planning vhen an immediate solution to the probem is needed.

On-site water reclamation and reuse ystems have been successfully used to solve hese problems. A rural school district in entral Texas experienced significant rowth, making it necessary to build a new 300-student high school. Numerous poential sites were evaluated. None of the cceptable and available locations were erved with public sewers, and poor soil onditions in the area made conventional eptic and drainfield wastewater management very difficult. Some means had to be ound to reduce the wastewater volume so he site could be served with only a small subsurface discharge. On-site, advanced wastewater treatment and use of reclaimed water for flushing toilets within the school educed the wastewater discharge by about 85%. This solution to a difficult wastewater management problem also had a major impact on water conservation for the entire school district.

In southwest Houston, Tex., the Alliance Bank and Trust Company owned several acres of prime commercial property. This site was served by the municipal sewer district, but years of growth and the inability to increase the capacity of the existing municipal wastewater facility resulted in a sewer moratorium. Under the moratorium, a new project could discharge no more than 1600 gpd of wastewater/ac, meaning new office construction could not exceed 16,000 sq ft/ac of property. This property's very high value could not support the small amount of development, which the sewers would permit. But using an on-site wastewater treatment and recycling system and water-conserving fixtures permitted construction of a 200,000-sq-ft facility on the site. The wastewater system is in the building's basement and provides reclaimed water for toilet flushing throughout the 12-story structure. The sewer discharge is less than 1000 gpd when the building is fully occupied.

Montgomery Township, N.J., a rural area adjacent to Princeton, is undergoing tremendous development pressure as a result of hi-tech growth near Princeton University. The township is without sewers and residents have no desire to build a wastewater facility that would encourage commercial and industrial development. But development in the township seems inevitable, and office and research facilities are therefore not discouraged. Local residents are concerned about the impact of this development on the local water supply resources and on groundwater quality.

In 1985, the Squibb Corporation began developing a 366,000-sq-ft office and R&D complex in Montgomery Township. Initial construction involved a 60,000-sq-ft office which would use a conventional septic and subsurface drainfield wastewater system. During initial construction, the New Jersey Department of Transportation established a new highway alignment that crossed through a major portion of the Squibb property. The only way to proceed with the project was to substantially reduce the wastewater volume and the corresponding size of the subsurface disposal system. On-site wastewater treatment and recycling of reclaimed water for toilet flushing was evaluated and found to satisfy project requirements. In addition, the on-site reclamation system was found to be less costly than alternatives.

The success of this project, which has been on-line for 3 years, has convinced the Montgomery Township officials of the environmental benefits of recycling, water conservation, and a much lower pollution impact, and now other projects within the township are on-line or are in the design phase. With on-site treatment and recycling, Montgomery Township has been able to control growth, avoid a major sewer infrastructure expense, and achieve environmental goals.

The city of Santa Monica, Calif., is also evaluating the impact of growth under severe resource restrictions. The city has a controlled but healthy development climate which has added many new facilities over the past few years. This continuing development however, is viewed with mixed emotions. In California, water supplies are limited. For years citizens have been incensed by periodic sewage overflows into Santa Monica Bay. Last year, Los Angeles County, from which Santa Monica contracts for wastewater disposal, issued a sewer moratorium which could severely restrict new development. These conflicts between growth and environmental resources have led Santa Monica to become an outspoken advocate of water conservation and environmental protection. The city has been a forerunner in adopting strict water conservation regulations. In addition, on several major development projects, it has required use of on-site wastewater treatment and water reclamation.

The first example of this aggressive approach to resource conservation is a project called Water Garden, a 1,300,000-sq-ft complex consisting of four buildings containing office and retail uses. The typical wastewater volume from a facility of this size is approximately 70,000 gpd. Using ultra-low flush toilets and other water conserving fixtures required under city ordinance, the projected flow can be reduced to 40,000 gpd. Using a creative mix of landscaping (which includes a small ornamental pond system), on-site wastewater treatment, and reclamation for landscape watering and pond evaporative loss makeup will virtually eliminate any sewer discharge during the project's first phase which includes two buildings comprising 650,000 sq ft. The need for potable water for landscape purposes is also eliminated. Phase two of the project is intended to incorporate a second on-site wastewater treatment system, which will recycle the reclaimed water for toilet flushing in the phase-two buildings. Total water use can be reduced by about 75% and wastewater discharge can be reduced by almost 95% in this project, which is currently under construction.

WASTEWATER TREATMENT

A critical component in establishing a successful on-site wastewater reclamation facility is providing a reliable treatment process that can produce reclaimed water on a consistent basis. The figure shows a system that has been used very effectively. The process includes on-line flow equalization and emergency storage tanks, biological nitrification and denitrification, membrane filtration, activated carbon, and disinfection. The emergency storage tank provides several days' flow accumulation in the event of any mechanical malfunction. Membrane filtration is used to provide fail-safe clarification of biological process solids down to a particle size of approximately .005 μ. Granular activated carbon is used for color removal and provides a backup for organic carbon removal. Disinfection with ultraviolet light or ozone provides an essentially pathogen-free effluent. Post-chlorination can also be added to provide a distribution system residual. Typical water quality achieved is BOD and TSS ≤ 5 mg/L, turbidity ≤ 0.5 NTU, and total coliform ≤ 2.2/100mL.

Just as critical and perhaps more important is the operation and management of the reclamation facility. There is no greater assurance of success than providing single responsibility for process equipment and system operation and management. Several years of providing systems under a wastewater management service contract have demonstrated that process performance is more reliable when routine preventive maintenance and inspection is provided rather than periodic emergency response. Long-term operating costs are most effectively controlled when the equipment manager is made responsible for parts and equipment replacement under a fixed management fee arrangement.

REGULATORY OBSTACLES

The use of on-site water reclamation and recycling, although a successful and growing practice, is relatively new and is not yet widely used. In many states, lack of experience with water reclamation and lack of specific standards and regulations have severely restricted its use. Four areas are often obstacles to reclamation.

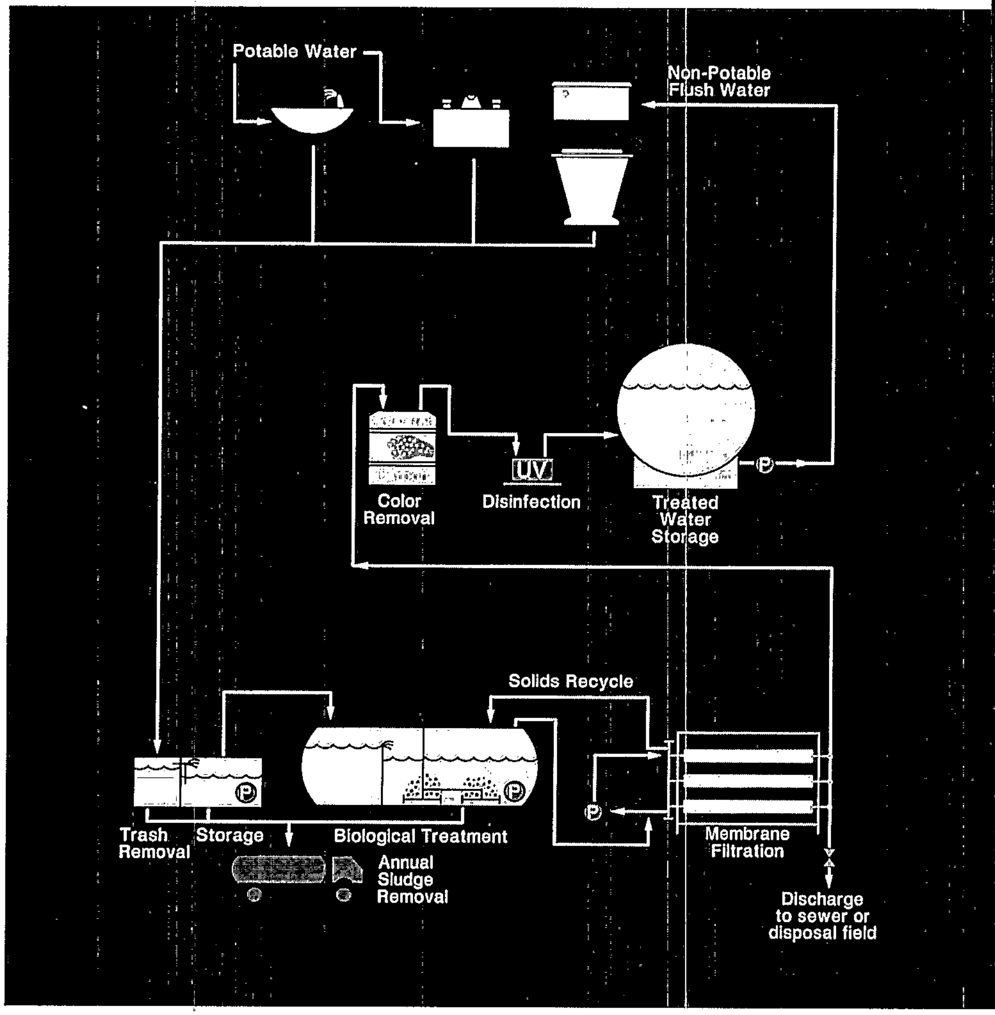
Regulatory codes. Some codes impose guidelines for wastewater treatment but don't recognize water conservation and water-reclamation activities. Many states use a "cookbook" code approach involving a lengthy variance procedure for applications which aren't part of the listed recipes.

Lack of a standard for reclaimed water quality. In many states projects can be rejected or significantly delayed in the absence of an approved standard.

Ambiguous plumbing codes. Most standards include language stating that each plumbing fixture (including toilets and urinals) shall be provided with potable water except where not deemed necessary by the administrative authority . The caveat "except where not deemed necessary by the administrative authority" was specifically added to the codes to encourage the use of safe applications for non-potable water, such as recycling. Many local administrators are not aware of the purpose of the enabling language and are unwilling to consider such proposals.

Lack of confidence in standard practices for controlling cross connections. Although all the experience with using reclaimed water for toilet flushing has been successful, many building and safety departments are reluctant to consider using non-potab[le] water in a building because of a lack [of] experience with procedures used [to] control dual plumbing systems.

More than 10 years of experience in t[he] U.S. with on-site wastewater treatment a[nd] recycling in commercial facilities has de[m]onstrated that it is a safe, environmenta[lly] superior, and economically viable practi[ce.] There have been no public health pro[b]lems and use of recycled water has no[t] caused any adverse reaction from buildin[g] owners or occupants. The systems are reliable, efficient in producing a high-qualit[y] water for toilet flushing or landscape irri[]gation, and have a positive impact on th[e] environment by conserving water and re[]turning a highly treated effluent back t[o] the environment. ■



John Irwin is vice president of Thetfor[d] Systems, Inc., in Ann Arbor, Mich. The abov[e] presentation was given at the Conserv 9[0] Conference in August 1990.

PRELUDE

Wastewater Reuse Gains Public Acceptance

Twelve years ago, Orange County, Calif., Water District's Water Factory 21 was completed. The widespread and growing attention given to wastewater reuse over the past dozen years is gratifying, if somewhat astonishing, to those of us who have been concerned with reuse during this period. It is clear that water resource planners now consider reuse as an acceptable alternative method of meeting increasing water demands, not only for agriculture, but also for municipal and industrial uses.

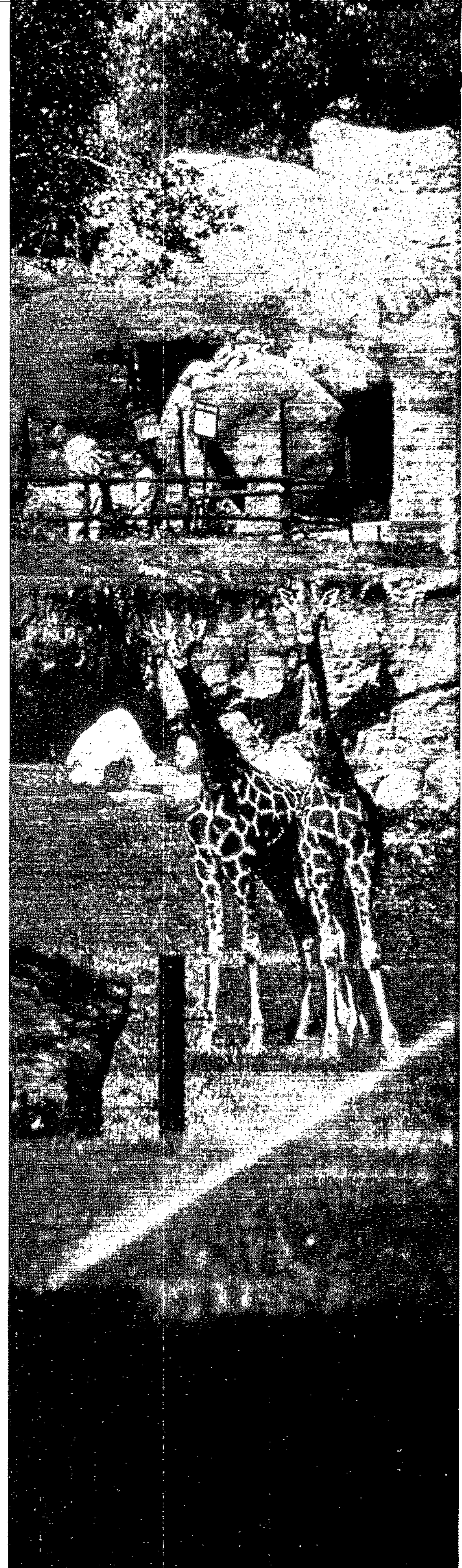
The technological and engineering concepts underlying wastewater reuse projects are becoming increasingly well understood. This is true even with our knowledge of health effects of potable reuse, which has been the most difficult area in which to achieve general acceptance. Indirect potable reuse, as from groundwater injection, appears to be fully accepted. Direct potable reuse is just a few years away from implementation in Denver, Colo., and its public acceptance is expected to be fairly uneventful.

Planners, engineers, and the public have accepted wastewater reuse; the spotlight next turns to the economists. These economists playfully ask, "Well, it works in practice, but I wonder if it will work in theory?"

On the Cover and In this Issue:

In this section, Water Environment & Technology publishes the third installment of a series on wastewater reuse and reclamation made possible by the Environmental Protection Agency. Economics and case studies in Irvine, Calif., and in Florida are the selected topics.

—Introduction to the paper, "Economics of Potable and Nonpotable Wastewater Reuse," *presented at the 1987* American Water Works Association Annual Conference *by J. Gordon Milliken of the Milliken Research Group in Littleton, Colo.*



Obstacles to Implementing Reuse Projects

In 1988 the American Water Works Association (AWWA) Research Foundation commissioned a study to determine what obstacles exist in water reuse implementation and to identify activities that could help remove these obstacles. Information about reuse projects, regulations, practices, and experience was collected through a questionnaire and follow-up telephone survey. The study included 188 participants, most of whom were selected because of their expressed interest in or experience with water reuse. The broad nature and experience of the individuals who provided input to the study served to significantly strengthen the recommendations and emphasized the need for action.

Based on the experience of the study participants, there are three obstacles of primary concern when implementing a reuse project: cost effectiveness, information dissemination and education, and water-quality and health issues.

The degree to which these issues become obstacles depends on the type of reuse anticipated and the environmental appeal of the project. For example, if the reuse application conserves a valuable water resource or benefits the environment, it is more likely to be acceptable to the community.

In a few states, special issues like water ownership are major deterrents to reuse. For example, in New Mexico, credits against groundwater pumping are given to those cities that return their treated effluent to the river system. Reuse would entail returning less effluent to the river system, thus constraining the utility to pump less groundwater. Therefore, while conservation is encouraged, reuse is not.

QUANTIFYING THE OBSTACLES

The cost effectiveness of reclaiming water varies significantly with current practices and raw water supply. Unusual circumstances would need to exist in order to proceed with a reuse project that is not cost effective. Most reuse projects have resulted from a need to identify new water sources. A number of reuse applications have also grown out of a need to find an alternative to more stringent discharge standards.

Survey results demonstrate that urban irrigation of public use areas such as golf courses and parks, industrial reuse, and agricultural reuse projects are easiest to accomplish. When project implementation is economically appropriate, few serious obstacles exist. This is demonstrated in California and Florida where irrigation projects number in the hundreds. The general public's attitude about health and water quality is an occasional implementation obstacle, but it is seldom the major issue. However, if education, water quality, and health issues are not properly dealt with, even these easily implemented reuse projects will be halted.

The principal obstacle limiting either direct or indirect potable reuse is public attitude. Cost effectiveness is also a significant obstacle to potable reuse projects. However, the results of the survey showed that, unless careful attention is paid to information dissemination and water-quality and health issues, a cost effective potable reuse project—either direct or indirect—will be difficult to implement.

Ten specific activities were recommended in the study. However, action is most urgently needed in information dissemination to all parties involved in potential reuse projects, including engineers, regulators and other technical staff, community officials, and the general public; and water-quality and health-effects guidance for the implementation of different types of reuse projects.

INFORMATION DISSEMINATION

Many of the barriers to reuse stem from a lack of information. Fortunately, much of the information needed already exists. One of the most pressing needs is to compile the body of knowledge into a format that those who are responsible for implementing reuse can use. Equally pressing is the need to assemble information into a format that can be presented and understood by the public that is trying to make an informed decision about a proposed reuse project in its community.

An information dissemination program covering the following subjects can be key to the success of a reuse program: the need for, availability and cost of, additional water supplies and the environmental impact of reuse versus developing additional raw water supplies; and the effectiveness of the water-reuse technology applicable to the type of reuse anticipated and the safeguards incorporated in the water reclamation and reuse processes. Utilities practicing indirect potable reuse found public awareness of a water shortage to be the best way to overcome a negative public attitude.

WATER QUALITY AND HEALTH EFFECTS

There is a universal call for consistency and informed decision making in the area of guidelines and regulations for reuse. A clearer definition of requirements for both potable and non-potable reuse projects is urgently needed.

A significant effort associated with current reuse projects involves the definition of treatment and water-quality standards. Even where state regulations exist, significant effort is often expended to define necessary treatment requirements or to demonstrate the efficacy of alternative treatment methods.

Assurances that the proposed method of water reuse is safe may not be adequate to allay public fears. Regulatory agencies and the general public want to know that the reuse system will consistently perform at levels that provide that safety.

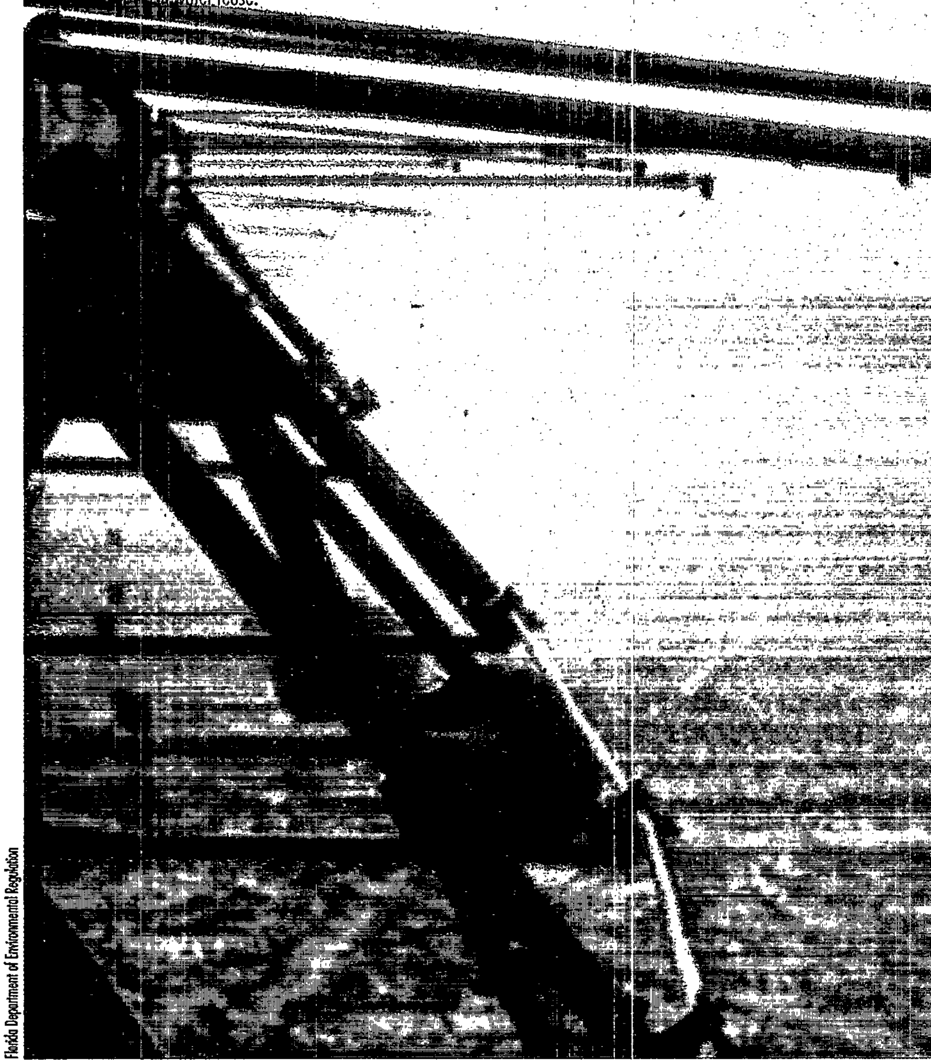
Reuse projects that are the first of their kind for a state or that involve potable reuse generally require a demonstration project. A well-thought-out and staged reuse plan that includes a demonstration program will serve to generate confidence and foster success.

CONCLUDING OBSERVATIONS

Attitudes will not change by themselves. A more concerted effort to make water reuse a universally understood and accepted water supply practice is needed.

—Scott B. Ahlstrom is division manager for water and wastewater at CH2M HILL in Denver, Colo.

To reduce reliance on limited water supplies, the Irvine Ranch Water District in Irvine, Calif., developed a dual-distribution [illegible] for wastewater reuse.



Florida Department of Environmental Regulation

The ever-increasing demands for water have thrust water reclamation practices to the forefront of water and wastewater system planning efforts throughout the world. Because of skyrocketing populations and limited water resources, water and wastewater districts in Southern California received early lessons on the importance of a careful, organized, and comprehensive approach to the successful design and implementation of water reuse systems. Maintaining control, from planning stages all the way to operational monitoring, is key to a system that operates effectively, economically, and, most importantly, safely.

The Irvine Ranch Water District (IRWD) serves an area of about 72,000 ac and an existing population of 100,000 people. The service population is expected to grow to over 300,000 after the year 2000. The district, located in Orange County about midway between Los Angeles and San Diego, provides potable water service, treats and disposes of wastewater, and also distributes irrigation water for landscape and agricultural uses.

The area is a semi-arid region receiving only about 12 to 14 in. of rain annually. The rainfall occurs during the winter months, not during the traditional growing season when demand is highest. Even with an extensive reservoir system built to capture natural runoff, the water does not provide a year-round source for irrigation for either landscape or agricultural crops. Additional water supply then must be either diverted from the Colorado River to the east and piped 240 miles to the district or imported from Northern California through a 450-mile system of canals, reservoirs, and large pumping stations. Natural groundwater provides an additional source.

To reduce the area's reliance on these limited supplies, IRWD began the installation of a dual distribution system in the 1960s.

Dual distribution system. The heart of the district's dual distribution system is the irrigation system which contains the network of pipelines that distributes reclaimed water to its users. When the system was designed, IRWD prepared an Irrigation Master Plan outlining future pipe sizes and locations so that adequate pressure and flow could be maintained for all the future uses. This was done to prevent growth and retrofitting problems.

The irrigation system provides water for three different uses. The first system is for the landscape users including parks, schools, street median strips, and homeowner associations that water open-space areas within the district. There are about 850 individual meters for these areas. Water is reclaimed mainly for agricultural purposes such as orchard crops—oranges and avocados—but it is also used in row crops such as asparagus, corn, pole tomatoes, peppers, and cabbage. There are 12 individual meters for different fields within the district.

The landscape irrigation and agricultural systems serve a network of about 107 miles of pipe varying from 2 to 54 in. in diameter. About 2050 ac are irrigated for landscape uses, while the agricultural land comprises about 1000 ac. The sizes of these two areas will vary as agricultural land is taken out of service and displaced by residential development in the growing city area.

The third system, which provides reclaimed water to high-rise buildings, is now in the development stages. It will be used for toilets, urinals, and trap drains, as up to 80% of the water used in a high-rise may be for toilet flushing.

IRVINE RANCH'S APPROACH TO WATER RECLAMATION

John Parsons

ENCOURAGING USE

Landscape irrigation is the main end use of reclaimed water from the dual system. Between 8000 and 9000 ac-ft/yr are used for landscape irrigation, while the agricultural system uses 3000 to 4000 ac-ft/yr. It is projected that ultimately the 15-mgd Michelson Water Reclamation Plant will be able to supply almost double the current amount for landscape users as the agricultural demand declines because of development in the district.

