The Small Flows Journal

NATIONAL SMALL FLOWS CLEARINGHOUSE

A collection of

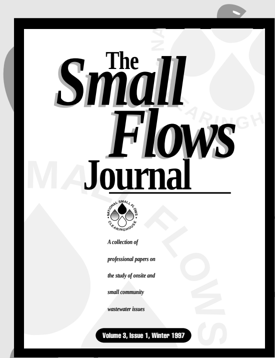
professional papers on

the study of onsite and

small community

wastewater issues

Volume 3, Issue 1, Winter 1997



The Small Flows Journal
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International Standard Serial Number
1079-1531

The Small Flows Journal
National Small Flows Clearinghouse
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P.O. Box 6064
Morgantown, WV 26506-6064
(800) 624-8301/(304) 293-4191
http://www.nsfc.wvu.edu

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Printed on Recycled Paper

Contents

From the Editor

The technical papers in this third issue of ***The Small Flows Journal*** examine innovative wastewater technologies that can provide solutions for small communities (i.e., communities with populations less than 10,000 or that handle less than one million gallons of wastewater flows per day). The information will be of interest to many local officials and small community leaders, as well as to public health officials, wastewater engineers, consultants, and other wastewater professionals.

The first paper, *A Decentralized Wastewater System for a Small Residential Development in California,* presents a case study of an innovative wastewater system designed for a very small community. The system uses a combination of alternative technologies to provide for wastewater collection, treatment, disinfection, and reuse. The disinfected wastewater is then used to irrigate a small landscaped area nearby. Readers interested in wastewater reuse or the alternative technologies described will find the paper informative, as will small communities considering similar solutions.

Shallow Intermittent Sand Filtration: Microorganism Removal, the second technical paper in this issue, is a follow-up to a study published in our previous issue. The new research examines the effect of specific hydraulic loading rates, dosing frequencies, and media on the filters' ability to remove microorganisms from the wastewater. The results of this study are important to wastewater professionals and communities who use this technology.

In addition, beginning on page 23, this issue includes news and information from our publisher, the National Small Flows Clearinghouse (NSFC). The NSFC also publishes the newsletters *Small Flows* and *Pipeline* and offers a variety of information, resources, technical assistance, and other services to small communities concerning wastewater issues. Readers who would like more information about the NSFC's products and services should call (800) 824-8301 or (304) 293-4191.

We hope that you find this issue of the journal to be as interesting and informative as past issues. If you are not yet on our mailing list and would like to receive a subscription, please fill out and return one of the subscription information cards on page 25.

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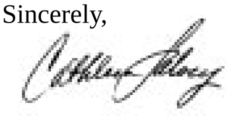
Sincerely,



Cathleen Falvey
Editor
The Small Flows Journal

A Decentralized Wastewater System for a Small Residential Development in California

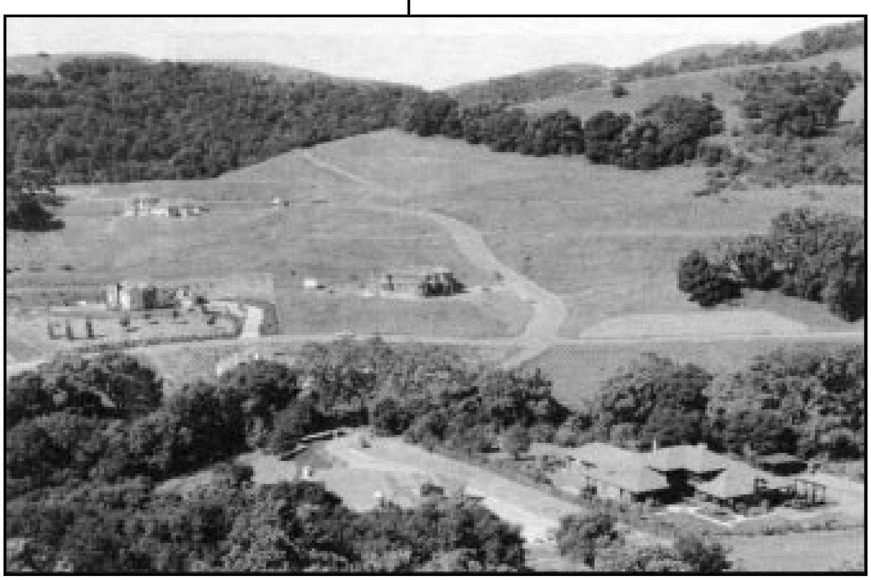
by Ron Crites, P.E.,
Craig Lekven, P.E.,
Steve Wert, C.P.S.S., W.W.S., and
George Tchobanoglous, Ph.D., P.E.

***ABSTRACT**: An innovative system was designed to provide for wastewater collection, treatment, disinfection, and reuse for a small residential development in California. The system combines the use of septic tanks, screened effluent filter vaults, high-head effluent pumps, small-diameter variable grade sewers, pressure sewers, a recirculating granular medium filter, an ultraviolet light disinfection unit, a subsurface drip irrigation system for wastewater reuse, and a community soil absorption field for winter-time disposal. The system has performed beyond required standards for wastewater reuse.*

In rural areas without wastewater collection systems, developers traditionally have had one method of wastewater treatment available to them—individual septic tanks with soil absorption fields. While these systems may be appropriate and adequate for many developments, there are site conditions that can restrict their use, including inappropriate or limited soils, high groundwater, and elevated nitrate concentrations in groundwater, among other factors. In some cases, developers may not want to use septic systems because of the homeowners' required involvement in keeping the systems operating properly.

Where traditional septic systems are not appropriate or desired, small, decentralized community wastewater systems can be designed to collect, treat, and dispose of the wastewater generated from developments. The system considered in this paper is an example of a small community design that also provides for wastewater disinfection and reuse.

PHOTO 1 ▼
view of the rolling terrain at Stonehurst development, Contra Costa County, California



Stonehurst Development

Stonehurst is a 47-lot subdivision located near the city of Martinez in Contra Costa County, California, approximately 25 miles east of San Francisco. The subdivision is located in a hilly, rural area that did not have a wastewater collection system. An overall view of the rolling terrain is shown in photo 1. The use of conventional septic tank/soil absorption systems was originally approved for the subdivision. However, the developer, Security Owners Corporation of Martinez, wanted to implement a community wastewater collection, treatment, and disposal system that would also provide for wastewater disinfection and reuse. The rationale for this approach was to free homeowners from concerns about possible absorption field failures and to protect the environment while providing for the subsurface irrigation of a small community park for the residents. As of January 1997, 15 of the 47 lots have been developed and are contributing wastewater to the system.

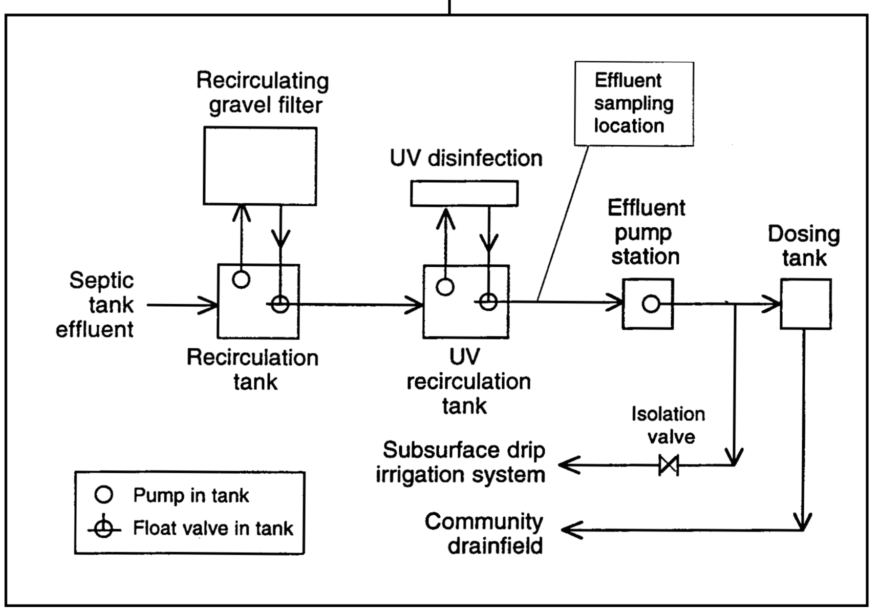
PHOTO 2 ▲
A view of typical homes in the Stonehurst development. Homes located below the roadway are provided with STEP systems.