The district requires new developments to be designed with dual distribution systems so that all appropriate areas can be irrigated with reclaimed water rather than potable water. In fact, IRWD has a set of rules and regulations similar to city ordinances that require developers to use reclaimed water as a water conservation measure in extending the supply of potable water throughout the district.

IRWD has established the authority and a procedure for expanding the dual system into the developing areas by working closely with developers, designers, and contractors as the systems are constructed. It has a set of standard specifications that outline the basic materials required for this type of system. These materials include the pipe, meters, strainers, and various fixtures that are required for irrigation.

The process of expanding the dual system is atypical of many governmental reviews, as it includes early contact with the developing company when it applies for a will-serve notice. The will-serve certifies that the district has reclaimed water available so the developer can proceed through the city planning process during which the tract map is reviewed and approved. For the development to receive approval, the developer's engineer must put together plans showing the distribution system to be built by the developer. This system is reviewed by the IRWD reclaimed water section staff that works with the engineer to finalize plans and specifications. Once the review is complete and the developer's plans are approved, the developer engages a contractor to construct facilities for the development.

CONFORMING TO THE SYSTEM

During construction, IRWD staff provides on-site inspection as all the facilities are built to ensure that they meet the standard specifications of the district.

Once the developer has completed a tentative tract map outlining the scope of his development and requested a will-serve, a service agreement is entered into with the district for water, sewer, and landscape irrigation service. As part of the agreement, the district collects funds to cover the plan check and inspection fees incurred during the process of designing and installing the system.

Most of the equipment and pipe used in the on-site facilities—those on the property owners' side of the meter—are typical for the irrigation industry. Special specifications required by the district are used to distinguish between the use of reclaimed water and potable water for irrigation. The health and safety reasons for this provide added protection to the customer.

One of the most important principles of irrigating with reclaimed water is that all facilities must be clearly marked so that there is no possibility of future cross connections to the potable system with reclaimed water or vice versa. This is carefully checked during the design phase when IRWD staff work with the design engineer to ensure compliance with the standard specifications.

Specifications include the prohibition of hose-bib connections to the reclaimed water system. This prevents incidental use and possible drinking of the water by users. Quick-coupling valves used in the reclaimed water system are operated by a key with an Acme thread. This thread is not used in the potable water system. The covers on reclaimed water quick-couplers are required to be green and made of rubber or vinyl. The potable system, on the other hand, is distinguished by having either brass or yellow covers. All pressure piping used for the reclaimed water system must be labeled as reclaimed water by using labeled purple pipe, marking the pipe with a colored tape, or by actually stenciling on the pipe "reclaimed water." If potable water pipe is also on the same site, it must also be labeled so that the difference is obvious.

When IRWD evaluates the development's plans, the acreage irrigated must be provided. This is used to predetermine watering rates using evapotranspiration data and to check meter readings for overwatering once the system is on-line. It's also important not to overlook basic items such as the point of connection where the landscape architect connects irrigation hose to the IRWD system. Often the architect will choose a location without checking the best available district facility, let alone whether or not there is an IRWD pipe on that particular street.

Pipe classes are required to ensure that they match district specifications, and water pressures and sprinkler patterns are set to cover areas properly without overwatering. If a project has several reclaimed water meters, they are checked to ensure that there are no cross connections. Reclaimed water meters cannot be cross-connected because of difficulty in isolating problems if several meters must be shut off. The wording in plan notes is checked to ensure that the district is not exposed to undue liability.

IRWD staff ensure that a master pressure regulator or pressure-regulating valves are used and require the strainer screen to be 30 mesh or greater to protect the sprinkler system and the pressure regulator. Another item is the inclusion of the plan notes regarding the installation of an on-site reclaimed water system. This is a must, as it points out to the landscape contractor what is required by the district inspection team and surveyor.

Last and not least, the IRWD looks for incorrect items such as a backflow device on the reclaimed water system. Backflow devices are not used in reclaimed water systems; if they are installed in a reclaimed water system they could cause confusion because of the similarity to the domestic water system.

During this plan check procedure, as each plan set is received it is given a permanent file number. File books containing all communication or comments made on a project from start of construction to operation are kept as a record for the future. The architect provides a set of mylar drawings of approved plans, which are kept on file, thus completing the file on each project.

Some of this information is input to a computer, allowing IRWD staff, by typing in the meter number or account number, to bring forward information on any irrigation project built in Irvine on the Reclaimed Water System.

FIELD REVIEW

Once the plans are approved, IRWD monitors the actual construction of the project to ensure proper installation and hook up. During the field review, which is accomplished by the same staff that did the plan review, various important points are stressed to again ensure compliance with the rules and regulations of the water district. The inspectors will look at meter and strainer devices to ensure that they are properly labeled and installed. The strainers are a safety precaution to ensure maintenance-free use of the system. Either Y-strainers or basket strainers provide a backup for maintaining an easy distribution of the water through the irrigation system. When improper water construction has taken place, the work must be corrected.

There are several common improper construction techniques. Domestic and reclaimed water lines may be too close together. There must be a vertical separation of at least 6 in. and a horizontal separation of 10 ft from either domestic water or sewer lines, and the reclaimed water line must be sleeved to 5 ft on either side of a perpendicular crossing of a domestic water line.

Improper labeling sometimes occurs. A contractor once put in 1.5 miles of reclaimed water line and taped the pipe with domestic tape instead of reclaimed water tape. The quick-connect coupling whick is checked; if the wrong type is used, reclaimed water could be used incorrectly. Pipe depths are checked, as building codes are not always followed.

Other important points include the application of the label tape so that future construction will be able to determine the type of water that is used in the pipeline. On some applications, the pressure in the distribution system may need to be reduced in order to best fit the design pressure used in the irrigation design. Pressure-reducing valves have been successfully used for extensive periods without any excessive maintenance or problems that might have

Irvine's Irrigation Guidelines

Irrigate between the hours of 9:00 p.m. and 6:00 a.m. only. Watering outside this time frame must be done manually with qualified supervisory personnel on-site. No system shall at any time be left unattended during use outside the normal schedule.

Irrigate in a manner that will minimize runoff pooling and ponding. The application rate shall not exceed the infiltration rate of the soil. Timers must be adjusted so as to be compatible with the lowest soil infiltration rate present. This procedure may be facilitated by the efficient scheduling of the automatic control clocks by employing the repeat function to break up the total irrigation time into cycles that will promote maximum soil absorption.

Adjust spray heads to eliminate overspray onto areas not under the control of the customer such as pool decks, private patios, streets, and sidewalks.

Monitor and maintain the system to minimize equipment and material failure. Broken sprinkler leads, leaks, and unreliable valves should be repaired as soon as they become apparent.

Educate all maintenance personnel, on a continuous basis, of the presence of reclaimed water and the fact that it is not approved for drinking purposes. Given the high turnover rate of employees in the landscape industry, it is important that this information be disseminated frequently. It is the landscape contractor who is responsible for educating each and every one of these employees.

Obtain prior approvals for all proposed changes and modifications to any on-site facilities. Such changes must be submitted to, and approved by, the IRWD engineering office and designed in accordance with district standards.

been caused by the quality of the water. The pressure regulator is used to minimize fogging and misting of sprinklers.

The final step in the field inspection is cross-connection control. A cross-connection control test is performed on all reclaimed water systems to be absolutely sure that there are no connections between the domestic and reclaimed water lines. The system is then tested to check the spray patterns of the sprinkler devices. Normally, typical irrigation products are used. These are important parts of the irrigation system.

Spray patterns are tested; one of the requirements is that overspraying not be allowed to prevent the reclaimed water from running into the storm drain system. Besides wasting water, this is important in Irvine because the water drains into a sensitive area that includes an ecological preserve and wetlands.

During the overspray test, the system is operated at full pressure with reclaimed water and, where improper spray patterns occur, the contractor is required to replumb the system or use different spray devices to control the overspray. There are also overspray aesthetic concerns, such as watering the concrete and asphalt and interfering with the appearance of a newly washed and waxed car, creating potential ill-will within the community.

MONITORING AND GUIDELINES

The IRWD uses guidelines that were developed in a joint effort between the local health departments. The guidelines (see Box) are posted in the system's control center in both Spanish and English. Compliance with these guidelines is frequently monitored.

The monitoring is designed to police the system to ensure that the facilities are maintained and operated properly so that new problems are not created. Monitoring includes working with the contract operators and irrigation users to make sure that timers are set so that water is used between the restricted hours of 9:00 p.m. and 6:00 a.m., when contact with the public is minimized. The automatic timer systems include Rainbird, Griswold, and Toro, and are the modern electronic timers used because, as the price of water continues to increase, it is easy to justify the use of sophisticated timers to control the application of water so that proper irrigation takes place.

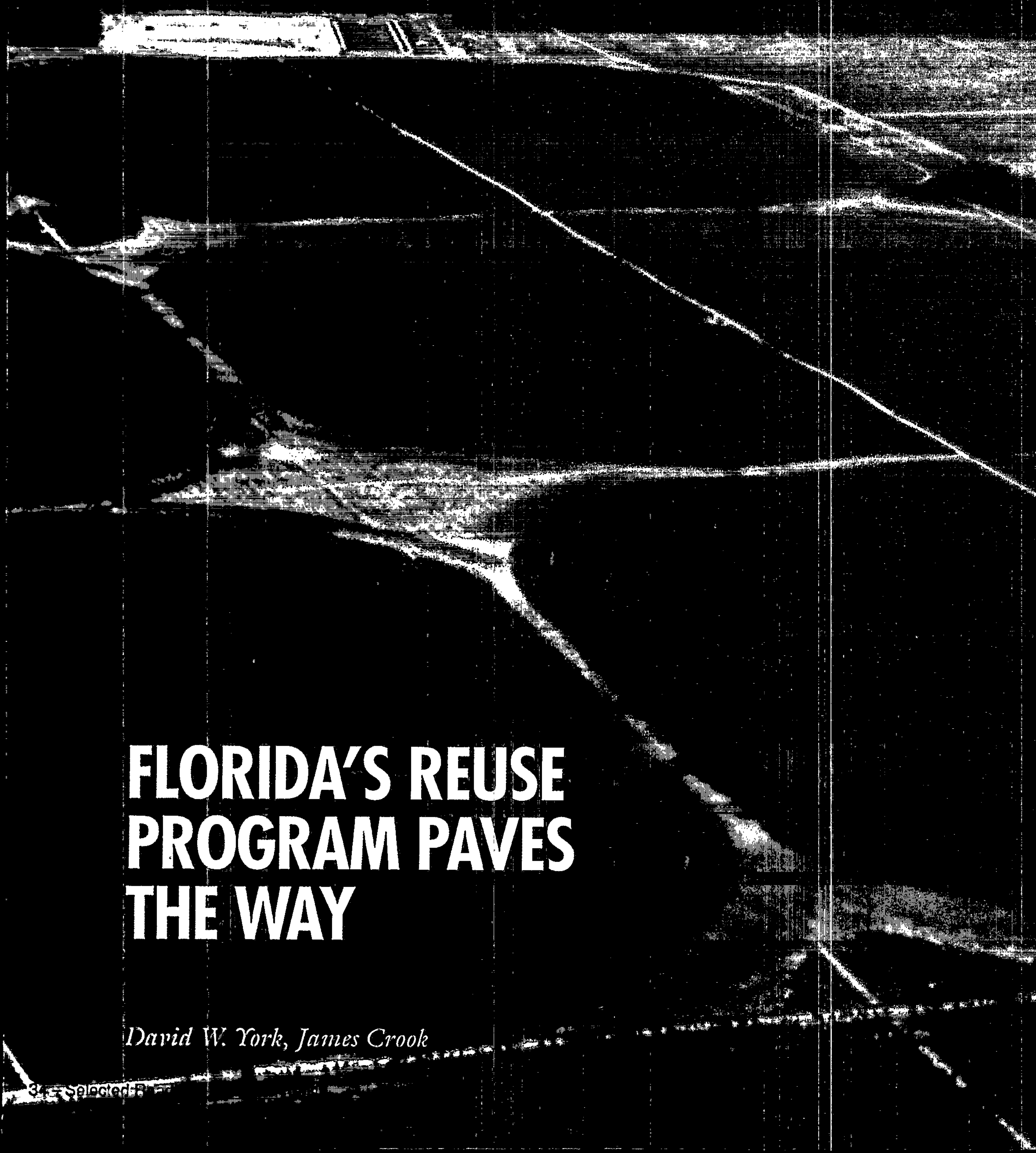
The monitoring work also includes detection of main breaks and other malfunctions in the system. This is done by selecting random evenings and actually patrolling the district during the evening hours between 9:00 p.m. and 6:00 a.m. to look for broken sprinkler heads, main breaks, and overwatering situations—especially when they cause gutter rivers, which are used to locate the problem. Monitoring also includes checking the water quality throughout the distribution system. Several stations or sampling points are located throughout the system and random samples are taken during the normal use times to ensure that the bacterial quality of the water is similar to the water's quality when it leaves the treatment plant.

Another important aspect of the monitoring program is the visual assessment of new construction areas. This is important because there is always someone trying to save time or money by building with no inspections or plan checks. This avoids many headaches by catching the contractor early before the transgressions endanger the public and become expensive to fix.

The previously mentioned 1.5 miles of pipe that were laid with the wrong pipe identification had to be dug up and re-labeled—an unnecessary expense that could easily have been avoided. Another example involved a sprinkler system that was installed without IRWD's knowledge. It was discovered around a new office building on a weekend inspection. The developer applied for a meter, but did not receive one because the plans were not approved by the district. To top it off, the installed system did not follow the reclaimed water rules and regulations, requiring costly field modifications.

IRWD is trying to avoid similar complications by getting involved in the initial planning stages for a development and then following through for the direction of the project. The district's goal is to maximize water reuse and limit the unnecessary use of potable water in the safest and most effective manner. Control from planning and permitting through operational monitoring is essential for this goal to be met. ■

John Parsons is irrigation services supervisor/engineering technician III for the Irvine Ranch Water District in Irvine, Calif.



Because conditions in Florida necessitate water reuse, spray irrigation systems using reclaimed water, such as this one in Tallahassee, are being encouraged by the state.

FLORIDA'S REUSE PROGRAM PAVES THE WAY

David W. York, James Crook

Florida is different than the major reuse states in the semi-arid southwest U.S. In Florida, it rains an average of 54 in./yr and the state seemingly has abundant water resources—particularly groundwater, which accounts for about 90% of all water used for domestic purposes. However, there are increasing demands on the state's water resources.

Florida continues to face rapid population growth. Its population, which nearly doubled from 1960 to 1980, continues to increase by more than 6000 persons each week. Between 1980 and 1990 the population rose 33%, and from 1990 to 2000 the population is expected to grow an additional 19%.

Almost 79% of Florida's 13 million people lives near the coast, and about 82% of the anticipated population growth will occur in coastal counties. These coastal growth areas are served primarily by shallow aquifers that are most vulnerable to overdraft and saltwater intrusion.

These conditions necessitate water reclamation and reuse. The state has developed programs that encourage the reuse of reclaimed water and comprehensive regulations that govern reuse projects. The rules provide detailed requirements for development of reuse projects that involve irrigation in public access areas such as parks, playgrounds, and golf courses, as well as irrigation of residential property and edible crops and must address the use of reclaimed water for fire protection, toilet flushing, and aesthetic purposes such as decorative ponds and fountains. The reuse rules provide requirements for preapplication treatment, reliability, operation control, buffer zones, storage, cross-connection control, and other design and operational features. These rules also provide a mechanism for limited discharge of excess reclaimed water during wet-weather, high-stream-flow conditions when demand for reclaimed water is lowered. Such limited wet-weather discharge provisions should encourage development of reuse projects by reducing storage requirements.

DEVELOPMENT OF REUSE

During the last 20 years, the primary driving force behind implementation of reuse projects in Florida has been effluent disposal. While the state has many streams, they typically have low flows, are shallow, have low gradients, flow slowly, are warm all year, and flow into lakes or estuaries. Most surface waters in Florida simply will not assimilate large quantities of effluent. As a result, many communities have turned to land application to dispose of unwanted effluent.

Regulations developed in the early 1980s for reuse and land application are in the manual, *Land Application of Domestic Wastewater Effluent in Florida*[1], that contains detailed design and operation requirements for slow-rate land application systems, rapid-rate land application systems, absorption fields, overland flow systems, and other land application systems. Irrigation of public access areas or edible crops was allowed, but requirements for such activities were incomplete.

Table 1 - Disinfection Levels Defined by Florida Rules

Disinfection level	Fecal coliform limit	Application
High-level	No detectable	Public access maximum fecal coliform TSS 5 mg/L. Irrigation and irrigation of edible crops, for discharge to Class I surface waters (potable water supplies).
Intermediate		14/100 mL. For discharge to waters tributary to Class II surface waters (shellfish propagation or harvesting).
Basic	200/100 mL	For most land application systems, for most discharges to surface waters.
Low-level	2400/100 mL maximum	For overland flow systems and some underdrained irrigation systems.

The land application manual was designed to be used in conjunction with *Chapter 17-6, Florida Administrative Code (FAC),* titled "Wastewater Facilities." As shown in Table 1, four levels of disinfection were defined in the rule.

The high-level disinfection requirements were developed in the early 1980s based largely on the testimony of epidemiologists and virologists before the Florida Environmental Regulation Commission. The criteria were designed to provide treated water that was essentially pathogen free. Where chlorine was used for disinfection, maintenance of a 1.0-mg/L total chlorine residual after a 15-minute contact time at maximum daily flow or after a 30-minute contact time at average daily flow was to be accepted as evidence that the fecal coliform criteria would be met.

Secondary treatment was established in *Chapter 17-6, FAC,* as the minimum pretreatment level for most land application and reuse systems. Florida's definition of secondary treatment requires that the wastewater treatment facility be designed to produce an effluent containing not more than 20 mg/L of biochemical oxygen demand (BOD) and total suspended solids (TSS) or 90% removal of BOD and TSS, whichever is more stringent. The annual average BOD and TSS concentrations may not exceed 20 mg/L and the monthly average may not exceed 30 mg/L. A lower level of secondary treatment—40 to 60 mg/L for BOD and TSS—was allowed for overland flow systems and for some underdrained irrigation systems.

In September 1989, *Chapter 17-6, FAC,* was rewritten into a new series of rules. Regulations governing domestic wastewater treatment and disinfection are now found in *Chapter 17-600, FAC,* titled "Domestic Wastewater Facilities."

During the 1970s and 1980s, the number of projects involving reuse

Florida Department of Environmental Regulation or land application increased substantially. By 1985, more than 100 individual projects involved some form of reuse, including several excellent reuse projects such as the St. Petersburg dual water distribution system, the Tallahassee spray irrigation system, and the CONSERV II citrus irrigation project serving Orlando and Orange Counties.

The *1990 Reuse Inventory*[2] identified about 200 reuse projects in Florida. These projects use about 320 mgd of reclaimed water for a wide range of beneficial uses.

With the growing popularity and acceptance of water reuse projects, the state has begun to promote water reclamation. Statewide comprehensive planning has been implemented to ensure that adequate infrastructure is provided. Increased attention is being placed on protection of water resources and provision of adequate water supply. Reuse of reclaimed water is receiving greater attention as a means to reduce demands on potable water resources and recharge groundwater.

Florida Department of Environmental Regulation

Wastewater restoration, occurring in this Orlando, Fla., wetland, is identified as a reuse application for surface-water enhancement.

THE STATE'S REUSE PROGRAM

Beginning in 1987, the Florida Department of Environmental Regulation embarked on an ambitious program of rule making designed to facilitate and encourage reuse of reclaimed water. Three rules were effected: *Chapter 17-6, FAC,* "Wastewater Facilities", *Chapter 17-40, FAC,* "Water Policy", and *Chapter 17-610, FAC,* "Reuse of Reclaimed Water and Land Application."

In addition, 1989 state legislation and other related rule making also affected reuse in Florida.

Updated reuse rules were developed with significant assistance from a technical advisory committee consisting of representatives of the Florida Pollution Control Association, Florida Engineering Society, American Water Works Association Florida Section, American Water Resources Association, a representative of a private utility, and the former head of California's reuse program. Committee members offered a wealth of experience and expertise covering a wide range of reuse activities.

Consistent definitions for reuse and reclaimed water were included in all three rules. *Reclaimed water* is water that has received at least secondary treatment and is reused after flowing out of a wastewater treatment facility. *Reuse* is the deliberate application of reclaimed water in compliance with applicable rules for a beneficial purpose.

The rules identify landscape irrigation, agricultural irrigation, aesthetic uses, groundwater recharge, industrial uses, and fire protection as legitimate beneficial purposes. Environmental enhancement of surface waters resulting from discharge of reclaimed water that has received at least advanced wastewater treatment or from discharge of reclaimed water for wetlands restoration also are identified as reuse applications.

Chapter 17-40, FAC The "Water Policy" rule outlines the state's policy for the use and regulation of water. It provides general guidance to the state's five water-management districts that are responsible for water-quantity management, including the consumptive-use permitting program.

An October 1988 amendment to *Chapter 17-40, FAC,* created a program for mandatory reuse of reclaimed water. The water-management districts were required to assess the water resources within their jurisdictions—including an estimate of water needs and sources for the next 20 years—and to publish a comprehensive district water-management plan. As part of this planning activity, the water-management districts were required to identify critical water-supply problem areas. Reuse will be required within critical water-supply problem areas that exist today, and in areas that are projected to develop over a 20-year planning horizon. The program will be in full operation by November 1991.

The rule also allows the water-management districts to require reuse outside of critical water-supply problem areas if reclaimed water is readily available to the applicant for a consumptive-use permit. This measure was designed to facilitate implementation of reuse at the local level. The primary responsibility for implementation of this program rests with the water-management districts through the consumptive-use permitting process.

Chapter 17-6, FAC Amendments to the rule focused on two areas. First, the high-level disinfection requirements were modified to reflect existing technology and experience. Revised high-level disinfection criteria include requirements that 75% of all fecal coliform observations be less than the detection limit and that no sample exceed 25/100 mL for fecal coliform. Daily sampling for fecal coliform was

Table 2 - Requirements for Reuse

Parameter	Requirements
Minimum treatment level	Secondary with filtration and chemical feed, maximum TSS of 5 mg/L.
Disinfection	High-level.
Minimum system size	378.5 m^3/d (0.1 mgd) for any public access irrigation system, 1893 m^3/d (0.5 mgd) for residential lawn irrigation or edible crop irrigation.
Reliability	Class I—requires multiple units or backup units and a second power source.
Staffing	24 hr/day, 7 days/wk; may be reduced to 6 hr/day, 7 days/wk, if additional reliability measures are included.
Continuous monitoring	Required for turbidity and disinfectant residual.
Operating protocol	Required—a formal statement of how the treatment facility will be operated to ensure compliance with treatment and disinfection requirements.
Storage requirements	System storage (minimum 3 days, may be unlined) or back-up system required; golf course lakes may be used for system storage.
Reject storage	Minimum 1 day, lined, to hold unacceptable quality product water for return for additional treatment.
Limits on reuse	Only product water meeting the criteria of the operating protocol shall be released to the reuse system; reclaimed water shall not be used to fill swimming pools, hot tubs, or wading pools.
Cross-connection control	Prohibit cross-connections to potable water systems; reclaimed water shall not enter a dwelling unit; minimum standards for separation of reclaimed water lines from water lines and sewers; color coding or marking required; back-flow prevention devices required on potable water sources entering property served by reclaimed water systems; dual check valves are acceptable.
Setback distances	22.9 m (75 ft) to potable water-supply wells; otherwise, none.
Other O&M requirements	Approved operating protocol; approved cross-connection control program; documentation of controls on individual users (agreements or ordinance); assess need for industrial pretreatment program.

included as a requirement for reuse systems. The TSS limitation remains at a maximum of 5 mg/L before application of the disinfectant. Turbidity is not incorporated in the rule as a permitting parameter. However, for public access irrigation and for irrigation of edible crops, continuous on-line turbidity monitoring is required as part of the operational control provision in *Chapter 17-610, FAC* Disinfection requirements are now found in *Chapter 17-600, FAC.*

Provisions for limited wet-weather discharge were added to the "Wastewater Facilities" rule. This section is designed to facilitate discharge of reclaimed water during wet-weather, high-flow periods when demand for reclaimed water normally is reduced. When the applicant demonstrates sufficient dilution during periods of high stream flow, the state will permit a discharge with minimal water quality review. Required dilution ratios are based on the quality of the reclaimed water and the anticipated frequency of discharge:

$$SDF = P(0.085\ CBOD_5 + 0.272\ TKN - 0.484)$$

Where

SDF = minimum required stream dilution factor, dimensionless;

P = percent of the days of the year that limited wet-weather discharge will occur during an average rainfall year;

$CBOD_5$ = the treatment facility's design monthly maximum limitation for carbonaceous BOD_5 in mg/L; and

TKN = the treatment facility's design monthly maximum limitation for total Kjeldahl nitrogen expressed in mg/L of nitrogen.