The Wastewater System

The wastewater system that was designed and constructed for the Stonehurst development incorporates a number of innovative technologies. The system uses 1,500-gallon (5,680-liter), two-compartment water-tight septic tanks with screened effluent filter vaults at each connection. The system also employs high-head effluent pumps, small-diameter variable grade sewers, two pressure sewers, a recirculating granular medium filter, an ultraviolet (UV) light disinfection unit, a subsurface drip irrigation system for wastewater reuse, and a community soil absorption field for winter-time disposal, when needed.

The system is designed to meet California standards for wastewater reuse, which require disinfected wastewater to have a 30-day average biochemical oxygen demand (BOD_5) and total suspended solids (TSS) of 15 mg/L, a settleable solids of 0.1mL/L, and a total coliform concentration equal to or less than 23 most probable number (MPN) per 100 mL. The system began operation in August 1993 with approximately six homes connected to the system.

FIGURE 1 ▼
flow diagram for wastewater treatment facilities at the Stonehurst development

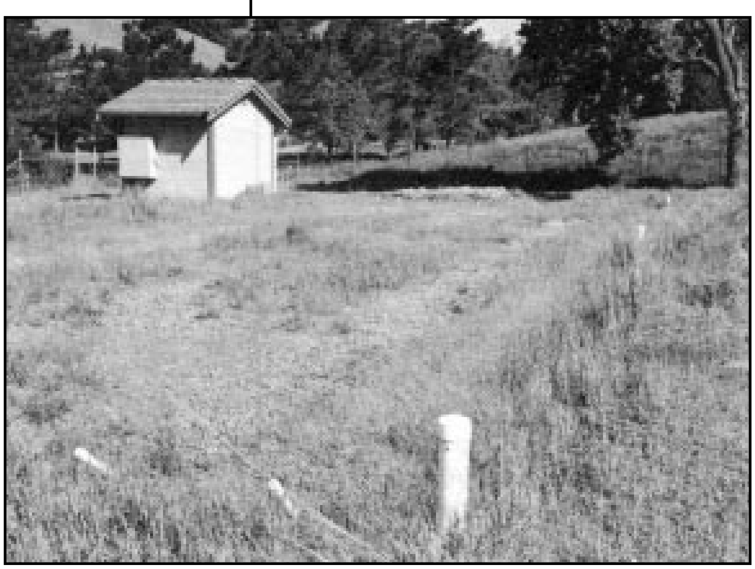


description	value
number of lots available	47
number of homes contributing wastewater	15
design flow per lot	300 gal/d (1,140 L/d)
total flow at build-out	14,100 gal/d (53,374)L/d
recirculation tank volume	14,100 gal
granular medium filter	
surface area	4,700 ft^2 (437m^2)
hydraulic loading rate	3 gal/ft^2•d (120 mm/d)
minimum recirculation ratio [a]	5:1
filter medium characteristics	
effective size, d_{10}	3 mm
uniformity coefficient	<2
depth of filter medium	2 ft (0.6 m)
ultraviolet disinfection	
type	open channel package unit
number of UV modules	3
lamps per UV module	2
minimum UV dose	95 mW•s/cm^2
community drainfield	
trench dimensions	24 in wide x 36 in deep (610 mm x 915 mm deep)
total trench length	5,000 linear ft (1,524 m)
total drainfield area	2.5 acres (10,117 m^2)
design loading rate	2.8 gal/lineal ft•d (0.0348 m^3/m•d)
drip irrigation system	
emitter type	non-clog, buried (6–12 in)
reuse area	1 acre park (4,047 m^2)
reuse crops	landscape, trees, and shrubs

[a] based on wastewater flow to treatment plant

TABLE 1 ▲
Stonehurst subdivision wastewater system design criteria

PHOTO 3 ▼
A view of half of the recirculating gravel medium filter is in the foreground. The building in the background is used to house the UV disinfection unit.



Wastewater Collection

Stonehurst's wastewater collection system is composed of three segments: a small-diameter variable-grade gravity sewer, a pressure sewer, and a pressure sewer force main. The system is designed so that at full build-out, septic tank effluent from 32 of the lots discharges to a 2-inch (50.8-mm) variable-grade gravity sewer located in the roadway of the development. The collection sewer drains into a wet-pit pump station.

The remaining 15 of the lots are located at elevations below the roadway (see photo 2) and cannot be served by a gravity system. Septic tank effluent pumps (STEP) are used to pump septic tank effluent from the low-lying lots into the pressure sewer. The pressure sewer used to connect the 15 low-lying lots also discharges to the wet-pit pump station. The combined flow is pumped through a force main from the wet-pit pump station to the treatment plant.

The centralized pump station was designed to reduce the operation and maintenance requirements for the collection system by reducing the total number of individual pumps requiring service.

Wastewater Treatment

The principal elements of the wastewater treatment system include: a recirculating granular medium filter for treatment and a UV system for disinfection. A schematic flow diagram of the treatment system is shown in figure 1. Design criteria for the treatment plant and disposal/reuse facilities are summarized in table 1.

Recirculating Granular Medium Filter. Treatment of the septic tank effluent is accomplished with a recirculating granular medium filter that is divided into two sections (see photo 3). Each filter section includes a recirculation tank, recirculation pumps, and a recirculating gravel medium filter. Each half of the filter consists of 24 inches (0.6 m) of 3-mm gravel sandwiched between layers of drain rock, which is coarse, washed gravel, approximately 1 to 2.5 inches (25 to 63 mm) in diameter. The 3-mm gravel is washed and rounded (not crushed) and contains less than two percent material finer than a number 10 sieve (2 mm).

Wastewater treatment is achieved through biological, chemical, and physical action within the filter. Treated effluent from the bottom of the filter is conveyed back to the recirculation tank. Wastewater is pumped from the recirculation tank to the filters at regular (adjustable) time intervals, usually set for five minutes every half hour. Wastewater is circulated through the filter approximately five times before being diverted by a float valve system to the UV supply sump. At the time of publication, only one half of the recirculating granular medium filter is being used.

Wastewater Disinfection. Disinfection of the treated wastewater is achieved using UV light (see photo 4). Treated wastewater flows through an open channel containing six low-pressure mercury vapor lamps, which emit UV light at a wavelength of 254 nm (see table 1) that inactivates most bacteria and pathogens. Two small pumps are used to transport the treated wastewater to the UV system.

Wastewater Reuse/Disposal

The treatment plant effluent is pumped to a 3,000-gallon (11,356-liter) dosing tank at the top of a nearby hill. Two dosing siphons in the tank alternately feed the two halves of a pressure-dosed, 2.5-acre (10,117 m^2) community soil absorption field. A series of hydrosplitters ensures that the absorption field trenches are all dosed evenly.

The soil absorption field was located on a hilltop because the soils in most other areas within the development were extremely high in clay and had seasonal high groundwater. The absorption field area has shallow, silty clay loam soils underlain by very soft, fractured sandstone. Soil depth in the absorption field varies from 20 to 30 inches (508 to 762 mm). Soil was tested using a shallow well pump-in test from which saturated hydraulic conductivity was determined. The hydraulic conductivity was used to design the soil absorption field to accept the daily wastewater flow plus additional flows during peak rainfall periods.

The soil absorption field is currently being used for disposal year round until more homes are built and the amount of wastewater flow increases. A number of monitoring wells, located downhill from the absorption field, are checked on a quarterly basis and have been dry.

The dosing tank also serves as a water storage reservoir for a subsurface drip irrigation system located at a small community park area near the subdivision entrance. The dosing tank is designed to provide adequate storage volume underneath the absorption field dosing siphons for the operation of the subsurface drip irrigation system.

Non-clog drip emitters are buried in short lengths of gravel-filled PVC pipe. The park is landscaped with drought-tolerant

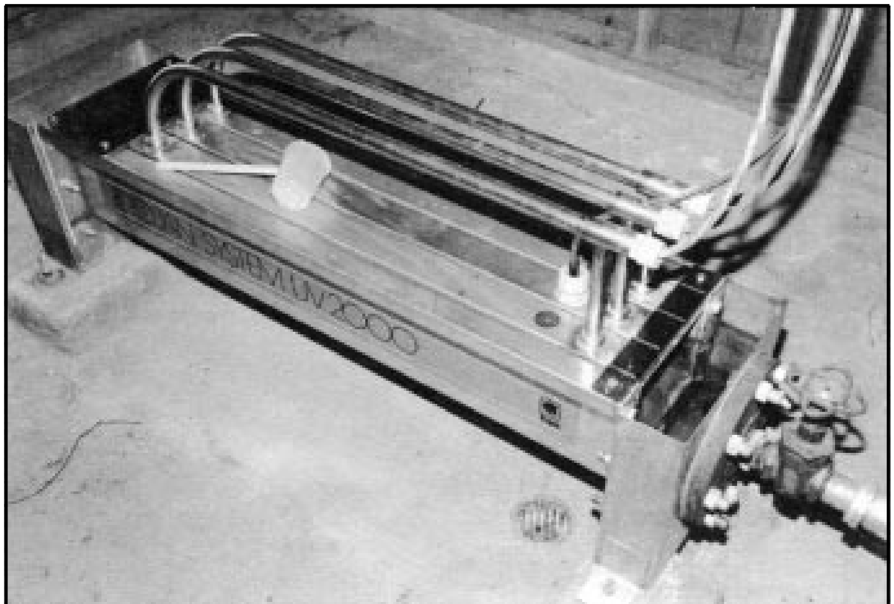


PHOTO 4 ▲
A view of the UV disinfection unit located in a building next to the gravel medium filter—the UV system consists of three modules, each of which has two lamps.

trees and shrubs. Three drip emitters are provided for each tree and one for each shrub. Application rates for the drip system were determined based on the needs of the vegetation and the rate of evapotranspiration anticipated. At full build-out, reclaimed water will provide 100 percent of the landscaped water demands at the one acre park. In the wet season, reclaimed water not needed for irrigation purposes will be disposed of automatically in the pressure-dosed community soil absorption system. Routine maintenance of the drip irrigation system will include periodically dosing the lines with chlorine to prevent clogging.

Well water is currently being used for irrigation of the park until reclaimed water volumes are adequate to maintain the landscaping. In time, the irrigation system will be disconnected from the potable water piping and connected to the reclaimed water piping.

Operation and Maintenance

To ensure proper operation and maintenance of wastewater systems, the regional water quality control board that includes Stonehurst in its jurisdiction only recognizes responsible agencies or districts (not individuals) for system operation and maintenance. To comply, a county sanitation district was formed to serve as owner of the Stonehurst community wastewater system. The wastewater system operation and maintenance is funded through annual property assessments. The special district is administered by the Contra Costa County Department of Public Works. Contra Costa County has contracted for the daily operation and maintenance with ES2, a national firm that specializes in the operation of wastewater treatment plants.

TABLE 2 ▼
quality of septic tank effluent applied to recirculating gravel filter at Stonehurst, along with comparative data on septic tank effluent characteristics

constituent [a]	unit	Stonehurst [b]	typical range
BOD_5	mg/L	100 - 130	80 - 300
COD	mg/L	430 - 600	300 - 500
TSS	mg/L	65 - 92	30 - 90
settleable solids	mL/L	< 0.1	< 0.1 - 0.4
turbidity	NTU		15 - 40
pH	unitless	7.0 - 7.5	6.5 - 8.5
NH_4-N	mg/L-N	60 - 65	20 - 60
$NO_2 + NO_3$	mg/L-N		0.0 - 1.0
organic N	mg/L-N		10 - 40
TKN	mg/L-N		30 - 100
total N	mg/L-N		30 - 100
total P	mg/L-P		6 - 12
oil and grease	mg/L		20 - 40
MBAS	mg/L		5 - 20
total coliform	MPN/100/mL		$10^6 - 10^7$
fecal coliform	MPN/100/mL		$10^5 - 10^6$
fecal streptococcus	MPN/100/mL		$10^4 - 10^5$
indigenous phage	PFU/mL		500 - 5,000

[a] BOD_5 = 5-day 20°C biochemical oxygen demand, COD = chemical oxygen demand
TSS = total suspended solids, pH = hydrogen ion concentration
NH_4 = ionic form of ammonia nitrogen, NO_2 = nitrite nitrogen
NO_3 = nitrate nitrogen, TKN = total kjeldahl nitrogen (organic N + NH_4)
P = phosphorus, MBAS = methylene blue active substances
[b] only the indicated constituents are monitored
[c] from Crites and Tchobanoglous (in press)

Performance Data

As noted previously, the wastewater system at Stonehurst began operation in August 1993. By September 1996, the flow to the treatment system was approximately 20 percent of the design flow at 2,800 gal/d (10,600 L/d). During the period from June 1994 through September 1996, the monthly flow has varied from about 5 to 25 percent of the design flow anticipated at full build-out. Based on daily meter readings from the first 15 homes that have come on line, the flow per home, which is about 180 gal/d (680 L/d), is less than the expected 300 gal/d (1,140 L/d).

At the present time, the hydraulic loading on the granular medium filter is about 1.2 $gal/ft^2 \cdot d$ (48 mm/d) using half of the filter. The characteristics of the septic tank effluent applied to the recirculating gravel filter are reported in table 2, along with typical septic tank effluent data as reported in the literature. As

TABLE 3 ◀
performance data for Stonehurst wastewater treatment system

Performance dated for Stonehurst wastewater treatment system for the 28-month period from June 1994 through September 1996. Effluent samples taken following recirculating gravel filter and UV disinfection as shown in figure 1.

				observed values [c]			
constituent [a]	unit	sample reporting period [b]	total samples to date	range	arithmetic mean	geometric mean	median
BOD_5	mg/L	monthly	56	0 - <5		<5	<5
COD	mg/L	monthly	120	1.0 - 18.0		4.7	5.0
TSS	mg/L	monthly	118	2.0 - 15.0		5.0	4.9
pH	unitless	monthly	120	6.96 - 8.65	d	d	7.61
total coliform	MPN/100mL	monthly	118	<2 - 12.5	d	d	<2
NH_4	mg/L	quarterly	9	0 - 15	e	e	0.0
NO_3	mg/L	quarterly	9	3.55 - 37.0		12.5	12.2
TKN	mg/L	quarterly	9	0 - 3	e	e	0.4
oil and grease	mg/L	quarterly	9	0 - 12	e	e	0.0
TDS	mg/L	quarterly	9	340 - 770	630		656
EC	µmhos/cm	quarterly	9	433 - 1,200	894		1,000

[a] TDS = total dissolved solids, EC = electrical conductivity
[b] Monthly values for BOD_5 are based on an average of two samples per month. Monthly values for TSS, COD, pH, and total coliform are based on an average of at least four samples per month.
[c] Arithmetic or geometric means are reported depending on the distribution of the monthly values (see table 4).
[d] Mean values cannot be reported for pH, which is a logarithmic function, and for total coliform, which is based on a Poisson distribution.
[e] Unable to define nature of distribution because of the number of zero values reported.

shown in table 2, the reported constituent concentrations at Stonehurst are typical of septic tank effluent.

Constituent Removal Data

Summary of performance data for the 28-month period from June 1994 through September 1996 are presented in table 3. Both monthly and quarterly values are reported. The reported monthly values for five-day biochemical oxygen demand (BOD_5) are based on an average of at least two samples per month. Monthly values reported for TSS, chemical oxygen demand (COD), pH, and total coliform are based on an average of at least four samples per month. The reported quarterly values are based on grab samples.