The dilution ratio is increased if travel time to sensitive downstream environments such as lakes, estuaries, and water supplies is less than 24 hours. Limited wet-weather discharge provisions were subsequently relocated to *Chapter 17-610, FAC.*

Chapter 17-610, FAC The "Reuse of Reclaimed Water and Land Application" rule was adopted in 1989. It supersedes and expands upon the old land application manual.[1] The focus of this rule making was to provide detailed requirements for the design and operation of reuse projects in public access areas, including irrigation of residential lawns, parks, golf courses, landscape areas, as well as for the irrigation of edible food crops. These requirements are contained in Part III of the rule.

Table 2 presents a summary of the key provisions of this part for public-access irrigation systems, irrigation of residential lawns, and irrigation of edible crops. Reclaimed water that has received high-level disinfection, secondary treatment, and filtration, and that meets the full requirements of Part III may also be used for toilet flushing in commercial and industrial facilities that do not contain dwelling units, for fire protection, for construction dust control, for aesthetic purposes, and for other uses.

Any reuse system regulated by Part III must provide a minimum of secondary treatment, filtration, and high-level disinfection. Class I reliability and full-time operator attendance are required; some reduction in operator attendance is allowed if additional reliability measures are provided. Each facility must develop an operating protocol; a clear statement of how the facility will be operated to ensure that only acceptable reclaimed water is discharged into the reuse system. While turbidity and disinfectant residual must be continuously monitored for operational control, these are not permit limitations. The facility must be operated such that the high-level disinfection criteria (TSS and fecal coliform limits) will be met. Unacceptable product water must be diverted to a lined, reject storage system for additional treatment before being released to the reuse system.

As shown in the Table, minimum system sizes were established for treatment facilities that make reclaimed water available for irrigation in public access areas or for irrigation of edible food crops. These minimum size limits reflect reduced confidence in a small facility's ability to continuously produce high-quality reclaimed water. Both the technical advisory committee and the Florida Department of Health and Rehabilitative Services recommended minimum size limits.

Rules that existed before 1989 allowed the irrigation of edible food crops if high-level disinfection was provided and the permit applicant demonstrated that processing of the food crop would inactivate or remove pathogens. Few edible crop irrigation systems were proposed.

The original provisions of the rule allowed irrigation of edible food crops without restriction beyond Part III requirements. This position represented a consensus from the technical advisory committee, which noted that the potential for disease transmission from an edible food crop irrigation system is not significantly different from that of a residential lawn irrigation system, as long as the full requirements of Part III are met. However, in response to concerns raised by the Florida Department of Health and Rehabilitative Services, the issue was revisited in July 1989. It was amended to prohibit direct contact of reclaimed water on edible food crops that will not be peeled, skinned, cooked, or thermally processed before human consumption. Indirect application methods such as ridge and furrow, drip irrigation, or subsurface distribution systems are still allowed for these crops. No restrictions were placed on the irrigation of citrus, tobacco, or other crops that are peeled, skinned, cooked, or thermally processed before consumption.

Other Legislation and Rule making. The Department of Environmental Regulation pursued state legislation in 1989 to allow the department to require that wastewater treatment facilities located within designated critical water-supply problem areas make reclaimed water available for reuse. Unfortunately, the resulting legislation[3] stopped short of vesting such authority. The law does require that, beginning in 1992, applicants for wastewater-management permits located within critical water-supply problem areas complete reuse feasibility studies. The law clearly establishes that reuse of reclaimed water and conservation of water are formal state objectives.

In 1989, the Department of Environmental Regulation also revised *Rule 17-302, FAC,* "Surface Water Quality Standards," and *Rule 17-4, FAC,* "Permits," to include an antidegradation policy. This policy requires that any new or expanded surface-water discharges be clearly in the public interest. The applicants for surface-water discharges must demonstrate that reuse of domestic reclaimed water is not economically or technologically reasonable.

Rule clean-up. *Chapter 17-610, FAC,* was revised in 1990. Setback distance (buffer zone) requirements were updated throughout the rules. Streamlined permitting requirements and associated forms were added. The use of reclaimed water for toilet flushing and fire protection was extended to motels, hotels, apartments, and other units where the resident does not have ready access to the plumbing system for repairs or modifications.

THE FUTURE

Reuse of reclaimed water will increase significantly during the next decade. Recent droughts in southern Florida emphasized the need for conservation of valuable potable water supplies and for reuse of reclaimed water. As the water-management districts identify critical water-supply problem areas and implement mandatory reuse provisions, additional pressures will be placed on communities to move toward reuse. Requirements for applicants for wastewater-management permits to conduct reuse feasibility studies also will focus the community's attention on the need for reuse. Continued population growth, most of which will occur in coastal areas, will increase the pressure on cities, counties, and utilities to protect valuable and fragile water resources by conserving water and reusing reclaimed water for non-potable purposes.

The Florida Department of Environmental Regulations strongly supports reuse of reclaimed water. The goal is to increase the amount of reuse in Florida by 40% above 1987 levels by 1992. Recently adopted technical reuse rules, the mandatory reuse program, 1989 state legislation, and the antidegradation policy will contribute to the promotion of reuse. ■

David W. York is reuse coordinator for the Florida Department of Environmental Regulation in Tallahassee, Fla.; James Crook is principal engineer with Camp Dresser & McKee, Inc., in Clearwater, Fla.

REFERENCES

1. *Land Application of Domestic Wastewater Effluent in Florida.* Florida Department of Environmental Regulation, Tallahassee, Fl. (1983).

2. *1990 Reuse Inventory.* Florida Department of Environmental Regulation, Tallahassee, Fla. (1990).

3. *Section 403.064, Florida Statutes.* State of Florida, Tallahassee, Fl. (1989).

ECONOMIC TOOL FOR REUSE PLANNING

J. Gordon Milliken

Economics provides several useful tools to guide planners contemplating a potential wastewater reuse project, but the tools and their applications to water-resource development are not universally well understood by engineers and managers. If cost-effectiveness, cost/benefit, and financial feasibility analyses and a market research pricing study are conducted, many of the key questions faced in water-resource planning can be answered.

MAKING DECISIONS

Planners in all areas have a common goal: meeting future water demands in the best possible manner. Local conditions complicate this common goal, throwing a variety of alternatives that must be considered into the ring. The simplest example involves the choice of either constructing a water reclamation plant or developing a new water supply and expanding the existing conventional wastewater treatment plant. It's never that easy in the real world, but the first question that must be answered is, among the alternatives, which is the best?

Cost/benefit calculations have been used for decades to compare the returns offered by different proposed investments. The costs of the resources required are related to the market value of the flow of benefits expected, using discounted cash-flow techniques.

When comparing alternatives that cause complex social and environmental effects, such as changes in the quality of life or permanent changes in rivers and forests, this technique is hard to use. The investments and expenditures really do not fit the cost/benefit framework because the outcomes often cannot be measured in dollars. In such cases, cost-effectiveness comparisons are more useful. This technique uses an effectiveness scale as a measurement concept.

The alternative methods for achieving water-resource (supply or quality) goals differ in many ways: in amount and timing of the capital investment required; in amount of operating and maintenance cost; in useful life of capital investment in facilities; in effectiveness, both as to magnitude of effect and certainty of effect; and in impact on the rest of the economy, the environment, public health, and other factors.

Cost-effectiveness. To establish a clear basis to compare the alternatives, this methodology requires a single, uniform measure of effectiveness such as the volume of water of a specified quality produced annually, either in added supply or in reduced demand, at a selected confidence level. All other measures of differences among alternatives are treated as costs or ranked according to their degree of effect. By this means, all of the alternatives can be equated on the basis of their ability to produce a unit quantity of water of a specified quality. Their relative types and degrees of cost, such as direct cost, quality of life effect, environmental effect, and others, can then be compared. The various costs and effects can be arrayed together to help planners choose among the competing alternatives.

Cost benefit and feasibility analyses. Once an alternative is selected, a true cost/benefit analysis should be conducted. The analysis should ask and answer two basic questions: Is this reuse project economically desirable—does society receive a net benefit if resources are used to build it? Are the total benefits greater than the total costs?

The analysis, if properly conducted, will identify the various beneficiaries of the project, estimate the amount of their benefits, and determine when these benefits will be received.

U.S. federal law specifies that federal agencies involved in water planning use the economic and environmental principles and guidelines developed by the U.S. Water Resources Council.[1] The framework provides the means to identify all costs and parties on whom the direct or indirect costs fall and to identify beneficiaries and the amount of benefit they will receive. To the extent possible, the framework provides the means to allocate costs appropriately to beneficiaries.

A financial feasibility analysis determines whether the plans for the proposed reuse plant are financially sound—if the costs of capital investment plus the costs of operation and maintenance can be covered by user charges and revenues from sales of reuse water.

Studies of financial feasibility require that reuse project costs be estimated with substantial accuracy, although some estimating uncertainty is inevitable. Capital costs may be paid from an existing capital construction fund (typical of an industrial firm) or by bonded debt (typical of a governmental utility). Bonded debt requires a forecast of the bond interest rate, which varies with the credit rating of the issuing organization, and the degree of risk of the bonds, whether backed by future revenues or by taxes. Operation and maintenance (O&M) costs will vary because of inflation of energy and labor costs and possible technological improvements in future operating efficiency.

In the financial feasibility analysis, the future stream of costs, including bond payments, is projected and compared with a future stream of revenues that will come from user fees and charges, contracts to sell reuse water, and perhaps from government grants. Although it violates sound economic principles, some revenue may be planned from tax subsidies if the user fees are considered so high as to be politically unacceptable.

In any case, the future revenues must equal the future costs for the plan to be financially sound. In industrial projects, it is customary to plan a reserve fund for ultimate replacement of the facility after its useful life ends or it becomes obsolete. This forward planning is less common in government because officials customarily do not consider that accruing reserves from taxes or excess user fees is good public policy.

Market pricing research. The financial feasibility analysis relies largely on market research pricing studies. Setting the price of reuse water may or may not be a complex problem, depending on several factors.

For example, if the reuse water is used by the governmental entity that produces it, such as by a municipality that operates both a water supply and a wastewater treatment utility, the question of pricing may never be raised. The price will be set as is customary on a cost-of-service basis—uniformly—for the blend of reuse water and the water from traditional sources.

A more complex problem arises when the reuse water is offered as a nonpotable supply to customers—usually industrial firms that have the option of buying it, buying potable water, or obtaining water from another source, such as a self-supplied groundwater or an in-plant reuse system. In such a case, a thorough market-research study is necessary to determine whether potential customers are willing to pay for reuse water and how this compares to the actual cost of producing suitable reclaimed water. The most comprehensive study to date was conducted in 1981 and involved 250 on-site interviews of industrial water users in Orange and Los Angeles Counties.

Significant Economic Factors Impacting Future Wastewater Reuse

- The rapidly rising costs of alternative sources of water in a great many metropolitan areas, not only the traditionally water-poor, semi-arid cities;
- The stabilization of wastewater reuse production costs and their increasing competitiveness with other water supply sources;
- The very serious limitations on water supply and the reduction in volume of traditional water supplies faced by certain cities; and
- The growing impact of water-quality regulations that place burdensome costs on wastewater discharges and thus narrow the cost differential between discharge and reuse.

ECONOMICS OF WASTEWATER RECYCLING

Simple economic models of a conventional water system and a wastewater recycling project exist.[2] The conventional water supply/wastewater treatment system costs component includes operating and maintenance costs and amortization of capital expenditures (Equation 1). The costs of an equivalent water reuse system are somewhat different (Equation 2).

An equivalent water supply system using recycled water would incur virtually identical costs for raw water treatment, distribution, and wastewater treatment. Some costs differ where recycling provides a portion of the water supply: the cost of water collection (raw supplies versus effluent); and the additional cost necessary to bring wastewater from the quality necessary for its discharge or disposal under applicable regulations to a useful and marketable quality as recycled water.

Some additional distribution costs also may be incurred as the recycled water must be transferred from the wastewater treatment location to a point where it can be reused or integrated into a supply system.

Primarily, however, the cost of renovated water is a direct function of the relative levels of wastewater treatment required for effluent disposal and the particular reuse contemplated. The higher the quality of treated wastewater, the lower the additional cost necessary to produce recycled water. The true cost of recycled water is only its net cost above the cost associated with all elements of a conventional water system. This additional cost is the appropriate one to use when comparing the cost of recycled water with that of new supplies from conventional sources.

The economic feasibility of a municipal or industrial wastewater reuse system, therefore, is a function of added costs less cost savings and revenues (see Box).

Transport costs may be substantial if they involve a dual distribution system. They will at least include the costs of transport from the reuse plant to the place of use or of integration into the supply system. For example, if the system is potable reuse, costs for transport into supply reservoirs or onto the spreading ground for groundwater recharge must be considered.

The interaction of these factors in individual cases will determine the cost of recycling as compared to the cost of once-through water use, and thus the advisability of reuse.

System Cost Equations

Equation 1

Total \$ Water Service = \$ Collection + \$ Treatment + \$ Distribution + \$ Wastewater treatment

Equation 2

Total \$ Water Service = \$ Conventional wastewater treatment + \$ Effluent collection + \$ Additional treatment for reuse + \$ Additional transportation to supply system + \$ Distribution

ECONOMIC FACTORS

Some economic factors that affect the decision to build a reuse facility are reasonably constant and predictable regardless of geographic location. Some vary widely depending on location, site conditions, and the use to be made of the reuse water.

Local supply and demand. If the local water supply is ample or inexhaustible, or if municipal demand is steady, reflecting no population growth, there is little incentive to create new water supplies through reuse. Reuse may still be chosen, however, for reasons related to wastewater quality regulations.

It is far more important to consider reuse when a municipality has exhausted all other supply alternatives and still faces growing demand, or when part of the existing supply is threatened with elimination. El Paso, Texas, and the Los Angeles/San Diego Region are examples. Both metropolitan areas have strong programs for water conservation and reuse because their historical supply sources are threatened with decline and no economical alternatives are available.

Costs of water from alternative sources. As cities grow and exhaust their traditional water supply sources, they must seek alternative supplies, usually by diversion from ever more distant streams or by buying agricultural water for municipal use. One scenario that includes building a large reservoir and diversions of water from the Colorado River drainage basin through the Continental Divide will have a capital cost of about \$8.11/m^3 (\$10,000/ac-ft) of safe annual yield. The marginal long-term capital cost of new supplies is estimated at \$11,000/household in addition to a share of the amortized cost of the existing water system.

Although the quantity of water available for reuse is strictly limited by state law to water imported from other basins, the relative cost of reuse is low. Nonpotable reuse, providing an annual safe yield of 12.1 X 10^6 m^3 (9830 ac-ft), would cost about \$0.45/m^3 • a (\$560/ac-ft/yr).

Potable reuse water from Denver's pioneering 3.79 X 10^6 L/d (1 mgd) Potable Water Reuse Project is currently produced at an operational cost, including facility O & M, of \$0.52/1000 L (\$1.97/1000 gal) or \$640/ac-ft. Based on 1989 experience, Denver expects a full-scale reuse plant to convert sewage effluent to potable water at a cost of \$0.45 to \$0.59/1000 L (\$1.72 to \$2.25/1000 gal), or from \$560 to \$733/ac ft, including amortized capital cost. This is substantially less than the cost of raw water obtained from structural diversion from the Colorado River Basin.

Quality standards for direct addition to potable supplies. Water-quality regulations can significantly affect the cost of reuse water produced for potable purposes. For example, in Southern California, Regional Water Quality Control Board regulations require that water injected in the groundwater aquifers which serve as seawater intrusion barriers have a maximum salinity level of 540 mg/L total dissolved solids (TDS). However, the wastewater effluent flowing into Water Factory 21 from the Santa Ana River and local wastewater treatment plants is at 700 mg/L TDS. Thus the water must be demineralized by reverse osmosis (RO) as well as treated for normal wastewater contaminants before recharge into the groundwater. The current RO cost at Water Factory 21 is \$0.34/m^3 (\$415/ac-ft), but the cost is expected to be reduced to \$0.30/m^3 (\$375/ac-ft) after investment in new pumps.

Currently, some 246 X 10^6 m^3 (200,000 ac-ft) of water are being discharged to the ocean from Orange County. As population and demand grow, there will be a growing incentive to increase reuse.

Regulatory constraints on wastewater discharge. Another economic incentive to re-use wastewater is the likelihood of increasing constraints on the quality of treated wastewater discharge that may degrade groundwater supplies. For example, the Santa Ana Regional Water Quality Control Board requires that water or wastewater used for groundwater replenishment, or discharged into the Santa Ana River or another open channel, cannot exceed the salinity of present groundwater or 600 mg/L TDS, whichever is less. If it does, more fresh water must be provided for dilution, the discharge must be treated to remove salt, or the discharge must be sent directly to an ocean outfall via a brine line. Thus far, capital costs for the brine line from the upper reaches of Riverside County are \$50 million. Another \$30 million in capital investment is being planned to extend the line into San Bernardino County. Current yearly O & M costs for the brine line are \$6.1 million, and these costs will rise to \$10.8 million before the year 2010.

In some areas, such high disposal costs may be spent instead on facilities that desalt and reuse the wastewater. Within the Santa Ana watershed, desalting plants are being planned or projected for future construction in three areas, with a potential capital cost of $58 million and annual O & M of up to $21 million. Two of these plants will be necessary for water supply purposes and one is necessary to successfully implement planned water reuse programs.

Under Arizona's new groundwater protection law, similar constraints on salinity levels of treated wastewater used for groundwater recharge may come into play in Tucson, once it receives deliveries of Central Arizona Project (CAP) water which is substantially more saline than Tucson's present supply. As CAP water is intended for direct use, to conserve groundwater supplies, the groundwater protection law may result in a requirement for demineralization of effluent.

Quality standards for nonpotable uses. Nonpotable reuse water used for landscape irrigation, or even some crop irrigation, is normally acceptable for use after secondary treatment. Restrictions apply to contact uses, such as swimming, and to irrigation of food chain crops. Nonpotable water also is acceptable for industrial cooling, although it may require cold lime softening to protect from scale, and the addition of biocides and biodispersants to water in cooling towers. For other industrial processes, a variety of treatment is used, and quality standards for reuse water prior to treatment are not usually severe. The primary criterion from industry's viewpoint is that the water supply be of consistent quality so that pretreatment can be maintained routinely.

Economies of scale. Some costs associated with reuse treatment are expected to remain nearly constant per unit volume of water treated, such as membranes, energy, chemicals, and other materials. Other costs related to facility construction, laboratory analysis, and labor for supervision and operation will decrease as plant size increases.

Significant economies of scale can be realized by large reuse plants but these economics can be achieved only as long as the plants operate at near capacity. Given the seasonal variation in urban water use and the variability of return flow, however, a plant designed to recycle the maximum amount of effluent will necessarily run at less than capacity for part of the year.

A more modest-sized plant, though it continually operates at capacity, not only will have the higher unit costs of a smaller plant but will also be unable to process all of the effluent. The overflow that cannot be recycled back into the system still must be treated to meet discharge standards, but it then is discharged and lost. In areas where water is scarce and expensive, this may be a costly loss.

The choice of plant capacity is therefore a complex one. It is worth noting, however, that the larger the metropolitan area and the greater the amount of effluent, the simpler the decision about plant size becomes, since even a large, efficient plant may have a capacity significantly lower than the total amount of effluent available for reuse.

Market behavior. Market behavior exhibits anomalies despite price differentials between conventional and recycled water. For example, Long Beach, Calif., obtains a high-quality nonpotable reuse water from the Los Angeles County Sanitation District that is tertiary-treated and chlorinated. The water is used without further treatment for landscape irrigation on parks, golf courses, and schools. The reuse water is available for sale to industrial users for $0.029/1000 L ($0.083/100 cu ft) compared with potable water selling for $0.25/1000 L ($0.71/100 cu ft).

Long Beach petroleum producers who are on an interruptible supply of potable water had considered using recycled water for reinjection and secondary recovery from oil wells, but have since opted to use the more expensive potable water instead. Evidently the reuse water must be treated with a chemical agent to avoid a slime condition that blocks the aquifer. Even though the cost of chemical treatment adds little to the cost of reuse water, the use of potable water avoids the inconvenience of treatment.

Economic Feasibility

Added costs of a reuse system

- Added capital facility costs.
- Added operating costs to collect wastewater effluent.
- Added operating costs to treat wastewater to quality standards.
- Added transport costs.

Savings of a reuse system

- Avoidance of part of the costs of treating wastewater to the extent necessary to meet pollution control requirements before discharge.
- Curtailment of water supply acquisition costs through extension of the use available from existing supplies, that is, reduction or postponement of water supply development costs.

Revenues for a reuse system

- Sale of water.
- Use by the municipality itself, following a first use.

CONCLUSION

The most significant economic factors impacting future potable and non-potable water reuse (see Box) show trends that favor the future expansion of both potable and nonpotable reuse. ■

J. Gordon Milliken is senior research economist with Milliken Research Group, Inc., in Littleton, Colo. *This paper was reprinted with permission from "1987 Annual Conference Proceedings," American Water Works Association.*

REFERENCES

1.U.S. Water Resources Council, *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies,* Government Printing Office, Washington, D.C. (1983).

2.Milliken, J. Gordon, and Trumbly, Anthony S., "Municipal Recycling of Wastewater," *Journal AWWA,* 71, 10, 548 (1979).

Water reuse: potable or nonpotable? There is a difference!

Water reclamation and reuse offers an increasingly attractive option for meeting the growing water shortages facing urban, industrial, and agricultural consumers throughout the world. However, the failure to identify clearly whether a project,a principle or practice, or a table of water-quality parameters refers to potable or nonpotable reuse may easily confuse the reader. Both potable and nonpotable reuse have the potential for adding to the water resource and reducing water pollution, but in every other aspect the two practices are very different.

This last segment in a series on reuse was made possible by a grant from EPA. WE&T hopes that the four segments in the series, which began in October, have provided readers with a better sense of the reuse potential of wastewater.

- Water-quality monitoring and treatment for potable reuse needs to address all parameters embodied in primary drinking-water regulations with due attention to the many contaminants soon to be included in the regulations. For nonpotable reuse, the concerns are only with microbiological contaminants and some parameters in secondary drinking-water regulations.
- A potable water reuse project requires extensive preliminary study including less conventional treatment processes and more intensive monitoring, often of organic compounds difficult to analyze. A nonpotable reuse project uses fewer and only conventional treatment processes and simple monitoring of only a handful of contaminants.
- There are hundreds of pipe-to-pipe nonpotable reuse systems in the U.S., Japan, and elsewhere, some of which incorporate full dual-distribution systems. On the other hand, there are no pipe-to-pipe potable reuse systems in service anywhere in the world. The discharge of reclaimed wastewater to a reservoir that formerly had only fresh water to supplement a potable supply may be more acceptable than pipe-to-pipe reuse, but it introduces new health concerns that those cities that now draw on run-of-river supplies already face.
- An obstacle that faces potable water reuse projects is public acceptance, and public education programs are vital. On the other hand, nonpotable reuse for urban, industrial, and agricultural purposes is widely accepted and engenders public enthusiasm as being environmentally appropriate.

EPA regulations state that "...priority should be given to selection of the purest source. Polluted sources should not be used unless other sources are economically unavailable..." Should we really be trying to persuade the public that we should draw our drinking water from sewers? To claim that it is better than some presently used waters does not inspire confidence. The distrust of public supplies is already widespread, with increased use of costly bottled water and point-of-use treatment devices.

Accordingly, while nonpotable reuse continues to be seen as having the potential to be immediately feasible, it should not have to carry this baggage of uncertainties and public resistance that constrain potable reuse. More precise labelling in the literature would be helpful.

Daniel A. Okun
Kenan Professor of Environmental Engineering, Emeritus
University of North Carolina at Chapel Hill

Report Sets New Water Reuse Guidelines

Christopher Powicki

For nearly 20 years, the U.S. World Health organization (WHO) has been considering the implications of reclaiming wastewater treatment plant effluent and has been evaluating the safeguards needed to protect human health. Most recently, in 1987, WHO sponsored a meeting of international experts in the wastewater treatment and public-health fields that resulted in the 1989 publication of a report, "Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture."

The report discusses historical and current reuse practices from a public-health perspective, recommends guidelines and alternative measures for the control of infectious diseases, and identifies areas of uncertainty that require future research. It affirms that wastewater is a viable and valuable resource needed to meet "perhaps the greatest challenge of the next century: appropriate management of the limited water resources available."

NEW GUIDELINES

Conventional primary and secondary treatment practices emphasize the reduction or removal of biochemical oxygen demand and suspended solids—the traditional parameters of water quality. Treatment for reuse requires the removal of pathogenic organisms for which conventional treatment practices are not very effective. Engineers designing reuse plants are further challenged by the variation in the maximum permissible concentrations of specified pathogenic organisms for the different end uses of reclaimed water. This variation is based on the potential levels of human exposure to the reclaimed water for each reuse scheme.

To achieve the highest level of health protection, engineers must have clearly defined quality standards for each end use, and they must consider economic and operational factors. According to the report, "wastewater of the required quality should be produced at all times...without the need for continuous monitoring. Emphasis must therefore be placed on careful selection and design of treatment plants rather than on a high degree of care in operation." The report states that this is most important in developing countries, where money and adequate infrastructure are lacking and there is limited experience in operating treatment plants. In these areas, "the simplest and cheapest technology will have the greatest chance of success."

Unfortunately, in many poor countries, organized water reuse programs have made little headway, primarily because many wealthy countries committed to reuse have relied on advanced and expensive technology, according to the report. Wealthy countries often rely on tertiary treatment, including rapid sand filtration and chlorination, to meet strict microbiological standards for effluents applied to agricultural lands.

Reuse is the greatest challenge of the next century.

The report states that recent epidemiological research indicates that the risks from irrigation with reclaimed water have been overestimated and that these standards are "unjustifiably restrictive, particularly with respect of bacterial pathogens." The report recommends new guidelines containing less stringent standards for fecal coliform.

The guidelines contain stricter standards for the concentration of helminth eggs (Ascaris sp., Trichuris sp., and hookworms), which are the main public-health risks associated with wastewater irrigation in areas where helminthic diseases are endemic, such as developing countries. According to the report, stabilization ponds with a retention time of 8 to 10 days are particularly effective in achieving helminth concentrations less than or equal to 1 egg/L.

The guidelines do not cover all helminths and protozoa that potentially threaten humans exposed to reclaimed water. For example, *Giardia* sp. are not cited. According to the report, the helminths that are covered should serve as indicator organisms for all large, settleable pathogens. Other pathogens of interest apparently become non-viable in long-retention-time pond systems. "It is thus implied by the guidelines that all helminth eggs and protozoan cysts will be removed to the same extent," states the report.

The previous high standards and the need for costly, sophisticated treatment technologies to meet them have caused poor countries to fail to incorporate wastewater reuse into new sewerage schemes, resulting in the uncontrolled use of raw sewage or treated effluent by farmers for irrigation purposes. The new guidelines, which are in line with the quality of river water used for the unrestricted irrigation of all crops in many countries without known ill effects, were designed to eliminate these problems. The idea was to "increase public-health protection for a greater number of people, while at the same time set targets that were both technologically and economically feasible."

The report states that the guidelines must be carefully interpreted and that they may need to be modified in light of local epidemiological, sociocultural, and environmental factors.

OTHER ISSUES

The report describes the treatment technologies that can be used to meet the revised guidelines in the most economical manner. It also outlines application methods and other measures that can reduce the risks associated with ingesting crops irrigated with wastewater. It suggests an institutional framework for the implementation of health safeguards including the development of appropriate regulations.

Research needs are outlined in several areas: water-quality assessment methods, treatment technologies, irrigation technologies, epidemiology, sociology, and economics.

—The report is available from the WHO Publications Centre, 49 Sheridan Ave., Albany, NY 12210.

CLARIFICATION AND FILTRATION TO MEET LOW TURBIDITY RECLAIMED WATER STANDARDS

Joel A. Faller, Robert A. Ryder

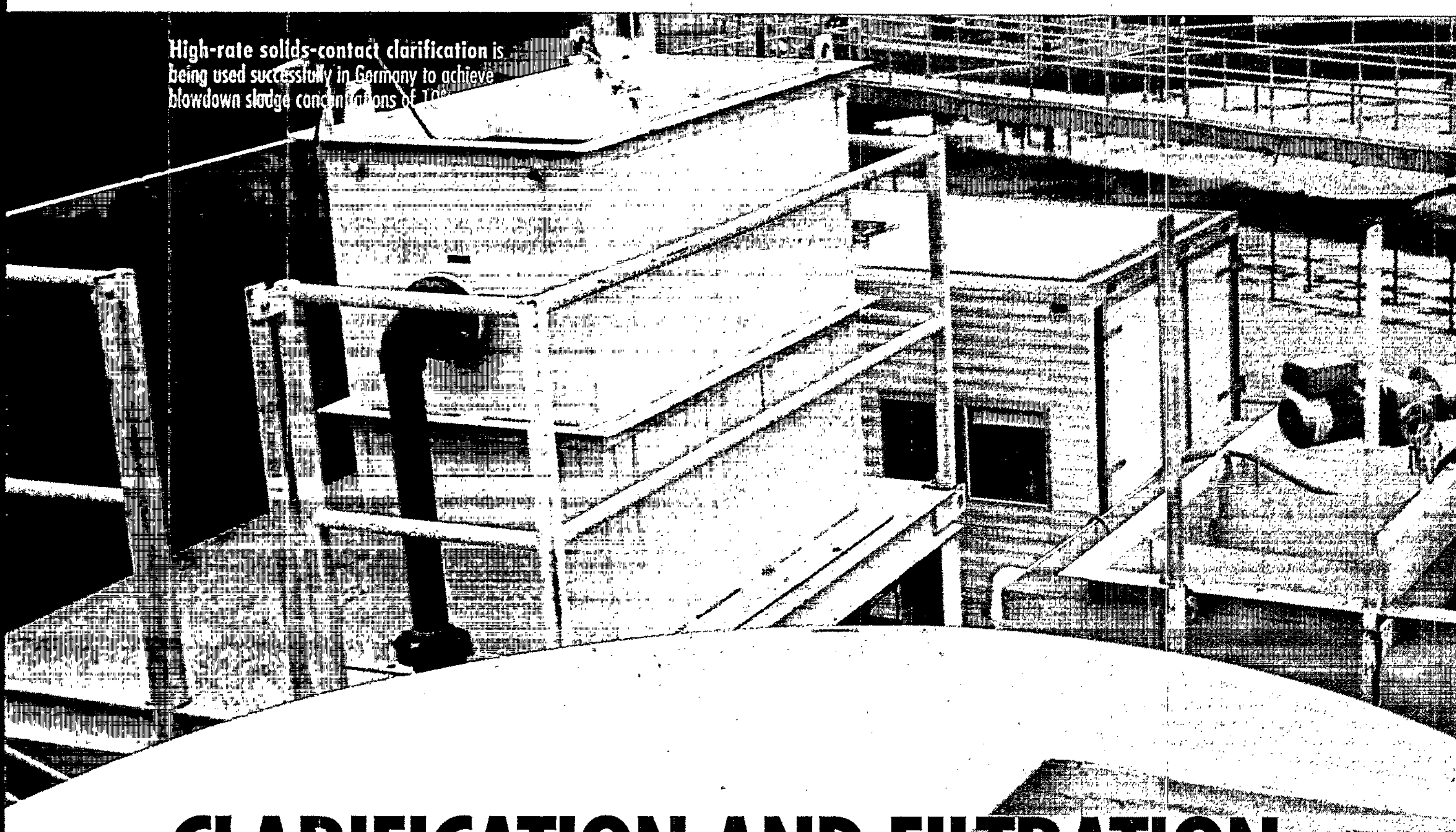
The use of treated wastewater for field and crop irrigation has a long history in the state of California but, in the last 25 years, wastewater reclamation has become even more prevalent in the state. This change was largely driven by the need for restrictions on wastewater effluent discharges to watercourses and by increased urbanization and groundwater depletion. Primary uses for reclaimed wastewater include irrigation of parks, green belts, and golf courses; impoundment of seasonal waste discharges; and percolation to recharge groundwater basins.

California water and wastewater management districts have been challenged to incorporate reclaimed water into existing treatment and conveyance systems while meeting tightening state water-quality standards. Wastewater treatment plants (WWTPs) using trickling filters in their secondary treatment train have a unique problem: trickling filter effluent meets secondary treatment standards, but has higher turbidity levels than effluent from the activated-sludge process. Therefore, for trickling-filter effluent, the standard reclamation approach—rapid sand filtration followed by chlorination—does not meet California's turbidity standard.

At a reclamation plant operated by the Marin Municipal Water District (MMWD), an in-depth evaluation of clarification and filtration options was undertaken to identify the most economical and effective process to treat trickling-filter effluent to meet turbidity standards for reclaimed water.

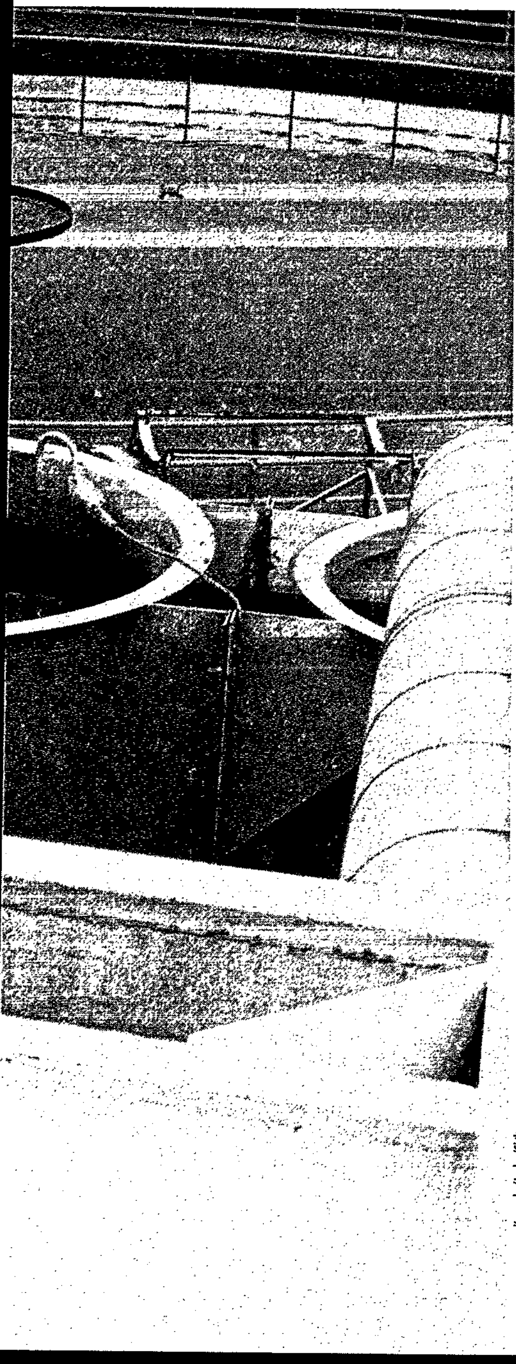
TIGHTER STANDARDS

In 1978, the MMWD constructed a water reclamation plant at Las Gallinas Valley Sanitary District's WWTP north of San Rafael, Calif. The 1-mgd reclamation plant used direct sand filtration and chlorination processes to treat effluent from the final clarifier of the adjacent two-stage trickling filter, secondary treatment plant. Reclaimed



wastewater has been used to irrigate nearby McInnis Park and freeway landscaping, and for utility services at the WWTP.

Before the reclamation facility was completed, the clarity requirements for reclaimed wastewater used for irrigation of unrestricted public-access landscaped facilities and recreational impoundments were modified. The California State Department of Health (DOHS) proposed reclamation criteria based on operation of several operating WWTPs. The DOHS required that reclaimed water for use on these areas have an average turbidity of less than 2 nephelometric turbidity units (NTUs), with a maximum not-to-exceed value of 5 NTU; and an average coliform count of less than 2.2/100 mL, with a maximum not-to-exceed value of 23/100 mL. Turbidity measurement was established as a surrogate for effective removal of pathogenic organisms, including viruses, following extensive testing of reclaimed water processes in California.



Kennedy/Jenks/Chilton

The reclamation plant was able to meet the bacterial requirement, but there was considerable difficulty meeting the clarity standard. This was despite the maintenance of good operations and the installation of several improvements, including chemical feed and prefiltration of the wastewater effluent.

Direct filtration processes, with the aid of chemical coagulants, have successfully operated when the secondary effluent turbidity is 10 NTU or less, as is typical for many activated-sludge secondary effluents. However, trickling-filter effluent typically has higher turbidity levels, and direct filtration as a single treatment process will not produce reclaimed water that meets the turbidity standard.

After extensive testing by MMWD staff, it was decided in 1987 that the criteria for unrestricted landscape irrigation could be met by the plant if the water was coagulated, settled, and filtered through improved media. Process improvements evaluated by on-site pilot-plant testing were recommended to determine the type of treatment necessary to achieve state reclamation standards. The pilot-plant tests would also identify the cost of modifications and attendant operational costs.

The MMWD authorized a study in winter 1987 to evaluate and test processes for improving wastewater treatment. The study would also suggest the apparent best process for providing a present capacity of 2 mgd, expandable to 4 mgd, that would use the current and projected dry-weather wastewater flows of Las Gallinas.

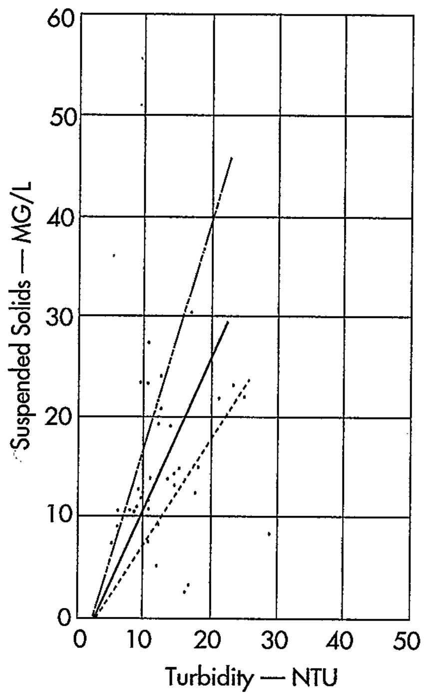
WASTEWATER TREATMENT

The processes and operations of Las Gallinas have major impacts on the operation and performance of the reclamation plant. The WWTP uses a two-stage, high-rate rock trickling-filter process that has a dry-weather capacity of 2.9 mgd and wet-weather peaks of up to 8 mgd. The WWTP was upgraded in 1984 to provide advanced secondary treatment through a nitrification fixed-film reactor tower and effluent polishing through deep-bed filters. Disposal to storage ponds for dry-season irrigation of pastures and hay fields, and to a marsh pond for effluent enhancement before wet-season discharge to Miller Creek was improved.

The MMWD reclamation plant was an in-line filtration facility that has alum and polymer coagulant addition and storage, a static rapid mixer, deep course-media silica-sand filtration, chlorination, and storage in a combination chlorine-contact and distribution reservoir.

The quality of influent delivered to the reclamation plant depends on whether the influent is pumped directly from the WWTP's final clarifier or from its filters. Average influent turbidity is 10 to 20 NTU. At times, turbidity is lower, but often it is much higher.

Figure 1—Suspended Solids/Turbidity Relationship

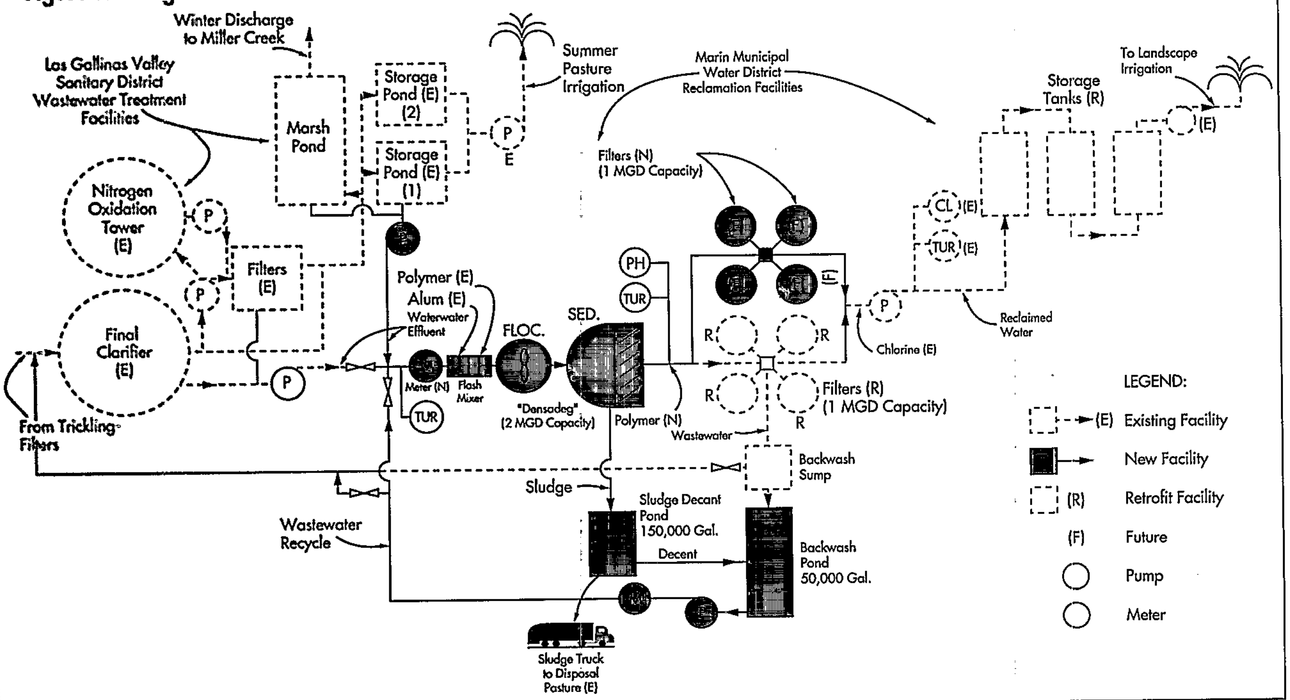


The existing reclamation plant removed most of the influent turbidity. Typically, the treated-water turbidity was 4 to 8 NTU, despite relatively high coagulant doses. It was apparent that the influent was highly variable and difficult to effectively coagulate, clarify, and filter with the available process facilities.

TRICKLING-FILTER QUALITY

Trickling filter effluent is usually

Figure 2—High-Rate Solids-Contact Clarification



related in terms of biochemical oxygen demand (BOD) and suspended solids (SS). EPA requires secondary treatment to reduce wastewater concentrations of both to 30 mg/L. Las Gallinas' permit has seasonal and temporal SS limits (Table 1).

To achieve the treatment levels, discharge from the secondary clarifiers is the final effluent from June to August, when discharge to San Francisco Bay is prohibited and the effluent is stored in holding ponds for irrigation. The nitrification fixed-film reactor and effluent filter are in use for the remainder of the year when the final effluent is discharged to San Francisco Bay via nearby Miller Creek. Reclaimed water is used for irrigation between April and November; thus, water-quality standards and effluent quality differ periodically.

For trickling-filter effluent, the SS concentration usually exceeds the turbidity value. A plot of the relationship of turbidity and SS for Las Gallinas effluent shows that the summer ratio was about 1.75:1, during the winter it was only 0.75:1, with an overall average of 1.25:1 and considerable scattering of data (Figure 1).

FILTRATION OF TRICKLING-FILTER EFFLUENT

The literature reports that the average removal of SS by rapid sand filters is two-thirds to three-fourths of the settled water concentration. In the nearby Ignacio WWTP that uses a shallow-bed rapid sand filter, SS is reduced by about 50%.

In fact, data on available technology was for direct filtration used mostly in activated-sludge treatment processes, while clarification and filtration were required for most trickling- filter effluents to achieve the standard of an average of less than 2 NTU (see Box). There are many references to support what has practically been found in the years of operation of Las Gallinas WWTP—that direct filtration alone is not sufficient to produce reclaimed water with an average turbidity of less than 2 NTU.

The DOHS recognized that, for wastewater reclamation plants with direct filtration, secondary effluent should have a turbidity of less than 10 NTU. This was not usually achieved

Direct and Tertiary Filtration

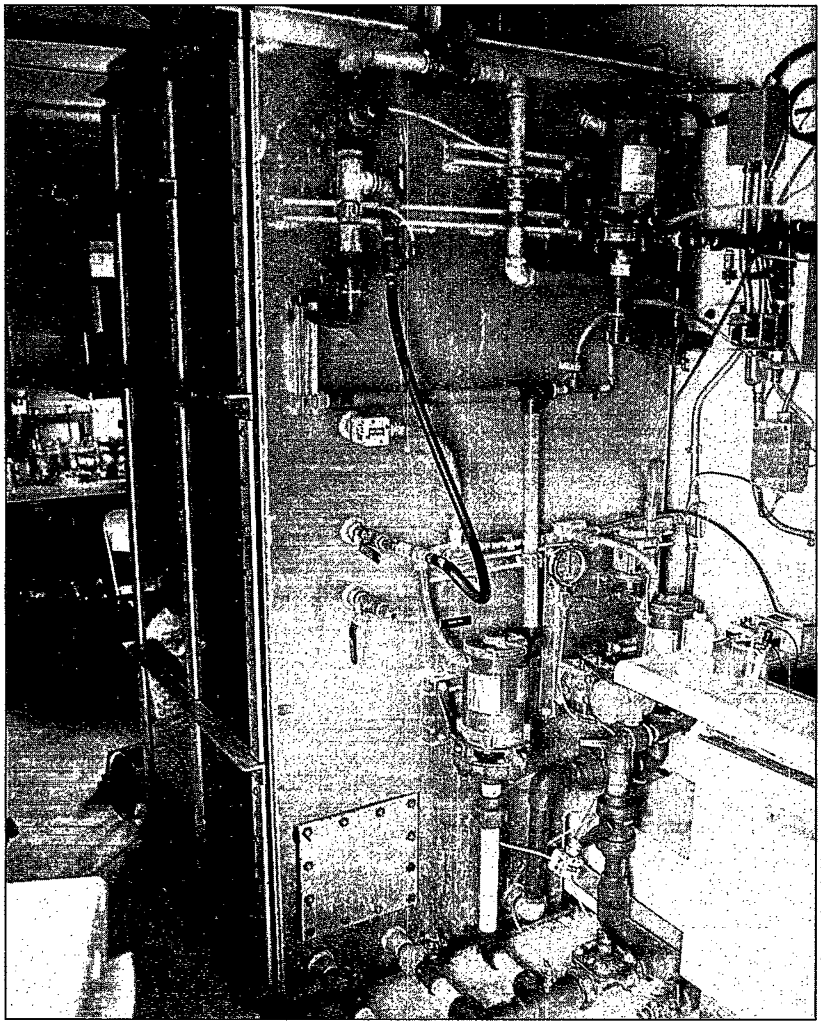
Trickling-filter effluent achieved a poorer degree of biological flocculation than activated sludge. The strength of the biological floc is also greater than chemical coagulation, as it is more difficult to achieve low turbidity by direct filtration of trickling filter effluent.

A review of tertiary filtration of wastewater found that the greatest factor affecting SS removal efficiency is the size of the particles in the influent wastewater, and that about 30% of trickling filter effluents contain very small particles that are not easily filtered. It was also found that trickling filter effluent contains large quantities of submicron colloidal material, and because of the stoichiometric effect for chemical destabilization, large coagulant doses can be required. Other tests conducted in Seattle found that over 95% of the number of particles in trickling filter effluent were in the 0.5 to 2 micron range and that they contributed the greatest portion of the turbidity. Also, only 30% of the particles in this size range were removed by filtration.

There are specific recommendations for treatment processes to produce a highly treated effluent; however, for reclaiming trickling filter effluent, full flocculation sedimentation before filtration is highly recommended, and for activated-sludge effluent, only direct filtration is recommended.

Table 1—Las Gallinas Effluent Limits for Suspended Solids, mg/L

	Measurement Period		
Period	Monthly average	Weekly maximum	Daily maximum
November to March	30	45	60
April to May	15	18	20
September to October	15	18	20
June to August	not required	not required	not required



Courtesy—Sug Kennedy/Jenks/Chilton

Upflow adsorption clarification is a new development that combines flocculation and solids capture in a granular-media bed before filtration.

at Las Gallinas for the WWTP's secondary clarifier or polishing filter processes.

There are effective means of upgrading trickling-filter effluent, usually by the installation of a coupled or short-detention aeration of activated sludge to achieve effective biological oxidation. In view of the district's existing plant layout and need for biological nitrification reaction, it was not a viable consideration.

CLARIFICATION PROCESSES

Several clarification processes were considered for Las Gallinas WWTP.

Conventional coagulation and settling. Conventional coagulation and settling have been used successfully to clarify wastewater before filtration to provide flexibility for coagulant chemical doses, flocculation energy, and sludge recirculation. Coagulation times range from 15 to 30 minutes, settling overflow rates range from 0.5 and 0.75 gpm/sq ft, and detention times are 1 to 2 hours. To provide effective conventional clarification of wastewater, it is normal that alum doses range from 75 to 250 mg/L and polymer doses range from 2 to 10 mg/L.

The tests conducted in this investigation found that conventional clarification used the normal amount of coagulant, flocculation energy, and time. The tests also showed that settling overflow rates that produced a settled-water turbidity of less than 3 NTU could then be filtered to produce a finished-water turbidity of 1.2 to 1.8 NTU. This requires a dose of 70 to 100 mg/L of alum, 2 to 5 mg/L of polymer, 10 to 15 minutes of flocculation, and an overflow rate of 0.75 gpm/sq ft.

High-rate inclined-plate tube settlers. Inclined-plate and tube settlers have been used in several clarification applications following flocculation.

In all instances, there is an accumulation of sludge near the top of the inclined tubes that is most effectively removed by periodically shutting off the plant and dropping the water level below the tubes. The floc slides off and plates or tubes are cleaned. This tube cleaning is necessary every 5 to 7 days and takes several hours. Water-jet cleaning of the surface of the tubes can also be used, but is more time consuming and less satisfactory than the draining practice.