The measured data for the individual constituents are reported in terms of the range of values observed, the arithmetic or geometric mean, and the median. Either the arithmetic or geometric mean are reported depending on the nature of the statistical distribution of the monthly or

TABLE 4 ▼
statistical parameters for the average monthly values of TSS and COD

statistic [a]	TSS	COD
minimum value	2.0 mg/L	1.0 mg/L
maximum value	15.0 mg/L	18.0 mg/L
sum	156.5 mg/L	163.8 mg/L
number of data points	28	28
arithmetic mean	5.6 mg/L	5.9 mg/L
median	4.9 mg/L	5.0 mg/L
RMS	6.3	7.1
standard deviation	2.9	4.1
variance	8.6	16.6
standard error	0.6	0.8
coefficient of skewness	1.2	1.2
coefficient of kurtosis	1.7	1.1

[a] The values of the coefficient of skewness and kurtosis for a normal distribution are equal to zero, as computed.

FIGURE 2 ▶
log-probability plot of average monthly TSS and COD data

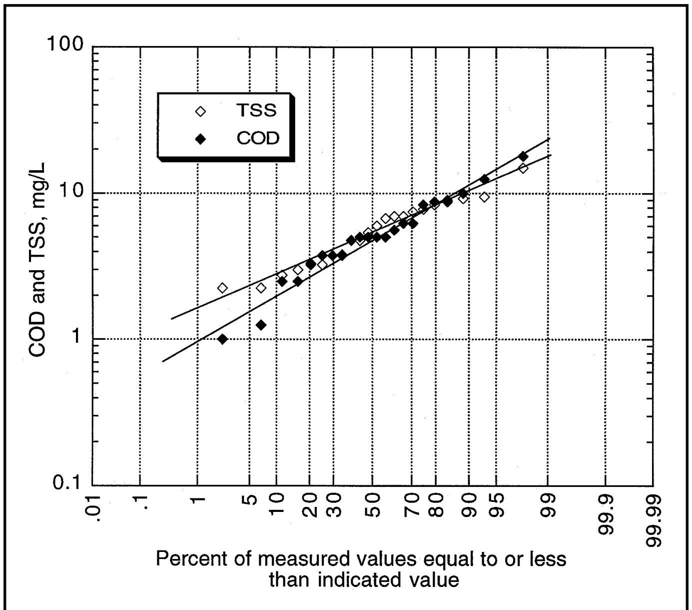


TABLE 5 ▼
comparison of performance of recirculating gravel filters

location	medium size, mm	loading rate, gal/d • ft ^{2}	effluent BOD_5, mg/L
Stonehurst, CA	3.0	1.2 [a]	<5
Oregon [b]	1.2	1.45	2.7
Paradise, CA [c]	3.0	2.5	8
Paradise, CA [c]	3.0	2.5	12

[a] Design value at full build-out = 3.0 gal/d•ft ^{2}; currently half of the filter is used.
[b] Ronayne et al., 1984
[c] Nolte and Associates, Inc., 1992

quarterly data. As shown, all of the values reported for BOD were either reported as zero or less than five. As a result, both the mean (assumed to be normally distributed) and the median values are reported as less than five.

The reported monthly values for TSS and COD were found to be log-normally distributed (i.e., skewed), as discussed below. Because of the number of zero values reported, it was not possible to define the nature of distribution for the total kjeldahl nitrogen (TKN), ammonium ion (NH_4), and oil and grease values. The total dissolved solids (TDS) and conductivity values were found to be normally distributed.

Statistical Analysis of Data

To determine whether the arithmetic mean can be used to describe the observed monthly values, a statistical analysis was performed. The results of the statistical analysis for the TSS and COD data are reported in table 4. Statistical parameters are given for both TSS and COD, assuming that the distribution of average monthly or the log of the monthly values is normally distributed.

As reported in table 4, both the TSS and COD data are skewed, as the coefficient of skewness for a normal distribution should be zero. Given that the value of the coefficient of kurtosis for a normal distribution should also be zero, it is clear that both distributions are relatively peaked. As reported below, both distributions were found to be logarithmically distributed.

A plot of the TSS and COD data on logarithmic probability paper is shown in figure 2. The finding that the distributions of the effluent concentration values for TSS and COD are log-normal is consistent with the findings of Niku et al. (1979). Based on an analysis of the data from a number of treatment plants, Niku et al. concluded that the log-normal distribution for effluent BOD and TSS may be used to predict the effluent quality performance and the reliability of wastewater treatment plants. The fact that the TDS and conductivity data are normally distributed is also consistent, given that the principal constituents that contribute to these values are related more closely to the water supply and that these constituents are not normally removed during conventional biological treatment.

Assessment of Performance Data

Based on the data reported in table 3, the treated effluent more than meets the applicable effluent discharge criteria standards. The monthly BOD values are consistent with the results that have been reported by others as summarized in table 5. In general, the effluent monthly BOD, TSS, and COD values are considerably better than those achieved in conventional centralized wastewater treatment systems, especially with respect to COD (Tchobanoglous and Burton, 1991). Another unusual feature of the treatment process is its robustness.

The robustness of a treatment process can be assessed by considering the ratio of the P_{90} to P_{50} or P_{50} to P_{10} values on the logarithmic-probability curve. In a perfectly stable system, all effluent values will be constant, resulting in a plot of zero slope and a ratio of one. A system with significant variability will typically result in a plot with a steep or discontinuous slope beyond a cumulative probablility value of 80 percent.

From figure 2, the ratio of the P_{90} to P_{50} values for TSS and COD are 2.0 and 2.6, respectively. Typical corresponding values for the activated sludge process are about 2.5 and 3.4 (WEF, 1991). The markedly steeper slopes observed with very small activated sludge systems are indicative of less stable systems.

Conclusion

The opportunity to reclaim wastewater from individual residences in small rural developments in a decentralized facility is an effective means of saving water, providing reliable wastewater services, and meeting regulatory requirements. The use of new equipment and technologies, such as screened effluent pump vaults, low-flow high-head pumps, small-diameter variable slope sewers, recirculating granular medium filters, three-way diversion valves, UV disinfection, and a combination of community absorption field and subsurface drip irrigation has made the implementation of small treatment systems a far more reliable undertaking. To date, the Stonehurst decentralized wastewater system has exceeded all expectations by performing beyond required standards for wastewater reuse.

Acknowledgments

System implementation and construction was accomplished by the owners Scott and Jim Busby of Security Owners Corporation. The project was planned and the soil acceptance rates were determined by Steve Wert. Operating data were provided by Bill Perley of ES2, the operating company.

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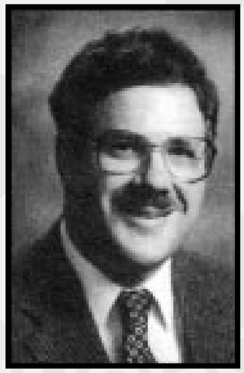

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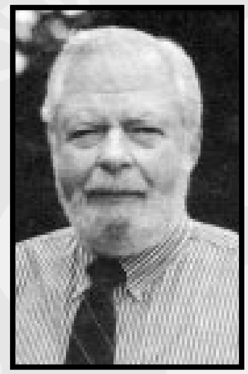

George Tchobanoglous, Ph.D., P.E.

George Tchobanoglous has recently retired as a professor emeritus in the Department of Civil and Environmental Engineering at the University of California, Davis.

If you would like more information about this project, write to Ron Crites, P.E., Nolte and Associates, Inc., 1750 Creekside Oaks Drive, Suite 200, Sacramento, CA 95833.