Solids-contact clarification. Solids-contact clarification has been used in several wastewater clarification processes. It usually combines high-rate flocculation with a turbine mixer and upflow clarification. Usual overflow rates are 1 to 1.5 gpm/sq ft.

A recently developed high-rate solids clarifier has been successfully used in Germany to clarify wastewater effluents with an overflow rate of 5 gpm/sq ft without tubes, and 10 gpm/sq ft with tubes. One advantage of this clarifier is that the blowdown sludge concentration can approach 10%, as compared to the usual 1% or less of conventional or upflow clarifiers. This new process was selected for the pilot-plant test at Las Gallinas.

Adsorption clarification. The adsorption clarification process is a new development that combines the functions of flocculation and solids capture in a granular-media bed before filtration. The process is akin to two stages of filtration in that the initial adsorption clarifier uses a high flow rate of 5 to 10 gpm/sq ft and large media of 3 to 5 mm. Coagulant chemicals are introduced before the adsorption clarifier and are flocculated within the granular bed by the high-flow energy and turbulence passing through the bed. This causes an enlargement of floc size and retention within the granular bed.

There are two basic types of adsorption clarifiers: the downflow mode and the upflow mode. The downflow mode, developed in the early 1970s, is used extensively in Europe and South America. Downflow adsorption clarifiers have had limited use in wastewater clarification. Both types of clarifiers use an air-wash-aided backwash, silica-sand, and 4 to 6 ft of anthracite media. The clarified-water turbidity is monitored to aid in the adjustment of coagulant dose, and a polyelectrolyte filter aid is used to enhance the filterability of the clarified water.

Pilot-plant trials of upflow adsorption clarification were conducted by the Desert Water Agency at the Palm Springs WWTP on trickling-filter effluent in 1984 and 1985. The clarifier used a 4-ft bed on polyethylene beads retained by a stainless-steel screen. The clarifier was back-washed by an air-water backwash cycle when the head loss was 4 ft through the bed.

The pilot-plant tests were successful in producing a reclaimed water with turbidity of less than 2 NTU at influent turbidity concentrations as high as 19 NTU when operating at a flow rate of 10 gpm/sq ft, using a minimal alum and an anionic polyelectrolyte dose controlled by a microprocessor that monitors filtered-water turbidity. Water production was 94.4% in summer when influent turbidity was less than 10 NTU, and 92.4% in winter when turbidity was between 10 and 19 NTU. Thus, a relatively high proportion of water is used in backwash—5.5% to 7.5%.

Based on these tests, the Desert Water Agency constructed a 5-mgd treatment facility using upflow adsorption clarification, and Las Gallinas pilot tested the same option. Dissolved-air flotation.

Dissolved-air flotation (DAF) has been used for clarification of wastewater effluents at several European installations with typical overflow rates of 1 to 2 gpm/sq ft. Bench-scale tests were conducted at Las Gallinas and it was found that direct flotation was not too successful, but recycle pressure flotation could provide a clarified water with a turbidity of less than 4 NTU at an overflow rate of 0.25 gpm/sq ft. This is not nearly as good as the 1-gpm/sq ft for a settling process. DAF did not seem to be a promising clarification process for wastewater reclamation at Las Gallinas.

Table 2-Capital Cost of Clarifier

		Treatment capacity		
Alternatives	**Process**	**1 mgd**	**2 mgd**	**Rank**
1	CRFS	$581 000	$1 025 000	9
2	CCSF	556 000	810 000	7
3	SCUC	360 000	540 000	6
4	FIPS	230 000	345 000	4
5	DAF	324 000	396 000	2
6	DEF	618 000	975 000	8
7	HRSFS	337 000	411 000	3
8	UAC	262 000	446 000	4
9	DAV	265 000	450 000	5

[1]Capital costs for construction of process units exclusive of any piping, electrical, sludge handling, site, or ancillary facilities at February 1988 costs.
[2]Based on 2 mgd capacity.

Diatomaceous-earth filtration. Diatomaceous-earth filtration (DEF) can, with adequate precoat, produce a highly clarified effluent with only a trace of suspended solids—but at a high cost. Frequently there is a problem in handling variations in suspended-solids loading, and automation of body feed and backwash are required for the process to be reliable.

Bench-scale tests of DEF on the direct filtered effluent of Las Gallinas achieved a reduction in turbidity from 2.2 to 1.7 NTU. Because of this relatively low turbidity reduction (30%), it was concluded that DEF would not provide sufficient polishing clarification when filtered-water turbidities were above 5 NTU. This process was, however, tested for a limited period at Las Gallinas and found to require excessive doses of diatomaceous earth to produce the desired low-turbidity effluent.

Ozonation microflocculation clarification. Ozonation, which has been used at several WWTPs for disinfection, may provide microflocculation of organic color compounds, decrease coagulant dose, and improve effectiveness. Usually, ozone doses for disinfection are high—from 10 to 25 mg/L. Doses of about 10 mg/L in wastewater effluent can provide microflocculation benefits with 5 to 10 minutes of contact time and reduce coagulant dose requirements by 50% before clarification and filtration. Chlorination is still required after filtration to produce a coliform concentration of less than 2.2/100 mL.

Clarification costs. Preliminary capital and operations and maintenance (O & M) costs were developed for each clarification alternative to relate probable cost-effectiveness (Tables 2 and 3). In addition, noncost factors including reliability, flexibility, implementation, and aesthetics were compared for each alternative (Table 4). This information determined the rationale for why certain processes were selected for pilot-plant testing. The information also provided a reference of the more detailed clarification process analyses that were used to formulate an apparent-best-process for upgrading Las Gallinas.

BENCH- AND PILOT-SCALE TESTING

Bench-scale studies were conducted to evaluate conventional coagulation, flocculation, and clarification processes. DAF and DEF processes were also screened. The bench-scale tests indicated that conventional flocculation and clarification were the best processes; however, high concentrations of alum—70 to 100 mg/L—were required to produce good settling.

The objective of the pilot-plant testing was to identify and demonstrate the effectiveness of various treatment processes in removing turbidity and suspended solids in the

Table 3—Operation and Maintenance Costs of Clarifier

Alternatives	Process	Energy hp	Energy $/yr	Chemical lb/day	Chemical $/yr	Operation hr/day	Operation $/yr	Maintenance $/yr	Total $/yr
1	CRFS	15	5,250	1,280	24,600	0.5	2,100	10,200	42,150
2	CCFS	14	4,900	1,280	24,600	0.5	2,100	8,200	39,800
3	SCUC	17	5,950	1,200	23,400	0.5	2,100	8,400	39,850
4	FIPS	6	2,100	1,280	24,600	1	4,200	6,900	37,800
5	DAF	27	9,450	1,680	30,400	1	4,200	7,300	51,350
6	DEF	150	52,500	5,000	121,800	2	8,400	9,800	192,500
7	HRSFS	14.5	5,100	1,030	20,000	1	4,200	8,250	37,550
8	UAC	3	1,050	600	20,000	1	4,200	13,400	38,650
9	DAC	6	2,100	600	20,000	1	4,200	13,600	39,900

Table 4—Comparison of Clarifier Alternatives for Cost and Non-Cost Factors

Alternative	Process Type	Capital cost[1]	O&M costs	Reliability[2]	Flexibility	Implement-ability	Permit-ability	Expand-ability	Aesthetics	Total valuation	Rank
Proportionate evaluation%		25	25	15	10	5	5	5	10	100	-
1	CRFS	0	25	15	10	1	5	1	10	52	7
2	CCFS	8	25	13	9	1	5	1	10	59	8
3	SCUC	18	25	12	8	1	3	1	8	76	4
4	FIPS	25	25	5	5	3	3	2	6	74	6
5	DAF	23	23	10	2	3	3	3	8	75	5
6	DEF	2	0	2	3	5	2	4	8	24	9
7	HRSFS	23	25	12	8	4	2	4	6	84	1
8	UAC	21	25	8	7	5	2	5	4	77	2
9	DAC	21	25	8	7	5	2	5	4	77	3

[1]Capital and annual O&M valuations are on the basis of full 25% for the lowest cost alternative and 0% for the most costly, with every other alternative as a cost proportion of this scale.
[2]Non-cost factors amount to 50% of worth and are based on estimate of process performance reliability; relative ease to implement at the site; and appearance, noise, and odor aesthetics.

wastewater effluent to meet the reclamation requirements. The pilot processes were evaluated on chemical coagulant requirements, loading rates, impact of source water-quality variables, waste volumes and concentrations, and O & M considerations.

Three pilot processes were tested: high-rate solids-contact and upflow clarification processes for treatment upstream of the existing direct filtration reclamation plant, and a DEF process for polishing treatment downstream of the existing sand filters.

All three of the pilot plants tested were successful in removing turbidity in the wastewater to less than 2 NTU. The upflow adsorption clarifier used the least amount of chemical coagulant but produced the most backwash water. This resulted in a low 90% net production of filtered water. The high-rate solids-contact clarifier required about twice the dose of chemical coagulant but produced little blowdown waste, resulting in a 99.7% net production of clarified water. The high-rate clarifier met the 2-NTU turbidity requirement without filtration; however, filtration was required to meet DOH's virus removal requirements. Because of filter backwash requirements, the net production of the combined high-rate solids contact clarification and filtration process exceeds 97%.

The DEF polishing was successful in producing a final effluent with turbidity less than 2 NTU, with the existing filters producing an effluent with a turbidity of 3.4 to 4.5 NTU. However, higher turbidities from the filters required greater body feed of diatomaceous earth and further reduced the short 9- to 10-hour filtration cycle. For this system to be effective, the existing filters would need to produce a constant effluent turbidity of less than 4.5 NTU.

CLARIFIER COMPARISONS

Results of the pilot-plant tests were evaluated to develop alternative plant process and operating configurations to meet requirements for virus-free water. Particular emphasis was given to pilot-plant testing of alternative clarification processes, effluent flow and water quality produced by Las Gallinas, operating experience and planning objectives of the current MMWD reclamation plant, and current and future requirements for reclaimed wastewater in California.

Alternative plant improvement facilities were compared on the basis on capital costs, O & M costs, annual cost effectiveness, and non-monetary factors including reliability, flexibility, ease in construction, ease in implementation, institutional and interagency requirements, aesthetics, and environmental factors. Proportionate ranking of these factors favored the high-rate solids-contact clarification process as the best project to design and construct (Figure 2).

The suggested improvement facilities included more than the clarification process. Other features of the project include a new inlet pump station and pipeline from Las Gallinas' storage and marsh ponds, improved and expanded filtration facilities, and washwater and sludge-handling facilities. ■

Joel A. Faller and Robert A. Ryder are environmental engineers for Kennedy/ Jenks/ Chilton in San Francisco, Calif.

Water reuse is becoming an increasingly common component of water resource planning as opportunities for conventional water-supply development dwindle and costs for wastewater disposal climb. Both nonpotable and potable reuses of reclaimed wastewater offer means to extend and maximize the utility of limited water resources.

Factors that contribute to the consideration of potable reuse as an alternative water supply include future water demand exceeding supply, limited locally available conventional surface-water and groundwater supplies; polluted local conventional supplies; lack of politically viable, demand-reduction measures; lack of economically viable nonpotable reuse opportunities; high cost of wastewater disposal; water rights favoring reuse rather than disposal; and high cost and environmental impacts of developing remote conventional water supplies.

Successful implementation of a potable reuse project hinges on satisfactory response to common concerns often raised regarding both planned indirect and direct potable reuse.

WATER-QUALITY STANDARDS AND PUBLIC HEALTH

For indirect, potable reuse, the recovered water must be of equal or better quality than the receiving water source. For instance, if the receiving water source is a potable water aquifer requiring only disinfection before distribution, then the recovered water recharged to the aquifer needs to be of drinking-water quality. Similarly, if the receiving water source is a river requiring full conventional water treatment before distribution, then the recovered water augmenting the river flow need only be of a quality equal to the natural quality of the river water. In either case, the recovered water should be of a quality to prevent deleterious effects in the receiving water source such as dissolved oxygen depletion, eutrophication, increased total dissolved solids, or accumulation of trace organics or inorganics.

For direct, potable reuse, the recovered water must be of equal or better quality than the finished water produced from the highest quality source water locally available.

At this stage in the development of potable reuse projects, a demonstration-scale plant is required to satisfy regulatory agencies that the recovered water quality is suitable for reuse. The recovered water should be produced for at least 1 year to document the reliability of the quality during seasonal variations. The recovered water should be subjected to extensive physical, chemical, microbiological, and toxicological testing for direct comparison to either the receiving water source (indirect potable reuse) or the highest quality finished water available (direct potable reuse). In addition, the recovered water quality should be compared with existing and proposed drinking-water standards and public health advisories.

The U.S. Environmental Protection Agency (EPA) does not explicitly regulate the practice of potable reuse. However, the Clean Water Act and the Safe Drinking Water Act (SDWA) establish laws that govern the operation of facilities that treat wastewater and drinking water. Outside of these constraints, EPA delegates permitting of specific wastewater reuse operations to the states. Currently, individual states prohibit potable reuse, do

Public Education Program

A public education program should consider the following subjects:

- The need for additional water supplies.
- The availability of additional water supplies.
- The cost of additional water supplies.
- The environmental impact of developing additional water supplies.
- The status of potable water recovery technology.
- The safeguards incorporated in potable water recovery and reuse processes such as multiple barriers, extensive monitoring, and possible blending of the recovered water with another water source.

Reuse Terms

Unplanned, indirect, potable reuse occurs when a water supply is withdrawn for potable purposes from a natural surface or underground water source that is fed in part by the discharge of a wastewater effluent. The wastewater effluent is discharged to the water source as a means of disposal and subsequent reuse of the effluent is a byproduct of the disposal plan. This type of potable reuse commonly occurs whenever an upstream water user discharges wastewater effluent into a water course that serves as a water supply for a downstream user.

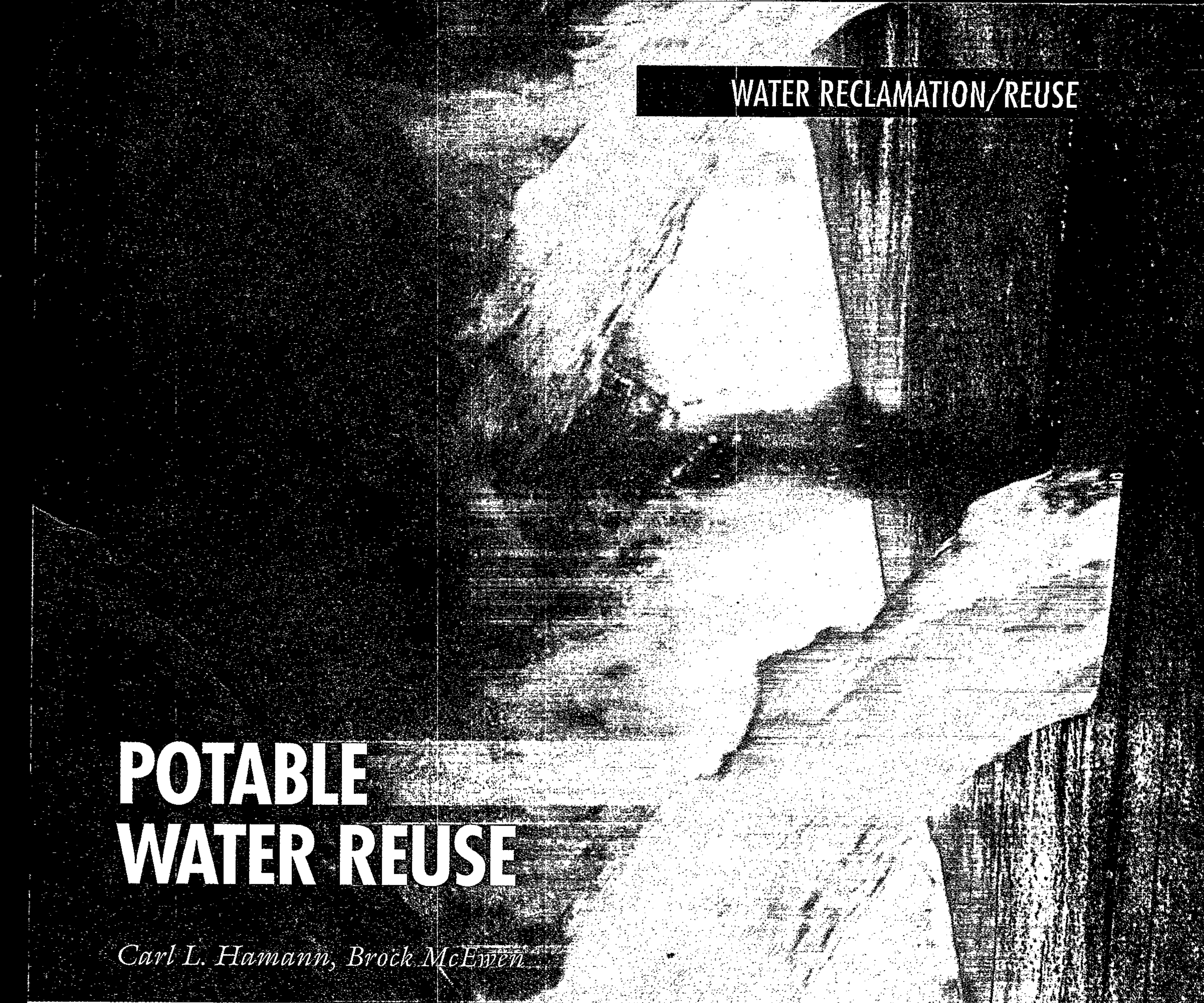
Planned, indirect potable reuse is similar to unplanned, indirect potable reuse; however, the wastewater effluent is discharged to the water source with the intent of reusing the water instead of as a means of disposal. This type of potable reuse is becoming more common as water resources become less plentiful and the luxury of wastewater disposal declines.

Direct potable reuse is the piped connection of water recovered from wastewater to a potable water-supply distribution system or a water treatment plant. Currently, there are no examples of direct potable reuse in practice in the U.S.; however, demonstration of direct potable reuse is occurring in Denver, Colo., and San Diego, Calif.

Conventional-plant water recovery involves linking the existing wastewater treatment plant with a new water resource recovery treatment facility designed to reclaim wastewater to a quality suitable for either indirect or direct potable reuse. The conventional-plant approach to water recovery has been the method of choice to date for most existing planned, indirect, potable reuse facilities.

Single-plant water recovery is the reclamation of previously untreated municipal wastewater to a quality suitable for either indirect or direct potable reuse in a single treatment facility. The single-plant approach may have advantages over the conventional-plant approach under some circumstances for the following reasons.

- A single plant can be located near both a source of untreated wastewater and a desired point of introduction to either a water source or a finished water distribution system. In contrast, a conventional plant is linked to an existing treatment plant that is often far removed from the



POTABLE WATER REUSE

Carl L. Hamann, Brock McEwen

desired point of recovered water distribution. Therefore, a single plant has increased siting flexibility that could reduce the cost of pumping associated with distribution of the recovered potable water.

• The siting flexibility of the single plant relative to the conventional plant could allow location near a wastewater interceptor conveying predominantly domestic wastewater as opposed to a conventional plant possibly downstream of industrial and commercial dischargers. Domestic wastewater is generally lower in contaminants, which eases the burden on the potable water recovery treatment process.

• Water recovery in a single plant may be more operationally convenient than water recovery in individual plant modules. A single plant would have a single treatment objective—to recover water for indirect or direct potable reuse from untreated wastewater—while the treatment plant link of the conventional plant may have two treatment objectives—to meet National Pollutant Discharge Elimination System requirements for disposal and to meet performance standards for contribution to a potable reuse treatment.

Multiple contaminant barriers refers to the provision of more than one unit process capable of treating the physical, chemical, and microbiological contaminants of concern. Multiple contaminant barriers provide treatment reliability because failure of one unit process to effectively remove a contaminant of concern does not preclude effective overall treatment, because additional contaminant barriers are available. For instance, provision of biological treatment, GAC adsorption, and reverse osmosis in a potable water recovery treatment train establishes multiple barriers to the passage of total organic carbon into the recovered water. Similarly, unit process combinations can be configured to deal with other contaminant categories such as heavy metals, nutrients, and pathogens. Fortunately, many unit processes act as barriers to move more than one contaminant category, so the number of unit processes required for potable water recovery does not become excessive.

Process redundancy refers to the provision of duplicate unit processes to provide treatment reliability in the event that equipment failure or maintenance requirements render a particular unit process inoperable.

not have regulations regarding potable reuse, or evaluate potable reuse projects on a case-by-case basis. Therefore, it is essential to identify and involve concerned state agencies early in a potable reuse assessment. Similarly, it is important to involve local agencies. Agencies should be identified that have specific responsibility to public health, water-quality standards, development of reclamation policies or requirements, water ownership issues, permit requirements, and potential funding sources.

Close involvement with such agencies is paramount to the development of a potable reuse implementation program that encourages a variance from regulation prohibition, serves as a catalyst for the development of potable reuse regulations, and persuades responsible agencies of the benefits and safety of the potable reuse project.

Public acceptance is generally the most crucial element in determining the success or failure of a potable reuse project, particularly because regulatory agencies often have political roots that react to public sentiment. A potable reuse project can be technically viable, the recovered water proven safe by the best scientific procedures available, and regulatory agencies poised for acceptance; yet, a project can still fail because of a lack of public acceptance. A public education program is vital to the success of a potable reuse program (see Box).

Several technical issues and concerns are often raised during the development of a potable reuse project, all of which can be addressed by the operation of a demonstration plant, thoughtful engineering design, and sound operations management (see Box).

POTABLE REUSE TREATMENT PROCESSES AND PERFORMANCE

Unit processes and their relative capabilities to remove specific contaminants are shown in the Figure. Contaminant removal is considered to be a relative measure of unit-process ability to act as a barrier to that contaminant. Unit processes identified as contaminant barriers are expected to remove at least 50% of the contaminant. Potable water recovery systems contain more contaminant barriers than a conventional water treatment plant, because wastewater is typically of poorer quality than a conventional surface-water or groundwater supply. Unit processes often included in a potable reuse facility are biological treatment with or without nitrogen removal, high-lime treatment with two-stage recarbonation, granular-media filtration, granular activated carbon (GAC), demineralization (membrane treatment), air stripping, rapid infiltration and recovery, and disinfection (see Box).

POTABLE REUSE CONCEPTUAL LAYOUT AND TREATMENT SELECTION

Selection of a potable reuse treatment and its planned integration into a water-supply system is site-specific. The geographic layout of a city's water resource system should be evaluated to determine factors that may inhibit or favor develop-

Potable Reuse Technical Issues and Concerns

The following are common issues of concern:

- The ability to recover potable water from wastewater, safe for either indirect or direct human consumption.
- The process redundancy or operational procedures necessary to assure product safety in the event of mechanical and operational malfunction.
- The flexibility to modify water recovery treatment processes in response to changes in raw water quality and new regulatory requirements.
- The method of reuse or disposal of potable water waste residuals.
- The distribution of recovered potable water so that the benefits are shared equitably.
- The chemistry and benefits of blending recovered potable water with other finished waters.
- The cost and reduced environmental impact of potable water recovery in comparison to other alternative water supplies.

Potable Reuse History

Unplanned, indirect, potable reuse has been in practice since humans first began disposing wastewater into watersheds that are hydrologically connected to raw water supplies. As population has increased, so has the quantity of wastewater and the technology to manage the increased volumes of wastewater. Potable reuse is one of the developing strategies to manage wastewater and recover and reuse water resources.

The following is a summary of some of the historical milestones marking the development of planned potable reuse as a viable component of a water resource management plan.

In 1931, Los Angeles, Calif., demonstrated that primary sedimentation, secondary biological treatment, and sand filtration treatment of wastewater created a recovered water suitable for spreading on soil, thereby contributing significantly to the groundwater supply without impairing its quality.

In 1956 and 1957, severe drought conditions forced the city of Chanute, Kans., to practice direct potable reuse. Secondary treated water was impounded and recycled back through the city's water treatment plant where it received super chlorination to inactivate the greater pathogen concentrations associated with the recycled effluent. No adverse health effects were noted; however, after several cycles, the water became pale yellow in color and was aesthetically unappealing.

In 1960, the Advanced Waste Treatment Research Program of the United States Public Health Service was directed to develop new treatment technology for renovating wastewater to allow more direct and deliberate water reuse.

In 1962, at Whittier Narrows, near Los Angeles, Calif., disinfected secondary effluent from a 10-mgd water reclamation plant was spread on the ground for infiltration to an underground potable water supply. This operation continues and the amount of reclaimed water recharged annually averages 16% of the total inflow to the groundwater basin. Depending on the physical characteristics, ment of indirect versus direct potable reuse and single-plant versus conventional-plant water recovery. The treatment selected should provide multiple contaminant barriers and process redundancy to assure product reliability. The conceptual layout and specific treatment selected should satisfactorily address health, regulatory, social, and technical issues and concerns.