Shallow Intermittent Sand Filtration: Microorganism Removal

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ABSTRACT: *Twelve shallow circular sand filters (0.38 m deep, nominal diameter of 1.2 m) were loaded intermittently with primary effluent to evaluate the effects of hydraulic loading rate (HLR)—coupled with a high dosing frequency (DF)—and filter medium characteristics on the removal of indigenous coliphages, total coliforms, turbidity, chemical oxygen demand (COD), and total suspended solids (TSS). HLRs between 0.041 and 0.162 m/d were applied during an 84-day period at a DF of 24 doses/d. Two types of filter media were investigated: medium-size and coarse sand and crushed glass. Effective sizes ranged from 0.44 to 3.3 mm, and uniformity coefficients ranged from 1.3 to 5.0. Average removal rates greater than 94, 96, and 92 percent occurred for turbidity, TSS, and COD, respectively, regardless of medium characteristics. Removal of microorganisms was found to be affected by the combination of HLR and DF, with an increase in HLR at a constant DF resulting in a decrease in the log removal of both total coliforms and indigenous coliphages. Indigenous coliphages appeared to be more sensitive to changes in HLR than seeded polioviruses.*
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In the U.S., approximately 60 million people use onsite systems for wastewater treatment and disposal. Onsite systems typically consist of a septic tank for primary treatment and a soil absorption system for secondary treatment and disposal. However, unsuitable soil and site conditions can preclude the use of such systems due to concerns of contamination of the groundwater by nutrients, bacteria, and viruses.

One of the greatest concerns over groundwater contamination is the occurrence and movement of viruses, which have been found to survive septic tanks and move with the percolating wastewater through the disposal field and the soil to reach groundwater (Hain and O'Brien, 1979). Septic tank systems are the most frequently reported cause of groundwater contamination associated with disease in the U.S. (Powelson and Gerba, 1994).

Intermittent sand filters (ISFs), because of their relatively low construction cost and their minimal maintenance and energy requirements, have been used as supplemental pretreatment for the soil absorption system at individual residences, small clusters of homes, business establishments, and rural communities to provide consistent, high quality effluent (Ball, 1991). Modern ISFs are typically 0.5 to 1 m deep and are operated at hydraulic loading rates (HLR) varying from 0.016 to 0.070 m/d (Ball, 1991) [1]. Typical dosing frequencies (DF) are 3 to 6 doses/d (Tchobanoglous and Burton, 1991). The vast majority of research related to ISFs

PHOTO 1 ▲
view of experimental filters with covers removed

has been directed toward optimizing the removal of organic material and nutrients (Grantham et al., 1949; Furman et al., 1955; Schwartz and Bendixen, 1970; Marshall and Middlebrooks, 1974; U.S. EPA, 1980; Siegrist and Boyle, 1981; Anderson et al., 1985; Andreadakis, 1987; Pell and Nyberg, 1989a,b,c; Pell et al., 1990; Peeples et al., 1991; Darby et al., 1996). The removal of bacteria (principally coliform bacteria) by ISFs is also well documented (Salvato, 1955; Allen, 1971; Marshall and Middlebrooks, 1974; U.S. EPA, 1977; Dymond, 1981; Ronayne et al., 1982; Anderson et al., 1985). However, of the studies that have investigated the removal of viruses by ISFs from wastewater (Green and Cliver, 1974; U.S. EPA, 1978; Wang et al., 1981; Gross and Mitchell, 1990), none have focused specifically on operation of modern field-scale shallow ISFs for optimal indigenous virus removal.

Darby et al. (1996) demonstrated that 0.38-m deep ISFs were capable of producing average removal rates of between 90 and 99 percent for biological oxygen demand (BOD), total suspended solids (TSS), organic and ammonia nitrogen, and turbidity and at least 81 percent for chemical oxygen demand (COD), regardless of medium characteristics, when dosed with primary effluent at an HLR of 0.163 m/d or less and a DF of 12 to 24 times/d. The study presented herein is an extension of the work reported by Darby et al. with the purpose of evaluating microorganism (principally indigenous coliphage) removal from field-scale shallow ISFs.

Experimental Methods

The experimental facilities were the same as those used in Darby et al. (1996). Twelve shallow sand filters were loaded intermittently with effluent from the primary settling tank of the University of California, Davis wastewater treatment plant. The experimental filters are shown in photo 1. A complete description of the filters' construction, except for media type, has been reported previously (Darby et al., 1996). A description of the filter media, filter design and operating parameters, sampling, and laboratory analyses are provided below.

Filtering Media

The depth of the medium in each filter was 0.38 m. Two filter media were used: (1) washed and kiln-dried medium-size and coarse sand with effective sizes (ES) and uniformity coefficients (UC) of 0.65 mm and 3.8, and 3.3 mm and 1.3, respectively, and (2) crushed glass from a recycling center that was washed on a number 100 mesh screen with an ES and UC of 0.44 mm and 5.0, respectively. The particle size distributions of the filter media are shown in figure 1 on page 14.

The medium-size sand was chosen for study because it has characteristics typical of those used in conventional ISFs (Tchobanoglous and Burton, 1991). The coarse sand was chosen for study because it is less likely to clog over an extended operating period, due to the large pores present. It should be noted that the effective size of the coarse sand is almost an order of magnitude larger than is typical for use with ISFs.

Crushed glass was chosen as a filter medium for study because it has chemical characteristics that are similar to sand and, therefore, would be expected to remove contaminants in a similar manner. Crushed glass currently has a cost of \$19.60/m and is readily available. The use of crushed glass is particularly advantageous in communities where adequate filter sand is not available locally, resulting in sand costs up to \$26/m. Glass can be supplied by local glass recycling efforts, eliminating the need to import filter media from distant locations, and can be crushed either on site using a portable crusher or at a local gravel processing plant. As the use of crushed glass in ISFs becomes more common, the price may decrease accordingly.

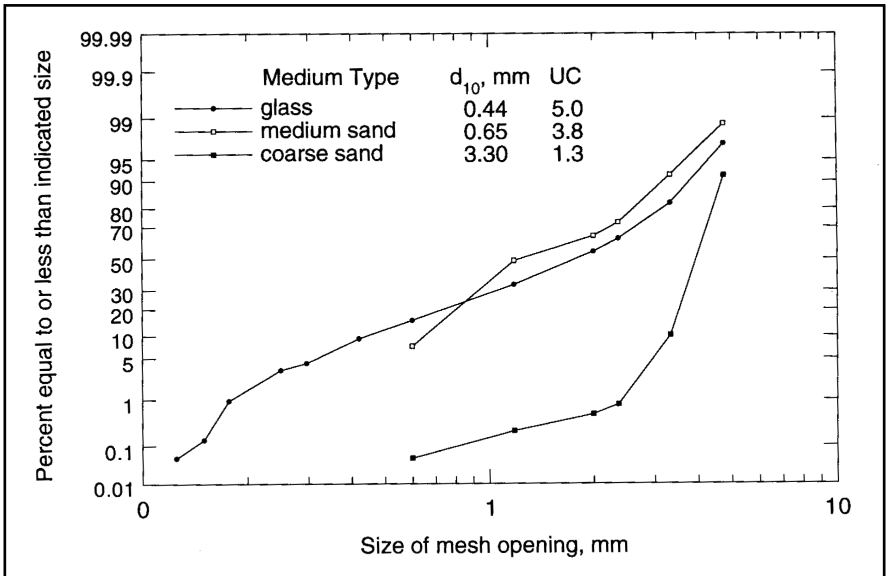


FIGURE 1 ▲
filter medium particle size distribution

Filter Design and Operating Parameters

The design and operating parameters of the filters are summarized in table 1. Three filter medium sizes, three HLRs, and a single DF were investigated resulting in five different treatment configurations. Redundancy was incorporated into the experimental design to ensure completeness in data collection in case of unforeseen problems with one or more filters and to provide process replication to ensure that reported observations were typical (e.g., filters 2, 3, and 4 were identical; filters 5, 6, and 7 were identical; and filters 8, 9, and 10 were identical). The DF utilized, 24 doses/d, was the optimal DF for wastewater contaminant removal reported by Darby et al. (1996). The HLR and filter medium were varied such that the effect of each parameter could be investigated systematically and independently.

Sampling

Grab samples were collected from the sampling ports connected to the effluent outlet pipe. The sampling port was

TABLE 1 ▼
filter medium characteristics and applied loading

filter number	filter material	effective size, mm	uniformity coefficient, UC	hydraulic loading rate, m/d	hydraulic application rate, mm/dose
1	crushed glass	0.44	5.0	0.040	1.7
2	medium sand	0.65	3.8	0.040	1.7
3	medium sand	0.65	3.8	0.040	1.7
4	medium sand	0.65	3.8	0.040	1.7
5	medium sand	0.65	3.8	0.081	3.4
6	medium sand	0.65	3.8	0.081	3.4
7	medium sand	0.65	3.8	0.081	3.4
8	medium sand	0.65	3.8	0.163	6.8
9	medium sand	0.65	3.8	0.163	6.8
10	medium sand	0.65	3.8	0.163	6.8
11	coarse sand	3.3	1.3	0.163	6.8
12	coarse sand	3.3	1.3	0.163	6.8

Note: All filters were dosed at a dosing frequency of 24 times/day.

TABLE 2 ▶
quality of wastewater applied to filters [a]

parameter	unit	range
turbidity	NTU	18 - 38
COD	mg/L	98 - 226
BOD_5	mg/L	38 - 105
TSS	mg/L	20 - 38
NH_3-N	mg/L-N	6.1 - 23.6
nitrate + nitrite	mg/L-N	0.0 - 1.1
organic N	mg/L-N	3.3 - 6.2
indigenous phage [b]	PFU/mL	640 - 2520
total coliform [b]	MPN/100/mL	4.9×10^6 - 1.1×10^7

[a] adapted from Darby et al. (1996) except where noted
[b] measured during the course of this study

opened and allowed to flow for approximately five minutes before sampling. Samples were collected over an 84-day period during the summer. An influent sample was collected each time effluent sampling occurred. Air temperatures were obtained from a climatological data collection facility 2 km from the filter site. The actual temperature of the media and the wastewater were not measured during the study.

Laboratory Analysis

Samples were immediately cooled and analyzed within three hours for naturally occurring coliphages, total coliforms, TSS, turbidity, and COD. All laboratory analyses were in accordance with Standard Methods, 17th edition, except as noted below.

Indigenous coliphages are bacterial viruses and were selected as the viral indicator because, like human enteric viruses, they occur naturally in wastewater and are associated with wastewater solids (Lehrer and Cabelli, 1993). The removal of indigenous coliphages, therefore, may indicate the likely removal of human viruses. The coliphage detection procedure used was a modified version of Coliphage Detection (Proposed) (method 9211D) outlined in Standard Methods, 19th edition—the difference being that *E. coli*, American Type Culture Collection (ATCC) 15597, was used as the host bacterium. Three replicate plates were made of each dilution with the median value of the replicates used for data presentation.

Total coliform bacteria were selected as the bacterial indicator because of their frequent use in permit discharge requirements. The multiple tube fermentation technique was used to determine the most probable number (MPN) of total coliform bacteria per 100 mL (method 9221 B). TSS was measured according to method 2540D. Turbidity was measured with a HACH Model 2100A turbidimeter. COD was determined colorimetrically following digestion.

Results and Discussion

Characteristics of the wastewater applied to the filters during the study period were similar to that described in Darby et al. (1996) and are presented in table 2. The values of BOD and TSS were in the lower one-third of the range that is typical for septic tank effluent. The air temperature during the study period had an average high of 27°C with a coefficient of variation of 26 percent and an average low of 9°C with a coefficient of variation of 42 percent.

Overall Performance

Effluent quality from all of the filters was excellent. Although TSS, COD, and turbidity removal was not the focus of this investigation, spot checks were conducted on the filters to assess their overall performance. Because no problems were ever encountered with the filters, and the performance of all the redundant filters were never statistically different, the data for all of the redundant filters were grouped together for data analysis and presentation. A summary of the performance is provided in table 3.

All of the filters, regardless of medium type or HLR, were able to remove turbidity to less than 2 nephelometric turbidity units (NTU), reduce TSS to less than 2 mg/L, and remove COD to less than 20 mg/L. There were no statistically significant differences in the performance of any of the filters in removing TSS, COD, and turbidity. The results from this study are the same as those reported by Darby et al. (1996). The ability to remove contaminants to such low levels in the filters utilizing the coarse sand (ES = 3.3 mm) is significant because the indication is made that large-size sand, when coupled with a high DF, is capable of producing a high quality effluent. The benefit of using coarse sand as the filter medium is that the chance of clogging over extended time periods is minimized, even when using a relatively high HLR. As reported in table 3, crushed glass performed essentially the same as the medium-size sand at a loading rate of 0.04 m/d. Additional research needs to be conducted on the long-term stability of each filter medium in resisting clogging.

Effect of HLR and DF on Microorganism Removal

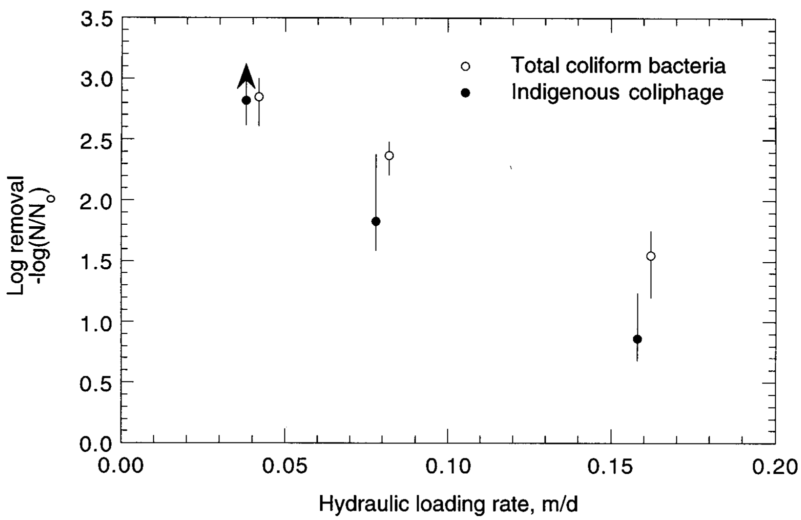
The effect of HLR, coupled with a DF of 24 doses/d, on total coliform and coliphage removal is illustrated in figure 2. Both total coliform and coliphage removal performance were evaluated for medium-size sand (d_{10} = 0.65, UC = 3.8) at a DF of 24 doses/d. Removal of coliform bacteria and coliphages did not significantly change over the study period. The data points in figure 2 for total coliform and coliphage removal at each HLR are the average of at least 14 and 6 measurements, respectively, taken over the course of 84 days.

Bacterial indicator. As shown in figure 2, an increase in the HLR resulted in a decrease in the log removal of total coliforms. This result is not unexpected and is consistent with results reported in

TABLE 3 ▼
summary of treatment achieved with intermittent sand filters (dosing frequency = 24 times/day)

	percent removal			effluent concentration [a] mg/L except NTU for turbidity		
parameter	average	minimum	maximum	average	minimum	maximum
crushed glass HLR = 0.040 m/d						
turbidity	98.1	97.7	98.5	0.40	0.31	0.50
TSS	>99	>99	>99	ND	ND	ND
COD	95.2	93.4	97.1	8	5	11
medium sand HLR = 0.040 m/d						
turbidity	98.3	97.6	99.0	0.36	0.22	0.47
TSS	>99	>99	>99	ND	ND	ND
COD	95.8	93.5	99.4	7.2	1.0	11.0
medium sand HLR = 0.081 m/d						
turbidity	98.1	95.3	98.8	0.40	0.26	0.90
TSS	>99	>99	>99	ND	ND	ND
COD	95.2	93.5	96.5	8.2	6	11
medium sand HLR = 0.163 m/d						
turbidity	96.4	88.4	98.7	0.75	0.27	2.2
TSS	>99	>99	>99	ND	ND	ND
COD	95.2	94.1	97.1	8.2	5	10
coarse sand HLR = 0.163 m/d						
turbidity	94.0	86.8	97.3	1.3	0.60	2.5
TSS	96.2	93.4	98.7	1.4	0.78	2.0
COD	92.2	88.7	94.7	13.3	9	19
concrete and filter sand [b]						
turbidity	97	91	99	0.7	0.3	1.7
TSS	98	94	>99	0.4	ND	1.8
COD	94	81	>99	8.8	1.0	42.0

[a] ND = nondetectable amounts in 2 liters of sample
[b] data taken from Darby et al. (1996) for the purpose of comparison



Note: Dosing frequency = 24 doses/day, see text.
Error bars indicate 95% confidence intervals.
Arrow indicates non-detectable amounts of coliphage in at least one sample resulting in unknown upper bound.