Conceptual layout. The selection of indirect versus direct potable reuse and single-plant versus conventional-plant water recovery starts with a review of the geographic layout of the overall water and wastewater system. Important factors to review and evaluate include location and character of existing and future water supplies and transmission systems, location and character of existing and future water treatment facilities and distribution systems, customer service area existing and future demographics and zoning, and location and character of existing and future wastewater collection and treatment facilities.

Treatment selection. Based on the conceptual layout of the potable reuse facility, a water recovery treatment system must be selected to reclaim the wastewater influent to a suitable quality for reuse. Usually, alternative systems are conceptually developed, evaluated, and screened to arrive at a selected alternative for further development. Generally, a qualitative and quantitative analysis of evaluation criteria is used to arrive at a selected treatment system (see Box).

Based on existing planned, indirect, potable reuse projects in operation and on existing or planned, demonstration-scale direct potable reuse projects, there are several likely treatment scenarios for the defined potable reuse systems. These treatments vary on a case-by-case basis.

Planned, indirect potable reuse with single plant water recovery and recycle to a groundwater of surface-water supply. Likely treatment includes primary treatment, secondary treatment, biological nitrogen removal, high-pH lime treatment with recarbonation, filtration, activated carbon adsorption, slip-stream reverse osmosis with decarbonation, ozonation, and storage.

Planned, indirect potable reuse with conventional plant water recovery and recycle to a groundwater or surface-water supply. Likely treatment is the same as the previous single-plant water recovery except the primary treatment, secondary treatment, and possibly the biological nitrogen removal would be offset to an existing treatment plant with such capabilities.

Direct potable reuse with single-plant water recovery and recycle to a finished water distribution system. Likely treatment includes primary

Unit Process Containment Barriers

Gross Containment Category	Biological Treatment	Biological Treatment with Nitrogen Removal	Biological Nitrogen Removal	High Lime with Recarbonation	Filtration	Granular Activated Carbon	Membrane Demineralization	Membrane Demineralization	Solar Distillation	Rapid Infiltration & Recovery	Chemical Oxidation/Disinfection
Suspended Solids	X	X	X	X	X		X		X	X	
Disolved Solids							X		X		
Biological Oxygen Demand	X	X	X	X		X	X		X	X	
Total Organic	X	X				X	X		X	X	
Volatile Organic Chemicals	X	X	X			X	X	X			X
Heavy Metals	X	X		X			X		X	X	
Nutrients		X	X	X			X	X	X	X	
Radionuclides	X	X	X				X		X	X	
Microbial Factors	X	X		X	X		X		X	X	X

location, and pumping history of a given well, the population drawing potable water from the groundwater basin is estimated to be exposed to a reclaimed wastewater percentage ranging from 0% to 23%. After extensive data acquisition, evaluation, and statistical analysis, no measurable adverse health effects have been correlated to the use of the groundwater replenished with recovered water.

In 1965, the South Lake Tahoe Water Reclamation Plant was the first large-scale facility to use advance wastewater treatment processes to remove nutrients and organics from wastewater.

In 1968, the Windhoek, South Africa, experimental direct potable reuse plant was commissioned; and in 1970, the experimental 1.2-mgd Strander Water Reclamation plant in Pretoria, South Africa, was commissioned. Since 1968, finished water from the Windhoek plant has occasionally been used to directly augment potable water supplies. No identifiable diseases have been associated with this water recovery and reuse practice.

In 1972, the Federal Water Pollution Control Act stated that discharge of pollutants into all navigable waters will be eliminated, thereby encouraging water recovery and reuse.

In 1976, the Orange County, Calif., Water District's Water Factory 21 began operation. The 15-mgd facility reclaims unchlorinated secondary effluent to drinking-water quality and recharges it into a heavily used groundwater supply to prevent salt water intrusion. The water recovery treatment includes lime clarification, air stripping, recarbonation, filtration, carbon adsorption, slip-stream reverse osmosis, and disinfection. Estimates project that no more than 5% of the recovered water actually comprises the domestic supply. The Orange County Water District has found no evidence that indicates that this indirect potable reuse practice poses a significant risk to users of the groundwater.

In 1978, the 15-mgd Upper Occoquan Sewage Authority (UOSA) Water Reclamation plant in Fairfax County, Va., began reclaiming wastewater for subsequent discharge to the Occoquan Reservoir. The Occoquan Reservoir serves more than 1 million people and is the principle water-supply reservoir in Northern Virginia. During

(continued on page 78)

treatment, secondary treatment, biological nitrogen removal, high-pH lime treatment with recarbonation, filtration, GAC adsorption, full-stream reverse osmosis, ozonation, residual disinfection, and storage.

Direct potable reuse with conventional plant water recovery and recycle to a finished water distribution system. Likely treatment is the same as the previous single-plant water recovery except the primary treatment, secondary treatment, and possibly the biological nitrogen removal would be offset to an existing treatment plant with such capabilities.

Based on these scenarios, the indirect and direct potable reuse water recovery plants are very similar, except that the direct potable reuse treatment includes residual disinfection and full-stream rather than slip-stream reverse osmosis. The difference seems marginal, but the cost for full-stream versus slip-stream reverse osmosis is substantial because of the difficulty in handling increased volumes of brine concentrate from the higher-capacity reverse osmosis process.

One method to reduce the direct potable reuse reverse osmosis requirement is to evaluate the including of a rapid infiltration and recovery process in the treatment train. This option, however, is highly site specific, as land requirements and soil and aquifer characteristics are crucial to its feasibility.

The treatment scenarios focused on the liquid side of the treatment; however, waste residuals such as primary and biological sludges, lime sludges, filter backwash wastewater, and spent activated carbon must also be handled.

Beyond liquid and waste treatment, there are often considerable costs associated with pumping and conveyance of the recovered water to the point of distribution. These requirements and costs are site specific and must be evaluated on a case-by-case basis.

POTABLE REUSE COSTS

The factors that have the greatest influence on the capital and operating costs associated with a potable reuse project include the capacity of the proposed potable reuse project; the level and type of treatment selected to recover the potable water; the volume and type of wastes requiring disposal; proximity of the potable reuse project to a wastewater source and recovered water point of distribution; and the provision of adequate storage capacity in the potable recycle stream to monitor potable quality before reuse. This storage may be natural (aquifers, lakes) or manmade (tanks, impoundments).

The economic feasibility of potable reuse should be based on a cost comparison of developing other raw water supplies. Those cost components that are the same, regardless of the source of the raw water supply, should be deleted to simplify the analysis. The cost benefits of potable reuse need to be accounted for; potable reuse deletes some wastewater disposal costs that would otherwise increase if water supplies were increased and reuse was not practiced.

The economics of potable reuse should be evaluated against other water supplies at the margin or increment of additional water supply. The financial feasibility of potable reuse, however, should be evaluated from a system-wide perspective. The financial feasibility of implementing a potable reuse project comes down to cash flow that depends on system-wide revenues and debt service.

POTABLE REUSE IMPLEMENTATION

The steps necessary to implement a potable reuse project address the issues and concerns regarding water-quality standards and public health; legal, regulatory, and political influences; public acceptance; and technical process engineering. First and foremost, early inclusion of all state, county, and local regulatory agencies in the development of a potable reuse project is paramount to project success and helps to clarify agency perspectives and identify potential flaws.

Second, a demonstration facility is required at this stage of potable reuse development in the U.S. Although demonstration projects are underway in Denver, Colo., San Diego, Calif., and Tampa, Fla., site-specific demonstration is necessary to address unique regulatory, public, and technical concerns.

Third, a regulatory approval program is required to promulgate potable reuse standards of performance and operation and to define procedures to gain acceptance.

Fourth, a public involvement program is required to educate and gain public acceptance of potable reuse.

Therefore, a potable reuse imple-

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extended droughts, the plant discharge has accounted for as much as 80% of the flow into the reservoir. The reclamation treatment includes primary treatment, secondary treatment, biological nitrification and denitrification, lime clarification and recarbonation, filtration, activated-carbon adsorption, and disinfection. The plant is currently being expanded to a 38-mgd average capacity to handle increased wastewater volumes. No negative health effects attributable to the plant or effluent discharges have been reported since the plant has been in operation.

Also, in 1978, the 4.83-mgd Tahoe-Truckee Sanitation Agency Water Reclamation Plant in Reno, Nev., began operation. This plant also uses advanced wastewater reclamation processes to recover water suitable for release to the Truckee River that is used as a water supply by Reno.

From 1981 to 1983, the 1-mgd Potomac Estuary Experimental Water Treatment Plant was operated with a plant influent blend of Potomac estuary water and nitrified secondary effluent to simulate the influent water quality expected during drought conditions when as much as 50% of the estuary flow would be comprised of treated wastewater. Treatment included aeration, coagulation, clarification, predisinfection, filtration, carbon adsorption, and post disinfection. An independent National Academy of Science and National Academy of Engineering panel reviewed the extensive testing performed by the Army Corps of Engineers. The panel concluded that the advanced treatment could recover water from a highly contaminated source that is similar in quality to three major water supplies for the Washington, D.C., metropolitan area.

In 1983, the 1-mgd Potable Reuse Demonstration Plant in Denver, Colo., began operation. This plant was designed to evaluate the feasibility of direct potable reuse of secondary-treated municipal wastewater. After several years of testing and evaluating alternative treatments, a conventional-plant potable water recovery system has been selected for comprehensive health-effects testing. The results of this health-effects testing will be integrated with chemical, physical, and microbiological examinations to provide a basis to determine the suitability of recovered

Unit Processes

Biological treatment removes gross levels of organic matter from water, thus preparing the water for further processing. Although biological treatment removes substantial amounts of suspended matter, its principal function is to reduce the dissolved organic matter to relatively low levels. Well-operated biological treatment plants produce effluent with soluble 5-day biochemical oxygen demand values of 1 to 2 mg/L. Additional benefits of biological treatment include reduction of pathogen content; removal of heavy metals and radionuclides depending on the food to microorganism ratio in the system, the sludge age, and the concentration of metals and radionuclides in the raw water; stripping 80% to 90% of volatile organic chemicals; and stripping radon if it is present in the wastewater.

Biological nitrogen removal by nitrification and denitrification produces water from secondary effluent with a total nitrogen content of 5 mg/L. It also results removes suspended solids, volatile organic chemicals, heavy metals, and pathogens.

High-lime treatment with two-stage recarbonation provides a number of barriers: coagulation and precipitation of suspended matter, where an average filtered water turbidity less than 0.5 NTU is routinely achievable; coagulation and precipitation of pathogen concentrations and a high pH at a level at which pathogens are destroyed; and precipitation of heavy metals, radionuclides, and phosphorus. High-lime treatment is the usual method of reducing the concentrations of nearly all heavy metals to less than SDWA limits.

Granular-media filtration removes the majority of suspended matter remaining after biological treatment or coagulation and precipitation. Following biological treatment, filtration produces turbidity levels of 1 to 2 NTU. Following coagulation, filtration reduces the turbidity to less than 0.5 NTU. The removal of suspended matter automatically results in a reduction of the microbial contamination of the water (approximately 1 to 2 logs).

The benefit of GAC is the removal of organic chemicals—whether biodegradable, synthetic, or volatile—by adsorption. Because the degree of adsorption depends on the nature of the compound, for example its molecular weight and polarity, and a number of other factors, exact removals cannot be predicted. However, the fact that GAC is used in all treatment systems concerned with producing high-quality water in compliance with SDWA requirements for organic compounds is an indication of its effectiveness.

Demineralization, specifically membrane treatment, is the one method that bars all contaminants, including pathogenic organisms, organic chemicals, heavy metals and radionuclides, nutrients, and dissolved solids. Reverse osmosis and ultrafiltration are the most widely used membrane processes. Although ultrafiltration is less costly to operate, reverse osmosis remains the favored process because of its greater removal efficiency.

Air stripping following membrane treatment removes excess carbon dioxide from the water. It also provides a barrier to volatile organic compounds.

Rapid infiltration and recovery bars the passing through of suspended matter and microbial organisms. Infiltration is also an effective barrier to heavy metals and radionuclides, depending on the ion exchange capacity of the soil. Suspended solids can be removed by infiltration, phosphorus by adsorption, and nitrogen by nitrification and denitrification in the soil. Nitrogen removal is dependent on the organic carbon content of the wastewater and is reduced as the biodegradable organic content of the water is reduced.

Chemical oxidation with ozone and hydroxyl radical promoters breaks down and conditions organics to a state more amenable to removal in subsequent unit processes. Breakpoint chlorination provides a means to remove nitrogen.

Disinfection is normally the final barrier to microbial organisms. It is most effective at the end of the treatment process where very little suspended matter remains in the water, and oxidant demand has been greatly reduced.

water as a drinking-water supply.

The final report, including the health-effects study results, will be completed in 1992. Based on analytical testing data to date, the water produced by this system will be the highest purity ever proposed for a municipal potable water supply. The treatment includes high-pH lime clarification, recarbonation, filtration, ultraviolet disinfection, activated-carbon adsorption, reverse osmosis, air stripping, ozonation, and chlorination as a residual disinfectant.

In 1983, the San Diego, Calif., 1-mgd single-plant potable water recovery demonstration facility was commissioned as part of a total resource recovery program established in San Diego. The treatment system includes primary treatment, a water hyacinth aquaculture system, coagulation, clarification, filtration, ultraviolet disinfection, reverse osmosis, aeration, carbon adsorption, and disinfection. The program still in progress includes an extensive health-effects study designed to determine the potential health effects resulting from reuse of the recovered water and to compare the recovered water to current supplies used by San Diego. Results of the health-effects study are pending. A change in California state law would be required to allow reuse of the recovered water for potable purposes.

In 1985, the 10-mgd Fred Hervey Water Reclamation Plant began operation in El Paso, Tex. Recovered water is recharged to a drinking-water aquifer where, over a 2-year period, the water travels to one of El Paso's potable water wells to become part of the potable water supply. The treatment of raw wastewater to recharge quality water includes primary treatment, activated-sludge and powdered activated-carbon treatment, lime treatment, recarbonation, filtration, ozonation, and GAC adsorption.

In 1986, the Tampa, Fla., Water Resource Recovery Pilot Plant began operation. The pilot project was designed to evaluate the feasibility of reclaiming denitrified secondary effluent to a quality suitable for blending with existing surface-water and groundwater sources for indirect potable reuse. Several alternative treatments were evaluated and one was selected for health-effects testing after 2 years of evaluation. The treatment selected includ-

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mentation plan should include three primary parallel programs with complementary objectives.

Technical Demonstration Program. A technical demonstration program should include elements and activities such as defining goals and objectives; the design and construction of the demonstration facility; the development of a demonstration-plant operation and maintenance manual, performance criteria, and reporting requirements; requirements for start-up, operation, shutdown, and process control; the design and implementation of water-quality monitoring and health-effects testing; and the formation of a technical awareness committee.

Public Involvement Program. The technical demonstration program should be developed with public involvement in mind. Emphasis should be placed on attractive architecture and beneficial uses of demonstration-plant product water. A public involvement program may include a community awareness committee to help disseminate information and media releases, and organize tours, educational programs, and research opportunities.

Regulatory Approval Program. The regulatory approval program is best developed by the appropriate regulatory agencies. Documentation, reports, meetings, or other supporting information should be identified early so these programs can be designed to satisfy regulatory requirements.

Successful completion of the demonstration phase of the potable reuse implementation plan would then allow progress toward design and construction of a full-scale facility.

CONCLUSION

Prudent use of our water resources assures that water in all its states of both natural beauty and manmade utility is available for future generations to enjoy. Potable reuse is one of many methods available to extend the utility of our existing water sources and reduce the pressure on other undeveloped water sources. ■

Carl L. Hamann is director of innovative technology and Brock McEwen is assistant director of water reuse at CH2M Hill in Denver, Colo.

Evaluation Criteria

- Water-quality results refer to the ability of an alternative water recovery treatment to meet physical, chemical, microbiological, and toxicological standards of performance and to meet or exceed the quality of the existing receiving water source (indirect reuse) or finished water (direct reuse).
- System reliability refers to the ability of the system to consistently produce the required water quality through the use of multiple contaminant barriers, process equipment redundancy, and provision of adequate storage to allow monitoring and assessment of water quality before reuse.
- System operability refers to the ease of operation of the system that can be based on the labor expertise and man-hours required to operate and maintain the system.
- System flexibility refers to the ability of the treatment system to respond to variations in source wastewater quality and quantity and to future variables that may affect performance requirements such as stricter recovered water standards and change over from indirect to direct reuse.
- Waste residuals refer to the quantity, character, and handling requirements to properly dispose of waste residuals. Disposal of brine concentrate from a reverse osmosis process is always a major consideration with potable reuse projects.
- Physical requirements refer to the land and housing requirements to support the water recovery system.
- System costs refer to the capital and operation and maintenance costs associated with the liquid processing and waste-residuals handling. Most important to this analysis is organizing these costs on a basis that provides fair comparison to other new water-supply alternatives. For instance, importing a remote groundwater source would entail costs for pumping and transmission, but also may include additional costs for necessary water and wastewater treatment, distribution, and collection systems to handle the increased water flow. However, development of a water recovery plant for potable reuse may preclude construction of water and wastewater treatment facilities.
- Regulatory and public acceptance refers to the site-specific concerns or biases that may inhibit development of a particular potable reuse system alternative.

ed aeration, high-pH lime clarification, two-stage recarbonation, filtration, GAC adsorption, and ozonation. Final results of the study should be available in 1990. If implemented, the recovered water would comprise as much as 30% of the Hillsboro River raw water supply during low flow conditions.

In 1988, the city of Phoenix, Ariz., conducted a potable reuse feasibility study to evaluate the cost-effectiveness, institutional constraints, and social constraints associated with direct potable reuse. The feasibility study results suggested that potable reuse is cost competitive with other alternative water-supply development projects for this desert-based city. The city is currently evaluating the pursuit of a 0.1-mgd demonstration plant to document technical feasibility and to gain public and regulatory acceptance.

In summary, planned, indirect potable reuse is currently practiced at the following locations in the U.S.:

- Whittier Narrows, Calif.,
- Orange County, Calif. Water District's Water Factory 21.,
- UOSA Water Reclamation Plant in Fairfax County, Va.,
- Tahoe-Truckee Sanitation Agency Water Reclamation Plant in Nevada County, Calif., and
- Fred Hervey Water Reclamation Plant in El Paso, Tex.

Direct potable reuse is still in the demonstration phase of development in the U.S. Results from the Denver and San Diego demonstration projects will contribute to the advancement of direct potable reuse as a technically feasible water-supply alternative. The major impediments to full-scale implementation of direct potable reuse will likely continue to be regulatory and social acceptance. Nevertheless, the existing evidence to date does not indicate that existing potable water recovery projects present an unusual or unacceptable risk to public health.

Potable Water Via Land Treatment and AWT

Sherwood Reed, Robert Bastian

"What would have been the result if the land treatment planners, designers, and community had opted for advanced wastewater treatment (AWT)?" Finding the answer to this question was, in part, the purpose of a study conducted for the U.S. Environmental Protection Agency (EPA). The study determined if land treatment systems constructed in the 1970s were meeting their original expectations with respect to performance and costs. The study included comparisons of land treatment systems and AWT systems operating in the same regions and having similar performance requirements. One of these comparisons involved water reuse: effluent from each system entered the potable water supply for its respective community.

As part of the study, two wastewater treatment systems were evaluated: a land treatment system in Clayton County, Ga. (see Box on Clayton County History), and an AWT system in Centerville, Va. (see Box on UOSA History). The Clayton County system is a municipally operated, forest-covered, slow-rate land treatment system; the Upper Occoquan Sewage Authority (UOSA) system, in Centerville, Va., uses AWT in a mechanical plant.

Although it was not the purpose of the study to critique the planning, design, and selection decisions made at the communities where the AWT processes actually exist, the study allowed a side-by-side comparison of a land treatment system and a realistic AWT alternative. In all cases, selecting AWT was appropriate.

Wastewater Treatment History, Clayton County

In the early 1970s, the county had several secondary treatment plants discharging to surface waters. Two of these, the Casey plant and the Jackson plant, discharged to the Flint River. The mean annual flow in this river is only 0.34 m^3/s (12 ft^3/s) and wastewater effluent discharges averaged 0.14 m^3/s (5 ft^3/s) in 1974. During summer months, the wastewater effluent exceeded natural streamflow. The state of Georgia imposed new discharge standards and a limited flow allocation for these existing systems. Because the projected wastewater flows were significantly higher that the discharge allocation, it was necessary to limit growth in the county, provide very high levels of treatment to satisfy the discharge limits, or develop a new treatment method discharging to another watershed.

SYSTEM DESCRIPTIONS

Clayton County, which is immediately south of Atlanta, Ga., is a suburban area with some light industrial and commercial establishments. The county government provides water supply, wastewater treatment and disposal, and power distribution. The population served by the land treatment system was about 85,000 in 1988.

The area has a relatively mild climate, with a mean annual temperature of 17°C. Typically one or two light snowfalls occur during the winter, and daily average minimum temperatures never fall below 0°C. Because of the mild climate, year-round operation is possible using suitable vegetation.

Major system components in the selected process (see Box on Choosing Land Treatment) included upgrades of the two existing treatment plants, the 0.1-m^3/s (2.3-mgd) Casey plant and the 0.5-m^3/s (11.8-mgd) Jackson plant, and a land application facility (Table 1).

The land treatment system recharges, via soil percolation, to Pates Creek, which is the major source for the Clayton County municipal water supply. The surface soils at the land treatment site are sandy clay loams with moderate permeabilities, the deeper soils and those underlying the surface drainage network are sandy clays and clays. The groundwater table varies from 2 to 24 m (10 to 80 ft) below the ground's surface depending on el-

Wastewater Treatment History, UOSA

In 1971, the state of Virginia determined that the 11 existing wastewater treatment plants discharging into the Occoquan watershed were accelerating eutrophication in the Occoquan Reservoir and increasing the potential risks to the potable water supply. As a result, the 11 systems were taken off-line, and the flow was combined and given state-of-the-art treatment in a regional AWT plant. UOSA was established as an independent regional authority to construct and operate the new facility.

Choosing Land Treatment in Clayton County

The major alternatives considered were providing high levels of AWT at the two existing activated sludge plants, or using land treatment at another location for wastewater management. Five potential land treatment sites were evaluated, all within 12 km (7.5 mi) of the two existing treatment systems, and all were forested to ensure that year-round operation would be possible. An extensive screening and evaluation process led to the selection of the largest contiguous site. It was 80% forested, had well-defined drainage networks, and would require displacing the fewest number of property owners. Detailed site investigations on this site confirmed the suitability for land treatment. The cost comparisons for developing this site versus AWT indicated that land treatment was the most cost effective alternative for Clayton County. It was also more cost-effective to upgrade the two existing plants to secondary treatment as compared to their abandonment and the construction of a new multiple-cell aerated lagoon.

A very positive public acceptance of the land treatment concept was obtained by an extensive education and information program. This involved meetings with local and state officials and environmental groups, tours for journalists and local officials to successful land treatment systems, special programs for affected property owners, and hearings for the general public. Public acceptance has continued and land adjacent to the operational forested site is in demand for residential developments. In many cases the house abuts the land treatment system and operating sprinklers are visible in the adjacent forest. The majority of homeowners see the system as a benefit because further development is unlikely. However, these residential developments around the perimeter of the site may limit the capability to expand the site if that proves necessary.

evation and location on the site.

The UOSA AWT system serves the cities of Manassas and Manassas Park, Va., which are in Fairfax and Prince William counties in Northern Virginia. The area served is residential with attendant commercial establishments. The 1987 population served by this system was approximately 90,000.

The area has a moderate climate with a mean annual temperature of 13°C. The low temperatures that occur in the winter include an average temperature in January of 3°C. There are about 20 days/yr with persistent snow cover. These conditions would have required some winter effluent storage for a slow-rate land treatment system.

The UOSA system discharges to a reservoir and then to a stream that flows to the Occoquan Reservoir, which is the municipal water supply source. The importance of this source is recognized in the UOSA discharge requirements, which call for very stringent nitrogen removals during low- flow stream conditions when the impact of the discharge has the potential to be the most detri-

Sherwood C. Reed

Whole-tree harvest at the Clayton County land treatment system. The growing trees remove nutrients, metals, and other wastewater constituents. The whole tree is then harvested and removed as wood chips on a 20-year rotational cycle.

Table 1—Clayton County System Components

Primary & activated sludge secondary treatment
Jackson plant and Casey plant
Transmission lines from the two treatment plants to a 20-mgd pumping station carrying undisinfected effluent.
Transmission line to the land application facility
Land application facility[a]
Effluent storage pond: 12 days detention, 66 ac
Distribution pumps: 3 each, 1500 hp; 2 each, 28,000 gpm.
Distribution pipes: 270 mi of buried pipe, 1.5 to 40 in.
Risers and sprinkler nozzles: 17,500
Land treatment area, 2650 ac
Buffer zones: 440 ac
Buildings and roads: 81 ac
Flood plains and inaccessible areas: 363 ac
Total site area: 3600 ac

[a]metric conversions are mgd × 0.04383 = m^3/s; ac × 0.404 = ha; hp × 0.745 = kW; mi × 1.609 = km; and in. × 25.4 = mm.

mental to the receiving water.