FIGURE 2 ▲
microorganism log survival plot

TABLE 4 ▶
analysis of volume per dose for various hydraulic loading rates and dosing frequencies

HLR, m/d	dosing frequency, doses/d	hydraulic application rate [a], m/dose	field capacity filled [b], percent
0.040	1	0.040	210
	2	0.020	105
	4	0.010	53
	8	0.005	26
	12	0.00333	18
	24	0.00167	9
0.081	1	0.081	426
	2	0.040	210
	4	0.020	105
	8	0.010	53
	12	0.00675	36
	24	0.00338	18
0.163	1	0.163	858
	2	0.082	432
	4	0.041	216
	8	0.020	105
	12	0.014	74
	24	0.00679	36

[a] HAR calculated with equation 1.

[b] Field capacity filled= $\dfrac{\text{HAR}}{\dfrac{\text{field capacity of filter}}{\text{surface area of filter}}}$

where field capacity is defined as (5%) x (total volume of filter) as per Bouwer, 1978, and total volume, surface area, and depth of each filter is 0.431 m^3, 1.13 m^2, and 0.38 m, respectively.

the literature (U.S. EPA, 1978; Dymond, 1981). A removal of 2 to 4 logs is reported as being typical (Anderson et al., 1985; Ronayne, 1982; Salvato, 1955).

Viral indicator. An increase in the HLR also resulted in a decrease in the log removal of indigenous coliphages (see figure 2). There was not a statistically significant difference between the removal of total coliform bacteria and the removal of indigenous coliphages. In considering the reduction of indigenous coliphages in this study, it is useful to define a new term, the hydraulic application rate (HAR). The HAR is defined as:

$$\text{HAR (m/dose)} = \frac{\text{HLR (m/d)}}{\text{DF (dose/d)}} \qquad (1)$$

The importance of the HAR is illustrated in table 4.

At an HLR of 0.040 m/d and a DF of 24 doses/d, the resulting HAR is 0.00167 m/dose, which corresponds to about 9 percent of the field capacity of the filter. With such a light HLR at each dose, the applied water is retained in the upper layer of the filter and does not immediately penetrate to the lower layers. Only with subsequent applications (doses) is the water displaced into the lower layers of the filter in a more-or-less plug flow regime (Boller et al., 1993).

When the HLR is increased to 0.163 m/d, the value of the HAR is 0.00679 m/dose, which corresponds to 36 percent of the field capacity. As the HAR increases, saturated conditions are more likely to occur along with deeper penetration into the filter of the applied dose and the potential for some direct wash-through due to more significant deviations from plug flow conditions (Boller et al., 1993).

Viruses pass more easily in saturated flow because under saturated flow conditions, viruses can be carried along with the percolating water and can break through even the most tortuous path (Sproul, 1975; U.S. EPA, 1977; Powelson and Gerba, 1994). In unsaturated flow (as is expected in this study), the liquid flows at a slower rate and in a film over the surface rather than filling the pore spaces, and, as a consequence, there is greater opportunity for the viruses to contact the absorbing surface (U.S. EPA, 1977). Additionally, unsaturated conditions allow deeper oxygen penetration in the pore spaces, providing for greater biological activity, which is positively correlated with virus removal (Sproul, 1975).

An important difference is noted between the sensitivity of indigenous coliphages to changes in HLR and the sensitivity of viral indicators that have been reported in the literature. In a seeded virus study, the U.S. EPA (1978) reported that a one or more log difference in effluent poliovirus concentration resulted when the HLR was increased from 0.05 to 0.50 m/d, an order of magnitude increase. In this study it was found that a one or more log difference in effluent indigenous coliphage concentration results from a simple doubling of the HLR, from 0.04 to 0.08 m/d. The relevant difference in experimental design between this study and U.S. EPA (1978) is that the U.S. EPA study utilized a one dose/d DF, whereas a 24 doses/d DF was utilized in this study. The difference in DF has been discussed above and would lead to the expectation that the opposite results should have occurred: a greater sensitivity to HLR should have been observed in the U.S. EPA study compared to this study.

The finding of greater sensitivity in the current study to an increase in HLR is hypothesized to be the result of the type of virus used as the viral indicator. Because virus removal is principally an adsorption phenomena, the virus coat protein likely plays an instrumental role in removal. Adsorption has been found to be affected by virus charge (Burge and Enkiri, 1978) and hydrophobic effects (Farrah et al., 1981; Farrah, 1982). Thus, indigenous coliphages may be less easily adsorbed due to the coat protein structure and therefore are more sensitive to an increase in shear forces that result with an increase in the HAR. This hypothesis would imply that indigenous coliphages are more sensitive indicators for filter virus pass-through testing than are polioviruses.

Effect of Medium Type on Microorganism Removal

Medium type was studied for its influence on microorganism removal at both a high and low HLR. In testing a low HLR of 0.04 m/d, medium-size sand and crushed glass were compared. In testing a high HLR of 0.163 m/d, medium- and coarse-size sand were compared. A summary of the results of these comparisons is provided in table 5. As reported in table 5, medium type was not a significant factor in either total coliform or coliphage removal. The sand and glass filters were similar in ES (0.44 and 0.65, respectively), but differed in their UCs (5.0 and 3.8, respectively). When loaded at an HLR of 0.04 m/d, the coliform and coliphage log removals for the glass-medium filter and the medium-size-sand filter were not significantly different statistically at the 95 percent confidence level; the filters performed similarly. Performance comparison between the medium-size sand (ES = 0.65 mm and UC = 3.8) and coarse sand (ES = 3.3 mm and UC = 1.3) when loaded at an HLR of 0.163 m/d also did not result in statistically significant differences at the 95 percent confidence level.

The results of this study are not consistent with previous studies in which it was reported that removal of bacteria was found to decrease with an increasing ES (Marshall and Middlebrooks, 1974; Allen, 1971; Dymond, 1981). Although media size differences in this study were even greater than that reported in other studies and would lead to the expectation that effects would be observed in microorganism removal, the effects were likely overshadowed by the high overall removal

Parameter	HLR = 0.04 m/d crushed glass d_{10} = 0.44 mm UC = 5.0	HLR = 0.04 m/d medium-size sand d_{10} = 0.65 mm UC = 3.8	HLR = 0.163 m/d medium-size sand d_{10} = 0.65 mm UC = 3.8	HLR = 0.163 m/d coarse sand d_{10} = 3.3 mm UC = 1.3
Coliphage	3.1[a]	2.9[a]	0.9[a]	0.8[a]
Total coliform	3.4[a]	3.0[a]	1.6[c]	1.8[c]

Note: Numbers with the same superscripts are statistically the same at the 95 percent confidence level. Numbers with different superscripts are statistically different from each other at the 95 percent confidence level.

TABLE 5 ▲
effect of HLR on microorganism log reduction as a function of medium size

rates associated with the high DF (and corresponding low HAR) used in this research. DF has been found to affect the removal of bacteria, with higher DF leading to greater bacterial removal (Ronayne, 1982).

Conclusions

For the conditions studied in this research, the following conclusions can be drawn:

- ISFs with a relatively shallow bed depth (0.38 m) are capable of removing both bacteria and viruses from wastewater. Both total coliform and coliphage removal are dependent on HLR in the range of 0.040 to 0.163 m/d when coupled with a DF of 24 doses/d. A decrease in the HLR results in an increase in the log removal of both total coliforms and indigenous coliphages.