The major components in the UOSA system are listed in Table 2. All of the components listed have at least one backup redundant unit.

DESIGN AND OPERATING CONDITIONS

Determining the land area needed for the treatment system was a critical step in the design and was based on the limiting design parameter (LDP) approach (see Box on LDP).

At Clayton County, the hydraulic capacity of the surface soils limits the design wastewater application rate to 6.4 cm/wk (2.5 in./wk). Thus, the design wastewater application would be 3.3 m/yr (10.8 ft/yr), and the average design daily hydraulic loading would be about 8 $L/m^2 \cdot d$ (0.2 $gal/ft^2 \cdot d$). At this loading rate, the design projections indicated that nitrate-nitrogen in percolate entering Pates Creek or the groundwater would be well below the 10-mg/L limit required for drinking water. Moreover, this rate is equivalent to the lower rates typically used for household leach-field systems and illustrates that the hydraulic loading on most slow-rate land treatment systems is quite conservative.

Land treatment operation. The wastewater is sprinkled, in rotation, on the forested units in the land treatment site. Some of the applied wastewater percolates vertically and reaches the native groundwater table, but most of the applied wastewater infiltrates to a relatively shallow depth, percolates laterally through the soil, and emerges as surface or subflow in the site's drainage network, which eventually flows into Pates Creek. Operating the land treatment system has significantly increased flow in Pates Creek. During very dry summers a major portion of the flow in this creek is probably percolate from the land treatment site.

The site was divided into 42 blocks, each averaging about 24 ha (60 ac). The dominant tree species on the site is loblolly pine, and there are also significant stands of mixed pine and hardwood trees. Open land was also planted with loblolly pine. Distribution piping was buried and wide access lanes were cleared at each sprinkler distribution row. Five blocks are irrigated every day. Seven blocks on the site are reserved for contingency use when other areas need maintenance or timber is being harvested. Currently, all of the sprinklers in a given section are replaced on a regular schedule, and the removed units are taken to the shop for repair and rehabilitation and then used as replacement units elsewhere. This is more efficient than trying to find and repair individual malfunctioning sprinklers.

The original management plan called for clear-cut harvesting for pulpwood of several blocks per year by a contractor on a 20-year rotation. The cleared areas would then be replanted with pine. This procedure was used for the first year of operations and then abandoned because of excessive erosion and

Table 2—UOSA AWT System, Major System Components[a]

Wastewater Management
Emergency storage pond, 45 × 10^6 gal
Screening, grit removal, and conventional primary treatment
Conventional activated sludge secondary treatment
Chemical clarification (lime + polymer)
Two-stage recarbonation, with settling
Flow equalization
Multi-media filtration
Granular activated carbon (GAC) adsorption
Nitrogen treatment
normal weather: nitrification only, total Kjeldahl nitrogen(TKN), 1 mg/L
drought conditions: ammonia removal with ion exchange
to 4 mg/L, breakpoint chlorination to 1 mg/L
Final filtration: ion-exchange columns
Chlorine disinfection and dechlorination
Final effluent reservoir, 180 × 10^6 gal
Final discharge to tributary of water supply reservoir
Solids Management
Biological solids: anaerobic digestion, filter press, composting
Chemical solids: thickeners, filter press, landfill
Spent GAC: on-site regeneration by carbon furnace
Ion Exchange Regeneration
Purge columns with sodium chloride, volatilize ammonia with sodium hydroxide, and strip the ammonia with sulfuric acid in adsorption tower. Final product is ammonium sulfate, which could be sold as a fertilizer

[a]metric conversion for gallons is 10^6 gal × 3785 = m^3.

Limiting Design Parameter

The LDP is the parameter or wastewater constituent that requires the largest land area for acceptable performance. The LDP might be based on the ability of the soil to pass the design volume of water or on some wastewater constituent such as nitrogen, phosphorus, organics, or metals. Experience with typical municipal effluents has shown that the LDP for this type of project is usually the hydraulic capacity of the soil or the ability to remove nitrogen and thereby maintain drinking-water levels for nitrate in the groundwater at the project boundary.

related problems caused by the contractor's equipment.

In-house staff has since harvested the trees to produce wood chips in the field. The wood chips are then trucked to the county's secondary treatment plants and either used as fuel for sludge drying and pelletizing or as a bulking agent for in-vessel composting.

AWT system. The design capacity of the UOSA system was 0.66 m^3/s (15 mgd) in 1987, and the actual flow that year averaged 0.53 m^3/s (12.2 mgd). Future expansions to 1.18 m^3/s (27 mgd) and then to 2.37 m^3/s (54 mgd) were planned. Stringent discharge limits were established for the UOSA design (Table 3). Nitrogen limits for normal weather and drought were established. In normal weather conditions, base flow from other surface streams that feed the Occaquan Reservoir would dilute the effluent nitrate to acceptable levels, and the concentration of the unoxidized nitrogen forms represented by total Kjeldahl nitrogen(TKN) was a suitable limit. In extreme droughts, water in surface streams is not adequate and the limit changes to 1 mg/L total nitrogen. Under extreme drought conditions, the AWT effluent is the major flow component of the reservoir.

The variable nitrogen limits require two different modes of operation for the activated sludge system component. Under normal weather conditions when the TKN limits prevail, the activated sludge component is operated in an extended aeration mode. This typically results in a final effluent having a TKN of 0.5 mg/L or less and a nitrate concentration of 19 mg/L or more, so that the total nitrogen concentration in the effluent approaches 20 mg/L. Under drought conditions, when the total nitrogen limit of 1 mg/L controls, the activated sludge process is operated with a short detention time to provide only carbon oxidation so that most of the ammonia remains unoxidized. Ion exchange and break-point chlorination will be used to remove remaining nitrogen.

The activated sludge component, when operated in the nitrification mode, requires more aeration energy, but produces less sludge. The effluent is more stable and easier to treat in the remaining AWT units. The ion exchange columns are also part of the process in the nitrification mode (see Box on Nitrogen Removal), but in this case serve as final filters to remove the carbon fines and other particulates in the granulated activated carbon (GAC) effluent. The 680×10^9-m^3 (180×10^6-gal) storage pond provides 12 days effluent storage at the 0.66-m^3/s (15-mgd) design flow.

The land area requirements for the Occoquan system were 24 ha (60 ac) for the treatment plant, 22 ha (55 ac) for the final effluent reservoir, and 20

Table 3—UOSA Discharge Limits

Chemical oxygen demand (COD), 10 mg/L
Total suspended solids (TSS), 1.0 mg/L
Phosphorus, 0.1 mg/L
Surfactants, 0.1 mg/L
Turbidity, 0.5 JTU
Total Kjeldahl nitrogen (TKN), 1.0 mg/L in normal weather
Total nitrogen, 1.0 mg/L during drought

Table 4—Clayton County System Annual Loadings

Parameter	Design assumption, lb/ac•yr	1987 actual load, lb/ac•yr
BOD_5	896	226
TSS	896	178
Total nitrogen	404	139
Total phosphorus	224	76

lb/ac•yr × 1.121 = kg/ha•yr

Table 5—Clayton County System Groundwater Quality

	Parameter, mg/L		
Year	Nitrogen	Phosphorus	Chloride
1979	0.69	0.03	1.0
1980	0.54	0.03	1.6
1981	0.63	0.04	2.3
1982	0.34	0.03	3.6
1983	0.44	0.02	10.8
1984	0.43	0.09	12.6
1985	0.15	0.01	15.4
1986	0.65	0.01	21.0
1987	0.18	0.04	21.5

Table 6—Pates Creek Water Quality

	Parameter, mg/L		
Year	Nitrogen	Phosphorus	Chloride
1978	0.65	0.05	1.0
1984	0.96	0.05	7.5
1985	1.15	0.26	13.3
1986	2.02	0.32	18.3
1987	1.04	0.17	18.9

Table 7—UOSA System Water Quality Concentration Data

Parameter	Influent, mg/L	Permit Limit, mg/L	Effluent, mg/L
BOD_5	200	—	<1.0
COD	400	10.0	8.0
TSS	170	1.0	0.1
Nitrogen			
normal weather	34.2 (total N)	1.0 (TKN)[a]	0.5 (TKN)[a] 19.3 (NO_3)[a]
drought periods	34.2 (total N)	1.0 (total N)	—
Phosphorus	9.0	0.1	0.05
Surfactants	5.3	0.1	0.04
Turbidity	—	0.5 JTU	0.1 JTU

[a]As nitrogen

Table 8—Clayton County System Capital Costs, $\$ \times 10^6$

Upgrade Casey Plant		6.95
Upgrade Jackson Plant		1.42
	Sub total	8.37
Pump station and transmission line		1.70
Land treatment facility		
Storage ponds		0.46
Pump and distribution system		5.30
Structures, roads, and the like		0.60
Land costs (3000 ac)[a]		10.30
	Sub total	16.66
	Total	26.73
Future salvage value of the land		-(10.30)
	Total, with salvage	16.43

[a]ac × 0.404 = ha

Table 9—Clayton County System Annual O & M Costs

Item	1976 Estimate, 1987 $	1987 Actual, 1987 $	1987, $/1000 gal[a]
Secondary treatment	1,251,000	2,084,000	0.40
Land treatment	837,000	1,015,000	0.20

[a]$/3.785 × 1000 = $/L

Nitrogen Removal

The UOSA system has never been required to operate in the nitrogen removal mode since the plant was constructed, so the more liberal TKN limits have prevailed. However, during a 4-month trial period in 1982, the ion-exchange system was operated for ammonia removal. This long-term test concluded that it was not practical to reach the 1-mg/L ammonia standard with just ion exchange. The current plans are to use the ion-exchange columns to reach 3 to 4 mg/L ammonia and then breakpoint chlorination will be used to achieve the required 1 mg/L.

ha (50 ac) for the sludge landfill. This total of 67 ha (165 ac) is much less than the 1477 ha (3650 ac) required for the Clayton County system.

SYSTEM PERFORMANCE

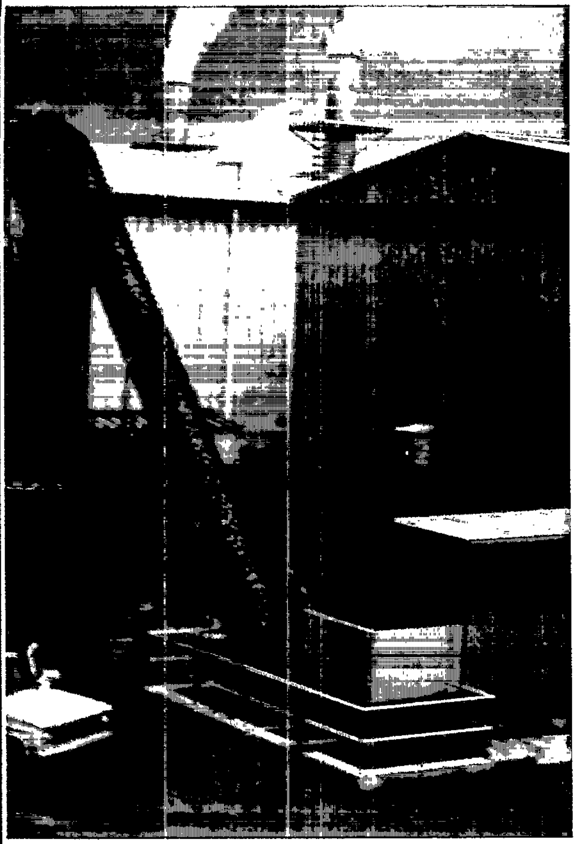
It was clear from the data that the existing activated sludge plants in Clayton County were producing better than secondary effluent with respect to 5-day biochemical oxygen demand (BOD_5) and TSS and it was likely that the short detention time in the storage pond contributed to further treatment. The total flow in 1987 was only 0.62 m^3/s (14.1 mgd), which was 0.14 m^3/s (3.4 mgd) lower than that assumed for design. Thus, the actual annual loadings on the 1072-ha (2650-ac) treatment area were lower than the assumed annual loadings (Table 4).

The data suggest that the design assumptions were conservative and that the land treatment site was not stressed and was underused during the first 10 years of operation. This then suggests that Clayton County might gain economically by reducing the performance efficiency at the activated sludge plants, thereby allowing removal of higher concentration of soluble BOD and the related nutrients on the land treatment site. System performance is evaluated using monitoring wells on the application sites and in Pates Creek as it flows away from the site. Nitrogen was the greatest concern, because nitrogen was the LDP for the Clayton County secondary treatment design. Nitrate contamination of drinking-water sources had to be avoided. Total nitrogen concentration in the groundwater and in Pates Creek at the project boundary were monitored because wastewater was applied beginning in 1979 (Tables 5 and 6). Phosphorus was monitored because of its eutrophication potential. Chlorides were monitored because they served as a tracer, confirming that wastewater percolate reached the sampling point.

The data indicate that chlorides increased significantly from start-up until 1986 and then leveled off. The final concentration of chlorides is about one-half of that present in the applied wastewater, indicating that there is significant mixing and dilution with the surface water and groundwater.

The nitrogen and phosphorus data indicate excellent removal efficiency and, although the pattern for nitrogen is somewhat erratic, the concentration has always remained below the 10-mg/L target value. At the present nitrogen loading rates, this performance can be expected to continue indefinitely. Even if the chloride values in the groundwater and surface water were to double, a phenomenon that would indicate the presence of wastewater percolate without any dilution, the nitrogen concentration should only increase proportionally and still not exceed 5 mg/L. If the nitrogen loadings ever reach the design values, the percolate nitrogen reaching the groundwater and Pates Creek may approach, but still not exceed, the 10-mg/L target value.

AWT system. In comparison,



Use of wood chips at the Clayton County land treatment system as the fuel source for a sludge pelletizing operation. Chips are also used as a bulking agent for composting.
Sherwood C. Reed

UOSA's performance is demonstrated by its effluent characteristics. Table 7 compares typical influent and effluent values to the permit requirements for the UOSA system.

MANPOWER AND COSTS

The 1987 Clayton County staffing requirements, including the secondary treatment and sludge pelletizing operations and the land treatment component, totalled 61. The staff at the land treatment facility increased from 13 people when land treatment operations began in 1978 to 24 people in 1987. Staff was needed to harvest trees and to maintain and repair the sprinklers and appurtenant equipment.

At the present flow rate of 0.62 m^3/s (14.1 mgd) of capacity the manpower requirements would be 9.8 people/m^3•s (4.3 people/mgd) of capacity.

The actual capital costs of the total project were within 2% of the estimate (Table 8). About 30% of the total was used to upgrade the existing activated sludge plants. If Clayton County had been required to build entirely new activated sludge systems, the cost for these components might have been about $10.2 million and the total would have been about $37 million, rather than the $26.73 million shown in the table. If the county had constructed aerated lagoons for preliminary treatment, the total costs might have been about $32 million (all 1976 dollars).

The salvage value of the land should be much higher at the end of the 20-year design period; the cost for land adjacent to the treatment site was approaching $27,750/ha ($10,000/ac) in 1988. The costs for just the land treatment facility would be about $13,600/ha ($5500/ac), not including the salvage value.

The actual annual operations and maintenance (O & M) costs for secondary treatment are about 67% higher than the original estimate because labor costs for the skill levels required to operate the system were higher than planned (Table 9). The land treatment costs are about 20% higher that the original estimate. In-house tree harvesting accounts for most of the increase. With respect to the distribution of these O & M costs for the secondary treatment system and the land treatment component, the labor costs for secondary treatment are two times that for the land treatment component, and costs reflect the skill levels involved—the number of people for each component is about the same (Table 10). The power costs for land treatment are slightly higher than for sec-

Table 10—Clayton County System Distribution of Direct 1987 O & M Costs

	Costs, $/1000 gal	
Item	Secondary treatment	Land treatment
Labor	0.14	0.07
Chemicals	0.03	0.00
Power	0.09	0.10
Other	0.14	0.03

[a]$/3.785 × 1000 gal = $/L

Table 11—Clayton County System Total Annual Costs (1987, $)[a]

Total direct costs		3,088,000
Depreciation/debt service		2,004,000
Indirect and administrative		1,595,000
Sale of sludge pellets		–(199,000)
	Total	6,488,000
Secondary treatment, $/1000 gal		0.85
Land treatment facility, $/1000 gal		0.41
	Total	1.26

[a]Total gallons treated = 5,146,500,000

Table 12—UOSA System Capital Costs, 1982 $ × 10[6][a]

Treatment system		52.04
Land acquisition		1.69
Engineering and administration		10.87
	Total	64.60

[a]Unit cost = $4.31 million/mgd($89.23 × 10^6/m^3•s)

Table 13—UOSA 1987 Total O & M Costs

Activity	Total Costs, 1987 $	Unit Costs, $/1000 gal[a]
Secondary treatment	2,229,333	0.50
Phosphorus removal	1,319,023	0.29
Filtration	363,508	0.08
Carbon adsorption	472,598	0.11
Final filters	270,851	0.06
Totals	4,655,313	1.04
Unit O & M with ion exchange	—	$1.72

[a]metric conversion for unit cost is $/3.785 × 1000 = $/L

Table 14—UOSA 1987 Total Annual Costs, 1987 $

Operation maintenance and management, $		4,655,313
Depreciation/debt service, $		2,077,280
	Total	6,732,593
ªNitrification mode, $/gal		1.50
Ion-exchange mode, $/gal		2.18
Ion-exchange plus breakpoint chlorination, $/gal		2.46

ªTotal gallons treated = 4,474,706,000 (16,936.76 m^3)

Table 15—Distribution of O & M Costs, UOSA and Clayton County

	Costs ($/1000 gal)	
Item	UOSA, Va	Clayton Co., Ga
Labor	0.52	0.21
Chemicals	0.11	0.03
Power	0.25	0.19
Other	0.16	0.17
Total	$1.04ª	0.60

ªwith ion exchange, costs are $1.72/1000 gal and with ion exchange and break-point chlorination costs are $2.00/1000 gal.

ondary treatment because of the need for transmission pumping to the site and then distribution pumping on the site. Using the wood chips as fuel however significantly reduces the cost of the pelletizing operation as compared to using natural gas or oil as a fuel source.

The total annual cost for secondary treatment was $225/L ($0.85 /1000 gal), and $108/L ($0.41/1000 gal) for the land treatment component, for a total of $333/L ($1.26/1000 gal) (Table 11).

If a completely new activated sludge plant had been built, the total annual cost might approach $373/L ($1.41/ 1000 gal) because of the higher capital costs and related debt service. If a new aerated lagoon had been constructed, the total annual costs would have been close to $356/L ($1.35/ 1000 gal).

The state of Georgia requires treating wastewater to secondary treatment levels before applying the wastewater. Experience elsewhere with slow-rate land treatment indicates excellent results with influent treated to primary standards. A partial relaxation of the secondary requirement might allow a significant expansion of future plant capacity without additional capital expense.

AWT system. UOSA 1987 staff requirements, including all on-site personnel, totalled 81. At this flow rate, UOSA uses 15 people/m^3•s (6.6 people/ mgd).

Capital costs for construction—at the plant site only—were about $64 million (Table 12). The total cost of the entire AWT system in 1982 dollars was $82 million. These costs include the provision of 100% redundancy in all components to protect the water supply system, but do not include the costs of the new break-point chlorination facilities. The unit cost at design capacity is $98 million/$m^3$•s ($4.31 million/mgd).

O & M costs for the UOSA system were compared in terms of the total annual expenditure and the unit costs per 3.8 m^3 (1000 gal) treated (Table 13). During this period, the system was in the nitrification mode and did not use ion exchange and break-point chlorination for ammonia removal, so these costs are not included. The unit costs with ion exchange for ammonia removal would be $454/L ($1.72/1000 gal) treated. The break-point chlorination facilities costs are not included in the analysis.

The total 1987 costs for the UOSA system are given in Table 14. The unit cost per 3.8 m^3 (1000 gal) is based on actual expenditures. The values for the unit costs with ion exchange and with ion exchange plus break-point chlorination are estimates.

COST COMPARISON

Because construction costs are higher in Northern Virginia as compared to Clayton County, a direct comparison is not possible. Adjusting the unit costs for location produces an estimate of $88 million/$m^3$•s ($3.84 million/mgd) if the system had been constructed in Georgia in 1982. Updating the previously cited Clayton County capital costs to 1982 dollars produces an estimate of $52 million/ m^3•s ($2.27 million/mgd) for comparison with the AWT value.

The Clayton County system paid $8500/ha ($3433/ac) for 1212 ha (3000 ac) of land; in Virginia, the unit cost was $25,350/ha ($10,242/ac) for 67 ha (165 ac). At that rate, the land costs in Northern Virginia would have been over $30 million for 1212 ha (3000 ac). This amount of land would not have been available in a single block or a few large parcels in Northern Virginia, so construction costs for the other land treatment components would have been much higher than at Clayton County. In addition, the soil characteristics in the vicinity of the UOSA plant are not well suited for a slow-rate land treatment system. It seems clear that land treatment would not have been an economical alternative for UOSA. However, the purpose of the analysis was to determine what the costs would be had the Clayton County authorities selected a similar AWT system instead of land treatment.

The UOSA O & M costs for operating in the nitrification mode for the gallons actually treated in 1987 are distributed to the major cost factors and are compared to the values from Clayton County (Table 15).

The addition of break-point chlorination might increase UOSA's total O&M costs to about $528/L ($2.00/ 1000 gal). The comparable cost for the Clayton County system, which achieves <1 mg/L total nitrogen, is $159/L ($0.60/1000 gal).

The labor costs for UOSA are significantly higher partly because of the location and because the skill levels required are much higher for the AWT process. The unit costs for the labor at the land treatment facility are significantly less than at the secondary treatment systems because less skilled labor is required.

The difference in chemical costs reflects the fact that Clayton County uses few chemicals. The difference in power costs are significant but are closer than many would expect. Land treatment systems such as Clayton County, where extensive transmission and distribution pumping are required, are not necessarily low-energy systems.

PROCESS COMPARISONS

Both systems are satisfying their project goals and producing a final product that is acceptable for reuse in their water supply systems. This capability, it seems, will not diminish over the long term.

UOSA's unit cost values can be compared to the $333/L ($1.26/1000 gal) for Clayton County's land treatment system as constructed, with upgrading of the existing secondary treatment units. However, such a comparison is biased in favor of land treatment because Occoquan had to build a completely new system including the secondary treatment components. It is estimated that if a new secondary treatment plant had been built at Clayton County, the total annual unit cost might be $373/L ($1.41/1000 gal). At this level, the cost advantage for land treatment is smaller, but still significant.

The cost comparison is also biased in favor of the AWT process because the $396/L ($1.50/1000 gal) represents the nitrification mode when the system is discharging close to 20 mg/L nitrate. The land treatment system discharges about 1 mg/L (average 1980 to 1987 0.7 mg/L) total nitrogen to groundwater and surface water. Therefore, on a water-quality basis, it is necessary to compare the land treatment process to the AWT ammonia removal process effluent to have equivalent water quality. On this basis, the total annual costs for land treatment with a new secondary treatment plant would be $373/L ($1.41/1000 gal) compared to $528/L ($2.00/1000 gal) for the AWT process. At the present flow, Clayton County would produce a cost savings of over $3 million/yr.

A typical sprinkler used for wastewater application at the Clayton County, Ga., land treatment system.