- Indigenous coliphages may be more suitable indicators for testing filters for virus removal than polioviruses because they are more sensitive to increases in HLR than are polioviruses. Additional research is required to ascertain the type of coliphages most commonly found in wastewater and their specific mechanism for removal.

- The influence of medium type on microorganism removal can be minimized by utilizing a high DF. It is hypothesized that the resulting low HAR maximizes plug flow conditions leading to greater microbial contaminant removal.

- Crushed glass is effective as a filter medium for the removal of TSS, COD, turbidity, total coliforms, and indigenous coliphages. Performance and cost of crushed glass medium is similar to that for sand.

Acknowledgments

The donation of pumps and dosing system controls by Orenco Systems, Inc. (Roseburg, Oregon) is gratefully acknowledged. Recycled glass was provided by the Washington State Community Trade and Economic Development Department and the Stuth Company, Inc. (Maple Valley, Washington).

Notes

1. 1 m/d is equivalent to 24.54 gal/ft^2 • d

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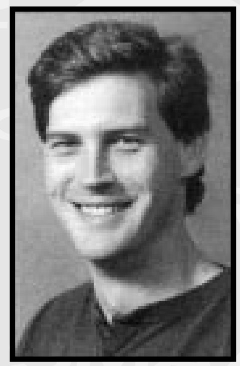

Robert W. Emerick

Robert Emerick is a doctoral student in the Department of Civil and Environmental Engineering at the University of California, Davis.

Rebecca M. Test

Rebecca Test currently works with Concern/America in Santa Ana, California. At the time of this research, she was a graduate student in the Department of Civil and Environmental Engineering at the University of California, Davis.

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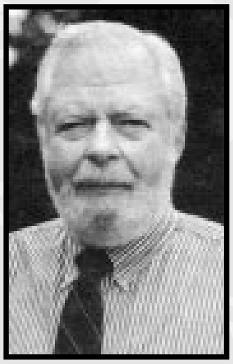

George Tchobanoglous, Ph.D., P.E.

George Tchobanoglous has recently retired as a professor emeritus in the Department of Civil and Environmental Engineering at the University of California, Davis.

Jeannie Darby, Ph.D., P.E.

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If you would like more information about this article, write to Jeannie Darby, Ph.D., P.E., Department of Civil and Environmental Engineering, University of California, Davis, 116 Everson Hall, Davis CA 95616.

NSFC News / Resources

The Small Flows Journal Online—NSFC Develops World Wide Web Site

The National Small Flows Clearinghouse (NSFC) went online last fall with its World Wide Web site.

Accessible via the address http://www.nsfc.wvu.edu, the site is updated regularly and now includes the latest issues of the NSFC's publications: *Small Flows*, *Pipeline*, and *The Small Flows Journal*.

The NSFC's *Guide to Products and Services*, which includes descriptions of more than 300 free or low-cost items, is also online, along with a listing of new products. An e-mail link allows for quick and easy ordering.

In addition, the NSFC's Web site provides a link to the NSFC's Wastewater Treatment Information Exchange Bulletin Board System, discusses new or enhanced program activities and services, offers public education information under the section "Wastewater Trivia", and includes more than a dozen links to other wastewater-related sites.

The NSFC invites you to visit us online and to leave messages or suggestions to the Web master under the "Contact Us" section.

NATIONAL SMALL FLOWS CLEARINGHOUSE

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Helping America's small communities meet their wastewater needs

NSFC To Release Unique Onsite Report

A unique report about onsite wastewater systems across the U.S. is being finalized and will be available soon from the National Small Flows Clearinghouse (NSFC).

Titled *National Onsite Wastewater Treatment: A National Small Flows Clearinghouse Summary of Onsite Systems in the United States, 1993,* the report provides a comprehensive examination of onsite system information collected from 1,567 local health agencies across the country.

"The NSFC has never attempted a study of this scope before," said NSFC Technical Assistance Specialist Tricia Angoli, who coordinated the project. "We learned a lot from the experience, and we have a considerable amount of information to pass on to the public."

Part of that information includes onsite system permit and installation costs, reasons for onsite system failures, the number of homes using onsite systems, and information about who inspects them.

The study uncovered both similarities and differences across states in the ways that systems are managed. This knowledge reinforces the fact that no one situation is unique, Angoli said.

The information represents the 1993 data of health departments who responded to an NSFC questionnaire. Data are presented individually by state, as well as summarized nationally.

The complete report will be available soon by calling (800) 624-8301 or (304) 293-4191 and ordering Item #WWBKGN89. Once available, it also may be ordered via the NSFC's Web site (see the article above). As of press time, the cost of the report had not yet been determined.

ETI Project To Disseminate Innovative Technology Information

Fact sheets that detail innovative wastewater technologies will be available soon through the National Small Flows Clearinghouse (NSFC) as part of the U.S. Environmental Protection Agency's (EPA) Environmental Technology Initiative (ETI).

The NSFC has been collecting information since October 1995 on approximately 600 innovative wastewater technology projects that were funded through the now defunct EPA Construction Grants Program. Under this program, about $1.1 billion was allocated for innovative technologies.

"The benefits gained from the Construction Grant-funded Innovative and Alternative (I/A) projects have been extremely valuable," said Clement Solomon, NSFC senior technical assistance specialist. "This project represents the next logical step in assessing the lessons learned from these I/A projects, and in making sure that information reaches those in the wastewater profession."

The information collected about these I/A projects will be used to develop 10 to 15 fact sheets this fiscal year. In addition, information about all I/A Construction Grants facilities will be housed in the NSFC's Facilities Database.

This newly redesigned database will serve as a networking tool by providing facility operator and manager contact information, so others can reach them to discuss specifics about their particular treatment and disposal technologies. The database also houses information about other innovative, alternative, and conventional systems around the country that serve a population of 10,000 or fewer or have flows of less than one million gallons per day.

ETI
Environmental Technology Initiative

The database complements the information detailed in the technology fact sheets. The fact sheets include specifics about design/system specifications, performance reliability and residuals, system limitations, operation and maintenance, and cost.

According to Solomon, fact sheets on ultraviolet light, chlorine, and ozone disinfection technologies and on fine pore aeration will be available soon. Other fact sheets are planned to address the following technology categories:

- clarifiers,
- digestion,
- energy conservation and recovery,
- filtration,
- fixed film biological reactors,
- land treatment, and
- nutrient removal.

Completed technology fact sheets will be promoted in future issues of Small Flows *and* Pipeline *and also will be available via the NSFC's Web site (see article on page 23). The NSFC welcomes information about specific wastewater facilities for inclusion in its database. Information may be submitted by calling the NSFC at (304) 293-4191 or (800) 624-8301 and requesting a Facilities Database Collection Form or by accessing the form via the Web.*

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Manuscripts submitted to ***The Small Flows Journal*** should not be submitted to another publication before or while under review by ***The Small Flows Journal***.

Manuscripts should be accompanied by an abstract of 150 words or less.

Authors are requested to follow the directions given in the American Society of Agricultural Engineers' *Guide for Refereed Publications, Monographs, and Textbooks* for preparing the text, tables, and figures of the manuscript. Contact the National Small Flows Clearinghouse to obtain a copy.

Manuscripts that are prepared on a personal computer or Macintosh should be submitted in WordPerfect 5.1, Microsoft Word, or ASCII format. Files should include (in this order) abstract, text, footnotes, references, and tables. Figures prepared on a computer should be submitted on diskette as separate files (*.tiff or *.eps) with accompanying "camera-ready" copy. Photographs should be sharp, glossy, black and white prints, when possible, and identified on the back. Submit electronic files on 3.5 inch diskettes, an original of the manuscript, and three printed copies to the editor.

Manuscripts should be submitted with four hard copies in addition to the copy on disk.

All manuscripts go through a blind review. Therefore, the title page of the manuscript should be on a separate page from the remainder of the manuscript. Names of authors should not appear in the manuscript except as a reference citation when appropriate.

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