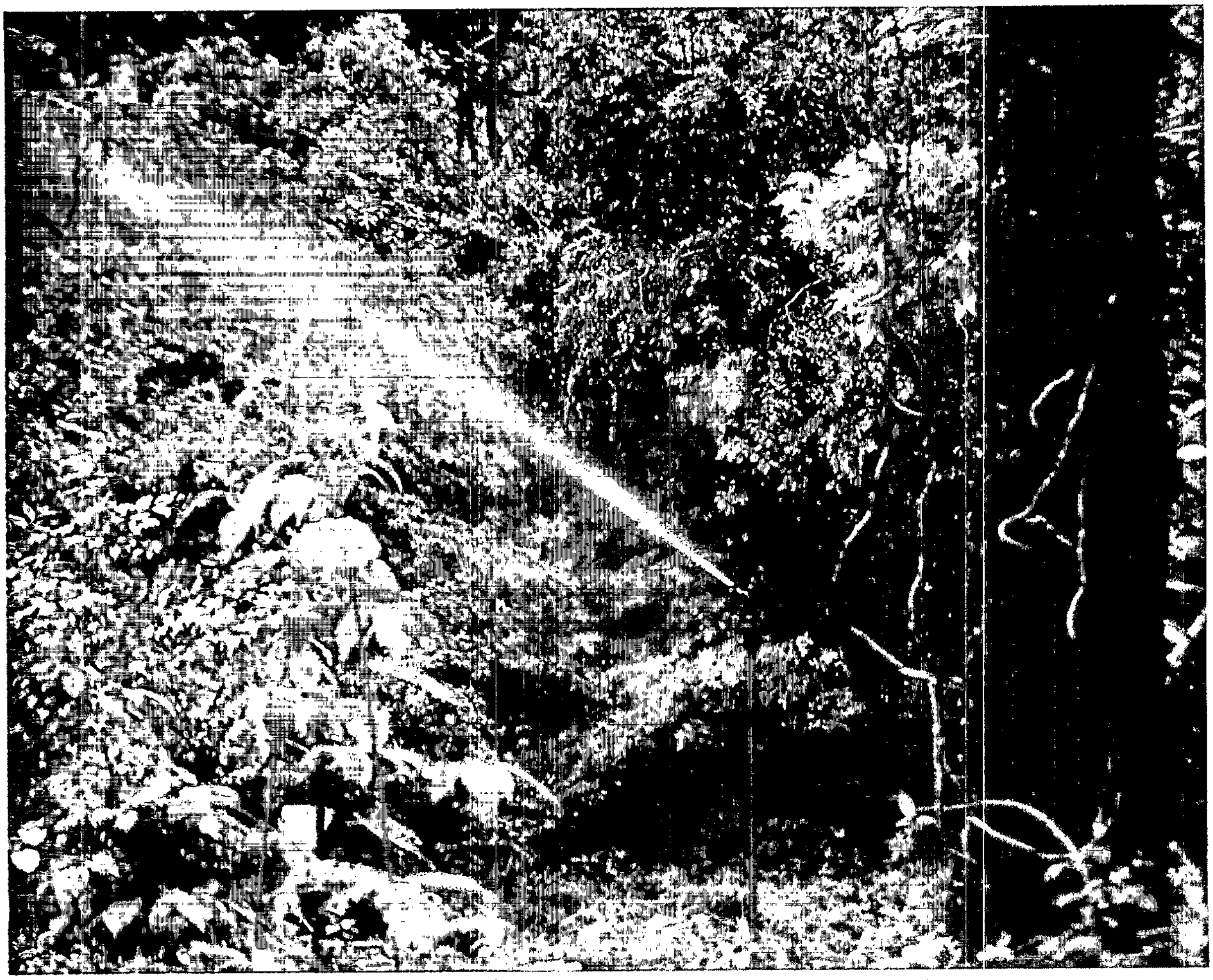
CONCLUSIONS

It can be concluded from the comparisons that the goals and projections for the Clayton County system were valid and that the land treatment concept was the proper choice. The land treatment system was, and remains, the most cost effective alternative for the situation in Clayton County, when compared to the costs for an AWT process capable of producing the same-quality final effluent. The Clayton County system continues, after 10 years, to produce a high-quality effluent that can be directly introduced into the drinking-water sources for the community. That capability is expected to continue indefinitely. Similarly, selection of the AWT process at Occoquan was the proper choice for the circumstances prevailing at that location.

The availability of a sufficient area of suitable land at a reasonable cost is probably the major factor for implementing a cost-effective land treatment system. The cost of all other components and the O & M requirements should be less for land treatment than for alternative processes.

The comparison indicated that the land treatment system could reliably produce an equivalent effluent at a significantly lower cost than the AWT process. This suggests that in locations where a sufficient area of suitable land is available at a reasonable cost, land treatment will be the more cost effective alternative. ■

Sherwood Reed is an environmental engineering consultant in Norwich, Vt.; Robert Bastian is a scientist at the U.S. Environmental Protection Agency in Washington, D.C.



Groundwater Recharge with Reclaimed Water in California

James Crook, Takashi Asano, Margaret Nellor

In California, increasing demands for water have given rise to surface water development and large-scale projects for water importation. Economic and environmental concerns associated with these projects have expanded interest in reclaiming municipal wastewater to supplement existing water supplies. Groundwater recharge represents a large potential use of reclaimed water in the state. For example, several projects have been identified in the Los Angeles area that could use up to 150 x 10^6 m^3/a (120,000 ac-ft/yr) of reclaimed water for groundwater recharge. Recharging groundwater with reclaimed wastewater has several purposes: to prevent saltwater intrusion into freshwater aquifers, to store the reclaimed water for future use, to control or prevent ground subsidence, and to augment nonpotable or potable groundwater aquifers.[1] Recharge can be accomplished by surface spreading or direct injection.

With surface spreading, reclaimed water percolates from spreading basins through an unsaturated zone to the groundwater. Direct injection entails pumping reclaimed water directly into the groundwater, usually into a confined aquifer. In coastal areas, direct injection effectively creates barriers that prevent saltwater intrusion. In other areas, direct injection may be preferred where groundwater is deep or where the topography or existing land use makes surface spreading impractical or too expensive. While only two large-scale, planned operations for groundwater recharge are using reclaimed water in California, incidental or unplanned recharge is widespread.

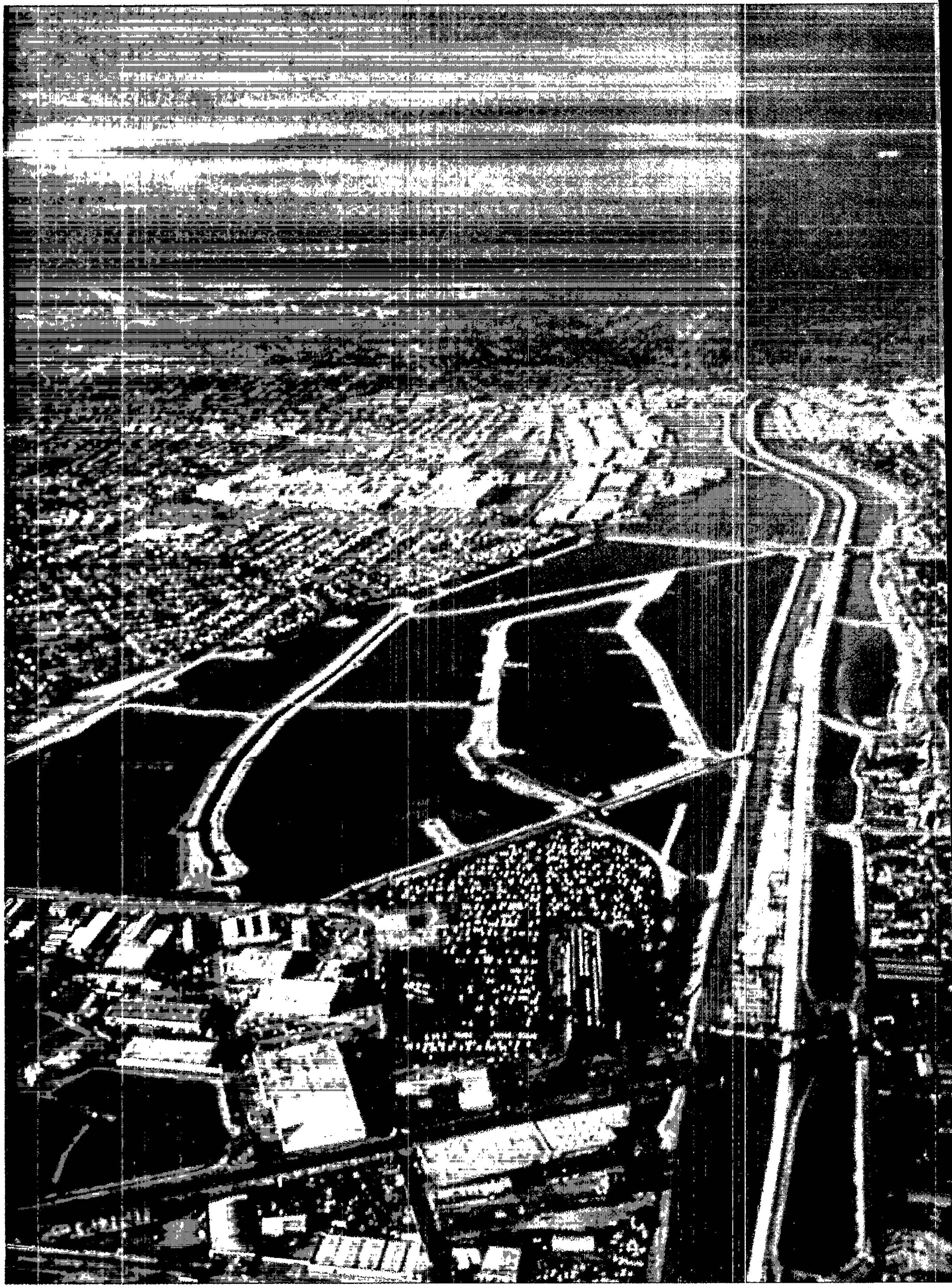
The constraints of groundwater recharge with reclaimed water include water quality, the potential for health hazards, economic feasibility, physical limitations, legal restrictions, and the availability of reclaimed water. Of these constraints, the health concerns are by far the most important, as they pervade all potential recharge projects. Health authorities emphasize that indirect potable reuse of reclaimed wastewater through groundwater recharge encompasses a much broader range of potential risks to the public's health than nonpotable uses of reclaimed water. Because the reclaimed water eventually becomes drinking water and is consumed, health effects associated with prolonged exposure to low levels of contaminants and acute health effects from pathogens or toxic substances must be considered. Particular attention must be given to organic and inorganic substances that may elicit adverse health responses in humans after many years of exposure.

HISTORICAL DEVELOPMENT

In the early 1970s several water-quality control plans (Basin Plans) were developed under the direction of the State Water Resources Control Board (SWRCB). The Basin Plans identified as many as 36 potential projects for groundwater recharge in the state. Regulatory agencies involved in wastewater reclamation and reuse play a key role in the management of California's water resources and any projects involving the recharge of groundwater with reclaimed water (see Box). In 1973, the Department of Health Services (DOHS) prepared a position statement in response to proposals in the Basin Plans for augmentation of domestic water sources with reclaimed water. Three uses of reclaimed water were considered in the statement: groundwater recharge by surface spreading, direct injection into an aquifer suitable for use as a domestic water source, and direct discharge of reclaimed water into a domestic water supply.

Position statement. The DOHS position statement recommended against direct discharge into a domestic water-supply system and direct injection into aquifers used as a source of a domestic water supply stating that some organic constituents of wastewater are not well enough understood to permit setting limits and creating treatment-control systems. In particular, the ingestion of water reclaimed from wastewater may produce long-term health effects associated with the stable organic materials that remain after treatment. It also stated that injection to prevent saline water intrusion could be considered in the future. With regard to surface spreading, the position statement contained the following: surface spreading appears to have great potential; information relative to health effects is uncertain; if new information indicates adverse effects are created with recharge, closure of basins may be necessary; specification of allowable percentages of reclaimed water in groundwater is inappropriate at this time because of a lack of information on health effects; proposals for the recharge of small basins with large quantities of reclaimed water will not be

Groundwater recharge, occurring at the Rio Hondo Spreading Grounds in Los Angeles, represents a large potential use of reclaimed water in California.



Milestones in Historical Development of Groundwater Recharge

1962 The first large-scale planned operation for groundwater recharge was implemented when secondary effluent from the Whittier Narrows Water Reclamation Plant in Los Angeles County was spread in the Montebello Forebay area of the Central Groundwater Basin.

1973 The California Department of Health Services (DOHS) developed a position statement on the uses of reclaimed water involving ingestion, essentially placing a moratorium on new projects for groundwater recharge.

1975 The State of California convened a Consulting Panel on the Health Aspects of Wastewater Reclamation for Groundwater Recharge to provide recommendations for research that would assist DOHS in the establishment of statewide criteria for groundwater recharge.

1976 DOHS developed draft regulations for groundwater recharge that were subsequently used as guidelines.

1976 Groundwater recharge by direct injection was initiated by the Orange County Water District to prevent saltwater intrusion.

1978 The Sanitation Districts of Los Angeles County (LACSD) initiated a 5-year Health Effects Study to investigate the health significance of using reclaimed water for groundwater replenishment.

1986 The state of California appointed a Scientific Advisory Panel on Groundwater Recharge with Reclaimed Wastewater to provide information needed for the establishment of statewide criteria for groundwater recharge.

1987 State regulatory agencies approved a 50% increase in the amount of reclaimed water that could be spread in the Montebello Forebay area.

Research Tasks

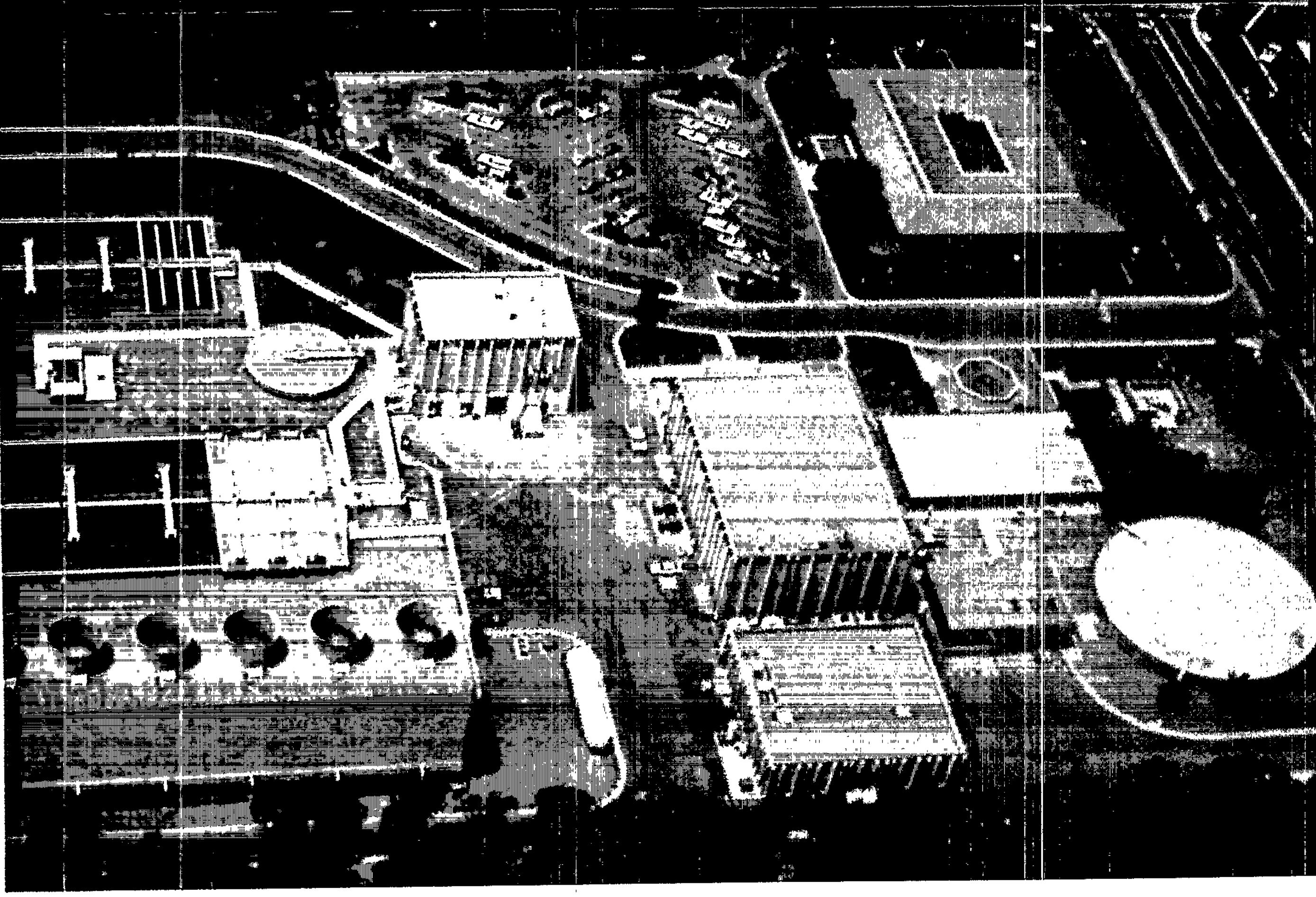
- Water-quality characterizations of groundwater, reclaimed water, and other recharge sources in terms of their microbiological and inorganic chemical content.
- Toxicological and chemical studies of groundwater, reclaimed water, and other recharge sources to isolate and identify health-significant organic constituents.
- Percolation studies to evaluate the efficacy of soil in attenuating inorganic and organic chemicals in reclaimed water.
- Hydrogeological studies to determine the movement of reclaimed water through groundwater and the relative contribution of reclaimed water to municipal water supplies.
- Epidemiological studies of populations ingesting groundwater containing reclaimed water to determine if their health characteristics differ significantly from a demographically similar control population.

recommended; proposals for recharge of large basins with small amounts of reclaimed water may be possible depending on community well locations and other conditions; and surface spreading as a future option may be a possibility.

Consulting panel. In 1975, a Consulting Panel on the Health Aspects of Wastewater Reclamation for Groundwater Recharge was established by three state agencies—DOHS, SWRCB, and the Department of Water Resources (DWR). Its purpose was to recommend a program of research that would provide information to assist DOHS in establishing reclamation criteria for groundwater recharge and to assist DWR and SWRCB in planning and implementing programs to encourage use of reclaimed water consistent with those criteria. A state-of-the-art report on the health aspects of wastewater reclamation for groundwater recharge was prepared as a background document.

The Consulting Panel confined its discussions to groundwater recharge by surface spreading and reached several conclusions. The panel concurred with DOHS that there were uncertainties regarding potential health effects associated with groundwater recharge using reclaimed wastewater. The panel suggested that comprehensive studies directed at the health aspects associated with groundwater recharge be initiated at existing projects, and that new demonstration projects would be needed to gain field information under selected and controlled conditions. The panel stated that to provide a database for estimating health risk, contaminant characterization, toxicology, and epidemiological studies of exposed populations were needed.

Health Effects Study. In the aftermath of the 1976-77 California drought, there was considerable pressure to use supplies of reclaimed water in southern California, particularly for groundwater recharge. However, an unofficial moratorium suspended new projects and the expansion of existing operations until some health-related issues associated with groundwater recharge were answered and the Consult-



ing Panel's recommendations were implemented. In 1978, the Sanitation Districts of Los Angeles County (LACSD) initiated a 5-year, $1.4 million study of the Montebello Forebay Groundwater Recharge Project that had been replenishing groundwater with reclaimed water since 1962. By 1978, the amount of reclaimed water spread averaged 33 x 10^6 m^3/a (26,500 ac-ft/yr) or 16% of the total inflow to the groundwater basin with no more than 40 x 10^6 m^3 (32,700 ac-ft) of reclaimed water spread in any year. The percentage of reclaimed water contained in the potable water supply ranged from 0 to 23% on an annual basis, and 0 to 11% on a long-term (1962-1977) basis.

Historical impacts on groundwater quality and human health and the relative impacts of the different replenishment sources—reclaimed water, stormwater runoff, and imported surface water—on groundwater quality were assessed after conducting a wide range of research tasks (see Box).

The study's results indicated that the risks associated with the three sources of recharged water were not significantly different and that the historical proportion of reclaimed water used for replenishment had no measurable impact on either groundwater quality or human health.[2] The Health Effects Study did not demonstrate any measurable adverse effects on the area's groundwater or the health of the population ingesting the water. The cancer-related epidemiological study findings were weakened by the minimal observed latency period (about 15 years) between first exposure and disease for human cancers. Because of the relatively short time that groundwater containing reclaimed water had been consumed, it is unlikely that examination of cancer incidence and mortality rates would have detected an effect of exposure to reclaimed water resulting from this groundwater recharge operation.

Groundwater recharge regulations. In 1976, DOHS developed draft regulations for groundwater recharge of reclaimed water by surface spreading. The proposed criteria were principally directed at the control of stable organics. The level of treatment specified in the draft regulations was conventional secondary treatment followed by carbon adsorption and percolation through at least 3 m (10 ft) of unsaturated soil. Reclaimed water-quality requirements were specified for inorganic chemicals, pesticides, radioactivity, chemical oxygen demand (COD), and total organic carbon (TOC). Requirements for groundwater quality were specified for inorganic chemicals and pesticides. An effluent monitoring program was proposed for 20 specific organic compounds. The draft regulations

Water Factory 21 is an advanced wastewater treatment facility whose effluent is used to prevent saltwater intrusion into potable water-supply aquifers.

Table 1—Analyses of Reclaimed Water—Montebello Forebay, 1988-1989

Constituent	Units	San Jose Creek	Whittier Narrows	Pomona	Discharge limits
Arsenic	mg/L	0.005	0.004	<0.004	0.05
Aluminum	mg/L	<0.06	<0.10	<0.08	1.0
Barium	mg/L	0.06	0.04	0.04	1.0
Cadmium	mg/L	ND	ND	ND	0.01
Chromium	mg/L	<0.02	<0.03	<0.03	0.05
Lead	mg/L	ND	ND	<0.05	0.05
Manganese	mg/L	<0.02	<0.01	<0.01	0.05
Mercury	mg/L	<0.0003	ND	<0.0001	0.002
Selenium	mg/L	<0.001	0.007	<0.004	0.01
Silver	mg/L	<0.005	ND	<0.005	0.05
Lindane	μg/L	0.05	0.07	<0.03	4
Endrin	μg/L	ND	ND	ND	0.2
Toxaphene	μg/L	ND	ND	ND	5
Methoxychlor	μg/L	ND	ND	ND	100
2,4-D	μg/L	ND	ND	ND	100
2,4,5-TP	μg/L	<0.11	ND	ND	10
Suspended solids	mg/L	<3	<2	<1	15
BOD	mg/L	7	4	4	20
Turbidity	TU	1.6	1.6	1.0	2
Total coliform	No./100mL	<1	<1	<1	2.2
Total dissolved solids	mg/L	598	523	552	700
Nitrate and nitrite	mg/L	1.55	2.19	0.69	10
Chloride	mg/L	123	83	121	250
Sulfate	mg/L	108	105	82	250
Fluoride	mg/L	0.57	0.74	0.50	1.6

ND means not detected.

restricted the maximum application of reclaimed water to not more than 50% of the total water spread during a 12-month period. A minimum residence time of 1 year in the underground before groundwater withdrawal was specified. Other proposed requirements included detailed reports on hydrogeology and spreading operations, establishment of a program to control industrial sources, development of contingency plans, and implementation of a program to monitor the health of the population receiving reclaimed water. Because the proposed regulations were based on the worst-case situation and it would have been virtually impossible for any individual project to comply with all of the requirements, the proposed regulations were not adopted as statewide criteria but were used as guidelines for new projects on groundwater recharge.

The DOHS revised the Wastewater Reclamation Criteria in 1978 to require that reclaimed water used for groundwater recharge of aquifers carrying domestic water supplies by surface spreading be of a quality that fully protects public health and that recharge recommendations be based on all relevant aspects of each project. Factors to be considered included treatment provided, effluent quality and quantity, spreading-area operations, soil characteristics, hydrogeology, residence time, and distance to withdrawal. The amendments required that the State Department of Heath Services (DOHS) hold public hearings before projects were approved.

Scientific Advisory Panel. In 1986, California commissioned a Scientific Advisory Panel on Groundwater Recharge with Reclaimed Wastewater that offered several recommendations for statewide water-reuse activities. The Scientific Advisory Panel concurred with the Health Effects Study's findings. The panel advised that the best available water in an area should be reserved for drinking water, the Whittier Narrows Groundwater Replenishment Project should continue, recharge via spreading is preferable to injection, reclaimed water should be disinfected before injection or spreading, and disinfection should not produce harmful by-products. The panel stated that available treatment processes can adequately remove organic constituents of concern, all proposed groundwater recharge projects should include prospective health surveillance of populations, biochemical tests of concentrates are necessary to determine whether likely harmful substances are present at low levels, state-of-the-art toxicology studies with animals are needed for risk evaluation, and there should be continued analytical chemistry investigation and monitoring to identify and quantify chemical constituents.

MAJOR GROUNDWATER-RECHARGE PROJECTS

Two significant projects for groundwater recharge have been implemented in California: one in Montebello Forebay and another in Orange County. Replenishing groundwater basins is accomplished by artificial recharge of aquifers in the Montebello Forebay area of south-central Los Angeles County. Waters used for recharge by surface spreading include local stormwater runoff, imported surface water from the Colorado River and state project, and reclaimed municipal wastewater. The latter has been used as a source of replenishment since 1962, when approximately 15 x 10^6 m^3/a (12,000 ac-ft/yr) of disinfected activated sludge from the LACSD Whittier Narrows Water Reclamation Plant's (WRP) secondary effluent was spread in the Montebello Forebay that has an estimated usable storage capacity of 960 x 106 m^3 (780,000 ac-ft). In 1973, the San Jose Creek WRP was placed in service and supplied secondary effluent for recharge. In addition, effluent from the Pomona WRP that is not reused for other purposes is discharged into San Jose Creek, a tributary of the San Gabriel River, and ultimately becomes a source for recharge in the Montebello Forebay. The use of effluent from the Pomona WRP is expected to decrease as the reclaimed water is used more for irrigation and industrial applications in the Pomona area.

In 1978, all three reclamation plants were upgraded to provide tertiary treatment with dual-media filtration or filtration with activated carbon and chlorination/dechlorination.[3] The groundwater replenishment program is operated by the Los Angeles County Department of Public Works (DPW), while overall management of the groundwater basin is administered by the Central and West Basin Water Replenishment District. The DPW has constructed special spreading areas designed to increase the indigenous percolation capacity. Specifically, this activity has consisted of modifications to the San Gabriel River channel and construction of off-stream spreading basins adjacent to the Rio Hondo and San Gabriel rivers. The Rio Hondo

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